SEAWATER INTAKE RISERS FOR FLOATING LIQUEFIED NATURAL GAS (FLNG) VESSELS

IAN CRAIG

A doctoral report and portfolio submitted in partial fulfilment of the requirements of the University of Sunderland for the degree of

Professional Doctorate

September 2018

CONFIDENTIALITY

This Portfolio and accompanying Doctoral Report contains information that is both commercially confidential and also commercially advantageous to the proprietary owner.

Consequently, this portfolio and accompanying report shall not be placed into public domain for a minimum of 5 years from the submission date and thereafter, only with express permission in writing from the Research Student who will seek the relevant approvals.

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INTRODUCTION

The contents of this Portfolio are submitted together with the Doctoral Report entitled;

SEAWATER INTAKE RISERS FOR
FLOATING LIQUEFIED NATURAL GAS (FLNG) VESSELS

in partial fulfilment of the requirements of the University of Sunderland for the degree of Professional Doctorate.

This portfolio contains information relevant to the professional competences of the research student to demonstrate the knowledge, skills and abilities required by the Professional Doctorate programme learning outcomes. It also includes documentary evidence to support the research work presented in the Doctoral Report and also includes a reflective account of the Professional Doctorate programme as experienced by the research student.

The following is an overview of the portfolio contents outlining the relevance of the information presented:

Section 1.0: Reflective Account of Professional Doctorate Programme

This section contains a reflective account of how the research student came to undertake the Professional Doctorate programme and how the Professional Doctorate programme has impacted on the values, thought processes and professionalism of the research student.

Section 2.0: Academic Qualifications & Professional Registrations

Having left secondary education in 1979 to commence an apprenticeship as a draughtsman at one of the shipyards on the River Tyne, the research student has undertaken a number of industry recognised technical qualifications including several bespoke training programmes in terms of continual professional development (CPD), the certificates for each of the following are presented:

- BEng (Hons) Engineering - First Class
- HND Engineering (Mechanical/Manufacture) - Distinction
- HNC Mechanical & Production Engineering - Distinction
- Certificate of Apprenticeship

- Orcaflex Training Course
- Financial Management for Engineers
- Further Offshore Emergency Training Course

The research student is registered with the Engineering Council as a Chartered Engineer, the registration certificate is presented together with requirements that are to be demonstrated to achieve this level of registration.

The research student is a full member of the Institute of Engineering & Technology (IET), for which he is also registered as an Assessor in relation to membership applications. The membership certificate and letter of appointment as Assessor are presented.

Also included is a recent (unrequested) commendation from a Client in respect of the professionalism of the research student engaged as Project Manager during the delivery of a Seawater Intake System.

Section 3.0: State of the Art Review

One of the objectives set within this research is a state of the art review of systems currently operating in the field on FPSO vessels. This section contains the full state of the art review undertaken from which a summary version is presented in Section 1.2 of the Doctoral Report.

Section 4.0: Field Data

As a part of the research, data from systems currently operating in the field was obtained and analysed. This section lists the vessels that were targeted, the initial contact correspondence and the field notes from the data received.

Section 5.0: Material Test Data

During the research presented in the Doctoral Report, and due to lack of available data, it was necessary to perform specific material tests to characterise some of the materials under consideration. This section contains the test reports from the material tests undertaken, namely;

- Textile Yarn Tensile Testing
- Textile Yarn Fatigue Testing
- Rubber Compound Compression Testing
- Foul Release Paint Testing

Section 6.0: Statistical Analysis Report

The results obtained from the fatigue testing of the textile yarn presented in Section 5.0, were used to generate a useable SN curve that could be used for the fatigue analysis of the flexible rubber pipe. This was achieved using a recognised statistical analysis technique, the details of which are presented within this section. The report also includes details of an SN curve generated from test results obtained for the fatigue testing of HDPE butt fusion welds.

Section 7.0: Flexible Rubber Pipe FEA Reports

During the course of the research, an external 3rd party analyst was commissioned and directed by the research student to undertake an FEA of the Flexible Rubber Pipe. Data from the FEA was used by the research student for the research and which is discussed within the Doctoral Report. The analysis reports prepared by the 3rd party are presented in this section, namely;

- PDL, 667-002:2015. 40" Suction Hose Fatigue Assessment; Global Analysis. Technical Report. Hexham: PDL Solutions (Europe) Ltd.
- PDL, 667-003:2015. 40" Suction Hose Fatigue Assessment; Local Analysis. Technical Report. Hexham: PDL Solutions (Europe) Ltd.
- PDL, 727-001:2015. 40" Suction Hose with Steel Reinforcement Fatigue Analysis; Local Analysis. Technical Report. Hexham: PDL Solutions (Europe) Ltd.
- PDL, 727-002:2015. 40" Suction Hose with Steel Reinforcement Fatigue Assessment; Global Analysis. Technical Report. Hexham: PDL Solutions (Europe) Ltd.

Section 8.0: Hydrodynamic Analysis Report

The selection and analysis of the proposed solution presented within the Doctoral Report included the use of Orcaflex software to perform hydrodynamic analyses.
This section contains details of the hydrodynamic analyses undertaken from which summary details are presented in Section 6.0 of the Doctoral Report.

Section 9.0: Flow Analysis Report

The proposed solution presented within the Doctoral Report was subject to a flow analysis to demonstrate that the seawater could be imported effectively.
This section contains details of the flow analyses from which summary details are presented in Section 6.0 of the Doctoral Report.

Section 10.0: Publications & Patent Applications

The research undertaken in the Doctoral Report has been supported by a private company (Emstec GmbH) who specialise in the subject area. The field data, material testing, statistical analysis and 3rd party analysis within Sections 4.0, 5.0, 6.0 & 7.0 respectively, have been obtained with the permissions and funding of Emstec GmbH, the results of which are commercially advantageous. While the details and outcomes of each these activities could form the subject of a technical paper, in doing so, this would disclose confidential information.

However, a subject not considered commercially advantageous was identified and a paper was written by the research student for presentation at an industry conference. This section contains a copy of the paper and also the certificate of presentation from the conference.

Also, during the research presented in the Doctoral Report, several features of the systems developed are considered innovative and as such patent applications were submitted, examined and accepted/granted within five separate jurisdictions, namely, Europe, Japan, South Korea, China and the US. Although the patent application is in the name of Emstec GmbH, the research student is listed as one of the inventors.

The two patents are publications; 3137799B which deals with general system improvements and 3137800B which deals with the specific innovation presented in the Doctoral Report.

Included is a summary from the patent attorney outlining the status of each patent within the relevant jurisdiction.

Section 11.0: Previous Reports & Presentations

Although not disseminated to the general community of practice, a body of work previously prepared by the research student has been submitted for review and approval by peers. This body of work consists of analysis reports for systems delivered into the field and paid studies commissioned by Clients in the subject area where the research student was engaged as the principal research engineer. As a contractual deliverable, each of the reports and studies were subject to review and approval by the Client, and in one case, also submitted to a 3rd party (DNV) for verification of the work. In the absence of industry publications, these studies form a body of work that have undergone varying degrees of peer review, a selection of which are presented, namely:

- SHELL PRELUDE: Workshop Presentation of Seawater Intake System Comparison: Single Pipe Concept v Bundled Concept
- YINSON: Hydrodynamic Analysis Report c/w DNV Verification Report.
- KBR: Seawater Intake Riser FEED c/w Client Comments Sheets
- STATOIL: Seawater Intake System Feasibility Study c/w Presentation Notes

Section 12.0: Directorships

In 2005, the research student was a founding Director of Techflow Marine Ltd., a private company that specialises in the supply of fluid transfer systems and which includes Seawater Intake Systems in the product range. This section contains an overview of the objectives set during the company start-up and achievements made during the tenure of the research student.

After leaving Techflow Marine Ltd. in 2011, the research student established a consultancy practice and has since been operating as a consultant engineer specialising in Seawater Intake Systems, details from the consultancy website are also presented in this section and which can be accessed at:

www.hartconsultancy.co.uk

Section 1.0: Reflective Account of Professional Doctorate Programme

REFLECTIVE ACCOUNT

of the

PROFESSIONAL DOCTORATE PROGRAMME

by

IAN CRAIG

Submitted in partial fulfilment of the requirements of the University of Sunderland for the degree of

Professional Doctorate

June 2018

At my first cohort day, we were given an opening address by the Professional Doctorate programme leader who told us that, at the end of the process, we will have changed the way we think. At the time I thought this seemed to be a bold claim given that the cohort consisted of mid-career professionals, all of whom had clearly been successful in their own field and with thought processes that had served them well. The fact that I'm now reflecting on this event is perhaps testament to that very claim.

Having been aware of the Professional Doctorate programme for some years, upon reflection, it was two incidents that occurred towards the end of 2011 that were primarily responsible for elevating this awareness to serious contemplation. The first incident involved an engineer that I had met briefly in Japan some years earlier and who had contacted me to say he was visiting the UK and would like to meet up with me. He travelled to the North East for our meeting where he explained that he was tasked by his employer (INPEX, a Japanese energy company) to investigate new technologies for a conceptual FLNG vessel under consideration. He said that he had contacted me as he had attended a presentation I'd given to INPEX some years earlier in regard to seawater intake systems and that, as I'd presented the system so well, he believed I was the person to speak to about these systems. We had our meeting and went our separate ways but the incident did make me think that perhaps I was becoming a leader in the field for these systems.

Not long after this meeting, a more light hearted incident occurred which had a similar impact. During a vacation in Cyprus with my wife (who is a Doctor), one of the hotel employees kept addressing me as 'Doctor' thinking that I was the Doctor in the relationship. Although he was corrected on a number of occasions, he continued to call me Doctor, which although amusing at the time, did make me realise that the title was universally respected and made me think 'if only….'.

During the ensuing 12 months, I persuaded myself that a Professional Doctorate was a realistic possibility on top of which I'd also developed an idea for a doctoral project. Upon learning that the University of Sunderland ran the Professional Doctorate programme, I contacted the programme leader at the time and explained to him my thoughts, and after a pleasant conversation he said, 'you might have something there'. That was the last piece of encouragement I needed and subsequently submitted my application and, having been accepted, enrolled as a part of the October 2013 cohort.

On that same first cohort day, we were given an introduction into the Research Methods module during which I was introduced to two concepts (and two words) that I had no previous knowledge of, namely, ontology and epistemology. The 'study of being' and the 'study of knowledge' were concepts that I was completely unfamiliar with but as I researched the theory behind ontology and epistemology, it enabled me to differentiate between the two and also to understand how to identify knowledge. The most succinct definition of knowledge that I found was that : **it must be justified, true, and believed** (Cardinal et al., 2004, p.128).

To create new knowledge, the three things instilled into me during the Professional Doctorate programme were that the subject needed to be; a) novel, b) systematically researched and c) academically underpinned. These three requisites can be compared with the above definition of knowledge in as much as, by its very definition 'new knowledge' must be novel, the generation of which must be justified by the methods used for the research and shown to be true through academic underpinning, the process of which demonstrates that the knowledge can be believed.

The range of methodologies behind research was something else I was unfamiliar with, but it became clear that the generation of new knowledge is achieved by systematically researching a theory, and to aid my understanding of this process, I created an illustration to visualise how this top level process was expanded to consider the various elements within a methodology.

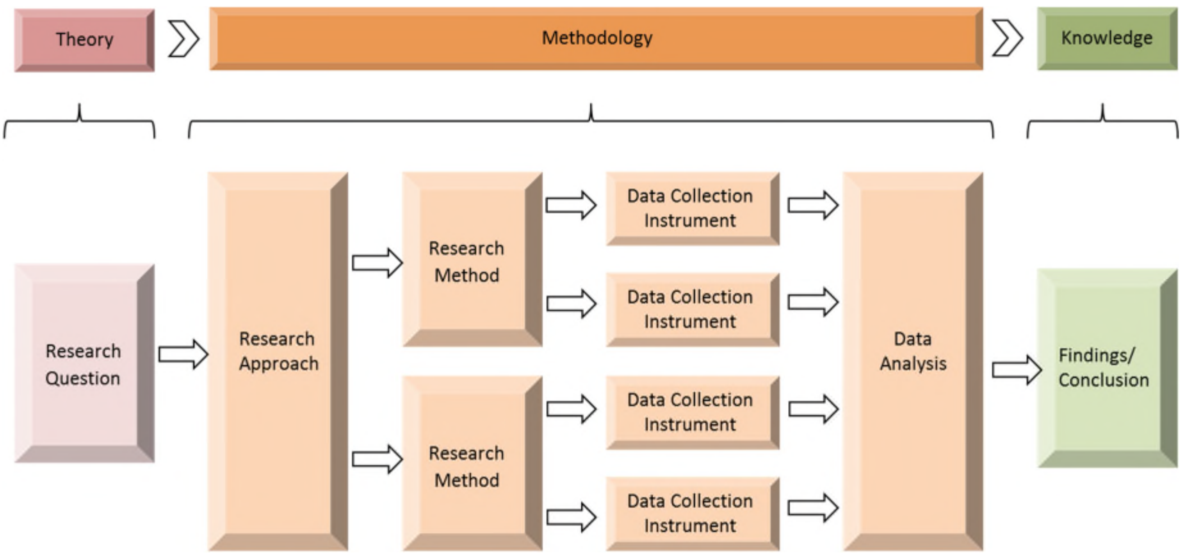

Fig. 1: Representation of Research Process (Developed by Ian Craig 2014)

The above illustration was developed further for my research question which can be found in my Doctoral Report, Section 3. Figure 3-1.

For my research subject, the predominant methodology adopted was the Scientific Method which involved the use of some classical empirical formulae used in engineering. Whereas in the course of my career this data would be accepted as 'known', in order to validate and provide a reference for these formulae in my Doctoral Report, I found myself revisiting their origins which in itself was a particularly interesting exercise. Part of my learning through this was the awareness and need to differentiate between a theory, an opinion and knowledge.

As my thought processes began to change, so did my understanding of my profession. As a part of the Reflective Practice module, I was tasked to investigate a critical incident that would reflect upon the values and norms of my profession at the time of that incident. To do this, I first needed to gain a better understanding of the values and norms in my profession which I achieved by researching the origins of engineering as a profession. I was unaware of how little I knew about the history of engineering as a profession; how it evolved, how the institutes came into being and how education and experience became an essential part of the profession. This study of the profession dovetailed perfectly with the Research Methods module where I was tasked to evaluate the range of methodologies used in my profession.

It was fascinating tracing the history of engineering back to the enlightenment and the origins of the Scientific Method to Galileo and Sir Francis Bacon (Gower, 1997) and also the influence of the Industrial Revolution which gave rise to the engineering institutes (Buchanan, 1989). I began to understand the importance of the institutes and how they were evolved to provide an opportunity for an engineering community to develop and acquire professional qualities, and how this community would determine their own rules, codes of conduct and specify the entry requirements. I also learned that it was the Parliamentary concern of the British manufacturing industry in the 1970's and the subsequent Finniston Report (Finniston, 1980) that gave rise to the modern day statutory body, the Engineering Council (Chapman & Levy, 2004), with which I am registered as a Chartered Engineer.

Having been a member of an engineering institute and registered with the Engineering Council for many years, I did recognise that these were measures of professionalism but perhaps what I didn't appreciate was the value of the institutes in creating and regulating the community of practice. As a consequence, I accepted an invitation to become an assessor of membership applications with the institute (a voluntary position), not only to contribute to my community of practice but also to develop a greater understanding of the workings of the institute.

As an exercise for one of the cohort days, we were asked to make a short presentation on how we saw our professional identity, for which I prepared the below illustration.

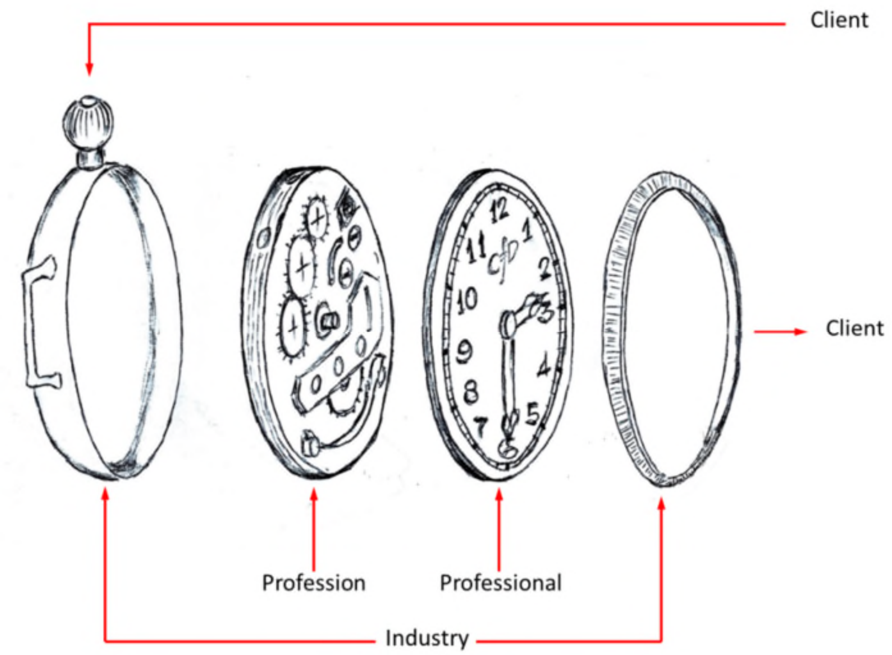

Fig. 2: Representation of Professional Identity (Developed by Ian Craig 2014)

I viewed the watch case as representing the industry, where the needs of society (or commercially ‘the Client’) are the drivers for the industry. Inside the watch, I likened the mechanism to the engineering profession and the watch face as where I saw my professional identity, that is, the interface between the profession and providing the Client with their needs, in this case the time. I include this illustration as an example of how the Professional Doctorate encouraged me to think about my professional identity and provided me with a greater understanding of where I fit into the industry, profession and community of practice.

The above illustration is one example of how my thought process has changed during the course of the programme but arguably more importantly, and what I hadn’t expected from the Professional Doctorate programme, was the insight it gave me into my own character. For the critical incident assignment referenced above, I reflected on an incident early in my career when I had an opportunity to work in Canada for a year. Although through good fortune I was granted a work permit, the critical incident reflected on how I felt exposed due to a lack of qualifications which gave rise to a feeling of inferiority to my peers and how that manifested into a feeling of shame. Over the years, I had recounted parts of the incident to various colleagues and friends, but had not previously synthesised the complete picture nor appreciated the effect this had on my career and persona. Upon reflection, it was this incident that shamed me into further education and set me on the pathway that ultimately led me to the Professional Doctorate programme.

As a part of the Contextualisation and Planning module, we were encouraged to look into the motivation behind our research. For this element of the module, my approach was firstly to research the theory behind motivation and then undertake an honest self-appraisal to determine what it was that motivated me. The model of motivation I used for this assignment was the one presented by Forgeard & Mecklenburg (2013) who suggest that there were four possible aspects of motivation, two of which were 'self-oriented' and two 'other-oriented' as shown below:

	Beneficiaries	
Locus of Motivation	*Self-oriented*	*Other-oriented*
Intrinsic: Process-focused motivators emphasizing learning goals	Intrinsic Self **(Growth)**: *e.g. personal feelings of interest, flow, positive emotion, meaning, competence etc*.	Intrinsic Others **(Guidance)**: *e.g. teaching and modelling for others, fulfilling mentors expectations, etc.*
Extrinsic: Outcome-focused motivators emphasizing performance goals	Extrinsic Self **(Gain)**: *e.g. obtaining rewards, recognition, praise, etc.*	Extrinsic Others **(Giving)**: *e.g. contributing to or helping others, etc.*

Fig. 3: Two-Dimensional Framework of Motivation
(Forgeard & Mecklenburg, 2013)

Using this model, I began to synthesise some of my findings from the Reflective Practice module and the Research Methods module and also other events in my career such as the incidents in 2011 (recounted above) that led me to the Professional Doctorate. Upon examination of these findings, I realised that, although all four aspects provided an element of motivation within me, the bias for my motivation was towards the self-oriented aspects.

To provide some indication as to the proportion of each aspect, I developed the below illustration:

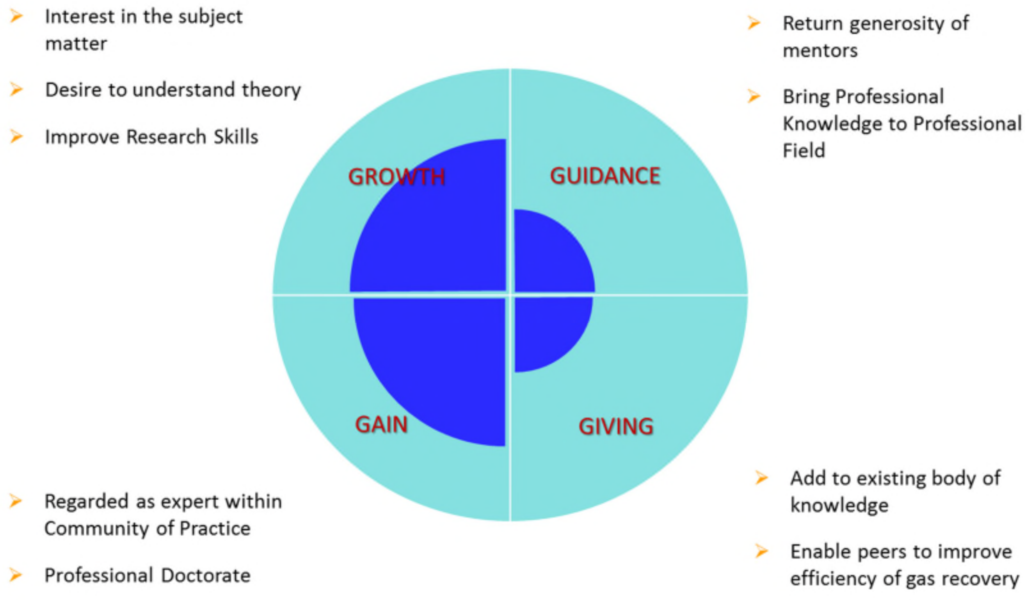

Fig. 4: Two-Dimensional Framework of Motivation
(Forgeard & Mecklenburg, 2013) (Illustrated by Ian Craig, 2014)

Individuation: *(in the psychology of Jung) the process by which the wholeness of the individual is established through the integration of consciousness and the collective unconscious*. (Collins, 2000)

In Jungian theory, the Ego is our conscious self and the Shadow is the unconscious part of the Ego, a receptacle where qualities we prefer not to be seen are placed (Mitchell, 2015). Prior to the Professional Doctorate programme I was conscious that, in my career, I was driven by a desire to be held in regard by my peers. This is still the case but the Professional Doctorate has made me conscious of other, not so noble, qualities that also drive my motivation, i.e. the potential feeling of inferiority and shame, that were residing in my Shadow. This individuation through the Professional Doctorate programme has given my Ego a more balanced feel and a greater insight into what 'makes me tick'.

Apart from the motivation required to undertake a Professional Doctorate, it also requires a level of perseverance to accomplish the research. There is much written on the trait of perseverance, often referred to as 'grit', and the research suggests that grit is genetically correlated with the Big Five trait of Conscientiousness (Rimfield et al., 2016). The research also suggests that grit can be grown over an individual's life span (Duckworth et al., 2007) and upon reflection I believe that this is the case with myself. As a child, I was not particularly athletic however, where I did seem to excel was in cross-country running, I was always able to keep going when others began to struggle, which at the time I attributed to as having good stamina and which I believed to be a physical characteristic. Research suggests that grit overlaps with the achievement aspect of conscientiousness but its emphasis is on long-term stamina rather than short term intensity (Duckworth et al., 2007) which does indicate that grit has always been one of my traits. This latent grit appears to have been ignited by the critical incident in Canada enabling it to grow and when I did re-engaged with further education, not only did I want to gain an HNC and HND, I wanted to achieve Distinctions in both, likewise, as an undergraduate I set myself the goal of a First Class Engineering degree.

Apart from my career, I can also relate grit to other interests of mine which includes health and fitness, an interest which perhaps not so coincidentally began in my mid-twenties when I was in working in Canada. I started participating in 10K runs and half marathons but by my mid to late thirties I found myself with less time to pursue this interest. After several years lay off, I resumed running but, due to age and lack of fitness, I suffered a number of recurring injuries which noticeably took longer to heal than in my youth. Nonetheless I persevered with physiotherapy and an exercise regime and have recently began participating in full marathons, completing two in 2016, two in 2017 and another planned for 2018. Asides from the grit to overcome the setback of injury, anyone who has completed a marathon will tell you that it is largely mental strength, or grit, that gets you through the latter stages. These examples of grit concur with the research that suggests individuals high in grit deliberately set themselves extremely long-term objectives and do not swerve from them;

> *"The gritty individual approaches achievement as a marathon, his or her advantage is stamina*" (Duckworth et al., 2007)

In summary, the Professional Doctorate programme has made an impact on me as a student, a professional and as a person. As a student, I now have a far greater understanding of what knowledge is, how new knowledge is created and the importance of research methodology in this process. As a professional, I have a much deeper understanding of Engineering as a profession which has engendered within me a greater respect for my community of practice and as a person, I have stripped away layers of myself and identified what it is that motivates me and which of my characteristics enact this motivation.

So reflecting on the claim made in the opening address on my first cohort day, I can endorse the statement that "the Professional Doctorate programme will change the way you think". Reflection has become a powerful tool in my locker but I will leave the last word on reflection to the late David Bowie:

"You have to accommodate your pasts within your persona… It helps you reflect on what you are now"

(David Bowie - Five Years, 2013)

References

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Section 2.0: Academic Qualifications & Professional Registrations

UNIVERSITY OF SUNDERLAND

Ian Craig

HAS BEEN AWARDED THE DEGREE OF

Bachelor of Engineering
First Class Honours

HAVING FOLLOWED AN APPROVED PROGRAMME IN

Engineering

JUNE 2012

Director of Academic Services

Vice-Chancellor and Chief Executive

Full award details, including module results, are provided in a separately issued transcript.

00040979

Higher National Diploma

BTEC

ENGINEERING (MECHANICAL/MANUFACTURE)

is awarded to

IAN CRAIG

who has completed a BTEC-approved programme at

NEWCASTLE COLLEGE

AUGUST 1996

Christina Townsend

Chief Executive, BTEC

39215 : G1473 : K274307 : 000173118 :27:08:63

BTEC

Notification of Performance on a BTEC approved programme

Student registration number | Student name

K274307 IAN CRAIG
HIGHER NATIONAL DIPLOMA
ENGINEERING (MECHANICAL/MANUFACTURE)

MODULE	VALUE	LEVEL	GRADE
NEWCASTLE COLLEGE			
COMMON SKILLS PROFILE			
Managing & developing self		H	DISTINCTION
Working with & relating to others		H	DISTINCTION
Communicating		H	DISTINCTION
Managing tasks & solving problems		H	DISTINCTION
Applying numeracy		H	DISTINCTION
Applying technology		H	DISTINCTION
Applying design & creativity		H	DISTINCTION
ENGINEERING MATERIALS	1.0	N/H	DISTINCTION
MATHEMATICS	1.0	N/H	DISTINCTION
MECHANICAL SCIENCE	1.0	N/H	DISTINCTION
QUALITY ASSURANCE	1.0	H	DISTINCTION
MANUFACTURING TECHNOLOGY	1.0	H	DISTINCTION
MANUFACTURING TECHNOLOGY B	1.0	H	DISTINCTION
MECHANICAL SCIENCE	1.0	H	DISTINCTION
MECHANICAL SCIENCE B	1.0	H	DISTINCTION
ENGINEERING DESIGN	1.0	H	DISTINCTION
COMPUTER AIDED ENGINEERING	1.0	H	DISTINCTION
PRODUCTION PLANNING & CONTROL	1.0	H	DISTINCTION
MATHEMATICS	1.0	H	DISTINCTION
PROJECT	2.0	H	DISTINCTION
MATERIALS FOR ENGINEERING	1.0	H	DISTINCTION
INDUSTRIAL STUDIES	1.0	H	DISTINCTION

****

THIS STUDENT HAS QUALIFIED FOR THE ABOVE AWARD

39215 : G1473 :27:08:63 AUGUST 1996

BTEC

Higher National Certificate

MECHANICAL AND PRODUCTION ENGINEERING

is awarded to

IAN CRAIG

who has completed a BTEC approved programme at

NEWCASTLE COLLEGE
JUNE 1994

HNC

Business & Technology Education Council

Chief Executive

Christina Townsend

39215 : F145 : H244226 : 000148043

BTEC

Notification of Performance on a BTEC approved programme

Student registration number | Student name

H244226 IAN CRAIG
HIGHER NATIONAL CERTIFICATE
MECHANICAL AND PRODUCTION ENGINEERING

MODULE	VALUE	LEVEL	GRADE
NEWCASTLE COLLEGE			
COMMON SKILLS PROFILE			
Managing & developing self		H	DISTINCTION
Working with & relating to others		H	DISTINCTION
Communicating		H	DISTINCTION
Managing tasks & solving problems		H	DISTINCTION
Applying numeracy		H	DISTINCTION
Applying technology		H	DISTINCTION
Applying design & creativity		H	DISTINCTION
MATHEMATICS	1.0	N/H	DISTINCTION
MECHANICAL SCIENCE	1.0	N/H	DISTINCTION
MANUFACTURING TECHNOLOGY	1.0	H	DISTINCTION
MECHANICAL SCIENCE	1.0	H	DISTINCTION
ENGINEERING DESIGN	1.0	H	DISTINCTION
COMPUTER AIDED ENGINEERING	1.0	H	DISTINCTION
PRODUCTION PLANNING & CONTROL	1.0	H	DISTINCTION
MATHEMATICS	1.0	H	DISTINCTION
PROJECT	1.0	H	MERIT
INDUSTRIAL STUDIES	1.0	H	DISTINCTION

****

THIS STUDENT HAS QUALIFIED FOR THE ABOVE AWARD

39215 : F145 JUNE 1994

SWAN HUNTER
SHIPBUILDERS LIMITED

A MEMBER OF BRITISH SHIPBUILDERS

CERTIFICATE OF APPRENTICESHIP

This is to certify that Ian Craig

was employed as an Apprentice Draughtsman

From: 27th August 1979 To: 26th August 1983

In accordance with the Confederation of Shipbuilding and Engineering Unions National Agreement December 1969.

BASIC TRAINING

Off the job training carried out at:

B.S. (TES) Ltd., Hebburn

PLANNED EXPERIENCE TRAINING

On the job training to the required Skill Standard, following an approved programme of training as recommended by British Shipbuilders Training Policy.

FURTHER EDUCATION QUALIFICATIONS

Technician Education Council Certificate Level 11 1981

Director of Personnel and
Industrial Relations.

Orcina

Orcina Ltd.
Daltongate
Ulverston
Cumbria LA12 7AJ U.K.
Tel: +44(0)1229 584742
Fax: +44(0)1229 587191
Email: orcina@orcina.com
Web: www.orcina.com

OrcaFlex Training
Certificate of Attendance

This is to certify that

Ian Craig

attended a training course in the use of OrcaFlex. This was held at Orcina's offices, Ulverston, UK on the 12th and 13th of August 2009.

The course was conducted by Sarah Ellwood of Orcina Ltd., the developers of OrcaFlex.

Sarah Ellwood.

....

for Orcina Ltd.

Registered in England No 1996191

PROFESSIONAL DEVELOPMENT TRAINING

Institution of MECHANICAL ENGINEERS

THIS IS TO CERTIFY THAT

Ian Craig

HAS SUCCESSFULLY COMPLETED THE

INTENSIVE CPD TRAINING COURSE

Financial Management for Engineers

PROVIDED BY THE

INSTITUTION OF MECHANICAL ENGINEERS

ON

November 11th – 12th 2009

DIRECTOR OF MEMBERSHIP AND INFORMATION SERVICES

CPD AND TRAINING MANAGER

PROGRESS

Improving the world through engineering

Certificate

Falck Safety Services Teesside

Ian Craig

Participant

has been assessed against the learning outcomes of the

Further Offshore Emergency Training (including EBS and First Aid)

OPITO Approved - Course Code 5858

0285858241014489572
Certificate Number

Falck Safety Services Teesside - 24.10.2014

Authorised Signature

Course Location and Date

31.10.2018

Valid Until

Haverton Hill Industrial Estate,Billingham, TS23 1PZ Tel:+44 8444 142142 bookings@uk.falcksafety.com www.falcksafety.com/uk

Falck
Safety Services

Engineering Council

Established for the promotion and development
of the knowledge and best practice of engineering

This is to certify that

Ian Craig

in membership of the

Institution of Engineering and Technology

has been registered by the Engineering Council and is hereby authorised
to use the style or title of

Chartered Engineer

Chairman

Chief Executive Officer

Date of Registration 10 May 2013

Date of Issue 13 May 2013

Registration No. 514568
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Returnable on request or de-registration

THE CHARTERED ENGINEER STANDARD

Chartered Engineers develop solutions to engineering problems using new or existing technologies, through innovation, creativity and change and/or they may have technical accountability for complex systems with significant levels of risk.

Chartered Engineers are able to demonstrate:

- The theoretical knowledge to solve problems in new technologies and develop new analytical techniques
- Successful application of the knowledge to deliver innovative products and services and/or take technical responsibility for complex engineering systems
- Accountability for project, finance and personnel management and managing trade-offs between technical and socio-economic factors
- Skill sets necessary to develop other technical staff
- Effective interpersonal skills in communicating technical matters.

The Competence and Commitment Standard for Chartered Engineers. **Chartered Engineers must be competent throughout their working life, by virtue of their education, training and experience, to:**	The examples given below are intended to help you identify activities you might quote to demonstrate the required competence and commitment for CEng registration. These are not exhaustive. Moreover, you are not required to give multiple examples to demonstrate competence and commitment.
A Use a combination of general and specialist engineering knowledge and understanding to optimise the application of existing and emerging technology.	
A1 Maintain and extend a sound theoretical approach in enabling the introduction and exploitation of new and advancing technology. This could include an ability to: • Identify the limits of own personal knowledge and skills • Strive to extend own technological capability • Broaden and deepen own knowledge base through research and experimentation.	Engage in formal post-graduate academic study. Learn and develop new engineering theories and techniques in the workplace. Broaden your knowledge of engineering codes, standards and specifications.

A2 Engage in the creative and innovative development of engineering technology and continuous improvement systems. This could include an ability to: • Assess market needs and contribute to marketing strategies • Identify constraints and exploit opportunities for the development and transfer of technology within own chosen field • Promote new applications when appropriate • Secure the necessary intellectual property (IP) rights • Develop and evaluate continuous improvement systems.	Lead/manage market research, and product and process research and development. Cross-disciplinary working involving complex projects. Conduct statistically sound appraisal of data. Use evidence from best practice to improve effectiveness.
B Apply appropriate theoretical and practical methods to the analysis and solution of engineering problems.	
B1 Identify potential projects and opportunities. This could include an ability to: • Establish and help develop solutions to meet users' requirements • Consider and implement new and emerging technologies • Enhance engineering practices, products, processes, systems and services • Use own knowledge of the employer's position to assess the viability of opportunities.	Involvement in the marketing of and tendering for new engineering products, processes and systems. Involvement in the specification and procurement of new engineering products, processes and systems. Set targets, and draft programmes and action plans. Schedule activities.
B2 Conduct appropriate research, and undertake design and development of engineering solutions. This could include an ability to: • Identify and agree appropriate research methodologies • Allocate and manage resources • Develop the necessary tests • Collect, analyse and evaluate the relevant data • Undertake engineering design • Prepare, present and agree design recommendations, with appropriate analysis of risk, and taking account of cost, quality, safety, reliability, appearance, fitness for purpose, security, intellectual property (IP) constraints and opportunities, and environmental impact.	Carry out formal theoretical research. Evaluate numerical and analytical tools. Carry out applied research on the job. Lead/manage value engineering and whole life costing. Lead design teams. Draft specifications. Develop and test options. Identify resources and costs of options. Produce concept designs, and develop these into detailed designs. Be aware of IP constraints and opportunities.

B3 Manage implementation of design solutions, and evaluate their effectiveness. This could include an ability to: • Ensure that the application of the design results in the appropriate practical outcome • Implement design solutions, taking account of critical constraints, including due concern for safety and sustainability • Determine the criteria for evaluating the design solutions • Evaluate the outcome against the original specification • Actively learn from feedback on results to improve future design solutions and build best practice.	Follow the design process through into product or service realisation and its evaluation. Prepare and present reports on the evaluation of the effectiveness of the designs, including risk, safety and life cycle considerations. Manage product improvement. Interpret and analyse performance. Determine critical success factors.
C Provide technical and commercial leadership.	
C1 Plan for effective project implementation. This could include an ability to: • Systematically review the factors affecting the project implementation including safety and sustainability considerations • Define a holistic and systematic approach to risk identification, assessment and management • Lead on preparing and agreeing implementation plans and method statements • Ensure that the necessary resources are secured and brief the project team • Negotiate the necessary contractual arrangements with other stakeholders (client, subcontractors, suppliers, etc).	Lead/manage project planning activities. Produce and implement procurement plans. Carry out project risk assessments. Collaborate with key stakeholders, and negotiate agreement to the plans. Plan programmes and delivery of tasks. Identify resources and costs. Negotiate and agree contracts/work orders.
C2 Plan, budget, organise, direct and control tasks, people and resources. This could include an ability to: • Set up appropriate management systems • Define quality standards, programme and budget within legal and statutory requirements • Organise and lead work teams, coordinating project activities • Ensure that variations from quality standards, programme and budgets are identified, and that corrective action is taken • Gather and evaluate feedback, and recommend improvements.	Take responsibility for and control project operations. Manage the balance between quality, cost and time. Manage risk register and contingency systems. Manage project funding, payments and recovery. Satisfy legal and statutory obligations. Lead/manage tasks within identified financial, commercial and regulatory constraints.

C3 Lead teams and develop staff to meet changing technical and managerial needs. This could include an ability to: • Agree objectives and work plans with teams and individuals • Identify team and individual needs, and plan for their development • Reinforce team commitment to professional standards • Lead and support team and individual development • Assess team and individual performance, and provide feedback.	Carry out/contribute to staff appraisals. Plan/contribute to the training and development of staff. Gather evidence from colleagues of the management, assessment and feedback that you have provided. Carry out/contribute to disciplinary procedures.
C4 Bring about continuous improvement through quality management. This could include an ability to: • Promote quality throughout the organisation and its customer and supplier networks • Develop and maintain operations to meet quality standards • Direct project evaluation and propose recommendations for improvement.	Plan and implement best practice methods of continuous improvement, eg ISO 9000, EFQM, balanced scorecard. Carry out quality audits. Monitor, maintain and improve delivery. Identify, implement and evaluate changes to meet quality objectives.
D **Demonstrate effective interpersonal skills.**	
D1 Communicate in English[3] with others at all levels. This could include an ability to: • Lead, chair, contribute to and record meetings and discussions • Prepare communications, documents and reports on complex matters • Exchange information and provide advice to technical and non-technical colleagues.	Reports, letters, emails, drawings, specifications and working papers (e.g. meeting minutes, planning documents, correspondence) in a variety of formats. Engaging or interacting with professional networks.
D2 Present and discuss proposals. This could include an ability to: • Prepare and deliver presentations on strategic matters • Lead and sustain debates with audiences • Feed the results back to improve the proposals • Raise the awareness of risk.	Presentations, records of discussions and their outcomes.

3 Any interviews will be conducted in English, subject only to the provisions of the Welsh Language Act 1993 and any Regulations which may be made in implementation of European Union directives on free movement of labour.

D3 Demonstrate personal and social skills. This could include an ability to: • Know and manage own emotions, strengths and weaknesses • Be aware of the needs and concerns of others, especially where related to diversity and equality • Be confident and flexible in dealing with new and changing interpersonal situations • Identify, agree and lead work towards collective goals • Create, maintain and enhance productive working relationships, and resolve conflicts.	Records of meetings. Evidence from colleagues of your personal and social skills. Take responsibility for productive working relationships. Apply diversity and anti-discrimination legislation.
E **Demonstrate a personal commitment to professional standards, recognising obligations to society, the profession and the environment.**	
E1 Comply with relevant codes of conduct. This includes an ability to: • Comply with the rules of professional conduct of own institution • Lead work within all relevant legislation and regulatory frameworks, including social and employment legislation.	Work with a variety of conditions of contract. Demonstrate initiative in and commitment to the affairs of your institution.
E2 Manage and apply safe systems of work. This could include an ability to: • Identify and take responsibility for own obligations for health, safety and welfare issues • Ensure that systems satisfy health, safety and welfare requirements • Develop and implement appropriate hazard identification and risk management systems and culture • Manage, evaluate and improve these systems • Apply a sound knowledge of health and safety legislation.	Undertake formal health and safety training. Work with health and safety legislation and best practice. In the UK, examples include HASAW 1974, CDM regulations, OHSAS 18001:2007 and company safety policies. Carry out safety audits. Identify and minimise hazards. Assess and control risks. Evaluate the costs and benefits of safe working. Deliver strategic health and safety briefings and inductions.

E3	Undertake engineering activities in a way that contributes to sustainable development. This could include an ability to: • Operate and act responsibly, taking account of the need to progress environmental, social and economic outcomes simultaneously • Use imagination, creativity and innovation to provide products and services which maintain and enhance the quality of the environment and community, and meet financial objectives • Understand and secure stakeholder involvement in sustainable development • Use resources efficiently and effectively.	Carry out environmental impact assessments. Carry out environmental risk assessments. Plan and implement best practice environmental management systems, eg ISO 14000. Manage best practice risk management systems eg ISO 31000. Work within environmental legislation. Adopt sustainable practices. Achieve social, economic and environmental outcomes.
E4	Carry out and record CPD necessary to maintain and enhance competence in own area of practice including: • Undertake reviews of own development needs • Plan how to meet personal and organisational objectives • Carry out planned (and unplanned) CPD activities • Maintain evidence of competence development • Evaluate CPD outcomes against any plans made • Assist others with their own CPD.	Keep up to date with national and international engineering issues. Maintain CPD plans and records. Involvement with the affairs of your institution. Evidence of your development through on-the-job learning, private study, in-house courses, external courses and conferences.
E5	Exercise responsibilities in an ethical manner.	Give an example of where you have applied ethical principles as described in the Statement of Ethical Principles on page 33. Give an example of where you have applied/upheld ethical principles as defined by your organisation or company, which may be in its company or brand values.

Education

Knowledge and understanding are important components of professional competence. Formal education is the usual, though not the only, way of demonstrating the necessary knowledge and understanding, and the following qualifications exemplify the required knowledge and understanding for Chartered Engineers:

- An accredited Bachelors degree with honours in engineering or technology, plus either an appropriate Masters degree or Engineering Doctorate (EngD) accredited by a professional engineering institution, or appropriate further learning to Masters level*;

- or an accredited integrated MEng degree.

*See **www.qaa.ac.uk** for qualification levels and HE reference points.

The Engineering Council website provides a searchable database of accredited programmes. Please check the Engineering Council website:
www.engc.org.uk/courses

Applicants who do not have exemplifying qualifications may demonstrate the required knowledge and understanding in other ways, but must clearly demonstrate they have achieved the same level of knowledge and understanding as those with exemplifying qualifications.

Ways to demonstrate this include:

- Taking further qualifications, in whole or in part, as specified by the institution to which they are applying

- Completing appropriate work-based or experiential learning

- Writing a technical report, based on their experience, and demonstrating their knowledge and understanding of engineering principles

- Until 2011, taking Engineering Council examinations.

Applicants should consult their institution for advice on the most appropriate option.

Professional development

This is the other key part of developing competence. It is how potential Chartered Engineers learn to apply their knowledge and understanding and begin to apply professional judgement. It can happen at the same time as some of the formal education referred to above, for example through an industrial placement during a higher education course, or alongside part-time study.

Many larger employers run well-established graduate training and development schemes. While these schemes are of course geared to the specific needs of their organisations, they are frequently designed to help graduates on the way to registration and may have been accredited by one or more of the institutions.

Potential Chartered Engineers in organisations without schemes of this type will need to develop profiles of competence and professional activity to help them prepare for registration. In some cases employers will use occupational standards or competence frameworks in determining job descriptions and staff development, and these may assist in developing a competence profile. Otherwise aspiring registrants should use the competence and commitment statements and seek advice and guidance from the relevant institution, which may be able to put them in touch with a mentor to assist them through the process and help them address any gaps in their development.

Those seeking Chartered Engineer registration should maintain a detailed record of their professional development, responsibilities and experience, verified by supervisors or mentors, to provide best evidence for the professional review (see page 8).

The Institution of Engineering and Technology

Founded 1871 Incorporated by Royal Charter 1921

This is to certify that

Ian Craig

Member of the Institution of Engineering and Technology
was registered on the 05 April 2013 as a

Chartered Engineer

President | Member of the Board of Trustees | Chief Executive and Secretary

The Institution of Engineering and Technology
Michael Faraday House
Six Hills Way, Stevenage
Hertfordshire, SG1 2AY
United Kingdom
T +44 (0)1438 313311
F +44 (0)1438 765526
www.theiet.org

IET Volunteering

Mr I Craig CEng MIET
11 Carisbrooke Road
Hartlepool
Cleveland
TS26 0AB

12 June 2014

Dear Mr Craig,

I am delighted to confirm that the IET Registration Group has approved your appointment as an Assessor assigned to Panel G (building services).

The post of Assessor is for a three year term extending from May 2014 to April 2017. Emma Norcott (Registration and Standards Support Officer) and I look forward to working with you in this capacity for the next three years. Our contact details are as follows:

Louise Parfrey
Manager, RSSU
lparfrey@theiet.org
+44 (0)1438 767422
+44 (0)7725 498121

Emma Norcott
RSSU Support Officer
enorcott@theiet.org
+44 (0)1438 765615

As part of the approval process for our Assessors you are now invited to attend a New Assessor / PRA training workshop designed to provide you with the necessary skills required to carry out your volunteering role. The workshops are being held at Institution of Mechanical Engineers (IMechE), 1 Birdcage Walk, Westminster London, SW1H 9JJ, on:

Thursday 16th October
Thursday 06th November

I would be grateful if you could advise Emma Norcott (contact details above), which date is most convenient for you. If attending, all supporting documentation will be sent out one week prior. Once you have attended the training workshop you will be "activated" on our system and sent electronic applications to review.

The IET will reimburse any necessary expenses incurred in connection with attending the workshop and carrying out activities relating to this volunteer position on the basis of rail travel, car mileage (mileage rates are on the expense claim form), light refreshments and station car parking. Please note that receipts must accompany any expense claim form.

The volunteer toolbox area of the IET website contains links and information to assist you in your volunteering role http://www.theiet.org/volunteers/profreg/volunteer-toolbox/index.cfm. Please familiarise yourself with the volunteer data protection policy guidelines http://www.theiet.org/volunteers/resources/policies/index.cfm. You will need to be logged on to the IET website to access the above.

The IET is most grateful to members such as yourself for the valuable work that you will be undertaking on its behalf.

If you require any further assistance, please do not hesitate to contact Emma or I.

Yours sincerely,

Louise Parfrey
Manager, Registration and Standards Support Unit
Tel: +44 (0)1438 767422
Mobile: +44 (0)7725 798121
Email: lparfrey@theiet.org

Ian Craig

From:	Vincent Goh <vincent.goh@yinsonproduction.com>
Sent:	06 October 2016 08:46
To:	Ian Craig
Subject:	RE: PO 1305.51.8220.XX.071 - Seawater Suction Hoses - Shipping Documents

Ian,

It have been my pleasure & honour working with Emstech through you as regards to this Pkg.
A very enriching & rewarding experience , you are a true professional

Thanks/regards
Vincent

From: Ian Craig [mailto:ian.craig@emstec.net]
Sent: 6. oktober 2016 3:32
To: Vincent Goh <vincent.goh@yinsonproduction.com>; 'Andreas Rekowski' <a.rekowski@emstec.net>
Cc: 'Sunaina Panday' <sunaina@altuslogistics.com>; 'Goh Tian Hock' <t.h.goh@altuslogistics.com>; Hafsah Mohd <hafsah.mohd@yinsonproduction.com>
Subject: RE: PO 1305.51.8220.XX.071 - Seawater Suction Hoses - Shipping Documents

Vincent,

Noted and thanks.

Best regards,
Ian Craig
- Project Manager -

EMSTEC GmbH
Gewerbering 8
22113 Oststeinbek
Germany

Tel.: +49 (0) 40 79 686 345
Fax: +49 (0) 40 79 686 702

Mail: ian.craig@emstec.net
Web: www.emstec.net

VAT-No.: DE286878278
Commercial Register Lübeck
HRB 13035 HL

Managing Director: Martin Kunzig

Section 3.0: State of the Art Review

SEAWATER INTAKE RISERS FOR
FLOATING LIQUEFIED NATURAL GAS (FLNG) VESSELS

IAN CRAIG

STATE OF THE ART TECHNOLOGY

Submitted in partial fulfilment of the requirements
of the University of Sunderland for the degree of
Professional Doctorate

June 2018

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LIST OF FIGURES

1. INTRODUCTION

With reference to the summary State of the Art Review presented in section 1.2 of the accompanying Doctoral Report, this report provides a more detailed review of the system under consideration, including the typical components within the system, common variants to the system and the known concepts and layouts.

The review is summarised at the end which highlights the main points from this state of the art review.

2. State of the Art Technology

2.1.1. FPSO

As the onshore, shallow water and more easily accessible oil reserves become depleted, oil companies are taking oil exploration and production to deeper and less accessible locations. This has seen an emergence of floating oil production installations, often referred to as FPSO (Floating Production Storage and Offloading) vessels, where the water depth makes a fixed leg platform impractical or where the reservoir location is too remote from a pipeline infrastructure. As the acronym suggests, an FPSO is a ship shape vessel that is moored to the seabed over the oil reservoir from which oil is delivered to the FPSO via flexible riser pipes. The oil is treated through an on-board process or 'production' facility and then stored in the tanks of the vessel. A sea going 'shuttle' tanker comes alongside and is connected to the FPSO, so that the stored oil can be transferred to the tanks of the shuttle tanker via an offloading system. The shuttle tanker then transports the oil onshore. Fig.2-1 shows the quantity and location of FPSO vessels currently in operation.

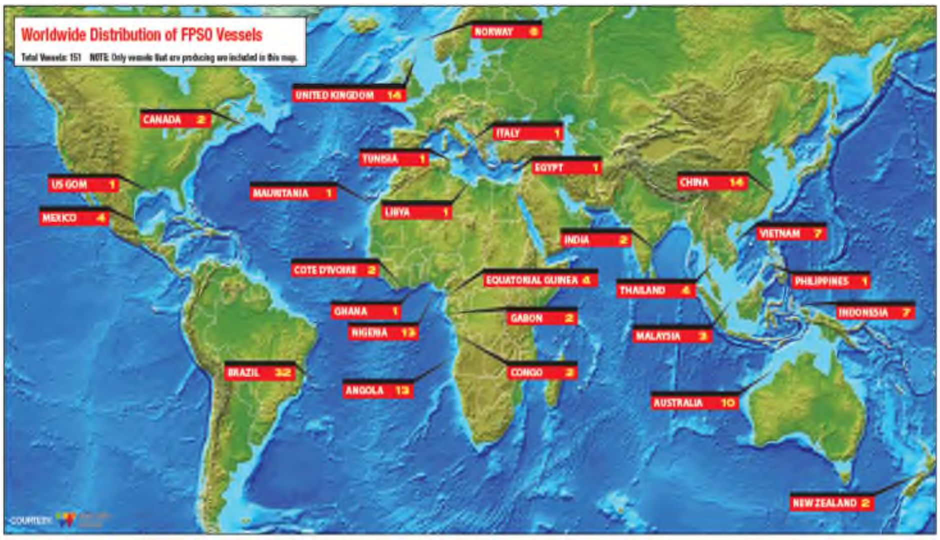

Fig.2-1: Worldwide Distribution of FPSO Vessels

(Nutter, 2014)

In many locations, particularly the warm water locations such as West Africa and Brazil, process engineers have found it beneficial to use cooler, cleaner and less oxygenated seawater from below sea level for the vessel's cooling, process, utility and water injection systems. This is achieved using a Seawater Intake Riser (SWIR) system, the utilization of which is fairly recent in the industry, with the first systems being installed circa. 2000. To date there are estimated to be approximately 150 FPSO vessels in operation of which approximately 60 are in deep water locations (Nutter, 2014) and likely to have a SWIR system installed, the functional requirements of each being similar in terms of volumetric flow and depth from which water is imported. While the system design has been refined over the years, the basic concept of the systems has not changed indicating that the current technologies are proven and industry accepted.

A SWIR system is effectively a number of flexible pipe sections connected together and suspended from the underside of the FPSO at the seawater inlets in the form of a free-hanging cantilever, enabling the seawater pumps to draw seawater from a specified depth below sea level. Each SWIR system is bespoke to each installation, designed accordingly and subject to a hydrodynamic analysis which considers the vessel response characteristics, the field specific environmental conditions and the flexible hose string properties which can be optimised to suit the required configuration. The length of each SWIR system is also field specific but to date, the maximum depths achieved have been approximately 120-130m. Consequently, the SWIR system cannot be installed at the onshore location during the vessel construction and must be deployed once the vessel has been moored over the reservoir, which creates a number of limitations to its design, most notably the weight restriction. The SWIR system is generally deployed using a similar technique to a drill string, that is, the first flexible pipe section is held in a vertical position while the next section is lowered into place by the on-board vessel crane and connected to the first section. The two connected sections are then lowered into the water by the vessel crane until the second section can be held to enable a third section to be connected, and so on until the desired length is achieved. It is desirable to utilise the on-board vessel crane for the installation (and recovery for maintenance and inspection) of the system as opposed to an external heavy lift crane which can be expensive to charter. Therefore, the capacity of the on-board vessel crane can limit the installation weight of the SWIR which is a function of the diameter and quantity of flexible pipe sections.

A typical configuration for a SWIR system installed on an FPSO would consist of three 20"NB SWIR, 50-100m in length, with a flow rate of 2000m^3/hr per SWIR. Each SWIR is normally fitted with a coarse strainer at the lower end to prevent the ingress of debris or sea life.

A marine growth protection system (MGPS) is normally installed in the system which consists of a small-bore sodium hypochlorite line attached to the flexible pipe sections, to enable sodium hypochlorite to be injected into the seawater via a dispersion ring fitted inside the strainer.

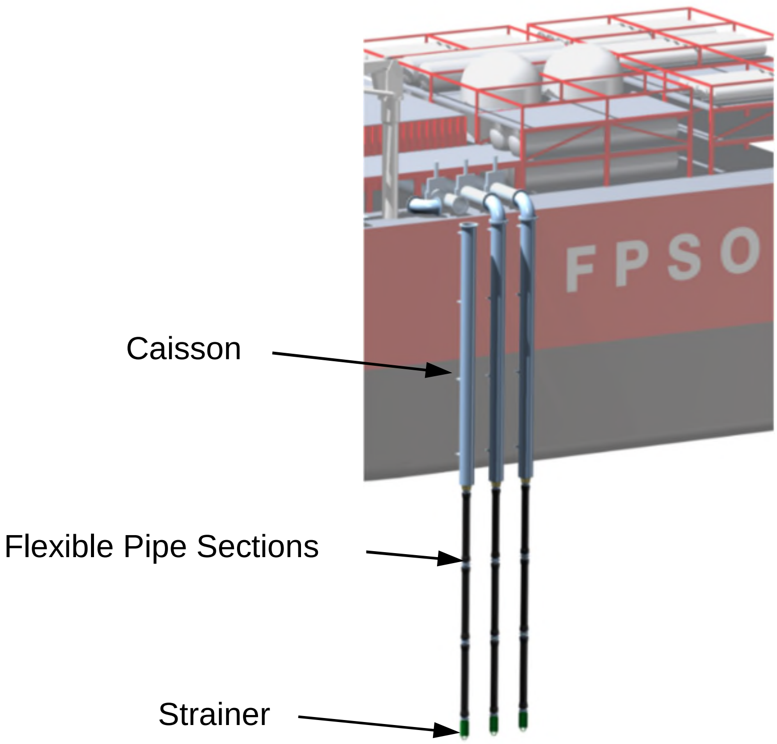

Fig.2-2: Typical SWIR System on an FPSO (External Caisson)

2.1.2. Typical Components of SWIR System

The following is an outline description and the function of the components that generally constitute a SWIR system.

- *Riser Seat*

The riser seat forms an integral part of the caisson. It is welded to bottom of the vessel caisson and incorporates an internal female conical seat to mate with and centralize the riser head. The structure also includes an internal circumferential bearing ring that mates with the riser head. To prevent the exposure of bare carbon steel at the mating faces, a super duplex machined overlay is installed to each seat face.

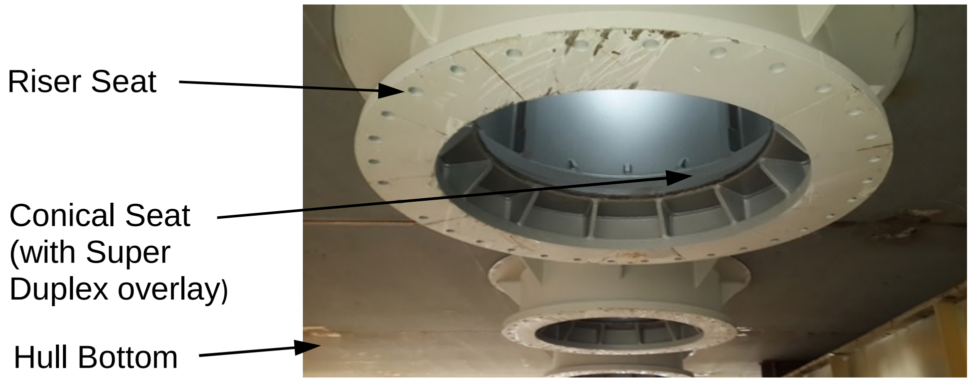

Fig.2-3: Installed Riser Seat

- *Riser Head*

The riser head provides the interface between the Riser Seat and flexible pipe sections and includes a male conical load ring to mate with the female conical seat within riser seat, preventing downward and lateral movement. To prevent tilting, the riser head includes an external upper circumferential bearing ring which mates with the riser seat internal circumferential bearing ring. The riser head has a flange connection to facilitate connection of the flexible hose sections.

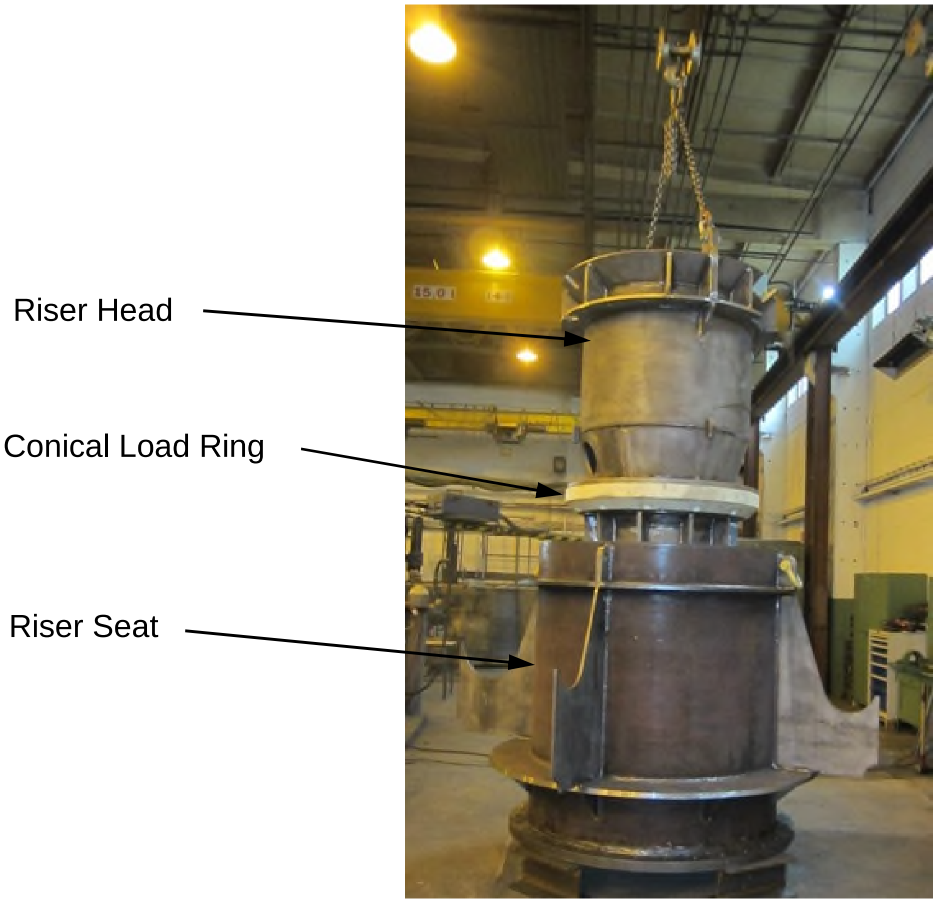

Fig.2-4: Factory trial fit of Riser Head into Riser Seat

- *Flexible Pipe Sections*

The flexible pipe sections are typically bonded rubber flexible pipe sections that are designed specifically for this application and are connected together in a 'string' for the conveyance of seawater. The flexible pipe properties are optimised to ensure that, during operation, the vessel motion and environmental conditions do not compromise the flexible pipe design parameters, whilst minimising the loads and moments into the caisson structure. The ends of the flexible pipe sections are flanged and hypochlorite hose supports are built in to secure and support the hypochlorite line. The flexible pipe sections are connected by means of stud bolts complete with full nuts and lock nuts.

Fig.2-5: Flexible Pipe Sections

- *Hypochlorite Line*

A hypochlorite delivery hose is normally attached to each seawater flexible pipe section and connected to form a continuous line from the top of the caisson to the strainer unit. The purpose is for the conveyance of sodium hypochlorite to the intake strainer, enabling it to be injected into the seawater as it is imported. All wetted metallic parts within the hypochlorite system are manufactured from titanium, this being resistant to chemical attack from sodium hypochlorite.

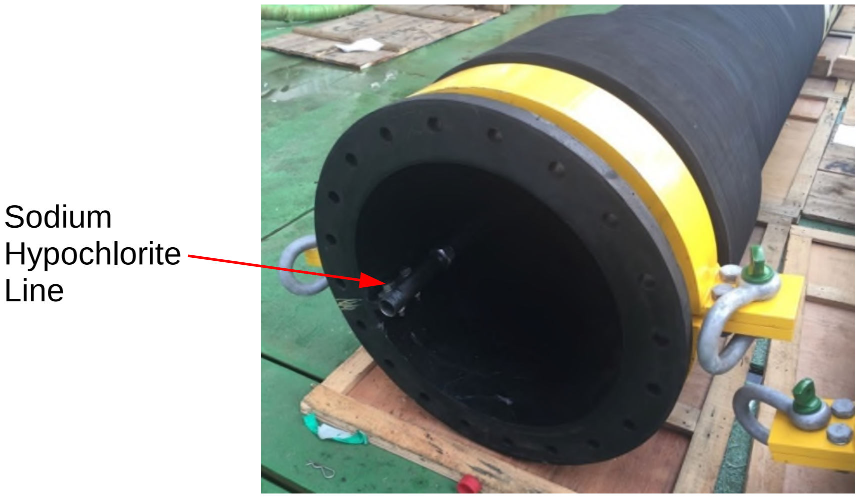

Fig.2-6: Sodium Hypochlorite Line

- *Strainer*

A coarse strainer is connected to the lower end of the seawater flexible pipe string to prevent the ingress of large sea life or debris into the seawater system. The strainer includes a hypochlorite dispersion ring which enables sodium hypochlorite to be injected into the seawater as it is drawn into the system.

- *Cathodic Protection*

Where required, sacrificial anodes are bolted to the metallic components in the system to provide cathodic protection to the system.

Fig.2-7: Strainer c/w Stud bolts & Cathodic Protection

2.1.3. Variants to the SWIR System

Since the first systems were introduced, the design of the SWIR has been optimised based on feedback from the field and a number of variants are now commonly considered for each project.

- *Diverless & Diver Assisted Installation*

  A SWIR system 'diverless installation' is installed through a caisson and without the aid of divers. The riser seat is supplied and pre-installed during the construction phase of the vessel. When the vessel is on station, the flexible pipe string is assembled and deployed through the caisson and lowered into place until the riser head, installed to the top end of the flexible pipe string, engages with the pre-installed riser seat structure. Using a hydraulically activated deployment tool, the release mechanism is activated by a hand pump at the caisson head, allowing the deployment tool to disengage from the installed SWIR and be retrieved through the caisson.

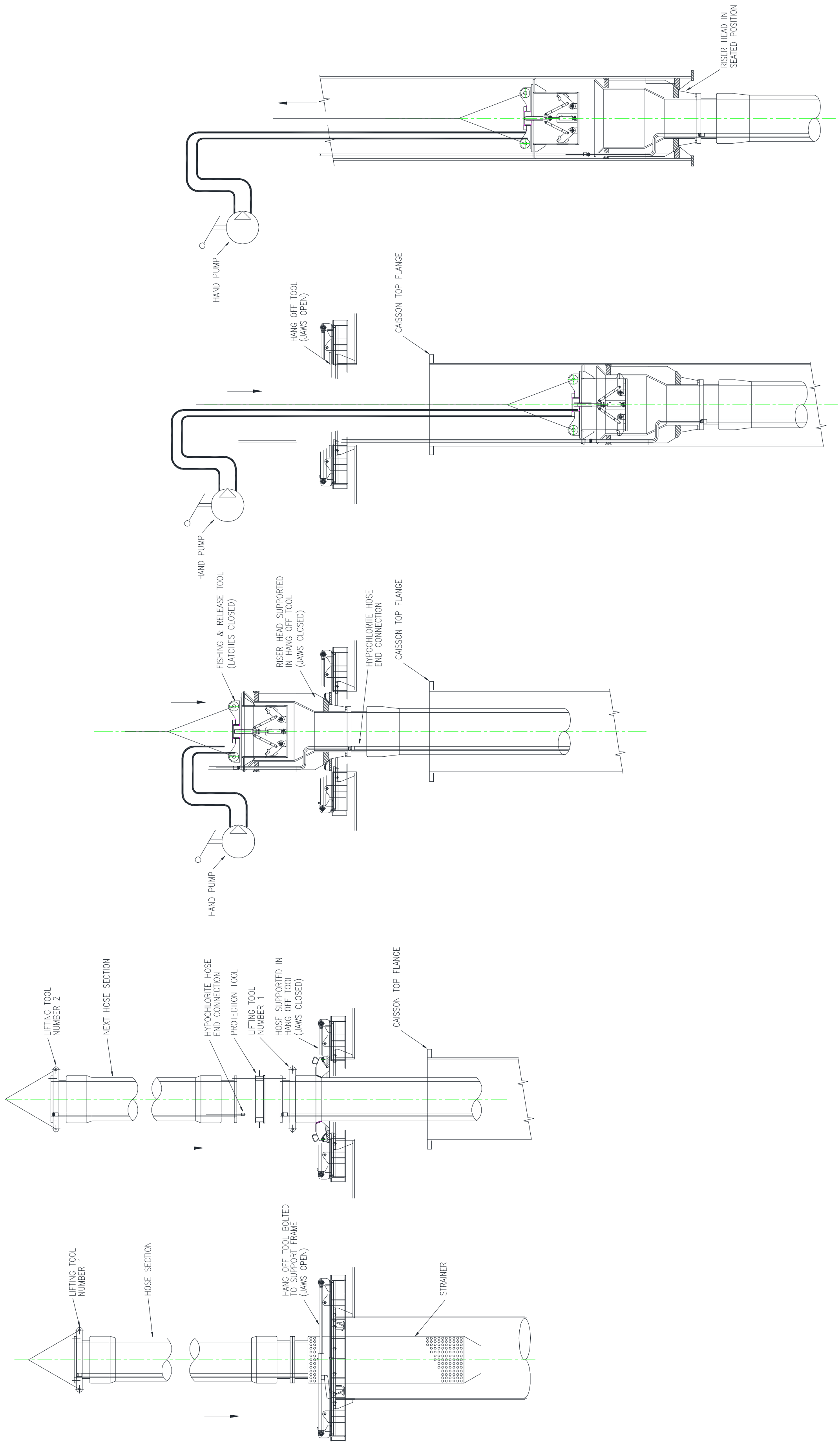

Fig.2-8: Installation Sequence for Diverless Installation System

A diver assisted system is assembled in a similar manner to the above except that it is assembled over the side of the vessel rather than through a caisson. Using the on-board vessel crane and a series of pull-in wires, the assembled flexible pipe string is lowered into the water over the side of the vessel and then pulled up to the underside of the caisson or sea chest connection. This connection is typically a bolted flange connection which needs to be made by divers.

Fig.2-9: Diver Assisted Installation

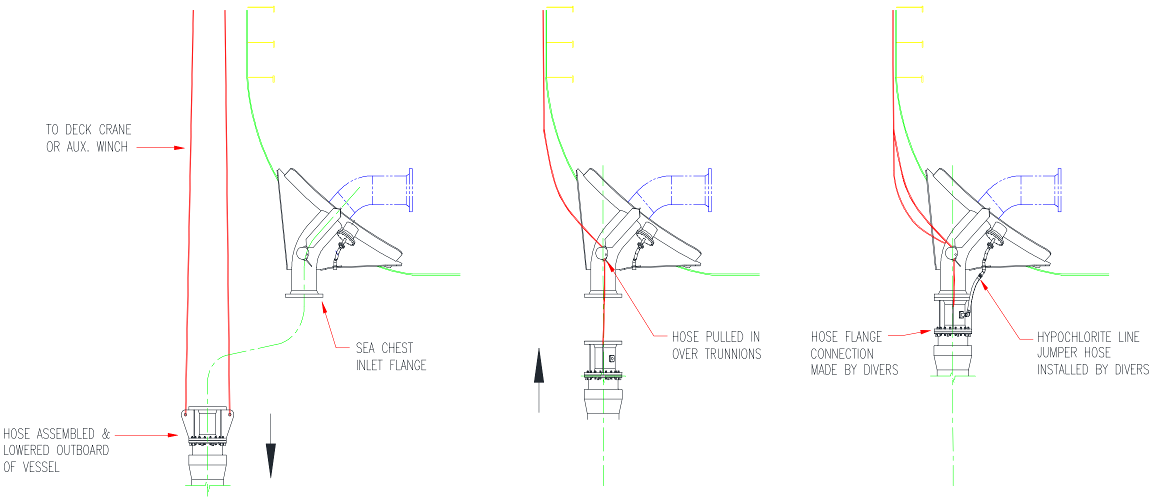

Fig.2-10: Installation Sequence for Diver Assisted Installation System

- *Rubber Hose or HDPE Sections*

Where the installation weight of the SWIR System has become critical, alternative configurations have been installed utilising High Density Polyethylene (HDPE) sections. HDPE is positively buoyant so once submerged, the crane hook load is relieved and the installed weight of the system is reduced. A typical configuration utilising HDPE will consist of a flexible rubber top hose, as this is where the main loads and bending occurs, with the lower sections from HDPE. Due to the reduced weight of this configuration, a ballast weight is normally installed at the lower end of the hose string to provide stability. Additional advantages of HDPE are that, it has a smoother surface than rubber which improves the pressure loss characteristics of the system, also, due to the smooth surface, marine growth does not readily attach to the surface.

Fig.2-11: HDPE Pipe Sections

- *External or Internal Hypochlorite Line*

To enable the injection of Sodium Hypochlorite, a small-bore hypochlorite line is commonly installed along the complete length of the flexible pipe string, terminating at a dispersion ring within the coarse strainer. When installed in a diverless system, the hypochlorite line is located inside the main seawater flexible pipe, fixed and supported at each hose flange connection (ref. Fig 1-6), to protect it from potential damage during installation.

For a diver assisted system, the hypochlorite line can be installed either internally of externally. When installed externally, the hypochlorite line is generally fitted helically around the main seawater pipe section.

For diver assisted systems, a diver installed jumper hose connects the hypochlorite line to the vessel MGPS.

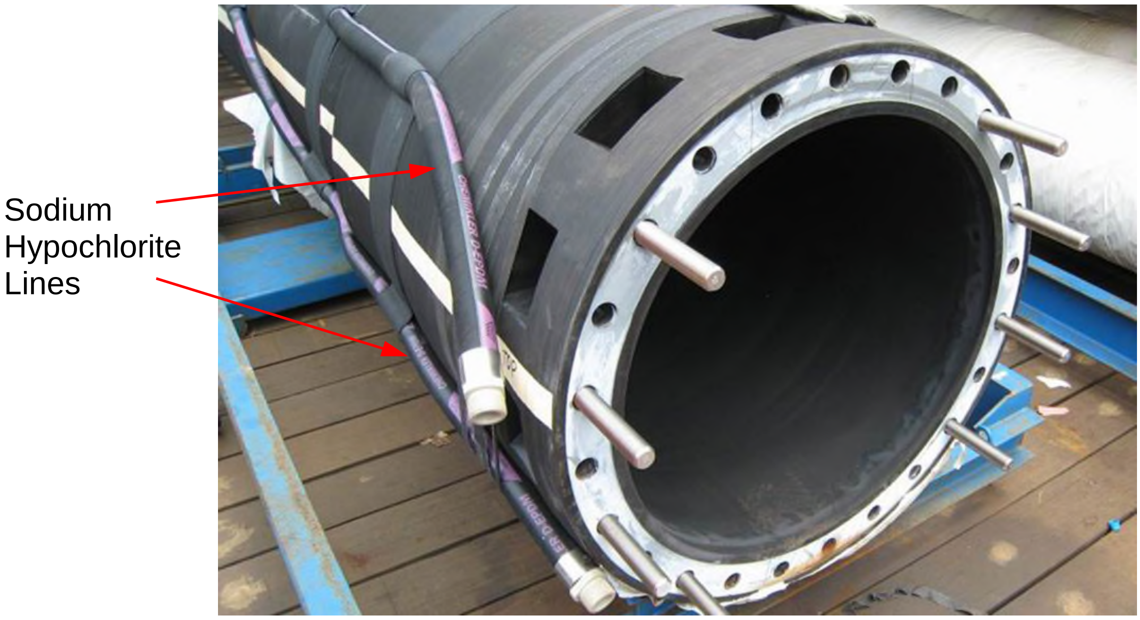

Fig.2-12: External Hypochlorite Line Arrangement (Dual Line shown)

- *Single or Dual Hypochlorite Line*

Due to the potential problems of marine growth being ingested into the system, for example, blockage of heat exchangers and associated shutdown costs, the marine growth protection system is considered by some operators as a critical system.

Therefore, to provide 100% redundancy capability of the system, it is common for projects to specify a dual hypochlorite line consisting of two completely independent hypochlorite lines and dispersion rings.

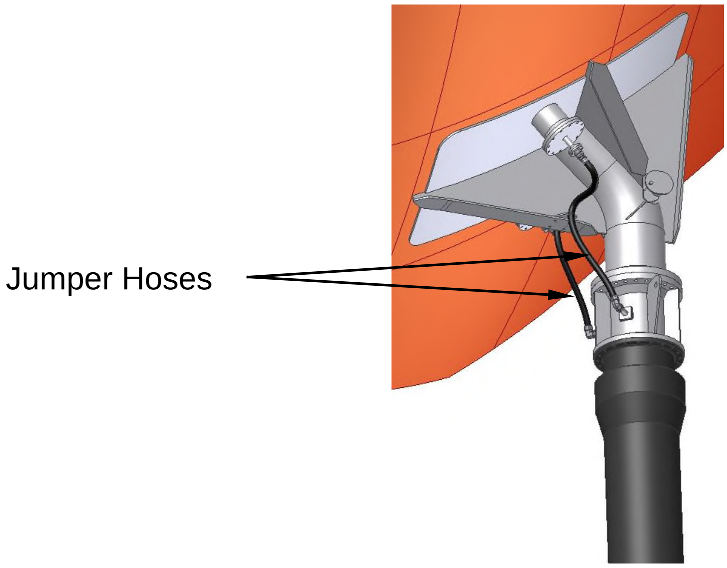

Fig.2-13: Dual Internal Hypochlorite Line (Diver Assisted Installation)

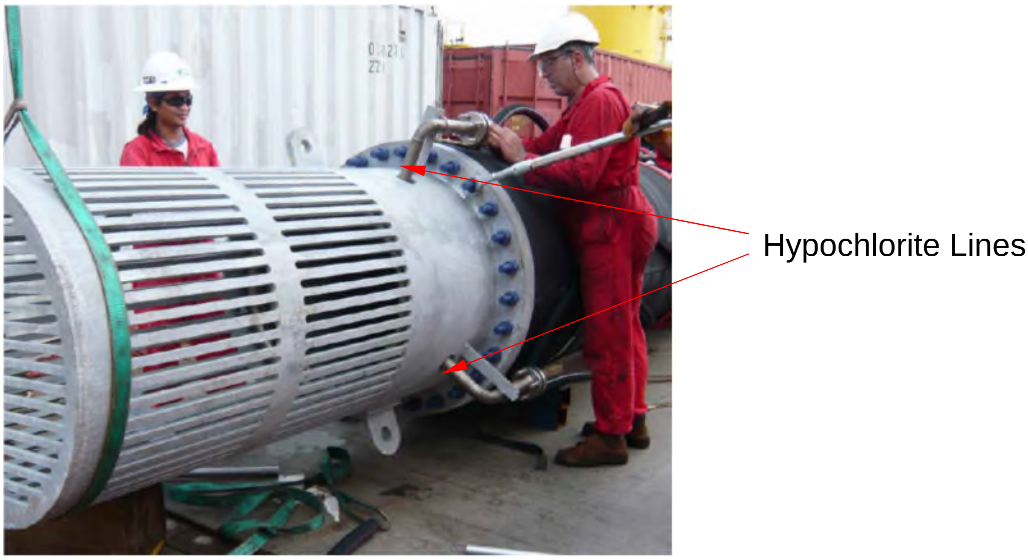

Fig.2-14: Dual External Hypochlorite Line

- *Cathodic Protection or Corrosion Resistant Materials*

The flexible rubber pipe sections generally used for SWIR are fully encapsulated with rubber and as such do not have any exposed metallic components.

However, other metallic components within a system include, riser seat, riser head, stud bolts and nuts and the strainer, and typically, each of these components will be manufactured from carbon steel and coated with an appropriate subsea paint system. The strainer is often coated with a foul release paint system to prevent marine growth and reduce the possibility of blockages. In addition to this, sacrificial anodes are fitted to provide cathodic protection (CP) for the submerged components, the exception usually being the riser seat which, being a part of the vessel hull, is connected to and protected by the vessel CP system.

For the metallic components within the system, there are a number of corrosion resistant materials currently in operation in the field. For example, the stud bolts and nuts have been manufactured from super duplex stainless steel on a number of projects and in one case titanium bolting was specified. This negates the requirement for sacrificial anodes thus reducing the potential maintenance requirements.

Fig.2-15: Flange Connection with Carbon Steel Stud bolts & Anodes

Fig.2-16: Flange Connection with Super Duplex Stud bolts (No Anodes)

Similarly, the strainer has been manufactured from super duplex stainless steel on previous projects, again negating the requirement for sacrificial anodes. Although it is not known if any are currently in the field, there has recently been more interest in manufacturing the strainer from a copper alloy to prevent the attachment of marine growth.

As the riser seat usually forms a part of the vessel hull and as the riser head is accessible, these components are generally manufactured from carbon steel, although there is one known system in the field where these components are manufactured from the super austenitic stainless steel 6Mo.

- *Guide Bar or Orientation Pipes*

To ensure that the hypochlorite line is not subjected to excessive loading during operation, it is necessary to prevent rotation of the installed SWIR once deployed. This is normally achieved by incorporating anti-rotation brackets onto the riser head which engage with stop plates fitted within the Riser Seat. Therefore, to ensure that the hypochlorite line and the anti-rotation brackets are correctly aligned during installation, two methods are currently considered.

A guide bar can be pre-installed along the full length of the caisson and the riser head and installation tools designed to have a corresponding cut-out (similar to a keyway), so that during deployment, the SWIR cannot rotate and is seated in the correct orientation.

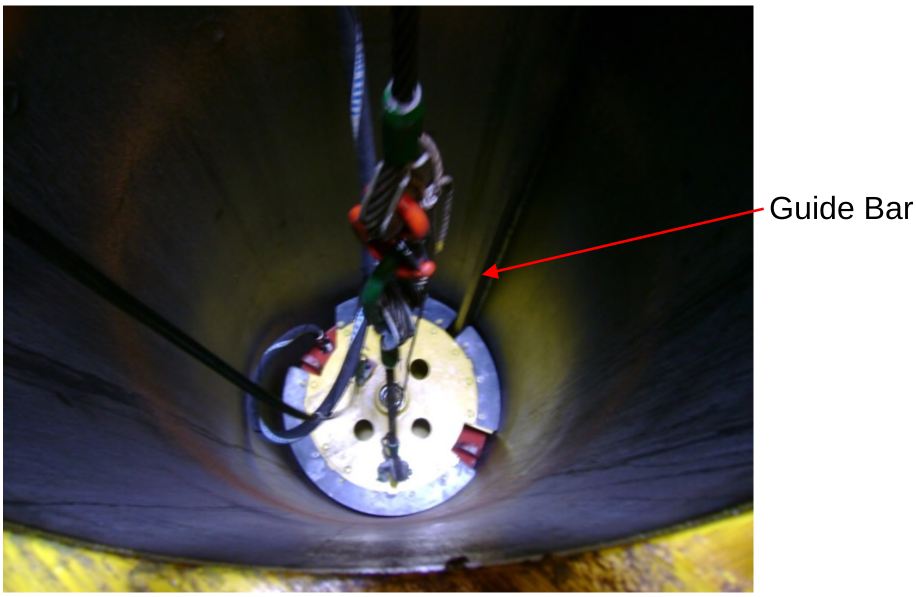

Fig.2-17: Installation using Guide Bar

Alternatively, a set of orientation pipes can be provided with the installation tools. These pipes are connected to the deployment tool as is it is lowered into the caisson. A datum point is marked at the top of the caisson which corresponds to a datum point on the Riser Seat.

The orientation pipes are marked accordingly such that, during deployment, a torque can be applied to the suspended SWIR string to ensure that the riser head is correctly aligned inside the Riser Seat.

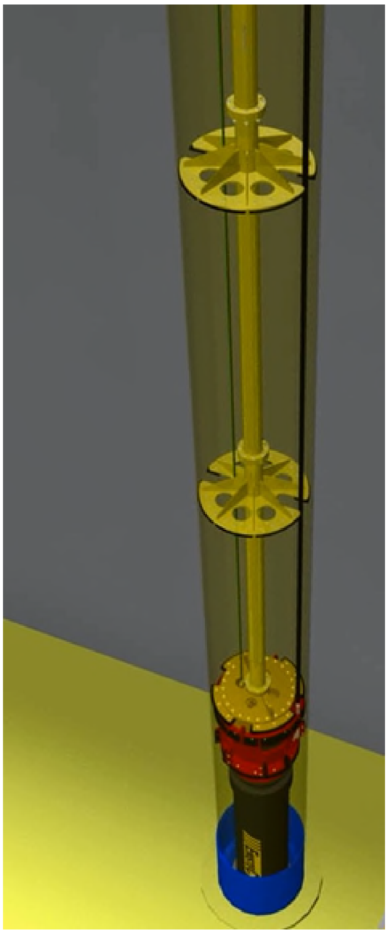

Fig.2-18: Installation using Orientation Pipes

- *Installation Tooling*

The installation tools that are supplied with the system have been optimised over the years with a great focus on the safe handling of the equipment during installation. Consequently, a number of safety features have been incorporated within the installation tools such as locking pins and positive spacers for hose connection.

2.1.4. SWIR Concepts and Layouts

- *Single Pipes*

A single pipe configuration refers to a SWIR that is not joined to another SWIR or structure and is free to move independently. This configuration can be connected directly to the seawater caisson or intake from the underside of the vessel using divers or it can be installed from the topsides through a caisson and without the aid of divers. On an FPSO it is common to have up to 6-off single pipe configurations installed in line either longitudinally or transversely in relation to the vessel centreline.

As an independent assembly, a single pipe configuration can be removed for inspection and maintenance without having to disturb another SWIR.

Previous analyses have shown that, when multiple SWIR have been installed, they each behave similarly to both current and vessel motions. However, there is a possible scenario whereby if a current with sufficient velocity is heading in line with the SWIR, the leading SWIR generates a wake and the subsequent SWIR react to that wake and behaves differently. Depending upon the spacing of the SWIR and the current velocity, the analyses have shown that in this scenario, there is a possibility that the strings may collide with one another.

- *Bundled Pipes*

A bundled pipe configuration is one where multiple seawater intake pipes are connected to one another and / or a structure. The conceptual feature of the bundle is to ensure that each of the intake pipes moves in conjunction with the others and do not clash with one another, thus removing the wake effect.

Although there are no bundled pipe configurations currently in operation, it is known that for the Shell Prelude FLNG project (Pipeline & Gas Journal, 2014) a bundled concept has been developed comprising of 8-off intake pipes and a central supporting structure.

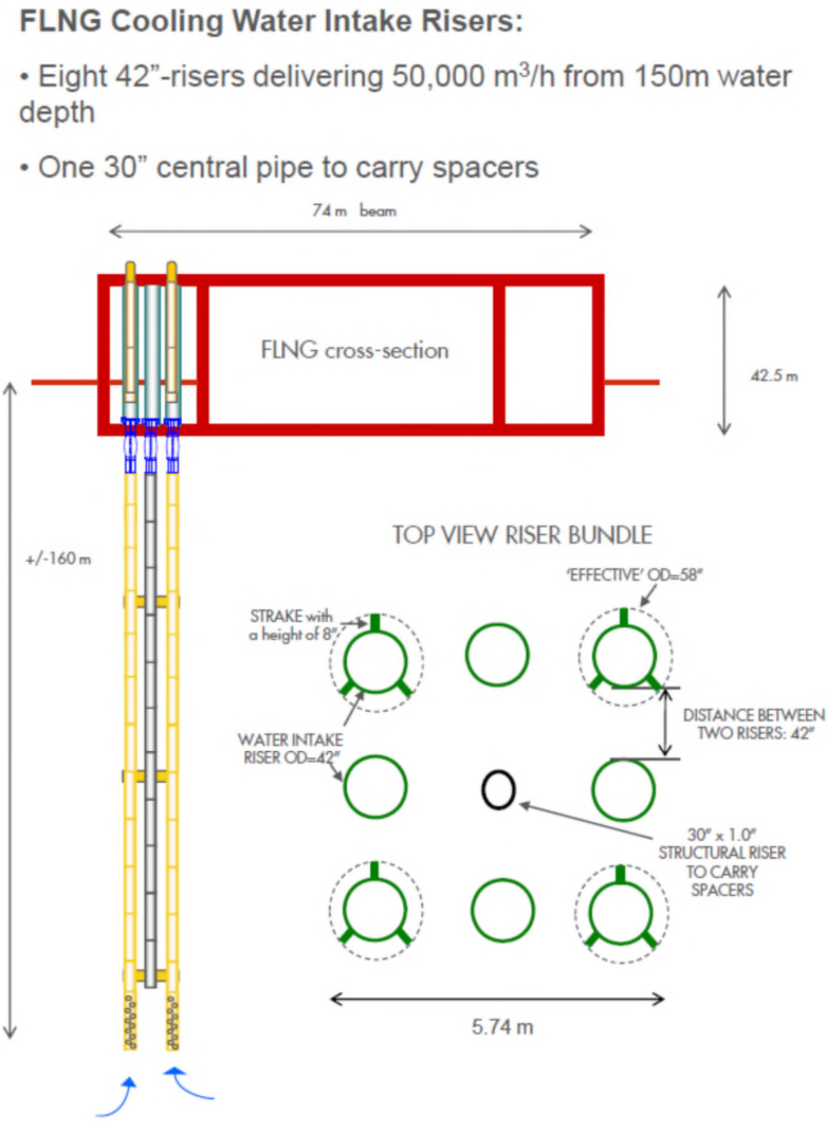

Fig.2-19: Shell Prelude FLNG Seawater Intake Riser (SWIR) Bundle (Project Connect, 2011)

The initial installation of this bundled system requires that the central supporting structure is installed from the underside of the vessel utilising a heavy lift crane. It also requires a temporary installation platform to assist with the deployment of the central supporting structure. The SWIR are then assembled and fed through caissons and through the openings in the central support structure. The risers are manufactured from steel and are each connected to the hang off point by a short flexible rubber pipe section. Within each of the rubber hose sections is an articulated link which accommodates the tensile load of the bundle. Although this system is not yet in service, and consequently unproven, it is known that scale model tests have been performed (Efthymiou, 2015).

- *Caisson Arrangements*

In offshore terminology, a caisson is an open tubular structure that is installed vertically from a position below the waterline of an installation to a position above the waterline. Caissons are commonly used for the intake of seawater by either installing a submersible pump within the caisson or by taking a branch from the caisson into an adjoining compartment where a centrifugal pump, or similar, can be connected.

Caissons can be installed either externally of internally, an external caisson being one that is attached to the outside of the vessel hull, whereas in internal caisson is incorporated into the hull structure, as shown below;

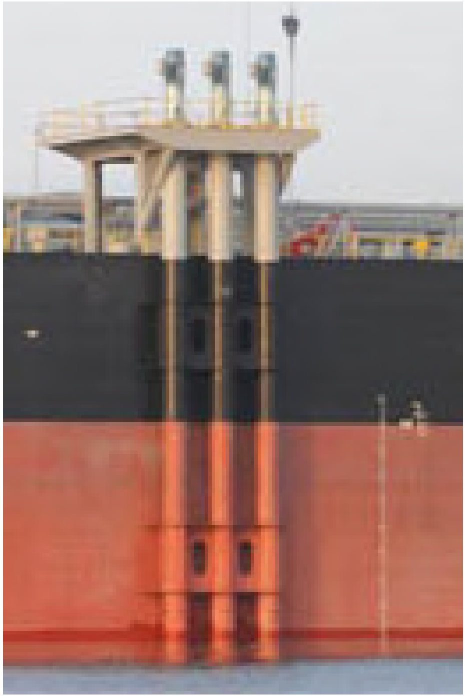

Fig.2-20: Vessel fitted with External Caissons

Fig.2-21: Vessel fitted with Internal Caissons (and riser heads in trial fit)

An external caisson would normally accommodate a submersible pump whereas an internal caisson may utilise both pump configurations. The type and location of caisson would normally be selected to suit the layout of the topsides process systems. In terms of design, the main difference is that, as an external caisson does not form part of the hull structure and will not affect the watertight integrity of the vessel if damaged, it is not subject to design approval by the classification society. An internal caisson does form a part of the vessel hull structure and therefore does require design approval by the classification society.

To provide system redundancy, a complete caisson, pump and SWIR are often specified to enable the maintenance of the other SWIR. Retrieval of the SWIR for maintenance and inspection would require that the submersible pump, if installed, would need to be removed first.

- *Sea Chest Arrangements*

Traditionally, a sea chest is a small compartment incorporated into the hull of a sea going vessel that is open to the sea and provides an intake point for the seawater

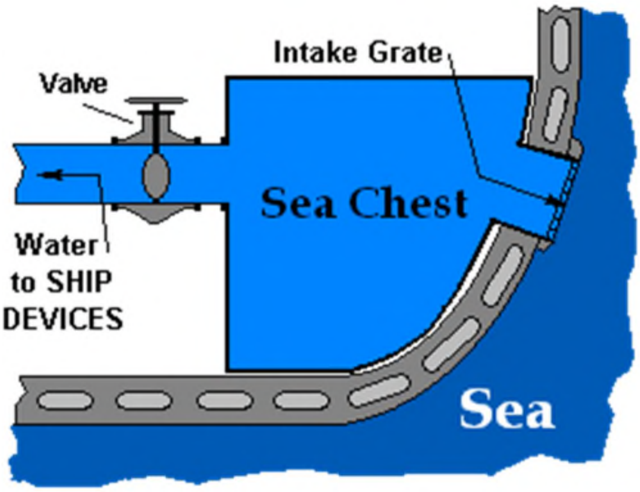

Fig.2-22: Traditional Sea Chest Arrangement

However, on an FPSO vessel with a SWIR requirement, a sea chest can differ from the traditional concept. For example, if an existing Oil Tanker is being converted into an FPSO, the existing sea chest may be modified and fitted with an inlet pipe to accommodate a SWIR as shown below.

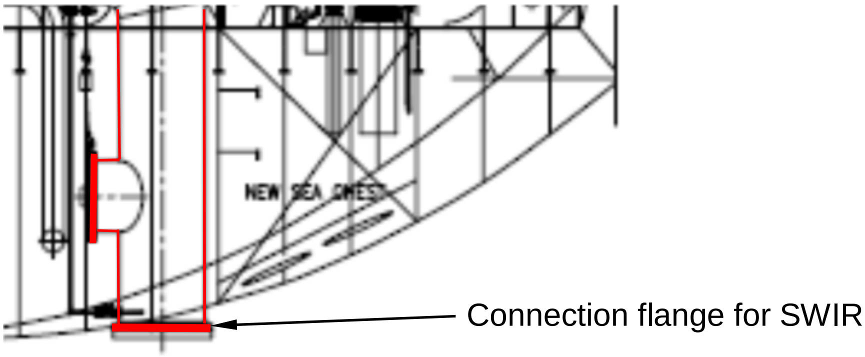

Fig.2-23: Sea chest with Intake Pipe

Alternatively, the sea chest may be a much larger compartment that is flooded and provides sufficient volume to feed multiple seawater pumps. The pumps selected in this arrangement could be a series of submersible pumps arranged within the flooded compartment or else centrifugal pumps, or similar, positioned outside the flooded compartment and connected to an outlet pipe. This larger flooded compartment would be fitted with an inlet pipe(s) to enable the installation of SWIR.

2.1.5. Summary

This state of the art review of systems currently operating in the field on FPSO vessels, has highlighted the following main points:

- There are numerous FPSO currently operating in the field that have seawater intake riser systems installed.
- To date, only the single pipe concept has been installed on FPSO vessels which indicates that the design, material selection and installation technique are all field proven and accepted by the industry. There are many variants to the single pipe seawater intake riser but the basic concept remains the same.
- To date, the bundle concept has not been installed on any vessel and is currently unproven. However, it is known that one project currently under construction will adopt the bundle concept.

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[Accessed 11 August 2014].

Section 4.0: Field Data

List of Existing Seawater Intake Systems - Suppled by Emstec GmbH (Nov 2016)

Project	Client	System Type	Equipment	Year	Contact Details	Contact Date	Response Received	Field Data Received	Comments
MV29 Cidade de Campos dos Goytacazes	MODEC	External Caisson Diverless Installation	6 x 22NB x 43m	2015	Not operational				
Ghana OCTP Development FPSO	YINSON	External Caisson Diverless Installation	2 x 36NB x 90m	2015	Not operational				
MV25 Tullow T.E.N.	MODEC	External Caisson Diverless Installation	3 x 22NB x 94m	2014	Not operational				
MV 27 Cidade de Caraguatatuba	MODEC	External Caisson Diverless Installation	4 x 20NB x 40m	2014	Not operational				
MV 26 Cidade de ITAGUAI	MODEC	External Caisson Diverless Installation	4 x 20NB x 40m	2013	Ng Chunchong ng.chunchong@modec.com	21.01.15	25.02.15		follow up (23.02.15), will try to get some data in coming months
Cidade de Paraty	SBM - Single Buoy Moorings Inc.	Sea Chest Diver Assisted Installation	2 x 26NB x 10m	2013	Ebert Vlasveld Ebert.Vlasveld@sbmoffshore.com	21.01.15	24.02.15		follow up (23.02.15), request forwarded to operations, awaiting response
Petronas PFLNG1 Project	TECHNIP PETRONAS	Internal Caisson Diverless Installation	5 x 26NB x 37m	2013	Not operational				
Cidade de Ilhabela (Guara Norte)	SBM - Single Buoy Moorings Inc.	Sea Chest Diver Assisted Installation	3 x 40NB x 18m	2013	Ebert Vlasveld Ebert.Vlasveld@sbmoffshore.com	21.01.15	24.02.15		follow up (23.02.15), request forwarded to operations, awaiting response
OSX 2	SBM - Single Buoy Moorings Inc.	External / Sea Chest	1 x 30NB x 18m	2012	Ebert Vlasveld Ebert.Vlasveld@sbmoffshore.com	21.01.15	24.02.15		follow up (23.02.15), request forwarded to operations, awaiting response
MV24 Cidade de Mangaratiba	MODEC	Internal Caisson Diverless Installation	4 x 20NB x 40m	2012	Ng Chunchong ng.chunchong@modec.com	21.01.15	25.02.15		follow up (23.02.15), will try to get some data in coming months
ASENG FPSO	SBM Offshore Noble Energy	Internal Caisson Diverless Installation	1 x 24NB x 97m	2010	Ebert Vlasveld Ebert.Vlasveld@sbmoffshore.com	21.01.15	24.02.15		follow up (23.02.15), request forwarded to operations, awaiting response
Petrobras FPSO Cidade de Sao Paulo MV23	MODEC	Internal Caisson Diverless Installation	3 x 20NB x 40m	2010	Ng Chunchong ng.chunchong@modec.com	21.01.15	25.02.15	YES	follow up (23.02.15), will try to get some data in coming months
JUBILEE DEEPWATER DEVELOPMENT	MODEC	Internal Caisson Diver Assisted Installation	3 x 20NB x 40m	2009	Ng Chunchong ng.chunchong@modec.com	21.01.15	25.02.15	YES	follow up (23.02.15), will try to get some data in coming months
PETROBRAS OPPORTUNITY GAS II	MODEC	Internal Caisson Diver Assisted Installation	2 x 18NB x 20m	2009	Ng Chunchong ng.chunchong@modec.com	21.01.15	25.02.15		follow up (23.02.15), will try to get some data in coming months
BP SKARV DEVELOPMENT PROJECT BL796	BP Norge	Internal Caisson Diverless Installation	3 x 30NB x 37m	2009	Frej Limayem frej.limayem@akersolutions.com	21.01.15			follow up (23.02.15)
Gjoa Semi Submersible	STATOIL	Internal Caisson Diverless Installation	3 x 24NB x 19m	2008	Dagfinn Thunestvedt dt@framo.no	21.01.15	26.02.15		follow up with Eirik Solhaug (23.02.15)
PETROBRAS OPPORTUNITY WH201	MODEC	Internal Caisson Diverless Installation	3 x 20NB x 20m	2008	Ng Chunchong ng.chunchong@modec.com	21.01.15	25.02.15		follow up (23.02.15), will try to get some data in coming months
GIMBOA FPSO	Saipem SA Energies	Internal Caisson Diverless Installation	2 x 20NB x 70m	2007	Maintenance Supervisor MSupt.CdVitoria@saipem.com	21.01.15	13.03.15		follow up (23.02.15), try MSUP.Gimboa@saipem.com (contacted 13.03.15)
P53 - MARLIM LESTE FPSO	Petrobras	Sea Chest Diver Assisted Installation	2 x 18NB x 32m	2006	not located	21.01.15			
AKPO	TECHNIP	Internal Caisson Diverless Installation	4 x 26NB x 81m	2006	Alain Goussain agoussain@technip.com	21.01.15	21.01.15		suggest contact Francois Dordain (contacted 22.01.15). Technip not respomsible fo rmaintenance, try Christophe Desforge (contacted 27.01.15/23.02.15). Directed to Oladapo Lawal (TOTAL) for maintenance (contacted 24.02.15)
AKPO	TECHNIP	Internal Caisson Diverless Installation	1 x 14NB x 16m	2006	Alain Goussain agoussain@technip.com	21.01.15	21.01.15		suggest contact Francois Dordain (contacted 22.01.15). Technip not respomsible fo rmaintenance, try Christophe Desforge (contacted 27.01.15/23.02.15). Directed to Oladapo Lawal (TOTAL) for maintenance (contacted 24.02.15)
Golfinho 2	Saipem SA Energies	Internal Caisson Diverless Installation	3 x 30NB x 103m	2006	Maintenance Supervisor MSupt.CdVitoria@saipem.com	21.01.15	24.02.15	YES	follow up (23.02.15)
AGBAMI	DSME	Internal Caisson Diverless Installation	3 x 26NB x 115m	2006	Steven Pagan steven.pagan@chevron.com	21.01.15	23.01.15		request forwarded (follow up 23.02.15)
PETROBRAS Espadarte RJS 409	MODEC	Internal Caisson Diverless Installation	2 x 20NB x 94m	2005	Ng Chunchong ng.chunchong@modec.com	21.01.15	25.02.15		follow up (23.02.15)

From: Ian Craig <ian.craig@emstec.net>
Sent: 21 January 2015 15:11
To: 'frej.limayem@akersolutions.com'
Cc: 'morten.brodersen@akersolutions.com'; 'Mike.McCormack@no.bp.com'; 'rutger.ogeman@akersolutions.com'; 'ger.rowlands@no.bp.com'
Subject: Seawater Intake Systems - Inspection & Maintenance
Attachments: Inspection and Maintenance of SWIR.PDF

Dear Frej,

I'm hoping you may be able to assist or point me in the right direction perhaps.

Emstec are continually trying to improve its products and services to their customers, currently we are evaluating the performance of Seawater Intake Systems in the field.

We believe that the Inspection and Maintenance of the Seawater Intake System is important and also provides an opportunity for feedback as to how the system is performing, attached is a Practitioner Paper in respect of this and highlights the areas of interest to us.

As we have supplied the Seawater Intake System for the BP Skarv Project via Aker Solutions we would appreciate any feedback you may have in relation to the system, e.g. Inspection and Maintenance Reports, Performance Measurement, Photographs etc.

Alternatively, we would welcome the opportunity to contact the responsible Maintenance Supervisor directly to discuss the system.

Finally, if BP/Aker has any planned Inspection or Maintenance of the Seawater Intake System in the near future, we would be grateful if you may consider facilitating the attendance of an Emstec representative offshore during these activities to gain field data at first hand.

We look forward to your favourable response.

Best regards,
Ian Craig
- Project Manager -

EMSTEC GmbH
Gewerbering 8
22113 Oststeinbek
Germany

Tel.: +49 (0) 40 79 686 345
Fax: +49 (0) 40 79 686 702

Mail: ian.craig@emstec.net
Web: www.emstec.net

VAT-No.: DE286878278
Commercial Register Lübeck
HRB 13035 HL

INSPECTION AND MAINTENANCE OF SEAWATER INTAKE RISERS

by

Ian Craig

Foreword

This is a practitioner paper, the purpose of which is to provide information for practitioners in the field who may be interested in the subject of Inspection and Maintenance of Seawater Intake Risers.

Introduction

Seawater Intake Risers (SWIR) are used on Floating Production Storage and Offloading (FPSO) vessels for the importation of seawater from varying depths to provide colder, cleaner and less oxygenated seawater for the process, cooling and utility systems on board the vessel. The first systems were installed in the late nineties and as such are a fairly recent innovation in the offshore oil and gas industry, consequently, very little field data is readily available in terms of functional performance, maintenance and inspection.

System Description

A typical SWIR system will include a series of flexible pipe string assemblies each consisting of a number of flanged flexible hose sections connected to one another by standard studbolts and nuts. The flexible pipe string is fitted with a suction strainer at the lower end and a riser head at the upper end. The riser head engages with a seat fitted within a caisson interface structure welded to the end of the caisson (or built into the vessel hull). Within each SWIR there is generally a facility to enable sodium hypochlorite to be injected and mixed into the seawater at the intake point to kill any marine organisms prior to entry to the on board seawater system. The sodium hypochlorite can be injected either as a continuous dose or a higher shock dose.

The flexible hose sections for SWIR are generally a bonded rubber construction for which there are two standards often referenced in relation to the design.

API 17K (American Petroleum Institute, 2005) is a specification for Bonded Flexible Pipe, the applications of which are specifically stated as :

- **discharge hoses** (i.e. positive pressure)
- **Production products**
- **design pressure of 15 bar or greater**.

and consequently, makes provision for features such as; Sour Service, Multiple Steel Reinforcement, Internal Steel Carcass etc. which are typical of High Pressure Production Hoses in the range of 2"NB - 8"NB. For hoses with a lower design pressure, API17K (American Petroleum Institute, 2005) refers to

OCIMF (Oil Companies International Marine Forum, 2009) the applications of which are specifically intended for

- **Suction and Discharge Hoses** (i.e. negative and positive pressure)
- **Oil Service**
- **Nominal Diameter of 150mm-600mm.**

As the hoses generally used within the SWIR are for the following service:

- **Suction Service** (i.e. negative pressure)
- **Seawater**
- **Nominal Diameter of >400-1000mm**

it can be seen that, technically, the Seawater Suction Hose is not directly covered by the scope of either API 17K (American Petroleum Institute, 2005) nor OCIMF (Oil Companies International Marine Forum, 2009).

However, as OCIMF (Oil Companies International Marine Forum, 2009) is intended for large bore, low pressure hoses and includes suction service, this standard is closer to the requirements of the Seawater Suction Hose and can be used as a basis for the testing of the Seawater Suction Hose.

Furthermore, and unlike API17K (American Petroleum Institute, 2005), OCIMF (Oil Companies International Marine Forum, 1995) also provide guidelines for the inspection and testing of large bore hoses in the field.

The Importance of Maintenance

During the design of the SWIR systems, the design life is generally specified as the design life of the FPSO vessel itself. However, with little empirical data relating to the functionality and conditions of the systems in the field, it has so far not been possible to correlate the design life with the actual in-service life.

Each FPSO vessel is located within a bespoke geographical location and therefore the SWIR systems are subject to field specific environmental conditions in terms of wave and current loading and marine growth formation and attachment.

Although hose sections generally utilised for SWIR are not directly covered by the OCIMF (Oil Companies International Marine Forum, 2009) guidelines, the OCIMF Guidelines for the Handling, Storage, Inspection and Testing of Hoses in the Field (Oil Companies International Marine Forum, 1995) does provide suggested maintenance and inspection guidelines for submarine hoses which can be adopted for the SWIR systems, i.e. :

> "It is recommended that individual sites build up a statistical database of wear, damage and failure frequency rates by comprehensive testing..... Until such criteria have been established, it is recommended that hoses initially be periodically tested to the following schedule."

Submarine Hose - 1-3 years

Given that OCIMF (Oil Companies International Marine Forum, 1995) hoses are specifically concerned with the transfer of oil, and the associated potential environmental risks, the test period for hoses in seawater service can be relaxed given that there is no risk of pollution in the event of failure. Nonetheless, it is essential that SWIR systems are subject to an initial inspection within 3-5 years of deployment. This may be a visual inspection in-situ using a remote operated vehicle (ROV) or else, a full (or partial) system retrieval which may be co-ordinated with the scheduled maintenance of the submersible seawater lift pump fed by the SWIR.

The maintenance and inspection of the SWIR enables a number of in-service factors to be corroborated against the system design, such as paint system condition and sacrificial anode condition, the actual marine growth profile versus the design marine growth profile and the effectiveness of the hose sections under the actual wave and current loadings.

Types of Inspection

In-Situ

An in-situ inspection may be performed by divers (dependent upon the length of the SWIR) or by deployment of a remote operated vehicle (ROV). This enables a visual inspection of the SWIR to be undertaken without having to close any of the pump intakes.

Partial System Retrieval

A partial system retrieval requires that the intake pump is shutdown and removed from within the caisson. The SWIR is then pulled up through the caisson and the riser head and top one or two hose sections are removed for inspection. The remainder of the string is suspended at the top of the caisson using the installation tools supplied with the system.

Full System Retrieval

A full system retrieval requires that the intake pump is shutdown and removed from within the caisson. The SWIR is then pulled up through the caisson and disassembled until all components, including the strainer, are retrieved

Assessment of Flexible Hose Section

Whereas an in-situ inspection of the SWIR may provide a visual indication of the condition of the system, a full or partial system retrieval would be required to measure the in-service condition of the flexible hose sections and assess their performance.

When retrieved, the top hose section should be pressure tested in accordance with the hydrostatic test procedure used during manufacture of the hose section and the elongation of the hose section measured. These measurements can then be compared to the elongation values of that specific hose section when first manufactured. The OCIMF (Oil Companies International Marine Forum, 1995) guidelines suggest that for hoses with a helix wire construction, if the difference exceeds 2%, then the hose should be retired, however for helix free hoses, the acceptable permanent and temporary elongations should be established by statistical analysis of field specific test data.

As it is the upper end of the SWIR that is subject to the main bending and tensile loads induced by the environmental loading and vessel motion, if permanent and temporary elongation of the top hose is within the acceptable values, it can be assumed that the lower sections are also acceptable therefore eliminating the requirement for a full retrieval. However, should a full system retrieval be undertaken, a random lower section may be tested in the same manner as the top hose section to verify this.

Surface Protection System and Sacrificial Anodes

The surface protection system applied to the metallic components of a SWIR system is generally in accordance with category C5M of ISO 12944 (International Organization for Standardization, 1998). Category C5M is a high durability system intended for marine, offshore, estuaries, coastal areas with high salinity where the first major maintenance is in excess of 15 years service, however, it should be noted that category C5M for offshore environments is being addressed via the new standard ISO 20340 (International Organization for Standardization, 2009). It is also common practice to apply an anti-fouling or foul-release top coat to the surface protection system which is intended to mitigate the attachment of marine growth.

An in-situ inspection of the system by an ROV would provide the operator with an indication of the effectiveness of the anti-fouling coat (if applicable) or the durability of the applied paint system. A partial system retrieval would enable the Riser Head component to be more closely inspected and paint thickness measurements taken whereas a full system retrieval would also enable the strainer unit to be assessed in the same way. Any repair works to the paint system could be performed during this operation.

In addition to the surface protection system, the carbon steel components in the system, i.e. Riser Head, Bolted Connections and Strainer, are protected by sacrificial anodes. The design of the sacrificial anodes is generally in accordance with the DNV (Det Norske Veritas, 2010), which provides a methodology for calculating the required anode mass based upon design life, surface area to protected and the environmental conditions. The design life can be specified to match the proposed inspection and maintenance interval or else in line with the design life of the vessel. An in-situ inspection would enable the operator to make an assessment of the sacrificial anode condition, however, a full or partial system retrieval would enable the anodes to be removed and weighed and compared against the installed mass to determine the actual depletion rate. A full system retrieval would be required if the sacrificial anodes were to be replaced.

Bolting Connections

Standard studbolts are generally used to connect the components of the flexible pipe string, and typically the selected material is carbon steel, although some systems are fitted with super duplex to remove the requirement for sacrificial anodes.

Where carbon steel studbolts are specified, they can be PTFE coated or hot dipped galvanised but, regardless of the coating, the studbolts are also protected by sacrificial anodes at each connection.

An in-situ inspection will enable to the operator to assess the conditions of the studbolts, whereas a full system retrieval would be required to change out the studbolts if they were found to be excessively corroded.

Marine Growth

Despite a vast amount of literature on marine growth, the type, formation, attachment rate and thickness is dependent upon the geographical location.

Generally, a marine growth profile is provided during the design of the SWIR system, however, the actual marine growth profile may be somewhat different in the field, for example it is known that marine growth attachment is dependent upon the characteristics of the substrate, such as the surface energy, which are not normally differentiated within the marine growth profile.

Stanczak (2004), describes how the growth of a biofilm can be such that it provides a foundation for the growth of seaweed, barnacles and other organisms although the conditions and substrate have a significant impact on the marine growth attachment. Harder and Lee (2009) make reference to the Baier Curve which provides a generalised relationship between the surface energy of a material and its resistance to bio-adhesion and Lebret et al (2009) describes how biofilm attachment begins to occur within seconds or minutes of a substrate submersion into seawater.

Marine Growth attachment can affect the SWIR in a number of ways, notably by adding mass and roughness. Increased roughness equates to increased drag on the SWIR and therefore increased hydrodynamic forces. The drag also affects the excursion of the free end of the hose, which theoretically would mean that the hose end would be at a shallower depth, increasing the intake temperature.

An in-situ inspection, but preferably a partial or full system retrieval, would enable the operator to make an assessment or measurement of the marine growth profile and compare this against the theoretical marine growth profile provided during design. The system could then be re-analysed based on the actual field data to determine the impact on system performance and fatigue.

Furthermore, a full or partial system retrieval would enable the internal bore of the hose sections to be inspected for marine growth and an assessment made as to the effectiveness of the sodium hypochlorite injection dosing. Also, if applicable, the pressure loss calculations, could be revisited based on the findings in terms of surface roughness.

Conclusion

To ensure that the functionality and in-service life of the SWIR systems are maintained, it is essential that the systems are inspected periodically and any maintenance work undertaken where necessary.

Furthermore, to create a body of knowledge around the performance and design of the SWIR, it is recommended that vessels operating with these systems undertake an inspection regime and document the findings to build up a statistical data base. This field data can then be used to re-evaluate the design of the systems in-service and will be invaluable in the design of new systems, ensuring the continued development and advancement of these systems.

The Author

Ian Craig is a Chartered Engineer holding a first class BEng(Hons) from the University of Sunderland and is currently studying Seawater Intake Risers for FLNG Vessels at Doctorate level in cooperation with Emstec GmbH, suppliers of Seawater Intake Riser systems.

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FIELD NOTE SUMMARY

Course:	Professional Doctorate Programme
Student:	Ian **CRAIG** *Student No:* *00987536S* *Student e-mail:* *ian.craig@research.sunderland.ac.uk*
Study Title:	Seawater Intake System for Floating Liquefied Natural Gas (FLNG) Vessel

Each of the keywords from the Field Notes was assigned one of the following main themes:

- Flexible Element
- Marine Growth
- Corrosion
- Maintenance

Keyword	Theme	Vessel			
		Golfinho	MV23	Kizomba	MV21
Rubber Hose Damage	Flexible Element	X			
HDPE	Flexible Element	X			
Ballast Weight	Corrosion	X			
Failure	Corrosion	X			
Pump Blockage	Marine Growth		X		
Pump Failure	Marine Growth		X		
Hypochlorite Damage	Marine Growth		X		
Caisson Failure	Corrosion			X	
Galvanic Corrosion	Corrosion			X	
Dissimilar Metals	Corrosion			X	
Installation Tools	Maintenance				X
Maintenance	Maintenance				X
Strainer	Marine Growth				X
Corrosion	Corrosion				X

Contact Details for further Information:	For further information or concerns relating to the research, please contact the following personnel at the University of Sunderland: Dr Kevin Burn *Director of Studies* kevin.burn@sunderland.ac.uk Tel: 0191 515 2778 Professor Gail Sanders *Programme Leader* gail.sanders@sunderland.ac.uk Tel: 0191 515 2682

FIELD NOTE

University of Sunderland

Course:	Professional Doctorate Programme
Student:	Ian **CRAIG** *Student No:* *00987536S* *Student e-mail:* *ian.craig@research.sunderland.ac.uk*
Study Title:	Seawater Intake System for Floating Liquefied Natural Gas (FLNG) Vessel
Date:	March 2015 — **Installation/ Location**: Golfinho / Brazil
System Details:	3-off x 30"NB x 100m long Rubber / HDPE / Ballast Weight
Contact Details:	Eoin O'Sullivan - Maintenance Superintendent MSupt.CdVitoria@saipem.com
Keywords:	Rubber Hose Damage/ HDPE / Ballast Weight / Failure
Field Notes:	After a period of operation, the ballast weight from the centre hose string became detached. This resulted in the hose string losing stability and 'crossing' the adjacent riser (video 01). It was noted that the studbolts and nuts used to fix the ballast weight were still in place (photo 01). This created a wear point and damaged the Rubber Hose of the adjacent riser (photo 02). Both hose strings were withdrawn and repaired. The damaged hose was replaced with a spare. To compensate for the missing ballast, the strainer section was turned upside down and filled with concrete. Photo's 04-06 show general marine growth formations
Initial Analysis:	The ballast weight was manufactured from cast iron. This was bolted to the flange of the strainer section using Super Duplex Stainless Steel bolting. Inserts were provided to isolate the cast iron from the SDSS. The isolation sets either failed or were not fitted which led to galvanic corrosion of the cast iron, resulting in the bolt holes increasing in size and passing over the studbolts and nuts. As the ballast weights of the two other risers have not failed, it is more likely that the isolation sets for the central riser were not fitted during installation. This could be due to a shift change or else an oversight.
Contact Details for further Information:	For further information or concerns relating to the research, please contact the following personnel at the University of Sunderland: Dr Kevin Burn *Director of Studies* kevin.burn@sunderland.ac.uk Tel: 0191 515 2778 Professor Gail Sanders *Programme Leader* gail.sanders@sunderland.ac.uk Tel: 0191 515 2682

Photo 01


Photo 02


Photo 03


Photo 04

Photo 05

Photo 06

FIELD NOTE

Course:	Professional Doctorate Programme
Student:	Ian **CRAIG** *Student No:* *00987536S* *Student e-mail:* *ian.craig@research.sunderland.ac.uk*
Study Title:	Seawater Intake System for Floating Liquefied Natural Gas (FLNG) Vessel
Date:	September 2015 — **Installation/ Location**: MV23 / Brazil
System Details:	3-off x 20"NB x 40m long Rubber
Contact Details:	Angelo Bresolin - Maintenance Engineer Angelo.Bresolin@modec.com
Keywords:	Pump Blockage / Pump Failure / Hypochlorite Damage
Field Notes:	A report was received that one of the SW pumps was not performing and the cause of some vibration. The maintenance team suspected the SWIR was blocked and was looking for assistance. The pump was removed and found to have a foreign object lodged in the impeller (Photo 01). It was initially thought that this may be part of the hose liner. Further investigation showed that the foreign object was from a different part of the pump that has become loose (Photo 02). The opportunity was taken to perform a boroscope inspection of the SWIR. This showed the SWIR to be clear with little orno marine growth formation (Photo 03-05). It did show that the hypochlorite line was damaged at the riser head location (Photo 06).
Initial Analysis:	The pump centraliser ring became loose and a part of it dropped into the pump suction region causing it to become lodged into the pump. It is suspected that the hypochlorite line was damaged at this time due to the foreign object being circulated violently in this location prior to becoming lodged into the pump suction. A maintenance and inspection of the SWIR is being planned to repair the damaged hypochlorite hose, which should also confirm/reveal the cause of the damage. Hypochlorite is still being injected into the line even though it is detached from the SWIR,
Contact Details for further Information:	For further information or concerns relating to the research, please contact the following personnel at the University of Sunderland: Dr Kevin Burn *Director of Studies* kevin.burn@sunderland.ac.uk Tel: 0191 515 2778 Professor Gail Sanders *Programme Leader* gail.sanders@sunderland.ac.uk Tel: 0191 515 2682

Photo 01

Photo 02

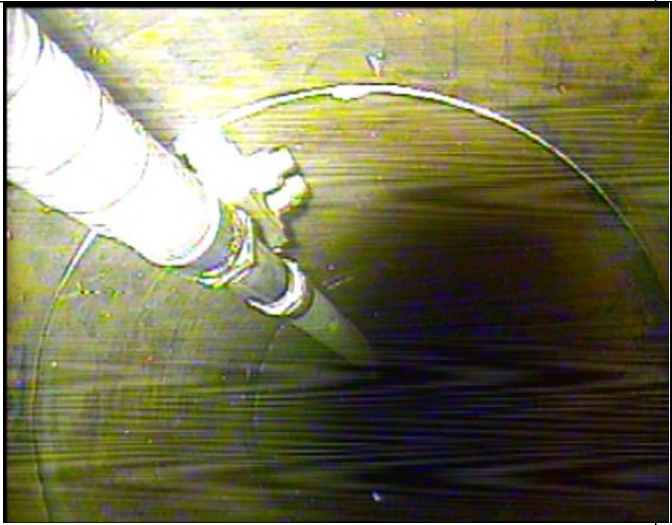


Photo 03

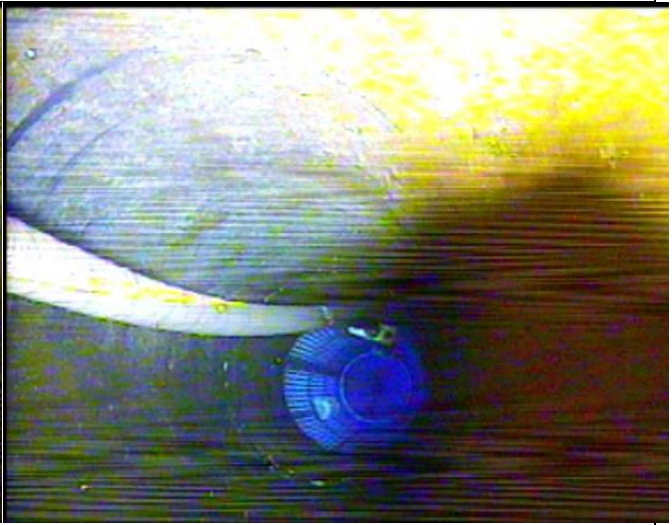


Photo 04

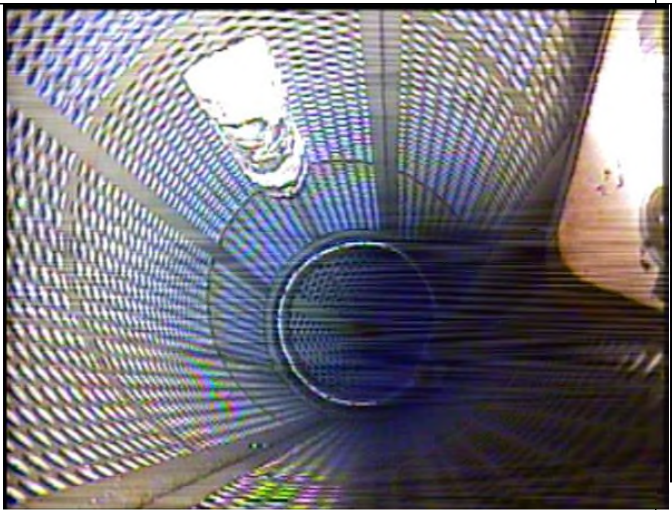


Photo 05

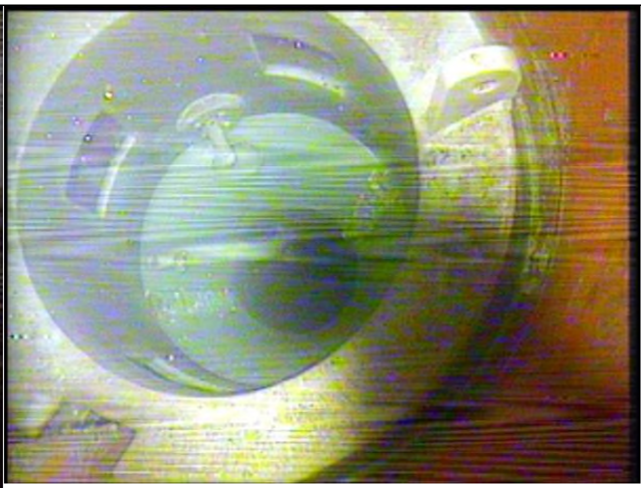


Photo 06

FIELD NOTE

Course:	Professional Doctorate Programme
Student:	Ian **CRAIG** *Student No:* *00987536S* *Student e-mail:* *ian.craig@research.sunderland.ac.uk*
Study Title:	Seawater Intake System for Floating Liquefied Natural Gas (FLNG) Vessel
Date:	February 2016 — **Installation/ Location**: Kizomba A / West Africa
System Details:	3-off x 24"NB x 74m long Rubber
Contact Details:	Nader Al-Qazzaz – Project Manager Nader.Al-Qazzaz@WorleyParsons.com
Keywords:	Caisson Failure / Galvanic Corrosion / Dissimilar Metals
Field Notes:	An enquiry was received for the replacement of a seawater intake hose string that had been lost due to the failure of the caisson pipe. Photographs were received that showed the caisson had broken at a circumferential break point adjacent to the SW pump bowl (Photo 01 & 02). Consequently, the complete lower caisson section, including the SWIR Riser Seat and hose string assembly had dropped to the seabed (photos 3-6) .
Initial Analysis:	The failure point was not at a circumferential weld but 1m below the nearest weld. The cause was thought to be galvanic corrosion accelerated by dissimilar metals of the pump stack (super duplex stainless steel) and the caisson (carbon steel). This is a relatively common problem (ref. Appendix A). Whilst this is not a failure of the SWIR, the photographs do provide some interesting observations. This system was installed circa 2004 and therefore has been in situ for more than 10 years without any reported maintenance activities, yet the marine growth can be seen to be minimal, even at the uppermost hose section (photo 04) and on the caisson itself (photos 01 & 02) both of which are in the most' active' zone for marine growth. The strainer (photo 6) shows that there is some marine growth formation at the lower part of the strainer but the upper part is clear, indicating that the flow path for the intake is concentrated at the upper part and not evenly distributed along the strainer.
Contact Details for further Information:	For further information or concerns relating to the research, please contact the following personnel at the University of Sunderland: Dr Kevin Burn *Director of Studies* kevin.burn@sunderland.ac.uk Tel: 0191 515 2778 Professor Gail Sanders *Programme Leader* gail.sanders@sunderland.ac.uk Tel: 0191 515 2682

Sea Water Lift Termination – Break off point at EL-19m

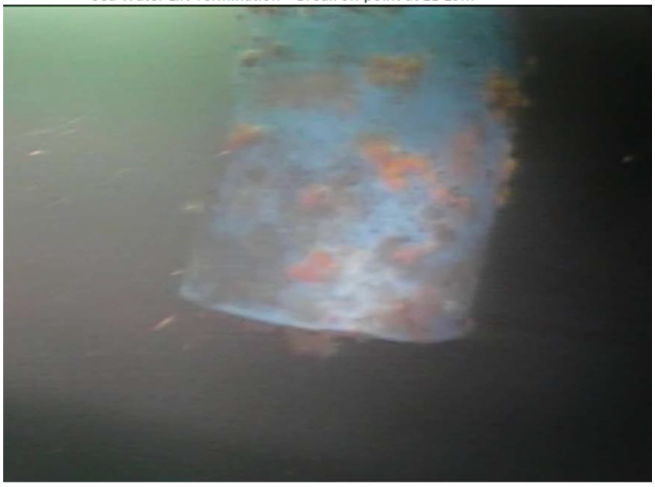


Photo 01

Break off point and Water pump

Photo 02

Cross Over 1

Photo 03

Transition

Photo 04

Cross Over 1

Photo 05

End Of Flexi Caisson

Photo 06

University of Sunderland

Appendix A:

NACE International Corrosion Conference & Expo 2011; Paper 11056
Sacrificial anodes for protection of seawater pump caissons against galvanic corrosion
Jan Heselmans, Nico (Ko) W. Buijs, Ephraim Isaac

FIELD NOTE

Course:	Professional Doctorate Programme		
Student:	Ian **CRAIG**	*Student No:* 00987536S *Student e-mail:* *ian.craig@research.sunderland.ac.uk*	
Study Title:	Seawater Intake System for Floating Liquefied Natural Gas (FLNG) Vessel		
Date:	July 2016	**Installation/ Location**	MV21 / Ghana
System Details:	3-off x 20"NB x 40m long Rubber		
Contact Details:	David Laws - Operations Support Superintendent dave.laws@modec.com		
Keywords:	Installation Tools / Preservation		
Field Notes:	A request was received regarding extending the existing SWIR from 40m to 100m. This would entail recovering the existing SWIR using the installation tools supplied with the original system. Photographs of the 'hang off' tool were made available to assess the condition and suitability for the proposed extension. With reference to photographs 1-5, the Yellow component is the 'hang off' tool, the grey structure is a support platform designed and installed by the client prior to the original installation. The maintenance instruction provided with the original supply, recommend that that the 'hang off' tool is dismounted, preserved and stored after installation of the system. Additionally, the 'hang off' tool was supplied with an air driven HPU to operate the tool that is no longer fitted, as shown in photograph 6 which is from the original installation.		
Initial Analysis:	Photographs 1-5 show that the condition of the 'hang off' tool to be well corroded. This, together with the fact that it has not been dismounted and preserved, suggests that, once the SWIR is installed, there is little importance attached to the inspection & maintenance of the system.		
Contact Details for further Information:	For further information or concerns relating to the research, please contact the following personnel at the University of Sunderland: Dr Kevin Burn *Director of Studies* kevin.burn@sunderland.ac.uk Tel: 0191 515 2778	Professor Gail Sanders *Programme Leader* gail.sanders@sunderland.ac.uk Tel: 0191 515 2682	

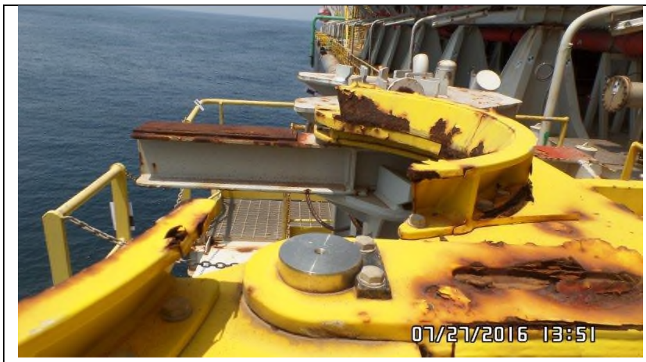


Photo 01

Photo 02

Photo 03

Photo 04

Photo 05


Photo 06

FIELD NOTE

Course:	Professional Doctorate Programme
Student:	Ian **CRAIG** *Student No:* *00987536S* *Student e-mail:* *ian.craig@research.sunderland.ac.uk*
Study Title:	Seawater Intake System for Floating Liquefied Natural Gas (FLNG) Vessel
Date:	Aug 2016 — **Installation/ Location** MV21 / Ghana
System Details:	3-off x 20"NB x 40m long Rubber
Contact Details:	David Laws - Operations Support Superintendent dave.laws@modec.com
Keywords:	Strainer / Corrosion
Field Notes:	Further to the previous field data in respect of the installation tooling, an inspection report was provided detailing the in situ cleaning of the strainers on the SWIR. Photographs 1 & 2 shows the strainer and the lower part of the SWIR 'as found' after approx. 5 years service. It also shows some large fish in the vicinity of the intakes. Photographs 3 & 4 show the strainers being cleaned in situ using an ROV with water jet attachment and photographs 5 & 6 show the strainers after they have been cleaned.
Initial Analysis:	The 'as found' condition shows that the marine growth is greater at the lower part of the strainer whereas at the upper section it is nearly clear indicating where the main intake flow path is concentrated. It should be noted that these strainers did not have a foul release coating applied. The flexible hose section does have a covering of marine growth although it is difficult to assess the thickness. After cleaning, the strainers appear to be in good condition without any corrosion and the sacrificial anodes appear to have significant mass remaining. The studbolts at the flange connections can be seen to be in good condition with the Teflon coating (blue film) intact. This suggests that the corrosion protection measures are suitable and the anode mass calculation is conservative. The presence of the large fish in the intake area reinforces the need for strainers to be fitted to ensure that they are not drawn into the intakes.
Contact Details for further Information:	For further information or concerns relating to the research, please contact the following personnel at the University of Sunderland: Dr Kevin Burn *Director of Studies* kevin.burn@sunderland.ac.uk Tel: 0191 515 2778 Professor Gail Sanders *Programme Leader* gail.sanders@sunderland.ac.uk Tel: 0191 515 2682

Photo 01

Photo 02

Photo 03

Photo 04

Photo 05

Photo 06

Section 5.0: Material Test Data

MATERIAL DATA SHEET

-TEXTILE COMPOUND MATERIAL SPECIFICATION FOR OIL-/PROJECT & DREDGE HOSES -

DOCUMENT CODE:	MDS-201409-00015	ESTABLISHED BY:	FR
RELEASE DATE:	11.09.2014	APPROVED BY:	RR/MR

DOCUMENT SCOPE:

THIS MATERIAL DATA SHEET INDICATES THE CORRECT DEFINITION AND SPECIFICATION OF TEXTILE MATERIAL USED FOR THE ENTIRE RANGE OF EMSTEC OIL-/PROJECT & DREDGE HOSES.

Internal Code	B014 - 1340
Material	Polyesther Textile-Reinforcing Textile
Description	Textile of Polyesther cords calandered with NBR Rubber
Colour	Black with cords (ocra)
Used for	Reinforcing Materials
Thickness	1,4 mm
Thickness Yarn	1,2 mm

Values Taken BEFORE Vulcanization		
Physical Properties	Value	Tolerance
Thickness [mm]	1,4	± 0,1
Density [g/cm³]	1,2	±0,01
Endcount per 100mm	55	± 1EC
Min. Strength at Break per Yarn [kg]	60	-0
Min. Elongation at Break per Yarn [%]	12	-0
Equivalent Tensile Strength [kg]	3300	N/A
Construction	500 D/6 - 5591 1340	

Values Taken AFTER Vulcanization		
Physical Properties	Value	Tolerance
Thickness [mm]	1,4	± 0,1
Density [g/cm³]	1,2	±0,01
Endcount per 100mm	55	± 1EC
Min. Strength at Break per Yarn [kg]	47	-0
Min. Elongation at Break per Yarn [%]	15	-0
Equivalent Tensile Strength [kg]	2585	N/A
Construction	500 D/6 - 5591 1340	

Delivery Condition	N/A
Current Supplier	B014 with Poly Merics Rubber Compound // 1340 with CDSR Rubber Compound
Package Method	N/A

BEFORE VULCANIZATION			AFTER VULCANIZATION		
Diameter(mm)		**1.4**	**Diameter(mm)**		**1.4**
Date		**27/08/2013**	**Date**		**27/08/2013**
#	**Force (N)**	**average elongation break (%)**	**#**	**Force (N)**	**average elongation break (%)**
1	813.90	12.01	1	574.20	15.6
2	834.10	13.58	2	439.20	12.63
3	840.10	13.34	3	595.00	15.57
4	846.20	13.2	4	664.80	17.15
5	824.00	13.72	5	519.10	13.39
6	800.50	12.28	6	569.50	14
7	764.20	13.05	7	555.40	14.83
8	768.30	12.6	8	469.40	12.49
9	768.90	12.6	9	618.50	15.81
10	820.00	12.83	10	550.00	14.06
average	808.0	12.921	**average**	555.5	14.6
MAX	846.20	13.72	**MAX**	664.80	17.15
MIN	764.20	12.01	**MIN**	439.20	12.49

BEFORE VULCANIZATION			AFTER VULCANIZATION		
Diameter(mm)		**1.4**	**Diameter(mm)**		**1.4**
Date		**29/08/2013**	**Date**		**29/08/2013**
#	**Force (N)**	**average elongation break (%)**	**#**	**Force (N)**	**average elongation break (%)**
1	798.50	14.44	1	619.20	15.51
2	706.50	12.02	2	513.70	14.05
3	739.40	13.01	3	543.30	14.58
4	840.10	13.13	4	549.30	14.28
5	775.60	13.06	5	486.90	13.23
6	807.20	14.68	6	439.20	12.47
7	710.50	12.62	7	519.80	13.99
8	768.30	13.17	8	549.30	14.01
9	837.40	14.6	9	513.10	13.31
10	773.00	13.92	10	619.80	16.15
average	775.7	13.465	**average**	535.4	14.2
MAX	840.10	14.68	**MAX**	619.80	16.15
MIN	706.50	12.02	**MIN**	439.20	12.47

Min breaking load Variation	-42.53%
Min Elongation Variation	4.00%

Min breaking load Variation	-37.83%
Min Elongation Variation	3.74%

		Kg
Average of averages	791.8	80.71712538
Average ov max	843.2	85.94801223
Average of min	735.4	74.95922528
Minimum of all	706.50	72.01834862

EMSTEC GmbH Gewerbering 8 22113 Oststeinbek - Germany	EMSTEC				
		Form:		Date:	
		Revision:		Category:	Oil & Gas

Cord Elongation Test

Submitted Unit	NA	**Batch Number**	NA
Name Of The Material	C014 (before curing)	**Test Date**	26/11/2014
Test Tamperature	20℃	**Test Speed**	300mm/min
Test Humidity	75%	**Scale Distance**	250mm
pre-tension	5.88 N	**Test Standard**	NA

No	F@break(N)	E@break(%)	E200N(%)
1	907.9	14.32	4.09
2	794.4	12.67	4.19
3	887.8	14.68	4.11
4	815.3	11.85	3.75
5	789.7	12.29	4.04
6	814.6	12.97	4.19
7	790.4	13.28	4.42
8	820.0	12.07	3.90
9	825.3	11.78	3.75
10	795.8	12.75	4.26

	F@break	E@break	E200N
Min	789.7	11.78	3.75
Max	907.9	14.68	4.42
Avg	824.1	12.87	4.07

Dia (mm)	1.4

Area (mm^2)
1.5394

	E (MPa)
	4354.826879
	4017.593639
	4161.031026
Average	4177.817182

At 200N

E (MPa)
3464.597401
2939.420872
3192.196622
3198.738298

EMSTEC GmbH
Gewerbering 8
22113 Oststeinbek - Germany

Form:		Date:	
Revision:		Category:	Oil & Gas

Cord Elongation Test

Submitted Unit	NA	**Batch Number**	NA
Name Of The Material	C014 (after curing)	**Test Date**	26/11/2014
Test Tamperature	20℃	**Test Speed**	300mm/min
Test Humidity	75%	**Scale Distance**	250mm
pre-tension	5.88 N	**Test Standard**	NA

No	F@break(N)	E@break(%)	E200N(%)
1	793.1	14.62	5.50
2	741.4	15.58	6.42
3	693.0	13.72	5.82
4	794.4	16.84	6.48
5	568.1	12.36	6.18
6	741.4	14.76	6.04
7	767.6	14.16	5.45
8	786.4	15.06	5.76
9	743.4	15.07	6.06
10	825.3	17.68	6.72

	F@break	E@break	E200N	E
Min	568.1	12.36	5.45	45.963
Max	825.3	17.68	6.72	46.68
Avg	745.4	14.99	6.04	49.744

Dia (m)	1.4

Area (m^2)
1.539380E+00

	E (MPa)
	2985.797608
	3032.380057
	3231.413349
Average	3083.197005

at 200N

E (MPa)
2383.897294
1933.369085
2149.965291
2155.74389

Intertek Wilton

Test Report

Characterisation of a Reinforcing Yarn by Tensile Fatigue Analysis

Test Report : **IWTN/W000003204RL001**

Prepared for : **Ian Craig**
EMSTEC GmbH

Gewerbering 8
22113 Oststeinbek
Germany

Prepared by:

Michele Hopley
Senior Experimental Scientist

Intertek Wilton
Room N135
ITS Testing Services (UK) Ltd
The Wilton Centre
Redcar
TS10 4RF

Telephone: 01642 435765
Fax: 01642 435777

Email: michele.hopley@intertek.com

UKAS TESTING
0967

TEST REPORT

Report Number:	IWTN/W000003204RL001
Chit Number:	ITWI-00000012096
Receipt Date:	22/07/2015
Lab Book Reference:	INT0110
File Reference Location:	L:\MPP\MECHTPRO\data\XL worksheets\Fatigue\Emstec GmbH
Number of Samples:	1
Method Reference:	MSG-LAB-SAM-MTP-77 Version 3

Samples Submitted

Intertek Sample Reference	Sample Description	Customer Identifier
IWTN/W000003204-1	Vulcanised yarn	Code 1340 vulcanised

Description of Work Required

Fatigue load versus number of cycles plot at 5 Hz 0.1 R ratio @ 23°C

Report Authorisation

Michele Hopley
Senior Experimental Scientist  Date: 17/09/2015

Julie Robinson
Senior Experimental Scientist 

Intertek Wilton welcomes feedback on all aspects of the service provided to you.
Please email any comments that you have to wilton.feedback@intertek.com

Characterisation of a Reinforcing Yarn by Tensile Fatigue Analysis

Samples

The sample was provided in the form of a roll of vulcanised rubber sheeting. The sheet contained reinforcing yarn.
The sample was referenced Code 1340 vulcanised.
The sample was stored in a laboratory at 23 ±2°C prior to being tested.

Apparatus

.
An Instron Servo-hydraulic testing machine, E5, fitted with a calibrated Sensordata 1kN cell, serial number 98064 and a set of roller-type grips were used to perform the tests.
The load cell was class 0.5 according to BS EN ISO 7500-1:2004.
The laboratory in which the tests were performed was at a controlled temperature of 23±2°C.

Aim

The aim was to produce a load versus no of cycles to failure curve at 23 ±2 °C. Testing was to be continued up to 10,000,000 cycles and any specimens going beyond this value were to be terminated.
The range of loads to be used in the tensile fatigue tests was to be based upon the ultimate break load (UBL) of the yarn. A couple of monotonic loading tests were carried out prior to the tensile fatigue tests in order to determine the UBL.

Method

Alignment of the grips was checked and the load cell was performance checked prior to use.
The monotonic loading was carried out at 100mm/min using a Bluehill software method.
The tensile fatigue testing was conducted at a frequency of 5Hz with an R ratio of 0.1.
Various percentages of the UBL were used as the maximum load values during the test i.e. from 90% UBL down to 25% UBL.
The set up for the experiment can be seen in Figure 2.
Reinforcing yarn specimens were taken from the sample simply by stripping them away from the sheet.
The length of yarn was then wrapped around the top and bottom roller grips. In order to better secure the yarn, four turns were made around each roller grip.
The rubber around the yarn was removed from the gauge length area.
The upper and lower areas of the gauge length were marked with a permanent marker. This made it clearer to asses if the failure had occurred in the gauge length region at the end of the test.
The procedure for testing the yarns is covered in our UKAS schedule of accreditation. However, there is a deviation in that the scope and field of testing in MSG-LAB-SAM-MTP-77 Version 3 covers specimens machined from sheet or injection moulded materials.

Results

The average UBL measured during the two monotonic tests was 600N.
The tensile fatigue results are given in tabular form in Table 1.
A plot of the load versus number of cycles is given in Figure 1.
The failure of all of the specimens, except the specimen under test with a maximum load of 25% UBL, failed in the gauge length. This specimen failed just outside the gauge length region, see figure 3.
Testing was carried out between the following dates 24-07-2015 and 17-09-2015.

Table 1 Tensile Fatigue Results at 5Hz, 23°C

Specimen	% UBL	Maximum Load N	Number of Cycles Reached	Test Start Date	Comments
1	90	540	43	24-7-2015	Failed in g.l.
2	80	480	52	24-7-2015	Failed in g.l.
3	70	420	1792	27-7-2015	Failed in g.l.
4	60	360	16878	27-7-2015	Failed in g.l.
5	50	300	19301	24-7-2015	Failed in g.l.
6	40	240	364357	31-7-2015	Failed in g.l.
7	30	180	8,236,502	03-8-2015	Failed in g.l.
8	25	150	9,759,399	25-08-2015	Failed just outside g.l.

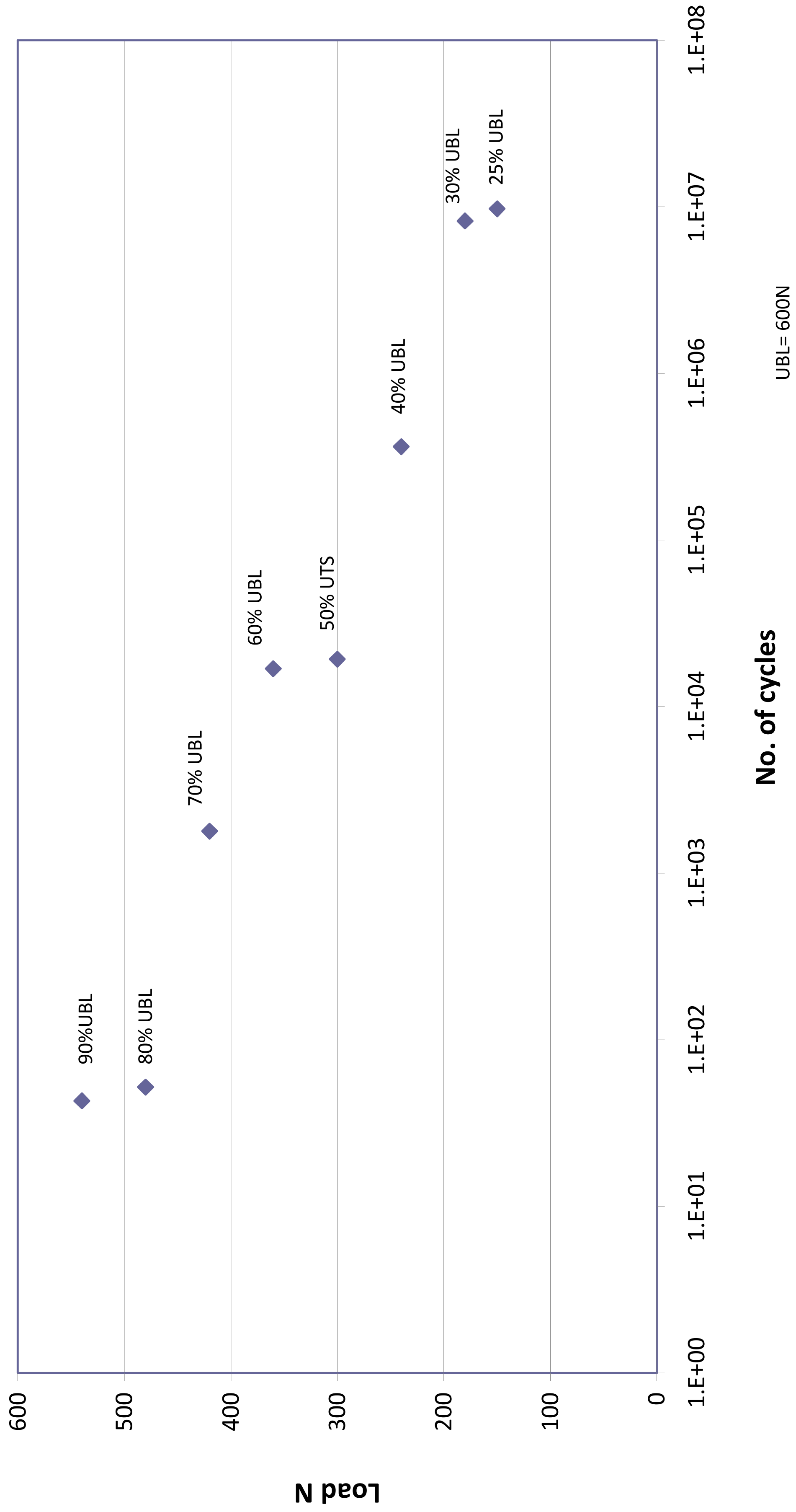


Figure 1 Load versus Number of Cycles

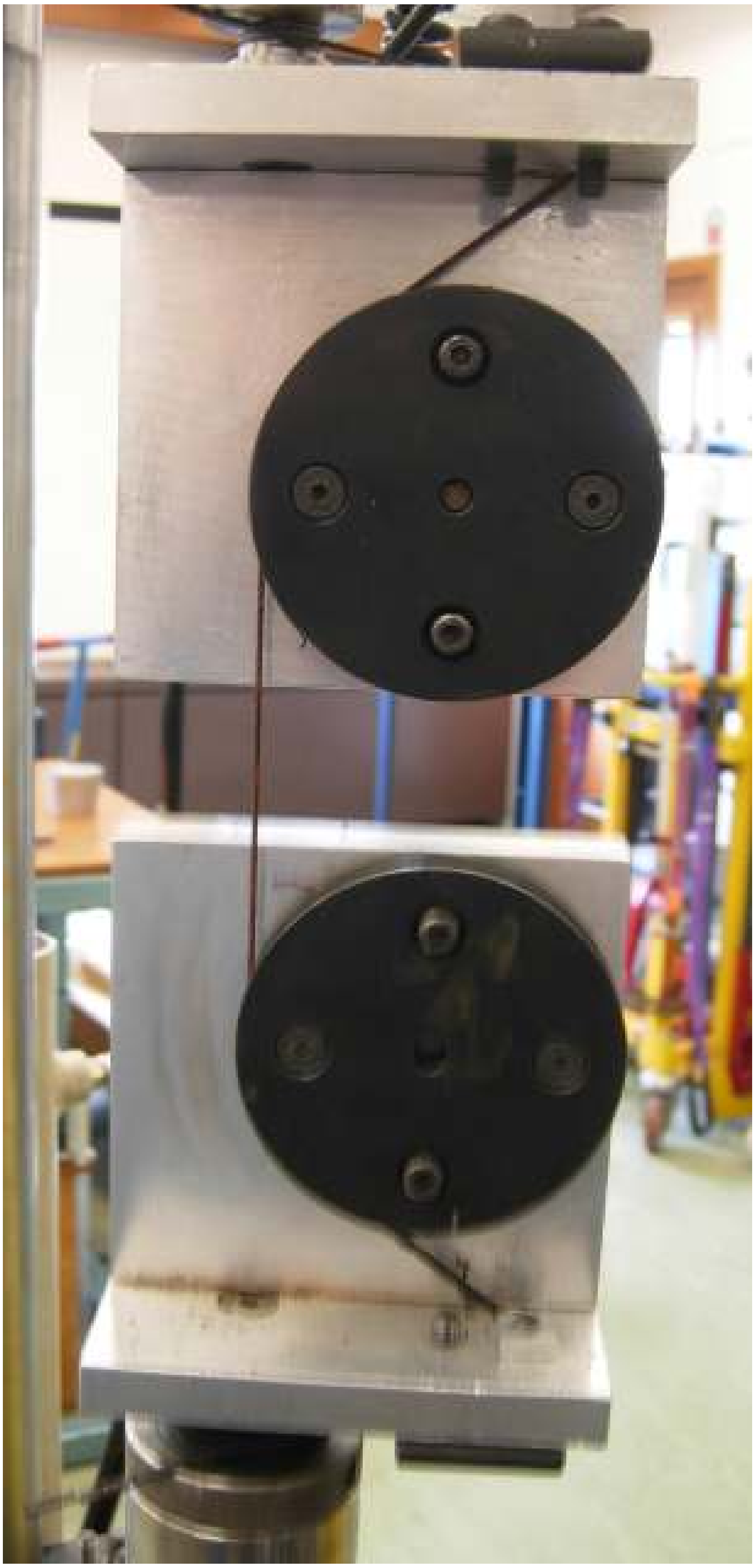


Figure 2 Set up for the Yarn Testing

Figure 3 the failed 25% UBL specimen showing failure just outside the gauge length

TEST REPORT

No. : SHIN1509042854MR
Date : Sep 23, 2015
Page: 1 of 4

CUSTOMER NAME:	EMSTEC GMBH
ADDRESS:	GEWERBERING 8, 22113 OSTSTEINBEK, GERMANY

The following sample(s) was/ were submitted and identified on behalf of the client as:

Sample Name	:	1607/001(shore 40°)/(shore 65°)
SGS Ref. No.	:	SHIN1509042837PS
Date of Receipt	:	Sep 17, 2015
Testing Start Date	:	Sep 17, 2015
Testing End Date	:	Sep 23, 2015
Test result(s)	:	For further details, please refer to the following page(s)

Signed for
SGS-CSTC Standards Technical
Services （Shanghai）Co., Ltd.

Suning Shi
Authorized signatory

No.69, Block 1159, East Kang Qiao Road, Pudong District, Shanghai, China 201319 t (86-21) 61196300 f (86-21) 68183122/68183920 www.sgsgroup.com.cn
中国・上海・浦东康桥东路1159弄69号 邮编: 201319 t (86-21) 61196300 f (86-21) 68183122/68183920 e sgs.china@sgs.com

TEST REPORT

Summary of Results:

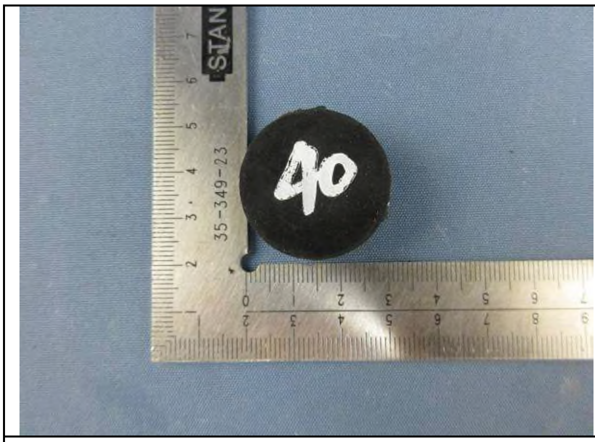
No.	Test Item	Test Method	Result	Conclusion
1	Compressive Test	ISO 7743:2007 Method A	See result	/

Note: Pass : Meet the requirements;

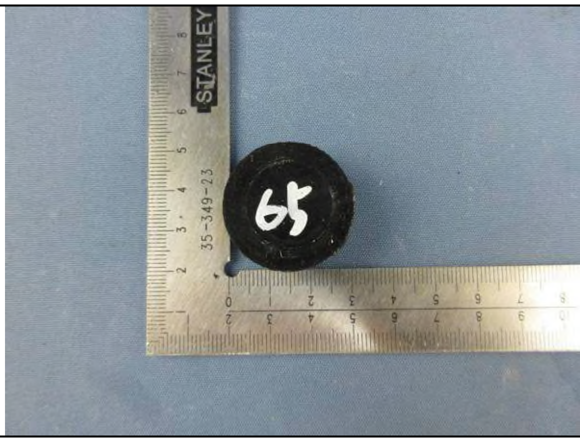
Fail : Does not meet the requirements;

/ : Not Apply to the judgment.

Original Sample Photo:



1607/001(shore 40°)



1607/001(shore 65°)

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中国・上海・浦东康桥东路1159弄69号 邮编: 201319 t (86-21) 61196300 f (86-21) 68183122/68183920 e sgs.china@sgs.com

TEST REPORT

Test Item: Compressive Test

Sample Description: Black rubber

Test Method: ISO 7743:2007 Method A

Test Condition:

Testing speed: 10 mm/min

Lab Environmental Condition: 23±2℃, 50±5%RH

Test Result:

1607/001(shore 40°)

Test Item	Test Condition	Test Result
Compressive Modulus at 10% strain	Specimen diameter: 28.27 mm Specimen thickness: 12.3 mm	2.4 MPa
Compressive Modulus at 20% strain		5.2 MPa

1607/001(shore 65°)

Test Item	Test Condition	Test Result
Compressive Modulus at 10% strain	Specimen diameter: 28.53 mm Specimen thickness: 12.7 mm	5.7 MPa
Compressive Modulus at 20% strain		11.9 MPa

Note: Compressive Modulus at X% strain=F/(A×ε)

F is the force at X% strain, in Newtons

A is the original cross-sectional area, in square millimeters, of the test pieces

ε is the compression strain.

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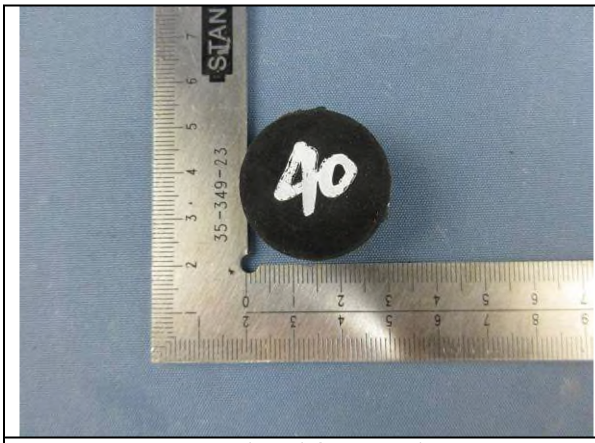
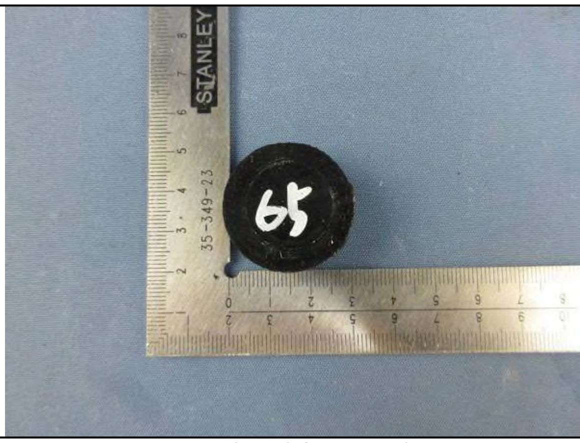
中国・上海・浦东康桥东路1159弄69号 邮编: 201319 t (86-21) 61196300 f (86-21) 68183122/68183920 e sgs.china@sgs.com

TEST REPORT

No. : SHIN1509042854MR
Date : Sep 23, 2015
Page: 4 of 4

Sample Photo:

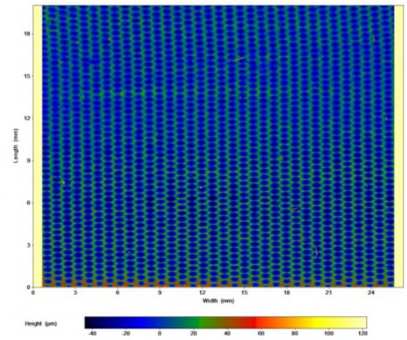
	
1607/001(shore 40°)	1607/001(shore 65°)

******** End of report********

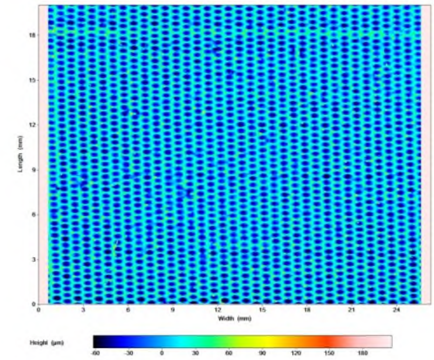
No.69, Block 1159, East Kang Qiao Road, Pudong District, Shanghai, China 201319 t (86-21) 61196300 f (86-21) 68183122/68183920 www.sgsgroup.com.cn
中国・上海・浦东康桥东路1159弄69号 邮编: 201319 t (86-21) 61196300 f (86-21) 68183122/68183920 e sgs.china@sgs.com

TEST NOTE

Course:	Professional Doctorate Programme
Student:	Ian **CRAIG** *Student No:* *00987536S* *Student e-mail:* *ian.craig@research.sunderland.ac.uk*
Study Title:	Seawater Intake System for Floating Liquefied Natural Gas (FLNG) Vessel
Date:	March 2015 — **Installation/ Location**: International Paints / Felling , UK
System Details:	Intersleek 1070 Adhesion Tests – Project Hose / OCIMF Hose Rubber Samples / HDPE Sample
Contact Details:	Brent Tyson - Sales Manager Intersleek T +44 191 401 2197 / M +44 7500 999 334 brent.tyson@akzonobel.com
Keywords:	Intersleek / Anti Fouling / Rubber Hose/ HDPE / Adhesion
Test Notes:	Rubber and HDPE samples were provided to International paints to enable them to carry out adhesion tests to determine suitability of Intersleek 1070 for application. Two Rubber compounds were tested PRJ (Project Hose) and Y002 (OCIMF hose) The surface roughness of the samples were measured before and after the application and recorded as follows: Average roughness (Sa): Y002 = 16.4 um (uncoated), 1 um (coated) – Scan 01 PRJ Cover = 24.6 um (uncoated), 1.6 um (coated) – Scan 02 The method used for roughness measurements was White Light Interferometry (WLI) which gives a good idea how Intersleek smooth's the surface (see photo xx for uncoated roughness) Preliminary results on adhesion suggest there are some significant differences between the two grades of rubber, Y002 (Photo 01) , PRJ-Cover being better (photo 24) The adhesion of Intersleek to the PE pipe was acceptable . ISO Standard and International Paint internal standards were used to grade the results, the Project hose was found to be ISO Grade 1 /2 (Good) and IP Grade 2 (Moderate) OCIMF hose was found to be ISO Grade 3 /4 (Poor) and IP Grade 2 (Moderate)
Initial Analysis:	The Project Hose has a rougher uncoated surface than the OCIMF hose which may contribute to the adhesion. However, it is more likely to be due to the composition of the Rubber Compound, the OCIMF hose has more additives such as Ozone protection, UV Protection. The exact difference may need to be explored further. At this stage, it is thought that it may be risky to apply to a live project.
Contact Details for further Information:	For further information or concerns relating to the research, please contact the following personnel at the University of Sunderland: Dr Kevin Burn *Director of Studies* kevin.burn@sunderland.ac.uk Tel: 0191 515 2778 Professor Gail Sanders *Programme Leader* gail.sanders@sunderland.ac.uk Tel: 0191 515 2682



Scan 01



Scan 02

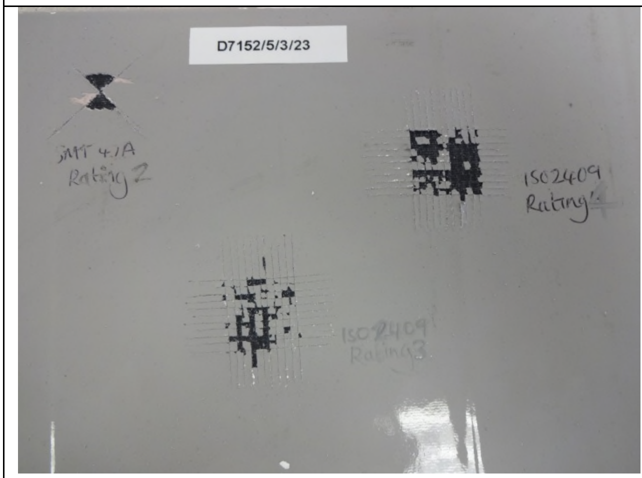


Photo 01

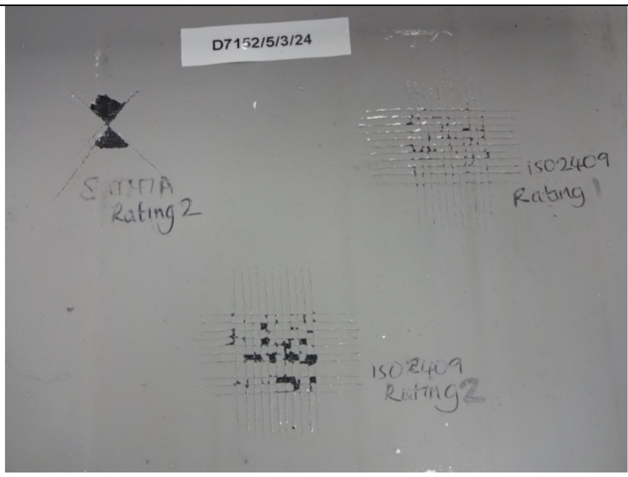


Photo 02

Section 6.0: Statistical Analysis Report

STATISTICAL ANALYSIS OF TEST DATA

IAN CRAIG

Submitted in partial fulfilment of the requirements
of the University of Sunderland for the degree of
Professional Doctorate

June 2018

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LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

As a part of the research, it was necessary to obtain fatigue data for some of the materials under consideration.

This was achieved by either undertaking material testing or else obtaining data from material testing previously performed in order to characterise the fatigue life of the materials in the form of Stress vs Number of Cycles (S-N).

To establish a useable S-N Curve for use in this research, it was necessary to subject the raw test data to a recognised statistical analysis technique such that a 95% confidence band could be determined.

This report details how the raw data obtained through testing was subjected to statistical analysis in accordance with ASTM E739 (ASTM, 2015) to provide useable S-N data.

2. ASTM E739

ASTM E739 (ASTM, 2015) is a recognised standard within the industry that is used to characterize the fatigue performance of a material from a random sample of test data. It is referenced within the latest revision of API 17K (API, 2018) for the statistical analysis of reinforcement materials and provides techniques to determine a 95% confidence interval for the material under consideration, meaning that the estimate would be expected to be correct 95 times in 100.

Using the techniques presented in the standard, the author prepared a spreadsheet so that the parameters could be established for a 95% confidence interval for the test data in hand. This spreadsheet was validated using the numerical example given within Section 8.3.1 of ASTM E739 and is presented in Appendix A.

3. TEXTILE REINFORCEMENT

Samples of yarn used for the textile reinforcement of bonded flexible pipe were subjected to tensile cycling at various loads relating to the measured ultimate tensile strength of the yarn. The number of cycles to failure were recorded for each loading and, from this, a report detailing the testing and results was produced (Intertek, 2015) which can be found in the Portfolio Section 5.0.

The raw data from this testing is reproduced below:

Table 1 Tensile Fatigue Results at 5Hz, 23°C

Specimen	% UBL	Maximum Load N	Number of Cycles Reached	Test Start Date	Comments
1	90	540	43	24-7-2015	Failed in g.l.
2	80	480	52	24-7-2015	Failed in g.l.
3	70	420	1792	27-7-2015	Failed in g.l.
4	60	360	16878	27-7-2015	Failed in g.l.
5	50	300	19301	24-7-2015	Failed in g.l.
6	40	240	364357	31-7-2015	Failed in g.l.
7	30	180	8,236,502	03-8-2015	Failed in g.l.
8	25	150	9,759,399	25-08-2015	Failed just outside g.l.

Table 3.1: Raw Data from Textile Reinforcement Testing

By processing the above raw data through the spreadsheet developed by the author, the linear model for the maximum likelihood estimators and the associated 95% confidence bands were established such that a useable S-N Curve was established.

The spreadsheet for this is presented in Appendix B, from which the resulting S-N Curve and the associated model are plotted below.

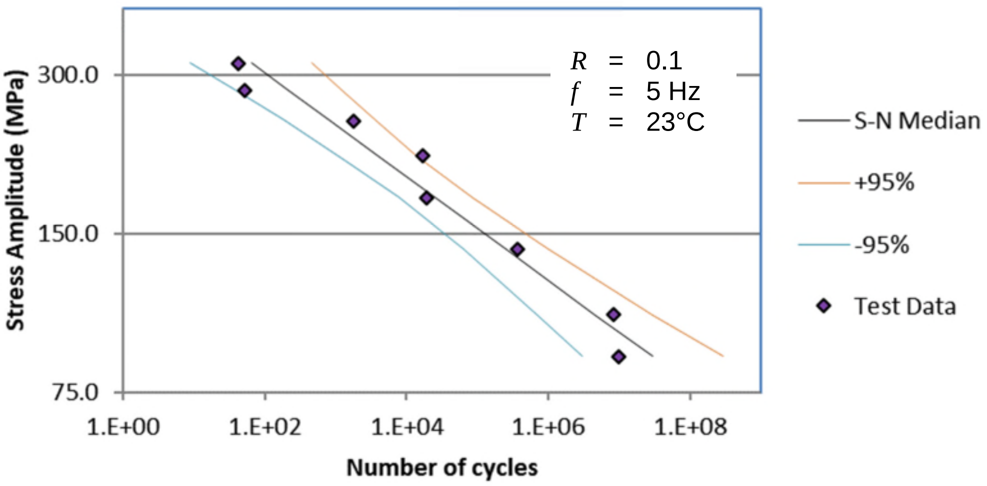


Fig. 3.1: S-N Curves derived for Textile Reinforcement

S-N Median: Log N = 27.233 – 10.173 * Log S

ASTM E739 Equation 10 is applied to the above curve for the relevant stress amplitude to obtain the number of cycles to failure from the -95% Confidence Band.

It should be noted that E739 gives guidelines in relation to the sample size and replication pending the intended use of the data. For research and development for testing of components, this is recommended as 6 to 12 specimens, with a percentage replication of 33 to 50 min. While the number of specimens tested satisfies this guideline, the percentage replication does not and it is therefore recommended that additional testing is performed in this regard.

4. HDPE BUTT FUSION WELD

Test data for fatigue resistance of PE100 thick walled pipe HDPE was obtained (Becetel, 2009) which details the fatigue testing of a butt fusion weld and provides the applied stresses and corresponding cycles to failure for each specimen. A copy of this report can be found in Section 5.0 of the Portfolio from which the raw data is reproduced below:

2.1.2.1. Test at 1,05 Hz

3780 cycles/h, 63 cycles/min, 90.720 cycles/day

Test	Bead	Sction b x h (mm x mm)	Span (mm)	Maximum stress σ (MPa)	Maximum load P (N)	Result (nr. of cycles)
1	with	81,7 x 69,4	680	9,0	3472	24.571
2	with	77,3 x 70,2	650	6,0	2344	132.297
3	without	76,1 x 68,8	600	8,5	3402	203.818
4	without	77,6 x 72,5	700	6,4	2486	541.485
5	without	74,2 x 67,4	600	3,8	1423	2.302.195
6	without	75,0 x 69,5	700	3,0	1035	5.413.974
7	without	80,7 x 69,8	700	2,0	749	13.896.106

2.1.2.2. Test at 9 Hz

540 cycles/min (32.400 cycles/min), 777.600 cyles/day

Test	Bead	Sction b x h (mm x mm)	Span (mm)	Maximum stress σ (MPa)	Maximum load P (N)	Result (nr. of cycles)
8	without	78,7 x 73,3	680	1.0	415	Running 1,8 x 10E8 (status (3/02/2009)

Table 4.1: Raw Data from HDPE Butt Fusion Weld Testing

By processing the above raw data through the spreadsheet developed by the author, the linear model for the maximum likelihood estimators and the associated 95% confidence bands were established such that a useable S-N Curve was established.

The spreadsheet for this is presented in Appendix C, from which the resulting S-N Curve and the associated model are plotted below.

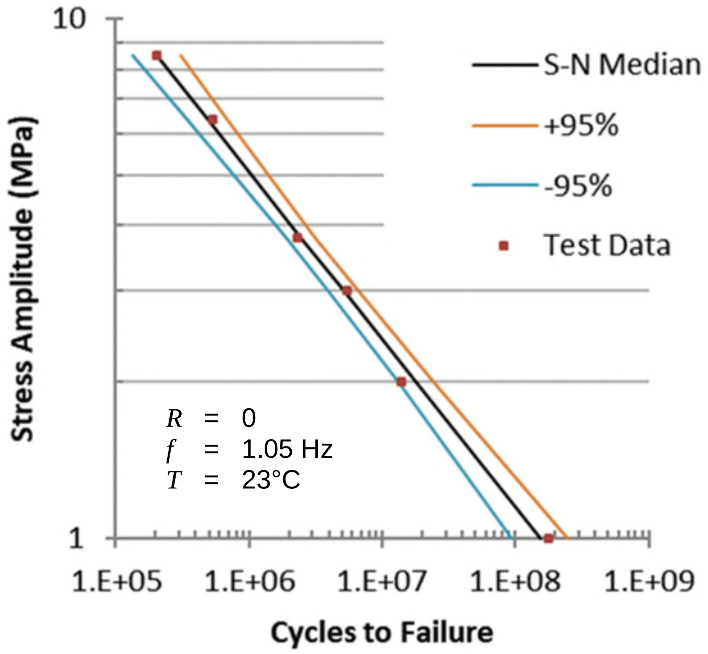


Fig. 4.1: S-N Curves derived for HDPE Butt Fusion Weld

S-N Median: $\text{Log } N = 8.187 - 3.099 * \text{Log } S$

ASTM E739 Equation 10 is applied to the above curve for the relevant stress amplitude to obtain the number of cycles to failure from the -95% Confidence Band.

It should be noted that ASTM E739 gives guidelines in relation to the sample size and replication pending the intended use of the data. For research and development for testing of components, this is given as 6 to 12 specimens, with a percentage replication of 33 to 50 min. While the number of specimens tested satisfies this guideline, the percentage replication does not. ASTM E739 also gives certain criteria for the test data, one of which is that there are no run-outs or suspensions. From the raw data it can be seen that the final test was still running at the time of reporting, which does not satisfy this requirement of ASTM E739. Based on these exceptions, it is recommended that additional testing is performed in this regard.

5. SUMMARY

A spreadsheet was developed by the author to enable raw test data to be processed in accordance with ASTM E739 to obtain usable S-N Curves for estimating the fatigue life of materials.

Two sets of test data were processed using this technique which is used for the research presented in the Doctoral Report.

It should be noted that certain guidelines within ASTM E739 were not met for each set of test data and that additional testing is recommended to fully satisfy the standard.

6. REFERENCES

API, 2018. *API 17K Specification for Bonded Flexible Pipe,* Washington: API Publishing.

ASTM, 2015. *ASTM E739 Standard Practice for Statisical Analysis of Linear or Linearised Stress-Life and Strain-Life Fatigue Data,* West Conshohocken: s.n.

Becetel, 2009. *Determination of the Notch and Fatigue Resisitance of PE100 HDPE Pipe,* Melle: (Commercially Sensitive - not publicly available).

Intertek, 2015. *Characterisation of a Reinforcing Yarn by Tensile Fatigue Analysis,* Redcar: s.n.

APPENDICES

APPENDIX A: Spreadsheet Validation using ASTM E739 Numerical Example

APPENDIX B: Spreadsheet for Textile Yarn Statistical Analysis

APPENDIX C: Spreadsheet for HDPE Butt Fusion Weld Statistical Analysis

APPENDIX A

Spreadsheet Validation using ASTM E739 Numerical Example

From E739:

the symbol "caret" (^) denotes estimate (estimator) — shown here as e.g. X^{caret}

the symbol "overbar" (¯) denotes average — shown here as e.g. X^{bar}

no. of samples (k)= 9

Sum X= -22.785

Sum Y= 30.869

X^{bar}= -2.5317

Y^{bar}= 3.430

X^{bar}^2= 6.40959

Maximum likelihood estimators:

A^{caret}= **-0.2447** *(eq 4)*

B^{caret}= **-1.4514** *(eq 5)*

Variance of normal distribution:

$sigma^2$= **0.011** *(eq 6)*

sigma= 0.1058

95% Confidence Interval

$F_p^{0.95}$= 4.7374 for n2= 7 *E739 table 2 (n1=2)*

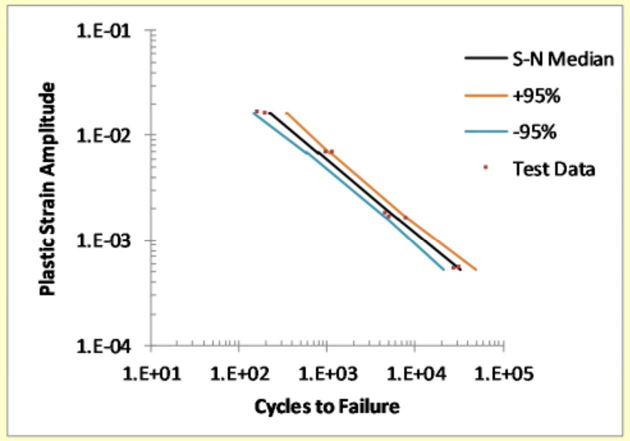
t_p = 2.3646 for k-2 = 7 *E739 table 1*

+/-

A^{caret}= 0.3987 *(eq 7)* so -95% A= -0.643 +95% A= 0.154

B^{caret}= 0.1540 *(eq 8)* so -95% B= -1.297 +95% B= -1.605

	X		Y								
Strain	Log S	No. of cycles	Log N	X_i-X^{bar}	Y_i-Y^{bar}	X_i-X^{bar} * Y_i-Y^{bar}	$(X_i$-$X^{bar})^2$	X/k	Y/k	Y_i^{bar}	$(Y_i$-$Y_i^{bar})^2$
0.01636	-1.786217	168	2.225309	0.74550	-1.205	-0.8980	0.555770	-0.19847	0.24726	2.347848	0.015016
0.01609	-1.793444	200	2.301030	0.73827	-1.129	-0.8334	0.545046	-0.19927	0.25567	2.358338	0.003284
0.00675	-2.170696	1,000	3.000000	0.36102	-0.430	-0.1552	0.130335	-0.24119	0.33333	2.905897	0.008855
0.00682	-2.166216	1,180	3.071882	0.36550	-0.358	-0.1309	0.133591	-0.24069	0.34132	2.899394	0.029752
0.00179	-2.747147	4,730	3.674861	-0.21543	0.245	-0.0528	0.046410	-0.30524	0.40832	3.742581	0.004586
0.00160	-2.795880	8,035	3.904986	-0.26416	0.475	-0.1255	0.069783	-0.31065	0.43389	3.813314	0.008404
0.00165	-2.782516	5,254	3.720490	-0.25080	0.291	-0.0729	0.062901	-0.30917	0.41339	3.793917	0.005392
0.00053	-3.275724	28,617	4.456624	-0.74401	1.027	-0.7639	0.553548	-0.36397	0.49518	4.509779	0.002825
0.00054	-3.267606	32,650	4.513883	-0.73589	1.084	-0.7977	0.541534	-0.36307	0.50154	4.497996	0.000252
Sum Total: 0.05213	**-22.78544592**	81834	**30.86907**		**Sum Total:**	**-3.8302**	**2.6389**	**-2.5317**	**3.4299**	**30.8691**	**0.0784**



Ref. E739 Section 8.1.2 - Confidence Band for the Entire Media S-N (see Chart)

(eq 10)

LogN	N	+/-	LogN-95%	LogN+95%	N-95%	N+95%
2.348	223	0.1847	2.1631	2.5326	146	341
2.358	228	0.1836	2.1748	2.5419	150	348
2.906	805	0.1305	2.7754	3.0364	596	1,087
2.899	793	0.1310	2.7684	3.0304	587	1,072
3.743	5,528	0.1168	3.6257	3.8594	4,224	7,235
3.813	6,506	0.1208	3.6925	3.9341	4,926	8,592
3.794	6,222	0.1196	3.6743	3.9136	4,724	8,195
4.510	32,343	0.1845	4.3253	4.6943	21,149	49,461
4.498	31,477	0.1832	4.3148	4.6812	20,645	47,992

APPENDIX B

Spreadsheet for Textile Yarn Statistical Analysis

From E739:

the symbol "caret" (^) denotes estimate (estimator) — shown here as e.g. X^{caret}

the symbol "overbar" (¯) denotes average — shown here as e.g. X^{bar}

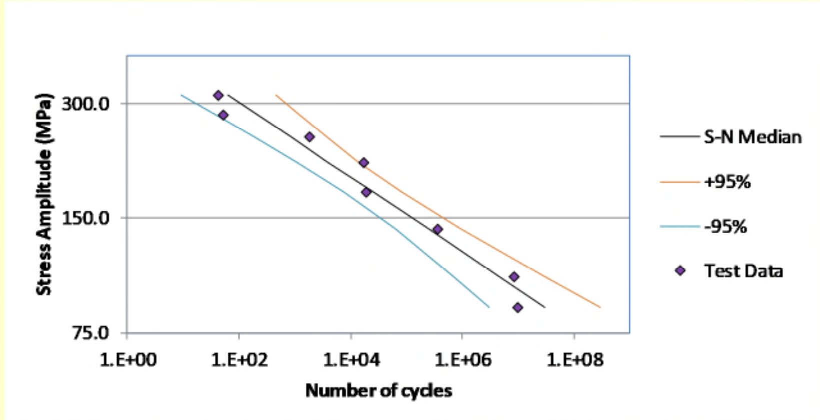
Yarn Diameter =	1.4	mm											
no. of samples (k)=	8												

95% Confidence Interval

$F_p^{0.95}$=	5.1433	for n2=	6	*E739 table 2 (n1=2)*						
t_p =	2.4469	for k-2 =	6	*E739 table 1*						
+/-										
A^{caret}=	4.7401	*(eq 7)*	*so*	-95%	A=	22.493	+95%	A=	31.973	
B^{caret}=	2.0974	*(eq 8)*	*so*	-95%	B=	-8.075	+95%	B=	-12.270	

Sum X=	18.017	Maximum likelihood estimators: A^{caret}=	27.233	*(eq 4)*
Sum Y=	34.582	B^{caret}=	-10.173	*(eq 5)*
X^{bar}=	2.2521	Variance of normal distribution:		
Y^{bar}=	4.323	$sigma^2$=	0.208	*(eq 6)*
		sigma=	0.456	
X^{bar}^2=	5.07210			

			X		Y								
% UTL	Load N	Stress	Log S	No. of cycles	Log N	X_i-X^{bar}	Y_i-Y^{bar}	X_i-X^{bar} * Y_i-Y^{bar}	$(X_i-X^{bar})^2$	X/k	Y/k	Y_i^{bar}	$(Y_i-Y_i^{bar})^2$
90	486	315.7	2.499290	43	1.633468	0.24716	-2.689	-0.6647	0.061087	0.31241	0.20418	1.808497	0.030635
80	432	280.6	2.448138	52	1.716003	0.19601	-2.607	-0.5109	0.038418	0.30602	0.21450	2.328863	0.375597
70	378	245.6	2.390146	1,792	3.253338	0.13801	-1.069	-0.1476	0.019048	0.29877	0.40667	2.918806	0.111911
60	324	210.5	2.323199	16,878	4.227321	0.07107	-0.095	-0.0068	0.005051	0.29040	0.52842	3.599846	0.393725
50	270	175.4	2.244018	19,301	4.285580	-0.00811	-0.037	0.0003	0.000066	0.28050	0.53570	4.405344	0.014344
40	216	140.3	2.147108	364,357	5.561527	-0.10502	1.239	-0.1301	0.011030	0.26839	0.69519	5.391195	0.029013
30	162	105.2	2.022169	8,236,502	6.915743	-0.22996	2.593	-0.5963	0.052883	0.25277	0.86447	6.662177	0.064296
25	135	87.7	1.942988	9,759,399	6.989423	-0.30914	2.667	-0.8244	0.095570	0.24287	0.87368	7.467676	0.228725
Sum Total:	**2403**	**1561.0**	**18.017**	**18,398,324**	**34.582**		**Sum Total:**	**-2.8805**	**0.283153**	**2.2521**	**4.323**	**34.582**	**1.248**



Ref. E739 Section 8.1.2 - Confidence Band for the Entire Media S-N (see Chart)

(eq 10)

LogN	N	+/-	LogN-95%	LogN+95%	N-95%	N+95%
1.808	64	0.8539	0.9546	2.6624	9	460
2.329	213	0.7469	1.5820	3.0758	38	1,191
2.919	829	0.6415	2.2774	3.5603	189	3,633
3.600	3,980	0.5529	3.0470	4.1527	1,114	14,214
4.405	25,430	0.5177	3.8877	4.9230	7,721	83,759
5.391	246,147	0.5923	4.7989	5.9835	62,929	962,800
6.662	4,593,852	0.8168	5.8454	7.4790	700,425	30,129,529
7.468	29,354,556	0.9949	6.4728	8.4626	2,970,179	290,113,781

Notes:

Stress Ratio: R= 0.1

Test Frequency: f = 5Hz

Test Temperature: T = 23°C

APPENDIX C

Spreadsheet for HDPE Butt Fusion Weld Statistical Analysis

From E739:

the symbol "caret" (^) denotes estimate (estimator) — shown here as e.g. X^{caret}

the symbol "overbar" (‾) denotes average — shown here as e.g. X^{bar}

no. of samples (k)= 6

Sum X= 3.094

Sum Y= 39.537

X^{bar}= 0.5156

Y^{bar}= 6.589

X^{bar}^2= 0.26583

Maximum likelihood estimators:

A^{caret}= **8.1873** *(eq 4)*

B^{caret}= **-3.0990** *(eq 5)*

Variance of normal distribution:

$sigma^2$= **0.005** *(eq 6)*

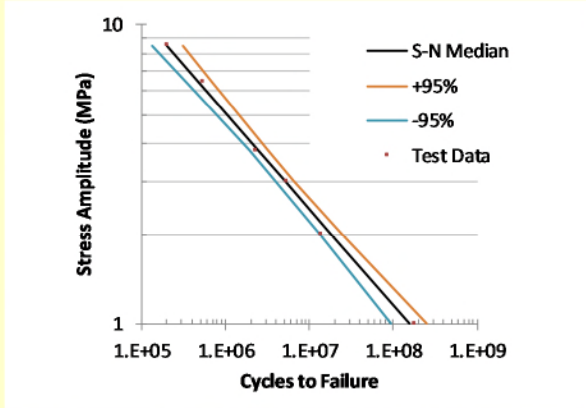
sigma= 0.0715

95% Confidence Interval

$F_p^{0.95}$=	6.9443	for n2=	4	*E739 table 2 (n1=2)*	
t_p =	2.7764	for k-2 =	4	*E739 table 1*	

	+/-							
A^{caret}=	0.1577	*(eq 7)*	*so*	-95% A=	8.030	+95% A=	8.345
B^{caret}=	0.2624	*(eq 8)*	*so*	-95% B=	-2.837	+95% B=	-3.361

	X		Y								
Stress	**Log S**	**No. of cycles**	**Log N**	X_i-X^{bar}	Y_i-Y^{bar}	X_i-X^{bar} * Y_i-Y^{bar}	$(X_i$-$X^{bar})^2$	X/k	Y/k	Y_i^{bar}	$(Y_i$-$Y_i^{bar})^2$
8.50000	0.929419	203,818	5.309243	0.41383	-1.280	-0.5298	0.171255	0.15490	0.88487	5.306975	5.14E-06
6.40000	0.806180	541,485	5.733586	0.29059	-0.856	-0.2487	0.084443	0.13436	0.95560	5.688895	0.001997
3.80000	0.579784	2,302,195	6.362142	0.06419	-0.227	-0.0146	0.004121	0.09663	1.06036	6.390502	0.000804
3.00000	0.477121	5,413,974	6.733516	-0.03847	0.144	-0.0055	0.001480	0.07952	1.12225	6.708654	0.000618
2.00000	0.301030	13,896,106	7.142893	-0.21456	0.553	-0.1187	0.046036	0.05017	1.19048	7.254364	0.012426
1.00000	0.000000	180,000,000	8.255273	-0.51559	1.666	-0.8589	0.265832	0.00000	1.37588	8.187262	0.004625
Sum Total: 24.7	**3.093533747**	**202357578**	**39.53665**		**Sum Total:**	**-1.7763**	**0.5732**	**0.5156**	**6.5894**	**39.5367**	**0.0205**



Ref. E739 Section 8.1.2 - Confidence Band for the Entire Media S-N (see Chart)
(eq 10)

LogN	N	+/-	LogN-95%	LogN+95%	N-95%	N+95%
5.307	202,757	0.1819	5.1251	5.4889	133,372	308,239
5.689	488,534	0.1494	5.5395	5.8383	346,325	689,138
6.391	2,457,546	0.1112	6.2793	6.5017	1,902,496	3,174,531
6.709	5,112,747	0.1097	6.5990	6.8183	3,971,547	6,581,864
7.254	17,962,403	0.1325	7.1219	7.3869	13,238,891	24,371,218
8.187	153,908,312	0.2117	7.9755	8.3990	94,525,003	250,597,915

Notes:

Stress Ratio: *R*= 0
Test Frequency: *f* = 1.05Hz (except sample at 1MPa = 9Hz)
Test Temperature: *T* = 23°C

Section 7.0: Flexible Hose FEA Reports

PDL	**PDL Solutions (Europe) Ltd.** 1 Tanners Yard Hexham Northumberland NE46 3NY **Tel :** +44 (0) 1 434 609 473 **Fax :** +44 (0) 1 434 606 292 **www.pdl-group.com**	**Technical Report** 40" Suction Hose Fatigue Assessment Local Analysis

Report Number:	PDL-EMS-667-003 (1)	**Project:**	40" Suction Hose Fatigue
Customer:	EMSTEC	**PDL Job No:**	667
Contact:	Ian Craig	**Quote Ref:**	SQDU-141 (3)

Technical Report

Abstract:	This document details the results of local analyses undertaken in support of the fatigue assessment of the EMSTEC 40” cooling water suction hose. All model setups and simplifications are detailed. The necessary inputs, load case definitions and assumptions are also described. The purpose of this document is to give a detailed description of the analysis work and the associated results. The key outputs were hose axial and bending stiffnesses and hose stress factors for use in the fatigue assessment conducted in Orcaflex and reported in PDL-EMS-667-002. The hose textile material consists of a polyester yarn/rubber sheet which reinforces the hose; this was considered in detail along with the metal parts of the flanged joint.

Revision History

1	31/03/2015	First issue for customer comment	RAF/DCU	DCU/RAF	AGR
Rev	**Date**	**Reason for change**	**Author**	**PDL Review**	**PDL Approval**

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1 Introduction

This report describes the steps taken in the local analysis of an EMSTEC 40” cooling water suction hose [1] operating from a new FLNG (floating liquefied natural gas) unit intended to be deployed off the coast of Mozambique. The main outputs of the analysis were the hose axial and bending stiffnesses and the hose axial and bending stress factors both for use in the fatigue assessment conducted in Orcaflex and reported separately in PDL-EMS-667-002 [19]. The polyester/rubber composite reinforcement was considered in detail along with the metal parts of the flanged joint. This work is part of a front end engineering and design study funded by Eni East Africa SPA.

EMSTEC intend for the hose to comply with the fatigue requirements of API 17K ‘Specification for Bonded Flexible Pipe’ (co-branded as BS EN ISO 13628-10) although it is recognised that this standard is not strictly intended to be used for suction hoses.

As part of the requirements for compliance with API 17K, all bonded flexible hoses must show suitable fatigue life under expected operating conditions. In order to verify that the EMSTEC suction hose complies with this requirement, PDL Solutions (Europe) was contracted to undertake a full fatigue analysis for a total hose length of 135m. Each section of hose is 9m long with steel flanges at either end so 15-off hose sections are required to make up the 135m total length. There is also a strainer at the open end of the hose. For compliance with API 17K, the suction hose must have a fatigue life of more than ten times the service life, which in this case means the calculated minimum life should exceed 250yrs.

2 Objective

The purpose of this report is to outline the input data that was used in the local analysis, to record how some of the material properties were generated and to detail the results.

Briefly, the local analysis comprised of the finite element (FE) analysis, conducted in ANSYS APDL, of two detailed models that were used to calculate the axial and bending stiffnesses and the axial and bending stress factors for use in the global analysis [19]:

1. An FE model of half (i.e. 4.5m long) a single 9m hose section including one flange was created. This model was subjected to three load cases: a bending test case consistent with GMPHOM [2], a hydrostatic pressure test case as described in the hose Data Book [3] and a tension case where the axial load was ramped up to a value greater than the worst expected hang-off load; see Section 3.
2. An FE model of back-to-back flanges where the main interest was the bolted joint and fillet weld. This model was subjected to axial and bending load cases; see Section 5.

Early in the project it was recognised that not all the required material data was likely to be available. It was therefore realised that an element of material property ‘tuning’ would be required. This tuning was carried out by comparing the distortions from the FE models with the distortions measured from the bending test and hydro test that had already been carried out on an actual hose.

3 Local Analysis Methodology – 4.5m Hose Model

3.1 Geometry

The main features of the hose section geometry are described below with the actual thicknesses taken from the CAD model supplied by EMSTEC [4].

The hose section geometry is shown in Figure 3-1. The inside diameter (ID) of the hose is 1.00m and the outside diameter (OD), away from the end fitting, is 1.22m. The end fitting OD is 1.30m; this applies to the flange and the enlarged section shown in Figure 3-1.

The textile plies carry the main structural loading. Across the full length of the hose there are 20 layers where the angle of the drawn polyester fibres is +/-40^{o} to the hose longitudinal axis; these are known as 'D layers'. In the end region there are 4 additional 'V layers', in two groups of two, which divide the D layers into two groups of 10 with the lay-up as follows: "VVDDDDDDDDDDVVDDDDDDDDDD" (this represents the lay-up from the inside radius to the outside). Within each layer, the filaments are parallel and embedded into a rubber sheet.

The ends of each bundle of textile layers are held in place by a set of 5mm diameter pre-tensioned steel wires that wrap around the end fitting in the hoop direction; the inboard set consists of 27 wraps in two layers, the outboard set consists of 87 wraps in two layers. There are two circumferential ribs welded to each steel end fitting to help control the axial location of the binding wire wraps. The tension in each wrap is approximately 100kg [10].

The inside layer of the hose is a 'wear liner' which extends along the full length of the hose; it has a constant thickness away from the end fittings but the OD tapers out to give a thicker layer underneath the steel end fitting.

The textile layers are reinforced by a set of 30mm diameter steel rings pitched at 210mm along the length of the hose with the first one located as shown in Figure 3-1. The rings are embedded in a layer of 'filler rubber' which is outside the wear liner but inside the textile layers.

There is a further layer of filler rubber outside of the textile layers which has a constant thickness away from the end fittings but the OD tapers out to give a substantially thicker layer in the region of the end fittings.

In the region of the end fitting there are three more textile layers known as 'R-layers', separated from each other by a thin layer of filler rubber and wrapped at an angle of 88^{o} to the hose longitudinal axis. These provide protection from impact loads and are not intended to contribute to the axial or bending capacity of the hose.

The outer most layer is a 'cover rubber' and this extends along the full length of the hose at a constant thickness except where it covers only the end fitting at which points it is a little thinner. This cover rubber also envelopes the entire end fitting including the flange contact faces.

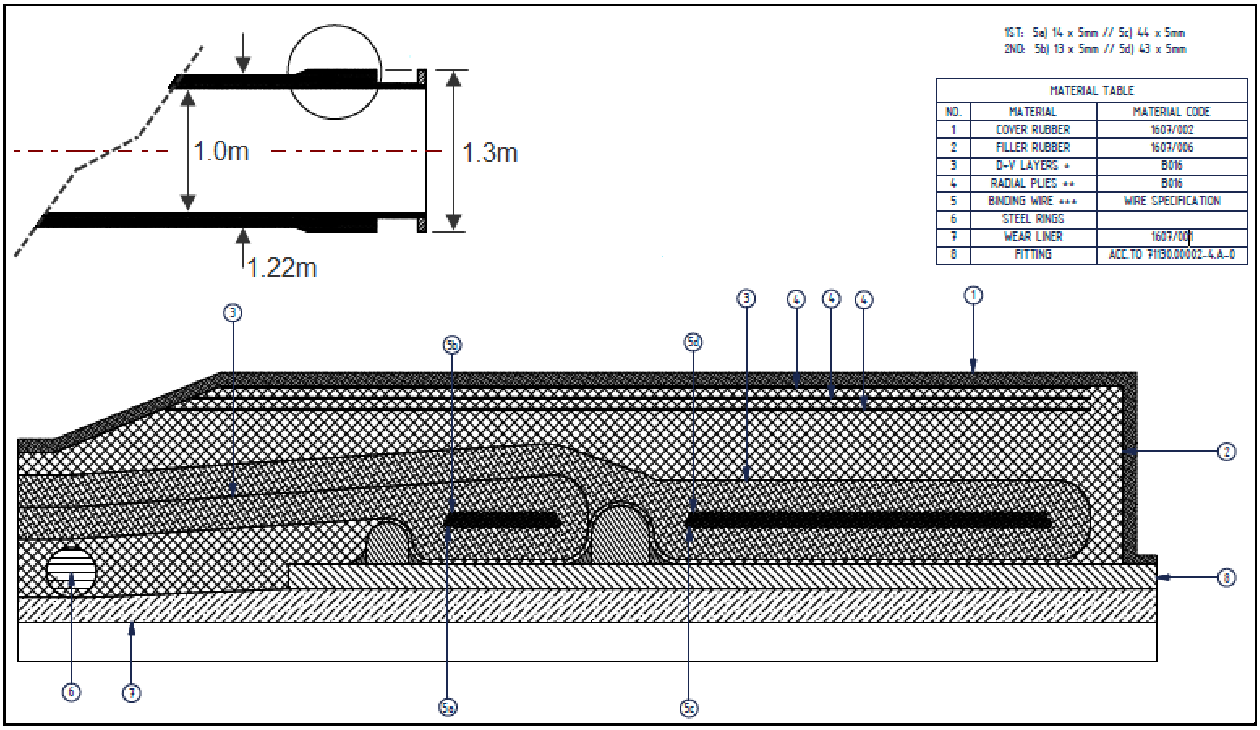

Figure 3-1 – Hose Geometry [1]

3.1.1 Model Simplifications

The geometry of the model was simplified in order to aid meshing and to ensure that the load path from the textile layers to the end fitting was realistic. The simplifications were as follows, see also Figure 3-2:

- The binding wires were not modelled individually but as a strip of steel with approximately the same volume as the combined set of wires. A sensitivity study was conducted to check the effect of binding wire tension on the stresses in the critical regions. This is detailed in Appendix B.
- Each steel ring was squared off and represented as a rectangular body; this was to simplify the model meshing process.
- The textile layers are held in place by the binding wires but loop back around the binding wires so that they terminate approximately in line with the left hand side (Figure 3-1) of the binding wires. A gap was included at this location so as to prevent a continuous hoop of textile sheet around the binding wires.
- The properties of the textile in the looped section were made equal to the isotropic properties of the matrix rubber as this end loop of the textile is not critical in terms of hose fatigue performance.
- The bolt holes in the flange were removed, these were considered in the back-to-back flange model, see section 5 and 6.
- The R layers were removed and replaced with filler rubber as they do not contribute to the axial stiffness of the hose.
- The V layers were removed and replaced with filler rubber as they are not continuous along the full length of the hose and therefore have minimal effect on its stiffness.
- A half hose model was used (length = 4.5m) and a symmetry condition was applied at the cut plane.

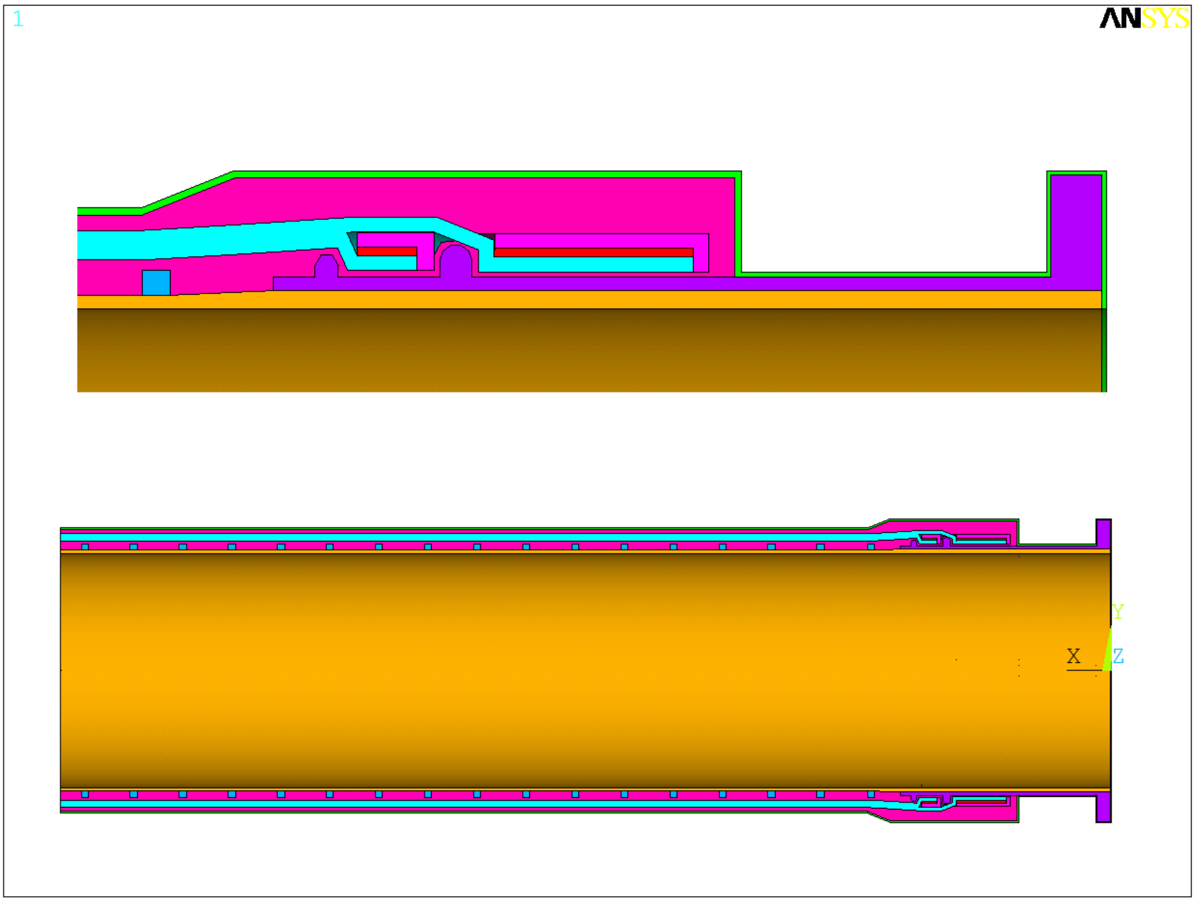

Figure 3-2 – Hose Model Geometry for FE Analysis

3.2 Coordinate System

The global Cartesian coordinate system is shown at the centre of the flange in Figure 3-2. Ox acts axially, Oy acts vertically and Oz acts normal to the XY plane. All loads and boundary conditions are specified with respect to this coordinate system.

3.3 Material Data

This section shows the material data that was used to develop the material models for the various hose components.

Linear models were used throughout. It is recognised that the stress-strain curve for rubber is typically non-linear but over the likely range of strains it was considered that a linear model would provide a reasonable approximation. This assumption was confirmed once realistic strains had been obtained via the global analysis [19] and referenced back to ASTM D 1415-88 [5] which states that linear properties are appropriate for well vulcanised rubbers. Rubber and steel material data is given in Table 3-1.

Material	Young's Modulus (MPa)	Poisson's Ratio	Density (g/cm^3)
Steel (end fittings, rings, bolts, binding wires)	207,000[1]	0.3[1]	7.85[1]
Cover rubber – 1607/002 – Shore A hardness = 62	3.9[3]	0.5[2]	1.23 [7]
Filler rubber – 1607/006 – Shore A hardness = 70	5.5[3]	0.5[2]	1.38 [6]
Wear liner – 1607/001 – Shore A hardness = 68	5.0[3]	0.5[2]	1.16 [8]
Composite calendaring rubber – Y003A – Shore A hardness = 55	2.9[3]	0.5[2]	1.26 [12]

Table 3-1 – Isotropic Material Data

1 – Standard values for steel.
2 – 0.5 is the standard value for rubber; the FE models will use 0.49 to aid convergence.
3 – Values derived from ASTM D 1415-88 [5], given that the Shore A hardness is similar to the IRHD (International Rubber Hardness Degrees) hardness used by ASTM.

In order to define the laminar properties of the composite sheet, nine properties are required as shown in Table 3-2. These properties should be derived from test data and this is recommended.

In the absence of such data, approximations can be made by modelling the components of the composite laminar sheet and applying nominal direct and shear forces. This requires the calendaring rubber and textile material data. The calendaring rubber material data is shown in Table 3-1 and was assumed to be isotropic.

The textile is in the form of a yarn (or cord) made up of a number of strands twisted together which are, in turn, made up of a number (192 [13]) of drawn polyester filaments twisted together. Filament strength and stiffness data in the axial direction, along the filament, and similar yarn data was available from references [13] and [11] respectively. However, like the composite itself, the yarn is orthotropic and requires nine material properties to properly define it. Because only one of the properties of the yarn was known (Ex), it was necessary to estimate the other eight. More detail on how this was done is given in Appendix A, the resulting composite test properties are given in Table 3-2. All these properties were tested and the best match taken forward to use in the generation of axial and bending stiffnesses and stress factors.

Property	Test 1	Test 2	Test 3	Test 4
Ex (MPa)	953	953	1906	953
Ey (MPa)	2.9	2.9	2.9	4.6
Ez (MPa)	2.9	2.9	2.9	4.7
νxy	0.275	0.32	0.275	0.92
νyz	0.99	0.5	0.99	0.96
νxz	0.245	0.31	0.245	0.94
Gxy (MPa)	2.1	2.1	4.2	2.1
Gyz (MPa)	0.73	0.96	0.73	1.2
Gxz (MPa)	3.4	3.4	6.8	3.4

Table 3-2 – Composite Material Property Trials

The derivation of the fatigue curves used for the textile, fasteners and weld material is given in [19].

3.4 Meshing

A solid model of a 4.5m half symmetry hose section was created. The finite element mesh was generated using 3D 8-Node structural solid shell elements (SOLSH190). This element type was adopted as it has a laminar layer option which was used to describe the orthotropic properties of the textile sheets which are laid up using +/-40^{o} fibre orientation on alternate layers. Additionally, this element type gives good accuracy in bending applications allowing the for number of integration points to be specified for each layer; in this case 3 integration points per layer were specified.

Other components were meshed using the same element type but without the layered section option, in this configuration the elements behave in a similar way to standard first order brick elements. The mesh was swept around the circumference for all regions that are hoop continuous.

Figure 3-3 to Figure 3-5 show images of the finite element mesh including a detailed image of the layup of the D layers. The angular layup orientations as defined in the analysis software are shown in Figure 3-6. Preliminary checks into the element stiffness behaviour as a function of lay-up angle were carried out to gain confidence in the element technology; this is detailed in Appendix C. Details of the mesh size are described in Table 3-3.

Mesh Detail	Value
Number of Nodes	447,409
Number of Elements	403,345
Number of Element divisions through Hose thickness	10
Number of Element divisions around Hose circumference	144
Element Edge Size in Axial Direction (mm)	17

Table 3-3 – 4.5m Hose Model – Mesh Size Details

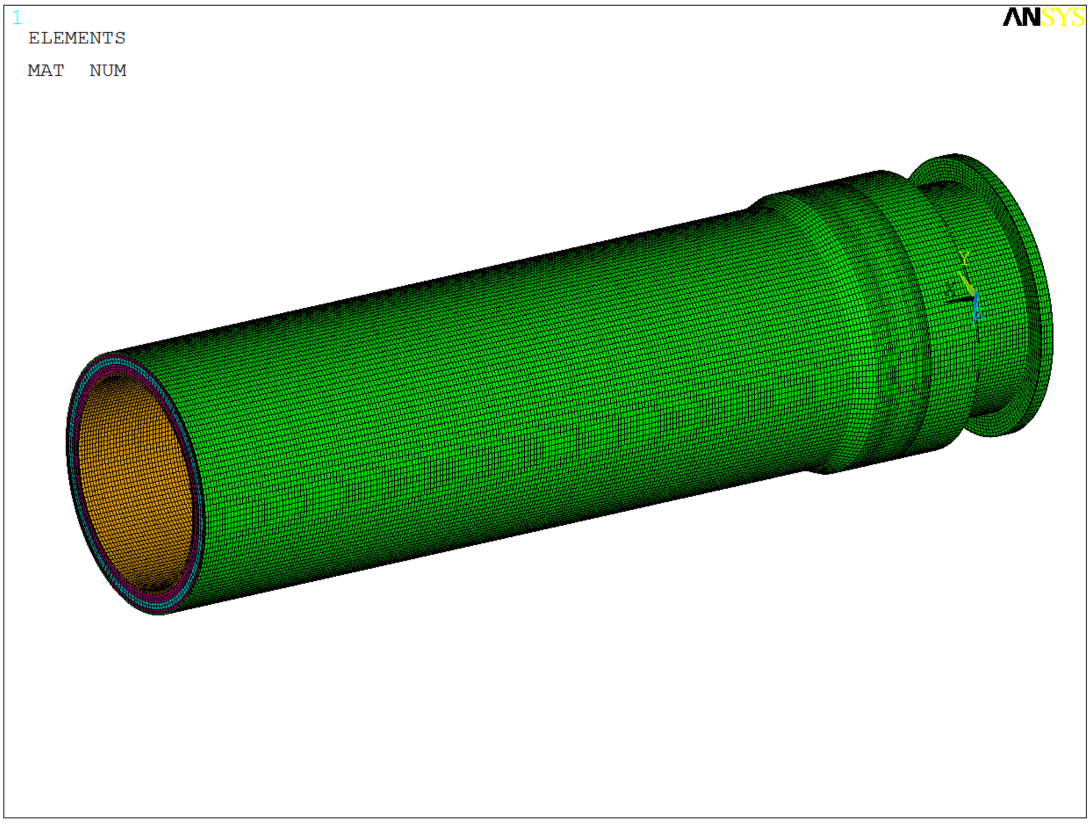

Figure 3-3 – 4.5m Hose Model Mesh for FE Analysis – External View

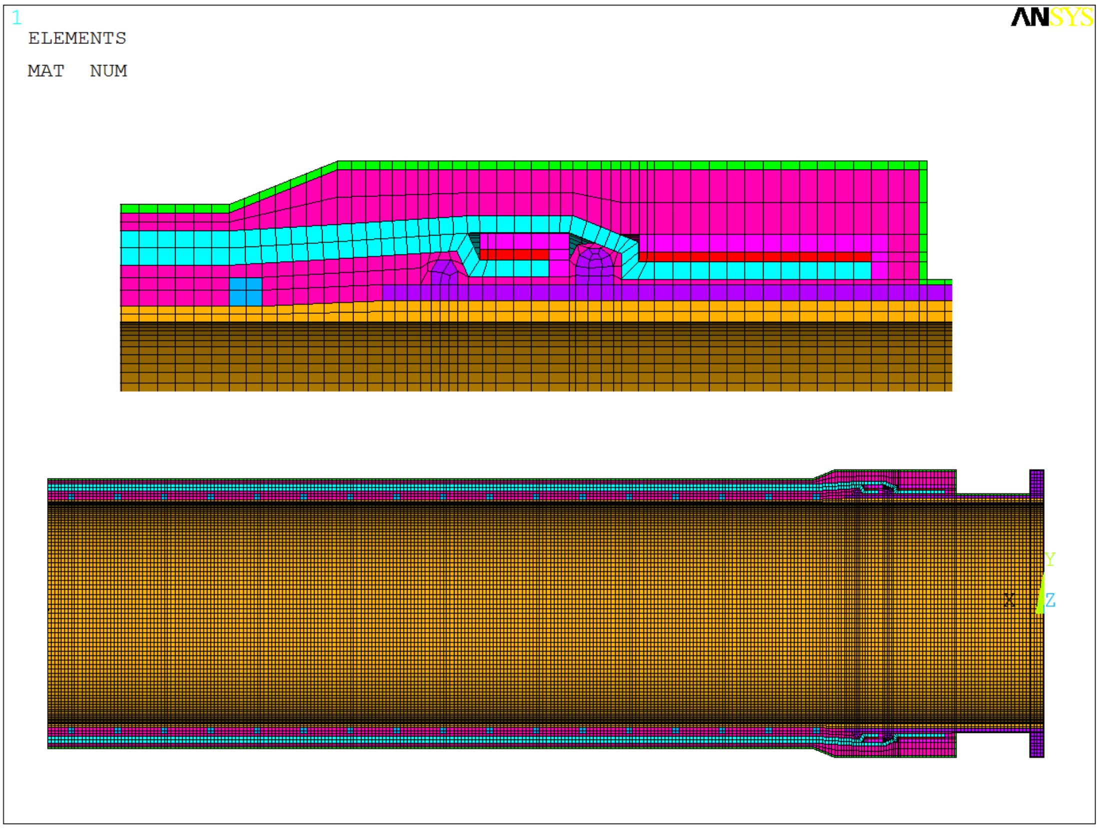

Figure 3-4 – 4.5m Hose Model Mesh for FE Analysis – Section View with End Fitting Detail

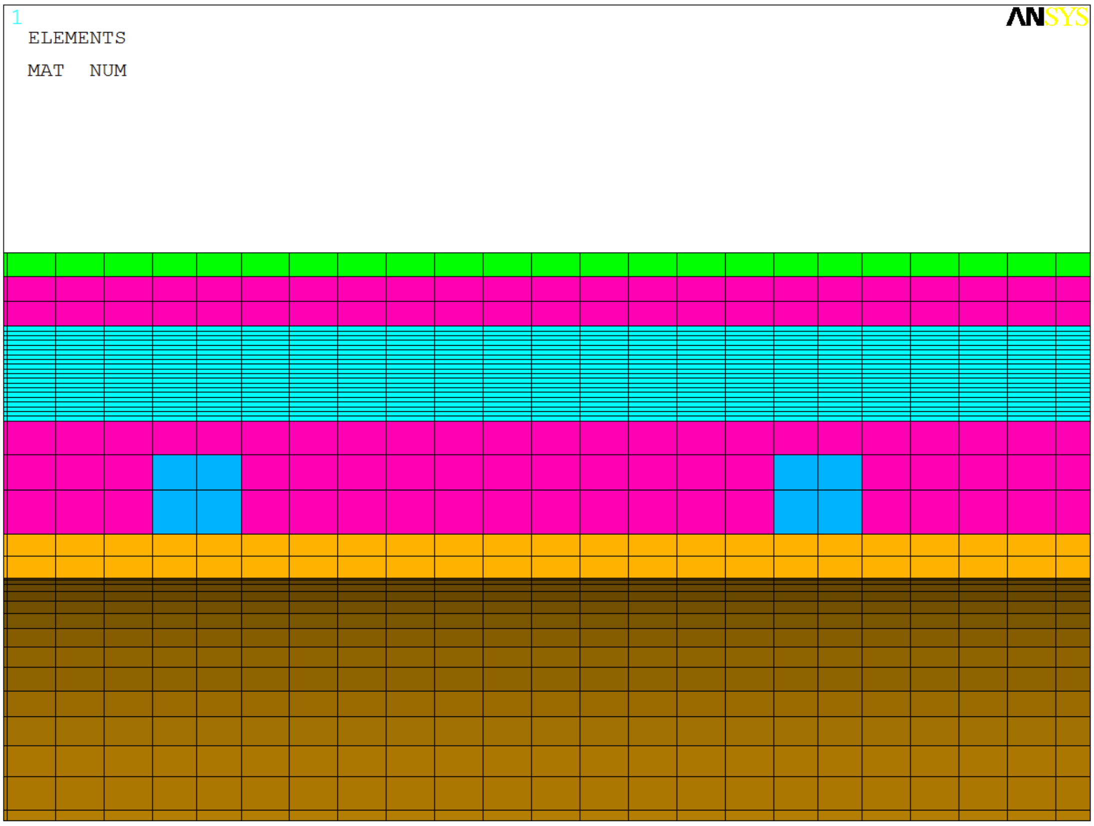

Figure 3-5 – 4.5m Hose Model Mesh for FE Analysis – Detail View of the D-Layers

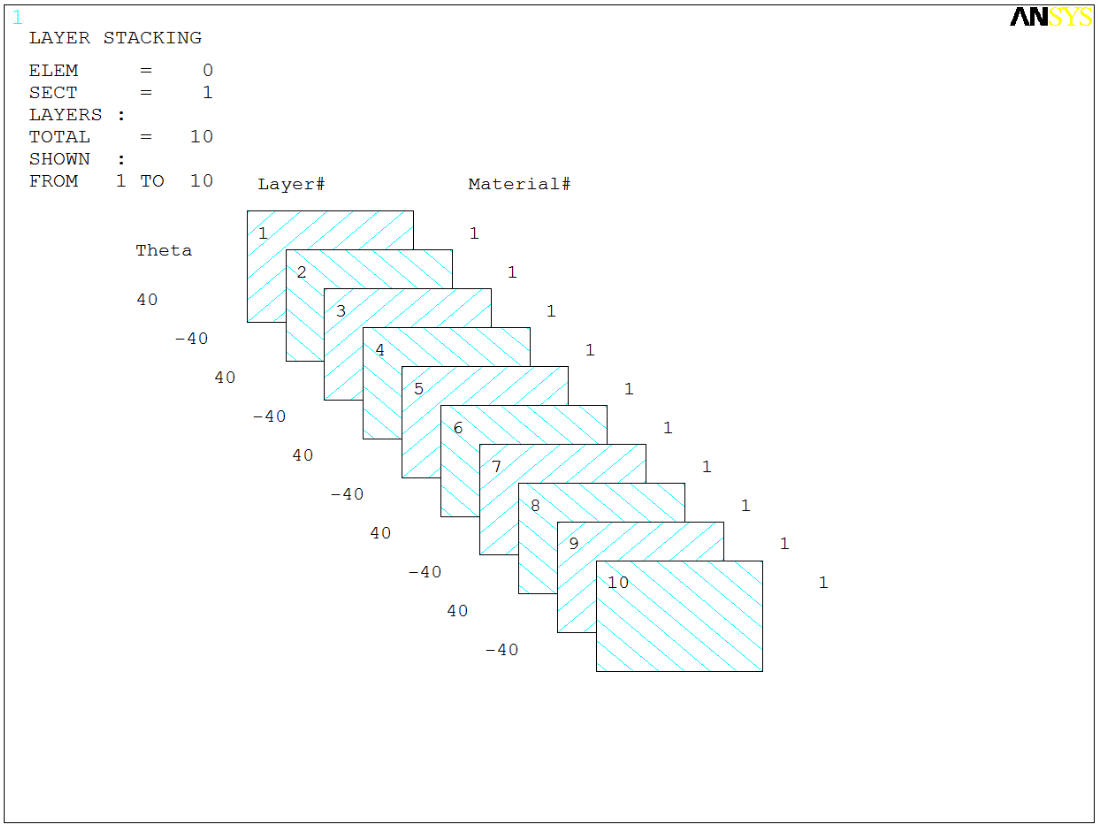

Figure 3-6 – 4.5m Hose Model – Details of D-Layer Stacking Orientations

3.5 Contact

A continuous mesh was defined between all materials throughout the hose; the process of autoclaving the hose should make this assumption realistic.

3.6 Boundary Conditions

For all load cases, a pilot node was defined at the flange end of the hose and was connected to the flange end face via rigid constraint equations. The pilot node was fixed in UY (deflection in the Y direction), UZ and ROTX (rotation about the X axis) degrees of freedom (DOFs). All the nodes on the symmetry plane were fixed in UX. The boundary conditions are shown in Figure 3-7.

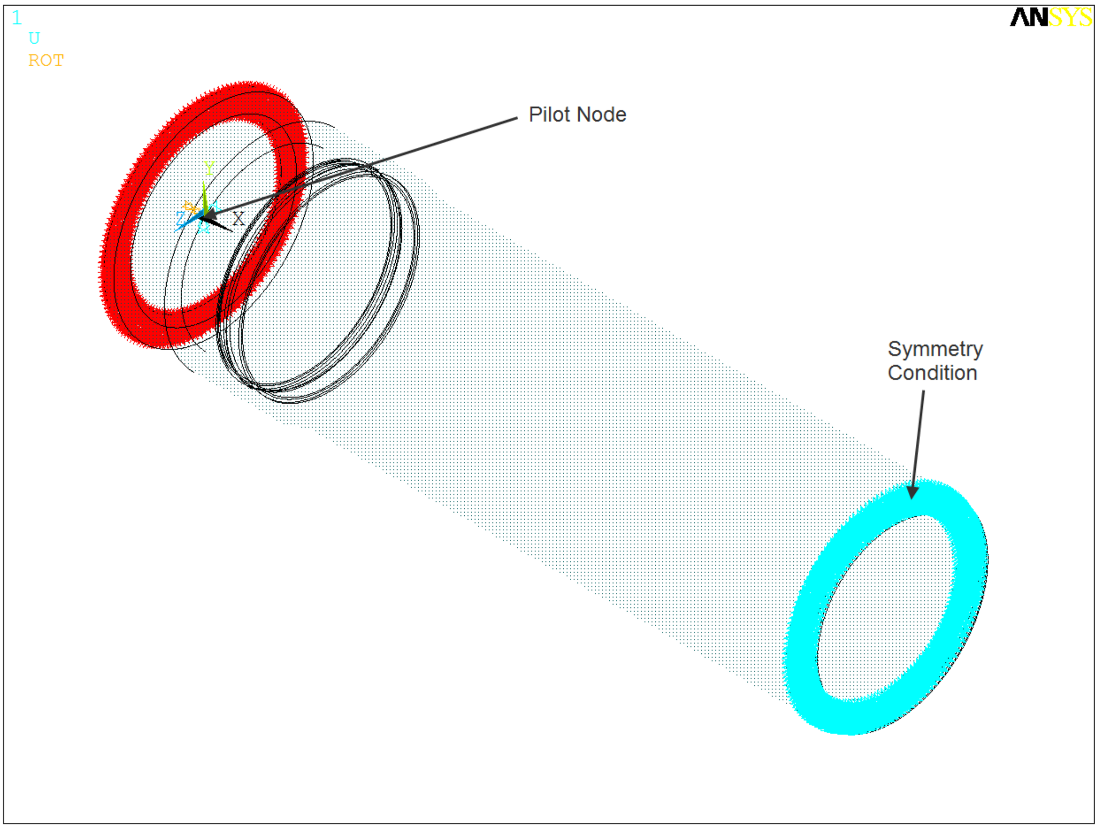

Figure 3-7 – 4.5m Hose Model – Boundary Conditions

3.7 Calibration Loadcases

Two virtual tests were run and the results compared with test data [3]. The main purpose of the validation tests was to ensure that the FE model had representative material properties applied and therefore that its stiffnesses, in tension and bending, were also representative. In particular, and as mentioned in Section 2, it was recognised that the full suite of composite material properties would not be available and that estimates of some of the properties would have to be made in lieu of specimen test data. Section 3.3 describes the tuning process in more detail.

Once the model behaviour matched the test data in hydrotest and bending a high level of confidence in the model's prediction of the hose component stress levels was then established. This is clearly important as it is the stress levels which drive the fatigue life calculations.

3.7.1 Hydrostatic Pressure Test

During hydrotest, the inside of the hose is pressurised to 10bar and the axial extension (or contraction) measured. From three tests, the average extension of the hose was found to be 36mm from the data given in [3], [15] and [16]. The hose diameter also increases during hydrotest but it was not possible to make use of the measured data because the diameter increase varies considerably depending on the proximity of the measurement point to the ring stiffeners and it was not known where the measurements were taken from.

In the FE modelling of the hydrotest, a half hose model was set up with the boundary conditions described in Section 3.6. The end cap force, Fx = -785kN was applied at the pilot node and pressure was applied to all internal surfaces. The pressure was ramped up in small increments so that any geometric non-linearity was identified.

The model was tuned, by varying the material properties of the textile in accordance with Table 3-2 until the properties which best represented the axial extension test data were identified.

3.7.2 Bending Stiffness Test

A bending stiffness of 217,000 kgm^2, based on a single test, was provided in [17], calculated using the methods described in [2]. The bending stiffness is obtained by multiplying the developed radius, in the central region of the hose, by the applied bending moment. In this case the hose was bent to a radius of 7.2m and so the intent of the FE modelling was to achieve that same radius. Note that [2] allows a bending stiffness error of up to 15% compared to the 'specified value' (usually obtained from prototype testing).

In the FE modelling of the bend test, the boundary conditions were setup as described in section 3.6. The pilot node was rotated until a tight a bend radius as possible (from an FE model convergence point of view) was achieved. The end rotation was ramped up in small increments so that the geometric non-linearity was identified. A graph of curvature versus bending moment was generated which was one of the required inputs to the Orcaflex analysis.

3.8 Operational Loadcases

In practice there will be very little pressure drop across the hose; the main load cases are tension and bending. The bending stiffness and stress factor was obtained from the calibration loadcase discussed in section 3.7.2.

3.8.1 Tension Test

Once the model had been tuned successfully, a tension-only case was run where a load, Fx = -785kN was applied (nominal loading, known to be higher than occurring during normal operation). The boundary conditions for this case were setup as described in section 3.6. The 785kN force was ramped up in small increments so that any geometric non-linearity was identified. A graph of tension versus extension was generated which was one of the requirements of the Orcaflex analysis.

3.8.2 Stress Factors

Using the results from Section 3.7.2 and Section 3.8.1, bending and tension stress factors were derived for the textile layers. These stress factors were required for the fatigue assessment which was conducted using tensions and bending moments derived from the Orcaflex global dynamic analysis work.

4 Local Analysis Results – 4.5m Hose Model

4.1 FE Model Calibration with Test Data

4.1.1 Hydrostatic Pressure Test

The aim of the hydrostatic pressure test case was to calibrate the FE model against test data in terms of the amount of axial extension observed. The hydrotest case was solved multiple times using the different material properties described in Table 3-1. The axial extension results from the 4 trials are summarised in Table 4-1. It is clear from this result that the 'Test 3' properties match the test data closest and will henceforth be referred to as 'best estimate properties'. A plot of axial extension for this case is shown in Figure 4-1.

Run	Material Properties	Axial Extension (on 4.5m Hose) (mm)
Test Data (Ave.)	Actual	18.0
FE Trial 1	'Test 1'	61.9
FE Trial 2	'Test 2'	61.8
FE Trial 3	'Test 3'	22.9
FE Trial 4	'Test 4'	65.7

Table 4-1 – Hydrotest Pressure Case – Axial Extension Calibration

In finding that the 'best estimate properties' had a modulus of elasticity for the yarn which was twice that initially proposed for 'FE Trial 1', an investigation into the effect this had on the fibre stress was undertaken. For both 'FE Trial 1' and 'FE Trial 3', the fibre stresses were extracted through the 20 layers at a position in the hose mid-way between the steel rings. It was found that the fibre stress was largely insensitive to the change in elastic modulus with the average stress through the section varying by less than 2%. This is thought to be due to the fact that the yarn stiffness is so much greater than the rubber stiffness that modest changes have only a minor effect on the proportion of load carried by the yarn i.e. the rubber carries little load.

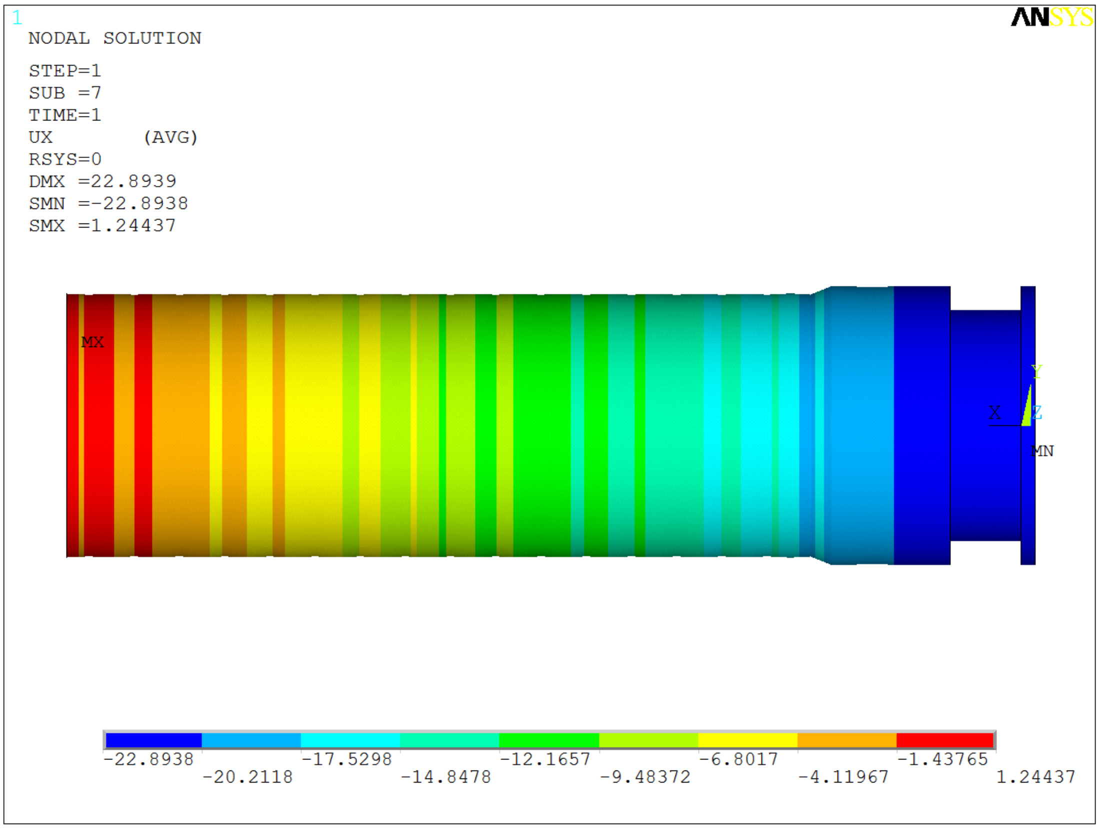

Figure 4-1 – Hydrostatic Pressure – 'Test 3' Material Data – Axial Extension (mm)

4.1.2 Bending Stiffness Test

The aim of this calibration load case was to replicate the 7.2m bend radius achieved on test and try to match the bend stiffness at the end point to the test data.

The initial FE modelling of the bending test was carried out using the 'best estimate properties' derived from the hydrostatic pressure test model. In FE modelling terms, a bend radius of 7.2m represents a high level of deformation and it was not possible to achieve a fully converged solution at such a tight radius. Contour plots of resultant deformation and maximum principal stress at the final converged time point are shown in Figure 4-2 and Figure 4-3 respectively. Figure 4-2 shows the buckling on the compression side of the hose; buckling is a phenomenon which typically reduces the stability of a finite element model and may explain the premature lack of convergence. In Figure 4-3 the location of the peak stress in the composite can be seen to be local to the most inboard welded rib. It should be noted that although the model did not converge all the way to the minimum bend radius (MBR) of the hose, it did converge far enough to give accurate data for the range of curvatures required for the fatigue assessment [19].

The bending moment versus curvature curve is shown in Figure 4-4. Extrapolation from the last solved data point to the known 'test data point' suggested that the estimated material properties were reasonable; however, the amount of extrapolation was considerable.

To counter the inherent error in the extrapolation, error bands were specified to define a stiffness 'envelope'. The maximum and minimum bounds were established by doubling and halving, respectively, the best estimate composite properties. The ends of each error band (where curvature=1/7.2m) were set using +/-15% of the 'test data point' value; this encompassed the variation which is accepted on test (see Section 3.7.2).

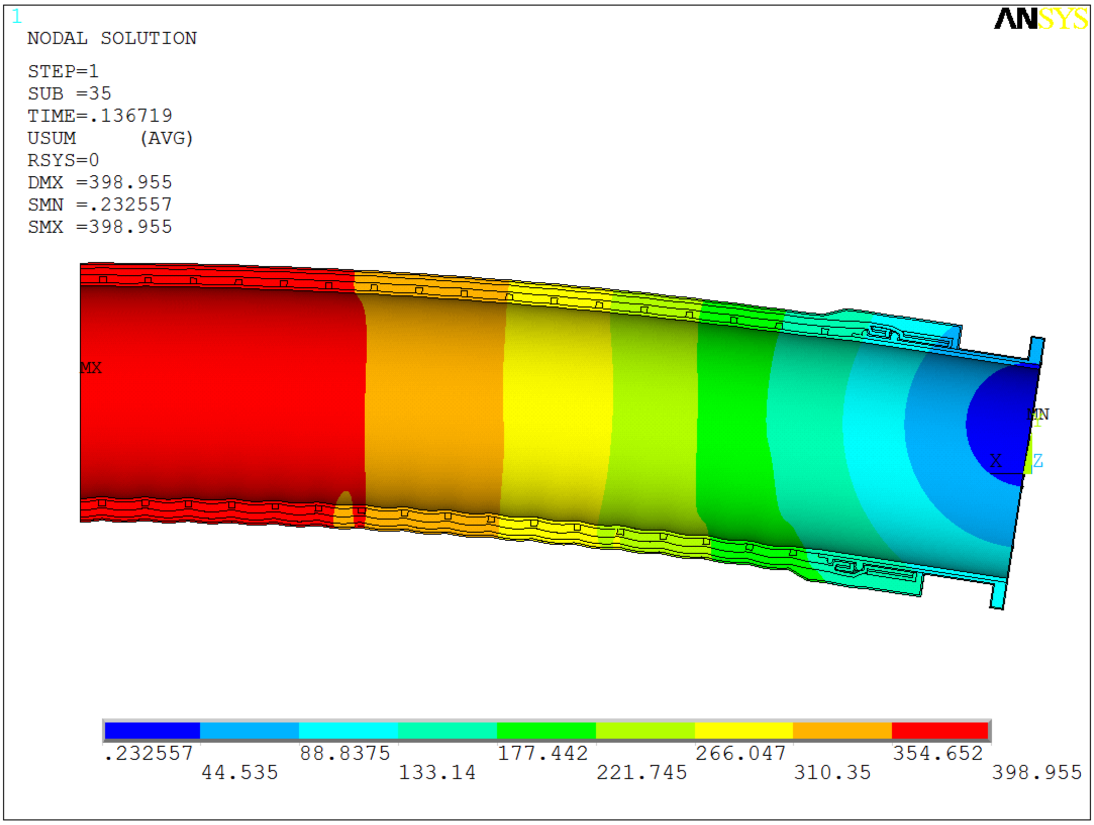

Figure 4-2 – Bend Stiffness Test – 'Best Estimate Properties' – Resultant Displacement (mm)

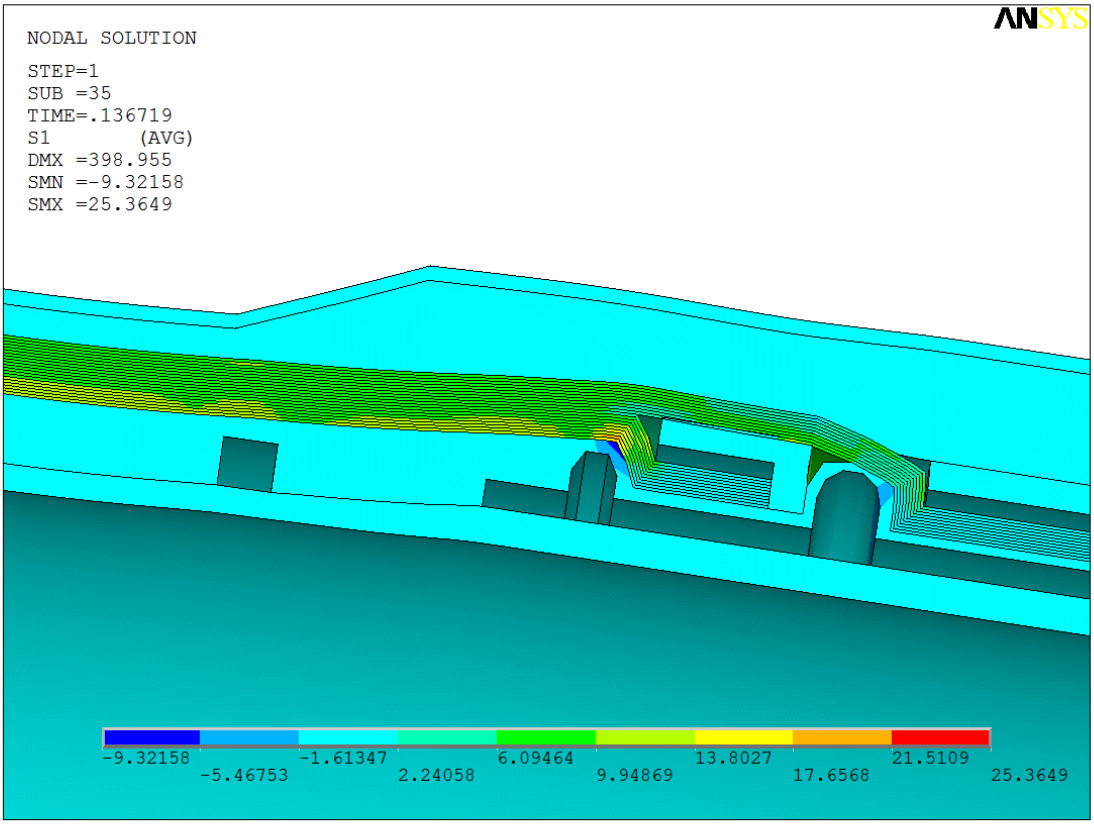

Figure 4-3 – Bend Stiffness Test – 'Best Estimate Properties' – Max Principal Stress (MPa)

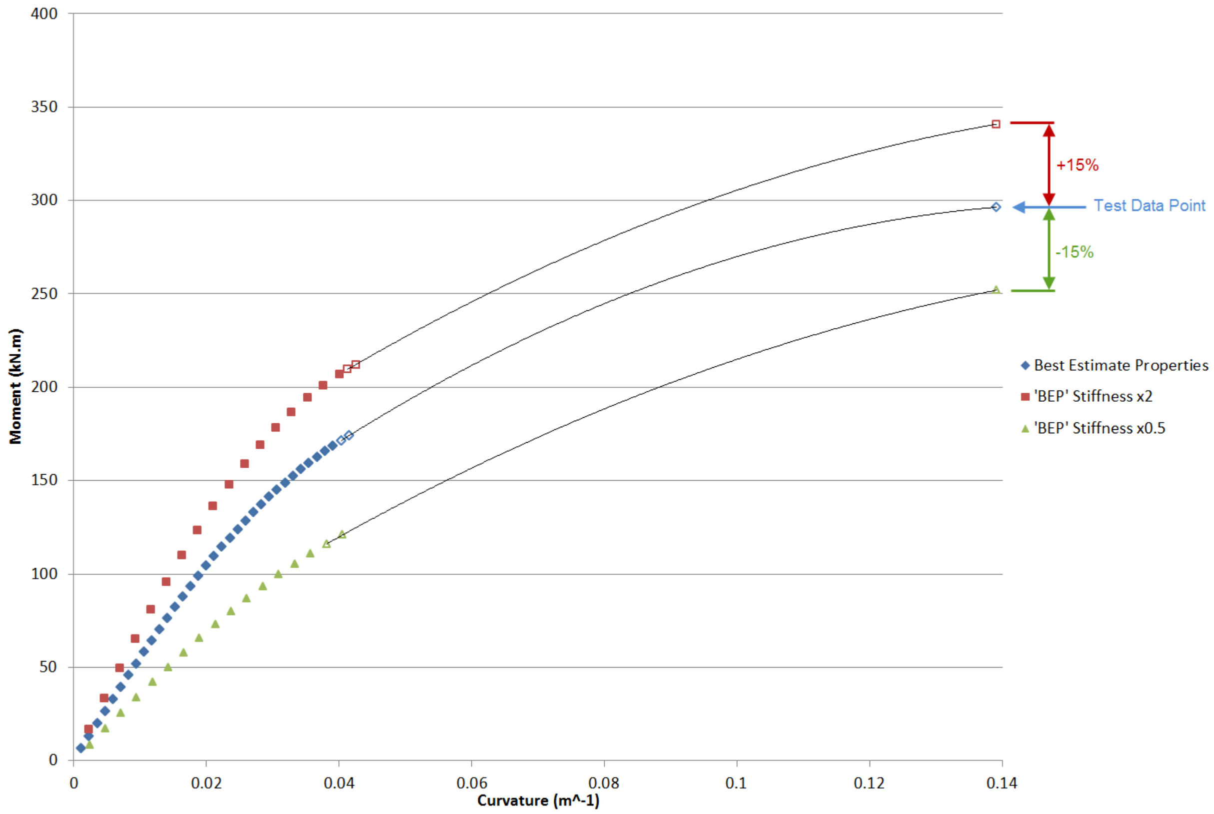

Figure 4-4 – Bending Stiffness Curve – Bending Moment vs Curvature

4.2 Stiffness

4.2.1 Bending Moment vs Curvature

The bending stiffness envelope extracted for use in the global Orcaflex analysis is as described in section 4.1.2 and shown graphically in Figure 4-4.

4.2.2 Tension vs Axial Displacement

A tension load case was solved as described in Section 3.8.1 using the 'best estimate properties' generated from the calibration cases. Contour plots of resultant deformation and maximum principal stress at the final time point are shown in Figure 4-5 and Figure 4-6 respectively. Figure 4-6 shows that the peak stress location is the same as for the bending case.

An axial stiffness curve was generated by extracting the tension and axial extension in the model as the load was incremented. The tension vs axial extension curve extracted for use in the global Orcaflex analysis is shown in Figure 4-7. It can be seen that the axial stiffness is approximately linear and has a magnitude of 16,060kN/m.

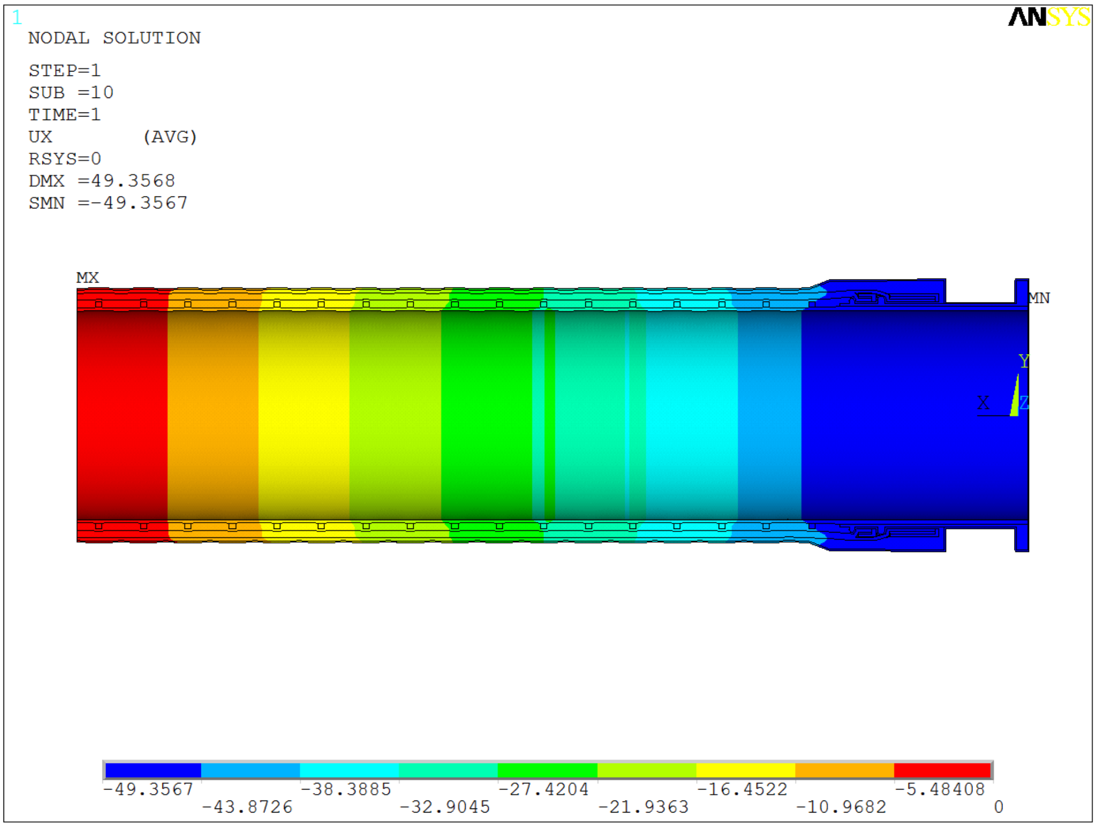

Figure 4-5 – Tension Test – 'Best Estimate Properties' – Axial Displacement (mm)

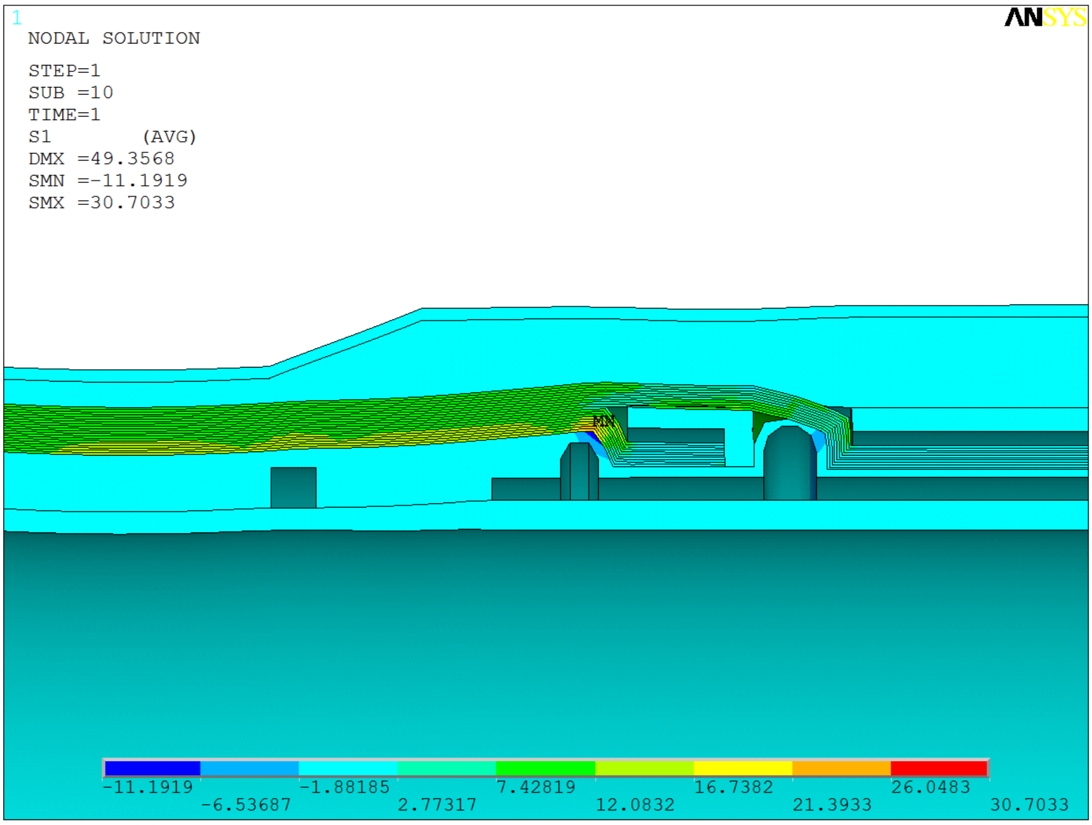

Figure 4-6 – Tension Test – 'Best Estimate Properties' – Max Principal Stress (MPa)

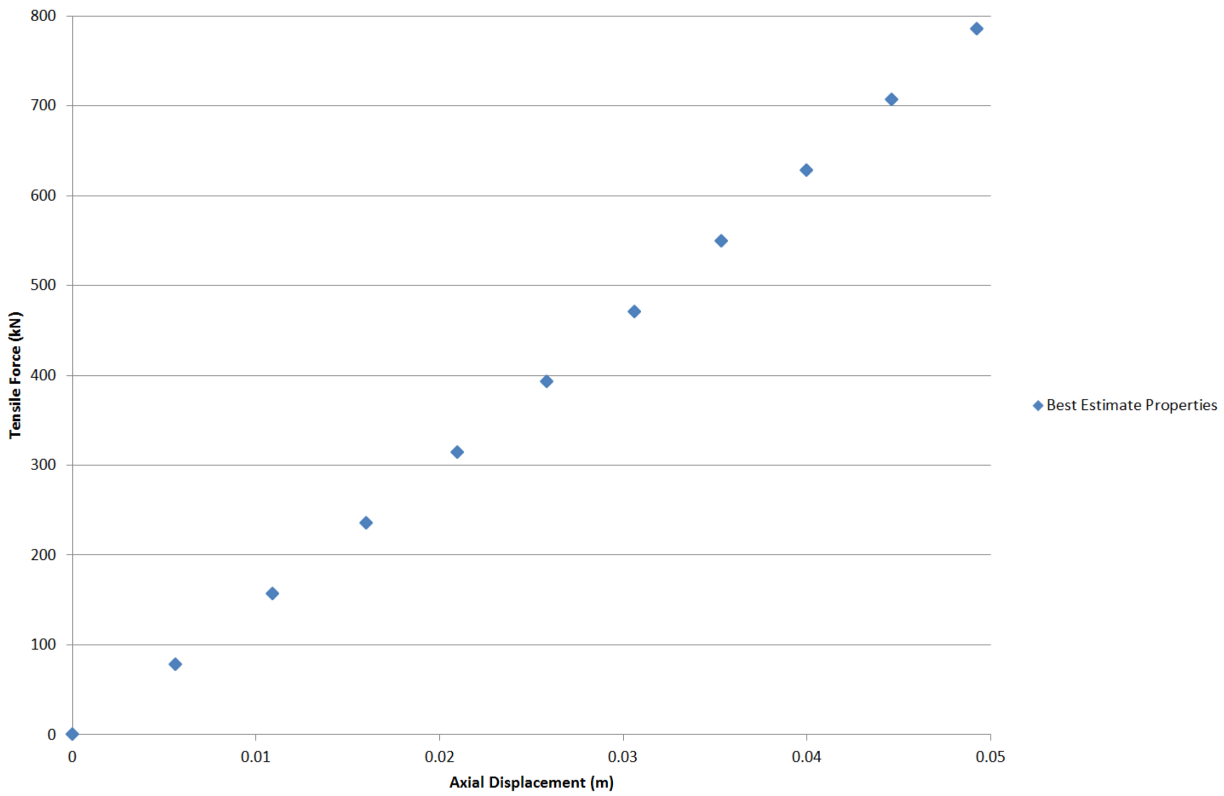

Figure 4-7 – Axial Stiffness Curve – Tension vs Axial Displacement

4.3 Stress Factors

4.3.1 Fibre Stress vs Curvature

The maximum principal stresses were extracted for all 20 layers at the three different locations shown in Figure 4-8. Further post-processing was carried out to identify which layer, at the three sample locations, produced the maximum stresses. Maximum principal stress (S1) vs curvature is shown for the most highly stressed layer at each of the three locations of interest in Figure 4-9. It is clear that the stress close to the end fitting is significantly larger than the stress in the main hose section due to the stress concentrating effects which occur there. This is the most highly stressed section of the textile in the hose.

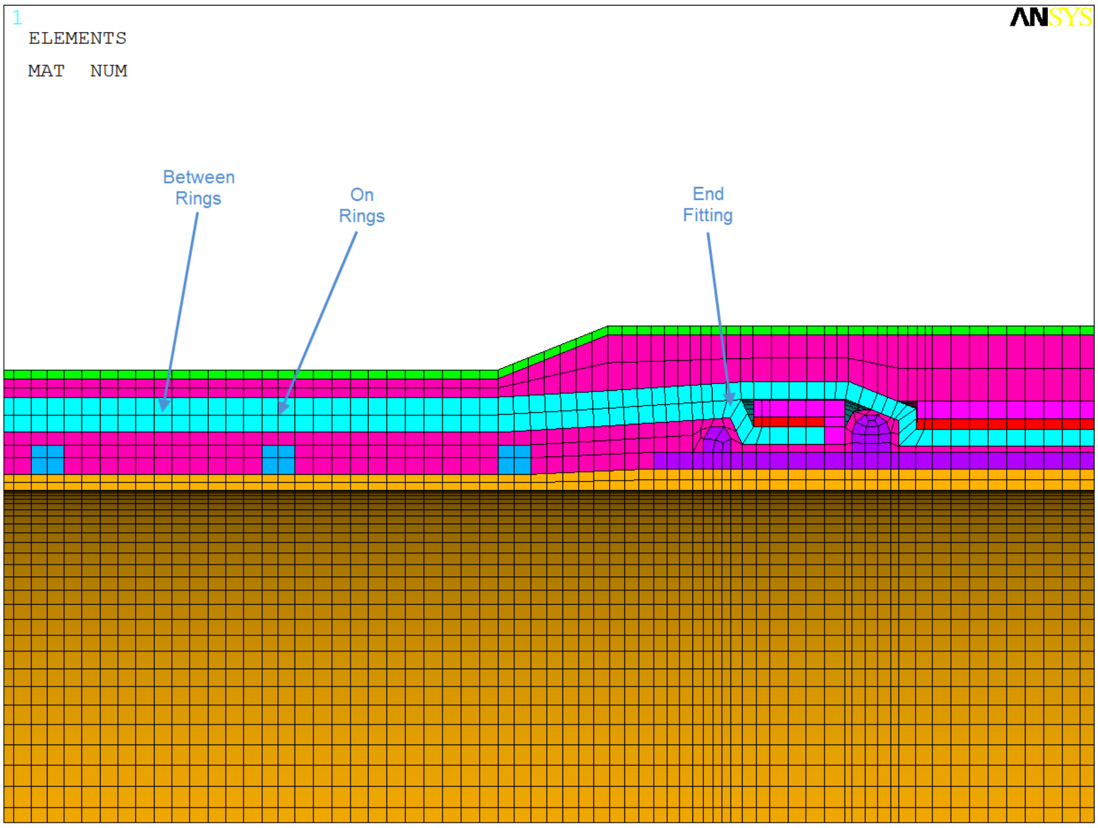

Figure 4-8 – Locations of Interest for Stress Extraction

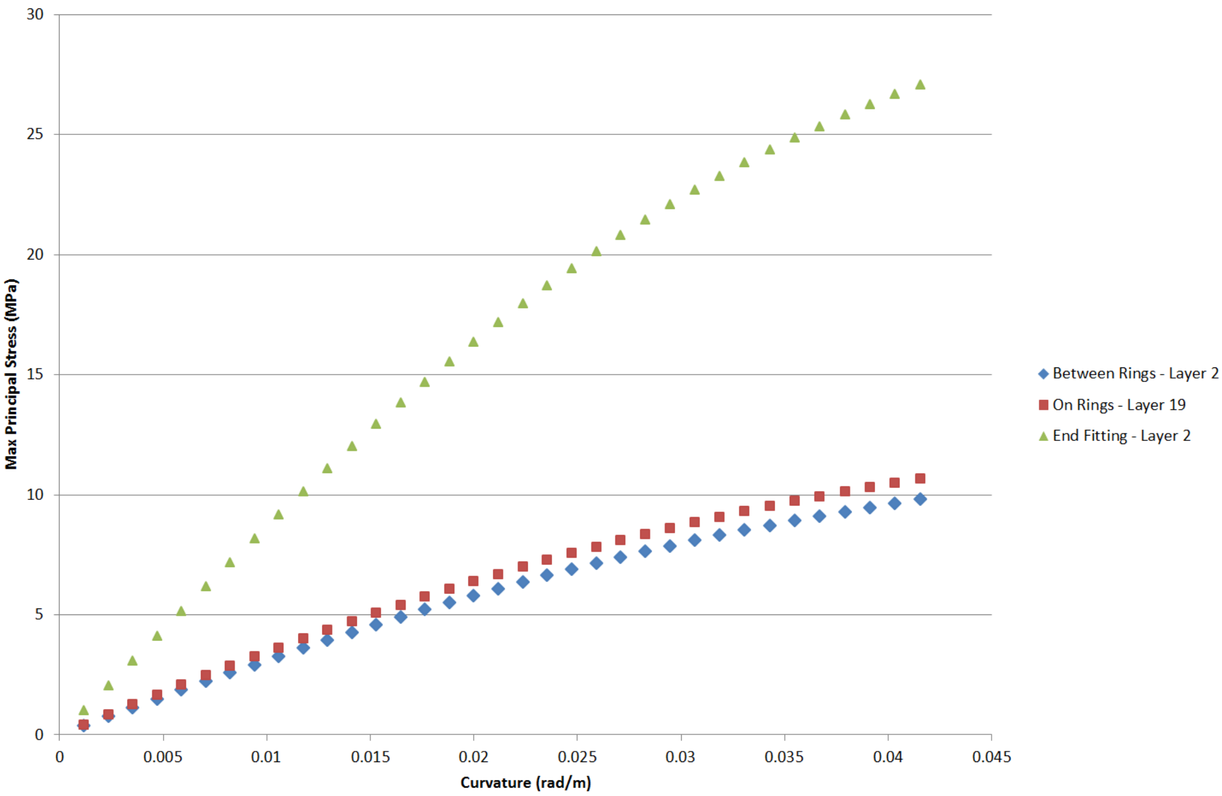

Figure 4-9 – S1 vs Curvature for 'Best Estimate Properties' at Locations of Interest

The stress extracted from the FE model is based on a cross sectional area equivalent to the yarn plus the rubber matrix. To convert this stress into a yarn stress, it must be divided by the area fraction. The area fraction was calculated as follows:

$$Area\ Fraction = \frac{Area\ of\ yarn}{Total\ area} = \frac{\pi \cdot \emptyset_y{}^2 \cdot N_y}{4} \cdot \frac{1}{100 \cdot t} = 0.44$$

Where: Sheet thickness, $t = 1.6mm$

Yarn nominal Diameter, $\emptyset_y = 1.4mm$

Number of yarns per 100mm, $N_y = 46$

The stresses at the end fitting were subsequently extracted for the 'BEP Stiffness x2' and 'BEP Stiffness x0.5' material models and converted to a yarn stress in the same manner. The curves produced from all three models are shown in Figure 4-10. These curves were output to Orcaflex in order to carry out the fatigue assessment.

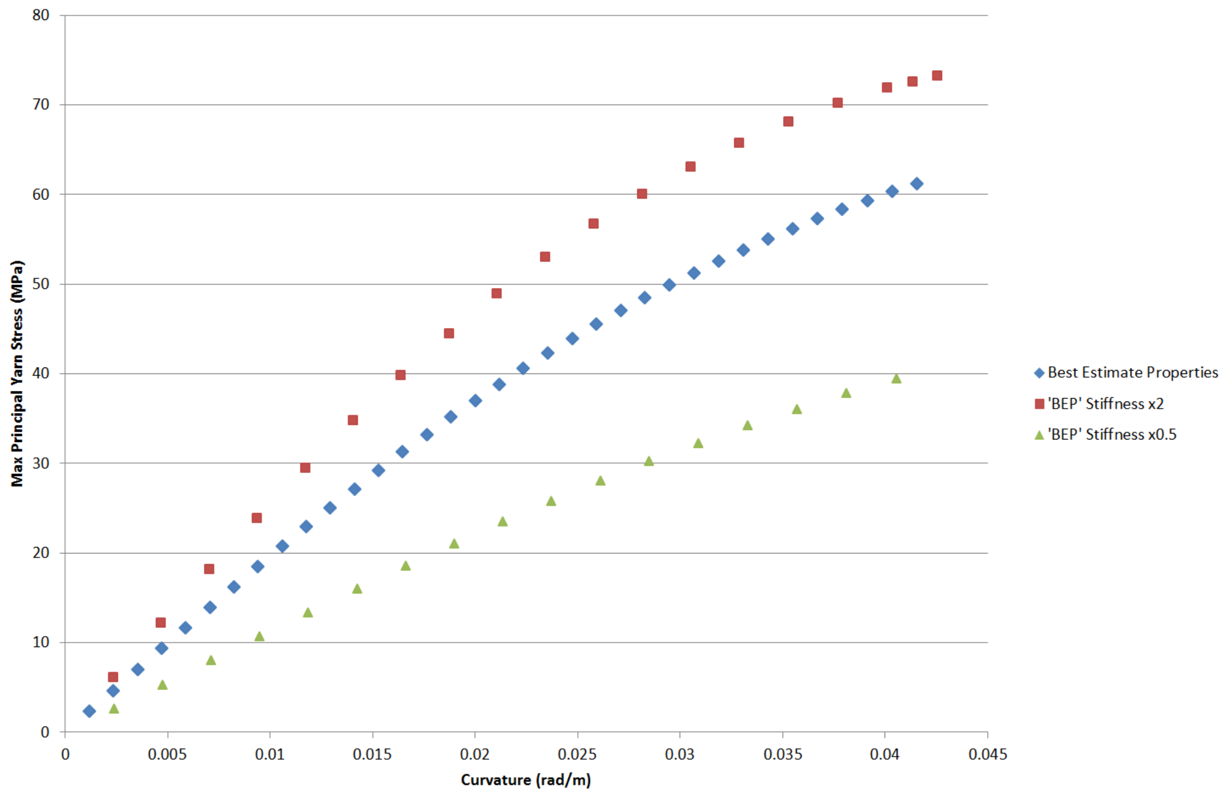

Figure 4-10 – Max Principal Yarn Stress vs Curvature - End Fitting Location

4.3.2 Yarn Stress vs Axial Load

Using the same methodology described in section 4.3.1, a curve of maximum principal yarn stress vs axial load was created; the 'Best Estimate Properties' were used here as it had been verified by test. As with the bending case, the most highly stressed region was located at the end fitting termination. For this case only the best estimate properties were used. The curve which was output to Orcaflex to carry out the fatigue assessment is shown in Figure 4-11. The curve is approximately linear and the yarn stress factor was taken to be 0.10 MPa/kN.

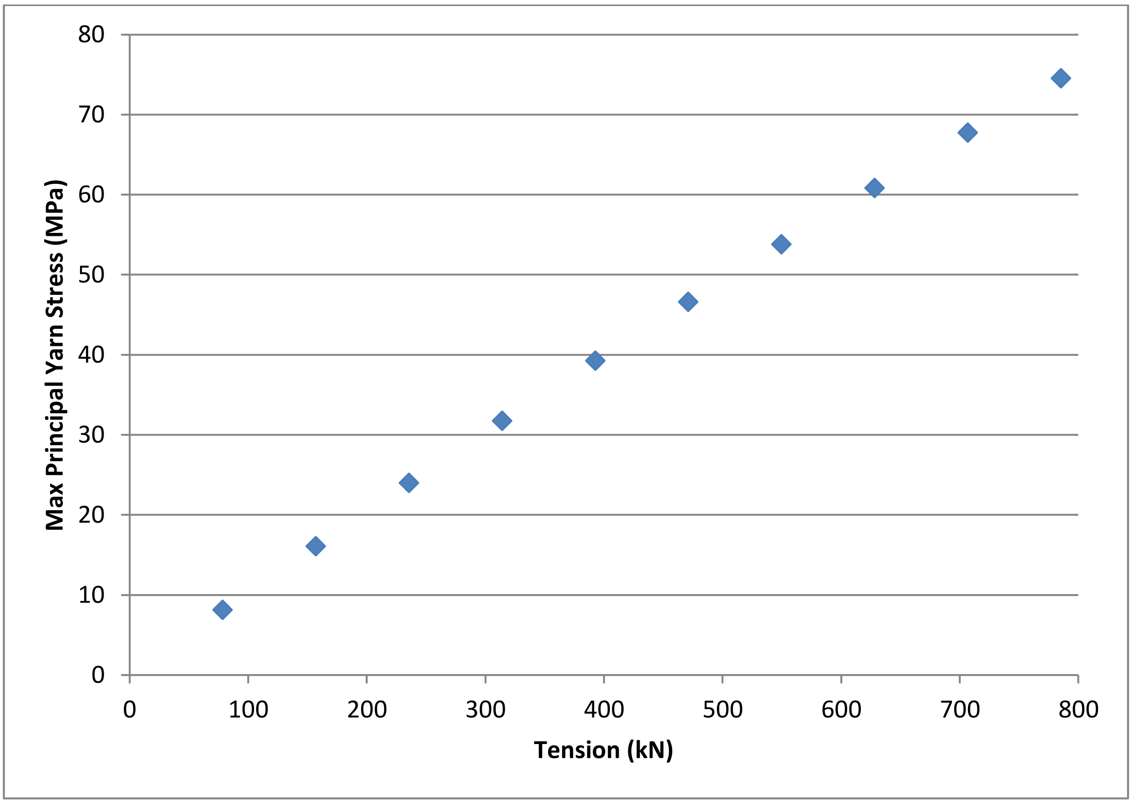

Figure 4-11 – Max Principal Yarn Stress vs Axial Load - End Fitting Location

5 Local Analysis Methodology – Back-to-back Flange Model

5.1 Geometry

The main features of the hose section geometry are described below but all thicknesses were taken from the CAD model supplied by EMSTEC [4].

The steel parts of the flange geometry are shown in Figure 5-1 with parameter values in Table 5-1. The end fitting is also rubber coated but, in terms of the structural analysis, this only affects the stiffness of the bolted joint so the rubber was only modelled in that region. A rubber thickness of 5mm was used.

The flanges are fixed together with 36-off M39s torqued up to 980 Nm. There are a set of 20mm thick steel flange plates (quadrants) fitted to either side of the flange to spread the loading from the nuts (not shown).

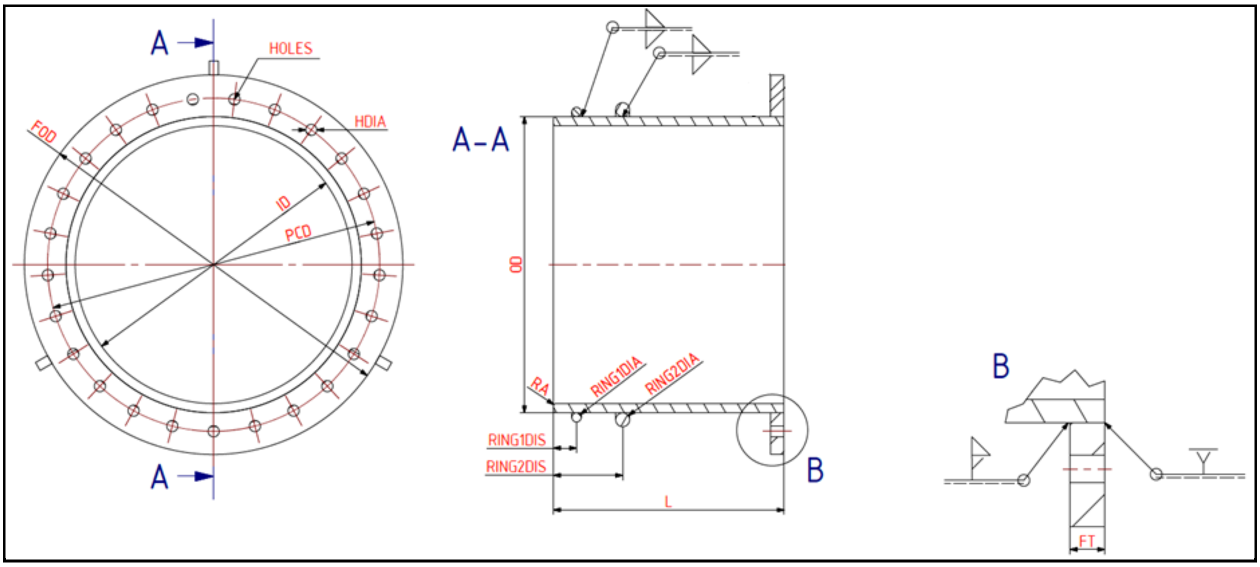

Figure 5-1 – Flange Geometry

Dimension	Label	Value	Unit
Inner diameter	ID	1040	mm
Outer diameter	OD	1070	mm
Flange OD	FOD	1290	mm
Flange thickness	FT	55	mm
Bolt Circle	PCD	1200.1	mm
Holes	HOLES	36	off
Hole diameter	HDIA	47	mm
Ring 1 Diameter	RING1DIA	25	mm
Distance Ring 1	RING1DIS	60	mm
Ring 2 Diameter	RING2DIA	35	mm
Distance Ring 2	RING2DIS	200	mm
Radius	RA	2	mm
Length	L	900	mm

Table 5-1 – Flange Geometry Parameters

5.1.1 Geometry Simplifications

The main area of interest in this model was the flange and its fasteners. The welded rings were excluded; these features were included in the hose section model in order to give accurate local stress results for the textile but were not critical for the flange fatigue assessment. The flange was cut-off at the first ring location reducing the overall length to approx. 700mm. The extent of the model is shown in Figure 5-2 with detail of the flange welds given in Figure 5-3. The 45deg fillet weld with a 13mm leg length was modelled explicitly in the FE model; the stresses at the weld toe were derived through the method described in Section 5.8. The discontinuity in the weld was not modelled but this was considered to be a minor adjustment as the effect on flange stiffness and weld stress would be minimal.

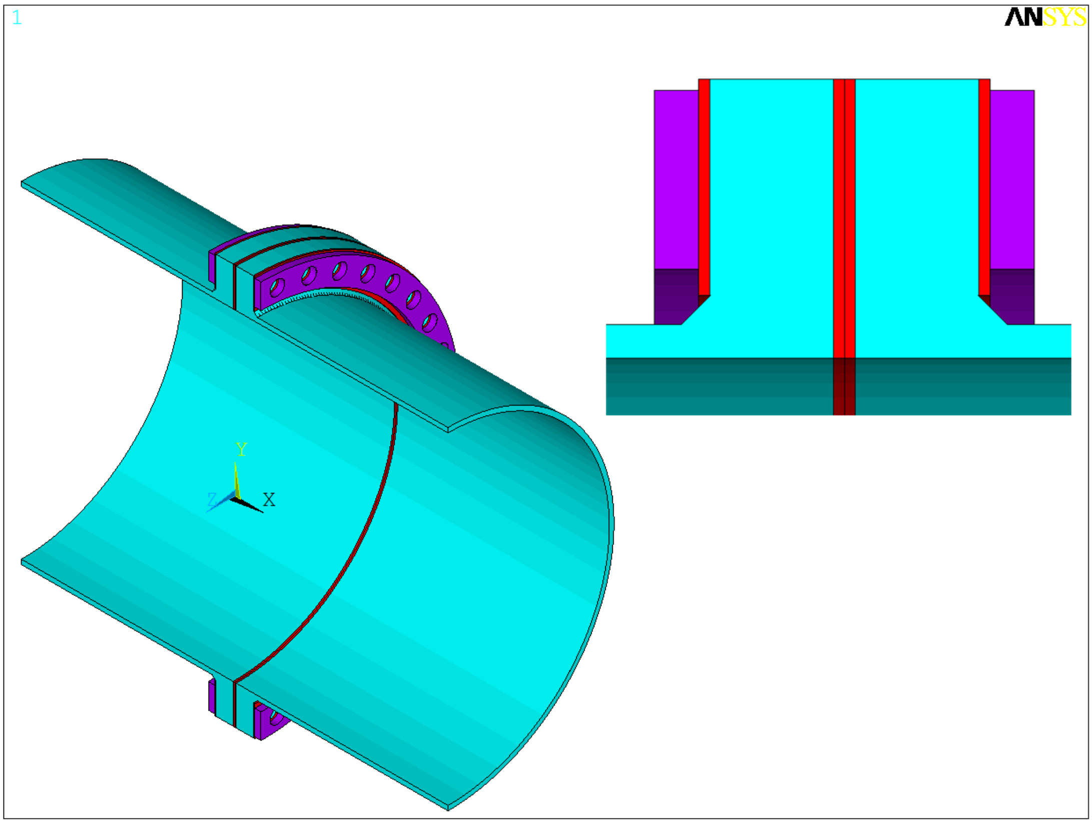

Figure 5-2 – Back-to-back Flange Model Geometry

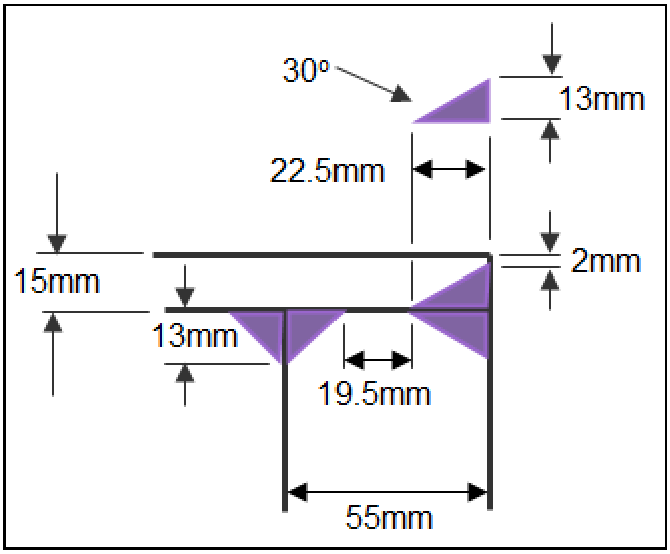

Figure 5-3 – Weld Preparation Detail

5.2 Coordinate System

The global Cartesian coordinate system is shown at the centre of the geometry in Figure 5-2. Ox acts axially, Oy acts vertically and Oz acts normal to the plane of symmetry. All loads and boundary conditions are specified with respect to this coordinate system.

5.3 Material Data

Steel and Cover rubber properties were taken from Table 3-1. The bolt grade is ASTM A193 B7, the flange is S355 J2.

5.4 Meshing

A half symmetry solid model was used to represent the back-to-back flanges and fasteners. The components were swept meshed using first order brick elements (SOLID185). The fasteners were modelled as second order beam elements (BEAM188) and were tied to the 20mm flange plates using constraint equations. Pre-tension elements (PRETS179) positioned at the centre of the beam elements were used to pre-load the fasteners.

Figure 5-4 and Figure 5-5 show images of the finite element mesh. Details of the mesh size are described in Table 5-2.

Mesh Detail	Value
Number of Nodes	245,224
Number of Elements	210,880
Min. Number of Element divisions through thickness	3
Number of Element divisions around circumference (half model)	180
General Element Edge Sizing (mm)	7.5

Table 5-2 – Back to Back Flange Model – Mesh Size Details

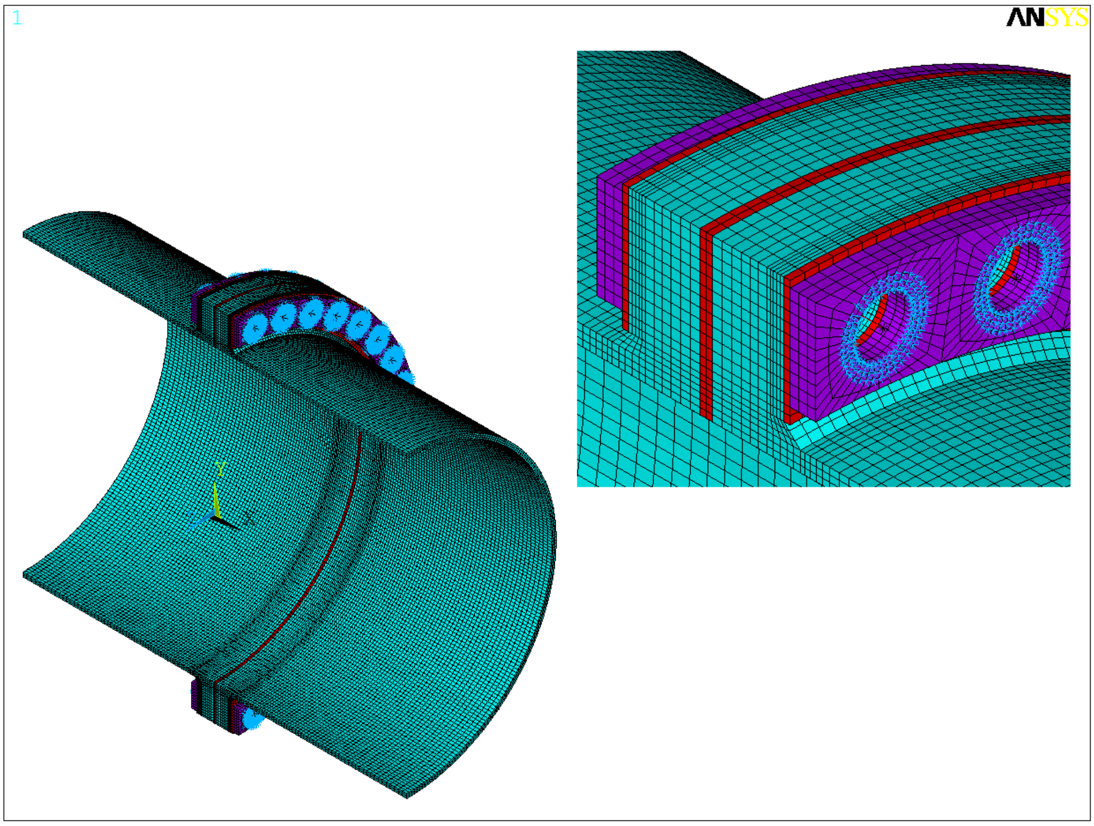

Figure 5-4 – Back to Back Flange Model Mesh for FE Analysis – Overview

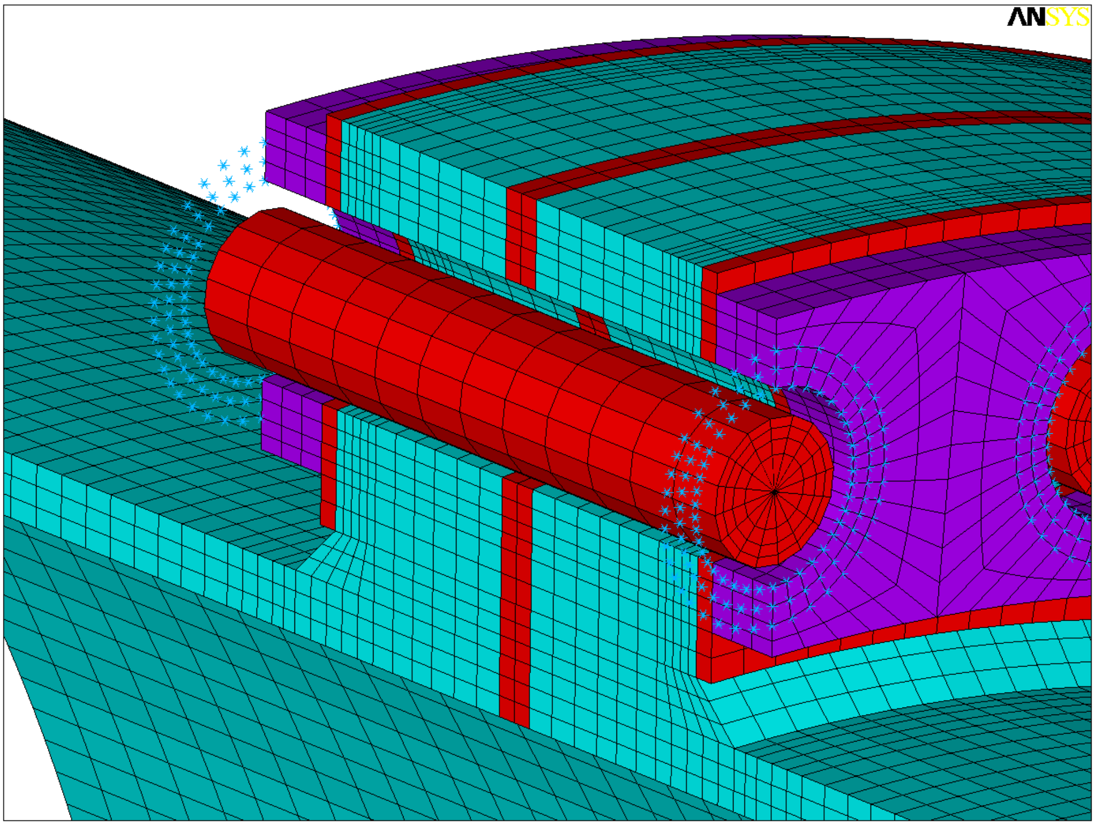

Figure 5-5 – Back to Back Flange Model Mesh for FE Analysis – Section View with Fastener Detail (Graphical expansion of beam cross section shown)

5.5 Contact

'Frictionless' contact behaviour was defined between the two back to back flange faces as shown in Figure 5-6. This contact behaviour allows separation of the bodies under loading and only compressive loads can be transferred between the two halves. The flanges were connected via a continuous mesh allowing direct load transfer between them.

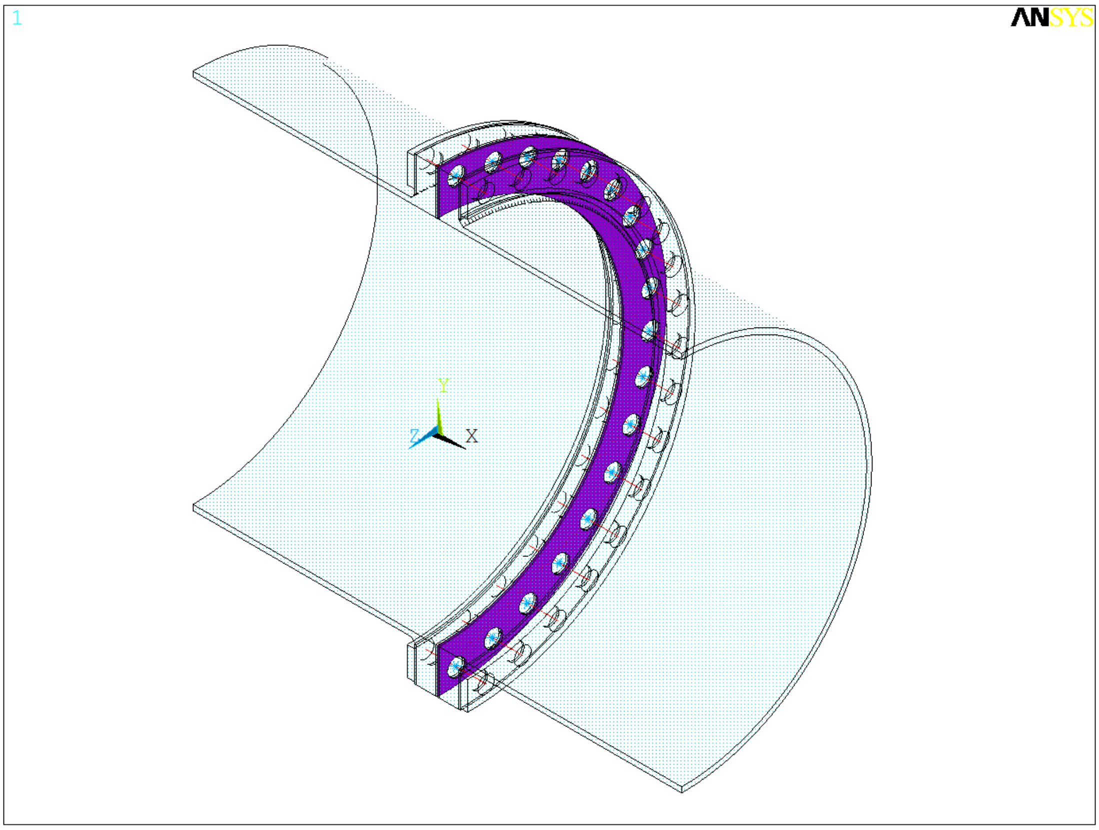

Figure 5-6 – Back to Back Flange Model – 'Frictionless' Contact Definition

5.6 Boundary Conditions

Two pilot nodes were defined at either end of the two end fittings. These nodes were connected to the end faces via force distributed constraint equations. The pilot node at one end was fixed in all DOFs; the pilot node at the other end was restrained in UZ, ROTX and ROTY for the bending case and UY, UZ, ROTX, ROTY and ROTZ for the tension case. All other nodes on the symmetry plane were fixed in UZ. The boundary conditions are shown in Figure 5-7.

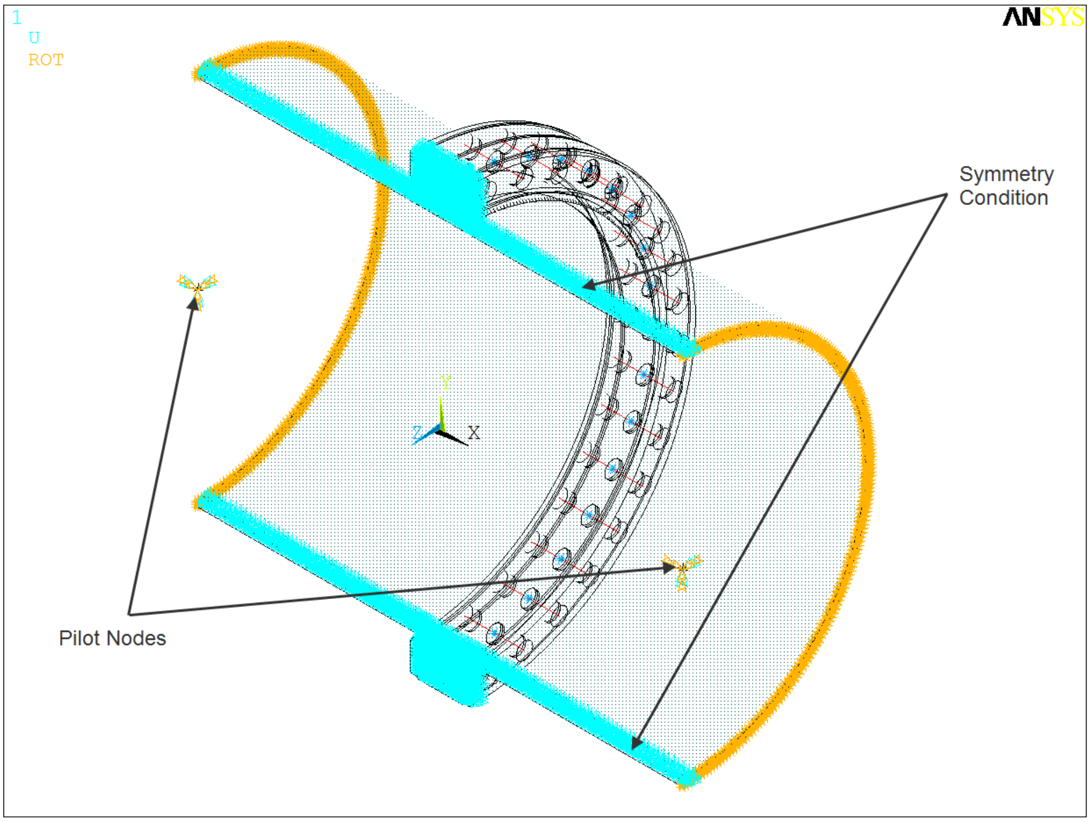

Figure 5-7 – Back to Back Flange Model – Boundary Conditions

5.7 Loadcases

Both load cases were solved in two time steps. In the first time step the bolt pretension of 125.6kN was applied (equivalent to 980Nm torque). This simulated the tightening of the fasteners. In the second time step the pre-load was 'locked' and the external load was applied.

5.7.1 Bending Case

In this load case, the free end was loaded with a bending moment, Mz = 100kNm (equivalent to 200kNm on a full model). The moment was applied through small increments so that any non-linearity could be identified.

5.7.2 Tension Case

In this load case, the free end was loaded with an axial tensile force, Fx = 250kN (equivalent to 500kN on a full model). The force was applied through small increments so that any non-linearity could be identified.

5.7.3 Stress Factors

Using the results from section 5.7.2 and section 5.7.1 tension and bending stress factors were derived for the fasteners and the flange material. These stress factors were required for the fatigue assessment which was conducted using tensions and bending moments derived from the Orcaflex global dynamic analysis work [19].

5.8 Derivation of Weld 'Hot Spot' Stress

The derivation of a weld 'hot spot' stress is necessary as part of the fatigue assessment as defined in DNV-RP-C203 [9]. The stress predicted directly at the weld toe in the FE model will be unreliable as a result of the influence of the discontinuity which is present there.

The 'Hot Spot' method, as discussed in Section 4.3 of the DNV standard, allows for the stress at the weld toe to be evaluated by linear extrapolation of the stress taken from two points in the near vicinity of the weld. A schematic of the 'Hot Spot' stress derivation is shown in Figure 5-8.

Having derived the weld toe stress in this manner it is necessary to use the applicable fatigue curve specified in the standard when carrying out the fatigue assessment. This is discussed in more detail in [19].

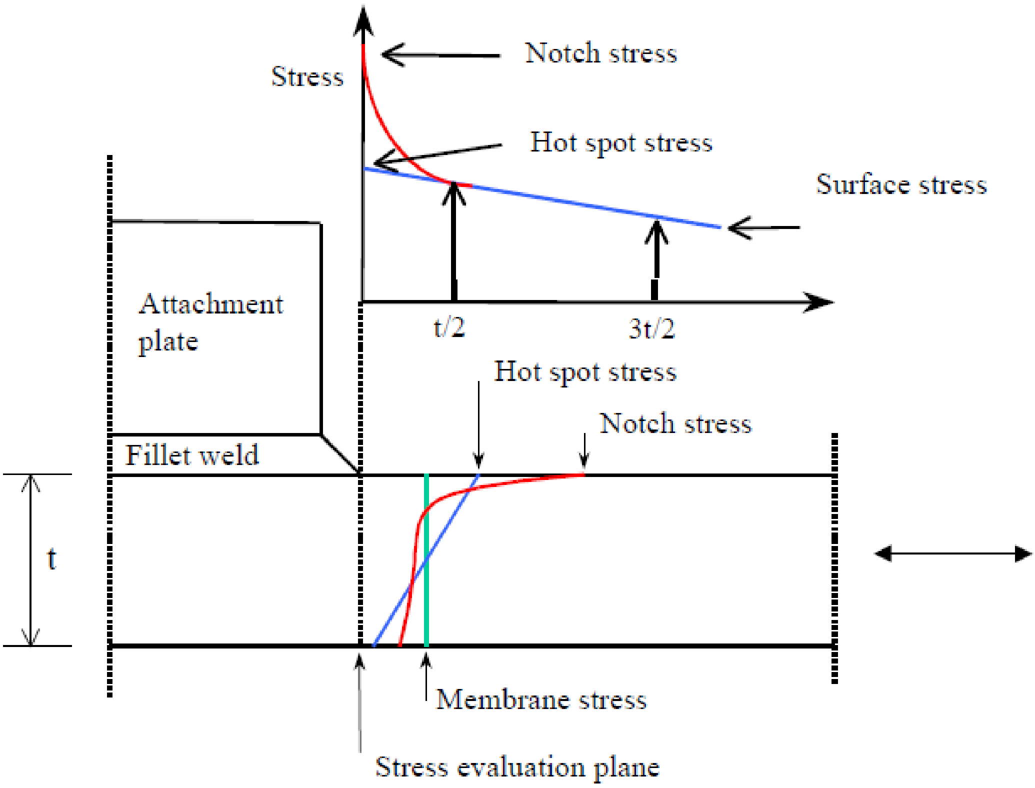

Figure 5-8 – 'Hot Spot' Stress Evaluation [9]

6 Local Analysis Results – Back-to-back Flange Model

6.1 Weld Stress Factors

6.1.1 Max Principal Stress vs Bending Moment

A contour plot of maximum principal stress due to bolt pre-tension +200kNm bending moment is shown local to the flange weld detail in Figure 6-1.

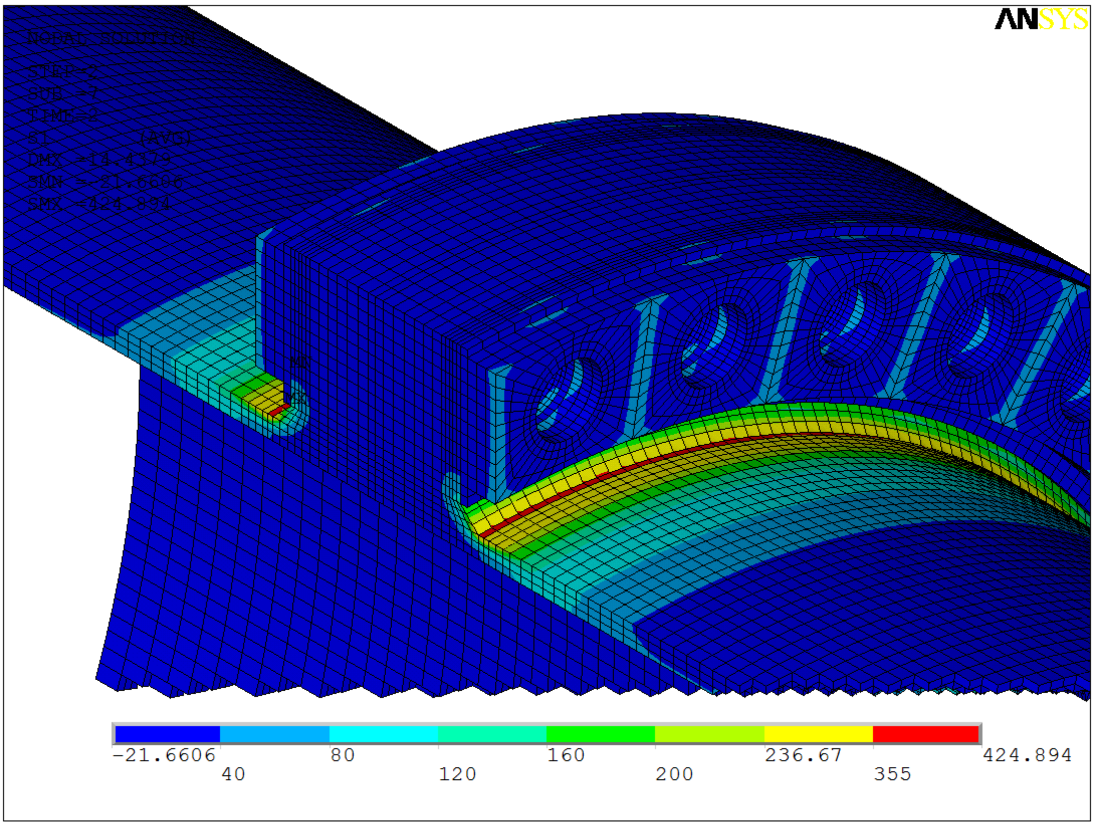

Figure 6-1 – Max Principal Stress (MPa) due to Preload + Bending Moment

A graph of maximum principal stress, σ_1 vs bending moment is shown for the weld toe in Figure 6-3. This stress was derived through linear extrapolation of the near field stresses as discussed in Section 5.8. It should be noted that when the bending moment is zero, the weld stress, σ_1=236MPa. This high static weld stress is due to the effect of bolt pre-tension and could be reduced by reducing the bolt pre-tension or the thickness of the rubber between the flanges. The alternating stress was given by the change in stress between the max bending moment and zero bending moment, $\Delta\sigma_1$=104MPa. The weld bending stress factor was approximately equal to 0.520MPa/kNm.

6.1.2 Max Principal Stress vs Tension

A contour plot of maximum principal stress due to bolt pre-tension +500kN tension is shown local to the flange weld detail in Figure 6-2.

Maximum principal stress, S_1 vs tension is shown for the weld toe in Figure 6-4. This chart was generated through the same method described in Section 6.1.1. The static stress in the weld due to pre-load was σ_1=236MPa as in Section 6.1.1; the alternating stress was given by the change in stress between the max tension and zero tension, $\Delta\sigma_1$=77MPa. The weld axial stress factor was approximately equal to 0.154MPa/kN. The same considerations for reducing the static stress due to pretension are applicable here.

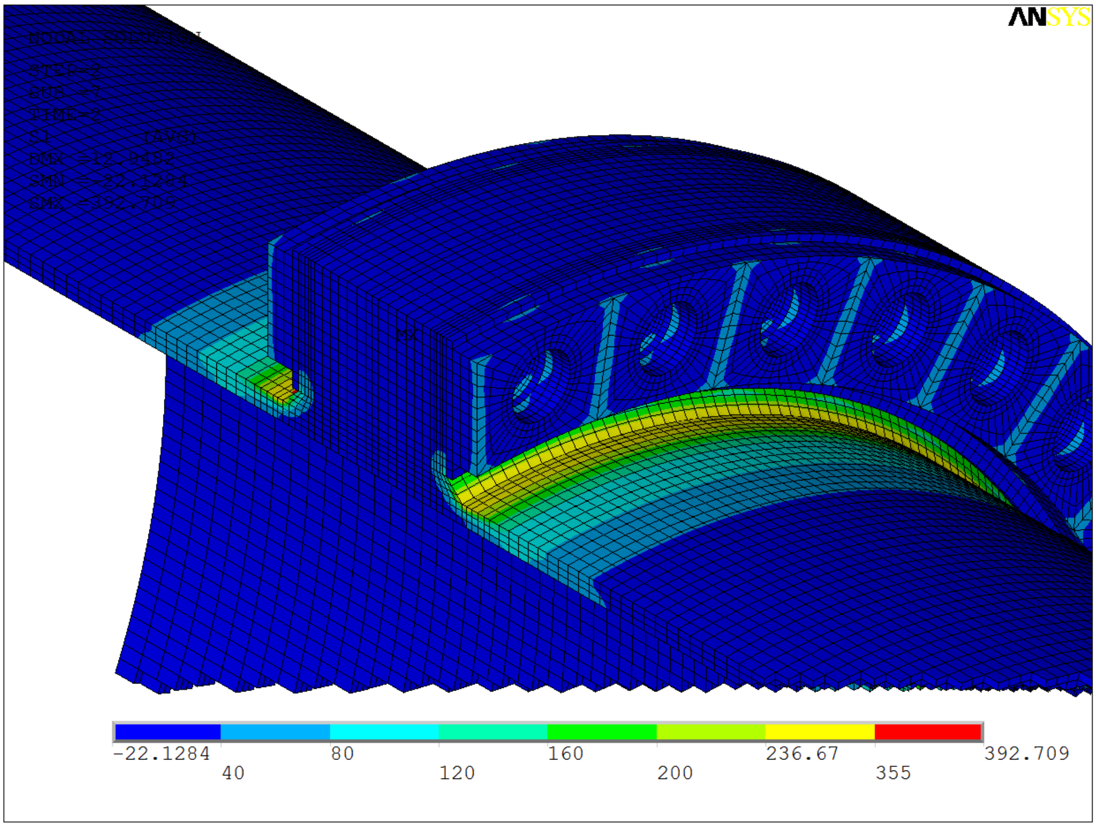

Figure 6-2 – Max Principal Stress (MPa) due to Preload + Tension

6.2 Bolt Stress Factors

6.2.1 Axial Stress vs Bending Moment

Axial stress vs bending moment is shown for the worst case bolt position in Figure 6-5. It is clear that when bending moment is zero, the axial stress is equal to the pretension stress, σ_a=129MPa. Relatively little increase in stress was observed in the fasteners as the external load was applied, $\Delta\sigma_a$=9MPa at 200kNm. Primarily this is because the bolts are over-sized with respect to the magnitude of the external loading. The bolt bending stress factor was approximately equal to 0.046MPa/kNm.

6.2.2 Axial Stress vs Tension

Axial stress vs tension is shown for the bolts in Figure 6-6. Note that all bolts experience equal load for this case. The pretension stress of σ_a=129MPa was again recorded prior to the application of external load. As with the bending case, the increase in bolt stress with applied tension was small, $\Delta\sigma_a$=6MPa at 500kN. The bolt axial stress factor was approximately equal to 0.012MPa/kN.

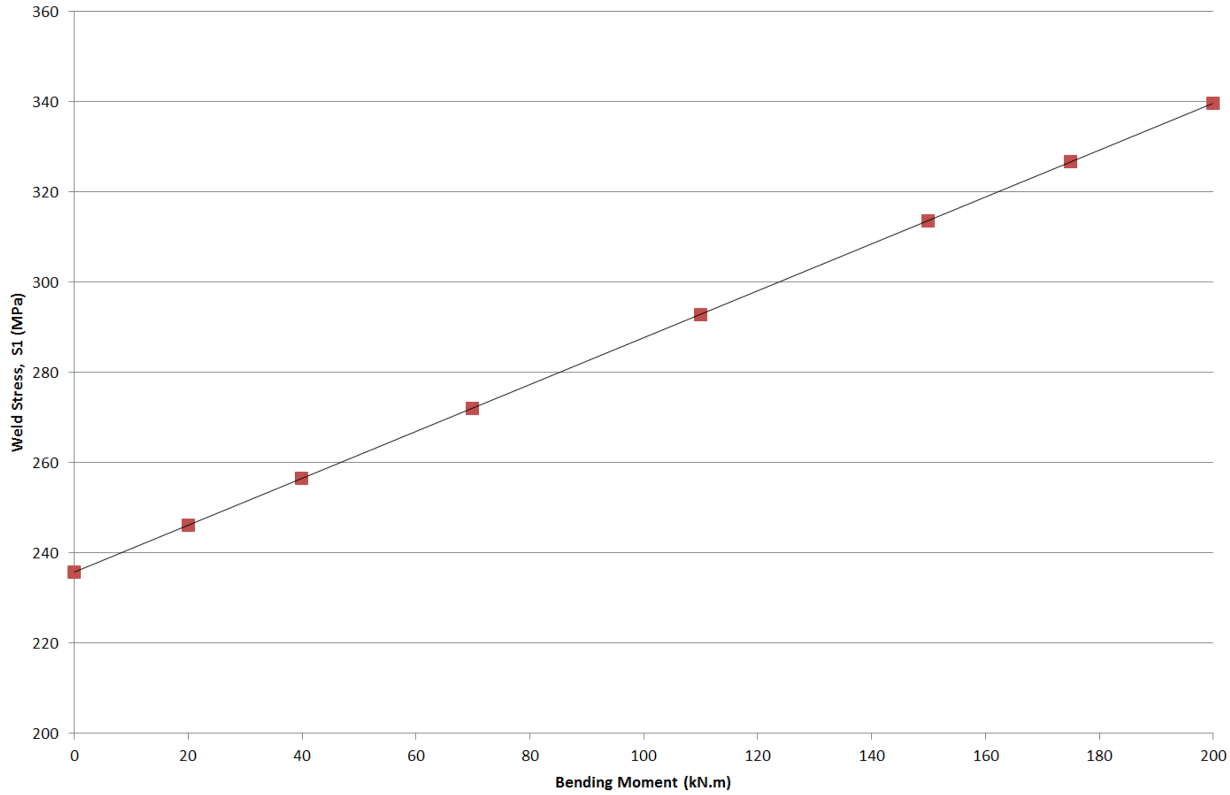

Figure 6-3 – Max Principal Stress vs Bending Moment – Weld Toe 'Hot Spot' Stress

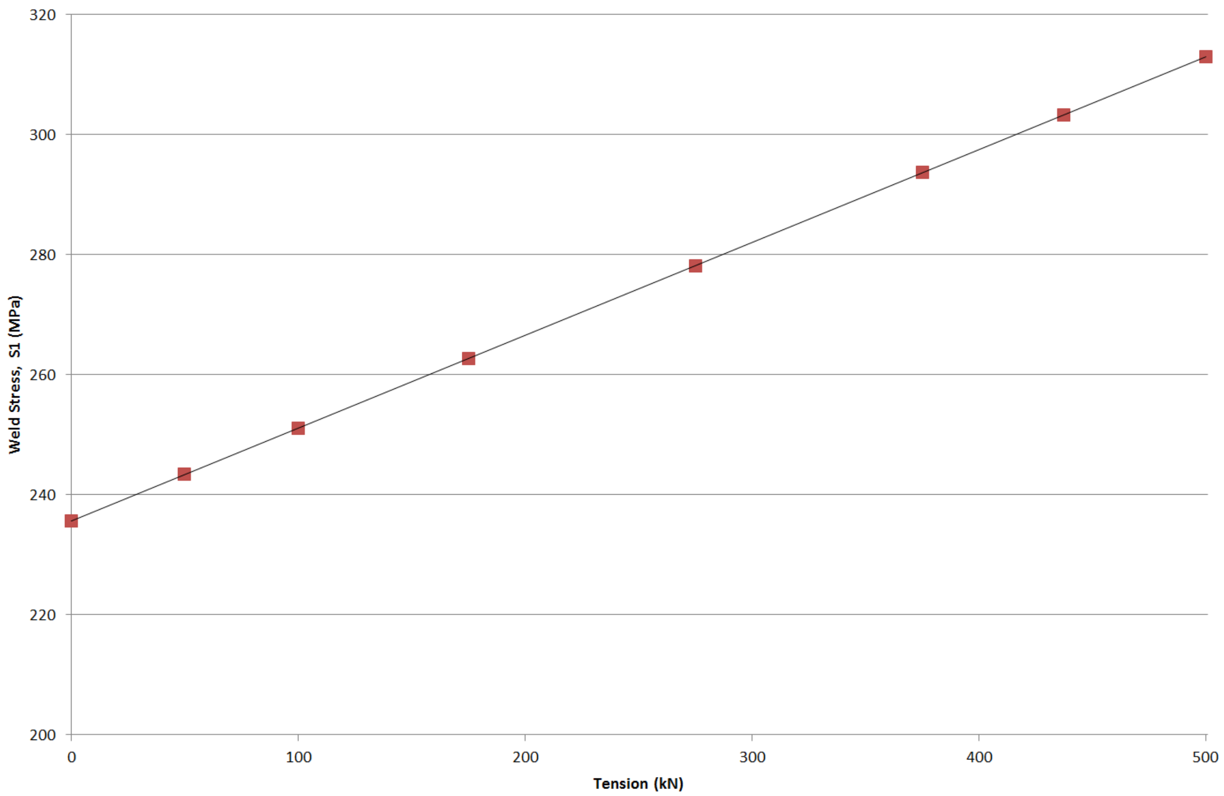

Figure 6-4 – Max Principal Stress vs Tension – Weld Toe 'Hot Spot' Stress

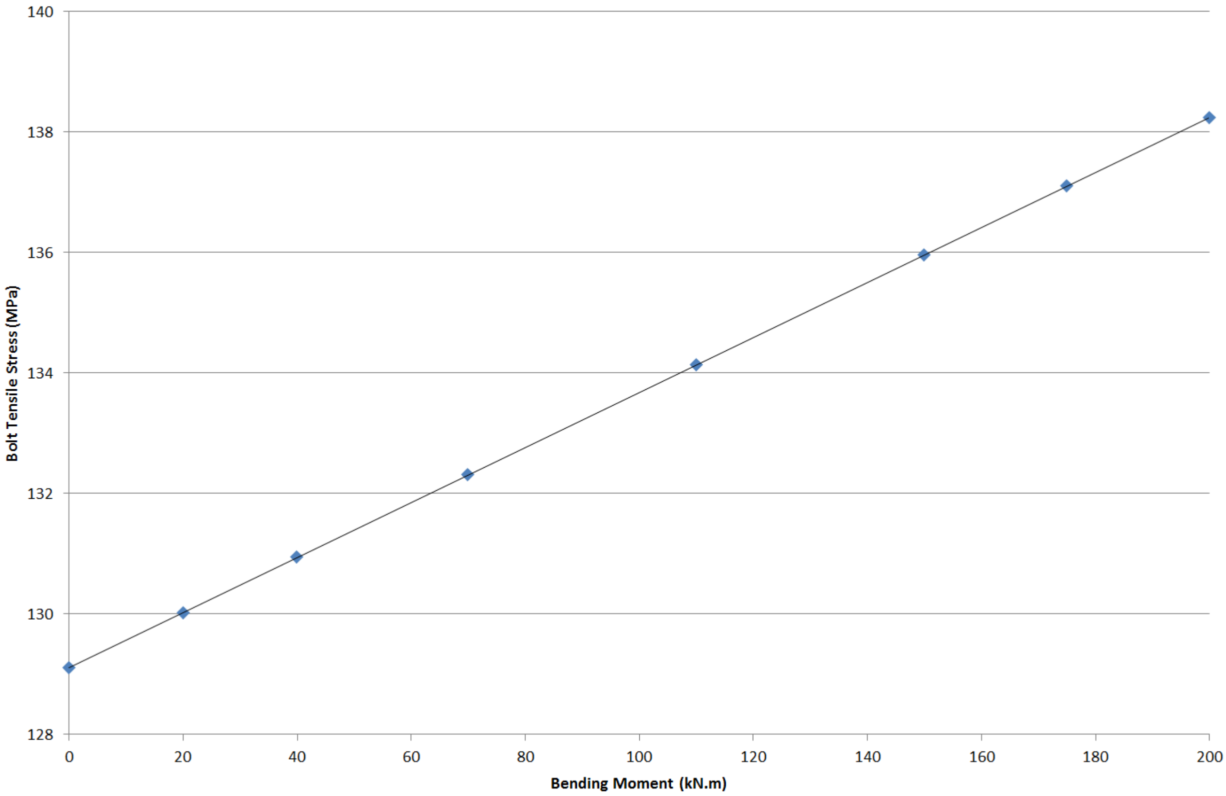

Figure 6-5 – Axial Stress vs Bending Moment – Studs

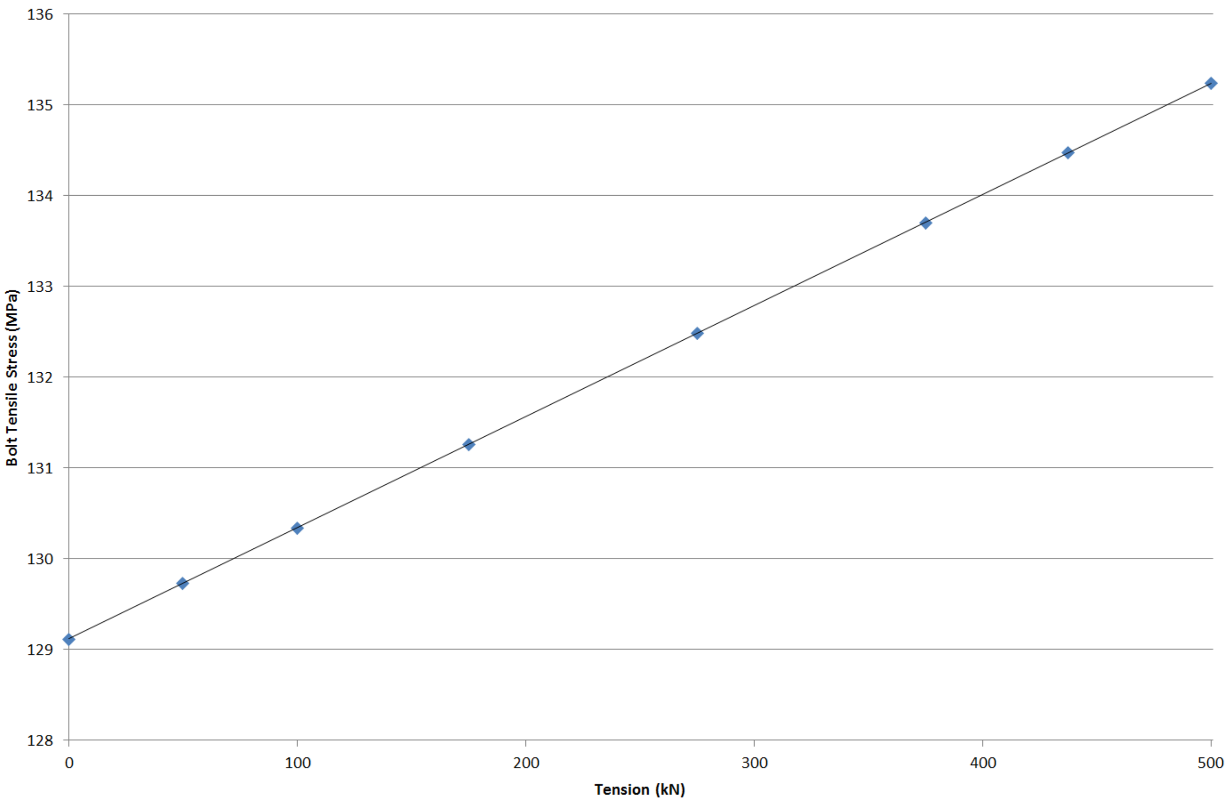

Figure 6-6 – Axial Stress vs Tension – Studs

7 Discussion and Conclusions

This report discusses the finite element modelling of an EMSTEC 40” bonded flexible hose. Composite material properties were ‘tuned’ such that the modelled behaviour of the hose under test conditions matched the actual data from real tests (test results recorded in [3], [15], [16] and [17]).

A set of composite material properties were developed which, when built into a full hose model, gave representative distortions in tension and bending (‘Test 3’ from Table 3-2). In the case of bending, it was necessary to give a range of properties due to modelling uncertainties.

The tuned model was then used to generate the following:

- Non-linear bending stiffness curve – full hose section (Figure 4-4)
- Non-linear axial stiffness curve – full hose section (Figure 4-7)
- Non-linear bending stress factor – composite yarn (Figure 4-10)
- Non-linear axial stress factor – composite yarn (Figure 4-11)
- Linear bending stress factor – flange weld (Figure 6-3)
- Linear axial stress factor – flange weld (Figure 6-4)
- Linear bending stress factor – studs (Figure 6-5)
- Linear axial stress factor – studs (Figure 6-6)

The tuned material properties suggested that the axial stiffness of the yarn was approximately 4.3 GPa based on a nominal diameter of 1.4mm (in reality there will be a number of strands twisted together such that the diameter of the ‘bundle’ or ‘tow’ is approximately 1.4mm). This stiffness is twice what was expected based on the EMSTEC cord testing [11]. The reason for the discrepancy is not fully understood but the following should be noted:

- The hose axial stiffness is sensitive to the composite layup angle (Figure C2-1). The axial stiffness for 38^o is approximately 48% higher than the axial stiffness for 42^o.
- The axial stiffness of the drawn polyester filaments is approximately 10GPa [18].
- Between the filament and the yarn there are three effects which reduce the axial stiffness:
    - The twist angle of the filaments within the strand (not known)
    - The twist angle of the strands within the yarn (not known but expected to be in the region of 20^o)
    - The actual loaded cross sectional area versus the nominal cross sectional area (not known)
- The axial pull test setup is not known i.e. it is not known whether the test setup allowed unwinding of the yarn or slippage.

It is recommended that some of these features/effects are investigated further so that the stiffness of the yarn is better understood.

8 References

[1] 99910.00001~2.A-0 Revision 0, 19-11-14.

[2] Guide to Manufacturing and Purchasing Hoses for Offshore Moorings (GMPHOM 2009).

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[4] 3D Model (Inventor), received by memory stick, 16-12-14.

[5] ASTM D 1415-88, 1999.

[6] EMSTEC Material Data Sheet: MDS-201409-00024, release date 21-09-14.

[7] EMSTEC Material Data Sheet: MDS-201409-00021, release date 21-09-14.

[8] EMSTEC Material Data Sheet: MDS-201409-00020, release date 17-09-14.

[9] DNV-RP-C203, 'Fatigue Design of Offshore Steel Structures', October 2012.

[10] EMSTEC e-mail, 'RE: Update', 23-01-15.

[11] 'Cord Elongation Test C012 C014 B&A.xls', received from EMSTEC, 23-01-15 [10].

[12] EMSTEC e-mail, 'RE: Query summary', 05-02-15.

[13] 'Certificate of Analysis – GHT', Zhejiang Guxiandao Industrial Fibre Co. Ltd., 22-04-14.

[14] EMSTEC Material Data Sheet: MDS-201409-00016, release date 11-09-14.

[15] EMSTEC Data Book: 4130105/701147-DB-24, 23-04-13.

[16] EMSTEC Data Book: 4130105/701147-DB-25, 23-04-13.

[17] EMSTEC Data Book: 4130105/701147-DB-22, 16-06-13.

[18] 'Characterisation of long term behaviour of polyester fibres and fibre assemblies for offshore mooring lines', Lechat, Davies, Bunsell and Burgoyne, March 2010.

[19] PDL-EMS-667-002 (1): 40" Suction Hose Fatigue Assessment Global Analysis, March 2015.

Appendix A – Composite Properties

A.1 Yarn Properties

The base properties of the textile/rubber composite sheet material, from [14], are shown below:

- Thickness = 1.6mm
- Yarn nominal diameter = 1.4mm
- Yarn pitch = 100/46 = 2.17mm

In order to estimate the composite properties, it was first necessary to estimate the properties of the yarn. From tests recorded in [11], for a nominal yarn of 1.4mm diameter, a load of 200N produced an average strain of 6.04% for the 'after cured' condition. This gives a Young's modulus of 2150 MPa. Providing the data in [11] was representative, this meant that the composite stiffness in the direction of the fibres (Ex in Table 3-2) could be accurately estimated given that the properties of the calendaring rubber were known as were the volume fractions of the rubber and yarn.

The Gxy and Gxz shear moduli of the yarn were based on the Ex Young's modulus assuming a small Poisson's ratio. Relative to Ex, small values were chosen for the transverse Young's moduli (Ey and Ez) and similarly a relatively small value of Gyz was used. Small values of νxy and νxz were used but the value of νyz was varied over a range as it was less clear what this parameter should be set to.

A.2 Composite Properties

Having established an envelope of yarn properties to trial, a composite model was built in ANSYS of the form shown in Figure A2-1. This model was loaded directly in three directions and in shear in three planes. The overall composite properties, all nine, could then be obtained from the results of running these various load cases. The results of the various trials are shown in Table 3-2.

From the results, it was clear that the composite transverse Young's moduli (Ey and Ez) and shear moduli are dominated by the rubber properties. It was also clear that the composite Poisson's ratios are very sensitive to the yarn Poisson's ratios. That being said, in terms of the hose stiffness, later model testing showed that by far the most important parameter was Ex.

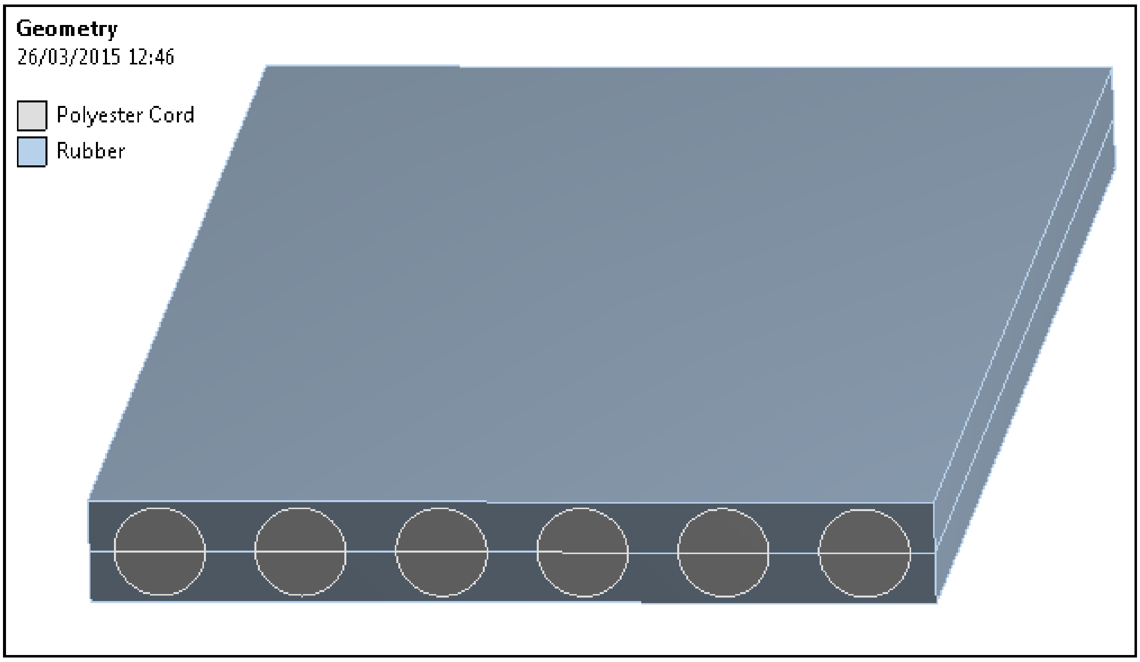

Figure A2-1 – Typical Composite Model

Appendix B – Effect of Binding Wire Tension

B.1 Introduction

The ends of each bundle of textile layers are held in place by a set of 5mm diameter pre-tensioned steel wires that wrap around the end fitting in the hoop direction; the inboard set consists of 27 wraps in two layers, the outboard set consists of 87 wraps in two layers. There are two circumferential ribs welded to each steel end fitting to help control the axial location of the binding wire wraps. The tension in each wrap is approximately 100kg [10].

It was proposed to investigate the effect of binding wire tension on the fibre stress as a separate task from the primary analysis model detailed in the main body of this report. Any significant effects on fibre stress could subsequently be added at the post-processing stage.

The model used for this study was the same as that used for the primary 4.5m hose analysis. The binding wire tension was created by applying a temperature drop causing a thermal contraction of the wires. A thermal expansion coefficient of 12×10^{-6} $°C^{-1}$ was specified in the binding wire material model; all other material models had no thermal expansion coefficient specified and therefore they were unaffected by the temperature change. A temperature drop, ΔT=-41.65°C, was subsequently applied resulting in the required tension of 100kg per wire.

B.2 Validation of Model Setup

Figure B2.1 and Figure B2.2 show the radial displacement and maximum principal stress respectively. It is clear from Figure B2.1 that a uniform radial contraction of approx. -0.17mm occurs around the binding wire as a result of the temperature drop indicating that the model behaviour is as intended.

Furthermore, the average maximum principal stress observed in the inboard binding wires in Figure B2.2 was approx. 44MPa and the cross sectional area in the FE model was approx. 600mm^2; this equates to a hoop tension of 26.4kN. This was approximately equal to the required tension of 27 x 100 x 9.81 = 26.5kN.

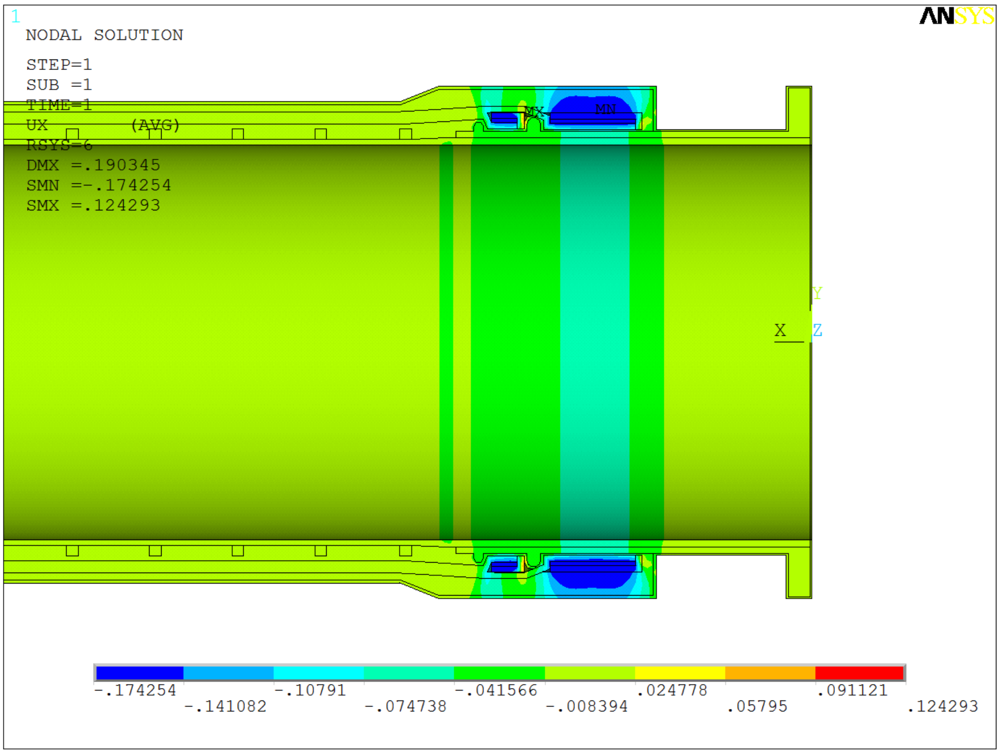

Figure B2-1 – Radial Displacement of Binding Wires

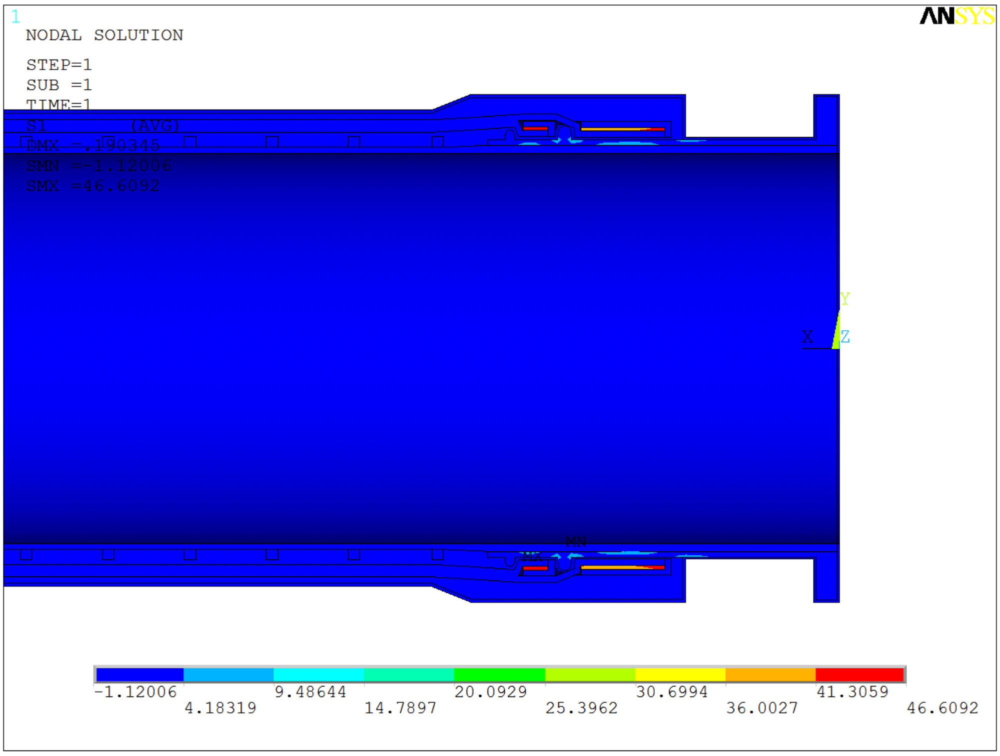

Figure B2-1 – Max Principal Stress in Binding Wires (occurs in hoop direction)

B.3 Results

A more detailed view of the maximum principal stress in the fibres is shown in Figure B3.1. It was apparent that the most significant effect occurred directly underneath the binding wires where the textile was put into compression. There were no regions of significant tensile stress.

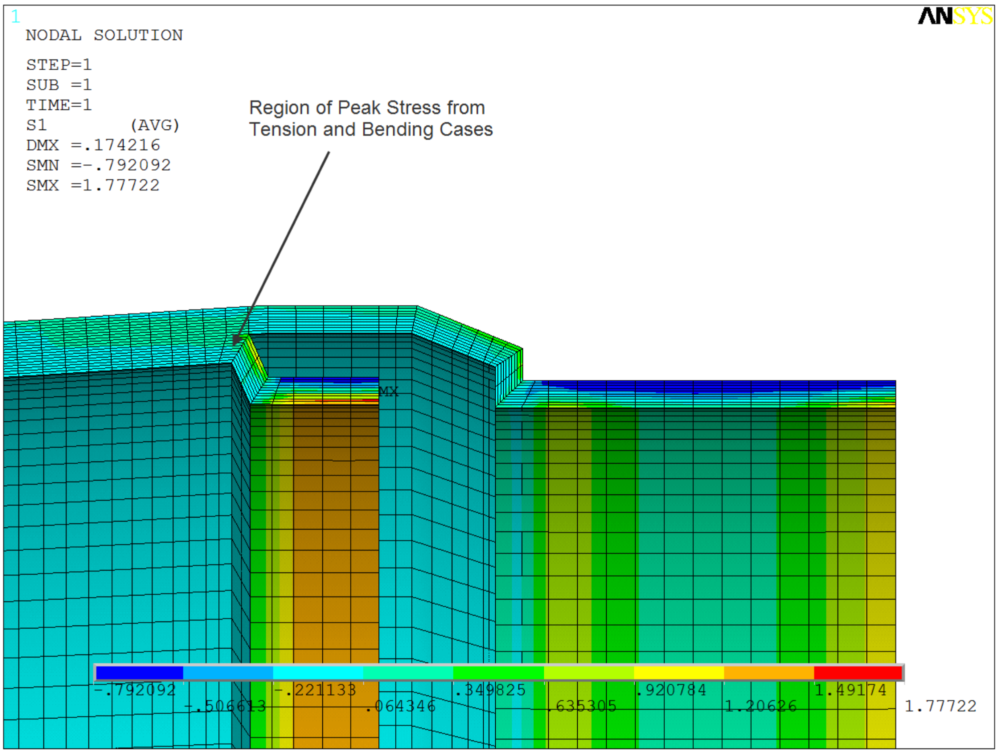

Figure B3-1 – Max Principal Stress in Textile Fibres due to Binding Wire Tension

Figure B3.2 shows a close-up of the region which was most highly stressed from the operational load cases in the main body of this report. It is clear from this image that the binding wire tension causes a negligible tensile stress at this location and can be neglected as a result.

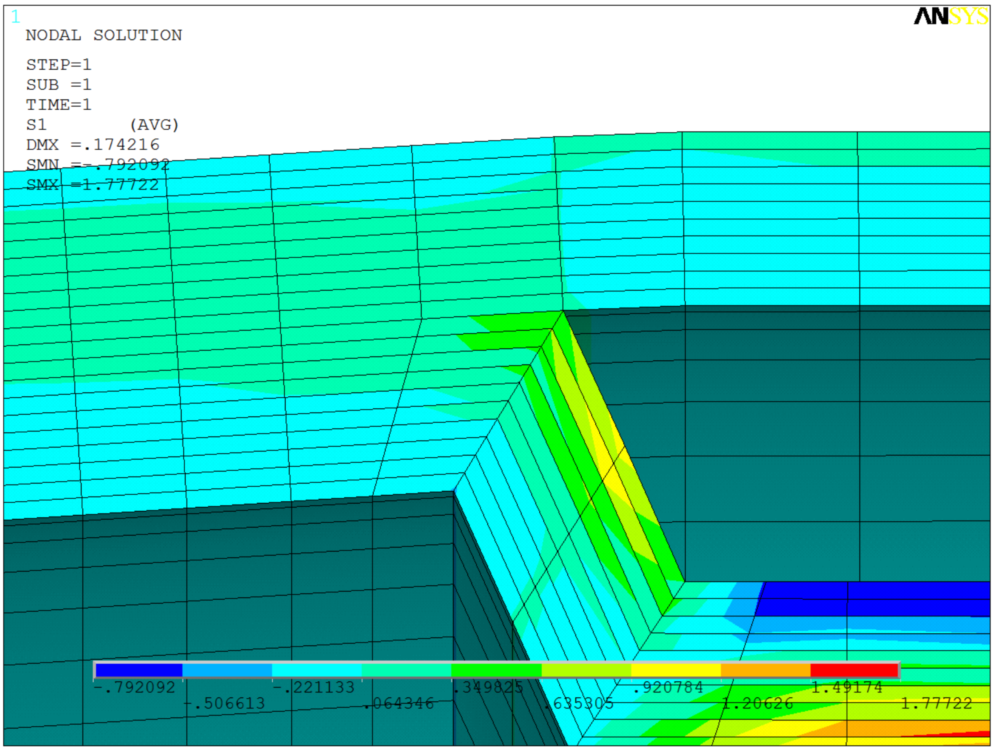

Figure B3-2 – Close-Up of Region of Interest from Operating Load Cases

Appendix C – Lay-Up Angle Behaviour Check

C.1 Introduction

Text book data is readily available which details how the axial load capacity should vary with lay-up angle. Typically, the curve should take the form shown in Figure C1.1 which is taken from "*NAFEMS EL-016 Composites – Session 1"* training material. Note that the graph is dependent on the strengths of the both the fibre and matrix materials.

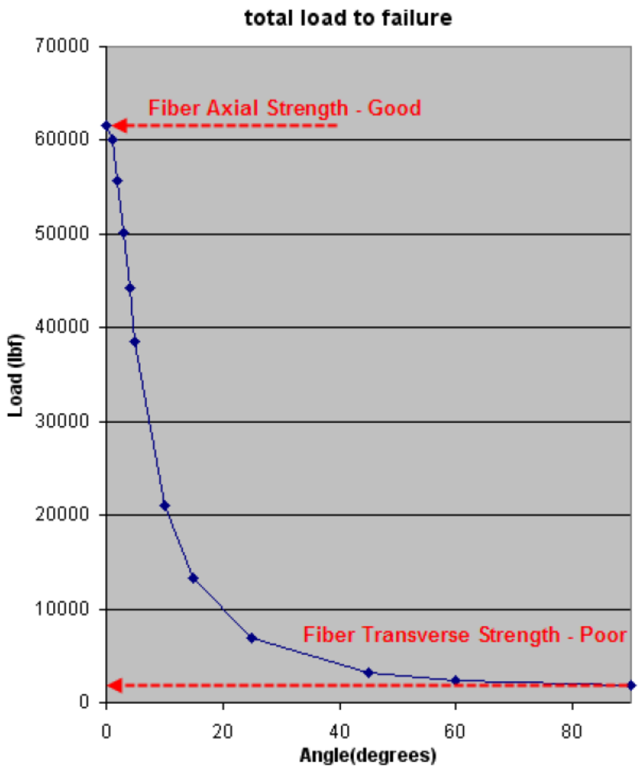

Figure C1-1 – Load vs Lay-Up Angle

A study to extract the axial stiffness as a function of lay-up angle was carried out in order to compare the result from the FE model with the expected text book trend. The intent was to give confidence in the element technology used to represent to composite textile layer.

A model consisting of a small group of elements was solved to extract the axial stiffness for varying lay-up angles between 0-90deg. One end of the model was fixed whilst the other end had unit axial displacement applied. The model is shown in Figure C1.2.

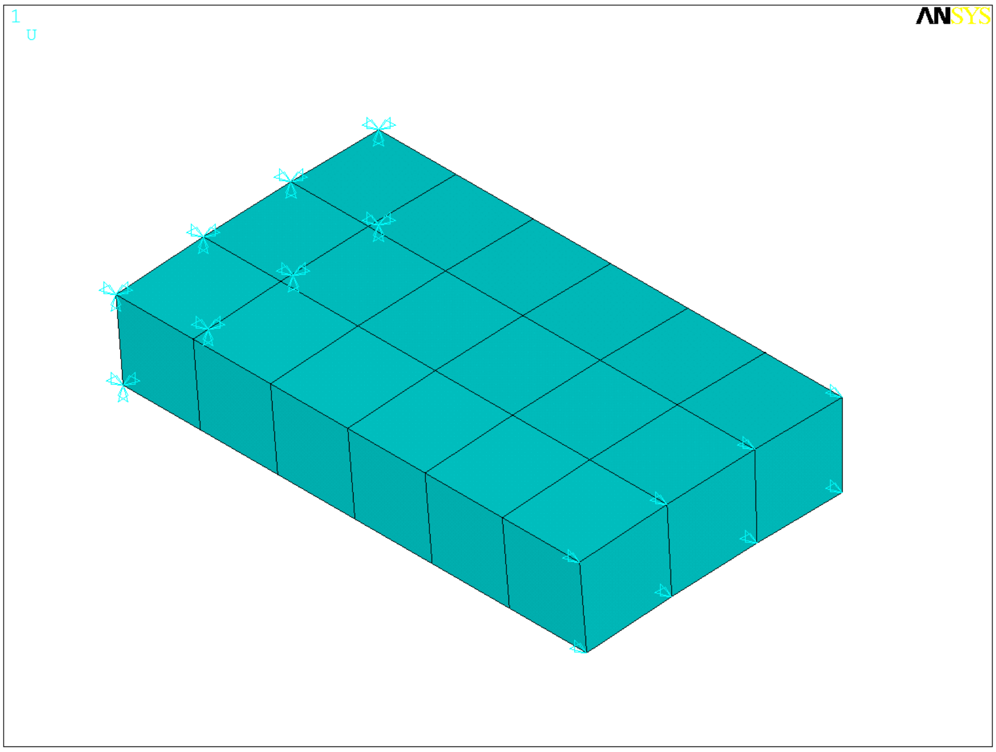

Figure C1-2 – Model used for Study

C.2 Results

The results of the study are shown in Figure C2.1. The trend of the curve is very similar to that shown in Figure C1.1 implying confidence in the FE model.

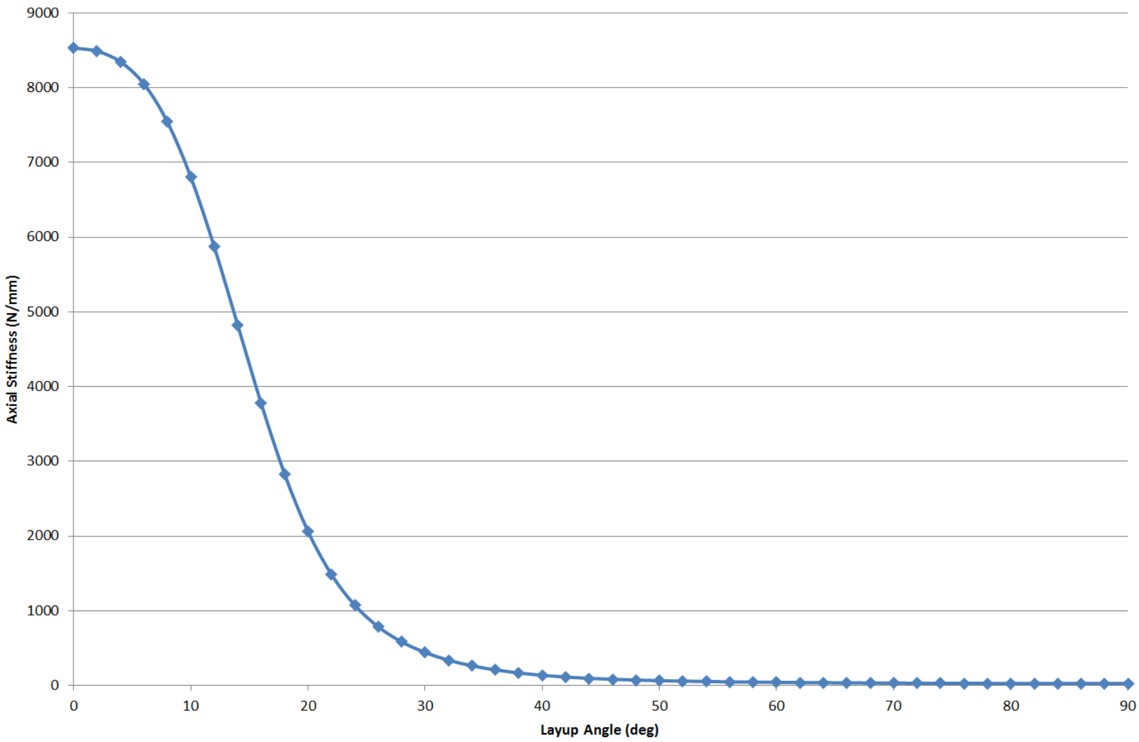

Figure C2-1 – Axial Stiffness vs Lay-Up Angle

PDL	**PDL Solutions (Europe) Ltd.** 1 Tanners Yard Hexham Northumberland NE46 3NY **Tel :** +44 (0) 1 434 609 473 **Fax :** +44 (0) 1 434 606 292 **www.pdl-group.com**	**Technical Report** 40” Suction Hose Fatigue Assessment Global Analysis

Report Number:	PDL-EMS-667-002 (2)	**Project:**	40” Suction Hose Fatigue
Customer:	EMSTEC	**PDL Job No:**	667
Contact:	Ian Craig	**Quote Ref:**	SQDU-141 (3)

Technical Report

Abstract:

This document details the results of global analyses undertaken in support of the fatigue assessment of the EMSTEC 40" cooling water suction hose.

All model setup and inputs are detailed. The load case definitions and assumptions are also described.

The purpose of this document is to give a detailed description of the analysis work and the associated results. The key outputs were the hose textile material and flange material fatigue lives. The hose bending and axial stiffnesses and stress factors required for the fatigue assessment were calculated using detailed finite element models described in PDL-EMS-667-003.

The hose textile material consists of a polyester yarn/rubber sheet which reinforces the hose; this was considered in detail along with the metal parts of the flanged joint.

Revision History

Rev	Date	Reason for change	Author	PDL Review	PDL Approval
2	02/04/2015	Minor update to fastener life	MAS	DCU	DCU
1	31/03/2015	First issue for customer comment	MAS	DCU	AGR

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1 Introduction

This report describes the steps taken in the global analysis of an EMSTEC 40” cooling water suction hose [1] operating from a new FLNG (floating liquefied natural gas) unit intended to be deployed off the coast of Mozambique. The main outputs of the analysis were the hose textile material and flange material fatigue lives. The work uses inputs from a local analysis described separately in PDL-EMS-667-003 [13]. The polyester/rubber composite reinforcement was considered in detail along with the metal parts of the flanged joint. This work is part of a front end engineering and design study funded by Eni East Africa SPA.

EMSTEC intend for the hose to comply with the fatigue requirements of API 17K ‘Specification for Bonded Flexible Pipe’ (co-branded as BS EN ISO 13628-10) although it is recognised that this standard is not strictly intended to be used for suction hoses.

As part of the requirements for compliance with API 17K, all bonded flexible hoses must show suitable fatigue life under expected operating conditions. In order to verify that the EMSTEC suction hose complies with this requirement, PDL Solutions (Europe) was contracted to undertake a full fatigue analysis for a total hose length of 135m. Each section of hose is 9m long with steel flanges at either end so 15-off hose sections are required to make up the 135m total length. There is also a strainer at the open end of the hose. For compliance with API 17K, the suction hose must have a fatigue life of more than ten times the service life, which in this case means the calculated minimum life should exceed 250yrs.

2 Objective

The global analysis, conducted in Orcaflex, consisted of a global dynamics fatigue assessment of a model representing the vessel and hose with hydrodynamic loading derived from relevant Metocean data [2].

The first purpose of this report is to outline the input data that was used in the global analysis and to describe how the data required for the fatigue assessment was generated. Assumptions have been listed and references given to indicate where the input data was sourced from. Secondly, the report describes the calculations that were conducted in Orcaflex to predict the fatigue lives of the critical components.

3 Global Analysis Methodology

This section describes the input data for the Orcaflex models and details how it was generated.

3.1 Geometry

The main features of the hose section geometry are described below; details were taken from the CAD model supplied by EMSTEC [3].

The hose section geometry is shown in Figure 3-1. The inside diameter (ID) of the hose is 1.00m and the outside diameter (OD), away from the end fitting, is 1.22m. The end fitting OD is 1.30m; this applies to the flange and the enlarged section shown in Figure 3-1.

The textile plies carry the main structural loading. Across the full length of the hose there are 20 layers where the angle of the drawn polyester fibres is +/-40^{o} to the hose longitudinal axis. Full geometrical details of the hose are given in [13].

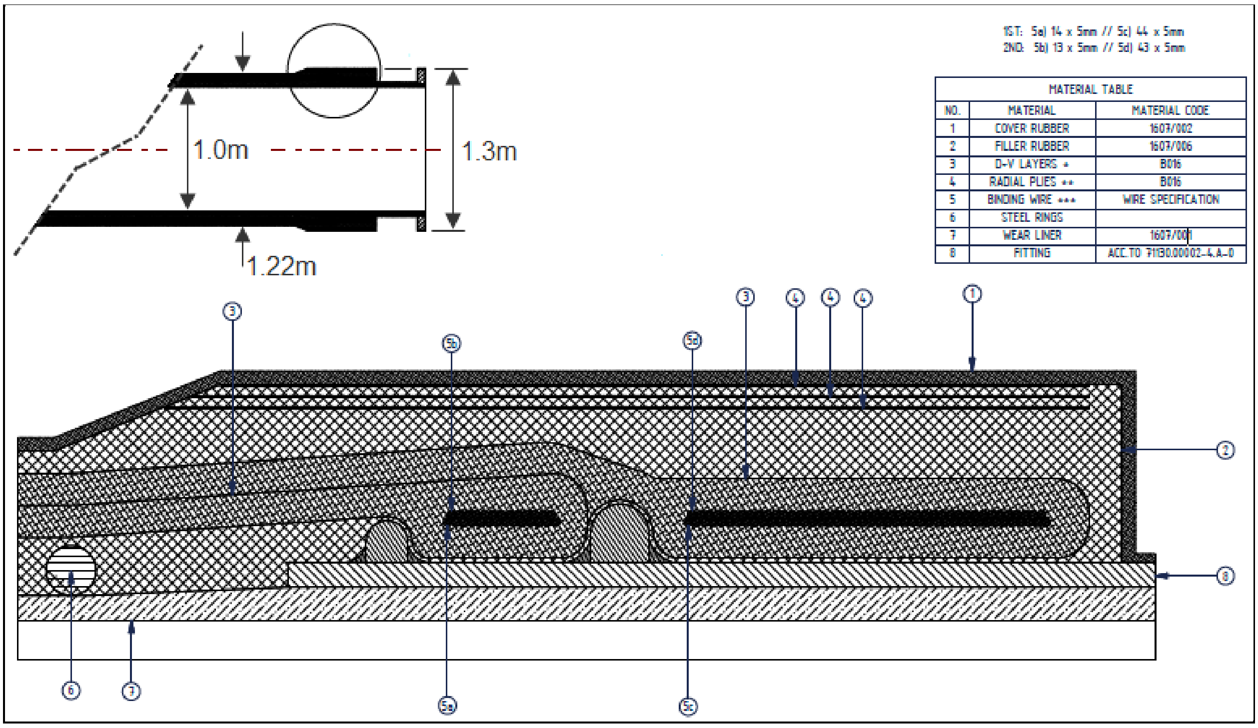

Figure 3-1 – Hose Geometry [1]

3.2 Hose Data

An example Orcaflex model was obtained from EMSTEC [6] for a 36" hose. The model was modified in all aspects other than the vessel data which is discussed in Section 3.3. Full details of the setup and modifications are given within this chapter. The hose was subdivided into three sections as indicated in Table 3-1. The first two sections are substantially the same; the division occurs at the point at which the marine growth runs out, see Section 3.2.2.

The mass per unit length of the '40" rubber' section was taken from measured data supplied by EMSTEC [14]. The outside diameter (OD) was set such that the hose weight in water matched the data supplied by EMSTEC [15]. This resulted in a diameter less than the actual diameter but note that the hose forces due to drag were not affected by this modification as the drag diameter was set separately to the correct value of 1.22m.

	Length (m)	OD (m)	ID (m)	MBR	Mass/Length (te/m)
40" Rubber	50	1.203	1.0	4.0	0.583
40" Rubber	85	1.203	1.0	4.0	0.583
40" Strainer	2.7	1.04	1.0	N/A	0.497

Table 3-1 – Water Intake Hose Geometric Properties as Modelled

The flange connection and marine growth details were applied using the Orcaflex 'Attachment' functionality as discussed in Sections 3.2.1 and 3.2.2 respectively.

Strainer details were provided by EMSTEC [16]; once again the OD was adjusted to give the correct weight in water and the drag diameter was set separately.

3.2.1 Flange Connectors

The OD was assumed to apply along the full length of the hose i.e. the flange geometry was not modelled explicitly.

Hose ancillaries were considered as point masses attached to the line along its length. The ancillaries considered in the model were 40" flange connectors at 9.0m intervals along the hose, and cathodic protection anodes.

Each attachment was considered as a clump weight, they were given zero area and zero volume so that they did not influence the hoses' response to hydrodynamic loading other than through the weight effect. The weight input into the model was the fully submerged weight of the connectors and accounts for the following components:

- 36 studs at 39mm diameter.
- 144 nuts (two at either end of stud) at 39mm diameter.
- 2 x 20mm thick backing plates at 1280mm diameter.
- 6 x 4kg aluminium anodes.

Combined, this gives a submerged weight of 0.277 tonnes per connection.

To account for the stud preload effect in the top flange (which was most critical from a fatigue point of view), an additional point mass of 156 tonnes was applied at a short distance from End A. This was required to model the preload of 236 MPa in the welds. The mass of the attachment was calculated accounting for the weld stress factor outlined in Section 3.2.5. The consequences on the fatigue analyses are outlined in Section 3.2.6.

Note that sensitivity studies were carried out to check that this additional mass did not influence the dynamic behaviour of the hose, the results of which showed that the minimum fatigue life of the composite part of the hose was the same with and without the point mass.

3.2.2 Marine Growth Profile

The marine growth (MG) profile considered in the analysis was taken from [17] and is summarised below for clarity:

- +2m to -10m : 100mm MG
- -10m to -65m : 25mm MG
- Below -65m : No MG

As the hang-off location for the flexible hose is situated at z = -15m, the full 100mm of marine growth was not used in the analysis.

The variable outer diameter of the hose accounting for marine growth is given in [17]; recall that this is based on a nominal hose OD of 1.22m, see Figure 3-2.

Note that the marine growth profile has only been considered in calculating the drag coefficient, contact diameter and mass per unit length of the hose. Any contribution to the bending stiffness of the line from marine growth is deemed negligible and is not accounted for in the analysis.

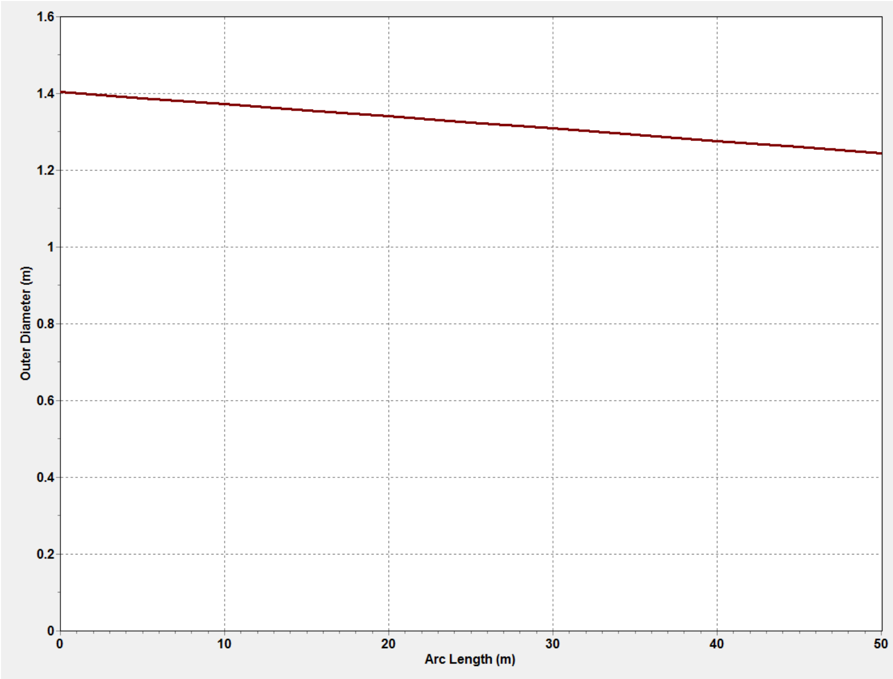

Figure 3-2 – Variable OD for Marine Growth

3.2.3 End Connection Stiffness

The end of the hose could have been fully fixed to the vessel but this was considered to be too conservative. In order to more accurately model the connection stiffness an approximate riser head/riser seat model was created using finite element (FE) analysis in ANSYS. The model was approximate because the riser head and seat for the 40” hose have not yet been designed, essentially, the geometry from a smaller riser head was scaled up based on the difference in hose diameter.

There is clearance between the riser head and the riser seat and there are soft (HDPE) pads attached to the outside of the riser head to avoid metal to metal contact between it and the riser seat. The objectives of the FE analysis model were to determine what degree of free rotation was allowed, and what connection stiffness develops once the riser head has reached its rotational limit. Figure 3-3 shows the setup of this riser head FE model. Two rigid blocks, either side of the riser head, were used to model the constraining effect of the riser seat. The following parameters, which should be updated once the riser head and riser seat designs work is complete, were used in the model:

- ID of riser seat = 1940mm
- OD (pads) of riser head = 1890mm
- Vertical distance between top of pad and bottom of bottom pad = 1180mm
- Thickness of riser seat tube = 20mm
- OD of tube = 1530mm
- Material of tube = steel
- Material of top pad = HDPE
- Material of bottom pad = steel; the reason this pad was modelled as steel rather than HDPE is that it was modelled potentially thicker than it would be in reality which would lead to a non-conservative stiffness if the material was modelled as HDPE.

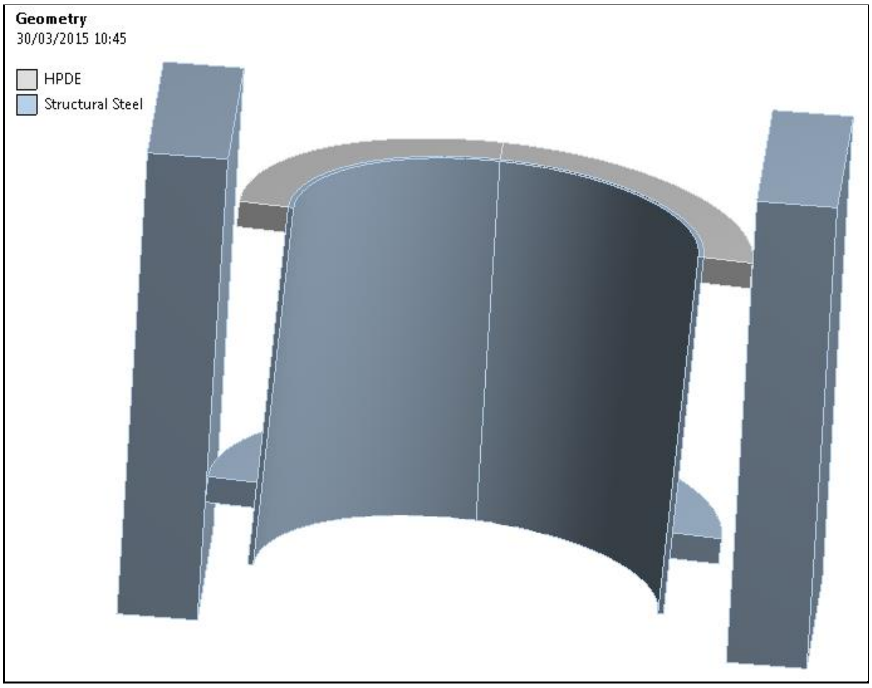

Figure 3-3 – Riser Head Model

The rotational limit of the riser head was deduced by rotating the geometry alone. Rotating the riser head until it touched the rise seat showed that the rotational limit was 2.5deg. The FE analysis model was held in this position and a number of representative bending moments were applied in order to determine the response of the connection. These moments were taken from the Orcaflex model and were moments expected to be experienced by the riser head during operation.

The models were solved and the rotation of the connection geometry obtained in order to construct a moment-rotation relationship that could be input into Orcaflex. This moment-rotation relationship is shown in Figure 3-4. Note that a slightly non-zero stiffness was applied up to 2.5°. This was required to aid (Orcaflex) model convergence; the change in gradient occurred at a relatively small 2kNm.

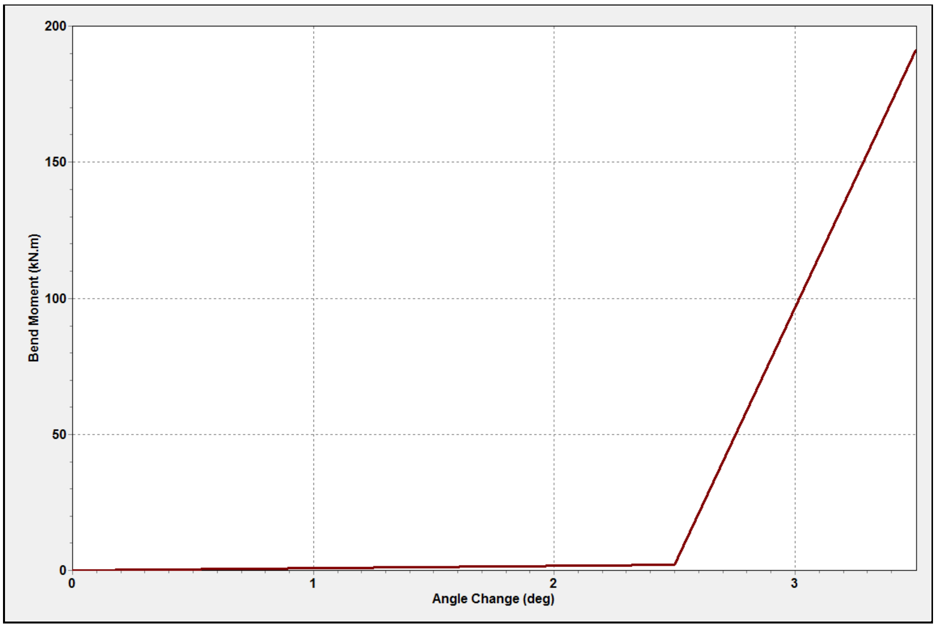

Figure 3-4 – Variable End Connection Stiffness

3.2.4 Variable Drag Coefficient

A variable drag coefficient was used on all parts of the line in order to model the variance in Cd with Reynolds number. Two separate profiles were used in the analyses – 'smooth' and 'rough'. These graphs were taken from [4] and are given in Figure 3-5 and Figure 3-6. The smooth graph was used for the hose sections where there was no marine growth and the rough for where there was.

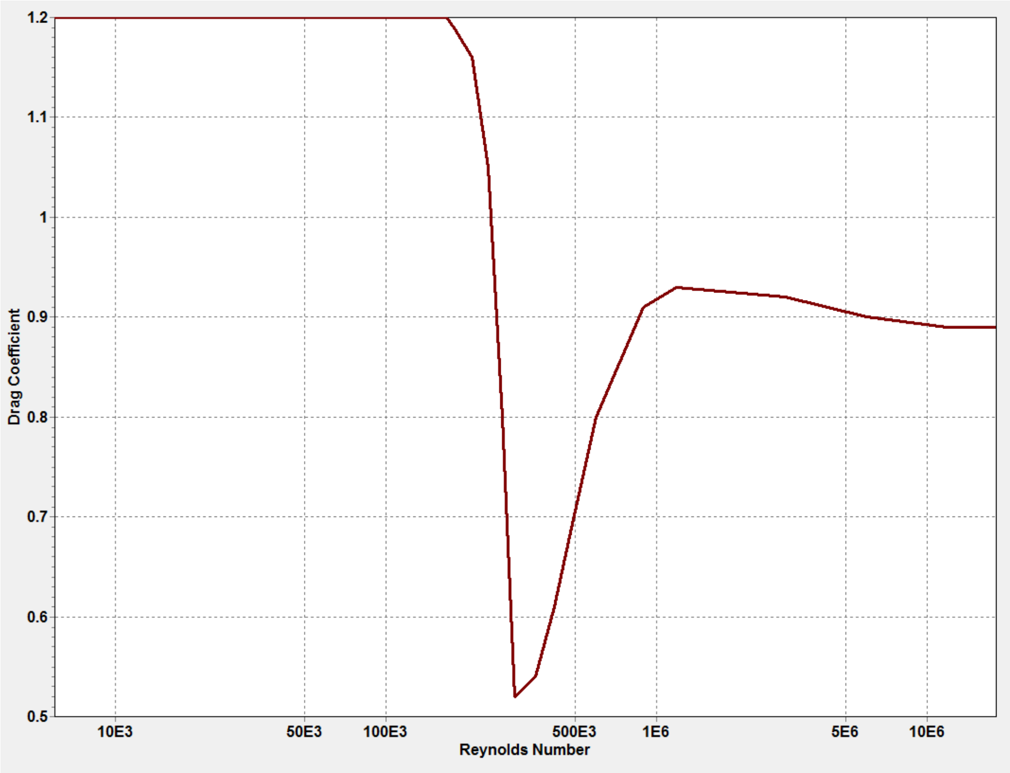

Figure 3-5 – Variable Drag Coefficient – Smooth

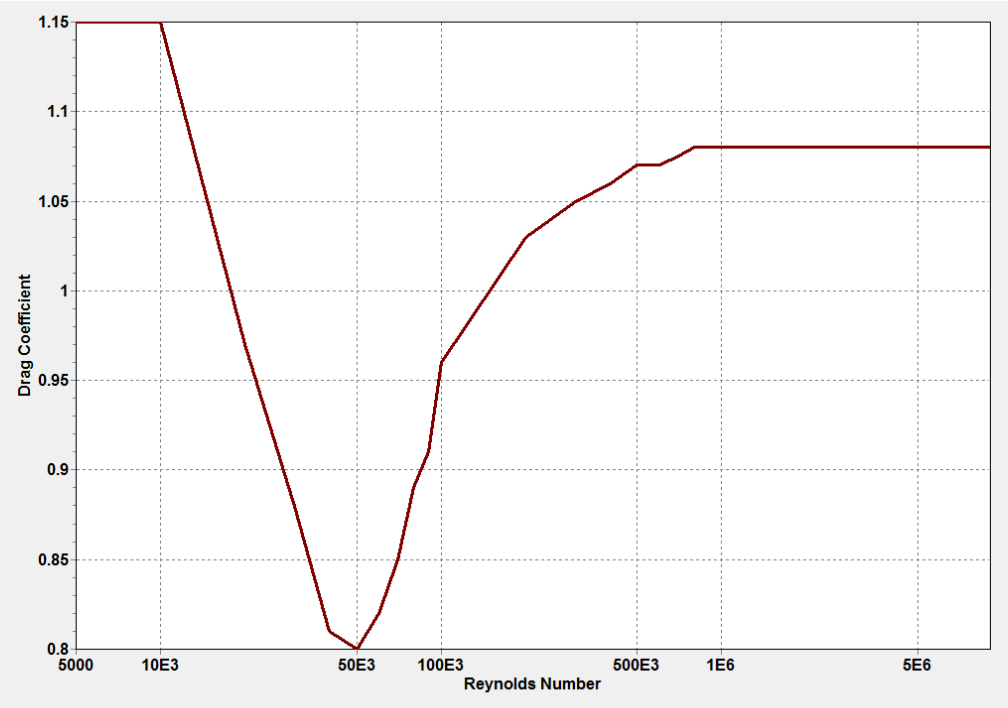

Figure 3-6 – Variable Drag Coefficient – Rough

3.2.5 Hose Stiffnesses

Bending and tension stiffnesses for the hose and the bending and tension stress factors for the textile layers, flange fasteners and flange weld were derived from the results of the local analysis [13]. The hose composite layer and the flange components were considered to be the critical components in terms of fatigue damage.

The stiffness data was required before the Orcaflex models could be run; there was some non-linearity in the stiffness data so the data was input in tabular form; equivalent plots are shown in Figure 3-7 and Figure 3-8.

Note that the bending stiffness data represents a worst case estimate based on a sensitivity study, see Appendix B. Three hose stiffness profiles were generated from the local analysis work in order to envelope the possible range of bending stiffnesses [13]. A sensitivity study was setup where stress levels were calculated using the three profiles. The profile that gave the highest stresses, and therefore lowest fatigue life, proved to be the maximum stiffness curve. The derivation of the three curves is discussed in detail in [13]. The maximum stiffness curve was used in the Orcaflex analysis and, as a result, the fatigue damage calculations for the composite material are considered to be conservative.

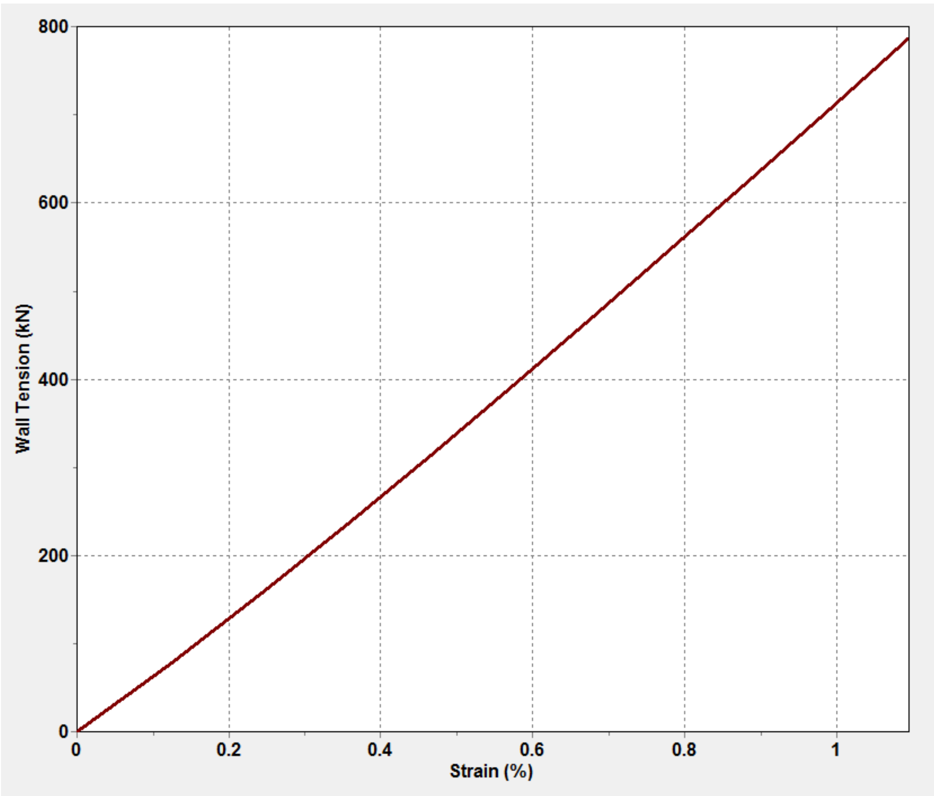

Figure 3-7 – Variable Axial Stiffness

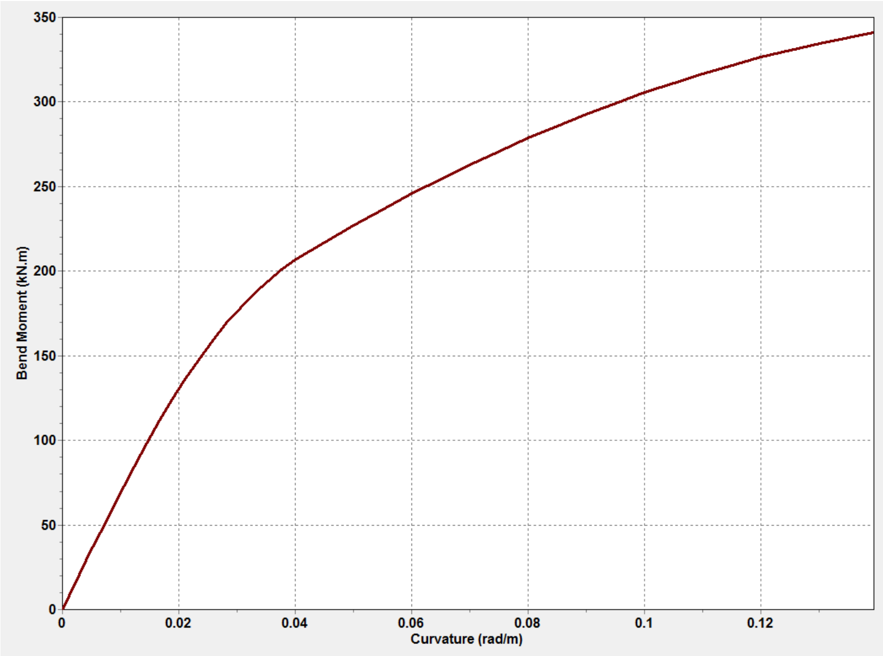

Figure 3-8 – Variable Bending Stiffness

3.2.6 Stress Factors

The stress factors were required at the post-processing stage when the fatigue damage was computed. The stress factors are shown in Table 3-2. The hose stress factor data was output directly from [13] i.e. stress versus tension and stress versus curvature data was detailed there. However, to add further conservatism the hose stress factors were doubled to allow for any modelling uncertainty. This doubling was considered to be very conservative but the hose showed acceptable behaviour with this assumption so it was not revisited. The hose bending stress factor is in reality non-linear so the value given in Table 3-2 represents the linear part of the curve where the curvature is low. The bending stiffness reduces at higher curvatures so the linear value is either accurate (low curvatures) or conservative (higher curvatures).

For the back-to-back flange model, the tension stress factor data was output in the same way but the bending stress factor had to be computed because it was not practical to output accurate curvature data from the ANSYS model. For the Orcaflex input, it was necessary to convert the bending moment to curvature. This was done using the linear part of the 'Best Estimate Properties x 2' curve from [13]. The reason this curve was used rather than the base 'Best Estimate Properties' curve was that it generated the most conservative results i.e. lower flange component fatigue lives.

The only other adjustment related to the size of the fasteners. If the nominal fastener size (M39 in this case) exceeds 25mm then DNV-RP-C203 [4] recommends that the detrimental effect of increased section size is taken into account by factoring up the input stress as follows (where t = 39mm, t_{ref} = 25mm and k = 0.25 [4]):

$$\Delta\sigma_{eff} = \Delta\sigma_{input} \times (t/t_{ref})^k$$

Component	Axial stress factor (MPa/kN)	Bending stress factor (MPa/rad/mm)
Hose	0.200	5.03E6
Flange fasteners	0.0133	0.357E6
Flange weld	0.154	3.60E6

Table 3-2 – Stress Factor Data (hose and fastener data factored up)

The full post-processing of the fatigue simulations was carried out within Orcaflex, utilising the program's stress factor approach for calculating damage. This was possible because, in the range of interest the stress factors were linear or could conservatively be assumed to be linear.

3.2.7 Fatigue Curves

Polyester/Rubber Composite Fatigue Curve

Besides the stress factors and the fatigue loading (that is discussed in Section 3.4.2) a material fatigue (SN) curve was also required for the textile layers.

It was considered that the most likely fatigue failure mechanism of the main hose section is tensile failure of the polyester filaments. No fatigue data is available for the composite material so it has been necessary to derive an approximate fatigue curve using published academic papers. The papers that were used [10] and [11] both relate to filament fatigue so it was necessary to scale down the fatigue strength so that the strength of the yarn was properly represented.

The mean filament strength in [10] is 1140 MPa. This is consistent with the EMSTEC filament data [8] which gives a strength of 1130 MPa for an assumed density of 1.39g/cm^3 [12]; giving confidence that the fatigue data was appropriate to use for the EMSTEC hose. The average strength of the yarn taken from EMSTEC tests was 484 MPa [5], post cure, assuming a nominal diameter of 1.4mm. Fatigue strength typically scales with the tensile strength so this implies that the fatigue strength in [10] should be scaled down by a factor of 2.36.

Approximately 15 data points were recorded for each load used in the filament fatigue test data in [10]; this data was used to find the mean and the standard deviation of the filament fatigue life for each load. The data in [11] followed a similar pattern. Minimum fatigue strength data is typically given for 2 standard deviations below the mean but in order to add further conservatism 3 standard deviations below the mean were used in this case.

The fatigue data expected by Orcaflex is fully reversed i.e. the minimum load equals the maximum load and the mean stress is zero (R = -1 where R = min stress/max stress from the test cycle). In filament or yarn testing it is not possible to fully reverse the load (as the specimens would buckle) so the testing in [10] maintained a minimum tension equal to 2% of the tensile strength (R = 0.025 approximately). In order to provide appropriate data for the Orcaflex assessment it was necessary to convert the R = 0.025 data to R = -1. This was done using the Goodman diagram with the mean UTS from [5] (i.e. 484 MPa as discussed above); using a minimum UTS would give less conservative results for this conversion.

The resulting fatigue data is shown in Figure 3-9; note that the data is presented with stress range rather than stress amplitude on the 'y' axis as the former is required by Orcaflex. In Figure 3-9 the lower line was used in the assessments as this is both simpler to use and conservative; it has the same gradient as the line between the last two points of the derived data but passes through the first data point. Mean stress effects were allowed for in the fatigue assessments, once again using the Goodman diagram. In this case, a minimum UTS derived from the measured data in [5] was used, this gives conservative results (relative to using a mean UTS). The minimum UTS of the yarn was taken to be 395 MPa based on minus two standard deviations from the mean of 10 samples tested by EMSTEC [5].

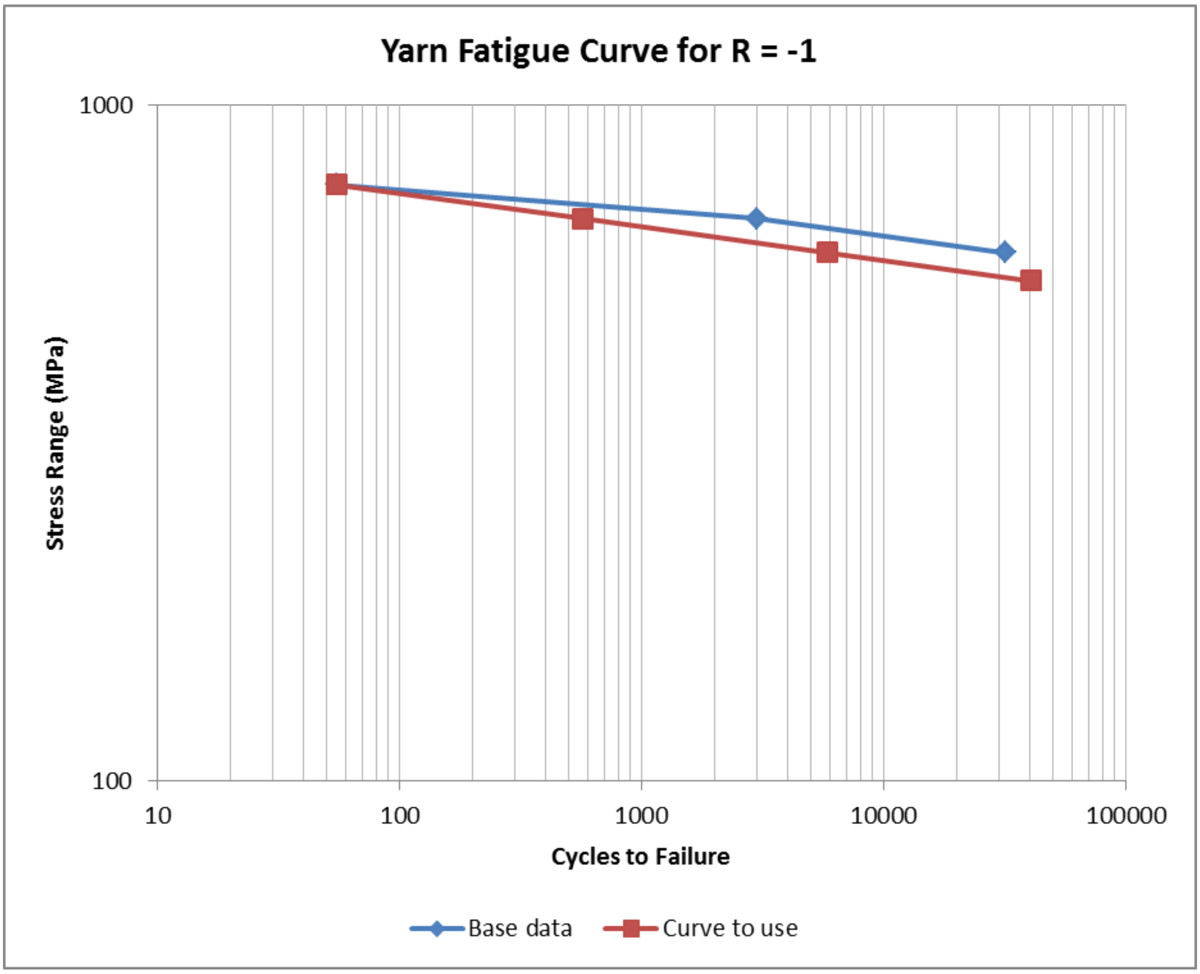

Figure 3-9 – Estimated Yarn Minimum Fatigue Data

Flange Weld Fatigue

The weld stresses proved to be more critical than the parent metal stresses so only the former were analysed in detail.

For the fatigue assessment of the flange weld metal, the 'D' fatigue curve from DNV-RP-C203 [4] was used as the basis. This particular curve is prescribed for use with the 'Hot Spot' method discussed in section 4.3 of the DNV standard. The 'Hot Spot' method is based on linear extrapolation of stress taken from two points in the near vicinity of the weld. The flange is protected by the rubber coating so it was considered appropriate to use the fatigue curves for an air environment.

DNV-RP-C203 [4] claims that mean stress effects are built into the fatigue curves but does not state what these mean stresses are. It was considered most likely that the testing conducted to generate the curves was done at R=0 i.e. the mean stress is equal to the alternating stress. This level of mean stress was considered to be insufficient in the case of the flange weld because a large amount of stress, 236 MPa, built up during the pre-loading of the fasteners [13], and then further mean stress is built up due to the weight of the hose. This level of mean stress would generally result in a positive R value which means that the curve provided by DNV is non-conservative.

In order to allow for this non-conservatism the Orcaflex model was adjusted so that an additional mass of 156 tonnes was added very close to the top of the hose sufficient to generate a weld stress of 236 MPa. The DNV curve was then converted from R=0 to R=-1 and, within Orcaflex, mean stress effects were switched on. The resulting curve is shown in Figure 3-10.

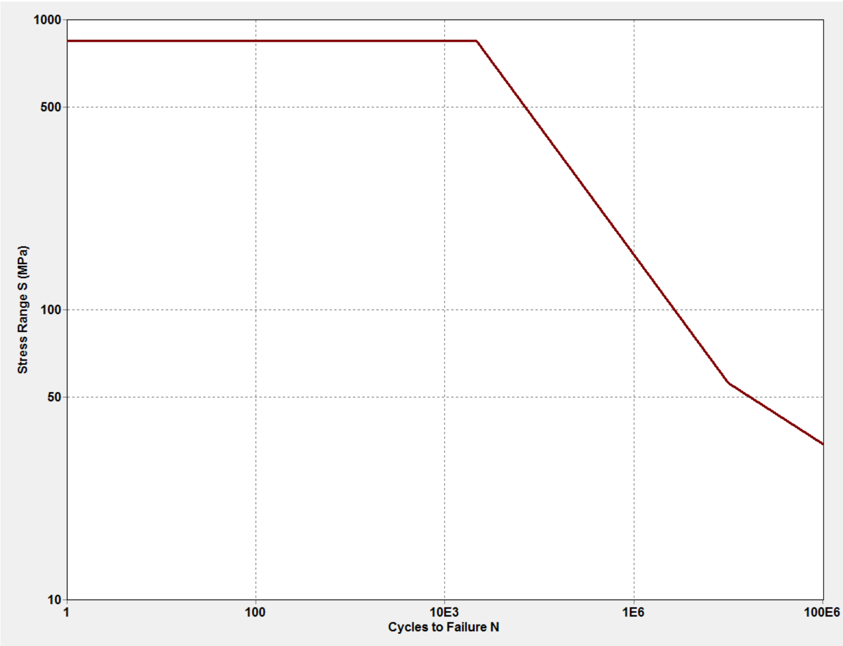

Figure 3-10 – DNV-RP-C203 Modified D Curve (R=-1, In Air)

Stud Fatigue

The fasteners are exposed to the sea water environment so the fatigue curves for sea water with cathodic protection were appropriate. It is expected that the fastener threads would be rolled rather than cut but to be conservative the more conservative fatigue curve was used i.e. the W3 curve [4]. As this curve is intended to be used for pre-loaded fasteners no additional assessment, as carried out for the weld, was deemed necessary. The fatigue curve is shown in Figure 3-11.

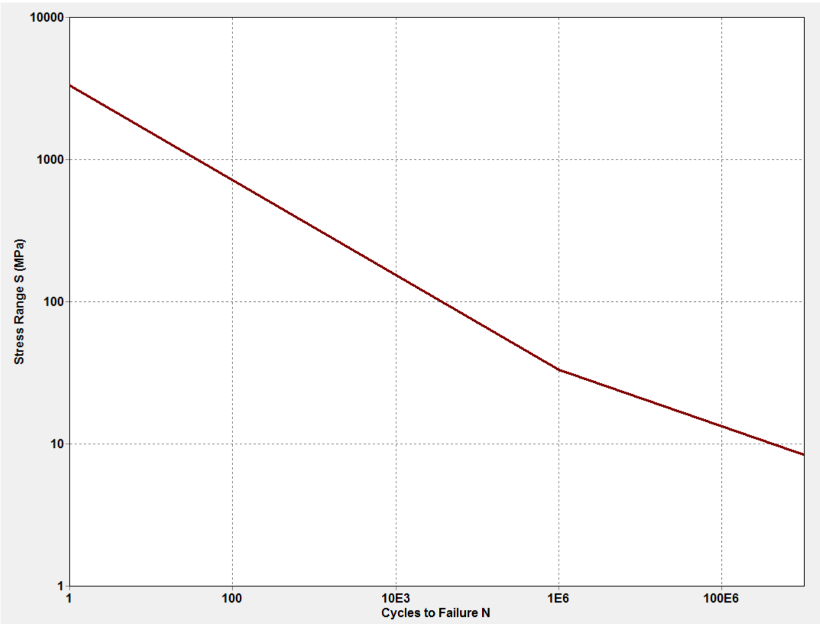

Figure 3-11 – DNV-RP-C203 W3 Curve (seawater with cathodic protection)

3.3 Vessel Data

3.3.1 Vessel RAOs

Vessel motion data was contained within the Orcaflex model supplied [6]. In order to verify this data, RAO (Response Amplitude Operator) plots were generated which are given in Appendix A. The RAO data supplied in the Orcaflex model was given in the range 0° - 180° as the vessel exhibits half symmetry. On inspection of the RAO plots, it was apparent that the vessel exhibits strong quarter-symmetry and so the RAO plots were reduced to this range for clarity.

From Figure A-4, it can be seen that the vessel's pitch period shows resonance at around 20s for small heading angles. However, this is not likely to cause significant issues within the fatigue analysis as waves of this period have relatively low occurrence, see Section 3.4.

The RAO data within the Orcaflex model has the following sign convention:

- Surge is positive forward
- Sway is positive to port
- Heave is positive upwards
- Pitch is positive to aft down
- Roll is positive starboard down
- Yaw is positive from bow to port

To give confidence that the RAOs had been set up correctly, they were sense checked by running the vessel through a number of waves. Each wave had an arbitrary height and period and was run in order to gauge the vessel's motion response. These sense checks validated the data which was contained within the Orcaflex model supplied to PDL solutions.

Within the Orcaflex model, the primary motion of the vessel was set to 'None' and the superimposed motion was set to 'Displacement RAOs + Harmonic Motion'. Physically, this meant that the vessel only experienced first order wave effects i.e. no slow drift.

3.4 Environmental Data

3.4.1 Current Data

Various profiles for current data were given in the Metocean report [2] and the Orcaflex model [6]. For the purposes of the fatigue analysis, the 1 year non-cyclonic current profile could have been has been used as shown in Figure 3-12.

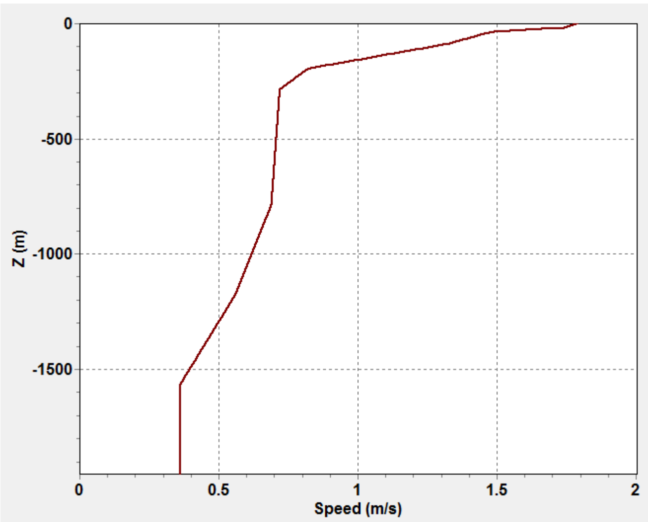

Figure 3-12 – 1-year Non-cyclonic Current Profile

However, on further inspection of the Metocean report, it was apparent that applying this current profile would be over-conservative for normal operation. For fatigue analysis, the Metocean report also lists 200 current profile bins ranked in order of descending occurrence. The surface current in each of the bins was either 0.2m/s, 0.6m/s or 1.0m/s; the first was most common and the last occurred rarely. To more accurately, but still conservatively, represent the current profile within Orcaflex, the average profile of the 10 most commonly occurring 0.6m/s profiles was used. This current profile was applied collinearly with each sea state in order to give the worst-case bending, see Figure 3-13.

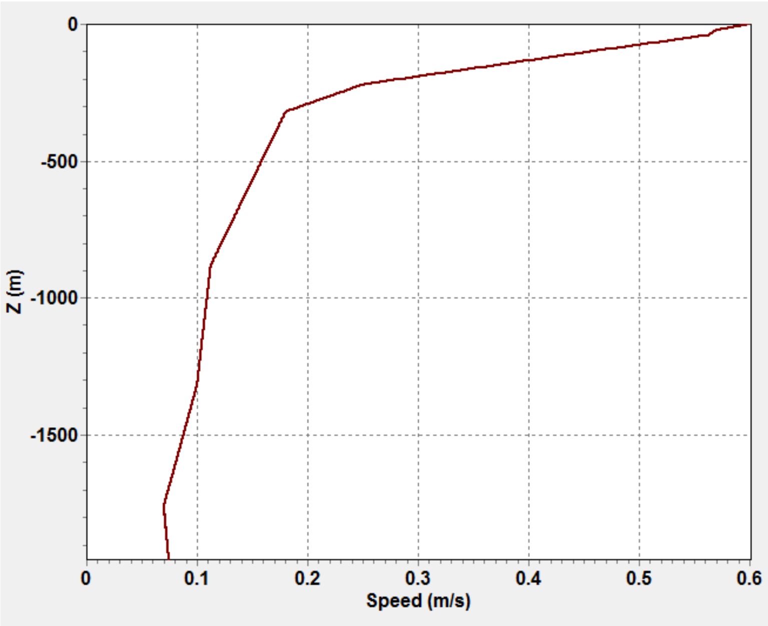

Figure 3-13 – 0.6m/s Averaged Current Profile

3.4.2 Wave Data

The methodology for obtaining the operation sea-state climate is outlined in the Metocean report [4]. This data was summarised and supplied in the manner of Hs-Tp scatter tables, from which regular wave bins representing the sea-state can be obtained. A set of regular wave heights and periods was generated, sufficient to accurately model the sea state. The Orcaflex wave scatter tool was then used to generate occurrence data for each bin. The accuracy of the wave scatter tool was controlled by the “probability covered” value, which was set to 0.98. This ensures that at least 98% of the energy of the original sea state is captured by the regular waves.

The data given in [7] gives the occurrence data in terms of probability. However, it does not give the probability associated with each wave heading. Thus, to calculate the expected number of cycles on a yearly basis, the Table 3-3 (taken from [4]) was used. The fatigue bins created by the Orcaflex scatter tool are shown in Table 3-4.

Dir. (°N)	Tp (sec)														
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	Total
0	0.00	0.01	0.19	1.38	1.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.68
30	0.00	0.05	0.95	4.22	4.56	0.85	0.08	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	10.75
60	0.00	0.18	1.51	3.61	3.40	1.54	0.26	0.21	0.10	0.03	0.03	0.00	0.00	0.00	0.00	10.89
90	0.00	0.20	1.48	5.23	7.83	3.46	0.97	0.40	0.24	0.05	0.03	0.03	0.02	0.01	0.00	19.95
120	0.00	0.30	4.50	5.63	5.44	4.57	2.10	0.90	0.35	0.19	0.06	0.03	0.01	0.00	0.00	24.09
150	0.00	0.19	3.93	9.43	5.07	4.46	2.89	0.93	0.25	0.09	0.02	0.00	0.00	0.00	0.01	27.28
180	0.00	0.01	0.27	1.37	1.66	0.64	0.15	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	4.16
210	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
240	0.00	0.01	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
270	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
330	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Total	0.00	0.99	12.90	30.92	29.03	15.57	6.46	2.50	0.97	0.38	0.16	0.07	0.03	0.01	0.01	100.00

Table 3-3 – Wave Occurrences with Direction

As the vessel considered weathervanes, there was no need to run the analyses for each wave heading. Rather, the waves were run in one direction as the vessel will always turn head-on to the incoming wave. This has two main benefits for the analyses – it allows the fatigue to be concentrated around the same hotspots for each wave considered and it significantly reduces the number of load cases considered.

Total Number of Occurrences														
Height (m)														
9			17.41	18.16	4.52									
7		47.71	612.70	482.67	118.11	18.89	2.79							
5		2543.17	14101.61	8531.22	2183.42	480.36	108.60	27.48	7.97	2.98	0.95			
3	554.69	104148.43	204743.25	91910.04	28364.61	8768.20	3017.94	1186.13	528.52	308.97	164.32	78.39	41.89	24.31
1	1467838.65	2152726.48	1244684.14	495087.73	197910.89	87655.26	43582.85	24016.06	14394.59	11125.41	7864.14	4848.09	3194.19	2214.58
Period (s)	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**23**	**26**	**29**	**32**

Table 3-4 – Omnidirectional Fatigue Scatter Table

There is a slight discrepancy in that the totals given in Table 3-3 suggest there are waves coming from 270° - 330°. The data given in [15] does not show any wave occurrences from these directions. However, as the sum of probabilities for these directions is 0.1% in Table 3-3, these waves are deemed negligible and the analysis has not considered these occurrences.

Note that Table 3-4 refers to the combined occurrences for all wave directions. Intervals of 2m have been used for period between 2s-20s, which are then widened to 3m between 20s-32s. This widening has been carried out in order to reduce the number of fatigue bins whilst keeping the probability covered sufficiently high.

The simulations were run for at least 5 wave cycles, which is long enough to achieve cyclic convergence. To obtain the total fatigue damage on the hose, the occurrence data for each direction was summed with respect to each H (height) vs T (period) pairing. Probability data supplied by EMSTEC [18] was used to calculate the fatigue damage on the hose, which can be interrogated at the request of EMSTEC to obtain the directional fatigue if required.

4 Results

4.1 Yarn

The fatigue life of the yarn was calculated using the method outlined above. Figure 4-1 shows the annual damage variation along the full length of the hose.

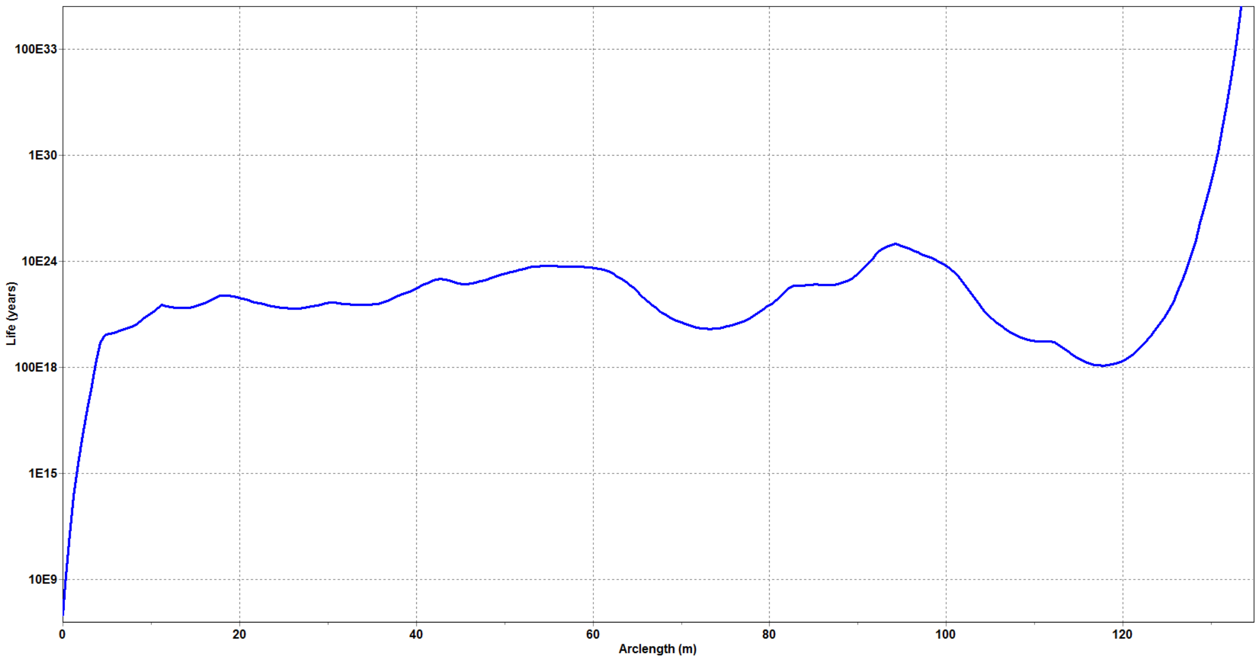

Figure 4-1 – Yarn Fatigue Life along Arc Length

As would be expected, the minimum fatigue life occurs at the connection to the riser head. This is where the majority of bending is concentrated, and as such this end of the hose experiences the largest stress range. The minimum fatigue life calculated at this location was 208E6 years.

A fatigue life of 208E6 years suggests the margin of safety is high but the gradient of the fatigue curve is very shallow (m=20) which means that doubling the stress would reduce the fatigue life by a factor of just over 1E6, bringing the fatigue life down to approximately 200 years i.e. below the target of 250 years.

4.2 Studs

Figure 4-2 shows the variation in life along the arc length of the hose. Note that the points plotted are the position of the flanges, taken to be at 9.0m intervals along the hose length.

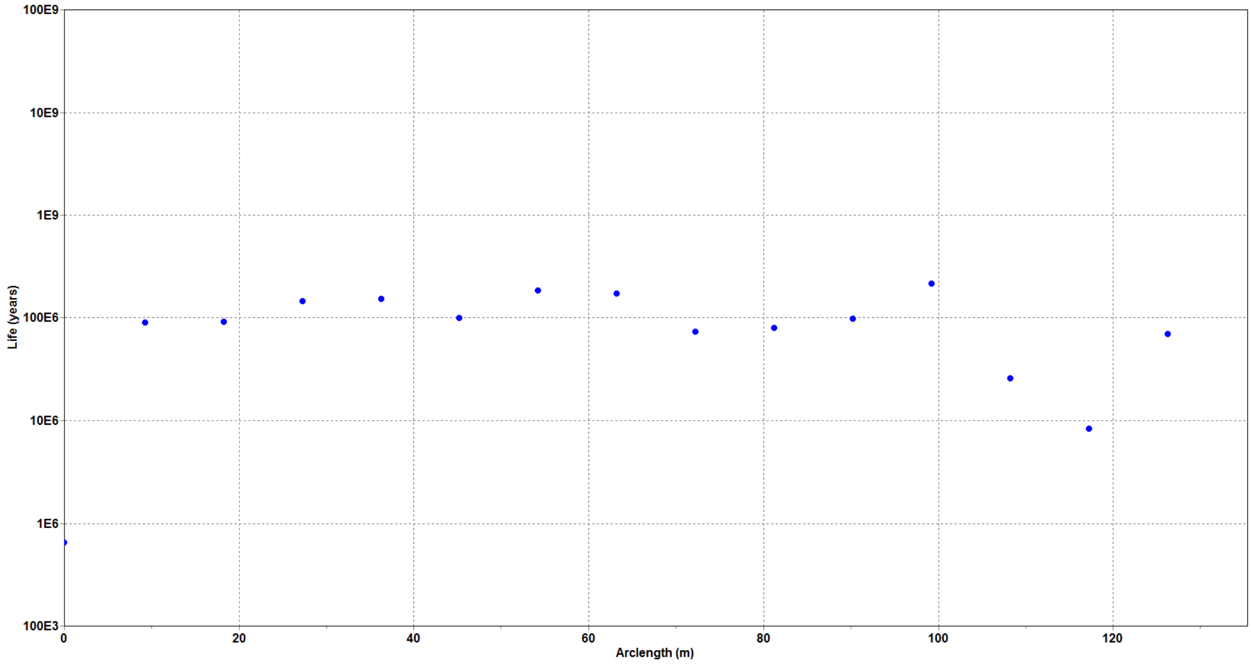

Figure 4-2 – Fatigue Life of Bolts at Flange Locations

The minimum fatigue life for the bolts occurs at the connection to the vessel, with an expected life of 648E3 years.

4.3 Welds

The minimum fatigue life for the welds occurs at the connection to the vessel with a minimum expected fatigue life of 933 years.

4.4 Peak Damage

Figure 4-3 shows a 3D surface plot of wave height, period and associated damage for each wave pairing. 2D views have also been given to show the relationship between wave height and damage and wave period and damage, see Figure 4-5 and Figure 4-6. The plots indicate that most damage is seen for a wave of height 5m and period 10s. This fatigue bin for this wave was responsible for 26% of the total damage seen in the welds. The dominating wave height of 5m is to be expected from the occurrence data as wave heights above 5m have a relatively low occurrence.

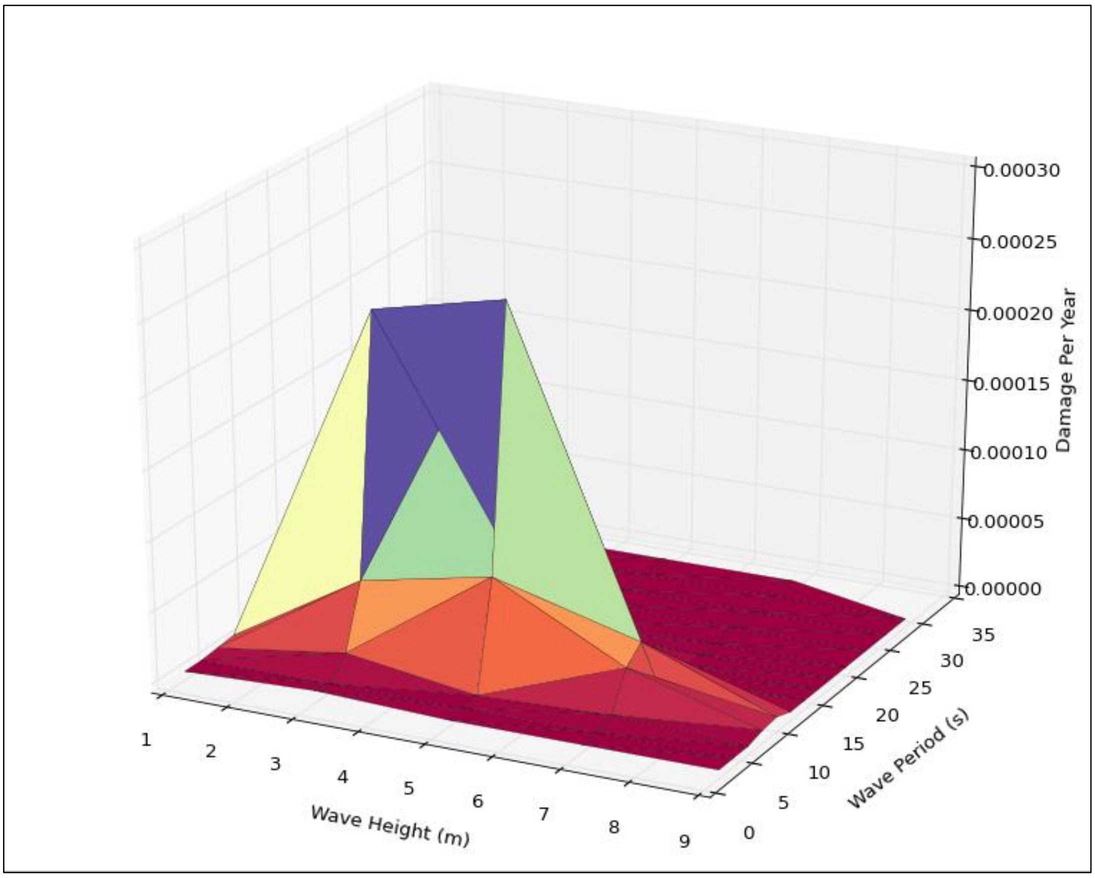

Figure 4-3 – Centre of Damage Plot

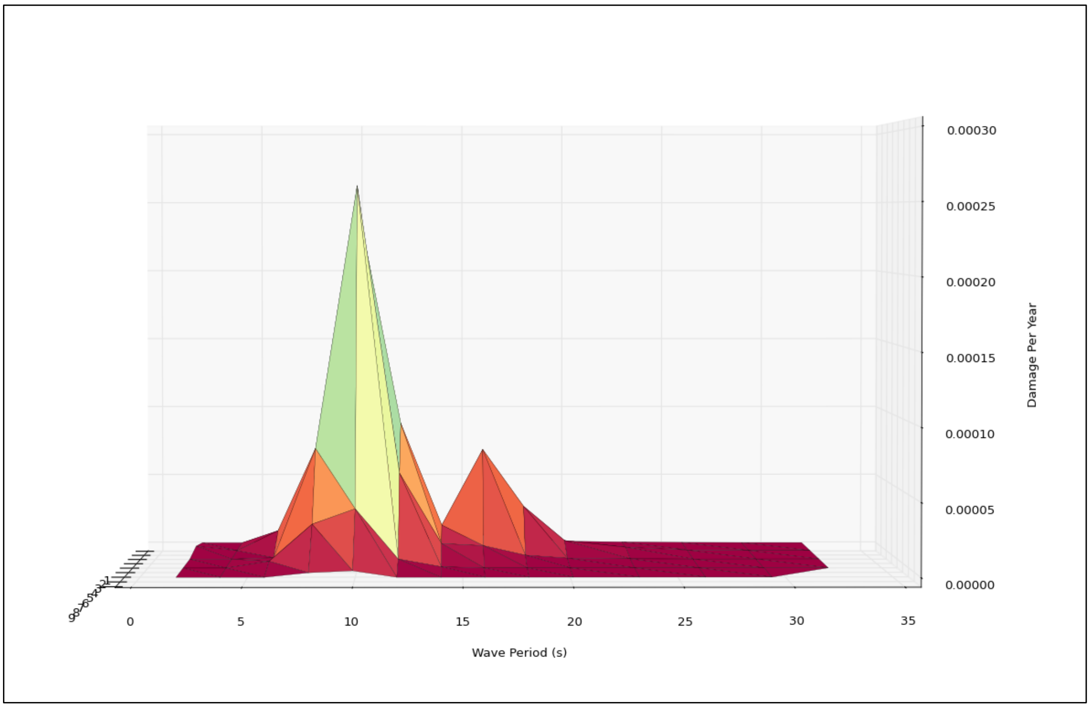

Figure 4-4 – Wave Period vs Damage

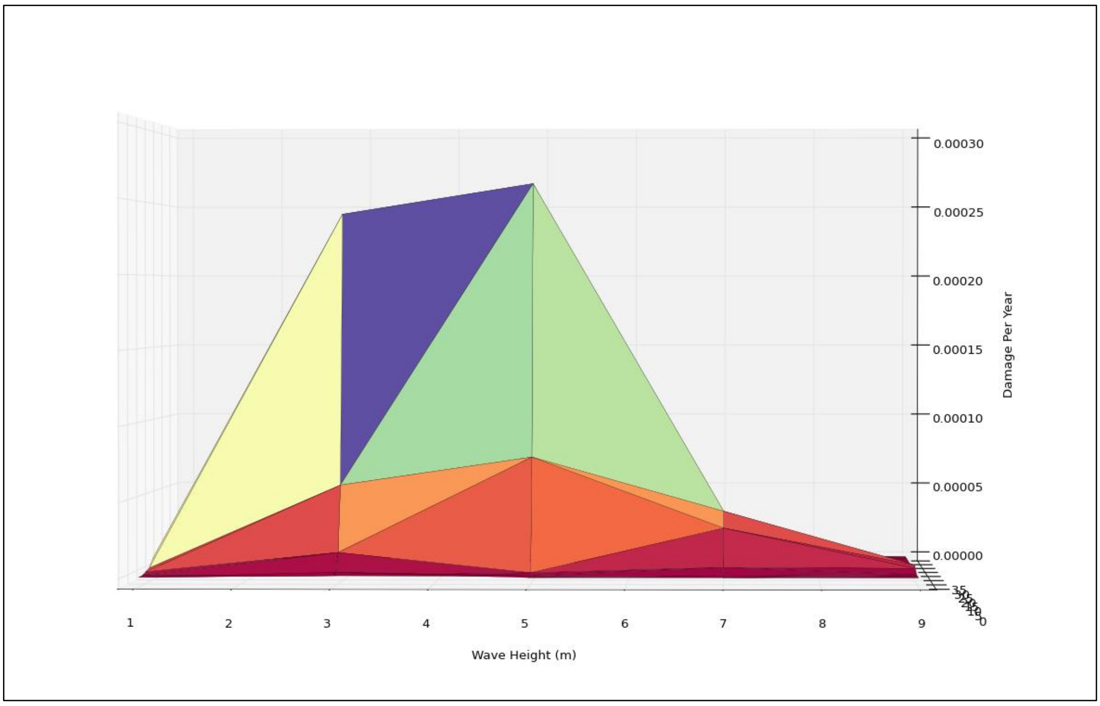

Figure 4-5 – Wave Height vs Damage

On closer inspection of the Orcaflex model, it appears that the large amount of damage associated with a period of 10s is due to a natural frequency of the hose. A modal analysis was carried out to determine the natural periods of the hose, which showed that the hose exhibits resonance at 10s for two separate orthogonal mode shapes; one parallel to the longitudinal axis of the vessel, the other transverse to it. The mode shape most likely to be excited is the one parallel to the vessel longitudinal axis as the wave heading is in the same direction; this is shown in Figure 4-6.

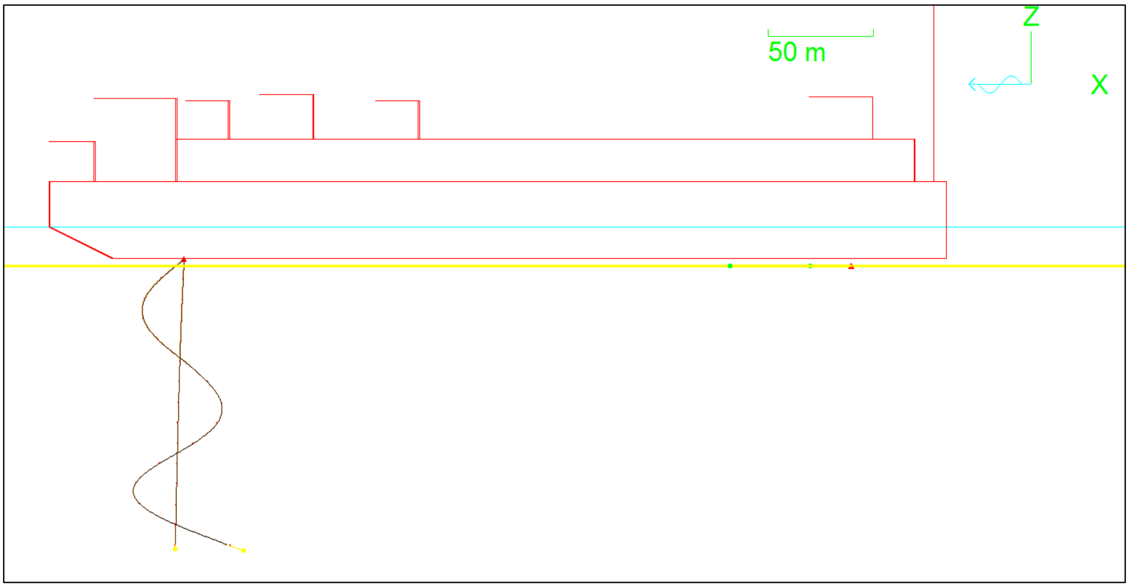

Figure 4-6 – Mode Shape 7, Inline Vibration

5 Conclusions and Recommendations

A fatigue analysis was carried out on a 135m length of EMSTEC bonded, flexible, 40” ID, cooling water suction hose deployed from an FLNG unit off the coast of Mozambique. The target life was 250 years i.e. 10 times the expected service life, as required by API 17K. The following can be noted:

- The minimum hose textile life was calculated to be 208E6 years.
- The minimum flange stud fatigue life was calculated to be 648E3 years.
- The minimum flange weld fatigue life was calculated to be 933 years.
- The hose stress factors were doubled to allow for uncertainties in the local analysis modelling. This is conservative but nevertheless resulted in an acceptable fatigue life. No such adjustments were made to the weld and fastener stress factors as there was more confidence in both the material models and the fatigue curves used.
- There is further conservatism in the textile fatigue results because the peak damage location in the Orcaflex model was taken right at the end connection point. In reality, the critical region of the textile is around 800mm away from the connection point where the fatigue damage is considerably less.
- As all the fatigue lives were acceptable, the hose is considered fit for purpose for the expected environmental conditions.
- It is recommended that specimen fatigue testing of the yarn and/or composite is conducted to give further confidence in the results.
- These results should be used with caution when considering alternative hose lengths or environmental conditions. With a length of 135m the hose has a natural period of 10s but changing the length or mass would change the hose’s natural period and therefore its response to the environment (for better or worse). It is therefore recommended that a fatigue assessment is undertaken for every specific location/configuration the hose may be used in.

6 References

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[3] 3D Model (Inventor), received by memory stick, 16-12-14.

[4] DNV-RP-C203, 'Fatigue Design of Offshore Steel Structures', October 2012.

[5] 'Cord Elongation Test C012 C014 B&A.xls', received from EMSTEC 23-01-15 by e-mail.

[6] Orcaflex Model, File 'basemodel100cyc.dat', received by memory stick, 16-12-14.

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[11] 'Tensile fatigue behaviour of PBO fibres', Davies, Bunsell and Chailleux, Journal of Materials Science, December 2010.

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[14] EMSTEC Data Book: 4130105/701147-DB-08, 23-04-13.

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[16] EMSTEC Drawing 53111.00002~2.C-0 Revision 0, 05-02-13.

[17] E-mail from Ian Craig to Martin Sharkey containing details of marine growth profile, 07-01-15

[18] 'Wave_climate&extremesTN022880.xls', received from EMSTEC 21-01-15 by e-mail.

Appendix A – RAO Plots

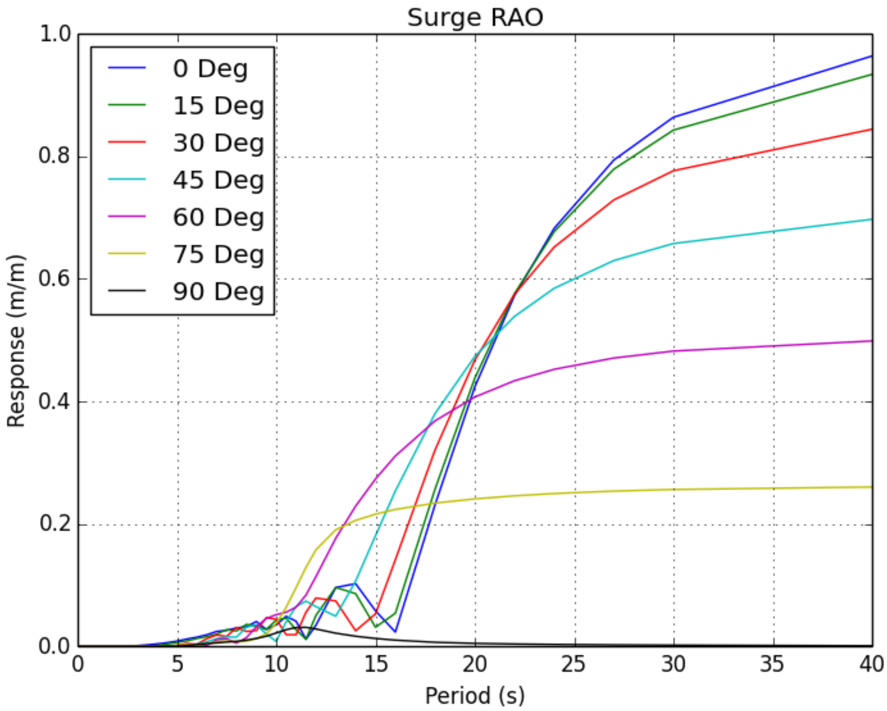

Figure A-1 – Surge RAO

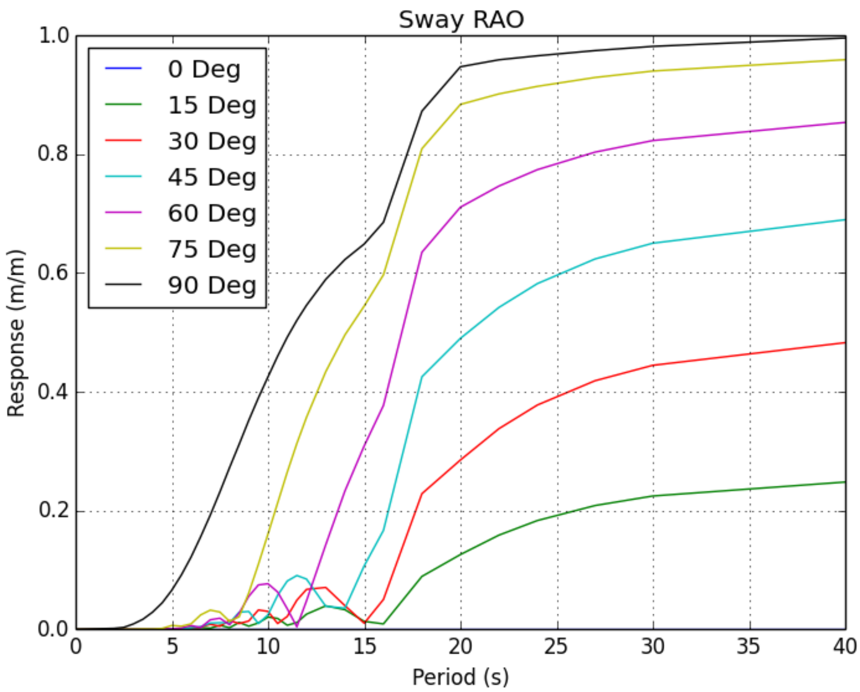

Figure A-2 – Sway RAO

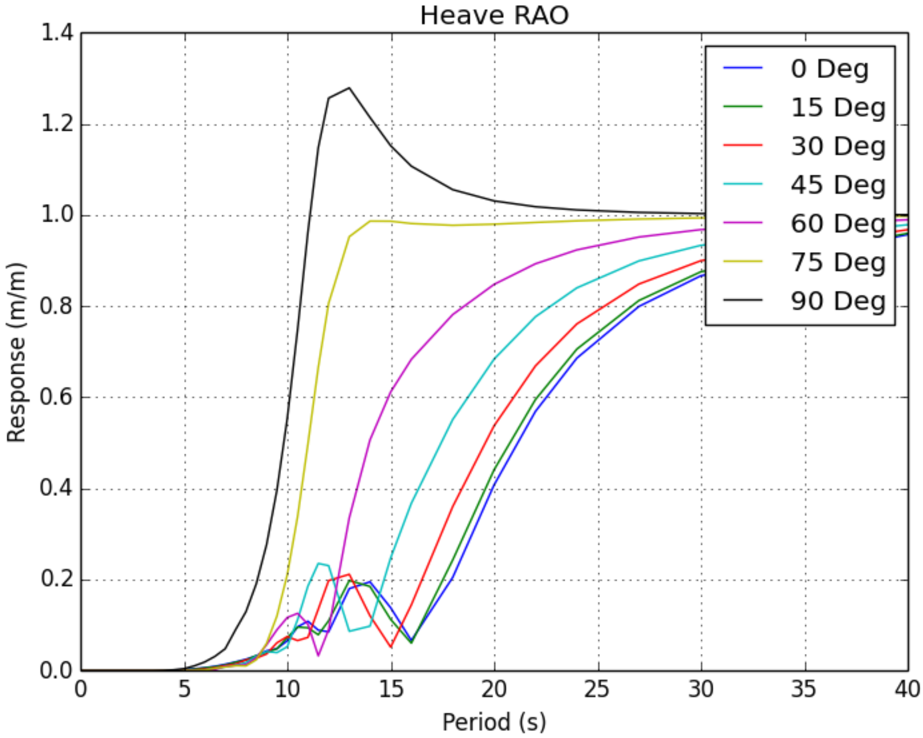

Figure A-3 – Heave RAO

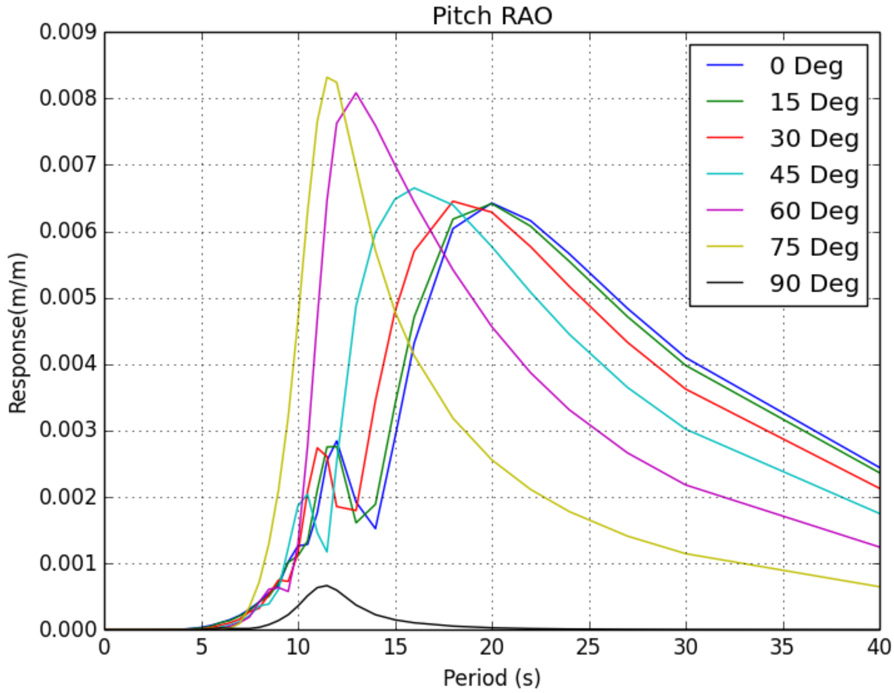

Figure A-4 – Pitch RAO

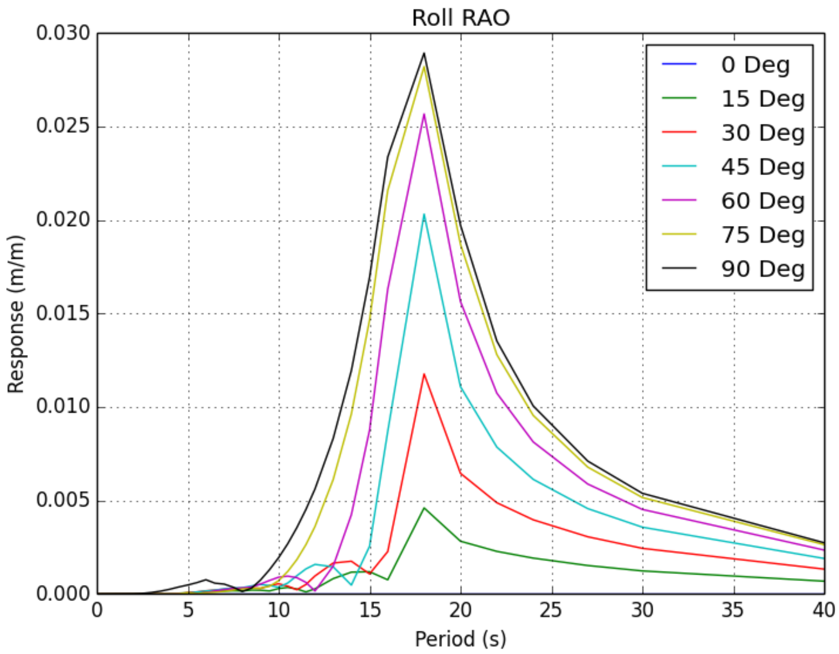

Figure A-5 – Roll RAO

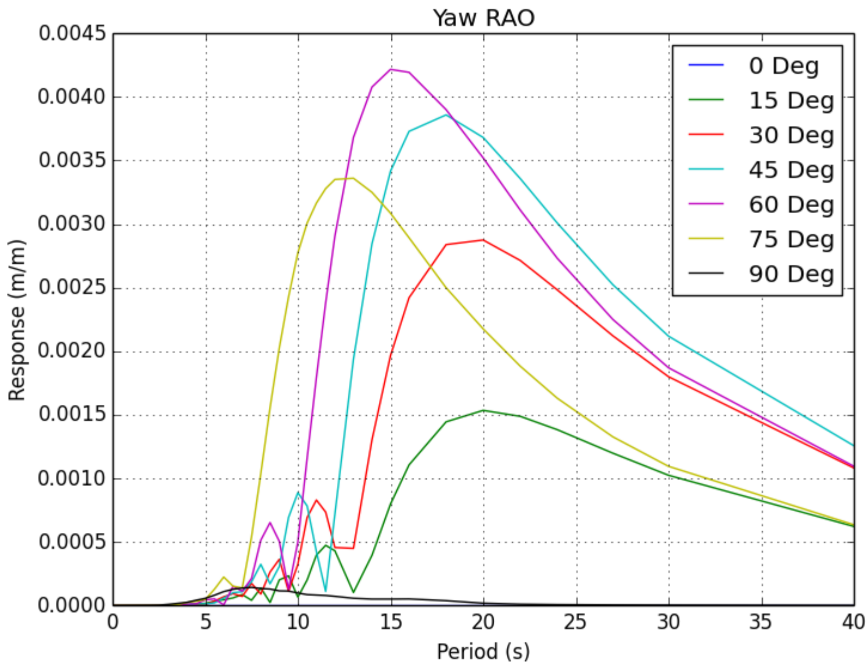

Figure A-6 – Yaw RAO

Appendix B – Hose Stiffness Sensitivity Study

The three fibre stiffness curves obtained from the local analysis were run for a nominal sea-state. The wave height was taken to be 5m with a period of 10s, which relates to the peak damage wave but is just an example. The curvature at the vessel connection was obtained for each of the three models; this can then be transformed into a yarn stress by using the appropriate stress factor for each curve. The sensitivity study showed that the 300% case was the worst, see Figure B-1, and so this stiffness curve was used in all hose analyses in order to be conservative.

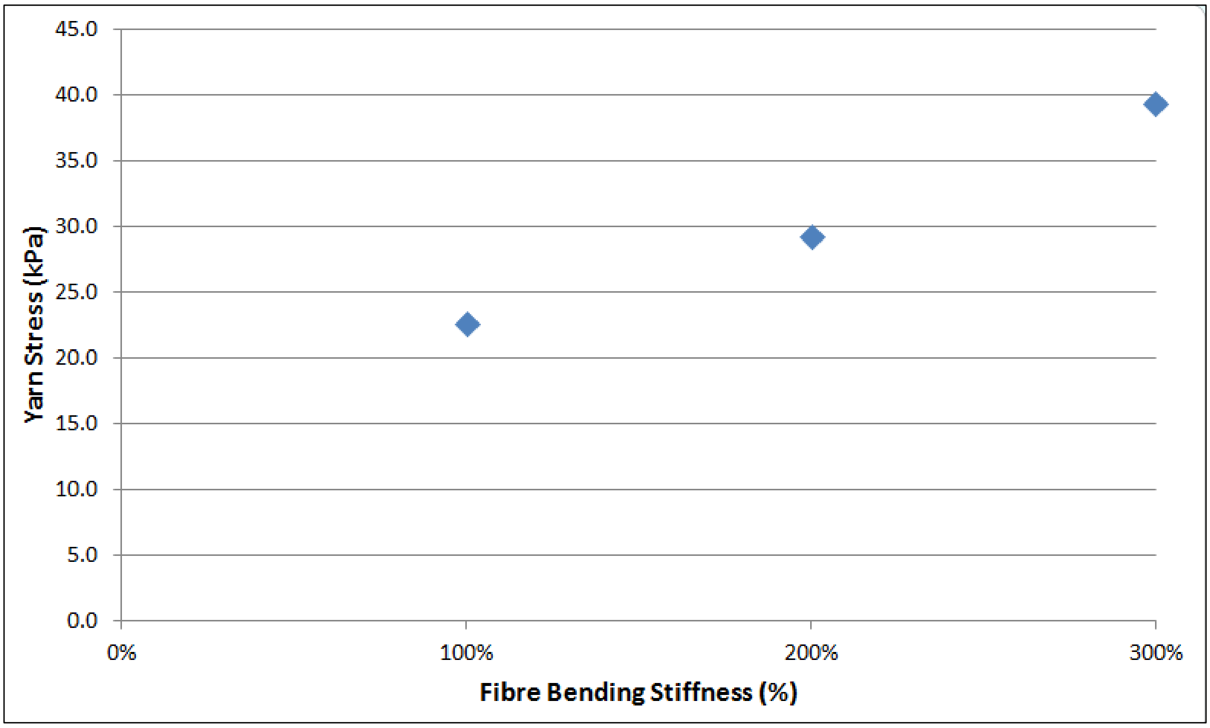

Figure B-1 – Hose Stiffness Sensitivity Results

PDL	**PDL Solutions (Europe) Ltd.** 1 Tanners Yard Hexham Northumberland NE46 3NY **Tel :** +44 (0) 1 434 609 473 **Fax :** +44 (0) 1 434 606 292 **www.pdl-group.com**	**Technical Report** 40" Suction Hose with Steel Reinforcement Fatigue Assessment Local Analysis

Report Number:	PDL-EMS-727-001 (1)	**Project:**	40" Suction Hose Fatigue
Customer:	EMSTEC	**PDL Job No:**	727
Contact:	Ian Craig	**Quote Ref:**	SQDU-152 (1)

Technical Report

Abstract:	This document details the results of the local analyses undertaken in support of the fatigue assessment of the EMSTEC 40” cooling water suction hose with steel reinforcement which accounts for the geometry and material property modifications of the hose model created under SQDU-141(3) [1]. All model setups and simplifications are detailed. The necessary inputs, load case definitions and assumptions are also described. The purpose of this document is to give a detailed description of the analysis work and the associated results. The key outputs were hose axial and bending stiffnesses and hose stress factors for use in the fatigue assessment conducted in Orcaflex and reported in PDL-EMS-727-002 [2]. The hose textile material consists of a steel wire/rubber matrix which reinforces the rubber hose. The metal parts of the flanged joint were considered previously in PDL-EMS-667-003 [3].

Revision History

1	21-10-2015	First issue	CHF	RAF	DCU
Rev	**Date**	**Reason for change**	**Author**	**PDL Review**	**PDL Approval**

Table of Contents

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1 Introduction

This report describes the steps taken in the local analysis of an EMSTEC 40” cooling water suction hose with steel reinforcement which accounts for the geometry and material property modifications of the hose which were specified previously under SQDU-141(3) [1]. The main outputs of the analysis were the hose axial and bending stiffnesses and the hose axial and bending stress factors both for use in the fatigue assessment conducted in Orcaflex and reported separately in PDL-EMS-727-002 [2]. The steel/rubber composite reinforcement was considered in detail. The metal parts of the flanged joint were considered previously in PDL-EMS-667-003 [3].

EMSTEC intend for the hose to comply with the fatigue requirements of API 17K ‘Specification for Bonded Flexible Pipe’ (co-branded as BS EN ISO 13628-10) although it is recognised that this standard is not strictly intended to be used for suction hoses.

As part of the requirements for compliance with API 17K, all bonded flexible hoses must show suitable fatigue life under expected operating conditions. In order to verify that the EMSTEC suction hose complies with this requirement, PDL Solutions (Europe) was contracted to undertake a full fatigue analysis for a total hose length of 135m. Each section of hose is 9m long with steel flanges at either end so 15-off hose sections are required to make up the 135m total length. There is also a strainer at the open end of the hose. For compliance with API 17K, the suction hose must have a fatigue life of more than ten times the service life, which in this case means the calculated minimum life should exceed 250yrs.

2 Objectives

The purpose of this report is to outline the input data that was used in the local analysis, to record how some of the material properties were generated and to detail the results.

Briefly, the local analysis comprised of the finite element (FE) analysis, conducted in ANSYS APDL, of two simplified models were used to calculate the axial and bending stiffnesses and the axial and bending stress in the central hose section for use in the global analysis [2]. For the reinforcement, the scale factor between the peak stress in the end fitting region and the stress in the central region of the hose, from the previous analysis [3], was applied to the calculated hose stresses from the central section of the present analysis to calculate the peak stress in the end fitting region. This scaling was done in a conservative manner and a factor of 3.0 was adopted. The most highly stressed region of the reinforcement is close to its termination, local to the steel rings of the end fitting. The stress factors generated in this way were then used in Orcaflex to calculate the fatigue life. The two models used are described below:

1. A FE bend sector model of 1.68m of the hose (includes eight steel rings along the continuous hose section i.e. inboard of the end fitting). This model was subjected to a bending moment induced by a prescribed rotation at the end face.
2. An FE axial sector model of 1.68m of the hose (includes eight steel rings along the continuous hose section i.e. inboard of the end fitting). This model was subjected to a tension case where the axial load was applied as a displacement.

To complete the global analysis the stress factors for the flange weld and fasteners were taken from report PDL-EMS-667-003 [3].

3 Local Analysis Methodology – Sector Hose Model

3.1.1 Geometry Changes from Model Used In PDL-EMS-667-003 [3]

The hose CAD model supplied by EMSTEC [4] which was used previously in PDL-EMS-667-003 [3] was modified to account for the geometry changes in the composite. The changes are recorded below and shown in Figure 3-1.

- Following discussions with EMSTEC, the composite layer changed along the full length of the hose from 10 x 1.6mm layers in each of the two layups, giving a total thickness of 32mm, to 3 x 2mm layers in each of the two layups giving a total thickness of 12mm. Hence the outside diameter (OD) away from the end fitting changed from 1.22m to 1.18m (new dimension shown in Figure 3-1).

- Across the full length of the hose there are six layers where the angle of the drawn steel cords are +/-40^{o} to the hose longitudinal axis; these are known as 'D layers'. Within each layer, the cords are parallel and embedded into a rubber sheet.

The main features which remained unchanged in the sector model are described below with the actual thicknesses taken from the CAD model supplied by EMSTEC [4]. Please note that any geometry exclusive to the end fitting has not been described, as this section was not modelled in the present work. The end fitting in Figure 3-1 is used for illustrative purposes for the different components.

The inside layer of the hose is a 'wear liner' which extends along the full length of the hose; it has a constant thickness away from the end fitting.

The textile layers are reinforced by a set of 30mm diameter steel rings pitched at 210mm along the length of the hose with the first one located as shown in Figure 3-1. The rings are embedded in a layer of 'filler rubber' which is outside the wear liner but inside the textile layers.

There is a further layer of filler rubber outside of the textile layers which has a constant thickness away from the end fitting.

The outermost layer is a 'cover rubber' and this extends along the full length of the hose at a constant thickness away from the end fitting.

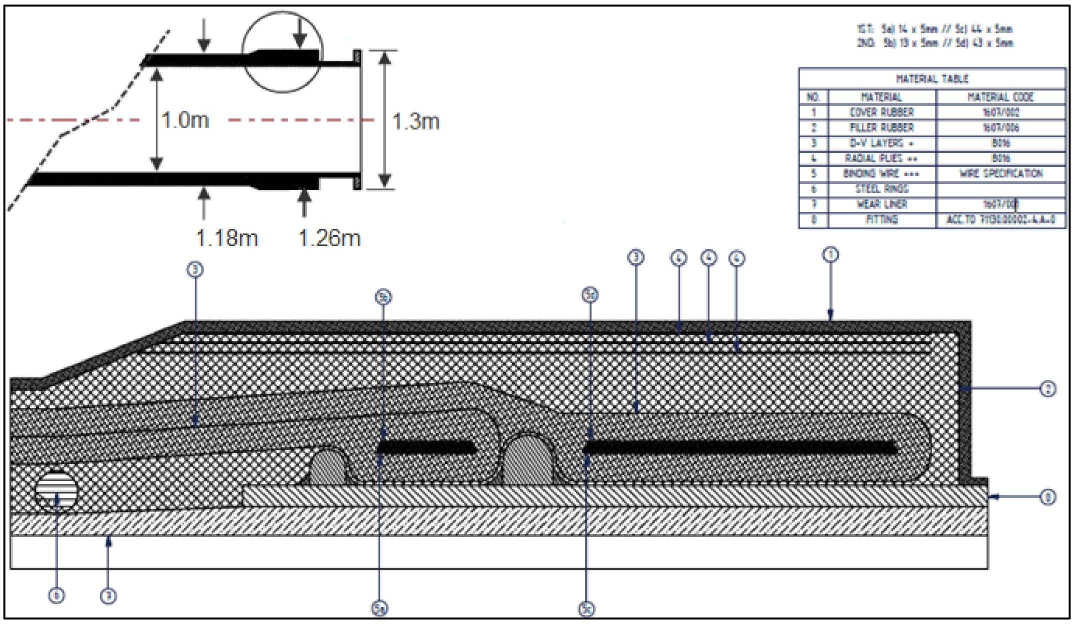

Figure 3-1 – Hose Geometry [1] (dimensions modified to suit new geometry)

3.1.2 Model Simplifications

The geometry of the model was simplified in order to aid meshing. The simplifications were as follows, see also Figure 3-2 and Figure 3-3:

- Two models were used for the axial and bending tests; they used the same geometry with different boundary conditions. A sensitivity study on the number of sectors used was carried out for both models and it was proven that eight sectors (1.68m) would provide reliable results. The two hose models were modelled as a 1.68m sector which included the geometry of eight steel rings. Each steel ring (pink sections Figure 3-3) was squared off and represented as a rectangular body; this was to simplify the model meshing process.

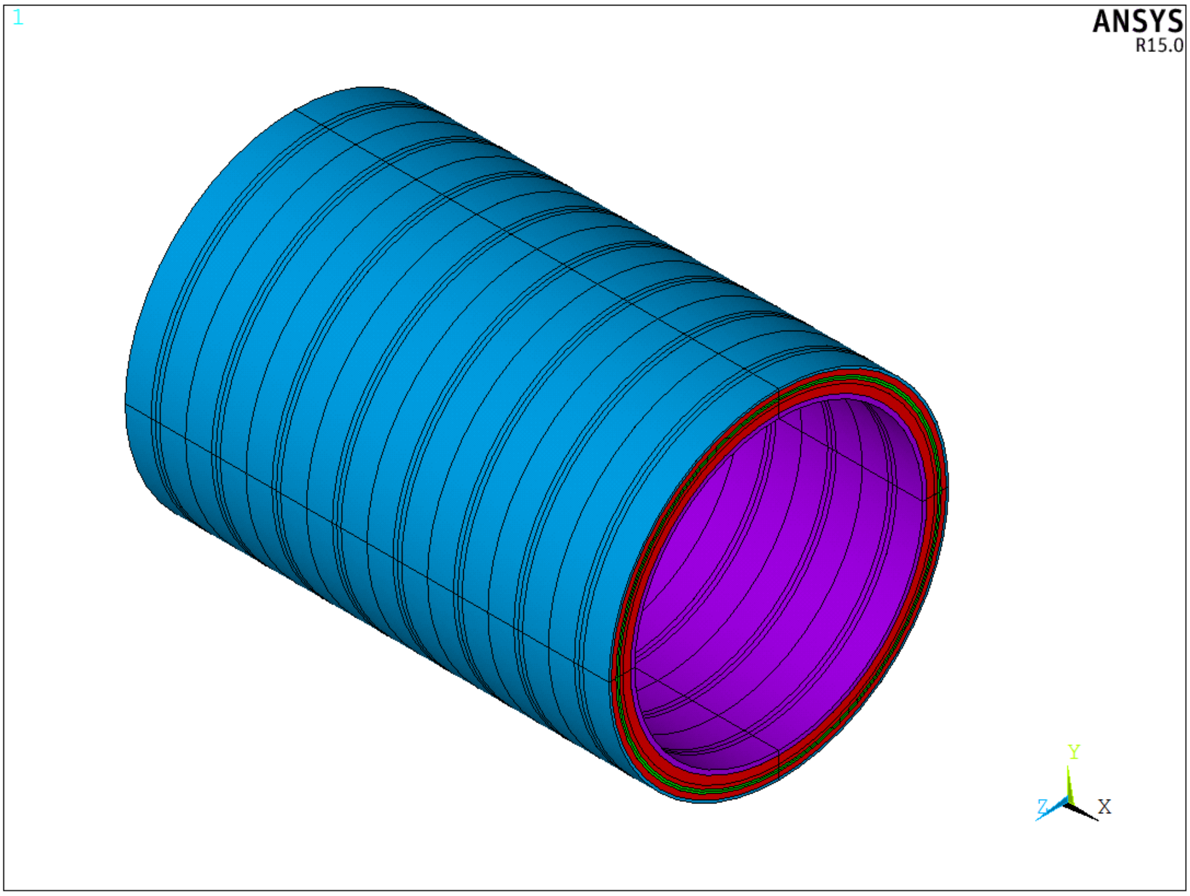

Figure 3-2 – Sector geometry for both Bend and Axial FE Analyses

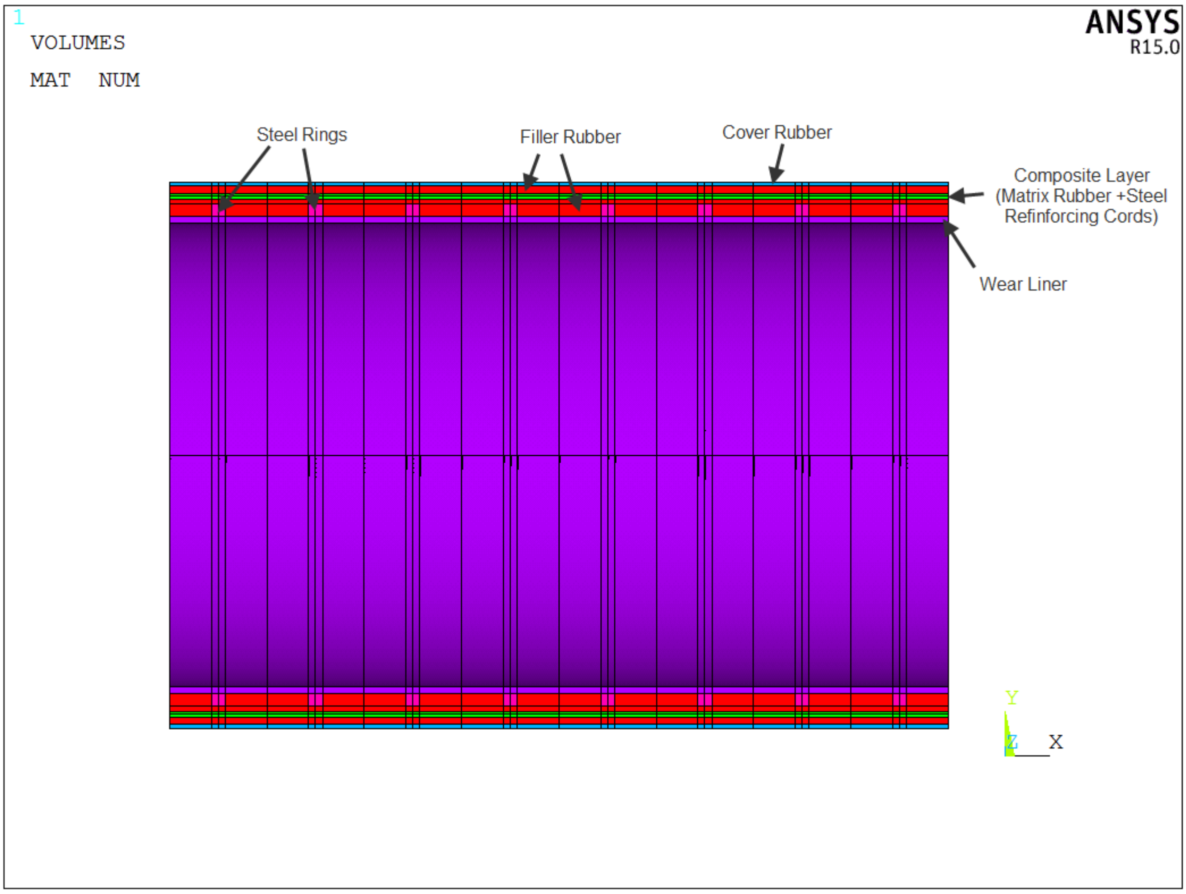

Figure 3-3 – Sector geometry for both Bend and Axial FE Analyses (section view)

3.2 Coordinate System

The global Cartesian coordinate system is shown at the bottom right corner of Figure 3-2 and Figure 3-3. Ox acts axially, Oy acts vertically and Oz acts normal to the XY plane. All loads and boundary conditions were specified with respect to this coordinate system.

3.3 Material Data

This section shows the material data that was used to develop the material models for the various hose components.

It is recognised that the stress-strain curve for rubber is typically non-linear, therefore the empirical equation used to create the stress-strain curves for the various rubbers was:

$$F = M(L^{-1} - L^{-2})expA(L - L^{-1}) \quad [5]$$

F is the stress based on the original-cross sectional area, and L is the ratio of stressed to unstressed length, M is the slope of the stress strain curve at L=1 and A normally has a value close to 0.38 [5]. The curves used assumed the ASTM D1415 derived Young's Modulus [6] is a stress value taken from the stress strain curve at 100% strain as this is one of the most commonly used points [7]. The material properties used to generate the nonlinear rubber curves are given in Table 1. The curves are shown below for Cover Rubber, Filler Rubber, Wear Liner and Matrix Rubber respectively. Linear elastic steel material data is also given in Table 1.

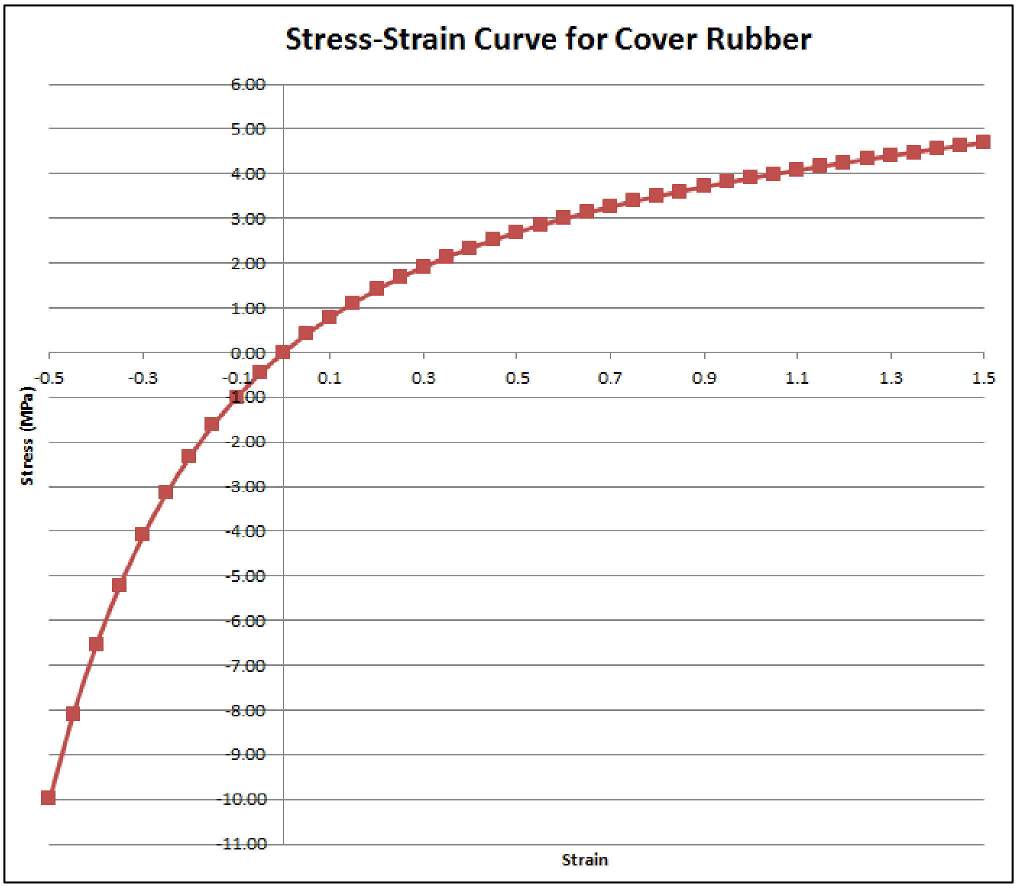

Figure 3-4 – Stress Strain Curve for Cover Rubber

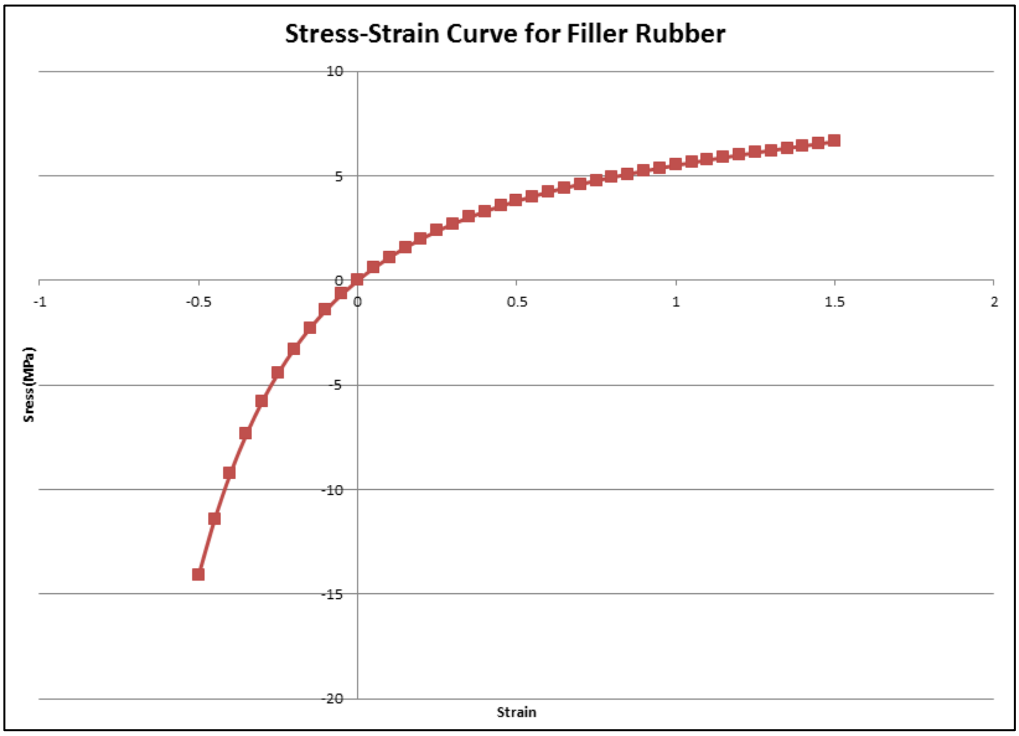

Figure 3-5 – Stress Strain Curve for Filler Rubber

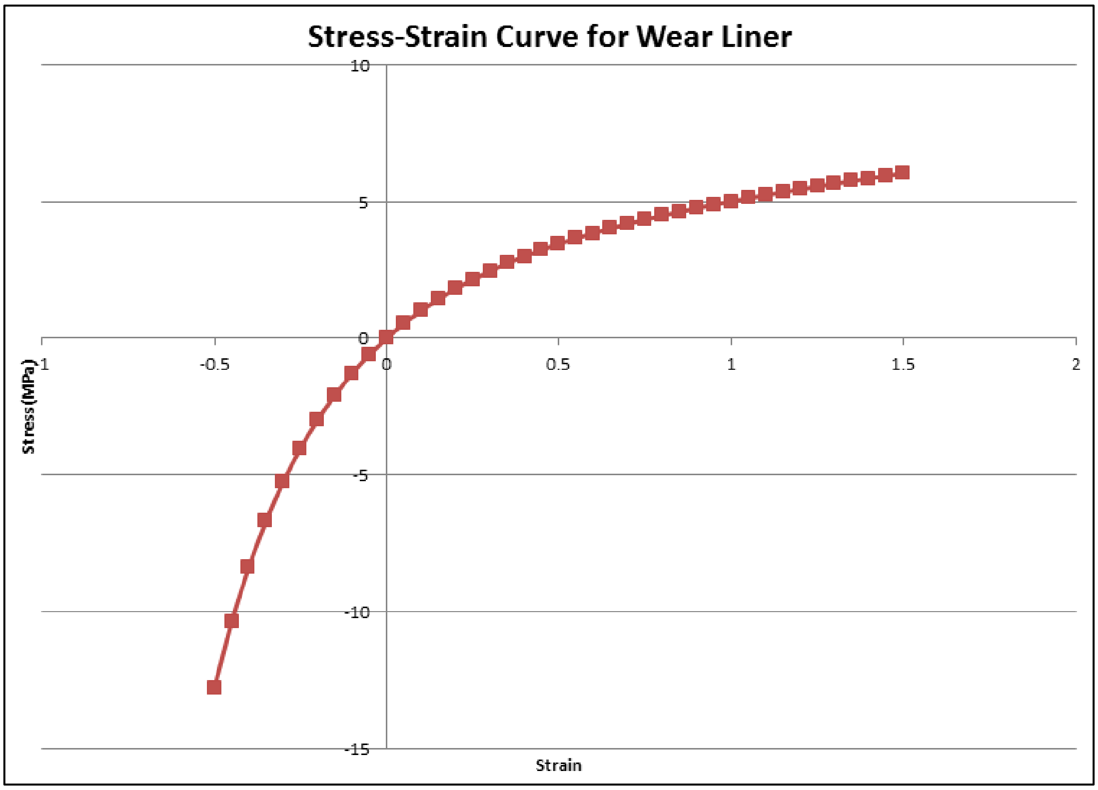

Figure 3-6 – Stress Strain Curve for Wear Liner

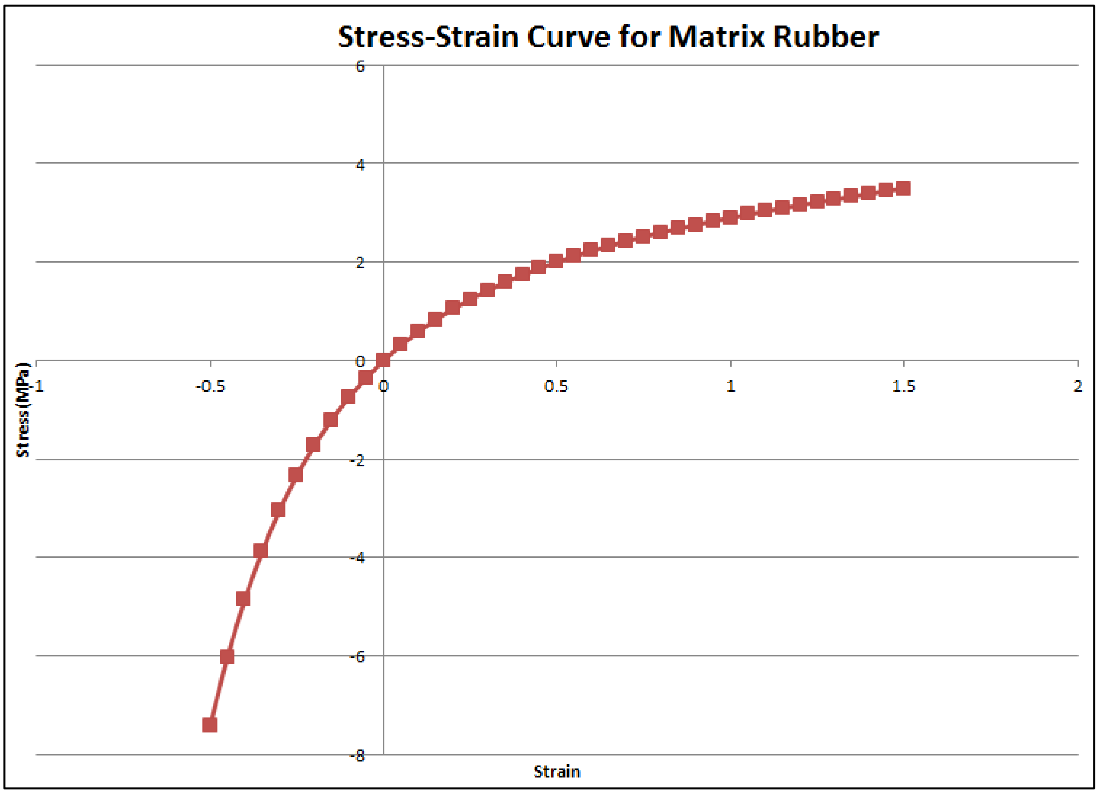

Figure 3-7 – Stress Strain Curve for Matrix Rubber

Material	Young's Modulus (MPa)	Poisson's Ratio	Density (g/cm^3)
Steel (Rings)	207,000[1]	0.3[1]	7.85[1]
Cover rubber – 1607/002 – Shore A hardness = 62	3.9[3]	0.5[2]	1.23 [8]
Filler rubber – 1607/006 – Shore A hardness = 70	5.5[3]	0.5[2]	1.38 [9]
Wear liner – 1607/001 – Shore A hardness = 68	5.0[3]	0.5[2]	1.16 [10]
Composite calendaring rubber (matrix rubber) – Y003A – Shore A hardness = 55	2.9[3]	0.5[2]	1.26 [11]

Table 3-1 – Isotropic Material Data

1 – Standard values for steel.
2 – 0.5 is the standard value for rubber; the FE models will use 0.49 to aid convergence.
3 – Values derived from ASTM D 1415-88 [12], given that the Shore A hardness is similar to the IRHD (International Rubber Hardness Degrees) hardness used by ASTM.

The wire strand is in the form of a cord made up of a number (19-off [13]) drawn steel fibres helically wound together. The steel cord was assumed to be isotropic. The element type used (section 3.4) to model the embedded steel cord required the Young's Modulus to be defined. The steel cord Young's Modulus data was calculated in Appendix A and the value is given below in Table 2. The poisson's ratio is insignificant in this element type as it is a smeared reinforcing element (described in detail in section 3.4) so the default value of 0.3 was used.

Material	Estimated Young's Modulus (MPa)	Density (g/cm^3)
Steel Cord	148,000	7.85[1]

Table 3-2 – Steel Cord Material Data

3.4 Meshing

To model the composite layers firstly, 3D 8-Node structural solid elements (SOLSH190) were used for the matrix rubber within the composite. The steel cords within the matrix rubber were then modelled using 3D smeared reinforcing elements (REINF265) which were laid up in 6 layers using +/-40^o fibre orientation on alternate layers. The cord's cross sectional area, pitch (60 cords per 10cm [14]) and Young's modulus from section 3.3 were also defined. This element type gives good accuracy for the steel cord in bending applications as it has an option to allow tension only in the reinforcing fibres which results in no stiffness in compression. In reality, at the onset of bending, the steel cord may carry some load on the compressive side of the hose but this would be small (because of the tendency to buckle) and was assumed to be negligible. It is worth noting that there is slightly more matrix rubber modelled than in reality as the steel cords are smeared elements i.e. they were not physically modelled. The effect of this approximation is expected to be minimal.

All other components were generated using 3D 8-Node structural solid elements (SOLSH190); in this configuration the elements behave as first order brick elements. The mesh was swept around the circumference for all regions that were hoop continuous. A sensitivity study on the mesh density was carried out for both models. It was proven a mesh size of 15mm in the axial direction would give reliable results.

Figure 3-8 to Figure 3-12 show images of the finite element model meshes including a detailed image of the layup of the D layers. The angular layup orientations as defined in the analysis software are shown in Figure 3-13. Details of the mesh size are described in Table 3 and Table 4.

Mesh Detail	Value
Number of Nodes	50,974
Number of Elements	54,180
Number of Element divisions through Hose thickness	10
Number of Element divisions around Bend Hose circumference	40
Element Edge Size in Axial Direction (mm)	15

Table 3-3 – Bending Hose Sector Model – Mesh Size Details

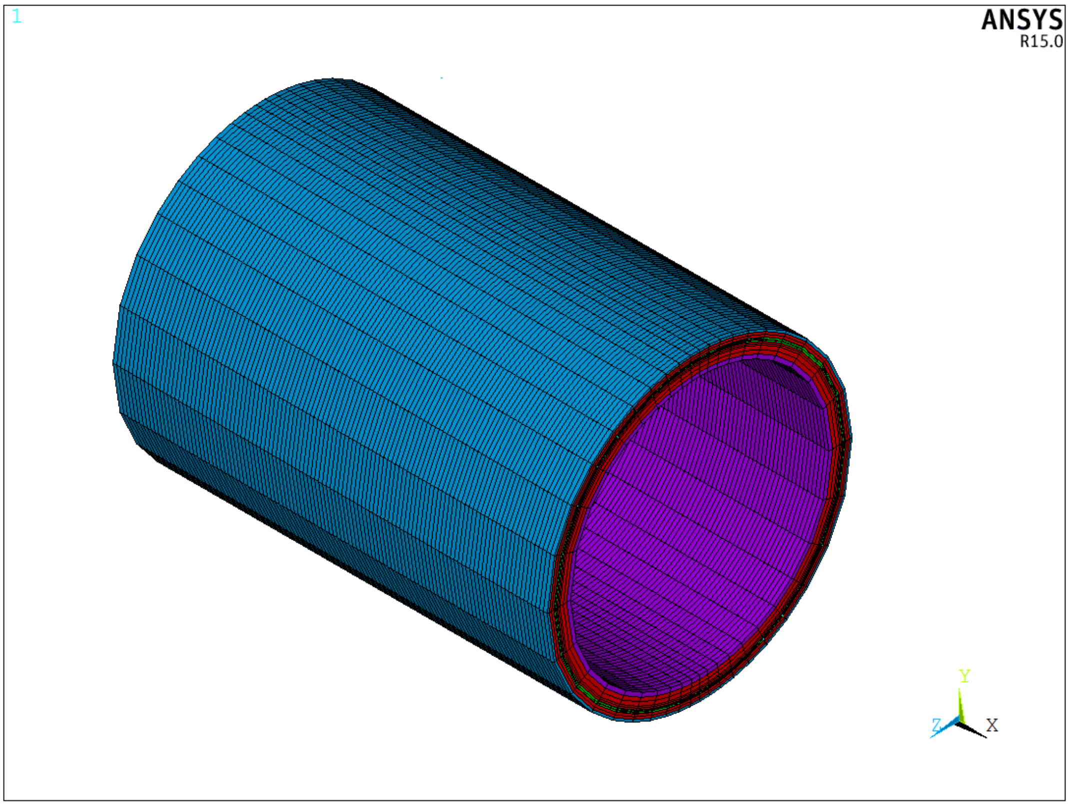

Figure 3-8 – Bending Sector Model, Model Mesh for FE Analysis – External View

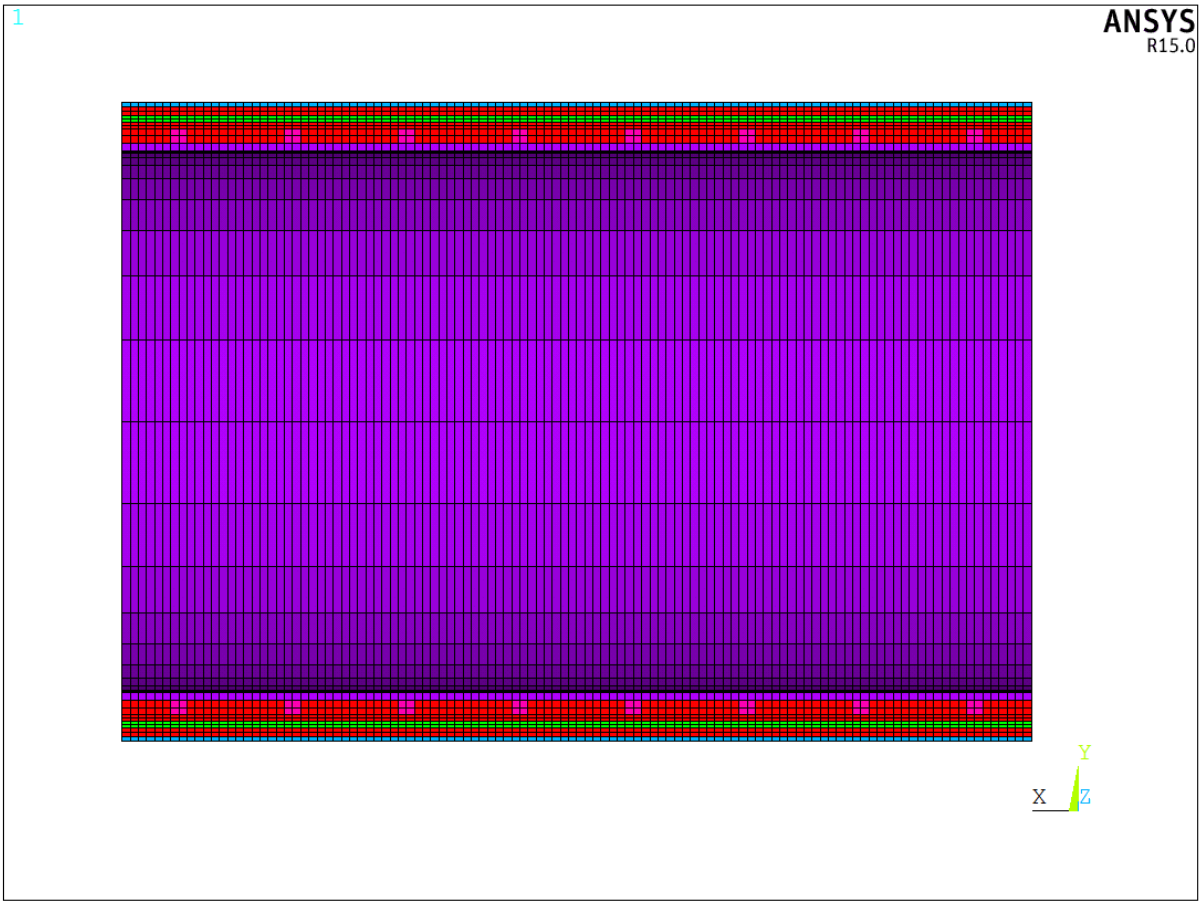

Figure 3-9 – Bending Sector Model, Model Mesh for FE Analysis – Section View

Mesh Detail	Value
Number of Nodes	149,167
Number of Elements	161,299
Number of Element divisions through Hose thickness	10
Number of Element divisions around Hose circumference	120
Element Edge Size in Axial Direction (mm)	15

Table 3-4 – Axial Pull Hose Sector Model – Mesh Size Details

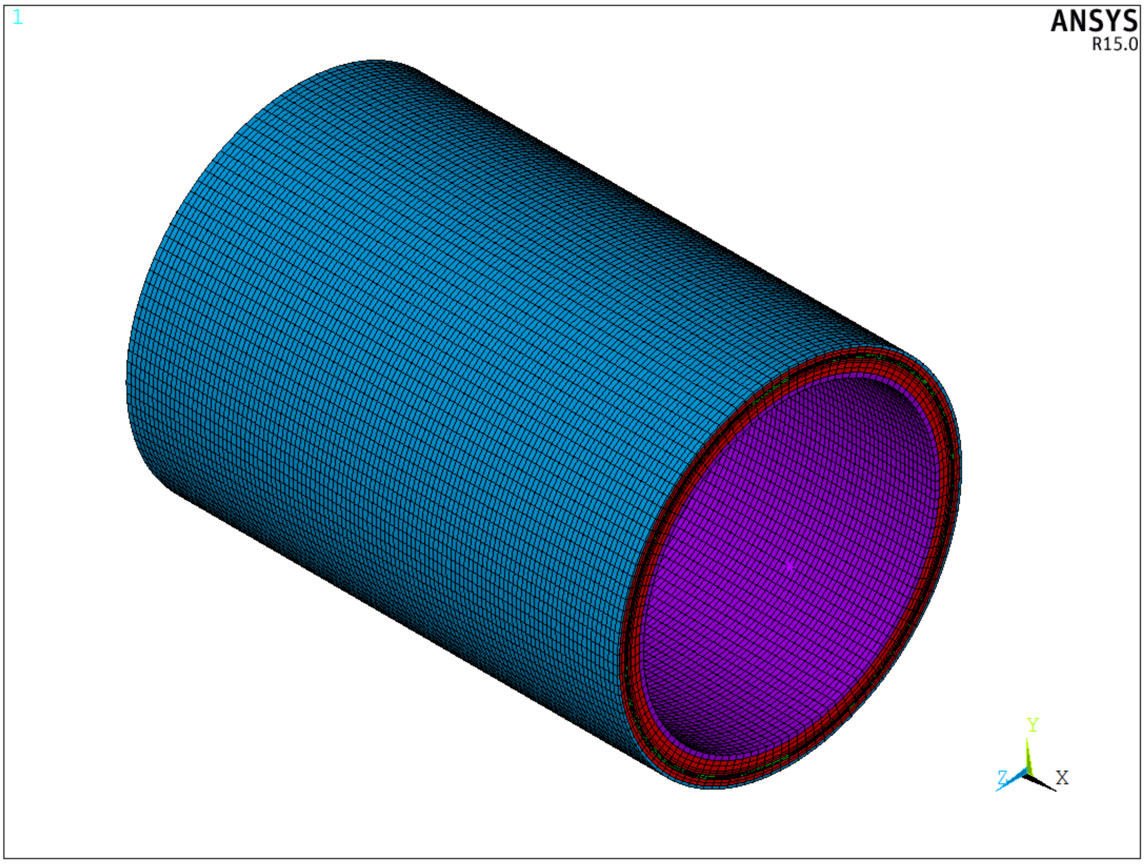

Figure 3-10 – Axial Pull Sector Model, Model Mesh for FE Analysis – External View

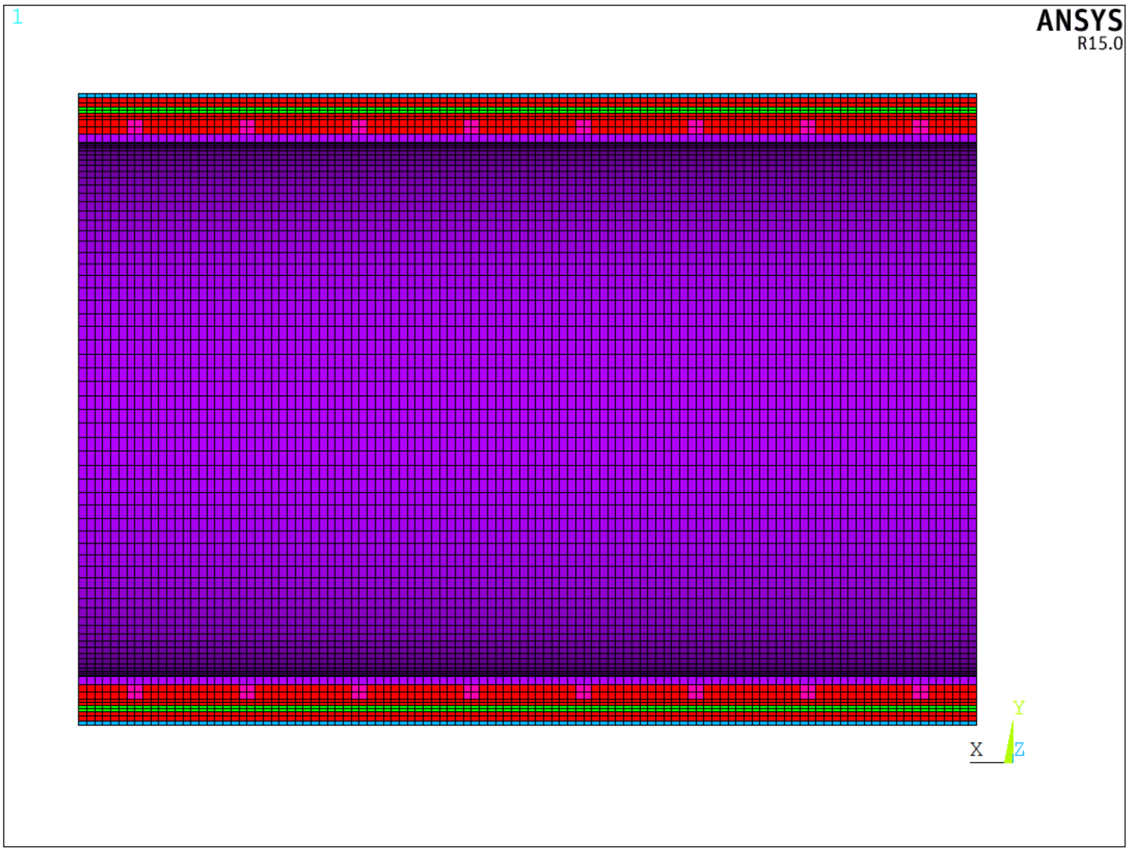

Figure 3-11 – Axial Pull Sector Model, Model Mesh for FE Analysis – Section View

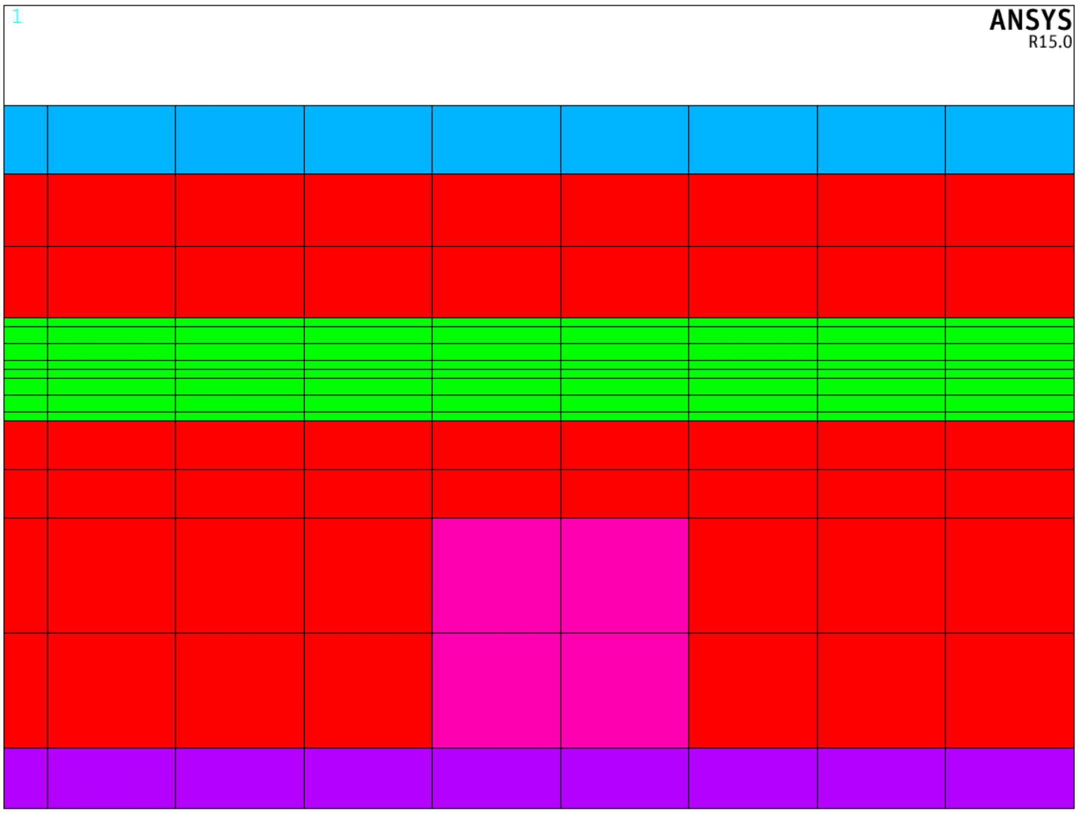

Figure 3-12 – Model Mesh for FE Analysis – Detail View

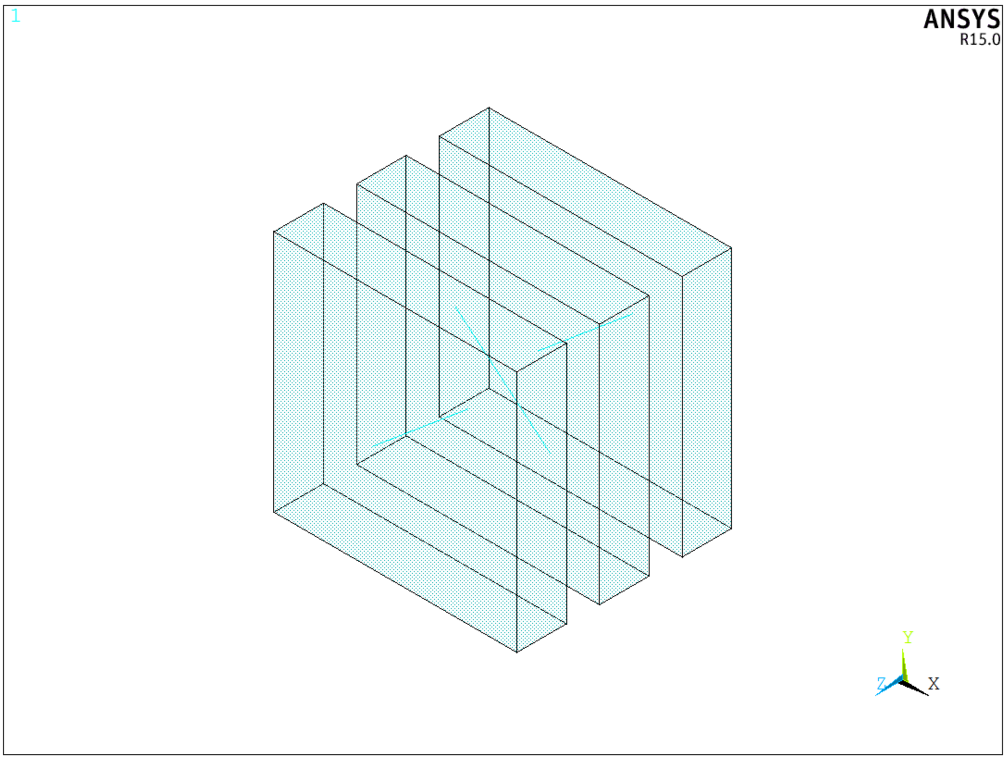

Figure 3-13 – Details of D-Layer Stacking Orientations for One Layup

3.5 Contact

A continuous mesh was defined between all materials throughout the hose; it was assumed that the process of autoclaving the hose makes this assumption realistic i.e. that it is fully bonded.

3.6 Boundary Conditions

For the bend load case, a rigid plane was defined at the end of the section which was connected to the section end face via a pilot node, which was where the rotations where applied about the Z axis (ROTZ). The pilot node was fixed in UY (deflection in the Y direction), UZ and ROTY degrees of freedom (DOFs). The nodes on the symmetry plane were constrained using a cylindrical coordinate system at X=0 and were fixed axially and tangentially. The boundary conditions are shown in Figure 3-14. For the axial pull load case, a pilot node was defined at the end of the section and was connected to the section end face via rigid constraint equations; this is where the axial displacement was applied in UX. The nodes on the symmetry plane at X=0 were fixed in UX and the pilot node was fixed in UY. The boundary conditions are shown in Figure 3-15.

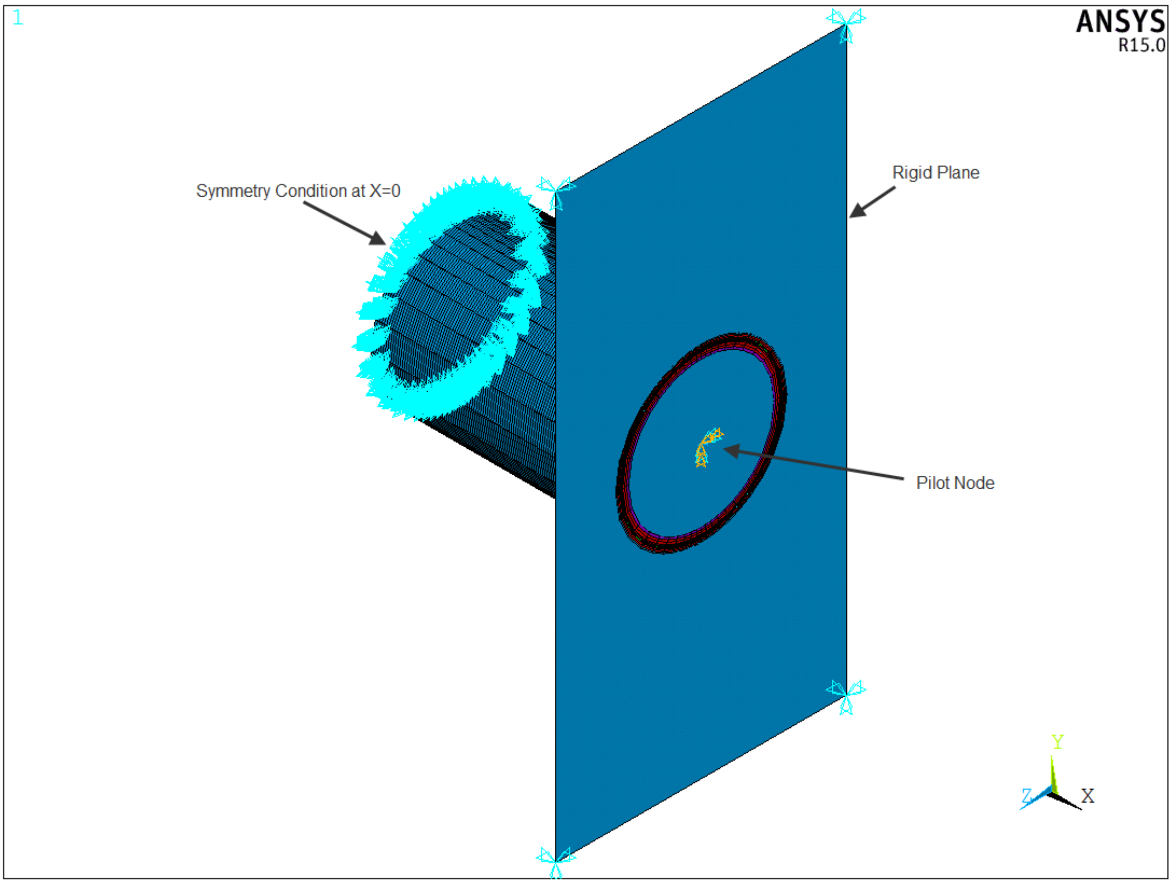

Figure 3-14 – Bending Sector Model – Boundary Conditions

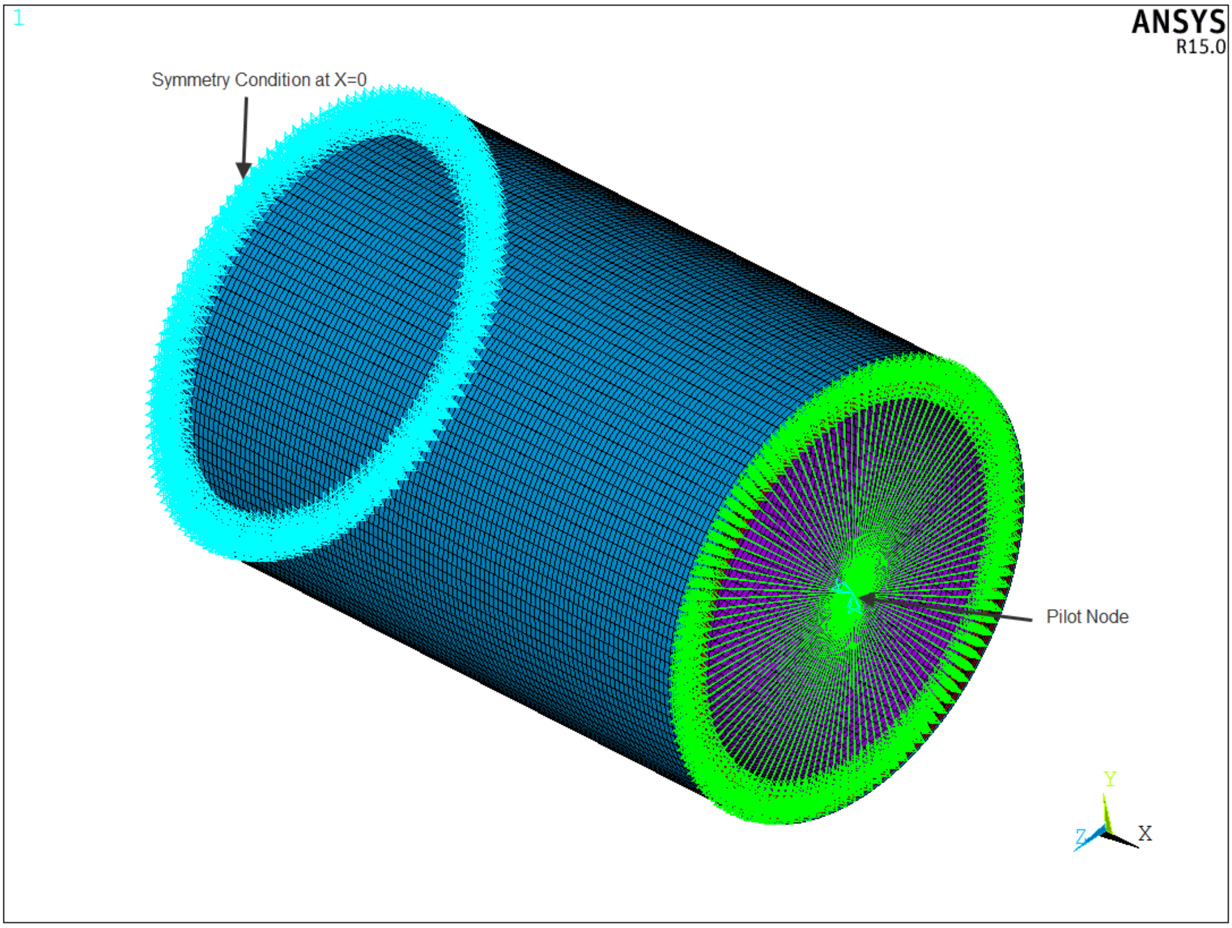

Figure 3-15 – Axial Pull Sector Model – Boundary Conditions

4 Local Analysis Results – Sector Hose Model

Previously in [3] a hydrostatic pressure test case was used to calibrate the FE model's material properties against test data in terms of the amount of axial extension observed. For bending, a calibration load case was used to replicate a 7.2m bend radius and the corresponding bend stiffness was compared against measured data. Such test data was not available for the new specification of hose detailed in this report.

4.1 Stiffness

4.1.1 Bending Stiffness Test - Bending Moment vs Curvature

Contour plots of resultant deformation and maximum principal stress at the final converged time point are shown in Figure 4-1 and Figure 4-5 respectively. The resultant deformation plot is in reference to the global coordinate system, the maximum resultant displacement was 66.9mm. Buckling occurs on the compression side of the hose; buckling is a phenomenon which typically reduces the stability of a finite element model and results in non-convergence. The model converged far enough to give accurate data for the range of curvatures required for the fatigue assessment [2].

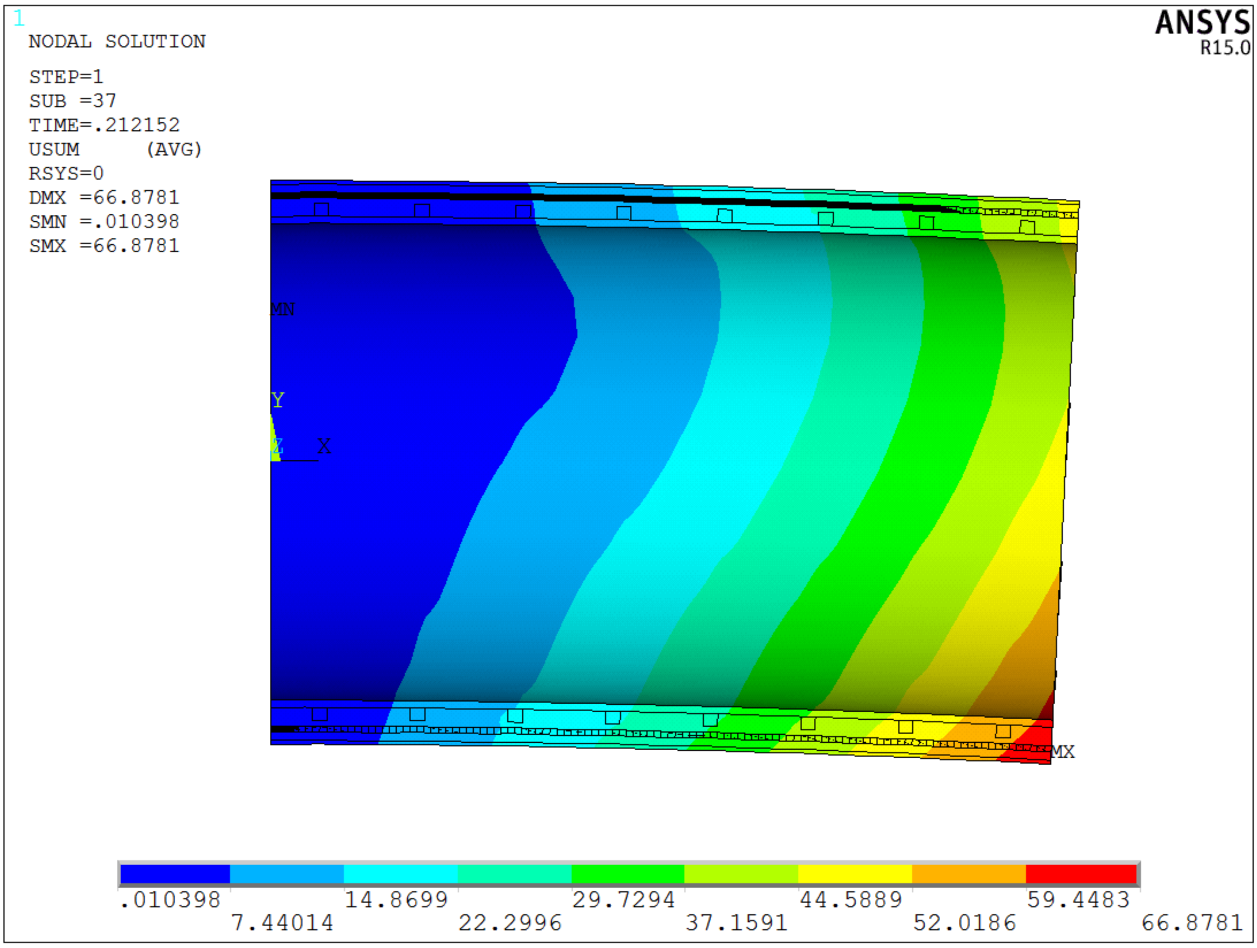

Figure 4-1 – Bend Stiffness Test– Resultant Displacement (mm) at last converged step (section view)

The bending stiffness extracted for use in the global Orcaflex analysis is shown graphically in Figure 4-2. The graph is used for the global Oraflex model.

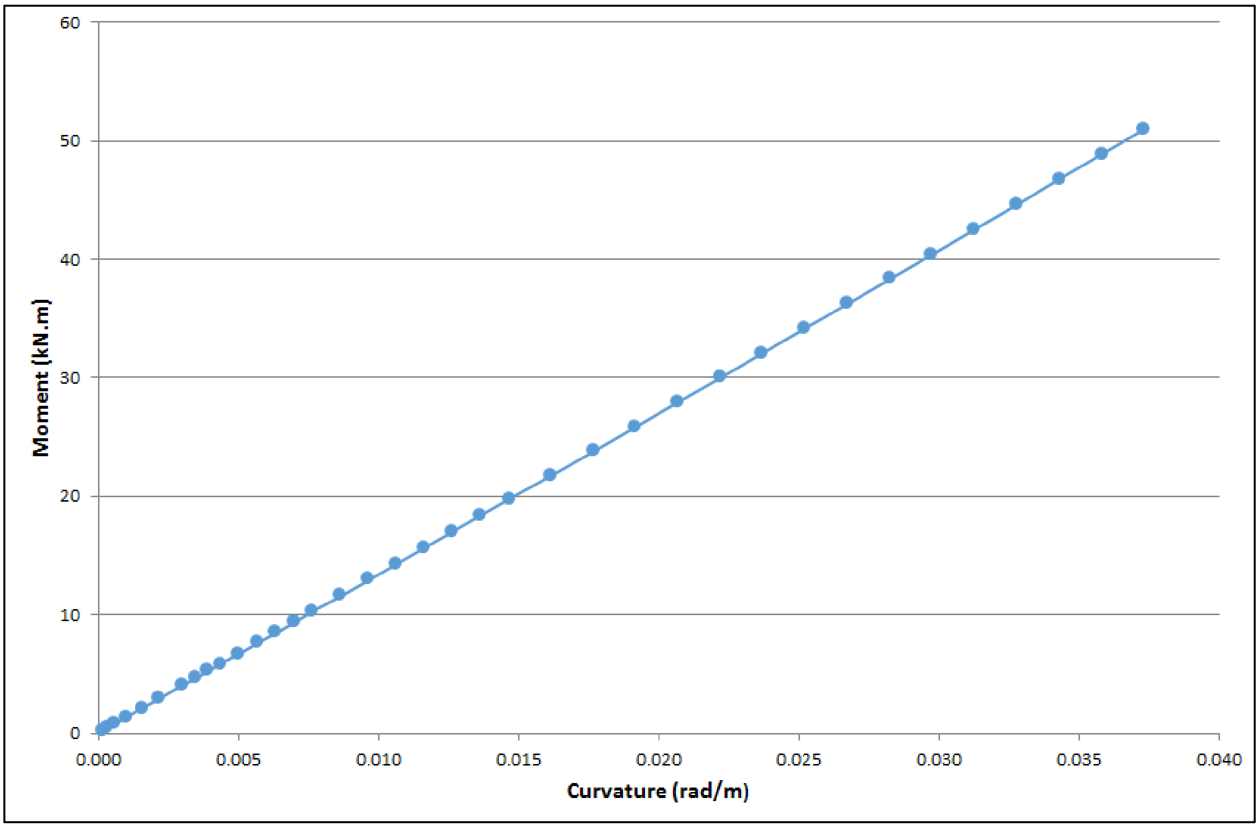

Figure 4-2 – Bending Stiffness Curve – Bending Moment vs Curvature

4.1.2 Axial Stiffness Test - Tension vs Axial Displacement

Contour plots of resultant deformation and maximum principal stress at the final time point are shown in Figure 4-3 and Figure 4-8 respectively.

An axial stiffness curve was generated by extracting the tension and axial extension in the model as the load was incremented. The tension vs axial extension curve extracted for use in the global Orcaflex analysis is shown in Figure 4-4.

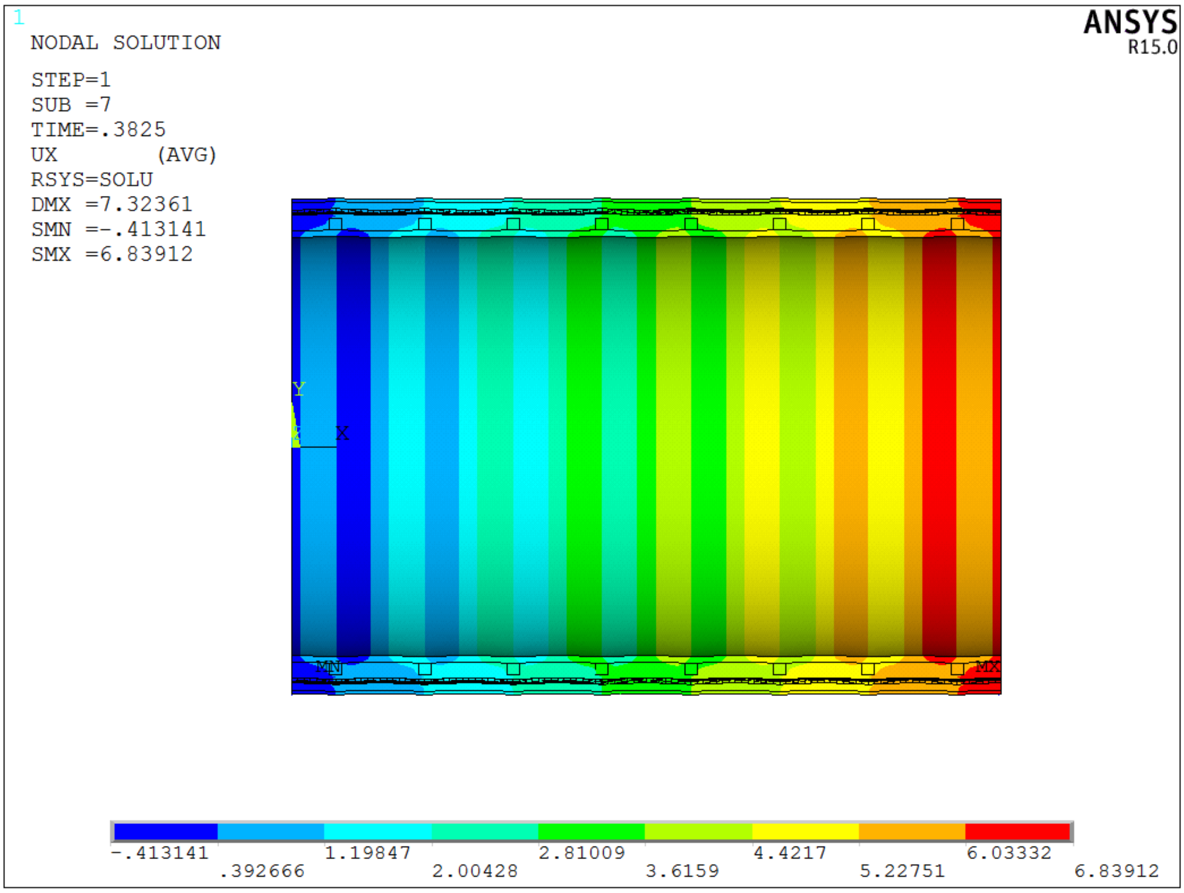

Figure 4-3 – Tension Test – Axial Displacement (mm) at last converged step (section view)

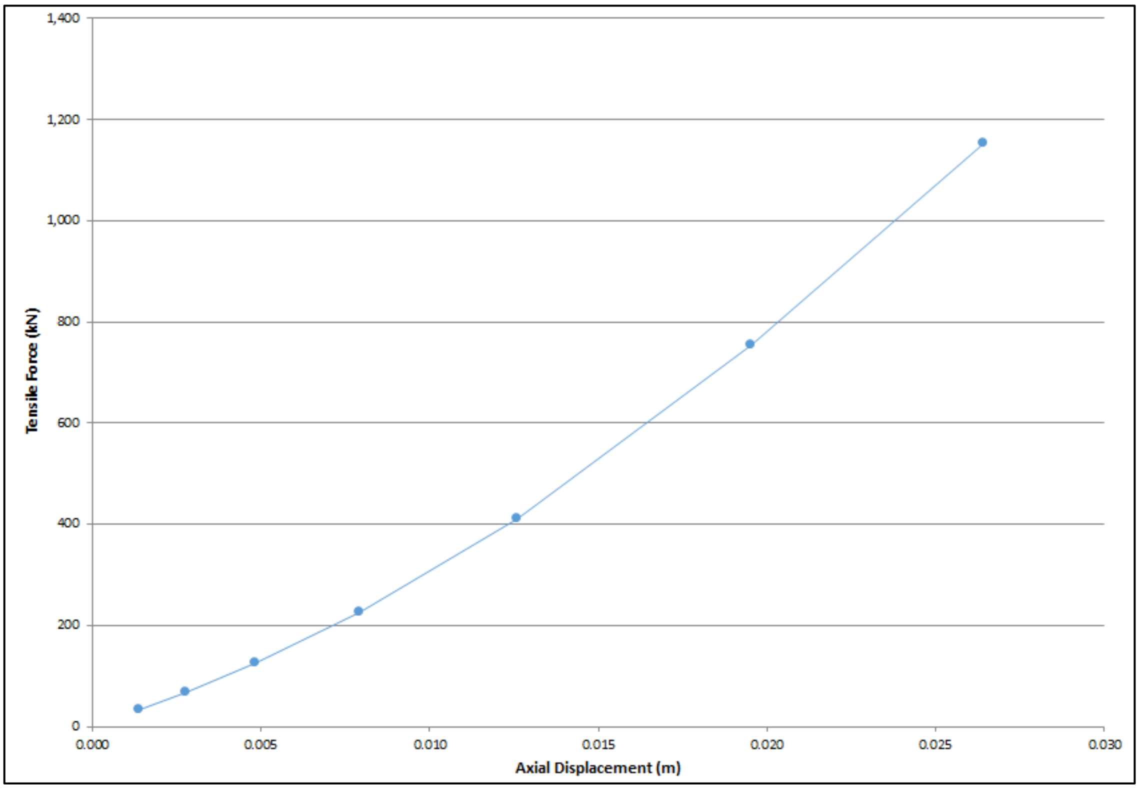

Figure 4-4 – Axial Stiffness Curve – Tension vs Axial Displacement

4.2 Stress Factors

4.2.1 Fibre Stress vs Curvature

As outlined in the introduction, in the previous analysis the stress factors were extracted from the end fitting [3] as this section had the highest stresses in the composite; these values were then used in Orcaflex to obtain the fatigue life. It was found from [3] that the stresses in the end fitting were approximately 3 times the stresses found away from the end fitting region due to the stress concentrating effects. The bending and axial stress factors extracted from the new sector model were factored by 3 to account for the stresses been taken away from end fitting.

In Figure 4-5 the location of the peak stress in the composite can be seen to be localised to where the rigid plane had been defined (where the rotation about the z axis was applied). The stresses were extracted away from this unrepresentative end effect.

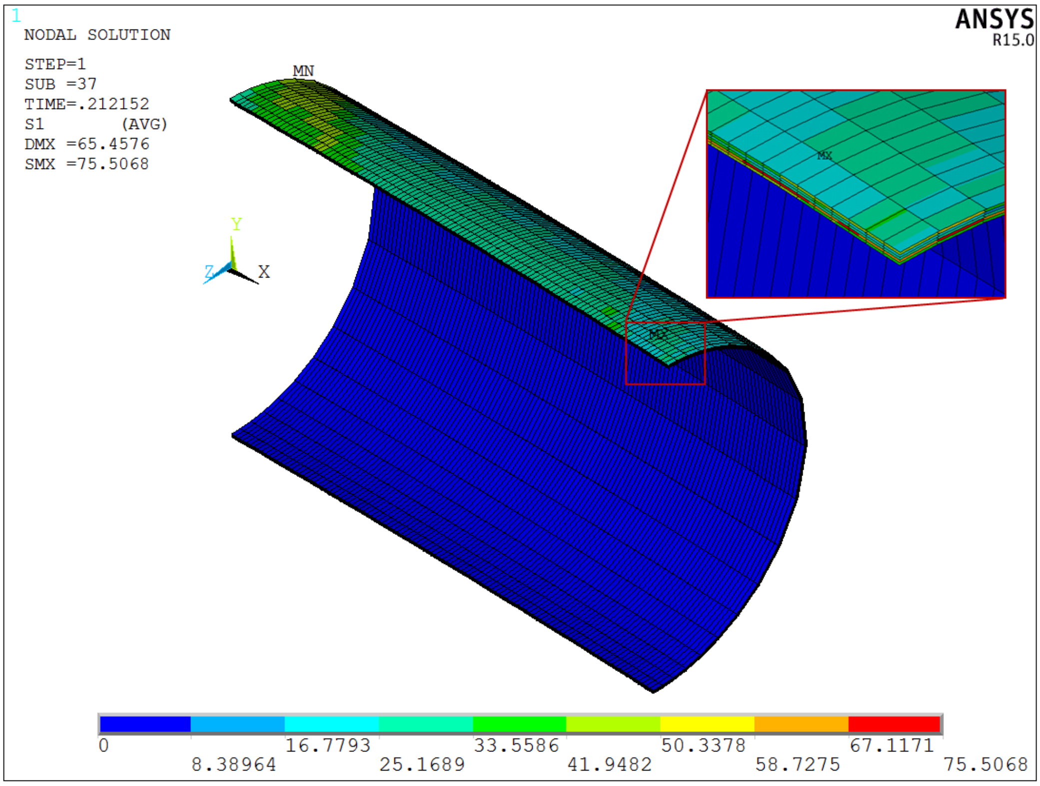

Figure 4-5 – Bend Stiffness Test – Cord Max Principal Stress (MPa) at last converged step (6 layers shown)

The maximum principal stress extracted from the FE model used the averaged cross sectional area of the reinforcing fibre and the averaged axial force:

$$\sigma_1 = \frac{Averaged\ Axial\ Force}{Averaged\ Cross\ Section\ Area\ of\ Reinforcing\ Fibers}$$

The maximum principal stress was extracted from the top 3 layers away from the boundary conditions to remove any unrealistic end effects. Maximum principal stress (S1) vs curvature is shown in Figure 4-6 for the hose sector. The stresses were then factored by an SCF of 3 to account for the concentration at the end fitting; this graph is shown in Figure 4-7 and was output to Orcaflex in order to carry out the fatigue assessment.

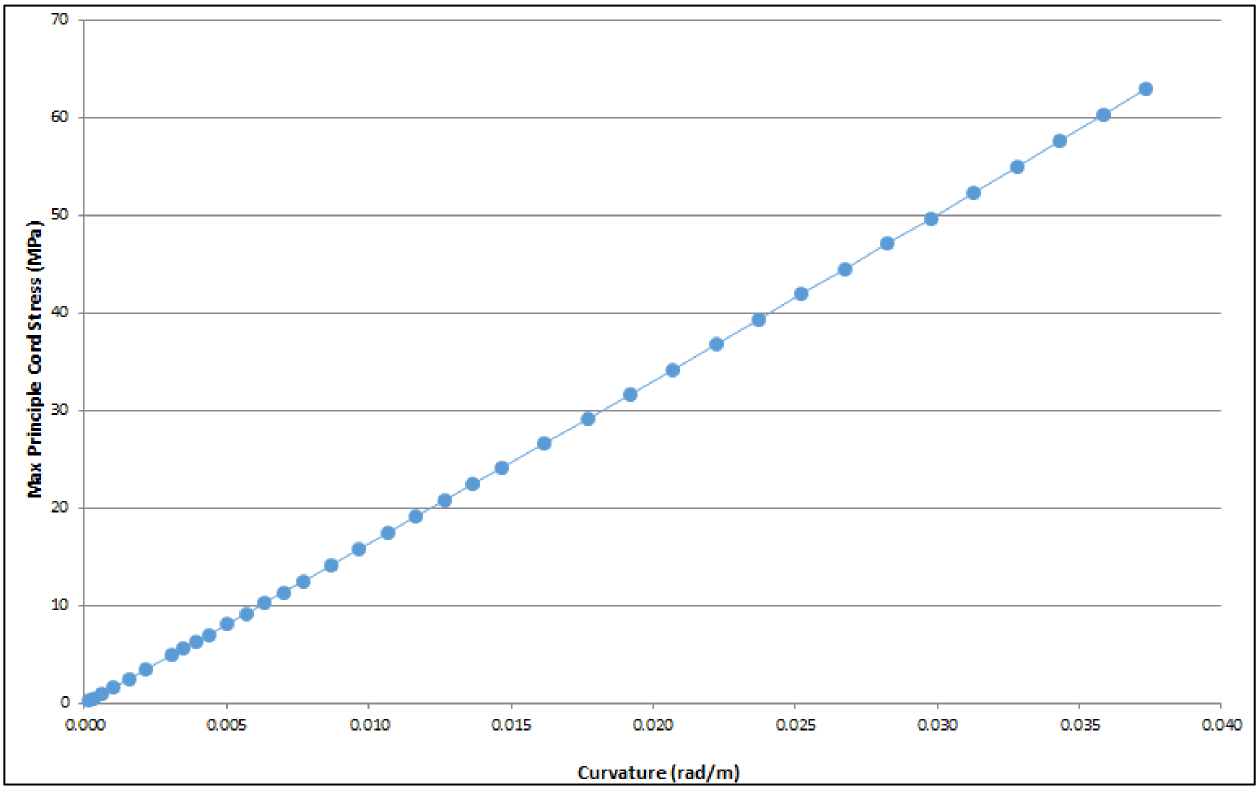

Figure 4-6 – Max Principal Cord Stress vs Curvature-Sector Model

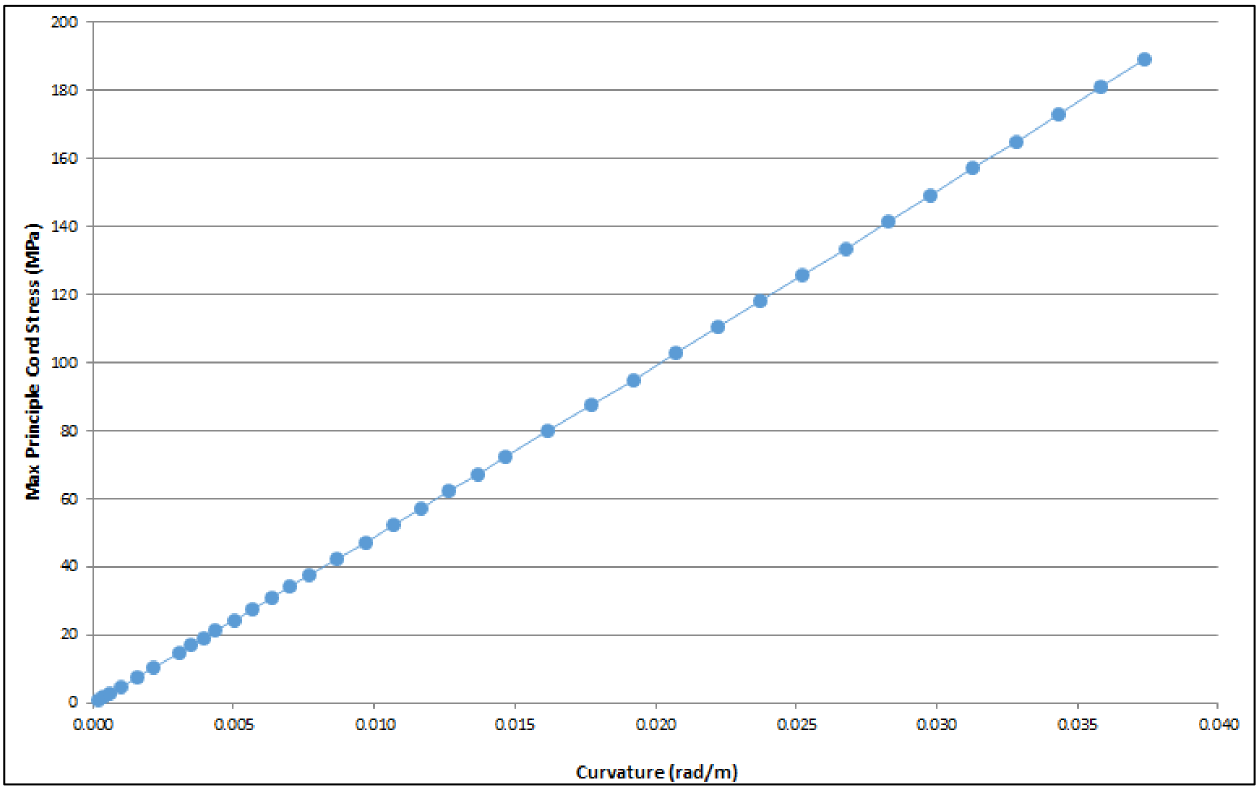

Figure 4-7 – Max Principal End Fitting Cord Stress vs Curvature - SCF of 3 applied

4.2.2 Cord Stress vs Axial Load

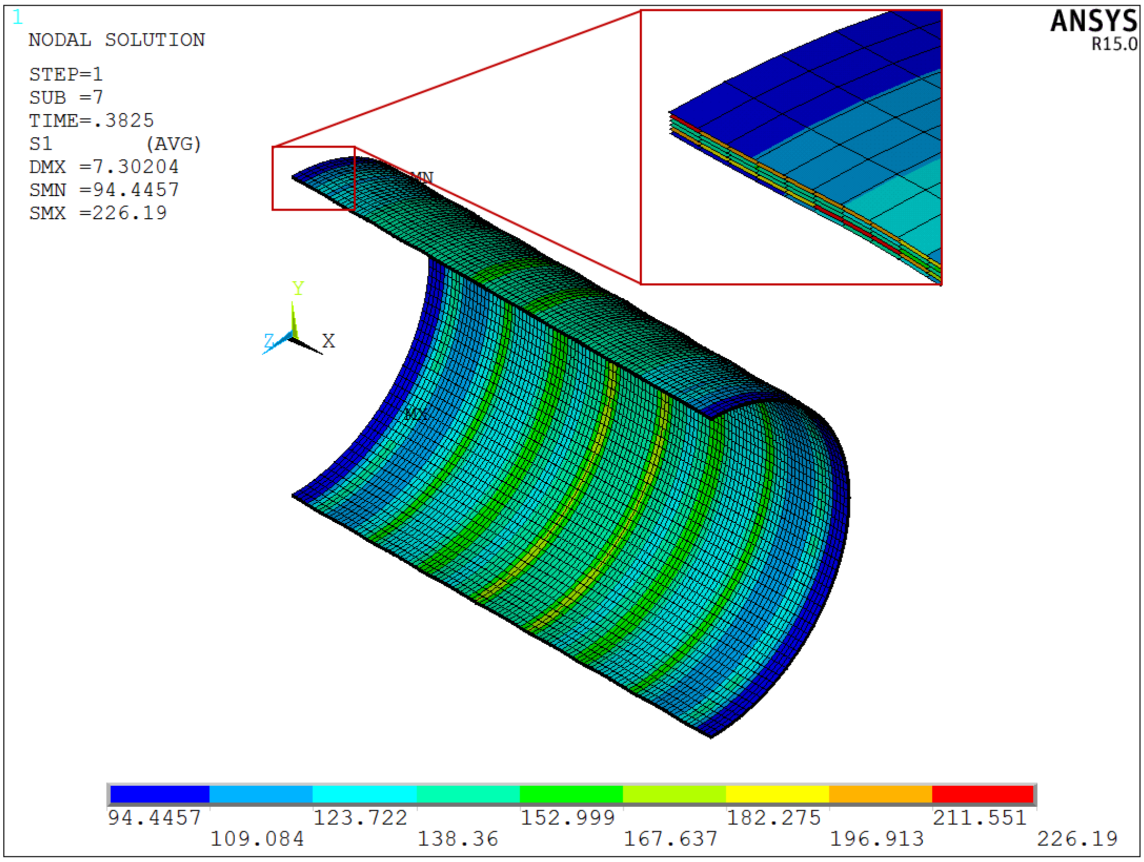

Figure 4-8 – Tension Test – Max Principal Stress (MPa) at last converged step (6 layers displayed)

Using the same methodology described in section 4.2.1, a curve of maximum principal cord stress vs axial load was created. The location of the peak stress in the composite can be seen to be localised where the symmetry condition was specified. The stresses were extracted away from unrealistic end effects. The graph is shown in Figure 4-9.

The most highly stressed region was previously located at the end fitting termination [3]; therefore to account for the end fitting stress an SCF of 3 has been applied; this graph is shown in Figure 4-10 and was output to Orcaflex in order to carry out the fatigue assessment.

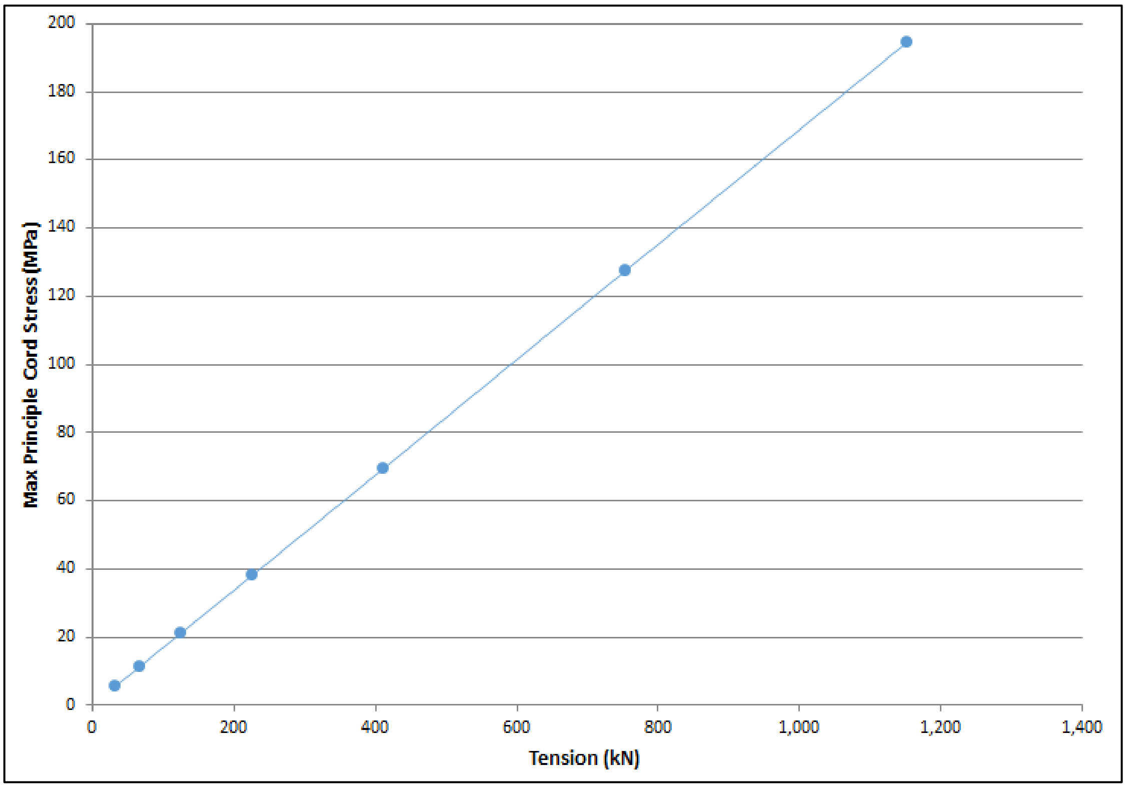

Figure 4-9 – Max Principal Cord Stress vs Axial Load-Sector Model

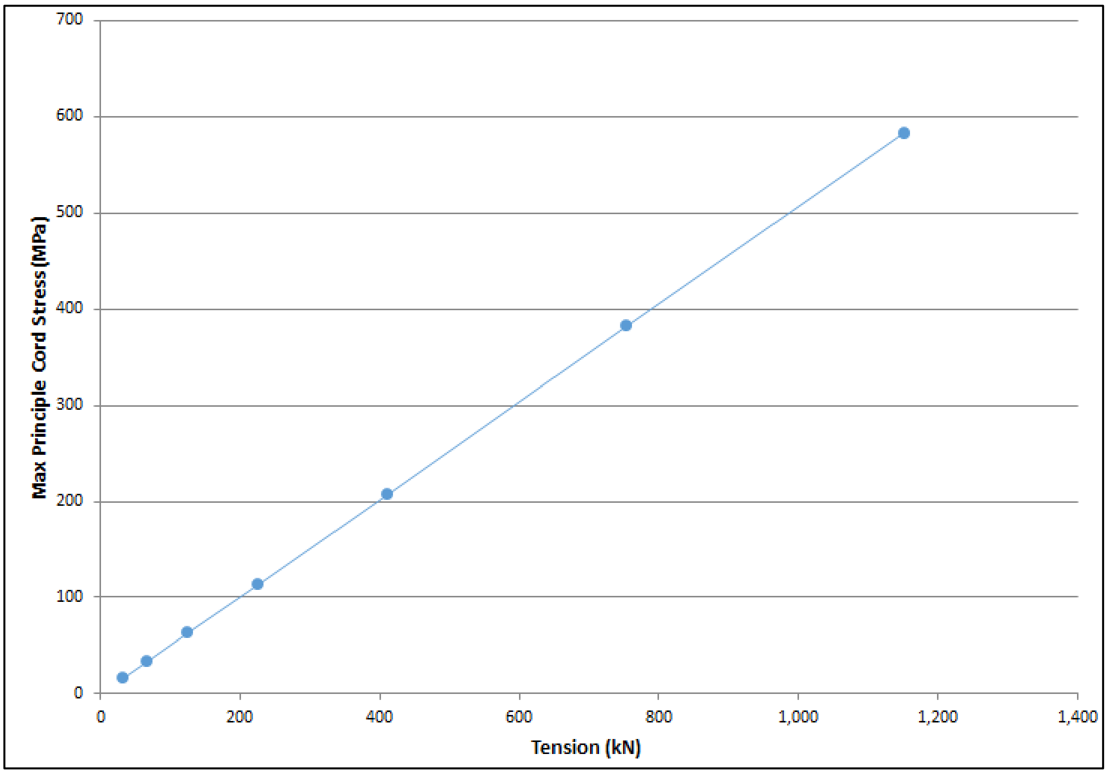

Figure 4-10 – Max Principal End Fitting Cord Stress vs Axial Load - SCF of 3 applied

5 Discussion and Conclusions

This report discusses the finite element modelling of an EMSTEC 40" bonded flexible hose with steel reinforcement. Composite material properties were estimated with a good level of confidence, see Appendix A. A full hose (sector) model was then created and loaded in tension and bending.

The models were then used to generate the following:

- Bending stiffness curve – bend hose sector model (Figure 4-2)
- Axial stiffness curve – axial hose sector model (Figure 4-4)
- Bending stress factor curve – composite cord hose central region (Figure 4-6)
- Bending stress factor curve – composite cord in end fitting (Figure 4-7)
- Axial stress factor curve – composite cord hose central (Figure 4-9)
- Axial stress factor curve – composite cord in end fitting (Figure 4-10)

To complete the fatigue analysis the stress factors for the flange weld and fasteners were taken from report PDL-EMS-667-003 [3].

6 References

[1] 99910.00001~2.A-0 Revision 0, 19-11-14.

[2] PDL-EMS-727-002 (1): 40" Suction Hose Fatigue Assessment Global Analysis

[3] PDL-EMS-667-003(1): 40" Suction Hose Fatigue Assessment Local Analysis 31-03-15

[4] 3D Model (Inventor), received by memory stick, 16-12-14.

[5] 'Stress-Strain Relation of Pure-Gum Rubber Vulcanizates in Compression and Tension' Lawrence A. Wood, 03-03-1950

[6] ASTM D1415 'Standard Test Method for Rubber Property-International Hardness' Reapproved 1999

[7] 'Physical Testing of Rubber' 4th Edition, by Roger Brown p133

[8] EMSTEC Material Data Sheet: MDS-201409-00021, release date 21-09-14.

[9] EMSTEC Material Data Sheet: MDS-201409-00024, release date 21-09-14.

[10] EMSTEC Material Data Sheet: MDS-201409-00020, release date 17-09-14.

[11] EMSTEC e-mail, 'RE: Query summary', 05-02-15.

[12] ASTM D 1415-88, 1999.

[13] EMSTEC e-mail received from Ian Craig, 'Analysis', 06-08-15

[14] EMSTEC e-mail received from Ian Craig, 'RE:Analysis', 07-08-15

[15] 'Bending of Helically twisted cables under variable bending stiffness due to internal friction, tensile force and cable curvature' Konstantin O.Papailiou 1995

Appendix A

A.1 Steel Cord Properties

The base properties of the textile/rubber composite sheet material are shown below:

- Thickness = 2mm
- Cord nominal diameter = 1.14 mm [13]
- Cord pitch = 100/60 = 1.67 mm [14]

For smeared REFINF265 elements used to model the steel cords in the matrix rubber, the Young's Modulus was required. In order to estimate the steel cord's Young's modulus, it was first necessary to make assumptions for the steel cord. The steel cord was assumed to be isotropic, as in terms of the hose stiffness previous model testing showed that by far the most important parameter was Ex [3]. The Young's modulus was calculated based on the actual cross sectional area of the fibres within the cord. The individual fibres were not modelled discretely; instead a cylindrical element was used to approximate the full cord using the nominal cross sectional area. The arrangement of fibres is shown in Figure A1-2. The helix angle was also taken into account. The method for calculating the steel cord's Young's modulus as shown below:

Firstly an estimate of the helix angle was calculated using the lay length of 16mm [14] for the outer fibre (diameter 0.225mm). The theory below in Figure A1-1 was then used from [15] to estimate the helix angle:

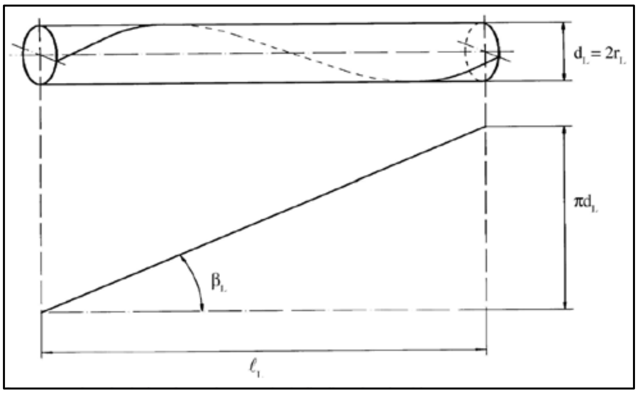

Figure A1-1 – Geometry of Wire Belonging to Layer L of a Helically Twisted Cable

$$\beta_L = Tan^{-1}\left(\frac{0.915\pi}{16}\right) = 10.19°$$

Estimated Helix Angle (β_L) = 10°

Nominal Area of Cord (A_c) = 1.021mm^2

Area of the Fibres (Figure A1-2) (A_f) = 0.765mm^2

Steels Young Modulus (E_s) = 207GPa

Estimated Young's Modulus (assuming cord is modelled as a cylinder of diameter 1.14mm):

$$Estimated\ E = \mathrm{Es} \times \frac{\mathrm{A_f}}{\mathrm{Ac}} \times \cos^3(\beta_L)$$

E = 148GPa

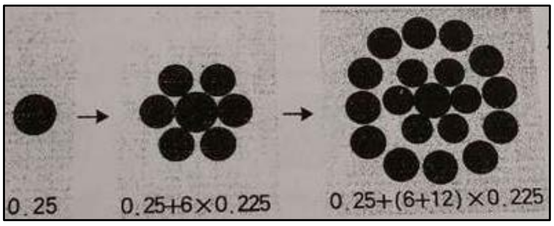

Figure A1-2 – Steel Fibre Dimensions within One Cord [14]

PDL	**PDL Solutions (Europe) Ltd.** 1 Tanners Yard Hexham Northumberland NE46 3NY **Tel :** +44 (0) 1 434 609 473 **Fax :** +44 (0) 1 434 606 292 **www.pdl-group.com**	**Technical Report** 40” Suction Hose with Steel Reinforcement Fatigue Assessment Global Analysis

Report Number:	PDL-EMS-727-002 (1)	**Project:**	40” Suction Hose Fatigue
Customer:	EMSTEC	**PDL Job No:**	727
Contact:	Ian Craig	**Quote Ref:**	SQDU-152 (1)

Technical Report	
Abstract:	This document details the results of global analyses undertaken in support of the fatigue assessment of the EMSTEC 40” cooling water suction hose with steel reinforcement which accounts for the geometry and material property modifications of the hose created under SQDU-141 [14]. All model setups and simplifications are detailed. The necessary inputs, load case definitions and assumptions are also described. The purpose of this document is to give a detailed description of the analysis work and the associated results. The key outputs were the fatigue life of the wire, flange and bolt components. Stress factors calculated in PDL-EMS-727-001 (1) were used for these calculations.

Revision History

2	12-11-2015	Updated stud life	MAS	DCU	DCU
1	06-11-2015	First issue	MAS	DCU	RAF
Rev	**Date**	**Reason for change**	**Author**	**PDL Review**	**PDL Approval**

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1 Introduction

This report describes the steps taken in the global analysis of an EMSTEC 40” cooling water suction hose intended for operation from a FLNG (floating liquefied natural gas) unit. This work carries on from document PDL-EMS-667-002 [1] where a full global analysis was carried out on a textile-reinforced hose. For the present analysis, the textile reinforcement was changed to steel wire reinforcement as described in the local analysis, PDL-EMS-727-001 [2]. The mass, bending stiffness and axial stiffness of the hose were modified to account for this change. All other parameters were kept constant. Therefore, a comparison could be made between the two hoses in order to understand the performance of one in relation to the other (see Appendix A).

As with PDL-EMS-667-002 [1], EMSTEC intend for this hose to comply with the fatigue requirements of API 17K ‘Specification for Bonded Flexible Pipe’ although it is recognised that this standard is not strictly intended to be used for suction hoses.

As part of the requirements for compliance with API 17K, all bonded flexible hose must show suitable fatigue life under expected operating conditions. To verify that the EMSTEC suction hose meets this requirement, PDL Solutions (Europe) was contracted to undertake a full fatigue analysis for a total hose length of 135m. Each section of the hose is 9m long with steel flanges at either end so 15-off hose sections are required to make up the total length. There is also a strainer at the open end of the hose. For compliance with API 17K, the hose must have a fatigue life of more than ten times the service life, which in this case means the calculated minimum life should exceed 250 years.

2 Objectives

The global analysis, conducted in Orcaflex, consisted of a global dynamics fatigue assessment of a model representing the vessel and hose with hydrodynamic loading derived from relevant Metocean data [3].

The first purpose of this report is to outline the input data that was used in the global analysis and to describe how the data required for the fatigue assessment was generated. Assumptions have been listed and references given to indicate where the input data was sourced from. Secondly, the report describes the calculations that were conducted in Orcaflex to predict the fatigue lives of the critical components.

3 Global Analysis Methodology

This section describes the input data for the Orcaflex models and details how it was generated.

3.1 Geometry

The inside diameter (ID) of the hose was 1m and the outside diameter (OD), away from the end fitting, was 1.18m. The steel reinforcement wires carry the main structural loading when the hose is in tension. Across the full length of the hose, there were six layers of reinforcement where the angle of the drawn steel wires was +/-40° to the hose longitudinal axis.

3.2 Hose Data

The Orcaflex model used in PDL-EMS-667-002 [1] was used in this analysis. Changes were made to the mass, axial stiffness and bending stiffness of the hose. New stress factors were obtained from the local analysis [2] which account for the use of steel reinforcement in place of textile.

The mass per unit length of the hose was found by modifying the mass used in [1] to account for the use of steel reinforcement. The mass of the embedded textile was removed from the overall mass and replaced by the mass of embedded steel. The calculation used to find the new mass accounted for the change in outer diameter of the hose and the change in embedded material mass including the difference in the number of reinforcement layers. From this, the line properties outlined in Table 3-1 were obtained. The overall mass of the new hose (excluding connector components, see section 3.2.1) was estimated to be 95% of that of the textile version, largely because of the reduced outer diameter.

	Length (m)	OD (m)	ID (m)	MBR	Mass/Length (te/m)
40" Rubber	50	1.18	1	4.0	0.552
40" Rubber	85	1.18	1	4.0	0.552
40" Strainer	2.7	1.04	1	N/A	0.497

Table 3-1 - Steel Reinforced Hose Properties

The flange connection and marine growth details were applied using the Orcaflex 'Attachment' functionality as discussed in Sections 3.2.1 and 3.2.2 respectively. Strainer properties were kept unchanged from PDL-EMS-667-002 [1].

3.2.1 Flange Connectors

Flange connectors were modelled as in PDL-EMS-667-002 [1] i.e. they were accounted for by adding a point mass at regular 9.0m intervals along the hose. Each point accounted for the mass of the 40" flange connectors and cathodic protection anodes.

Each attachment was considered as a clump weight and given zero area and zero volume so that they did not influence the hoses' response to hydrodynamic loading by any means other than through the added weight. The weight input into the model was the fully submerged weight of the connectors and accounts for the following components:

- 36 studs at 39mm diameter.
- 144 nuts (two at either end of stud) at 39mm diameter.
- 2 x 20mm thick backing plates at 1280mm diameter.
- 6 x 4kg aluminium anodes.

Combined, this gives a submerged weight of 0.277 tonnes per connection.

To account for the stud preload effect in the top flange (which was most critical from a fatigue point of view), an additional point mass of 57 tonnes was applied at a short distance from End A. This was required to model the preload of 88 MPa in the welds (this is less than the 236 MPa used in [1] for reasons explained in Appendix A). The mass of the attachment was calculated accounting for the weld stress factor outlined in Section 3.2.5. The consequences on the fatigue analyses are outlined in Section 3.2.6.

Note that sensitivity studies were carried out to check that this additional mass did not influence the dynamic behaviour of the hose, the results of which showed that the minimum fatigue life of the composite part of the hose was the same with and without the point mass.

3.2.2 Marine Growth Profile

The marine growth (MG) profile was taken to be the same as that used in PDL-EMS-667-002 [1]. Thus, a 100mm max, linearly decreasing profile was used in order to calculate the additional weight and drag loading on the hose. As with the textile-reinforced hose analysis, the hang-off location of the hose was situated at z = -15m. As such, the full 100mm of marine growth was not considered to act on the hose. The complete profile is summarised below:

- +2m to -10m : 100mm MG
- -10m to -65m : 25mm MG
- Below -65m : No MG

The variable outer diameter of the hose accounting for marine growth is given in [4]; recall that this is based on a nominal hose OD of 1.18m, see Figure 3-1. Note that zero on the x axis corresponds to z = -15m and 50m corresponds to z = -65m.

Note that the marine growth profile has only been considered in calculating the drag coefficient, contact diameter and mass per unit length of the hose. Any contribution to the bending stiffness of the line from marine growth is deemed negligible and is not accounted for in the analysis.

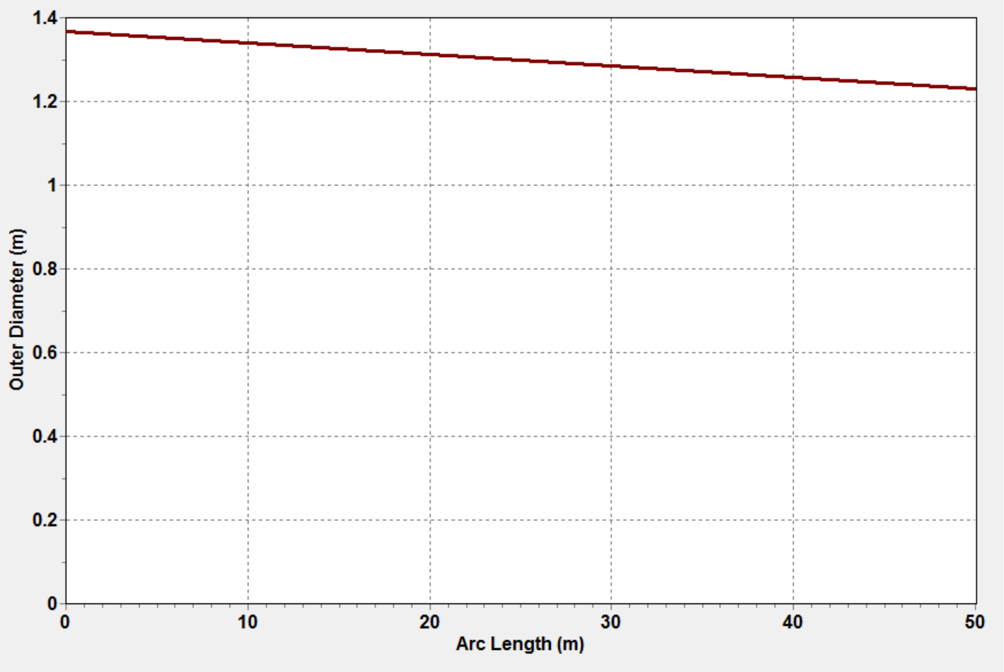

Figure 3-1 - Marine Growth Profile

3.2.3 End Connection Stiffness

The end of the hose could have been fully fixed to the vessel but this was considered to be too conservative. In order to more accurately model the connection stiffness an approximate riser head/riser seat model was created using finite element (FE) analysis in ANSYS. The model was approximate because the riser head and seat for the 40" hose have not yet been designed; therefore, the geometry from a smaller riser head was scaled up based on the difference in hose diameter.

There is clearance between the riser head and the riser seat and there are soft (HDPE) pads attached to the outside of the riser head to avoid metal to metal contact between it and the riser seat. The objectives of the FE analysis model were to determine what degree of free rotation was allowed, and what connection stiffness develops once the riser head has reached its rotational limit. Figure 3-2 shows the setup of this riser head FE model. Two rigid blocks, either side of the riser head, were used to model the constraining effect of the riser seat. The following parameters, which should be updated once the riser head and riser seat design work is complete, were used in the model:

- ID of riser seat = 1940mm
- OD (pads) of riser head = 1890mm
- Vertical distance between top of pad and bottom of bottom pad = 1180mm
- Thickness of riser seat tube = 20mm
- OD of tube = 1530mm
- Material of tube = steel

- Material of top pad = HDPE
- Material of bottom pad = steel; the reason this pad was modelled as steel rather than HDPE is that it was modelled potentially thicker than it would be in reality which would lead to a non-conservative stiffness if the material was modelled as HDPE.

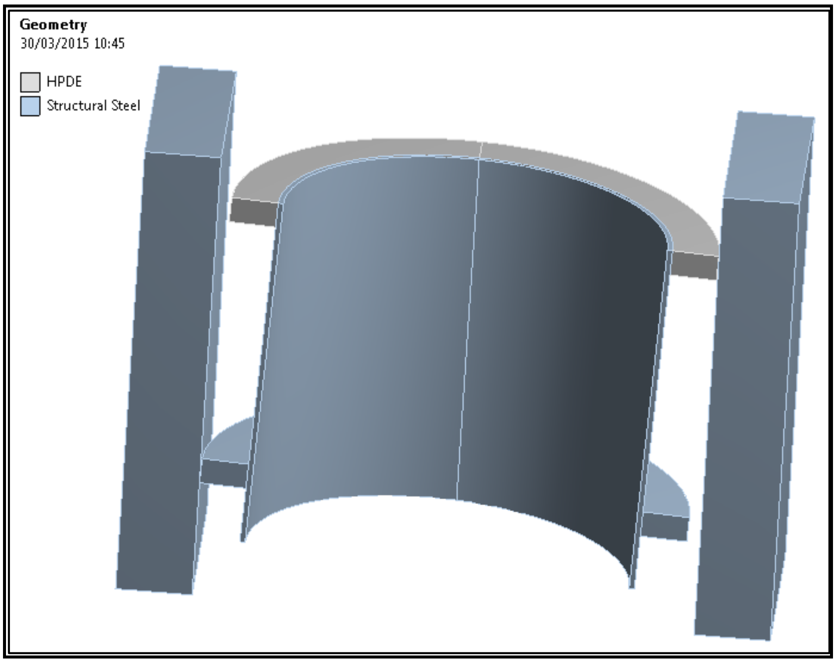

Figure 3-2 - Riser Head Model

The rotational limit of the riser head was deduced by rotating the geometry alone. Rotating the riser head until it touched the rise seat showed that the rotational limit was 2.5deg. The FE analysis model was held in this position and a number of representative bending moments were applied in order to determine the response of the connection. These moments were taken from the Orcaflex model and were moments expected to be experienced by the riser head during operation.

The models were solved and the rotation of the connection geometry obtained in order to construct a moment-rotation relationship that could be input into Orcaflex. This moment-rotation relationship is shown in Figure 3-3. Note that a slightly non-zero stiffness was applied up to 2.5°. This was required to aid (Orcaflex) model convergence; the change in gradient occurred at a relatively small 2kNm.

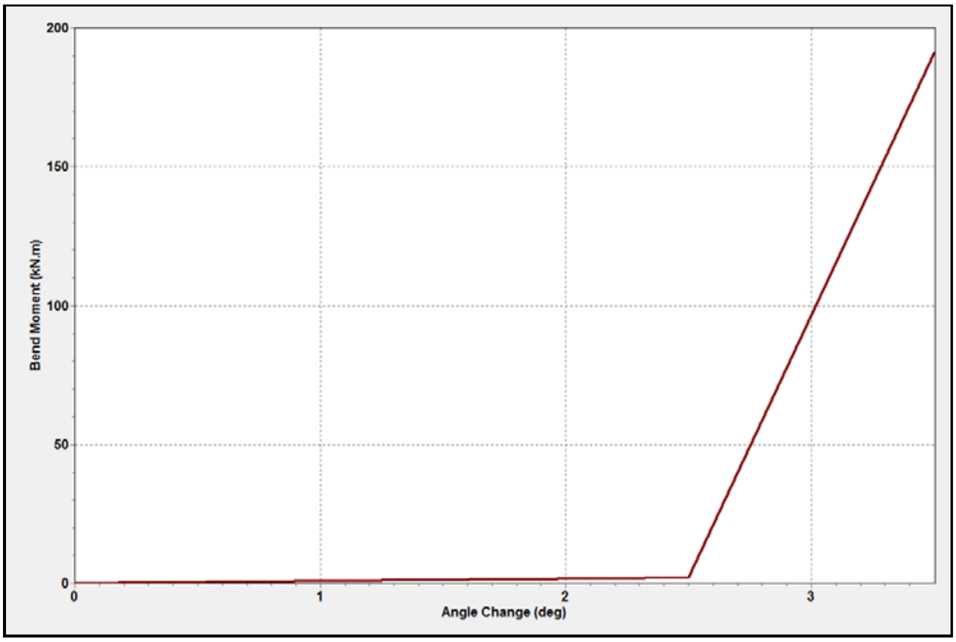

Figure 3-3 - Variable End Connection Stiffness

3.2.4 Variable Drag Coefficient

A variable drag coefficient was used on all parts of the line in order to model the variance in Cd with Reynolds number. Two separate profiles were used in the analyses – 'smooth' and 'rough'. These graphs were taken from DNV-RP-C205 [6] and are given in Figure 3-4 and Figure 3-5. The smooth graph was used for the hose sections where there was no marine growth and the rough for where there was.

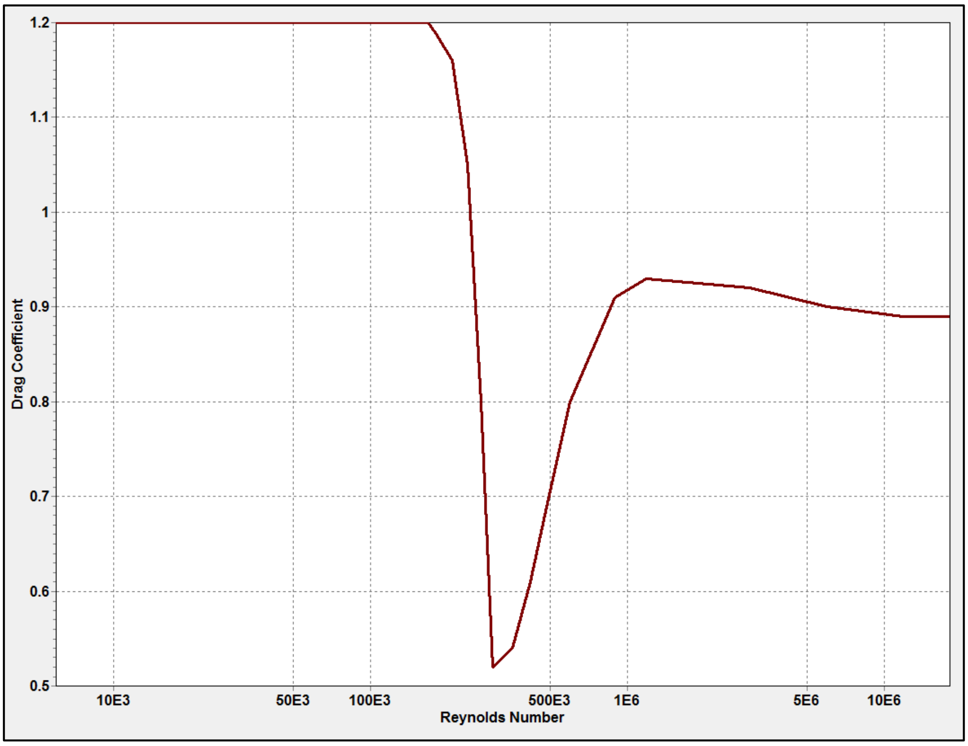

Figure 3-4 - Smooth Hose, Cd

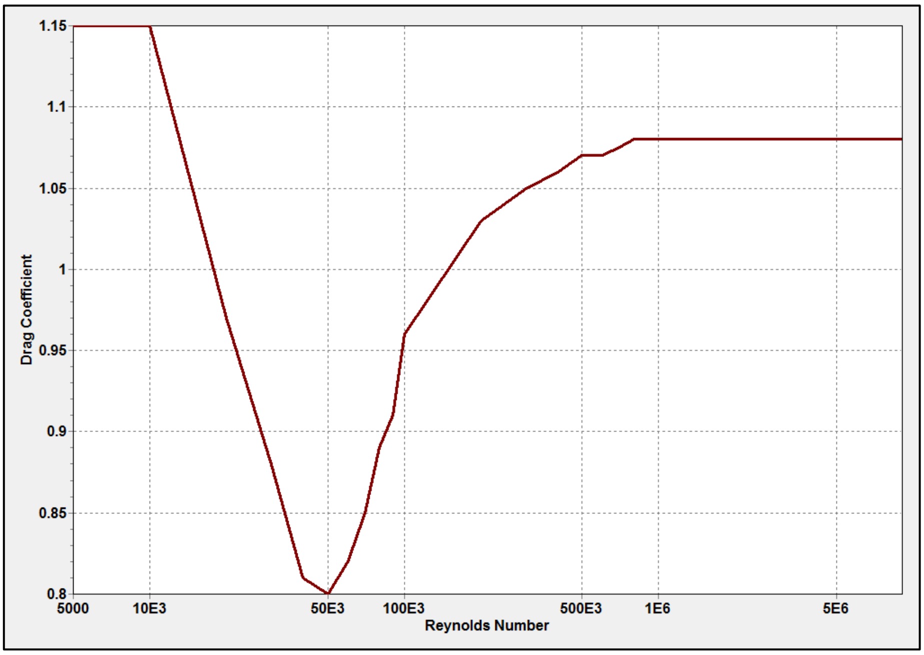

Figure 3-5 - Rough Hose, Cd

3.2.5 Hose Stiffnesses

Bending and axial stiffnesses for the hose and bending and tension stress factors for the steel wire layer, flange fasteners and flange welds were derived from the results of the local analysis [2]. The hose composite layer and flange components were considered to be the critical components in terms of fatigue damage.

The bending stiffness and axial stiffnesses are shown in Figure 3-6 and Figure 3-7 and are discussed in [2].

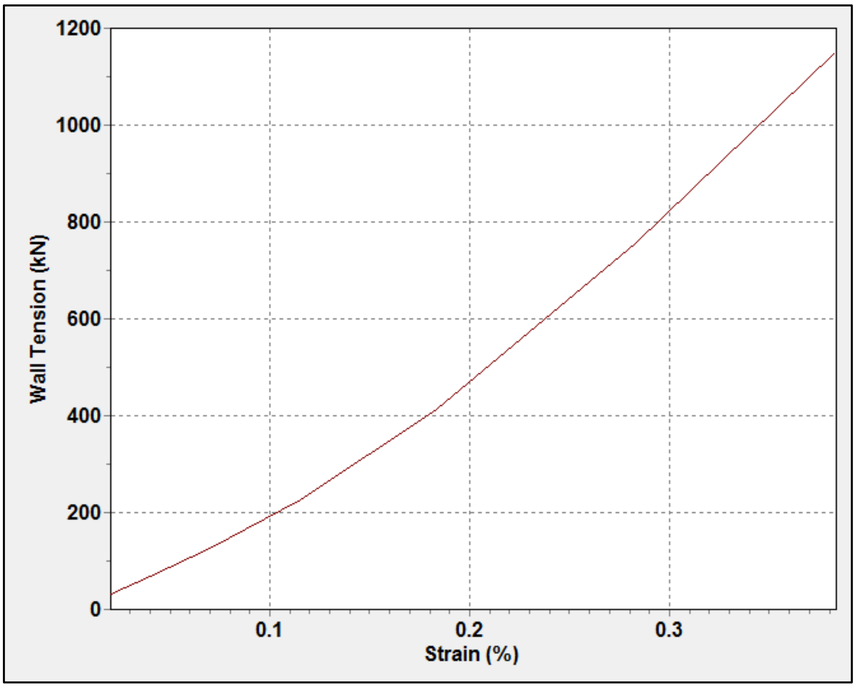

Figure 3-6 - Axial Stiffness

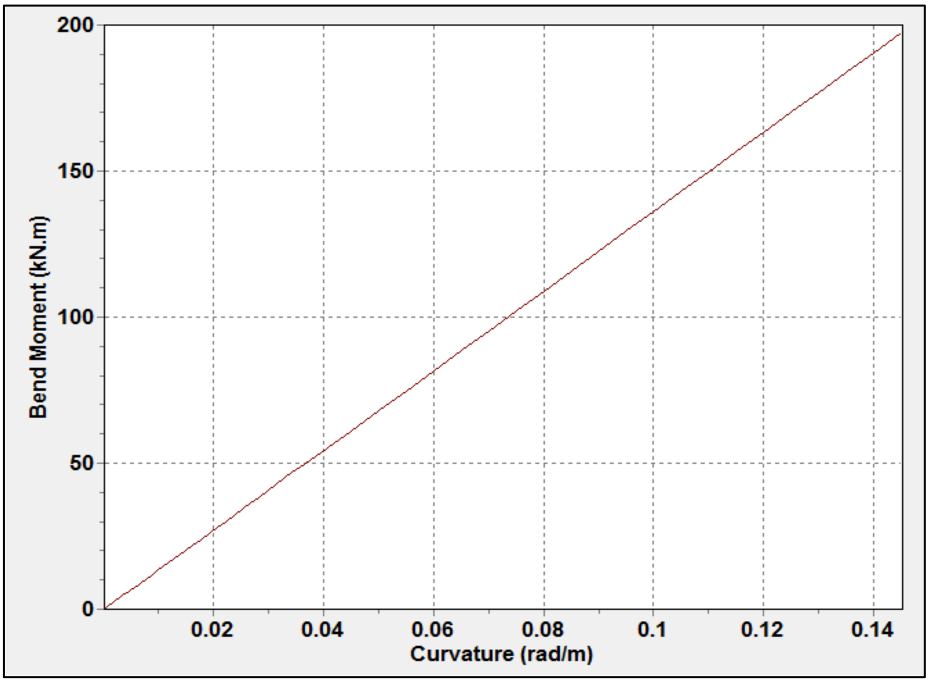

Figure 3-7 - Bending Stiffness

3.2.6 Stress Factors

Hose stress factors for bending and tension were taken directly from [2]; both were linear and could be represented by single values as shown in Table 3-2.

Stress factors for the flange fasteners and welds had to be derived from work carried out in the original local analysis work [5]. Because the geometry was unchanged, the stress versus axial load and stress versus bending moment were unchanged. However, because Orcaflex requires the bending stress factor in terms of curvature, rather than moment, a conversion was required; this was achieved using Figure 3-8:

- For the weld, 0.52MPa/kNm becomes 709,000MPa/rad/mm
- For the studs, 0.046MPa/kNm becomes 63,000MPa/rad/mm

These results are summarised in Table 3-2.

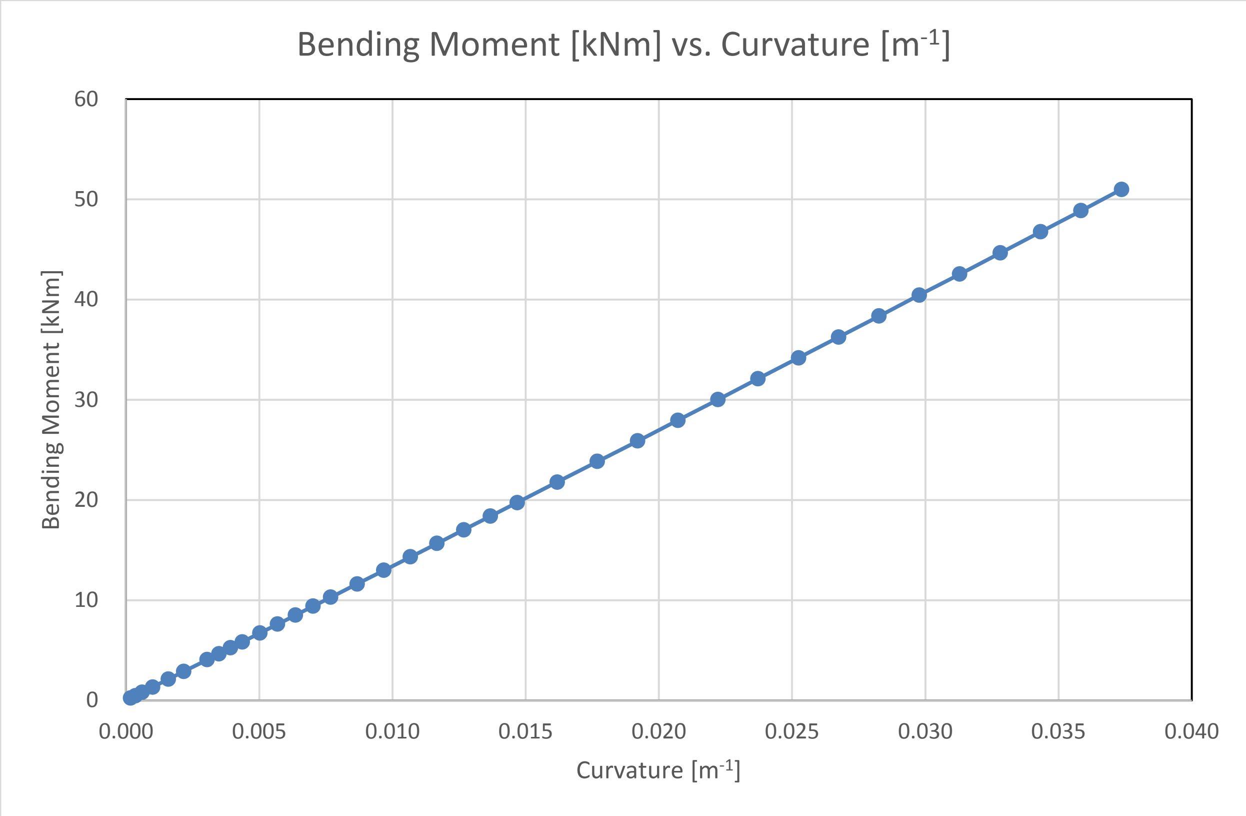

Figure 3-8 - Hose Bending Moment versus Curvature

Component	Axial stress factor (MPa/kN)	Bending stress factor (MPa/rad/mm)
Hose	0.17	4.95E6
Flange fasteners	0.012	63E3
Flange weld	0.154	709E3

Table 3-2 - Stress Factors

Note that the axial stress factor for the hose was increased from the calculated value of 0.017 to 0.02 within the fatigue analysis. This was to account for the lack of available data regarding the submerged weight of the hose. For the previous analysis [1], the actual value for submerged weight was found to be slightly higher than that found by calculation. Thus, this increase in axial stress factor accounts for the potential lack of accuracy in calculating the new component's submerged weight. The full post-processing of the fatigue simulations was then carried out within Orcaflex, utilising the program's stress factor approach for calculating damage.

3.2.7 Fatigue Curves

Steel/Rubber Composite Fatigue Curve

Besides the stress factors and the fatigue loading (discussed in Section 3.4.2) a material fatigue (SN) curve was also required for the composite, in particular the steel wire.

The basis of the S-N curve for the wire reinforcement was obtained from API-RP-2SK [7]. This standard relates to the station-keeping of floating structures and outlines various T-N curve data for different line geometries. For the purpose of this fatigue analysis, the T-N curve relating to "Spiral Strand" was used. The generic formula for generating the fatigue curve is shown below:

$$NR^M = K$$

Where:

N = number of cycles

R = ratio of tension range to nominal breaking strength

M = slope of T-N curve (= 5.05 [7])

K = intercept of T-N curve = $10^{(3.25 - 3.43\, Lm)}$

Lm = ratio of mean load to catalogue breaking strength

In order to use this curve in Orcaflex, it was first necessary to convert it to stress. The K value was found based on the reference breaking strength of the wire and the mean load observed in the wire. From data supplied by EMSTEC [8], the reference breaking stress was calculated to be 2180MPa based on the nominal wire diameter of 1.14mm. The mean load in the line is caused by the submerged weight of the hose and varies linearly with length. The static value at the top end of the hose was 400kN; this was then converted to a wire stress, of 68 MPa, based on the axial stress factor for this component. This gives a K value of 1390. For a tension range to ultimate tension ratio of 1.0 the stress range would be 2180 MPa in the wire, using the nominal diameter of 1.14mm. The intercept for the S-N curve is then $1390 \times 2180^{5.05} = 1.01 \times 10^{20}$.

For the purposes of Orcaflex, the M and log 'a' values were 5.05 and 20.0 respectively.

Flange Weld Fatigue

The weld stresses proved to be more critical than the parent metal stresses so only the former were analysed in detail.

For the fatigue assessment of the flange weld metal, the 'D' fatigue curve from DNV-RP-C203 [9] was used as the basis. This particular curve is prescribed for use with the "hot spot" method discussed in Section 4.3 of the DNV standard. The 'hot spot' method is based on linear extrapolation of stress taken from two points in the near vicinity of the weld. The flange is protected by the rubber coating so it was considered appropriate to use the fatigue curve for an air environment.

DNV-RP-C203 [9] claims that mean stress effects are built into the fatigue curves but does not state what these mean stresses are. It was considered most likely that the testing conducted to generate the curves was done at R=0 i.e. the mean stress was equal to the alternating stress. There were concerns over the level of mean stress accounted for in these curves; therefore, two curves were analysed for the welds:

- DNV D, unmodified, mean stress effects switched off in Orcaflex.
- DNV D, modified to convert R=0 to R=-1, mean stress effects included in Orcaflex with the minimum UTS set to 470 MPa [17].

As discussed in [1], the reason for the concern about the applicability of the DNV fatigue curves was the high level of pre-stress in the weld just from the bolt torque up process. The back-to-back flange model from [5] was updated as part of the current work as more data on the compressive stress of the rubber had become available [18]. This data suggested that a compressive Young's Modulus of 47 MPa was appropriate for small compressive strains in the cover rubber. This Young's Modulus was higher than the value used in [5] and resulted in a weld stress, due to bolt pre-load, of 88 MPa (instead of 236 MPa found in [5]). An additional mass of 57 tonnes was added very close to the top of the hose in order to generate a weld stress of 88MPa. The weld assessment was conducted within Orcaflex, the worst-case results of which are reported in Section 4.

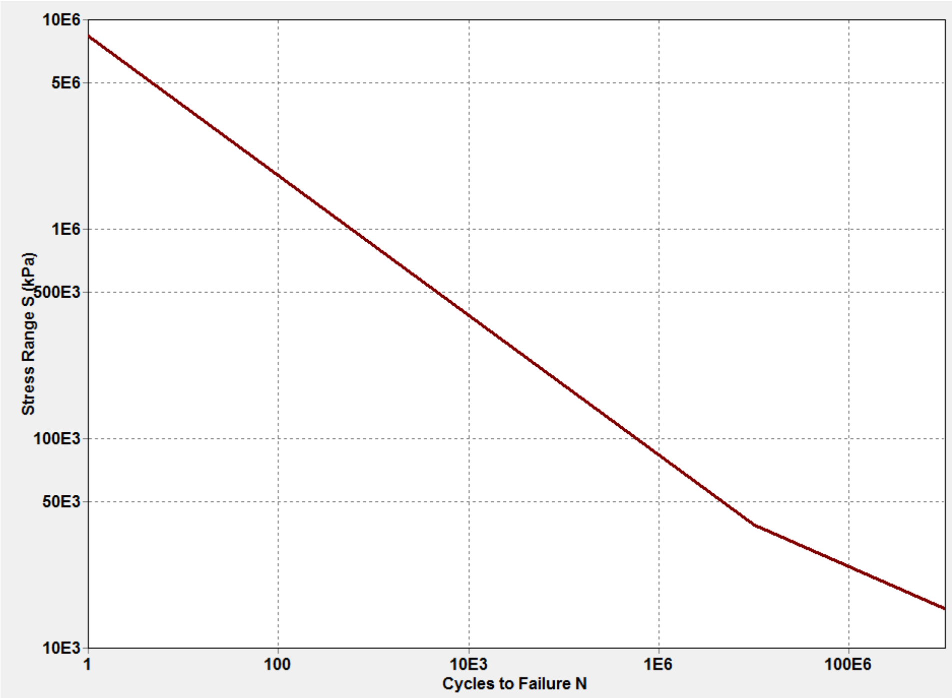

Figure 3-9 - DNV 'D' Curve

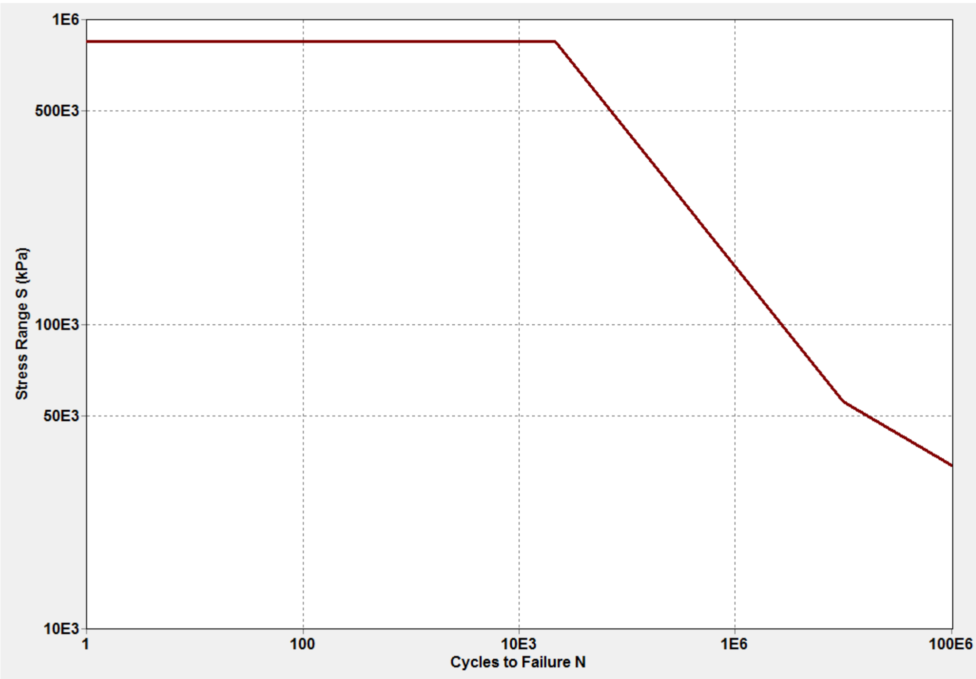

Figure 3-10 - DNV 'D' Curve: modified to R = -1

Stud Fatigue

The fasteners are exposed to the sea water environment so the fatigue curves for sea water with cathodic protection were appropriate. It is expected that the fastener threads would be rolled rather than cut but to be conservative the more conservative fatigue curve was used i.e. the W3 curve [9]. As this curve is intended to be used for pre-loaded fasteners no additional assessment, as carried out for the weld, was deemed necessary. The fatigue curve is shown in Figure 3-11.

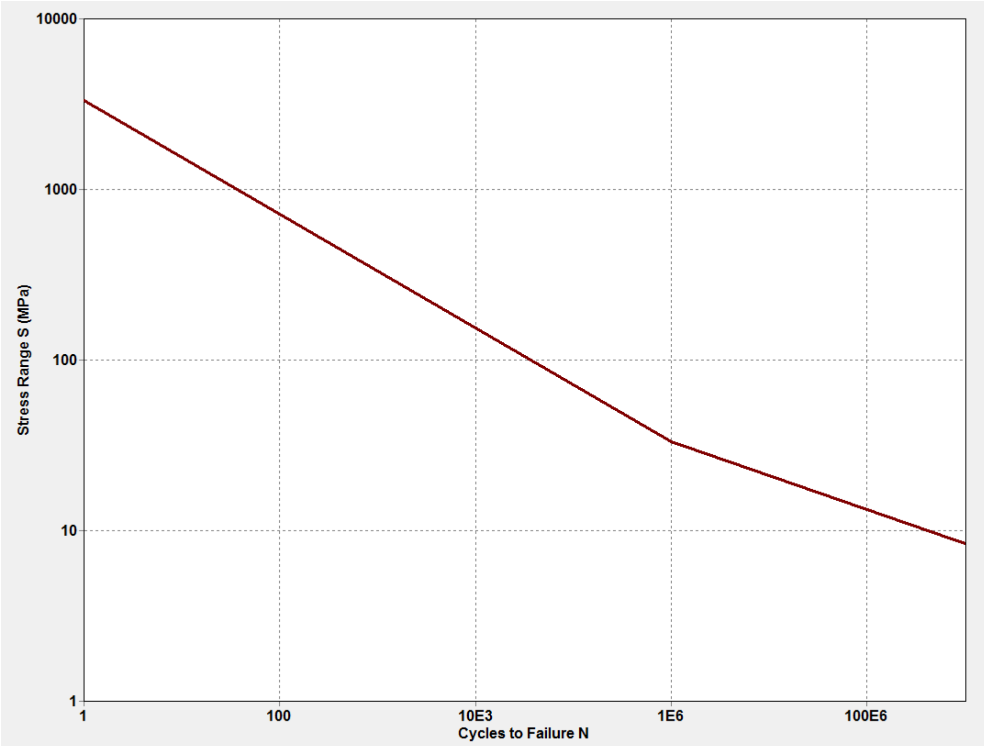

Figure 3-11 - DNV 'W3' Curve

3.3 Vessel Data

3.3.1 Vessel RAOs

Vessel motion data was contained within the Orcaflex model supplied [15]. In order to verify this data, RAO (Response Amplitude Operator) plots were generated which are given in Appendix A. The RAO data supplied in the Orcaflex model was given in the range 0° - 180° as the vessel exhibits half symmetry. On inspection of the RAO plots, it was apparent that the vessel exhibits strong quarter-symmetry and so the RAO plots were reduced to this range for clarity.

From Figure A-4, it can be seen that the vessel's pitch period shows resonance at around 20s for small heading angles. However, this is not likely to cause significant issues within the fatigue analysis as waves of this period have relatively low occurrence, see Section 3.4.

The RAO data within the Orcaflex model has the following sign convention:

- Surge is positive forward
- Sway is positive to port
- Heave is positive upwards
- Pitch is positive to aft down
- Roll is positive starboard down
- Yaw is positive from bow to port

To give confidence that the RAOs had been set up correctly, they were sense checked by running the vessel through a number of waves. Each wave had an arbitrary height and period and was run in order to gauge the vessel's motion response. These sense checks validated the data which was contained within the Orcaflex model supplied to PDL solutions.

Within the Orcaflex model, the primary motion of the vessel was set to 'None' and the superimposed motion was set to 'Displacement RAOs + Harmonic Motion'. Physically, this meant that the vessel only experienced first order wave effects i.e. no slow drift.

3.4 Environmental Data

3.4.1 Current Data

Various profiles for current data were given in the Metocean report [3]. For the purposes of the fatigue analysis, the 1 year non-cyclonic current profile could have been has been used as shown in Figure 3-12.

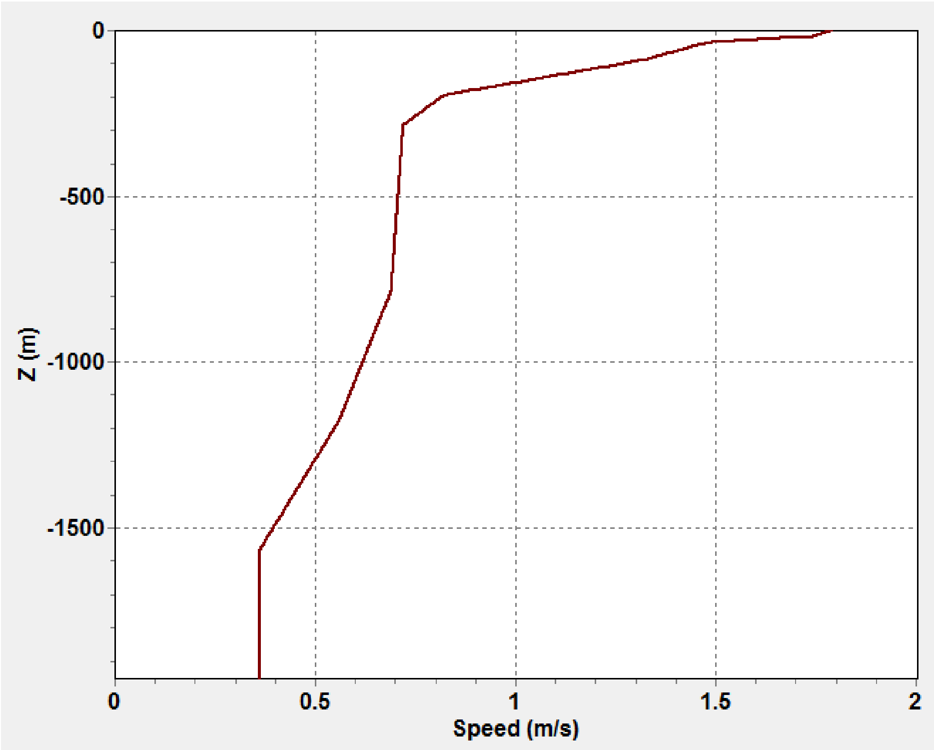

Figure 3-12 - 1-year Non-cyclonic Current Profile

However, on further inspection of the Metocean report, it was apparent that applying this current profile would be over-conservative for normal operation. For fatigue analysis, the Metocean report also lists 200 current profile bins ranked in order of descending occurrence. The surface current in each of the bins was either 0.2m/s, 0.6m/s or 1.0m/s; the first was most common and the last occurred rarely. To more accurately, but still conservatively, represent the current profile within Orcaflex, the average profile of the 10 most commonly occurring 0.6m/s profiles was used. This current profile was applied collinearly with each sea state in order to give the worst-case bending, see Figure 3-13.

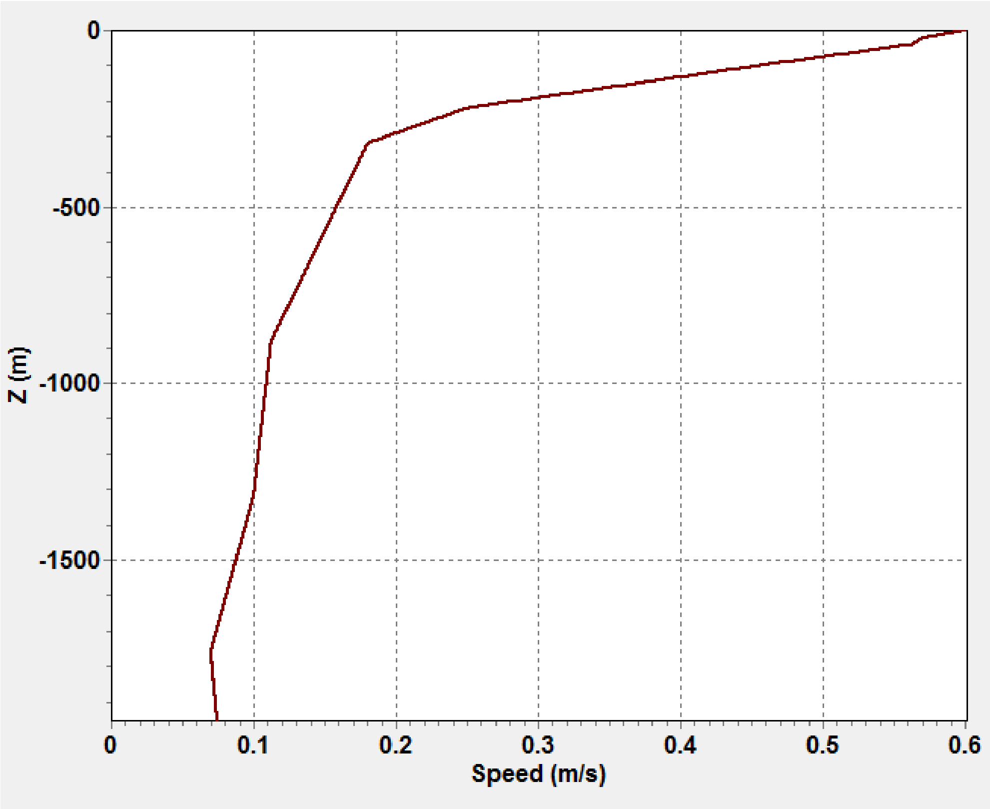

Figure 3-13 - 0.6m/s Averaged Current Profile

3.4.2 Wave Data

The methodology for obtaining the operation sea-state climate is outlined in the Metocean report [3]. This data was summarised and supplied in the manner of Hs-Tp scatter tables, from which regular wave bins representing the sea-state can be obtained. A set of regular wave heights and periods was generated, sufficient to accurately model the sea state. The Orcaflex wave scatter tool was then used to generate occurrence data for each bin. The accuracy of the wave scatter tool was controlled by the "probability covered" value, which was set to 0.98. This ensures that at least 98% of the energy of the original sea state is captured by the regular waves.

The data given in [10] gives the occurrence data in terms of probability. However, it does not give the probability associated with each wave heading. Thus, to calculate the expected number of cycles on a yearly basis, the values in Table 3-3 (taken from [6]) were used. The fatigue bins created by the Orcaflex scatter tool are shown in Table 3-4.

Dir. (°N)	Tp (sec)														
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	Total
0	0.00	0.01	0.19	1.38	1.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.68
30	0.00	0.05	0.95	4.22	4.56	0.85	0.08	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	10.75
60	0.00	0.18	1.51	3.61	3.40	1.54	0.26	0.21	0.10	0.03	0.03	0.00	0.00	0.00	0.00	10.89
90	0.00	0.20	1.48	5.23	7.83	3.46	0.97	0.40	0.24	0.05	0.03	0.03	0.02	0.01	0.00	19.95
120	0.00	0.30	4.50	5.63	5.44	4.57	2.10	0.90	0.35	0.19	0.06	0.03	0.01	0.00	0.00	24.09
150	0.00	0.19	3.93	9.43	5.07	4.46	2.89	0.93	0.25	0.09	0.02	0.00	0.00	0.00	0.01	27.28
180	0.00	0.01	0.27	1.37	1.66	0.64	0.15	0.04	0.02	0.01	0.00	0.00	0.00	0.00	0.00	4.16
210	0.00	0.00	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
240	0.00	0.01	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
270	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
300	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
330	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
Total	0.00	0.99	12.90	30.92	29.03	15.57	6.46	2.50	0.97	0.38	0.16	0.07	0.03	0.01	0.01	100.00

Table 3-3 - Wave Occurrences with Direction

As the vessel considered weathervanes, there was no need to run the analyses for each wave heading. Rather, the waves were run in one direction as the vessel will always turn head-on to the incoming wave. This has two main benefits for the analyses – it allows the fatigue to be concentrated around the same hotspots for each wave considered and it significantly reduces the number of load cases considered.

Total Number of Occurrences														
Height (m)														
9			17.41	18.16	4.52									
7		47.71	612.70	482.67	118.11	18.89	2.79							
5		2543.17	14101.61	8531.22	2183.42	480.36	108.60	27.48	7.97	2.98	0.95			
3	554.69	104148.43	204743.25	91910.04	28364.61	8768.20	3017.94	1186.13	528.52	308.97	164.32	78.39	41.89	24.31
1	1467838.65	2152726.48	1244684.14	495087.73	197910.89	87655.26	43582.85	24016.06	14394.59	11125.41	7864.14	4848.09	3194.19	2214.58
Period (s)	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**23**	**26**	**29**	**32**

Table 3-4 - Number of Occurrences

There is a slight discrepancy in that the totals given in Table 3-3 suggest there are waves coming from 270° - 330°. The data given in [11] does not show any wave occurrences from these directions. However, as the sum of probabilities for these directions is 0.1% in Table 3-3, these waves are deemed negligible and the analysis has not considered these occurrences.

Note that Table 3-4 refers to the combined occurrences for all wave directions. Intervals of 2m have been used for periods between 2s-20s, which are then widened to 3m between 20s-32s. This widening has been carried out in order to reduce the number of fatigue bins whilst keeping the probability covered sufficiently high.

The simulations were run for at least 4 wave cycles, which is long enough to achieve cyclic convergence. To obtain the total fatigue damage on the hose, the occurrence data for each direction was summed with respect to each H (height) vs T (period) pairing. Probability data supplied by EMSTEC [12] was used to calculate the fatigue damage on the hose, which can be interrogated at the request of EMSTEC to obtain the directional fatigue if required.

4 Results

4.1 Wire

The fatigue life of the wire was calculated using the method outlined above. Figure 4-1 shows the variation of fatigue life along the full length of the hose. The minimum life indicated on Figure 4-1 is 49,000 years, which occurs at the connection to the vessel. However, as the hose wire does not start immediately at the vessel connection, it is necessary to take the fatigue life at a point at least 0.25m away from this position. At an arc length of 0.25m, the fatigue life was 100,000 years.

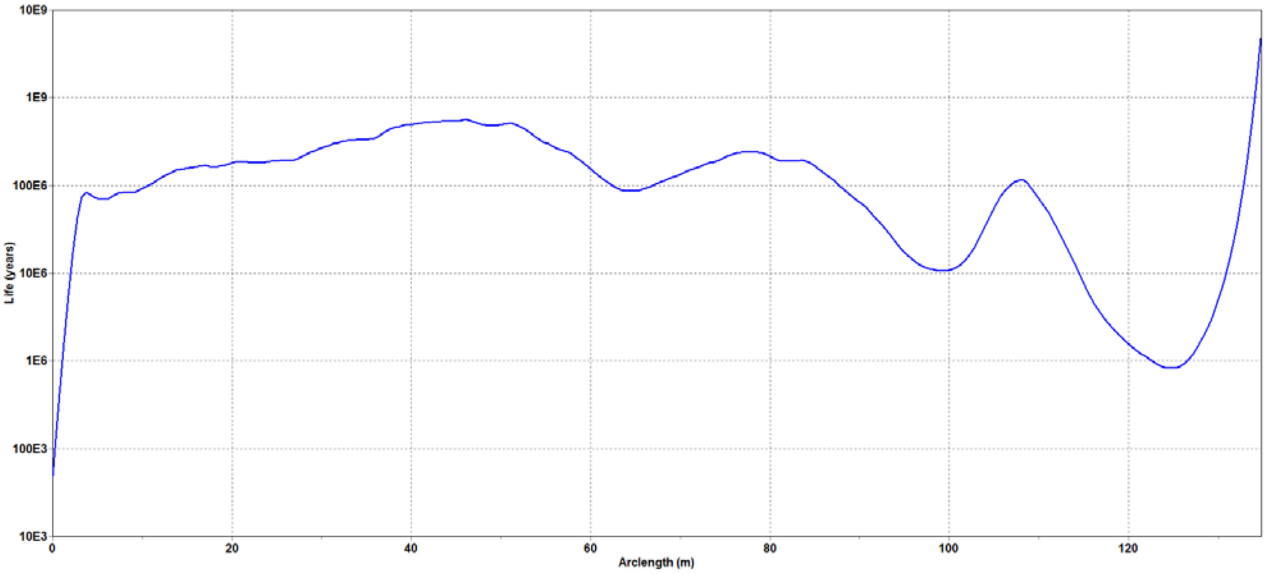

Figure 4-1 - Fatigue Life of Wire-reinforced Hose

4.2 Studs

Figure 4-2 shows the variation in life along the arc length of the hose. Note that the points plotted are the position of the flanges, taken to be at 9.0m intervals along the hose length.

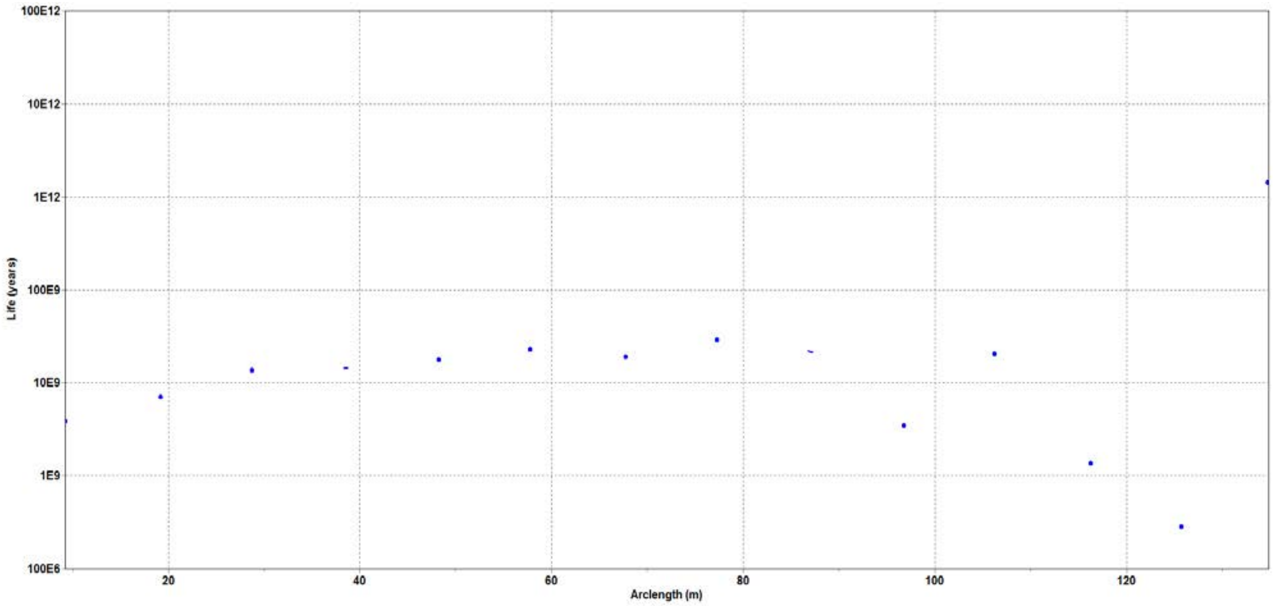

Figure 4-2 - Fatigue Life of Bolts at Flange Locations

The maximum fatigue damage for the bolts occurred at an arc length of 126m, with a calculated life of 2.8E8 years.

4.3 Welds

The minimum fatigue life for the welds occurred at the connection to the vessel, with an expected life of 3,900 years. This value is obtained by using the DNV D curve, modified to account for R=-1 as discussed in Section 3. Because the analysis accounts for mean stress effects, which are only present in the top weld, the fatigue life over the arc length cannot be provided as it would be inaccurate for all welds beyond the first.

5 Conclusions

A fatigue analysis was carried out on a 135m length of EMSTEC bonded, flexible, cooling water suction hose. The work carried on from [1], where a full global analysis was carried out on a textile-reinforced hose. For this analysis, the textile (drawn polyester) reinforcement was changed to steel, with 20-off layers reduced to 6-off, the nominal fibre diameter decreased from 1.4mm to 1.14mm, the fibre pitch decreased from 2.22mm to 1.67mm and the overall OD of the hose reduced from 1220mm to 1880mm. All other aspects of the analysis were kept constant. From the results, the following conclusions can be drawn:

- The minimum hose (steel reinforcement) life was found to be 100,000 years at a location of 0.25m from the vessel connection.
- The minimum flange stud life was found to be 2.8E8 years.
- The minimum flange weld life was found to be 3,900 years.
- New local analysis methodologies [2] were used to obtain the bending and axial stiffnesses as well as the bending and axial stress factors. It is believed that these updated values are more accurate than those previously used. Appendix A therefore revisits the results from PDL-EMS-667-002 [1].
- All fatigue lives were found to be acceptable, the hose is considered fit for purpose for the expected environmental conditions.

6 References

[1] PDL-EMS-667-002 (2), '40" Suction Hose – Fatigue Assessment – Global Analysis', 02-04-15.

[2] PDL-EMS-727-001 (1), '40" Suction Hose with Steel Reinforcement – Fatigue Assessment – Local Analysis', 21/10/15.

[3] Metocean Design Basis for Floating FLNG (Coral) Issue 5, 25-08-14.

[4] E-mail from Ian Craig to Martin Sharkey containing details of marine growth profile, 07-01-15.

[5] PDL-EMS-667-003 (1), '40" Suction Hose Fatigue Assessment Local Analysis', March 2015.

[6] DNV-RP-C205, 'Environmental Conditions and Loads', October 2010.

[7] API-RP-2SK, 'Recommended Practice for Design and Analysis of Stationkeeping Systems for Floating Structures', March 1997.

[8] EMSTEC e-mail received from Ian Craig, 'RE:Analysis', 07-08-15.

[9] DNV-RP-C203, 'Fatigue Design of Offshore Steel Structures', October 2012.

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[11] EMSTEC Data Book: 4130105/701147-DB-15, 23-04-13.

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[14] SQDU 141 (3) – 40 inch suction hose fatigue assessment.

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[16] 'Cord Elongation Test C012 C014 B&A.xls', received from EMSTEC 23-01-15 by e-mail.

[17] Norsok Standard M-123 (1), 'Forged Structural Steel', 2003.

[18] 'SHIN1509042854MR.PDF', received from EMSTEC 23-09-15 by e-mail.

7 Appendix A – Hose with textile reinforcement

This section updates the results from [1] with more recent S-N data supplied by EMSTEC [13] and new bending and axial stiffnesses generated using the same methods used in [2]. The updated fatigue curve was generated based on testing eight specimens of yarn post vulcanisation. Because of the small number of specimens, a number of different confidence intervals were provided rather than standard deviation data. For the purpose of this analysis, a best fit line was plotted through the test data in order to derive an appropriate S-N curve with a straight line on log-log axes. This best fit line was then shifted such that the minimum life was 1/20th of the mean life. This is considered to be conservative for the purpose of this study.

The S-N curve developed was modified to account for the effect of mean stress by making use of the Goodman correction method. The test data supplied correlated with R = 0.1, whereas Orcaflex requires data for R = -1; thus, the S-N curve was adjusted to account for this. The final S-N curve used in Orcaflex is shown in Figure A-1: the gradient is 8.05 and the log 'a' value is 22.2. Goodman correction was switched on and the UTS value was taken as the lowest from a sample of 10 specimens (568N [16], equivalent to 369 MPa based on a nominal diameter of 1.4mm).

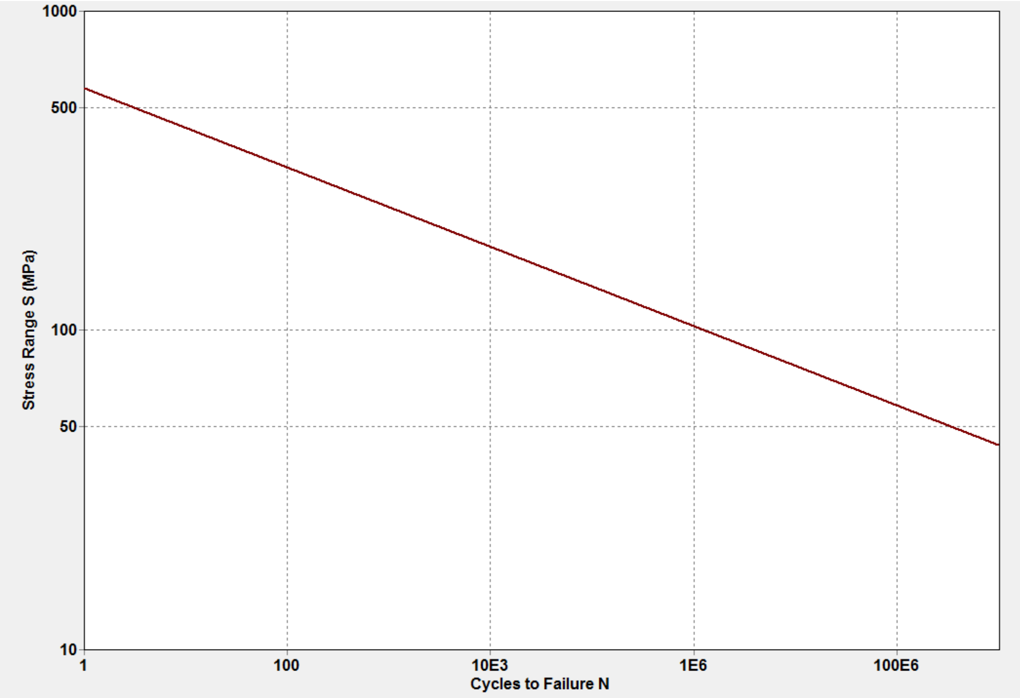

Figure A-1 - S-N Curve for Textile-reinforced Hose

Details behind the generation of the stiffness values for the wire-reinforced version of the hose are outlined in [2]; the same techniques were applied to the textile-reinforced version. The bending stiffness of the textile-reinforced version of the hose was found to be approximately 10% higher than the wire-reinforced version (probably because of the larger outside diameter) but the axial stiffness was found to be considerably less i.e. around 15% to 20% of the wire-reinforced version for tensions in the region of interest (see Figure A-2). This apparent discrepancy arises because the bending stiffness is dominated by the rubber properties whilst the axial stiffness is dominated by the fibre properties.

Because of the new analysis technique, new stress factors had to be used in the analysis. New curvature/tension vs stress plots were generated using the methods in [2]. For the textile yarn, these gave axial and bending stress factors of 27.65MPa/MN and 640 MPa/rad/m respectively. The weld and fastener bending stress factors (when considered as stress versus curvature) also increased slightly because of the higher bending stiffness of the textile-reinforced version.

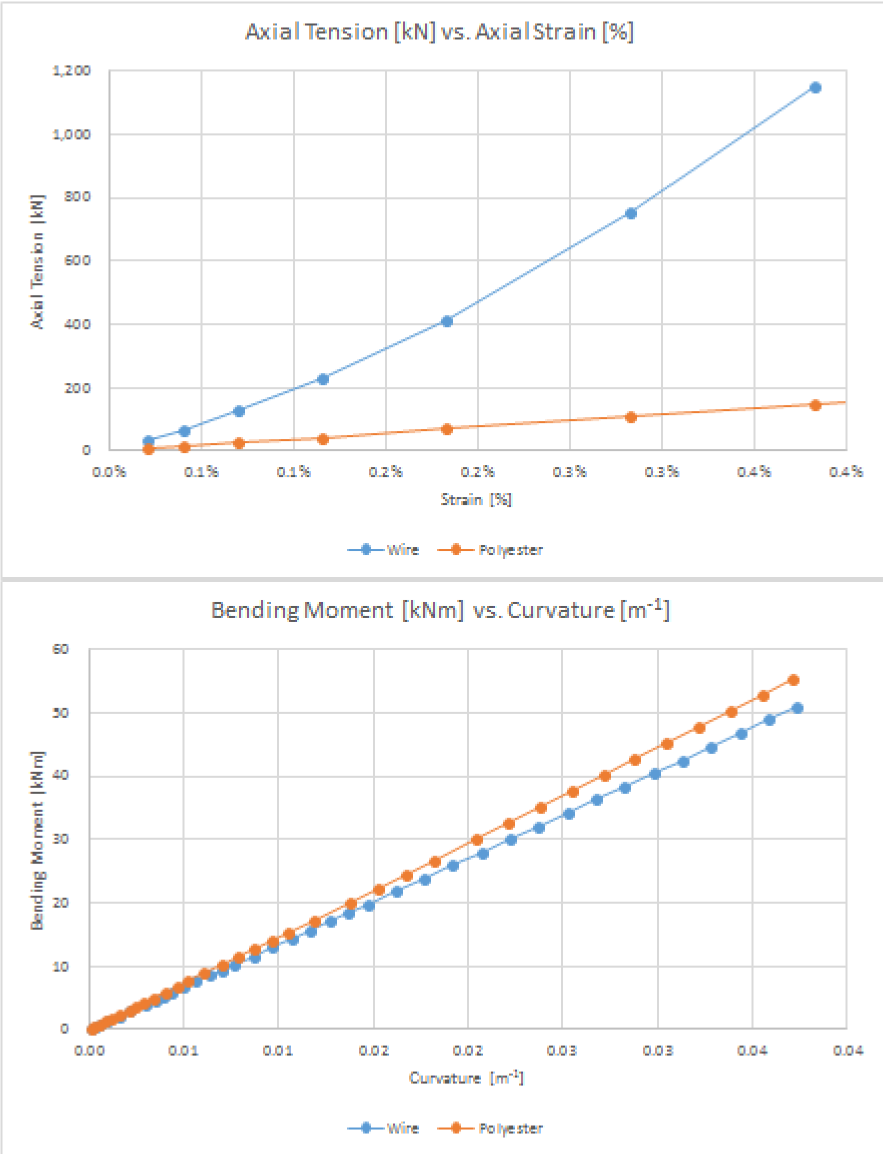

Figure A-2 - Comparative Stiffness Data

Using the same environmental data as used in the main body of this report the fatigue life of the textile yarn was calculated along the full length of the hose. The fatigue life was also calculated at the position of the welds. Table 5 outlines the results of this revised assessment.

Component	Minimum Life (Years)	Arc length (m)
Textile (yarn)	41E6	0
Fasteners	1.3E9	126
Welds	2,200	0

Table A-1 - Textile-reinforced Hose Revised Component Fatigue Lives

From Table 5, it can be seen that all components have a sizable margin against fatigue failure i.e. the 250 year target. Thus, the textile-reinforced hose (modelled using the revised techniques and using the updated fatigue curve) is considered fit for purpose.

Section 8.0: Hydrodynamic Analysis Report

SEAWATER INTAKE RISERS FOR
FLOATING LIQUEFIED NATURAL GAS (FLNG) VESSELS

IAN CRAIG

HYDRODYNAMIC ANALYSIS

Submitted in partial fulfilment of the requirements
of the University of Sunderland for the degree of
Professional Doctorate

June 2018

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ABBREVIATIONS & ACRONYMS

API	American Petroleum Institute
Cd	Drag Coefficient
DNV	Det Norske Veritas
ESDU	Engineering Sciences Data Unit
FLNG	Floating Liquefied Natural Gas
FPSO	Floating Production Storage & Offloading
HDPE	High Density Polyethylene
NB	Nominal Bore
RAO	Response Amplitude Operators
Re	Reynolds Number
SWIR	Seawater Intake Riser
VIV	Vortex Induced Vibration

1. INTRODUCTION

This report investigates the structural characteristics of the Sea Water Intake Risers (SWIR) under consideration. In particular, two aspects are investigated, namely, the strength and the fatigue characteristics.

The analyses makes use of the industry accepted software package Orcaflex by Orcina, details of which can be found at www.orcina.com.

The software package enables the geometric and response characteristics of an FLNG vessel to be modelled by way of Response Amplitude Operator (RAO) data. The physical and structural properties of each element within the SWIR can be assigned and the SWIR modelled and connected to the vessel. Once the model is built, appropriate environmental conditions can be simulated, i.e. the form, magnitude and direction of the wave and currents.

The outputs from the resulting simulations can then be extracted and the structural loads induced into the SWIR can be compared against the allowable values to verify the strength of the SWIR. The same software can also be used to determine the expected loads and occurrences induced into the SWIR during the course of its service life and compare them against the S-N data for each material to verify the fatigue capabilities of the SWIR.

1.1. Executive Summary

A number of SWIR configurations were modelled and subjected to a preliminary analysis to determine the most optimum configuration in terms of stability and loading into the vessel.

A more detailed analysis was then performed on the selected configuration to verify the in-service strength and fatigue capabilities of the SWIR. The analysis included a number of sensitivities such as geographical location, vessel size, riser length and riser damping.

The analysis suggests that the selected configuration is suitable for the intended applications in terms of strength and fatigue, although the expected life of certain components within the SWIR is close to the typical service life of such a system.

2. CONFIGURATION SELECTION

Using the materials under consideration for the SWIR (ref. Doctoral Report section 5.0) the 40"NB x 500m long SWIR configurations shown in Fig. 2-1 were modelled.

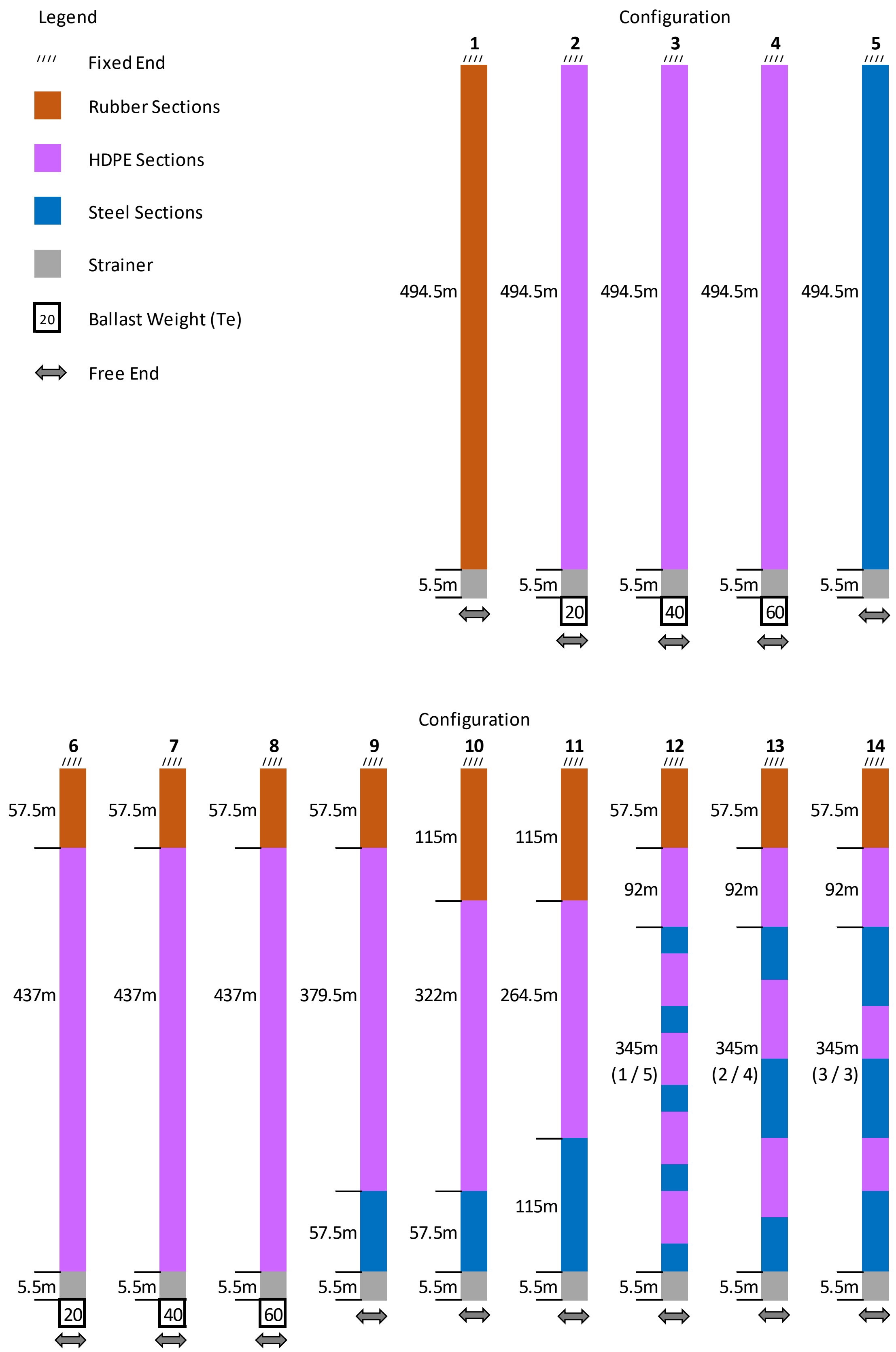


Fig.2-1: SWIR Configurations

Configurations 1 to 5 are uniform cantilevers, that is the material is the same for the complete length of the SWIR and are included in the preliminary analysis primarily for comparison against the non-uniform configurations 6 to 14. The non-uniform configurations consist of a combination of materials to form the SWIR. It should be noted that configurations 2, 3 and 4 are all HDPE uniform risers but with differing ballast weights attached at the lower end. HDPE has positive buoyancy therefore a ballast weight is required to prevent the SWIR from 'floating' to the surface. Configuration 6 to 14 all consist of flexible rubber sections at the upper end as, from the authors experience of systems on FPSO vessels, this is where the largest axial and bending loads occur. For configurations 12, 13 and 14, the lower section consists of alternating steel and HDPE sections in the ratios shown (e.g. 1/5 = 1 Steel section after every 5 HDPE sections).

2.1. Preliminary Analysis

2.1.1. Boundary Conditions

The models of the above configurations were built in Orcaflex and 'free flooding' with zero internal pressure selected. The upper end of the SWIR was set as 'fixed' and the lower end 'free'.

Full details of the input data are shown in the Model Data Files presented in Appendix A.

2.1.2. Static Analysis

A static analysis was performed so that the natural frequency of each SWIR configuration could be obtained by a modal analysis of the results.

2.1.3. Dynamic Analysis

A dynamic analysis of the SWIR configurations was performed to identify the stability of the line in terms of vortex induced vibration (VIV) response and lower end excursion due to current plus the comparable loadings in to the vessel connection point.

A series of uniform currents from 0.1m/s to 1.5m/s were simulated for 500s to ensure that the VIV response became settled. The Orcaflex 'Milan Wake Oscillator' tool was selected for each configuration as this has shown good correlation with experiments for uniform currents.

2.2. Results

2.2.1. Natural Frequency

The natural frequency of each configuration was extracted from the static analysis and are plotted below in Figs. 2-2 & 2-3. As the natural frequency of configuration 5 (uniform steel SWIR) is exceptionally high, it is omitted from Fig.2-3 for clarity.

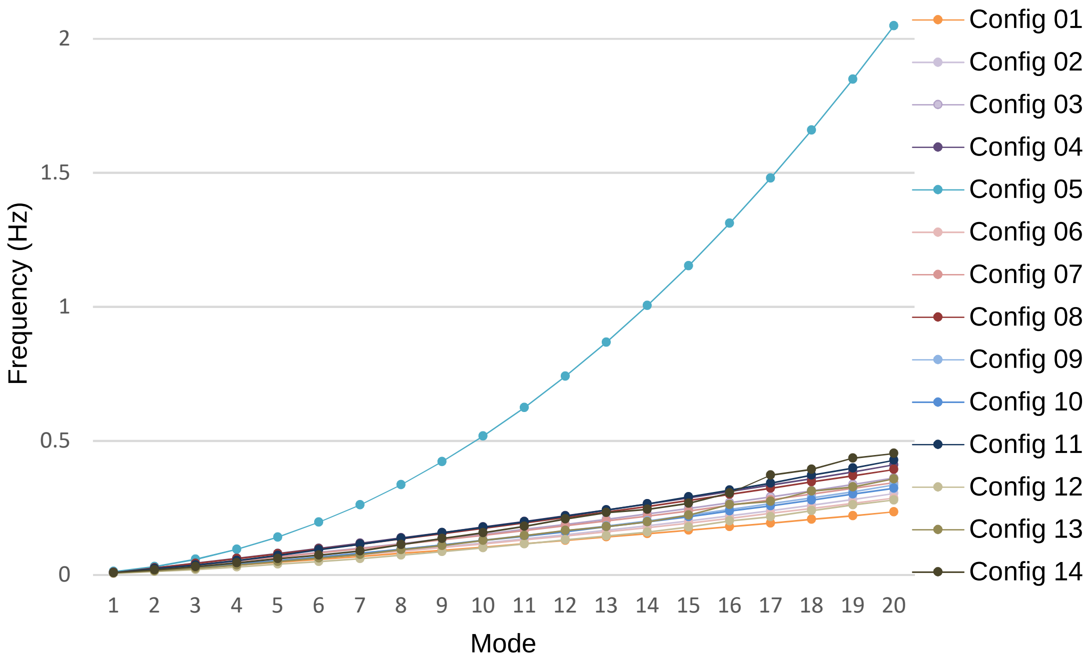


Fig.2-2: Natural Frequency of SWIR Configuration

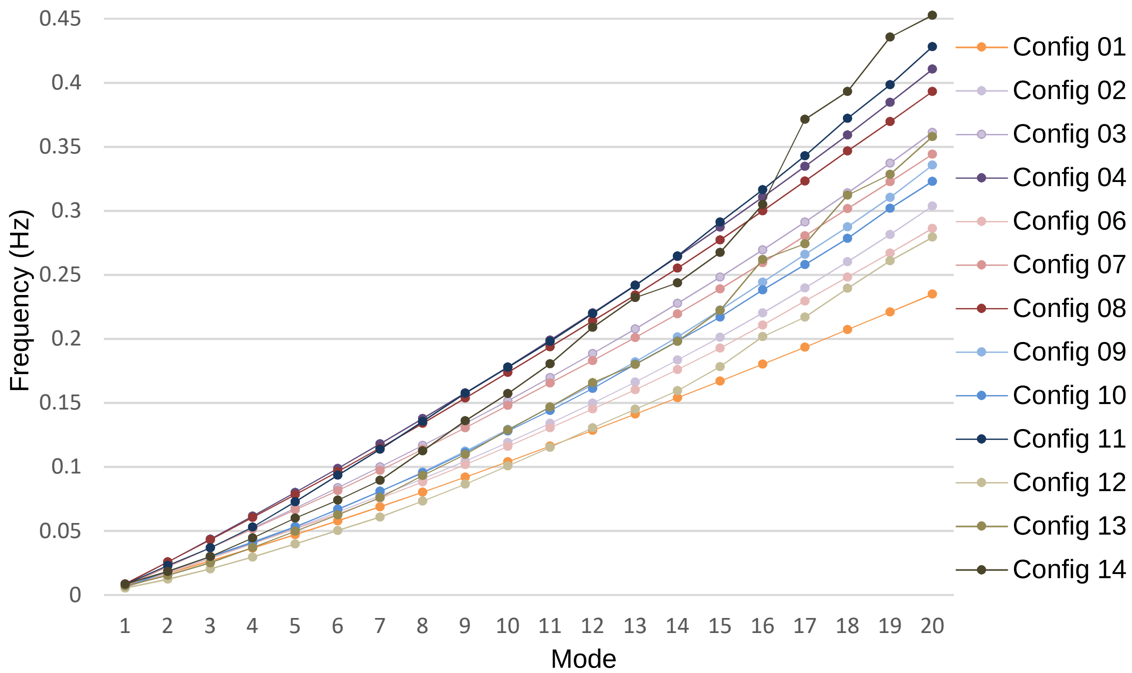


Fig.2-3: Natural Frequency of SWIR Configuration (excl. 5)

2.2.2. VIV Response

The VIV response time history for the riser mid point is shown in Fig.2-4 which shows the response to be established and settled after 500s.

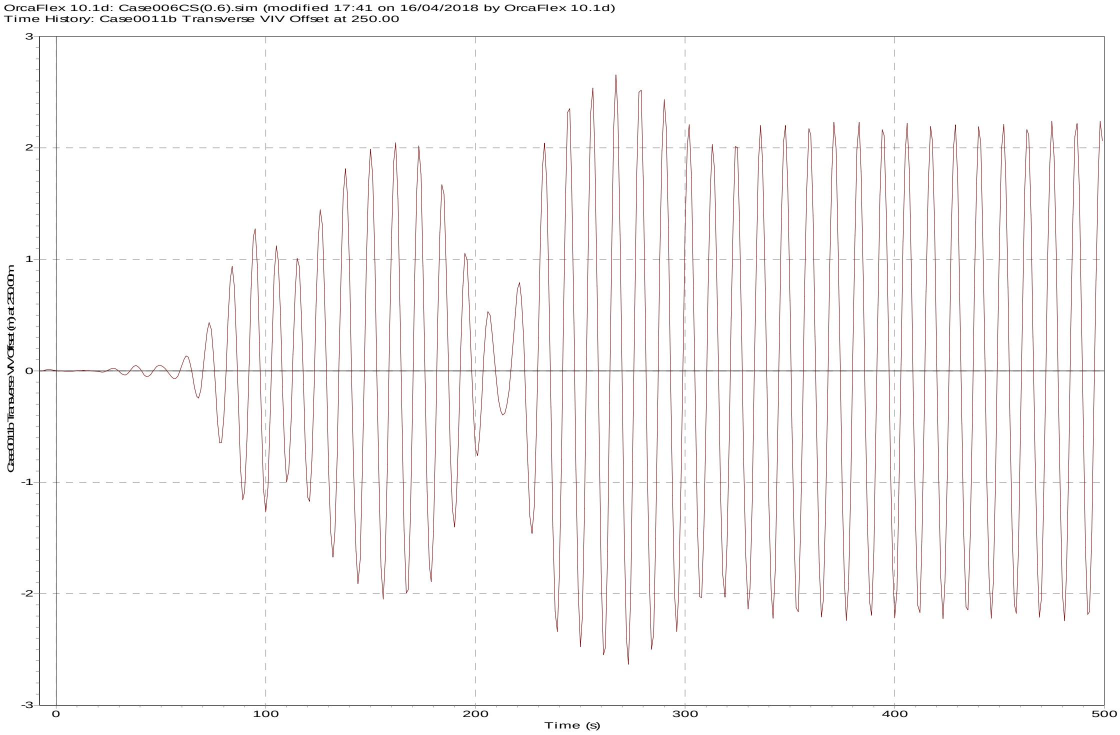


Fig.2-4: SWIR Mid-Point Time History

The VIV response of each configuration was extracted from the dynamic simulations in the form of maximum VIV offset amplitude and maximum VIV offset curvature and are plotted below in Figs.2-5 and 2-6 respectively:

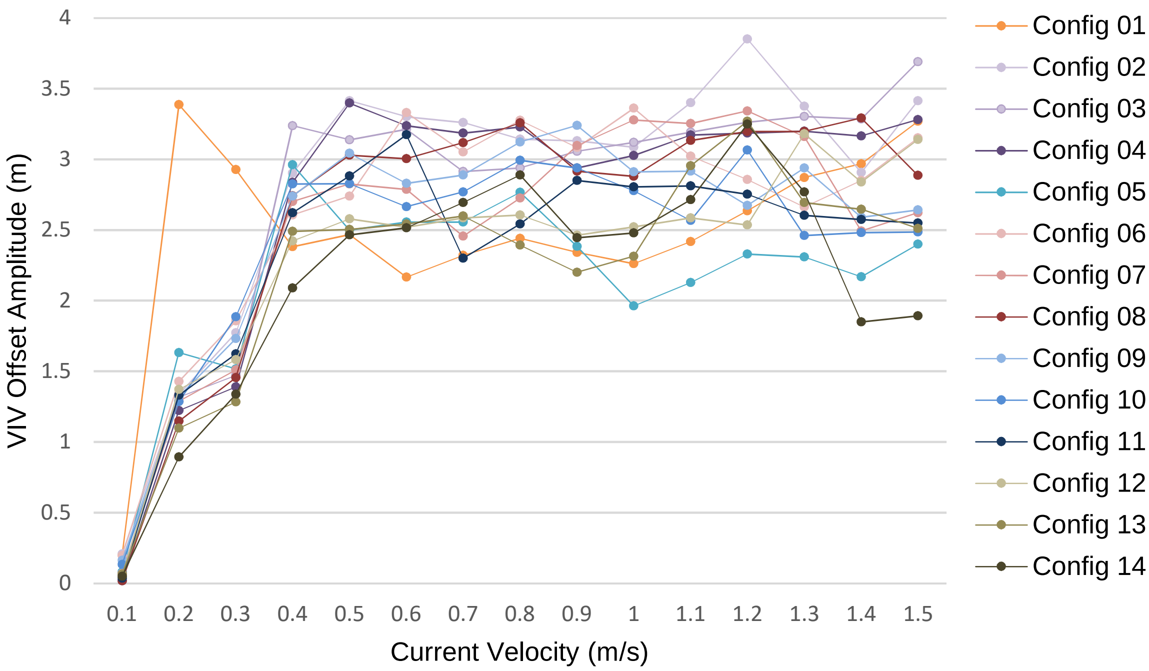


Fig.2-5: Maximum VIV Offset Amplitude of SWIR Configurations

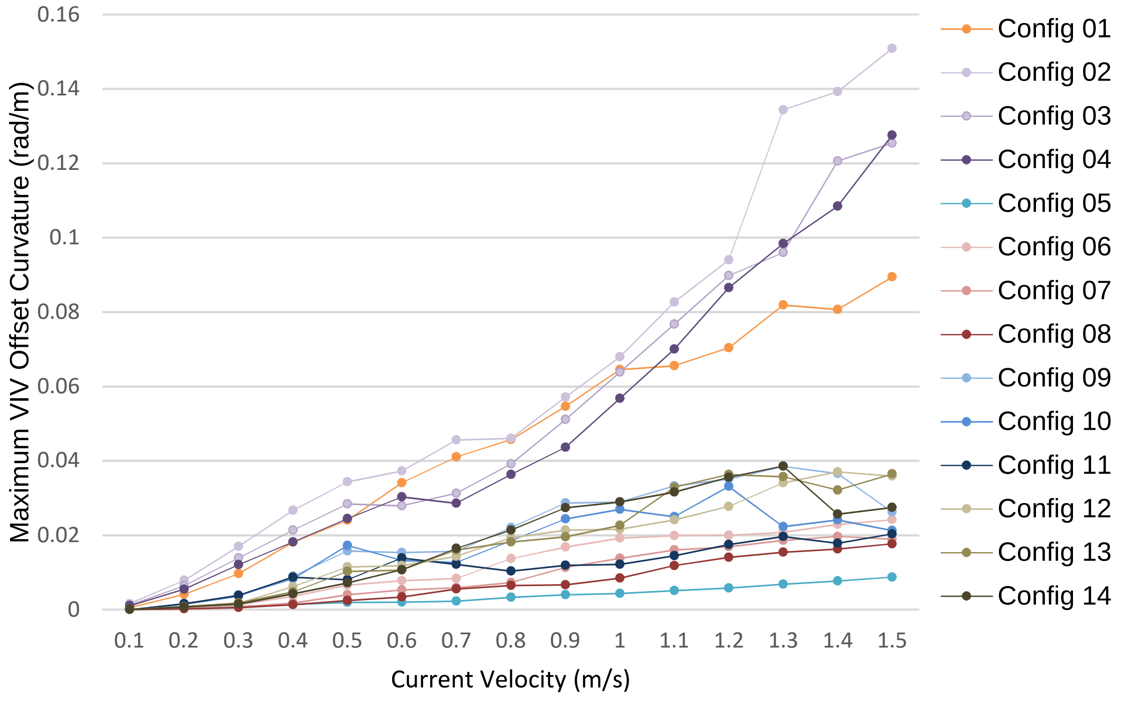


Fig.2-6: Maximum VIV Offset Curvature of SWIR Configurations

2.2.3. Lower End Excursion

The maximum lower end excursion in metres was extracted from each of the dynamic simulations and are plotted below in Fig.2-7.

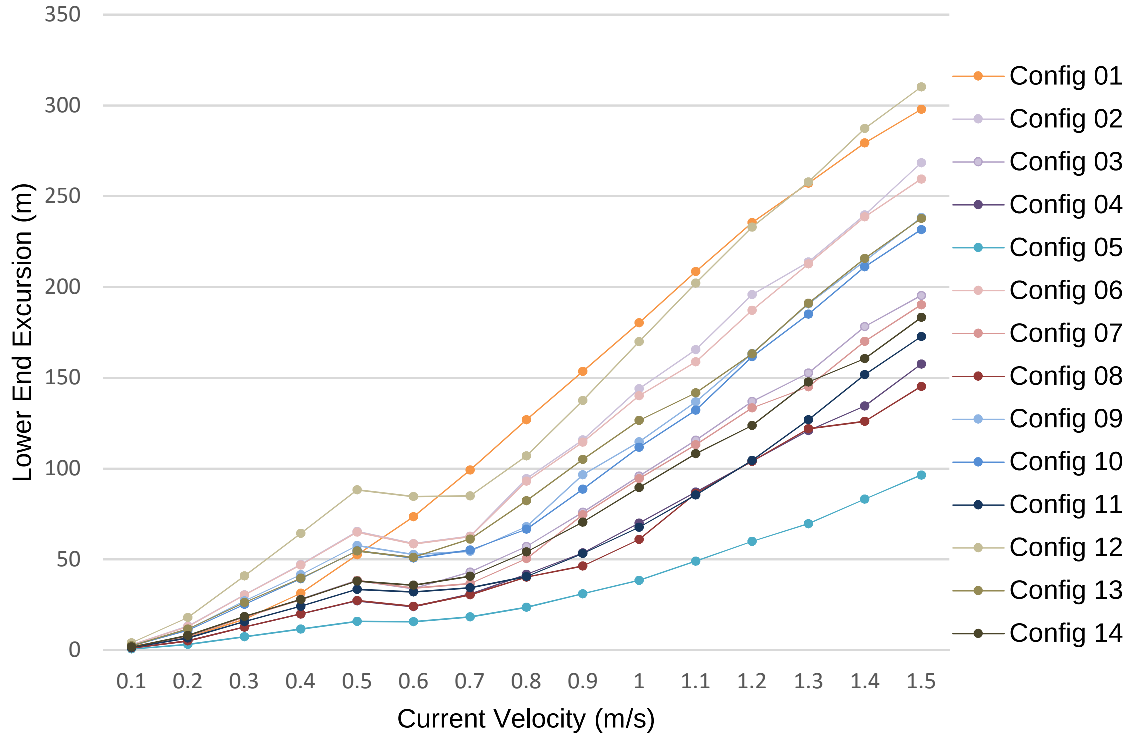


Fig.2-7: Maximum Lower End Excursion of SWIR Configurations

2.2.4. Loading into Connection Point

The maximum loads into the hull connection point in terms of tension and bending moment were extracted from the dynamic analysis for each configuration and are plotted below in Figs. 2-8 thru 2-11. As the loads from configuration 5 (uniform steel SWIR) are exceptionally high, they are omitted from Figs.2-9 and 2-11 for clarity.

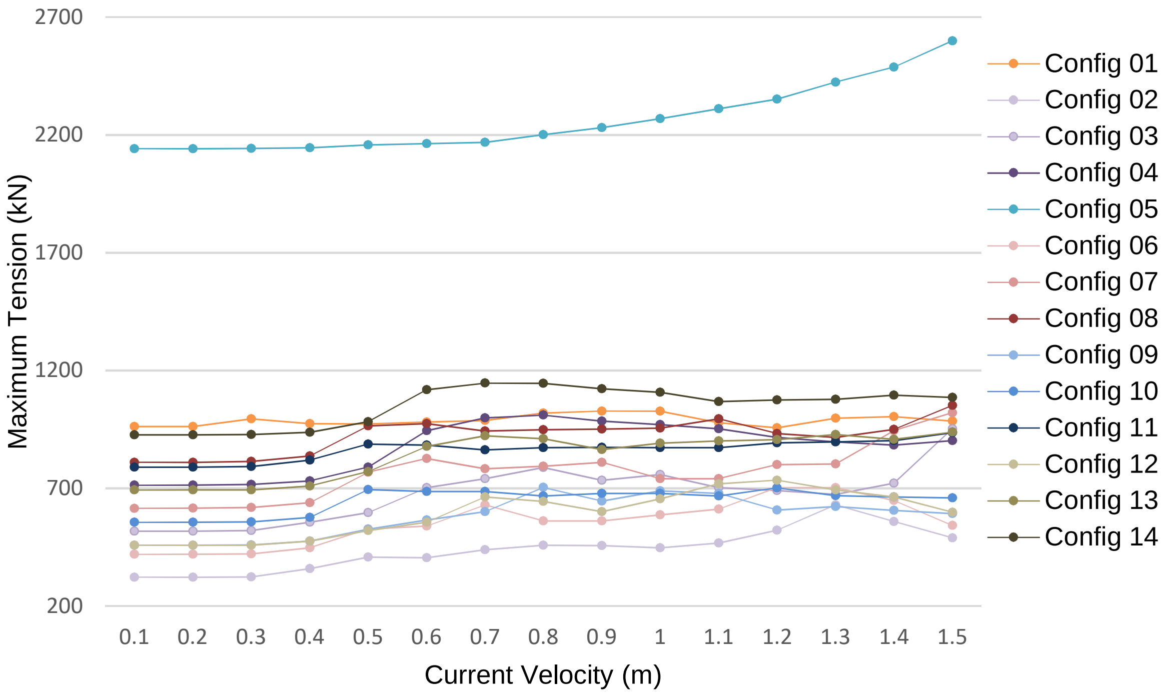


Fig.2-8: Maximum End Tension of SWIR Configurations

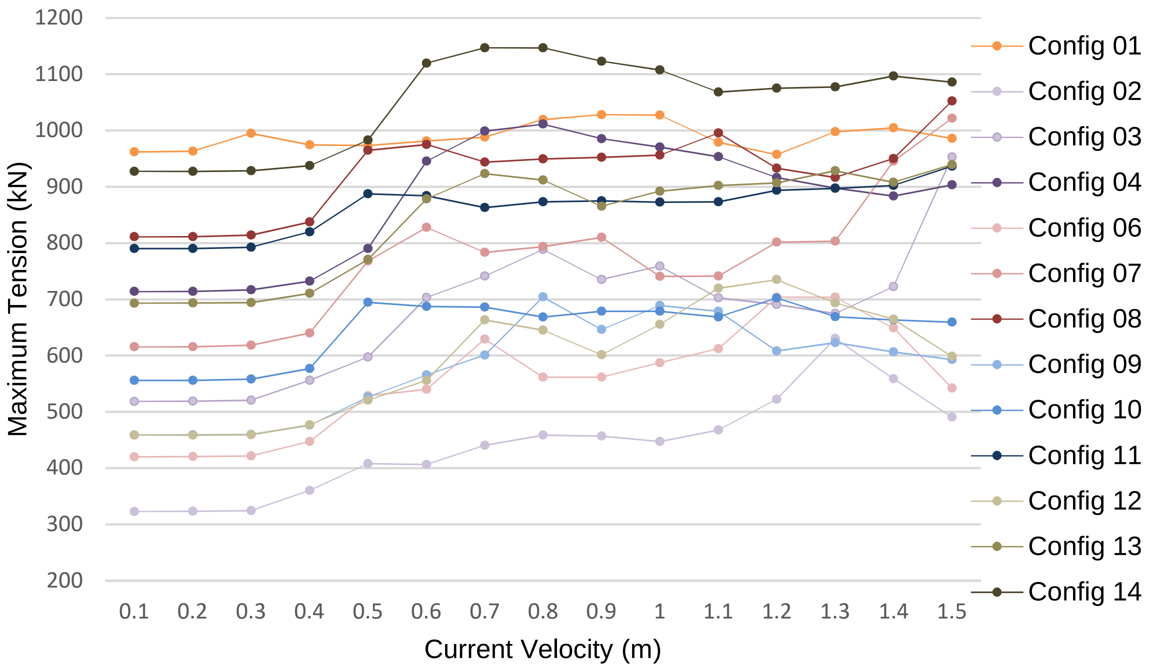


Fig.2-9: Maximum End Tension of SWIR Configurations (excl. 5)

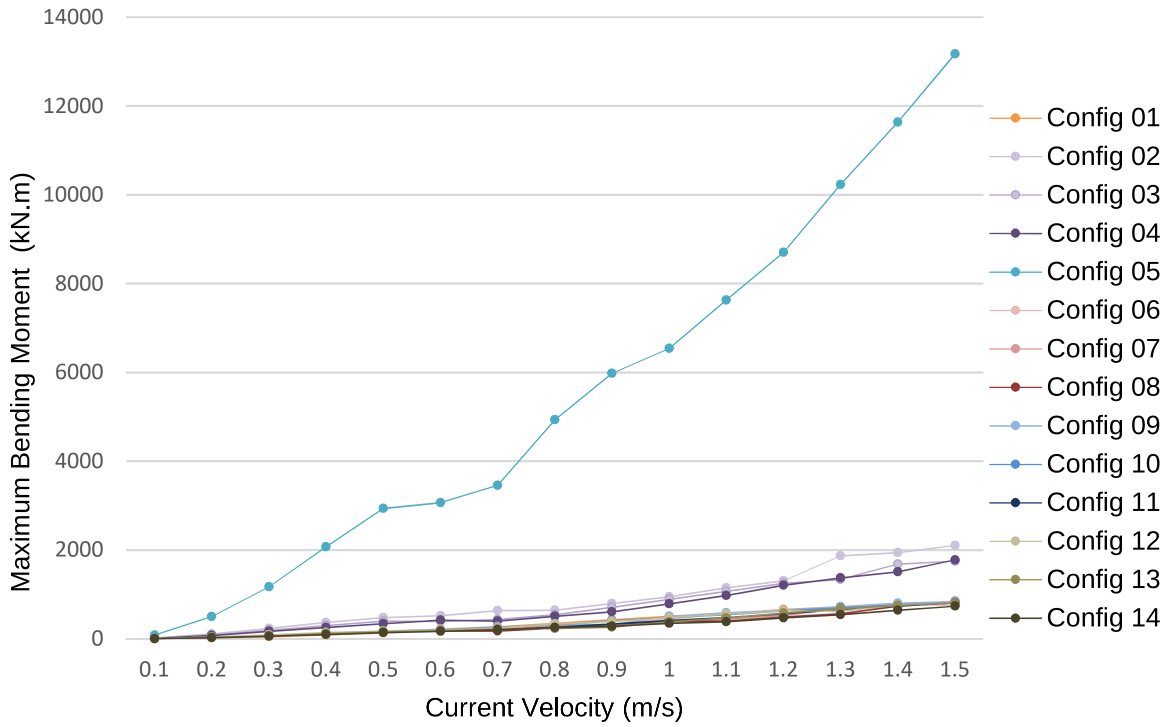


Fig.2-10: Maximum Bending Moment of SWIR Configurations

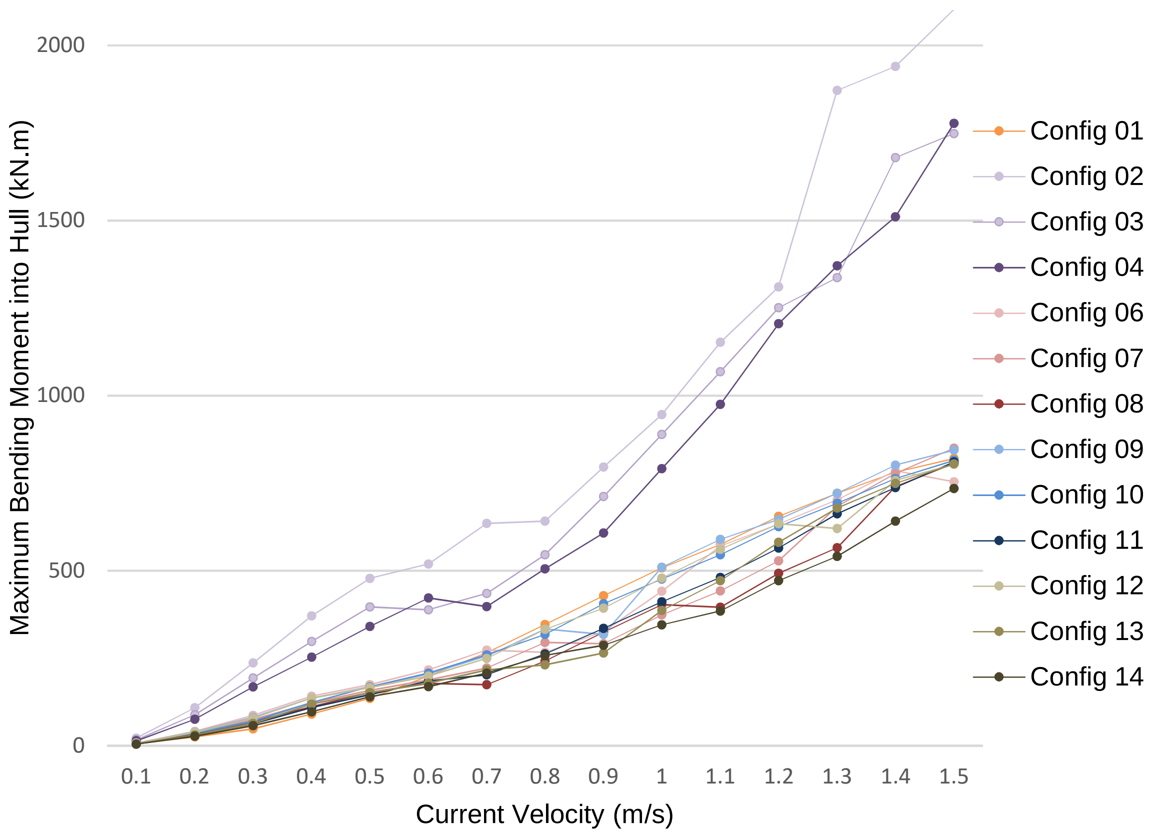


Fig.2-11: Maximum Bending Moment of SWIR Configurations (excl. 5)

2.2.5. Discussion

From the above analyses the following observations can be made. With the exception of configuration 5 (uniform steel SWIR), the natural frequencies of each of the configurations are in a similar range but can be sub-divided into three groups, where configuration 01 has the lowest natural frequencies then configurations 2, 3, 6, 7, 9, 10, 12, and 13 in the mid-range and with configurations 4, 8, 11 and 14 having the highest natural frequencies. Configuration 1 (uniform rubber SWIR) is the most flexible riser so would expect to have the lowest natural frequency. It can also be seen from configurations 2, 3 and 4 and also 6, 7 and 8 that, as more weight is added, the riser becomes stiffer and the natural frequencies increase accordingly which is also expected. Generally, the lower the natural frequency, the lower the number of oscillations if the SWIR is excited and theoretically lower cyclical damage, therefore a low natural frequency would be preferred.

From the VIV response plots, it can be seen, for current velocities above 0.4m/s, the VIV offset amplitudes range from 2m – 3.5m for nearly all of the configurations, and apart from configuration 5 (lowest) and configuration 2 (highest) the varying offsets of the remaining configurations means they cannot be easily sub-grouped. However, from the VIV offset curvature plot, it can be seen that configuration 5 (uniform steel SWIR) has the lowest curvature which, being the most rigid, would be expected. After that, configurations 6, 7, 8 and 11 have the next lowest VIV offset curvatures with configurations 10, 12, 13 and 14 slightly higher. Configurations 1, 2, 3 and 4 have the highest range of VIV offset curvatures. The curvature is examined because, for a common VIV offset amplitude, the lower the curvature, the lower excitation mode of the riser, so theoretically, if the SWIR is excited, the lower the cyclical damage due to bending. Therefor a lower VIV offset curvature would be preferred.

The lower end excursion plots show that, again, configuration 5 (uniform steel SWIR) has the lowest excursion which being the most rigid would be expected. After that, the configurations can be divided into three sub-groups, with configurations 3, 4, 7, 8, 11 and 14, having the lowest excursions, then configurations 2, 6, 10 and 13 in the middle group with configurations 1 and 12 having the highest excursions. To reduce the possibility of the SWIR interfering with other risers and mooring lines, a minimal lower end excursion is preferred.

From plots showing the loadings into the connection point, it can be seen that configuration 5 (uniform steel SWIR) has values significantly higher than the other configurations which due to its weight and rigidity would be expected. For the tension into the connection point, with the exception of configuration 2 (lowest) and configuration 14 (highest), the remaining configurations can be sub-divided into two groups. Configurations 3, 6, 7, 9, 10 and 12 having lower tensions (although configurations 3 and 7 increase dramatically at the highest current velocities) and configurations 1, 4, 8, 11, and 13 having higher tensions into the connection point. For the bending moments into the connection point, with the exception of configurations 2, 3 and 4 which have the highest values, the remaining configurations all have similar values and cannot be readily divided into sub-groups.

2.3. Summary

In summary, the most optimum configuration is determined as follows. Due to the excessive loads into the connection point configuration 5 can be discounted.

Configurations 3, 4, 7 8 11 and 14 have the lowest lower end excursion and from these configurations 7, 8 and 11 have the lowest VIV offset curvatures suggesting the lower cyclical damage. Configuration 7 does have a lower tension into the connection point, but this does increase dramatically at the higher current velocities suggesting erratic stability.

This leaves configurations 8 and 11 which both have natural frequencies in the same higher range but which are still comparatively low. Due to the practicalities of incorporating and handling 60 tonnes of ballast weight offshore in addition to the pipe sections that would be necessary for configuration 8, configuration 11 is selected as the most optimum solution and will be analysed further in the next section.

When building the model of the selected Configuration 11 for a more detailed analysis, a number of test runs were undertaken to verify the accuracy and robustness of the model. These test runs included some fatigue simulations which highlighted a ‘weak’ area at the connection between the lower end of the HDPE and the upper end of the steel pipe sections. This was attributed to the high bending moments from the rigid steel sections being transmitted into the less rigid HDPE sections.

To overcome this, the last HDPE section and the first steel pipe section were replaced by bonded flexible rubber pipe sections which provided a more flexible transition between the HDPE and steel pipe sections. The resulting Configuration 11a being as shown in Fig.2-12 below:

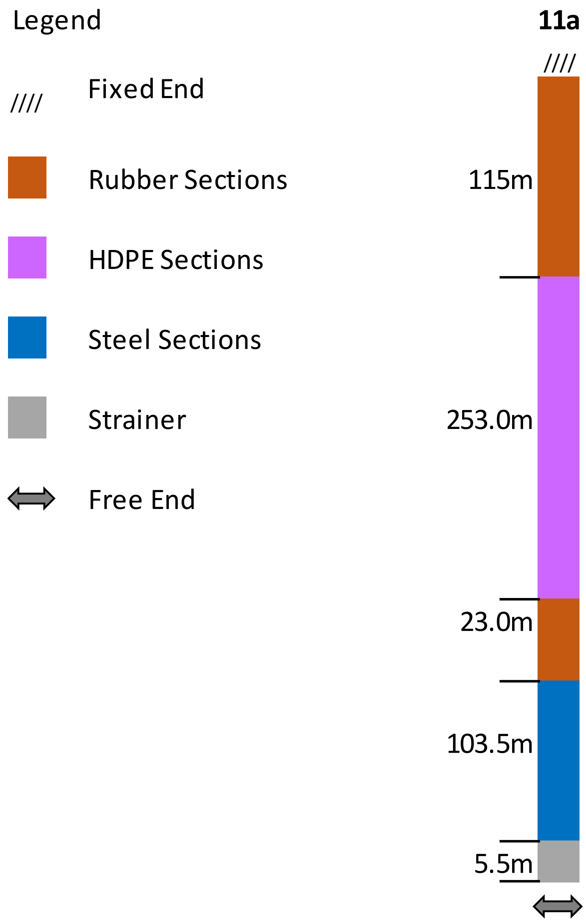


Fig.2-12: SWIR Configuration 11a

To validate this modification, the amended configuration 11a was analysed as described in Section 2.1 and the outputs compared to the original configuration 11 as shown below in Figs.2-13 thru' 2-18.

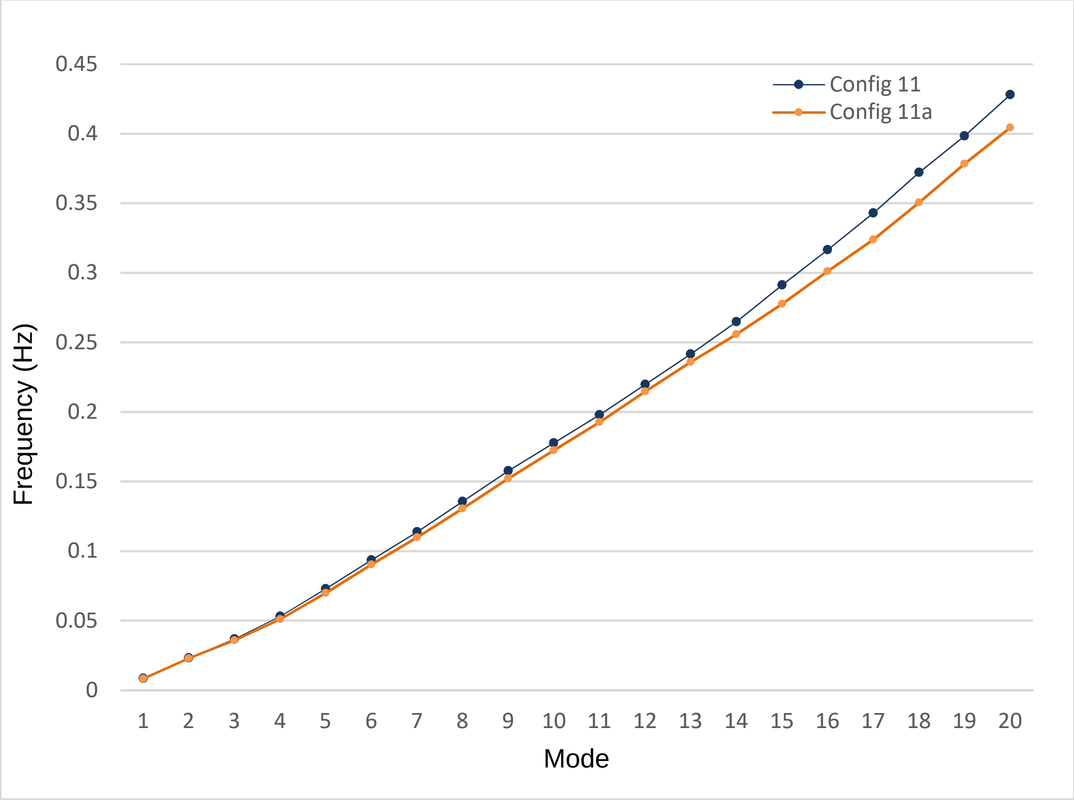


Fig.2-13: Natural Frequency of SWIR Config. 11 v 11a

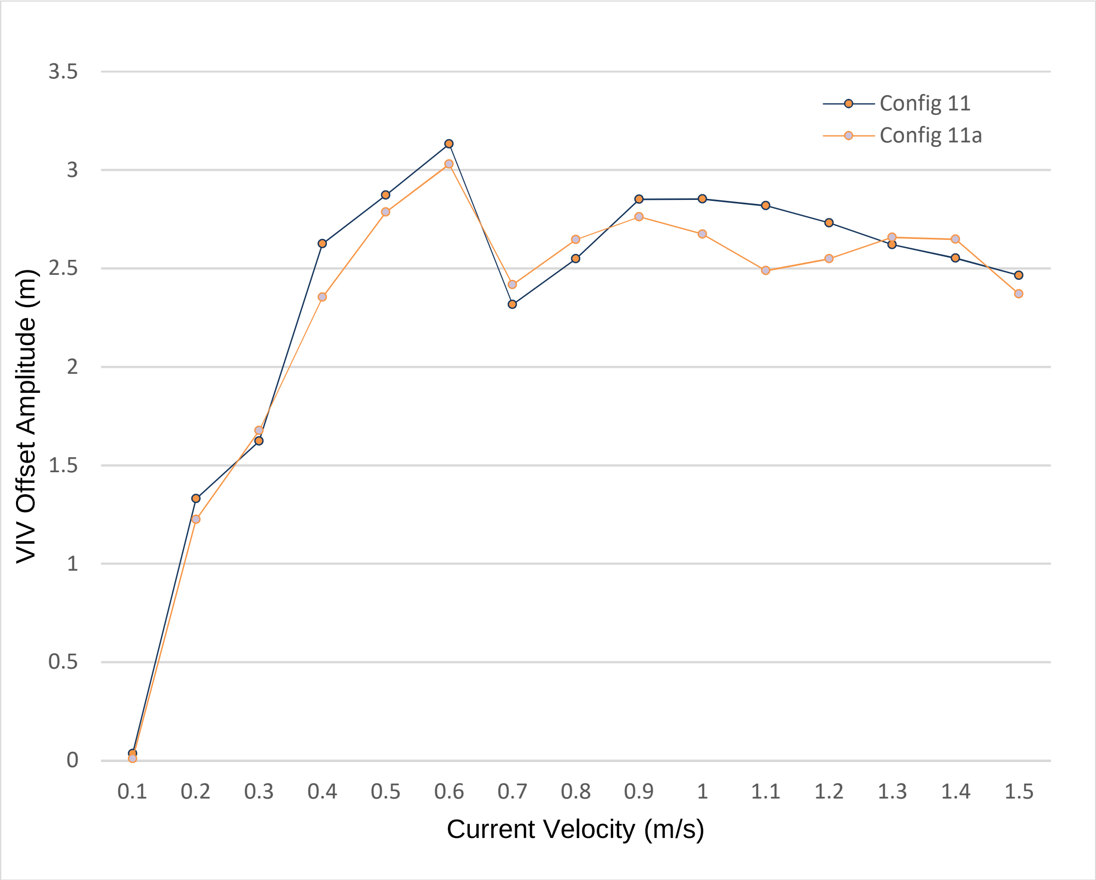


Fig.2-14: Maximum VIV Offset Amplitude of SWIR Config. 11 v 11a

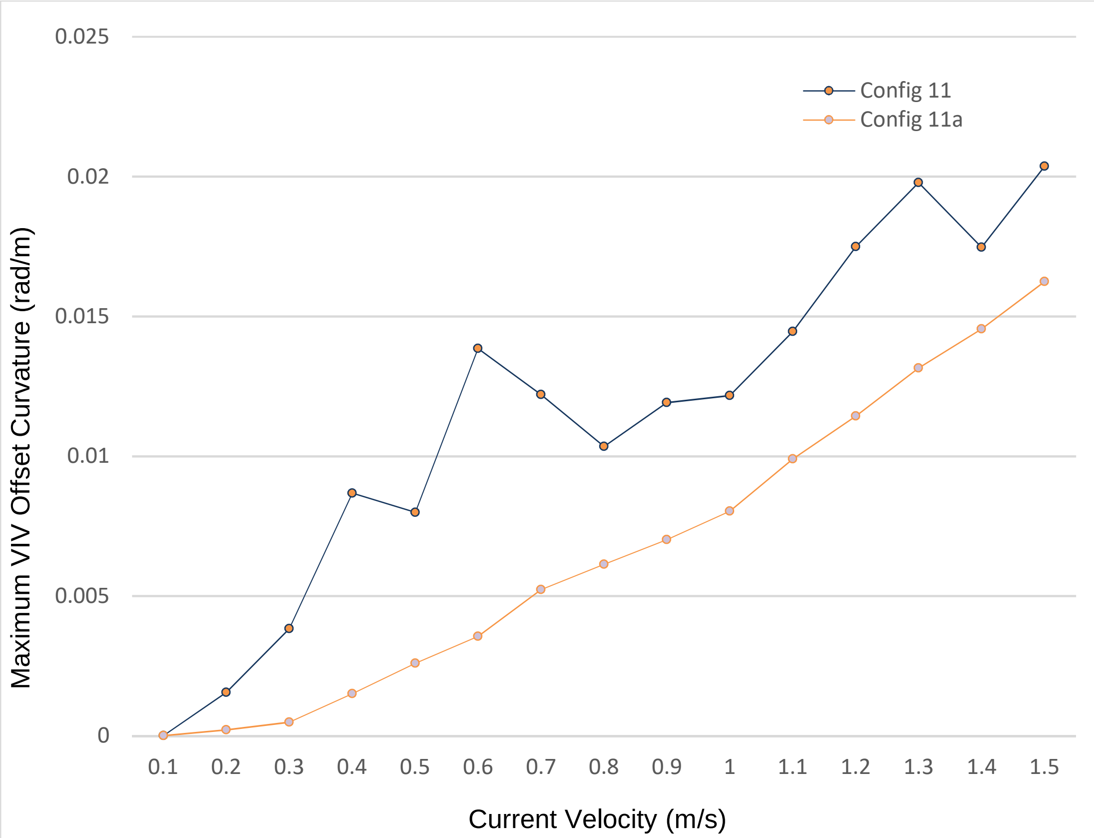


Fig.2-15: Maximum VIV Offset Curvature of SWIR Config. 11 v 11a

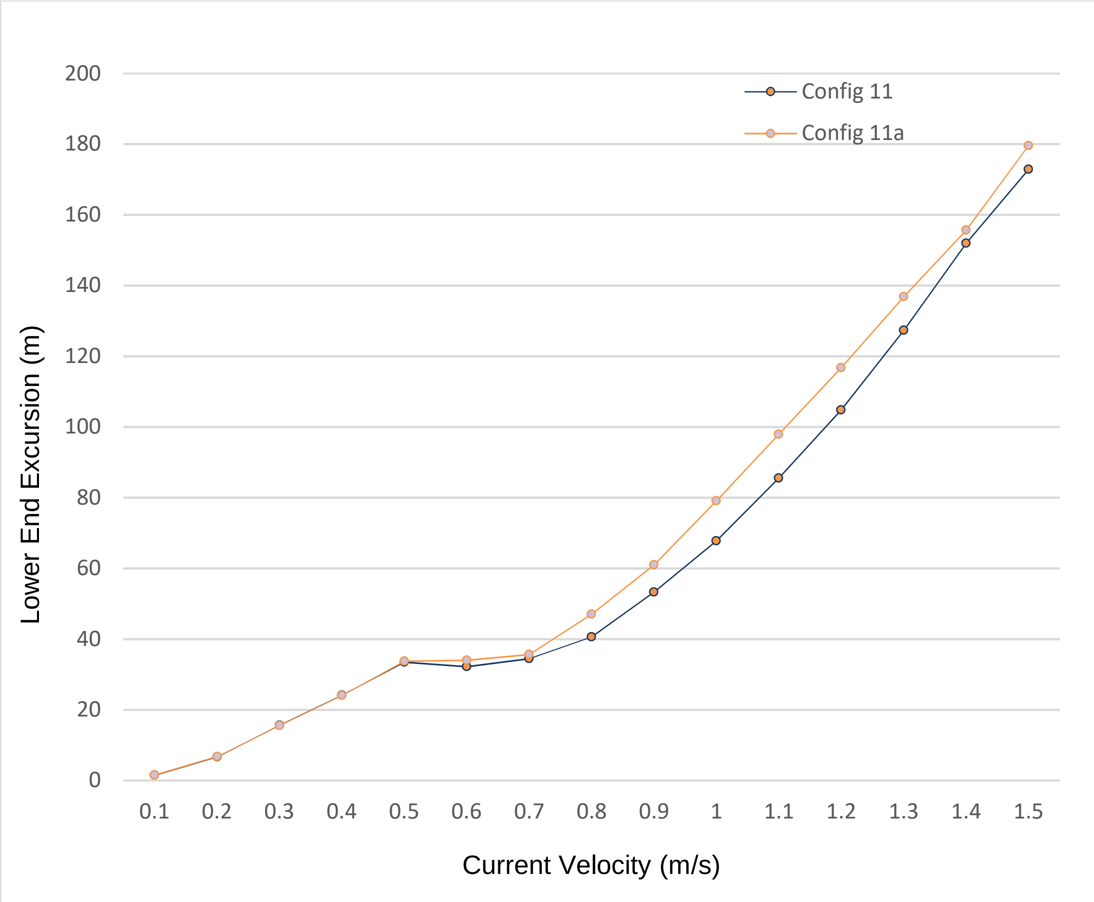


Fig.2-16: Maximum Lower End Excursion of SWIR Config. 11 v 11a

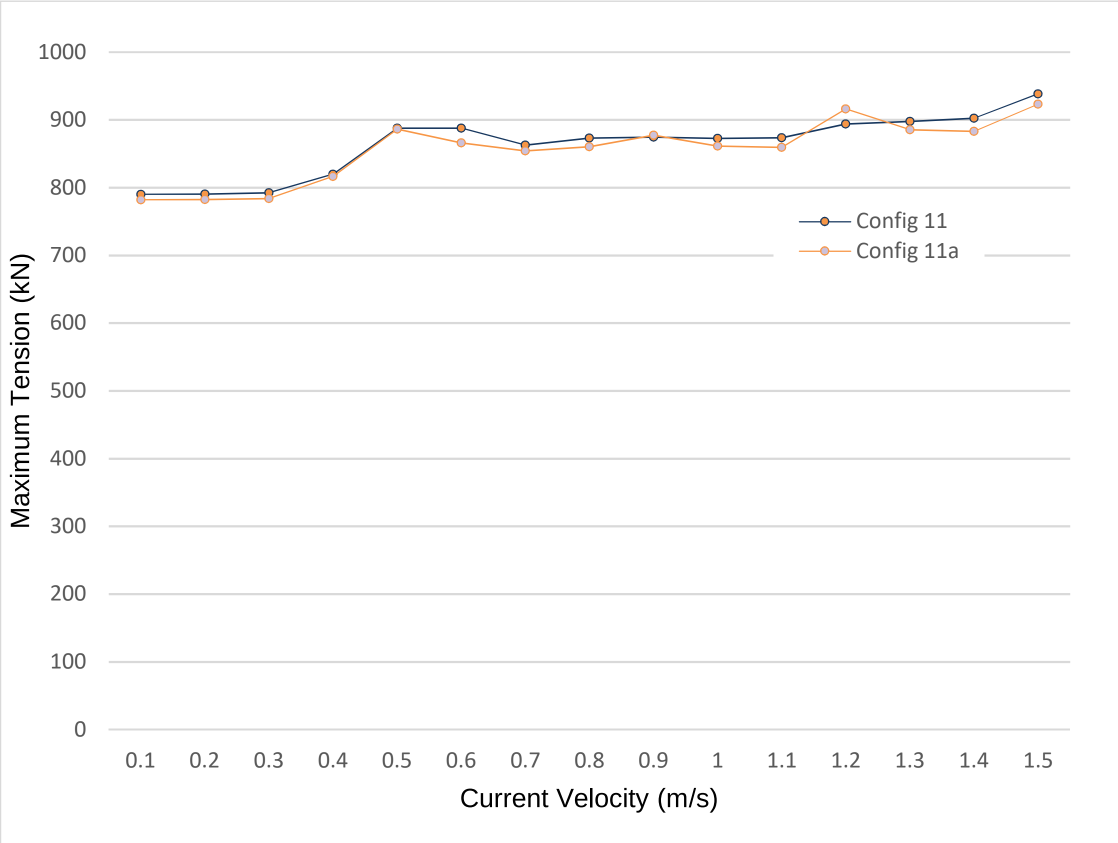


Fig.2-17: Maximum End Tension of SWIR Config. 11 v 11a

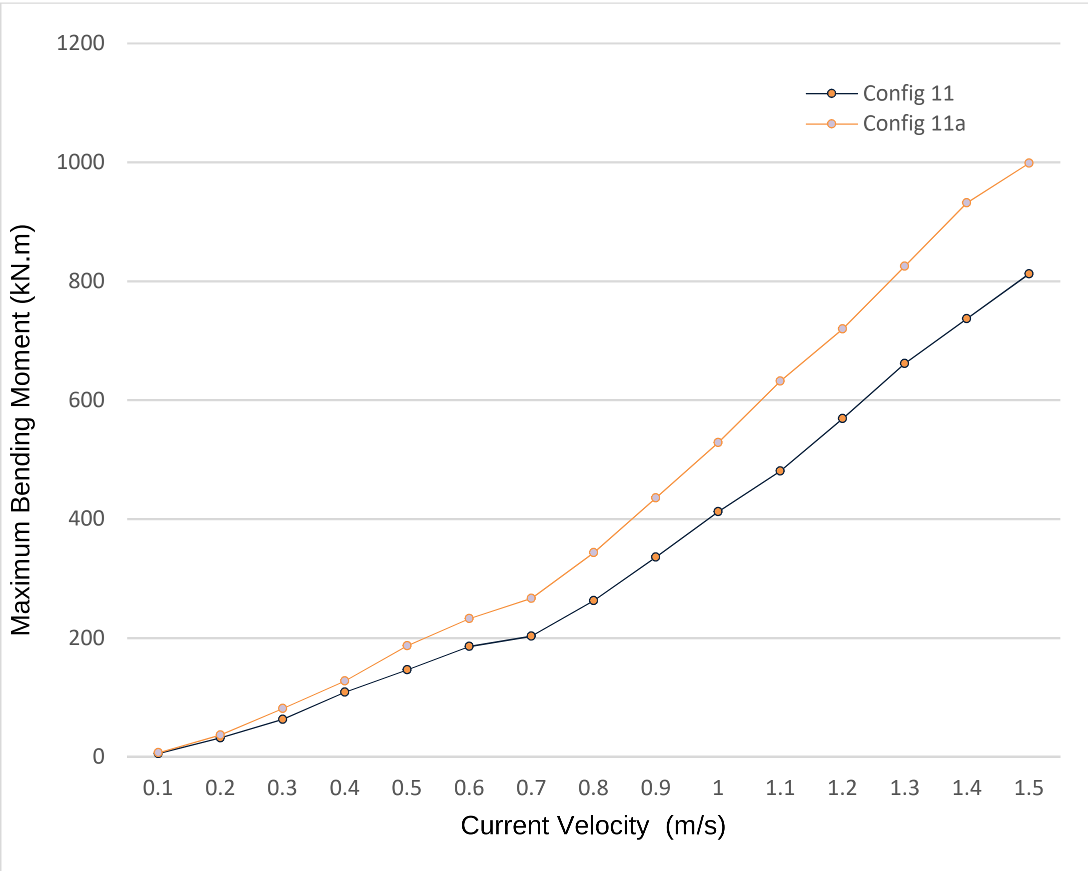


Fig.2-18: Maximum Bending Moment of SWIR Config. 11 v 11a

It can be seen that the impact of the modification is slight with the exception the Bending Moment into the connection point which increases particularly at the higher current velocities. However, the VIV offset curvature is reduced and more consistent which is more desirable in terms of fatigue damage, therefore the original selection rationale remains valid.

The next section presents a more detailed analysis of configuration 11a.

3. INPUT DATA

Based upon the discussion in section 2.0, a more detailed analysis of configuration 11 is performed. Using the materials under consideration (ref. Doctoral Report section 5.0) this analysis considers both a 40"NB x 500m long SWIR and also a 60"NB x 500m long SWIR and is based on the vessel characteristics and environmental conditions of a known and current FLNG project.

Full details of the input data are shown in the Model Data Files presented in Appendix A.

3.1. Vessel Data

The vessel data considered is in the form of an Orcaflex data (.dat) file (Statoil, 2014) and represents a vessel corresponding to a displacement of approximately 370,000m^3 and a length of approximately 425m, which are typical of the FLNG vessels currently under consideration by other operators. The FLNG vessel under consideration is a turret moored vessel as described in the Doctoral Report section 2.8.

The vessel RAO data is taken from a WAMIT output (.out) file (Statoil, 2014) which includes two sets of RAO data namely, Haskind and Diffraction, from which the Haskind set is imported into the Orcaflex .dat file.

3.2. Mooring Line Configuration

A report detailing the mooring system optimisation to maximise the length of the seawater hoses (Statoil, 2014), (sections 2.3.2-2.3.4) is used to model mooring lines.

3.3. Environmental Data

The metocean data considered is taken from a report for a specific gas field in offshore Tanzania (Statoil, 2010). Although each field will have its own metocean data, the data considered is typical for gas fields under consideration by other operators.

3.3.1. Direction Convention

Wave: specified direction is FROM where the waves are coming

Current: specified direction is TO where the current is flowing

3.3.2. Return Periods

With reference to the metocean report (Statoil, 2010), Section 1.3.4, the return periods are identified by the following Annual Probabilities of Exceedance:

Return Period	Annual Probability of Exceedance
1 year	0.63
10 year	10^{-1}
100 year	10^{-2}
10,000 year	10^{-4}

Table 3-1: Return Period v Annual Probability of Exceedance

Environmental data will be referred to by 'Return Period' from hereon in.

3.3.3. Waves

3.3.3.1. Strength Analysis

As suggested within the metocean report (Statoil, 2010), Section 3.4, for short term analysis, the wave data from Table 3.7 is used and reproduced below:

Table 3.7 **Omni-directional extreme significant wave heights and corresponding spectral peak periods; mean values and 90 % confidence bands.**

Annual probability of exceedance	Significant wave height H_S – (m)	Spectral peak period T_P – (s)		
		5 %	Mean	95 %
0.63	2.9	8.5	10.4	12.5
10^{-1}	3.8	9.4	11.1	12.9
10^{-2}	4.8	10.3	11.9	13.6
10^{-4}	6.7	11.6	13.2	14.8

The most consistent estimate for the q-annual probability load/response is obtained by performing a full long term analysis. For the area under consideration, it is recommended that this is done using a POT formulation of the long term response analysis. Time histories for environmental characteristics during storm can be provided. The long term analysis must account both for the variability of the maximum storm response and the long term variability of the storm severity. For early phase considerations, a short term analysis can possibly give results of sufficient accuracy. In case of a short term analysis, one shall select extreme Hs from Table 3.7 together with the most unfavourable period of the period band provided by the table. The duration of the sea state shall be taken as 3 hours, and the q-probability response can be estimated by the 90% value of the 3-hour extreme value distribution for the target response quantity.

Table 3-2: Wave Data – Strength Analysis (Statoil, 2010)

It is generally accepted that the 100yr return period is considered for the analysis, as recommended API 17B (API, 2014) table 9.

As suggested in the footnote in Table 8-2, a sensitivity study was carried out for the 100yr return (10^{-2}) wave to determine the worst-case period between 10.3s and 13.6s as presented in the metocean report (Statoil, 2010), Table 3.7.

The associated maximum wave height (H_{max}) was determined using the Orcina recommendation of:

$$\boldsymbol{H_{max}} = k * Hs * [½ * ln(N)]^{½} \qquad \text{(Orcina, 2014)}$$

where: $N = T/Tz$

$T = 10800\text{s (3 hours)}$

$Tz = Tp / 1.29$

$k = 0.9$

and applied to 5 periods within the range.

The vessel accelerations at the hose connection point were extracted which showed that the most onerous period was the mean Tp (11.9s) which is used for all subsequent analysis.

3.3.3.2. Fatigue Analysis

For the fatigue analysis of the SWIR due to waves, the wave scatter data provided in the metocean report (Statoil, 2010) Table 3.5 is used and is reproduced below:

Table 3.5 Scatter diagram of significant wave height (H_S) and spectral peak period (T_p) for the period 1987 – 2009 (23 years). Duration of sea state is 3 hours.

	Spectral peak period (T_p) - (s)																			
H_S (m)	0-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	> 20	Sum
0.0 0.5				5																5
0.5-1.0		4	56	2215	3653	2310	810	1012	463	121	44	17	21	14	12	5				10757
1.0-1.5		1	96	2702	9106	8808	6696	4931	3396	845	215	84	105	120	53	37				37195
1.5-2.0				198	2622	4631	3299	3789	1438	349	53	29	42	86	37	30				16603
2.0-2.5				2	121	651	686	531	241	29	3	7		2	5	3				2281
2.5-3.0					10	39	68	83	84	3				3	3					293
3.0-3.5						8	10	11	25	3					0					57
3.5-4.0									3	6	1				0					10
4.0-4.5						5				2					0					7
Sum	0	5	152	5122	15512	16452	11569	10357	5650	1358	316	137	168	225	110	75	0	0	0	67208

Table 3-3: Wave Scatter Diagram

(Statoil, 2010)

3.3.4. Current

3.3.4.1. Strength Analysis

For the strength analysis, current profiles provided in the metocean report (Statoil, 2010), Table 4.22 are used and are reproduced below:

Table 4.22 Extreme current profiles at Block 2 Station C3.

	Annual probability of exceedance		
Water depth	**0.63**	**10^{-1}**	**10^{-2}**
m	**cm/s**	**cm/s**	**cm/s**
0	174	188	200
-47	158	171	182
-108	142	152	162
-147	89	94	98
-207	85	91	96
-307	83	89	95
-508	76	82	88
-748	66	72	78
-1008	64	71	77
-1410	40	44	48
-1982	28	31	34

Table 3-4: Current Profiles

(Statoil, 2010)

3.3.4.2. Fatigue Analysis

Vortex Induced Vibration (VIV) occurs when a steady flow of air or water passes a slender structure and forms vortices downstream of that structure. If these vortices become regular and periodic and are close to the natural frequency of the structure, the structure can become excited leading to accelerated fatigue.

For the fatigue analysis due vortex induced vibration induced by the current, the 1 yr (0.63 Annual probability of exceedance) return period as shown in Table 3-4 is used. As this value is a maximum, the profile is factored from 0 to 1 (1 being the maximum) in units of 0.05, and the density of each factor determined using a Weibull distribution.

3.3.5. Marine Growth

Marine Growth data is provided within the metocean report (Statoil, 2010) Section 8, Table 8.1 and reproduced below:

Table 8.1 Marine growth profile estimates. Data are obtained from [8].

Level	Thickness	Roughness	Weight in air	Weight in seawater
m below MSL	**mm**	**mm**	**kg/m^2**	**kg/m^2**
+2	100	50	9.5	3.2
-10	100	50	9.5	3.2
-65	25	18	2.4	0.8
Below -65	0	3	0.0	0.0

Table 3-5: Marine Growth Profile

3.4. Seawater Intake Riser (SWIR) Data

As per the discussion in the Doctoral Report section 6.10, the analysis considers SWIR of two different diameters, i.e. 40”NB & 60”NB. With reference to Section 5.0 of the Doctoral Report, the following material properties are used for the SWIR components.

3.4.1. Material Properties

3.4.1.1. Bonded Rubber Flexible Pipe

- *Physical Properties*

Description	Bonded Rubber Flexible Pipe	
	40”NB	**60”NB**
Outside Diameter (m)	1.220	1.760
Inside Diameter (m)	1.0	1.5
Section Length (m)	11.5	11.5
Section weight [in air] (kg)	6,400	11,990
Section weight [in water] (kg)	2,200	4,145

Table 3-6: Bonded Flexible Rubber Pipe – Physical Properties

- *Mechanical Properties*

Description	Bonded Rubber Flexible Pipe	
	40”NB	**60”NB**
Bending Stiffness (kN.m^2)	2,129	9,122
Axial Stiffness (kN)	17,000	25,500
Axial Strength (kN)	3,141	7,068
Minimum Bend Radius (m)	4.0	6.0

Table 3-7: Bonded Flexible Rubber Pipe – Mechanical Properties

- *Fatigue Properties*

Description	Bonded Rubber Flexible Pipe	
	40”NB	**60”NB**
Tensile Stress Factor (MPa/kN)	0.02765	0.00686
Curvature Stress Factor (MPa/Rad/m)	640	1099
Ultimate Tensile Strength (MPa)	369	369
SN Curve Parameters:	Ref. Fig. 3-1 (-95% Conf Band)	

Table 3-8: Bonded Flexible Rubber Pipe – Reinforcement Fatigue Properties

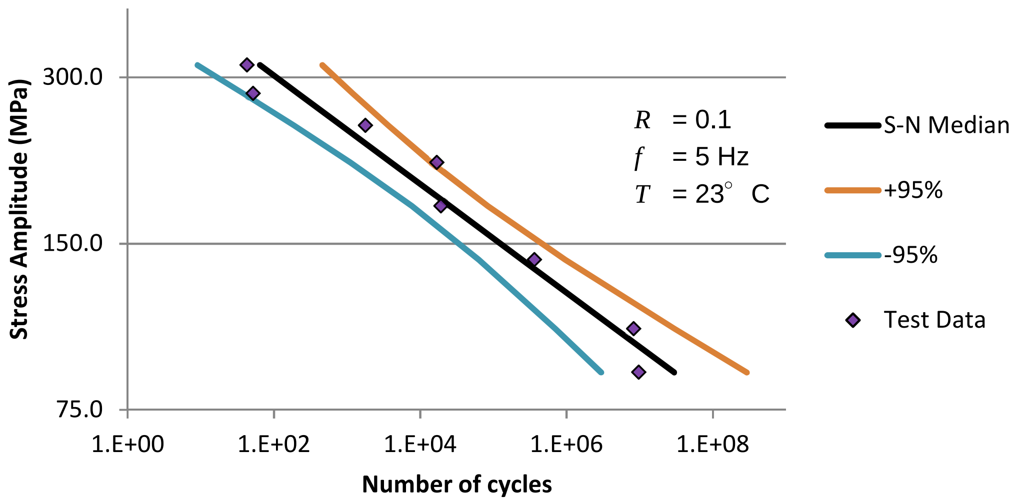


Fig.3-1: Bonded Flexible Rubber Pipe – SN Curve

Flange Weld

Description	Bonded Rubber Flexible Pipe	
	40"NB	**60"NB**
Tensile Stress Factor (MPa/kN)	0.154	0.0689
Curvature Stress Factor (MPa/Rad/m)	0.520	0.1788
SN Curve Parameters: log a1 =	12.164	12.164
log a2 =	15.606	15.606
m1 =	3	3
m2 =	5	5
Fatigue Limit @ 10^7 cycles (MPa)	52.63	52.63

Table 3-9: Bonded Flexible Rubber Pipe Flange Weld – Fatigue Properties

Stud bolts

Description	Bonded Rubber Flexible Pipe	
	40"NB	**60"NB**
Tensile Stress Factor (MPa/kN)	0.012	0.01714
Curvature Stress Factor (MPa/Rad/m)	0.046	0.0321
SN Curve Parameters: log a1 =	10.570	10.570
log a2 =	13.617	13.617
m1 =	3	3
m2 =	5	5
Fatigue Limit @ 10^7 cycles (MPa)	21.05	21.05

Table 3-10: Bonded Flexible Rubber Pipe Stud bolts – Fatigue Properties

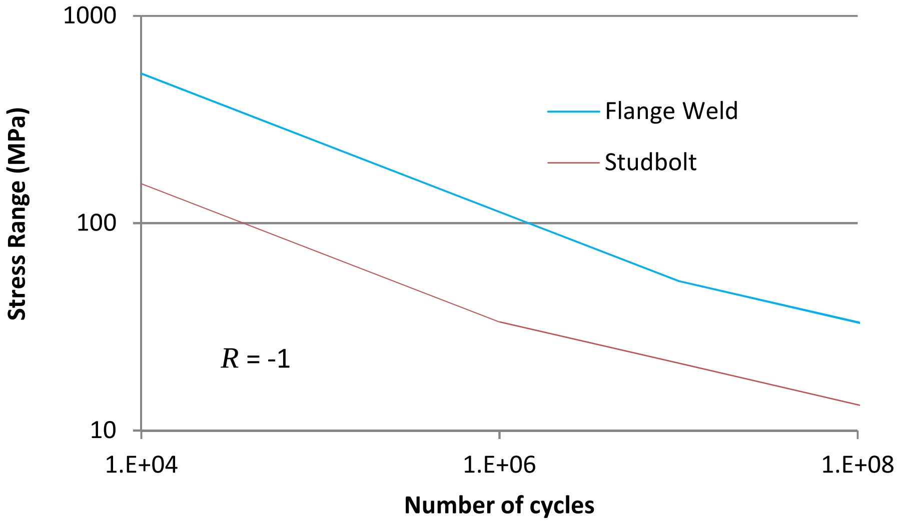


Fig.3-2: SWIR Connection SN Curves

It should be noted that the testing of the textile reinforcement was undertaken with a stress ratio of R=0.1 therefore the SN data generated has a positive mean stress.

However, for the flange weld and studbolts, the SN data has a stress ratio of R=-1 which is a full reversal and therefore has zero mean stress. As the system under consideration will always have a positive stress, it is necessary allow for a positive mean stress.

For the flange weld and studbolt fatigue calculations, the Goodman correction will be selected:

$$\sigma_e = \frac{\sigma_r}{\left[1-\left(\frac{\sigma_m}{SMTS}\right)\right]} \qquad \text{(Orcina, 2014)}$$

where: σ_e = Equivalent Stress

σ_r = True Stress Range

σ_m = Mean Stress

$SMTS$ = Ultimate Tensile Strength

3.4.1.2. HDPE Pipe Sections

- *Physical Properties*

Description	HDPE Pipe	
	40”NB	60”NB
Outside Diameter (m)	1.067	1.600
Inside Diameter (m)	0.985	1.478
Section Length (m)	11.5	11.5
Section weight [in air] (kg)	1,451	3,239
Section weight [in water] (kg)	-107	-237

Table 3-11: HDPE Pipe – Physical Properties

- *Mechanical Properties*

Description	HDPE Pipe			
	40”NB		60”NB	
	Short Term	*Long Term*	*Short Term*	*Long Term*
Creep Modulus (N/mm^2)	800	239	800	239
Allowable Stress (N/mm^2)	9	6.15	9	6.15
Poisson’s Ratio	0.40		0.40	
Minimum Bend Radius (m) [4)]	36.28		54.40	

Table 3-12: HDPE Pipe – Mechanical Properties

- *Fatigue Properties*

Description	HDPE Pipe	
	40”NB	60”NB
Parent Pipe:	Ref. Fig.3-3 (Intec)	
Butt Fusion Weld:	Ref. Fig. 3-4 (-95% Conf Band)	

Table 3-13: HDPE Pipe – Fatigue Properties

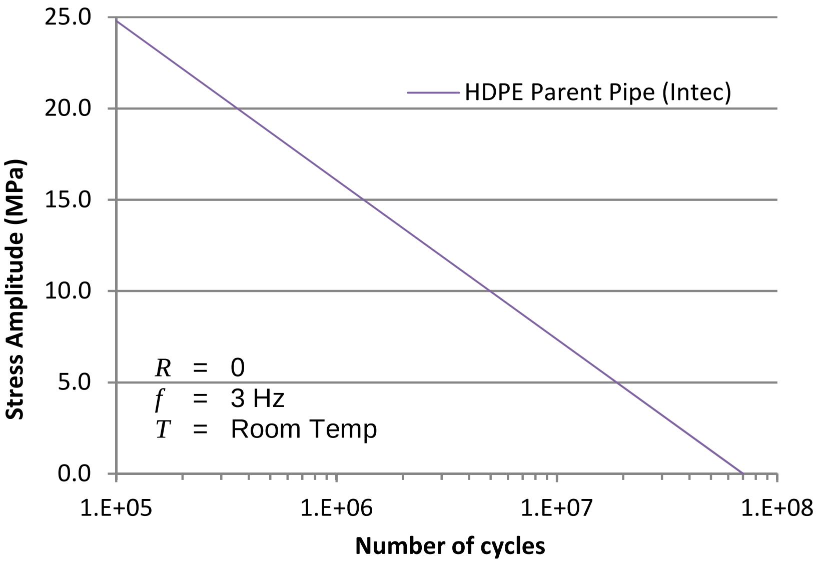


Fig.3-3: HDPE Parent Pipe – SN Curve

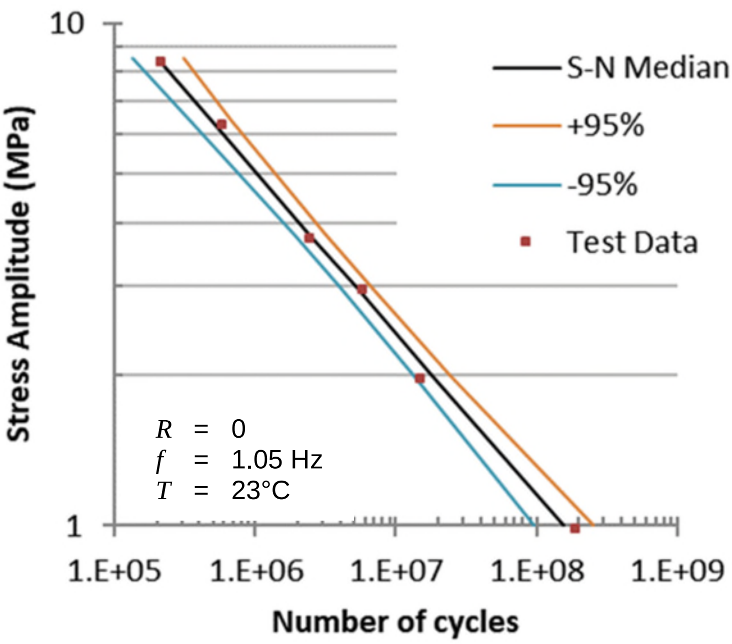


Fig.3-4: HDPE Pipe Butt Fusion Weld – SN Curve

It should be noted that the testing of the HDPE butt fusion weld was undertaken with a stress ratio of R=0 therefore the SN data generated has a positive mean stress.

For the parent pipe, the SN data has a stress ratio of R=-1 which is a full reversal and therefore has zero mean stress. As the system under consideration will always have a positive stress, it is necessary allow for a positive mean stress.

The Goodman correction will be selected for the parent pipe in the Orcaflex fatigue results tool to allow for the mean stress effects.

3.4.1.3. Steel Pipe Sections

- *Physical Properties*

Description	Steel Pipe	
	40”NB	60”NB
Outside Diameter (m)	1.016	1.524
Inside Diameter (m)	0.978	1.486
Section Length (m)	11.5	11.5
Section weight [in air] (kg)	5,386	8,130
Section weight [in water] (kg)	4,683	7,070

Table 3-14: Steel Pipe – Physical Properties

- *Mechanical Properties*

Description	Steel Pipe	
	40”NB	60”NB
Young’s Modulus (N/mm^2)	203,450	203,450
Allowable Stress (N/mm^2)	137.9	137.9
Poisson’s Ratio	0.3	0.3
Minimum Bend Radius (m)	749	1124

Table 3-15: Steel Pipe – Mechanical Properties

- *Fatigue Properties*

Description	Steel Pipe	
	40”NB	60”NB
Parent Pipe SN Curve [Category C]:		
log a1 =	12.192	12.192
log a2 =	16.320	16.320
m1 =	3.0	3.0
m2 =	5.0	5.0
Fatigue Limit @ 10^7 cycles (MPa)	73.10	73.10
Butt Weld SN Curve [Category D]:		
log a1 =	11.764	11.764
log a2 =	15.606	15.606
m1 =	3.0	3.0
m2 =	5.0	5.0
Fatigue Limit @ 10^7 cycles (MPa)	52.63	52.63

Table 3-16: Steel Pipe – Fatigue Properties

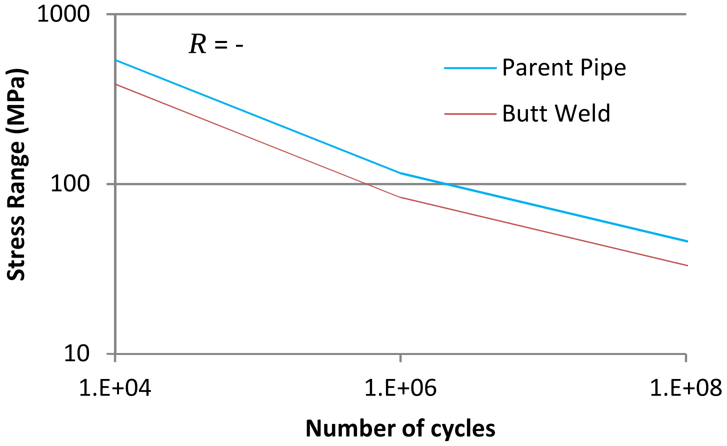


Fig.3-5: Steel Pipe – SN Curve

It should be noted that the SN data has a stress ratio of R=-1 which is a full reversal and therefore has zero mean stress. As the system under consideration will always have a positive stress, it is necessary allow for a positive mean stress.

The Goodman correction will be selected for the parent pipe and butt welds in the Orcaflex fatigue results tool to allow for the mean stress effects.

3.4.1.4. Other Components

In addition to the SWIR elements detailed above, the following components are also used to model the SWIR:

Component	**O/D** *(mm)*	**I/D** *(mm)*	**Section Length** *(m)*	**Mass in Air** *(kg)*	**Weight in Water** *(kg)*
Steel Riser Head	Clump Weight			2,500	2,175
Flange Connections	Clump Weight			350	305
Steel Strainer	1300	1280	5.5	1,750	1,520

Table 3-17: 40"NB SWIR – Additional Component Data

Component	**O/D** *(mm)*	**I/D** *(mm)*	**Section Length** *(m)*	**Mass in Air** *(kg)*	**Weight in Water** *(kg)*
Steel Riser Head	Clump Weight			3,500	3,043
Flange Connections	Clump Weight			800	695
Steel Strainer	1855	1835	5.5	2,250	1,955

Table 3-18: 60"NB SWIR – Additional Component Data

3.4.2. Configuration

When building the model of the selected Configuration 11, a number of test runs were undertaken to verify the accuracy and robustness of the model. These test runs included some fatigue simulations which highlighted a 'weak' area at the connection between the lower end of the HDPE and the upper end of the steel pipe sections. This was attributed to the high bending moments from the rigid steel sections being transmitted into the less rigid HDPE sections. To overcome this, the last HDPE section and the first steel pipe section were replaced by bonded flexible rubber pipe sections which provided a more flexible transition between the HDPE and steel pipe sections. The resulting Configuration 11a being as shown in Fig. 3-6 Below:

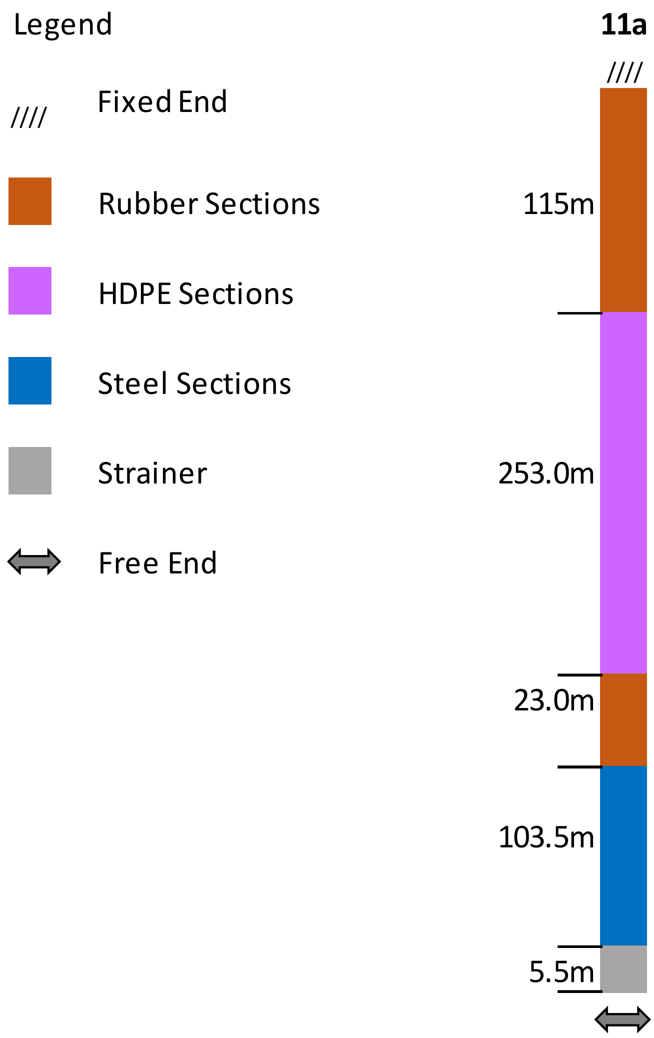


Fig.3-6: Configuration for Analysis

which can be tabulated as follows for each SWIR:

Component	Quantity	Length *(m)*	Mass in Air *(kg)*	Weight in Water *(kg)*
Steel Riser Head	1	-	2,500	2,175
Hose Section	10	115	64,000	22,000
HDPE Section	22	253	31,922	-2,354
Hose Section	2	23	12,800	4,400
Steel Pipe	9	103.5	48,474	42,147
Flange Connections	44	-	15,400	13,420
Steel Strainer	1	5.5	1,750	1,1061,520
TOTAL		**500**	**176,846**	**83,308**

Table 3-19: 40"NB SWIR Configuration

Component	Quantity	Length *(m)*	Mass in Air *(kg)*	Weight in Water *(kg)*
Steel Riser Head	1	-	3,500	3,043
Hose Section	10	115	119,900	41,450
HDPE Section	22	253	71,258	-5,214
Hose Section	2	23	23,980	8,290
Steel Pipe	9	103.5	73,170	63,630
Flange Connections	44	-	35,200	30,580
Steel Strainer	1	5.5	2,250	1,955
TOTAL		**500**	**329,258**	**143,734**

Table 3-20: 60"NB SWIR Configuration

The SWIR assemblies are modelled in Orcaflex as flexible elements with sufficient nodal points to allow curvature. The strainer is modelled as a section of straight pipe whereas the riser head and flange connections are modelled as clump weights of appropriate mass and volume. The flange connections are modelled with a normal drag area equal to the protruding area of the relevant flange diameter.

The model was set to have a flow of seawater through the riser from the free end to the fixed end at a velocity of 3m/s.

Damping is set to zero since, within broad limits, structural damping has little influence on the results of the hydrodynamic simulation unless the system is subject to very rapid variations in tension or bending. Additionally, such damping is negligible compared to the damping applied by hydrodynamic resistance in submarine hoses.

The Seawater Flexible Pipe String Assemblies are connected to the underside of the vessel hull at the following locations relative to the vessel origin, i.e.:

X = Turret Centreline

Y = Vessel Centreline

Z= Hull Bottom

SWIR		40”NB (P)	60”NB (S)
Connection Location (from Vessel Origin)	X	-399m	-399m
	Y	25m	-25m
	Z	0 m	0 m

Table 3-21: Relative Position of SWIR Connection

3.4.3. Drag Coefficients

The normal drag coefficient (Cd) is dependent upon the Reynolds number (Re), which in turn is a function of the surface roughness and diameter of the hose, as well as the fluid flow velocity. Using the technique provided within ESDU 80025 (ESDU, 2010), the Cd values are determined for the corresponding Re number for the various SWIR section types.

Surface roughness values used to calculate the Drag Coefficients are specified as:

- Rubber Hose = 3mm (DNV, 2014) Table 6-1*
- HDPE Pipe = 0.0015mm (PPI, 2008) Ch.6 Table 2-1
- Steel Pipe = 0.05mm (DNV, 2014) Table 6-1

*similar to value for concrete

The Cd values are input into Orcaflex as a variable which calculates the Reynolds number and applies the corresponding Cd for any given fluid velocity. The strainer value is set at Cd = 1.0 based upon drag coefficients for perforated cylinders as specified by ESDU 80025 Fig. 6 (ESDU, 2010). Axial drag coefficient is set as a constant 0.008 for plain pipe.

The flange connections are modelled as clump weights and a drag area equal to the protruding flange specified and an axial drag coefficient of 1.9, in accordance with DNV-RP-C205 ((DNV, 2014) Table E1, applied for the vertical direction.

4. ANALYSIS

4.1. Strength Analysis

4.1.1. Design Condition

As indicated in section 3.3.3.1, it is generally accepted that the 100yr return period is considered for the design analysis, as recommended (API, 2014) table 9.

It is assumed that wave and current data of the same return period (100yr) occur at the same time, although this is a pessimistic assumption as it is unlikely that they will coincide.

As the vessel is Turret Moored, it is assumed that it will be always be heading into the waves, however, the current is considered to be independent of the wave direction and is therefore modelled at 5 directions (assuming symmetry) around the vessel heading.

As recommended in the metocean report (Statoil, 2010) Section 3.5, a Torsethaugen random wave profile is selected and ran in Orcaflex for 10,800 secs (3 hour) using the 100yr Hs value of 4.8m and most onerous corresponding Tp value of 11.9s, which creates a random wave profile similar to that shown below.

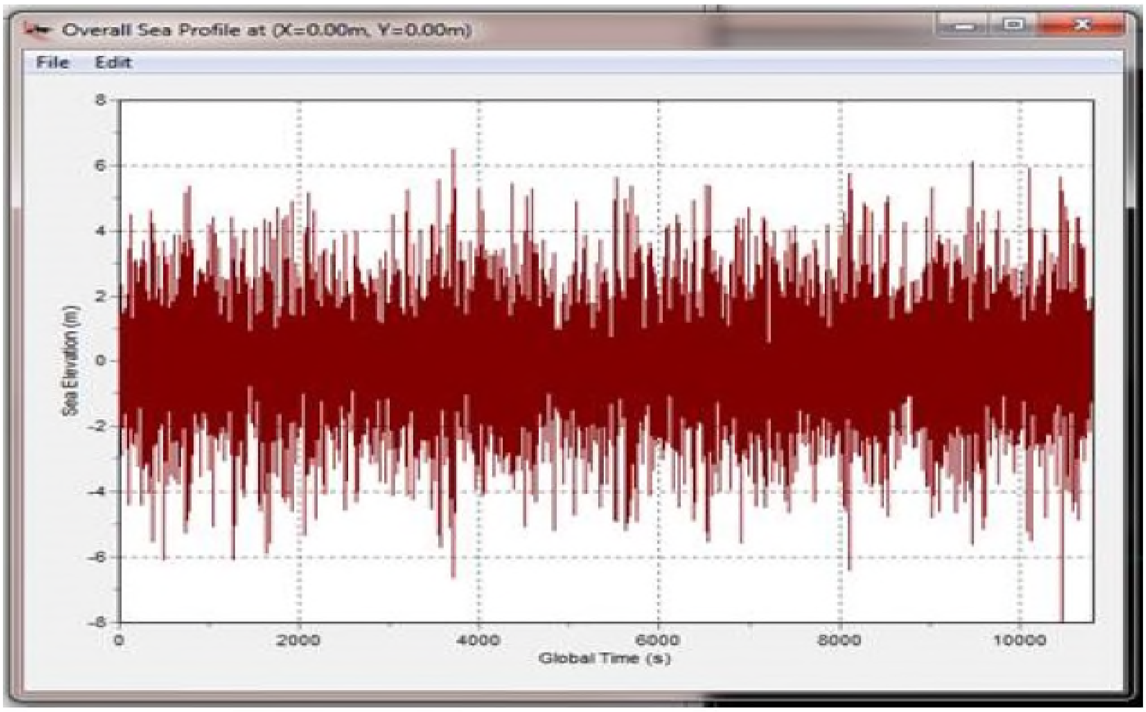


Fig 4-1: Typical 3-hour random wave profile

From this 10,800s profile, the maximum Rise and Fall is identified for both the maximum associated period and the minimum associated period. With reference to the load cases presented in 4.1.2 of the report, this gives four events within the wave profile, namely;

- $Tass_{min}$ *Rise*
- $Tass_{min}$ *Fall*
- $Tass_{max}$ *Rise*
- $Tass_{max}$ *Fall*

where: $Tass_{min} = 1.05 * Tz$ (Orcina, 2014)

$Tass_{max} = 1.4 * Tz$ (Orcina, 2014)

Having identified each event by Global Time, a time origin is selected 150 secs before the event with a duration of 300 secs. This ensures that the event is captured and occurs at the midpoint in the 300s wave packet. For example, the maximum Rise on the above profile occurs at 3708 secs, so the time origin would be set to 3558 secs with a duration of 300 secs, thus the wave profile for this load case would be as shown below:

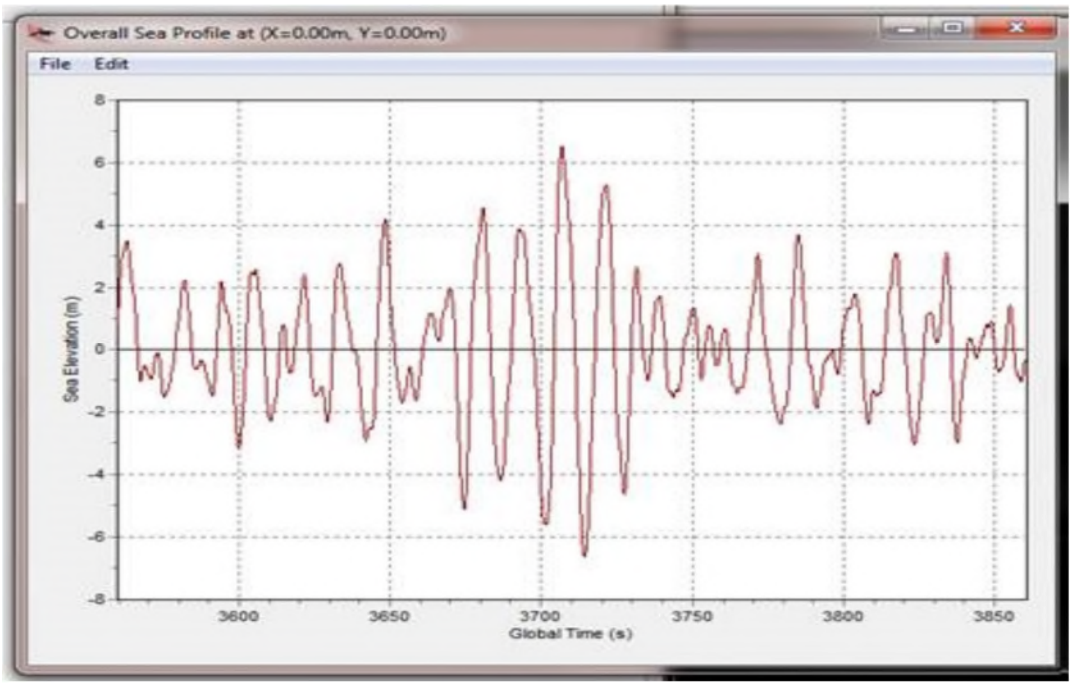


Fig 4-2: Typical 300s wave packet from random wave profile

Consequently, each of the load cases is analysed at a maximum Rise or Fall, therefore the results are representative of the statistical maximum of each condition.

4.1.2. Load Cases

From the above considerations, the following load case combinations are identified for the strength analysis:

Case	Marine Growth	Current Direction	Wave Event	Case	Marine Growth	Current Direction	Wave Event
1	No	0	$Tass_{min}$ Rise	21	Yes	0	$Tass_{min}$ Rise
2	No	0	$Tass_{min}$ Fall	22	Yes	0	$Tass_{min}$ Fall
3	No	0	$Tass_{max}$ Rise	23	Yes	0	$Tass_{max}$ Rise
4	No	0	$Tass_{max}$ Fall	24	Yes	0	$Tass_{max}$ Fall
5	No	45	$Tass_{min}$ Rise	25	Yes	45	$Tass_{min}$ Rise
6	No	45	$Tass_{min}$ Fall	26	Yes	45	$Tass_{min}$ Fall
7	No	45	$Tass_{max}$ Rise	27	Yes	45	$Tass_{max}$ Rise
8	No	45	$Tass_{max}$ Fall	28	Yes	45	$Tass_{max}$ Fall
9	No	90	$Tass_{min}$ Rise	29	Yes	90	$Tass_{min}$ Rise
10	No	90	$Tass_{min}$ Fall	30	Yes	90	$Tass_{min}$ Fall
11	No	90	$Tass_{max}$ Rise	31	Yes	90	$Tass_{max}$ Rise
12	No	90	$Tass_{max}$ Fall	32	Yes	90	$Tass_{max}$ Fall
13	No	135	$Tass_{min}$ Rise	33	Yes	135	$Tass_{min}$ Rise
14	No	135	$Tass_{min}$ Fall	34	Yes	135	$Tass_{min}$ Fall
15	No	135	$Tass_{max}$ Rise	35	Yes	135	$Tass_{max}$ Rise
16	No	135	$Tass_{max}$ Fall	36	Yes	135	$Tass_{max}$ Fall
17	No	180	$Tass_{min}$ Rise	37	Yes	180	$Tass_{min}$ Rise
18	No	180	$Tass_{min}$ Fall	38	Yes	180	$Tass_{min}$ Fall
19	No	180	$Tass_{max}$ Rise	39	Yes	180	$Tass_{max}$ Rise
20	No	180	$Tass_{max}$ Fall	40	Yes	180	$Tass_{max}$ Fall

Table 4-1: Load Case Combinations (Strength Analysis)

4.2. Fatigue Analysis

4.2.1. General

As specified by API 17K (American Petroleum Institute, 2005), an acceptable method for fatigue damage calculation of bonded flexible rubber pipe is Miners method using design S-N curves validated for the reinforcing materials used. Miners method being:

$$D = \sum_{i=1}^{k} \frac{n_i}{N_i}$$ (DNVGL, 2014) eq. 2.2.1

Where: k = Number of stress blocks

n_i = number of stress cycles in stress block i

N_i = Number of cycles to failure at constant stress range

D = Accumulated Fatigue Damage

Therefore, the S-N curves presented in section 3.4.1.1 and were input into the Orcaflex fatigue analysis tool which uses Miners method to calculate the fatigue damage for the flexible pipe reinforcement which can be inversed to predict the life of the component in service.

As indicated in DVS2205 (DVS, 2015), Miners method can also be used to determine the damage accumulation in HDPE pipes, therefore, as above, using the S-N curves presented in section 3.4.1.2, the Orcaflex fatigue analysis tool was used to calculate the fatigue damage for the HDPE pipe sections which can be inversed to predict the life of the component in the field..

This same technique is also used to calculate the fatigue damage to the steel

4.2.2. Due to Waves

To determine the fatigue damage due to waves, the Wave Scatter data presented in section 3.3.3.2 is used. The data provided is first converted into percentage occurrences and then into the annual number of occurrences as shown below:

Percentage of Occurences

= No of Recorded Occurences / Total Number of Recorded Occurences * 100

Hs (m)	3	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	Sum
0.25	0	0	0	0.00744	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.75	0	0.005952	0.083323	3.295739	5.435365	3.437091	1.205214	1.505773	0.688906	0.180038	0.065468	0.025295	0.031246	0.020831	0.017855	0.00744	0	0	0	16
1.25	0	0.001488	0.14284	4.020355	13.54898	13.10558	9.9631	7.336924	5.05297	1.257291	0.319902	0.124985	0.156231	0.17855	0.07886	0.055053	0	0	0	55
1.75	0	0	0	0.294608	3.901321	6.890549	4.908642	5.637722	2.139626	0.519283	0.07886	0.04315	0.062493	0.127961	0.055053	0.044638	0	0	0	25
2.25	0	0	0	0.002976	0.180038	0.968635	1.020712	0.790085	0.358588	0.04315	0.004464	0.010415	0	0.002976	0.00744	0.004464	0	0	0	3
2.75	0	0	0	0	0.014879	0.058029	0.101178	0.123497	0.124985	0.004464	0	0	0	0.004464	0.004464	0	0	0	0	0
3.25	0	0	0	0	0	0.011903	0.014879	0.016367	0.037198	0.004464	0	0	0	0	0	0	0	0	0	0
3.75	0	0	0	0	0	0	0	0	0.004464	0.008928	0.001488	0	0	0	0	0	0	0	0	0
4.25	0	0	0	0	0	0.00744	0	0	0	0.002976	0	0	0	0	0	0	0	0	0	0
Sum	0	0	0	8	23	24	17	15	8	2	0	0	0	0	0	0	0	0	0	100

Annual Number of Occurences

= % Occurences * Secs per year / PeriodTp

Tp	3	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.5	Sum
Tz	2.33	2.71	3.49	4.26	5.04	5.81	6.59	7.36	8.14	8.91	9.69	10.47	11.24	12.02	12.79	13.57	14.34	15.12	15.89	
Hs (m)																				
0.25	0	0	0	427	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	427
0.75	0	536	5839	188972	263707	144523	44715	49985	20691	4937	1652	591	680	424	341	134	0	0	0	727727
1.25	0	134	10010	230520	657355	551064	369643	243555	151762	34478	8071	2920	3398	3633	1507	992	0	0	0	2269041
1.75	0	0	0	16892	189280	289734	182116	187149	64262	14240	1990	1008	1359	2603	1052	804	0	0	0	952490
2.25	0	0	0	171	8735	40729	37870	26227	10770	1183	113	243	0	61	142	80	0	0	0	126324
2.75	0	0	0	0	722	2440	3754	4100	3754	122	0	0	0	91	85	0	0	0	0	15068
3.25	0	0	0	0	0	501	552	543	1117	122	0	0	0	0	0	0	0	0	0	2835
3.75	0	0	0	0	0	0	0	0	134	245	38	0	0	0	0	0	0	0	0	416
4.25	0	0	0	0	0	313	0	0	0	82	0	0	0	0	0	0	0	0	0	394
Sum	0	670	15850	436981	1119799	1029303	638649	511559	252490	55410	11862	4762	5437	6811	3128	2011	0	0	0	4094723

Table 4-2: Wave Scatter Data per annum

Orcaflex has a Wave Scatter Conversion tool which converts a scatter table of sea states (i.e. irregular waves) to a scatter table of regular waves. The conversion method uses the formula of Longuet-Higgins (Longuet-Higgins, 1983) to give a probability density of individual wave in a random sea. The resulting scatter table of regular waves is presented below.

Regular Wave Scatter Table

OrcaFlex 10.0a: fatigue.sct (modified 18:02 on 22/05/2016 by OrcaFlex 10.0a)

Total duration	
(hours)	(years)
8766.0	1.0

Total probability covered by table: 0.962

Total number of bins: 146

Number of Occurrences

Height (m)																			
4.5					5	50	98	79	40	16	6	2	1	1	0	0			
4.0				0	26	213	342	241	112	43	16	7	3	1	1	0	0		
3.5				2	170	977	1236	777	343	130	49	20	9	5	2	1	1	0	0
3.0				23	1130	4370	4486	2615	1147	442	171	73	34	17	9	5	3	1	1
2.5			0	294	7015	17557	15314	8646	3931	1623	674	300	145	74	39	22	12	7	5
2.0			12	3798	39098	63194	47718	26702	12893	5864	2697	1305	669	361	203	119	72	45	29
1.5			439	38276	167257	190164	129832	73133	37849	19153	9889	5319	2997	1764	1082	689	453	308	215
1.0		20	19278	239944	453907	386108	246725	143195	81059	46428	27418	16808	10701	7060	4812	3379	2436	1799	1356
0.5	130755	238726	484162	697823	600726	396141	241071	146302	91161	58907	39528	27477	19714	14544	10993	8488	6677	5339	4331
Period (s)	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	13.5	14.5	15.5	16.5	17.5	18.5

Table 4-3: Converted Regular Wave Scatter Data per annum

Using this output, the data files for the relevant load cases were generated for simulation.

From Fig.4-3, the most frequent annual current velocity, i.e. 0.25 x maximum 1yr was specified for each simulation.

The fatigue results tool in Orcaflex was used to calculate the annual fatigue damage of each SWIR. The 'regular' method was selected which uses the data from the last full cycle of each simulation and the annual occurrences from table 4-3 to calculate the damage.

4.2.3. Due to Current

To determine the fatigue damage due to current, the 1yr return maximum current profile, as shown in Table 3-4, is factored and the density of each factor determined using a Weibull distribution. The Weibull shape factor of 2.45 is taken from the metocean report (Statoil, 2010), Table 4.12 for the most frequent current direction (i.e. 0°)

This gives a current speed distribution as shown in Fig. 4-3 below.

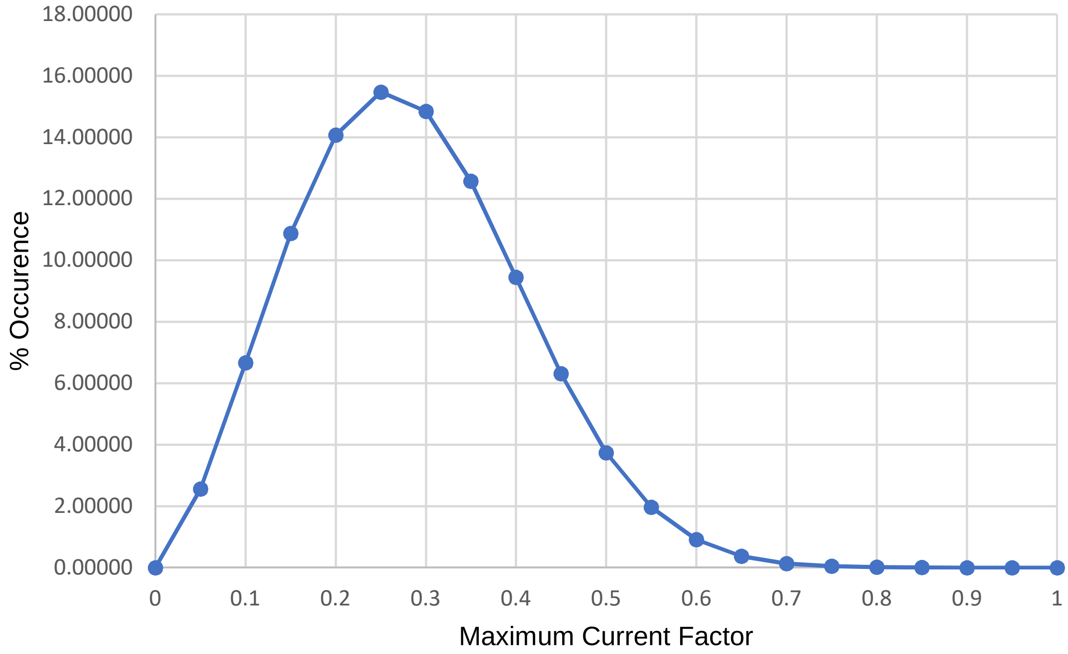


Fig.4-3: Current Speed Distribution

From the distribution, the annual hours of exposure can be determined for the damage calculation, as shown in Table 4-4 below:

Factor	Surface Current (cm/s)	Weibull Density	as %	as annual hours
0	0	0.00000000	0.00000	0.000
0.05	8.7	0.00293522	2.55558	224.023
0.1	17.4	0.00765090	6.66135	583.934
0.15	26.1	0.01248940	10.87405	953.219
0.2	34.8	0.01616658	14.07563	1233.870
0.25	43.5	0.01777324	15.47449	1356.494
0.3	52.2	0.01704932	14.84420	1301.242
0.35	60.9	0.01443884	12.57135	1102.005
0.4	69.6	0.01084873	9.44558	828.000
0.45	78.3	0.00724262	6.30587	552.773
0.5	87	0.00429456	3.73911	327.771
0.55	95.7	0.00225850	1.96639	172.374
0.6	104.4	0.00105122	0.91526	80.232
0.65	113.1	0.00043199	0.37611	32.970
0.7	121.8	0.00015630	0.13609	11.930
0.75	130.5	0.00004966	0.04323	3.790
0.8	139.2	0.00001381	0.01202	1.054
0.85	147.9	0.00000335	0.00292	0.256
0.9	156.6	0.00000071	0.00062	0.054
0.95	165.3	0.00000013	0.00011	0.010
1	174	0.00000002	0.00002	0.002

Table 4-4: Current Speed Annual Exposure

For each current velocity factor, a simulation was ran with the ‘Iwans Blevins Wake Oscillator’ tool selected and using explicit integration, for 400s so that the VIV response became settled.

The fatigue results tool in Orcaflex was used to calculate the annual fatigue damage of each SWIR. The ‘rainflow half cycle’ method was selected and the annual exposure hours from Table 4-4 specified for the relevant factor simulation. The simulation period between 300-400s was chosen to ensure that the settled VIV response was used in the damage calculation.

Fig. 4-4 Shows the time history from the SWIR mid-point showing that the VIV response becomes established and settled in this period.

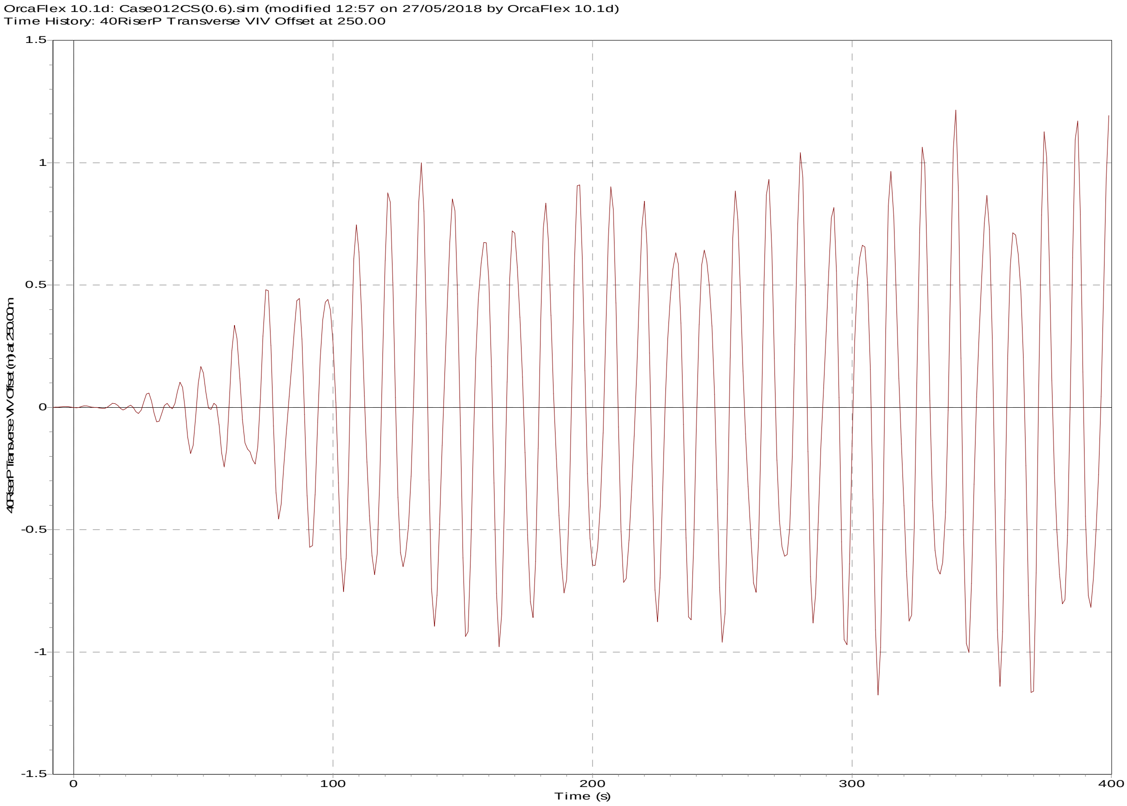


Fig.4-4: SWIR Mid-Point Time History

4.3. Lower End Excursion

External fluid flow around the SWIR is caused by the ocean currents which vary in strength and profile depending upon the geographical location. One consequence of external fluid flow is the possibility of vortex induced vibration (VIV) and its contribution to fatigue damage which was investigated in the previous section. Another is the potential interference with other risers or mooring lines due to the excursion of the lower end of the SWIR.

Two approaches were used to evaluate the excursion of the proposed SWIR;

4.3.1. Lower End Excursion due to Extreme Current

The simulations used in the strength analysis were interrogated to find the maximum lower end excursion due to the 100yr extreme current profile as shown in Fig.4-5 below.

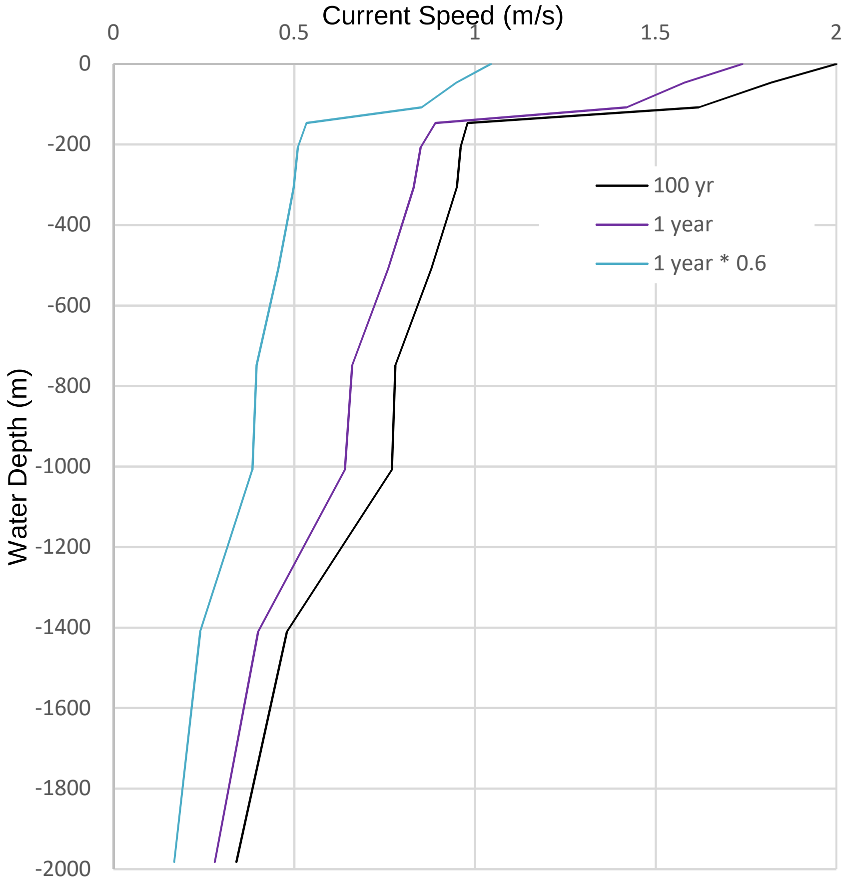


Fig.4-5: Current Profiles

Is this scenario, the drag coefficients for the SWIR were established using the technique presented in ESDU (2010).

4.3.2. Lower End Excursion Due to VIV Drag Amplification

Drag amplification occurs when VIV is established in a line and experiments by Vandiver (1983) gave good agreement with the following empirical formula;

$$C_D = C_{Do}[1 + 1.043 \left(\frac{2 * A_{rms}}{D}\right)^{0.65}] \qquad \text{(Vandiver, 1983)}$$

where:

	C_D	=	Drag Coefficient
	C_{Do}	=	Drag Coefficient for stationary cylinder
	A	=	Amplitude of cross flow vibration (m)
	D	=	Member Diameter (m)

The Vandiver method, also presented in DNV-RP-C205 ((DNV, 2014) Sect 9.2.2.2, was used to determine the VIV Drag Amplification Factor (DAF) and applied to the simulations using the Iwans and Blevin Wake Oscillator model for the 1 year and the 1 year * 0.6 current profiles (as shown in Fig. 6-46) as these were found to have the largest VIV offsets and therefore, the largest VIV DAF.

The SWIR excursion profiles are presented below in Figs.4-6, 4-7 & 4-8.

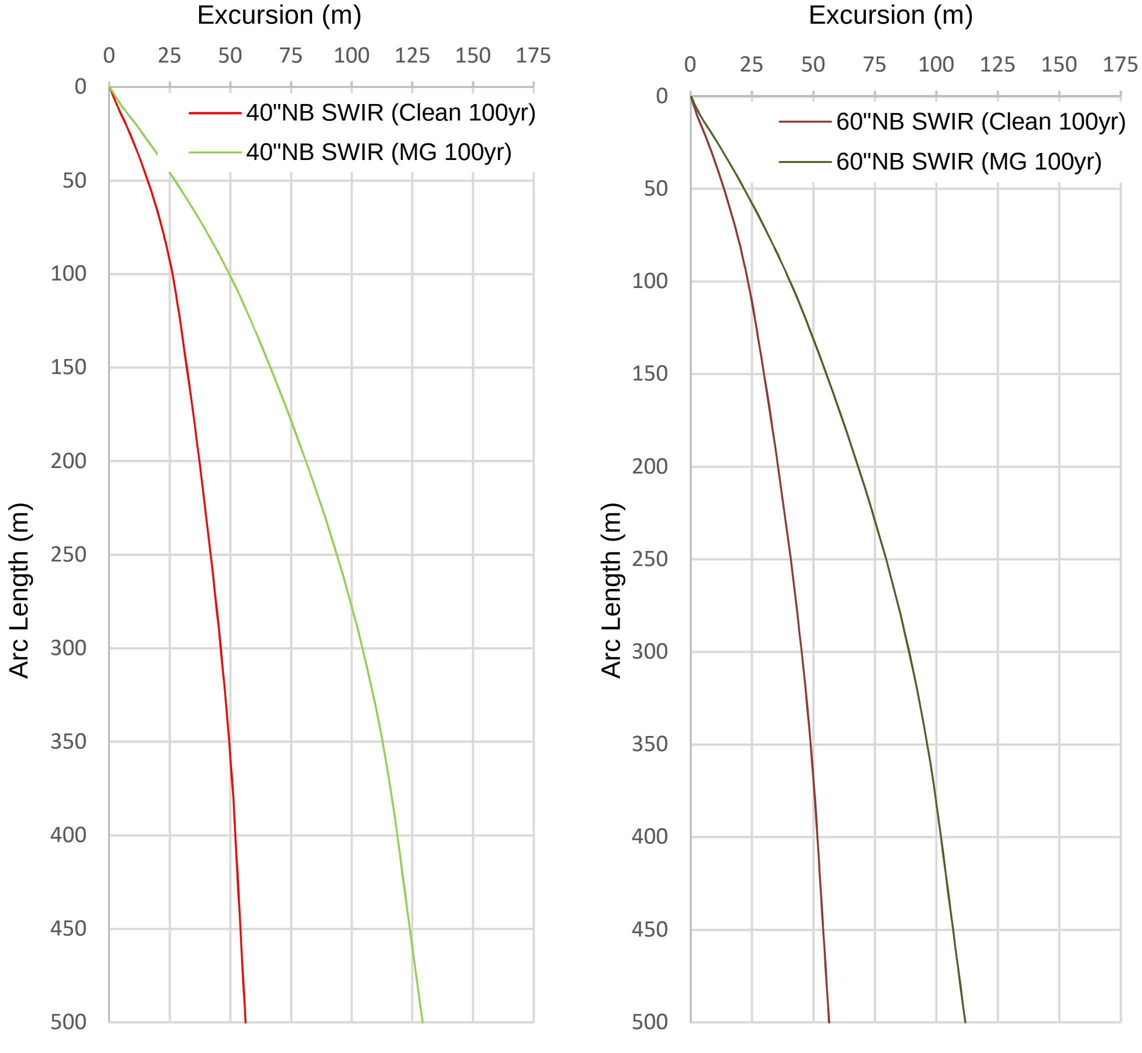


Fig.4-6: Lower End Excursion – 100yr Current Profile

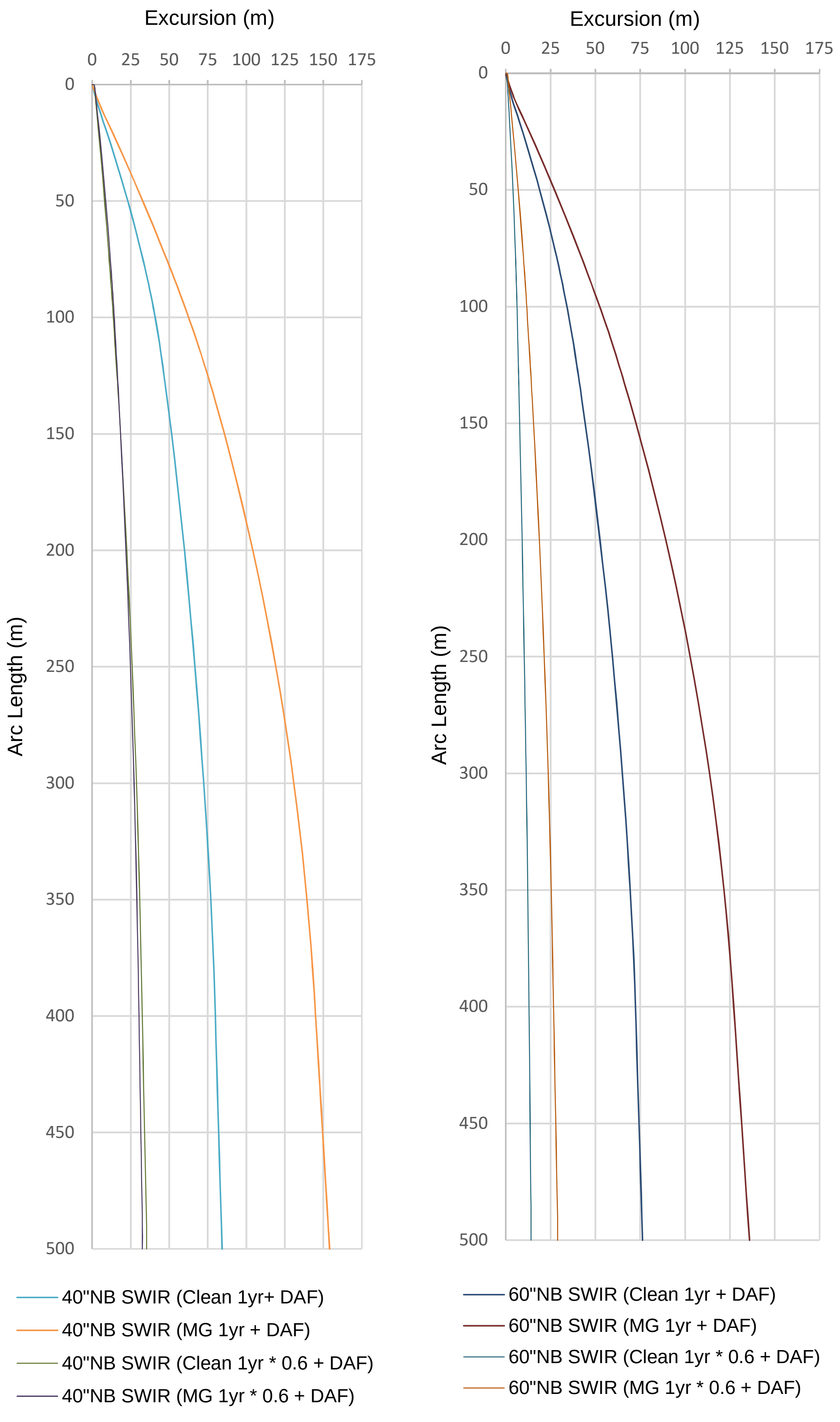


Fig.4-7: Lower End Excursion – 1yr Current Profile + DAF

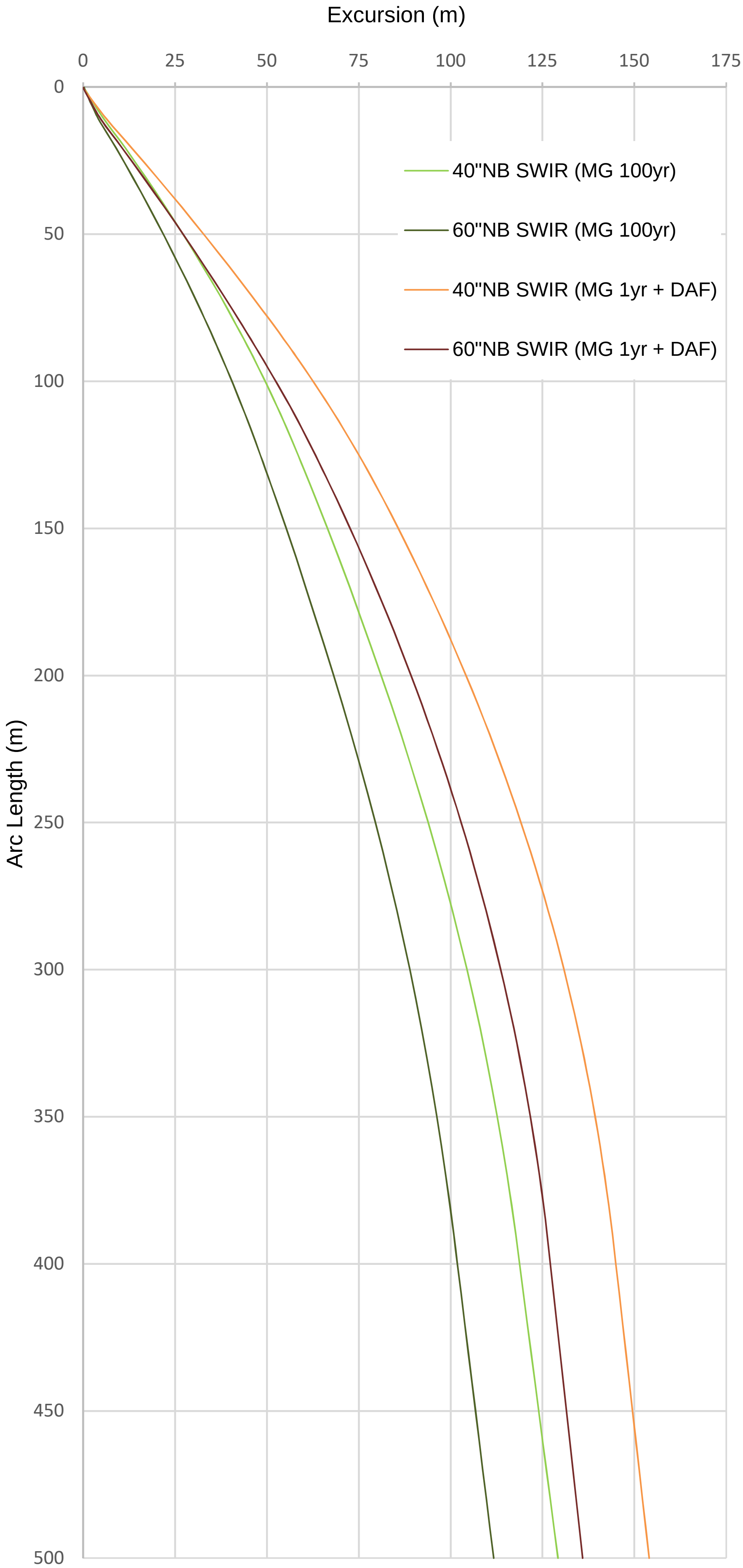


Fig.4-8: Maximum Lower End Excursions

It can be seen from Fig.4-6 that the SWIR with marine growth attachment gives the largest excursion under the maximum 100yr current conditions. Similarly, in Fig.4-7 the SWIR with marine growth show the largest excursion under the maximum 1 year conditions with the DAF applied. Fig.4-8 compares the two approaches and shows that the 1 year current with a DAF applied has a greater excursion than the 100 yr return conditions. This suggests that the large excursions may occur frequently and should be assessed carefully in regard to interference with adjacent risers or structures.

4.3.3. Potential for adjacent SWIR Interference

If more than one SWIR is installed on a vessel, there is a possibility that the current direction can be aligned with the two risers and if so, the upstream riser may create a wake and alter the behaviour of the downstream riser.

As stated in DNV-RP-F203 (DNV, 2009) Section 3.3, there is limited information available regarding VIV behaviour of a riser located in the wake of an upstream one, and that as a first estimate, no VIV response should be applied to the downstream riser. Therefore, to provide an indication of the behaviour of two SWIR in an aligned current, the maximum SWIR excursion determined from the 1yr return condition with the DAF applied is compared against the same without the DAF applied.

Fig.4-9 shows the maximum excursion of each line and the approximate spacing required between the SWIR to avoid contact, which is approx. 57m and 52m for the 40NB SWIR and 60NB SWIR respectively.

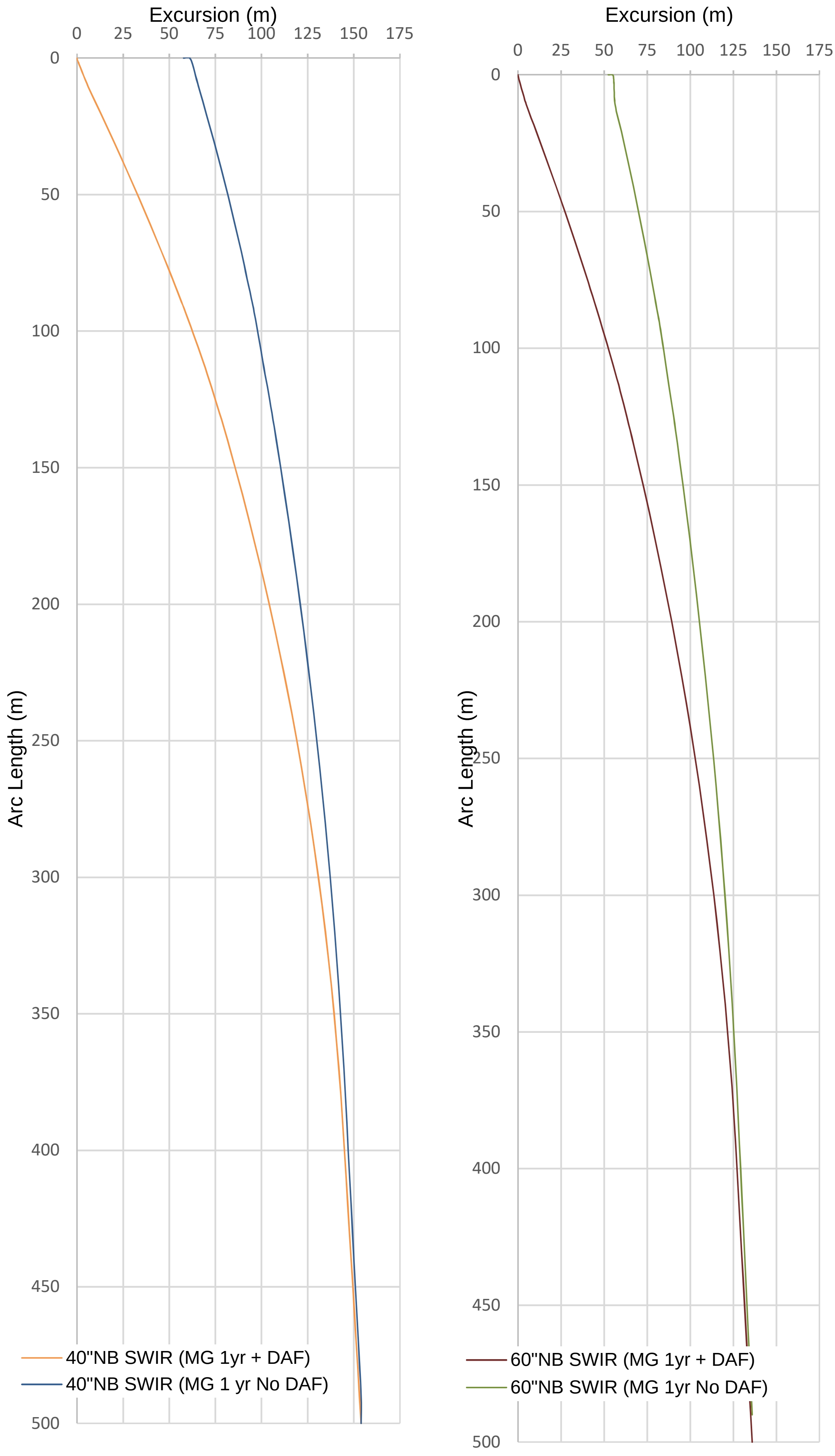


Fig.4-9: SWIR Interference from Lower End Excursions

5. RESULTS

5.1. Strength Analysis (40”NB SWIR)

The results are summarised below:

- *Maximum Values for Hang-Off Design*

	Max.	Corresponding Maximum Value			Load Case
		End Force (kN)	**Bending Moment** (kNm)	**Shear Force** (kN)	
End Force (kN)	**837.3**		644.6	321.1	**4**
Bending Moment (kNm)	**969.1**	697.4		422.0	**39**
Shear Force (kN)	**433.7**	704.4	968.76		**21**

Table 5-1: Maximum Values for 40”NB Hang Off Design

- *Flexible Rubber Pipe Section*

	Max	Allowable 1)	Load Case
Tension (kN)	**808.0**	**3141**	**4**
MBR (m)	**4.1**	**4.0**	**39**

Table 5-2: 40”NB SWIR – Flexible Rubber Pipe Results

- *HDPE Pipe Section*

	Max	Allowable 1)	Load Case
Tensile Stress (MPa)	**3.2**	**9**	**3**
Bending Stress (MPa)	**0.7**	**9**	**23**
Von Mises Stress (MPa)	**4.9**	**9**	**23**
MBR (m)	**593.8**	**36.28**	**23**

Table 5-3: 40”NB SWIR – HDPE Pipe Section Results

- *Steel Pipe Section*

	Max	Allowable 1)	Load Case
Tensile Stress (MPa)	**4.0**	**137.9**	**39**
Bending Stress (MPa)	**7.7**	**137.9**	**11**
Von Mises Stress (MPa)	**12.8**	**137.9**	**11**
MBR (m)	**13431**	**749**	**11**

Table 5-4: 40”NB SWIR – Steel Pipe Section Results

1) Refer to section 3.4.1 for allowable values

Figs.5-1 & 5-2 show the time history for End A tension and bending moments respectively.

Fig.5-1: 40”NB SWIR End A Tension Time History

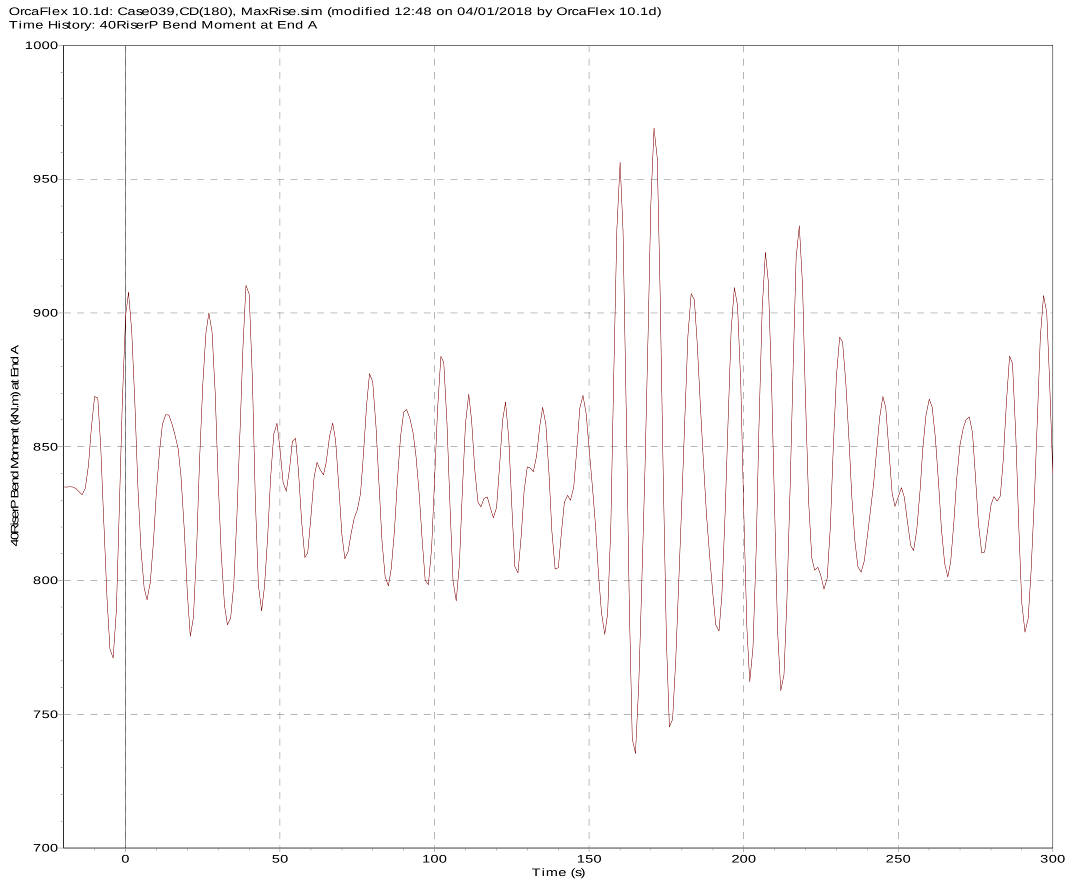


Fig.5-2: 40”NB SWIR End A Bending Moment Time History

5.2. Fatigue Analysis (40”NB SWIR)

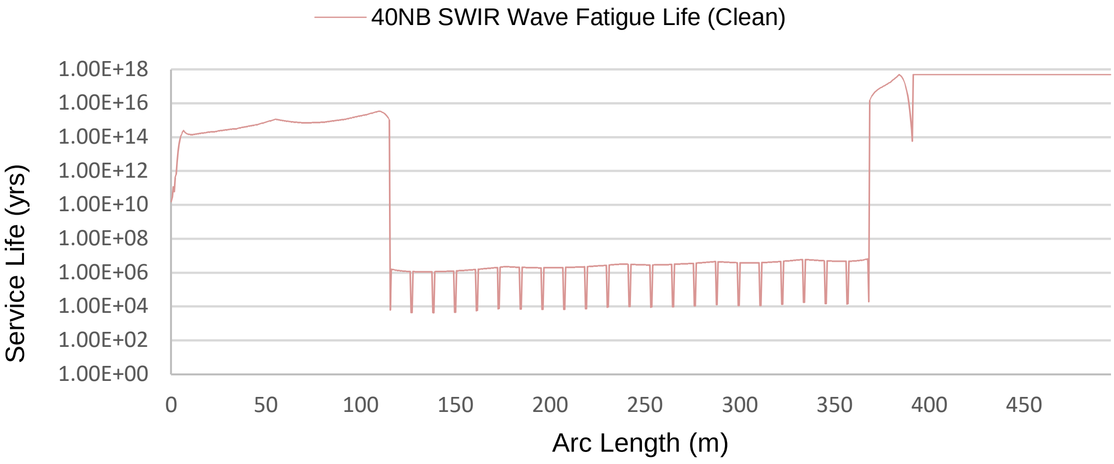


Fig.5-3: 40”NB SWIR (Clean) Fatigue Life due to Waves

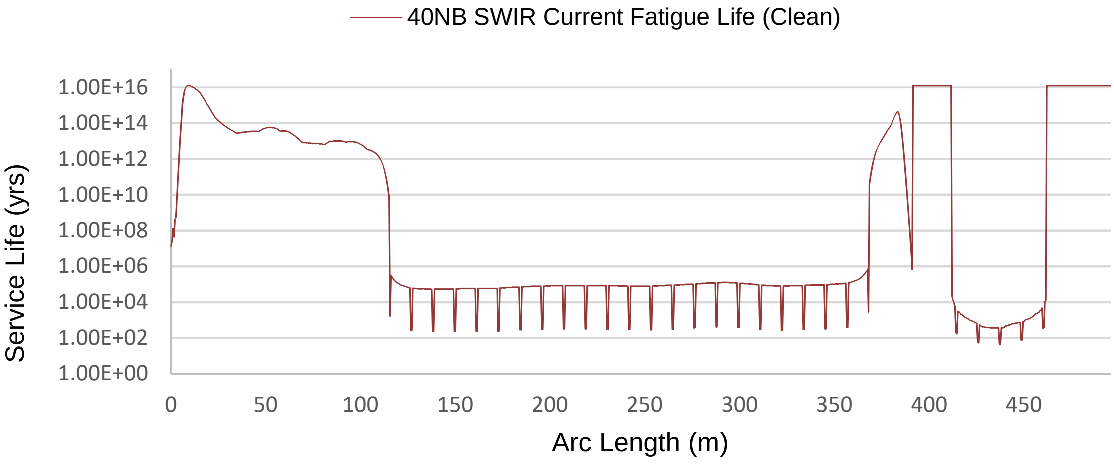


Fig.5-4: 40”NB SWIR (Clean) Fatigue Life due to Current

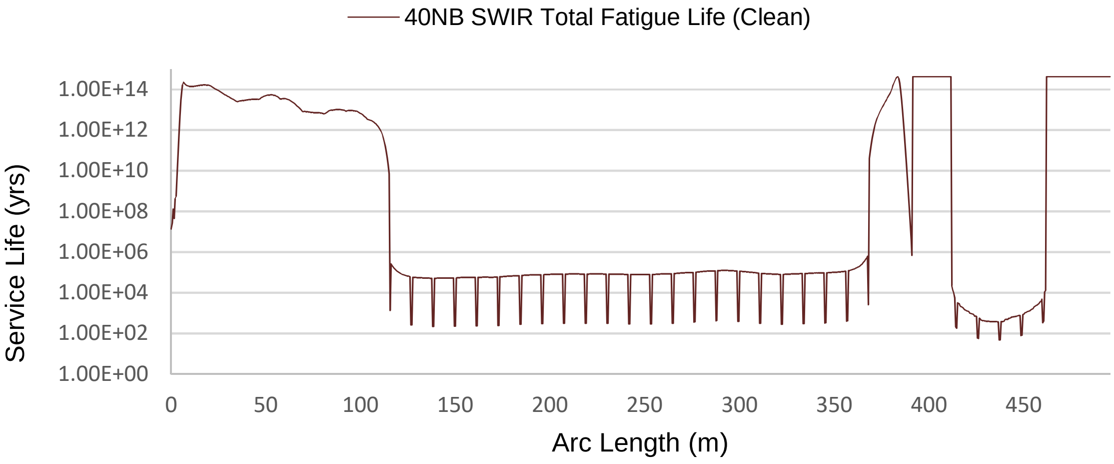


Fig.5-5: 40”NB SWIR (Clean) Total Fatigue Life

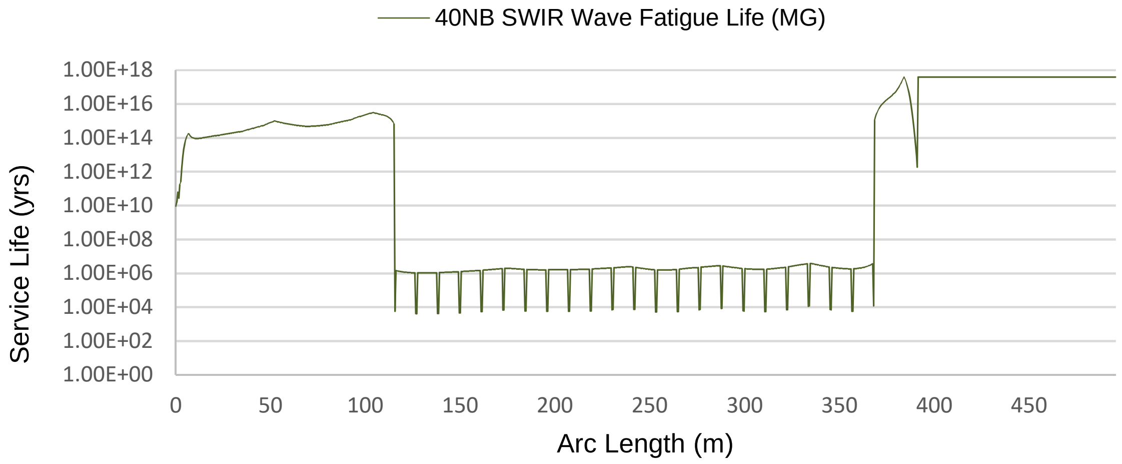


Fig.5-6: 40"NB SWIR (MG) Fatigue Life due to Waves

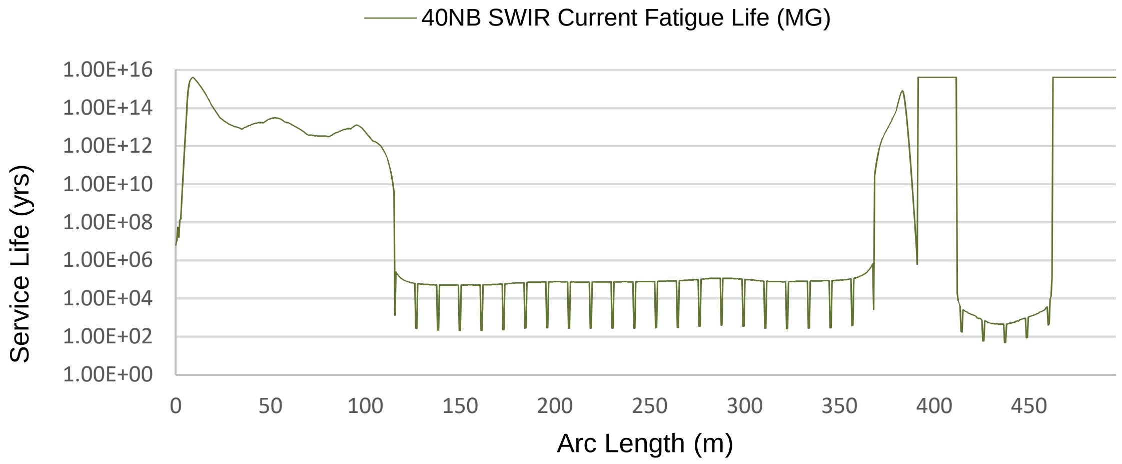


Fig.5-7: 40"NB SWIR (MG) Fatigue Life due to Current

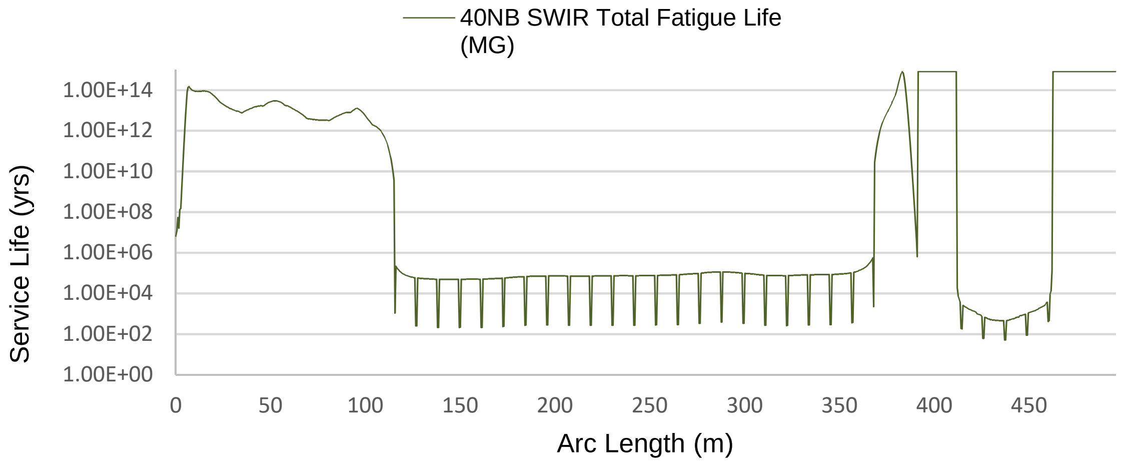


Fig.5-8: 40"NB SWIR (MG) Total Fatigue Life

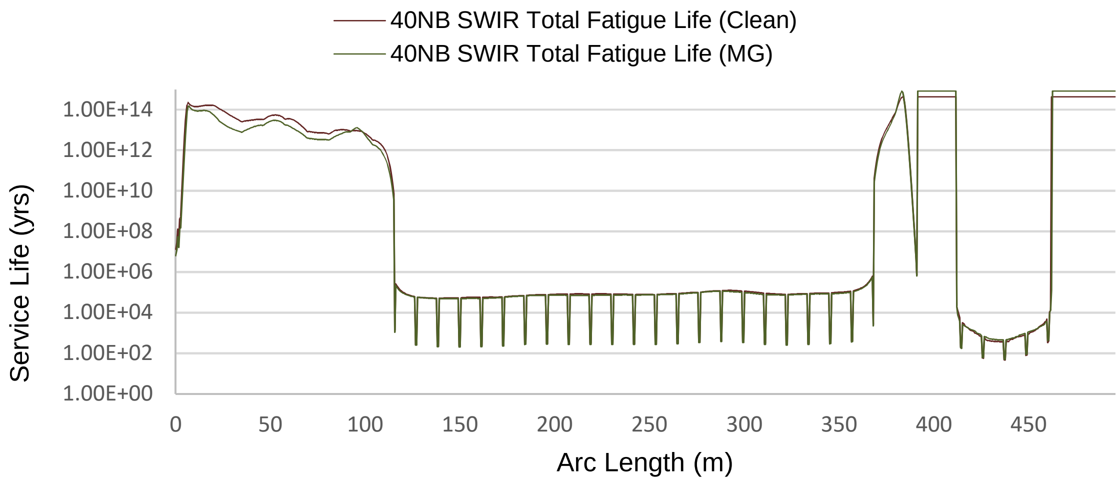


Fig.5-9: 40”NB SWIR Total Fatigue Life Comparison – Clean v MG

5.3. Strength Analysis (60”NB SWIR)

The results are summarised below:

- *Maximum Values for Hang-Off Design*

	Max.	Corresponding Maximum Value			Load Case
		End Force (kN)	**Bending Moment** (kNm)	**Shear Force** (kN)	
End Force (kN)	**1508.9**		1473.7	502.2	**4**
Bending Moment (kNm)	**2141.8**	1317.7		677.9	**21**
Shear Force (kN)	**677.9**	1317.7	2141.8		**21**

Table 5-5: Maximum Values for 60”NB Hang Off Design

- *Flexible Rubber Pipe Section*

	Max	Allowable 1)	Load Case
Tension (kN)	**1451.0**	**7068.0**	**4**
MBR (m)	**7.0**	**6.0**	**21**

Table 5-6: 60”NB SWIR – Flexible Rubber Pipe Results

- *HDPE Pipe Section*

	Max	Allowable 1)	Load Case
Tensile Stress (MPa)	**2.0**	**9**	**17**
Bending Stress (MPa)	**0.8**	**9**	**23**
Von Mises Stress (MPa)	**3.8**	**9**	**27**
MBR (m)	**803.6**	**36.28**	**23**

Table 5-7: 60”NB SWIR – HDPE Pipe Section Results

- *Steel Pipe Section*

	Max	Allowable 1)	Load Case
Tensile Stress (MPa)	**4.2**	**137.9**	**37**
Bending Stress (MPa)	**8.8**	**137.9**	**11**
Von Mises Stress (MPa)	**14.2**	**137.9**	**11**
MBR (m)	**17554**	**749**	**11**

Table 5-8: 60”NB SWIR – Steel Pipe Section Results

1) Refer to section 3.4.1 for allowable values

5.4. Fatigue Analysis (60"NB SWIR)

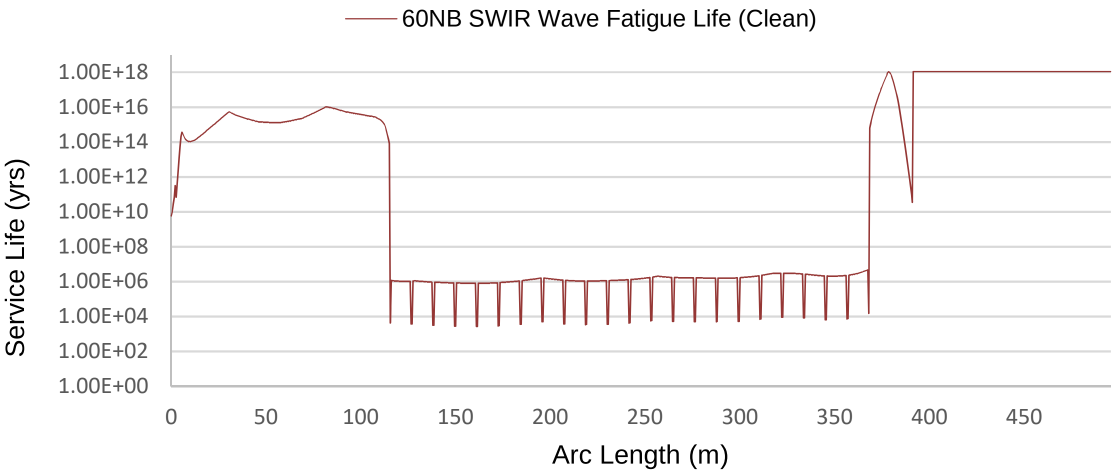


Fig.5-10: 60"NB SWIR (Clean) Fatigue Life due to Waves

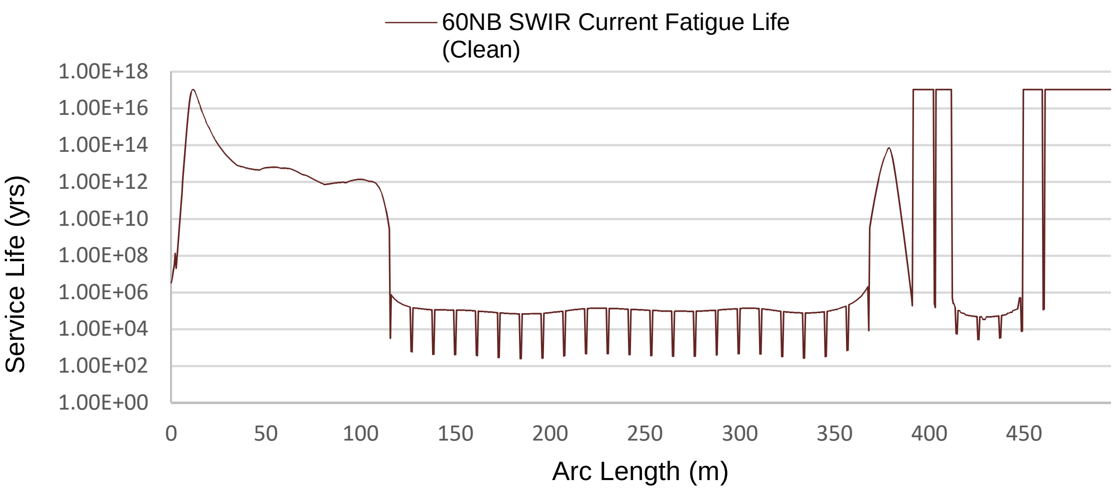


Fig.5-11: 60"NB SWIR (Clean) Fatigue Life due to Current

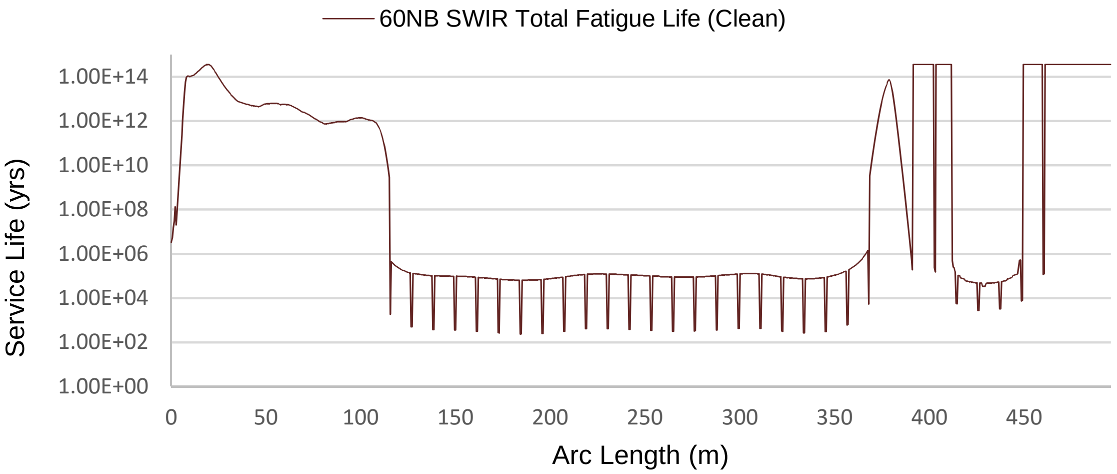


Fig.5-12: 60"NB SWIR (Clean) Total Fatigue Life

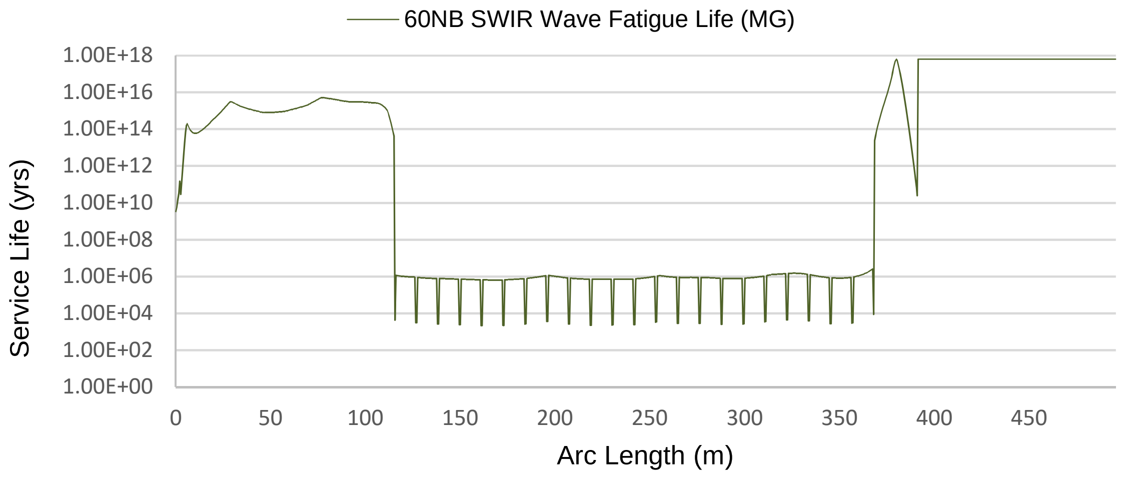


Fig.5-13: 60"NB SWIR (MG) Fatigue Life due to Waves

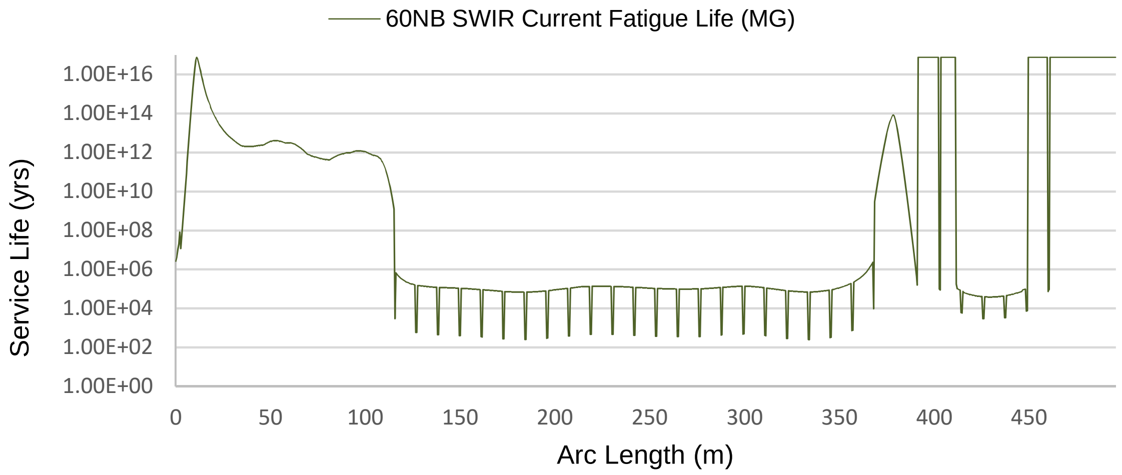


Fig.5-14: 60"NB SWIR (MG) Fatigue Life due to Current

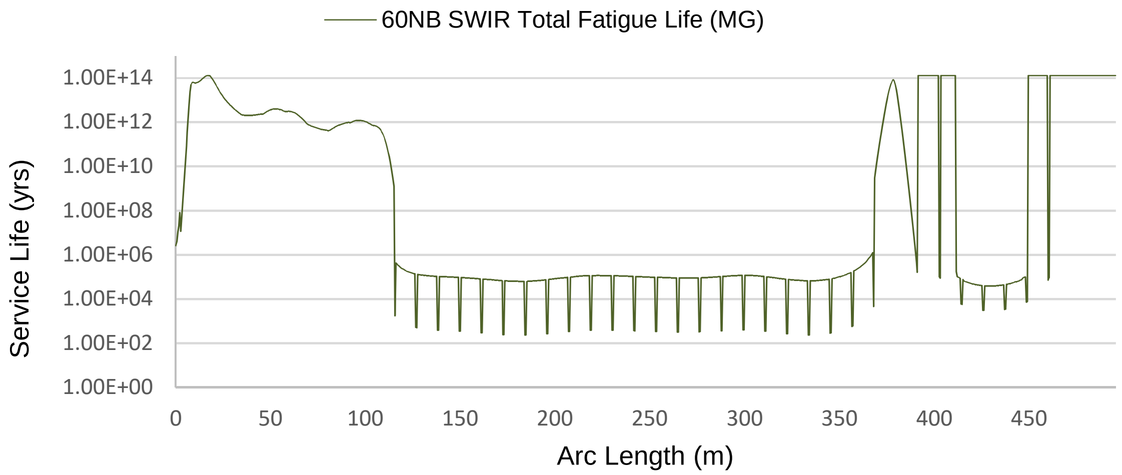


Fig.5-15: 60"NB SWIR (MG) Total Fatigue Life

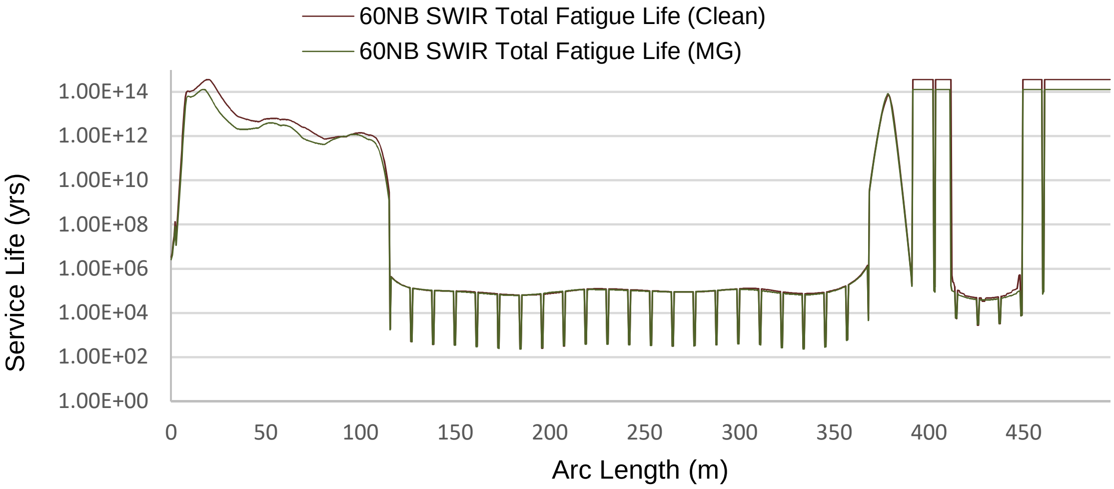


Fig.5-16: 60"NB SWIR Total Fatigue Life Comparison – Clean v MG

Note that the 'spikes' in the HDPE and steel sections correspond to the locations of the welds in the SWIR. Also, some positions in the steel sections report 'infinite' life, however, for illustration purposes, where this is the case, the service life of the steel is set to correspond with the maximum life of the flexible rubber pipe sections.

It can be seen that the current excites the steel pipe sections for which further analysis shows it to be the current profile with a factor of 0.6 causing the most damage. A sensitivity on this case was undertaken using thinner walled steel pipe (12.7mm) and thicker steel wall pipe (25.4mm) and it was found that using thinner wall pipe increases the fatigue damage increase whereas a thicker wall pipe reduces the fatigue damage as shown in Fig.5-15.

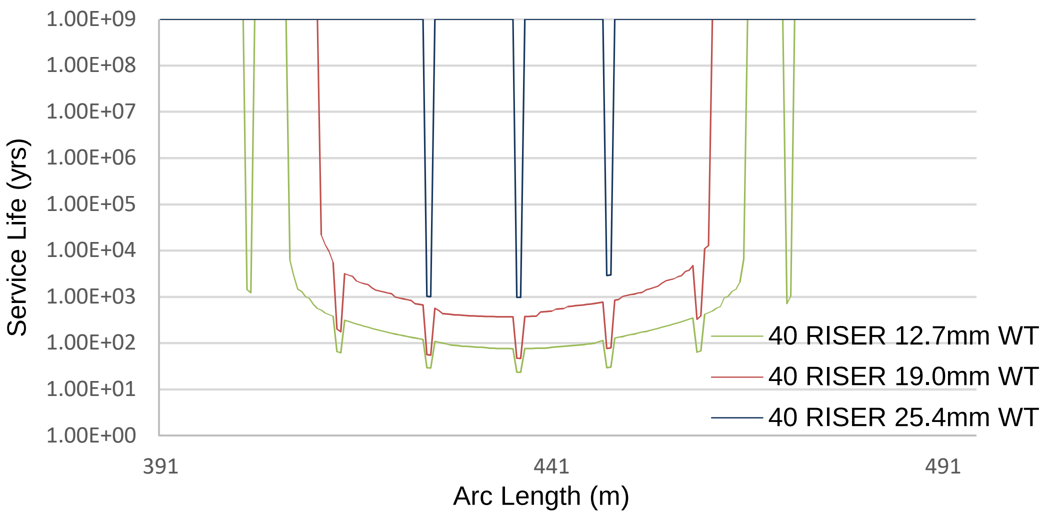


Fig.5-17: 40"NB SWIR – Steel Pipe Wall Thickness Sensitivity

5.5. Summary

The above hydrodynamic analysis has indicated that, in terms of strength, each of the components are within its allowable limits.

The fatigue life of each component is also with the typical design life of such a vessel and although the minimum service life of the HDPE butt fusion welds is around 100 years, this is considered a conservative estimate in as much as the analysis assumes that the waves and current are unidirectional and therefore the fatigue damage will be concentrated in the same radial position on the SWIR. In practice, the waves and current will be multi-directional therefore the fatigue damage will be distributed radially around the SWIR which, theoretically, would increase the service life of the components. It is also assumed that vibration is always present in the SWIR whereas, it could be argued that, due to current speed and directional changes, vibration requires a period of time to become established during which time the fatigue damage is lower.

It was also found that the consideration of marine growth onto the SWIR did not significantly change the fatigue life of the components.

The next section investigates some sensitivity cases for the analysis.

6. SENSITIVITY ANALYSIS

6.1. Riser Damping

Blevins (2001) indicates that damping can be increased by using materials with high internal damping such as rubber, therefore a further SWIR was modelled where two of the steel pipe sections were replaced by flexible rubber pipe sections as shown in Fig. 6-1.

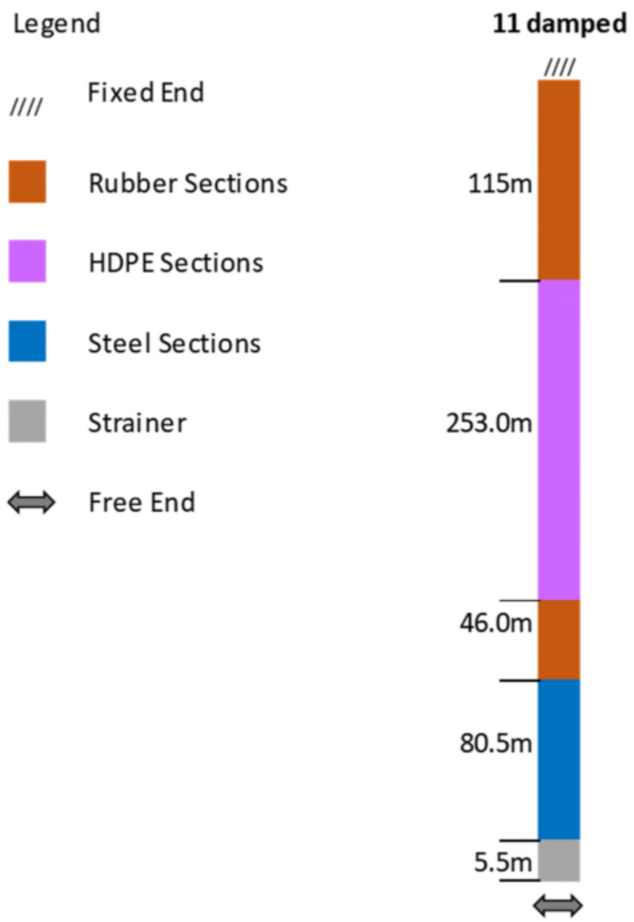


Fig.6-1: Damped SWIR Configuration

The natural frequency of this configuration (referred to as damped SWIR) is lower than that of the original SWIR as shown in Fig.6-2.

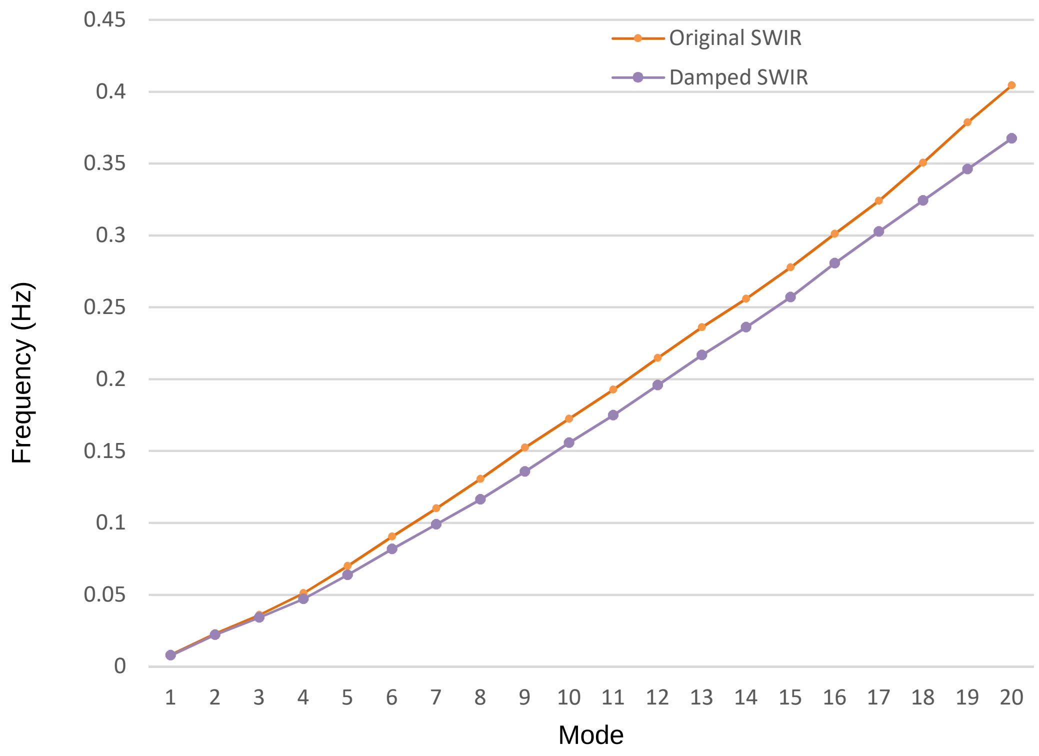


Fig.6-2: Natural Frequency of 40"NB SWIR - Original v Damped

The damped SWIR was subjected to the same fatigue analysis as the original SWIR, ref. section 4.2, and the results extracted and compared as shown in Figs. 6-3 & 6-4 for the 40"NB & 60"NB SWIR respectively.

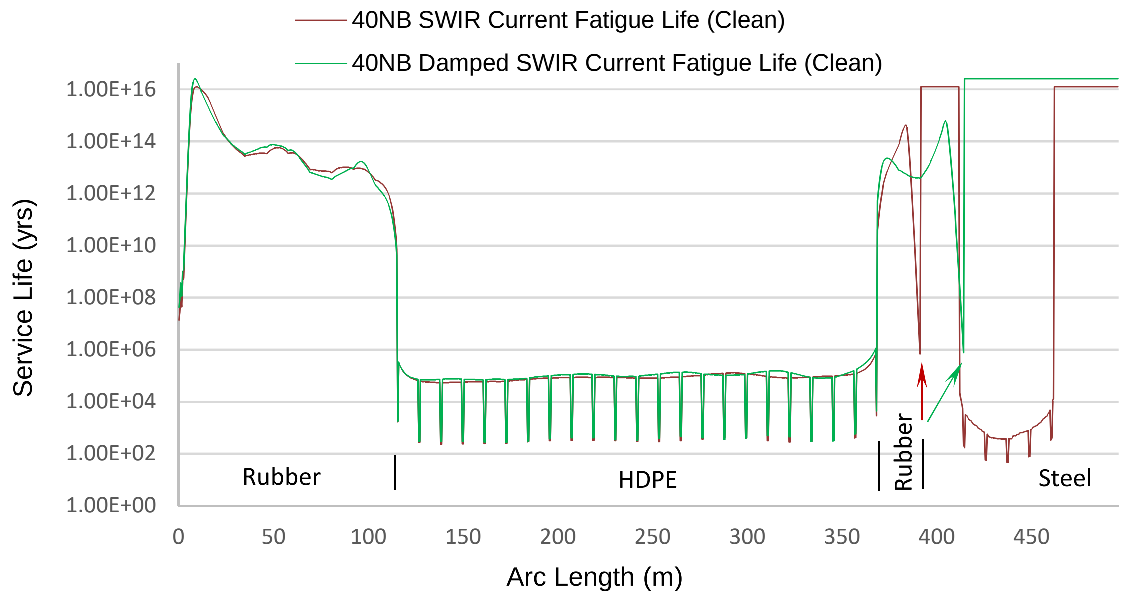


Fig.6-3: 40"NB SWIR Current Fatigue – Original v Damped

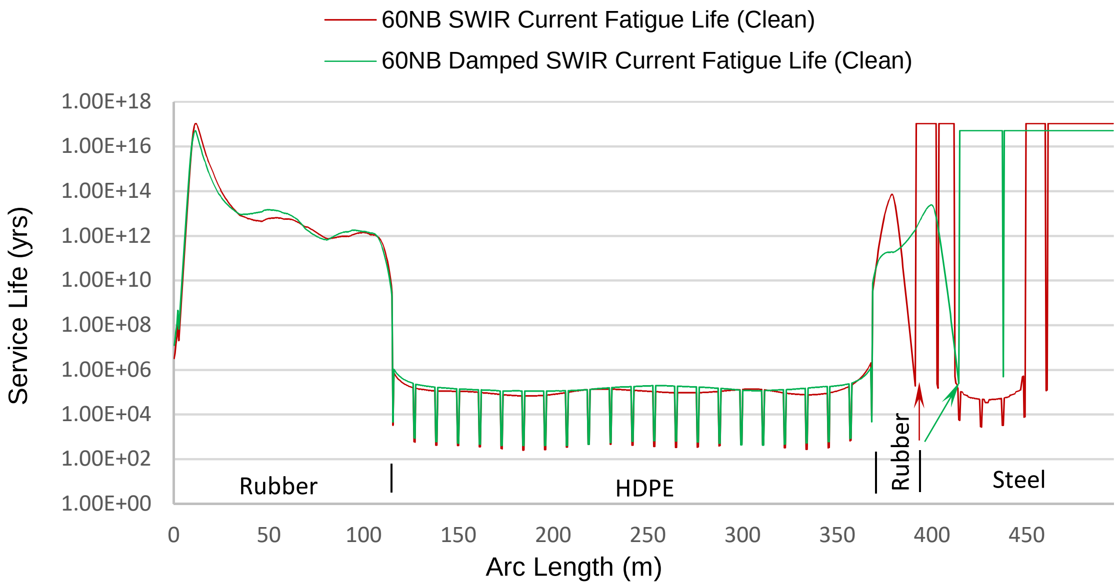


Fig.6-4: 60"NB SWIR Current Fatigue – Original v Damped

Fig.6-3 shows that the fatigue in the steel pipe sections is eliminated for the 40"NB damped SWIR, this is the same for the 60"NB damped SWIR with the exception of one reduced 'spike' as shown in Fig.6-4.

This suggests that by adjusting the number of flexible rubber sections and steel pipe sections, the SWIR damping can be 'tuned' to mitigate the VIV and therefore extend the fatigue life due to current.

6.2. Riser Length

The above analysis considered a SWIR length of 500m, however, sensitivities were performed on both a shorter and longer variant of the damped SWIR to determine the effect that the length has on the fatigue life of the SWIR. For the shorter SWIR, 4-off x 11.5m HDPE sections were removed, giving a total SWIR length of 454m, and for the longer SWIR, 4-off x 11.5m HDPE pipe sections were added giving a total SWIR length of 546m.

A fatigue analysis as described in section 4.2 was performed for the shorter and longer damped SWIR and the results compared to the 500m damped SWIR as shown in Figs 6-5 & 6-6.

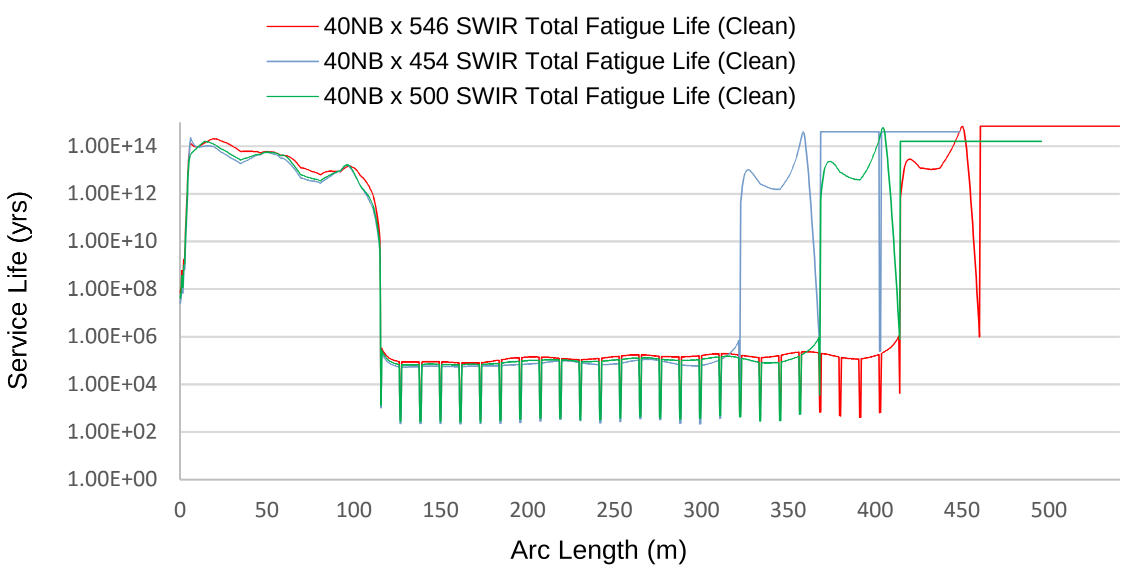


Fig.6-5: 40"NB SWIR Current Fatigue – 500m v 454m & 546m

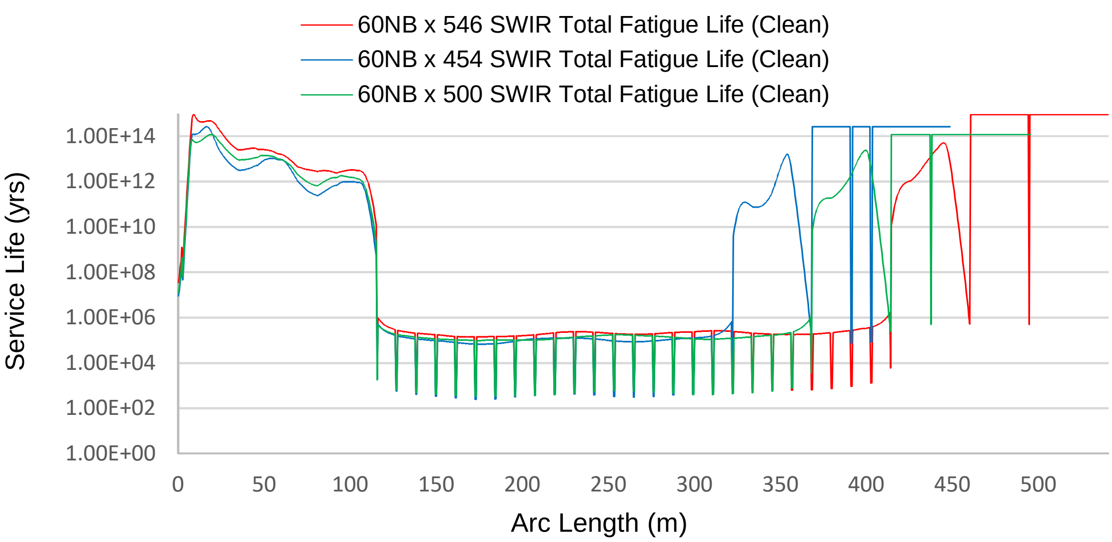


Fig.6-6: 60"NB SWIR Current Fatigue – 500m v 454m & 546m

It can be seen that varying the length of the SWIR has a small effect on its fatigue life in as much as the short SWIR fatigue life is reduced and the long SWIR fatigue life is increased as summarised in table 6-1.

SWIR Dia.	**Minimum Fatigue Life** *(years)*		
	SWIR Length *(m)*		
	454	**500**	**546**
40"NB	218	263	319
60"NB	247	346	515

Table 6-1: SWIR Length Variants– Min. Fatigue Life Strength

6.3. Geographical Location

There are several geographical locations where offshore stranded gas is prevalent. One of the locations indicated is Africa, which has been considered for the above analysis, another is South America.

Therefore to assess the impact of differing geographical locations, the damped SWIR was subject to the same fatigue analysis using metocean data from the Campos Basin in Brazil (Petrobras, 2010) as shown below:

Period → Height ↓	0 – 2	2 – 4	4 - 6	6 - 8	8 - 10	10-12	12-14	14-16	16-18	18-20	20-22	22-24	Total	%
0.0-0.5	85171	166779	50632	10991	2167	425	110	25	13	7	5	0	316325	17.27
0.5-1.0	11867	208032	229458	111698	40289	11835	2862	547	132	49	17	0	616786	33.70
1.0-1.5	322	47777	164356	145537	73169	27184	7458	1481	271	55	32	0	467642	25.53
1.5-2.0	6	6545	64094	85930	53460	23925	7570	1592	266	41	25	0	243454	13.30
2.0-2.5	0	742	19753	38224	27785	14938	5669	1263	190	37	13	2	108616	5.93
2.5-3.0	0	82	5311	14769	12522	8057	3290	798	149	11	3	0	44992	2.46
3.0-3.5	0	6	1277	5433	5522	4149	1907	510	90	10	3	0	18907	1.03
3.5-4.0	0	1	309	2006	2350	1963	987	265	51	3	0	0	7935	.43
4.0-4.5	0	0	69	733	1117	973	535	168	33	1	0	0	3629	.20
4.5-5.0	0	0	12	234	513	507	321	60	11	0	0	0	1658	.09
5.0-5.5	0	0	4	83	230	271	165	52	6	0	0	0	811	.04
5.5-6.0	0	0	1	30	115	123	86	23	1	0	0	0	379	.02
6.0-6.5	0	0	0	8	39	69	35	12	0	0	0	0	163	.00
6.5-7.0	0	0	0	3	21	26	16	2	0	0	0	0	68	.00
7.0-7.5	0	0	0	0	5	18	15	2	0	0	0	0	40	.00
7.5-8.0	0	0	0	2	3	3	7	0	0	0	0	0	15	.00
8.0-8.5	0	0	0	0	2	3	1	0	0	1	0	0	7	.00
8.5-9.0	0	0	0	0	0	2	2	0	0	0	0	0	4	.00
9.0-9.5	0	0	0	0	1	2	1	0	0	0	0	0	4	.00
9.5-10.0	0	0	0	0	1	1	2	0	0	0	0	0	4	.00
10.0-10.5	0	0	0	0	0	2	0	0	0	0	0	0	2	.00
10.5-11.0	0	0	0	0	0	0	0	0	0	0	0	0	.00	-
11.0-11.5	0	0	0	0	0	0	0	0	0	0	0	0	.00	-
11.5-12.0	0	0	0	0	0	1	0	0	0	0	0	0	1	.00
Total	97366	429964	535276	415681	219311	94475	31041	6800	1213	215	98	2	1831442	100.00
%	5.32	23.48	29.23	22.70	11.97	5.16	1.69	.37	.07	.01	.00	.00		

Table 6-2: Wave Scatter Data – Campos Basin (DN)

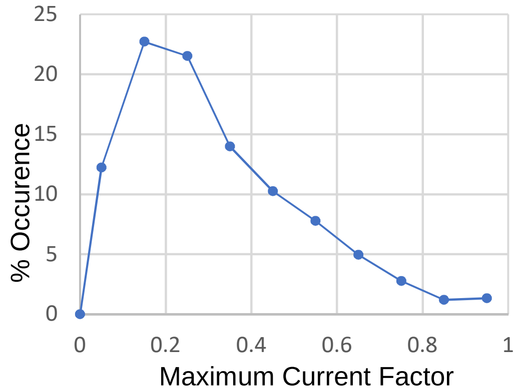
	RETURN PERIOD (YEARS)						
	1	10	20	30	50	100	DIRECTION
Surface	1.14	1.29	1.34	1.36	1.39	1.44	SE
100m	0.72	0.78	0.79	0.80	0.81	0.83	SE
350m	0.52	0.58	0.60	0.61	0.62	0.63	N
500m	0.68	0.79	0.81	0.83	0.85	0.88	N
1000m	0.39	0.46	0.48	0.49	0.50	0.52	N
1250m	0.39	0.46	0.48	0.49	0.50	0.52	N
1500m	0.30	0.35	0.37	0.38	0.39	0.40	N-NE
2000m	0.28	0.36	0.38	0.40	0.41	0.44	NE
2500m	0.28	0.36	0.38	0.40	0.41	0.44	NE

Table 6-3: Maximum Current Profiles – Campos Basin (DN)

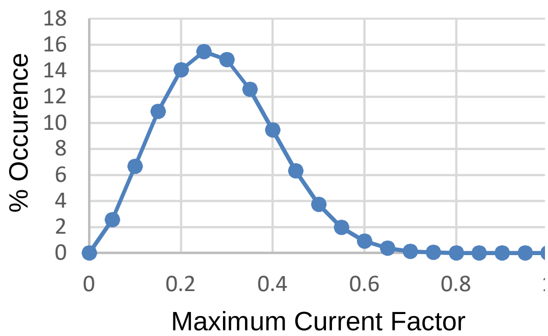
Speed (m/s)		N	NE	E	SE	S	SW	W	NW	Freq	%	Mean Dir
0.0	0.1	521	469	705	1059	1290	1103	583	530	6260	12.22	178.91
0.1	0.2	437	469	799	1841	4042	2704	963	381	11636	22.72	186.81
0.2	0.3	227	215	310	1882	5100	2656	383	249	11022	21.52	184.39
0.3	0.4	118	172	171	1532	3825	1089	162	91	7160	13.98	176.34
0.4	0.5	144	84	235	1947	2476	295	58	23	5262	10.27	161.03
0.5	0.6	113	80	316	1871	1382	174	29	17	3982	7.78	150.42
0.6	0.7	78	49	336	1593	407	66	11	6	2546	4.97	135.33
0.7	0.8	7	39	209	1026	139	1	4	1	1426	2.78	131.35
0.8	0.9	12	19	127	420	36	0	4	0	618	1.21	126.05
0.9	1.0	1	29	163	480	7	0	0	0	680	1.33	118.91
1.0	1.1	0	36	172	202	0	0	0	0	410	0.8	106.18
1.1	1.2	0	57	31	18	0	0	0	0	106	0.21	79.18
1.2	1.3	0	56	6	2	0	0	0	0	64	0.12	63.18
1.3	1.4	0	35	4	0	0	0	0	0	39	0.08	60.51
1.4	1.5	0	1	0	0	0	0	0	0	1	0	56
1.5	1.6	0	0	0	0	0	0	0	0	0	0	999.9
Freq		1658	1810	3584	13873	18704	8088	2197	1298	51212		
%		3.24	3.53	7.00	27.09	36.52	15.79	4.29	2.53			
Mean Speed		0.24	0.35	0.41	0.44	0.3	0.22	0.18	0.16	0.33		

Table 6-4: Current Speed Distribution – Campos Basin (DN)

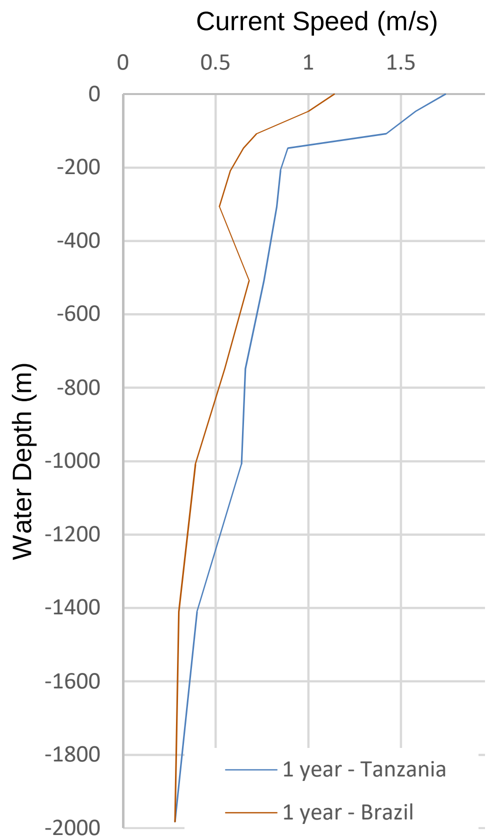
The environmental conditions for Brazil differ from Tanzania, for example, the current velocities in Brazil are lower than those in Tanzania however, the distribution of current velocity is less concentrated as shown in Fig.6-7.



i) Distribution - Brazil



ii) Distribution - Tanzania



iii) 1 yr Current Profiles

Fig.6-7: Current Distribution & Profile Comparison

The results from the fatigue analysis are compared to the damped SWIR in offshore Tanzania as shown in Figs 6-8 thru 6-13;

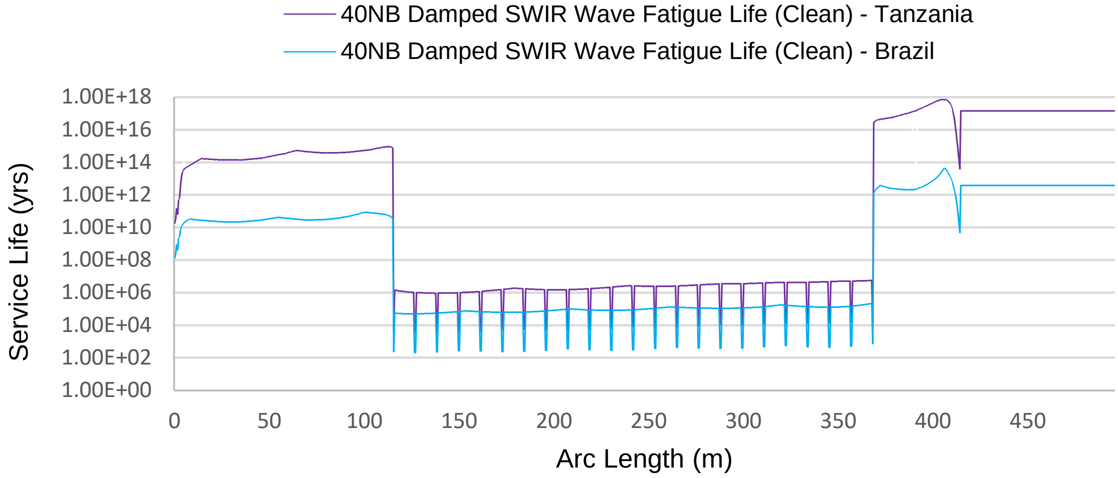


Fig.6-8: 40"NB SWIR Wave Fatigue – Tanzania v Brazil

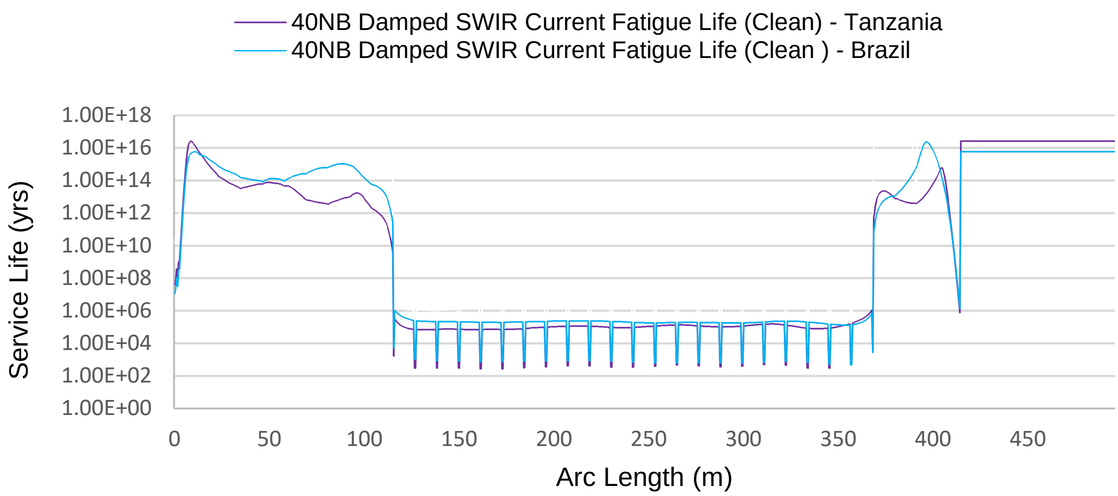


Fig.6-9: 40"NB SWIR Current Fatigue – Tanzania v Brazil

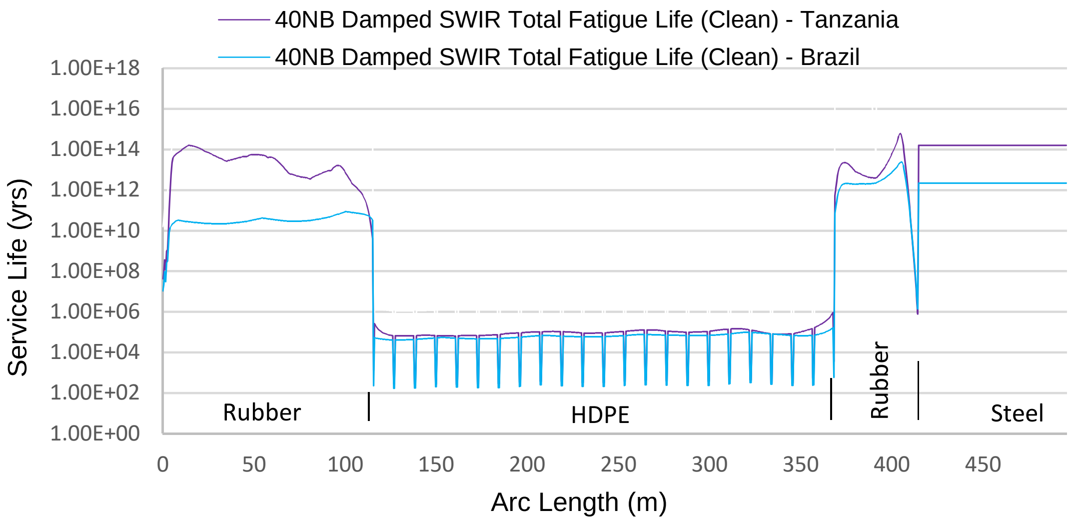


Fig.6-10: 40"NB SWIR Total Fatigue – Tanzania v Brazil

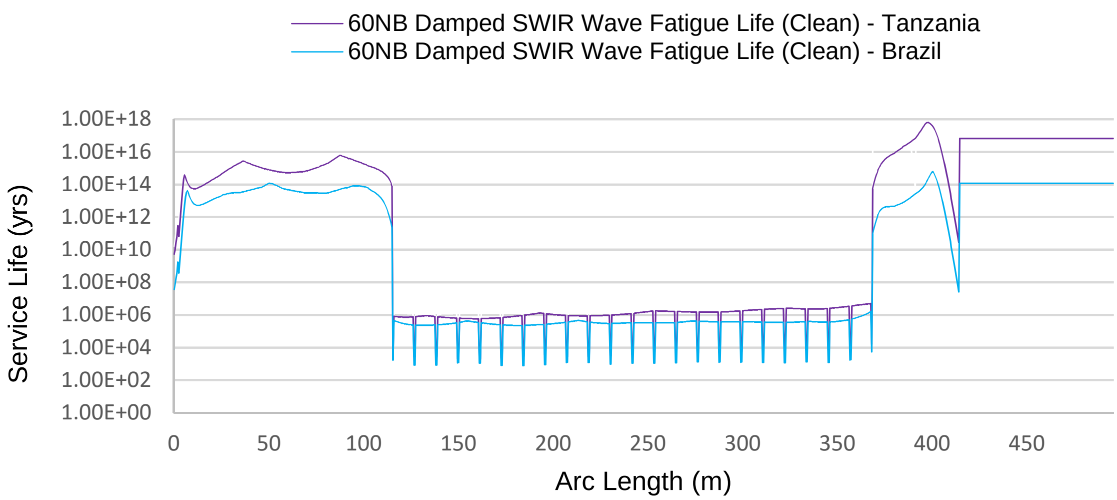


Fig.6-11: 60"NB SWIR Wave Fatigue – Tanzania v Brazil

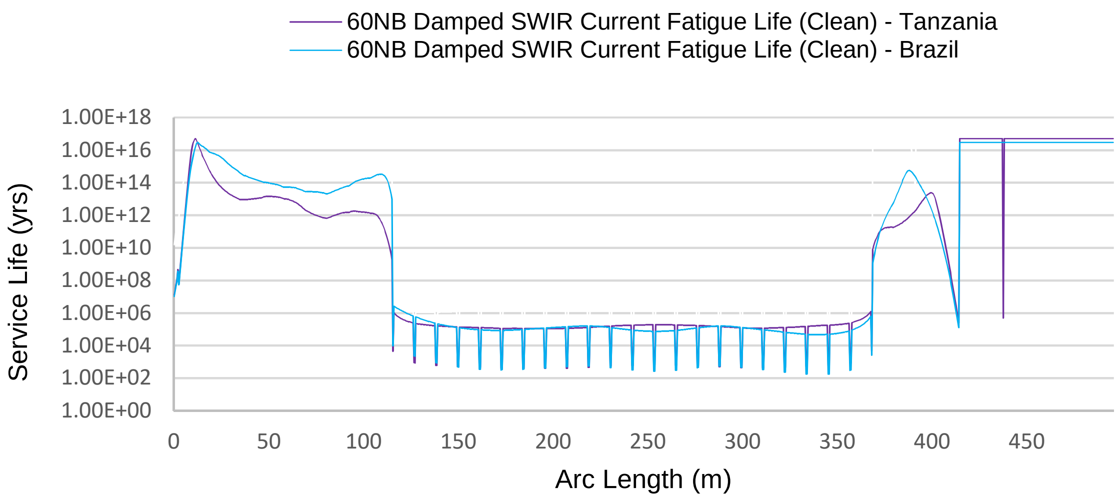


Fig.6-12: 60"NB SWIR Current Fatigue – Tanzania v Brazil

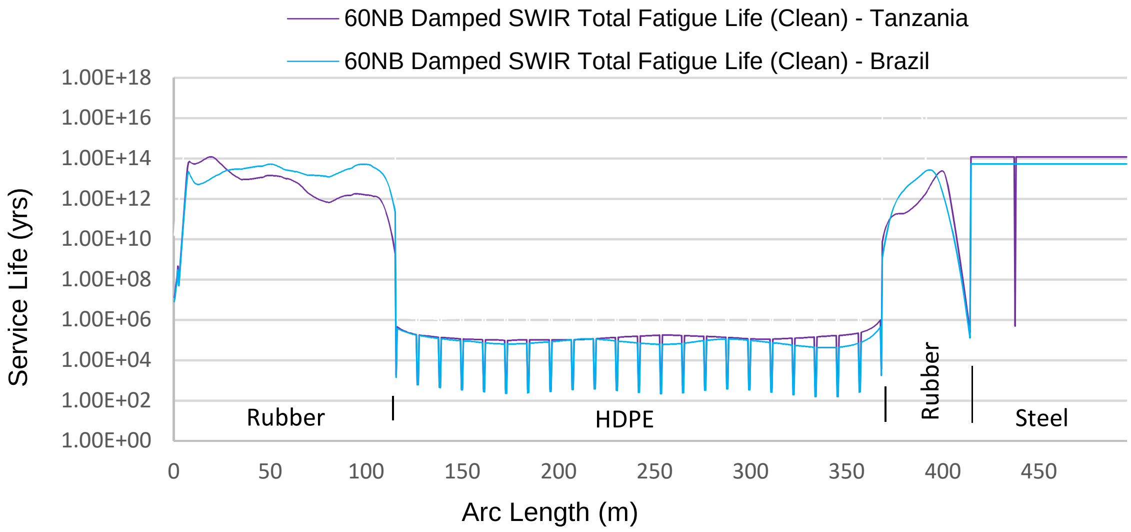


Fig.6-13: 60"NB SWIR Total Fatigue – Tanzania v Brazil

It can be seen from the above that although the maximum 1 year current speed is lower in Brazil, the current speed distribution is such that the fatigue life in both geographical locations is similar. It should be noted that, for the 60"NB SWIR, the VIV 'spike' in the steel pipe section is not present in the Brazil waters indicating that VIV in the SWIR is geographically sensitive.

6.4. Vessel Size

A smaller vessel such as an FPSO may be more responsive to sea states and therefore the SWIR may be subject to increased loading. To assess the impact of installing the proposed SWIR onto a smaller vessel, the fatigue analysis due to waves for the damped SWIR was performed as per section 4.2.2 but using the RAO data from a typical FPSO (MODEC, 2015). The resulting fatigue damage due to waves is extracted and compared against the fatigue damage on an FLNG vessel as shown in Figs.6-14 & 6-15.

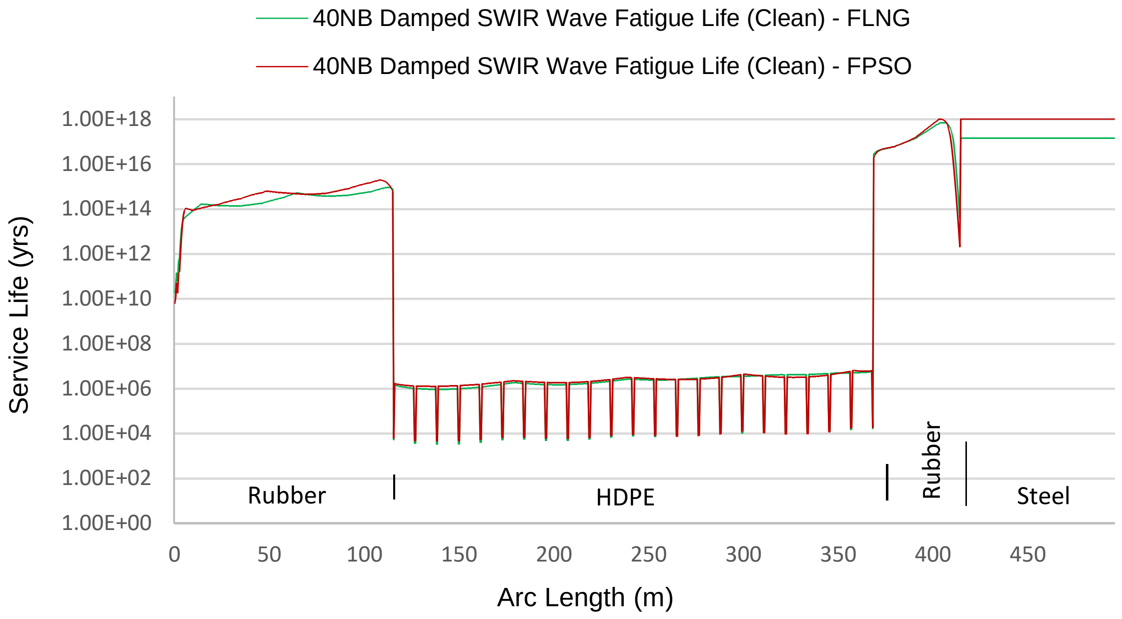


Fig.6-14: 40"NB SWIR Wave Fatigue – FLNG v FPSO

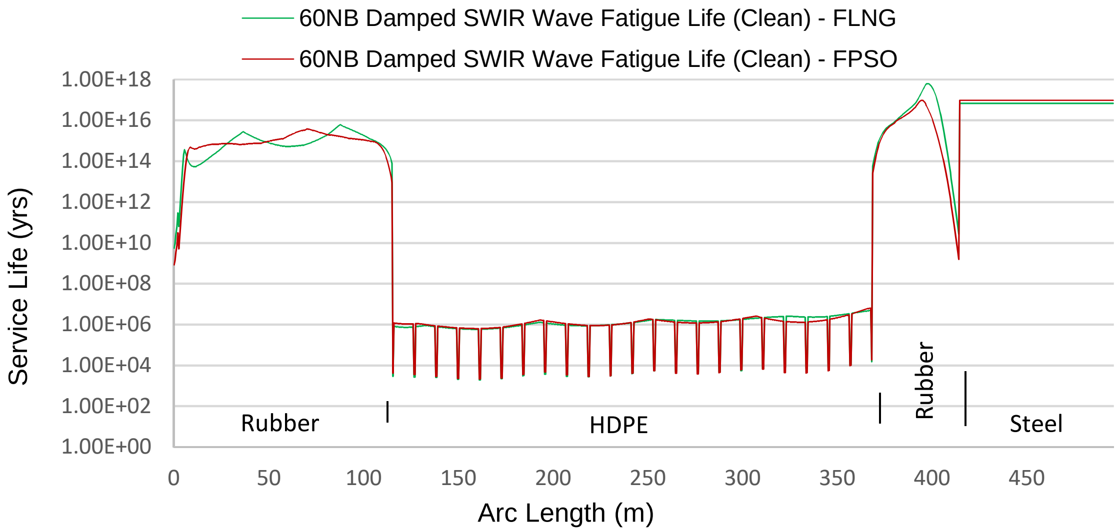


Fig.6-15: 60"NB SWIR Wave Fatigue – FLNG v FPSO

The effect on the total fatigue damage due to current and waves is shown in Figs.6-16 & 6-17.

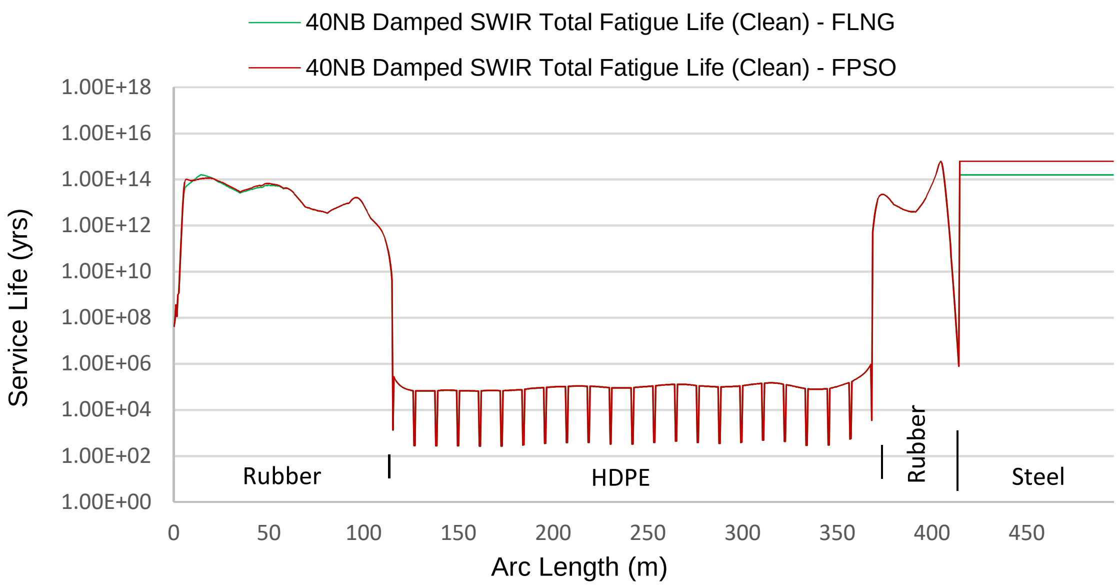


Fig.6-16: 40"NB SWIR Total Fatigue – FLNG v FPSO

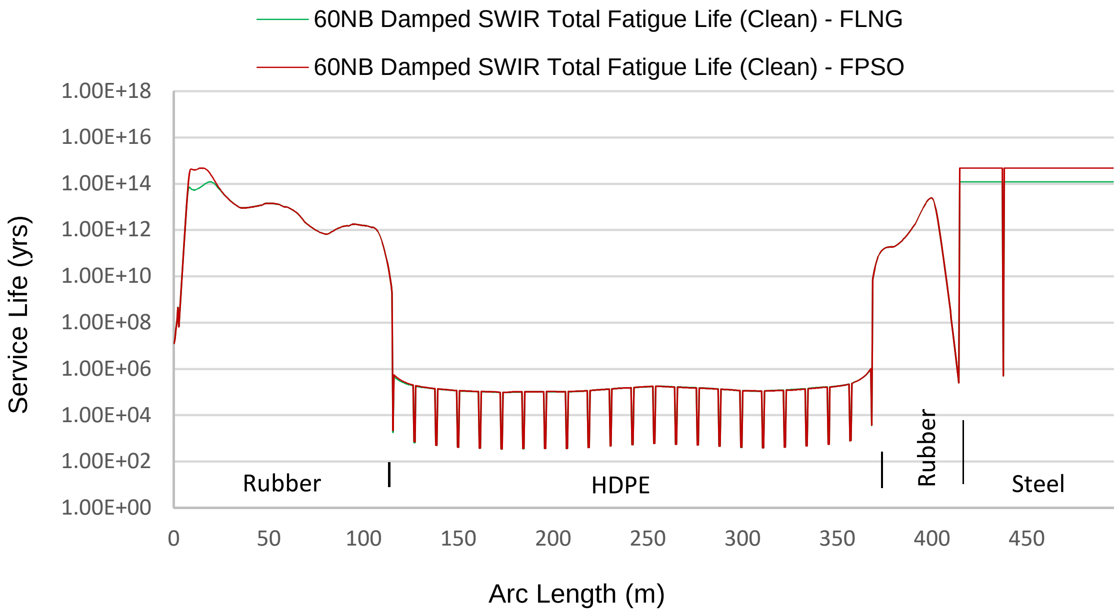


Fig.6-17: 60"NB SWIR Total Fatigue – FLNG v FPSO

A strength analysis was also performed as per section 4.1 to assess the impact the vessel response would have on the strength of the proposed SWIR and also the loads induced into the hull. The resulting analysis yielded the maximum values which are compared against the values reported for the FLNG vessel in Tables 6-5 & 6-6:

	Maximum Values	
	FLNG	**FPSO**
Flexible Rubber Pipe Section		
• **Tension** (kN)	**808.0**	**811.7**
• **Curvature** (Rad/m) *as MBR* *(m)*	**0.244** *4.1*	**0.242** *4.1*
HDPE Pipe Section		
• **Tensile Stress** (MPa)	**3.2**	**3.1**
• **Bending Stress** (MPa)	**0.7**	**0.7**
• **Von Mises Stress** (MPa)	**4.9**	**4.8**
• **Curvature** (Rad/m) *as MBR* *(m)*	**0.00168** *593.8*	**0.00165** *605.3*
Steel Pipe Section		
• **Tensile Stress** (MPa)	**4.0**	**4.0**
• **Bending Stress** (MPa)	**7.7**	**8.3**
• **Von Mises Stress** (MPa)	**12.8**	**13.3**
• **Curvature** (Rad/m) *as MBR* *(m)*	**0.00007445** *13431*	**0.00008** *12510*

Table 6-5: 40”NB SWIR Strength Analysis Results - FLNG v FPSO

	Maximum Values	
	FLNG	**FPSO**
Flexible Rubber Pipe Section		
• **Tension** (kN)	**1451.0**	**1487.6**
• **Curvature** (Rad/m) *as MBR (m)*	**0.1429** *7.0*	**0.1429** *7.0*
HDPE Pipe Section		
• **Tensile Stress** (MPa)	**2.0**	**2.0**
• **Bending Stress** (MPa)	**0.8**	**0.8**
• **Von Mises Stress** (MPa)	**3.8**	**3.9**
• **Curvature** (Rad/m) *as MBR (m)*	**0.001244** *803.6*	**0.00123** *815.3*
Steel Pipe Section		
• **Tensile Stress** (MPa)	**4.2**	**4.2**
• **Bending Stress** (MPa)	**8.8**	**9.7**
• **Von Mises Stress** (MPa)	**14.2**	**15.0**
• **Curvature** (Rad/m) *as MBR (m)*	**0.00005697** *17554*	**0.00006244** *16014*

Table 6-6: 60”NB SWIR Strength Analysis Results - FLNG v FPSO

The loads induced into the hull that can be used for the hang-off design are presented and compared against the values reported for the FLNG vessel in Tables 6-7 & 6-8:

- *Maximum Values for Hang-Off Design*

	Maximum Values	
	FLNG	**FPSO**
End Force (kN)	**837.3**	**843.1**
Bending Moment (kNm)	**969.1**	**966.7**
Shear Force (kN)	**433.7**	**427.2**

Table 6-7: Maximum Values for 40”NB Hang Off Design - FLNG v FPSO

- *Maximum Values for Hang-Off Design*

	Maximum Values	
	FLNG	**FPSO**
End Force (kN)	**1508.9**	**1545.1**
Bending Moment (kNm)	**2141.8**	**2144.0**
Shear Force (kN)	**677.9**	**672.2**

Table 6-8: Maximum Values for 60"NB Hang Off Design - FLNG v FPSO

It can be seen from the above that the total fatigue life of the SWIR and the loads induced into the SWIR from the FPSO vessel differ only slightly from those of the FLNG, the same can be seen for the loads induced into the hull of the vessel.

This suggests that the size of vessel, within the dimensions used within the industry, has a negligible effect on the strength and fatigue capabilities of the SWIR and although this may change with geographical location, the environmental conditions in the areas under consideration are relatively benign.

6.5. VIV Excitation Zone

It can be seen from the predicted service life of the SWIR that generally the HDPE sections have the lowest predicted service life, and specifically at the butt fusion welds.

Interestingly however, for the 40"NB SWIR, it is the steel pipe sections which have the lowest expected fatigue life of approximately 50 years due to the VIV response. Further examination reveals that, for the Tanzanian waters, it is the 1 year current profiles with a factor of 0.5 - 0.6 which excites the steel pipe sections and causes the most fatigue damage within the SWIR. For these current profiles, the frequency of oscillation was found to be 0.07 and 0.09Hz for current profiles 0.5 and 0.6 respectively. Examination of the simulations indicates that within this frequency range, it is modes 5 and 6 which are excited.

From this, and using the techniques presented in DNV-RP-F204 (DNV, 2010), the effective velocity U_{eff} can be estimated as follows:

$$f_s = St * U_{eff} / D_h$$ (DNV, 2010) Eq. 4.4

where: St = Strouhal Number

U_{eff} = Effective Velocity

D_h = Outside Diameter

Therefore: $U_{eff} = f_s * D_h / St$

and: $St =$ ~0.20 (DNV, 2014) Fig 9-1

$D_h =$ 1.067m (HDPE)

$fs =$ 0.07 – 0.09 Hz

so: U_{eff} = |0.07:0.09| * 1.068 / 0.2

U_{eff} = 0.374 – 0.480 m/s

And then plotting this range on the current profile indicates the depth of the effective velocity as shown in Fig.6-18:

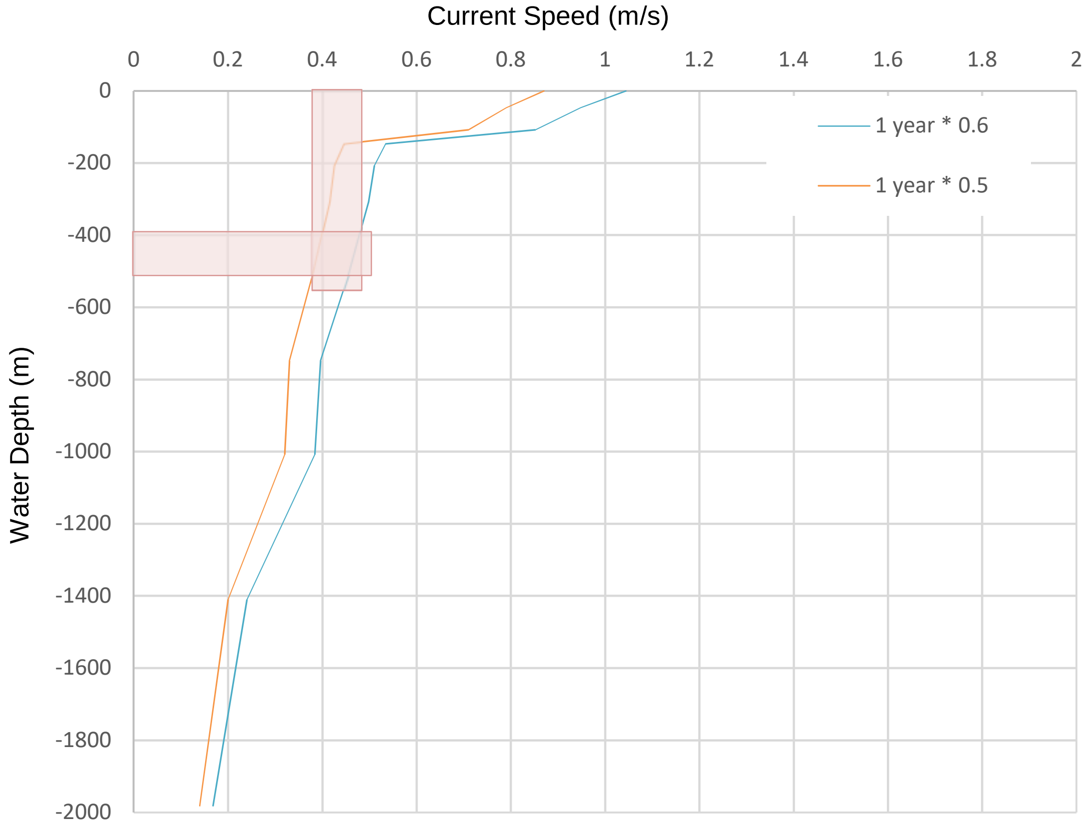


Fig.6-18: 40”NB SWIR – VIV Excitation Zone (Tanzania)

If this classic theory applies, it would suggest that the excitation zone is between 400-500m which is the lower region of the SWIR. This differs from that of a top tensioned riser where the excitation length is considered to be the part of the riser where the velocity is 2/3 of the maximum velocity (DNV, 2010) Sect 4.3, which would be the upper region of the riser.

Using the same theory as above, the effective velocity was calculated for the Brazilian waters as 0.425 – 0.530 m/s and is plotted on the current profiles in Fig.6-19.

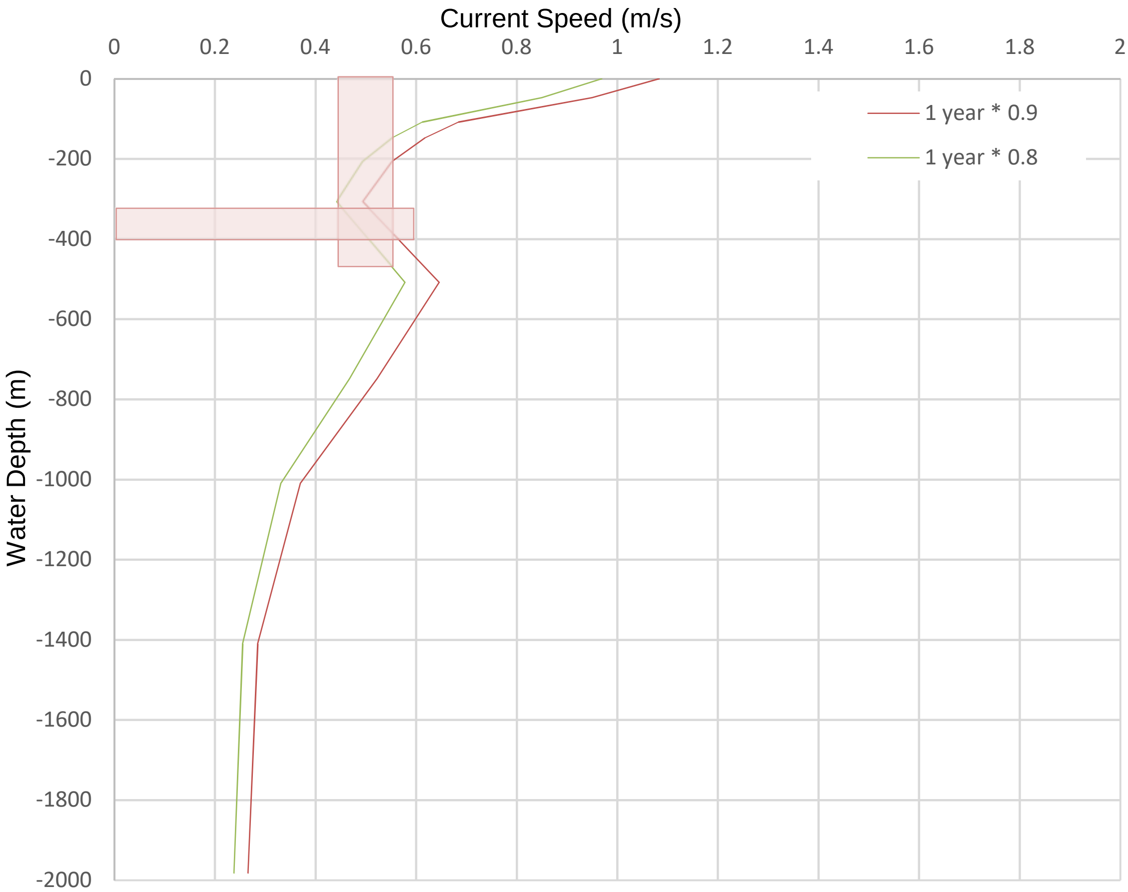


Fig.6-19: 40”NB Damped SWIR – VIV Excitation Zone (Brazil)

Although the Brazilian current profile is more irregular, it is feasible that this is in agreement with the earlier suggestion that the excitation zone is at the lower end of the SWIR.

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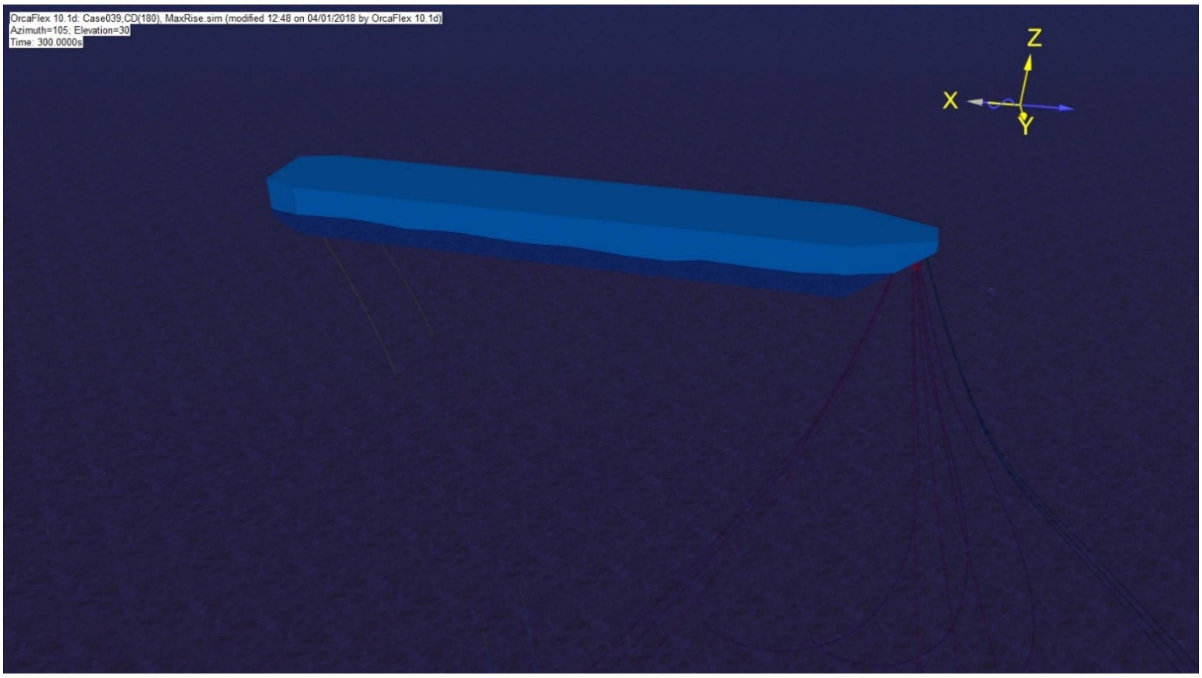
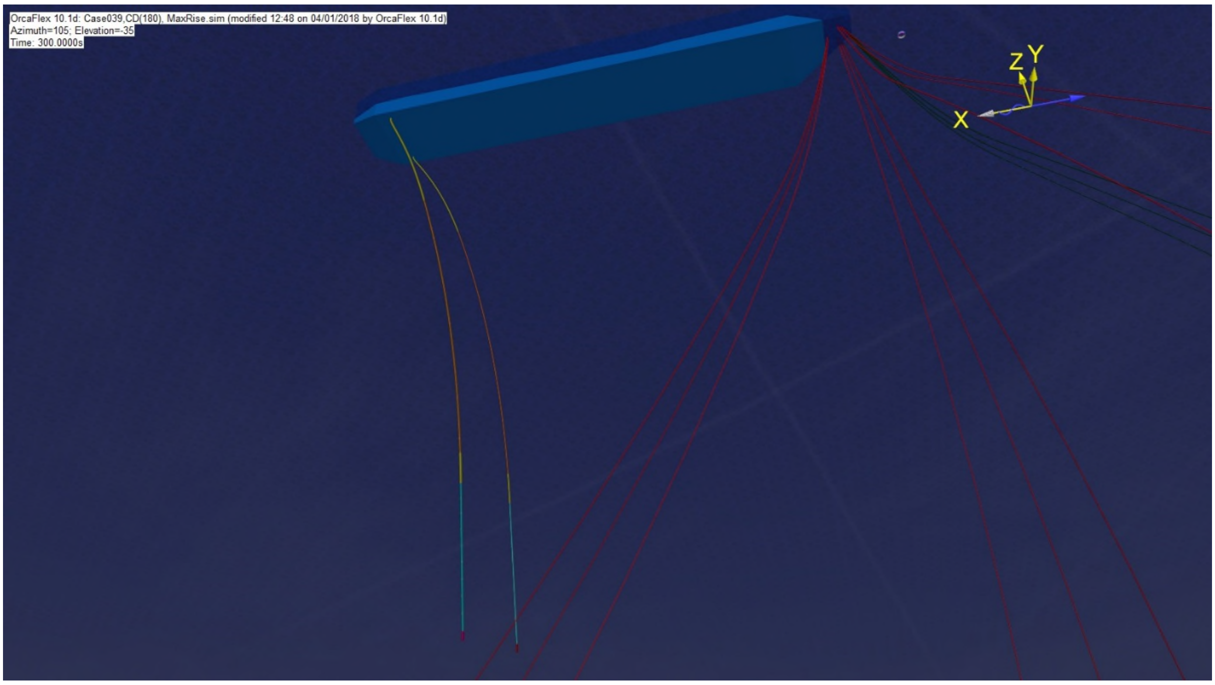
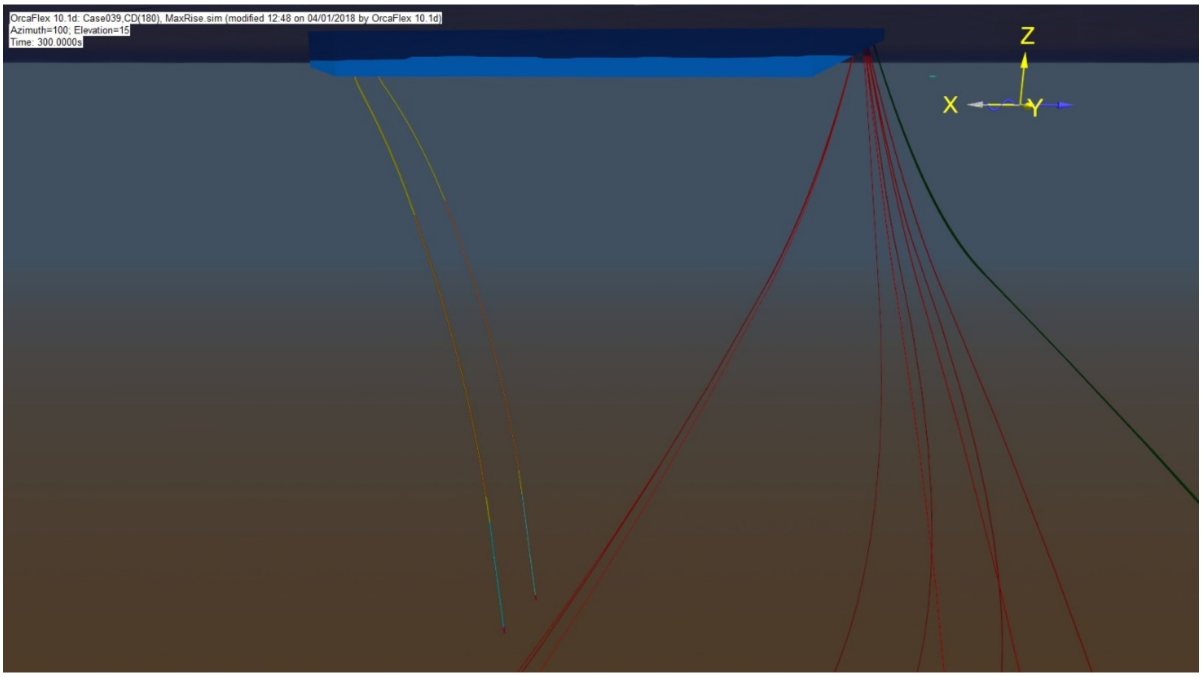
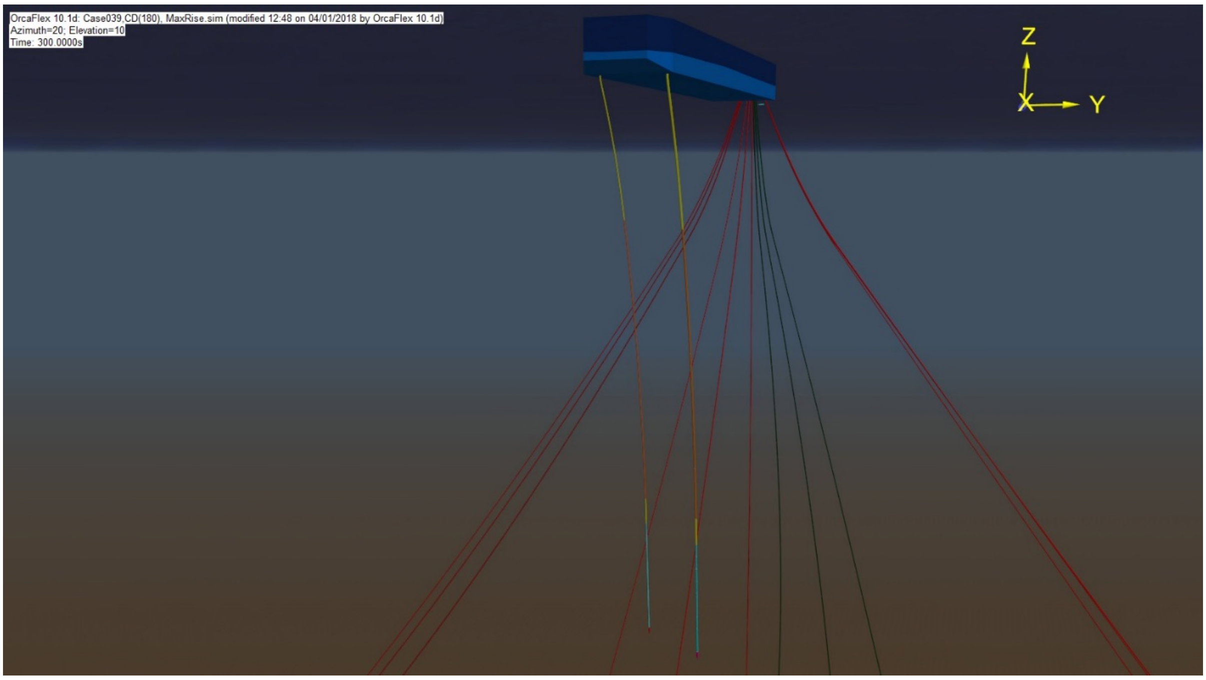
APPENDICES

APPENDIX A: MODEL SCREENSHOTS






OrcaFlex 10.1d: Case039,CD(180), MaxRise.sim (modified 12:48 on 04/01/2018 by OrcaFlex 10.1d)
Azimuth=100; Elevation=15
Time: 300.0000s
Z
X
Y


OrcaFlex 10.1d: Case039,CD(180), MaxRise.sim (modified 12:48 on 04/01/2018 by OrcaFlex 10.1d)
Azimuth=20; Elevation=10
Time: 300.0000s
Z
X
Y

APPENDIX B: MODEL DATA FILES

-Configuration Selection

-Strength Analysis

-Fatigue Analysis (Waves)

-Fatigue Analysis (Current)

Model Data File - Configuration Selection

```yaml
%YAML 1.1
# Type: Model
# Program: OrcaFlex 10.1d
# File: C:\Users\Ian\Desktop\Config Selection.yml
# Created: 15:56 on 03/06/2018
# User: Ian
# Machine: IAN-PC
---
General:
  # Units
  UnitsSystem: SI
  # Statics
  BuoysIncludedInStatics: Individually Specified
  StaticsMaxIterations: 800
  StaticsMinDamping: 2
  StaticsMaxDamping: 50
  # Dynamics
  DynamicsSolutionMethod: Explicit time domain
  AlwaysUseRecommendedTimeSteps: Yes
  InnerTimeStep: 79E-6
  TargetOuterTimeStep: 0.0023
  RecommendedInnerTimeStepRatio: 10
  RecommendedOuterTimeStepToInnerMultiple: 30
  RecommendedOuterTimeStepToWavePeriodRatio: 40
  RecommendedOuterTimeStepToWakeOscillatorStrouhalPeriodRatio: 200
  AxialTargetDamping: 10
  BendingTargetDamping: 10
  TorsionTargetDamping: 10
  LogPrecision: Single
  TargetLogSampleInterval: 1
  LogStartTime: ~
  # Stages
  StageDuration:
    - 8
    - 500
  # Drawing
  Pen: [1, Solid, Yellow]
  NorthDirectionDefined: Yes
  NorthDirection: 90
  # Default view parameters
  DefaultViewMode: Wire frame
  DefaultViewSize: 583.532627843579
  DefaultViewCentre: [201.56372757738, 4.12145186646211, -248.996087857083]
  DefaultViewAzimuth: 270
  DefaultViewElevation: 0
VariableData:
  KinematicViscosity:
    - Name: 3.5% Salinity
      IndependentValue, DependentValue:
        - [0, 1.82842473024E-6]
        - [0.555555555555556, 1.79516544192E-6]
        - [1.11111111111111, 1.76274228096E-6]
        - [1.66666666666667, 1.73143395648E-6]
        - [2.22222222222222, 1.70096175936E-6]
        - [2.77777777777778, 1.67141859264E-6]
        - [3.33333333333333, 1.64271155328E-6]
        - [3.88888888888889, 1.61484064128E-6]
        - [4.44444444444444, 1.58780585664E-6]
        - [5, 1.56142139328E-6]
        - [5.55555555555556, 1.53587305728E-6]
        - [6.11111111111111, 1.51088213952E-6]
        - [6.66666666666667, 1.48663444608E-6]
        - [7.22222222222222, 1.46303707392E-6]
        - [7.77777777777778, 1.44009002304E-6]
```

```
      - [8.33333333333333, 1.41760748736E-6]
      - [8.88888888888889, 1.39577527296E-6]
      - [9.44444444444444, 1.37459337984E-6]
      - [10, 1.35378309888E-6]
      - [10.5555555555556, 1.33353023616E-6]
      - [11.1111111111111, 1.31383479168E-6]
      - [11.6666666666667, 1.2946038624E-6]
      - [12.2222222222222, 1.27574454528E-6]
      - [12.7777777777778, 1.2574426464E-6]
      - [13.3333333333333, 1.23960526272E-6]
      - [13.8888888888889, 1.22204658816E-6]
      - [14.4444444444444, 1.2049524288E-6]
      - [15, 1.18832278464E-6]
      - [15.5555555555556, 1.1719718496E-6]
      - [16.1111111111111, 1.15599252672E-6]
      - [16.6666666666667, 1.140384816E-6]
      - [17.2222222222222, 1.12514871744E-6]
      - [17.7777777777778, 1.11028423104E-6]
      - [18.3333333333333, 1.09569845376E-6]
      - [18.8888888888889, 1.0813913856E-6]
      - [19.4444444444444, 1.06736302656E-6]
      - [20, 1.05370627968E-6]
      - [20.5555555555556, 1.04032824192E-6]
      - [21.1111111111111, 1.02722891328E-6]
      - [21.6666666666667, 1.01431539072E-6]
      - [22.2222222222222, 1.00177348032E-6]
      - [22.7777777777778, 989.417376E-9]
      - [23.3333333333333, 977.3399808E-9]
      - [23.8888888888889, 965.44839168E-9]
      - [24.4444444444444, 953.83551168E-9]
      - [25, 942.5013408E-9]
      - [25.5555555555556, 931.352976E-9]
      - [26.1111111111111, 920.39041728E-9]
      - [26.6666666666667, 909.61366464E-9]
      - [27.2222222222222, 899.11562112E-9]
      - [27.7777777777778, 888.80338368E-9]
      - [28.3333333333333, 878.58404928E-9]
      - [28.8888888888889, 868.643424E-9]
      - [29.4444444444444, 858.8886048E-9]
      - [30, 849.31959168E-9]

DragCoefficient:
    - Name: 60Rubber
    IndependentValue, DependentValue:
      - [4940, 1.2]
      - [9870, 1.2]
      - [24.7E3, 1.2]
      - [49.4E3, 1.2]
      - [138E3, 1.2]
      - [148E3, 1.2]
      - [173E3, 1.16]
      - [197E3, 1.06]
      - [222E3, 0.8]
      - [247E3, 0.57]
      - [296E3, 0.61]
      - [346E3, 0.68]
      - [395E3, 0.76]
      - [494E3, 0.88]
      - [740E3, 0.97]
      - [987E3, 0.99]
      - [2.47E6, 0.98]
      - [4.94E6, 0.96]
      - [9.87E6, 0.94]
      - [14.8E6, 0.94]
```

```
- Name: 60HDPE
  IndependentValue, DependentValue:
    - [9990, 1.2]
    - [20E3, 1.2]
    - [49.9E3, 1.2]
    - [99.9E3, 1.2]
    - [280E3, 1.2]
    - [300E3, 1.19]
    - [350E3, 1.16]
    - [400E3, 1.05]
    - [449E3, 0.8]
    - [499E3, 0.46]
    - [599E3, 0.28]
    - [699E3, 0.28]
    - [799E3, 0.3]
    - [999E3, 0.36]
    - [1.5E6, 0.47]
    - [2E6, 0.52]
    - [4.99E6, 0.56]
    - [9.99E6, 0.55]
    - [20E6, 0.53]
    - [30E6, 0.52]
- Name: 60Steel
  IndependentValue, DependentValue:
    - [9790, 1.2]
    - [19.6E3, 1.2]
    - [48.9E3, 1.2]
    - [97.9E3, 1.2]
    - [274E3, 1.2]
    - [294E3, 1.19]
    - [343E3, 1.16]
    - [392E3, 1.05]
    - [440E3, 0.8]
    - [489E3, 0.46]
    - [587E3, 0.31]
    - [685E3, 0.32]
    - [783E3, 0.35]
    - [979E3, 0.41]
    - [1.47E6, 0.53]
    - [1.96E6, 0.58]
    - [4.89E6, 0.61]
    - [9.79E6, 0.59]
    - [19.6E6, 0.57]
    - [29.4E6, 0.57]
    - Name: 40Rubber
  IndependentValue, DependentValue:
    - [4100, 1.21]
    - [8210, 1.21]
    - [20.5E3, 1.21]
    - [41E3, 1.21]
    - [115E3, 1.2]
    - [123E3, 1.2]
    - [144E3, 1.16]
    - [164E3, 1.06]
    - [185E3, 0.8]
    - [205E3, 0.62]
    - [246E3, 0.67]
    - [287E3, 0.74]
    - [328E3, 0.81]
    - [410E3, 0.91]
    - [615E3, 1]
    - [821E3, 1.02]
    - [2.05E6, 1.01]
    - [4.1E6, 0.99]
```

```
      - [8.21E6, 0.98]
      - [12.3E6, 0.98]
  - Name: 40HDPE
    IndependentValue, DependentValue:
      - [9980, 1.2]
      - [20E3, 1.2]
      - [49.9E3, 1.2]
      - [99.8E3, 1.2]
      - [279E3, 1.2]
      - [299E3, 1.19]
      - [349E3, 1.16]
      - [399E3, 1.05]
      - [449E3, 0.8]
      - [499E3, 0.46]
      - [599E3, 0.28]
      - [699E3, 0.28]
      - [799E3, 0.3]
      - [998E3, 0.36]
      - [1.5E6, 0.47]
      - [2E6, 0.53]
      - [4.99E6, 0.57]
      - [9.98E6, 0.55]
      - [20E6, 0.53]
      - [29.9E6, 0.53]
  - Name: 40Steel
    IndependentValue, DependentValue:
      - [9690, 1.2]
      - [19.4E3, 1.2]
      - [48.4E3, 1.2]
      - [96.9E3, 1.2]
      - [271E3, 1.2]
      - [291E3, 1.19]
      - [339E3, 1.16]
      - [387E3, 1.05]
      - [436E3, 0.8]
      - [484E3, 0.46]
      - [581E3, 0.32]
      - [678E3, 0.33]
      - [775E3, 0.36]
      - [969E3, 0.43]
      - [1.45E6, 0.55]
      - [1.94E6, 0.59]
      - [4.84E6, 0.62]
      - [9.69E6, 0.61]
      - [19.4E6, 0.59]
      - [29.1E6, 0.58]

BendingStiffness:
  - Name: 40"stiffness
    IndependentValue, DependentValue:
      - [0, 0]
      - [0.02, 100]
      - [0.03, 134]
      - [0.04, 168]
      - [0.06, 210]
      - [0.08, 240]
      - [0.1, 265]
      - [0.12, 283]
      - [0.14, 295]
    Hysteretic: No
  - Name: 60"stiffness
    IndependentValue, DependentValue:
      - [0, 0]
      - [0.02, 550]
```

```
        - [0.04, 900]
        - [0.06, 1200]
        - [0.08, 1475]
        - [0.1, 1675]
        - [0.12, 1800]
        - [0.14, 1890]
      Hysteretic: No
    - Name: 60"Stiffness1
      IndependentValue, DependentValue:
        - [0, 0]
        - [0.02, 485]
        - [0.04, 825]
        - [0.06, 1060]
        - [0.08, 1210]
        - [0.0952, 1285]
        - [0.1, 1300]
      Hysteretic: No
    - Name: 40"stiffness linear
      IndependentValue, DependentValue:
        - [0, 0]
        - [0.14, 295]
      Hysteretic: No
    - Name: 60"stiffness linear
      IndependentValue, DependentValue:
        - [0, 0]
        - [0.14, 1277]
      Hysteretic: No
Environment:
  # Sea
  WaterSurfaceZ: 0
  KinematicViscosity: 3.5% Salinity
  SeaTemperature: 10
  ReynoldsNumberCalculation: Cross Flow
  # Sea Density
  HorizontalWaterDensityFactor: ~
  VerticalDensityVariation: Constant
  Density: 1.025
  # Seabed
  SeabedType: Flat
  SeabedOrigin: [0, 0]
  WaterDepth: 2600
  SeabedSlopeDirection: 0
  SeabedSlope: 0
  SeabedModel: Elastic
  SeabedNormalStiffness: 100
  SeabedShearStiffness: ~
  SeabedDamping: 100
  # Waves
  SimulationTimeOrigin: 0
  KinematicStretchingMethod: Vertical Stretching
  WaveTrains:
    - Name: Wave1
      WaveType: Airy
      WaveDirection: 0
      WaveHeight: 0
      WavePeriod: 10.4
      WaveOrigin: [0, 0]
      WaveTimeOrigin: 0
  # WaveCalculation
  WaveKinematicsCutoffDepth: Infinity
  WaveCalculationMethod: Instantaneous Position (exact)
  WaveCalculationTimeInterval: 0
  WaveCalculationSpatialInterval: 0
  # Current
```

```
  MultipleCurrentDataCanBeDefined: No
  CurrentRamp: No
  HorizontalCurrentFactor: ~
  CurrentApplyVerticalStretching: No
  CurrentMethod: Interpolated
  RefCurrentSpeed: 0.5
  RefCurrentDirection: 90
  CurrentDepth, CurrentFactor, CurrentRotation:
    - [0, 1, 0]
    - [1982, 1, 0]
  # Wind
  IncludeVesselWindLoads: Yes
  IncludeLineWindLoads: No
  IncludeBuoyWingWindLoads: No
  VerticalWindVariationFactor: ~
  AirDensity: 0.00128
  WindType: Constant
  WindSpeed: 0
  WindDirection: 0
  # Drawing
  SeaSurfacePen: [1, Solid, $FF8080]
  SeabedPen: [1, Solid, $004080]
  SeabedProfilePen: [2, Solid, White]
VesselTypes:
  - Name: Generic_FLNG
    Length: 425
    # Conventions
    RAOResponseUnits: degrees
    RAOWaveUnit: amplitude
    WavesReferredToBy: period (s)
    RAOPhaseConvention: leads
    RAOPhaseUnitsConvention: degrees
    RAOPhaseRelativeToConvention: crest
    SurgePositive: forward
    SwayPositive: port
    HeavePositive: up
    RollPositiveStarboard: down
    PitchPositiveBow: down
    YawPositiveBow: port
    Symmetry: None
    CurrentCoeffSymmetry: XZ plane
    WindCoeffSymmetry: XZ plane
    QTFConventionsRotationOrder: RzRyRx
    QTFConventionsRotationAxes: Rotated
    QTFConventionsFrameOfReference: Body-Fixed
    Draughts:
      - Name: 14m
        Mass: 8800
        MomentOfInertiaTensorX, MomentOfInertiaTensorY, MomentOfInertiaTensorZ:
          - [249E3, 0, 0]
          - [0, 5.83E6, 0]
          - [0, 0, 5.83E6]
        CentreOfGravity: [-233.48, 0.22, 23.08]

RayleighDampingCoefficients:
  - Name: Damping-mass and stiffness proportional
    Mode: Mass and Stiffness Proportional
    DampingRatio: 0
    ApplyToGeometricStiffness: No
LineTypes:
  - Name: FPSOchain_Tanzania_Jugal3
    Category: General
    # Geometry & Mass
    OD: 0.228
```

```
    ID: 0
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.316
    # Limits
    CompressionIsLimited: Yes
    AllowableTension: ~
    MinRadius: [~, ~]
    # Structure
    EI: [0, ~]
    EA: 1.469E6
    PoissonRatio: 0.5
    GJ: 0
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 0.4891
    ClashStiffness: 0
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0.08]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [2.4, ~, 0.4]
    Cl: 0
    NormalDragLiftDiameter: 0.127
    AxialDragLiftDiameter: 0.02509555142673
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # API RP 2RD Code Check
    APIRP2RDCorrosionThickness: 0
    APIRP2RDSMYS: 360E3
    # Drawing
    Pen: [1, Solid, Red]
  - Name: FPSOpoly-Tanzania_Jugal3
    Category: General
    # Geometry & Mass
    OD: 0.163
    ID: 0
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.028
    # Limits
    CompressionIsLimited: Yes
    AllowableTension: ~
    MinRadius: [~, ~]
    # Structure
    EI: [0, ~]
    EA: 122.6E3
    PoissonRatio: 0.5
    GJ: 0
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: ~
```

```
    ClashStiffness: 0
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [1.8, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: 0.213
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # API RP 2RD Code Check
    APIRP2RDCorrosionThickness: 0
    APIRP2RDSMYS: 360E3
    # Drawing
    Pen: [1, Solid, Red]
  - Name: 60" Rubber
    Category: General
    # Geometry & Mass
    OD: 1.76
    ID: 1.5
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 1.042
    # Limits
    CompressionIsLimited: No
    AllowableTension: 1767
    MinRadius: [6, 6]
    # Structure
    EI: [60"stiffness linear, 60"stiffness linear]
    EA: 25.5E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.76
    ClashStiffness: 5000
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [60Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
```

```yaml
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Drawing
    Pen: [1, Solid, $4080FF]
  - Name: 60"Rubber Rigid
    Category: General
    # Geometry & Mass
    OD: 1.76
    ID: 1.5
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 1.042
    # Limits
    CompressionIsLimited: No
    AllowableTension: 1767
    MinRadius: [6, 6]
    # Structure
    EI: [15E3, 15E3]
    EA: 25.5E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.76
    ClashStiffness: 5000
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [60Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Drawing
    Pen: [1, Solid, $4080FF]
  - Name: 60"RubberTransition
    Category: General
    # Geometry & Mass
    OD: 1.76
    ID: 1.5
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 1.042
    # Limits
    CompressionIsLimited: No
```

```
    AllowableTension: 1767
    MinRadius: [6, 6]
    # Structure
    EI: [14E3, 14E3]
    EA: 25.5E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.76
    ClashStiffness: 5000
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [60Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Drawing
    Pen: [1, Solid, $4080FF]
  - Name: 60" Rubber MG
    Category: General
    # Geometry & Mass
    OD: 1.81
    ID: 1.5
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 1.056
    # Limits
    CompressionIsLimited: No
    AllowableTension: 1767
    MinRadius: [6, 6]
    # Structure
    EI: [60"stiffness linear, 60"stiffness linear]
    EA: 25.5E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: ~
    ClashStiffness: 5000
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [60Rubber MG18mm, ~, 0.008]
```

```
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Drawing
    Pen: [1, Solid, $4080FF]
  - Name: 60"HDPE SDR26
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.6
    ID: 1.478
    MaterialDensity: 0.955
    # Structure
    E: 239E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 60HDPE
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 6150
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Fuchsia]
  - Name: 60"HDPE SDR26 MG1
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.6
    ID: 1.478
    MaterialDensity: 0.995
    # Structure
    E: 239E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 60HDPE MG18mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
```

```
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 6150
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Fuchsia]
  - Name: 60"HDPE SDR26 MG2
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.6
    ID: 1.478
    MaterialDensity: 0.955
    # Structure
    E: 239E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 60HDPE MG3mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 6150
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Fuchsia]
  - Name: 60"Pipe 0.75" wall
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.524
    ID: 1.486
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 60Steel
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
```

```
    ClashDamping: 0
    # Stress
    AllowableStress: 137.9E3
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Aqua]
  - Name: 60"Pipe 0.75"wall MG
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.524
    ID: 1.486
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 60Steel MG3mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 137.9E3
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Aqua]
  - Name: 60"strainer
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.855
    ID: 1.835
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 1
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 137.9E3
    # Coating & Lining
```

```
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Silver]
  - Name: 40" Rubber
    Category: General
    # Geometry & Mass
    OD: 1.22
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.556
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [2129, 2129]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.205
    ClashStiffness: 5000
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Drawing
    Pen: [1, Solid, $4080FF]
  - Name: 40"Rubber Rigid
    Category: General
    # Geometry & Mass
    OD: 1.22
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.556
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [4000, 4000]
    EA: 17E3
```

```
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.205
    ClashStiffness: 5000
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Drawing
    Pen: [1, Solid, $4080FF]
  - Name: 40"RubberTransition
    Category: General
    # Geometry & Mass
    OD: 1.22
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.556
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [2750, 2750]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.205
    ClashStiffness: 5000
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
```

```
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Drawing
    Pen: [1, Solid, $4080FF]
  - Name: 40"Rubber MG
    Category: General
    # Geometry & Mass
    OD: 1.27
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.566
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [40"stiffness linear, 40"stiffness linear]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: ~
    ClashStiffness: 0
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber MG18mm, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Drawing
    Pen: [1, Solid, $4080FF]
  - Name: 40"HDPE SDR26
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.067
    ID: 0.985
    MaterialDensity: 0.955
    # Structure
    E: 800E3
```

```
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 40HDPE
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 6150
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Fuchsia]
  - Name: 40"HDPE SDR26 MG1
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.067
    ID: 0.985
    MaterialDensity: 1.015
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 40HDPE MG18mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 0
    ClashDamping: 0
    # Stress
    AllowableStress: 6150
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Fuchsia]
  - Name: 40"HDPE SDR26 MG2
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.067
    ID: 0.985
    MaterialDensity: 0.955
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 40HDPE MG3mm
    Cdz: 0.008
```

```
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 0
    ClashDamping: 0
    # Stress
    AllowableStress: 6150
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Fuchsia]
  - Name: 40"Pipe 0.75" wall
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.016
    ID: 0.978
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 40Steel
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 137.9E3
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $FFFF80]
  - Name: 40"Pipe 0.75" wall MG
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.016
    ID: 0.978
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 40Steel MG3mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
```

```
      Ce: 0
      # Friction
      SeabedNormalFrictionCoefficient: 0.5
      SeabedAxialFrictionCoefficient: ~
      # Contact
      ClashStiffness: 0
      ClashDamping: 0
      # Stress
      AllowableStress: 137.9E3
      # Coating & Lining
      CoatingThickness: 0
      LiningThickness: 0
      # Drawing
      Pen: [1, Solid, $FFFF80]
    - Name: 40" Strainer
      Category: Homogeneous Pipe
      # Geometry & Density
      OD: 1.3
      ID: 1.28
      MaterialDensity: 7.85
      # Structure
      E: 203.45E6
      PoissonRatio: 0.3
      # Drag, Lift, Added Mass & Slam
      Cdn: 1
      Cdz: 0.008
      Cl: 0
      Can: 1
      Caz: 0
      Cs: 0
      Ce: 0
      # Friction
      SeabedNormalFrictionCoefficient: 0.5
      SeabedAxialFrictionCoefficient: ~
      # Contact
      ClashStiffness: 5000
      ClashDamping: 0
      # Stress
      AllowableStress: 137.9E3
      # Coating & Lining
      CoatingThickness: 0
      LiningThickness: 0
      # Drawing
      Pen: [1, Solid, Silver]
  ClumpTypes:
    - Name: Counter Weight 20T
      Mass: 22.922
      Volume: 2.92
      Height: 1
      Offset: 0
      AlignWith: Global Axes
      DragArea: [0.6, ~, 0.6]
      Cd: [1.1, ~, 1.1]
      Ca: [1, ~, 1]
    - Name: Counter Weight 40T
      Mass: 45.844
      Volume: 5.84
      Height: 4
      Offset: 0
      AlignWith: Global Axes
      DragArea: [0.6, ~, 0.6]
      Cd: [1.1, ~, 1.1]
      Ca: [1, ~, 1]
    - Name: Counter Weight 60T
```

```
    Mass: 68.766
    Volume: 8.76
    Height: 4
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: 60 Riser Head
    Mass: 3.5
    Volume: 0.446
    Height: 2.5
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: Flange Connection
    Mass: 0.3
    Volume: 0.2
    Height: 0.25
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
    Pen: [4, Solid, Fuchsia]
  - Name: 60 Flange Conn with bq
    Mass: 0.8
    Volume: 0.0954
    Height: 0.04755
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, 0, 0.692]
    Cd: [0, 0, 1.9]
    Ca: [1, ~, 1]
  - Name: 60flange conn withut bq
    Mass: 0.5
    Volume: 0.06
    Height: 0.03
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, 0, 0.692]
    Cd: [0, 0, 1.9]
    Ca: [1, ~, 1]
  - Name: 60 Counterweight
    Mass: 25
    Volume: 3.148
    Height: 1.6
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: Mid Counter
    Mass: 12.5
    Volume: 1.574
    Height: 0.79
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: stabiliser weight
```

```
    Mass: 5
    Volume: 0.636
    Height: 1
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: 60 CW 100t
    Mass: 100
    Volume: 12.6
    Height: 6.4
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: Strainer
    Mass: 1
    Volume: 0.1273
    Height: 3
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: 40 flg conn with bq
    Mass: 0.35
    Volume: 0.03
    Height: 0.04
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, ~, 0.411]
    Cd: [0, 0, 1.9]
    Ca: [1, ~, 1]
  - Name: 40 flg conn without bq
    Mass: 0.225
    Volume: 0.02
    Height: 0.02
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, ~, 0.411]
    Cd: [0, 0, 1.9]
    Ca: [1, ~, 1]
  - Name: 40 Riser Head
    Mass: 2.5
    Volume: 0.3185
    Height: 2
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, ~, 0]
    Cd: [0, 0, 0]
    Ca: [1, ~, 1]
WakeModels:
  - Name: Huse
    Model: Huse
    HuseK1: 0.25
    HuseK2: 1
    HuseK3: 0.693
Lines:
  - Name: Case001
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
```

```
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: Milan Wake Oscillator
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Fixed, 0, 0, 0, 90, 180, 0, ~]
      - [Free, 0, 0, -500, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [Infinity, ~]
      - []
    # Sections
    Sections:
      - LineType: 40" Rubber
        Length: 0.75
        TargetSegmentLength: 2
        DisturbanceVessel: None
        # VIV
        VIVDiameter: ~
        VIVDynamicsEnabledForSection: Yes
        VIVInlineDragAmplificationFactor: 1
        VIVForceFactorTransverse: 1
      - LineType: 40"RubberTransition
        Length: 1
        TargetSegmentLength: 2
        DisturbanceVessel: None
        # VIV
        VIVDiameter: ~
        VIVDynamicsEnabledForSection: Yes
        VIVInlineDragAmplificationFactor: 1
        VIVForceFactorTransverse: 1
      - LineType: 40" Rubber
        Length: 492.75
        TargetSegmentLength: 2
        DisturbanceVessel: None
        # VIV
        VIVDiameter: ~
        VIVDynamicsEnabledForSection: Yes
        VIVInlineDragAmplificationFactor: 1
        VIVForceFactorTransverse: 1
      - LineType: 40" Strainer
        Length: 5.5
        TargetSegmentLength: 2
        DisturbanceVessel: None
        # VIV
        VIVDiameter: ~
        VIVDynamicsEnabledForSection: Yes
        VIVInlineDragAmplificationFactor: 1
        VIVForceFactorTransverse: 1
    # Attachments
    AttachmentType, Attachmentx, Attachmenty, Attachmentz, AttachmentzRel:
      - [40 Riser Head, 0, 0, 0, End A]
      - [40 flg conn with bq, 0, 0, 11.5, End A]
      - [40 flg conn with bq, 0, 0, 23, End A]
      - [40 flg conn with bq, 0, 0, 34.5, End A]
      - [40 flg conn with bq, 0, 0, 46, End A]
      - [40 flg conn with bq, 0, 0, 57.5, End A]
      - [40 flg conn with bq, 0, 0, 69, End A]
      - [40 flg conn with bq, 0, 0, 80.5, End A]
      - [40 flg conn with bq, 0, 0, 92, End A]
      - [40 flg conn with bq, 0, 0, 103.5, End A]
      - [40 flg conn with bq, 0, 0, 115, End A]
```

```
      - [40 flg conn with bq, 0, 0, 126.5, End A]
      - [40 flg conn with bq, 0, 0, 138, End A]
      - [40 flg conn with bq, 0, 0, 149.5, End A]
      - [40 flg conn with bq, 0, 0, 161, End A]
      - [40 flg conn with bq, 0, 0, 172.5, End A]
      - [40 flg conn with bq, 0, 0, 184, End A]
      - [40 flg conn with bq, 0, 0, 195.5, End A]
      - [40 flg conn with bq, 0, 0, 207, End A]
      - [40 flg conn with bq, 0, 0, 218.5, End A]
      - [40 flg conn with bq, 0, 0, 230, End A]
      - [40 flg conn with bq, 0, 0, 241.5, End A]
      - [40 flg conn with bq, 0, 0, 253, End A]
      - [40 flg conn with bq, 0, 0, 264.5, End A]
      - [40 flg conn with bq, 0, 0, 276, End A]
      - [40 flg conn with bq, 0, 0, 287.5, End A]
      - [40 flg conn with bq, 0, 0, 299, End A]
      - [40 flg conn with bq, 0, 0, 310.5, End A]
      - [40 flg conn with bq, 0, 0, 322, End A]
      - [40 flg conn with bq, 0, 0, 333.5, End A]
      - [40 flg conn with bq, 0, 0, 345, End A]
      - [40 flg conn with bq, 0, 0, 356.5, End A]
      - [40 flg conn with bq, 0, 0, 368, End A]
      - [40 flg conn with bq, 0, 0, 379.5, End A]
      - [40 flg conn with bq, 0, 0, 391, End A]
      - [40 flg conn with bq, 0, 0, 402.5, End A]
      - [40 flg conn with bq, 0, 0, 414, End A]
      - [40 flg conn with bq, 0, 0, 425.5, End A]
      - [40 flg conn with bq, 0, 0, 437, End A]
      - [40 flg conn with bq, 0, 0, 448.5, End A]
      - [40 flg conn with bq, 0, 0, 460, End A]
      - [40 flg conn with bq, 0, 0, 471.5, End A]
      - [40 flg conn with bq, 0, 0, 483, End A]
      - [40 flg conn with bq, 0, 0, 494.5, End A]
    # Contents
    ContentsMethod: Free Flooding
    IncludeAxialContentsInertia: No
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: Full Statics
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 359.55773942442
    AsLaidTension: 0
    # VIV
    VIVFilterPeriod: 250
    VIVMilanWakeOscillatorModelParameters: Default
    # Drawing
    NodePen: [1, Dot, $4080FF]
    DrawShadedNodesAsSpheres: Yes
    # VIV Drawing
    VIVDrawDetailFrom, VIVDrawDetailTo:
      - [~, ~]
  - Name: Case002
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: Milan Wake Oscillator
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Fixed, -10, 0, 0, 90, 180, 0, ~]
```

```
      - [Free, -10, 0, -500, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [Infinity, ~]
      - []

Groups:
  Structure:
    Case001: Model
    Case002: Model
    Case003: Model
    Case004: Model
    Case005: Model
    Case006: Model
    Case007: Model
    Case008: Model
    Case009: Model
    Case0010: Model
    Case0011: Model
    Case0012: Model
    Case0013: Model
    Case0014: Model
  State:
    Collapsed:
      - Variable Data
...
```

Model Data File - Strength Analysis

%YAML 1.1
Type: Model
Program: OrcaFlex 10.1d
File: C:\Users\Ian\Desktop\strength analysis.yml
Created: 15:57 on 03/06/2018
User: Ian
Machine: IAN-PC

General:
  # Units
  UnitsSystem: SI
  # Statics
  BuoysIncludedInStatics: Individually Specified
  StaticsMaxIterations: 800
  StaticsMinDamping: 2
  StaticsMaxDamping: 50
  # Dynamics
  DynamicsSolutionMethod: Implicit time domain
  ImplicitUseVariableTimeStep: Yes
  ImplicitVariableMaxTimeStep: 0.1
  ImplicitVariableMaxNumOfIterations: 10
  ImplicitTolerance: 1E-6
  LogPrecision: Single
  TargetLogSampleInterval: 1
  LogStartTime: ~
  # Stages
  StageDuration:
    - 20
    - 300
  # Drawing
  Pen: [1, Solid, Yellow]
  NorthDirectionDefined: Yes
  NorthDirection: 90
  # Default view parameters
  DefaultViewMode: Wire frame
  DefaultViewSize: 583.532627843579
  DefaultViewCentre: [201.56372757738, 4.12145186646211, -248.996087857083]
  DefaultViewAzimuth: 270
  DefaultViewElevation: 0
VariableData:
  KinematicViscosity:
    - Name: 3.5% Salinity
      IndependentValue, DependentValue:
        - [0, 1.82842473024E-6]
        - [0.555555555555556, 1.79516544192E-6]
        - [1.11111111111111, 1.76274228096E-6]
        - [1.66666666666667, 1.73143395648E-6]
        - [2.22222222222222, 1.70096175936E-6]
        - [2.77777777777778, 1.67141859264E-6]
        - [3.33333333333333, 1.64271155328E-6]
        - [3.88888888888889, 1.61484064128E-6]
        - [4.44444444444444, 1.58780585664E-6]
        - [5, 1.56142139328E-6]
        - [5.55555555555556, 1.53587305728E-6]
        - [6.11111111111111, 1.51088213952E-6]
        - [6.66666666666667, 1.48663444608E-6]
        - [7.22222222222222, 1.46303707392E-6]
        - [7.77777777777778, 1.44009002304E-6]
        - [8.33333333333333, 1.41760748736E-6]
        - [8.88888888888889, 1.39577527296E-6]
        - [9.44444444444444, 1.37459337984E-6]
        - [10, 1.35378309888E-6]
        - [10.5555555555556, 1.33353023616E-6]
        - [11.1111111111111, 1.31383479168E-6]

```
    - [11.6666666666667, 1.2946038624E-6]
    - [12.2222222222222, 1.27574454528E-6]
    - [12.7777777777778, 1.2574426464E-6]
    - [13.3333333333333, 1.23960526272E-6]
    - [13.8888888888889, 1.22204658816E-6]
    - [14.4444444444444, 1.2049524288E-6]
    - [15, 1.18832278464E-6]
    - [15.5555555555556, 1.1719718496E-6]
    - [16.1111111111111, 1.15599252672E-6]
    - [16.6666666666667, 1.140384816E-6]
    - [17.2222222222222, 1.12514871744E-6]
    - [17.7777777777778, 1.11028423104E-6]
    - [18.3333333333333, 1.09569845376E-6]
    - [18.8888888888889, 1.0813913856E-6]
    - [19.4444444444444, 1.06736302656E-6]
    - [20, 1.05370627968E-6]
    - [20.5555555555556, 1.04032824192E-6]
    - [21.1111111111111, 1.02722891328E-6]
    - [21.6666666666667, 1.01431539072E-6]
    - [22.2222222222222, 1.00177348032E-6]
    - [22.7777777777778, 989.417376E-9]
    - [23.3333333333333, 977.3399808E-9]
    - [23.8888888888889, 965.44839168E-9]
    - [24.4444444444444, 953.83551168E-9]
    - [25, 942.5013408E-9]
    - [25.5555555555556, 931.352976E-9]
    - [26.1111111111111, 920.39041728E-9]
    - [26.6666666666667, 909.61366464E-9]
    - [27.2222222222222, 899.11562112E-9]
    - [27.7777777777778, 888.80338368E-9]
    - [28.3333333333333, 878.58404928E-9]
    - [28.8888888888889, 868.643424E-9]
    - [29.4444444444444, 858.8886048E-9]
    - [30, 849.31959168E-9]
   - Name: 60Rubber
  IndependentValue, DependentValue:
    - [4940, 1.2]
    - [9870, 1.2]
    - [24.7E3, 1.2]
    - [49.4E3, 1.2]
    - [138E3, 1.2]
    - [148E3, 1.2]
    - [173E3, 1.16]
    - [197E3, 1.06]
    - [222E3, 0.8]
    - [247E3, 0.57]
    - [296E3, 0.61]
    - [346E3, 0.68]
    - [395E3, 0.76]
    - [494E3, 0.88]
    - [740E3, 0.97]
    - [987E3, 0.99]
    - [2.47E6, 0.98]
    - [4.94E6, 0.96]
    - [9.87E6, 0.94]
    - [14.8E6, 0.94]
- Name: 60HDPE
  IndependentValue, DependentValue:
    - [9990, 1.2]
    - [20E3, 1.2]
    - [49.9E3, 1.2]
    - [99.9E3, 1.2]
    - [280E3, 1.2]
    - [300E3, 1.19]
```

```
    - [350E3, 1.16]
    - [400E3, 1.05]
    - [449E3, 0.8]
    - [499E3, 0.46]
    - [599E3, 0.28]
    - [699E3, 0.28]
    - [799E3, 0.3]
    - [999E3, 0.36]
    - [1.5E6, 0.47]
    - [2E6, 0.52]
    - [4.99E6, 0.56]
    - [9.99E6, 0.55]
    - [20E6, 0.53]
    - [30E6, 0.52]
- Name: 60Steel
  IndependentValue, DependentValue:
    - [9790, 1.2]
    - [19.6E3, 1.2]
    - [48.9E3, 1.2]
    - [97.9E3, 1.2]
    - [274E3, 1.2]
    - [294E3, 1.19]
    - [343E3, 1.16]
    - [392E3, 1.05]
    - [440E3, 0.8]
    - [489E3, 0.46]
    - [587E3, 0.31]
    - [685E3, 0.32]
    - [783E3, 0.35]
    - [979E3, 0.41]
    - [1.47E6, 0.53]
    - [1.96E6, 0.58]
    - [4.89E6, 0.61]
    - [9.79E6, 0.59]
    - [19.6E6, 0.57]
    - [29.4E6, 0.57]
- Name: 60Steel MG3mm
  IndependentValue, DependentValue:
    - [4610, 1.2]
    - [9220, 1.2]
    - [23.1E3, 1.2]
    - [46.1E3, 1.2]
    - [129E3, 1.2]
    - [138E3, 1.2]
    - [161E3, 1.16]
    - [184E3, 1.06]
    - [208E3, 0.8]
    - [231E3, 0.59]
    - [277E3, 0.63]
    - [323E3, 0.71]
    - [369E3, 0.78]
    - [461E3, 0.89]
    - [692E3, 0.98]
    - [922E3, 1]
    - [2.31E6, 0.99]
    - [4.61E6, 0.97]
    - [9.22E6, 0.96]
    - [13.8E6, 0.96]
- Name: 60HDPE MG18mm
  IndependentValue, DependentValue:
    - [1900, 1.23]
    - [3800, 1.23]
    - [9510, 1.23]
    - [19E3, 1.23]
```

```
      - [53.2E3, 1.22]
      - [57E3, 1.22]
      - [66.5E3, 1.18]
      - [76.1E3, 1.08]
      - [85.6E3, 0.88]
      - [95.1E3, 0.89]
      - [114E3, 0.92]
      - [133E3, 0.95]
      - [152E3, 0.98]
      - [190E3, 1.02]
      - [285E3, 1.06]
      - [380E3, 1.07]
      - [951E3, 1.07]
      - [1.9E6, 1.07]
      - [3.8E6, 1.07]
      - [5.7E6, 1.07]
  - Name: 60HDPE MG3mm
    IndependentValue, DependentValue:
      - [4720, 1.2]
      - [9440, 1.2]
      - [23.6E3, 1.2]
      - [47.2E3, 1.2]
      - [132E3, 1.2]
      - [142E3, 1.2]
      - [165E3, 1.16]
      - [189E3, 1.06]
      - [212E3, 0.8]
      - [236E3, 0.58]
      - [283E3, 0.62]
      - [330E3, 0.7]
      - [378E3, 0.78]
      - [472E3, 0.89]
      - [708E3, 0.98]
      - [944E3, 1]
      - [2.36E6, 0.98]
      - [4.72E6, 0.97]
      - [9.44E6, 0.95]
      - [14.2E6, 0.95]
  - Name: 60Rubber MG18mm
    IndependentValue, DependentValue:
      - [1980, 1.22]
      - [3960, 1.22]
      - [9900, 1.22]
      - [19.8E3, 1.22]
      - [55.4E3, 1.22]
      - [59.4E3, 1.22]
      - [69.3E3, 1.18]
      - [79.2E3, 1.07]
      - [89.1E3, 0.86]
      - [99E3, 0.87]
      - [119E3, 0.9]
      - [139E3, 0.94]
      - [158E3, 0.97]
      - [198E3, 1.01]
      - [297E3, 1.05]
      - [396E3, 1.06]
      - [990E3, 1.07]
      - [1.98E6, 1.07]
      - [3.96E6, 1.07]
      - [5.94E6, 1.07]
  - Name: 40Rubber
    IndependentValue, DependentValue:
      - [4100, 1.21]
      - [8210, 1.21]
```

```
    - [20.5E3, 1.21]
    - [41E3, 1.21]
    - [115E3, 1.2]
    - [123E3, 1.2]
    - [144E3, 1.16]
    - [164E3, 1.06]
    - [185E3, 0.8]
    - [205E3, 0.62]
    - [246E3, 0.67]
    - [287E3, 0.74]
    - [328E3, 0.81]
    - [410E3, 0.91]
    - [615E3, 1]
    - [821E3, 1.02]
    - [2.05E6, 1.01]
    - [4.1E6, 0.99]
    - [8.21E6, 0.98]
    - [12.3E6, 0.98]
- Name: 40HDPE
  IndependentValue, DependentValue:
    - [9980, 1.2]
    - [20E3, 1.2]
    - [49.9E3, 1.2]
    - [99.8E3, 1.2]
    - [279E3, 1.2]
    - [299E3, 1.19]
    - [349E3, 1.16]
    - [399E3, 1.05]
    - [449E3, 0.8]
    - [499E3, 0.46]
    - [599E3, 0.28]
    - [699E3, 0.28]
    - [799E3, 0.3]
    - [998E3, 0.36]
    - [1.5E6, 0.47]
    - [2E6, 0.53]
    - [4.99E6, 0.57]
    - [9.98E6, 0.55]
    - [20E6, 0.53]
    - [29.9E6, 0.53]
- Name: 40Steel
  IndependentValue, DependentValue:
    - [9690, 1.2]
    - [19.4E3, 1.2]
    - [48.4E3, 1.2]
    - [96.9E3, 1.2]
    - [271E3, 1.2]
    - [291E3, 1.19]
    - [339E3, 1.16]
    - [387E3, 1.05]
    - [436E3, 0.8]
    - [484E3, 0.46]
    - [581E3, 0.32]
    - [678E3, 0.33]
    - [775E3, 0.36]
    - [969E3, 0.43]
    - [1.45E6, 0.55]
    - [1.94E6, 0.59]
    - [4.84E6, 0.62]
    - [9.69E6, 0.61]
    - [19.4E6, 0.59]
    - [29.1E6, 0.58]
- Name: 40Rubber MG18mm
  IndependentValue, DependentValue:
```

```
    - [1710, 1.24]
    - [3420, 1.24]
    - [8560, 1.24]
    - [17.1E3, 1.24]
    - [47.9E3, 1.23]
    - [51.4E3, 1.23]
    - [59.9E3, 1.19]
    - [68.5E3, 1.08]
    - [77.1E3, 0.93]
    - [85.6E3, 0.94]
    - [103E3, 0.97]
    - [120E3, 0.99]
    - [137E3, 1.01]
    - [171E3, 1.04]
    - [257E3, 1.07]
    - [342E3, 1.08]
    - [856E3, 1.09]
    - [1.71E6, 1.09]
    - [3.42E6, 1.09]
    - [5.14E6, 1.09]
- Name: 40HDPE MG18mm
  IndependentValue, DependentValue:
    - [1650, 1.24]
    - [3300, 1.24]
    - [8250, 1.24]
    - [16.5E3, 1.24]
    - [46.2E3, 1.24]
    - [49.5E3, 1.23]
    - [57.7E3, 1.2]
    - [66E3, 1.09]
    - [74.2E3, 0.96]
    - [82.5E3, 0.96]
    - [99E3, 0.99]
    - [115E3, 1.01]
    - [132E3, 1.03]
    - [165E3, 1.06]
    - [247E3, 1.08]
    - [330E3, 1.09]
    - [825E3, 1.1]
    - [1.65E6, 1.1]
    - [3.3E6, 1.1]
    - [4.95E6, 1.1]
- Name: 40HDPE MG3mm
  IndependentValue, DependentValue:
    - [3850, 1.21]
    - [7700, 1.21]
    - [19.3E3, 1.21]
    - [38.5E3, 1.21]
    - [108E3, 1.2]
    - [116E3, 1.2]
    - [135E3, 1.17]
    - [154E3, 1.06]
    - [173E3, 0.8]
    - [193E3, 0.64]
    - [231E3, 0.69]
    - [270E3, 0.76]
    - [308E3, 0.83]
    - [385E3, 0.92]
    - [578E3, 1.01]
    - [770E3, 1.02]
    - [1.93E6, 1.02]
    - [3.85E6, 1]
    - [7.7E6, 0.99]
    - [11.6E6, 0.99]
```

```
  - Name: 40Steel MG3mm
    IndependentValue, DependentValue:
      - [3750, 1.21]
      - [7510, 1.21]
      - [18.8E3, 1.21]
      - [37.5E3, 1.21]
      - [105E3, 1.2]
      - [113E3, 1.2]
      - [131E3, 1.17]
      - [150E3, 1.06]
      - [169E3, 0.8]
      - [188E3, 0.65]
      - [225E3, 0.7]
      - [263E3, 0.77]
      - [300E3, 0.83]
      - [375E3, 0.93]
      - [563E3, 1.01]
      - [751E3, 1.02]
      - [1.88E6, 1.02]
      - [3.75E6, 1]
      - [7.51E6, 0.99]
      - [11.3E6, 0.99]
BendingStiffness:
  - Name: 40"stiffness
    IndependentValue, DependentValue:
      - [0, 0]
      - [0.02, 100]
      - [0.03, 134]
      - [0.04, 168]
      - [0.06, 210]
      - [0.08, 240]
      - [0.1, 265]
      - [0.12, 283]
      - [0.14, 295]
    Hysteretic: No
  - Name: 60"stiffness
    IndependentValue, DependentValue:
      - [0, 0]
      - [0.02, 550]
      - [0.04, 900]
      - [0.06, 1200]
      - [0.08, 1475]
      - [0.1, 1675]
      - [0.12, 1800]
      - [0.14, 1890]
    Hysteretic: No
  - Name: 60"Stiffness1
    IndependentValue, DependentValue:
      - [0, 0]
      - [0.02, 485]
      - [0.04, 825]
      - [0.06, 1060]
      - [0.08, 1210]
      - [0.0952, 1285]
      - [0.1, 1300]
    Hysteretic: No
  - Name: 40"stiffness linear
    IndependentValue, DependentValue:
      - [0, 0]
      - [0.14, 295]
    Hysteretic: No
  - Name: 60"stiffness linear
    IndependentValue, DependentValue:
      - [0, 0]
```

```yaml
        - [0.14, 1277]
      Hysteretic: No
Environment:
  # Sea
  WaterSurfaceZ: 0
  KinematicViscosity: 3.5% Salinity
  SeaTemperature: 10
  ReynoldsNumberCalculation: Cross Flow
  # Sea Density
  HorizontalWaterDensityFactor: ~
  VerticalDensityVariation: Constant
  Density: 1.025
  # Seabed
  SeabedType: Flat
  SeabedOrigin: [0, 0]
  WaterDepth: 2600
  SeabedSlopeDirection: 0
  SeabedSlope: 0
  SeabedModel: Elastic
  SeabedNormalStiffness: 100
  SeabedShearStiffness: ~
  # Waves
  SimulationTimeOrigin: 1282.24
  KinematicStretchingMethod: Vertical Stretching
  UserSpecifiedRandomWaveSeeds: Yes
  WaveFrequencySpectrumDiscretisationMethod: Equal energy, 9.3a, deprecated
  WaveTrains:
    - Name: Wave1
      WaveType: Torsethaugen
      WaveDirection: 0
      WaveHs: 4.8
      WaveTp: 11.9
      WaveOrigin: [0, 0]
      WaveTimeOrigin: 0
      WaveNumberOfSpectralDirections: 1
      WaveSeed: 12345
      WaveNumberOfComponents: 200
      WaveSpectrumMinRelFrequency: 0.5
      WaveSpectrumMaxRelFrequency: 10
      WaveSpectrumMaxComponentFrequencyRange: ~
  # WaveCalculation
  WaveKinematicsCutoffDepth: Infinity
  WaveCalculationMethod: Instantaneous Position (exact)
  WaveCalculationTimeInterval: 0
  WaveCalculationSpatialInterval: 0
  # Current
  MultipleCurrentDataCanBeDefined: Yes
  Currents:
    - Name: Max Current
      CurrentRamp: No
      HorizontalCurrentFactor: ~
      CurrentApplyVerticalStretching: No
      CurrentMethod: Interpolated
      RefCurrentSpeed: 1
      RefCurrentDirection: 180
      CurrentDepth, CurrentFactor, CurrentRotation:
        - [0, 2, 0]
        - [47, 1.82, 0]
        - [108, 1.62, 0]
        - [147, 0.98, 0]
        - [207, 0.96, 0]
        - [307, 0.95, 0]
        - [508, 0.88, 0]
        - [748, 0.78, 0]
```

```
        - [1008, 0.77, 0]
        - [1410, 0.48, 0]
        - [1982, 0.34, 0]
    - Name: Mean Current
      CurrentRamp: No
      HorizontalCurrentFactor: ~
      CurrentApplyVerticalStretching: No
      CurrentMethod: Interpolated
      RefCurrentSpeed: 1
      RefCurrentDirection: 180
      CurrentDepth, CurrentFactor, CurrentRotation:
        - [0, 1.74, 0]
        - [47, 1.58, 0]
        - [108, 1.42, 0]
        - [147, 0.89, 0]
        - [207, 0.85, 0]
        - [307, 0.83, 0]
        - [508, 0.76, 0]
        - [748, 0.66, 0]
        - [1008, 0.64, 0]
        - [1410, 0.4, 0]
        - [1982, 0.28, 0]
  ActiveCurrent: Max Current
  # Wind
  IncludeVesselWindLoads: Yes
  IncludeLineWindLoads: No
  IncludeBuoyWingWindLoads: No
  VerticalWindVariationFactor: ~
  AirDensity: 0.00128
  WindType: Constant
  WindSpeed: 0
  WindDirection: 0
  # Drawing
  SeaSurfacePen: [1, Solid, $FF8080]
  SeabedPen: [1, Solid, $004080]
  SeabedProfilePen: [2, Solid, White]
VesselTypes:
  - Name: Generic_FLNG
    Length: 425
    # Conventions
    RAOResponseUnits: degrees
    RAOWaveUnit: amplitude
    WavesReferredToBy: period (s)
    RAOPhaseConvention: leads
    RAOPhaseUnitsConvention: degrees
    RAOPhaseRelativeToConvention: crest
    SurgePositive: forward
    SwayPositive: port
    HeavePositive: up
    RollPositiveStarboard: down
    PitchPositiveBow: down
    YawPositiveBow: port
    Symmetry: None
    CurrentCoeffSymmetry: XZ plane
    WindCoeffSymmetry: XZ plane
    QTFConventionsRotationOrder: RzRyRx
    QTFConventionsRotationAxes: Rotated
    QTFConventionsFrameOfReference: Body-Fixed
    Draughts:
      - Name: 14m
        Mass: 8800
        MomentOfInertiaTensorX, MomentOfInertiaTensorY, MomentOfInertiaTensorZ:
          - [249E3, 0, 0]
          - [0, 5.83E6, 0]
```

```yaml
        - [0, 0, 5.83E6]
      CentreOfGravity: [-233.48, 0.22, 23.08]
      DisplacementRAOs:
        RAOOrigin: [-233.48, 0.22, 23.08]
        PhaseOrigin: [~, ~, 0]

LineTypes:
  - Name: FPSOchain_Tanzania_Jugal3
    Category: General
    # Geometry & Mass
    OD: 0.228
    ID: 0
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.316
    # Limits
    CompressionIsLimited: Yes
    AllowableTension: ~
    MinRadius: [~, ~]
    # Structure
    EI: [0, ~]
    EA: 1.469E6
    PoissonRatio: 0.5
    GJ: 0
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 0.4891
    ClashStiffness: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0.08]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [2.4, ~, 0.4]
    Cl: 0
    NormalDragLiftDiameter: 0.127
    AxialDragLiftDiameter: 0.02509555142673
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # API RP 2RD Code Check
    APIRP2RDCorrosionThickness: 0
    APIRP2RDSMYS: 360E3
    # Drawing
    Pen: [1, Solid, Red]
  - Name: FPSOpoly-Tanzania_Jugal3
    Category: General
    # Geometry & Mass
    OD: 0.163
    ID: 0
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.028
```

```
    # Limits
    CompressionIsLimited: Yes
    AllowableTension: ~
    MinRadius: [~, ~]
    # Structure
    EI: [0, ~]
    EA: 122.6E3
    PoissonRatio: 0.5
    GJ: 0
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: ~
    ClashStiffness: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [1.8, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: 0.213
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # API RP 2RD Code Check
    APIRP2RDCorrosionThickness: 0
    APIRP2RDSMYS: 360E3
    # Drawing
    Pen: [1, Solid, Red]
  - Name: 60" Rubber
    Category: General
    # Geometry & Mass
    OD: 1.76
    ID: 1.5
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 1.042
    # Limits
    CompressionIsLimited: No
    AllowableTension: 1767
    MinRadius: [6, 6]
    # Structure
    EI: [60"stiffness linear, 60"stiffness linear]
    EA: 25.5E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.76
    ClashStiffness: 5000
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
```

```
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [60Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
  - Name: 60"Rubber Rigid
    Category: General
    # Geometry & Mass
    OD: 1.76
    ID: 1.5
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 1.042
    # Limits
    CompressionIsLimited: No
    AllowableTension: 1767
    MinRadius: [6, 6]
    # Structure
    EI: [15E3, 15E3]
    EA: 25.5E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.76
    ClashStiffness: 5000
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [60Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
```

```
  RayleighDampingCoefficients: (no damping)
- Name: 60"RubberTransition
  Category: General
  # Geometry & Mass
  OD: 1.76
  ID: 1.5
  CG: [0, 0]
  BulkModulus: Infinity
  MassPerUnitLength: 1.042
  # Limits
  CompressionIsLimited: No
  AllowableTension: 1767
  MinRadius: [6, 6]
  # Structure
  EI: [14E3, 14E3]
  EA: 25.5E3
  PoissonRatio: 0.5
  GJ: 80
  TensionTorqueCoupling: 0
  # Contact
  ContactDiameter: 1.76
  ClashStiffness: 5000
  # Added Mass, Inertia & Slam
  Ca: [1, ~, 0]
  Cm: [~, ~, ~]
  Cs: 0
  Ce: 0
  # Drag & Lift
  Cd: [60Rubber, ~, 0.008]
  Cl: 0
  NormalDragLiftDiameter: ~
  AxialDragLiftDiameter: ~
  # Stress
  StressOD: ~
  StressID: ~
  AllowableStress: ~
  TensileStressLoadingFactor: 1
  BendingStressLoadingFactor: 1
  ShearStressLoadingFactor: 1
  TorsionalStressLoadingFactor: 1
  # Friction
  SeabedNormalFrictionCoefficient: 0.5
  SeabedAxialFrictionCoefficient: ~
  # Structural Damping
  RayleighDampingCoefficients: (no damping)
- Name: 60" Rubber MG
  Category: General
  # Geometry & Mass
  OD: 1.81
  ID: 1.5
  CG: [0, 0]
  BulkModulus: Infinity
  MassPerUnitLength: 1.056
  # Limits
  CompressionIsLimited: No
  AllowableTension: 1767
  MinRadius: [6, 6]
  # Structure
  EI: [60"stiffness linear, 60"stiffness linear]
  EA: 25.5E3
  PoissonRatio: 0.5
  GJ: 80
  TensionTorqueCoupling: 0
  # Contact
```

```
    ContactDiameter: ~
    ClashStiffness: 5000
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [60Rubber MG18mm, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
  - Name: 60"HDPE SDR26
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.6
    ID: 1.478
    MaterialDensity: 0.955
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 60HDPE
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 9000
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $0080FF]
  - Name: 60"HDPE SDR26 MG1
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.6
    ID: 1.478
    MaterialDensity: 0.995
    # Structure
    E: 800E3
```

```
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 60HDPE MG18mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 9000
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $0080FF]
  - Name: 60"HDPE SDR26 MG2
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.6
    ID: 1.478
    MaterialDensity: 0.955
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 60HDPE MG3mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 9000
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $0080FF]
  - Name: 60"Pipe 0.75" wall
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.524
    ID: 1.486
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
```

```
    Cdn: 60Steel
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 137.9E3
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Aqua]
  - Name: 60"Pipe 0.75"wall MG
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.524
    ID: 1.486
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 60Steel MG3mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 137.9E3
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Aqua]
  - Name: 60"strainer
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.855
    ID: 1.835
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 1
    Cdz: 0.008
```

```
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 137.9E3
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $8000FF]
  - Name: 40" Rubber
    Category: General
    # Geometry & Mass
    OD: 1.22
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.556
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [40"stiffness linear, 40"stiffness linear]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.205
    ClashStiffness: 5000
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Drawing
```

```
    Pen: [1, Solid, $80FFFF]
  - Name: 40"Rubber Rigid
    Category: General
    # Geometry & Mass
    OD: 1.22
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.556
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [4000, 4000]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.205
    ClashStiffness: 5000
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
  - Name: 40"RubberTransition
    Category: General
    # Geometry & Mass
    OD: 1.22
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.556
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [2750, 2750]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
```

```
    ContactDiameter: 1.205
    ClashStiffness: 5000
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
  - Name: 40"Rubber MG
    Category: General
    # Geometry & Mass
    OD: 1.27
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.566
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [40"stiffness linear, 40"stiffness linear]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: ~
    ClashStiffness: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber MG18mm, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
```

```
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
  - Name: 40"HDPE SDR26
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.067
    ID: 0.985
    MaterialDensity: 0.955
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 40HDPE
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 9000
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $4080FF]
  - Name: 40"HDPE SDR26 MG1
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.067
    ID: 0.985
    MaterialDensity: 1.015
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 40HDPE MG18mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 0
    # Stress
    AllowableStress: 9000
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
```

```
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $4080FF]
  - Name: 40"HDPE SDR26 MG2
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.067
    ID: 0.985
    MaterialDensity: 0.955
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 40HDPE MG3mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 0
    # Stress
    AllowableStress: 9000
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $4080FF]
  - Name: 40"Pipe 0.75" wall
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.016
    ID: 0.978
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 40Steel
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 137.9E3
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
```

```
    Pen: [1, Solid, $FFFF80]
  - Name: 40"Pipe 0.75" wall MG
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.016
    ID: 0.978
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 40Steel MG3mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 0
    # Stress
    AllowableStress: 137.9E3
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $FFFF80]
  - Name: 40" Strainer
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.3
    ID: 1.28
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 1
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 137.9E3
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Red]
ClumpTypes:
```

```
- Name: Counter Weight
  Mass: 20
  Volume: 0.3
  Height: 1
  Offset: 0
  AlignWith: Global Axes
  DragArea: [0.6, ~, 0.6]
  Cd: [1.1, ~, 1.1]
  Ca: [1, ~, 1]
- Name: 60 Riser Head
  Mass: 3.5
  Volume: 0.446
  Height: 2.5
  Offset: 0
  AlignWith: Global Axes
  DragArea: [0.6, ~, 0.6]
  Cd: [1.1, ~, 1.1]
  Ca: [1, ~, 1]
- Name: Flange Connection
  Mass: 0.3
  Volume: 0.2
  Height: 0.25
  Offset: 0
  AlignWith: Global Axes
  DragArea: [0.6, ~, 0.6]
  Cd: [1.1, ~, 1.1]
  Ca: [1, ~, 1]
  Pen: [4, Solid, Fuchsia]
- Name: 60 Flange Conn with bq
  Mass: 0.8
  Volume: 0.0954
  Height: 0.04755
  Offset: 0
  AlignWith: Global Axes
  DragArea: [0, 0, 0.692]
  Cd: [0, 0, 1.9]
  Ca: [1, ~, 1]
- Name: 60flange conn withut bq
  Mass: 0.5
  Volume: 0.06
  Height: 0.03
  Offset: 0
  AlignWith: Global Axes
  DragArea: [0, 0, 0.692]
  Cd: [0, 0, 1.9]
  Ca: [1, ~, 1]
- Name: 60 Counterweight
  Mass: 25
  Volume: 3.148
  Height: 1.6
  Offset: 0
  AlignWith: Global Axes
  DragArea: [0.6, ~, 0.6]
  Cd: [1.1, ~, 1.1]
  Ca: [1, ~, 1]
- Name: Mid Counter
  Mass: 12.5
  Volume: 1.574
  Height: 0.79
  Offset: 0
  AlignWith: Global Axes
  DragArea: [0.6, ~, 0.6]
  Cd: [1.1, ~, 1.1]
  Ca: [1, ~, 1]
```

```
  - Name: stabiliser weight
    Mass: 5
    Volume: 0.636
    Height: 1
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: 60 CW 100t
    Mass: 100
    Volume: 12.6
    Height: 6.4
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: Strainer
    Mass: 1
    Volume: 0.1273
    Height: 3
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: 40 flg conn with bq
    Mass: 0.35
    Volume: 0.03
    Height: 0.04
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, ~, 0.411]
    Cd: [0, 0, 1.9]
    Ca: [1, ~, 1]
  - Name: 40 flg conn without bq
    Mass: 0.225
    Volume: 0.02
    Height: 0.02
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, ~, 0.411]
    Cd: [0, 0, 1.9]
    Ca: [1, ~, 1]
  - Name: 40 Riser Head
    Mass: 2.5
    Volume: 0.3185
    Height: 2
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, ~, 0]
    Cd: [0, 0, 0]
    Ca: [1, ~, 1]
WakeModels:
  - Name: Huse
    Model: Huse
    HuseK1: 0.25
    HuseK2: 1
    HuseK3: 0.693
Vessels:
  - Name: Oct2010 FLNG
    Locked: Yes
    VesselType: Generic_FLNG
```

```
    Draught: Haskind
    Length: ~
    InitialPosition: [0, 0, -14]
    Orientation: [0, 0, 180]
    # Calculation
    IncludedInStatics: None
    PrimaryMotion: None
    SuperimposedMotion: Displacement RAOs + Harmonic Motion
    IncludeAppliedLoads: No
    IncludeWaveLoad1stOrder: No
    IncludeWaveDriftLoad2ndOrder: No
    IncludeWaveDriftDamping: No
    IncludeSumFrequencyLoad: No
    IncludeAddedMassAndDamping: No
    IncludeManoeuvringLoad: No
    IncludeOtherDamping: No
    IncludeCurrentLoad: No
    IncludeWindLoad: No
    # Drawing
    PenMode: Use Vessel Type's own pen
    # Shaded Drawing
    ShadedDrawingCullingMode: Anticlockwise
Lines:
  - Name: ML5
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, 734.788079488412E-18, -6, 25.5, 0, 0, 0, ~]
      - [Anchored, 0, 2277.4, 0.24455, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [0, ~]
      - [0, ~]
    # Sections
    LineType, Length, TargetSegmentLength:
      - [FPSOchain_Tanzania_Jugal3, 200, 10]
      - [FPSOpoly-Tanzania_Jugal3, 3200, 100]
      - [FPSOchain_Tanzania_Jugal3, 100, 10]
    # Contents
    ContentsMethod: Uniform
    IncludeAxialContentsInertia: Yes
    ContentsDensity: 0
    ContentsPressureRefZ: ~
    ContentsPressure: 0
    ContentsFlowRate: 0
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: None
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 225
    AsLaidTension: 0
    # Drawing
    DrawShadedNodesAsSpheres: Yes
    DrawContact: No
  - Name: ML6
    IncludeTorsion: No
```

```
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, 1.04, -5.91, 25.5, 0, 0, 0, ~]
      - [Anchored, -395.46, 2242.8, 0.24455, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [0, ~]
      - [0, ~]
    # Sections
    LineType, Length, TargetSegmentLength:
      - [FPSOchain_Tanzania_Jugal3, 200, 10]
      - [FPSOpoly-Tanzania_Jugal3, 3200, 100]
      - [FPSOchain_Tanzania_Jugal3, 100, 10]
    # Contents
    ContentsMethod: Uniform
    IncludeAxialContentsInertia: Yes
    ContentsDensity: 0
    ContentsPressureRefZ: ~
    ContentsPressure: 0
    ContentsFlowRate: 0
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: None
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 235
    AsLaidTension: 0
    # Drawing
    DrawShadedNodesAsSpheres: Yes
    DrawContact: No
  - Name: ML7
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, 5.91, -1.04, 25.5, 0, 0, 0, ~]
      - [Anchored, -2242.8, 395.46, 0.24455, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [0, ~]
      - [0, ~]
    # Sections
    LineType, Length, TargetSegmentLength:
      - [FPSOchain_Tanzania_Jugal3, 200, 10]
      - [FPSOpoly-Tanzania_Jugal3, 3200, 100]
      - [FPSOchain_Tanzania_Jugal3, 100, 10]
    # Contents
    ContentsMethod: Uniform
    IncludeAxialContentsInertia: Yes
    ContentsDensity: 0
    ContentsPressureRefZ: ~
```

```
    ContentsPressure: 0
    ContentsFlowRate: 0
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: None
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 305
    AsLaidTension: 0
    # Drawing
    SegmentPenMode: Use Segment Pen
    DrawShadedNodesAsSpheres: Yes
    SegmentPen: [2, Solid, $004000]
    DrawContact: No
  - Name: ML8
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, 6, 734.788079488412E-18, 25.5, 0, 0, 0, ~]
      - [Anchored, -2277.4, 0, 0.24455, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [0, ~]
      - [0, ~]
    # Sections
    LineType, Length, TargetSegmentLength:
      - [FPSOchain_Tanzania_Jugal3, 200, 10]
      - [FPSOpoly-Tanzania_Jugal3, 3200, 100]
      - [FPSOchain_Tanzania_Jugal3, 100, 10]
    # Contents
    ContentsMethod: Uniform
    IncludeAxialContentsInertia: Yes
    ContentsDensity: 0
    ContentsPressureRefZ: ~
    ContentsPressure: 0
    ContentsFlowRate: 0
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: None
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 315
    AsLaidTension: 0
    # Drawing
    SegmentPenMode: Use Segment Pen
    DrawShadedNodesAsSpheres: Yes
    SegmentPen: [2, Solid, $004000]
    DrawContact: No
  - Name: ML9
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
```

```
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec, 
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, 5.91, 1.04, 25.5, 0, 0, 0, ~]
      - [Anchored, -2242.8, -395.46, 0.24455, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [0, ~]
      - [0, ~]
    # Sections
    LineType, Length, TargetSegmentLength:
      - [FPSOchain_Tanzania_Jugal3, 200, 10]
      - [FPSOpoly-Tanzania_Jugal3, 3200, 100]
      - [FPSOchain_Tanzania_Jugal3, 100, 10]
    # Contents
    ContentsMethod: Uniform
    IncludeAxialContentsInertia: Yes
    ContentsDensity: 0
    ContentsPressureRefZ: ~
    ContentsPressure: 0
    ContentsFlowRate: 0
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: None
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 325
    AsLaidTension: 0
    # Drawing
    SegmentPenMode: Use Segment Pen
    DrawShadedNodesAsSpheres: Yes
    SegmentPen: [2, Solid, $004000]
    DrawContact: No
  - Name: ML10
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec, 
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, 1.04, 5.91, 25.5, 0, 0, 0, ~]
      - [Anchored, -395.46, -2242.8, 0.24455, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [0, ~]
      - [0, ~]
    # Sections
    LineType, Length, TargetSegmentLength:
      - [FPSOchain_Tanzania_Jugal3, 200, 10]
      - [FPSOpoly-Tanzania_Jugal3, 3200, 100]
      - [FPSOchain_Tanzania_Jugal3, 100, 10]
    # Contents
    ContentsMethod: Uniform
    IncludeAxialContentsInertia: Yes
    ContentsDensity: 0
    ContentsPressureRefZ: ~
    ContentsPressure: 0
    ContentsFlowRate: 0
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
```

```
    StaticsStep2: None
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 35
    AsLaidTension: 0
    # Drawing
    DrawShadedNodesAsSpheres: Yes
    DrawContact: No
  - Name: ML11
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, -734.788079488412E-18, 6, 25.5, 0, 0, 0, ~]
      - [Anchored, 0, -2277.4, 0.24455, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [0, ~]
      - [0, ~]
    # Sections
    LineType, Length, TargetSegmentLength:
      - [FPSOchain_Tanzania_Jugal3, 200, 10]
      - [FPSOpoly-Tanzania_Jugal3, 3200, 100]
      - [FPSOchain_Tanzania_Jugal3, 100, 10]
    # Contents
    ContentsMethod: Uniform
    IncludeAxialContentsInertia: Yes
    ContentsDensity: 0
    ContentsPressureRefZ: ~
    ContentsPressure: 0
    ContentsFlowRate: 0
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: None
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 45
    AsLaidTension: 0
    # Drawing
    DrawShadedNodesAsSpheres: Yes
    DrawContact: No
  - Name: ML12
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, -1.04, 5.91, 25.5, 0, 0, 0, ~]
      - [Anchored, 395.47, -2242.8, 0.24455, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [0, ~]
      - [0, ~]
    # Sections
```

```
    LineType, Length, TargetSegmentLength:
      - [FPSOchain_Tanzania_Jugal3, 200, 10]
      - [FPSOpoly-Tanzania_Jugal3, 3200, 100]
      - [FPSOchain_Tanzania_Jugal3, 100, 10]
    # Contents
    ContentsMethod: Uniform
    IncludeAxialContentsInertia: Yes
    ContentsDensity: 0
    ContentsPressureRefZ: ~
    ContentsPressure: 0
    ContentsFlowRate: 0
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: None
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 55
    AsLaidTension: 0
    # Drawing
    DrawShadedNodesAsSpheres: Yes
    DrawContact: No
  - Name: ML1
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, -5.91, 1.04, 25.5, 0, 0, 0, ~]
      - [Anchored, 2242.8, -395.46, 0.24455, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [0, ~]
      - [0, ~]
    # Sections
    LineType, Length, TargetSegmentLength:
      - [FPSOchain_Tanzania_Jugal3, 200, 10]
      - [FPSOpoly-Tanzania_Jugal3, 3200, 100]
      - [FPSOchain_Tanzania_Jugal3, 100, 10]
    # Contents
    ContentsMethod: Uniform
    IncludeAxialContentsInertia: Yes
    ContentsDensity: 0
    ContentsPressureRefZ: ~
    ContentsPressure: 0
    ContentsFlowRate: 0
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: None
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 125
    AsLaidTension: 0
    # Drawing
    DrawShadedNodesAsSpheres: Yes
    DrawContact: No
  - Name: ML2
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
```

```
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, -6, -734.788079488412E-18, 25.5, 0, 0, 0, ~]
      - [Anchored, 2277.4, 0, 0.24455, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [0, ~]
      - [0, ~]
    # Sections
    LineType, Length, TargetSegmentLength:
      - [FPSOchain_Tanzania_Jugal3, 200, 10]
      - [FPSOpoly-Tanzania_Jugal3, 3200, 100]
      - [FPSOchain_Tanzania_Jugal3, 100, 10]
    # Contents
    ContentsMethod: Uniform
    IncludeAxialContentsInertia: Yes
    ContentsDensity: 0
    ContentsPressureRefZ: ~
    ContentsPressure: 0
    ContentsFlowRate: 0
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: None
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 135
    AsLaidTension: 0
    # Drawing
    DrawShadedNodesAsSpheres: Yes
    DrawContact: No
  - Name: ML3
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, -5.91, -1.04, 25.5, 0, 0, 0, ~]
      - [Anchored, 2242.8, 395.46, 0.24455, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [0, ~]
      - [0, ~]
    # Sections
    LineType, Length, TargetSegmentLength:
      - [FPSOchain_Tanzania_Jugal3, 200, 10]
      - [FPSOpoly-Tanzania_Jugal3, 3200, 100]
      - [FPSOchain_Tanzania_Jugal3, 100, 10]
    # Contents
    ContentsMethod: Uniform
    IncludeAxialContentsInertia: Yes
    ContentsDensity: 0
    ContentsPressureRefZ: ~
    ContentsPressure: 0
    ContentsFlowRate: 0
```

```
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: None
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 145
    AsLaidTension: 0
    # Drawing
    DrawShadedNodesAsSpheres: Yes
    DrawContact: No
  - Name: ML4
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, -1.04, -5.91, 25.5, 0, 0, 0, ~]
      - [Anchored, 395.46, 2242.8, 0.24455, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [0, ~]
      - [0, ~]
    # Sections
    LineType, Length, TargetSegmentLength:
      - [FPSOchain_Tanzania_Jugal3, 200, 10]
      - [FPSOpoly-Tanzania_Jugal3, 3200, 100]
      - [FPSOchain_Tanzania_Jugal3, 100, 10]
    # Contents
    ContentsMethod: Uniform
    IncludeAxialContentsInertia: Yes
    ContentsDensity: 0
    ContentsPressureRefZ: ~
    ContentsPressure: 0
    ContentsFlowRate: 0
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: None
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 215
    AsLaidTension: 0
    # Drawing
    DrawShadedNodesAsSpheres: Yes
    DrawContact: No
  - Name: 40RiserP
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, -399, 25, 0, 270, 180, 0, ~]
      - [Free, 266.699388783337, -268.580758734422, -520.887512342582, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
```

```
  - [Infinity, ~]
  - []
# Sections
LineType, Length, TargetSegmentLength:
  - [40"Rubber Rigid, 0.75, 0.5]
  - [40"RubberTransition, 1, 0.5]
  - [40" Rubber, 113.25, 0.5]
  - [40"HDPE SDR26, 253, 0.5]
  - [40" Rubber, 23, 0.5]
  - [40"Pipe 0.75" wall, 103.5, 0.5]
  - [40" Strainer, 5.5, 0.5]
# Attachments
AttachmentType, Attachmentx, Attachmenty, Attachmentz, AttachmentzRel:
  - [40 Riser Head, 0, 0, 0, End A]
  - [40 flg conn with bq, 0, 0, 11.5, End A]
  - [40 flg conn with bq, 0, 0, 23, End A]
  - [40 flg conn with bq, 0, 0, 34.5, End A]
  - [40 flg conn with bq, 0, 0, 46, End A]
  - [40 flg conn with bq, 0, 0, 57.5, End A]
  - [40 flg conn with bq, 0, 0, 69, End A]
  - [40 flg conn with bq, 0, 0, 80.5, End A]
  - [40 flg conn with bq, 0, 0, 92, End A]
  - [40 flg conn with bq, 0, 0, 103.5, End A]
  - [40 flg conn with bq, 0, 0, 115, End A]
  - [40 flg conn with bq, 0, 0, 126.5, End A]
  - [40 flg conn with bq, 0, 0, 138, End A]
  - [40 flg conn with bq, 0, 0, 149.5, End A]
  - [40 flg conn with bq, 0, 0, 161, End A]
  - [40 flg conn with bq, 0, 0, 172.5, End A]
  - [40 flg conn with bq, 0, 0, 184, End A]
  - [40 flg conn with bq, 0, 0, 195.5, End A]
  - [40 flg conn with bq, 0, 0, 207, End A]
  - [40 flg conn with bq, 0, 0, 218.5, End A]
  - [40 flg conn with bq, 0, 0, 230, End A]
  - [40 flg conn with bq, 0, 0, 241.5, End A]
  - [40 flg conn with bq, 0, 0, 253, End A]
  - [40 flg conn with bq, 0, 0, 264.5, End A]
  - [40 flg conn with bq, 0, 0, 276, End A]
  - [40 flg conn with bq, 0, 0, 287.5, End A]
  - [40 flg conn with bq, 0, 0, 299, End A]
  - [40 flg conn with bq, 0, 0, 310.5, End A]
  - [40 flg conn with bq, 0, 0, 322, End A]
  - [40 flg conn with bq, 0, 0, 333.5, End A]
  - [40 flg conn with bq, 0, 0, 345, End A]
  - [40 flg conn with bq, 0, 0, 356.5, End A]
  - [40 flg conn with bq, 0, 0, 368, End A]
  - [40 flg conn with bq, 0, 0, 379.5, End A]
  - [40 flg conn with bq, 0, 0, 391, End A]
  - [40 flg conn with bq, 0, 0, 402.5, End A]
  - [40 flg conn with bq, 0, 0, 414, End A]
  - [40 flg conn with bq, 0, 0, 425.5, End A]
  - [40 flg conn with bq, 0, 0, 437, End A]
  - [40 flg conn with bq, 0, 0, 448.5, End A]
  - [40 flg conn with bq, 0, 0, 460, End A]
  - [40 flg conn with bq, 0, 0, 471.5, End A]
  - [40 flg conn with bq, 0, 0, 483, End A]
  - [40 flg conn with bq, 0, 0, 494.5, End A]
# Contents
ContentsMethod: Free Flooding
IncludeAxialContentsInertia: No
# Statics
IncludedInStatics: Yes
StaticsStep1: Catenary
StaticsStep2: Full Statics
```

```
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 359.55773942442
    AsLaidTension: 0
    # Drawing
    NodePen: [1, Dot, $4080FF]
    DrawShadedNodesAsSpheres: Yes
  - Name: 60RiserS
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec, 
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, -399, -25, 0, 270, 180, 0, ~]
      - [Free, 266.699388783337, -268.580758734422, -520.887512342582, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [Infinity, ~]
      - []
    # Sections
    LineType, Length, TargetSegmentLength:
      - [60"Rubber Rigid, 0.75, 0.5]
      - [60"RubberTransition, 1, 0.5]
      - [60" Rubber, 113.25, 0.5]
      - [60"HDPE SDR26, 253, 0.5]
      - [60" Rubber, 23, 0.5]
      - [60"Pipe 0.75" wall, 103.5, 0.5]
      - [60"strainer, 5.5, 0.5]
    # Attachments
    AttachmentType, Attachmentx, Attachmenty, Attachmentz, AttachmentzRel:
      - [60 Riser Head, 0, 0, 0, End A]
      - [60 Flange Conn with bq, 0, 0, 11.5, End A]
      - [60 Flange Conn with bq, 0, 0, 23, End A]
      - [60 Flange Conn with bq, 0, 0, 34.5, End A]
      - [60 Flange Conn with bq, 0, 0, 46, End A]
      - [60 Flange Conn with bq, 0, 0, 57.5, End A]
      - [60 Flange Conn with bq, 0, 0, 69, End A]
      - [60 Flange Conn with bq, 0, 0, 80.5, End A]
      - [60 Flange Conn with bq, 0, 0, 92, End A]
      - [60 Flange Conn with bq, 0, 0, 103.5, End A]
      - [60 Flange Conn with bq, 0, 0, 115, End A]
      - [60 Flange Conn with bq, 0, 0, 126.5, End A]
      - [60 Flange Conn with bq, 0, 0, 138, End A]
      - [60 Flange Conn with bq, 0, 0, 149.5, End A]
      - [60 Flange Conn with bq, 0, 0, 161, End A]
      - [60 Flange Conn with bq, 0, 0, 172.5, End A]
      - [60 Flange Conn with bq, 0, 0, 184, End A]
      - [60 Flange Conn with bq, 0, 0, 195.5, End A]
      - [60 Flange Conn with bq, 0, 0, 207, End A]
      - [60 Flange Conn with bq, 0, 0, 218.5, End A]
      - [60 Flange Conn with bq, 0, 0, 230, End A]
      - [60 Flange Conn with bq, 0, 0, 241.5, End A]
      - [60 Flange Conn with bq, 0, 0, 253, End A]
      - [60 Flange Conn with bq, 0, 0, 264.5, End A]
      - [60 Flange Conn with bq, 0, 0, 276, End A]
      - [60 Flange Conn with bq, 0, 0, 287.5, End A]
      - [60 Flange Conn with bq, 0, 0, 299, End A]
      - [60 Flange Conn with bq, 0, 0, 310.5, End A]
      - [60 Flange Conn with bq, 0, 0, 322, End A]
      - [60 Flange Conn with bq, 0, 0, 333.5, End A]
```

```
      - [60 Flange Conn with bq, 0, 0, 345, End A]
      - [60 Flange Conn with bq, 0, 0, 356.5, End A]
      - [60 Flange Conn with bq, 0, 0, 368, End A]
      - [60 Flange Conn with bq, 0, 0, 379.5, End A]
      - [60 Flange Conn with bq, 0, 0, 391, End A]
      - [60 Flange Conn with bq, 0, 0, 402.5, End A]
      - [60 Flange Conn with bq, 0, 0, 414, End A]
      - [60 Flange Conn with bq, 0, 0, 425.5, End A]
      - [60 Flange Conn with bq, 0, 0, 437, End A]
      - [60 Flange Conn with bq, 0, 0, 448.5, End A]
      - [60 Flange Conn with bq, 0, 0, 460, End A]
      - [60 Flange Conn with bq, 0, 0, 471.5, End A]
      - [60 Flange Conn with bq, 0, 0, 483, End A]
      - [60 Flange Conn with bq, 0, 0, 494.5, End A]
    # Contents
    ContentsMethod: Free Flooding
    IncludeAxialContentsInertia: No
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: Full Statics
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 359.55773942442
    AsLaidTension: 0
    # Drawing
    NodePen: [1, Dot, $4080FF]
    DrawShadedNodesAsSpheres: Yes

Groups:
  Structure:
    Oct2010 FLNG: Model
    ML Turret Radius: Model
    CWR Turret Radius: Model
    Umbilical Turret Radius: Model
    PR Turret Radius: Model
    Watch circle: Model
    Lazy_free_risers: Model
    ML1: Model
    ML2: Model
    ML3: Model
    ML4: Model
    ML5: Model
    ML6: Model
    ML7: Model
    ML8: Model
    ML9: Model
    ML10: Model
    ML11: Model
    ML12: Model
    Shape1: Model
    40RiserP: Model
    60RiserS: Model
  State:
    Collapsed:
      - Variable Data
...
```

Model Data File - Fatigue Analysis (Waves)

```
%YAML 1.1
# Type: Model
# Program: OrcaFlex 10.1d
# File: C:\Users\Ian\Desktop\fatigue waves.yml
# Created: 15:57 on 03/06/2018
# User: Ian
# Machine: IAN-PC
---
General:
  # Units
  UnitsSystem: SI
  # Statics
  BuoysIncludedInStatics: Individually Specified
  StaticsMaxIterations: 800
  StaticsMinDamping: 2
  StaticsMaxDamping: 50
  # Dynamics
  DynamicsSolutionMethod: Implicit time domain
  ImplicitUseVariableTimeStep: Yes
  ImplicitVariableMaxTimeStep: 0.1
  ImplicitVariableMaxNumOfIterations: 10
  ImplicitTolerance: 1E-6
  LogPrecision: Single
  TargetLogSampleInterval: 0.0125
  LogStartTime: ~
  # Stages
  StageDuration:
    - 0.5
    - 2.5
  # Drawing
  Pen: [1, Solid, Yellow]
  NorthDirectionDefined: Yes
  NorthDirection: 90
  # Default view parameters
  DefaultViewMode: Wire frame
  DefaultViewSize: 583.532627843579
  DefaultViewCentre: [201.56372757738, 4.12145186646211, -248.996087857083]
  DefaultViewAzimuth: 270
  DefaultViewElevation: 0
VariableData:
  KinematicViscosity:
    - Name: 3.5% Salinity
      IndependentValue, DependentValue:
        - [0, 1.82842473024E-6]
        - [0.555555555555556, 1.79516544192E-6]
        - [1.11111111111111, 1.76274228096E-6]
        - [1.66666666666667, 1.73143395648E-6]
        - [2.22222222222222, 1.70096175936E-6]
        - [2.77777777777778, 1.67141859264E-6]
        - [3.33333333333333, 1.64271155328E-6]
        - [3.88888888888889, 1.61484064128E-6]
        - [4.44444444444444, 1.58780585664E-6]
        - [5, 1.56142139328E-6]
        - [5.55555555555556, 1.53587305728E-6]
        - [6.11111111111111, 1.51088213952E-6]
        - [6.66666666666667, 1.48663444608E-6]
        - [7.22222222222222, 1.46303707392E-6]
        - [7.77777777777778, 1.44009002304E-6]
        - [8.33333333333333, 1.41760748736E-6]
        - [8.88888888888889, 1.39577527296E-6]
        - [9.44444444444444, 1.37459337984E-6]
        - [10, 1.35378309888E-6]
        - [10.5555555555556, 1.33353023616E-6]
        - [11.1111111111111, 1.31383479168E-6]
```

    - [11.6666666666667, 1.2946038624E-6]
    - [12.2222222222222, 1.27574454528E-6]
    - [12.7777777777778, 1.2574426464E-6]
    - [13.3333333333333, 1.23960526272E-6]
    - [13.8888888888889, 1.22204658816E-6]
    - [14.4444444444444, 1.2049524288E-6]
    - [15, 1.18832278464E-6]
    - [15.5555555555556, 1.1719718496E-6]
    - [16.1111111111111, 1.15599252672E-6]
    - [16.6666666666667, 1.140384816E-6]
    - [17.2222222222222, 1.12514871744E-6]
    - [17.7777777777778, 1.11028423104E-6]
    - [18.3333333333333, 1.09569845376E-6]
    - [18.8888888888889, 1.0813913856E-6]
    - [19.4444444444444, 1.06736302656E-6]
    - [20, 1.05370627968E-6]
    - [20.5555555555556, 1.04032824192E-6]
    - [21.1111111111111, 1.02722891328E-6]
    - [21.6666666666667, 1.01431539072E-6]
    - [22.2222222222222, 1.00177348032E-6]
    - [22.7777777777778, 989.417376E-9]
    - [23.3333333333333, 977.3399808E-9]
    - [23.8888888888889, 965.44839168E-9]
    - [24.4444444444444, 953.83551168E-9]
    - [25, 942.5013408E-9]
    - [25.5555555555556, 931.352976E-9]
    - [26.1111111111111, 920.39041728E-9]
    - [26.6666666666667, 909.61366464E-9]
    - [27.2222222222222, 899.11562112E-9]
    - [27.7777777777778, 888.80338368E-9]
    - [28.3333333333333, 878.58404928E-9]
    - [28.8888888888889, 868.643424E-9]
    - [29.4444444444444, 858.8886048E-9]
    - [30, 849.31959168E-9]

- Name: 60Rubber
  IndependentValue, DependentValue:
    - [4940, 1.2]
    - [9870, 1.2]
    - [24.7E3, 1.2]
    - [49.4E3, 1.2]
    - [138E3, 1.2]
    - [148E3, 1.2]
    - [173E3, 1.16]
    - [197E3, 1.06]
    - [222E3, 0.8]
    - [247E3, 0.57]
    - [296E3, 0.61]
    - [346E3, 0.68]
    - [395E3, 0.76]
    - [494E3, 0.88]
    - [740E3, 0.97]
    - [987E3, 0.99]
    - [2.47E6, 0.98]
    - [4.94E6, 0.96]
    - [9.87E6, 0.94]
    - [14.8E6, 0.94]
- Name: 60HDPE
  IndependentValue, DependentValue:
    - [9990, 1.2]
    - [20E3, 1.2]
    - [49.9E3, 1.2]
    - [99.9E3, 1.2]
    - [280E3, 1.2]

```
    - [300E3, 1.19]
    - [350E3, 1.16]
    - [400E3, 1.05]
    - [449E3, 0.8]
    - [499E3, 0.46]
    - [599E3, 0.28]
    - [699E3, 0.28]
    - [799E3, 0.3]
    - [999E3, 0.36]
    - [1.5E6, 0.47]
    - [2E6, 0.52]
    - [4.99E6, 0.56]
    - [9.99E6, 0.55]
    - [20E6, 0.53]
    - [30E6, 0.52]
- Name: 60Steel
  IndependentValue, DependentValue:
    - [9790, 1.2]
    - [19.6E3, 1.2]
    - [48.9E3, 1.2]
    - [97.9E3, 1.2]
    - [274E3, 1.2]
    - [294E3, 1.19]
    - [343E3, 1.16]
    - [392E3, 1.05]
    - [440E3, 0.8]
    - [489E3, 0.46]
    - [587E3, 0.31]
    - [685E3, 0.32]
    - [783E3, 0.35]
    - [979E3, 0.41]
    - [1.47E6, 0.53]
    - [1.96E6, 0.58]
    - [4.89E6, 0.61]
    - [9.79E6, 0.59]
    - [19.6E6, 0.57]
    - [29.4E6, 0.57]
- Name: 60Steel MG3mm
  IndependentValue, DependentValue:
    - [4610, 1.2]
    - [9220, 1.2]
    - [23.1E3, 1.2]
    - [46.1E3, 1.2]
    - [129E3, 1.2]
    - [138E3, 1.2]
    - [161E3, 1.16]
    - [184E3, 1.06]
    - [208E3, 0.8]
    - [231E3, 0.59]
    - [277E3, 0.63]
    - [323E3, 0.71]
    - [369E3, 0.78]
    - [461E3, 0.89]
    - [692E3, 0.98]
    - [922E3, 1]
    - [2.31E6, 0.99]
    - [4.61E6, 0.97]
    - [9.22E6, 0.96]
    - [13.8E6, 0.96]
- Name: 60HDPE MG18mm
  IndependentValue, DependentValue:
    - [1900, 1.23]
    - [3800, 1.23]
    - [9510, 1.23]
```

```
    - [19E3, 1.23]
    - [53.2E3, 1.22]
    - [57E3, 1.22]
    - [66.5E3, 1.18]
    - [76.1E3, 1.08]
    - [85.6E3, 0.88]
    - [95.1E3, 0.89]
    - [114E3, 0.92]
    - [133E3, 0.95]
    - [152E3, 0.98]
    - [190E3, 1.02]
    - [285E3, 1.06]
    - [380E3, 1.07]
    - [951E3, 1.07]
    - [1.9E6, 1.07]
    - [3.8E6, 1.07]
    - [5.7E6, 1.07]
- Name: 60HDPE MG3mm
  IndependentValue, DependentValue:
    - [4720, 1.2]
    - [9440, 1.2]
    - [23.6E3, 1.2]
    - [47.2E3, 1.2]
    - [132E3, 1.2]
    - [142E3, 1.2]
    - [165E3, 1.16]
    - [189E3, 1.06]
    - [212E3, 0.8]
    - [236E3, 0.58]
    - [283E3, 0.62]
    - [330E3, 0.7]
    - [378E3, 0.78]
    - [472E3, 0.89]
    - [708E3, 0.98]
    - [944E3, 1]
    - [2.36E6, 0.98]
    - [4.72E6, 0.97]
    - [9.44E6, 0.95]
    - [14.2E6, 0.95]
- Name: 60Rubber MG18mm
  IndependentValue, DependentValue:
    - [1980, 1.22]
    - [3960, 1.22]
    - [9900, 1.22]
    - [19.8E3, 1.22]
    - [55.4E3, 1.22]
    - [59.4E3, 1.22]
    - [69.3E3, 1.18]
    - [79.2E3, 1.07]
    - [89.1E3, 0.86]
    - [99E3, 0.87]
    - [119E3, 0.9]
    - [139E3, 0.94]
    - [158E3, 0.97]
    - [198E3, 1.01]
    - [297E3, 1.05]
    - [396E3, 1.06]
    - [990E3, 1.07]
    - [1.98E6, 1.07]
    - [3.96E6, 1.07]
    - [5.94E6, 1.07]
- Name: 40Rubber
  IndependentValue, DependentValue:
    - [4100, 1.21]
```

```
    - [8210, 1.21]
    - [20.5E3, 1.21]
    - [41E3, 1.21]
    - [115E3, 1.2]
    - [123E3, 1.2]
    - [144E3, 1.16]
    - [164E3, 1.06]
    - [185E3, 0.8]
    - [205E3, 0.62]
    - [246E3, 0.67]
    - [287E3, 0.74]
    - [328E3, 0.81]
    - [410E3, 0.91]
    - [615E3, 1]
    - [821E3, 1.02]
    - [2.05E6, 1.01]
    - [4.1E6, 0.99]
    - [8.21E6, 0.98]
    - [12.3E6, 0.98]
- Name: 40HDPE
  IndependentValue, DependentValue:
    - [9980, 1.2]
    - [20E3, 1.2]
    - [49.9E3, 1.2]
    - [99.8E3, 1.2]
    - [279E3, 1.2]
    - [299E3, 1.19]
    - [349E3, 1.16]
    - [399E3, 1.05]
    - [449E3, 0.8]
    - [499E3, 0.46]
    - [599E3, 0.28]
    - [699E3, 0.28]
    - [799E3, 0.3]
    - [998E3, 0.36]
    - [1.5E6, 0.47]
    - [2E6, 0.53]
    - [4.99E6, 0.57]
    - [9.98E6, 0.55]
    - [20E6, 0.53]
    - [29.9E6, 0.53]
- Name: 40Steel
  IndependentValue, DependentValue:
    - [9690, 1.2]
    - [19.4E3, 1.2]
    - [48.4E3, 1.2]
    - [96.9E3, 1.2]
    - [271E3, 1.2]
    - [291E3, 1.19]
    - [339E3, 1.16]
    - [387E3, 1.05]
    - [436E3, 0.8]
    - [484E3, 0.46]
    - [581E3, 0.32]
    - [678E3, 0.33]
    - [775E3, 0.36]
    - [969E3, 0.43]
    - [1.45E6, 0.55]
    - [1.94E6, 0.59]
    - [4.84E6, 0.62]
    - [9.69E6, 0.61]
    - [19.4E6, 0.59]
    - [29.1E6, 0.58]
- Name: 40Rubber MG18mm
```

```
  IndependentValue, DependentValue:
    - [1710, 1.24]
    - [3420, 1.24]
    - [8560, 1.24]
    - [17.1E3, 1.24]
    - [47.9E3, 1.23]
    - [51.4E3, 1.23]
    - [59.9E3, 1.19]
    - [68.5E3, 1.08]
    - [77.1E3, 0.93]
    - [85.6E3, 0.94]
    - [103E3, 0.97]
    - [120E3, 0.99]
    - [137E3, 1.01]
    - [171E3, 1.04]
    - [257E3, 1.07]
    - [342E3, 1.08]
    - [856E3, 1.09]
    - [1.71E6, 1.09]
    - [3.42E6, 1.09]
    - [5.14E6, 1.09]
- Name: 40HDPE MG18mm
  IndependentValue, DependentValue:
    - [1650, 1.24]
    - [3300, 1.24]
    - [8250, 1.24]
    - [16.5E3, 1.24]
    - [46.2E3, 1.24]
    - [49.5E3, 1.23]
    - [57.7E3, 1.2]
    - [66E3, 1.09]
    - [74.2E3, 0.96]
    - [82.5E3, 0.96]
    - [99E3, 0.99]
    - [115E3, 1.01]
    - [132E3, 1.03]
    - [165E3, 1.06]
    - [247E3, 1.08]
    - [330E3, 1.09]
    - [825E3, 1.1]
    - [1.65E6, 1.1]
    - [3.3E6, 1.1]
    - [4.95E6, 1.1]
- Name: 40HDPE MG3mm
  IndependentValue, DependentValue:
    - [3850, 1.21]
    - [7700, 1.21]
    - [19.3E3, 1.21]
    - [38.5E3, 1.21]
    - [108E3, 1.2]
    - [116E3, 1.2]
    - [135E3, 1.17]
    - [154E3, 1.06]
    - [173E3, 0.8]
    - [193E3, 0.64]
    - [231E3, 0.69]
    - [270E3, 0.76]
    - [308E3, 0.83]
    - [385E3, 0.92]
    - [578E3, 1.01]
    - [770E3, 1.02]
    - [1.93E6, 1.02]
    - [3.85E6, 1]
    - [7.7E6, 0.99]
```

```
      - [11.6E6, 0.99]
    - Name: 40Steel MG3mm
      IndependentValue, DependentValue:
        - [3750, 1.21]
        - [7510, 1.21]
        - [18.8E3, 1.21]
        - [37.5E3, 1.21]
        - [105E3, 1.2]
        - [113E3, 1.2]
        - [131E3, 1.17]
        - [150E3, 1.06]
        - [169E3, 0.8]
        - [188E3, 0.65]
        - [225E3, 0.7]
        - [263E3, 0.77]
        - [300E3, 0.83]
        - [375E3, 0.93]
        - [563E3, 1.01]
        - [751E3, 1.02]
        - [1.88E6, 1.02]
        - [3.75E6, 1]
        - [7.51E6, 0.99]
        - [11.3E6, 0.99]
  BendingStiffness:
    - Name: 40"stiffness
      IndependentValue, DependentValue:
        - [0, 0]
        - [0.02, 100]
        - [0.03, 134]
        - [0.04, 168]
        - [0.06, 210]
        - [0.08, 240]
        - [0.1, 265]
        - [0.12, 283]
        - [0.14, 295]
      Hysteretic: No
    - Name: 60"stiffness
      IndependentValue, DependentValue:
        - [0, 0]
        - [0.02, 550]
        - [0.04, 900]
        - [0.06, 1200]
        - [0.08, 1475]
        - [0.1, 1675]
        - [0.12, 1800]
        - [0.14, 1890]
      Hysteretic: No
    - Name: 60"Stiffness1
      IndependentValue, DependentValue:
        - [0, 0]
        - [0.02, 485]
        - [0.04, 825]
        - [0.06, 1060]
        - [0.08, 1210]
        - [0.0952, 1285]
        - [0.1, 1300]
      Hysteretic: No
    - Name: 40"stiffness linear
      IndependentValue, DependentValue:
        - [0, 0]
        - [0.14, 295]
      Hysteretic: No
    - Name: 60"stiffness linear
      IndependentValue, DependentValue:
```

```
      - [0, 0]
      - [0.14, 1277]
    Hysteretic: No
InlineDragAmplificationFactor:
  - Name: 40HDPEDAF
    IndependentValue, DependentValue:
      - [0.047, 1.164]
      - [0.094, 1.257]
      - [0.141, 1.335]
      - [0.187, 1.403]
      - [0.234, 1.466]
      - [0.281, 1.525]
      - [0.328, 1.58]
      - [0.375, 1.633]
      - [0.422, 1.683]
      - [0.469, 1.732]
      - [0.515, 1.778]
      - [0.562, 1.824]
      - [0.609, 1.868]
      - [0.656, 1.911]
      - [0.703, 1.952]
      - [0.75, 1.993]
      - [0.797, 2.033]
      - [0.843, 2.072]
      - [0.89, 2.11]
      - [0.937, 2.148]
      - [0.984, 2.185]
      - [1.031, 2.221]
      - [1.078, 2.257]
      - [1.125, 2.293]
      - [1.172, 2.327]
      - [1.218, 2.362]
      - [1.265, 2.395]
      - [1.312, 2.429]
      - [1.359, 2.462]
      - [1.406, 2.494]
      - [1.453, 2.527]
      - [1.5, 2.558]
      - [1.546, 2.59]
      - [1.593, 2.621]
      - [1.64, 2.652]
      - [1.687, 2.682]
      - [1.734, 2.713]
      - [1.781, 2.743]
      - [1.828, 2.772]
      - [1.874, 2.802]
  - Name: 40RubberDAF
    IndependentValue, DependentValue:
      - [0.041, 1.164]
      - [0.082, 1.257]
      - [0.123, 1.335]
      - [0.164, 1.403]
      - [0.205, 1.466]
      - [0.246, 1.525]
      - [0.287, 1.58]
      - [0.328, 1.633]
      - [0.369, 1.683]
      - [0.41, 1.732]
      - [0.451, 1.778]
      - [0.492, 1.824]
      - [0.533, 1.868]
      - [0.574, 1.911]
      - [0.615, 1.952]
      - [0.656, 1.993]
```

```
    - [0.697, 2.033]
    - [0.738, 2.072]
    - [0.779, 2.11]
    - [0.82, 2.148]
    - [0.861, 2.185]
    - [0.902, 2.221]
    - [0.943, 2.257]
    - [0.984, 2.293]
    - [1.025, 2.327]
    - [1.066, 2.362]
    - [1.107, 2.395]
    - [1.148, 2.429]
    - [1.189, 2.462]
    - [1.23, 2.494]
    - [1.27, 2.527]
    - [1.311, 2.558]
    - [1.352, 2.59]
    - [1.393, 2.621]
    - [1.434, 2.652]
    - [1.475, 2.682]
    - [1.516, 2.713]
    - [1.557, 2.743]
    - [1.598, 2.772]
    - [1.639, 2.802]
- Name: 40SteelDAF
  IndependentValue, DependentValue:
    - [0.049, 1.164]
    - [0.098, 1.257]
    - [0.148, 1.335]
    - [0.197, 1.403]
    - [0.246, 1.466]
    - [0.295, 1.525]
    - [0.344, 1.58]
    - [0.394, 1.633]
    - [0.443, 1.683]
    - [0.492, 1.732]
    - [0.541, 1.778]
    - [0.591, 1.824]
    - [0.64, 1.868]
    - [0.689, 1.911]
    - [0.738, 1.952]
    - [0.787, 1.993]
    - [0.837, 2.033]
    - [0.886, 2.072]
    - [0.935, 2.11]
    - [0.984, 2.148]
    - [1.033, 2.185]
    - [1.083, 2.221]
    - [1.132, 2.257]
    - [1.181, 2.293]
    - [1.23, 2.327]
    - [1.28, 2.362]
    - [1.329, 2.395]
    - [1.378, 2.429]
    - [1.427, 2.462]
    - [1.476, 2.494]
    - [1.526, 2.527]
    - [1.575, 2.558]
    - [1.624, 2.59]
    - [1.673, 2.621]
    - [1.722, 2.652]
    - [1.772, 2.682]
    - [1.821, 2.713]
    - [1.87, 2.743]
```

```
    - [1.919, 2.772]
    - [1.969, 2.802]
- Name: 60HDPEDAF
  IndependentValue, DependentValue:
    - [0.031, 1.129]
    - [0.063, 1.203]
    - [0.094, 1.264]
    - [0.125, 1.318]
    - [0.156, 1.367]
    - [0.188, 1.414]
    - [0.219, 1.457]
    - [0.25, 1.499]
    - [0.281, 1.538]
    - [0.313, 1.577]
    - [0.344, 1.613]
    - [0.375, 1.649]
    - [0.406, 1.684]
    - [0.438, 1.718]
    - [0.469, 1.75]
    - [0.5, 1.783]
    - [0.531, 1.814]
    - [0.563, 1.845]
    - [0.594, 1.875]
    - [0.625, 1.905]
    - [0.656, 1.934]
    - [0.688, 1.963]
    - [0.719, 1.991]
    - [0.75, 2.019]
    - [0.781, 2.046]
    - [0.813, 2.073]
    - [0.844, 2.1]
    - [0.875, 2.126]
    - [0.906, 2.152]
    - [0.938, 2.178]
    - [0.969, 2.203]
    - [1, 2.228]
    - [1.031, 2.253]
    - [1.063, 2.277]
    - [1.094, 2.302]
    - [1.125, 2.326]
    - [1.156, 2.35]
    - [1.188, 2.373]
    - [1.219, 2.397]
    - [1.25, 2.42]
- Name: 60RubberDAF
  IndependentValue, DependentValue:
    - [0.028, 1.129]
    - [0.057, 1.203]
    - [0.085, 1.264]
    - [0.114, 1.318]
    - [0.142, 1.367]
    - [0.17, 1.414]
    - [0.199, 1.457]
    - [0.227, 1.499]
    - [0.256, 1.538]
    - [0.284, 1.577]
    - [0.313, 1.613]
    - [0.341, 1.649]
    - [0.369, 1.684]
    - [0.398, 1.718]
    - [0.426, 1.75]
    - [0.455, 1.783]
    - [0.483, 1.814]
    - [0.511, 1.845]
```

```
    - [0.54, 1.875]
    - [0.568, 1.905]
    - [0.597, 1.934]
    - [0.625, 1.963]
    - [0.653, 1.991]
    - [0.682, 2.019]
    - [0.71, 2.046]
    - [0.739, 2.073]
    - [0.767, 2.1]
    - [0.795, 2.126]
    - [0.824, 2.152]
    - [0.852, 2.178]
    - [0.881, 2.203]
    - [0.909, 2.228]
    - [0.938, 2.253]
    - [0.966, 2.277]
    - [0.994, 2.302]
    - [1.023, 2.326]
    - [1.051, 2.35]
    - [1.08, 2.373]
    - [1.108, 2.397]
    - [1.136, 2.42]
- Name: 60SteelDAF
  IndependentValue, DependentValue:
    - [0.033, 1.129]
    - [0.066, 1.203]
    - [0.098, 1.264]
    - [0.131, 1.318]
    - [0.164, 1.367]
    - [0.197, 1.414]
    - [0.23, 1.457]
    - [0.262, 1.499]
    - [0.295, 1.538]
    - [0.328, 1.577]
    - [0.361, 1.613]
    - [0.394, 1.649]
    - [0.427, 1.684]
    - [0.459, 1.718]
    - [0.492, 1.75]
    - [0.525, 1.783]
    - [0.558, 1.814]
    - [0.591, 1.845]
    - [0.623, 1.875]
    - [0.656, 1.905]
    - [0.689, 1.934]
    - [0.722, 1.963]
    - [0.755, 1.991]
    - [0.787, 2.019]
    - [0.82, 2.046]
    - [0.853, 2.073]
    - [0.886, 2.1]
    - [0.919, 2.126]
    - [0.951, 2.152]
    - [0.984, 2.178]
    - [1.017, 2.203]
    - [1.05, 2.228]
    - [1.083, 2.253]
    - [1.115, 2.277]
    - [1.148, 2.302]
    - [1.181, 2.326]
    - [1.214, 2.35]
    - [1.247, 2.373]
    - [1.28, 2.397]
    - [1.312, 2.42]
```

```yaml
Environment:
  # Sea
  WaterSurfaceZ: 0
  KinematicViscosity: 3.5% Salinity
  SeaTemperature: 10
  ReynoldsNumberCalculation: Cross Flow
  # Sea Density
  HorizontalWaterDensityFactor: ~
  VerticalDensityVariation: Constant
  Density: 1.025
  # Seabed
  SeabedType: Flat
  SeabedOrigin: [0, 0]
  WaterDepth: 2600
  SeabedSlopeDirection: 0
  SeabedSlope: 0
  SeabedModel: Elastic
  SeabedNormalStiffness: 100
  SeabedShearStiffness: ~
  # Waves
  SimulationTimeOrigin: 0
  KinematicStretchingMethod: Vertical Stretching
  WaveTrains:
    - Name: Wave1
      WaveType: Airy
      WaveDirection: 0
      WaveHeight: 0.5
      WavePeriod: 0.5
      WaveOrigin: [0, 0]
      WaveTimeOrigin: 0
  # WaveCalculation
  WaveKinematicsCutoffDepth: Infinity
  WaveCalculationMethod: Instantaneous Position (exact)
  WaveCalculationTimeInterval: 0
  WaveCalculationSpatialInterval: 0
  # Current
  MultipleCurrentDataCanBeDefined: Yes
  Currents:
    - Name: Max Current
      CurrentRamp: No
      HorizontalCurrentFactor: ~
      CurrentApplyVerticalStretching: No
      CurrentMethod: Interpolated
      RefCurrentSpeed: 1
      RefCurrentDirection: 180
      CurrentDepth, CurrentFactor, CurrentRotation:
        - [0, 2, 0]
        - [47, 1.82, 0]
        - [108, 1.62, 0]
        - [147, 0.98, 0]
        - [207, 0.96, 0]
        - [307, 0.95, 0]
        - [508, 0.88, 0]
        - [748, 0.78, 0]
        - [1008, 0.77, 0]
        - [1410, 0.48, 0]
        - [1982, 0.34, 0]
    - Name: Mean Current
      CurrentRamp: No
      HorizontalCurrentFactor: ~
      CurrentApplyVerticalStretching: No
      CurrentMethod: Interpolated
      RefCurrentSpeed: 0.25
      RefCurrentDirection: 180
```

```
      CurrentDepth, CurrentFactor, CurrentRotation:
        - [0, 1.74, 0]
        - [47, 1.58, 0]
        - [108, 1.42, 0]
        - [147, 0.89, 0]
        - [207, 0.85, 0]
        - [307, 0.83, 0]
        - [508, 0.76, 0]
        - [748, 0.66, 0]
        - [1008, 0.64, 0]
        - [1410, 0.4, 0]
        - [1982, 0.28, 0]
  ActiveCurrent: Mean Current
  # Wind
  IncludeVesselWindLoads: Yes
  IncludeLineWindLoads: No
  IncludeBuoyWingWindLoads: No
  VerticalWindVariationFactor: ~
  AirDensity: 0.00128
  WindType: Constant
  WindSpeed: 0
  WindDirection: 0
  # Drawing
  SeaSurfacePen: [1, Solid, $FF8080]
  SeabedPen: [1, Solid, $004080]
  SeabedProfilePen: [2, Solid, White]
VesselTypes:
  - Name: Generic_FLNG
    Length: 425
    # Conventions
    RAOResponseUnits: degrees
    RAOWaveUnit: amplitude
    WavesReferredToBy: period (s)
    RAOPhaseConvention: leads
    RAOPhaseUnitsConvention: degrees
    RAOPhaseRelativeToConvention: crest
    SurgePositive: forward
    SwayPositive: port
    HeavePositive: up
    RollPositiveStarboard: down
    PitchPositiveBow: down
    YawPositiveBow: port
    Symmetry: None
    CurrentCoeffSymmetry: XZ plane
    WindCoeffSymmetry: XZ plane
    QTFConventionsRotationOrder: RzRyRx
    QTFConventionsRotationAxes: Rotated
    QTFConventionsFrameOfReference: Body-Fixed
    Draughts:
      - Name: 14m
        Mass: 8800
        MomentOfInertiaTensorX, MomentOfInertiaTensorY, MomentOfInertiaTensorZ:
          - [249E3, 0, 0]
          - [0, 5.83E6, 0]
          - [0, 0, 5.83E6]
        CentreOfGravity: [-233.48, 0.22, 23.08]
        DisplacementRAOs:
          RAOOrigin: [-233.48, 0.22, 23.08]
          PhaseOrigin: [~, ~, 0]

Li
  - Name: 60" Rubber
    Category: General
    # Geometry & Mass
```

```
    OD: 1.76
    ID: 1.5
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 1.042
    # Limits
    CompressionIsLimited: No
    AllowableTension: 1767
    MinRadius: [6, 6]
    # Structure
    EI: [60"stiffness linear, 60"stiffness linear]
    EA: 25.5E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.76
    ClashStiffness: 5000
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [60Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
  - Name: 60"Rubber Rigid
    Category: General
    # Geometry & Mass
    OD: 1.76
    ID: 1.5
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 1.042
    # Limits
    CompressionIsLimited: No
    AllowableTension: 1767
    MinRadius: [6, 6]
    # Structure
    EI: [15E3, 15E3]
    EA: 25.5E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.76
    ClashStiffness: 5000
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
```

```
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [60Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
  - Name: 60"RubberTransition
    Category: General
    # Geometry & Mass
    OD: 1.76
    ID: 1.5
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 1.042
    # Limits
    CompressionIsLimited: No
    AllowableTension: 1767
    MinRadius: [6, 6]
    # Structure
    EI: [14E3, 14E3]
    EA: 25.5E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.76
    ClashStiffness: 5000
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [60Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
```

```
  RayleighDampingCoefficients: (no damping)
- Name: 60" Rubber MG
  Category: General
  # Geometry & Mass
  OD: 1.81
  ID: 1.5
  CG: [0, 0]
  BulkModulus: Infinity
  MassPerUnitLength: 1.056
  # Limits
  CompressionIsLimited: No
  AllowableTension: 1767
  MinRadius: [6, 6]
  # Structure
  EI: [60"stiffness linear, 60"stiffness linear]
  EA: 25.5E3
  PoissonRatio: 0.5
  GJ: 80
  TensionTorqueCoupling: 0
  # Contact
  ContactDiameter: ~
  ClashStiffness: 5000
  # Added Mass, Inertia & Slam
  Ca: [1, ~, 0]
  Cm: [~, ~, ~]
  Cs: 0
  Ce: 0
  # Drag & Lift
  Cd: [60Rubber MG18mm, ~, 0.008]
  Cl: 0
  NormalDragLiftDiameter: ~
  AxialDragLiftDiameter: ~
  # Stress
  StressOD: ~
  StressID: ~
  AllowableStress: ~
  TensileStressLoadingFactor: 1
  BendingStressLoadingFactor: 1
  ShearStressLoadingFactor: 1
  TorsionalStressLoadingFactor: 1
  # Friction
  SeabedNormalFrictionCoefficient: 0.5
  SeabedAxialFrictionCoefficient: ~
  # Structural Damping
  RayleighDampingCoefficients: (no damping)
- Name: 60"HDPE SDR26
  Category: Homogeneous Pipe
  # Geometry & Density
  OD: 1.6
  ID: 1.478
  MaterialDensity: 0.955
  # Structure
  E: 800E3
  PoissonRatio: 0.4
  # Drag, Lift, Added Mass & Slam
  Cdn: 60HDPE
  Cdz: 0.008
  Cl: 0
  Can: 1
  Caz: 0
  Cs: 0
  Ce: 0
  # Friction
  SeabedNormalFrictionCoefficient: 0.5
```

```
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 9000
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $0080FF]
  - Name: 60"HDPE SDR26 MG1
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.6
    ID: 1.478
    MaterialDensity: 0.995
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 60HDPE MG18mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 9000
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $0080FF]
  - Name: 60"HDPE SDR26 MG2
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.6
    ID: 1.478
    MaterialDensity: 0.955
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 60HDPE MG3mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
```

```
    ClashStiffness: 5000
    # Stress
    AllowableStress: 9000
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $0080FF]
  - Name: 60"Pipe 0.75" wall
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.524
    ID: 1.486
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 60Steel
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 137.9E3
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Aqua]
  - Name: 60"Pipe 0.75"wall MG
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.524
    ID: 1.486
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 60Steel MG3mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
```

```
    AllowableStress: 137.9E3
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Aqua]
  - Name: 60"strainer
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.855
    ID: 1.835
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 1
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 137.9E3
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $8000FF]
  - Name: 40" Rubber
    Category: General
    # Geometry & Mass
    OD: 1.22
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.556
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [40"stiffness linear, 40"stiffness linear]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.205
    ClashStiffness: 5000
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
```

```
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Drawing
    Pen: [1, Solid, $80FFFF]
  - Name: 40"Rubber Rigid
    Category: General
    # Geometry & Mass
    OD: 1.22
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.556
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [4000, 4000]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.205
    ClashStiffness: 5000
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
```

```
    RayleighDampingCoefficients: (no damping)
  - Name: 40"RubberTransition
    Category: General
    # Geometry & Mass
    OD: 1.22
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.556
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [2750, 2750]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.205
    ClashStiffness: 5000
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
  - Name: 40"Rubber MG
    Category: General
    # Geometry & Mass
    OD: 1.27
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.566
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [40"stiffness linear, 40"stiffness linear]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
```

```
    ContactDiameter: ~
    ClashStiffness: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber MG18mm, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
  - Name: 40"HDPE SDR26
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.067
    ID: 0.985
    MaterialDensity: 0.955
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 40HDPE
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 9000
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $4080FF]
  - Name: 40"HDPE SDR26 MG1
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.067
    ID: 0.985
    MaterialDensity: 1.015
    # Structure
    E: 800E3
```

```
  PoissonRatio: 0.4
  # Drag, Lift, Added Mass & Slam
  Cdn: 40HDPE MG18mm
  Cdz: 0.008
  Cl: 0
  Can: 1
  Caz: 0
  Cs: 0
  Ce: 0
  # Friction
  SeabedNormalFrictionCoefficient: 0.5
  SeabedAxialFrictionCoefficient: ~
  # Contact
  ClashStiffness: 0
  # Stress
  AllowableStress: 9000
  # Structural Damping
  RayleighDampingCoefficients: (no damping)
  # Coating & Lining
  CoatingThickness: 0
  LiningThickness: 0
  # Drawing
  Pen: [1, Solid, $4080FF]
- Name: 40"HDPE SDR26 MG2
  Category: Homogeneous Pipe
  # Geometry & Density
  OD: 1.067
  ID: 0.985
  MaterialDensity: 0.955
  # Structure
  E: 800E3
  PoissonRatio: 0.4
  # Drag, Lift, Added Mass & Slam
  Cdn: 40HDPE MG3mm
  Cdz: 0.008
  Cl: 0
  Can: 1
  Caz: 0
  Cs: 0
  Ce: 0
  # Friction
  SeabedNormalFrictionCoefficient: 0.5
  SeabedAxialFrictionCoefficient: ~
  # Contact
  ClashStiffness: 0
  # Stress
  AllowableStress: 9000
  # Structural Damping
  RayleighDampingCoefficients: (no damping)
  # Coating & Lining
  CoatingThickness: 0
  LiningThickness: 0
  # Drawing
  Pen: [1, Solid, $4080FF]
- Name: 40"Pipe 0.75" wall
  Category: Homogeneous Pipe
  # Geometry & Density
  OD: 1.016
  ID: 0.978
  MaterialDensity: 7.85
  # Structure
  E: 203.45E6
  PoissonRatio: 0.3
  # Drag, Lift, Added Mass & Slam
```

```
    Cdn: 40Steel
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 137.9E3
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $FFFF80]
  - Name: 40"Pipe 0.75" wall MG
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.016
    ID: 0.978
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 40Steel MG3mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 0
    # Stress
    AllowableStress: 137.9E3
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $FFFF80]
  - Name: 40" Strainer
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.3
    ID: 1.28
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 1
    Cdz: 0.008
```

```
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    # Stress
    AllowableStress: 137.9E3
    # Structural Damping
    RayleighDampingCoefficients: (no damping)
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Red]
ClumpTypes:
  - Name: Counter Weight
    Mass: 20
    Volume: 0.3
    Height: 1
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: 60 Riser Head
    Mass: 3.5
    Volume: 0.446
    Height: 2.5
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: Flange Connection
    Mass: 0.3
    Volume: 0.2
    Height: 0.25
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
    Pen: [4, Solid, Fuchsia]
  - Name: 60 Flange Conn with bq
    Mass: 0.8
    Volume: 0.0954
    Height: 0.04755
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, 0, 0.692]
    Cd: [0, 0, 1.9]
    Ca: [1, ~, 1]
  - Name: 60flange conn withut bq
    Mass: 0.5
    Volume: 0.06
    Height: 0.03
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, 0, 0.692]
```

```
    Cd: [0, 0, 1.9]
    Ca: [1, ~, 1]
  - Name: 60 Counterweight
    Mass: 25
    Volume: 3.148
    Height: 1.6
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: Mid Counter
    Mass: 12.5
    Volume: 1.574
    Height: 0.79
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: stabiliser weight
    Mass: 5
    Volume: 0.636
    Height: 1
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: 60 CW 100t
    Mass: 100
    Volume: 12.6
    Height: 6.4
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: Strainer
    Mass: 1
    Volume: 0.1273
    Height: 3
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: 40 flg conn with bq
    Mass: 0.35
    Volume: 0.03
    Height: 0.04
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, ~, 0.411]
    Cd: [0, 0, 1.9]
    Ca: [1, ~, 1]
  - Name: 40 flg conn without bq
    Mass: 0.225
    Volume: 0.02
    Height: 0.02
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, ~, 0.411]
    Cd: [0, 0, 1.9]
```

```
    Ca: [1, ~, 1]
  - Name: 40 Riser Head
    Mass: 2.5
    Volume: 0.3185
    Height: 2
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, ~, 0]
    Cd: [0, 0, 0]
    Ca: [1, ~, 1]
WakeModels:
  - Name: Huse
    Model: Huse
    HuseK1: 0.25
    HuseK2: 1
    HuseK3: 0.693
Vessels:
  - Name: Oct2010 FLNG
    Locked: Yes
    VesselType: Generic_FLNG
    Draught: Haskind
    Length: ~
    InitialPosition: [0, 0, -14]
    Orientation: [0, 0, 180]
    # Calculation
    IncludedInStatics: None
    PrimaryMotion: None
    SuperimposedMotion: Displacement RAOs + Harmonic Motion
    IncludeAppliedLoads: No
    IncludeWaveLoad1stOrder: No
    IncludeWaveDriftLoad2ndOrder: No
    IncludeWaveDriftDamping: No
    IncludeSumFrequencyLoad: No
    IncludeAddedMassAndDamping: No
    IncludeManoeuvringLoad: No
    IncludeOtherDamping: No
    IncludeCurrentLoad: No
    IncludeWindLoad: No
    # Drawing
    PenMode: Use Vessel Type's own pen
    # Shaded Drawing
    ShadedDrawingCullingMode: Anticlockwise
Lines:
  - Name: 40RiserP
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec, 
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, -399, 25, 0, 270, 180, 0, ~]
      - [Free, 266.699388783337, -268.580758734422, -520.887512342582, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [Infinity, ~]
      - []
    # Sections
    LineType, Length, TargetSegmentLength:
      - [40"Rubber Rigid, 0.75, 0.5]
      - [40"RubberTransition, 1, 0.5]
```

```
  - [40" Rubber, 113.25, 0.5]
  - [40"HDPE SDR26, 253, 0.5]
  - [40" Rubber, 46, 0.5]
  - [40"Pipe 0.75" wall, 80.5, 0.5]
  - [40" Strainer, 5.5, 0.5]
# Attachments
AttachmentType, Attachmentx, Attachmenty, Attachmentz, AttachmentzRel:
  - [40 Riser Head, 0, 0, 0, End A]
  - [40 flg conn with bq, 0, 0, 11.5, End A]
  - [40 flg conn with bq, 0, 0, 23, End A]
  - [40 flg conn with bq, 0, 0, 34.5, End A]
  - [40 flg conn with bq, 0, 0, 46, End A]
  - [40 flg conn with bq, 0, 0, 57.5, End A]
  - [40 flg conn with bq, 0, 0, 69, End A]
  - [40 flg conn with bq, 0, 0, 80.5, End A]
  - [40 flg conn with bq, 0, 0, 92, End A]
  - [40 flg conn with bq, 0, 0, 103.5, End A]
  - [40 flg conn with bq, 0, 0, 115, End A]
  - [40 flg conn with bq, 0, 0, 126.5, End A]
  - [40 flg conn with bq, 0, 0, 138, End A]
  - [40 flg conn with bq, 0, 0, 149.5, End A]
  - [40 flg conn with bq, 0, 0, 161, End A]
  - [40 flg conn with bq, 0, 0, 172.5, End A]
  - [40 flg conn with bq, 0, 0, 184, End A]
  - [40 flg conn with bq, 0, 0, 195.5, End A]
  - [40 flg conn with bq, 0, 0, 207, End A]
  - [40 flg conn with bq, 0, 0, 218.5, End A]
  - [40 flg conn with bq, 0, 0, 230, End A]
  - [40 flg conn with bq, 0, 0, 241.5, End A]
  - [40 flg conn with bq, 0, 0, 253, End A]
  - [40 flg conn with bq, 0, 0, 264.5, End A]
  - [40 flg conn with bq, 0, 0, 276, End A]
  - [40 flg conn with bq, 0, 0, 287.5, End A]
  - [40 flg conn with bq, 0, 0, 299, End A]
  - [40 flg conn with bq, 0, 0, 310.5, End A]
  - [40 flg conn with bq, 0, 0, 322, End A]
  - [40 flg conn with bq, 0, 0, 333.5, End A]
  - [40 flg conn with bq, 0, 0, 345, End A]
  - [40 flg conn with bq, 0, 0, 356.5, End A]
  - [40 flg conn with bq, 0, 0, 368, End A]
  - [40 flg conn with bq, 0, 0, 379.5, End A]
  - [40 flg conn with bq, 0, 0, 391, End A]
  - [40 flg conn with bq, 0, 0, 402.5, End A]
  - [40 flg conn with bq, 0, 0, 414, End A]
  - [40 flg conn with bq, 0, 0, 425.5, End A]
  - [40 flg conn with bq, 0, 0, 437, End A]
  - [40 flg conn with bq, 0, 0, 448.5, End A]
  - [40 flg conn with bq, 0, 0, 460, End A]
  - [40 flg conn with bq, 0, 0, 471.5, End A]
  - [40 flg conn with bq, 0, 0, 483, End A]
  - [40 flg conn with bq, 0, 0, 494.5, End A]
# Contents
ContentsMethod: Uniform
IncludeAxialContentsInertia: No
ContentsDensity: 1.025
ContentsPressureRefZ: ~
ContentsPressure: 0
ContentsFlowRate: -2.41
# Statics
IncludedInStatics: Yes
StaticsStep1: Catenary
StaticsStep2: Full Statics
IncludeSeabedFrictionInStatics: Yes
LayAzimuth: 359.55773942442
```

```
    AsLaidTension: 0
    # Drawing
    NodePen: [1, Dot, $4080FF]
    DrawShadedNodesAsSpheres: Yes
  - Name: 60RiserS
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: None
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Oct2010 FLNG, -399, -25, 0, 270, 180, 0, ~]
      - [Free, 266.699388783337, -268.580758734422, -520.887512342582, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [Infinity, ~]
      - []
    # Sections
    LineType, Length, TargetSegmentLength:
      - [60"Rubber Rigid, 0.75, 0.5]
      - [60"RubberTransition, 1, 0.5]
      - [60" Rubber, 113.25, 0.5]
      - [60"HDPE SDR26, 253, 0.5]
      - [60" Rubber, 46, 0.5]
      - [60"Pipe 0.75" wall, 80.5, 0.5]
      - [60"strainer, 5.5, 0.5]
    # Attachments
    AttachmentType, Attachmentx, Attachmenty, Attachmentz, AttachmentzRel:
      - [60 Riser Head, 0, 0, 0, End A]
      - [60 Flange Conn with bq, 0, 0, 11.5, End A]
      - [60 Flange Conn with bq, 0, 0, 23, End A]
      - [60 Flange Conn with bq, 0, 0, 34.5, End A]
      - [60 Flange Conn with bq, 0, 0, 46, End A]
      - [60 Flange Conn with bq, 0, 0, 57.5, End A]
      - [60 Flange Conn with bq, 0, 0, 69, End A]
      - [60 Flange Conn with bq, 0, 0, 80.5, End A]
      - [60 Flange Conn with bq, 0, 0, 92, End A]
      - [60 Flange Conn with bq, 0, 0, 103.5, End A]
      - [60 Flange Conn with bq, 0, 0, 115, End A]
      - [60 Flange Conn with bq, 0, 0, 126.5, End A]
      - [60 Flange Conn with bq, 0, 0, 138, End A]
      - [60 Flange Conn with bq, 0, 0, 149.5, End A]
      - [60 Flange Conn with bq, 0, 0, 161, End A]
      - [60 Flange Conn with bq, 0, 0, 172.5, End A]
      - [60 Flange Conn with bq, 0, 0, 184, End A]
      - [60 Flange Conn with bq, 0, 0, 195.5, End A]
      - [60 Flange Conn with bq, 0, 0, 207, End A]
      - [60 Flange Conn with bq, 0, 0, 218.5, End A]
      - [60 Flange Conn with bq, 0, 0, 230, End A]
      - [60 Flange Conn with bq, 0, 0, 241.5, End A]
      - [60 Flange Conn with bq, 0, 0, 253, End A]
      - [60 Flange Conn with bq, 0, 0, 264.5, End A]
      - [60 Flange Conn with bq, 0, 0, 276, End A]
      - [60 Flange Conn with bq, 0, 0, 287.5, End A]
      - [60 Flange Conn with bq, 0, 0, 299, End A]
      - [60 Flange Conn with bq, 0, 0, 310.5, End A]
      - [60 Flange Conn with bq, 0, 0, 322, End A]
      - [60 Flange Conn with bq, 0, 0, 333.5, End A]
      - [60 Flange Conn with bq, 0, 0, 345, End A]
      - [60 Flange Conn with bq, 0, 0, 356.5, End A]
```

```
      - [60 Flange Conn with bq, 0, 0, 368, End A]
      - [60 Flange Conn with bq, 0, 0, 379.5, End A]
      - [60 Flange Conn with bq, 0, 0, 391, End A]
      - [60 Flange Conn with bq, 0, 0, 402.5, End A]
      - [60 Flange Conn with bq, 0, 0, 414, End A]
      - [60 Flange Conn with bq, 0, 0, 425.5, End A]
      - [60 Flange Conn with bq, 0, 0, 437, End A]
      - [60 Flange Conn with bq, 0, 0, 448.5, End A]
      - [60 Flange Conn with bq, 0, 0, 460, End A]
      - [60 Flange Conn with bq, 0, 0, 471.5, End A]
      - [60 Flange Conn with bq, 0, 0, 483, End A]
      - [60 Flange Conn with bq, 0, 0, 494.5, End A]
    # Contents
    ContentsMethod: Uniform
    IncludeAxialContentsInertia: No
    ContentsDensity: 1.025
    ContentsPressureRefZ: ~
    ContentsPressure: 0
    ContentsFlowRate: -5.43
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: Full Statics
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 359.55773942442
    AsLaidTension: 0
    # Drawing
    NodePen: [1, Dot, $4080FF]
    DrawShadedNodesAsSpheres: Yes
Groups:
  Structure:
    Oct2010 FLNG: Model
    40RiserP: Model
    60RiserS: Model
  State:
    Collapsed:
      - Variable Data
...
```

Model Data File - Fatigue Analysis (Current)

%YAML 1.1
Type: Model
Program: OrcaFlex 10.1d
File: C:\Users\Ian\Desktop\fatigue current.yml
Created: 15:58 on 03/06/2018
User: Ian
Machine: IAN-PC

General:
  # Units
  UnitsSystem: SI
  # Statics
  BuoysIncludedInStatics: Individually Specified
  StaticsMaxIterations: 800
  StaticsMinDamping: 2
  StaticsMaxDamping: 50
  # Dynamics
  DynamicsSolutionMethod: Explicit time domain
  AlwaysUseRecommendedTimeSteps: Yes
  InnerTimeStep: 43E-6
  TargetOuterTimeStep: 0.0012
  RecommendedInnerTimeStepRatio: 10
  RecommendedOuterTimeStepToInnerMultiple: 30
  RecommendedOuterTimeStepToWavePeriodRatio: 40
  RecommendedOuterTimeStepToWakeOscillatorStrouhalPeriodRatio: 200
  AxialTargetDamping: 10
  BendingTargetDamping: 10
  TorsionTargetDamping: 10
  LogPrecision: Single
  TargetLogSampleInterval: 1
  LogStartTime: ~
  # Stages
  StageDuration:
    - 8
    - 400
  # Drawing
  Pen: [1, Solid, Yellow]
  NorthDirectionDefined: Yes
  NorthDirection: 90
  # Default view parameters
  DefaultViewMode: Wire frame
  DefaultViewSize: 583.532627843579
  DefaultViewCentre: [201.56372757738, 4.12145186646211, -248.996087857083]
  DefaultViewAzimuth: 270
  DefaultViewElevation: 0
VariableData:
  KinematicViscosity:
    - Name: 3.5% Salinity
      IndependentValue, DependentValue:
        - [0, 1.82842473024E-6]
        - [0.555555555555556, 1.79516544192E-6]
        - [1.11111111111111, 1.76274228096E-6]
        - [1.66666666666667, 1.73143395648E-6]
        - [2.22222222222222, 1.70096175936E-6]
        - [2.77777777777778, 1.67141859264E-6]
        - [3.33333333333333, 1.64271155328E-6]
        - [3.88888888888889, 1.61484064128E-6]
        - [4.44444444444444, 1.58780585664E-6]
        - [5, 1.56142139328E-6]
        - [5.55555555555556, 1.53587305728E-6]
        - [6.11111111111111, 1.51088213952E-6]
        - [6.66666666666667, 1.48663444608E-6]
        - [7.22222222222222, 1.46303707392E-6]
        - [7.77777777777778, 1.44009002304E-6]

    - [8.33333333333333, 1.41760748736E-6]
    - [8.88888888888889, 1.39577527296E-6]
    - [9.44444444444444, 1.37459337984E-6]
    - [10, 1.35378309888E-6]
    - [10.5555555555556, 1.33353023616E-6]
    - [11.1111111111111, 1.31383479168E-6]
    - [11.6666666666667, 1.2946038624E-6]
    - [12.2222222222222, 1.27574454528E-6]
    - [12.7777777777778, 1.2574426464E-6]
    - [13.3333333333333, 1.23960526272E-6]
    - [13.8888888888889, 1.22204658816E-6]
    - [14.4444444444444, 1.2049524288E-6]
    - [15, 1.18832278464E-6]
    - [15.5555555555556, 1.1719718496E-6]
    - [16.1111111111111, 1.15599252672E-6]
    - [16.6666666666667, 1.140384816E-6]
    - [17.2222222222222, 1.12514871744E-6]
    - [17.7777777777778, 1.11028423104E-6]
    - [18.3333333333333, 1.09569845376E-6]
    - [18.8888888888889, 1.0813913856E-6]
    - [19.4444444444444, 1.06736302656E-6]
    - [20, 1.05370627968E-6]
    - [20.5555555555556, 1.04032824192E-6]
    - [21.1111111111111, 1.02722891328E-6]
    - [21.6666666666667, 1.01431539072E-6]
    - [22.2222222222222, 1.00177348032E-6]
    - [22.7777777777778, 989.417376E-9]
    - [23.3333333333333, 977.3399808E-9]
    - [23.8888888888889, 965.44839168E-9]
    - [24.4444444444444, 953.83551168E-9]
    - [25, 942.5013408E-9]
    - [25.5555555555556, 931.352976E-9]
    - [26.1111111111111, 920.39041728E-9]
    - [26.6666666666667, 909.61366464E-9]
    - [27.2222222222222, 899.11562112E-9]
    - [27.7777777777778, 888.80338368E-9]
    - [28.3333333333333, 878.58404928E-9]
    - [28.8888888888889, 868.643424E-9]
    - [29.4444444444444, 858.8886048E-9]
    - [30, 849.31959168E-9]

- Name: 60Rubber
  IndependentValue, DependentValue:
    - [4940, 1.2]
    - [9870, 1.2]
    - [24.7E3, 1.2]
    - [49.4E3, 1.2]
    - [138E3, 1.2]
    - [148E3, 1.2]
    - [173E3, 1.16]
    - [197E3, 1.06]
    - [222E3, 0.8]
    - [247E3, 0.57]
    - [296E3, 0.61]
    - [346E3, 0.68]
    - [395E3, 0.76]
    - [494E3, 0.88]
    - [740E3, 0.97]
    - [987E3, 0.99]
    - [2.47E6, 0.98]
    - [4.94E6, 0.96]
    - [9.87E6, 0.94]
    - [14.8E6, 0.94]
- Name: 60HDPE

```
  IndependentValue, DependentValue:
    - [9990, 1.2]
    - [20E3, 1.2]
    - [49.9E3, 1.2]
    - [99.9E3, 1.2]
    - [280E3, 1.2]
    - [300E3, 1.19]
    - [350E3, 1.16]
    - [400E3, 1.05]
    - [449E3, 0.8]
    - [499E3, 0.46]
    - [599E3, 0.28]
    - [699E3, 0.28]
    - [799E3, 0.3]
    - [999E3, 0.36]
    - [1.5E6, 0.47]
    - [2E6, 0.52]
    - [4.99E6, 0.56]
    - [9.99E6, 0.55]
    - [20E6, 0.53]
    - [30E6, 0.52]
- Name: 60Steel
  IndependentValue, DependentValue:
    - [9790, 1.2]
    - [19.6E3, 1.2]
    - [48.9E3, 1.2]
    - [97.9E3, 1.2]
    - [274E3, 1.2]
    - [294E3, 1.19]
    - [343E3, 1.16]
    - [392E3, 1.05]
    - [440E3, 0.8]
    - [489E3, 0.46]
    - [587E3, 0.31]
    - [685E3, 0.32]
    - [783E3, 0.35]
    - [979E3, 0.41]
    - [1.47E6, 0.53]
    - [1.96E6, 0.58]
    - [4.89E6, 0.61]
    - [9.79E6, 0.59]
    - [19.6E6, 0.57]
    - [29.4E6, 0.57]
- Name: 60Steel MG3mm
  IndependentValue, DependentValue:
    - [4610, 1.2]
    - [9220, 1.2]
    - [23.1E3, 1.2]
    - [46.1E3, 1.2]
    - [129E3, 1.2]
    - [138E3, 1.2]
    - [161E3, 1.16]
    - [184E3, 1.06]
    - [208E3, 0.8]
    - [231E3, 0.59]
    - [277E3, 0.63]
    - [323E3, 0.71]
    - [369E3, 0.78]
    - [461E3, 0.89]
    - [692E3, 0.98]
    - [922E3, 1]
    - [2.31E6, 0.99]
    - [4.61E6, 0.97]
    - [9.22E6, 0.96]
```

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    - [13.8E6, 0.96]
- Name: 60HDPE MG18mm
  IndependentValue, DependentValue:
    - [1900, 1.23]
    - [3800, 1.23]
    - [9510, 1.23]
    - [19E3, 1.23]
    - [53.2E3, 1.22]
    - [57E3, 1.22]
    - [66.5E3, 1.18]
    - [76.1E3, 1.08]
    - [85.6E3, 0.88]
    - [95.1E3, 0.89]
    - [114E3, 0.92]
    - [133E3, 0.95]
    - [152E3, 0.98]
    - [190E3, 1.02]
    - [285E3, 1.06]
    - [380E3, 1.07]
    - [951E3, 1.07]
    - [1.9E6, 1.07]
    - [3.8E6, 1.07]
    - [5.7E6, 1.07]
- Name: 60HDPE MG3mm
  IndependentValue, DependentValue:
    - [4720, 1.2]
    - [9440, 1.2]
    - [23.6E3, 1.2]
    - [47.2E3, 1.2]
    - [132E3, 1.2]
    - [142E3, 1.2]
    - [165E3, 1.16]
    - [189E3, 1.06]
    - [212E3, 0.8]
    - [236E3, 0.58]
    - [283E3, 0.62]
    - [330E3, 0.7]
    - [378E3, 0.78]
    - [472E3, 0.89]
    - [708E3, 0.98]
    - [944E3, 1]
    - [2.36E6, 0.98]
    - [4.72E6, 0.97]
    - [9.44E6, 0.95]
    - [14.2E6, 0.95]
- Name: 60Rubber MG18mm
  IndependentValue, DependentValue:
    - [1980, 1.22]
    - [3960, 1.22]
    - [9900, 1.22]
    - [19.8E3, 1.22]
    - [55.4E3, 1.22]
    - [59.4E3, 1.22]
    - [69.3E3, 1.18]
    - [79.2E3, 1.07]
    - [89.1E3, 0.86]
    - [99E3, 0.87]
    - [119E3, 0.9]
    - [139E3, 0.94]
    - [158E3, 0.97]
    - [198E3, 1.01]
    - [297E3, 1.05]
    - [396E3, 1.06]
    - [990E3, 1.07]
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    - [1.98E6, 1.07]
    - [3.96E6, 1.07]
    - [5.94E6, 1.07]
- Name: 40Rubber
  IndependentValue, DependentValue:
    - [4100, 1.21]
    - [8210, 1.21]
    - [20.5E3, 1.21]
    - [41E3, 1.21]
    - [115E3, 1.2]
    - [123E3, 1.2]
    - [144E3, 1.16]
    - [164E3, 1.06]
    - [185E3, 0.8]
    - [205E3, 0.62]
    - [246E3, 0.67]
    - [287E3, 0.74]
    - [328E3, 0.81]
    - [410E3, 0.91]
    - [615E3, 1]
    - [821E3, 1.02]
    - [2.05E6, 1.01]
    - [4.1E6, 0.99]
    - [8.21E6, 0.98]
    - [12.3E6, 0.98]
- Name: 40HDPE
  IndependentValue, DependentValue:
    - [9980, 1.2]
    - [20E3, 1.2]
    - [49.9E3, 1.2]
    - [99.8E3, 1.2]
    - [279E3, 1.2]
    - [299E3, 1.19]
    - [349E3, 1.16]
    - [399E3, 1.05]
    - [449E3, 0.8]
    - [499E3, 0.46]
    - [599E3, 0.28]
    - [699E3, 0.28]
    - [799E3, 0.3]
    - [998E3, 0.36]
    - [1.5E6, 0.47]
    - [2E6, 0.53]
    - [4.99E6, 0.57]
    - [9.98E6, 0.55]
    - [20E6, 0.53]
    - [29.9E6, 0.53]
- Name: 40Steel
  IndependentValue, DependentValue:
    - [9690, 1.2]
    - [19.4E3, 1.2]
    - [48.4E3, 1.2]
    - [96.9E3, 1.2]
    - [271E3, 1.2]
    - [291E3, 1.19]
    - [339E3, 1.16]
    - [387E3, 1.05]
    - [436E3, 0.8]
    - [484E3, 0.46]
    - [581E3, 0.32]
    - [678E3, 0.33]
    - [775E3, 0.36]
    - [969E3, 0.43]
    - [1.45E6, 0.55]
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    - [1.94E6, 0.59]
    - [4.84E6, 0.62]
    - [9.69E6, 0.61]
    - [19.4E6, 0.59]
    - [29.1E6, 0.58]
- Name: 40Rubber MG18mm
  IndependentValue, DependentValue:
    - [1710, 1.24]
    - [3420, 1.24]
    - [8560, 1.24]
    - [17.1E3, 1.24]
    - [47.9E3, 1.23]
    - [51.4E3, 1.23]
    - [59.9E3, 1.19]
    - [68.5E3, 1.08]
    - [77.1E3, 0.93]
    - [85.6E3, 0.94]
    - [103E3, 0.97]
    - [120E3, 0.99]
    - [137E3, 1.01]
    - [171E3, 1.04]
    - [257E3, 1.07]
    - [342E3, 1.08]
    - [856E3, 1.09]
    - [1.71E6, 1.09]
    - [3.42E6, 1.09]
    - [5.14E6, 1.09]
- Name: 40HDPE MG18mm
  IndependentValue, DependentValue:
    - [1650, 1.24]
    - [3300, 1.24]
    - [8250, 1.24]
    - [16.5E3, 1.24]
    - [46.2E3, 1.24]
    - [49.5E3, 1.23]
    - [57.7E3, 1.2]
    - [66E3, 1.09]
    - [74.2E3, 0.96]
    - [82.5E3, 0.96]
    - [99E3, 0.99]
    - [115E3, 1.01]
    - [132E3, 1.03]
    - [165E3, 1.06]
    - [247E3, 1.08]
    - [330E3, 1.09]
    - [825E3, 1.1]
    - [1.65E6, 1.1]
    - [3.3E6, 1.1]
    - [4.95E6, 1.1]
- Name: 40HDPE MG3mm
  IndependentValue, DependentValue:
    - [3850, 1.21]
    - [7700, 1.21]
    - [19.3E3, 1.21]
    - [38.5E3, 1.21]
    - [108E3, 1.2]
    - [116E3, 1.2]
    - [135E3, 1.17]
    - [154E3, 1.06]
    - [173E3, 0.8]
    - [193E3, 0.64]
    - [231E3, 0.69]
    - [270E3, 0.76]
    - [308E3, 0.83]
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      - [385E3, 0.92]
      - [578E3, 1.01]
      - [770E3, 1.02]
      - [1.93E6, 1.02]
      - [3.85E6, 1]
      - [7.7E6, 0.99]
      - [11.6E6, 0.99]
  - Name: 40Steel MG3mm
    IndependentValue, DependentValue:
      - [3750, 1.21]
      - [7510, 1.21]
      - [18.8E3, 1.21]
      - [37.5E3, 1.21]
      - [105E3, 1.2]
      - [113E3, 1.2]
      - [131E3, 1.17]
      - [150E3, 1.06]
      - [169E3, 0.8]
      - [188E3, 0.65]
      - [225E3, 0.7]
      - [263E3, 0.77]
      - [300E3, 0.83]
      - [375E3, 0.93]
      - [563E3, 1.01]
      - [751E3, 1.02]
      - [1.88E6, 1.02]
      - [3.75E6, 1]
      - [7.51E6, 0.99]
      - [11.3E6, 0.99]
BendingStiffness:
  - Name: 40"stiffness
    IndependentValue, DependentValue:
      - [0, 0]
      - [0.02, 100]
      - [0.03, 134]
      - [0.04, 168]
      - [0.06, 210]
      - [0.08, 240]
      - [0.1, 265]
      - [0.12, 283]
      - [0.14, 295]
    Hysteretic: No
  - Name: 60"stiffness
    IndependentValue, DependentValue:
      - [0, 0]
      - [0.02, 550]
      - [0.04, 900]
      - [0.06, 1200]
      - [0.08, 1475]
      - [0.1, 1675]
      - [0.12, 1800]
      - [0.14, 1890]
    Hysteretic: No
  - Name: 60"Stiffness1
    IndependentValue, DependentValue:
      - [0, 0]
      - [0.02, 485]
      - [0.04, 825]
      - [0.06, 1060]
      - [0.08, 1210]
      - [0.0952, 1285]
      - [0.1, 1300]
    Hysteretic: No
  - Name: 40"stiffness linear
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    IndependentValue, DependentValue:
      - [0, 0]
      - [0.14, 295]
    Hysteretic: No
  - Name: 60"stiffness linear
    IndependentValue, DependentValue:
      - [0, 0]
      - [0.14, 1277]
    Hysteretic: No
InlineDragAmplificationFactor:
  - Name: 40RubberDAF
    IndependentValue, DependentValue:
      - [0.041, 1.164]
      - [0.082, 1.257]
      - [0.123, 1.335]
      - [0.164, 1.403]
      - [0.205, 1.466]
      - [0.246, 1.525]
      - [0.287, 1.58]
      - [0.328, 1.633]
      - [0.369, 1.683]
      - [0.41, 1.732]
      - [0.451, 1.778]
      - [0.492, 1.824]
      - [0.533, 1.868]
      - [0.574, 1.911]
      - [0.615, 1.952]
      - [0.656, 1.993]
      - [0.697, 2.033]
      - [0.738, 2.072]
      - [0.779, 2.11]
      - [0.82, 2.148]
      - [0.861, 2.185]
      - [0.902, 2.221]
      - [0.943, 2.257]
      - [0.984, 2.293]
      - [1.025, 2.327]
      - [1.066, 2.362]
      - [1.107, 2.395]
      - [1.148, 2.429]
      - [1.189, 2.462]
      - [1.23, 2.494]
      - [1.27, 2.527]
      - [1.311, 2.558]
      - [1.352, 2.59]
      - [1.393, 2.621]
      - [1.434, 2.652]
      - [1.475, 2.682]
      - [1.516, 2.713]
      - [1.557, 2.743]
      - [1.598, 2.772]
      - [1.639, 2.802]
  - Name: 40RubberMGDAF
    IndependentValue, DependentValue:
      - [0.039, 1.16]
      - [0.079, 1.25]
      - [0.118, 1.326]
      - [0.157, 1.393]
      - [0.197, 1.454]
      - [0.236, 1.511]
      - [0.276, 1.565]
      - [0.315, 1.617]
      - [0.354, 1.666]
      - [0.394, 1.713]
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    - [0.433, 1.758]
    - [0.472, 1.802]
    - [0.512, 1.845]
    - [0.551, 1.887]
    - [0.591, 1.928]
    - [0.63, 1.968]
    - [0.669, 2.006]
    - [0.709, 2.044]
    - [0.748, 2.082]
    - [0.787, 2.119]
    - [0.827, 2.155]
    - [0.866, 2.19]
    - [0.906, 2.225]
    - [0.945, 2.259]
    - [0.984, 2.293]
    - [1.024, 2.327]
    - [1.063, 2.359]
    - [1.102, 2.392]
    - [1.142, 2.424]
    - [1.181, 2.456]
    - [1.22, 2.487]
    - [1.26, 2.518]
    - [1.299, 2.549]
    - [1.339, 2.579]
    - [1.378, 2.609]
    - [1.417, 2.639]
    - [1.457, 2.668]
    - [1.496, 2.698]
    - [1.535, 2.727]
    - [1.575, 2.755]
- Name: 40HDPEDAF
  IndependentValue, DependentValue:
    - [0.047, 1.164]
    - [0.094, 1.257]
    - [0.141, 1.335]
    - [0.187, 1.403]
    - [0.234, 1.466]
    - [0.281, 1.525]
    - [0.328, 1.58]
    - [0.375, 1.633]
    - [0.422, 1.683]
    - [0.469, 1.732]
    - [0.515, 1.778]
    - [0.562, 1.824]
    - [0.609, 1.868]
    - [0.656, 1.911]
    - [0.703, 1.952]
    - [0.75, 1.993]
    - [0.797, 2.033]
    - [0.843, 2.072]
    - [0.89, 2.11]
    - [0.937, 2.148]
    - [0.984, 2.185]
    - [1.031, 2.221]
    - [1.078, 2.257]
    - [1.125, 2.293]
    - [1.172, 2.327]
    - [1.218, 2.362]
    - [1.265, 2.395]
    - [1.312, 2.429]
    - [1.359, 2.462]
    - [1.406, 2.494]
    - [1.453, 2.527]
    - [1.5, 2.558]

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    - [1.546, 2.59]
    - [1.593, 2.621]
    - [1.64, 2.652]
    - [1.687, 2.682]
    - [1.734, 2.713]
    - [1.781, 2.743]
    - [1.828, 2.772]
    - [1.874, 2.802]
- Name: 40SteelDAF
  IndependentValue, DependentValue:
    - [0.049, 1.164]
    - [0.098, 1.257]
    - [0.148, 1.335]
    - [0.197, 1.403]
    - [0.246, 1.466]
    - [0.295, 1.525]
    - [0.344, 1.58]
    - [0.394, 1.633]
    - [0.443, 1.683]
    - [0.492, 1.732]
    - [0.541, 1.778]
    - [0.591, 1.824]
    - [0.64, 1.868]
    - [0.689, 1.911]
    - [0.738, 1.952]
    - [0.787, 1.993]
    - [0.837, 2.033]
    - [0.886, 2.072]
    - [0.935, 2.11]
    - [0.984, 2.148]
    - [1.033, 2.185]
    - [1.083, 2.221]
    - [1.132, 2.257]
    - [1.181, 2.293]
    - [1.23, 2.327]
    - [1.28, 2.362]
    - [1.329, 2.395]
    - [1.378, 2.429]
    - [1.427, 2.462]
    - [1.476, 2.494]
    - [1.526, 2.527]
    - [1.575, 2.558]
    - [1.624, 2.59]
    - [1.673, 2.621]
    - [1.722, 2.652]
    - [1.772, 2.682]
    - [1.821, 2.713]
    - [1.87, 2.743]
    - [1.919, 2.772]
    - [1.969, 2.802]
- Name: 60RubberDAF
  IndependentValue, DependentValue:
    - [0.028, 1.129]
    - [0.057, 1.203]
    - [0.085, 1.264]
    - [0.114, 1.318]
    - [0.142, 1.367]
    - [0.17, 1.414]
    - [0.199, 1.457]
    - [0.227, 1.499]
    - [0.256, 1.538]
    - [0.284, 1.577]
    - [0.313, 1.613]
    - [0.341, 1.649]
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    - [0.369, 1.684]
    - [0.398, 1.718]
    - [0.426, 1.75]
    - [0.455, 1.783]
    - [0.483, 1.814]
    - [0.511, 1.845]
    - [0.54, 1.875]
    - [0.568, 1.905]
    - [0.597, 1.934]
    - [0.625, 1.963]
    - [0.653, 1.991]
    - [0.682, 2.019]
    - [0.71, 2.046]
    - [0.739, 2.073]
    - [0.767, 2.1]
    - [0.795, 2.126]
    - [0.824, 2.152]
    - [0.852, 2.178]
    - [0.881, 2.203]
    - [0.909, 2.228]
    - [0.938, 2.253]
    - [0.966, 2.277]
    - [0.994, 2.302]
    - [1.023, 2.326]
    - [1.051, 2.35]
    - [1.08, 2.373]
    - [1.108, 2.397]
    - [1.136, 2.42]
- Name: 60RubberMGDAF
  IndependentValue, DependentValue:
    - [0.028, 1.127]
    - [0.055, 1.199]
    - [0.083, 1.259]
    - [0.11, 1.312]
    - [0.138, 1.361]
    - [0.166, 1.406]
    - [0.193, 1.449]
    - [0.221, 1.49]
    - [0.249, 1.529]
    - [0.276, 1.566]
    - [0.304, 1.602]
    - [0.331, 1.637]
    - [0.359, 1.671]
    - [0.387, 1.705]
    - [0.414, 1.737]
    - [0.442, 1.768]
    - [0.47, 1.799]
    - [0.497, 1.83]
    - [0.525, 1.859]
    - [0.552, 1.888]
    - [0.58, 1.917]
    - [0.608, 1.945]
    - [0.635, 1.973]
    - [0.663, 2]
    - [0.691, 2.027]
    - [0.718, 2.054]
    - [0.746, 2.08]
    - [0.773, 2.106]
    - [0.801, 2.131]
    - [0.829, 2.156]
    - [0.856, 2.181]
    - [0.884, 2.206]
    - [0.912, 2.23]
    - [0.939, 2.254]
```

```
    - [0.967, 2.278]
    - [0.994, 2.302]
    - [1.022, 2.325]
    - [1.05, 2.348]
    - [1.077, 2.371]
    - [1.105, 2.394]
- Name: 60HDPEDAF
  IndependentValue, DependentValue:
    - [0.031, 1.129]
    - [0.063, 1.203]
    - [0.094, 1.264]
    - [0.125, 1.318]
    - [0.156, 1.367]
    - [0.188, 1.414]
    - [0.219, 1.457]
    - [0.25, 1.499]
    - [0.281, 1.538]
    - [0.313, 1.577]
    - [0.344, 1.613]
    - [0.375, 1.649]
    - [0.406, 1.684]
    - [0.438, 1.718]
    - [0.469, 1.75]
    - [0.5, 1.783]
    - [0.531, 1.814]
    - [0.563, 1.845]
    - [0.594, 1.875]
    - [0.625, 1.905]
    - [0.656, 1.934]
    - [0.688, 1.963]
    - [0.719, 1.991]
    - [0.75, 2.019]
    - [0.781, 2.046]
    - [0.813, 2.073]
    - [0.844, 2.1]
    - [0.875, 2.126]
    - [0.906, 2.152]
    - [0.938, 2.178]
    - [0.969, 2.203]
    - [1, 2.228]
    - [1.031, 2.253]
    - [1.063, 2.277]
    - [1.094, 2.302]
    - [1.125, 2.326]
    - [1.156, 2.35]
    - [1.188, 2.373]
    - [1.219, 2.397]
    - [1.25, 2.42]
- Name: 60SteelDAF
  IndependentValue, DependentValue:
    - [0.033, 1.129]
    - [0.066, 1.203]
    - [0.098, 1.264]
    - [0.131, 1.318]
    - [0.164, 1.367]
    - [0.197, 1.414]
    - [0.23, 1.457]
    - [0.262, 1.499]
    - [0.295, 1.538]
    - [0.328, 1.577]
    - [0.361, 1.613]
    - [0.394, 1.649]
    - [0.427, 1.684]
    - [0.459, 1.718]
```

```
        - [0.492, 1.75]
        - [0.525, 1.783]
        - [0.558, 1.814]
        - [0.591, 1.845]
        - [0.623, 1.875]
        - [0.656, 1.905]
        - [0.689, 1.934]
        - [0.722, 1.963]
        - [0.755, 1.991]
        - [0.787, 2.019]
        - [0.82, 2.046]
        - [0.853, 2.073]
        - [0.886, 2.1]
        - [0.919, 2.126]
        - [0.951, 2.152]
        - [0.984, 2.178]
        - [1.017, 2.203]
        - [1.05, 2.228]
        - [1.083, 2.253]
        - [1.115, 2.277]
        - [1.148, 2.302]
        - [1.181, 2.326]
        - [1.214, 2.35]
        - [1.247, 2.373]
        - [1.28, 2.397]
        - [1.312, 2.42]
Environment:
  # Sea
  WaterSurfaceZ: 0
  KinematicViscosity: 3.5% Salinity
  SeaTemperature: 10
  ReynoldsNumberCalculation: Cross Flow
  # Sea Density
  HorizontalWaterDensityFactor: ~
  VerticalDensityVariation: Constant
  Density: 1.025
  # Seabed
  SeabedType: Flat
  SeabedOrigin: [0, 0]
  WaterDepth: 2600
  SeabedSlopeDirection: 0
  SeabedSlope: 0
  SeabedModel: Elastic
  SeabedNormalStiffness: 100
  SeabedShearStiffness: ~
  SeabedDamping: 100
  # Waves
  SimulationTimeOrigin: 0
  KinematicStretchingMethod: Vertical Stretching
  WaveTrains:
    - Name: Wave1
      WaveType: Airy
      WaveDirection: 0
      WaveHeight: 0
      WavePeriod: 10.4
      WaveOrigin: [0, 0]
      WaveTimeOrigin: 0
  # WaveCalculation
  WaveKinematicsCutoffDepth: Infinity
  WaveCalculationMethod: Instantaneous Position (exact)
  WaveCalculationTimeInterval: 0
  WaveCalculationSpatialInterval: 0
  # Current
  MultipleCurrentDataCanBeDefined: Yes
```

```
  Currents:
    - Name: Max Current
      CurrentRamp: No
      HorizontalCurrentFactor: ~
      CurrentApplyVerticalStretching: No
      CurrentMethod: Interpolated
      RefCurrentSpeed: 1
      RefCurrentDirection: 180
      CurrentDepth, CurrentFactor, CurrentRotation:
        - [0, 2, 0]
        - [47, 1.82, 0]
        - [108, 1.62, 0]
        - [147, 0.98, 0]
        - [207, 0.96, 0]
        - [307, 0.95, 0]
        - [508, 0.88, 0]
        - [748, 0.78, 0]
        - [1008, 0.77, 0]
        - [1410, 0.48, 0]
        - [1982, 0.34, 0]
    - Name: Mean Current
      CurrentRamp: No
      HorizontalCurrentFactor: ~
      CurrentApplyVerticalStretching: No
      CurrentMethod: Interpolated
      RefCurrentSpeed: 0.05
      RefCurrentDirection: 180
      CurrentDepth, CurrentFactor, CurrentRotation:
        - [0, 1.74, 0]
        - [47, 1.58, 0]
        - [108, 1.42, 0]
        - [147, 0.89, 0]
        - [207, 0.85, 0]
        - [307, 0.83, 0]
        - [508, 0.76, 0]
        - [748, 0.66, 0]
        - [1008, 0.64, 0]
        - [1410, 0.4, 0]
        - [1982, 0.28, 0]
  ActiveCurrent: Mean Current
  # Wind
  IncludeVesselWindLoads: Yes
  IncludeLineWindLoads: No
  IncludeBuoyWingWindLoads: No
  VerticalWindVariationFactor: ~
  AirDensity: 0.00128
  WindType: Constant
  WindSpeed: 0
  WindDirection: 0
  # Drawing
  SeaSurfacePen: [1, Solid, $FF8080]
  SeabedPen: [1, Solid, $004080]
  SeabedProfilePen: [2, Solid, White]
VesselTypes:
  - Name: Generic_FLNG
    Length: 425
    # Conventions
    RAOResponseUnits: degrees
    RAOWaveUnit: amplitude
    WavesReferredToBy: period (s)
    RAOPhaseConvention: leads
    RAOPhaseUnitsConvention: degrees
    RAOPhaseRelativeToConvention: crest
    SurgePositive: forward
```

```
    SwayPositive: port
    HeavePositive: up
    RollPositiveStarboard: down
    PitchPositiveBow: down
    YawPositiveBow: port
    Symmetry: None
    CurrentCoeffSymmetry: XZ plane
    WindCoeffSymmetry: XZ plane
    QTFConventionsRotationOrder: RzRyRx
    QTFConventionsRotationAxes: Rotated
    QTFConventionsFrameOfReference: Body-Fixed
    Draughts:
      - Name: 14m
        Mass: 8800
        MomentOfInertiaTensorX, MomentOfInertiaTensorY, MomentOfInertiaTensorZ:
          - [249E3, 0, 0]
          - [0, 5.83E6, 0]
          - [0, 0, 5.83E6]
        CentreOfGravity: [-233.48, 0.22, 23.08]
        DisplacementRAOs:
          RAOOrigin: [-233.48, 0.22, 23.08]
          PhaseOrigin: [~, ~, 0]

LineTypes:
  - N
  - Name: 60" Rubber
    Category: General
    # Geometry & Mass
    OD: 1.76
    ID: 1.5
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 1.042
    # Limits
    CompressionIsLimited: No
    AllowableTension: 1767
    MinRadius: [6, 6]
    # Structure
    EI: [60"stiffness linear, 60"stiffness linear]
    EA: 25.5E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.76
    ClashStiffness: 5000
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [60Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
```

```
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
  - Name: 60"Rubber Rigid
    Category: General
    # Geometry & Mass
    OD: 1.76
    ID: 1.5
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 1.042
    # Limits
    CompressionIsLimited: No
    AllowableTension: 1767
    MinRadius: [6, 6]
    # Structure
    EI: [15E3, 15E3]
    EA: 25.5E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.76
    ClashStiffness: 5000
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [60Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
  - Name: 60"RubberTransition
    Category: General
    # Geometry & Mass
    OD: 1.76
    ID: 1.5
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 1.042
    # Limits
    CompressionIsLimited: No
    AllowableTension: 1767
    MinRadius: [6, 6]
    # Structure
    EI: [14E3, 14E3]
    EA: 25.5E3
    PoissonRatio: 0.5
    GJ: 80
```

```
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.76
    ClashStiffness: 5000
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [60Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
  - Name: 60" Rubber MG
    Category: General
    # Geometry & Mass
    OD: 1.81
    ID: 1.5
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 1.056
    # Limits
    CompressionIsLimited: No
    AllowableTension: 1767
    MinRadius: [6, 6]
    # Structure
    EI: [60"stiffness linear, 60"stiffness linear]
    EA: 25.5E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: ~
    ClashStiffness: 5000
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [60Rubber MG18mm, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
```

```
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
  - Name: 60"HDPE SDR26
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.6
    ID: 1.478
    MaterialDensity: 0.955
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 60HDPE
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 9000
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $0080FF]
  - Name: 60"HDPE SDR26 MG1
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.6
    ID: 1.478
    MaterialDensity: 0.995
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 60HDPE MG18mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 9000
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
```

```
    Pen: [1, Solid, $0080FF]
  - Name: 60"HDPE SDR26 MG2
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.6
    ID: 1.478
    MaterialDensity: 0.955
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 60HDPE MG3mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 9000
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $0080FF]
  - Name: 60"Pipe 0.75" wall
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.524
    ID: 1.486
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 60Steel
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 137.9E3
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Aqua]
  - Name: 60"Pipe 0.75"wall MG
    Category: Homogeneous Pipe
    # Geometry & Density
```

```
    OD: 1.524
    ID: 1.486
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 60Steel MG3mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 137.9E3
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Aqua]
  - Name: 60"strainer
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.855
    ID: 1.835
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 1
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 137.9E3
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $8000FF]
  - Name: 40" Rubber
    Category: General
    # Geometry & Mass
    OD: 1.22
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
```

```
    MassPerUnitLength: 0.556
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [40"stiffness linear, 40"stiffness linear]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.205
    ClashStiffness: 5000
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Drawing
    Pen: [1, Solid, $80FFFF]
  - Name: 40"Rubber Rigid
    Category: General
    # Geometry & Mass
    OD: 1.22
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.556
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [4000, 4000]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.205
    ClashStiffness: 5000
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
```

```
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
  - Name: 40"RubberTransition
    Category: General
    # Geometry & Mass
    OD: 1.22
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.556
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [2750, 2750]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: 1.205
    ClashStiffness: 5000
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
  - Name: 40"Rubber MG
    Category: General
    # Geometry & Mass
    OD: 1.27
```

```
    ID: 1
    CG: [0, 0]
    BulkModulus: Infinity
    MassPerUnitLength: 0.566
    # Limits
    CompressionIsLimited: No
    AllowableTension: 785
    MinRadius: [4, 4]
    # Structure
    EI: [40"stiffness linear, 40"stiffness linear]
    EA: 17E3
    PoissonRatio: 0.5
    GJ: 80
    TensionTorqueCoupling: 0
    # Contact
    ContactDiameter: ~
    ClashStiffness: 0
    ClashDamping: 0
    # Added Mass, Inertia & Slam
    Ca: [1, ~, 0]
    Cm: [~, ~, ~]
    Cs: 0
    Ce: 0
    # Drag & Lift
    Cd: [40Rubber MG18mm, ~, 0.008]
    Cl: 0
    NormalDragLiftDiameter: ~
    AxialDragLiftDiameter: ~
    # Stress
    StressOD: ~
    StressID: ~
    AllowableStress: ~
    TensileStressLoadingFactor: 1
    BendingStressLoadingFactor: 1
    ShearStressLoadingFactor: 1
    TorsionalStressLoadingFactor: 1
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
  - Name: 40"HDPE SDR26
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.067
    ID: 0.985
    MaterialDensity: 0.955
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 40HDPE
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 9000
```

```
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $4080FF]
  - Name: 40"HDPE SDR26 MG1
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.067
    ID: 0.985
    MaterialDensity: 1.015
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 40HDPE MG18mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 0
    ClashDamping: 0
    # Stress
    AllowableStress: 9000
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, $4080FF]
  - Name: 40"HDPE SDR26 MG2
    Category: Homogeneous Pipe
    # Geometry & Density
    OD: 1.067
    ID: 0.985
    MaterialDensity: 0.955
    # Structure
    E: 800E3
    PoissonRatio: 0.4
    # Drag, Lift, Added Mass & Slam
    Cdn: 40HDPE MG3mm
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 0
    ClashDamping: 0
    # Stress
    AllowableStress: 9000
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
```

```
  Pen: [1, Solid, $4080FF]
- Name: 40"Pipe 0.75" wall
  Category: Homogeneous Pipe
  # Geometry & Density
  OD: 1.016
  ID: 0.978
  MaterialDensity: 7.85
  # Structure
  E: 203.45E6
  PoissonRatio: 0.3
  # Drag, Lift, Added Mass & Slam
  Cdn: 40Steel
  Cdz: 0.008
  Cl: 0
  Can: 1
  Caz: 0
  Cs: 0
  Ce: 0
  # Friction
  SeabedNormalFrictionCoefficient: 0.5
  SeabedAxialFrictionCoefficient: ~
  # Contact
  ClashStiffness: 5000
  ClashDamping: 0
  # Stress
  AllowableStress: 137.9E3
  # Coating & Lining
  CoatingThickness: 0
  LiningThickness: 0
  # Drawing
  Pen: [1, Solid, $FFFF80]
- Name: 40"Pipe 0.75" wall MG
  Category: Homogeneous Pipe
  # Geometry & Density
  OD: 1.016
  ID: 0.978
  MaterialDensity: 7.85
  # Structure
  E: 203.45E6
  PoissonRatio: 0.3
  # Drag, Lift, Added Mass & Slam
  Cdn: 40Steel MG3mm
  Cdz: 0.008
  Cl: 0
  Can: 1
  Caz: 0
  Cs: 0
  Ce: 0
  # Friction
  SeabedNormalFrictionCoefficient: 0.5
  SeabedAxialFrictionCoefficient: ~
  # Contact
  ClashStiffness: 0
  ClashDamping: 0
  # Stress
  AllowableStress: 137.9E3
  # Coating & Lining
  CoatingThickness: 0
  LiningThickness: 0
  # Drawing
  Pen: [1, Solid, $FFFF80]
- Name: 40" Strainer
  Category: Homogeneous Pipe
  # Geometry & Density
```

```
    OD: 1.3
    ID: 1.28
    MaterialDensity: 7.85
    # Structure
    E: 203.45E6
    PoissonRatio: 0.3
    # Drag, Lift, Added Mass & Slam
    Cdn: 1
    Cdz: 0.008
    Cl: 0
    Can: 1
    Caz: 0
    Cs: 0
    Ce: 0
    # Friction
    SeabedNormalFrictionCoefficient: 0.5
    SeabedAxialFrictionCoefficient: ~
    # Contact
    ClashStiffness: 5000
    ClashDamping: 0
    # Stress
    AllowableStress: 137.9E3
    # Coating & Lining
    CoatingThickness: 0
    LiningThickness: 0
    # Drawing
    Pen: [1, Solid, Red]
ClumpTypes:
  - Name: Counter Weight
    Mass: 20
    Volume: 0.3
    Height: 1
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: 60 Riser Head
    Mass: 3.5
    Volume: 0.446
    Height: 2.5
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
  - Name: Flange Connection
    Mass: 0.3
    Volume: 0.2
    Height: 0.25
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0.6, ~, 0.6]
    Cd: [1.1, ~, 1.1]
    Ca: [1, ~, 1]
    Pen: [4, Solid, Fuchsia]
  - Name: 60 Flange Conn with bq
    Mass: 0.8
    Volume: 0.0954
    Height: 0.04755
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, 0, 0.692]
    Cd: [0, 0, 1.9]
```

```
  Ca: [1, ~, 1]
- Name: 60flange conn withut bq
  Mass: 0.5
  Volume: 0.06
  Height: 0.03
  Offset: 0
  AlignWith: Global Axes
  DragArea: [0, 0, 0.692]
  Cd: [0, 0, 1.9]
  Ca: [1, ~, 1]
- Name: 60 Counterweight
  Mass: 25
  Volume: 3.148
  Height: 1.6
  Offset: 0
  AlignWith: Global Axes
  DragArea: [0.6, ~, 0.6]
  Cd: [1.1, ~, 1.1]
  Ca: [1, ~, 1]
- Name: Mid Counter
  Mass: 12.5
  Volume: 1.574
  Height: 0.79
  Offset: 0
  AlignWith: Global Axes
  DragArea: [0.6, ~, 0.6]
  Cd: [1.1, ~, 1.1]
  Ca: [1, ~, 1]
- Name: stabiliser weight
  Mass: 5
  Volume: 0.636
  Height: 1
  Offset: 0
  AlignWith: Global Axes
  DragArea: [0.6, ~, 0.6]
  Cd: [1.1, ~, 1.1]
  Ca: [1, ~, 1]
- Name: 60 CW 100t
  Mass: 100
  Volume: 12.6
  Height: 6.4
  Offset: 0
  AlignWith: Global Axes
  DragArea: [0.6, ~, 0.6]
  Cd: [1.1, ~, 1.1]
  Ca: [1, ~, 1]
- Name: Strainer
  Mass: 1
  Volume: 0.1273
  Height: 3
  Offset: 0
  AlignWith: Global Axes
  DragArea: [0.6, ~, 0.6]
  Cd: [1.1, ~, 1.1]
  Ca: [1, ~, 1]
- Name: 40 flg conn with bq
  Mass: 0.35
  Volume: 0.03
  Height: 0.04
  Offset: 0
  AlignWith: Global Axes
  DragArea: [0, ~, 0.411]
  Cd: [0, 0, 1.9]
  Ca: [1, ~, 1]
```

```
  - Name: 40 flg conn without bq
    Mass: 0.225
    Volume: 0.02
    Height: 0.02
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, ~, 0.411]
    Cd: [0, 0, 1.9]
    Ca: [1, ~, 1]
  - Name: 40 Riser Head
    Mass: 2.5
    Volume: 0.3185
    Height: 2
    Offset: 0
    AlignWith: Global Axes
    DragArea: [0, ~, 0]
    Cd: [0, 0, 0]
    Ca: [1, ~, 1]
WakeModels:
  - Name: Huse
    Model: Huse
    HuseK1: 0.25
    HuseK2: 1
    HuseK3: 0.693
Lines:
  - Name: 40RiserP
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: Iwan and Blevins Wake Oscillator
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Fixed, 399, -25, -14, 90, 180, 0, ~]
      - [Free, 266.699388783337, -268.580758734422, -520.887512342582, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [Infinity, ~]
      - []
    # Sections
    Sections:
      - LineType: 40"Rubber Rigid
        Length: 0.75
        TargetSegmentLength: 0.5
        DisturbanceVessel: None
        # VIV
        VIVDiameter: ~
        VIVDynamicsEnabledForSection: Yes
        VIVInlineDragAmplificationFactor: 40RubberDAF
        VIVForceFactorTransverse: 1
      - LineType: 40"RubberTransition
        Length: 1
        TargetSegmentLength: 0.5
        DisturbanceVessel: None
        # VIV
        VIVDiameter: ~
        VIVDynamicsEnabledForSection: Yes
        VIVInlineDragAmplificationFactor: 40RubberDAF
        VIVForceFactorTransverse: 1
      - LineType: 40" Rubber
        Length: 113.25
```

```
    TargetSegmentLength: 0.5
    DisturbanceVessel: None
    # VIV
    VIVDiameter: ~
    VIVDynamicsEnabledForSection: Yes
    VIVInlineDragAmplificationFactor: 40RubberDAF
    VIVForceFactorTransverse: 1
  - LineType: 40"HDPE SDR26
    Length: 253
    TargetSegmentLength: 0.5
    DisturbanceVessel: None
    # VIV
    VIVDiameter: ~
    VIVDynamicsEnabledForSection: Yes
    VIVInlineDragAmplificationFactor: 40HDPEDAF
    VIVForceFactorTransverse: 1
  - LineType: 40" Rubber
    Length: 46
    TargetSegmentLength: 0.5
    DisturbanceVessel: None
    # VIV
    VIVDiameter: ~
    VIVDynamicsEnabledForSection: Yes
    VIVInlineDragAmplificationFactor: 40RubberDAF
    VIVForceFactorTransverse: 1
  - LineType: 40"Pipe 0.75" wall
    Length: 80.5
    TargetSegmentLength: 0.5
    DisturbanceVessel: None
    # VIV
    VIVDiameter: ~
    VIVDynamicsEnabledForSection: Yes
    VIVInlineDragAmplificationFactor: 40SteelDAF
    VIVForceFactorTransverse: 1
  - LineType: 40" Strainer
    Length: 5.5
    TargetSegmentLength: 0.5
    DisturbanceVessel: None
    # VIV
    VIVDiameter: ~
    VIVDynamicsEnabledForSection: Yes
    VIVInlineDragAmplificationFactor: 1
    VIVForceFactorTransverse: 1
# Attachments
AttachmentType, Attachmentx, Attachmenty, Attachmentz, AttachmentzRel:
  - [40 Riser Head, 0, 0, 0, End A]
  - [40 flg conn with bq, 0, 0, 11.5, End A]
  - [40 flg conn with bq, 0, 0, 23, End A]
  - [40 flg conn with bq, 0, 0, 34.5, End A]
  - [40 flg conn with bq, 0, 0, 46, End A]
  - [40 flg conn with bq, 0, 0, 57.5, End A]
  - [40 flg conn with bq, 0, 0, 69, End A]
  - [40 flg conn with bq, 0, 0, 80.5, End A]
  - [40 flg conn with bq, 0, 0, 92, End A]
  - [40 flg conn with bq, 0, 0, 103.5, End A]
  - [40 flg conn with bq, 0, 0, 115, End A]
  - [40 flg conn with bq, 0, 0, 126.5, End A]
  - [40 flg conn with bq, 0, 0, 138, End A]
  - [40 flg conn with bq, 0, 0, 149.5, End A]
  - [40 flg conn with bq, 0, 0, 161, End A]
  - [40 flg conn with bq, 0, 0, 172.5, End A]
  - [40 flg conn with bq, 0, 0, 184, End A]
  - [40 flg conn with bq, 0, 0, 195.5, End A]
  - [40 flg conn with bq, 0, 0, 207, End A]
```

      - [40 flg conn with bq, 0, 0, 218.5, End A]
      - [40 flg conn with bq, 0, 0, 230, End A]
      - [40 flg conn with bq, 0, 0, 241.5, End A]
      - [40 flg conn with bq, 0, 0, 253, End A]
      - [40 flg conn with bq, 0, 0, 264.5, End A]
      - [40 flg conn with bq, 0, 0, 276, End A]
      - [40 flg conn with bq, 0, 0, 287.5, End A]
      - [40 flg conn with bq, 0, 0, 299, End A]
      - [40 flg conn with bq, 0, 0, 310.5, End A]
      - [40 flg conn with bq, 0, 0, 322, End A]
      - [40 flg conn with bq, 0, 0, 333.5, End A]
      - [40 flg conn with bq, 0, 0, 345, End A]
      - [40 flg conn with bq, 0, 0, 356.5, End A]
      - [40 flg conn with bq, 0, 0, 368, End A]
      - [40 flg conn with bq, 0, 0, 379.5, End A]
      - [40 flg conn with bq, 0, 0, 391, End A]
      - [40 flg conn with bq, 0, 0, 402.5, End A]
      - [40 flg conn with bq, 0, 0, 414, End A]
      - [40 flg conn with bq, 0, 0, 425.5, End A]
      - [40 flg conn with bq, 0, 0, 437, End A]
      - [40 flg conn with bq, 0, 0, 448.5, End A]
      - [40 flg conn with bq, 0, 0, 460, End A]
      - [40 flg conn with bq, 0, 0, 471.5, End A]
      - [40 flg conn with bq, 0, 0, 483, End A]
      - [40 flg conn with bq, 0, 0, 494.5, End A]
    # Contents
    ContentsMethod: Uniform
    IncludeAxialContentsInertia: No
    ContentsDensity: 1.025
    ContentsPressureRefZ: ~
    ContentsPressure: 0
    ContentsFlowRate: -2.41
    # Statics
    IncludedInStatics: Yes
    StaticsStep1: Catenary
    StaticsStep2: Full Statics
    IncludeSeabedFrictionInStatics: Yes
    LayAzimuth: 359.55773942442
    AsLaidTension: 0
    # VIV
    VIVFilterPeriod: 250
    VIVIwanBlevinsWakeOscillatorModelParameters: Default
    # Drawing
    NodePen: [1, Dot, $4080FF]
    DrawShadedNodesAsSpheres: Yes
    # VIV Drawing
    VIVDrawDetailFrom, VIVDrawDetailTo:
      - [~, ~]
  - Name: 60RiserS
    IncludeTorsion: No
    TopEnd: End A
    PyModel: (none)
    DragFormulation: Standard
    StaticsVIV: None
    DynamicsVIV: Iwan and Blevins Wake Oscillator
    WaveCalculationMethod: Specified by Environment
    # End Connections
    Connection, ConnectionX, ConnectionY, ConnectionZ, ConnectionAzm, ConnectionDec,
ConnectionGamma, ReleaseStage, ConnectionzRelativeTo:
      - [Fixed, 399, 25, -14, 90, 180, 0, ~]
      - [Free, 266.699388783337, -268.580758734422, -520.887512342582, 0, 0, 0, ~]
    # End Connection Stiffness
    ConnectionStiffnessX, ConnectionStiffnessY:
      - [Infinity, ~]

```
  - []
# Sections
Sections:
  - LineType: 60"Rubber Rigid
    Length: 0.75
    TargetSegmentLength: 0.5
    DisturbanceVessel: None
    # VIV
    VIVDiameter: ~
    VIVDynamicsEnabledForSection: Yes
    VIVInlineDragAmplificationFactor: 60RubberDAF
    VIVForceFactorTransverse: 1
  - LineType: 60"RubberTransition
    Length: 1
    TargetSegmentLength: 0.5
    DisturbanceVessel: None
    # VIV
    VIVDiameter: ~
    VIVDynamicsEnabledForSection: Yes
    VIVInlineDragAmplificationFactor: 60RubberDAF
    VIVForceFactorTransverse: 1
  - LineType: 60" Rubber
    Length: 113.25
    TargetSegmentLength: 0.5
    DisturbanceVessel: None
    # VIV
    VIVDiameter: ~
    VIVDynamicsEnabledForSection: Yes
    VIVInlineDragAmplificationFactor: 60RubberDAF
    VIVForceFactorTransverse: 1
  - LineType: 60"HDPE SDR26
    Length: 253
    TargetSegmentLength: 0.5
    DisturbanceVessel: None
    # VIV
    VIVDiameter: ~
    VIVDynamicsEnabledForSection: Yes
    VIVInlineDragAmplificationFactor: 60HDPEDAF
    VIVForceFactorTransverse: 1
  - LineType: 60" Rubber
    Length: 46
    TargetSegmentLength: 0.5
    DisturbanceVessel: None
    # VIV
    VIVDiameter: ~
    VIVDynamicsEnabledForSection: Yes
    VIVInlineDragAmplificationFactor: 60RubberDAF
    VIVForceFactorTransverse: 1
  - LineType: 60"Pipe 0.75" wall
    Length: 80.5
    TargetSegmentLength: 0.5
    DisturbanceVessel: None
    # VIV
    VIVDiameter: ~
    VIVDynamicsEnabledForSection: Yes
    VIVInlineDragAmplificationFactor: 60SteelDAF
    VIVForceFactorTransverse: 1
  - LineType: 60"strainer
    Length: 5.5
    TargetSegmentLength: 0.5
    DisturbanceVessel: None
    # VIV
    VIVDiameter: ~
    VIVDynamicsEnabledForSection: Yes
```

```
    VIVInlineDragAmplificationFactor: 1
    VIVForceFactorTransverse: 1
# Attachments
AttachmentType, Attachmentx, Attachmenty, Attachmentz, AttachmentzRel:
  - [60 Riser Head, 0, 0, 0, End A]
  - [60 Flange Conn with bq, 0, 0, 11.5, End A]
  - [60 Flange Conn with bq, 0, 0, 23, End A]
  - [60 Flange Conn with bq, 0, 0, 34.5, End A]
  - [60 Flange Conn with bq, 0, 0, 46, End A]
  - [60 Flange Conn with bq, 0, 0, 57.5, End A]
  - [60 Flange Conn with bq, 0, 0, 69, End A]
  - [60 Flange Conn with bq, 0, 0, 80.5, End A]
  - [60 Flange Conn with bq, 0, 0, 92, End A]
  - [60 Flange Conn with bq, 0, 0, 103.5, End A]
  - [60 Flange Conn with bq, 0, 0, 115, End A]
  - [60 Flange Conn with bq, 0, 0, 126.5, End A]
  - [60 Flange Conn with bq, 0, 0, 138, End A]
  - [60 Flange Conn with bq, 0, 0, 149.5, End A]
  - [60 Flange Conn with bq, 0, 0, 161, End A]
  - [60 Flange Conn with bq, 0, 0, 172.5, End A]
  - [60 Flange Conn with bq, 0, 0, 184, End A]
  - [60 Flange Conn with bq, 0, 0, 195.5, End A]
  - [60 Flange Conn with bq, 0, 0, 207, End A]
  - [60 Flange Conn with bq, 0, 0, 218.5, End A]
  - [60 Flange Conn with bq, 0, 0, 230, End A]
  - [60 Flange Conn with bq, 0, 0, 241.5, End A]
  - [60 Flange Conn with bq, 0, 0, 253, End A]
  - [60 Flange Conn with bq, 0, 0, 264.5, End A]
  - [60 Flange Conn with bq, 0, 0, 276, End A]
  - [60 Flange Conn with bq, 0, 0, 287.5, End A]
  - [60 Flange Conn with bq, 0, 0, 299, End A]
  - [60 Flange Conn with bq, 0, 0, 310.5, End A]
  - [60 Flange Conn with bq, 0, 0, 322, End A]
  - [60 Flange Conn with bq, 0, 0, 333.5, End A]
  - [60 Flange Conn with bq, 0, 0, 345, End A]
  - [60 Flange Conn with bq, 0, 0, 356.5, End A]
  - [60 Flange Conn with bq, 0, 0, 368, End A]
  - [60 Flange Conn with bq, 0, 0, 379.5, End A]
  - [60 Flange Conn with bq, 0, 0, 391, End A]
  - [60 Flange Conn with bq, 0, 0, 402.5, End A]
  - [60 Flange Conn with bq, 0, 0, 414, End A]
  - [60 Flange Conn with bq, 0, 0, 425.5, End A]
  - [60 Flange Conn with bq, 0, 0, 437, End A]
  - [60 Flange Conn with bq, 0, 0, 448.5, End A]
  - [60 Flange Conn with bq, 0, 0, 460, End A]
  - [60 Flange Conn with bq, 0, 0, 471.5, End A]
  - [60 Flange Conn with bq, 0, 0, 483, End A]
  - [60 Flange Conn with bq, 0, 0, 494.5, End A]
# Contents
ContentsMethod: Uniform
IncludeAxialContentsInertia: No
ContentsDensity: 1.025
ContentsPressureRefZ: ~
ContentsPressure: 0
ContentsFlowRate: -5.43
# Statics
IncludedInStatics: Yes
StaticsStep1: Catenary
StaticsStep2: Full Statics
IncludeSeabedFrictionInStatics: Yes
LayAzimuth: 359.55773942442
AsLaidTension: 0
# VIV
VIVFilterPeriod: 250
```

```
    VIVIwanBlevinsWakeOscillatorModelParameters: Default
    # Drawing
    NodePen: [1, Dot, $4080FF]
    DrawShadedNodesAsSpheres: Yes
    # VIV Drawing
    VIVDrawDetailFrom, VIVDrawDetailTo:
      - [~, ~]
Groups:
  Structure:
    40RiserP: Model
    60RiserS: Model
  State:
    Collapsed:
      - Variable Data
...
```

Section 9.0: Flow Analysis Report

SEAWATER INTAKE RISERS FOR FLOATING LIQUEFIED NATURAL GAS (FLNG) VESSELS

IAN CRAIG

FLOW ANALYSIS

Submitted in partial fulfilment of the requirements
of the University of Sunderland for the degree of
Professional Doctorate

June 2018

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LIST OF FIGURES

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ABBREVIATIONS & ACRONYMS

CFD	Computational Fluid Dynamics
FLNG	Floating Liquefied Natural Gas
IPA	Industrial Perforators Association
NB	Nominal Bore
NPSH	Net Positive Suction Head
SWIR	Seawater Intake Riser
SWLP	Seawater Lift Pump

1. INTRODUCTION

This report investigates the flow characteristics of the seawater as it is imported through the Sea Water Intake Risers (SWIR). Two aspects of the flow are analysed, namely, the pressure loss characteristics and the temperature gain characteristics.

These two characteristics are of primary importance to the process engineers as, the Seawater Lift Pumps (SWLP) that are installed to import the seawater generally have a minimum net positive suction head (NPSH) requirement to ensure that the pumps operate satisfactorily. The NPSH is the pressure generated by the column of water above the pump impeller therefore any pressure losses within the system that may influence the NPSH must be considered when specifying the pump. This includes the frictional losses as a result of the seawater being transported through the SWIR. Also, the purpose of the SWIR is to import cold seawater from below the sea surface to improve the efficiency of the cooling process on board the FLNG, consequently, the likely temperature gain of the seawater through the system is also of interest.

This report seeks to quantify both the pressure losses and the temperature gains using known techniques and empirical data.

1.1. Executive Summary

The flow of seawater through the SWIR was analysed and the expected pressure losses calculated for a range of flow rates. A number of sensitivities were run to determine the effects of water temperature on the pressure loss which appeared negligible but should be given consideration during system design. Similarly, the effect of internal roughness due to marine growth or wear was investigated and found to have a non-negligible effect pending the roughness value.

The temperature gain of the seawater inside the SWIR was calculated for a range of flow rates and were found to be mostly negligible. However, once the flow rate was reduced to the point where the seawater velocity through the SWIR was <0.2m/s, the increase in temperature gain became very steep.

The flow analysis demonstrates that, within the general design parameters considered for SWIR, seawater can be imported effectively.

2. PRESSURE LOSSES

2.1. Pressure Losses through the Pipe String

To predict the pressure losses through the SWIR pipe string due to friction, two techniques are considered and compared, namely the Darcy Weisbach method and the Hazen Williams method. The flow rate through the pipe string is required for both methods and the Darcy Weisbach method requires the density and viscosity of the media to be transported, which are established as follows;

2.1.1. Flow Rates

As the pressure loss is a function of the velocity through the system, maximum pressure loss will occur at the maximum design velocity and hence the maximum design flow rate.

The Norwegian NORSOK standard P-001 (NORSOK, 2006) specifies a maximum velocity of 3 metres per second (m/s) for untreated seawater through carbon steel pipes. Similarly, the Plastic Pipe Institute (PPI, 2000) give a general design velocity of 5-10 feet per second (1.52 – 3.04 m/s) for water flow through plastic pipe.

Therefore, the maximum flow rates are calculated using maximum velocity of 3m/s, hence:

$Q = V \cdot A$ where: Q = Flow Rate (m^3/s)

V = Velocity (m/s)

A = Cross Sectional Area of Pipe (m^2)

For a 40"NB (1m) pipe string:

$$Q = 3 \cdot \frac{\pi \cdot 1^2}{4}$$

$Q = 2.3562$ m^3/s = 8,480 m^3/hr **say 8,400 m^3/hr**

And for a 60"NB (1.5m) pipe string:

$$Q = 3 \cdot \frac{\pi \cdot 1.5^2}{4}$$

$Q = 5.301$ m^3/s = 19,085 m^3/hr **say 19,000 m^3/hr** which can be summarised as follows:

SWIR Diameter	**Maximum Flow Rate** (m^3/hr)
40”NB	8,400
60”NB	19,000

Table 2-1: SWIR Maximum Flow Rates

2.1.2. Seawater Properties

The properties for seawater were obtained from the International Towing Tank Conference Recommended Procedure (ITTC, 2011) and which are derived from the international standard specified by the International Association for the Properties of Water and Steam (IAPWS). For the imported seawater under consideration, the below properties are used:

Seawater Temperature (°C)	**Density** (kg/m^3)	**Viscosity** (m^2/s)
3.8°C	1027.85	1.6365E-06

Table 2-2: Properties of Imported Seawater

2.1.3. Darcy Weisbach Method

The Darcy Weisbach equation is the general method for evaluating pressure losses through pipework;

$$\Delta P = \frac{f \cdot \rho \cdot L \cdot v^2}{2 \cdot D}$$ (Crane, 2013) Eq. 1-17

where:

ΔP	=	Pressure Loss (Pa)
f	=	Friction Factor
ρ	=	Density (kg/m^3)
L	=	Length of Pipe (m)
v	=	Velocity (m/s)
D	=	ID of Pipe (m)

This technique requires a friction factor f, for which the most useful and widely used data have been presented by L.F. Moody (Crane, 2013), a copy of which is reproduced in Appendix A1.5.

The friction factor f is a function of the Reynolds number and the relative roughness of the inside bore of the pipe section under consideration, the relative roughness being the quotient of the absolute roughness (ϵ) and the pipe inside diameter (D).

The 'ϵ' values considered for the various riser materials are as follows:

Riser Section	**Absolute Roughness 'ϵ'** (mm)	**Source**
Rubber	0.2	Hose Manufacturer (Emstec)
HDPE	0.0015	(PPI, 2008) Ch.6, Table 2-1
Steel	0.05	(Crane, 2013) Chart A-23

Table 2-3: Roughness Factors (ϵ) for Riser Elements

Using the above variables, a pressure loss calculation was performed using the Darcy Weisbach technique for the 40"NB pipe string under consideration and is presented in Appendix A1.

2.1.4. Hazen Williams Method

The Hazen Williams equation is an alternate commonly used technique for calculating pressure losses but uses a pipe roughness coefficient ‘C’ which, unlike the Darcy Weisbach equation, is not based on a Reynolds number.

$$\Delta P = 6.05 * 10^5 \left(\frac{Q^{1.85}}{C^{1.85} . d^{4.87}}\right) * L$$ (Crane, 2013) Eq. 1-23

where:

ΔP = Pressure Loss (Bar)

Q = Flow Rate (m^3/hour)

C = Hazen Williams Factor

d = I/D of pipe (mm)

L = Length of pipe (m)

The Hazen Williams pipe roughness factor ‘C’ considered for the various pipe materials are as follows:

Riser Section	**‘*C*’ factor**	**Source**
Rubber	130	(Giles, et al., 2014) Table 6 (as Cast Iron)
HDPE	150	(PPI, 2008, p. 175)
Steel	140	(Giles, et al., 2014) Table 6

Table 2-4: Hazen Williams Pipe Roughness Factors (*C*) for Riser Elements

Using the above variables, a pressure loss calculation was performed using the Hazen Williams technique for the 40”NB pipe string under consideration and is presented in Appendix A2.

2.2. Pressure Loss through the Strainer

Like any restriction within a flow path, the strainer installed at the lower end of the SWIR is known to generate pressure losses. Although origins of the strainer specifications are unclear, it is generally accepted by the industry to manufacture from perforated plate with a hole pattern in accordance with DIN 24041 Rv 20 25 (DIN, 2002).

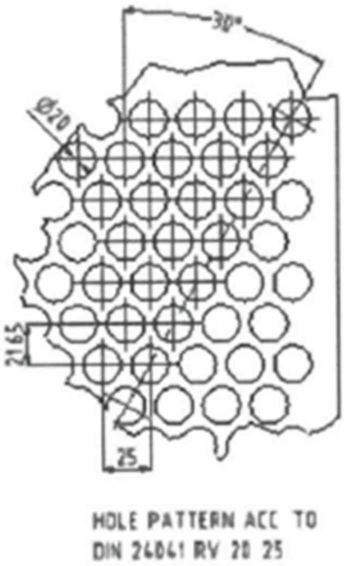

Fig.2-1: Hole Pattern in Strainer
(DIN 24041 RV 20 25)

According to the DIN 24041 (DIN, 2002), this provides and open area of 58%, however, due to stiffening sections and transition pieces, and for conservatism, the open area of the final fabrication is generally considered to be nearer to 40%.

In designing the strainer, an open area of six times the cross-sectional area of the SWIR pipe is considered to reduce the velocity through the strainer and thus reduce the pressure losses, which for a velocity of 3m/s through the pipe string would give a velocity through the strainer of ~0.5m/s.

To evaluate the pressure losses through the strainer, two techniques have been considered. The first technique uses experimental data provided by Boyles Laboratories through the Industrial Perforators Association (Boyle Engineering Laboratories, 1985), a copy of which is presented in Appendix A3.4.

It should be noted that the pressure loss curves presented within this graph do not extend to the region of below 100 feet per minute (~0.5m/s) which is the area of interest for this application, therefore they are manually approximated.

A pressure loss calculation was performed using the Industrial Perforators Association (IPA) data for the 40"NB Seawater Intake Riser under consideration and is presented in Appendix A3.

The second technique uses Computational Fluid Dynamic (CFD) software. During the development of the CFD simulation, several simplified models were considered, and it was found that if the model was scaled proportionally, i.e. maintaining the same ratio between the open area of the strainer and the cross-sectional area of the pipe, the pressure loss at the equivalent flow rates remained the same. Consequently, a 3D model from a manufactured strainer (ref. Fig. 2-2) was imported into the software, and the rated flow through the strainer simulated, details of which are presented in Appendix A4 and the full report in Appendix C.

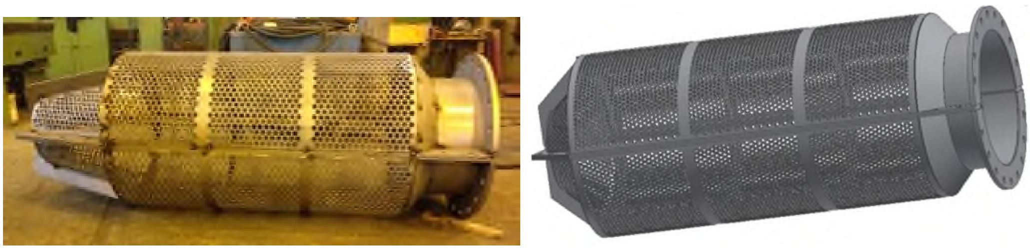

Fig.2-2: Manufactured Strainer Unit and associated model

The same model was then used to run a series of simulations for various velocity values through the pipe string to enable a pressure loss curve to be generated (ref. Fig.2-3)

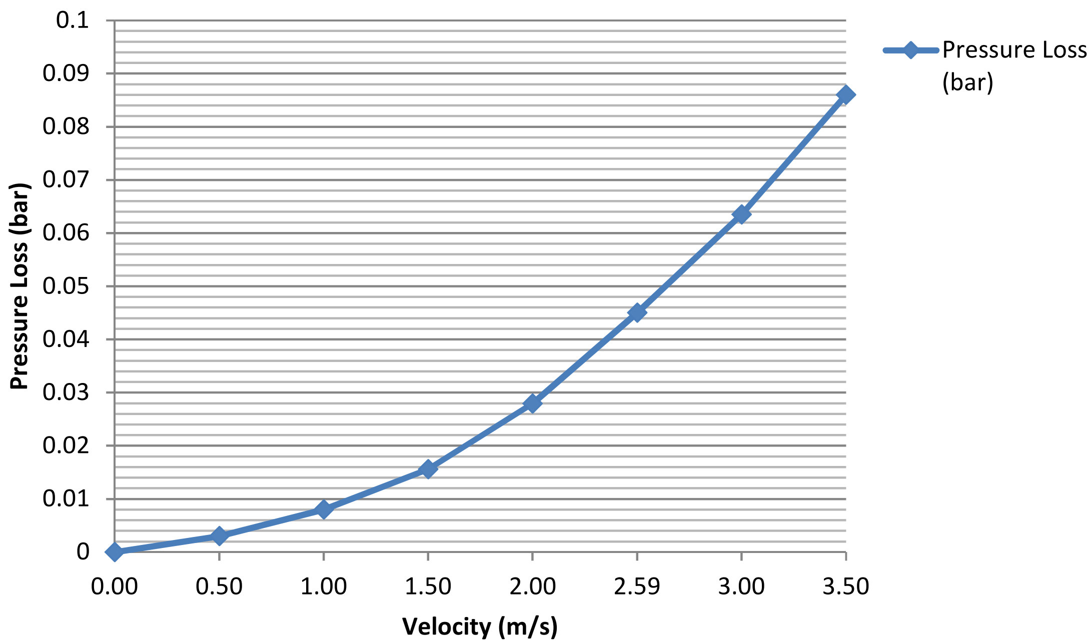

Fig.2-3: Strainer Pressure Loss Curve

2.3. Spreadsheet Calculation

The techniques used to calculate the pressure losses through the pipe string and the strainer were used to develop a spreadsheet to enable the expedient calculation of a range of flow rates for both the 40”NB SWIR and the 60”NB SWIR.

For the Darcy Weisbach calculation, the friction factor variable f is obtained from a Moody Chart Solver worksheet developed by Cimbala (Cimbala, 2012).

For the strainer calculation using the IPA data, the pressure loss was read from the Boyles Engineering Laboratory graph (Boyle Engineering Laboratories, 1985) and manually input into the spreadsheet.

For the Strainer calculation using the CFD results, the pressure loss values were extracted from the pressure loss curve generated by a series of simulations.

2.4. Results

Using the developed spreadsheet, the pressure loss calculations for a 40"NB pipe string and a 60"NB pipe string for a range of flow rates were calculated using both of the considered techniques and are summarised and compared below.

Flow Rate *(m3/hour)*	**Pressure Loss** *(bar)*		**Discrepancy** *(%)*
	Darcy Weisbach	**Hazen Williams**	
0	0	0	0%
1000	0.0054	0.0053	1.70%
2000	0.0192	0.0190	1.05%
3000	0.0408	0.0403	1.32%
4000	0.0698	0.0686	1.87%
5000	0.1062	0.1036	2.47%
6000	0.1496	0.1452	3.09%
7000	0.2002	0.1931	3.70%
8000	0.2578	0.2472	4.28%
9000	0.3223	0.3073	4.85%

Table 2-5: Pressure Losses through 40"NB Pipe String

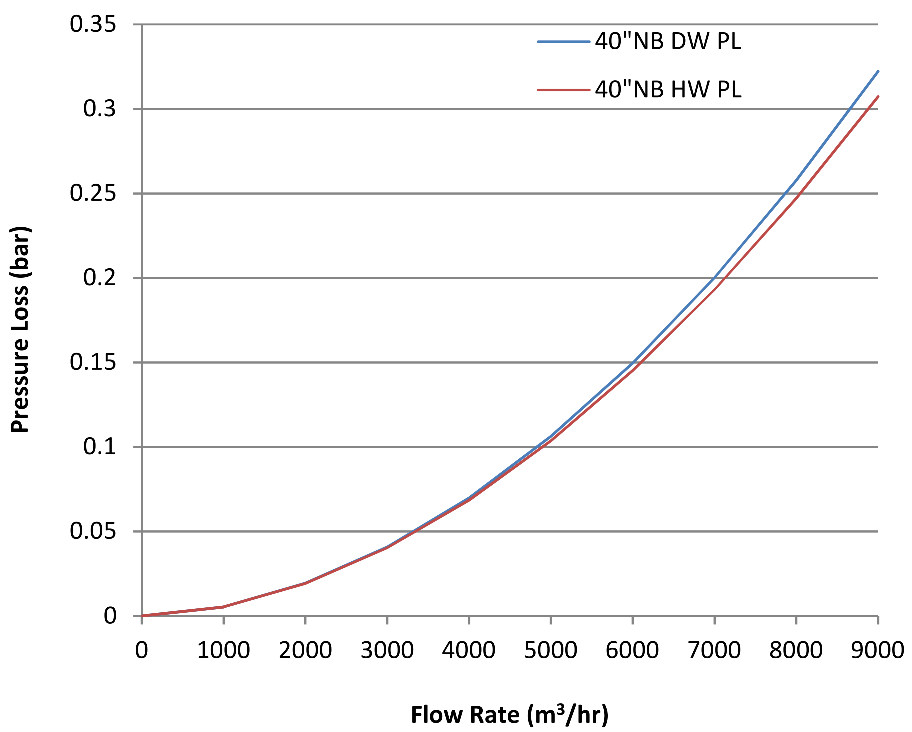

Fig.2-4: Pressure Losses through 40"NB Pipe String

Flow Rate *(m3/hour)*	**Pressure Loss** *(bar)*		**Discrepancy** *(%)*
	Darcy Weisbach	**Hazen Williams**	
0	0	0	0%
2000	0.00263	0.0026	1.15%
4000	0.00941	0.00938	0.32%
6000	0.01997	0.01986	0.55%
8000	0.03418	0.03381	1.09%
10000	0.05195	0.0511	1.66%
12000	0.07321	0.07159	2.26%
14000	0.09792	0.09522	2.84%
16000	0.12605	0.1219	3.40%
18000	0.15756	0.15158	3.95%
20000	0.19244	0.1842	4.47%

Table 2-6: Pressure Losses through 60"NB Pipe String

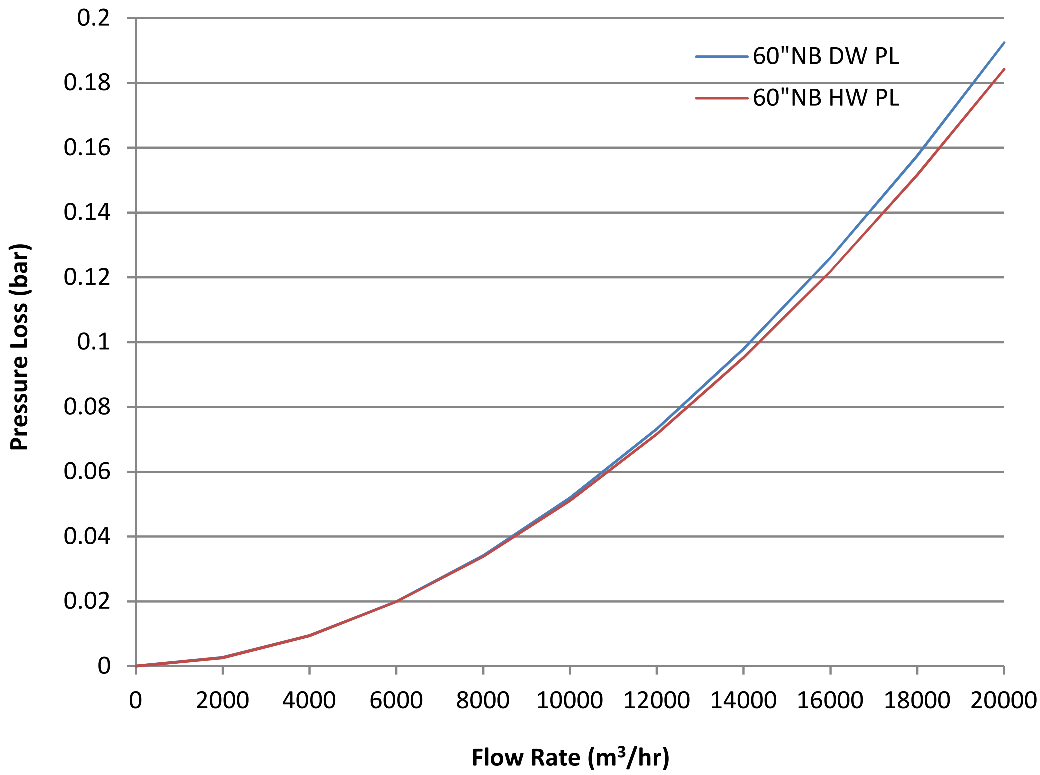

Fig.2-5: Pressure Losses through 60"NB Pipe String

It can be seen that for both the 40"NB pipe string and the 60"NB pipe string, the discrepancy between the techniques is very small and therefore provides good correlation.

The same spreadsheet was also used to calculate the pressure loss through the strainer unit for a 40”NB SWIR and a 60”NB SWIR for a range of flow rates using both of the considered techniques and are summarised and compared below;

Flow Rate *(m3/hour)*	**Pressure Loss** *(bar)*		**Discrepancy** *(%)*
	CFD	**IPA Graph**	
0	0	0	0%
1000	0.0022	0.0020	+10%
2000	0.0054	0.0048	+13%
3000	0.0097	0.0099	-3%
4000	0.0153	0.0157	-3%
5000	0.0242	0.0248	-2%
6000	0.0342	0.0329	+4.1%
7000	0.0449	0.0425	+5.5%
8000	0.0617	0.0511	+20%
9000	0.0784	0.0588	+33%

Table 2-7: Pressure Losses through 40”NB Strainer

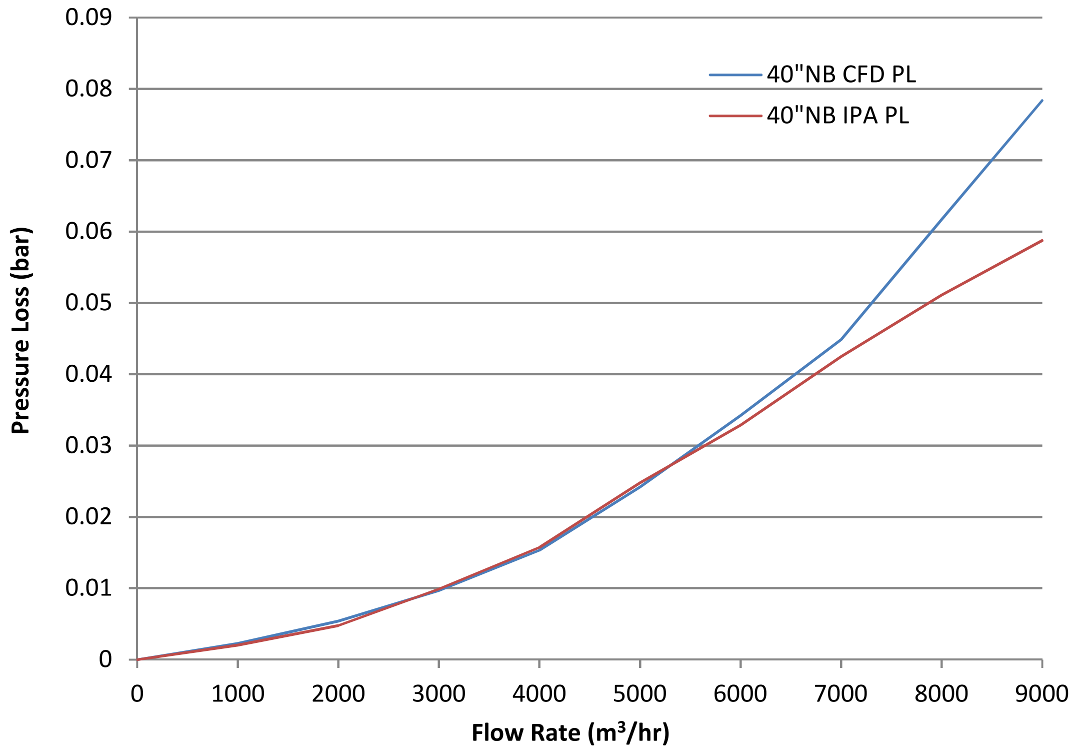

Fig.2-6: Pressure Losses through 40”NB Strainer

Flow Rate *(m3/hour)*	**Pressure Loss** *(bar)*		**Discrepancy** *(%)*
	CFD	**IPA Graph**	
0	0	0	0%
2000	0.00194	0.00195	-1%
4000	0.00443	0.00612	-28%
6000	0.00761	0.00912	-17%
8000	0.01229	0.01536	-20%
10000	0.01814	0.02346	-23%
12000	0.02603	0.02973	-13%
14000	0.03491	0.03653	-4%
16000	0.04411	0.04384	+1%
18000	0.05826	0.05169	+12%
20000	0.07277	0.06006	+21%

Table 2-8: Pressure Losses through 60"NB Strainer

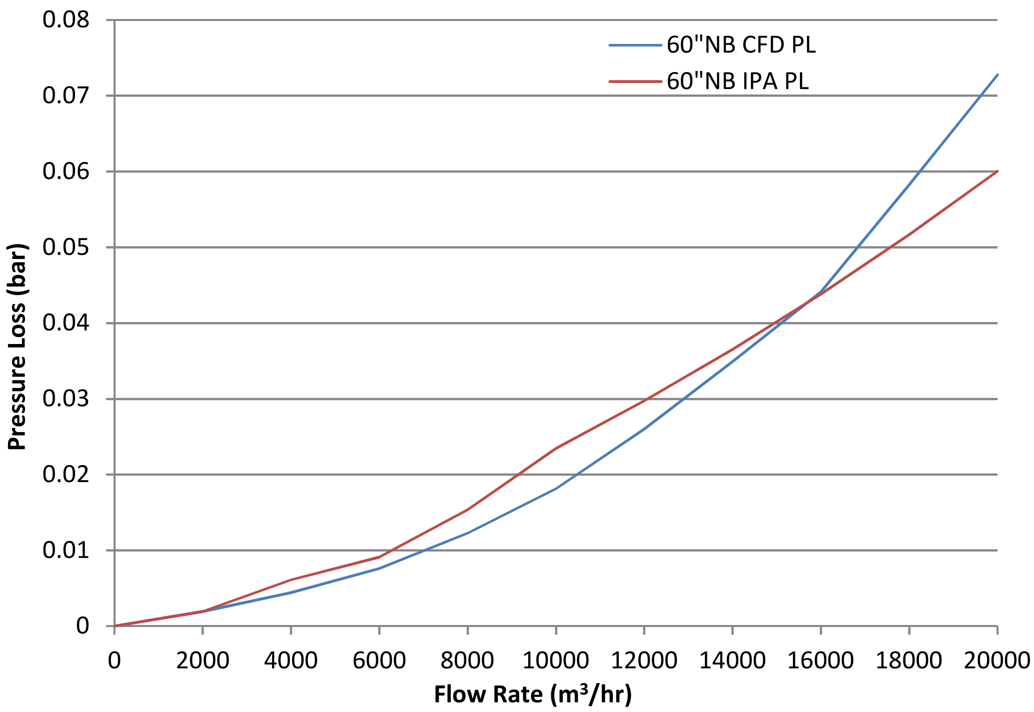

Fig.2-7: Pressure Losses through 60"NB Strainer

It can be seen that for both the 40"NB strainer and the 60"NB strainer, the discrepancy between the techniques varies depending upon the flow rate but provides reasonable correlation, in particular at the lower flow rates.

For the pressure loss through the pipe string, the Darcy Weisbach technique yields slightly higher values than the Hazen Williams technique therefore, for conservatism, and as recommended by (Crane, 2013), the outputs from the Darcy Weisbach technique are used for the combined pressure losses through the pipe string and strainer unit (ref. Table 2-9 & 2-10).

Likewise, for the strainer pressure losses, the CFD technique yields slightly higher pressure losses than the IPA Graph technique and is arguably more accurate than the use of extrapolated curves from the IPA graph, therefore the values from the CFD technique are used for the combined pressure losses.

Flow Rate *(m3/hour)*	**Combined Pressure Loss** *(bar)*
0	0
1000	0.0077
2000	0.0247
3000	0.0504
4000	0.0846
5000	0.1291
6000	0.1814
7000	0.2411
8000	0.3136
9000	0.3924

Table 2-9: Combined Pressure Losses through 40”NB SWIR

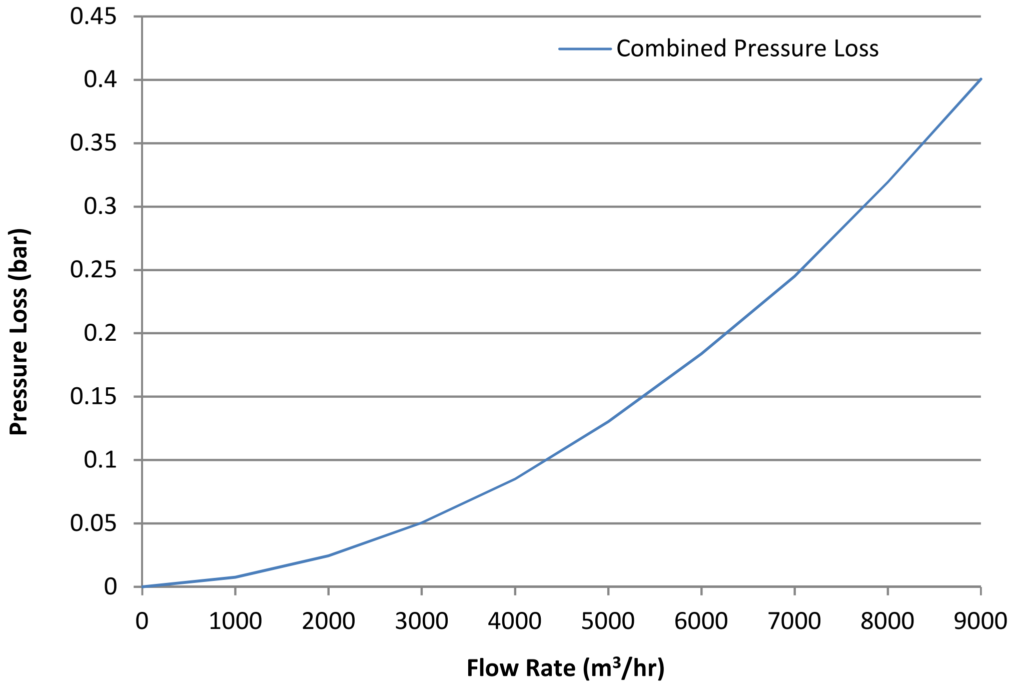

Fig.2-8: Combined Pressure Losses through 40”NB SWIR

Flow Rate *(m3/hour)*	**Pressure Loss** *(bar)*
0	0
2000	0.00454
4000	0.01368
6000	0.02712
8000	0.0455
10000	0.0684
12000	0.0966
14000	0.12901
16000	0.16488
18000	0.20882
20000	0.25622

Table 2-10: Combined Pressure Losses through 60”NB SWIR

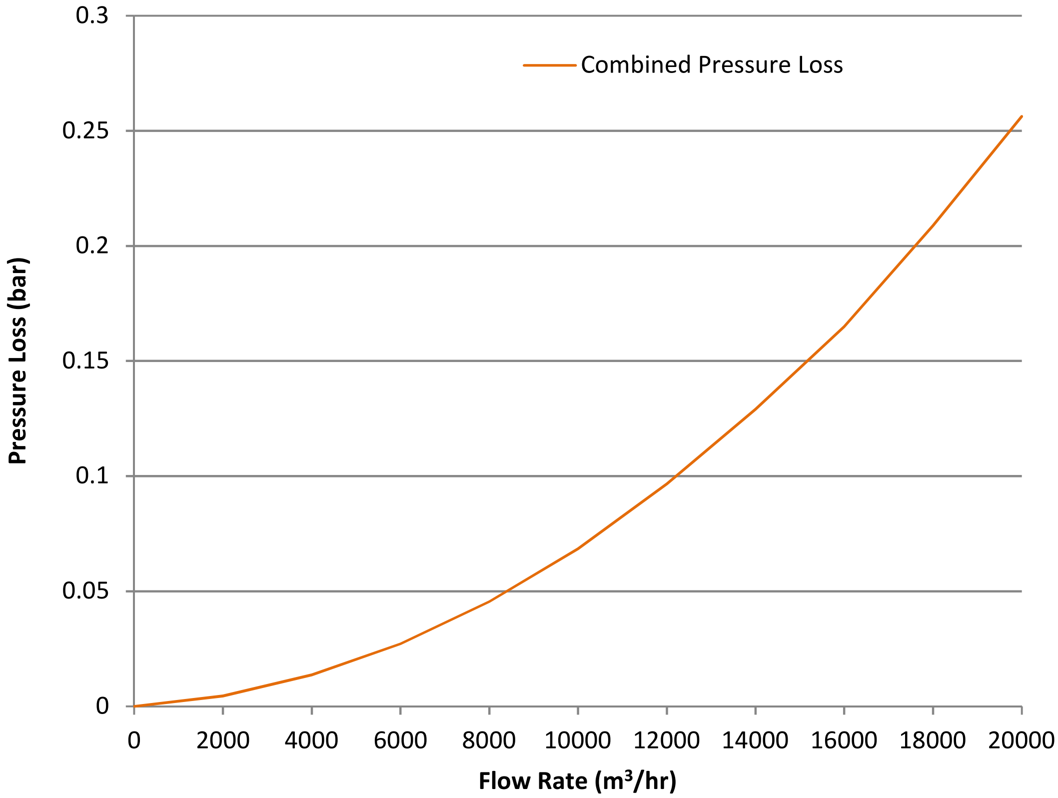

Fig.2-9: Combined Pressure Losses through 60”NB SWIR

2.5. Sensitivities

Sensitivities were performed for some of the variables that the SWIR may encounter during service, namely, internal roughness and seawater temperature.

2.5.1. Internal Roughness

The pressure losses due to an increased internal roughness was evaluated to simulate the effect of marine growth or wear inside the SWIR.

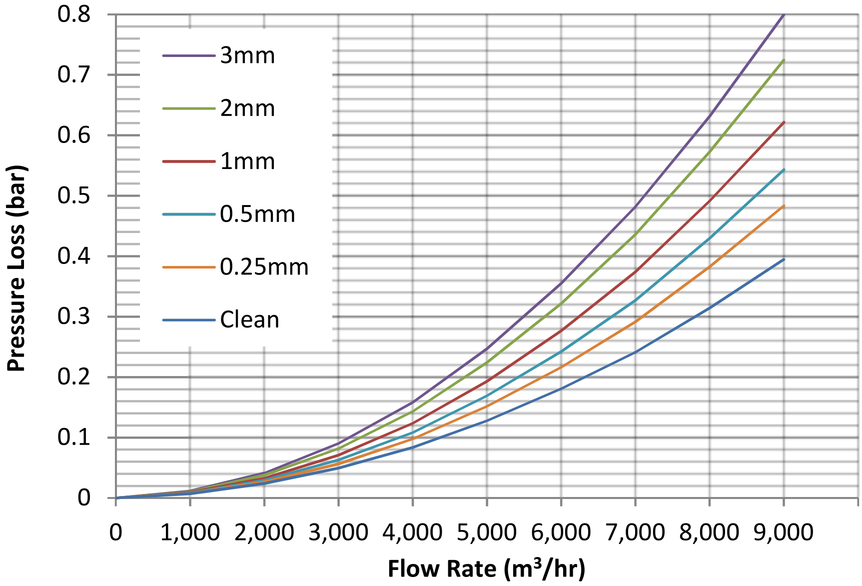

Fig.2-10: Internal Roughness Effect on Pressure Losses (40"NB SWIR)

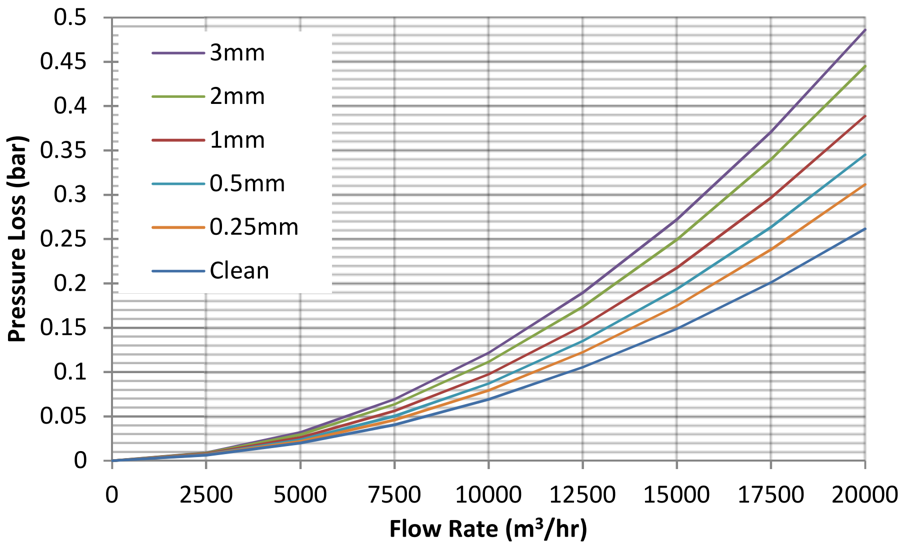

Fig.2-11: Internal Roughness Effect on Pressure Losses (60"NB SWIR)

Figs. 2-10 and 2-11 show that the pressure losses can increase significantly due to the internal roughness of the SWIR, for the higher flow rates with a 3mm roughness, the pressure loss is approximately twice as that of a clean system. This effect should be taken into consideration during the design of the system and emphasises the advantages of an effective marine growth protection system.

2.5.2. Seawater Temperature

The physical properties of seawater changes with temperature in as much as the colder the seawater, the higher the density and the greater the viscosity. Using the range of seawater temperatures and the corresponding properties shown in Table 2-11, a number of sensitivities were performed to quantify the effect of this on pressure loss through the system:

Seawater Properties (ITTC, 2011)		
Temp (°C)	**Density** (kg/m^3)	**Viscosity** *(m^2/s)*
22.9	1024	9.82E-07
21.1	1024.5	1.02E-06
19.3	1025	1.07E-06
17.3	1025.5	1.12E-06
15.1	1026	1.19E-06
12.7	1026.5	1.26E-06
10	1027	1.36E-06
6.7	1027.5	1.50E-06
2.2	1028	1.72E-06

Table 2-11: Seawater Properties

The effect of seawater temperature on pressure loss through the system for a number of flow rates are shown in Figs 2-12 and Fig. 2-13 for the 40”NB SWIR and 60”NB SWIR respectively.

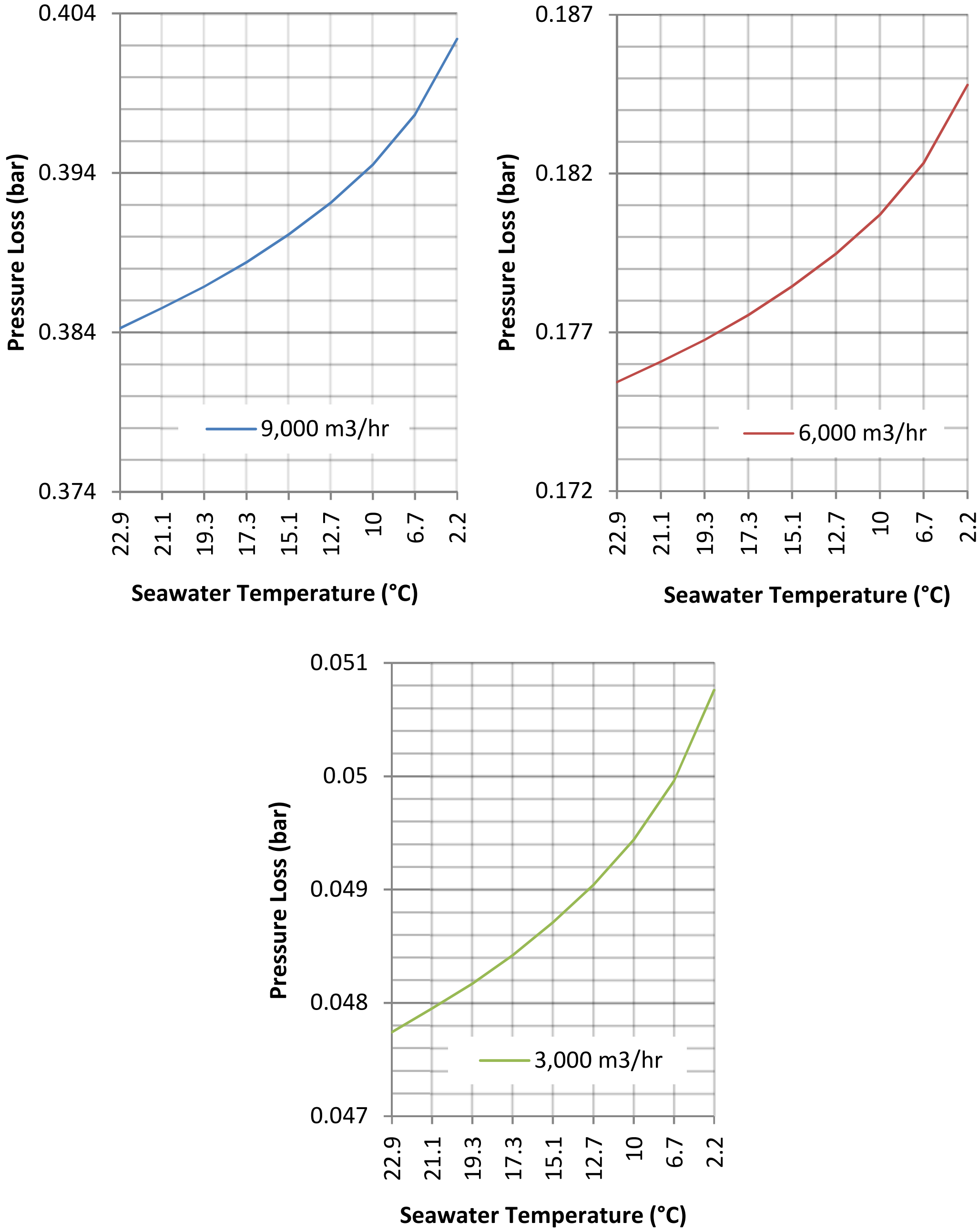

Fig.2-12: Seawater Temperature effect on Pressure Losses (40"NB SWIR)

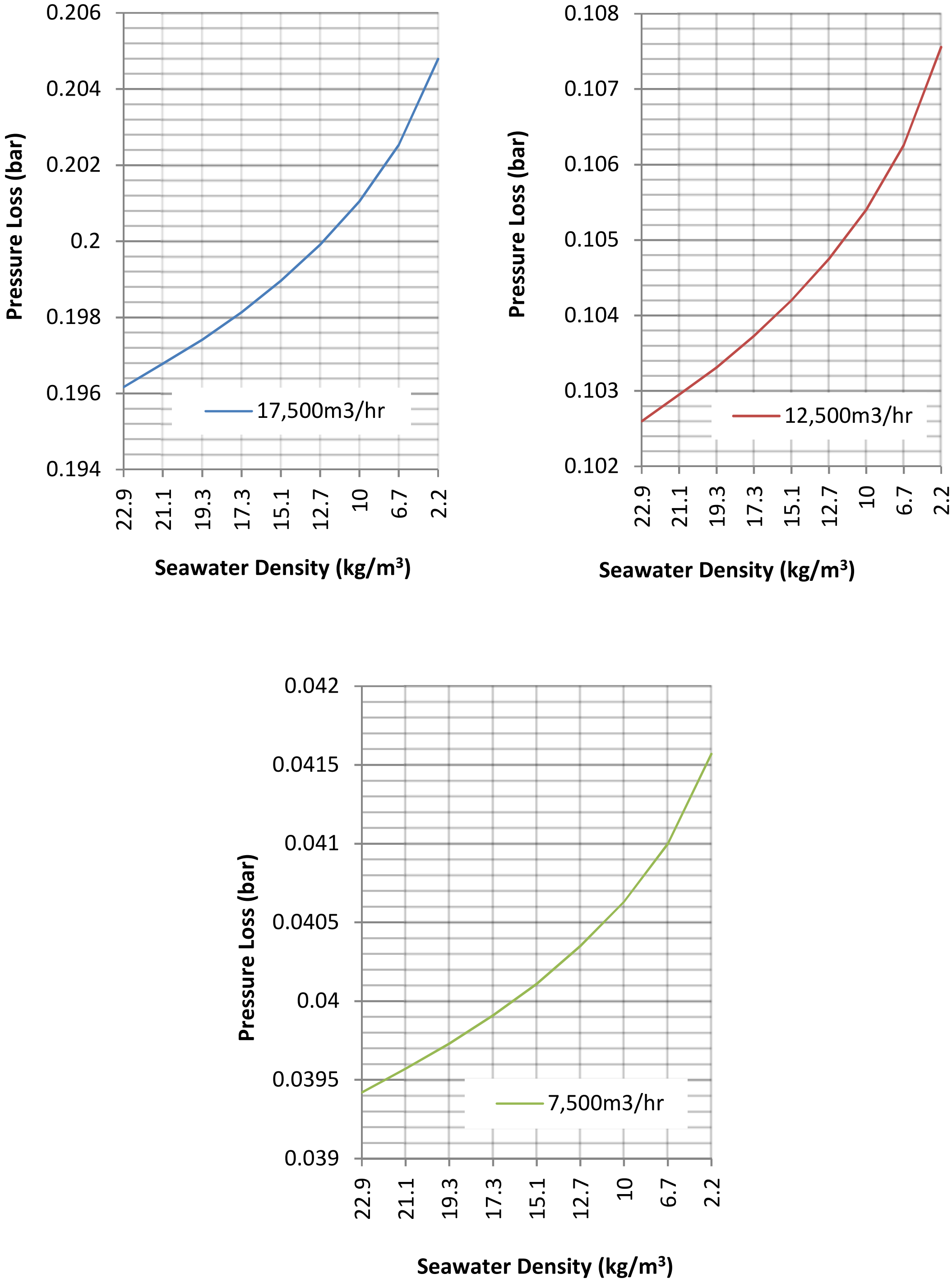

Fig.2-13: Seawater Temperature effect on Pressure Losses (60"NB SWIR)

Figs. 2-12 and 2-13 show that the pressure losses do increase as the seawater temperature at the inlet point reduces however, these losses are in the order of 18mbar for the 40"NB SWIR at maximum flow rate to 2mbar for the 60"NB SWIR at reduced flow rate. Although these losses appear negligible, 18mbar represents approximately 9% of the generally accepted design parameter of 200mbar (0.2bar) so should be taken into consideration during the system design.

3. TEMPERATURE GAIN

For the calculation of temperature gain through the SWIR, two techniques were considered. The first techniques was a manual calculation based on the thermal conductivity of each of the materials. Secondly, CFD software was used to validate the manual calculation by performing a simplified simulation of the flow through a section of the SWIR. A spreadsheet was developed based on the manual calculation to enable an expedient calculation of the temperature gain through the complete SWIR.

The manual calculation, CFD and spreadsheet are presented in Appendix B1, B2 & B3 respectively, and the results are summarised in section 3.2.

3.1. Temperature Gain Calculation

The temperature gain calculation was based on the following equations:

$$\dot{Q} = \lambda \cdot A_m \cdot \frac{T_1 - T_2}{t}$$ (Gieck, 1996) eq. O62

$$A_m = \pi \cdot d_m \cdot L$$ (Gieck, 1996) eq. O63

$$d_m = \frac{d_a - d_i}{ln\left(\frac{d_a}{d_i}\right)}$$ (Gieck, 1996) eq. O63

Where:

$\dot{Q}$ = Heat Energy/unit of time (J/s)

λ = Thermal Conductivity (W/m K)

A_m = Mean Logarithmic Area (m^2)

T_1-T_2 = Temperature Differential (K)

t = Wall thickness (m)

d_m = Mean Diameter (m)

L = Length of Pipe (m)

d_a = Outside Diameter (m)

d_i = Inside Diameter (m)

The thermal conductivity values considered for the various pipe materials are as follows:

Riser Section	λ (W/m K)	Source
Rubber	0.3	(Gieck, 1996) Table Z3
HDPE	0.43	(PPI, 2004) p.3-36
Steel	50	(Gieck, 1996) Table Z3

Table 3-1: Thermal Conductivity values (λ) for Riser Elements

From the above, the transferred Heat Energy per unit of time from the external surface to the internal surface was determined for a given length of pipe. Using the calculated value of Heat Energy transferred, the change in temperature from the pipe inlet to the pipe outlet for the given length of pipe was determined using the following equations:

$$c_p = \frac{Q}{m \cdot \Delta t} \qquad \text{(Gieck, 1996) eq. O9}$$

Where: c_p = Specific Heat (J/kg K)

Q = Heat Energy (J)

m = mass (kg)

Δt = Temperature Differential (K)

Autodesk Simulation CFD Software was used to validate a sample calculation using the same parameters, the sample calculation is presented in Appendix B and the corresponding CFD report in Appendix C..

Then, using the above formulae, a spreadsheet was developed to enable the temperature gain per metre section of pipe to be calculated, whereby, (working from the inlet of the seawater intake riser), the calculated outlet temperature of each metre section of pipe would form the inlet temperature of the next section of pipe.

The typical low latitude temperature profile was reproduced within the spreadsheet (ref. Fig 3-1 below) and was used to provide the input for the external surface temperature of the SWIR for each metre increment of pipe.

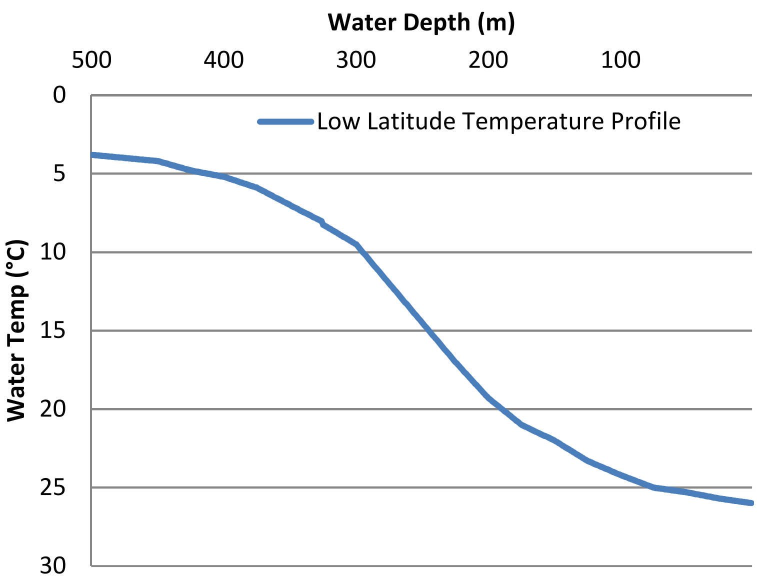

Fig.3-1: Reproduction of Low Latitude Temperature Profile

3.2. Temperature Gain Results

The manual calculation and the CFD simulation provided good correlation for a 40"NB x 10m steel pipe section with an internal/external temperature differential of 10°C, as shown below:

Flow Rate (m^3/hr)	**Length** (m)	**ΔT** (°C)	**Temperature Gain** (°C)		**Discrepancy** (%)
			Calculation	***CFD***	
8,400	10	10	0.08217	0.0807	+1.8%

Table 3-2: Correlation of Manual Calculation vs CFD

Using the developed spreadsheet, the temperature gain through a 40"NB SWIR for the considered flow rate of 8,400m^3/hr was **0.0724°C**

The temperature gain through a 60"NB SWIR for the considered flow rate of 19,000m^3/hr was **0.0466°C**

3.3. Flow Rate vs Temperature Gain Calculation

Using the developed spreadsheet, the temperature gain for a range of seawater flow rates was calculated and a curve produced for both the 40”NB SWIR and the 60”NB SWIR to illustrate the trend (ref. Fig. 3-2 & Fig. 3-3) as shown below.

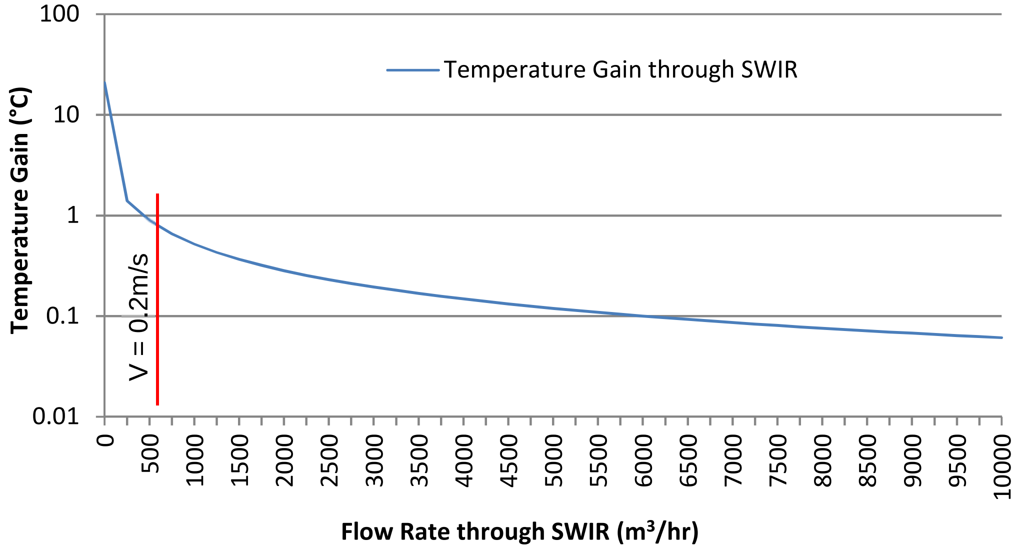

Fig.3-2: Temperature Gain vs Flow Rate thru’ 40”NB SWIR

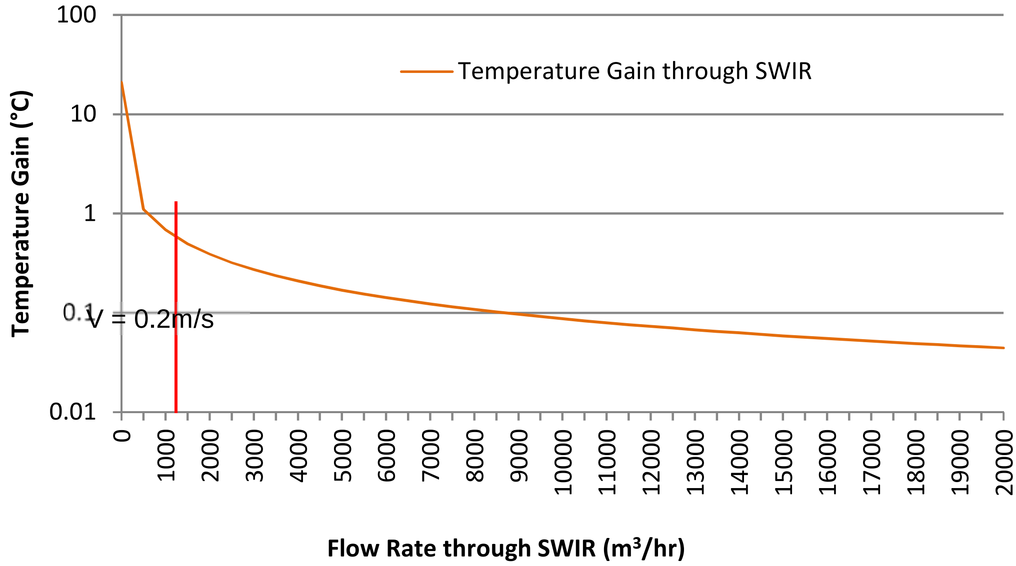

Fig.3-3: Temperature Gain vs Flow Rate thru’ 60”NB SWIR

4. SUMMARY

The above analysis of the seawater intake risers show that both the pressure loss characteristics and the temperature gain characteristics are a function of the flow rate through the seawater intake riser. As the flow rate increases, the pressure losses also increase, whereas the temperature gain decreases.

At the optimum flow rate, it was found that the pressure losses were in an acceptable region similar to the acceptable losses used on current systems and the temperature gain was negligible.

Sensitivities indicate that consideration should be given to the effect of internal roughness on pressure loss calculations when specifying suction pump requirements, whereas the effect of water temperature was negligible.

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APPENDICES

APPENDIX A: PRESSURE LOSS CALCULATIONS

A1 PRESSURE LOSSES IN 40”NB SWIR – DARCY WEISBACH

$$\Delta P = \frac{f \cdot \rho \cdot L \cdot v^2}{2 \cdot D}$$ (Crane, 2013) Eq. 1-17

and $$V = \frac{Q}{A}$$

$$Re = \frac{V \cdot D}{v'}$$

$$\text{Relative Roughness} = \frac{\varepsilon}{D * 1000}$$

where:	ΔP	=	Pressure Loss *(Pa)*
	f	=	Friction factor
	ρ	=	Fluid Density *(kg/m³)*
	L	=	Length of hose *(m)*
	V	=	Velocity *(m/s)*
	D	=	I/D of seawater hose (*m*)
	Q	=	Flow Rate *(m^3/hour)*
	A	=	x-sect area seawater hose *(m^2)*
	v'	=	Kinematic Viscosity *(m^2/s)*
	ε	=	Absolute Roughness of pipe (*mm)*
	Re	=	Reynolds Number

A1.1 PRESSURE LOSSES IN 40"NB FLEXIBLE RUBBER PIPE SECTION

for the SWIR under consideration:

ρ = 1027.85 *(kg/m³)*

L = 138 *(m)*

D = 1.000 (*m*)

Q = 8,400 *(m³/hour)*

v' = 1.6365E-06 *(m²/s)*

ε = 0.2 (*mm*)

so $V = \dfrac{Q}{A}$ where: $A = \dfrac{\pi \cdot D^2}{4}$

A* = 0.785 *m²

$$V = \frac{8400}{0.785 * 3600}$$

V* = 2.971 *m/s

$$Re = \frac{2.971 \times 1.000}{1.6365E\text{-}06}$$

$\therefore$ Re = **1 815 460**

Relative Roughness = $\dfrac{0.2}{1000}$

$\therefore$ Relative Roughness = **0.0002**

Using the Moody diagram to determine Friction Factor *f* = **0.0143**

Therefore: $$\Delta P = \frac{1027.85 * 0.0143 * 138 * 2.971^2}{2 * 1}$$

ΔP = 8 952 Pa

ΔP = 0.08952 barg

A1.2 PRESSURE LOSSES IN HDPE PIPE SECTION

for the SWIR under consideration:

ρ = 1027.85 (kg/m3)

L = 253 *(m)*

D = 0.985 (*m*)

Q = 8,400 *(m³/hour)*

v' = 1.6365E-06 *(m²/s)*

ε = 0.0015 (*mm)*

so $V = \frac{Q}{A}$ where: $A = \frac{\pi \cdot D^2}{4}$

A* = 0.754 *m²

$V = \frac{8400}{0.754 * 3600}$

V* = 3.062 *m/s

$Re = \frac{3.062 \times 0.985}{1.6365E-06}$

∴ *Re* = **1 843 000**

Relative Roughness = $\frac{0.0015}{985}$

∴ Relative Roughness = **0.000001523**

Using the Moody diagram to determine Friction Factor *f* = **0.0106**

Therefore: $\Delta P = \frac{1027.85 * 0.0106 * 253 * 3.062^2}{2 * 0.985}$

ΔP = 13 119 Pa

ΔP = 0.13119 barg

A1.3 PRESSURE LOSSES IN STEEL PIPE SECTION

for the SWIR under consideration:

ρ = 1027.85 *(kg/m³)*

L = 103.5 *(m)*

D = 0.978 *(m)*

Q = 8,400 *(m3/hour)*

v' = 1.6365E-06 *(m2/s)*

ε = 0.05 *(mm)*

so $V = \frac{Q}{A}$ where: $A = \frac{\pi \cdot D^2}{4}$

A* = 0.751 *m²

$$V = \frac{8400}{0.751 * 3600}$$

V* = 3.106 *m/s

$$Re = \frac{3.106 \times 0.978}{1.6365E-06}$$

$\therefore$ Re = **1 856 231**

$$\text{Relative Roughness} = \frac{0.05}{978}$$

$\therefore$ Relative Roughness = **0.00005**

Using the Moody diagram to determine Friction Factor f = **0.0119**

Therefore: $$\Delta P = \frac{1027.85 * 0.0119 * 103.5 * 3.106^2}{2 * 0.978}$$

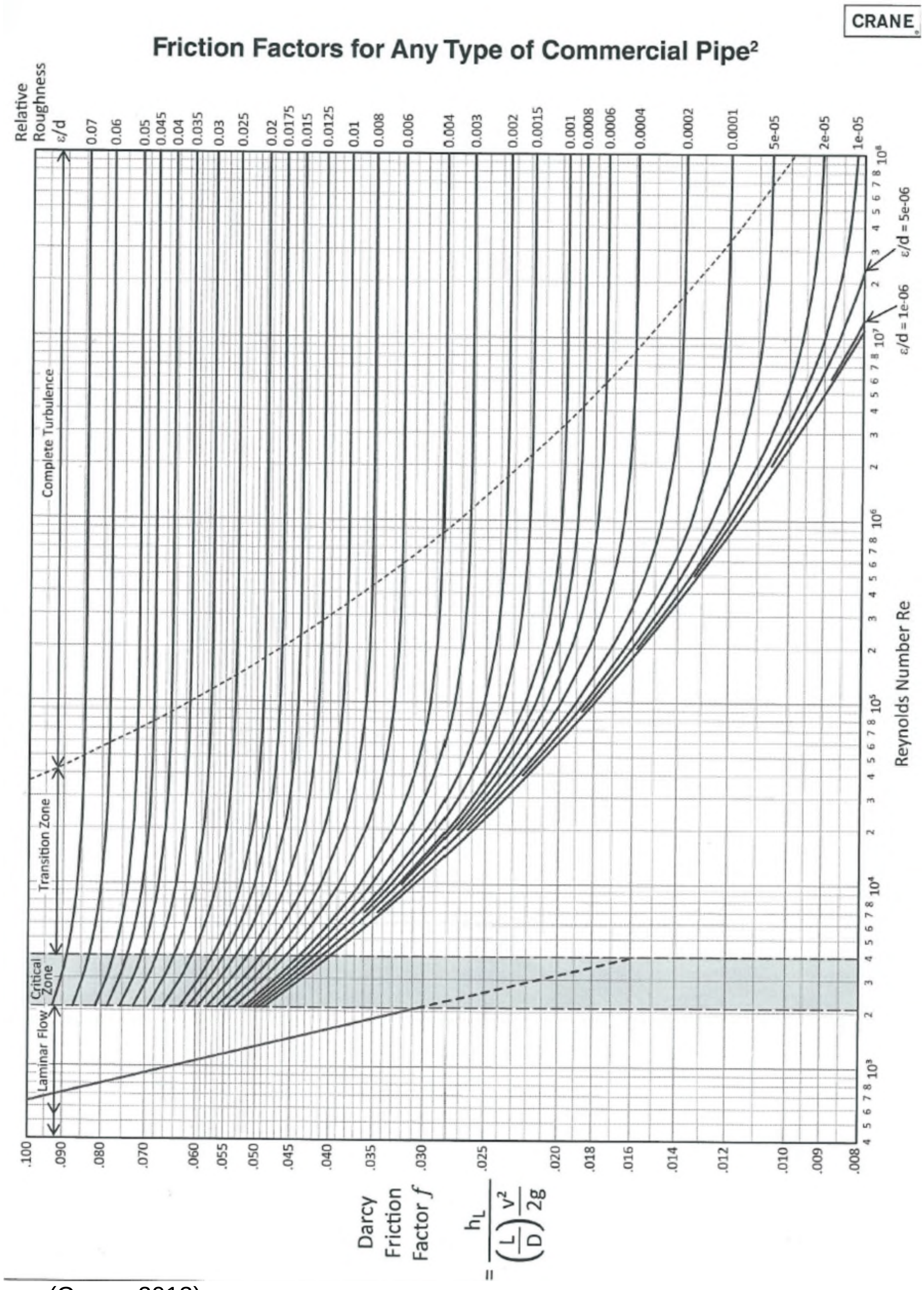
ΔP = 6 244 Pa

ΔP = 0.06244 barg

A1.4 SUMMARY OF PRESSURE LOSSES IN 40”NB PIPE SECTIONS

FLEXIBLE RUBBER PIPE SECTION:	0.08952 barg
HDPE PIPE SECTION:	0.13119 barg
STEEL PIPE SECTION:	0.06244 barg
Sub Total	**0.28315 barg**

A1.5 MODIFIED MOODY DIAGRAM



(Crane, 2013)

A2 PRESSURE LOSSES IN 40"NB SWIR – HAZEN WILLIAMS

$\Delta P = 6.05 * 10^5 \left(\frac{Q^{1.85}}{C^{1.85} \cdot d^{4.87}}\right) * L$ (Crane, 2013) Eq. 1-23

where:
ΔP = *Pressure Loss (Bar)*
Q = Flow Rate *(l/min)*
C = Hazen Williams Factor
d = I/D of pipe *(mm)*
L = Length of pipe *(m)*

A2.1 PRESSURE LOSSES IN 40"NB FLEXIBLE RUBBER PIPE SECTION

for the SWIR under consideration

Q = 140,000 *l/min*
C =130
D = 1000*mm*
L = 138*m*

$$\Delta P = 6.05 * 10^5 \left(\frac{140{,}000^{1.85}}{130^{1.85} \cdot 1000^{4.87}}\right) * 138$$

ΔP = 0.0834 barg

A2.2 PRESSURE LOSSES IN 40"NB HDPE PIPE SECTION

for the SWIR under consideration:

Q = 140,000 *l/min*
C =150
D = 985*mm*
L = 253*m*

$$\Delta P = 6.05 * 10^5 \left(\frac{140{,}000^{1.85}}{150^{1.85} \cdot 985^{4.87}}\right) * 253$$

ΔP = 0.12630 barg

A2.3 PRESSURE LOSSES IN 40"NB STEEL PIPE SECTION

for the SWIR under consideration:

Q = 140,000 *l/min*
C = 140
D = 978*mm*
L = 103.5*m*

$$\Delta P = 6.05 * 10^5 \left(\frac{140{,}000^{1.85}}{140^{1.85} \cdot 978^{4.87}}\right) * 103.5$$

ΔP = 0.06078 barg

A2.4 SUMMARY OF PRESSURE LOSSES IN 40”NB PIPE SECTIONS

FLEXIBLE RUBBER PIPE SECTION:	0.08340 barg
HDPE PIPE SECTION:	0.12630 barg
STEEL PIPE SECTION:	0.06078 barg
Sub Total	**0.27048 barg**

A3 PRESSURE LOSSES THROUGH STRAINER – IPA GRAPH

A3.1 PRESSURE LOSSES IN PIPE INLET

Pressure Loss in 40”NB Seawater Intake Riser at the Pipe Inlet:

$$H_i = \frac{K \cdot V^2}{2g}$$ (Crane, 2013) Eq. 3-14

where H_i = Head Loss *(m)*

K = factor for pipe inlet

V = Velocity through Inlet *(m/s)*

For the SWIR under consdieration:

for Flush/Sharp Edge	K =	0.5	(Crane, 2013) A-29
and	V =	3.106m/s	Appendix C1.3

$$H_i = \frac{0.5 \cdot 3.106^2}{2 \cdot 9.81}$$

$$H_i = 0.246m$$

and $h = \frac{p}{0.0981 \cdot SG}$

so $p = 0.0981 \cdot h \cdot SG$

$$p = 0.0981 \cdot 0.246 \cdot 1.025$$

ΔP = 0.02474 barg

A3.2 PRESSURE LOSSES THROUGH PERFORATED PLATE

Inside diameter of Riser = 1.0m

Total Open Area of Strainer = 6.5 x Suction Hose Area

$= 6.5 \times \frac{\pi 1.0^2}{4}$

$= 5.105\ m^2$

Flow through Strainer = $8400\ m^3$/hour

Fluid Velocity through Strainer $= \frac{8400}{3600 \times 5.105}$

= 0.457 m/s

Convert to Feet per Minute = 0.457 x 197 = 90 fpm

Perforated Plate used for Strainer has an Open Area of: 35%

Using the graph provided by Industrial Perforators Association (IPA), for a uniform impact velocity of 90 fpm and an open area of 35%, the pressure loss is given as:

0.8” of Mercury

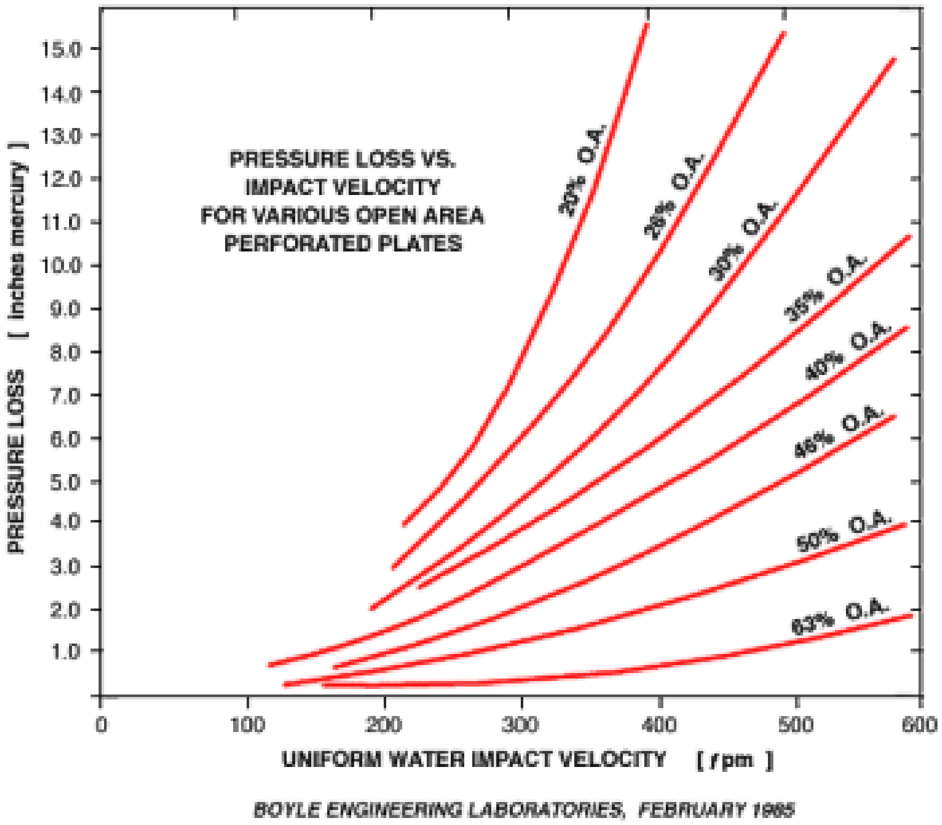
Converting to barg: 0.8” x 0.0339 = 0.02712 barg

Pressure Loss through Strainer = 0.02712 barg

A3.3 SUMMARY OF PRESSURE LOSSES IN STRAINER

PIPE INLET:	0.02474 barg
STRAINER:	0.02712 barg
Sub Total	**0.05186 barg**

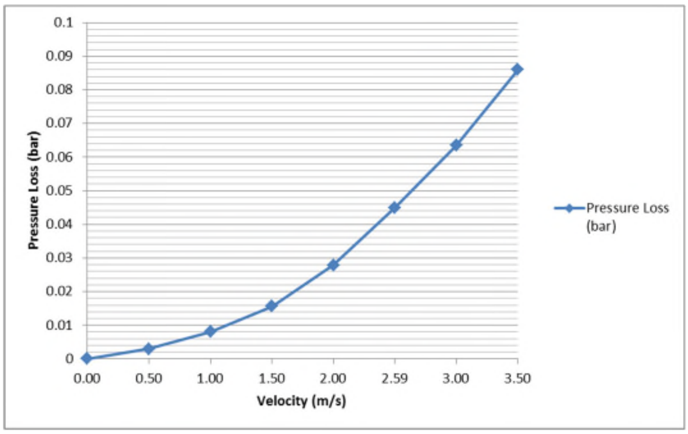
A3.4 IPA GRAPH

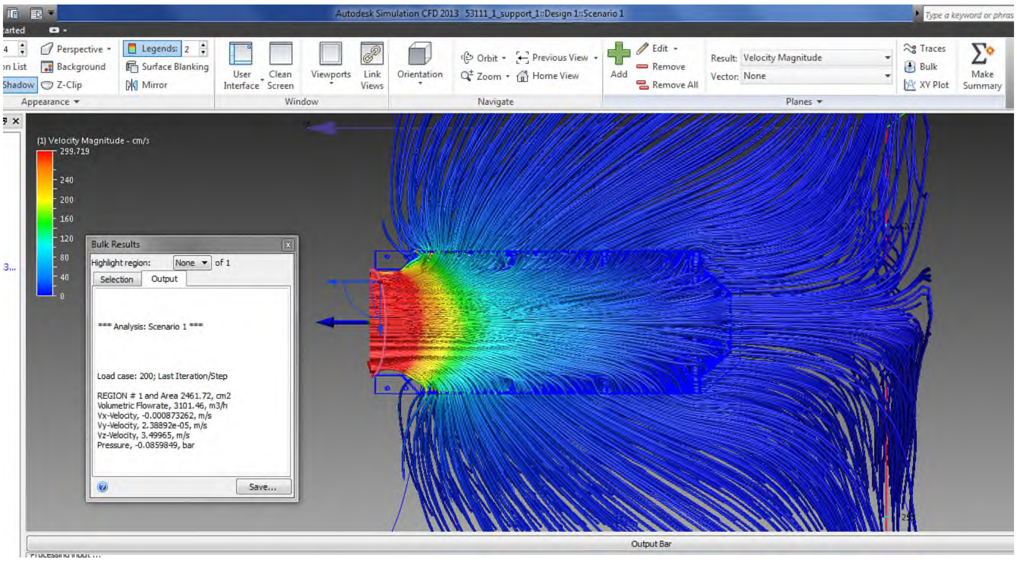


(Boyle Engineering Laboratories, 1985)

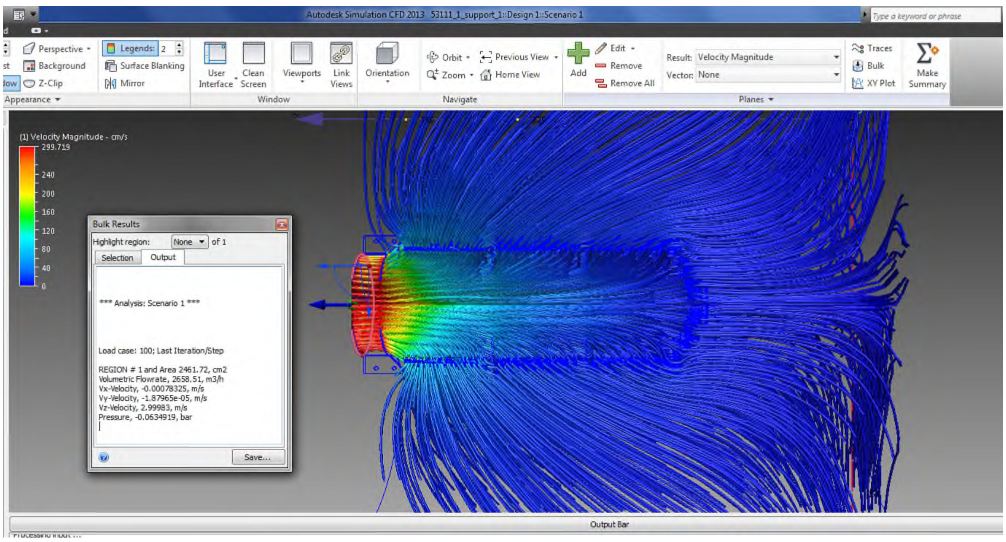
A4 PRESSURE LOSSES THROUGH STRAINER – CFD SOFTWARE

A model was developed for a previously manufactured strainer unit and a series of simulations was run to develop the pressure loss curve below:

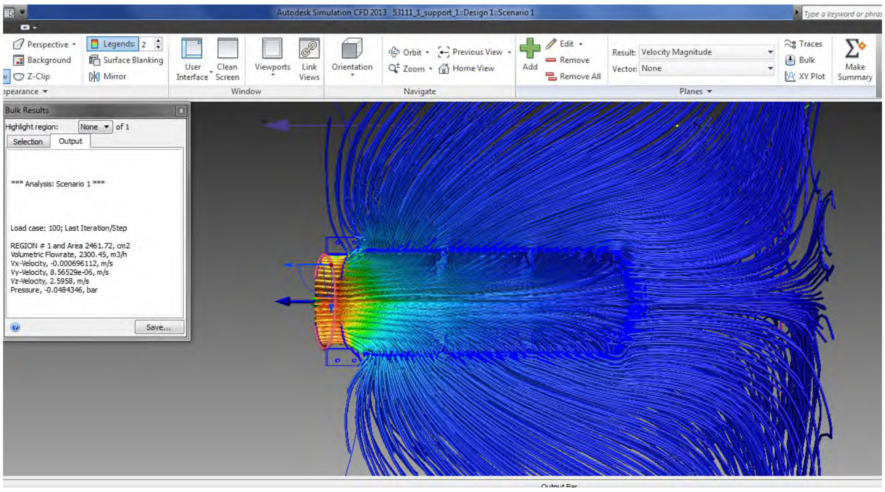




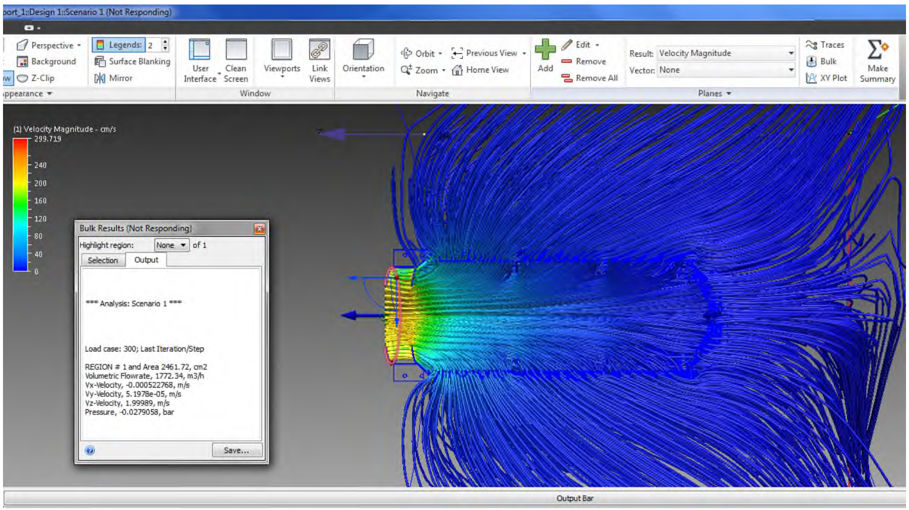
SWIR Velocity = 3.5m/s



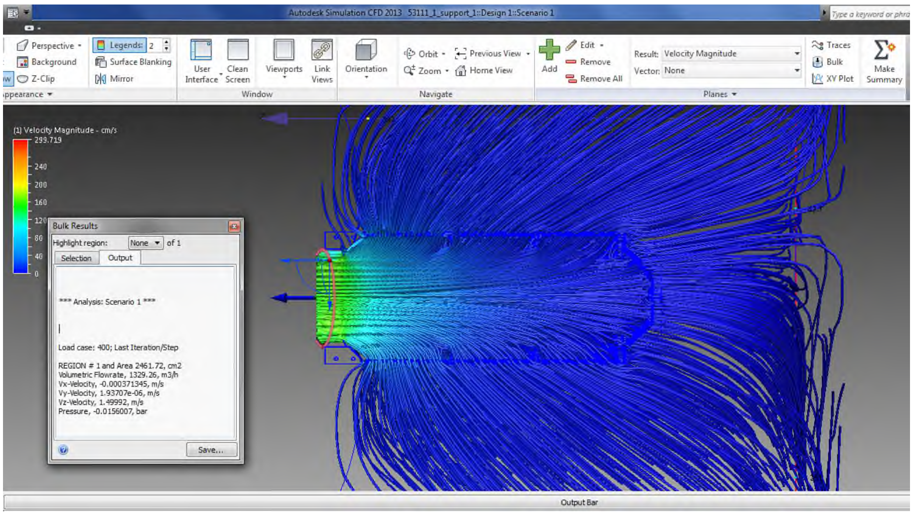
SWIR Velocity = 3.0m/s



SWIR Velocity = 2.5m/s



SWIR Velocity = 2.0m/s



SWIR Velocity = 1.5m/s

A5 SPREADSHEET CALCULATION OF PRESSURE LOSSES THROUGH 40"NB SWIR

Pressure Loss through Hose String

Enter Values in | WHITE | *cells only*

Section	Rubber	HDPE	Steel		
Length of Hose	138	253	103.5	*m*	
Outside Diameter	-	1067	1016	*mm*	
Wall Thickness	-	41	19.05	*mm*	
Inside Diameter	1000	985	977.9	*mm*	
Roughness	0.2	0.0015	0.05	*mm*	*Ref. Table 9.1*
Density of Fluid	1027.85			*kg/m^3*	
Viscosity of Fluid	1.6365E-06			*m^2/s*	
Flow Rate	8400			*m^3/hr*	
Velocity	2.97	3.06	3.11	*m/s*	
Relative Roughness	2.0E-04	1.5E-06	5.1E-05		
Reynolds No	1815394	1843040	1856421		
Friction Factor	0.0143	0.0106	0.0119	*Look up from Moody Tab*	
Hazen Williams Coefficient	130	150	140	*Ref. Table 9.1*	
Pressure Drop per Section	8944	13076	6253	*Pa*	*Note 1*
	0.089	0.131	0.063	*Bar*	
Total Pressure Loss	0.28272			*Bar*	
Pressure Drop per Section	0.083	0.126	0.061	*Bar*	*Note 2*
Total Pressure Loss	0.27051			*Bar*	
Strainer	0.06840			*Bar*	*Note 3*
Strainer	0.05849			*Bar*	*Note 4*
Combined Pressure Loss	**0.35112**			*Bar*	*Note 5*

Notes:

1. Pressure Loss calculated using D'Arcy-Weisbach Equation
2. Pressure Loss calculated using Hazen Williams Equation
3. Pressure Loss Calcualted from CFD analysis
4. Pressure Loss Calcualted using IPA graph
5. Combined Pressure Loss using D'Arcy-Weisbach & CFD Analysis Values

APPENDIX B: TEMPERATURE GAIN CALCULATIONS

B1 CALCULATION OF TEMPERATURE GAIN THROUGH 40”NB SEAWATER INTAKE RISER

[1]	$\dot{Q} = \lambda \cdot A_m \cdot \frac{T_1 - T_2}{t}$	(Gieck, 1996) eq. O62
[2]	$A_m = \pi \cdot d_m \cdot L$	(Gieck, 1996) eq. O63
[3]	$d_m = \frac{d_a - d_i}{ln\left(\frac{d_a}{d_i}\right)}$	(Gieck, 1996) eq. O63
[4]	$c_p = \frac{Q}{m \cdot \Delta t}$	(Gieck, 1996) eq. O9
[5]	$\varrho = \frac{m}{V}$	(Gieck, 1996) eq. O5

Where:

$\dot{Q}$ = Heat Energy/unit of time *(J/s)*

Q = Heat Energy *(J)*

λ = Thermal Conductivity *(W/m K)*

A_m = Mean Logarithmic Area *(m²)*

T_1-T_2 = Temperature Differential *(Pipe OD v Pipe ID) (K)*

t = Wall thickness *(m)*

d_m = Mean Diameter *(m)*

L = Length of Pipe *(m)*

d_a = Outside Diameter *(m)*

d_i = Inside Diameter *(m)*

c_p = Specific Heat *(J/kg K)*

m = mass *(kg)*

Δt = Temperature Differential *(Pipe Inlet v Pipe Outlet) (K)*

ρ = density *(kg/m³)*

V = Volume *(m³)*

The following sample calculation is considered to correlate the manual calculation technique with the CFD software:

λ = 50 *(W/m K)* - Steel

T_1-T_2 = 10 *(°C)*

L = 10 *(m)*

d_a = 1.016 (*m*)

d_i = 0.978 *(m)*

c_p = 4.182 *(kJ/kg K)* - Seawater

ρ = 1027.85 *(kg/m³)* – Seawater

V = 8,400 *(m³/hr)*

Transposing equations [1], [2] & [3] gives:

$$\dot{Q} = \frac{2\pi \cdot \lambda \cdot L \cdot (T_1 - T_2)}{\ln\left(\frac{d_a}{d_i}\right)}$$

So $$\dot{Q} = \frac{2\pi \cdot 50 \cdot 10 \cdot (10)}{\ln\left(\frac{1.016}{0.978}\right)}$$

$$\dot{Q} = 824154.9 \text{ J/s}$$

Transposing equations [4] & [5] gives:

$$\Delta t = \frac{\dot{Q}}{\dot{m} \cdot c_p}$$

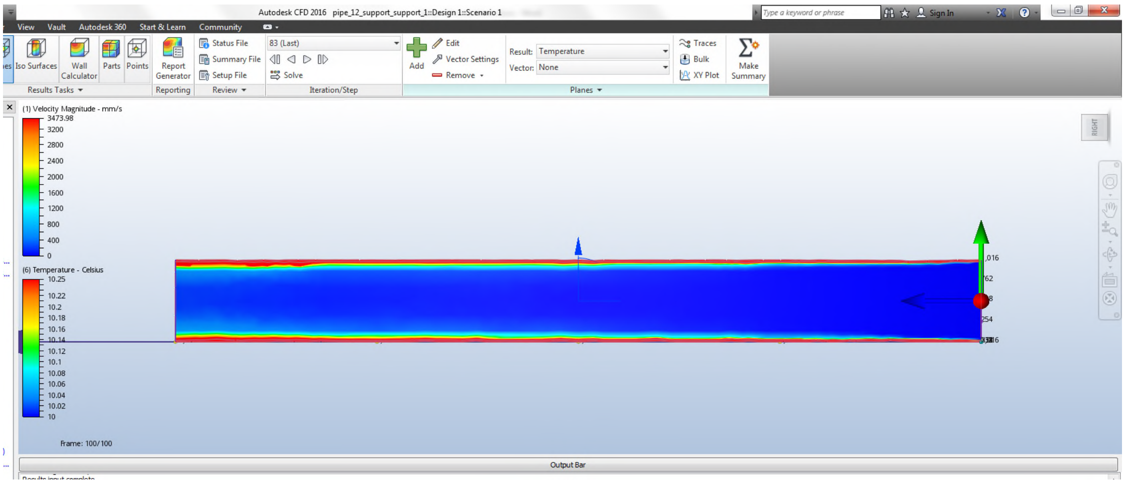
So $$\Delta t = \frac{824154.9}{\left(\frac{8400}{3600}\right) * 1027.85 * (4.182 * 1000)}$$

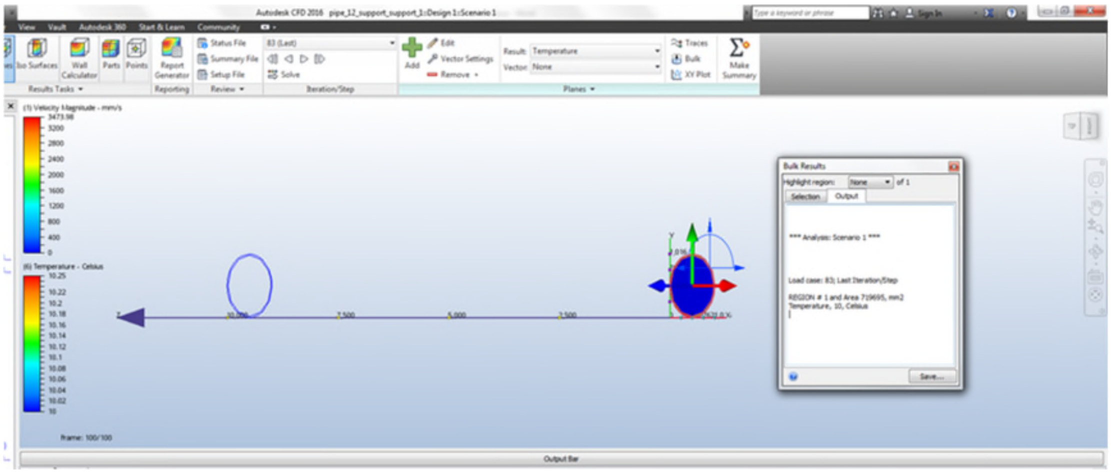
$$\Delta t = 0.082171 \text{ K (°C)}$$

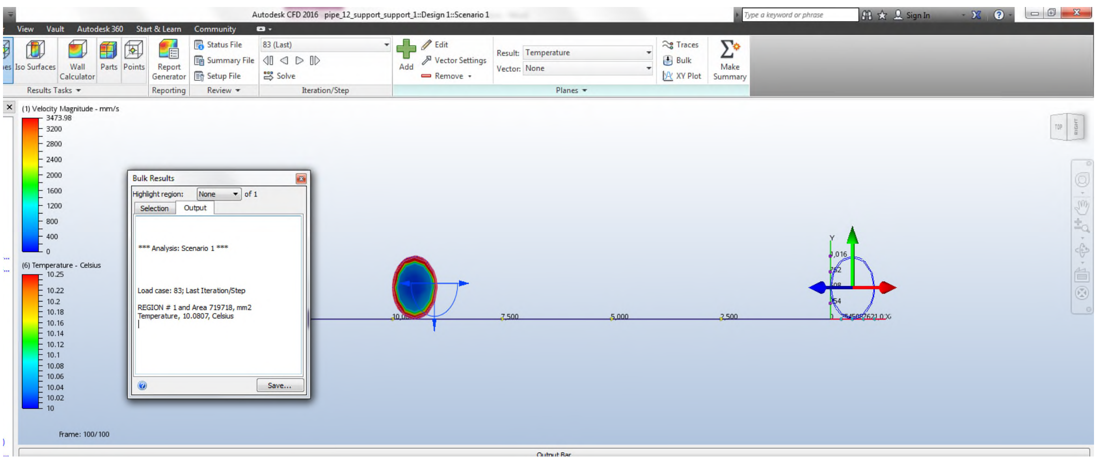
Using the above calculation, the spreadsheet presented in Appendix D3 was developed.

B2 CFD OF TEMPERATURE GAIN THROUGH 40"NB SWIR

To validate the sample calculation presented in Appendix D1, the same configuration was modelled and simulated in the Autodesk Simulation CFD 2013. Images and the results from the simulation are shown below:







B3 SPREADSHEET CALCULATION OF TEMPERATURE GAIN THROUGH 40”NB SWIR

Enter Values | White | cells only

Seawater Intake Riser Properties

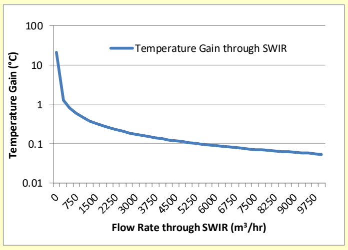
		Rubber	HDPE	Steel	
Thermal Conductivity	k	0.3	0.43	50	W/mK
Pipe OD	OD	1.22	1.067	1.016	m
Pipe ID	ID	1	0.98	0.978	m

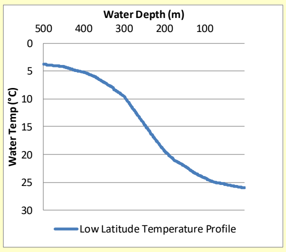
Seawater Properties

Flow Rate	f	10000	m^3/hr
Density	d	1.02785	SG
Specific Heat Capacity	cP	3.985	J/(kg.K)

Results

Inlet Temeprature	T_{in}	3.8000000	°C
Outlet Temperature	T_{out}	3.8610321	°C
Temperature Differential	T_{delta}	0.0610321	°C





Seawater Depth (m)	Seawater Temp (°C)	Riser Material	OD (m)	ID (m)	k (W/mK)	Inlet Temp (°C)	Heat Energy (W)	Temp Gain (°C)	Outlet Temp (°C)
500	3.8	Steel	1.0160	0.978	50	3.8	0	0	3.8
499	3.808	Steel	1.0160	0.978	50	3.8	65.93239291	5.7949E-06	3.800005795
498	3.816	Steel	1.0160	0.978	50	3.80000579	131.8170272	1.1586E-05	3.80001738
497	3.824	Steel	1.0160	0.978	50	3.80001738	197.6539373	1.7372E-05	3.800034752
496	3.832	Steel	1.0160	0.978	50	3.80003475	263.443158	2.3154E-05	3.800057907
495	3.84	Steel	1.0160	0.978	50	3.80005791	329.1847238	2.8932E-05	3.800086839
494	3.848	Steel	1.0160	0.978	50	3.80008684	394.8786691	3.4706E-05	3.800121545
493	3.856	Steel	1.0160	0.978	50	3.80012155	460.5250284	4.0476E-05	3.800162021
492	3.864	Steel	1.0160	0.978	50	3.80016202	526.1238363	4.6242E-05	3.800208263
491	3.872	Steel	1.0160	0.978	50	3.80020826	591.6751272	5.2003E-05	3.800260266
490	3.88	Steel	1.0160	0.978	50	3.80026027	657.1789355	5.776E-05	3.800318026
489	3.888	Steel	1.0160	0.978	50	3.80031803	722.6352955	6.3513E-05	3.800381539
488	3.896	Steel	1.0160	0.978	50	3.80038154	788.0442418	6.9262E-05	3.800450801
487	3.904	Steel	1.0160	0.978	50	3.8004508	853.4058085	7.5007E-05	3.800525808
486	3.912	Steel	1.0160	0.978	50	3.80052581	918.72003	8.0747E-05	3.800606555
485	3.92	Steel	1.0160	0.978	50	3.80060656	983.9869407	8.6484E-05	3.800693039
484	3.928	Steel	1.0160	0.978	50	3.80069304	1049.206575	9.2216E-05	3.800785254
483	3.936	Steel	1.0160	0.978	50	3.80078525	1114.378966	9.7944E-05	3.800883198
482	3.944	Steel	1.0160	0.978	50	3.8008832	1179.50415	0.00010367	3.800986866
481	3.952	Steel	1.0160	0.978	50	3.80098687	1244.58216	0.00010939	3.801096254
480	3.96	Steel	1.0160	0.978	50	3.80109625	1309.613029	0.0001151	3.801211357
479	3.968	Steel	1.0160	0.978	50	3.80121136	1374.596794	0.00012081	3.801332172
478	3.976	Steel	1.0160	0.978	50	3.80133217	1439.533486	0.00012652	3.801458694
477	3.984	Steel	1.0160	0.978	50	3.80145869	1504.423141	0.00013223	3.801590919
476	3.992	Steel	1.0160	0.978	50	3.80159092	1569.265793	0.00013792	3.801728843
475	4	Steel	1.0160	0.978	50	3.80172884	1634.061476	0.00014362	3.801872463
474	4.008	Steel	1.0160	0.978	50	3.80187246	1698.810223	0.00014931	3.802021773
473	4.016	Steel	1.0160	0.978	50	3.80202177	1763.512069	0.000155	3.80217677
472	4.024	Steel	1.0160	0.978	50	3.80217677	1828.167048	0.00016068	3.802337449
471	4.032	Steel	1.0160	0.978	50	3.80233745	1892.775194	0.00016636	3.802503807
470	4.04	Steel	1.0160	0.978	50	3.80250381	1957.33654	0.00017203	3.802675839
469	4.048	Steel	1.0160	0.978	50	3.80267584	2021.85112	0.0001777	3.802853542
468	4.056	Steel	1.0160	0.978	50	3.80285354	2086.318969	0.00018337	3.80303691
467	4.064	Steel	1.0160	0.978	50	3.80303691	2150.74012	0.00018903	3.803225941
466	4.072	Steel	1.0160	0.978	50	3.80322594	2215.114607	0.00019469	3.80342063
465	4.08	Steel	1.0160	0.978	50	3.80342063	2279.442464	0.00020034	3.803620972
464	4.088	Steel	1.0160	0.978	50	3.80362097	2343.723724	0.00020599	3.803826964
463	4.096	Steel	1.0160	0.978	50	3.80382696	2407.958422	0.00021164	3.804038602
462	4.104	Steel	1.0160	0.978	50	3.8040386	2472.146591	0.00021728	3.804255882
461	4.112	Steel	1.0160	0.978	50	3.80425588	2536.288264	0.00022292	3.804478799
460	4.12	Steel	1.0160	0.978	50	3.8044788	2600.383476	0.00022855	3.804707349
20	25.76	Rubber	1.2200	1	0.3	3.86066535	207.5891127	1.8245E-05	3.860683591
19	25.772	Rubber	1.2200	1	0.3	3.86068359	207.7026906	1.8255E-05	3.860701847
18	25.784	Rubber	1.2200	1	0.3	3.86070185	207.8162685	1.8265E-05	3.860720112
17	25.796	Rubber	1.2200	1	0.3	3.86072011	207.9298463	1.8275E-05	3.860738387
16	25.808	Rubber	1.2200	1	0.3	3.86073839	208.043424	1.8285E-05	3.860756672
15	25.82	Rubber	1.2200	1	0.3	3.86075667	208.1570015	1.8295E-05	3.860774967
14	25.832	Rubber	1.2200	1	0.3	3.86077497	208.270579	1.8305E-05	3.860793272
13	25.844	Rubber	1.2200	1	0.3	3.86079327	208.3841564	1.8315E-05	3.860811587
12	25.856	Rubber	1.2200	1	0.3	3.86081159	208.4977337	1.8325E-05	3.860829912
11	25.868	Rubber	1.2200	1	0.3	3.86082991	208.6113109	1.8335E-05	3.860848247
10	25.88	Rubber	1.2200	1	0.3	3.86084825	208.7248881	1.8345E-05	3.860866593
9	25.892	Rubber	1.2200	1	0.3	3.86086659	208.8384651	1.8355E-05	3.860884948
8	25.904	Rubber	1.2200	1	0.3	3.86088495	208.952042	1.8365E-05	3.860903313
7	25.916	Rubber	1.2200	1	0.3	3.86090331	209.0656188	1.8375E-05	3.860921688
6	25.928	Rubber	1.2200	1	0.3	3.86092169	209.1791956	1.8385E-05	3.860940073
5	25.94	Rubber	1.2200	1	0.3	3.86094007	209.2927722	1.8395E-05	3.860958467
4	25.952	Rubber	1.2200	1	0.3	3.86095847	209.4063487	1.8405E-05	3.860976872
3	25.964	Rubber	1.2200	1	0.3	3.86097687	209.5199252	1.8415E-05	3.860995287
2	25.976	Rubber	1.2200	1	0.3	3.86099529	209.6335015	1.8425E-05	3.861013712
1	25.988	Rubber	1.2200	1	0.3	3.86101371	209.7470778	1.8435E-05	3.861032147
0	26	Rubber	1.2200	1	0.3	3.86103215	0	0	3.861032147

Low LatitudeTemperature Profile

Water Depth (m)	*Temperature (°C)*
500	3.8
499	3.808
498	3.816
497	3.824
496	3.832
495	3.84
494	3.848
493	3.856
492	3.864
491	3.872
490	3.88
489	3.888
488	3.896
487	3.904
486	3.912
485	3.92
484	3.928
483	3.936
482	3.944
481	3.952
480	3.96
479	3.968
478	3.976
477	3.984
476	3.992
475	4
474	4.008
473	4.016
472	4.024
471	4.032
470	4.04
469	4.048
468	4.056
467	4.064
466	4.072
465	4.08
464	4.088
463	4.096
462	4.104
461	4.112
460	4.12
20	25.76
19	25.772
18	25.784
17	25.796
16	25.808
15	25.82
14	25.832
13	25.844
12	25.856
11	25.868
10	25.88
9	25.892
8	25.904
7	25.916
6	25.928
5	25.94
4	25.952
3	25.964
2	25.976
1	25.988
0	26

APPENDIX C: CFD SIMULATION REPORTS

C1 CFD REPORT - STRAINER PRESSURE LOSS

STRAINER CFD

Prepared by: Ian Craig

Date: Thursday, June 07, 2018

Report Contents

Summary

DESCRIPTION

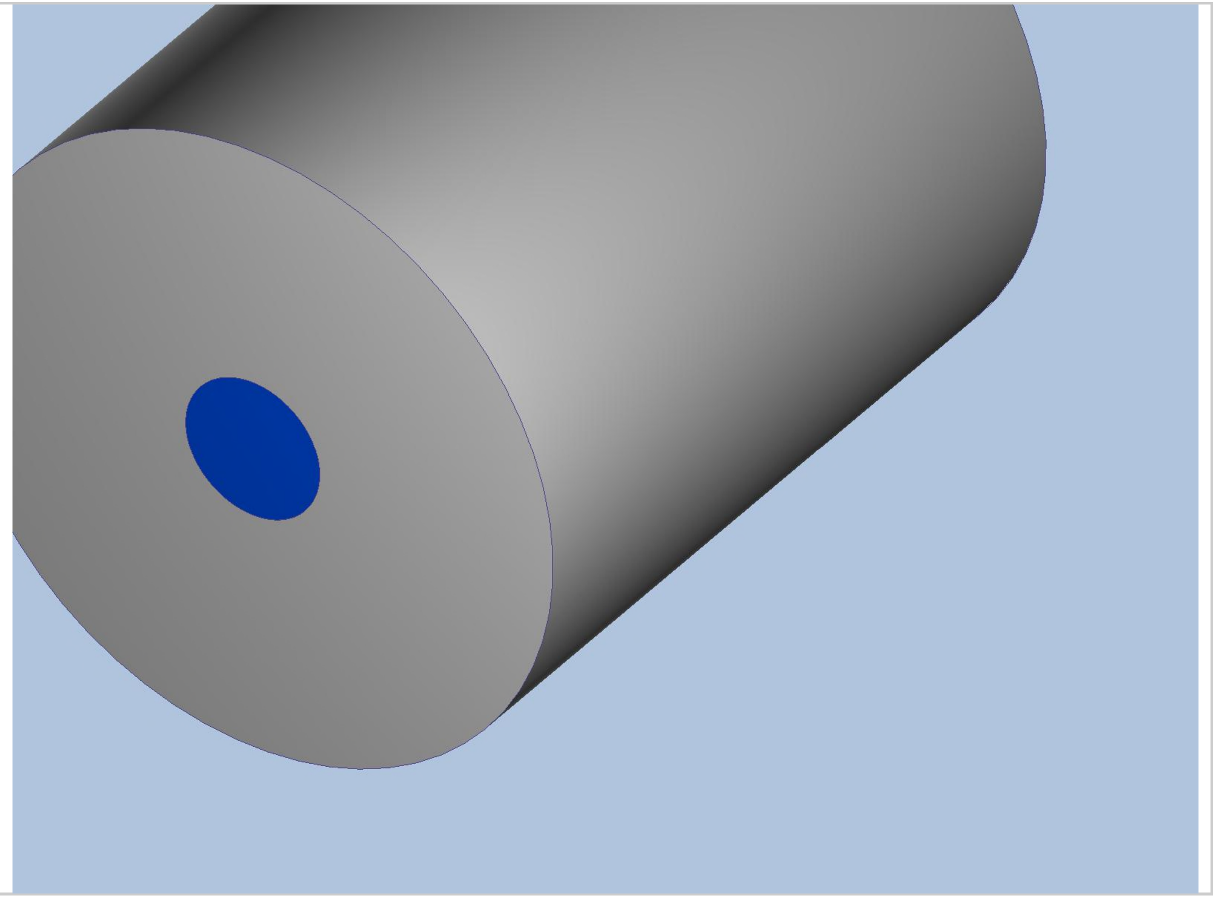
CFD to generate pressure loss curves through SWIR Strainer

Design 1

Length units	meter
Coordinate system	Cartesian 3D

SCENARIO 1

MATERIALS



NAME	ASSIGNED TO	PROPERTIES	
Steel	Part1.Solid1	X-Direction	Piecewise Linear
		Y-Direction	Same as X-dir.
		Z-Direction	Same as X-dir.
		Density	7833.0 kg/m3
		Specific heat	465.0 J/kg-K
		Emissivity	0.3
		Transmissivity	0.0
		Electrical resistivity	1.7e-07 ohm-m
		Wall roughness	0.0 meter
Sea Water (Liquid phase)	CFDCreatedVolume	Density	1021.2 kg/m3
		Viscosity	0.0011404 Pa-s
		Conductivity	0.59 W/m-K
		Specific heat	5608.2 J/kg-K
		Compressibility	2431320000.0 Pa
		Emissivity	1.0
		Wall roughness	0.0 meter
		Phase	Linked Vapor Material

BOUNDARY CONDITIONS

TYPE	ASSIGNED TO
Pressure(0 Pa Gage)	Surface:9359
Volume Flow Rate(441 m3/h)	Surface:9361

INITIAL CONDITIONS

TYPE	ASSIGNED TO

MESH

Automatic Meshing Settings

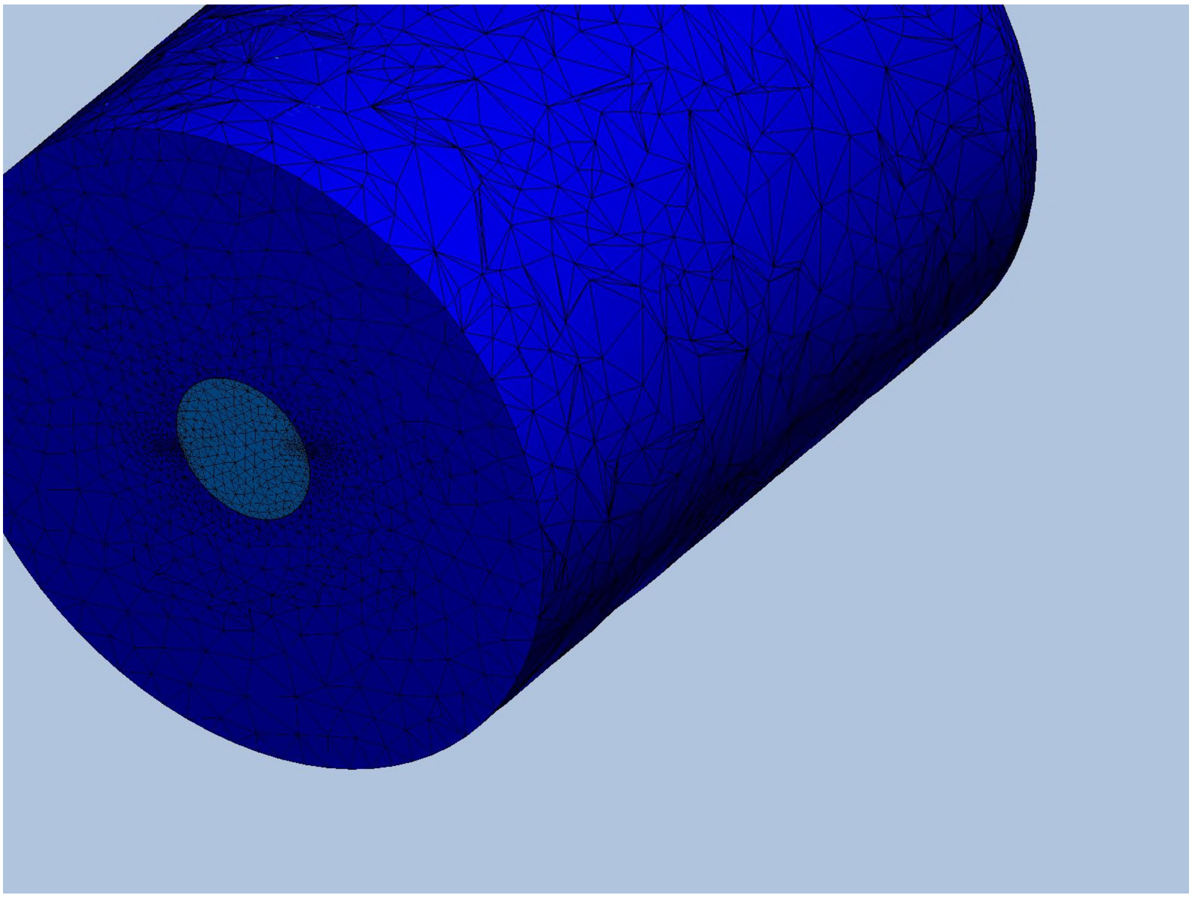
Surface refinement	0
Gap refinement	0
Resolution factor	1.0

Edge growth rate	1.1
Minimum points on edge	2
Points on longest edge	10
Surface limiting aspect ratio	20

Mesh Enhancement Settings

Mesh enhancement	1
Enhancement blending	0
Number of layers	3
Layer factor	0.45
Layer gradation	1.05

Meshed Model



Number of Nodes	918034
Number of Elements	4410104

PHYSICS

Flow	On
Compressibility	Incompressible
Heat Transfer	Off
Auto Forced Convection	Off
Gravity Components	0.0, 0.0, 0.0
Radiation	Off
Scalar	No scalar
Turbulence	On

SOLVER SETTINGS

Solution mode	Steady State
Solver computer	MyComputer
Intelligent solution control	On
Advection scheme	ADV 1
Turbulence model	k-epsilon

CONVERGENCE

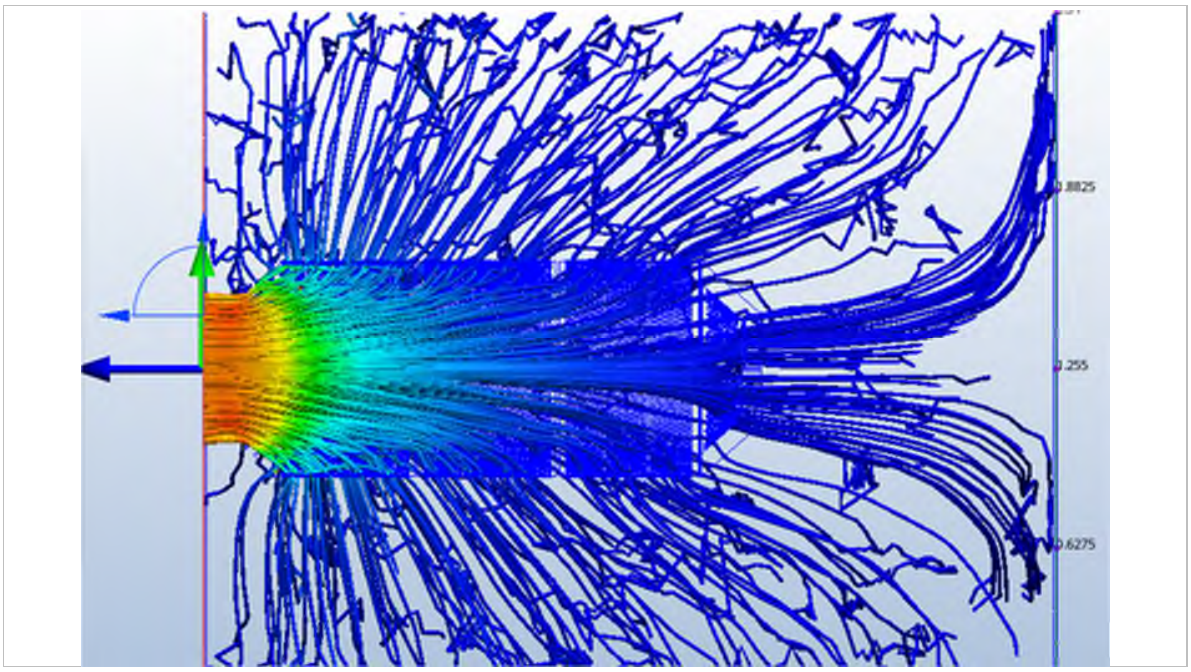
Iterations run	1167
Solve time	3783 seconds
Solver version	16.0.20150322

Energy Balance

Mass Balance

	IN	OUT
Mass flow	-125.097 kg/s	N.A.
Volume flow	-0.1225 m^3/s	N.A.

RESULTS



Inlets and Outlets

inlet 1	inlet bulk pressure	-145.813 N/m^2
	inlet bulk temperature	-0.0 C
	inlet mach number	3.41968e-08
	mass flow in	-125.097 kg/s
	minimum x,y,z of	0.0
	node near minimum	101294.0
	reynolds number	221173.0
	surface id	9361.0
	total mass flow in	-125.097 kg/s
	total vol. flow in	-0.1225 m^3/s
	volume flow in	-0.1225 m^3/s

Field Variable Results

VARIABLE	MAX	MIN
cond	54.4 W/m-K	0.59 W/m-K
dens	7833.0 kg/m^3	1021.2 kg/m^3
econd	590000.0 W/m-K	0.0 W/m-K
emiss	1.0	0.0
evisc	1140.4 kg/m-s	0.0 kg/m-s
gent	162654000.0 1/s	0.0 1/s
press	5732.16 N/m^2	-4693.13 N/m^2

ptotl	5732.16 N/m^2	-4693.13 N/m^2
scal1	0.0	0.0
seebeck	0.0 V/K	0.0 V/K
shgc	0.0	0.0
spech	5608.2 J/kg-K	465.0 J/kg-K
temp	0.0 C	0.0 C
transmiss	0.0	0.0
turbd	1.0126e+13 m^2/s^3	3.38774e-12 m^2/s^3
turbk	11025300.0 m^2/s^2	1.17287e-07 m^2/s^2
ufactor	0.0	0.0
visc	0.0011404 kg/m-s	0.0 kg/m-s
vx vel	1.32304 m/s	-1.75977 m/s
vy vel	2.24922 m/s	-1.89282 m/s
vz vel	1.73812 m/s	-2.07836 m/s
wrough	0.0 m	0.0 m

Component Thermal Summary

PART	MINIMUM TEMPERATURE	MAXIMUM TEMPERATURE	VOLUME AVERAGED TEMPERATURE
Part1.Solid1	0	0	0
CFDCreatedVolume	0	0	0

Fluid Forces on Walls

pressx	-184.33 Newtons
pressy	241.94 Newtons
pressz	-132.25 Newtons
shearx	-2.8376 Newtons
sheary	1.2754 Newtons
shearz	0.75847 Newtons

C2 CFD REPORT – SAMPLE PIPE TEMPERATURE GAIN REPORT

TEMPERATURE GAIN CALCULATION

Prepared by: Ian Craig

Date: Thursday, June 07, 2018

Report Contents

Summary

DESCRIPTION

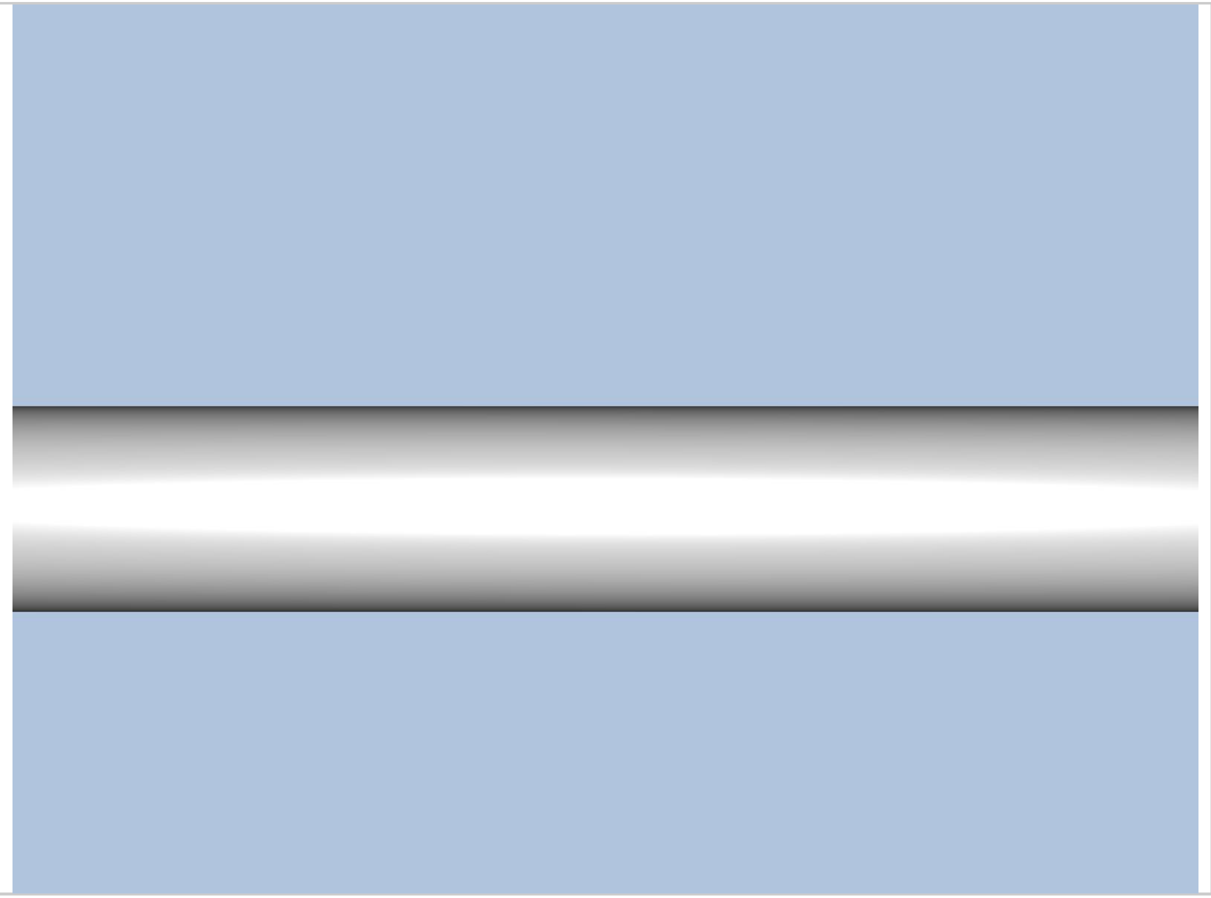
CFD to validate manual temperature gain calculation

Design 1

Length units	mm
Coordinate system	Cartesian 3D

SCENARIO 1

MATERIALS



NAME	ASSIGNED TO	PROPERTIES	
Steel	pipe	X-Direction	Piecewise Linear
		Y-Direction	Same as X-dir.
		Z-Direction	Same as X-dir.
		Density	7833.0 kg/m3
		Specific heat	465.0 J/kg-K
		Emissivity	0.3
		Transmissivity	0.0
		Electrical resistivity	1.7e-07 ohm-m
		Wall roughness	0.0 meter
Sea Water (Liquid phase)	CFDCreatedVolume	Density	0.00102785 g/mm3
		Viscosity	0.0011404 Pa-s
		Conductivity	0.59 W/m-K
		Specific heat	4.182 J/g-K
		Compressibility	2431320000.0 Pa
		Emissivity	1.0
		Wall roughness	0.0 meter
		Phase	Linked Vapor Material

BOUNDARY CONDITIONS

TYPE	ASSIGNED TO
Temperature(20 Celsius)	Surface:1
Volume Flow Rate(8400 m3/h)	Surface:5 Surface:6
Temperature(10 Celsius)	Surface:5

INITIAL CONDITIONS

TYPE	ASSIGNED TO

MESH

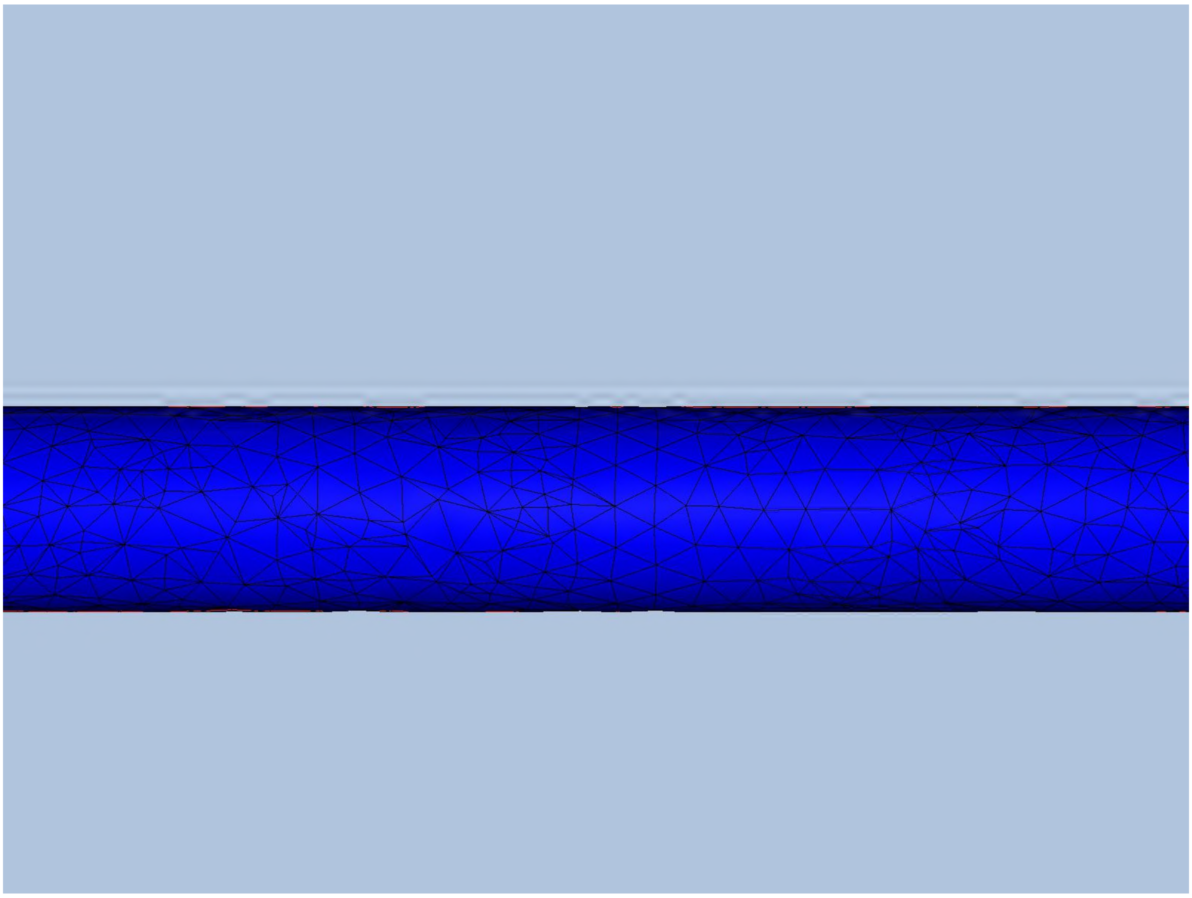
Automatic Meshing Settings

Surface refinement	0
Gap refinement	0
Resolution factor	1.0
Edge growth rate	1.1
Minimum points on edge	2
Points on longest edge	10
Surface limiting aspect ratio	20

Mesh Enhancement Settings

Mesh enhancement	1
Enhancement blending	0
Number of layers	3
Layer factor	0.45
Layer gradation	1.05

Meshed Model



Number of Nodes	5030
Number of Elements	16579

PHYSICS

Flow	On
Compressibility	Incompressible
Heat Transfer	On
Auto Forced Convection	Off
Gravity Components	0.0, 0.0, 0.0
Radiation	Off
Scalar	No scalar
Turbulence	Off

SOLVER SETTINGS

Solution mode	Steady State
Solver computer	MyComputer
Intelligent solution control	On
Advection scheme	ADV 1
Turbulence model	

CONVERGENCE

Iterations run	83
Solve time	6 seconds
Solver version	16.0.20150322

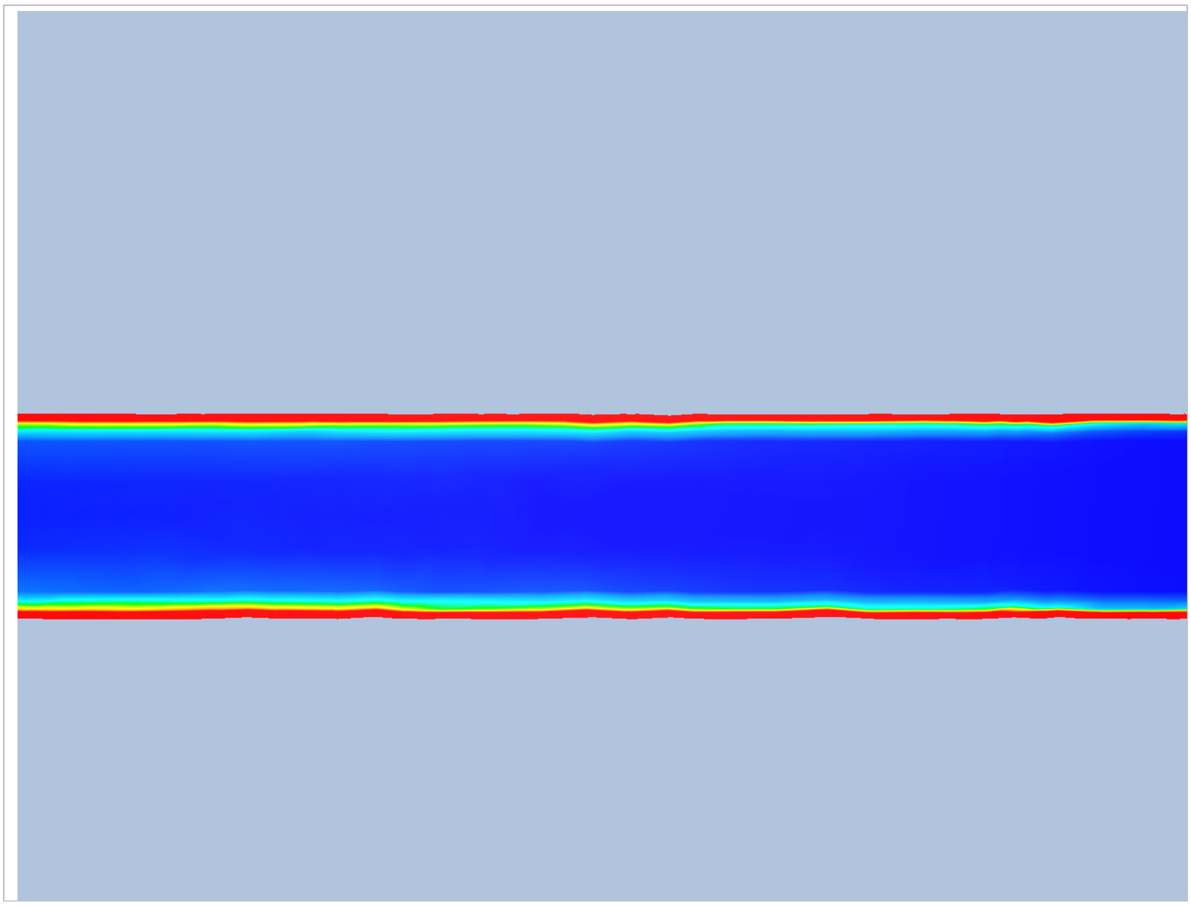
Energy Balance

Fluid Energy Balance Information	(numerical) energy out -	-597.59 Watts
	heat transfer due to sources in	0.0 Watts
	heat transfer from wall to	797130.0 Watts
	mdotin x cp x (tout - tin)	-1.103e-06 Watts
Solid Energy Balance Information	heat transfer due to sources in	0.0 Watts
	heat transfer from exterior to	805770.0 Watts
	heat transfer from fluid to	-797130.0 Watts

Mass Balance

	IN	OUT
Mass flow	0.0 g/s	N.A.
Volume flow	0.0 mm^3/s	N.A.

RESULTS



Inlets and Outlets

inlet 1	inlet bulk pressure	2452.48 N/m^2
	inlet bulk temperature	10.0807 C
	inlet mach number	2.21339e-07
	mass flow in	-2398310.0 g/s
	minimum x,y,z of	0.0
	node near minimum	66.0
	reynolds number	2479280.0
	surface id	6.0
	volume flow in	-2333330000.0
inlet 2	inlet bulk pressure	2452.0 N/m^2
	inlet bulk temperature	10.0 C
	inlet mach number	2.2137e-07
	mass flow in	2398310.0 g/s
	minimum x,y,z of	0.0

	node near minimum	57.0
	reynolds number	2479280.0
	surface id	5.0
	total mass flow in	9.31323e-10 g/s
	total vol. flow in	9.53674e-07 mm^3/s
	volume flow in	2333330000.0

Field Variable Results

VARIABLE	MAX	MIN
cond	0.0544 W/mm-K	0.00059 W/mm-K
dens	0.007833 g/mm^3	0.00102785 g/mm^3
econd	0.0 W/mm-K	0.0 W/mm-K
emiss	1.0	0.0
evisc	0.0 g/mm-s	0.0 g/mm-s
gent	1.0 1/s	0.0316228 1/s
press	2578.94 N/m^2	2452.0 N/m^2
ptotl	8654.34 N/m^2	0.0 N/m^2
scal1	0.0	0.0
seebeck	0.0 V/K	0.0 V/K
shgc	0.0	0.0
spech	4.182 J/g-K	0.465 J/g-K
temp	20.0 C	10.0 C
transmiss	0.0	0.0
turbd	0.0 mm^2/s^3	0.0 mm^2/s^3
turbk	0.0 mm^2/s^2	0.0 mm^2/s^2
ufactor	0.0	0.0
visc	0.0011404 g/mm-s	0.0 g/mm-s
vx vel	118.312 mm/s	-85.4687 mm/s
vy vel	156.144 mm/s	-121.219 mm/s
vz vel	3473.94 mm/s	0.0 mm/s
wrough	0.0 mm	0.0 mm

Component Thermal Summary

PART	MINIMUM TEMPERATURE	MAXIMUM TEMPERATURE	VOLUME AVERAGED TEMPERATURE
pipe	10	20	16.385
CFDCreatedVolume	10	10.9672	10.1213

Fluid Forces on Walls

pressx	-379230.0 microNewtons
pressy	-939090.0 microNewtons
pressz	275350.0 microNewtons
shearx	204.12 microNewtons
sheary	903.82 microNewtons
shearz	3965800.0 microNewtons

Decision Center

Section 10.0: Publications & Patents

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Review of Bonded Rubber Flexible Hose Design Codes and Guidelines in Relation to Sea Water Intake Risers on FPSO Vessels

Ian Craig, Hart Consultancy Services

Abstract

Sea Water Intake Risers (SWIR) used on Floating Production Storage and Offloading (FPSO) vessels generally comprise of a series of bonded flexible rubber hose sections suspended as a free hanging cantilever from the underside of the vessel, a configuration unique to this application. This paper identifies the industry codes and guidelines associated with the design and manufacture of bonded flexible rubber hoses and determines those most appropriate for a SWIR application to assure the satisfactory operation and life in field.

The associated industry codes and guidelines are analysed and critically appraised to determine which provide the most relevant verification and validation criteria for the design and manufacture of bonded flexible rubber hoses used in a SWIR application with due consideration given to the specific requirements of these bonded flexible rubber hoses which, in addition to the transportation of untreated seawater, also need to accommodate the loads induced by self-weight, vessel motion and environmental forces.

The paper concludes that there are a number of industry codes and guidelines related to the design and manufacture of bonded flexible rubber hoses. However, whilst there are criteria from several of these industry codes and guidelines that may be applied, the design and manufacture of bonded flexible rubber hoses for a SWIR application is not specifically covered by the scope of any one of the documents reviewed. Consequently, the paper identifies the most relevant criteria from the reviewed documents and sets out a propped methodology to verify and validate the design and manufacture of a flexible hose in a SWIR application.

Although this paper proposes a set of verification and validation criteria specifically intended for the design and manufacture of bonded flexible rubber hoses used for SWIR applications on FPSO vessels, it should be noted that these systems are also currently being considered by several stakeholders for similar application on the emerging Floating Liquefied Natural Gas (FLNG) vessels.

Introduction

As the onshore, shallow water and more easily accessible oil reserves become depleted, oil companies are taking oil exploration and production to deeper and less accessible locations. This has seen an emergence of floating oil production installations, often referred to as FPSO (Floating Production Storage and Offloading) vessels, where the water depth makes a fixed leg platform impractical or where the reservoir location is too remote from a pipeline infrastructure. In many locations, particularly the warm water locations such as West Africa and Brazil, process engineers have found it beneficial to use cooler, cleaner and less oxygenated seawater from below sea level for the vessel's cooling, process, utility and water injection systems. This is achieved using Seawater Intake Risers, the utilization of which is fairly recent in the industry, with the first systems being installed circa. 2000.

A Seawater Intake Riser (SWIR) is effectively a number of flexible pipe sections suspended as a cantilever from the underside of the vessel (a configuration unique to this application), connected to the lower end of the seawater caissons or sea chests, which enable the seawater pumps to import seawater from below the surface. The quantity, length and diameter of the SWIR is specific to the requirements of each installation but to date, the maximum depths achieved have been approximately 120-130m with diameters of typically between 20"NB-40"NB. Each SWIR is field specific and is designed accordingly, i.e. subject to a hydrodynamic analysis which considers the vessel response characteristics, the field specific metocean data and extreme conditions and the flexible pipe properties, which can be optimised to suit the required configuration.

As the dependency of these systems increases then so does the criticality and consequently stakeholders are seeking assurances of asset integrity for the SWIR. A key element within the SWIR is the flexible pipe section itself, and in particular the top hose that connects the system to the underside of the vessel, as this is the component that will see the most arduous conditions in terms loads and moments during service. Bonded flexible pipes have been preferred for this application due to the robustness, short length and ease of handling and to ensure that the bonded flexible pipe is fit for purpose, design codes and guidelines are often included within the Purchase Specifications provided by stakeholders.

The objective of this paper is to identify the industry codes and guidelines associated with the design and manufacture of bonded flexible pipes and determine those most appropriate to assure satisfactory operation and life in field for a SWIR application.

However, before reviewing the relevant industry codes and guidelines, it is first necessary to understand the function of the SWIR. As indicated above, the SWIR transports raw seawater and operates at a negative pressure as opposed to a positive pressure. The SWIR is open ended and free flooding and therefore not exposed to external hydrostatic pressure. Diameters of SWIR currently in operation are typically between 20"- 40"NB (500-1000mm), although recent studies have been undertaken for SWIR up to 60"NB (1500mm) for the emerging FLNG market. The configuration of the SWIR is that of a free hanging cantilever, it is fixed at the upper end but unconnected at the lower end, the figure below shows a typical arrangement of SWIR on an FPSO.

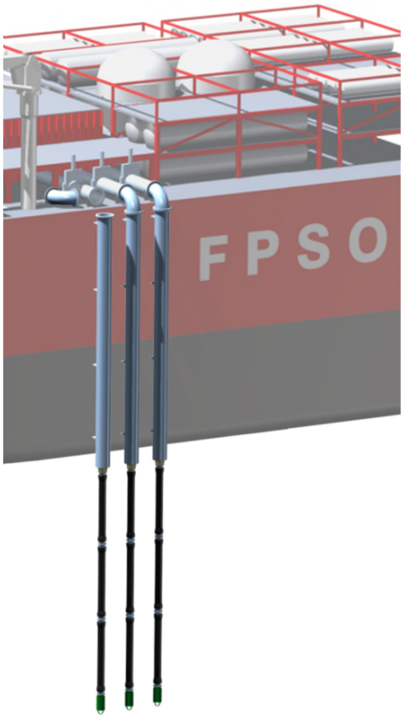

Fig 1.: Typical Seawater Intake Riser (SWIR) Arrangement on FPSO

Whereas steels rings or helixes are generally used to provide circumferential strength against collapse due to suction, the tensile capabilities of the bonded flexible pipes are achieved through reinforcement with steel or textile cord. As the SWIR is not pressure containing, the main function of the reinforcement layers is to provide axial strength as opposed to circumferential strength and as such, textile reinforcement is often preferred as it enables a high axial strength to be achieved without the corresponding circumferential strength. Steel reinforcement cables are typically utilised to provide high axial and circumferential strength for pressure containment associated with high pressure discharge hoses. In addition to this, the use of textile reinforcement enables the hose to be designed with inherent axial flexibility which acts as a damping spring when the hose system is subject to the vessel and environmental motions. Steel reinforcement cables do not offer as much axial flexibility which can be considered disadvantageous in this application. It is also known that steel cable reinforcement does not perform well under compressive loads. As the SWIR is constantly submerged during operation, should any undetected damage occur during installation, seawater may penetrate the outer cover and come into contact with the reinforcement layers which for textile reinforcement would not be detrimental. However, if steel reinforcement cables became exposed to seawater, corrosion of the reinforcement would be inevitable. It has generally been considered within the industry that textile reinforced hoses have better fatigue properties than steel cable reinforced hoses, and recent analysis overseen by the author supports this opinion.

Therefore, from the above, the general functions of the bonded flexible pipe within a SWIR can be summarised as follows:

- *Pressure: Negative (i.e. Suction)*
- *Media: Seawater*
- *Nominal Diameter: 20”–40”NB (500mm-1000mm)*
- *Configuration: Free Hanging Cantilever*

Industry Codes and Guidelines

Large bore bonded flexible pipes have been used in the marine industry for many years, the first application of such hoses could arguably be within the dredging industry where both suction and discharge hoses are used to transport seawater, silt and rocks from the seabed to dredge vessels. However, as the offshore oil and gas industry has evolved, then so too have a number of specifications, standards and guidelines relating to bonded flexible pipes within the industry. The following is an overview of the industry codes and guidelines most commonly associated with the design, manufacture and testing of bonded flexible pipes:

EN ISO 1403 Rubber Hoses, textile-reinforced, for general-purpose water applications (1)

The scope of EN ISO 1403 (ISO 1403) specifies the requirements of general-purpose textile reinforced rubber water hose with a maximum working pressure of 2.5MPa (25 bar). The hose bore is specified as between 10mm–100mm (3/8”-4”) diameter (although provision is made for smaller or larger dimensions). The application is general purpose water hose but specifically excludes a number of applications e.g. fire-fighting, potable water. The standard includes a number of test requirements, including tensile test, accelerated ageing, hydrostatic test, adhesion, ozone resisitance and low temperature flexibility.

Oil Companies International Marine Forum (OCIMF). Guide to Manufacturing and Purchasing Hoses for Offshore Mooring (GMPHOM2009) (2)

OCIMF Guide to Manufacturing and Purchasing Hoses for Offshore Mooring (GMPHOM2009) (OCIMF) states it’s purpose as providing technical recommendations and guidance to ensure satisfactory performance of elastomer, reinforced, smooth bore, oil suction and discharge hoses commonly used at offshore moorings. The scope is specified as single or double carcass hoses and includes submarine hoses, floating hoses, part-floating hoses, tanker rail hoses, tapered bore hoses, catenary hoses and reeling hoses. The diameters covered by OCIMF are stated as 150mm, 200mm, 250mm, 300mm, 400mm, 500mm and 600mm (6”-24”NB) with pressure ratings of between 15-21 barg (1.5-2.1MPa).

ISO 13628 Design and operation of subsea production systems - Part 10 Specification for Bonded Flexible Pipe (API 17K) (3)

The applications addressed by ISO 13628 Part 10 (API 17K) are stated as sweet and sour production (including export and injection applications) and include oil, gas, water and injection chemicals and applies to static and dynamic flexible pipes used as flowlines, risers, jumpers and offloading and discharge hoses. It does not specify a range of diameters but is intended for pipes with a design pressure greater than or equal to 15 barg. It indicates that it can be used for lower pressure but states that the requirements of low pressure pipes have not been specifically addressed.

ISO 13628-11:2007 (Identical), Petroleum and natural gas indistries - Design and operation of subsea production systems - Part 11 Flexible pipe systems for subsea and marine applications (API RP 17B Recommended Practice for Flexible Pipe) (4)

The scope of ISO 13628 Part 11 (API RP17B) is to provide guidelines for the design, analysis, manufacture, testing, installation and operation of flexible pipes and systems and supplements ISO 13628-10 (API 17K).

API 16C Specification for Choke and Kill System (5)

The purpose of API 16C Specification for Choke and Kill System (API 16C) is to ensure safe and functionally interchangeable choke and kill system equipment used for drilling oil and gas wells. The application of the specification covers most equipment normallly associated with these systems including flexible choke and kill lines with bores sizes of between 2”-4”NB (50-100mm) and pressure ratings of between 345-1380barg (34.5-138MPa). The specific function of flexible Choke and Kill lines are as an integral part of the well control system.

API 7K Specification for Drilling and Well Servicing Equipment (6)

The scope of API 7K Specification for Drilling and Well Servicing Equipment (API 7K) provides general principles and specifies requirements for design, manufacture and testing of new drilling and well servicing equipment.

This specification includes a section applicable to high pressure mud and cement hoses assemblies with bores sizes of between 2”-6”(50-150mm) and pressure ratings of between 103-1034barg (10.3-103.4MPa).

EN ISO 28017 Rubber hoses and hose assemblies, wire or textile reinforced, for dredging application (7)

EN ISO 28017 (ISO 28017) specifies the requirements of wire or textile reinforced dredging hoses with bore sizes ranging from 100–1200mm (4”-48”NB) and pressure ratings up to 40bar (4MPa). The service is stated as delivery or suction of seawater or fresh water mixed with silt, sand, coral and small stones with an SG range from 1.0 to 2.3. The standard covers both floating (delivery only) and submarine (delivery and suction) type hoses.

Table 1 below summarises the main scope of each of the above industry codes and guidelines and table 2 identifies the comparable parameters of a bonded flexible pipe utilized within a SWIR:

Code or Guideline	Flexible Pipe Diameter	Suction or Discharge	Pressure Rating	Reinforcement		Service
				Wire	Textile	
ISO 1403	10-100mm (3/8”-4”NB)	Discharge	<25 bar (<2.5 MPa)		X	Water
OCIMF	150-600mm (6”NB-24”NB)	Suction & Discharge	15-21 bar (1.5-2.1 MPa)	X	X	Oil
API 17K	Not specified	Discharge	>15 bar (>1.5 MPa)	X	Note 1)	Production Products
API 17B	Not specified	Discharge	>15 bar (>1.5 MPa)	X	Note 1)	Production Products
API`16C	2”-4” (50-100mm)	Discharge	345-1080 bar (34.5-108 MPa)	X		Choke & Kill Fluid
API 7K	2”-6” (50-150mm)	Discharge	103-1034 bar (10.3-103.4MPa)	X		Mud & Cement
ISO 28017	100-1200mm (4”-48”NB)	Suction & Discharge	<40 bar (<4.0 MPa)	X	X	Fresh Water, Seawater, Silt, etc.

Notes:
1) Not specifically addressed

Table 1: Summary of Scope of Industry Codes and Guidelines

Code or Guideline	Flexible Pipe Diameter	Suction or Discharge	Pressure Rating	Reinforcement		Service
				Wire	Textile	
-	(20”-40”NB) 500-1000mm	Suction	<10 bar (typ) (<1.0 MPa)		Preferred	Seawater

Table 2: Seawater Intake Riser (SWIR) Parameters

When comparing the scope of table 1 with the SWIR parameters within table 2, a number of the codes and guidelines can be discounted. For example, the scope of ISO 1403 is for small bore, low pressure delivery hoses typically used in industrial applications. Likewise, API 16C and API 7K are specifically for small bore, high pressure delivery hoses intended for Choke & Kill Systems and Mud & Cement Hoses respectively, used in drilling applications.

Therefore the following appraisal is made on the following three documents OCIMF, API17K and ISO 28017. For the purposes of this document, wherever, API 17K is referred to, it includes the supplementary document API RP 17B. The appraisal contrasts and compares a number of aspects of each of these documents, namely; Scope & Application, Design, Materials, Manufacture, Test and Documentation.

Scope & Application

OCIMF is specifically intended for the loading and offloading of oil in both suction and delivery applications. The guideline covers single and double carcass hoses, (double carcass hoses having a secondary carcass to provide containment of a potential leak in the primary carcass) and makes provision for both textile and steel reinforcement layers.

API 17K has a more general scope although further examination of the specification indicates that it is intended for hydrocarbon products with a delivery pressure of 15 bar or greater, but does state that, although not specifically addressed, it can be used for lower design pressures, however it refers the user to OCIMF for guidelines on these pipes. Consequently, it makes provision for features such as; Sour Service, Multiple Steel Reinforcement, Internal Steel Carcass etc. It does state that the specification can be applied to flexible pipes using non-metallic reinforcement in a water supply application but advises that no effort was made to address the specific and unique aspects of either of these. It goes on to state that the onus is on the purchaser to specify the design and test requirements relating to the use non-metallic reinforcement

The scope of ISO28017 is for wire or textile reinforced hoses intended for the dredging industry, transporting seawater or fresh water mixed with silt, sand, coral and small stones. It specifies two types of hose, namely, Type 1 & Type 2 but as Type 1 is floating delivery hose, only Type 2 (submarine, delivery and suction) is applicable. Type 2 is further divided into three grades, namely A,B or C but as grade C is for delivery hoses, only grade A & B need to be considered. Grades A & B are then sub-divided into three classes based on maximum working pressure, 5, 10 or 15 bar.

Design

OCIMF does specify a number of performance requirements such as rated working pressure, operating velocity, allowable axial load and flexibility. Although the guideline does not specifically address life in field, it does provide certain design requirements such as minimum liner and cover thickness and tensile strength of reinforcement wires.

API 17K does provide a basis of design for flexible pipes which includes determination of loads and load effects and design criteria. It also includes a design methodology and design requirements for each of the components within the composite structure including fatigue analysis parameters. It effectively requires that the flexible pipe design should be demonstrably suitable for the intended service and life in the field. It should be noted that a design fatigue factor (DFF) of 10 is specified by API 17K.

ISO 28017 does not specify requirements relating to the service life of the hoses, instead it indicates that this should be the responsibility of the customer in consultation with the hose manufacturer. It does however provide minimum requirements in terms of rubber liner and cover thickness in relation to hose diameters.

Materials

OCIMF specifies material grades for end fittings and minimum tensile strength of reinforcement wires. It also requires that material testing of the rubber compounds is conducted and recorded and specifies the required tests, test method and acceptance criteria. Furthermore, adhesion tests are required to verify the adhesion strength between the composite plies, with an acceptance criteria stated.

API 17K states that the manufacturer should have records to demonstrate that all materials used within bonded flexible pipe are suitable for the functional requirements throughout the service life of the pipe. It provides a comprehensive matrix of property requirements tests for both the elastomer materials and the metallic components. It goes on to provide test methods for each of these tests.

ISO 28017 specifies material tests, including test methods and acceptance criteria, for the liner and outer cover.

Manufacture

OCIMF requires that a prototype of each hose type is manufactured at the manufacturers plant in conditions representative to that of normal hose production. The prototype hose is to be built in accordance with the manufacturers specification and tested in accordance with the manufacturers test procedures. Each prototype hose will be subject to a suite of tests, witnessed and verified by a Classification Society, to obtain approval. Only when the prototype has demonstrably met the acceptance criteria can the design be approved by OCIMF. Subsequent production hoses are to be manufactured in accordance with the approved prototype hose specifications and procedures and subject to a series of individual tests.

API 17K provides comprehensive requirements in regard to manufacturing. It requires that all the major processes shall be documented in the manufacturers specifications and procedures which should also include handling of the products. It states that the process control should be effected by a quality control plan and the lists the general requirements and inspection and acceptance criteria for various layers of the construction. Testing is to be performed on samples during production to verify the processes and tolerances for the finished pipes are to be in accordance with the manufacturers specification. API will grant approval once all requirements have been satisfactorily met.

ISO 28017 provides dimensional and tolerance specifications for the diameter and hose length.

Test

OCIMF specifies two ranges of tests, one set for each prototype hose and another for each production hose, these tests can be summarized as follow:

Test	Prototype Hose	Production Hose	Comments
Material Tests	X	X	
Adhesion Tests	X	X	
Buoyancy Recovery Test	X		
Weight Test	X	X	
Collar Test	X		
Minimum Bend Radius Test	X	X	
Bending Stiffness Test	X	X	
Torsion Test	X	X*	*if specified
Tensile Test	X	X*	*if specified
Dynamic Test	X		
Hydrostatic Pressure Test	X	X	
Kerosene Test	X	X*	*if specified
Vacuum Test	X	X	
Electrical Test	X	X	
Burst Test	X		
Double Carcass Burst Test	X		
Float Hydrostatic Test		X	
Lifting Lug Acceptance Test	X	X	
Crush Test	X		

Table 3: Summary of Tests required by OCIMF

API17K specifies a number of factory acceptance tests for the finished pipe and also the acceptance criteria for each test. These can be summarized as follows:

Test	Without Cathodic Protection		With Cathodic Protection		Comments
	With Carcass	*Without Carcass*	*With Carcass*	*Without Carcass*	
Gauge Test	X		X		
Hydrostatic Pressure Test	X	X	X	X	
Electrical Resistance Test			X		
Electrical Continuity			X	X	
Kerosene Test		X*		X*	*upon customer request
Vacuum Test		X*		X*	*upon customer request

Table 4: Summary of Tests required by API 17K

It should be noted that API RP 17B provides guidelines for prototype tests (to be agreed between manufacturer and purchaser) but also indicates that, alternatively, the design requirements can be satisfied with objective evidence such as field experience, test data, FEA etc. The prototype tests can be summarized as follows:

Class	Type	Description	Comments
I	Standard Prototype Tests	Burst pressure test	
		Axial tension test	
		Collapse test	
II	Special Prototype Tests	Dynamic fatigue test	
		Crush strength test	
		Combined bending & tensile test	
		Sour-service test	
		Fire test	
		Erosion test	
		TFL test	
		Vacuum test	
		Kerosene test	
		Adhesion test	
		Full-scale blistering test	
III	Characterization and other prototype tests	Bending stiffness test	
		Torsional stiffness test	
		Abrasion test	
		Rapid decompression test	
		Axial compression test	
		Thermal-characteristics test	
		Temperature test	
		Arctic test	
		Weathering test	
		Structural damping test	

Table 5: Summary of Prototype Tests listed in API RP 17B

ISO 28017 provides two sets of tests, one entitled Type Tests and the other Routine Tests. The Type Tests are to be applied to a prototype of each hose type and repeated every 10 years whereas the Routine Tests are to be applied to each finished hose prior to dispatch into the field. These test can be summarised as follows:

Test	Type Test	Routine Test	Comments
Compound Tests	X	X	
Dimensional Tests (ID, OD, Length & Flange)	X	X	
Burst Test	X		
Change in Length at MWP	X	X*	*frequency to be agreed
Bending Test	X	X*	*frequency to be agreed
Leak Test	X	X*	*frequency to be agreed
Reserve Buoyance Check	X	X	
Buoyancy Recovery Test	X		
Adhesion Test	X		
Tensile Test	X		
Vacuum Test	X	X	
Visual examination	X	X	

Table 6: Summary of Tests required by ISO 28017

Documentation

OCIMF requires that an Inspection and Test Certificate is provided for each individual hose and specifies the minimum data to be included within the report. It also requires that a Manufacturers Report is provided and lists the documentation to be included within that reports.

The minimum documentation requirements of API17K include Design Premise, and Design Reports, Manufacturing Quality Plan, Fabrication Specification, As Built Documentation, Operation Manual.

ISO28017 requires a test certificate or test report to supplied with the hoses.

Discussion

From the above review of the design codes and guidelines, a number of comparisons and contrasts can be drawn. The scope and application of OCIMF and ISO28017 are more specific than that of API 17K which covers numerous services and applications. Nonetheless, none of the documents are specifically intended for, nor cover, the flexible pipe functional requirements of an SWIR.

API 17K makes provision for features such as; sour-service, multiple steel reinforcement layers, internal steel carcass etc. which are typical of small to mid-bore high pressure production hoses commonly used to transport hydrocarbons in various phases. This is supported by Antal et al (8), who provide a number of such examples that were considered during the development of API 17K to which they contributed. The environmental and safety implications of a failure in a high pressure hose transporting hydrocarbons are significant and which are reflected in the comprehensive design methodology, manufacturing processes and testing requirements. Significantly, the design fatigue factor (DFF) is stated as 10 which is indicative of the potential implications of a failure in such a hose. However, it should be noted that, as indicated by Lotveit (9 p. 12), two flexible pipe manufacturers with OCIMF approved offloading hoses also have API 17K approval and makes reference to an application of such a hose (9 p. 22). Since publication of Lotveit (9), this application suffered a failure in the field resulting in catastrophic environmental impact and a costly fine being imposed (the payment of which has yet to be resolved) (10). This suggests that, although, API 17K addresses the life in the field for the intended function, such guarantees are difficult to assure.

It is noted that API 17K specifically advises that no effort was made to address low pressure hoses, textile reinforcement nor water supply service, all of which are features of the SWIR flexible pipe.

OCIMF provides guidelines for hoses up to 24”NB intended for loading and discharge of oil products and, although these hoses operate at a relatively low pressure, similar environmental and safety concerns exist in regard to a potential failure. Lotveit (9 p. 19) suggests that these hoses are considered as consumable items within the industry with a service life of around 5 years (and even less in more critical applications) and that OCIMF does not address service life in detail. This suggestion is supported by the provision for leak detection systems and double carcass design within OCIMF, that is, potential leaks are detected and contained. However, Lotveit (9 p. 12) agrees that the OCIMF requirements relating to design and manufacturing are general, and it could be argued that there is a greater weighting placed on the performance of the prototype hose to verify the design as opposed to a design methodology.

No such environmental concerns exist for hoses built in accordance with ISO28017 for the dredging industry as a failure would simply result in seawater being discharged into seawater. The main concern of ISO28017 is that of wear due to abrasion from silt and rocks and by external handling and it could be argued that dredging hoses are subjected to more arduous conditions than OCIMF or API 17K hoses in terms of physical service and handling making consideration of service life more difficult. Like OCIMF, ISO28017 places an emphasis on verification of design through prototype testing.

With regard to manufacturing, most leading hose manufacturers will operate an accredited Quality Management System (QMS) such as ISO 9001:2008 (11) which requires the manufacturer to have documented procedures and quality assurance controls for all processes. Whereas OCIMF and ISO 28017 require that the prototype and production hoses are built in the same facility, they do not provide manufacturing guidelines, instead relying on verification through test. API 17K however, provides specific requirements regarding the manufacturing process which may duplicate or even override the manufacturers accredited QMS.

As discussed earlier, OCIMF and ISO 28017 both place a high importance on testing of, firstly a prototype hose and then the subsequent production hoses. API 17K on the other hand appears to have less onerous test programme for finished production hoses, instead focusing on the testing of the individual components making up the structure. Provision is made for prototype testing although this can be waived if demonstrated by evidence.

The level of documentation requirements differs significantly with ISO 28017 only requiring a test certificate or report. OCIMF and, in particular, API 17K have significantly greater documentation requirements which can be attributed to the fact that, given the volatility of the products transported, a higher degree of documentary evidence is required to provide assurances or, in the event of a failure, greater traceability.

Conclusion

Although there are a number of industry codes and guidelines related to the design and manufacture of bonded flexible pipes, the design and manufacture of bonded flexible rubber pipes for a SWIR application is not specifically addressed by the scope of any one of the documents reviewed. Although it could be argued that provision is made for SWIR flexible pipes within the scope of API 17K, the depth of these requirements are clearly not intended for low pressure, large bore textile reinforced seawater hoses. Nonetheless, there are criteria from several of these industry codes and guidelines that may be applied

Therefore, to specifically address the functional requirements of a flexible bonded pipe intended for an SWIR, the following is suggested to verify and validate such a design.

The main function of a SWIR pipe is to transport seawater through suction. However, the SWIR, and in particular, the flexible pipe section connected to the vessel, is required to accommodate the loads induced into the system through vessel motion, environmental forces and self-weight. The service life in the field of the SWIR is intended to be the same as that of the vessel it is serving, therefore the design of the hose needs to address this for both design strength and fatigue capabilities.

For the design strength, the flexible pipe needs to accommodate the maximum axial loads and bending induced by the vessel motion and extreme environmental loads. These loads can be predicted using hydrodynamic analysis software, such as the industry accepted ORCAFLEX (12) software. The software enables the vessel response characteristics to be input and the SWIR modelled. The various environmental loads can then be applied and the behaviour of the SWIR recorded and interrogated. API 17K table 5 provides a list of load cases and combinations for consideration.

The output of the analysis can provide a theoretical evaluation of the axial load and bending radii expected during extreme (and abnormal) conditions which can be used to formulate the design specification for the flexible pipe.

Current analysis supervised by the author has shown that the most likely cause of fatigue failure within the SWIR would be at the reinforcement and specifically at the end of the flexible pipe. There are several techniques available for prediction of fatigue failure such as Miner's method and which is specified within API 17K. To effect this, an appropriate SN curve for the reinforcement components is required and if not available should be established.

Based on the field metocean data, the hydrodynamic analysis software can be used predict the range of loads and moments and their occurrences during the life of the vessel . Using an appropriate FEA tool, the bonded flexible pipe can be modelled from which the relevant stress factors for the reinforcement can be obtained and applied to calculate the fatigue damage.

DNV Recommended Practice, DNV-RP-F204 Riser Fatigue (13) table 6-1, provides design fatigue factors (DFF) according to the safety risk presented by risers with adequate reliability, and, as noted earlier, the DFF specified in API 17K is given as 10 which is in agreement with DNV-RP-F204 table 6-1 for a riser with a 'High' safety class. Although the SWIR is a critical system in terms on functionality, given that the media is non-hazardous and the threat to life from failure is low, and that current systems in the field provide evidence of adequate reliability, it is suggested that a DFF of 3 is applied as per DNV-RP-F204 table 6-1 for 'Low' safety class.

Therefore, drawing on elements of each of the reviewed documentation, the following methodology for the design, manufacture and test of a bonded flexible rubber pipe used in a SWIR application on FPSO vessels (and also the emerging FLNG market) is presented below for consideration:

Item	Description	Input Data	Process	Output	Acceptance Criteria
1	Flexible Hose Design	Design Specification Component Properties	Build FEA Model Simulate Axial & Bending Loading Extract Results	Axial & Bending Stiffness Reinforcement Stress Factors	Within strength and fatigue requirements of application
2	Hydrodynamic Analysis	Vessel RAO Data Meteocean Data Riser Properties	Build Model Establish Design & Survival Load Case Combinations Run Analyses Extract Results	Hose Maximum Tension Hose MBR	Hose allowable tension not exceed Hose MBR not exceed
3	Hose Fatigue Analysis	Vessel RAO Data Meteocean Data SN Data	Establish Hs / Tz Occurrences Define Fatigue Bins Run Orcaflex wave scatter tool Extract fatigue load cases Run Analyses Extract Results	Bending Moment & Tension ranges	Predicted fatigue of Hose Reinforcement Materials within S-N allowable (DFF = 3)

Table 7: Seawater Intake Riser Flexible Pipe Proposed Design Methodology

A similar design methodology to determine the strength and fatigue capabilities are presented by Antal et al (8).

For the manufacture of the flexible pipe, as discussed earlier, a hose manufacturer with an accredited QMS is obliged to have documented procedures with quality assurance controls in place. Therefore, it is suggested that an accredited QMS such as ISO9001 (11) provides sufficient assurance regarding the manufacturing quality. However, as required by OCIMF and ISO28017, it is proposed that a prototype of each hose type is manufactured at the manufacturers plant in conditions representative to that of normal hose production, and that the criteria for 'hose type' is as defined in ISO 28017, i.e.

"Whenever a change in the method of manufacture, the basic construction, the design or the materials, in particular the reinforcement materials, used occurs…. Hose assemblies with a diameter smaller than that of a successfully tested type, but within the same basic construction and fabricated by the same method, although having fewer reinforcement plies due to the smaller diameter but required to have at least the same burst strength, do not require a type test unless specified by the purchaser"

With regard to testing, from the documentation reviewed, the prototype testing and production hose test requirements have a number of common test requirements however several of the tests are not applicable for SWIR, therefore table 8 is a suggested suite of tests to validate the flexible pipe design for SWIR application:

Test	Prototype Hose	Production Hose	Comments
Material Tests (Rubber Compounds)	X	X	in accordance with ISO28017
Material Tests (Reinforcement)	X		Tensile & Fatigue tests on representative samples
Adhesion Tests	X	X	in accordance with OCIMF
Weight Test	X	X	in accordance with OCIMF
Minimum Bend Radius Test	X	X	in accordance with OCIMF
Bending Stiffness Test	X	X	in accordance with OCIMF
Axial compression test	X		not for textile reinforcement
Tensile Test	X		in accordance with ISO28017
Dynamic Test	X		See note 1)
Hydrostatic Pressure Test	X	X	in accordance with ISO28017
Change in Length at MWP	X	X	in accordance with ISO28017
Vacuum Test	X	X	in accordance with OCIMF
Electrical Continuity Test	X	X	in accordance with OCIMF
Burst Test	X		in accordance with OCIMF
Dimensional Tests (ID, OD, Length & Flange)	X	X	
Visual examination	X	X	

Notes:

1) Accelerated Fatigue Test on the Prototype Hose. As the analysis shows that the bending component of the hose is the most likely cause of fatigue failure, the hose would be subject to a minimum of 100,000 bending cycles, overloaded by a factor from the fatigue curve to represent the life in field of the hose. Upon completion of testing, the hose would be subject to a pressure test to demonstrate that the degradation of the hose structure is minimal.

Table 8: Seawater Intake Riser Flexible Pipe Proposed Testing Requirements

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Abbreviations

API	American Petroleum Institute
DFF	Design Fatigue Factor
FEA	Finite Element Analysis
FLNG	Floating Liquefied Natural Gas
FPSO	Floating Production Storage & Offloading
NB	Nominal Bore
OCIMF	Oil Companies International Marine Forum
QMS	Quality Management System
SN	Stress v Number of Cycles
SWIR	Sea Water Intake Riser

Ian Craig

From: Claire Gray <Claire.Gray@Murgitroyd.com>
Sent: 24 May 2018 11:47
To: ian.craig@emstec.net
Cc: b.brink@emstec.net; Tom Olbrich; Devan Carr
Subject: Emstec GmbH : IP Status Schedule
Attachments: Emstec - IP Status Schedule.pdf

Dear Ian,

Emstec GmbH
IP Summary
Patent Titles: Water Suction Hoses & An Improved Seawater Suction System

Further to your telephone call with Tom, please find attached an Official summary of the current status of all Emstec's IP rights.

If you require any further information, please do not hesitate to contact me.

Kind regards,

Claire

Claire Gray
Senior Patent Administrator to
TOM OLBRICH

Claire Gray
Senior Patent Administrator
Claire.Gray@Murgitroyd.com

MURGITROYD

Collingwood House, 3 Collingwood Street, Newcastle Upon Tyne, NE1 1JW, UK
Tel :+44 (0) 191 211 3550
murgitroyd.com

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EMSTEC GMBH – IP STATUS SCHEDULE

Case Type	Murg. Number	Country	Status	Application No.	Publication No.	Publication Date.	Grant Date.
PATENTS							
	169389.BE.01	Belgium (Validated European No. 3137799)	GRANTED	15798448.5	3137799B	08-Mar-2017	10-Jan-2018
	169389.CH.01	Switzerland (Validated European No. 3137799)	GRANTED	15798448.5	3137799B	08-Mar-2017	10-Jan-2018
	169389.CN.01	China	ACCEPTED	201580036644.9	106662271A	10-May-2017	
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(54) IMPROVEMENT IN OR RELATING TO WATER SUCTION HOSES

VERBESSERUNG AN ODER IM ZUSAMMENHANG MIT WASSERANSAUGSCHLÄUCHEN

AMÉLIORATIONS APPORTÉES À DES TUYAUX D’ASPIRATION D’EAU OU LES CONCERNANT

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(73) Proprietor: **Emstec GmbH**
22113 Oststeinbek (DE)

(72) Inventors:
- **BRINK, Burghard**
  8835 Feusisberg (CH)
- **CRAIG, Ian**
  Hartlepool
  Cleveland TS26 0AB (GB)

(74) Representative: **Murgitroyd & Company**
Scotland House
165-169 Scotland Street
Glasgow G5 8PL (GB)

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Description

[0001] The present invention relates to a hose section, particularly, but not exclusively, to a hose section for a seawater suction hose system and a method of assembling a seawater suction hose.

Introduction

[0002] Conventional seawater suction hose systems such as those installed on Floating Production Storage and Offloading (FPSO) vessels typically comprise a plurality of hoses and caissons. Each hose typically comprises of a plurality of hose sections interconnected to form a continuous hose. The continuous hose combines with a caisson on the FPSO to form the seawater suction system.

[0003] The free end of the hose is fitted with a suction strainer for straining seawater that is drawn into the hose. The suction strainer is fitted with a hypochlorite dispersion ring, which is used to disperse hypochlorite around the suction strainer as seawater is drawn through the hose. The dispersion of hypochlorite prevents marine growth in the suction hose system and associated pipework of the FPSO. WO 2008/017937 A1 discloses a sea water suction hose with a suction strainer.

[0004] In order to supply hypochlorite to the dispersion ring it is necessary to provide a hypochlorite supply line within the hose. The hypochlorite supply line comprises a plurality of line sections.

[0005] In order to prevent the hypochlorite supply line from breaking, each line section is required to be secured within the hose. This is achieved by providing a plurality of hose adaptors between each hose section. Each hose adaptor provides an internal mount for securing each hypochlorite line section thereto. Installing a hose adaptor between each hose section is costly and increases the assembly time of the hose. Furthermore, the presence of a hose adaptor between each hose section increases the potential for corrosion and the number of potential leakage points in the hose.

[0006] It is an object of the present invention to provide an improved seawater suction hose system comprising an improved hose section and a method of assembling a seawater suction hose which obviates or mitigates one or more of the disadvantages referred to above.

Summary of the Invention

[0007] According to a first aspect of the present invention there is provided a seawater suction hose comprising:

> at least one hose section, comprising a plurality of attachment means for attaching an auxiliary hose section thereto, positioned adjacent to an end of the hose section and each including at least one fixing hole for attaching the auxiliary hose section thereto, wherein each of said plurality of attachment means has a protective coating;
>
> a suction hose head connected to one end of the hose section; and
>
> characterised by a suction strainer connected to the other end of the hose section, said suction strainer further comprising at least a first strainer member, having a first fluid inlet, a first fluid passage and a first fluid outlet, and a second strainer member, having a second fluid inlet, a second fluid passage and a second fluid outlet, first and second strainer members are fluidly separate, and wherein the first strainer member is adapted to be coupled to the other end of the hose section, so as to form at least a two-stage strainer arrangement with the first and second fluid inlets arranged adjoiningly along a longitudinal axis of the hose section, and the first and second fluid outlets forming a combined outlet interface fluidly coupleable to the other end of the hose section, and wherein the strainer member is adapted to matingly engage with the second strainer arrangement so as to form a stack along the longitudinal axis.

[0008] Advantageously, the suction strainer may further comprise at least a third strainer member, having a third fluid inlet, a third fluid passage and a third fluid outlet, fluidly separate from the first and second strainer member, and wherein the third strainer member is adapted to be coupled to the other end of the hose section, so as to form a three-stage strainer arrangement with the first, second and third fluid inlets arranged adjoiningly along the longitudinal axis of the hose section, and the first, second and third fluid outlets forming a combined outlet interface fluidly coupleable to the other end of the hose section, and wherein the second strainer member may be adapted to matingly engage with the third strainer arrangement so as to form a stack along the longitudinal axis.

[0009] Advantageously, the attachment means may be mounted within an internal fluid passage of the hose section.

[0010] Preferably, the attachment means may be externally mounted to the hose section.

[0011] Advantageously, the seawater suction hose may further comprise at least one auxiliary hose section secured to the attachment means of the hose section.

[0012] Preferably, the auxiliary hose section may also be secured to the suction strainer and the suction hose head.

[0013] Even more preferably, the auxiliary hose section may be a hypochlorite supply hose.

[0014] Advantageously, the seawater suction hose may comprise a plurality of hose sections.

[0015] Advantageously, the seawater suction hose may comprise a plurality of auxiliary hose sections.

[0016] Advantageously, the attachment means may be positioned at the nipple of the hose section.

[0017] Preferably, the attachment means may be weld-

ed to the hose section.
Even more preferably, the protective coating may be resilient. Even more preferably, the protective coating may be rubber.

[0018] Advantageously, the hose section may further comprise connecting means at either end thereof. Preferably, the connecting means may have a protective coating. Even more preferably, the hose section may be flexible.

[0019] According to a second aspect of the present invention there is provided a seawater suction hose system comprising:

at least one caisson; and
at least one seawater suction hose according to the first aspect of the invention, wherein the caisson is configured to receive and hold the hose in suspension.

[0020] Advantageously, the seawater suction hose system may further comprise a caisson interface between the caisson and the seawater suction hose.

[0021] Advantageously, the caisson may comprise a suspension apparatus, adapted to selectively secure the hose section during assembly.

[0022] Preferably, the suspension apparatus may be removably coupleable to a top end of the caisson when *in situ*.

[0023] Advantageously, the suspension apparatus may comprise a spring operated mechanism adapted to lockingly engage with the hose section.

[0024] Advantageously, the suspension apparatus may further comprise a hose section adapter, configured to compensate for a predetermined difference of the external diameters of the hose section.

[0025] Preferably, the seawater suction hose system may be configured to be attached to an FPSO vessel.

[0026] Even more preferably, the seawater suction hose system may be configured to be formed within the hull of an FPSO vessel.

[0027] According to a third aspect of the present invention there is provided a FPSO vessel comprising a seawater suction hose system according to the second aspect of the invention.

[0028] According to a fourth aspect of the present invention there is provided a method of assembling a seawater suction hose comprising the steps of:

providing at least two seawater hose sections each having an attachment means for attaching an auxiliary hose section thereto;
attaching an auxiliary hose section to each seawater hose section; connecting the auxiliary hose sections together; and connecting the seawater hose sections together.

[0029] Advantageously, the auxiliary hose sections may be hypochlorite supply hoses.

[0030] According to a fifth aspect of the present invention there is provided a method of assembling a seawater suction hose comprising the steps of:

providing at least one seawater hose section having an attachment means for attaching an auxiliary hose section thereto;
attaching an auxiliary hose section to the seawater hose section;
connecting a suction hose head to one end of the seawater hose section;
connecting a suction strainer to the other end of the seawater hose section; and
connecting the auxiliary hose section to the suction strainer and the suction hose head.

[0031] Advantageously, the auxiliary hose section may be a hypochlorite supply hose.

Brief Description of the Drawings

[0032] An embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a side view of a hose section for a seawater suction hose in accordance with the first aspect of the present invention;
Figure 2 is a cross-sectional side view of the hose section of Figure 1;
Figure 2a is a partial end view of the hose section of Figures 1 and 2, detailing the attachment means;
Figure 3 is a side view of a suction strainer which is used with the hose section of Figure 1;
Figure 4 is a cross-sectional side view of the suction strainer of Figure 3;
Figure 5 is a side view of a suction hose head which is used with the hose section of Figure 1;
Figure 6 is a cross-sectional side view of the suction hose head of Figure 5;
Figure 7 is a cross-sectional partial side view of a caisson interface installed within a caisson in the hull of an FPSO;
Figure 8 is a side view of a seawater suction hose system in accordance with the fourth aspect of the present invention;
Figure 9 is a cross-sectional side view of the seawater suction hose system of Figure 8;
Figure 10 is a perspective view of a suspension apparatus installed to the caisson top on, for example, an FPSO platform, securing a first conduit during assembly, and
Figure 11 is a perspective schematic view of the suspension apparatus of Figure 12 with one spring loaded engagement member opened.
Figure 12 is a schematic sectional view of a three-stage strainer, each strainer stage having a fluidly separate inlet, fluid passage and outlet, wherein all

strainer outlets are combined into a single outlet interface fluidly coupleable to the second conduit;

Figure 13 is a schematic view of the three strainer members when disassembled into (a) stage one, (b) stage two and (c) stage three;

Detailed description of the preferred embodiment(s)

[0033] Figures 1 and 2 illustrate a hose section 10 for a seawater suction hose. The hose section has a cylindrical body 12 forming an internal fluid passage with flanges 14 located at either end thereof (flanges 14 being an example of connecting means).

[0034] With reference to Figures 2 and 2a, the hose section 10 further comprises an attachment means 18 for attaching a hypochlorite hose section 20 thereto (a hypochlorite hose section being an example of an auxiliary hose section).

[0035] The attachment means 18 is welded to the internal surface of the hose section 10 adjacent the hose section nipple (not referenced). The attachment means 18 includes at least one fixing hole 22, which is used to secure the hypochlorite hose section 20 thereto.

[0036] The hose section 10 and the hypochlorite hose section 20 are flexible and include tensile reinforcement to reduce weight, increase corrosion resistance and proved excellent fatigue properties. The attachment means 18 and the flanges 14 have a protective coating to prevent corrosion. The protective coating is a resilient material, e.g. rubber.

[0037] Figures 3 and 4 illustrate a suction strainer 24 for use with the hose section 10. The suction strainer 24 strains seawater, which is drawn through the hose section 10. The suction strainer is generally cylindrical in shape and is fitted with a hypochlorite dispersion assembly 26, which is used to disperse hypochlorite around the suction strainer 24. The dispersion of hypochlorite prevents marine growth in the suction hose system and associated pipework of the FPSO. The suction strainer 24 also includes a flange 28, which is used to connect the strainer 24 to the hose section 10.

[0038] Figures 5 and 6 illustrate a suction hose head 30, which is used with the hose section 10. The suction hose head 30 provides the interface between the hose section 10 and a caisson of a seawater suction hose system. The head 30 includes a male conical seat 32 which mates with a female conical seat of a caisson interface, preventing downward movement of the suction hose (see below).

[0039] To prevent tilting, the head 30 includes an external upper circumferential bearing ring 34 which mates with a caisson interface internal circumferential bearing ring (see below).

[0040] The head 30 also includes a flange 36, which is used to connect a hose section 10 thereto. The head 30 also includes a hypochlorite hose assembly 38. There is also provided engagement means 40 for engaging a deployment/retrieval tool therein (see below). Figure 7 illustrates a cross-sectional partial side view of a caisson interface 42 installed within a caisson 44 in the hull of an FPSO. The caisson interface 42 includes a female conical seat 46 which mates with the male conical seat 32 of the suction hose head 30 to centralise the head 30. The caisson interface 42 also includes an internal circumferential bearing ring 48 which mates with the external upper circumferential bearing ring 34 of the suction hose head 30.

[0041] Figures 8 and 9 illustrate an assembled seawater hose 50 held in suspension from the caisson interface 42 of the caisson 44 of an FPSO. The hose 50 comprises a plurality of hose sections 10, a suction strainer 24 and a suction hose head 30. The seawater hose 50 and the caisson 44 form a seawater suction hose system.

[0042] The assembly of the seawater hose 50 is carried out in a conventional manner, i.e. by suspending each hose section 10 at the top of the caisson 44 whilst each subsequent hose section 10 is attached thereto. The hose sections 10 are bolted together at the flanges 14.

[0043] In particular, a hypochlorite hose section 20 is attached to the attachment means 18 of each hose section 10 prior to assembly of the hose sections 10. During assembly, the hypochlorite hose section 20 of a lower hose section 10 is firstly connected to they hypochlorite hose section 20 of an upper hose section 10 prior to connection of the upper and lower hose sections 10. The result is that a continuous hypochlorite hose extends the entire length of the assembled hose 50. In order to make the connection of the hose sections 10 safer, there may be provided a safety collar (not shown), which is connected to a lower hose section 10 whilst the hypochlorite hose sections 20 of the lower and upper hose sections 10 are being connected together. Once the hypochlorite hose sections 20 have been connected, the safety collar is removed and the hose sections 10 bolted together, as described above.

[0044] Of course, the suction strainer 24 is connected to the lower free end of the first hose section 10 prior to insertion in the caisson 44. The hypochlorite hose section 20 in the first hose section 10 is connected to the hypochlorite dispersion assembly 26 of the strainer 24 prior to the strainer 24 being bolted to the hose section 10.

[0045] The suction hose head 30 is connected to the last upper hose section 10. The hypochlorite hose section 20 in the last hose section 10 is connected to the hypochlorite hose assembly 38 of the head 30 prior to the head being bolted to the hose section 10.

[0046] The seawater hose 50 may be lowered in and out of the caisson 44 in a conventional manner by a deployment/retrieval tool (not shown).

[0047] The seawater hose 50 is disassembled in a conventional manner, i.e. by lifting the hose 50 toward the top of the caisson 44 and reversing the assembly steps described above.

[0048] The hose section 10 therefore obviates or mitigates some disadvantages of previous proposals by proving an attachment means 18 for attaching an auxiliary hose section 20 thereto. Providing a hose section 10 including an attachment means 18 removes the requirement for a hose adaptor to be provided between each hose section of a seawater suction hose to support the hypochlorite supply line. A seawater suction hose 50 comprising a plurality of hose sections 10 has an increased field life, increased reliability and makes the assembly of the hose 50 simpler. By eliminating the hose adaptors:

- The number of sub-sea steel components exposed to seawater is significantly reduced, thus reducing cost and minimizing the potential for corrosion.
- There is no risk in damaging any protective coating applied to the hose adaptors during installation. As the assembly through the caisson is "blind" the damage to the protective coating is not identified until there is an inspection or failure of the hose.
- The level of cathodic protection is reduced.
- The number of flanged joints is significantly reduced, thus minimizing potential leakage points.
- The internal bore of the hose 50 is smooth, i.e. there are no internal anodes. This reduces the pressure losses through the hose 50.

[0049] Modifications and improvements may be made to the above without departing from the scope of the present invention. For example, although the attachment means 18 has been illustrated and described above as being located on an inner surface of the hose section 10, it should be appreciated that the attachment means 18 could be located on an external surface of the hose section 10.

[0050] Furthermore, although each hose section 10 has been described above as comprising a single attachment means 18, it should be appreciated that each hose section 10 could comprise two or more attachment means located at various positions in/on the hose section 10. Also, although the seawater suction hose 50 has been illustrated and described above as being installed within a caisson 44 in the hull of an FPSO, it should be appreciated that the seawater hose 50 could be installed in a caisson arranged on the side of an FPSO.

[0051] Furthermore, although attachment means 18 has been illustrated and described above as including at least one fixing hole 22 which is used to secure the hypochlorite line thereto, it should be appreciated that the attachment means may comprise any means suitable for attaching the hypochlorite supply line to the hose section 10.

[0052] Figures 10 and 11 show a more detailed view of a suspension apparatus or tool 244, when in use and mounted to the caisson top (Figure 10) and as a separate entity in an open, disengaged state (Figure 11). In particular, the suspension apparatus or tool 244 comprises two spring-loaded engagement members 248, 250 that are operably connected to a mount 252. The mount 252 is adapted to be mounted to the top of a caisson 44. The spring mechanism of the suspension apparatus or tool 244 is adapted to secure the hose section 10 during assembly, i.e. suspending the conduit string while another conduit section is being connected. The suspension apparatus or tool 244 is lighter in weight and much more compact than a conventional hydraulic suspension tool, therefore, allowing for installations in space restricted areas.

[0053] In addition, Figure 10 also shows part of the hose section 10 having two auxiliary fluid lines 146, 148 for providing, for example, hypochlorite fluid that are installed within the internal fluid passage of the hose section 10. The two auxiliary fluid lines 146, 148 are led, for example, to the top of a strainer 24, 118 where they each connect, for example, to a separate dispersion ring (not shown) allowing a more concentrated / higher dosage of hypochlorite to be moved into the internal fluid passage of the section hose string 10. In addition, providing two separate auxiliary fluid lines 146, 148, provides for an increased fluid volume and a degree of redundancy.

[0054] Figures 12 and 13 illustrate another example embodiment of a suction strainer 118 that is fluidly coupleable to an end section of the hose section 10. The strainer 118 comprises three fluidly separate strainer members, first strainer member 120, second strainer member 122, and third strainer member 124, that can be assembled into the three-stage strainer 118. Each of the strainer members 120, 122, 124 comprises a fluidly separate inlet section 126, 128, 130, a fluid passage 132, 134, 136, and an outlet 138, 140, 142. The strainer members 120, 122, 124 are formed in such a way that the second strainer member 122 can be matingly stacked onto the third strainer member 124, and the first strainer member 120 can be matingly stacked onto the second strainer member 122. When assembled the three outlets 138, 140 and 142 form a combined interface 144 that is fluidly coupleable to the hose section 10. During use, fluid is moved through all three inlet sections 126, 128, 130 and separately passed through the fluid passages 132, 134 and 136 to exit the combined outlets 138, 140, 142 into the internal fluid passage of the hose section 10.

[0055] It will be appreciated by persons skilled in the art that the above embodiment has been described by way of example only and not in any limitative sense, and that various alterations and modifications are possible without departing from the scope of the invention as defined by the appended claims.

Claims

1. A seawater suction hose comprising:

at least one hose section (10), comprising a plurality of attachment means (18) for attaching an auxiliary hose section (20) thereto, positioned adjacent to an end of the hose section and each including at least one fixing hole for attaching the auxiliary hose section thereto, wherein each of said plurality of attachment means has a protective coating;

a suction hose head (30) connected to one end of the hose section; and

characterized by a suction strainer (118) connected to the other end of the hose section, said suction strainer further comprising at least a first strainer member (120), having a first fluid inlet (126), a first fluid passage (132) and a first fluid outlet (138), and a second strainer member (122), having a second fluid inlet (128), a second fluid passage (134) and a second fluid outlet (140), first and second strainer members are fluidly separate, and wherein the suction strainer (118) is adapted to be coupled to the other end of the hose section, so as to form at least a two-stage strainer arrangement with the first and second fluid inlets (126, 128) arranged adjoiningly along a longitudinal axis of the hose section, and the first and second fluid outlets (138, 140) forming a combined outlet interface fluidly coupleable to the other end of the hose section, and wherein the first strainer member (120) is adapted to matingly engage with the second strainer member (122) so as to form a stack along the longitudinal axis.

2. A seawater suction hose according to claim 1, wherein the suction strainer (118) further comprises at least a third strainer member (124), having a third fluid inlet (130), a third fluid passage (136) and a third fluid outlet (142), fluidly separate from the first and second strainer member (120, 122), and wherein the third strainer member is adapted to be coupled to the other end of the hose section, so as to form a three-stage strainer arrangement with the first, second and third fluid inlets arranged adjoiningly along the longitudinal axis of the hose section, and the first, second and third fluid outlets forming a combined outlet interface fluidly coupleable to the other end of the hose section, and wherein the second strainer member is adapted to matingly engage with the third strainer member so as to form a stack along the longitudinal axis.

3. A seawater suction hose according to any one of the preceding claims, wherein the attachment means is mounted within an internal fluid passage of the hose section.

4. A seawater suction hose according to any one of claims 1 to 2, wherein the attachment means is externally mounted to the hose section.

5. A seawater suction hose according to any one of claims 1 to 4, wherein the seawater suction hose further comprises at least one auxiliary hose section secured to the attachment means of the hose section, and wherein the auxiliary hose section is a hypochlorite supply hose that is also secured to the suction strainer and the suction hose head.

6. A seawater suction hose according to any one of the preceding claims, wherein the hose section further comprises connecting means (14) at either end thereof.

7. A seawater suction hose according to claim 6, wherein the connecting means have a protective coating.

8. A seawater suction hose system comprising:

at least one caisson (44); and
at least one seawater suction hose according to any of claims 1 to 7, wherein the caisson is configured to receive and hold the hose in suspension.

9. A seawater suction hose system according to claim 8, wherein the seawater suction hose system further comprises a caisson interface between the caisson and the seawater suction hose.

10. A seawater suction hose system according to any one of claims 8 and 9, wherein the caisson comprises a suspension apparatus (244), adapted to selectively secure the hose section during assembly.

11. A seawater suction hose system as claimed in claim 10, wherein the suspension apparatus is removably coupleable to a top end of the caisson when *in situ.*

12. A seawater suction hose system as claimed in any one of claims 10 and 11, wherein the suspension apparatus comprises a spring operated mechanism adapted to lockingly engage with the hose section.

13. A seawater suction hose system as claimed in any one of claims 10 to 12, wherein the suspension apparatus further comprises a hose section adapter (248, 250), configured to compensate for a predetermined difference of the external diameters of the hose section.

14. A FPSO vessel comprising a seawater suction hose system according to any of claims 8 to 13.

15. A method of assembling a seawater suction hose according to any one of claims 1 to 7, comprising the steps of:

providing at least one seawater hose section having an attachment means for attaching an auxiliary hose section thereto;
attaching an auxiliary hose section to the seawater hose section;
connecting a suction hose head to one end of the seawater hose section;
connecting a suction strainer (118) to the other end of the seawater hose section; and
connecting the auxiliary hose section to the suction strainer and the suction hose head.

Patentansprüche

1. Ein Meerwassersaugschlauch, beinhaltend:

mindestens einen Schlauchabschnitt (10), beinhaltend eine Vielzahl von Befestigungsmitteln (18) zum Befestigen eines zusätzlichen Schlauchabschnitts (20) daran, die neben einem Ende des Schlauchabschnitts positioniert sind und jeweils mindestens ein Fixierloch zum Befestigen des zusätzlichen Schlauchabschnitts daran umfassen, wobei jedes der Vielzahl von Befestigungsmitteln eine Schutzschicht aufweist;
einen Saugschlauchkopf (30), der mit einem Ende des Schlauchabschnitts verknüpft ist; und
gekennzeichnet durch ein Saugsieb (118), das mit dem anderen Ende des Schlauchabschnitts verknüpft ist, wobei das Saugsieb ferner mindestens ein erstes Siebelement (120) mit einem ersten Fluideinlass (126), einem ersten Fluiddurchgang (132) und einem ersten Fluidauslass (138) und ein zweites Siebelement (122) mit einem zweiten Fluideinlass (128), einem zweiten Fluiddurchgang (134) und einem zweiten Fluidauslass (140) beinhaltet, wobei das erste und das zweite Siebelement fluidisch getrennt sind und wobei das Saugsieb (118) angepasst ist, um an das andere Ende des Schlauchabschnitts gekoppelt zu werden, um mindestens eine Zwei-Stufen-Siebanordnung zu bilden, wobei der erste und der zweite Fluideinlass (126, 128) entlang einer Längsachse des Schlauchabschnitts angrenzend angeordnet sind und der erste und der zweite Fluidauslass (138, 140) eine kombinierte Auslassverbindung bilden, die an das andere Ende des Schlauchabschnitts fluidisch koppelbar ist, und wobei das erste Siebelement (120) angepasst ist, um mit dem zweiten Siebelement (122) passend in Eingriff zu kommen, um entlang der Längsachse eine Stapelung zu bilden.

2. Meerwassersaugschlauch gemäß Anspruch 1, wobei das Saugsieb (118) ferner mindestens ein drittes Siebelement (124) mit einem dritten Fluideinlass (130), einem dritten Fluiddurchgang (136) und einem dritten Fluidauslass (142) beinhaltet, das von dem ersten und dem zweiten Siebelement (120, 122) fluidisch getrennt ist, und wobei das dritte Siebelement angepasst ist, um an das andere Ende des Schlauchabschnitts gekoppelt zu werden, um eine Drei-Stufen-Siebanordnung zu bilden, wobei der erste, der zweite und der dritte Fluideinlass entlang der Längsachse des Schlauchabschnitts angrenzend angeordnet sind und der erste, der zweite und der dritte Fluidauslass eine kombinierte Auslassverbindung bilden, die an das andere Ende des Schlauchabschnitts fluidisch koppelbar ist, und wobei das zweite Siebelement angepasst ist, um mit dem dritten Siebelement passend in Eingriff zu kommen, um entlang der Längsachse eine Stapelung zu bilden.

3. Meerwassersaugschlauch gemäß einem der vorhergehenden Ansprüche, wobei das Befestigungsmittel innerhalb eines inneren Fluiddurchgangs des Schlauchabschnitts montiert ist.

4. Meerwassersaugschlauch gemäß einem der Ansprüche 1 bis 2, wobei das Befestigungsmittel außen an dem Schlauchabschnitt montiert ist.

5. Meerwassersaugschlauch gemäß einem der Ansprüche 1 bis 4, wobei der Meerwassersaugschlauch ferner mindestens einen zusätzlichen Schlauchabschnitt beinhaltet, der an dem Befestigungsmittel des Schlauchabschnitts gesichert ist, und wobei der zusätzliche Schlauchabschnitt ein Hypochloritzuführungsschlauch ist, der auch an dem Saugsieb und dem Saugschlauchkopf gesichert ist.

6. Meerwassersaugschlauch gemäß einem der vorhergehenden Ansprüche, wobei der Schlauchabschnitt ferner an jedem Ende davon ein Verknüpfungsmittel (14) beinhaltet.

7. Meerwassersaugschlauch gemäß Anspruch 6, wobei das Verknüpfungsmittel eine Schutzschicht aufweist.

8. Ein Meerwassersaugschlauchsystem, beinhaltend:

mindestens einen Senkkasten (44); und
mindestens einen Meerwassersaugschlauch gemäß einem der Ansprüche 1 bis 7,
wobei der Senkkasten konfiguriert ist, um den Schlauch aufzunehmen und hängend zu halten.

9. Meerwassersaugschlauchsystem gemäß Anspruch 8, wobei das Meerwassersaugschlauchsystem ferner zwischen dem Senkkasten und dem Meerwassersaugschlauch eine Senkkastenverbindung beinhaltet.

10. Meerwassersaugschlauchsystem gemäß einem der Ansprüche 8 und 9, wobei der Senkkasten eine Aufhängungsvorrichtung (244) beinhaltet, die angepasst ist, um den Schlauchabschnitt während des Zusammenbaus selektiv zu sichern.

11. Meerwassersaugschlauchsystem gemäß Anspruch 10, wobei die Aufhängungsvorrichtung entfernbar an ein oberes Ende des Senkkastens koppelbar ist, wenn *in situ.*

12. Meerwassersaugschlauchsystem gemäß einem der Ansprüche 10 und 11, wobei die Aufhängungsvorrichtung einen federbetriebenen Mechanismus beinhaltet, der angepasst ist, um mit dem Schlauchabschnitt arretierend in Eingriff zu kommen.

13. Meerwassersaugschlauchsystem gemäß einem der Ansprüche 10 bis 12, wobei die Aufhängungsvorrichtung ferner eine Schlauchabschnittanpassungsvorrichtung (248, 250) beinhaltet, die konfiguriert ist, um einen zuvor bestimmten Unterschied bei den Außendurchmessern des Schlauchabschnitts zu kompensieren.

14. Ein FPSO-Fahrzeug, beinhaltend ein Meerwassersaugschlauchsystem gemäß einem der Ansprüche 8 bis 13.

15. Ein Verfahren zum Zusammenbauen eines Meerwassersaugschlauchs gemäß einem der Ansprüche 1 bis 7, beinhaltend die folgenden Schritte:

Bereitstellen mindestens eines Meerwasserschlauchabschnitts mit einem Befestigungsmittel zum Befestigen eines zusätzlichen Schlauchabschnitts daran;
Befestigen eines zusätzlichen Schlauchabschnitts an dem Meerwasserschlauchabschnitt;
Verknüpfen eines Saugschlauchkopfs mit einem Ende des Meerwasserschlauchabschnitts;
Verknüpfen eines Saugsiebs (118) mit dem anderen Ende des Meerwasserschlauchabschnitts; und
Verknüpfen des zusätzlichen Schlauchabschnitts mit dem Saugsieb und dem Saugschlauchkopf.

Revendications

1. Un tuyau d'aspiration d'eau de mer comprenant :

au moins une section de tuyau (10), comprenant une pluralité de moyens d'attache (18) pour attacher une section de tuyau auxiliaire (20) à celle-ci, positionnés de façon adjacente à une extrémité de la section de tuyau et incluant chacun au moins un trou de fixation pour attacher la section de tuyau auxiliaire à celle-ci, chaque moyen d'attache de ladite pluralité de moyens d'attache ayant un revêtement protecteur ;
une tête de tuyau d'aspiration (30) raccordée à une extrémité de la section de tuyau ; et
caractérisé par un filtre d'aspiration (118) raccordé à l'autre extrémité de la section de tuyau, ledit filtre d'aspiration comprenant en outre au moins un premier élément de filtre (120), ayant une première entrée de fluide (126), un premier passage de fluide (132) et une première sortie de fluide (138), et un deuxième élément de filtre (122), ayant une deuxième entrée de fluide (128), un deuxième passage de fluide (134) et une deuxième sortie de fluide (140), les premier et deuxième éléments de filtre sont fluidiquement séparés, et le filtre d'aspiration (118) étant conçu pour être couplé à l'autre extrémité de la section de tuyau, de façon à former au moins un arrangement de filtre à deux étages, les première et deuxième entrées de fluide (126, 128) étant arrangées de façon contigüe le long d'un axe longitudinal de la section de tuyau, et les première et deuxième sorties de fluide (138, 140) formant une interface de sortie combinée pouvant être couplée fluidiquement à l'autre extrémité de la section de tuyau, et le premier élément de filtre (120) étant conçu pour se mettre en prise par accouplement avec le deuxième élément de filtre (122) de façon à former un empilement le long de l'axe longitudinal.

2. Un tuyau d'aspiration d'eau de mer selon la revendication 1, dans lequel le filtre d'aspiration (118) comprend en outre au moins un troisième élément de filtre (124), ayant une troisième entrée de fluide (130), un troisième passage de fluide (136) et une troisième sortie de fluide (142), fluidiquement séparés du premier et du deuxième élément de filtre (120, 122), le troisième élément de filtre étant conçu pour être couplé à l'autre extrémité de la section de tuyau, de façon à former au moins un arrangement de filtre à trois étages, les première, deuxième et troisième entrées de fluide étant arrangées de façon avoisinante le long de l'axe longitudinal de la section de tuyau, et les première, deuxième et troisième sorties de fluide formant une interface de sortie combinée pouvant être couplée fluidiquement à l'autre extrémité de la section de tuyau, et le deuxième élément de filtre étant conçu pour se mettre en prise par accouplement avec le troisième élément de filtre de façon à former un empilement le long de l'axe longitudinal.

3. Un tuyau d'aspiration d'eau de mer selon n'importe laquelle des revendications précédentes, dans lequel le moyen d'attache est monté au sein d'un passage de fluide interne de la section de tuyau.

4. Un tuyau d'aspiration d'eau de mer selon n'importe laquelle des revendications 1 à 2, dans lequel le moyen d'attache est monté de façon externe sur la section de tuyau.

5. Un tuyau d'aspiration d'eau de mer selon n'importe laquelle des revendications 1 à 4, le tuyau d'aspiration d'eau de mer comprenant en outre au moins une section de tuyau auxiliaire assujettie au moyen d'attache de la section de tuyau, et la section de tuyau auxiliaire étant un tuyau d'approvisionnement en hypochlorite qui est également assujetti au filtre d'aspiration et à la tête de tuyau d'aspiration.

6. Un tuyau d'aspiration d'eau de mer selon n'importe laquelle des revendications précédentes, dans lequel la section de tuyau comprend en outre un moyen de raccordement (14) au niveau de chaque extrémité de celle-ci.

7. Un tuyau d'aspiration d'eau de mer selon la revendication 6, dans lequel les moyens de raccordement ont un revêtement protecteur.

8. Un système de tuyau d'aspiration d'eau de mer comprenant :

au moins un caisson (44) ; et
au moins un tuyau d'aspiration d'eau de mer selon n'importe lesquelles des revendications 1 à 7, dans lequel le caisson est configuré pour recevoir et maintenir le tuyau en suspension.

9. Un système de tuyau d'aspiration d'eau de mer selon la revendication 8, le système de tuyau d'aspiration d'eau de mer comprenant en outre une interface de caisson entre le caisson et le tuyau d'aspiration d'eau de mer.

10. Un système de tuyau d'aspiration d'eau de mer selon n'importe laquelle des revendications 8 et 9, dans lequel le caisson comprend un appareil de suspension (244), conçu pour assujettir de façon sélective la section de tuyau pendant l'assemblage.

11. Un système de tuyau d'aspiration d'eau de mer tel que revendiqué dans la revendication 10, dans lequel l'appareil de suspension peut être couplé de façon amovible à une extrémité de dessus du caisson lorsqu'il est in situ.

12. Un système de tuyau d'aspiration d'eau de mer tel que revendiqué dans n'importe laquelle des revendications 10 et 11, dans lequel l'appareil de suspension comprend un mécanisme actionné par ressort conçu pour se mettre en prise par verrouillage avec la section de tuyau.

13. Un système de tuyau d'aspiration d'eau de mer tel que revendiqué dans n'importe laquelle des revendications 10 à 12, dans lequel l'appareil de suspension comprend en outre un adaptateur de section de tuyau (248, 250), configuré pour compenser une différence prédéterminée des diamètres externes de la section de tuyau.

14. Un bâtiment FPSO comprenant un système de tuyau d'aspiration d'eau de mer selon n'importe lesquelles des revendications 8 à 13.

15. Une méthode d'assemblage d'un tuyau d'aspiration d'eau de mer selon n'importe laquelle des revendications 1 à 7, comprenant les étapes consistant à :

fournir au moins une section de tuyau pour eau de mer ayant un moyen d'attache pour attacher une section de tuyau auxiliaire à celle-ci ;
attacher une section de tuyau auxiliaire à la section de tuyau pour eau de mer ;
raccorder une tête de tuyau d'aspiration à une extrémité de la section de tuyau pour eau de mer ;
raccorder un filtre d'aspiration (118) à l'autre extrémité de la section de tuyau pour eau de mer ; et
raccorder la section de tuyau auxiliaire au filtre d'aspiration et à la tête de tuyau d'aspiration.

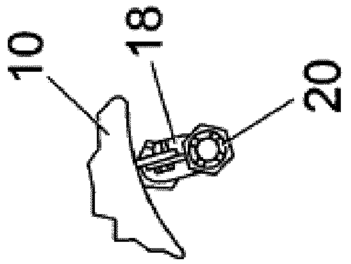

Fig. 2a

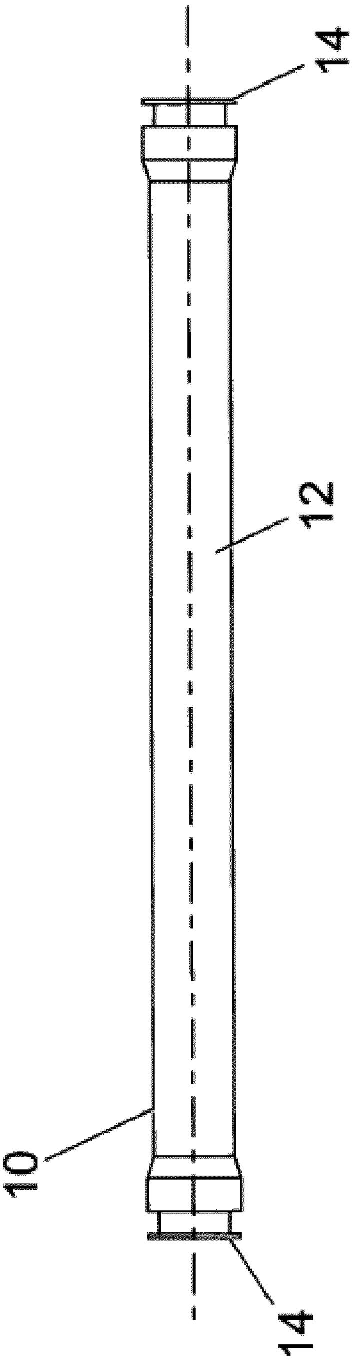

Fig. 1

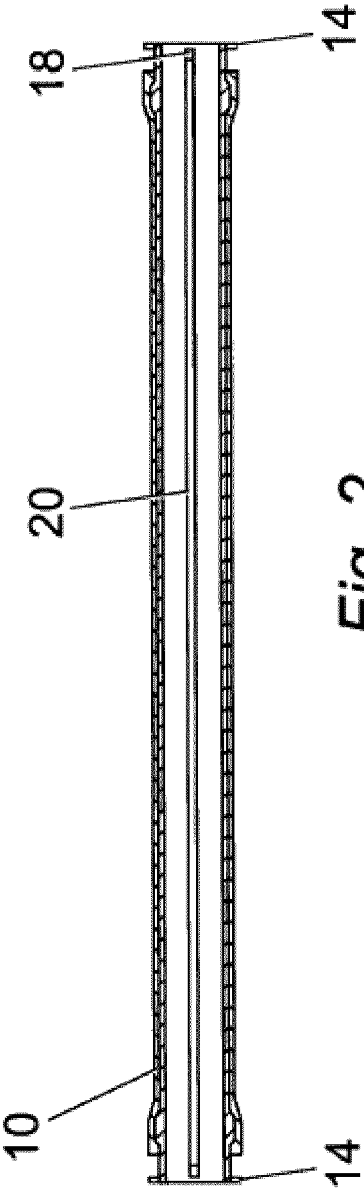

Fig. 2

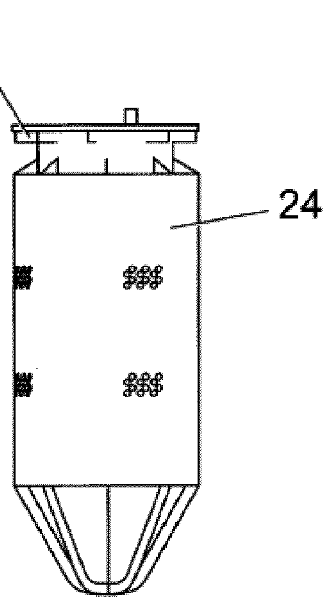

Fig. 3

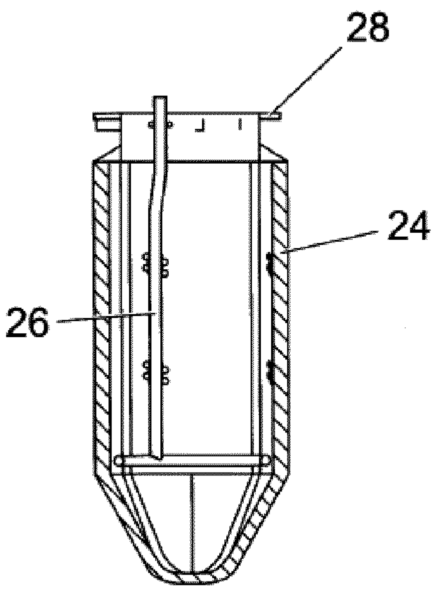

Fig. 4

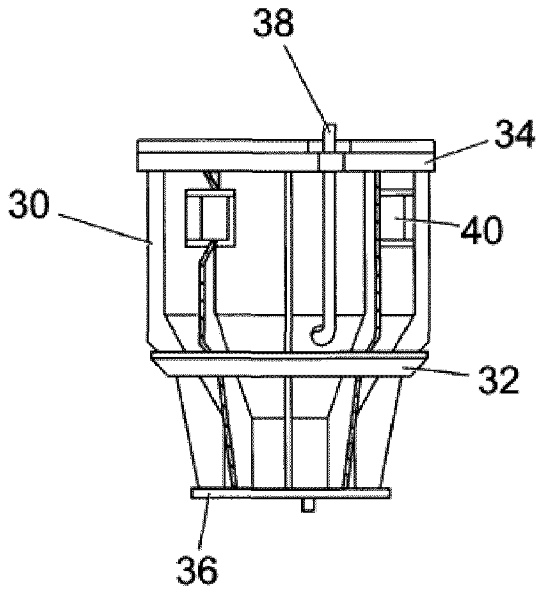

Fig. 5

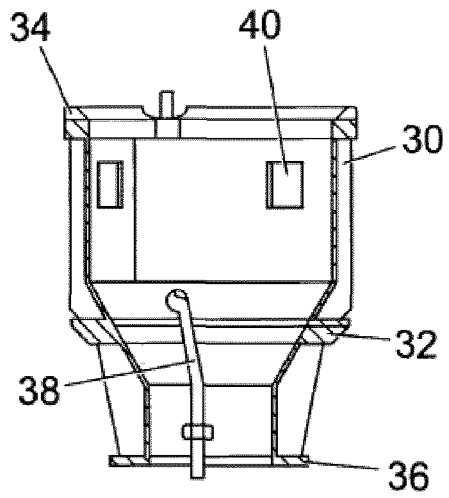

Fig. 6

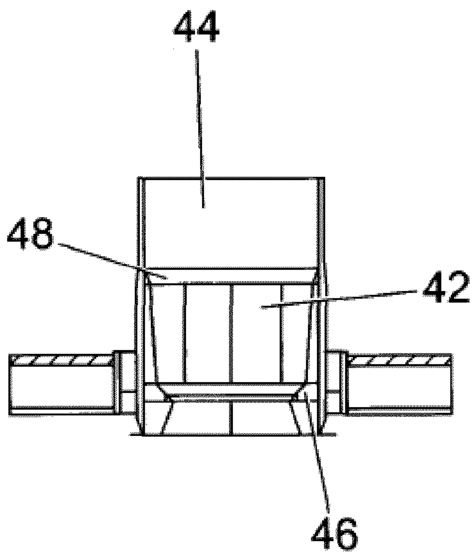

Fig. 7

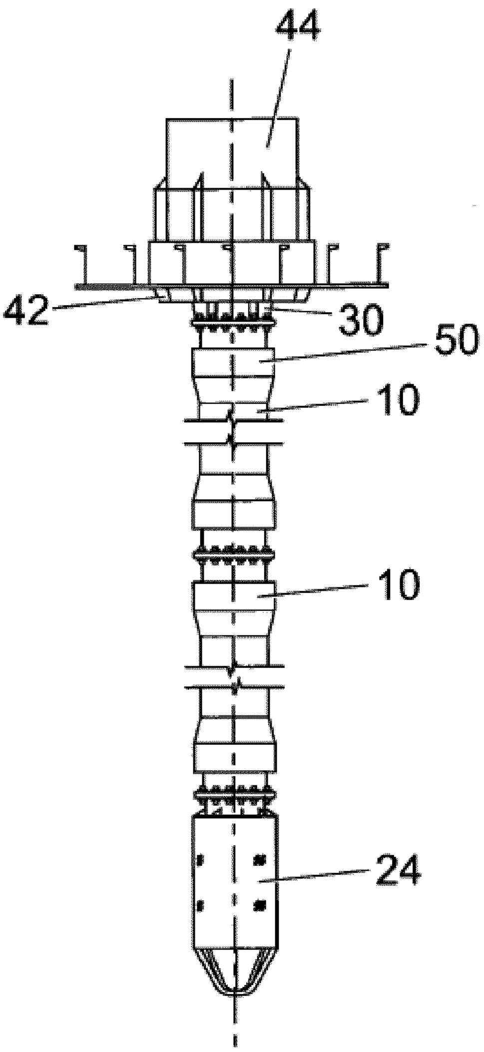

Fig. 8

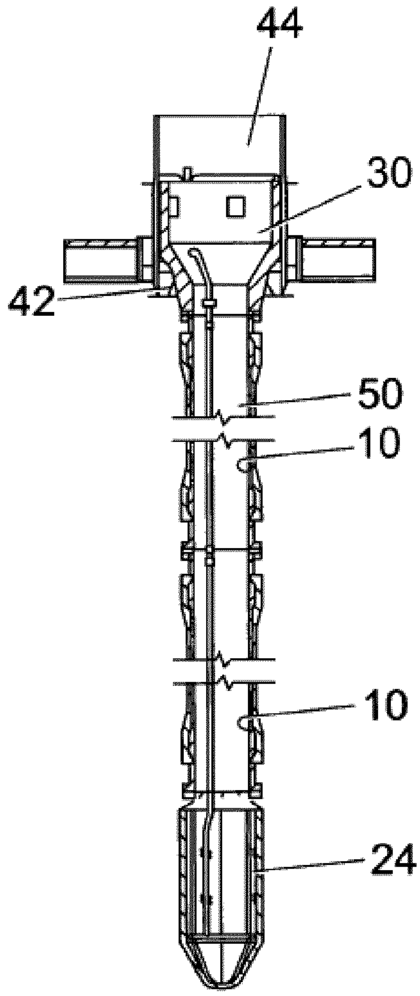

Fig. 9

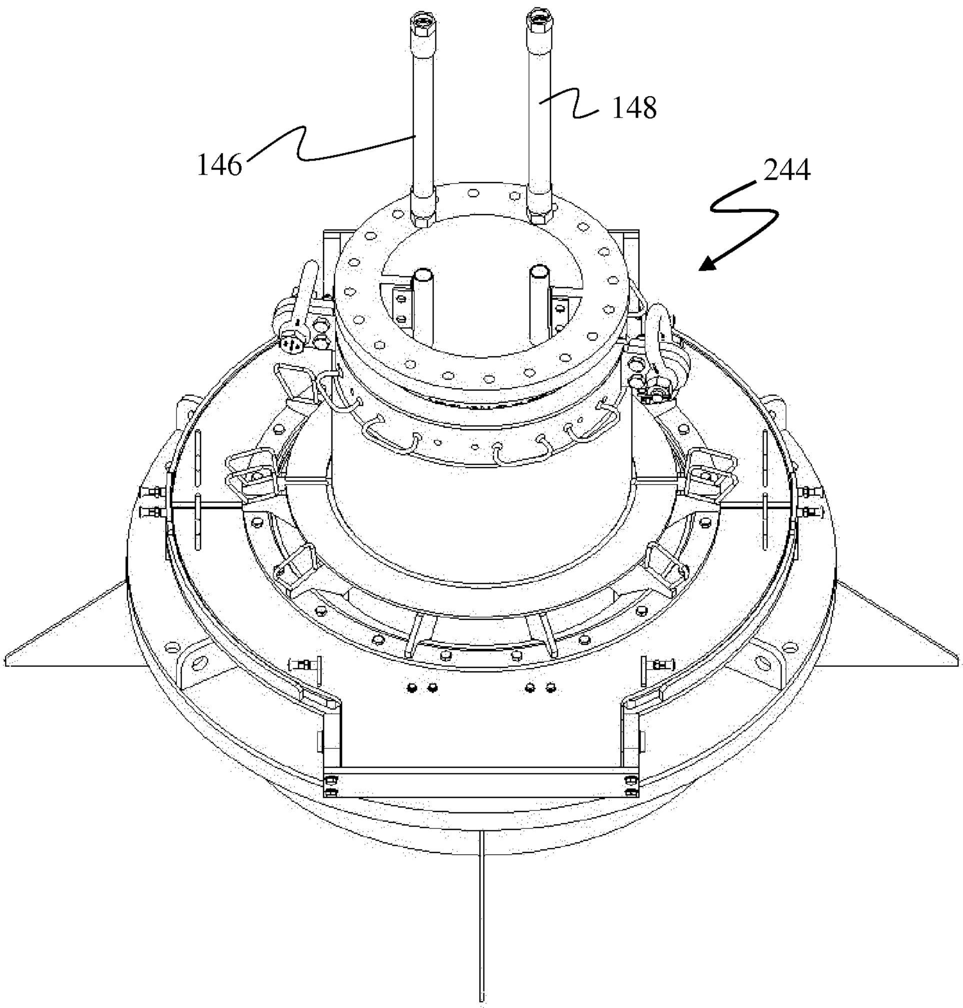

Fig. 10

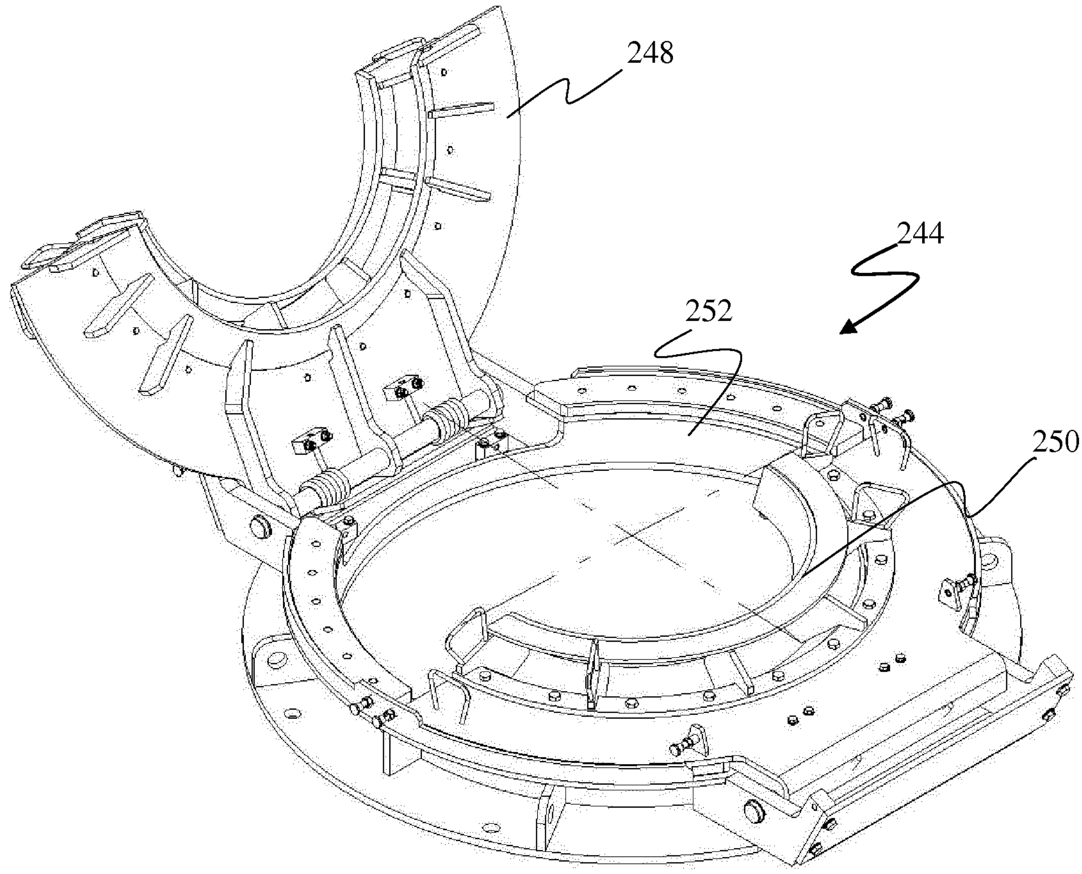

Fig. 11

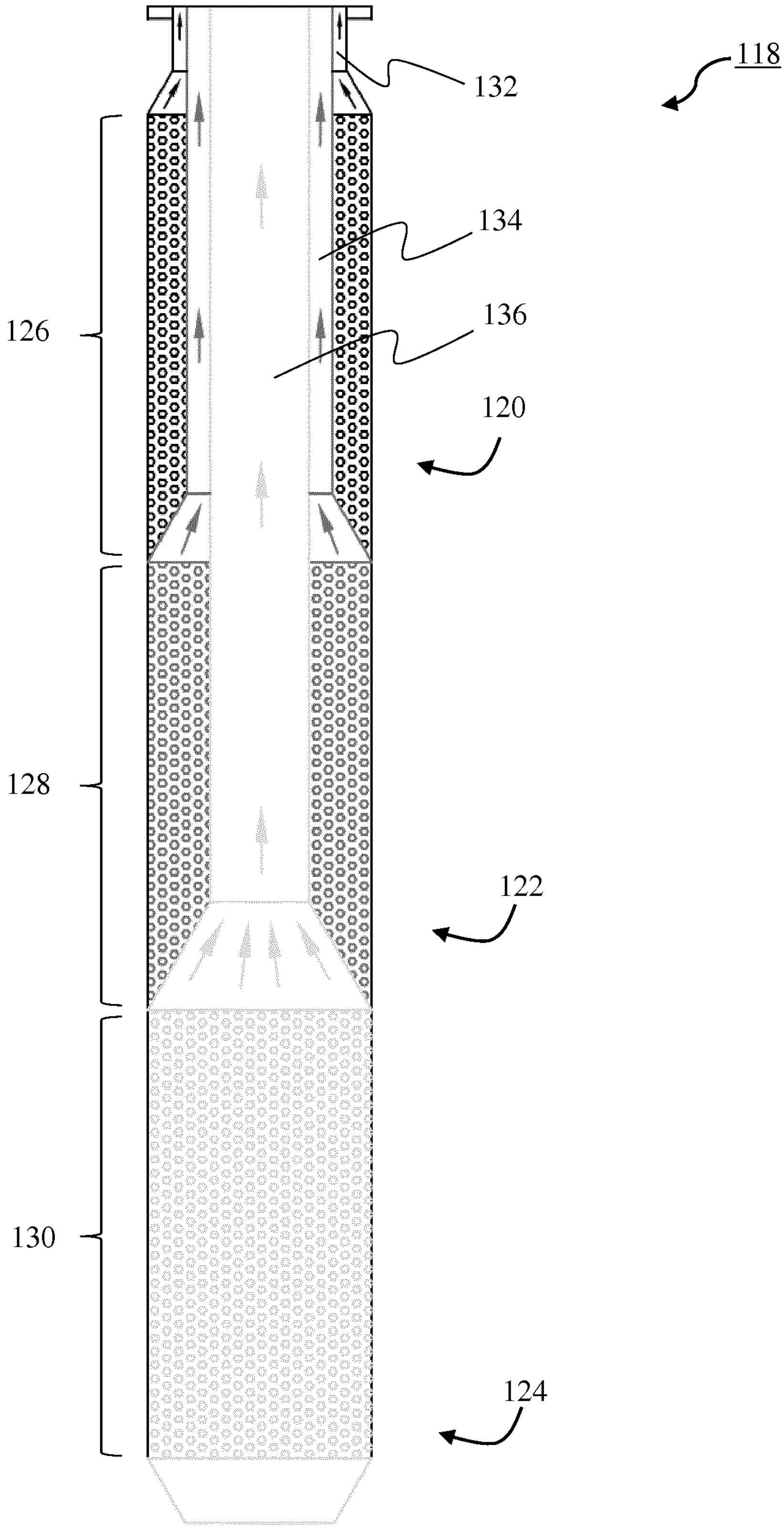

Fig. 12

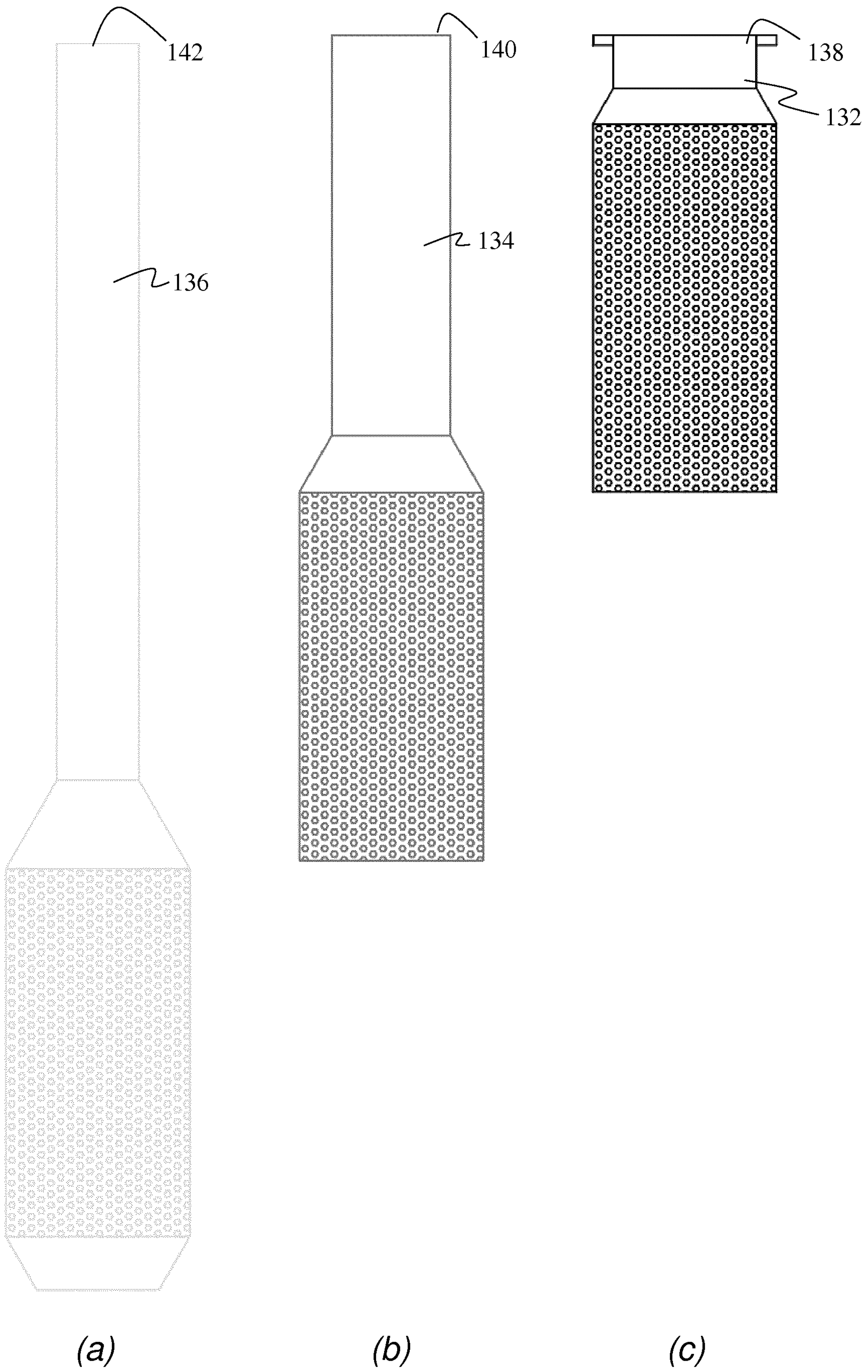

Fig. 13

REFERENCES CITED IN THE DESCRIPTION

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(54) AN IMPROVED SEAWATER SUCTION SYSTEM

VERBESSERTES SALZWASSERANSAUGSYSTEM

SYSTÈME D'ASPIRATION D'EAU DE MER AMÉLIORÉ

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(73) Proprietor: **Emstec GmbH**
22113 Oststeinbek (DE)

(72) Inventors:
- **BRINK, Burghard**
8835 Feusisberg (CH)
- **CRAIG, Ian**
Hartlepool
Cleveland TS26 0AB (GB)

(74) Representative: **Murgitroyd & Company**
165-169 Scotland Street
Glasgow G5 8PL (GB)

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EP 3 137 800 B1

Description

[0001] The present invention relates to a seawater suction system particularly, although not exclusively, suited for use with a Floating Production Storage and Offloading (FPSO) vessel.

Introduction

[0002] Conventional seawater suction systems used by FPSO vessels typically comprise a plurality of hoses and caissons. Each hose typically comprises a plurality of flexible hose sections interconnected to form a continuous hose. The continuous hose combines with a caisson on the FPSO to pass seawater into the FPSO. The free end of the hose is fitted with a suction strainer for straining sea water which is drawn into the hose. The suction strainer is fitted with a hypochlorite dispersion ring, which is used to disperse hypochlorite around the suction strainer as seawater is drawn through the hose, thereby preventing marine growth in the suction system and the associated pipework of the FPSO. An example of such an arrangement can be seen in WO2008/017937 to the same applicant. WO2010/010500 discloses also a seawater suction system according to the preamble of claim 1. Each of the hose sections of such conventional suction systems is typically manufactured from number of layers of material, starting with a flexible rubber liner in which a plurality of steel or wire reinforcement rings are embedded at intervals along the length of the liner. Wrapped around the reinforced liner are a number of layers of a suitable textile ply, and a marine/weather resistant rubber outer layer is placed over the textile ply layers. Steel nipples and flanges are provided at either end of each hose section so that the sections can be attached to one another.

An example of a flexible hose section used in a conventional suction system has a nominal bore, or internal diameter, of 20 inches (508mm) and a length of 11500mm. A hose section having these dimensions and being manufactured in the manner described above would weigh approximately 1900kg, predominantly due to the layers of material needed and the reinforcement rings. The weight of each section of hose presents handling difficulties on the deck of the vessel during installation of the system at sea. Furthermore, the weight of a system comprising a number of these heavy hose sections, along with drag and other hydrodynamic factors, imparts large loadings on the surface vessel.

[0003] Additionally, marine growth can occur in conventional flexible rubber hose sections, which necessitates the provision of a Hypochlorite distribution line to counter the marine growth. Providing a Hypochlorite line increases the complexity, cost and time of installing the system.

[0004] It is an object of the present invention to obviate or mitigate one or more of the aforementioned disadvantages.

Summary of the Invention

[0005] According to a first aspect of the present invention there is provided a seawater suction system comprising first and second conduits connected to one another so as to form an internal fluid passage allowing fluid communication between the two conduits, wherein the first conduit is formed from at least two layers of a first material and the second conduit is formed from a single layer of a second material which is different from the first material, a suction head connected to a free end of the first conduit; characterised by at least one caisson (24) adapted to receive and hold the suction head of the first conduit, the caisson comprising a suspension apparatus (44), adapted to selectively secure the first and second conduits during assembly, comprising a spring operated mechanism adapted to lockingly engage with the first and second conduit, and a conduit adapter (48, 50) configured to compensate for any difference between the external diameters of the first and second conduits.

[0006] The internal fluid passage of the second conduit has an internal diameter that is substantially identical to an internal diameter of the internal fluid passage of the first conduit, and the second conduit has an external diameter that may be less than an external diameter of the first conduit. The internal and external diameters of the first and second conduits may be substantially constant. The first material may be rubber.

[0007] The second material may be a plastics material. The second material may be high-density polyethylene (HDPE). The second conduit may comprise at least one flange member having an outer surface of which at least a portion has a parabolic cross-sectional profile. The at least one flange member may further comprise at least one load ring arranged circumferentially around the outer surface at a predetermined distance from an end portion of the flange member.

[0008] The system may further comprise a strainer formed in the second conduit. The strainer may comprise a plurality of fluid apertures formed in the second conduit to allow fluid flow into the second conduit. Alternatively, the strainer may be connected to a free end of the second conduit.

[0009] The strainer may comprise at least a first strainer member, having a first fluid inlet, a first fluid passage and a first fluid outlet, and a second strainer member, having a second fluid inlet, a second fluid passage and a second fluid outlet, first and second strainer members are fluidly separate, and wherein the first strainer member is adapted to be coupled to the second fluid member so as to form at least a two-stage strainer arrangement with the first and second fluid inlets arranged adjoiningly along a longitudinal axis of the second conduit, and the first and second fluid outlets forming a combined outlet interface fluidly coupleable to the second conduit.

[0010] Additionally, the strainer may further comprise at least a third strainer member, having a third fluid inlet, a third fluid passage and a third fluid outlet, fluidly separate from the first and second strainer member, and wherein the third strainer member is adapted to be coupled to the second fluid member so as to form three-stage strainer arrangement with the first, second and third fluid inlets arranged adjoiningly along the longitudinal axis of the second conduit, and the first, second and third fluid outlets forming a combined outlet interface fluidly coupleable to the second conduit.

[0011] Advantageously, the first strainer member may be adapted to matingly engage with the second strainer arrangement so as to form a stack along the longitudinal axis, and the second strainer member may be adapted to matingly engage with the third strainer arrangement so as to form a stack along the longitudinal axis.

Preferably, the strainer may be formed from the second material.

[0012] The system may further comprise a weight member suspended from a free end of the second conduit. Advantageously, the weight member may be at least a third conduit fluidly coupleable to the second conduit and made of a non-buoyant material when *in-situ.* Preferably, the non-buoyant material is a metal.

[0013] The system may comprise a plurality of successive first conduits connected to a plurality of successive second conduits. In other words, a number of first conduits may be connected together in series and then connected to a number of second conduits, which are also connected together in series.

The caisson may be located within the hull of Floating Production Storage and Offloading (FPSO) vessel.

[0014] Preferably, the suspension apparatus may be removably coupleable to a top end of the caisson when *in situ.*

[0015] The second material may alternatively be a carbon-based steel or reinforced fibreglass. The system may further comprise at least one auxiliary fluid line located within the internal fluid passage of the first and second conduits and adapted to supply a predetermined fluid to the free end of the second conduit. Advantageously, the system may further comprise at least one second auxiliary fluid line arranged parallel to the first auxiliary fluid line and located within the internal fluid passage of the first and second conduits, and adapted to supply the predetermined fluid to the free end of the second conduit.

Preferably, the first and second auxiliary fluid line may be fluidly coupled to a dispersion member operably coupled between the second conduit and the strainer, so as to allow the predetermined fluid to flow into the internal fluid passage during use.

According to a second aspect of the present invention there is provided a method of assembling a seawater suction system comprising the steps of: providing at least one first conduit and at least one second conduit, wherein the first conduit is formed from at least two layers of a first material and the second conduit is formed from a single layer of a second material which is different from the first material, and the first and second conduits are connectable together so as to allow fluid communication between the two conduits; connecting the two conduits together; and connecting a suction head to a free end of the first conduit; providing a caisson adapted to receive and hold the suction head, and mounting the suction head and first and second conduits within the caisson. The method may also include the further step of connecting a strainer to a free end of the second conduit.

The method may also comprise the further step of connecting a weight member to a free end of the strainer or second conduit.

[0016] The method may also comprise the further step of attaching at least one auxiliary fluid line within the internal fluid passage of the first and second conduits such that the auxiliary fluid line supplies a fluid to the free end of the second conduit.

Brief Description of the Drawings

[0017] An embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

- **Figure 1** shows a seawater suction system comprising a number of conduits;
- **Figure 2** is a schematic sectional view of a number of additional components of the seawater suction system located within a Floating Production Storage and Offloading (FPSO) vessel;
- **Figure 3** is a sectional view of a detail of the components shown in Figure 2;
- **Figure 4** is a sectional view of a further detail of the components shown in Figure 2;
- **Figure 5** is a schematic sectional view of a three-stage strainer, each strainer stage having a fluidly separate inlet, fluid passage and outlet, wherein all strainer outlets are combined into a single outlet interface fluidly coupleable to the second conduit;
- **Figure 6** is a schematic view of the three strainer members when disassembled into (a) stage one, (b) stage two and (c) stage three;
- **Figure 7** is a perspective view of a suspension apparatus installed to the caisson top on, for example, an FPSO platform, securing a first conduit during assembly, and
- **Figure 8** is a perspective schematic view of the suspension apparatus of Figure 7 with one spring-loaded engagement member opened,
- **Figure 9** is a side view of a second conduit (HDPE) comprising a dedicated flange having an outer surface with a parabolic cross-sectional profile and a circumferential load ring, therefore providing improved strength and fatigue characteristics, and
- **Figure 10** is a close-up cross-sectional view of the dedicated flange of Figure 9.

Detailed description of the preferred embodiment(s)

[0018] Figure 1 shows a seawater suction system 10 comprising a first conduit 12 and a pair of second conduits 14 connected in series with the first conduit 12. Each of the first and second conduits 12, 14 has a generally cylindrical body forming an internal fluid passageway with connecting means located at either end of the body. In this illustrated example, the connecting means are flanges 16 having a plurality of connecting apertures (not shown) therein. The conduits 12,14 are connected to one another by abutting the corresponding flanges 16 from adjacent conduits 12,14 such that their respective connecting apertures are aligned. A suitable mechanical fixing means such as a studbolt (not shown) is then passed through each of the aligned apertures and a nut tightened onto the end of the studbolt, thereby connecting the adjacent conduits 12,14 to one another. The connecting of the conduits 12,14 is typically undertaken on-board a vessel with which the suction system 10 is to be used. The first conduit 12 is formed from at least two layers of a first material such as, for example, rubber. The first conduit 12 is of a known type having a rubber liner, or inner layer, in which a plurality of steel or wire reinforcement rings are embedded at intervals along the length of the liner. Wrapped around the reinforced liner are a number of intermediate layers of a suitable textile ply, and a marine/weather resistant rubber outer layer is placed over the textile ply layers.

[0019] The second conduits 14 are each formed from a single piece or layer of a second material different from the first material. As the second conduits 14 only have a single layer of material and no reinforcing rings, each of the second conduits 14 weighs less than the first conduit 12 despite each conduit 12,14 having substantially the same dimensions. Additionally, each of the first and second conduits 12, 14 has a substantially identical internal diameter. However, because the second conduit 14 has only a single layer of material the second conduits 14 have an external diameter that is less than the external diameter of the first conduit 12. The second conduits 14 are therefore thinner than the first conduit 12. The internal and external diameters of the first and second conduits 12, 14 are preferably constant along their respective lengths.

[0020] In the preferred embodiment illustrated, the second material from which the second conduits 14 are formed is high-density polyethylene (HDPE).

[0021] The connecting means of the first conduit 12 are preferably formed from steel and encapsulated in a protective coating of the first material to prevent corrosion. The connecting means of the second conduits 14 are preferably formed from the second material and provided with steel backing rings, which have been treated with a corrosion-inhibiting coating. The lower of the two second conduits 14 (when viewed in Figure 1) is provided with a strainer 18 for use with the system 10. The strainer 18 strains seawater that is drawn through the system 10. The strainer 18 may be formed in the lower second conduit 14 from a plurality of fluid apertures 18a, which allow seawater to pass into the interior of the second conduits 14. In this example embodiment, the fluid apertures 18a each have a diameter of 30mm. Figures 5 and 6 illustrate an alternative embodiment of a strainer 118 that is fluidly coupleable to an end section of the second conduit 14. The strainer 118 comprises three fluidly separate strainer members, first strainer member 120, second strainer member 122, and third strainer member 124, that can be assembled into the three-stage strainer 118. Each of the strainer members 120, 122, 124 comprises a fluidly separate inlet section 126, 128, 130, a fluid passage 132, 134, 136, and an outlet 138, 140, 142. The strainer members 120, 122, 124 are formed in such a way that the second strainer member 122 can be matingly stacked onto the third strainer member 124, and the first strainer member 120 can be maitingly stacked onto the second strainer member 122. When assembled the three outlets 138, 140 and 142 form a combined interface 144 that is fluidly coupleable to the second conduit 14. During use, fluid is moved through all three inlet sections 126, 128, 130 and separately passed through the fluid passages 132, 134 and 136 to exit the combined outlets 138, 140, 142 into the internal fluid passage of the second conduit 14.

[0022] The system 10 may also comprise a weight member 20 connected to the free end of the lower second conduit 14 for added ballast. The weight member may be a third conduit (not shown) connected to the second conduit 14 or the strainer 18, 118. The weight member 20 is made from a non-buoyant material, preferably from metal, and even more preferably from steel.

[0023] Referring now to Figures 2-4, a schematic section view through the hull 22 of an FPSO vessel is shown in Figure 2, with more detailed views of certain components shown in Figures 3 and 4. Figure 2 shows a number of caissons 24 located within the hull 22. Each caisson 24 may form an additional component of the suction system 10 when the first and second conduits 12, 14 are connected thereto. To facilitate the connection of the first and second conduits 12, 14 to the caisson 24 the system may further comprise a caisson interface, or riser seat, 26 and a riser head or suction head 28. As best illustrated in Figures 3 and 4, each caisson interface 26 is installed on the underside of the keel 30 of the vessel and includes a female conical seat 32 which mates with a male conical seat 34 of the suction head 28 to centralise the head 28 and prevent downward movement of the first and second conduits 12,14. The caisson interface 26 also includes an internal circumferential bearing ring 33 which mates with an external upper circumferential bearing ring 35 of the suction head 28 to prevent tilting of the head 28 relative to the interface 26. The head 28 also includes a connecting flange 36, which is used to connect the upper connecting flange 16 of the first conduit 12 to the head 28. Figures 2 and 4 also show a suction pump 40 deployed in the caisson 24 on the right hand side (when viewed in Figure 2) for sucking seawater into the vessel. A number of centralisers 42 located at intervals within the caisson 24 ensure the pump 40 remains centralised.

[0024] Referring to Figures 2 and 3, a suspension tool 44 and a deployment/retrieval tool 46 are shown in the middle caisson 24 (when viewed in Figure 2). These tools 44, 46 are used for the assembly and disassembly of the various components of the suction system 10. The suspension tool 44 is mounted at the top of the caisson 24 and provides a means for securing and suspending the part-assembled suction system in the caisson 24 whilst other components are being fitted.

[0025] Figures 7 and 8 show a more detailed view of the suspension apparatus or tool 44, when in use and mounted to the caisson top (Figure 7) and as a separate entity in an open, dis-engaged state (Figure 8). The suspension apparatus or tool 44 comprises two spring-loaded engagement members 48, 50 that are operably connected to a mount 52. The mount 52 is adapted to be mounted to the top of a caisson. The spring mechanism of the suspension apparatus or tool 44 is adapted to be hand operated by a user to secure the first or second conduits 12, 14 during assembly, i.e. suspending the conduit string while another conduit section is being connected. In use the user simple moves the spring-biased engagement members 48, 50 into or out of engagement with the conduit 12, 14. In particular, during engagement, the contact surfaces of the engagement members 48, 50 contact the outer surface of the conduits so as to provide a cam-like action, as well as, a friction resistance, securing the conduit in place simply by the gravity force acting on the conduits. The suspension apparatus or tool 44 is lighter in weight and much more compact than a conventional hydraulic suspension tool, therefore, allowing for installations in space restricted areas.

[0026] In addition, Figure 7 also shows a section of the second conduit 14 having two auxiliary fluid lines 146, 148 for providing, for example, hypochlorite fluid that are installed within the internal fluid passage of the second conduit 14. The two auxiliary fluid lines 146, 148 are led, for example, to the top of the strainer 18, 118 where they each connect to a separate dispersion ring (not shown) allowing a more concentrated / higher dosage of hypochlorite to be moved into the internal fluid passage of the first and second conduits 12,14. In addition, providing two separate auxiliary fluid lines 146, 148 provides for and increased fluid volume and a degree of redundancy.

[0027] The deployment/retrieval tool 46 deploys and retrieves the assembled system 10 to and from the caisson 24. The deployment/retrieval tool 46 is remotely operated for releasing the system once it is in the correct position.

[0028] The assembly of the seawater suction system 10 is carried out in a conventional manner, i.e. by suspending each conduit 12, 14 at the top of the caisson 24 whilst each subsequent conduit 12,14 hose section 10 is attached thereto by their respective flanges 16. Preferably, the second conduits (HDPE) 14 may be connected by particularly designed flanges 200 that are configured to provide improved strength and fatigue properties compared to conventional flanges, especially when subjected to the expected forces during assembly of the conduits 14. As shown in Figure 9, a parabolic cross sectional flange profile 202 is provided at the attachment end of the flange member 200 to optimise the stress distribution within the material and thereby minimise "structural hotspots" and consequently maximise its strength and fatigue life.

In addition, when connecting the second conduits 14 (e.g. HDPE), it is necessary to suspend the lower section in the vertical position while the upper section is lowered onto it and connected. The lower section must be able to support the loads applied during assembly and, at the same time, enable the sections 14 to be connected. Accordingly, flange 200 may comprise a load ring 204 configured to have sufficient strength to accommodate for the loads induced during assembly whilst enabling the sections 14 to be connected. The load ring 204 is a circumferential ring integral with the flange 200 so as to allow the dedicated hang-off tool (not shown) to support the hose string while respective flanges 200 can be bolted together without any obstruction.

[0029] The suction system 10 is also disassembled in a conventional manner, i.e. by lifting the system 10 toward the top of the caisson 24 and reversing the assembly steps described above.

[0030] The seawater suction system of the present invention provides a number of advantages over previous proposals. By comprising the system of a first conduit formed in a conventional manner from layers of rubber or a similarly flexible first material, and one or more second conduits formed from a single layer of a second material, the system has a reduced weight compared to conventional suction systems. However, retaining at least one first conduit of the type described above ensures that the system retains strength and load-bearing capabilities in spite of the weight reduction. Reducing the weight of certain components of the system makes for easier handling of the components during installation and retrieval, with a consequent reduction in the time and cost of carrying out these tasks. Forming the second conduits in a single layer reduces weight and also reduces hydrodynamic loadings on the associated vessel whilst the system is deployed under the water. This reduces vessel draft and improves vessel stability.

[0031] If the second conduits are formed from HDPE, the invention has the additional benefit that marine growth cannot form within the second conduits. Marine growth in the system can increase the overall weight of the system, the loadings on the vessel and the drag created by the system. These problems are removed in the present invention without having to resort to the use of a Hypochlorite treatment line in the system. This again speeds up assembly/disassembly of the system and additionally has environmental benefits to the sub-sea ecosystem. HDPE also has an exceptionally smooth surface finish, thereby providing a smoother internal bore in the second conduits. The smoother bore improves flow characteristics in the system whilst at the same time reducing pressure drop across the system.

[0032] The illustrated embodiment of the system comprises one first conduit and a pair of second conduits. However, it should be recognised that the number of first and second conduits in the system is not limited to this arrangement and may be varied according to requirements. The minimum requirement for the system is one first conduit and one second conduit. The number of second conduits in the system need only be limited by practical considerations. However, it is preferred that a maximum of three first conduits are used in the system to avoid negating the benefits associated with the system. Where respective pluralities of first and second conduits are used, they are preferably arranged in successive groups instead of alternating the first and second conduits with one another.

[0033] Whilst the preferred embodiment of the system shows a strainer formed at one end of one of the second conduits, the strainer may alternatively be a separate component formed from the second material and connected to the free end of the lower second conduit 14.

[0034] Whilst preferred, the invention is not limited to the use of second conduits formed from HDPE. Examples of other suitable second materials are carbon-based steel and reinforced fibreglass. A single piece or layer of either of these alternative materials may also be used to form the second conduit(s), with the same benefits in terms of reduction of weight, hydrodynamic forces and drag. Where the second conduits are formed from either of these alternative materials, an auxiliary fluid line is included in the system for the supply of Hypochlorite to the free end of the system.

[0035] It will be appreciated by persons skilled in the art that the above embodiment has been described by way of example only and not in any limitative sense, and that various alterations and modifications are possible without departing from the scope of the invention as defined by the appended claims.

Claims

1. A seawater suction system (10) comprising:

- first (12) and second (14) conduits connected to one another, so as to form an internal fluid passage allowing fluid communication between the two conduits (12, 14), wherein the first conduit (12) is formed from at least two layers of a first material and the second conduit (14) is formed from a single layer of a second material, which is different from the first material;
- a suction head (28) connected to a free end of the first conduit (12) ; **characterised by**:
- at least one caisson (24) adapted to receive and hold the suction head (28) of the first conduit (12): **characterized by**: - the caisson (24) comprising:
- a suspension apparatus (44), adapted to selectively secure the first (12) and second (14) conduits during assembly, comprising a spring operated mechanism adapted to lockingly engage with the first (12) and second (14) conduit, and a conduit adapter (48, 50) configured to compensate for any difference between the external diameters of the first (12) and second (14) conduits.

2. A seawater suction system as claimed in claim 1, wherein the internal fluid passage of the second conduit has an internal diameter that is substantially identical to an internal diameter of the internal fluid passage of the first conduit, and the second conduit has an external diameter, which is less than an external diameter of the first conduit.

3. A seawater suction system as claimed in claim 1 or claim 2, wherein the first material is rubber and the second material is a plastics material, or a carbon-based steel, or reinforced fibreglass.

4. A seawater suction system as claimed in claim 3, wherein the second material is high density polyethylene (HDPE).

5. A seawater suction system as claimed in claim 4, wherein the second conduit comprises at least one flange member (200) having an outer surface of which at least a portion has a parabolic cross-sectional profile (202).

6. A seawater suction system as claimed in claim 5, wherein said at least one flange member further comprises at least one load ring (204) arranged circumferentially around the outer surface at a predetermined distance from an end portion of the flange member.

7. A seawater suction system as claimed in any preceding claim, wherein the system further comprises a strainer (18) formed in the second conduit and including a plurality of fluid apertures (18a) formed in the second conduit to allow fluid flow into the second conduit.

8. A seawater suction system as claimed in any preceding claim, wherein the system comprises a plurality of successive first conduits connected to a plurality of successive second conduits.

9. A seawater suction system as claimed in any of the preceding claims, wherein the caisson is located within the hull of a Floating Production Storage and Offloading (FPSO) vessel.

10. A seawater suction system as claimed in of the preceding claims, wherein the suspension apparatus is removably coupleable to a top end of the caisson when *in situ.*

11. A seawater suction system as claimed in any preceding claim, wherein the system further comprises at least one first auxiliary fluid line (146) located within the internal fluid passage of the first and second conduits and adapted to supply a predetermined fluid to the free end of the second conduit.

12. A seawater suction system as claimed in claim 11, wherein the system further comprises at least one second auxiliary fluid line (148) arranged parallel to the first auxiliary fluid line and located within the internal fluid passage of the first and second conduits, and adapted to supply the predetermined fluid to the free end of the second conduit.

13. A seawater suction system as claimed in claim 12, when depending on claim 11 and any one of claims 7 to 10, wherein the first and second auxiliary fluid line are fluidly coupled to a dispersion member operably coupled between the second conduit and the strainer, so as to allow the predetermined fluid to flow into the internal fluid passage during use.

14. A method of assembling a seawater suction system according to any one of the preceding claims, comprising the steps of:

- providing at least one first conduit and at least one second conduit, wherein the first conduit is formed from at least two layers of a first material and the second conduit is formed from a single layer of a second material, which is different from the first material, and the first and second conduits are connectable together, so as to allow fluid communication between the two conduits;
- connecting the two conduits together;
- connecting a suction head to a free end of the first conduit, and
- providing a caisson adapted to receive and hold the suction head, and mounting the suction head and first and second conduits within the caisson.

15. A method of assembling a seawater suction system as claimed in claim 14, wherein the second conduit comprises a strainer formed in the second conduit and including a plurality of fluid apertures formed in the second conduit to allow fluid flow into the second conduit.

Patentansprüche

1. Ein Meerwasseransaugsystem (10), das Folgendes beinhaltet:

- eine erste (12) und zweite (14) Leitung, die miteinander verbunden sind, um einen inneren Fluiddurchgang zu bilden, der eine Fluidkommunikation zwischen den beiden Leitungen (12, 14) ermöglicht, wobei die erste Leitung (12) aus mindestens zwei Schichten eines ersten Materials gebildet ist und die zweite Leitung (14) aus einer einzelnen Schicht eines zweiten Materials gebildet ist, welches sich von dem ersten Material unterscheidet;
- einen Saugkopf (28), der mit einem freien Ende der ersten Leitung (12) verbunden ist;
- mindestens einen Senkkasten (24), der angepasst ist, um den Saugkopf (28) der ersten Leitung (12) aufzunehmen und zu halten; **dadurch gekennzeichnet, dass**: der Senkkasten (24) Folgendes beinhaltet:

    - eine Aufhängungsvorrichtung (44), die angepasst ist, um die erste (12) und zweite (14) Leitung während des Zusammenbaus selektiv zu sichern, die einen federbetriebenen Mechanismus, der angepasst ist, um arretierend in die erste (12) und zweite (14) Leitung einzugreifen, und einen Leitungsadapter (48, 50), der konfiguriert ist, um jegliche Differenz zwischen den Außendurchmessern der ersten (12) und zweiten (14) Leitung zu kompensieren, beinhaltet.

2. Meerwasseransaugsystem gemäß Anspruch 1, wobei der innere Fluiddurchgang der zweiten Leitung einen Innendurchmesser aufweist, der im Wesentlichen identisch mit einem Innendurchmesser des inneren Fluiddurchgangs der ersten Leitung ist, und die zweite Leitung einen Außendurchmesser aufweist, der geringer als ein Außendurchmesser der ersten Leitung ist.

3. Meerwasseransaugsystem gemäß Anspruch 1 oder Anspruch 2, wobei das erste Material Gummi ist und das zweite Material ein Kunststoffmaterial oder ein Stahl auf Kohlenstoffbasis oder glasfaserverstärkter Kunststoff ist.

4. Meerwasseransaugsystem gemäß Anspruch 3, wobei das zweite Material Polyethylen hoher Dichte (HDPE) ist.

5. Meerwasseransaugsystem gemäß Anspruch 4, wobei die zweite Leitung mindestens ein Flanschelement (200) mit einer äußeren Oberfläche beinhaltet, von der mindestens ein Teil ein parabolisches Querschnittsprofil (202) aufweist.

6. Meerwasseransaugsystem gemäß Anspruch 5, wobei das mindestens eine Flanschelement ferner mindestens einen Lastring (204) beinhaltet, der in einem vorgegebenen Abstand von einem Endteil des Flanschelements im Umfang um die äußere Oberfläche eingerichtet ist.

7. Meerwasseransaugsystem gemäß einem der vorhergehenden Ansprüche, wobei das System ferner ein Filter (18) beinhaltet, das in der zweiten Leitung gebildet ist und eine Vielzahl von in der zweiten Leitung gebildeten Fluidöffnungen (18a) umfasst, um einen Fluidfluss in die zweite Leitung zu ermöglichen.

8. Meerwasseransaugsystem gemäß einem der vorhergehenden Ansprüche, wobei das System eine Vielzahl von aufeinanderfolgenden ersten Leitungen beinhaltet, die mit einer Vielzahl von aufeinander folgenden zweiten Leitungen verbunden sind.

9. Meerwasseransaugsystem gemäß einem der vorhergehenden Ansprüche, wobei der Senkkasten innerhalb des Rumpfes eines Schiffs mit Produktions-, Lager- und Verladesystem (FPSO, Floating Production Storage and Offloading) befindlich ist.

10. Meerwasseransaugsystem gemäß den vorhergehenden Ansprüchen, wobei die Aufhängungsvorrichtung entfernbar an ein oberes Ende des Senkkastens koppelbar ist, wenn *in situ.*

11. Meerwasseransaugsystem gemäß einem der vorhergehenden Ansprüche, wobei das System ferner mindestens eine erste Fluidhilfsleitung (146) beinhaltet, die innerhalb des inneren Fluiddurchgangs der ersten und zweiten Leitung befindlich ist und angepasst ist, um dem freien Ende der zweiten Leitung ein vorgegebenes Fluid zuzuführen.

12. Meerwasseransaugsystem gemäß einem Anspruch 11, wobei das System ferner mindestens eine zweite Fluidhilfsleitung (148) beinhaltet, die parallel zu der ersten Fluidhilfsleitung eingerichtet und innerhalb des inneren Fluiddurchgangs der ersten und zweiten Leitung befindlich ist und angepasst ist, um dem freien Ende der zweiten Leitung ein vorgegebenes Fluid zuzuführen.

13. Meerwasseransaugsystem gemäß Anspruch 12, wenn von Anspruch 11 und einem der Ansprüche 7 bis 10 abhängig, wobei die erste und zweite Fluidhilfsleitung fluidisch an ein Dispersionselement gekoppelt sind, welches betriebsbereit zwischen die zweite Leitung und das Filter gekoppelt ist, um während des Gebrauchs ein Fließen des vorgegebenen Fluids in den inneren Fluiddurchgang zu ermöglichen.

14. Ein Verfahren zum Zusammenbauen eines Meerwasseransaugsystems gemäß einem der vorhergehenden Ansprüche, das die folgenden Schritte beinhaltet:

- Bereitstellen mindestens einer ersten Leitung und mindestens einer zweiten Leitung, wobei die erste Leitung aus mindestens zwei Schichten eines ersten Materials gebildet ist und die zweite Leitung aus einer einzelnen Schicht eines zweiten Materials gebildet ist, welches sich von dem ersten Material unterscheidet, und die erste und zweite Leitung miteinander verbunden werden können, um eine Fluidkommunikation zwischen den beiden Leitungen zu ermöglichen;
- Verbinden der beiden Leitungen miteinander;
- Verbinden eines Saugkopfs mit einem freien Ende der ersten Leitung; und
- Bereitstellen eines Senkkastens, der angepasst ist, um den Saugkopf aufzunehmen und zu halten, und Montieren des Saugkopfs und der ersten und zweiten Leitung innerhalb des Senkkastens.

15. Verfahren zum Zusammenbauen eines Meerwasseransaugsystems gemäß Anspruch 14, wobei die zweite Leitung ein Filter beinhaltet, das in der zweiten Leitung gebildet ist und eine Vielzahl von in der zweiten Leitung gebildeten Fluidöffnungen umfasst, um einen Fluidfluss in die zweite Leitung zu ermöglichen.

Revendications

1. Un système d'aspiration d'eau de mer (10) comprenant :

- une première (12) et une deuxième (14) conduites raccordées l'une à l'autre, de manière à former un passage de fluide intérieur permettant une communication fluidique entre les deux conduites (12, 14) où la première conduite (12) est formée d'au moins deux couches d'un premier matériau et la seconde conduite (14) est formée d'une seule couche d'un deuxième matériau, qui est différent du premier matériau ;
- une tête d'aspiration (28) raccordée à une extrémité libre de la première conduite (12) ;
- au moins un caisson (24) conçu pour accueillir et maintenir la tête d'aspiration (28) de la première conduite (12) ; **caractérisé par : le fait que** le caisson (24) comprend :

  - un appareil de suspension (44), conçu pour assujettir de façon sélective les première (12) et deuxième (14) conduites lors de l'assemblage, comprenant un mécanisme actionné par ressort conçu pour se mettre en prise par verrouillage avec les première (12) et deuxième (14) conduites, et un adaptateur de conduite (48, 50) configuré pour compenser toute différence entre les diamètres extérieurs des première (12) et deuxième (14) conduites.

2. Un système d'aspiration d'eau de mer tel que revendiqué dans la revendication 1, où le passage de fluide intérieur de la deuxième conduite présente un diamètre intérieur qui est substantiellement identique à un diamètre intérieur du passage de fluide intérieur de la première conduite, et la deuxième conduite présente un diamètre extérieur, qui est inférieur à un diamètre externe de la première conduite.

3. Un système d'aspiration d'eau de mer tel que revendiqué dans la revendication 1 ou la revendication 2, où le premier matériau est du caoutchouc et le deuxième matériau est une matière plastique, ou un acier à base de carbone, ou de la fibre de verre renforcée.

4. Un système d'aspiration d'eau de mer tel que revendiqué dans la revendication 3, où le deuxième matériau est du polyéthylène à haute densité (HDPE).

5. Un système d'aspiration d'eau de mer tel que revendiqué dans la revendication 4, où la deuxième conduite comprend au moins un élément formant bride (200) présentant une surface externe dont au moins une partie présente un profil de section transversale parabolique (202).

6. Un système d'aspiration d'eau de mer tel que revendiqué dans la revendication 5, où ledit au moins un élément formant bride comprend en outre au moins un cercle de charge (204) disposé de façon circonférentielle autour de la surface externe à une distance prédéterminée d'une partie d'extrémité de l'élément formant bride.

7. Un système d'aspiration d'eau de mer tel que revendiqué dans n'importe quelle revendication précédente, où le système comprend en outre une crépine (18) formée dans la deuxième conduite et incluant une pluralité d'orifices de fluide (18a) formés dans la deuxième conduite pour permettre l'écoulement de fluide dans la deuxième conduite.

8. Un système d'aspiration d'eau de mer tel que revendiqué dans n'importe quelle revendication précédente, où le système comprend une pluralité de premières conduites successives raccordées à une pluralité de deuxièmes conduites successives.

9. Un système d'aspiration d'eau de mer tel que revendiqué dans n'importe laquelle des revendications précédentes, où le caisson est situé à l'intérieur de la coque d'un bâtiment flottant de production, de stockage et de déchargement (FPSO).

10. Un système d'aspiration d'eau de mer tel que revendiqué dans laquelle des revendications précédentes, où l'appareil de suspension peut être couplé de façon amovible à une extrémité supérieure du caisson lorsque qu'il se trouve *in situ.*

11. Un système d'aspiration d'eau de mer tel que revendiqué dans n'importe quelle revendication précédente, où le système comprend en outre au moins une première ligne de fluide auxiliaire (146) située à l'intérieur du passage de fluide intérieur des première et deuxième conduites et conçue pour fournir un fluide prédéterminé à l'extrémité libre de la deuxième conduite.

12. Un système d'aspiration d'eau de mer tel que revendiqué dans la revendication 11, où le système comprend en outre au moins une deuxième ligne de fluide auxiliaire (148) disposée parallèlement à la première ligne de fluide auxiliaire et située à l'intérieur du passage de fluide intérieur des première et deuxième conduites, et conçue pour fournir le fluide prédéterminé à l'extrémité libre de la deuxième conduite.

13. Un système d'aspiration d'eau de mer tel que revendiqué dans la revendication 12, lorsqu'elle dépend de la revendication 11 et de n'importe laquelle des revendications 7 à 10, où la première et la deuxième ligne de fluide auxiliaire sont fluidiquement couplées à un élément de dispersion fonctionnellement couplé entre la deuxième conduite et la crépine, de manière à permettre au fluide prédéterminé de s'écouler dans le passage de fluide intérieur lors de l'utilisation.

14. Une méthode d'assemblage d'un système d'aspiration d'eau de mer selon n'importe laquelle des revendications précédentes, comprenant les étapes consistant à :

- fournir au moins une première conduite et au moins une deuxième conduite, où la première conduite est formée d'au moins deux couches d'un premier matériau et la deuxième conduite est formée d'une seule couche d'un deuxième matériau, qui est différent du premier matériau, et les première et deuxième conduites peuvent être raccordées entre elles, de manière à permettre une communication fluidique entre les deux conduites ;
- raccorder les deux conduites entre elles ;
- raccorder une tête d'aspiration à une extrémité libre de la première conduite, et

- fournir un caisson conçu pour recevoir et maintenir la tête d'aspiration, et monter la tête d'aspiration et les première et deuxième conduites à l'intérieur du caisson.

15. Une méthode d'assemblage d'un système d'aspiration d'eau de mer tel que revendiqué dans la revendication 14, où la deuxième conduite comprend une crépine formée dans la deuxième conduite et incluant une pluralité d'orifices de fluide formés dans la deuxième conduite afin de permettre l'écoulement de fluide dans la deuxième conduite.

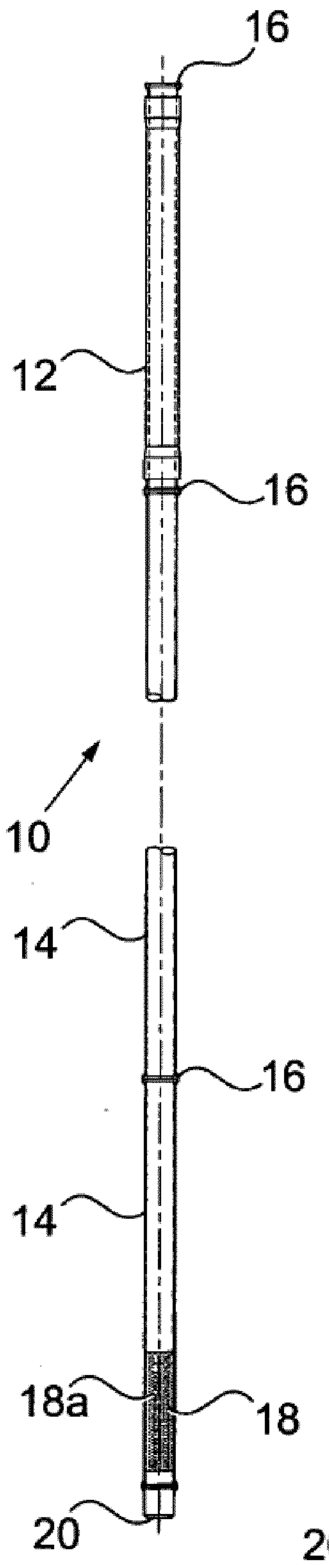

16
12
16
10
14
16
14
18a
18
20

Fig. 1

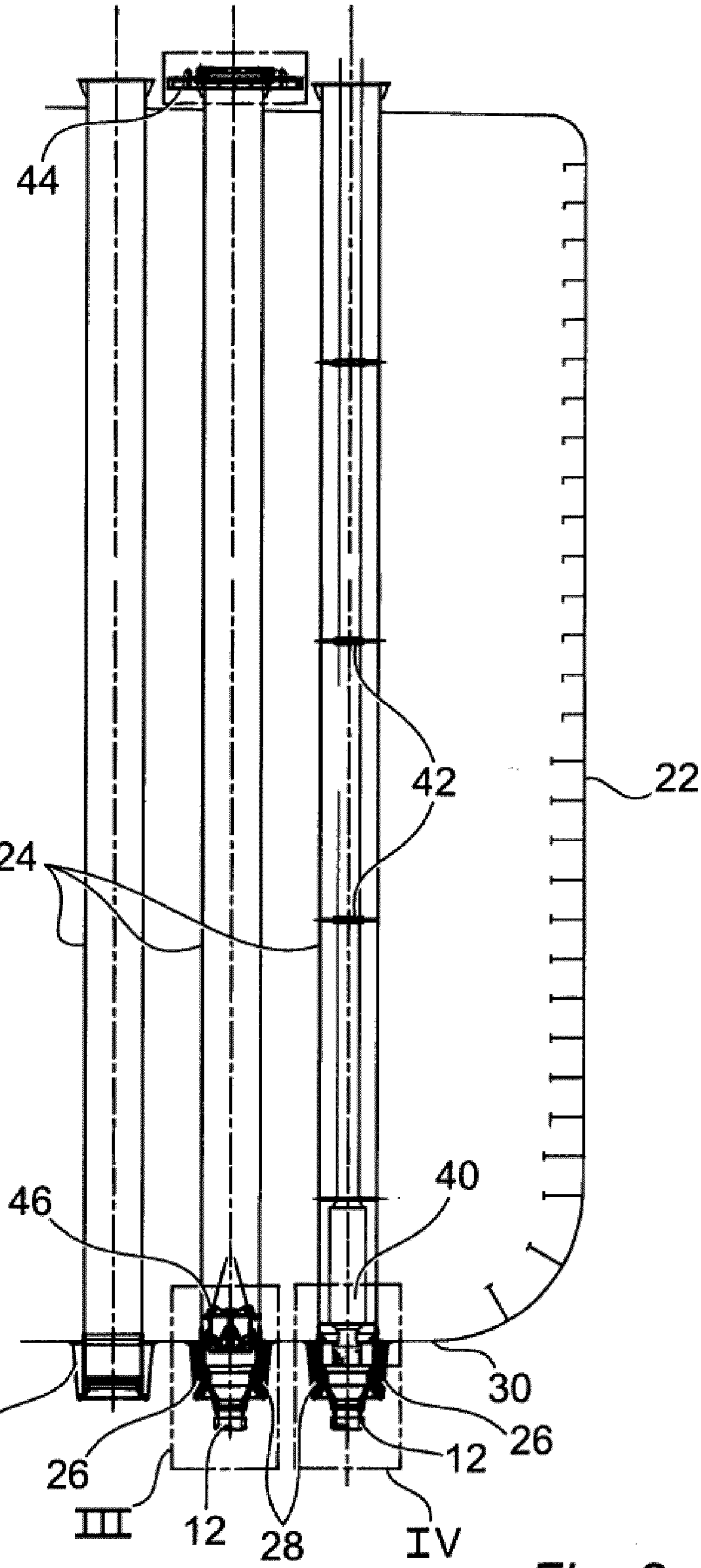

44
42
22
24
46
40
30
26
26
26
12
12
28
III
IV

Fig. 2

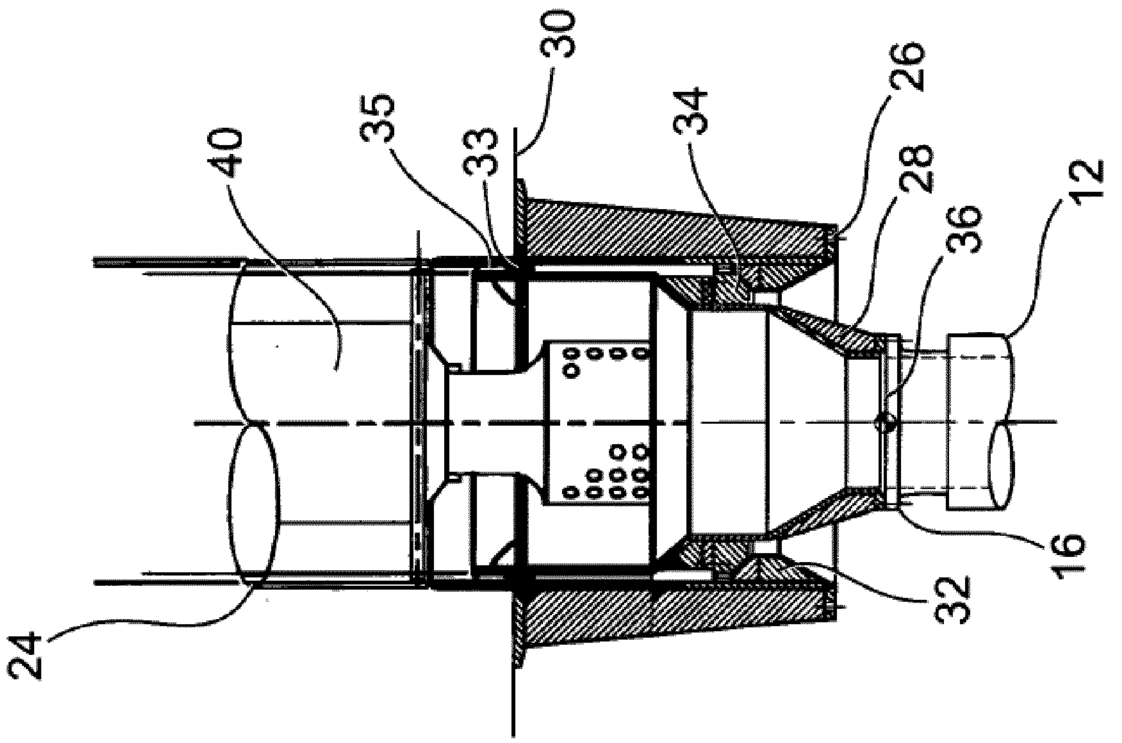


Fig. 4

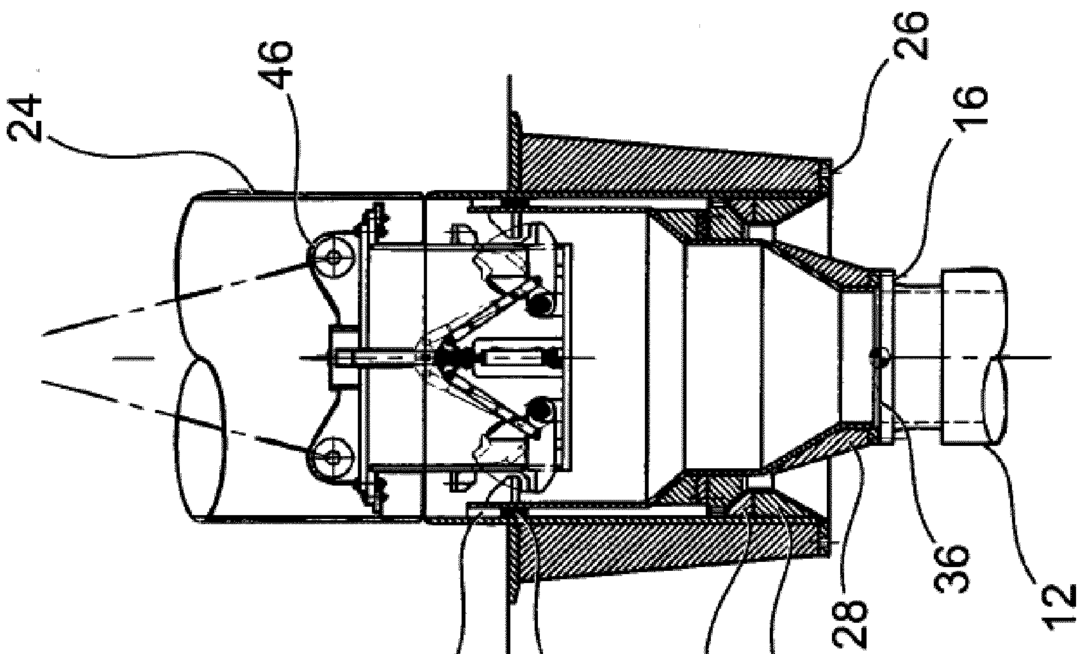


Fig. 3

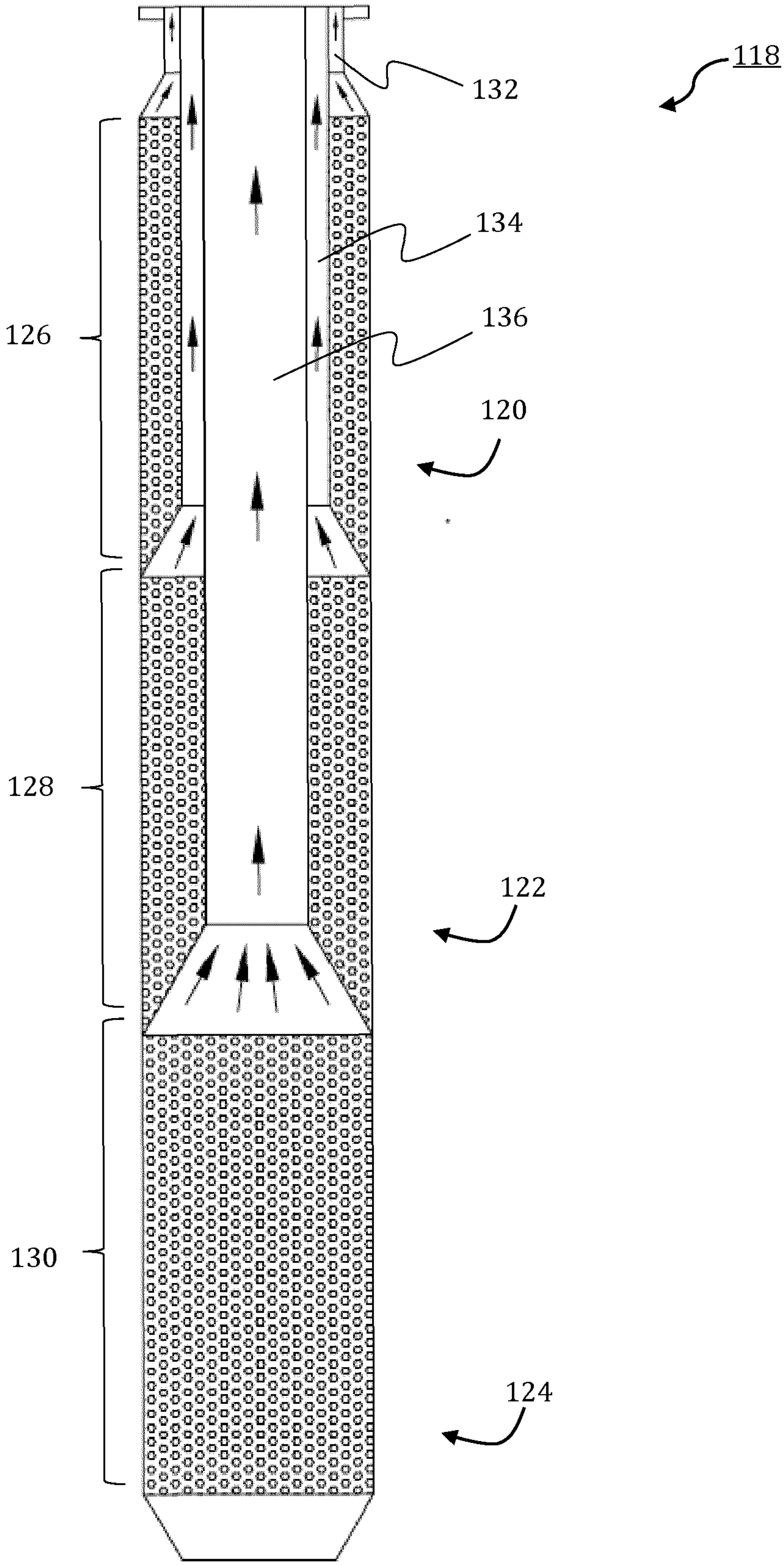
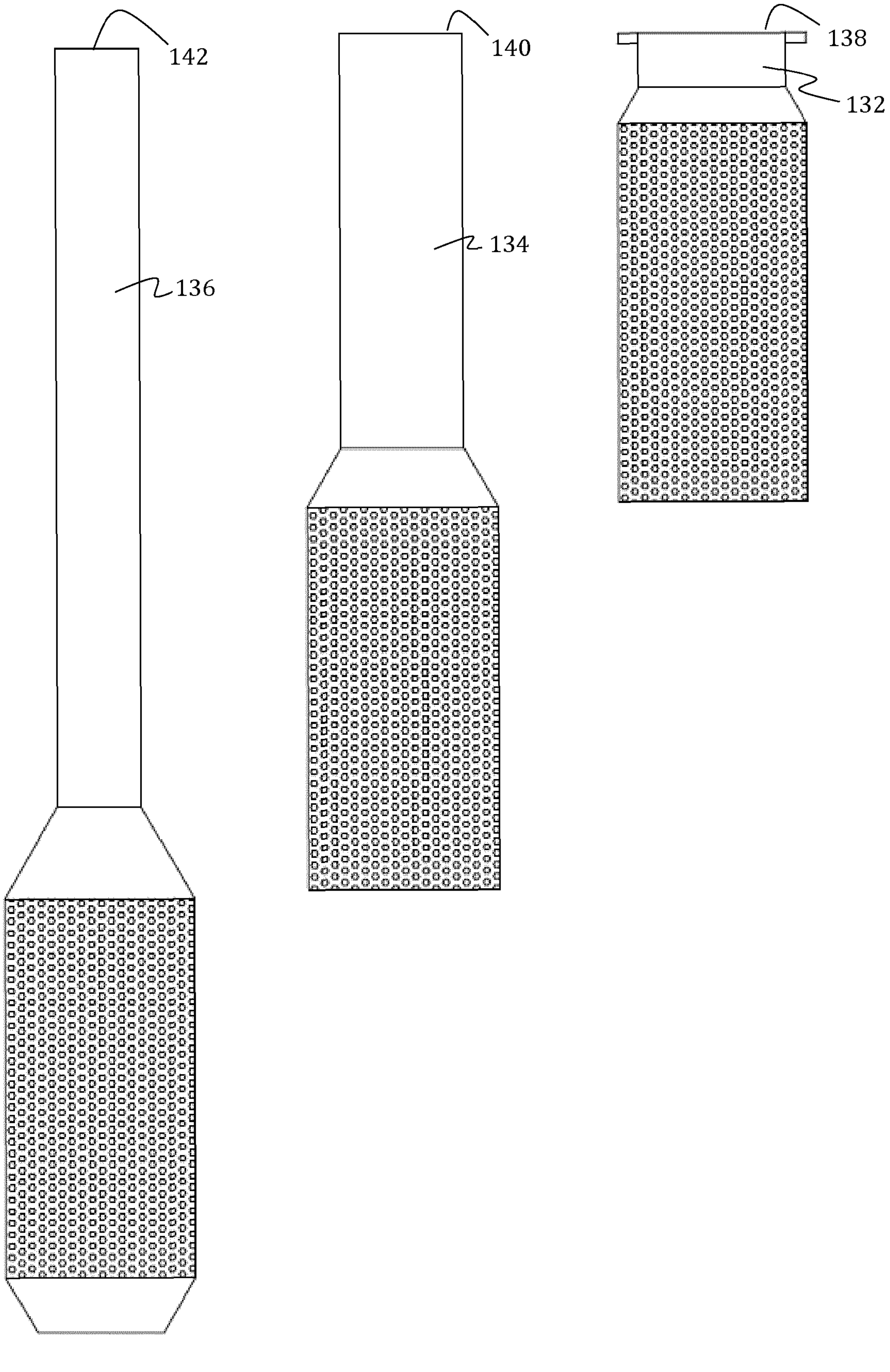


Fig. 5



(a) (b) (c)

Fig. 6

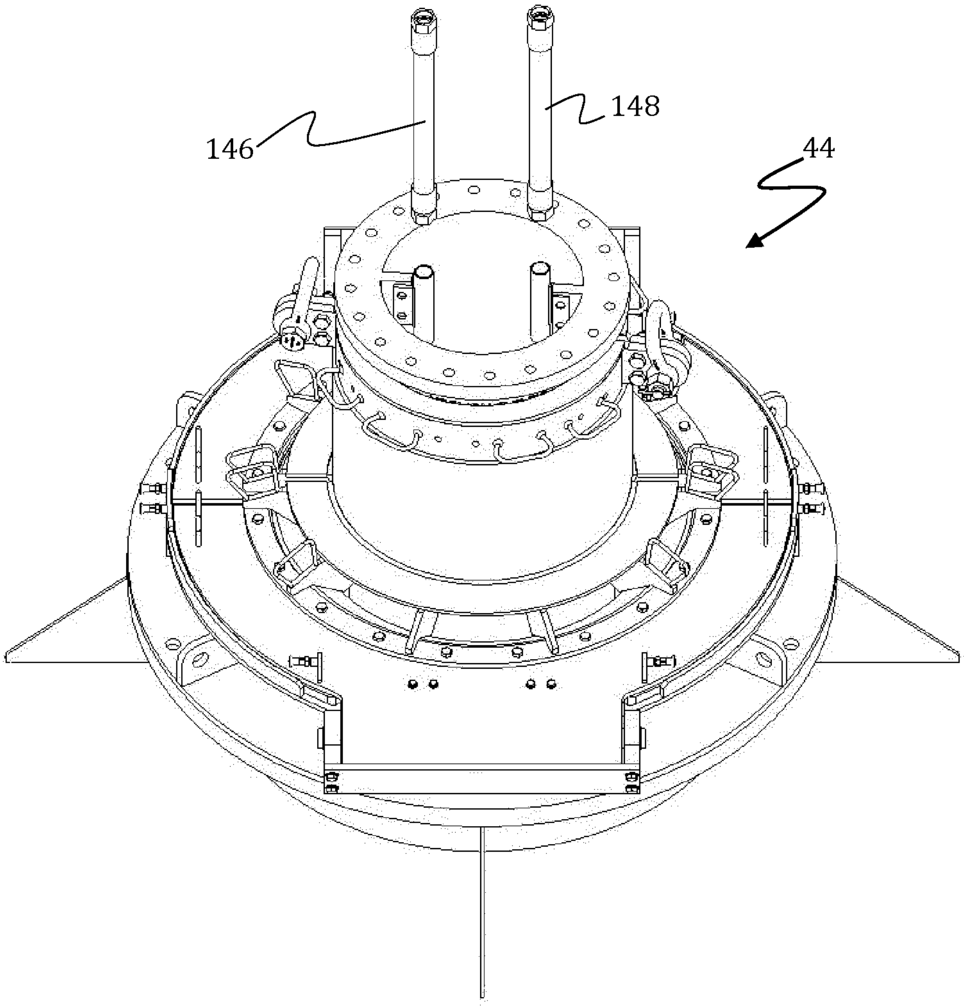


Fig. 7

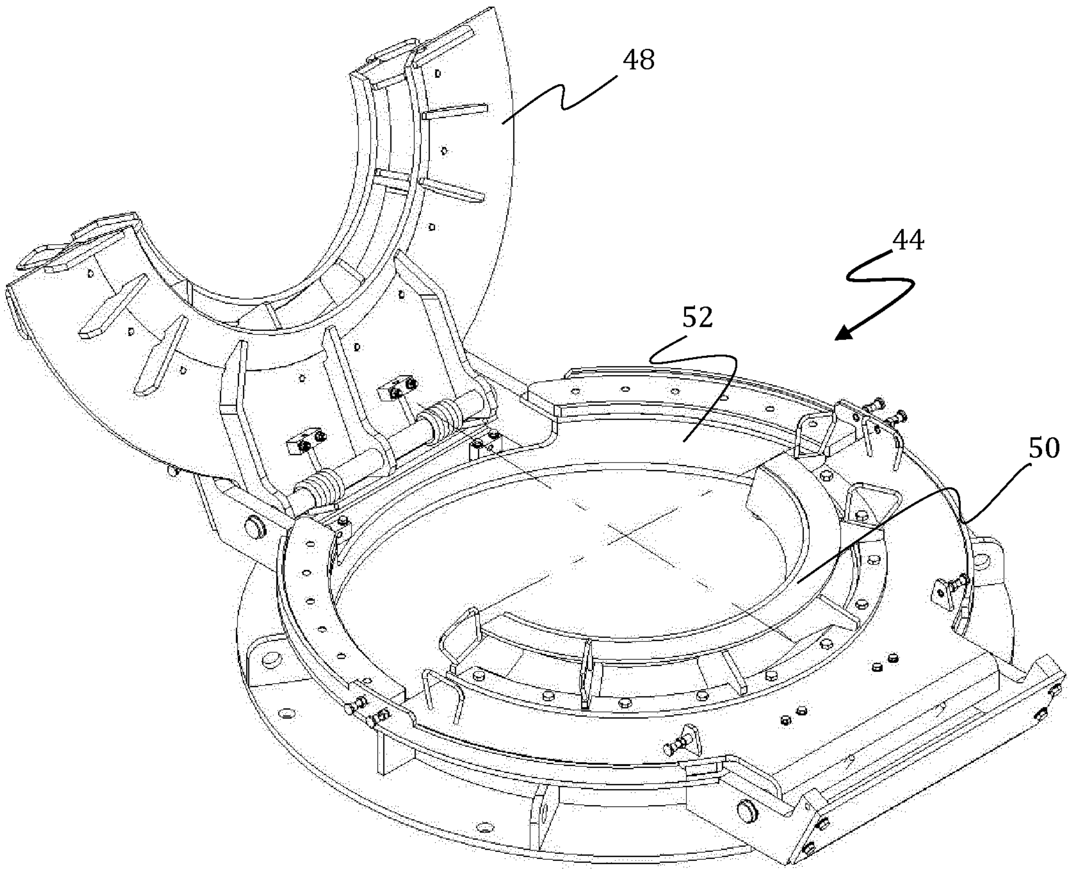


Fig. 8

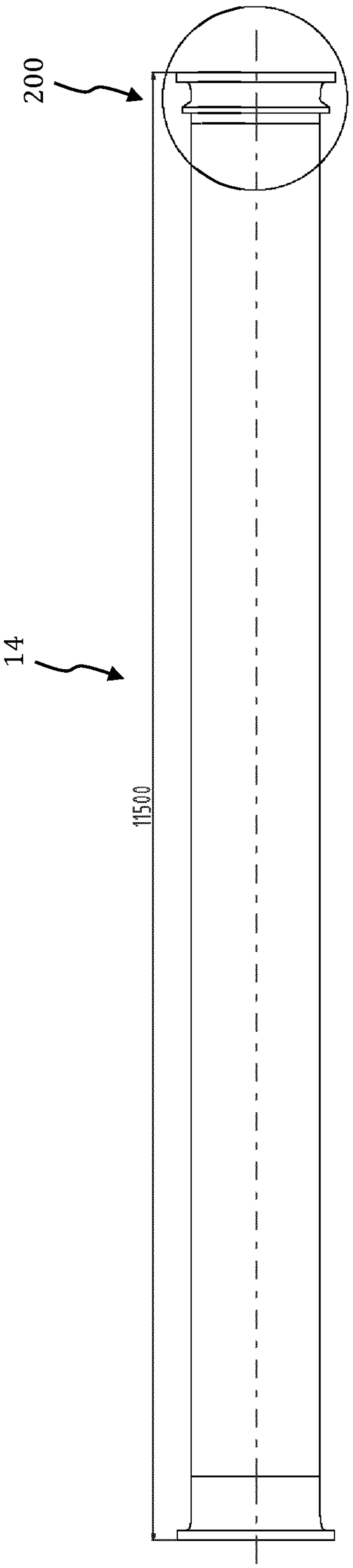


FIG. 9

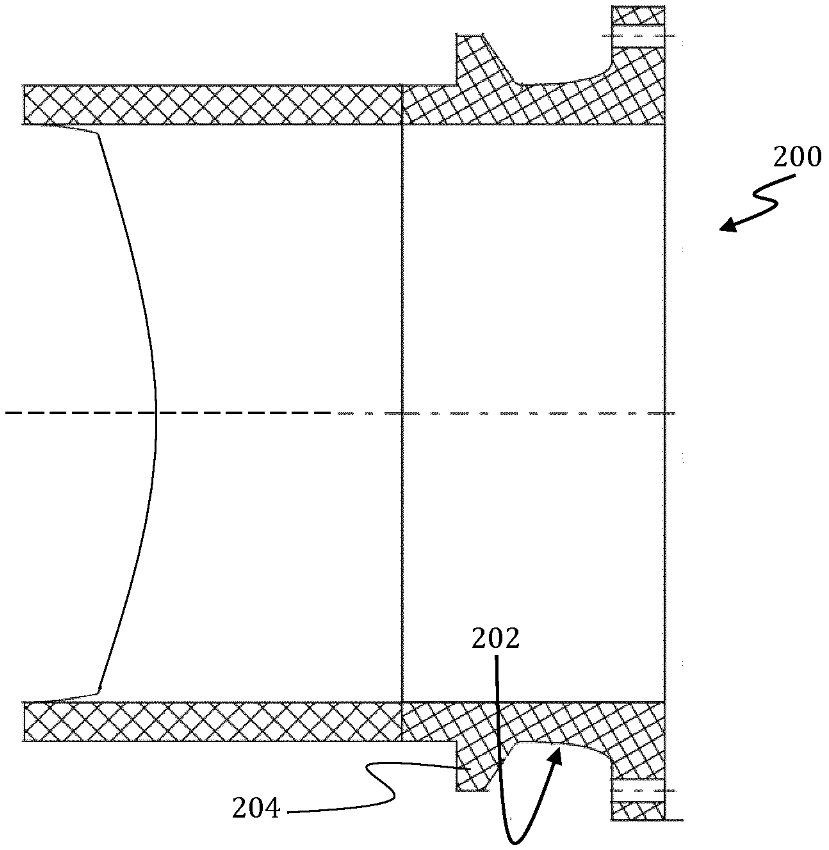


FIG. 10

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- WO 2008017937 A **[0002]**
- WO 2010010500 A **[0002]**

Section 11.0: Previous Reports & Presentations

Ian Craig

From: Ian Craig <ian.craig@emstec.net>
Sent: 19 October 2009 09:18
To: 'zbacha@technip.com'
Cc: 'premy@technip.com'
Subject: FW: gFLNG - EMSTEC / Your Presentation on 15/09/2009
Attachments: Hose Loads.pdf; Emstec Presentation Sept 2009.pdf

Dear Mr Bacha,

Thank you for your e-mail.

Attached is a pdf copy of the Powerpoint presentation delivered in Technip's office on 15th September 2009.

Unfortunately the native Powerpoint file is too large to transmit by e-mail.

Furthermore, page 37 of the presentation has a link to an Installation DVD and page 42 has links to Analyses Simulation Files which, again, are too large to send by e-mail (the Analyses Summary which has a link on page 42 is attached for your information).

In the meantime, if you require any further information, please do not hesitate to contact us.

Best Regards,

Ian Craig

------ Weitergeleitete Nachricht
Von: <zbacha@technip.com>
Datum: Fri, 16 Oct 2009 12:41:21 +0200
An: <info@emstec.net>
Cc: <premy@technip.com>
Betreff: Fw: gFLNG - EMSTEC / Your Presentation on 15/09/2009

Dear Sir,

Could you please send you presentation of riser / r-system for the gFLNG project presented in Technip office on 15/09/2009.

Thank you for your cooperation

Best regards, Mit freundlichen Grüßen,

Zine BACHA

Shell-FLNG-gFEED
TECHNIP - Rotating Equipment Engineer
Tel: 00 33(0)147786452
Mobile: 0607540129
Email: zbacha@technip.com

Ian Craig

From: Ian Craig <ian.craig@emstec.net>
Sent: 01 February 2011 17:05
To: 'Alain Goussain'
Subject: Intake riser
Attachments: Shell fLNG.pdf; Hose Loads.pdf; Hose Loads 2.pdf

Alain,

Please find attached a pdf presentation of our proposed alternative system.

The presentation includes the results from the analysis we have performed (I have attached them separately also for your convenience).

Note that the analysis assumes that each of the steel risers move independently, i.e. the support structure allows them to move such that they do not impose loads on adjacent risers.

Budget cost for the Emstec Rubber/HDPE system : **EUR**

Cost to include:

8-off 42"NB x 134m/147m Rubber/HDPE Riser Assemblies (inc Strainer and Riser Head)
8-off Riser Seats (for welding into hull)
1-set Installation Tools
1-set Documentation

I hope the above and attached provide sufficient detail at this point, however, if you require any further information, please do not hesitate to contact us.

Best Regards,

Ian Craig

EMSTEC

...your innovative provider of high integrity equipment.

Customised service and individual solutions

www.emstec.net

Seawater Intake Systems

Providing Seawater from below surface

- Cooler
- Cleaner
- Less oxygenated

EMSTEC Seawater Intake Systems

Developed over many years

- Using field experience
- Bespoke design to suit site conditions
- Adaptive to Client Specifications
- Design for life of vessel
  (see attached FEA sample showing fatigue calculations)
- Utilising advanced material selection *(see below photographs)*
- Focus on Corrosion Resistance *(see below photographs)*
- Low maintenance *(see below photographs)*

EMSTEC Seawater Intake Systems

Riser Head:
Manufactured from 6Mo
HDPE Seat / Pads at contact points

Riser Seat:
Manufactured from 6Mo
CS Stiffeners/Rings for Interface with Hull

EMSTEC Seawater Intake Systems

Flexible Hose Connections:
Titanium Bolting / Backing Quadrants
Hose flanges encapsulated with Rubber
No exposed CS in Hose Section

HDPE Connection:
Super Duplex Bolting / Backing Rings
HDPE Corrosion Resistant

EMSTEC Seawater Intake Systems

Flexible Hose Connections:
CS Bolting / Backing Quadrants
Bespoke Designed Sacrificial Anodes Installed for Cathodic Protection
No exposed CS in Hose Section

EMSTEC Seawater Intake Systems

HDPE Sections / Strainer:
Lightweight
Super Duplex Backing Rings
Corrosion Resistant

EMSTEC Seawater Intake Systems

Features:

- Diverless and Diver Assisted Installations
- Full Hydrodynamic Analysis
- Localised Structural Analysis
- Pressure losses minimised
  - *Minimal obstructions through internal flow path*
  - *Smooth bore for improved flow characteristics*
  - *Strainer design optimised*
- Inlet velocity optimised

EMSTEC Seawater Intake Systems

Features (Contd.):

- Responsibility for pump interface
  - *Designed to suit pump inlet elevation*
  - *Fluid velocity / pressure losses to suit pump design*
  - *Proximity check with impeller strainer / anodes*
  - *Pump centraliser design wrt to Hypochlorite Line*
  - *Installation tools to suit caisson flange / pump design*
- Minimal exposed metallic components *(see above photographs)*
- No metal to metal contact *(see above photographs)*
- Integral Hypochlorite Line
- Optional corrosion resistant materials *(see above photographs)*
- Optional weight saving materials *(see above phtographs)*

EMSTEC Seawater Intake Systems

Diverless Installations

- System includes all installation tooling
- System installation requires minimal site utilities
- System installed from topsides at caisson head
- System installed utilising vessel cranage
- System supplied containerised
- System maintenance using vessel facilities

See below photographs

EMSTEC Seawater Intake Systems

Installation Tools:
- All installation tools supplied with system
- Installation tools used for system inspection
- Lifting collar for hose handling
- Spreader beam for working height limitations
- All lifting tools load tested & certified by 3rd party

Installation Tools:
- Suspension tool fitted directly to caisson flange
- Utility air line drives hydraulic power pack
- Designed to suit hose/HDPE profile
- Safety features to prevent accidental opening
- Load tested and certified by 3rd party

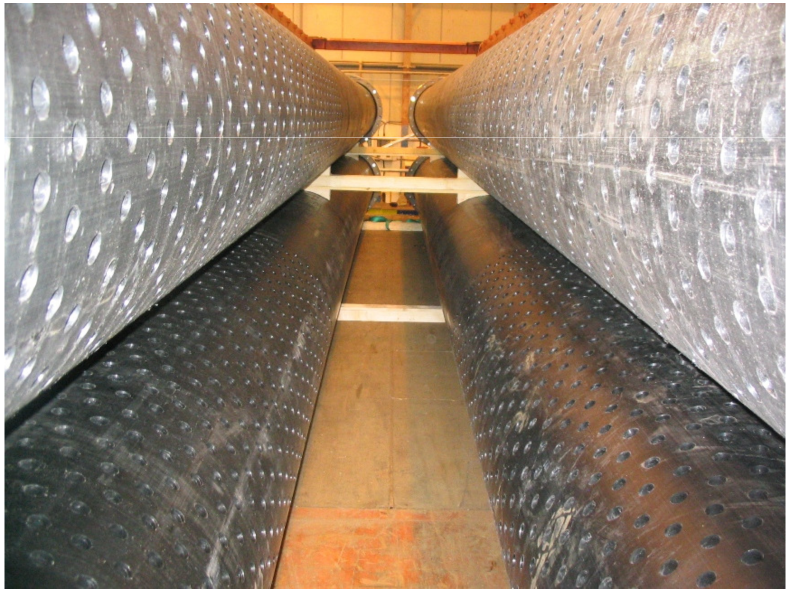
EMSTEC Seawater Intake Systems

Installation using dedicated runway beam:
- Reduced hose section length due to height restrictions
- No external crane required
- Installation tools designed to suit vessel capabilities

Installation using Vessel Onboard Crane:
- No external crane required
- System design considers vessel capabilities

EMSTEC Seawater Intake Systems

System Supplied Containerised:
No special transportation requirements
Storage at dockside facilities



EMSTEC Seawater Intake Systems

Project Specific Considerations

- Flow Rate
- Allowable Pressure Loss
- Maximum Velocity
- Suction Depth
- Available Cranage / Laydown Area
- Environmental Conditions
- Vessel Response Characteristics

EMSTEC Seawater Intake Systems

System Design

- Hose System Diameter
- Required Hose Stiffness
- Weight in Air / Weight in Water
- Flexible Section Configuration
  - ➢ Full Rubber Flexible Hose System
  - ➢ Rubber / HDPE Combination System
- Material Selection
  - ➢ Metallic Components
  - ➢ Bolting / Backing Quadrants
  - ➢ Strainer

EMSTEC Seawater Intake Systems

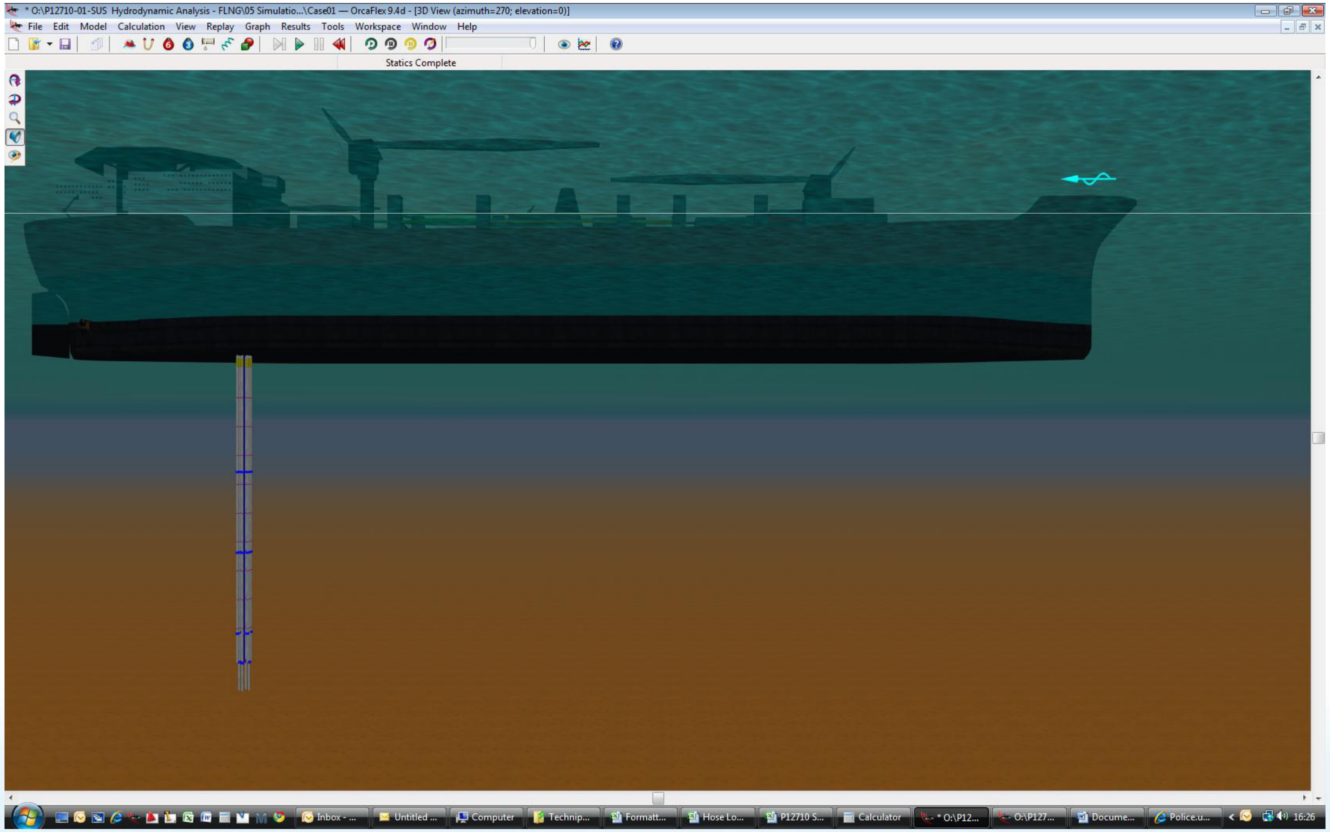
Shell LNG Project – Basic Design

- 8-off 42"NB System : (8 x 7000m^3/hr = 56,000m3/hr) *
- Rubber / HDPE Combination System
- Basic Environmental Data (1yr / 100yr)
- Typical Vessel Response Characteristics

* Subject to availability of suitable pumps, the following alternate configurations could provide further savings in terms of Capital Cost and Installation Cost
- 7-off 48"NB System : (7 x 8000m^3/hr = 56,000m^3/hr)
- 6-off 48"NB System : (6 x 9333m^3/hr = 56,000m$^{3/}$hr)

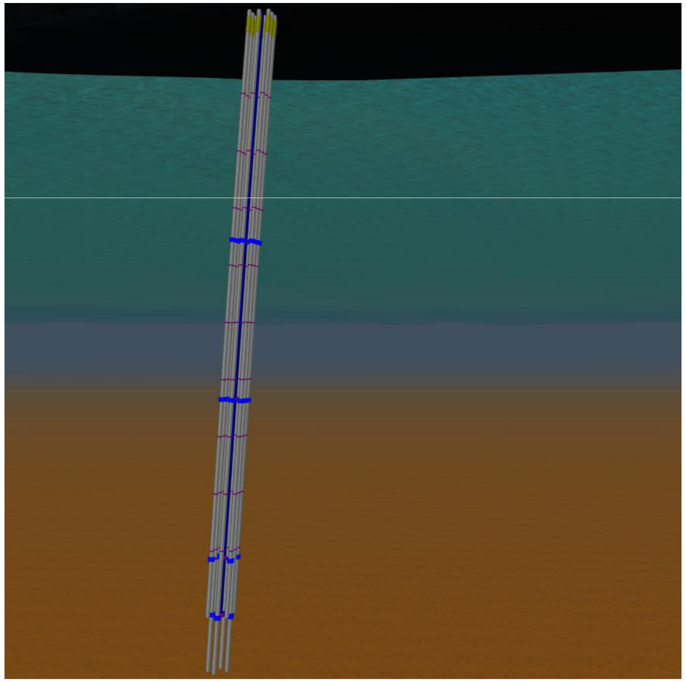
EMSTEC Seawater Intake Systems

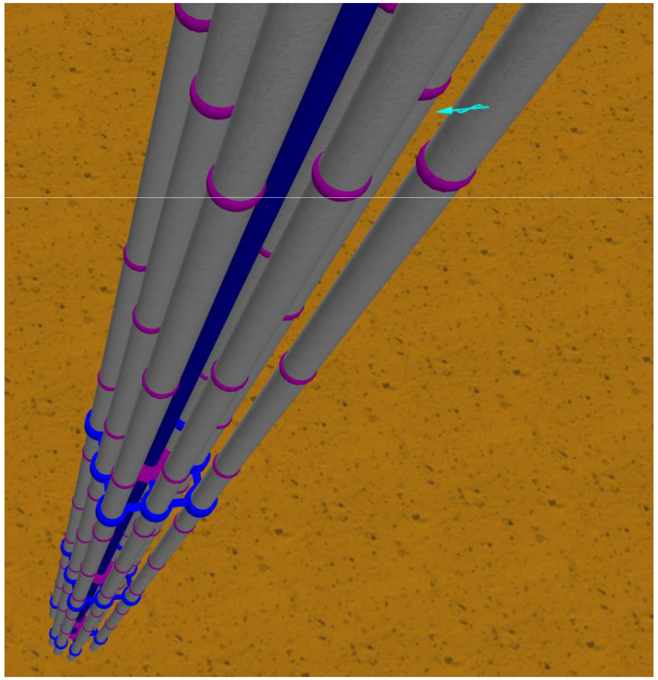
Shell LNG Project - Hydrodynamic Analysis (Model)



EMSTEC Seawater Intake Systems

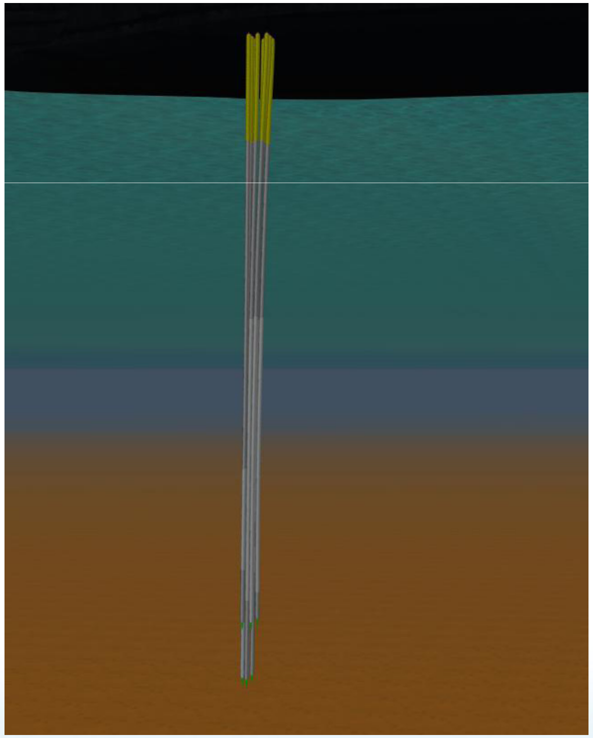
Shell LNG Project - Hydrodynamic Analysis (Steel Risers)

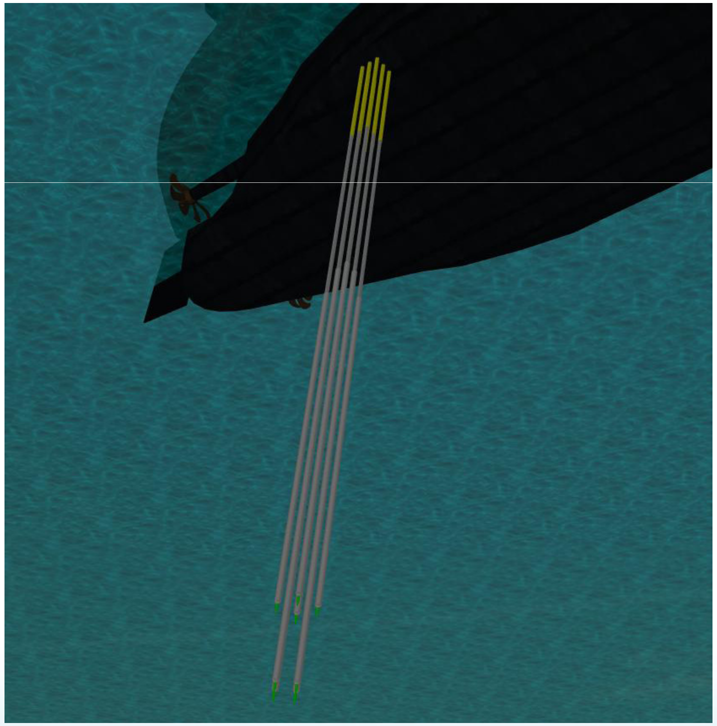




EMSTEC Seawater Intake Systems

Shell LNG Project - Hydrodynamic Analysis (Rubber/HDPE Risers)





EMSTEC Seawater Intake Systems

Flexible Hose and HDPE Pipe System

Composition of Risers:
Length 147/134m
Top 23.6m - 40" Flexible Hose
Remainder of Riser - 42" HDPE Pipe
5te weight at foot of Riser

Total Mass per short riser approx (te)	48.1
Total Mass per long riser approx (te)	51.0
Total Bundle Mass (te)	396.0
Total Weight in Water (te)	106.0

Steel Riser System

Length 147/134m
Top 3.6m - Flexible 40" Hose,
Remainder of Riser - 42" Steel Pipe
Central support riser included in simulation

Total Mass per short riser approx (te)	146.6
Total Mass per long riser approx (te)	150.2
Mass of centre riser and Spacers approx (te)	153.0
Total bundle Mass (te)	1354.6
Total Weight in Water (te)	1047.2

Normal (1yr)

Wave 1: Wave Height: 1.5m, Period: 3 sec, Angle to vessel, 0° (JONSWAP model)
Current: 0.5 m/s at Surface, reducing linearly to 0m/s at 200m depth.

Flexible Hose and HDPE Pipe System

Max Tension (kN)	136
End Shear Force (kN)	9.9
End Bend Moment (kN.m)	27.3
Min Curvature Radius (m)	37.3

Steel Riser System

Max Tension (kN)	1317
End Shear Force (kN)	12.5
End Bend Moment (kN.m)	19.7
Min Curvature Radius (m)	25.6

Extreme Survival (10,000yr)

Wave 1: Wave Height: 20.m, Period:20.2 sec, Angle to vessel, 0° (JONSWAP model)
Current: 2 m/s at Surface, reducing linearly to 0m/s at 200m depth.

Flexible Hose and HDPE Pipe System

Max Tension (kN)	615.5
End Shear Force (kN)	395.5
End Bend Moment (kN.m)	631.3
Min Curvature Radius in hose section (m)	2.9

Steel Riser System

Max Tension (kN)	1894.8
End Shear Force (kN)	715.0
End Bend Moment (kN.m)	1146.1
Min Curvature Radius in hose section (m)	3.1

EMSTEC Seawater Intake Systems

Riser System	Load Case	Significant Wave Height	Wave Period Tz	Current Velocity at Surface	Load	Riser 1	Riser 2	Riser 3	Riser 4	Riser 5	Riser 6	Riser 7	Riser 8	Structural Riser
Steel Riser System	Maximum Period Rise	19.74	15.66	2.00	Max Tension (kN)	1333	1339	1336	1336	1221	1221	1215	1215	1495
					Max Shear Load (kN)	364	373	368	368	415	415	405	405	230
					Max Bend Moment at End (kN.m)	562	575	568	568	654	654	639	639	332
	Maximum Period Fall	19.55	15.66	2.00	Max Tension (kN)	1370	1373	1371	1371	1253	1253	1251	1251	1662
					Max Shear Load (kN)	339	344	341	341	375	375	366	366	237
					Max Bend Moment at End (kN.m)	520	529	524	524	591	591	574	574	342
	Minimum Period Rise	20.15	15.66	2.00	Max Tension (kN)	1419	1427	1423	1423	1299	1299	1291	1291	1887
					Max Shear Load (kN)	485	495	490	490	552	552	541	541	315
					Max Bend Moment at End (kN.m)	749	766	758	758	872	872	853	853	468
	Minimum Period Fall	20.08	15.66	2.00	Max Tension (kN)	1436	1450	1443	1443	1317	1317	1305	1305	1895
					Max Shear Load (kN)	619	641	630	630	715	715	691	691	381
					Max Bend Moment at End (kN.m)	972	1008	990	990	1146	1146	1107	1107	566
	Light Conditions	1.50	3.00	0.50	Max Tension (kN)	1209	1209	1209	1209	1109	1109	1109	1109	1317
					Max Shear Load (kN)	11	11	11	11	12	12	12	12	11
					Max Bend Moment at End (kN.m)	17	16	17	17	20	20	20	20	15
	Static State	0.0	0.0	0.0	Static Tension (kN)	1201	1201	1201	1201	1102	1102	1102	1102	1311
Hose and HDPE Riser System	Maximum Period Rise	19.74	15.66	2.00	Max Tension (kN)	245	287	237	294	237	266	280	256	
					Max Shear Load (kN)	233	218	185	135	123	128	142	135	
					Max Bend Moment at End (kN.m)	435	430	384	308	300	289	309	294	
	Maximum Period Fall	19.55	15.66	2.00	Max Tension (kN)	415	445	415	427	427	354	376	355	
					Max Shear Load (kN)	167	205	159	119	129	117	164	122	
					Max Bend Moment at End (kN.m)	365	377	347	317	307	298	330	291	
	Minimum Period Rise	20.15	15.66	2.00	Max Tension (kN)	400	562	372	567	602	467	615	503	
					Max Shear Load (kN)	209	326	209	222	236	184	273	192	
					Max Bend Moment at End (kN.m)	447	561	472	483	494	421	481	407	
	Minimum Period Fall	20.08	15.66	2.00	Max Tension (kN)	362	493	401	415	477	389	549	446	
					Max Shear Load (kN)	260	376	257	295	316	275	395	282	
					Max Bend Moment at End (kN.m)	542	631	534	520	552	553	631	557	
	Light Conditions	1.50	3.00	0.50	Max Tension (kN)	133	136	133	135	135	134	136	134	
					Max Shear Load (kN)	9	10	9	4	4	3	4	3	
					Max Bend Moment at End (kN.m)	24	27	24	12	12	10	11	10	
	Static State	0.0	0.0	0.0	Static Tension (kN)	129	130	129	130	130	129	130	129	

EMSTEC Seawater Intake Systems

Vortex Induce Vibration (VIV):

There are many criteria contributing to VIV, but prior to a full VIV analysis, it is possible to perform a VIV assessment which identifies the main criteria and assesses the likelihood of VIV. One of the criteria contributing to VIV is the Reynolds number (Re).

For Re up to about 3x10^5, the shedding of vortices is regular and periodic - we are in the 'subcritical' flow regime.

Much above this Re value we are in an area of increasing turbulence which effectively acts to destroy the regularity of the vortex shedding. Hence decreases the drag coefficient.

At much higher values of Re (>5x10^6) we enter the post critical regime. Here there may be some re-establishment of a vortex street, which may increase the drag coefficient, but not above that found in the laminar, subcritical regime.

The provisional hydrodynamic analysis indicates Re values in the region of 3.6x10^5 . These fall in the flow regime which experiments suggest would give the lowest values of in-line drag coefficients, with minimal vortex shedding.

EMSTEC Seawater Intake Systems

Advantages of Emstec Proposed System

- **Proven System** – Installation and Operation

  Ref : Saipem Golfinho FPSO = 3-off 30"NB x 103m long (Installed 2006)
  Saipem Gimboa FPSO = 2-off 20"NB x 70m long (Installed 2007)

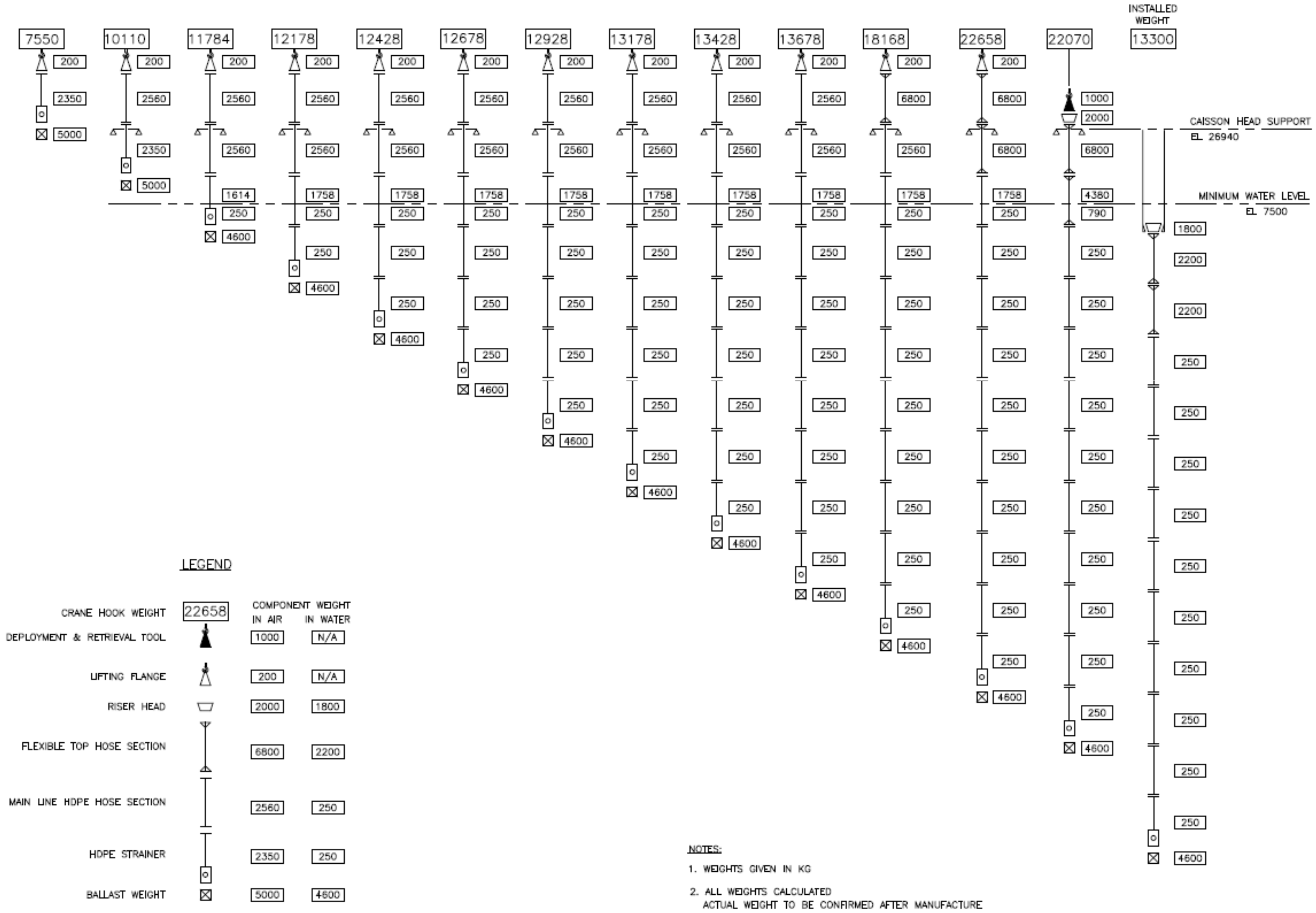
  Similar system installed/operating on Saipem Erha FPSO (Installed 2005)

- **Reduced Weight**

	Steel	HDPE*
Weight In Air (Bundle)	1354 te	396 te
Weight in Water (Bundle)	1047 te	106 te

*See below Weight Installation Diagram for Rubber / HDPE System

SHELL gFLNG VESSEL – SEA WATER INTAKE SYSTEM – INSTALLATION WEIGHTS



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EMSTEC Seawater Intake Systems

Advantages of Emstec Proposed System

- Lower Capital Cost
- Lower Installation Cost
- Lower Maintenance / Inspection Costs
- Reduced forces into hull structure
- Better Corrosion Resistance
- Reduced Pressure Losses
- Resistant to Marine Growth
- Redundant Pump/Intake String can be maintained inspected / without interruption to others

...your innovative provider of high integrity equipment.

Contact

EMSTEC GmbH & Co. KG
Sniers Achterhoff 11

D-21224 Rosengarten

Tel.: +49 40 79 686 345
Fax: +49 40 79 686 702
E-mail: info@emstec.net
web: www.emstec.net

DNV·GL

DESIGN VERIFICATION REPORT

Report No.:
PP142957-1XEAF09-1
Rev.: 1

DNV GL PROJECT NO.: **PP142957**
VERIFICATION OBJECTS: **SEAWATER SUCTION HOSE A (YINSON PRODUCTION TAG NO.: 51XX002A) AND SEAWATER SUCTION HOSE B (YINSON PRODUCTION TAG NO.: 51XX002B) FOR YINSON GHANA OCTP FPSO**
OWNER: **YINSON PRODUCTION PTE. LTD.**
DESIGNER: **EMSTEC GmbH**

This is to state that the above stated Seawater Suction Hoses A and B as described in the documents listed below have been verified and found to be in accordance with the applicable project specifications as well as codes and standards listed in this report.

The design verification was performed by way of desktop review of the hydrodynamic analysis report for the flexible hose and HDPE section of the seawater suction hose system.

Applicable Project Specifiations, Codes and Standards:

- 1305-EM-51-R-SA-00001, Seawater suction hose system technical specification, Rev A1
- 1305-YP-51-R-AS-00001, Seawater suction hoses specification, Rev B2
- DNV-RP-F203, Riser Interference, 2009
- DNV-RP-C205, Environmental Conditions and Environmental Loads, 2014
- API 17K, Specification for bonded flexible pipe, 2005
- API RP 17B, Recommended practice for flexible pipe, 2002

Design Documents Submitted for Review:

Document No.	Document Title	Rev. No.	Review Status
1305-EM-51-R-CA-00002	Seawater Suction Hose System Hydrodynamic Analysis Report	C2	Verified
1305-EM-51-R-XD-00001	Seawater Suction Hose System General Arrangement	C1	For Information

Comment Sheet

- PP142957-001, Rev. 02, Comment Sheet for Seawater Suction Hose System Hydrodynamic Analysis Report

Verification Limitations

- The new built seawater suction hose system covered in this design verification consists of the following items:
    - Fleixble hose section, consists of flexible hose steel nipple section, transition section and mainline section
    - HDPE section, consists of mainline section and strainer section

- The main design data of the flexible hose and HDPE section are listed below:

Section	Items	ID	OD	Length	Bending Stiffness	Axial Stiffness	Torsional Stiffness
		mm	mm	m	$KN.m^2$	KN	$KN.m^2$
Flexible Hose Section	Steel Nipple	900	1060	0.75	3500	12,000	80
	Transition	900	1060	0.75	2250	12,000	80
	Mainline	900	1060	10	1735	12,000	80
HDPE Section	Mainline	882	1000	80.5	18,789	150,848	80
	Strainer	882	1000	6	18,789	150,848	80

- Ballast weight of the hose string is 5 t.
- Design for Ghana OCTP FPSO. The FPSO particulars are as below:
  - Length, overall Loa = 330 m
  - Length, Between Perpendiculars, Lpp = 318 m
  - Breadth moulded = 58 m
  - Depth = 31.25 m
  - Summer Draft = 22.5 m
- The locations of the hang-off points of the seawater suction hoses with regard to the vessel origin (i.e. midship, one centreline, and one baseline) are:
  - Seawater suction hose A: X = -24.51 m, Y = -30.325 m, Z = -0.3 m
  - Seawater suction hose B: X = -29.21 m, Y = -30.325 m, Z = -0.3 m
- The seawater suction hose design verificaiton have been carried out for the following conditions:
  - Extreme condition (100yr return period total sea)
  - Survival condition (vessel heel to a maximum of 15 deg)
- The design verification covers the clash analysis and check of seawater suction hose A and seawater suction hose B. The space of the two hoses is 4.7 m apart.
- The structural design of the Riser Seat and Riser Head are not covered in this design verification.

Issued in **Singapore** on **2015-12-21**
for **DNV GL**

Chia Chor Yew
Manager
Subsea, Structures and Pipelines

Li Lu
Engineer
Subsea, Structures and Pipelines

Project Title:	DESING VERIFICAITON OF SEAWATER SUCTION HOSE SYSTEM FOR GHANA OCTP FPSO				Project Job No: PP142957
Doc. No.:	1305-EM-51-R-CA-00002	Rev.: C2	Transmittal No. : -		
Doc. Title:	SEAWATER SUCTION HOSE SYSTEM HYDRODYNAMIC ANALYSIS REPORT				
Comment Sheet (C.S.) Ref. No.:	PP142957-001	Rev.: 2			
VERIFICATION COMMENTS		Reviewed by: Li, Lu	Checked by: Phan, Anh Phi Hung		Date: 30-Oct-15

Comment No.	Description	Criticality **)	Status *)
1	**General** The basis for the review of this document is the following codes / standards and company specifications: • DNV-RP-F203, Riser Interference, 2009 • DNV-RP-C205, Environmental Conditions and Environmental Loads, 2014 • API 17K, Specification for bonded flexible pipe, 2005 • API RP 17B, Recommended practice for flexible pipe, 2002 • DVS2205-1, Design calculations for containers and apparatus made from thermoplastics – characteristics value • 1305-EM-51-R-SA-00001, Seawater suction hose system technical specification, Rev A1 • 1305-YP-51-R-AS-00001, Seawater suction hoses specification, Rev B2	-	-
2	**Abnormal Operation** Referring to API 17K, Table 5, the abnormal operation condition, where environmental loads for survival condition is considered, is one of the load conditions need to be considered in the analysis. However, this was not mentioned in the report. Please clarify. Emstec Response (28/09/15) As per 1305-YP-51-R-SA-00001 Section 5.9, operational and extreme conditions were considered in the analysis. Additional load cases can be considered where required, details to be discussed and agreed. DNV GL Reply The above reference section 5.9 could not be found in the mentioned document. Please advise if the above mentioned additional load condition to be discussed and agreed between Emstec and Yinson. If so, please provide the outcome of the agreement for the abnormal load condition. Emstec Response (21/10/15) Errata: should have read Section 5.8. Yinson have since advised that there is a survival condition for the vessel due to unintentional flooding of the tanks which would cause the vessel to heel 15° (max). This condition was simulated as a part of the additional analysis recommended in point 6 and the findings presented in the Appendix D of the Hydrodynamic Analysis Report (Technical Note P13966-RL-102)	TQ	C

Comment No.	Description	Criticality **)	Status *)
	<u>DNV GL Reply</u> Noted and closed.		

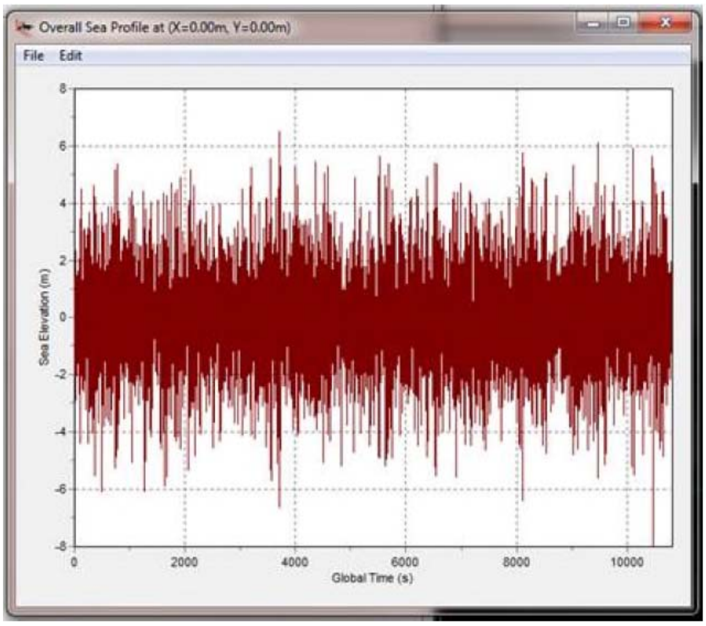
3	**<u>Section 2.1.2, RAOs</u>**
	It is noted that motion RAO origin at vessel COG has been checked. Please also confirm that the motion RAO conventions are correctly checked and applied in Ocaflex for the followings:
	• The input RAOs coordinate system
	• The input RAOs phases origin
	  o Lags or leads
	  o Relative to wave (crest or trough)
	So that the vessel 1st order wave motion calculated in report 1305-IN-91-J-RA-00004-Motion Analysis Report are correctly simulated in the analysis.
	
	<u>Emstec Response (28/09/15)</u>
	The Company provided RAO's were transposed to Orcaflex conventions.
	*** OrcaFlex Conventions Start ***
	RAOResponseUnits = degrees
	RAOWaveUnit = amplitude
	RAOPhaseConvention = leads
	RAOPhaseUnitsConvention = degrees
	RAOPhaseRelativeToConvention = crest
	SurgePositive = forward
	SwayPositive = port
	HeavePositive = up
	RollPositiveStarboard = down
	PitchPositiveBow = down
	YawPositiveBow = port
	*** OrcaFlex Conventions End ***
	
	<u>DNV GL Reply</u>
	Noted and Closed.
		TQ	C

4	**<u>Section 2.3.2, Hose String Assemblies</u>** Based on section 2.2.1 Overall hose string properties, it is noted that Emstec will not provide the hose property information and detailed analysis hose model due to its confidentiality. Therefore, the detailed hose analysis model with component characteristic for the flexible hose, HDPE mainline and strainer sections in the analysis model are not able to be verified. Please provide the material properties of the suction hose system that used in the analysis and advise the basis of this information. <u>Emstec Response (28/09/15)</u> For the flexible hose section, a bending stiffness value (EI) = 1735KN.m^2 was	TQ	C

*) O = Open; C = Closed; CI = Closed if implemented in document.
**) NC = Non Conformance (Response required); TQ = Technical Query (Response required); A=Advice (No response required).

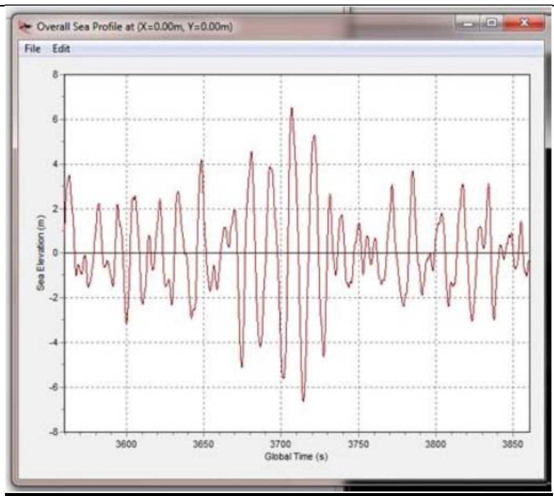
Comment No.	Description	Criticality **)	Status *)
	used. This is empirical data based on measured values from previous hose constructions. For the HDPE sections, a bending stiffness value of 18,789 KN.m^2 was used. This is based on the short term E value for PE100 as advised by various manufactures. When actual bending stiffness values become available, the analysis will be re-run to verify any deviation to the theoretical values. DNV GL Reply Noted. Please provide the test record of the bending stiffness of the flexible hose for our reference. When the actual bending stiffness values for the HDPE section become available, please re-run the analysis to verify any deviation to the theoretical values as clarified above. Close if implemented. Emstec Response (21/10/15) Test records for 30"NB & 40"NB Hose section attached which were used to estimate value for 36"NB hose. DNV GL Reply Noted and closed.		
5	**Analysis model – Interface at vessel and suction hose system** Please advise and document the boundary condition for the hose analysis model at the interface with riser head in the report. Emstec Response (28/09/15) Boundary condition at the interface with the Riser Head is considered a "fixed" connection. To be documented in next revision of report. DNV GL Reply Noted. Please update the report. Closed if implemented. DNV GL Reply Implemented and closed.	TQ	C
6	**Section 3.1, Extreme Conditions Analysis** It is noted that 300s simulation was run for the analysis. This 300s simulation can be for screening purpose. Referring to API RP 17B, Section 8, We recommend to carry out 3 hours irregular wave time domain analysis with at 5 different seeds for the following cases: • Cases with maximum end force (e.g. effective tension, bending moment, shear loads) at riser head	TQ	C

*) O = Open; C = Closed; CI = Closed if implemented in document.
**) NC = Non Conformance (Response required); TQ = Technical Query (Response required); A=Advice (No response required).

Comment No.	Description	Criticality **)	Status *)
	• Cases with maximum hose tension and minimum bend radius (MBR) • Cases with maximum HDPE tension and minimum bending radius (MBR) The statistical extreme value of the relevant responses shall be obtained from the 3 hours irregular wave time domain analysis. <u>Emstec Response (28/09/15)</u> For each of the Wave Directions we run a 10,800 sec (3 hour) JONSWAP random wave profile in Orcaflex using the Hs, Tp, gamma ect. Parameters provided and specific to each Wave Direction. This provides a Wave Profile for each Wave Direction, similar to that shown below.  From this 10,800 sec profile, we identify the maximum Rise and Fall for both the maximum associated period and the minimum associated period. With reference to the Load Cases presented in Appendix B of the report, this gives four events for each Wave Profile, namely; T_{assmax}Rise, T_{assmax}Fall, T_{assmin}Rise, T_{assmin}Fall. Having identified each event by Global Time, we specify a time origin 150 secs before the event for a duration of 300 secs. This ensures that the event is captured and occurs at the midpoint in the 300s wave packet. For example, the maximum Riser on the above profile occurs at 3708 secs, so we would set the time origin to 3558 secs with a duration of 300 sec, thus the Wave Profile for the Load Case would be as shown below:		

*) O = Open; C = Closed; CI = Closed if implemented in document.
**) NC = Non Conformance (Response required); TQ = Technical Query (Response required); A=Advice (No response required).

Comment No.	Description	Criticality **)	Status *)



Consequently, each of the load cases is analysed at a maximum Rise or Fall, therefore the results are representative of the statistical maximum of each condition.

Further analysis can be performed in accordance with the above recommendations. If required, details to be discussed and agreed.

<u>DNV GL Reply</u>

The 300s time domain analysis description above is noted.

However, The maximal riser force/displacement is not necessary occur at the maximal Riser and Fall conditions during the 300s wave packet. The 300s wave packet near the observed maximal Rise and Fall condition from the 3 hour wave time series reconstructed from the JONSWAP wave spectra cannot represent the statistical maximum extreme value of the riser response due to the following variables:

- Different seed number used to reconstruct the wave time series from JONSWAP spectra will produce different wave time series from the same JONSWAP spectra.
- The maximal floater motion reconstructed by floater motion RAOs and site specific wave time series does not necessarily occur only at the 300s wave packet.
- The maximal riser force/displacement does not necessarily occur at the 300s wave packet.

Therefore, the 300s riser time domain analysis is still only sufficient for the riser screening analysis to determine the critical load cases.

Referring to API RP 17B, Section 8, We recommend to carry out 3 hours irregular wave time domain analysis with at least 5 different seeds for each of the following cases:

- Cases with maximum end force (e.g. effective tension, bending moment, shear loads) at riser head

*) O = Open; C = Closed; CI = Closed if implemented in document.
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<table>
<tr><th>Comment No.</th><th>Description</th><th>Criticality **)</th><th>Status *)</th></tr>
<tr><td></td><td>

- Cases with maximum hose tension and minimum bend radius (MBR)
- Cases with maximum HDPE tension and minimum bending radius (MBR)

The statistical extreme value of relevant riser force/displacement shall be obtained from the resulted 3 hour time series.

<u>Emstec Response (21/10/15)</u>
Recommended additional analysis has been undertaken and the findings presented in Appendix D of the Hydrodynamic Analysis Report (Technical Note P13966-RL-102).

<u>DNV GL Reply</u>
Noted and closed.
</td><td></td><td></td></tr>
<tr><td>7</td><td>

<u>Appendix B and Section 3.1, Load Cases</u>

Please clarify more details for what are the max. Riser and Fall wave events and min. Riser and Fall wave events (e.g. T_{assmax}Rise, T_{assmax}Fall, T_{assmin}Rise, and T_{assmin}Rise) for the load cases.

<u>Emstec Response (28/09/15)</u>
Please refer to point 6 above. T_{ass} is dedined by Ocaflex as: $1.05T_z < T_{ass} < 1.4T_z$

The upper and lower values are used as T_{assmin} and T_{assmax} respectively.

<u>DNV GL Reply</u>
Noted and Closed.
</td><td>TQ</td><td>C</td></tr>
<tr><td>8</td><td>

<u>Clashing Check</u>

According to 1305-YP-51-R-AS-00001, Seawater suction hoses specification, Rev B2, it is required that analysis and recommendation on minimum distance required between two hoses to avoid clashes need to be provided. However, this was not mentioned in the report. Please clarify.

<u>Emstec Response (28/09/15)</u>
This matter was highlighted/advised during technical clarifications.

<table><tr><td>2.15</td><td>Provide analysis and recommendation on minimum distance required between hoses to avoid clashes due to water currents and bending radii of hoses</td><td>Required</td><td>Included - Refer to note in Section 3.3 of Technical & Commercial Proposal</td></tr></table>

<u>DNV GL Reply</u>
According to Section 3 in Emstec document 1305-EM-51-R-SA-00001, it is assumed that the clashing checks have been carried out and the level of clash energy is proved to be NOT problematic. Please provide the clashing checks analysis report in which justification for acceptance of clash, if any, shall be provided.

<u>Emstec Response (21/10/15)</u>
Please refer Appendix E of the Hydrodynamic Analysis Report (Technical Note
</td><td>TQ</td><td>C</td></tr>
</table>

*) O = Open; C = Closed; CI = Closed if implemented in document.
**) NC = Non Conformance (Response required); TQ = Technical Query (Response required); A=Advice (No response required).

Comment No.	Description	Criticality **)	Status *)
	P13966-RL-103). <u>DNV GL Reply</u> Noted and closed.		
9	**<u>Ocaflex Input/Output</u>** Please provide a typical Ocaflex input/output file for reference. <u>Emstec Response (28/09/15)</u> Please find attached input file “Base Case.dat”. Note, simulation files (output) are too large to transmit via e-mail. <u>DNV GL Reply</u> Received. Referring the Ocaflex input file “Base Case.dat”, it is noted that the flexible hose section is modelled into three parts, namely “Rubber Rigid”, “Rubber Transition”, and “Rubber”. However, it appears that the details of the “Rubber Rigid” and “Rubber Transition” sections could not be found on Drawing 1305-EM-51-R-XD-00001, Rev C1. Please clarify. <u>Emstec Response (21/10/15)</u> The flexible hose design consists of a steel nipple at each end of the hose section. This steel nipple is approximately 500mm in length and creates a ‘rigid’ length of hose section. Additional reinforcement is included at the area were the ‘rigid’ section transitions into the main body of the hose section. To simulate this in the model at the connection to the vessel, a stiffer rigid section and transition section are modelled. <u>DNV GL Reply</u> Noted and closed.	TQ	C

-END-

*) O = Open; C = Closed; CI = Closed if implemented in document.
**) NC = Non Conformance (Response required); TQ = Technical Query (Response required); A=Advice (No response required).

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Ghana OCTP Development Project
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C1	EX-DE	00	04.09.2015	IFC – Issued for Construction	IC	AR	BB
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Yinson Production Pte. Ltd.
3 Church Street, Samsung Hub
#17-05 Singapore 049483

Emstec GmbH
Gewerbering 8
22113 Oststeinbek
Germany

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TABLE OF CONTENTS

1 INTRODUCTION

The Seawater Uptake System supplied for the Ghana OCTP Development FPSO consists of a 2-off 36"NB Seawater Uptake Hose Strings, ~98m in length, supported from the underside of the SW Intake Caissons by a fixed riser head arrangement.

To confirm the suitability of the Seawater Suction Hose string configuration and to determine the loads transmitted into the SW Intake Caissons, it was necessary to perform a hydrodynamic analysis of the Seawater Suction Hose system. This analysis was carried out using the Orcaflex software package, developed by Orcina Ltd (www.orcina.com) specifically for analysis of flexible lines in the offshore environment.

This report has been prepared to outline the input data, the analysis methodology used and to report the results and conclusions from the hydrodynamic analysis.

The report was subject to a Design Review by DNVGL who recommended additional analysis to be undertaken, this additional analysis is presented in Appendix D and also includes a Damage Condition subsequently advised by Yinson.

A Clash Analysis if presented in Appendix E.

1.1 Executive Summary

Simulations were run for 100yr return total wave data (multidirectional) with each of the 100yr return current conditions (12-off directions) applied and were repeated for the Ballast and Full vessel drafts as specified by the client, with and without marine growth. A total of that total of 576 simulations were run covering all permutations of these conditions. Each simulation was of 300 seconds duration.

It was shown that maximum hose tension and bend radius remain within acceptable limits during all simulated conditions. Maximum hose end tensions, bending moments and shear loads were obtained for use in the design of the riser head and caisson interface.

The results from the analysis confirm the suitability of the Seawater Suction Hose string and provide the necessary input data for the Structural Analysis of the riser seat and riser head arrangement.

2 INPUT DATA

2.1 Vessel Data

2.1.1 FPSO Particulars

The Ghana OCTP Development FPSO was modelled in OrcaFlex with the characteristics provided in [1] Table 3-1 and reproduced below:

Main Particulars of the Yinson FPSO	
Length, over all L_{oa}	330.000 m
Length, between perpendiculars, L_{pp}	318.000 m
Breadth moulded, $B_{moulded}$	58.000 m
Depth, $D_{moulded}$	31.250 m
Summer draft , T	22.50 m

Table 3-1 Main dimensions for Yinson FPSO

Table 3-1 [1] FPSO Particulars

2.1.2 Response Amplitude Operators (RAO)

A full set of Response Amplitude Operators (RAOs) were provided in electronic format by Yinson [2] for the vessel 100yr conditions, covering the three loading conditions, namely; Ballast Draft, Inter Draft and Full Draft.

The loading condition for each draft were cross referenced with [1] Section 4 and the RAO origin set as the relevant CoG as provided in [1] Table 4-1, i.e.;

Draft	Loading Condition	LCG (from AP)	TCG (from CL)	VCG (from Keel)
Ballast	LC No 4	156.8m	0.0m	15.41m
Inter	LC No.6	169.4m	0.0m	16.00m
Full	LC No.8	169.5m	0.0m	17.76m

Table 2.1.2 – Vessel CoG

This enables accurate simulation of vessel motions in response to given wave conditions.

2.2 Seawater Suction Hose Data

Each Seawater Suction Hose string assembly model consists of:

Section	Qty per Assembly	I/D (mm)	O/D (mm)	Section Length (m)	Mass in Air (kg)	Weight in Water (kg)	Axial Strength (kN):	Min. Bend Radius (m)
Steel Riser Head	1	N/A	N/A	N/A	3385	2940	N/A	N/A
Hose Section	1	900	1060	11.5	5336	2475	~4946	3.6
HDPE Mainline Section	7	882	1000	11.5	2100	-150	~4000	36.0
HDPE Strainer Section	1	882	1000	5.5	1050	-75	~4000	36.0
Ballast Weight	1	N/A	N/A	N/A	9050	4425	N/A	N/A

Note: A nominal mass of 250kg was added at each flange connection to allow for the studbolts & nuts, backing quadrants and hypochlorite line

Table 2-1 – Hose String Composition

2.2.1 Overall hose string properties

- Total Length of Hose String: 98m
- Total Weight of Hose String in Air: ~33,521kg
- Total Weight of Hose String in Water: ~10,470kg

The axial stiffness, bending stiffness and torsional stiffness values of the hose are proprietary information and deemed confidential and are therefore not disclosed within this report.

2.3 System Configuration

2.3.1 Hose String Locations

The Seawater Suction Hose string assemblies are connected to the lower end of the outboard Sea Water Caissons with the locations provided in [3] and amended by [4].

The caissons located 30.325m from the CL on the starboard side of the vessel and are spaced 4.7m apart, with the forwardmost caisson located at 2.160m fwd Fr.77. The lower edge of the caisson is 0.3m below the Hull Bottom level.

This translates to the following coordinates relative to the vessel origin, i.e. midships, on centreline and on baseline:

Hose String Assembly		A	B
Connection Location (from Vessel Origin)	x	-24.510m	-29.210m
	y	-30.325m	-30.325m
	z	-0 3m	-0.3 m

A visual representation of the model in a static state is presented in Appendix A

2.3.2 Hose String Assemblies

The hose string assemblies were modelled as flexible elements with sufficient nodal points to allow curvature. The riser head and ballast weight were modelled as clump weights of appropriate mass and volume. A nominal mass was added at each flange connection to allow for the studbolts & nuts, backing quadrants and hypochlorite line

Hose damping is set to zero since, within broad limits, structural damping has little influence on the results of the hydrodynamic simulation unless the system is subject to very rapid variations in tension or bending. Additionally, such damping is negligible compared to the damping applied by hydrodynamic resistance in submarine hoses.

2.3.3 Boundary Condition

Boundary condition at the interface with the Riser Head is considered a “fixed” connection

2.3.4 Damage Condition

Refer to Additional Analysis (Appendix D).

2.3.5 Drag Coefficients

The normal drag coefficient (Cd) is dependent upon the Reynolds number (Re), which in turn is a function of the surface roughness and diameter of the hose, as well as the fluid flow velocity. Using the technique provided within ESDU 80025 [5], the Cd values were determined for the corresponding Re number for the various hose sections types.

Surface roughness values used to calculate the Drag Coefficients were specified as:

Rubber Hose	= 3mm	(value similar to concrete given in [6] Table 6-1)
HDPE Pipe	= 0.003mm	(ref. [7])
Marine Growth	= 50mm	(ref. Section 2.3.5 & [6] Table 6-1)

The Cd values were input into Orcaflex which calculates the Reynolds number and applies the corresponding Cd for any given fluid velocity.

The strainer value was set at Cd = 1.0 based upon drag coefficients for perforated cylinders as specified in [5] Figure 6.

Axial drag coefficient was set as a constant 0.008 for plain pipe.

The flange connections modelled as clump weights and a drag area equal to the protruding flange specified and an axial drag coefficient of 1.9 [6] Table E1 (item 12) applied for the vertical direction.

2.3.6 Marine Fouling

Marine Growth data was provided by Yinson [8] Section 12, which specifies marine growth thickness of 0.1m to a depth of 50m. A roughness of 50mm and a density of 1325kg/m^3 was also specified.
The additional mass and diameter of the hose sections due to marine growth was considered within the model.

2.4 Environmental Data

The environmental data provided by Yinson [8] included the Wave and Current data for 1, 10 and 100 year return conditions. Wind was not considered as this will not directly affect the seawater uptake system.

2.4.1 Direction Convention

The directions specified in [8] do not correspond with Orcaflex Direction convention and need to be transposed as follows, such that the vessel heading is 180°:

Convention	**Heading (°)**											
Metocean Data	0	30	60	90	120	150	180	210	240	270	300	330
Orcaflex	30	0	330	300	270	240	210	180	150	120	90	60

From hereonin, all references to direction will be in accordance with the Orcaflex Direction Convention

- Wave: specified direction is FROM where the wave is heading
- Current: specified direction is TO where the current is heading

2.4.2 Extreme Condition

For the extreme condition, the 100yr return period total sea was considered concurrent with each of the 100yr return period current profiles. This is a pessimistic assumption as it is unlikely that they will coincide.

As the vessel is Spread Moored, it is assumed that the Wave heading can vary, therefore multiple wave directions are considered. For each wave heading, current profiles for each the twelve current headings was considered.

2.4.3 Total Sea

The 100yr return period total sea conditions provided in [8] Table 7-19 were considered and are reprodced below:

Direction	1 year			10 years			100 years		
(°N)	HS(m)	Hmax(m)	TP(sec)	HS(m)	Hmax(m)	TP(sec)	HS(m)	Hmax(m)	TP(sec)
0	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-
120	-	-	-	-	-	-	-	-	-
150	2.64	4.48	14.08	3.04	5.15	14.78	3.35	5.66	15.29
180	2.92	4.95	14.55	3.35	5.66	15.29	3.73	6.28	15.98
210	2.80	4.75	14.34	3.32	5.61	15.24	3.78	6.36	16.07
240	-	-	-	1.29	2.23	11.05	1.70	2.92	12.12
270	-	-	-	-	-	-	-	-	-
300	-	-	-	-	-	-	-	-	-
330	-	-	-	-	-	-	-	-	-
Omnidir	3.03	5.13	14.74	3.44	5.80	15.45	3.81	6.41	16.13

Table 7-19 : Directional extremes of Hs, Hmax and Tp for total waves.

Table 7-19 [8]: Directional Extremes of Hs, Hmax and Tp for total waves

2.4.4 Current

The 100yr return period current profiles provided in [8] Table 7-19 were considered and are reprodced below:

Return Period	WD (m)	Direction (°N)												
		0	30	60	90	120	150	180	210	240	270	300	330	Omnidir
		CS(m/s)	CS(m/s)	CS(m/s)	CS(m/s)	CS(m/s)	CS(m/s)	CS(m/s)	CS(m/s)	CS(m/s)	CS(m/s)	CS(m/s)	CS(m/s)	CS(m/s)
1 year	2 m	0.49	0.67	0.69	1.58	1.61	0.93	0.35	0.25	0.26	0.26	0.45	0.50	1.61
	20 m	0.53	0.47	0.61	0.69	0.61	0.60	0.34	0.29	0.46	0.93	0.88	0.63	0.93
	50 m	0.35	0.36	0.37	0.44	0.42	0.38	0.30	0.30	0.36	0.55	0.64	0.53	0.64
	100 m	0.26	0.29	0.26	0.38	0.36	0.26	0.25	0.26	0.36	0.42	0.41	0.39	0.42
	200 m	0.29	0.21	0.28	0.33	0.37	0.38	0.21	0.24	0.33	0.41	0.46	0.32	0.46
	400 m	0.23	0.26	0.32	0.28	0.24	0.24	0.28	0.28	0.25	0.23	0.25	0.23	0.30
	750 m	0.23	0.26	0.32	0.28	0.24	0.24	0.28	0.28	0.25	0.23	0.25	0.23	0.30
	900 m	0.23	0.26	0.32	0.28	0.24	0.24	0.28	0.28	0.25	0.23	0.25	0.23	0.30
	1m a.s.b.	0.19	0.19	0.21	0.21	0.19	0.23	0.24	0.24	0.17	0.18	0.18	0.18	0.24
10 years	2 m	0.56	0.78	0.77	1.81	1.81	1.12	0.41	0.29	0.31	0.32	0.54	0.63	1.81
	20 m	0.62	0.54	0.69	0.77	0.66	0.68	0.41	0.35	0.56	1.08	0.97	0.70	1.08
	50 m	0.38	0.41	0.41	0.49	0.46	0.42	0.34	0.34	0.40	0.61	0.70	0.59	0.71
	100 m	0.29	0.34	0.29	0.43	0.40	0.29	0.29	0.31	0.43	0.46	0.45	0.45	0.47
	200 m	0.35	0.24	0.33	0.37	0.41	0.45	0.26	0.29	0.38	0.45	0.51	0.37	0.51
	400 m	0.26	0.30	0.37	0.32	0.27	0.26	0.32	0.31	0.28	0.26	0.28	0.26	0.32
	750 m	0.26	0.30	0.37	0.32	0.27	0.26	0.32	0.31	0.28	0.26	0.28	0.26	0.32
	900 m	0.26	0.30	0.37	0.32	0.27	0.26	0.32	0.31	0.28	0.26	0.28	0.26	0.32
	1m a.s.b.	0.22	0.22	0.25	0.26	0.22	0.25	0.27	0.26	0.19	0.20	0.20	0.20	0.27
100 years	2 m	0.62	0.87	0.84	2.00	2.00	1.31	0.46	0.32	0.35	0.37	0.63	0.75	2.00
	20 m	0.70	0.62	0.77	0.84	0.70	0.75	0.47	0.40	0.65	1.21	1.06	0.76	1.21
	50 m	0.42	0.46	0.45	0.53	0.50	0.45	0.37	0.38	0.44	0.67	0.76	0.65	0.77
	100 m	0.32	0.39	0.31	0.48	0.43	0.31	0.33	0.35	0.49	0.51	0.49	0.51	0.51
	200 m	0.41	0.27	0.38	0.40	0.44	0.53	0.30	0.34	0.43	0.49	0.56	0.41	0.56
	400 m	0.28	0.33	0.42	0.35	0.29	0.29	0.35	0.34	0.31	0.28	0.30	0.29	0.35
	750 m	0.28	0.33	0.42	0.35	0.29	0.29	0.35	0.34	0.31	0.28	0.30	0.29	0.35
	900 m	0.28	0.33	0.42	0.35	0.29	0.29	0.35	0.34	0.31	0.28	0.30	0.29	0.35
	1m a.s.b.	0.24	0.24	0.28	0.29	0.25	0.28	0.28	0.28	0.21	0.22	0.22	0.22	0.29

Table 8-43 – Directional and omnidirectional extremes at different depth and for 1, 10 and 100 years return time.

Table 8-43 [8]: Directional and omnidirectional Extremes at different depth and direction for 1, 10 and 100years return time

3 HYDRODYNAMIC ANALYSIS SIMULATIONS

3.1 Extreme Conditions Analysis

The Wave parameters for the 100yr return period and the heading were set asvariables. Each of the 12-off 100yr Current profiles were set with direction fixed accordingly.

The Ballast and Full draft conditions were considered and the RAO data set for the corresponding 100yr conditions selected.

A 300s wave packet was identified for each of the 100ry wave parameters under consideration which included the max. Rise and Fall wave events for the associated wave periods, and simulation period set so that the event occurred at the mid-point of the wave packet. A build up period of 8 seconds was defined prior to the main simulation to ensure that any sudden transients were avoided.

A total of 288 load cases were identified from the above combinations.The model was then modified to included Marine Growth and the same load cases considered giving a further 288 load ceas (576 in total)

The load case configurations are listed in Appendix B

4 RESULTS

The results of the Hydrodynamic Analyses were stored, evaluated and exported using the Orcaflex post processing facilities. These results are summarised below and presented in more detail at Appendix C.

4.1 Extreme Conditions Analysis

Appendix C lists in full the maximum peak loads from each of the simulations with Marine Growth (as this is the most onerous condition).

This section identifies each of the worst case load magnitudes and the associated loads. This data can be used for the design of the riser head and riser seat It must be noted that these values are individual maximums encountered during a given 300 second simulation. These values will not necessarily occur simultaneously.

4.1.1 Maximum End Force at Riser Head

Load Case M113 - Line 1

Highest Force (kN)	**Corresponding worst:**		
	Shear Load (kN)	Bend Moment (kNm)	Hose Tension (kN)
178.08	52.47	196.44	178.08

4.1.2 Maximum Bending Moment at Riser Head

Load Case M137 – Line 1

Highest Bending Moment (kNm)	**Corresponding worst:**		
	Shear Load (kN)	End Force (kN)	Bend Radius (m)
334.16	88.17	166.70	8.28

4.1.3 Maximum Shear Load at Riser Head

Load Case M137 – Line 1

Shear Load (kN)	**Corresponding worst:**		
	End Force (kN)	Bend Moment (kNm)	Bend Radius (m)
88.17	166.70	334.16	8.28

4.1.4 Maximum Hose Tension

Load Case M113 – Line 1

Highest Tension (kN)	**Corresponding worst:**		
	Shear Load (kN)	Bend Moment (kNm)	Bend Radius (m)
178.08	52.47	196.44	13.47

4.1.5 Minimum Bend Radius (Rubber Hose)

Load Case M137 –Line 1

Bend Radius (m)	**Corresponding worst:**		
	Shear Load (kN)	Bend Moment (kNm)	End Force (kN)
8.28	88.16	334.16	166.70

4.1.6 Maximum HDPE Tension

Load Case M282 – Line 1

Highest Tension (kN)	**Corresponding worst:**		
	Shear Load (kN)	Bend Moment (kNm)	Bend Radius (m)
95.83	8.22	96.46	194.78

4.1.7 Minimum Bend Radius (HDPE)

Load Case M133 – Line 1

Bend Radius (m)	**Corresponding worst (in HDPE Section):**		
	Shear Load (kN)	Bend Moment (kNm)	Tensile Force (kN)
116.72	14.68	160.96	81.55

5 CONCLUSION

From the results presented in Section 4.0, the following can be concluded:

5.1 Extreme Conditions Analysis

5.1.1 Maximum Hose Tension (Rubber Hose)

From Analysis, Maximum Hose Tension = **178.08 kN**
From Table 2-2, Allowable Max Hose Tension = **4,946 kN**

The induced hose tension does not exceed the maximum axial strength and is therefore ACCEPTABLE.

5.1.2 Minimum Bend Radius (Rubber Hose)

From Analysis, Hose Minimum Bend Radius (MBR) = **8.28 m**
From Table 2-2, Allowable Hose MBR = **3.6 m**

The induced hose bend radius does not infringe the hose MBR and is therefore ACCEPTABLE.

5.1.3 Maximum Hose Tension (HDPE)

From Analysis, Maximum HDPE Tension = **95.83 kN**
From Table 2-2, Allowable Max Hose Tension = ~**4,000 kN**

The induced HDPE tension does not exceed the maximum axial strength and is therefore ACCEPTABLE.

5.1.4 Minimum Bend Radius (HDPE)

From Analysis, Hose Minimum Bend Radius (MBR) = **116.72 m**
From Table 2-2, Allowable Hose MBR = **36.0 m**

The induced HDPE bend radius does not infringe the hose MBR and is therefore ACCEPTABLE.

Therefore the Seawater Suction Hose is suitable for the configuration and environmental conditions that it will be subjected to during the life of the system.

The results presented in Section 4.0 can be used to verify the design of the Riser Head and Riser Seat Components. It should be noted that the results represent the worst case loading from the 100yr return conditions.

REFERENCES

[1] 1305-IN-91-J-RA-00004 Rev B2: Motion Analysis Report

[2] rao_ball_100yr.txt; rao_Inter_100yr.txt; rao_full_100yr.txt – (received by e-mail:Nasir/Craig 26.03.15)

[3] 1305-LO-91-N-XG-00022 RevA1: Sea Water Caisson Arrangement and Details

[4] External Caisson (Ammended [sic]).pdf - (received by e-mail:Nasir/Craig 31.03.15)

[5] ESDU 80025 Mean forces, pressures and flow field velocities for circular cylindrical structures

[6] DNV-RP-C205 : DNV Recommended Practice – Environmental Conditions and Environmental Loads

[7] Vindex – Hydraulic Design for PE Pipes (http://www.vinidex.com.au/technical/pe-pressure-pipe/hydraulic-design-for-pe-pipes)

[8] 351400BGRB09411 Rev 00: Ghana OCTP Development Project - Metocean Design Basis

APPENDIX A – MODEL SCREENSHOTS

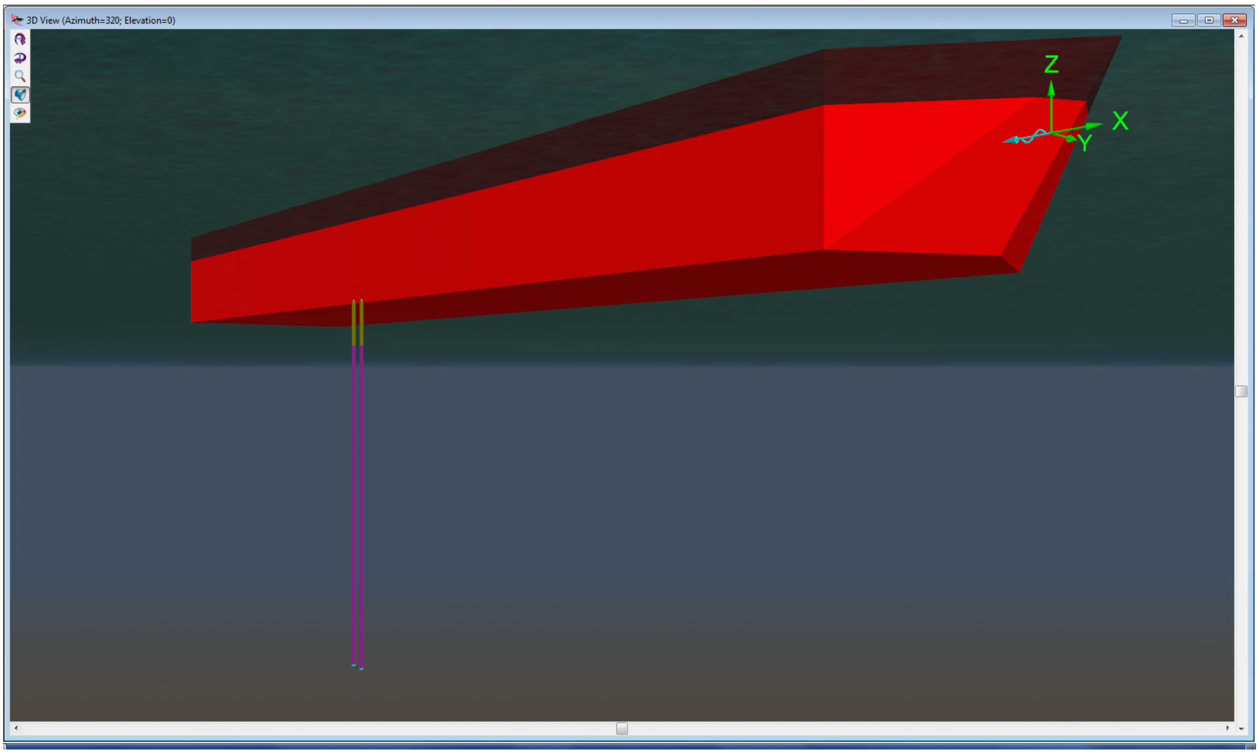

Fig 1 : Clean Riser – Static Condition

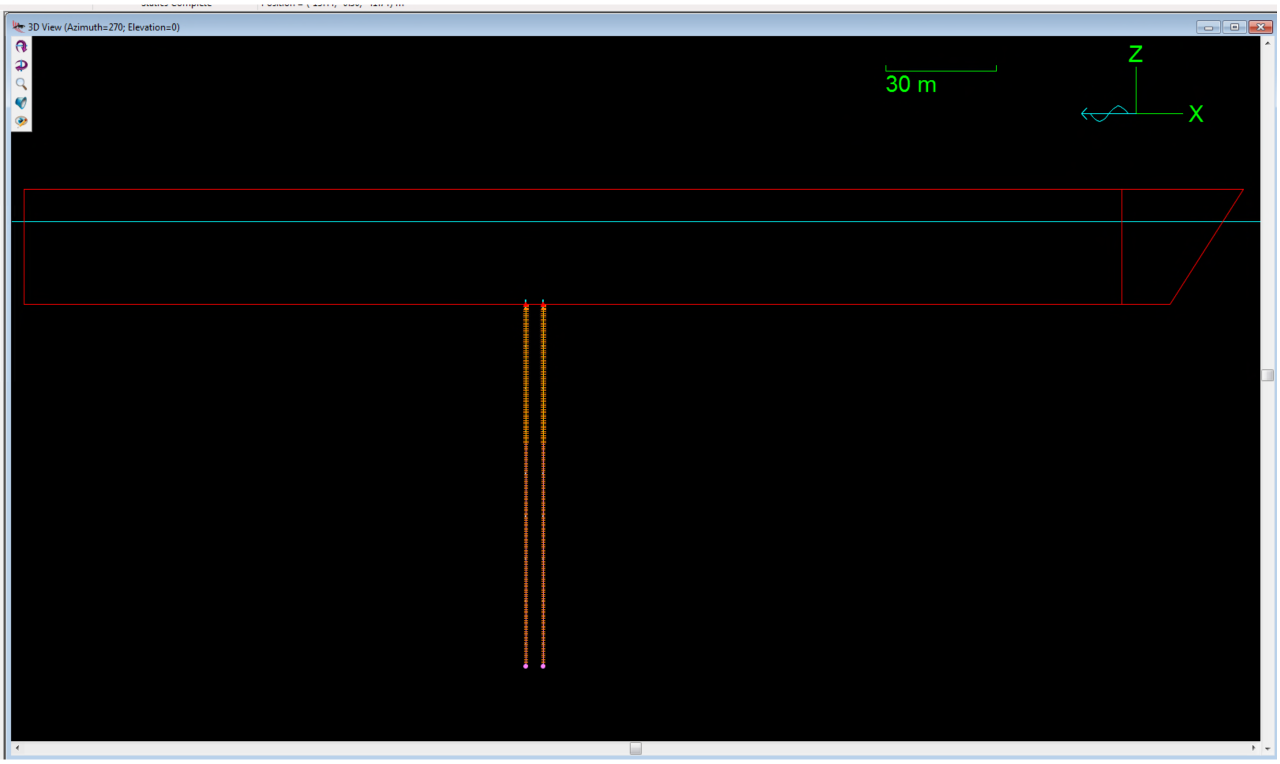

Fig 2 : Riser with Marine Growth – Static Condition

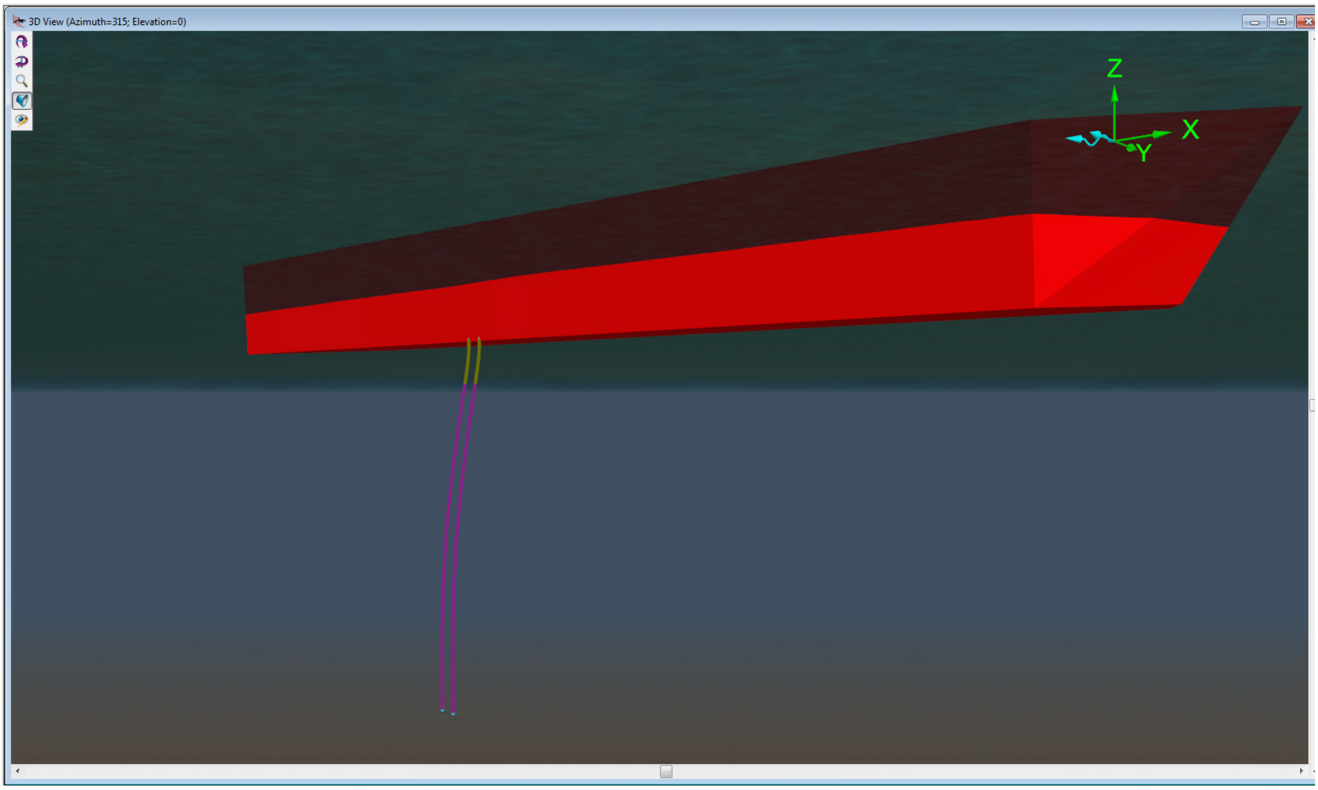

Fig 3 : Clean Riser – Load Case 133

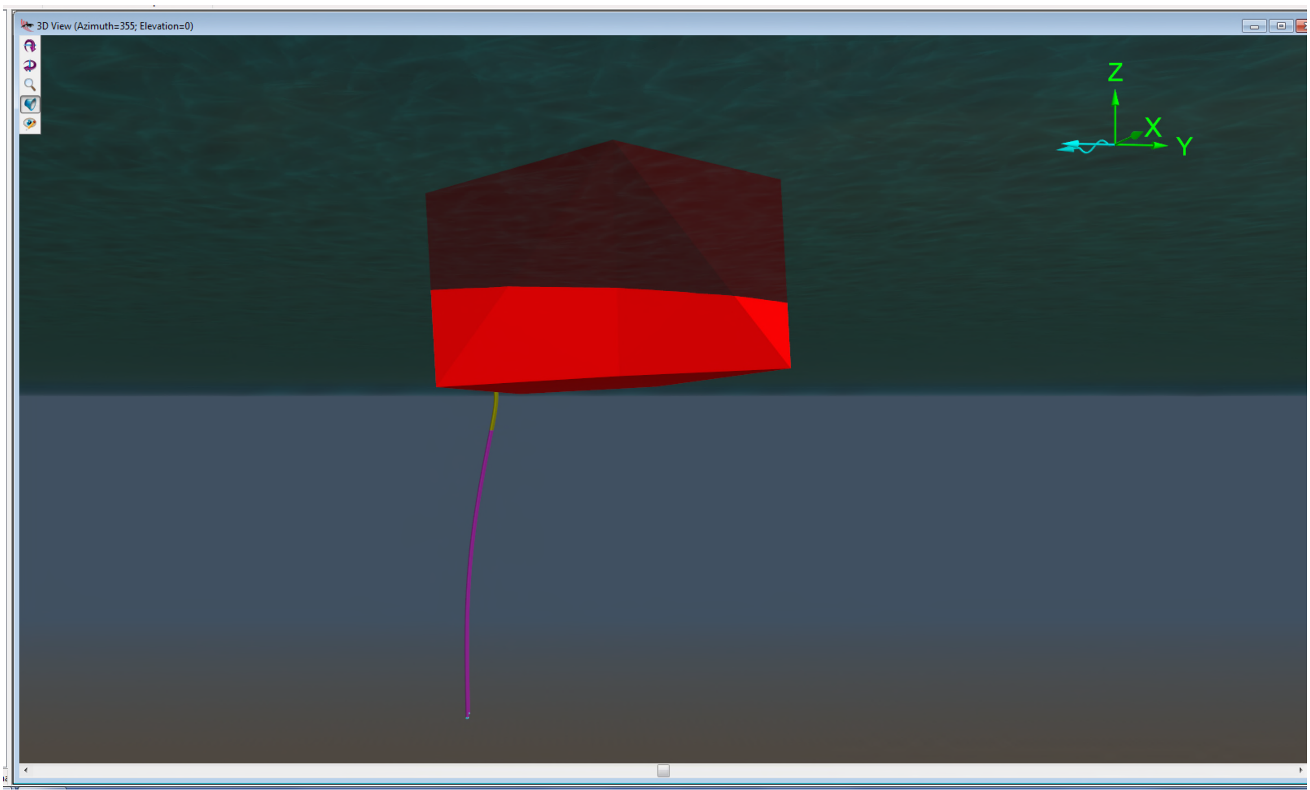

Fig 4 : Clean Riser – Load Case 133

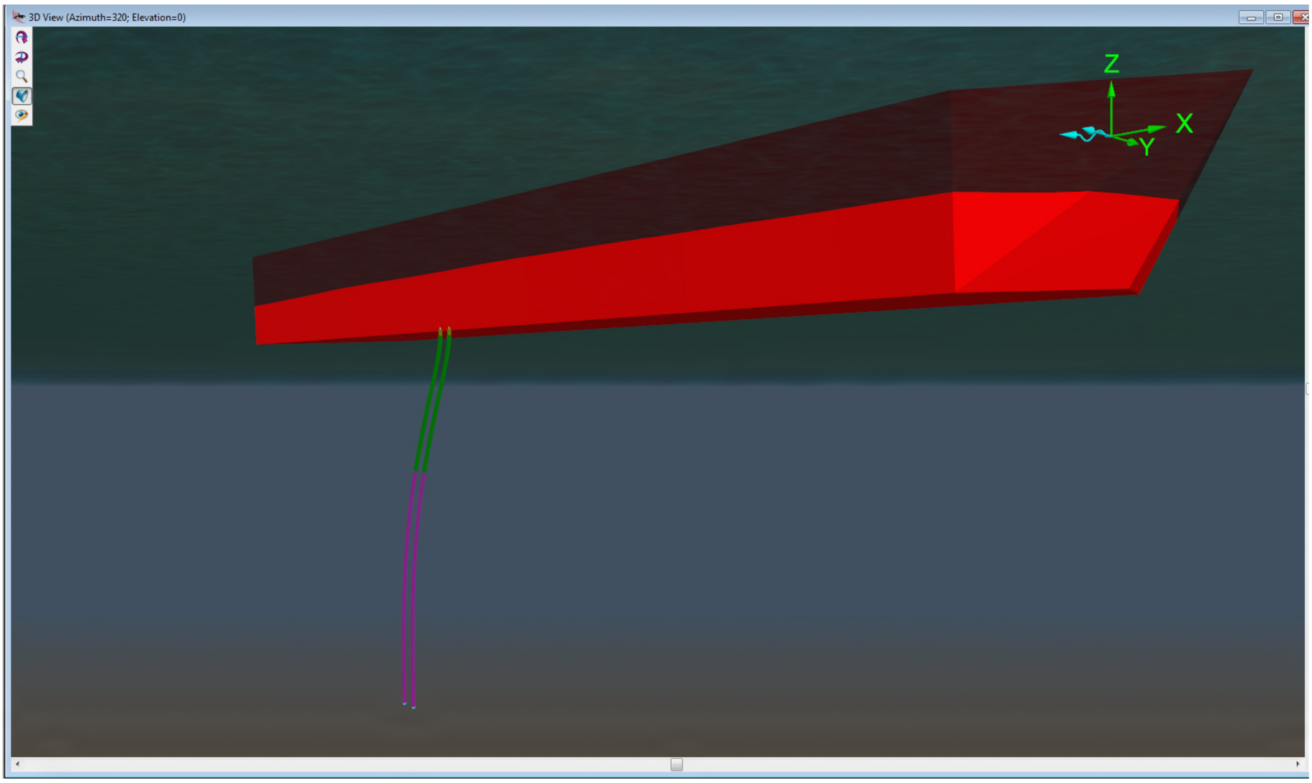

Fig 5 : Riser with Marine Growth – Load Case M133

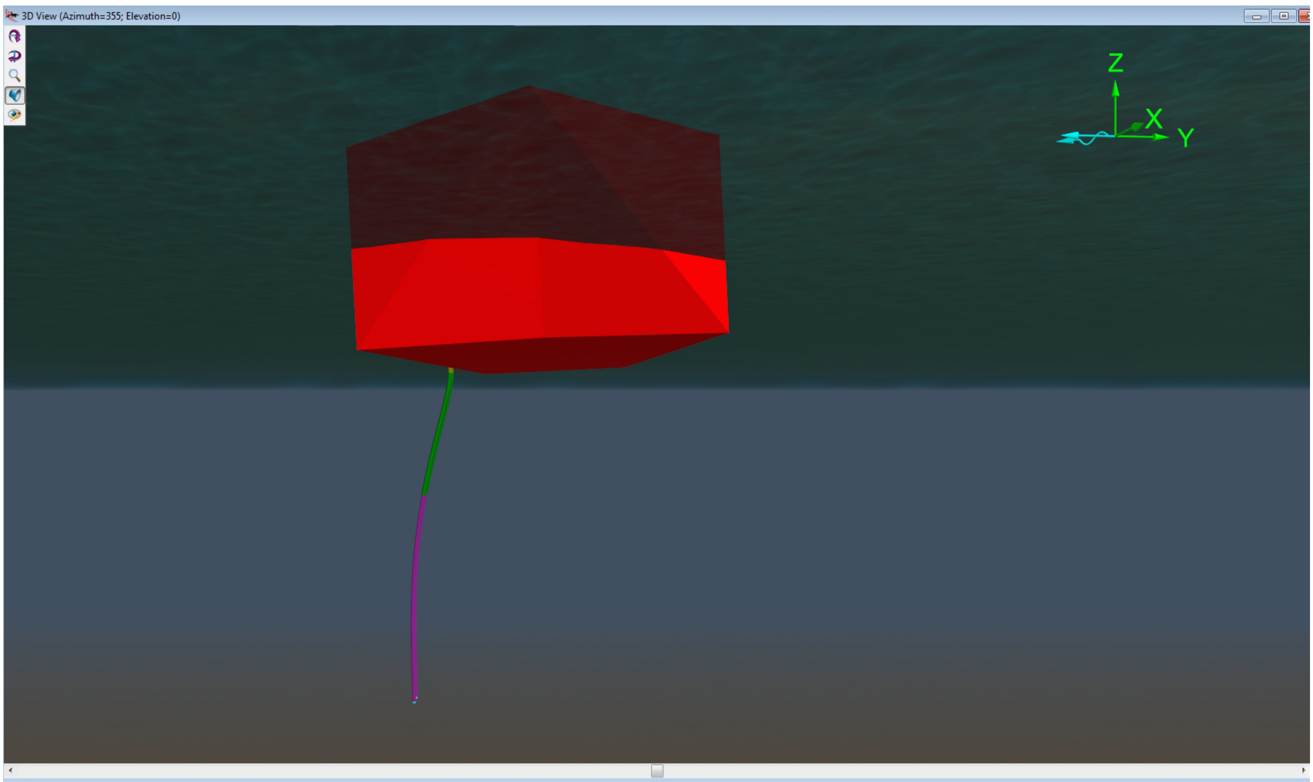

Fig 6 : Riser with Marine Growth – Load Case M133

APPENDIX B – LOAD CASES

Clean Risers

Case	FPSO Draft	Current Direction	Wave Direction	Wave Event	Case	FPSO Draft	Current Direction	Wave Direction	Wave Event
1	Ballast	0	180	T_{assmax} Rise	49	Ballast	0	210	T_{assmax} Rise
2	Ballast	0	180	T_{assmax} Fall	50	Ballast	0	210	T_{assmax} Fall
3	Ballast	0	180	T_{assmin} Rise	51	Ballast	0	210	T_{assmin} Rise
4	Ballast	0	180	T_{assmin} Fall	52	Ballast	0	210	T_{assmin} Fall
5	Ballast	30	180	T_{assmax} Rise	53	Ballast	30	210	T_{assmax} Rise
6	Ballast	30	180	T_{assmax} Fall	54	Ballast	30	210	T_{assmax} Fall
7	Ballast	30	180	T_{assmin} Rise	55	Ballast	30	210	T_{assmin} Rise
8	Ballast	30	180	T_{assmin} Fall	56	Ballast	30	210	T_{assmin} Fall
9	Ballast	60	180	T_{assmax} Rise	57	Ballast	60	210	T_{assmax} Rise
10	Ballast	60	180	T_{assmax} Fall	58	Ballast	60	210	T_{assmax} Fall
11	Ballast	60	180	T_{assmin} Rise	59	Ballast	60	210	T_{assmin} Rise
12	Ballast	60	180	T_{assmin} Fall	60	Ballast	60	210	T_{assmin} Fall
13	Ballast	90	180	T_{assmax} Rise	61	Ballast	90	210	T_{assmax} Rise
14	Ballast	90	180	T_{assmax} Fall	62	Ballast	90	210	T_{assmax} Fall
15	Ballast	90	180	T_{assmin} Rise	63	Ballast	90	210	T_{assmin} Rise
16	Ballast	90	180	T_{assmin} Fall	64	Ballast	90	210	T_{assmin} Fall
17	Ballast	120	180	T_{assmax} Rise	65	Ballast	120	210	T_{assmax} Rise
18	Ballast	120	180	T_{assmax} Fall	66	Ballast	120	210	T_{assmax} Fall
19	Ballast	120	180	T_{assmin} Rise	67	Ballast	120	210	T_{assmin} Rise
20	Ballast	150	180	T_{assmin} Fall	68	Ballast	150	210	T_{assmin} Fall
21	Ballast	150	180	T_{assmax} Rise	69	Ballast	150	210	T_{assmax} Rise
22	Ballast	150	180	T_{assmax} Fall	70	Ballast	150	210	T_{assmax} Fall
23	Ballast	150	180	T_{assmin} Rise	71	Ballast	150	210	T_{assmin} Rise
24	Ballast	150	180	T_{assmin} Fall	72	Ballast	150	210	T_{assmin} Fall
25	Ballast	180	180	T_{assmax} Rise	73	Ballast	180	210	T_{assmax} Rise
26	Ballast	180	180	T_{assmax} Fall	74	Ballast	180	210	T_{assmax} Fall
27	Ballast	180	180	T_{assmin} Rise	75	Ballast	180	210	T_{assmin} Rise
28	Ballast	180	180	T_{assmin} Fall	76	Ballast	180	210	T_{assmin} Fall
29	Ballast	210	180	T_{assmax} Rise	77	Ballast	210	210	T_{assmax} Rise
30	Ballast	210	180	T_{assmax} Fall	78	Ballast	210	210	T_{assmax} Fall
31	Ballast	210	180	T_{assmin} Rise	79	Ballast	210	210	T_{assmin} Rise
32	Ballast	210	180	T_{assmin} Fall	80	Ballast	210	210	T_{assmin} Fall
33	Ballast	240	180	T_{assmax} Rise	81	Ballast	240	210	T_{assmax} Rise
34	Ballast	240	180	T_{assmax} Fall	82	Ballast	240	210	T_{assmax} Fall
35	Ballast	240	180	T_{assmin} Rise	83	Ballast	240	210	T_{assmin} Rise
36	Ballast	240	180	T_{assmin} Fall	84	Ballast	240	210	T_{assmin} Fall
37	Ballast	270	180	T_{assmax} Rise	85	Ballast	270	210	T_{assmax} Rise
38	Ballast	270	180	T_{assmax} Fall	86	Ballast	270	210	T_{assmax} Fall
39	Ballast	270	180	T_{assmin} Rise	87	Ballast	270	210	T_{assmin} Rise
40	Ballast	270	180	T_{assmin} Fall	88	Ballast	270	210	T_{assmin} Fall
41	Ballast	300	180	T_{assmax} Rise	89	Ballast	300	210	T_{assmax} Rise
42	Ballast	300	180	T_{assmax} Fall	90	Ballast	300	210	T_{assmax} Fall
43	Ballast	300	180	T_{assmin} Rise	91	Ballast	300	210	T_{assmin} Rise
44	Ballast	300	180	T_{assmin} Fall	92	Ballast	300	210	T_{assmin} Fall
45	Ballast	330	180	T_{assmax} Rise	93	Ballast	330	210	T_{assmax} Rise
46	Ballast	330	180	T_{assmax} Fall	94	Ballast	330	210	T_{assmax} Fall
47	Ballast	330	180	T_{assmin} Rise	95	Ballast	330	210	T_{assmin} Rise
48	Ballast	330	180	T_{assmin} Fall	96	Ballast	330	210	T_{assmin} Fall

Case	FPSO Draft	Current Direction	Wave Direction	Wave Event	Case	FPSO Draft	Current Direction	Wave Direction	Wave Event
97	Ballast	0	240	T_{assmax} Rise	145	Full	0	180	T_{assmax} Rise
98	Ballast	0	240	T_{assmax} Fall	146	Full	0	180	T_{assmax} Fall
99	Ballast	0	240	T_{assmin} Rise	147	Full	0	180	T_{assmin} Rise
100	Ballast	0	240	T_{assmin} Fall	148	Full	0	180	T_{assmin} Fall
101	Ballast	30	240	T_{assmax} Rise	149	Full	30	180	T_{assmax} Rise
102	Ballast	30	240	T_{assmax} Fall	150	Full	30	180	T_{assmax} Fall
103	Ballast	30	240	T_{assmin} Rise	151	Full	30	180	T_{assmin} Rise
104	Ballast	30	240	T_{assmin} Fall	152	Full	30	180	T_{assmin} Fall
105	Ballast	60	240	T_{assmax} Rise	153	Full	60	180	T_{assmax} Rise
106	Ballast	60	240	T_{assmax} Fall	154	Full	60	180	T_{assmax} Fall
107	Ballast	60	240	T_{assmin} Rise	155	Full	60	180	T_{assmin} Rise
108	Ballast	60	240	T_{assmin} Fall	156	Full	60	180	T_{assmin} Fall
109	Ballast	90	240	T_{assmax} Rise	157	Full	90	180	T_{assmax} Rise
110	Ballast	90	240	T_{assmax} Fall	158	Full	90	180	T_{assmax} Fall
111	Ballast	90	240	T_{assmin} Rise	159	Full	90	180	T_{assmin} Rise
112	Ballast	90	240	T_{assmin} Fall	160	Full	90	180	T_{assmin} Fall
113	Ballast	120	240	T_{assmax} Rise	161	Full	120	180	T_{assmax} Rise
114	Ballast	120	240	T_{assmax} Fall	162	Full	120	180	T_{assmax} Fall
115	Ballast	120	240	T_{assmin} Rise	163	Full	120	180	T_{assmin} Rise
116	Ballast	150	240	T_{assmin} Fall	164	Full	150	180	T_{assmin} Fall
117	Ballast	150	240	T_{assmax} Rise	165	Full	150	180	T_{assmax} Rise
118	Ballast	150	240	T_{assmax} Fall	166	Full	150	180	T_{assmax} Fall
119	Ballast	150	240	T_{assmin} Rise	167	Full	150	180	T_{assmin} Rise
120	Ballast	150	240	T_{assmin} Fall	168	Full	150	180	T_{assmin} Fall
121	Ballast	180	240	T_{assmax} Rise	169	Full	180	180	T_{assmax} Rise
122	Ballast	180	240	T_{assmax} Fall	170	Full	180	180	T_{assmax} Fall
123	Ballast	180	240	T_{assmin} Rise	171	Full	180	180	T_{assmin} Rise
124	Ballast	180	240	T_{assmin} Fall	172	Full	180	180	T_{assmin} Fall
125	Ballast	210	240	T_{assmax} Rise	173	Full	210	180	T_{assmax} Rise
126	Ballast	210	240	T_{assmax} Fall	174	Full	210	180	T_{assmax} Fall
127	Ballast	210	240	T_{assmin} Rise	175	Full	210	180	T_{assmin} Rise
128	Ballast	210	240	T_{assmin} Fall	176	Full	210	180	T_{assmin} Fall
129	Ballast	240	240	T_{assmax} Rise	177	Full	240	180	T_{assmax} Rise
130	Ballast	240	240	T_{assmax} Fall	178	Full	240	180	T_{assmax} Fall
131	Ballast	240	240	T_{assmin} Rise	179	Full	240	180	T_{assmin} Rise
132	Ballast	240	240	T_{assmin} Fall	180	Full	240	180	T_{assmin} Fall
133	Ballast	270	240	T_{assmax} Rise	181	Full	270	180	T_{assmax} Rise
134	Ballast	270	240	T_{assmax} Fall	182	Full	270	180	T_{assmax} Fall
135	Ballast	270	240	T_{assmin} Rise	183	Full	270	180	T_{assmin} Rise
136	Ballast	270	240	T_{assmin} Fall	184	Full	270	180	T_{assmin} Fall
137	Ballast	300	240	T_{assmax} Rise	185	Full	300	180	T_{assmax} Rise
138	Ballast	300	240	T_{assmax} Fall	186	Full	300	180	T_{assmax} Fall
139	Ballast	300	240	T_{assmin} Rise	187	Full	300	180	T_{assmin} Rise
140	Ballast	300	240	T_{assmin} Fall	188	Full	300	180	T_{assmin} Fall
141	Ballast	330	240	T_{assmax} Rise	189	Full	330	180	T_{assmax} Rise
142	Ballast	330	240	T_{assmax} Fall	190	Full	330	180	T_{assmax} Fall
143	Ballast	330	240	T_{assmin} Rise	191	Full	330	180	T_{assmin} Rise
144	Ballast	330	240	T_{assmin} Fall	192	Full	330	180	T_{assmin} Fall

Case	FPSO Draft	Current Direction	Wave Direction	Wave Event	Case	FPSO Draft	Current Direction	Wave Direction	Wave Event
193	Full	0	210	T_{assmax} Rise	241	Full	0	240	T_{assmax} Rise
194	Full	0	210	T_{assmax} Fall	242	Full	0	240	T_{assmax} Fall
195	Full	0	210	T_{assmin} Rise	243	Full	0	240	T_{assmin} Rise
196	Full	0	210	T_{assmin} Fall	244	Full	0	240	T_{assmin} Fall
197	Full	30	210	T_{assmax} Rise	245	Full	30	240	T_{assmax} Rise
198	Full	30	210	T_{assmax} Fall	246	Full	30	240	T_{assmax} Fall
199	Full	30	210	T_{assmin} Rise	247	Full	30	240	T_{assmin} Rise
200	Full	30	210	T_{assmin} Fall	248	Full	30	240	T_{assmin} Fall
201	Full	60	210	T_{assmax} Rise	249	Full	60	240	T_{assmax} Rise
202	Full	60	210	T_{assmax} Fall	250	Full	60	240	T_{assmax} Fall
203	Full	60	210	T_{assmin} Rise	251	Full	60	240	T_{assmin} Rise
204	Full	60	210	T_{assmin} Fall	252	Full	60	240	T_{assmin} Fall
205	Full	90	210	T_{assmax} Rise	253	Full	90	240	T_{assmax} Rise
206	Full	90	210	T_{assmax} Fall	254	Full	90	240	T_{assmax} Fall
207	Full	90	210	T_{assmin} Rise	255	Full	90	240	T_{assmin} Rise
208	Full	90	210	T_{assmin} Fall	256	Full	90	240	T_{assmin} Fall
209	Full	120	210	T_{assmax} Rise	257	Full	120	240	T_{assmax} Rise
210	Full	120	210	T_{assmax} Fall	258	Full	120	240	T_{assmax} Fall
211	Full	120	210	T_{assmin} Rise	259	Full	120	240	T_{assmin} Rise
212	Full	150	210	T_{assmin} Fall	260	Full	150	240	T_{assmin} Fall
213	Full	150	210	T_{assmax} Rise	261	Full	150	240	T_{assmax} Rise
214	Full	150	210	T_{assmax} Fall	262	Full	150	240	T_{assmax} Fall
215	Full	150	210	T_{assmin} Rise	263	Full	150	240	T_{assmin} Rise
216	Full	150	210	T_{assmin} Fall	264	Full	150	240	T_{assmin} Fall
217	Full	180	210	T_{assmax} Rise	265	Full	180	240	T_{assmax} Rise
218	Full	180	210	T_{assmax} Fall	266	Full	180	240	T_{assmax} Fall
219	Full	180	210	T_{assmin} Rise	267	Full	180	240	T_{assmin} Rise
220	Full	180	210	T_{assmin} Fall	268	Full	180	240	T_{assmin} Fall
221	Full	210	210	T_{assmax} Rise	269	Full	210	240	T_{assmax} Rise
222	Full	210	210	T_{assmax} Fall	270	Full	210	240	T_{assmax} Fall
223	Full	210	210	T_{assmin} Rise	271	Full	210	240	T_{assmin} Rise
224	Full	210	210	T_{assmin} Fall	272	Full	210	240	T_{assmin} Fall
225	Full	240	210	T_{assmax} Rise	273	Full	240	240	T_{assmax} Rise
226	Full	240	210	T_{assmax} Fall	274	Full	240	240	T_{assmax} Fall
227	Full	240	210	T_{assmin} Rise	275	Full	240	240	T_{assmin} Rise
228	Full	240	210	T_{assmin} Fall	276	Full	240	240	T_{assmin} Fall
229	Full	270	210	T_{assmax} Rise	277	Full	270	240	T_{assmax} Rise
230	Full	270	210	T_{assmax} Fall	278	Full	270	240	T_{assmax} Fall
231	Full	270	210	T_{assmin} Rise	279	Full	270	240	T_{assmin} Rise
232	Full	270	210	T_{assmin} Fall	280	Full	270	240	T_{assmin} Fall
233	Full	300	210	T_{assmax} Rise	281	Full	300	240	T_{assmax} Rise
234	Full	300	210	T_{assmax} Fall	282	Full	300	240	T_{assmax} Fall
235	Full	300	210	T_{assmin} Rise	283	Full	300	240	T_{assmin} Rise
236	Full	300	210	T_{assmin} Fall	284	Full	300	240	T_{assmin} Fall
237	Full	330	210	T_{assmax} Rise	285	Full	330	240	T_{assmax} Rise
238	Full	330	210	T_{assmax} Fall	286	Full	330	240	T_{assmax} Fall
239	Full	330	210	T_{assmin} Rise	287	Full	330	240	T_{assmin} Rise
240	Full	330	210	T_{assmin} Fall	288	Full	330	240	T_{assmin} Fall

Marine Growth on Risers

Case	FPSO Draft	Current Direction	Wave Direction	Wave Event	Case	FPSO Draft	Current Direction	Wave Direction	Wave Event
M1	Ballast	0	180	T_{assmax} Rise	M49	Ballast	0	210	T_{assmax} Rise
M2	Ballast	0	180	T_{assmax} Fall	M50	Ballast	0	210	T_{assmax} Fall
M3	Ballast	0	180	T_{assmin} Rise	M51	Ballast	0	210	T_{assmin} Rise
M4	Ballast	0	180	T_{assmin} Fall	M52	Ballast	0	210	T_{assmin} Fall
M5	Ballast	30	180	T_{assmax} Rise	M53	Ballast	30	210	T_{assmax} Rise
M6	Ballast	30	180	T_{assmax} Fall	M54	Ballast	30	210	T_{assmax} Fall
M7	Ballast	30	180	T_{assmin} Rise	M55	Ballast	30	210	T_{assmin} Rise
M8	Ballast	30	180	T_{assmin} Fall	M56	Ballast	30	210	T_{assmin} Fall
M9	Ballast	60	180	T_{assmax} Rise	M57	Ballast	60	210	T_{assmax} Rise
M10	Ballast	60	180	T_{assmax} Fall	M58	Ballast	60	210	T_{assmax} Fall
M11	Ballast	60	180	T_{assmin} Rise	M59	Ballast	60	210	T_{assmin} Rise
M12	Ballast	60	180	T_{assmin} Fall	M60	Ballast	60	210	T_{assmin} Fall
M13	Ballast	90	180	T_{assmax} Rise	M61	Ballast	90	210	T_{assmax} Rise
M14	Ballast	90	180	T_{assmax} Fall	M62	Ballast	90	210	T_{assmax} Fall
M15	Ballast	90	180	T_{assmin} Rise	M63	Ballast	90	210	T_{assmin} Rise
M16	Ballast	90	180	T_{assmin} Fall	M64	Ballast	90	210	T_{assmin} Fall
M17	Ballast	120	180	T_{assmax} Rise	M65	Ballast	120	210	T_{assmax} Rise
M18	Ballast	120	180	T_{assmax} Fall	M66	Ballast	120	210	T_{assmax} Fall
M19	Ballast	120	180	T_{assmin} Rise	M67	Ballast	120	210	T_{assmin} Rise
M20	Ballast	150	180	T_{assmin} Fall	M68	Ballast	150	210	T_{assmin} Fall
M21	Ballast	150	180	T_{assmax} Rise	M69	Ballast	150	210	T_{assmax} Rise
M22	Ballast	150	180	T_{assmax} Fall	M70	Ballast	150	210	T_{assmax} Fall
M23	Ballast	150	180	T_{assmin} Rise	M71	Ballast	150	210	T_{assmin} Rise
M24	Ballast	150	180	T_{assmin} Fall	M72	Ballast	150	210	T_{assmin} Fall
M25	Ballast	180	180	T_{assmax} Rise	M73	Ballast	180	210	T_{assmax} Rise
M26	Ballast	180	180	T_{assmax} Fall	M74	Ballast	180	210	T_{assmax} Fall
M27	Ballast	180	180	T_{assmin} Rise	M75	Ballast	180	210	T_{assmin} Rise
M28	Ballast	180	180	T_{assmin} Fall	M76	Ballast	180	210	T_{assmin} Fall
M29	Ballast	210	180	T_{assmax} Rise	M77	Ballast	210	210	T_{assmax} Rise
M30	Ballast	210	180	T_{assmax} Fall	M78	Ballast	210	210	T_{assmax} Fall
M31	Ballast	210	180	T_{assmin} Rise	M79	Ballast	210	210	T_{assmin} Rise
M32	Ballast	210	180	T_{assmin} Fall	M80	Ballast	210	210	T_{assmin} Fall
M33	Ballast	240	180	T_{assmax} Rise	M81	Ballast	240	210	T_{assmax} Rise
M34	Ballast	240	180	T_{assmax} Fall	M82	Ballast	240	210	T_{assmax} Fall
M35	Ballast	240	180	T_{assmin} Rise	M83	Ballast	240	210	T_{assmin} Rise
M36	Ballast	240	180	T_{assmin} Fall	M84	Ballast	240	210	T_{assmin} Fall
M37	Ballast	270	180	T_{assmax} Rise	M85	Ballast	270	210	T_{assmax} Rise
M38	Ballast	270	180	T_{assmax} Fall	M86	Ballast	270	210	T_{assmax} Fall
M39	Ballast	270	180	T_{assmin} Rise	M87	Ballast	270	210	T_{assmin} Rise
M40	Ballast	270	180	T_{assmin} Fall	M88	Ballast	270	210	T_{assmin} Fall
M41	Ballast	300	180	T_{assmax} Rise	M89	Ballast	300	210	T_{assmax} Rise
M42	Ballast	300	180	T_{assmax} Fall	M90	Ballast	300	210	T_{assmax} Fall
M43	Ballast	300	180	T_{assmin} Rise	M91	Ballast	300	210	T_{assmin} Rise
M44	Ballast	300	180	T_{assmin} Fall	M92	Ballast	300	210	T_{assmin} Fall
M45	Ballast	330	180	T_{assmax} Rise	M93	Ballast	330	210	T_{assmax} Rise
M46	Ballast	330	180	T_{assmax} Fall	M94	Ballast	330	210	T_{assmax} Fall
M47	Ballast	330	180	T_{assmin} Rise	M95	Ballast	330	210	T_{assmin} Rise
M48	Ballast	330	180	T_{assmin} Fall	M96	Ballast	330	210	T_{assmin} Fall

Case	FPSO Draft	Current Direction	Wave Direction	Wave Event	Case	FPSO Draft	Current Direction	Wave Direction	Wave Event
M97	Ballast	0	240	T_{assmax} Rise	M145	Full	0	180	T_{assmax} Rise
M98	Ballast	0	240	T_{assmax} Fall	M146	Full	0	180	T_{assmax} Fall
M99	Ballast	0	240	T_{assmin} Rise	M147	Full	0	180	T_{assmin} Rise
M100	Ballast	0	240	T_{assmin} Fall	M148	Full	0	180	T_{assmin} Fall
M101	Ballast	30	240	T_{assmax} Rise	M149	Full	30	180	T_{assmax} Rise
M102	Ballast	30	240	T_{assmax} Fall	M150	Full	30	180	T_{assmax} Fall
M103	Ballast	30	240	T_{assmin} Rise	M151	Full	30	180	T_{assmin} Rise
M104	Ballast	30	240	T_{assmin} Fall	M152	Full	30	180	T_{assmin} Fall
M105	Ballast	60	240	T_{assmax} Rise	M153	Full	60	180	T_{assmax} Rise
M106	Ballast	60	240	T_{assmax} Fall	M154	Full	60	180	T_{assmax} Fall
M107	Ballast	60	240	T_{assmin} Rise	M155	Full	60	180	T_{assmin} Rise
M108	Ballast	60	240	T_{assmin} Fall	M156	Full	60	180	T_{assmin} Fall
M109	Ballast	90	240	T_{assmax} Rise	M157	Full	90	180	T_{assmax} Rise
M110	Ballast	90	240	T_{assmax} Fall	M158	Full	90	180	T_{assmax} Fall
M111	Ballast	90	240	T_{assmin} Rise	M159	Full	90	180	T_{assmin} Rise
M112	Ballast	90	240	T_{assmin} Fall	M160	Full	90	180	T_{assmin} Fall
M113	Ballast	120	240	T_{assmax} Rise	M161	Full	120	180	T_{assmax} Rise
M114	Ballast	120	240	T_{assmax} Fall	M162	Full	120	180	T_{assmax} Fall
M115	Ballast	120	240	T_{assmin} Rise	M163	Full	120	180	T_{assmin} Rise
M116	Ballast	150	240	T_{assmin} Fall	M164	Full	150	180	T_{assmin} Fall
M117	Ballast	150	240	T_{assmax} Rise	M165	Full	150	180	T_{assmax} Rise
M118	Ballast	150	240	T_{assmax} Fall	M166	Full	150	180	T_{assmax} Fall
M119	Ballast	150	240	T_{assmin} Rise	M167	Full	150	180	T_{assmin} Rise
M120	Ballast	150	240	T_{assmin} Fall	M168	Full	150	180	T_{assmin} Fall
M121	Ballast	180	240	T_{assmax} Rise	M169	Full	180	180	T_{assmax} Rise
M122	Ballast	180	240	T_{assmax} Fall	M170	Full	180	180	T_{assmax} Fall
M123	Ballast	180	240	T_{assmin} Rise	M171	Full	180	180	T_{assmin} Rise
M124	Ballast	180	240	T_{assmin} Fall	M172	Full	180	180	T_{assmin} Fall
M125	Ballast	210	240	T_{assmax} Rise	M173	Full	210	180	T_{assmax} Rise
M126	Ballast	210	240	T_{assmax} Fall	M174	Full	210	180	T_{assmax} Fall
M127	Ballast	210	240	T_{assmin} Rise	M175	Full	210	180	T_{assmin} Rise
M128	Ballast	210	240	T_{assmin} Fall	M176	Full	210	180	T_{assmin} Fall
M129	Ballast	240	240	T_{assmax} Rise	M177	Full	240	180	T_{assmax} Rise
M130	Ballast	240	240	T_{assmax} Fall	M178	Full	240	180	T_{assmax} Fall
M131	Ballast	240	240	T_{assmin} Rise	M179	Full	240	180	T_{assmin} Rise
M132	Ballast	240	240	T_{assmin} Fall	M180	Full	240	180	T_{assmin} Fall
M133	Ballast	270	240	T_{assmax} Rise	M181	Full	270	180	T_{assmax} Rise
M134	Ballast	270	240	T_{assmax} Fall	M182	Full	270	180	T_{assmax} Fall
M135	Ballast	270	240	T_{assmin} Rise	M183	Full	270	180	T_{assmin} Rise
M136	Ballast	270	240	T_{assmin} Fall	M184	Full	270	180	T_{assmin} Fall
M137	Ballast	300	240	T_{assmax} Rise	M185	Full	300	180	T_{assmax} Rise
M138	Ballast	300	240	T_{assmax} Fall	M186	Full	300	180	T_{assmax} Fall
M139	Ballast	300	240	T_{assmin} Rise	M187	Full	300	180	T_{assmin} Rise
M140	Ballast	300	240	T_{assmin} Fall	M188	Full	300	180	T_{assmin} Fall
M141	Ballast	330	240	T_{assmax} Rise	M189	Full	330	180	T_{assmax} Rise
M142	Ballast	330	240	T_{assmax} Fall	M190	Full	330	180	T_{assmax} Fall
M143	Ballast	330	240	T_{assmin} Rise	M191	Full	330	180	T_{assmin} Rise
M144	Ballast	330	240	T_{assmin} Fall	M192	Full	330	180	T_{assmin} Fall

Case	FPSO Draft	Current Direction	Wave Direction	Wave Event	Case	FPSO Draft	Current Direction	Wave Direction	Wave Event
M193	Full	0	210	T_{assmax} Rise	M241	Full	0	240	T_{assmax} Rise
M194	Full	0	210	T_{assmax} Fall	M242	Full	0	240	T_{assmax} Fall
M195	Full	0	210	T_{assmin} Rise	M243	Full	0	240	T_{assmin} Rise
M196	Full	0	210	T_{assmin} Fall	M244	Full	0	240	T_{assmin} Fall
M197	Full	30	210	T_{assmax} Rise	M245	Full	30	240	T_{assmax} Rise
M198	Full	30	210	T_{assmax} Fall	M246	Full	30	240	T_{assmax} Fall
M199	Full	30	210	T_{assmin} Rise	M247	Full	30	240	T_{assmin} Rise
M200	Full	30	210	T_{assmin} Fall	M248	Full	30	240	T_{assmin} Fall
M201	Full	60	210	T_{assmax} Rise	M249	Full	60	240	T_{assmax} Rise
M202	Full	60	210	T_{assmax} Fall	M250	Full	60	240	T_{assmax} Fall
M203	Full	60	210	T_{assmin} Rise	M251	Full	60	240	T_{assmin} Rise
M204	Full	60	210	T_{assmin} Fall	M252	Full	60	240	T_{assmin} Fall
M205	Full	90	210	T_{assmax} Rise	M253	Full	90	240	T_{assmax} Rise
M206	Full	90	210	T_{assmax} Fall	M254	Full	90	240	T_{assmax} Fall
M207	Full	90	210	T_{assmin} Rise	M255	Full	90	240	T_{assmin} Rise
M208	Full	90	210	T_{assmin} Fall	M256	Full	90	240	T_{assmin} Fall
M209	Full	120	210	T_{assmax} Rise	M257	Full	120	240	T_{assmax} Rise
M210	Full	120	210	T_{assmax} Fall	M258	Full	120	240	T_{assmax} Fall
M211	Full	120	210	T_{assmin} Rise	M259	Full	120	240	T_{assmin} Rise
M212	Full	150	210	T_{assmin} Fall	M260	Full	150	240	T_{assmin} Fall
M213	Full	150	210	T_{assmax} Rise	M261	Full	150	240	T_{assmax} Rise
M214	Full	150	210	T_{assmax} Fall	M262	Full	150	240	T_{assmax} Fall
M215	Full	150	210	T_{assmin} Rise	M263	Full	150	240	T_{assmin} Rise
M216	Full	150	210	T_{assmin} Fall	M264	Full	150	240	T_{assmin} Fall
M217	Full	180	210	T_{assmax} Rise	M265	Full	180	240	T_{assmax} Rise
M218	Full	180	210	T_{assmax} Fall	M266	Full	180	240	T_{assmax} Fall
M219	Full	180	210	T_{assmin} Rise	M267	Full	180	240	T_{assmin} Rise
M220	Full	180	210	T_{assmin} Fall	M268	Full	180	240	T_{assmin} Fall
M221	Full	210	210	T_{assmax} Rise	M269	Full	210	240	T_{assmax} Rise
M222	Full	210	210	T_{assmax} Fall	M270	Full	210	240	T_{assmax} Fall
M223	Full	210	210	T_{assmin} Rise	M271	Full	210	240	T_{assmin} Rise
M224	Full	210	210	T_{assmin} Fall	M272	Full	210	240	T_{assmin} Fall
M225	Full	240	210	T_{assmax} Rise	M273	Full	240	240	T_{assmax} Rise
M226	Full	240	210	T_{assmax} Fall	M274	Full	240	240	T_{assmax} Fall
M227	Full	240	210	T_{assmin} Rise	M275	Full	240	240	T_{assmin} Rise
M228	Full	240	210	T_{assmin} Fall	M276	Full	240	240	T_{assmin} Fall
M229	Full	270	210	T_{assmax} Rise	M277	Full	270	240	T_{assmax} Rise
M230	Full	270	210	T_{assmax} Fall	M278	Full	270	240	T_{assmax} Fall
M231	Full	270	210	T_{assmin} Rise	M279	Full	270	240	T_{assmin} Rise
M232	Full	270	210	T_{assmin} Fall	M280	Full	270	240	T_{assmin} Fall
M233	Full	300	210	T_{assmax} Rise	M281	Full	300	240	T_{assmax} Rise
M234	Full	300	210	T_{assmax} Fall	M282	Full	300	240	T_{assmax} Fall
M235	Full	300	210	T_{assmin} Rise	M283	Full	300	240	T_{assmin} Rise
M236	Full	300	210	T_{assmin} Fall	M284	Full	300	240	T_{assmin} Fall
M237	Full	330	210	T_{assmax} Rise	M285	Full	330	240	T_{assmax} Rise
M238	Full	330	210	T_{assmax} Fall	M286	Full	330	240	T_{assmax} Fall
M239	Full	330	210	T_{assmin} Rise	M287	Full	330	240	T_{assmin} Rise
M240	Full	330	210	T_{assmin} Fall	M288	Full	330	240	T_{assmin} Fall

APPENDIX C – FULL RESULTS (LOAD CASE M PREFIX)

	LOAD CASE (M Prefix)																																Max		
DESCRIPTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32			
Line 1 End Force (End A) Max	134.4	132.9	134.8	132.7	133.8	132.5	133.5	132.2	133.5	131.7	132.7	131.4	133.2	130.8	131.9	130.2	133.3	130.1	131.2	129.8	134.4	131.5	132.4	131.1	134.9	131.9	133.0	131.8	134.6	131.7	132.7	131.5	134.9	kN	
Line 2 End Force (End A) Max	133.3	132.5	133.2	132.6	133.3	132.3	132.8	132.4	132.5	131.5	132.0	131.6	132.3	130.7	131.3	130.4	132.4	129.7	130.8	129.2	133.5	131.1	132.1	130.5	134.1	132.4	133.4	132.0	133.7	131.4	132.4	130.8	134.1	kN	
Line 1 End Force (End A) Min	142.8	143.5	144.3	143.0	143.5	143.7	143.7	142.8	143.7	143.7	144.0	143.2	142.9	142.9	144.1	143.2	141.4	141.8	143.2	143.2	141.5	142.1	143.4	143.5	141.3	141.6	143.0	143.6	141.5	142.2	143.6	143.5	144.3	kN	
Line 2 End Force (End A) Min	143.1	144.6	142.4	142.3	143.4	144.6	143.3	142.8	143.6	144.5	143.6	143.1	142.8	143.5	143.6	143.1	142.2	142.4	143.9	143.2	142.3	142.7	143.9	143.4	142.9	143.4	143.7	142.9	142.3	142.8	143.9	143.4	144.6	kN	
Line 1 Bend Moment (End A)	53.3	42.3	44.2	44.1	74.4	63.0	63.1	63.9	92.0	82.2	82.0	80.4	89.0	85.8	87.6	84.6	115.9	111.1	110.6	109.4	102.0	89.7	91.1	88.8	94.9	85.0	87.6	85.6	94.3	81.9	83.3	81.3	115.9	kNm	
Line 2 Bend Moment (End A)	78.8	66.0	66.9	63.4	79.4	66.1	66.2	63.2	96.0	84.6	84.4	82.4	88.8	86.0	87.4	84.2	116.8	111.4	112.7	110.7	104.0	91.7	94.4	90.5	65.8	52.2	53.8	49.8	96.4	83.9	86.7	83.0	116.8	kNm	
Line 1 Shear Force (End A)	14.3	11.7	11.6	12.0	19.5	16.2	16.8	15.9	24.2	21.3	21.5	20.6	24.2	21.9	22.6	21.7	33.2	29.8	30.1	29.7	30.0	24.9	25.0	25.0	27.8	23.4	23.1	23.0	27.7	22.6	22.9	22.7	33.2	kN	
Line 2 Shear Force (End A)	20.9	16.6	17.5	15.9	20.9	16.9	17.6	16.3	25.3	21.9	22.2	21.2	24.2	22.0	22.4	21.7	33.5	30.1	29.9	29.8	30.6	25.4	25.4	25.3	20.0	14.4	15.2	14.5	28.1	23.2	23.2	23.0	33.5	kN	
Line 1 Effective Tension Max (Rubber)	134.4	132.9	134.8	132.7	133.8	132.5	133.5	132.2	133.5	131.7	132.7	131.4	133.2	130.8	131.9	130.2	133.3	130.1	131.2	129.8	134.4	131.5	132.4	131.1	134.9	131.9	133.0	131.8	134.6	131.7	132.7	131.5	134.9	kN	
Line 2 Effective Tension Max (Rubber)	133.3	132.5	133.2	132.6	133.3	132.3	132.8	132.4	132.5	131.5	132.0	131.6	132.3	130.7	131.3	130.4	132.4	129.7	130.8	129.2	133.5	131.1	132.1	130.5	134.1	132.4	133.4	132.0	133.7	131.4	132.4	130.8	134.1	kN	
Line 1 Effective Tension Max (HDPE)	64.8	62.6	65.1	65.0	64.4	62.9	64.4	64.9	64.3	62.6	64.1	64.9	64.2	62.5	63.6	64.3	64.3	62.6	63.0	63.7	64.4	62.7	62.8	63.8	64.8	62.8	62.6	64.4	64.4	62.7	62.8	63.9	65.1	kN	
Line 2 Effective Tension Max (HDPE)	64.6	63.8	65.2	65.4	64.6	63.7	64.8	65.3	64.5	63.4	64.6	65.2	64.2	62.6	64.0	64.7	64.1	62.4	63.5	64.0	64.1	62.5	63.2	64.0	64.7	62.6	63.7	64.7	64.2	62.5	63.2	64.1	65.4	kN	
Line 1 Curvature (Rubber)	0.020	0.015	0.016	0.016	0.027	0.023	0.024	0.024	0.034	0.030	0.031	0.030	0.033	0.032	0.032	0.031	0.042	0.041	0.040	0.040	0.035	0.032	0.033	0.032	0.034	0.030	0.032	0.032	0.032	0.029	0.030	0.030	0.0416	24.02	m
Line 2 Curvature (Rubber)	0.029	0.025	0.025	0.024	0.029	0.025	0.025	0.024	0.035	0.031	0.031	0.030	0.033	0.032	0.032	0.031	0.042	0.041	0.041	0.041	0.036	0.032	0.034	0.033	0.023	0.019	0.019	0.018	0.033	0.030	0.031	0.030	0.0416	24.02	m
Line 1 Curvature (HDPE)	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.005	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.004	0.003	0.004	0.003	0.004	0.003	0.003	0.003	0.0045	220.21	m
Line 2 Curvature (HDPE)	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.005	0.004	0.004	0.003	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.0048	208.51	m

	LOAD CASE (M Prefix)																																Max		
DESCRIPTION	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64			
Line 1 End Force (End A) Max	133.4	130.2	131.3	129.9	130.7	127.8	128.7	127.4	129.4	127.5	128.5	127.7	132.8	131.8	132.4	131.6	140.3	138.6	136.9	141.4	141.0	138.8	137.3	142.1	141.9	139.5	137.7	142.7	142.4	140.6	138.2	143.2	143.2	kN	
Line 2 End Force (End A) Max	132.5	129.7	130.8	129.4	129.8	127.5	128.3	127.5	129.4	127.3	127.8	128.0	132.8	131.6	131.7	131.9	141.1	137.8	136.5	141.2	141.7	138.6	137.0	141.7	142.2	139.6	137.1	142.2	142.8	140.5	137.5	142.8	142.8	kN	
Line 1 End Force (End A) Min	141.0	141.6	143.0	142.8	142.4	142.2	143.7	142.6	143.2	143.6	143.5	142.3	142.8	143.5	143.1	142.4	136.6	132.6	135.8	132.0	135.9	132.2	135.3	131.4	135.6	132.0	135.2	131.6	135.9	132.2	134.9	131.7	143.7	kN	
Line 2 End Force (End A) Min	141.4	142.0	143.3	142.8	142.5	142.9	143.2	142.6	143.2	144.4	143.1	142.3	143.0	144.3	142.7	142.4	135.9	133.6	135.4	131.9	135.5	132.9	135.2	131.7	135.2	132.6	135.1	131.9	135.6	132.7	134.8	132.1	144.4	kN	
Line 1 Bend Moment (End A)	115.0	115.4	113.1	113.3	142.7	139.3	141.0	138.6	165.4	155.0	156.1	157.0	104.0	91.5	92.4	91.5	68.4	59.1	53.7	55.4	85.3	66.0	74.7	74.7	99.3	93.6	92.6	99.2	98.5	105.0	102.0	100.6	165.4	kNm	
Line 2 Bend Moment (End A)	116.1	115.2	114.2	114.9	142.7	139.8	141.1	138.4	168.2	156.9	157.6	158.0	108.9	94.5	95.5	93.0	89.3	77.7	78.4	75.4	88.9	68.9	77.1	73.6	103.2	92.7	91.8	97.8	99.1	104.8	100.6	99.9	168.2	kNm	
Line 1 Shear Force (End A)	31.5	28.9	29.2	28.8	36.3	34.9	35.4	34.6	41.7	39.2	40.0	39.1	26.5	22.9	23.8	23.6	18.0	13.9	13.1	13.0	23.3	17.3	18.8	17.3	27.6	22.3	23.2	23.7	24.4	25.4	24.7	24.4	41.7	kN	
Line 2 Shear Force (End A)	31.7	28.8	28.9	28.8	36.1	35.0	35.3	34.5	42.6	39.7	40.6	39.4	27.8	23.6	24.7	24.2	24.0	19.5	20.0	19.0	24.3	18.1	19.3	18.0	28.7	22.0	23.9	23.8	24.4	25.3	24.4	24.5	42.6	kN	
Line 1 Effective Tension Max (Rubber)	133.4	130.2	131.3	129.9	130.7	127.8	128.7	127.4	129.4	127.5	128.5	127.7	132.8	131.8	132.4	131.6	140.3	138.6	136.9	141.4	141.0	138.8	137.3	142.1	141.9	139.5	137.7	142.7	142.4	140.6	138.2	143.2	143.2	kN	
Line 2 Effective Tension Max (Rubber)	132.5	129.7	130.8	129.4	129.8	127.5	128.3	127.5	129.4	127.3	127.8	128.0	132.8	131.6	131.7	131.9	141.1	137.8	136.5	141.2	141.7	138.6	137.0	141.7	142.2	139.6	137.1	142.2	142.8	140.5	137.5	142.8	142.8	kN	
Line 1 Effective Tension Max (HDPE)	64.2	62.5	63.2	63.7	64.1	62.4	63.6	64.3	64.2	62.9	64.3	65.0	64.1	63.2	64.7	65.1	71.9	69.1	67.5	70.6	72.6	69.7	67.6	70.4	72.7	70.2	67.8	70.7	72.4	70.4	67.8	70.8	72.7	kN	
Line 2 Effective Tension Max (HDPE)	64.0	62.4	63.5	64.1	64.0	62.6	64.1	64.6	64.6	63.8	64.8	65.5	64.9	64.0	65.1	65.6	73.4	70.2	68.1	71.4	73.9	70.5	68.2	71.1	74.1	70.9	68.4	71.5	73.7	71.1	68.7	71.7	74.1	kN	
Line 1 Curvature (Rubber)	0.044	0.043	0.043	0.042	0.053	0.052	0.052	0.052	0.061	0.057	0.059	0.058	0.039	0.034	0.035	0.034	0.026	0.023	0.021	0.021	0.031	0.025	0.028	0.029	0.036	0.036	0.035	0.038	0.038	0.040	0.039	0.038	0.0611	16.37	m
Line 2 Curvature (Rubber)	0.044	0.043	0.043	0.043	0.053	0.052	0.052	0.052	0.062	0.058	0.059	0.059	0.040	0.035	0.036	0.035	0.033	0.029	0.030	0.028	0.032	0.025	0.029	0.029	0.037	0.036	0.035	0.037	0.038	0.040	0.038	0.038	0.0621	16.11	m
Line 1 Curvature (HDPE)	0.005	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.005	0.004	0.004	0.004	0.004	0.003	0.004	0.003	0.005	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.004	0.003	0.004	0.004	0.003	0.004	0.0048	206.97	m
Line 2 Curvature (HDPE)	0.005	0.004	0.004	0.004	0.004	0.003	0.004	0.003	0.005	0.004	0.004	0.004	0.004	0.003	0.004	0.003	0.005	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.005	0.004	0.004	0.004	0.0049	203.51	m

DESCRIPTION	LOAD CASE (M Prefix)																															Max	
	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96		
Line 1 End Force (End A) Max	141.4	140.5	137.7	142.5	140.4	140.1	138.0	142.1	138.7	139.3	137.8	140.8	137.5	138.1	136.6	139.8	133.3	135.7	132.9	136.0	129.4	132.0	128.7	132.2	131.7	130.5	129.4	132.4	138.8	136.4	135.3	139.6	142.5	kN
Line 2 End Force (End A) Max	141.9	140.3	137.1	142.2	140.9	139.9	137.3	141.9	140.1	139.1	136.5	141.5	137.9	137.1	135.7	139.5	133.8	134.3	132.1	135.8	131.0	130.6	128.5	132.0	132.8	129.1	129.2	132.0	139.8	136.3	135.0	139.2	142.2	kN
Line 1 End Force (End A) Min	137.0	132.0	135.4	131.9	137.7	132.4	136.0	131.9	138.1	131.7	136.1	132.5	138.6	132.9	136.6	132.8	139.5	133.6	137.3	133.5	140.5	135.0	138.2	134.0	139.5	135.6	138.3	133.6	137.3	133.9	136.4	132.3	140.5	kN
Line 2 End Force (End A) Min	136.8	132.9	135.2	132.2	137.5	132.9	135.8	132.3	137.1	133.0	136.1	132.2	138.3	133.3	136.5	133.1	139.6	134.2	137.2	133.8	140.2	135.5	138.1	134.5	138.4	136.3	138.4	134.0	136.7	134.5	136.4	132.6	140.2	kN
Line 1 Bend Moment (End A)	112.1	122.5	119.6	118.7	105.1	101.9	105.5	99.0	102.6	90.8	95.9	91.3	103.7	87.8	90.4	95.5	141.8	133.3	133.9	137.7	184.1	184.3	173.6	181.8	185.2	192.9	186.2	184.6	112.6	106.8	104.0	105.4	192.9	kNm
Line 2 Bend Moment (End A)	113.5	122.9	121.1	119.6	108.4	103.7	108.2	101.4	69.4	66.2	65.8	61.2	105.6	88.3	92.1	97.2	140.0	132.3	133.7	136.7	183.3	182.1	173.0	181.6	184.7	192.9	186.5	184.8	114.3	108.3	106.1	106.8	192.9	kNm
Line 1 Shear Force (End A)	30.3	30.7	30.8	29.7	29.1	26.3	27.4	25.9	26.8	23.4	24.5	22.6	25.8	23.4	23.0	24.6	34.8	34.3	33.0	34.5	46.5	46.6	44.1	46.4	48.0	50.2	48.4	48.1	29.5	27.2	27.1	26.4	50.2	kN
Line 2 Shear Force (End A)	30.9	31.3	31.2	29.9	30.1	27.1	28.1	26.5	19.8	15.7	17.3	16.0	27.0	22.9	23.9	25.3	34.3	34.0	32.9	34.4	46.4	46.1	43.9	46.4	48.2	50.4	48.7	48.2	30.1	27.7	27.9	26.8	50.4	kN
Line 1 Effective Tension Max (Rubber)	141.4	140.5	137.7	142.5	140.4	140.1	138.0	142.1	138.7	139.3	137.8	140.8	137.5	138.1	136.6	139.8	133.3	135.7	132.9	136.0	129.4	132.0	128.7	132.2	131.7	130.5	129.4	132.4	138.8	136.4	135.3	139.6	142.5	kN
Line 2 Effective Tension Max (Rubber)	141.9	140.3	137.1	142.2	140.9	139.9	137.3	141.9	140.1	139.1	136.5	141.5	137.9	137.1	135.7	139.5	133.8	134.3	132.1	135.8	131.0	130.6	128.5	132.0	132.8	129.1	129.2	132.0	139.8	136.3	135.0	139.2	142.2	kN
Line 1 Effective Tension Max (HDPE)	71.7	70.1	67.5	70.9	70.3	68.5	66.4	69.9	69.2	67.4	66.0	69.3	69.1	67.0	65.8	68.2	68.0	66.0	65.0	66.7	68.8	66.0	65.0	66.1	70.7	67.6	66.2	68.3	71.7	69.0	67.1	70.0	71.7	kN
Line 2 Effective Tension Max (HDPE)	72.6	70.8	68.0	71.0	71.4	69.2	66.9	70.1	71.6	68.4	66.9	70.0	70.4	67.7	66.0	68.3	69.2	66.7	65.1	66.9	70.3	66.8	65.4	67.0	72.0	68.3	66.7	69.1	73.1	69.8	67.8	70.9	73.1	kN
Line 1 Curvature (Rubber)	0.042	0.046	0.044	0.044	0.038	0.039	0.039	0.037	0.039	0.036	0.036	0.034	0.039	0.033	0.034	0.035	0.053	0.050	0.050	0.051	0.068	0.068	0.065	0.067	0.068	0.070	0.068	0.067	0.041	0.040	0.039	0.039	0.0702	14.25 m
Line 2 Curvature (Rubber)	0.042	0.047	0.045	0.045	0.039	0.040	0.040	0.038	0.026	0.026	0.024	0.023	0.040	0.034	0.034	0.036	0.053	0.049	0.050	0.051	0.068	0.067	0.064	0.067	0.067	0.070	0.068	0.067	0.042	0.040	0.039	0.040	0.0701	14.26 m
Line 1 Curvature (HDPE)	0.005	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.006	0.004	0.004	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.0055	180.46 m
Line 2 Curvature (HDPE)	0.005	0.004	0.004	0.004	0.006	0.004	0.004	0.004	0.006	0.004	0.004	0.004	0.006	0.004	0.004	0.004	0.006	0.004	0.005	0.005	0.005	0.005	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.0058	172.00 m

DESCRIPTION	LOAD CASE (M Prefix)																															Max	
	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121	122	123	124	125	126	127	128		
Line 1 End Force (End A) Max	175.0	163.4	165.5	154.7	174.9	164.7	166.2	155.6	175.2	166.1	166.8	157.1	176.3	168.0	168.3	158.6	178.1	168.4	168.4	159.0	177.5	166.2	167.4	157.6	176.9	164.1	166.1	156.1	175.8	162.0	164.4	154.0	178.1	kN
Line 2 End Force (End A) Max	173.4	163.4	164.8	153.9	173.8	165.2	165.7	155.4	174.0	166.6	166.2	156.9	174.9	168.5	167.3	158.4	176.8	168.9	167.7	159.0	176.1	166.8	166.7	157.5	175.4	164.8	165.4	156.6	174.6	162.4	164.0	154.0	176.8	kN
Line 1 End Force (End A) Min	90.9	100.8	99.2	114.9	90.2	99.8	98.7	114.8	89.2	98.8	97.7	114.0	88.5	98.7	97.9	112.9	88.8	99.9	97.8	113.4	89.0	100.5	97.9	113.8	90.2	102.1	99.3	114.9	91.4	103.2	100.6	116.0	116.0	kN
Line 2 End Force (End A) Min	92.1	100.1	99.6	116.1	91.1	99.1	99.1	115.0	90.1	98.1	98.0	114.5	89.4	98.0	98.1	113.5	89.7	99.3	98.1	113.7	89.9	99.9	98.2	114.4	91.1	100.7	99.2	115.5	92.3	102.7	100.8	116.4	116.4	kN
Line 1 Bend Moment (End A)	136.8	113.1	105.0	84.9	125.3	123.4	107.9	100.7	164.8	158.6	148.5	137.0	182.7	172.0	161.9	147.4	196.4	184.4	172.8	158.1	162.2	150.9	139.7	127.8	144.7	129.0	118.0	101.7	182.2	165.3	152.0	129.0	196.4	kNm
Line 2 Bend Moment (End A)	148.2	122.8	118.0	95.8	124.6	122.9	108.0	100.6	163.9	157.4	148.0	136.5	182.0	170.6	161.2	146.5	196.1	183.2	172.0	157.0	161.9	150.2	138.7	127.6	131.4	111.0	100.6	82.0	181.7	166.4	150.4	129.9	196.1	kNm
Line 1 Shear Force (End A)	33.6	27.5	24.8	20.3	29.9	28.5	27.2	25.2	43.2	39.3	39.3	35.8	48.4	44.1	42.9	38.7	52.5	47.3	46.3	41.6	41.2	37.3	35.2	33.1	34.9	32.3	29.9	25.7	45.1	42.3	39.1	32.2	52.5	kN
Line 2 Shear Force (End A)	37.0	30.2	28.7	23.6	29.5	28.3	27.1	25.1	42.7	38.8	38.9	35.4	47.9	43.6	42.7	38.4	52.1	46.9	46.0	41.3	40.8	36.9	34.9	32.9	31.4	27.1	24.6	19.3	45.0	42.5	38.6	32.5	52.1	kN
Line 1 Effective Tension Max (Rubber)	175.0	163.4	165.5	154.7	174.9	164.7	166.2	155.6	175.2	166.1	166.8	157.1	176.3	168.0	168.3	158.6	178.1	168.4	168.4	159.0	177.5	166.2	167.4	157.6	176.9	164.1	166.1	156.1	175.8	162.0	164.4	154.0	178.1	kN
Line 2 Effective Tension Max (Rubber)	173.4	163.4	164.8	153.9	173.8	165.2	165.7	155.4	174.0	166.6	166.2	156.9	174.9	168.5	167.3	158.4	176.8	168.9	167.7	159.0	176.1	166.8	166.7	157.5	175.4	164.8	165.4	156.6	174.6	162.4	164.0	154.0	176.8	kN
Line 1 Effective Tension Max (HDPE)	84.7	81.4	82.5	75.5	84.6	83.4	82.9	76.4	86.0	85.6	83.5	77.4	88.1	87.1	84.8	78.8	88.8	87.7	84.9	79.2	87.5	84.2	84.3	77.6	87.0	81.9	83.6	76.6	86.1	79.6	82.3	75.3	88.8	kN
Line 2 Effective Tension Max (HDPE)	83.6	82.2	82.1	75.7	84.1	84.0	82.6	76.4	85.6	86.0	83.1	77.5	87.4	87.5	84.2	78.9	88.2	88.0	84.4	79.3	86.5	84.7	83.8	77.5	85.6	82.4	83.1	76.5	85.3	79.9	81.9	75.2	88.2	kN
Line 1 Curvature (Rubber)	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0742	13.47 m
Line 2 Curvature (Rubber)	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0742	13.48 m
Line 1 Curvature (HDPE)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0075	133.97 m
Line 2 Curvature (HDPE)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0075	133.34 m

DESCRIPTION	LOAD CASE (M Prefix)																																Max		
	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160			
Line 1 End Force (End A) Max	172.7	157.3	162.2	151.6	167.9	154.5	158.6	148.9	166.7	153.5	158.2	147.0	172.2	160.9	163.0	152.2	134.4	131.3	133.9	133.9	133.9	130.8	133.1	133.6	133.2	130.2	132.5	132.9	132.0	129.4	131.3	131.4	172.7		kN
Line 2 End Force (End A) Max	171.6	157.5	161.9	151.0	166.8	153.8	158.3	148.4	165.6	153.8	157.9	146.6	171.0	161.2	162.6	151.8	133.9	130.9	133.6	134.4	134.1	131.0	133.7	134.1	133.4	130.4	133.1	133.4	132.2	129.2	131.9	131.9	171.6		kN
Line 1 End Force (End A) Min	95.1	107.2	103.8	118.2	99.1	109.9	107.1	121.1	99.0	108.3	106.3	121.2	93.6	102.6	101.1	117.0	143.7	146.8	144.4	144.6	143.3	146.7	144.4	144.4	143.3	146.8	144.6	144.5	143.4	146.4	144.9	144.5	146.8		kN
Line 2 End Force (End A) Min	96.0	107.0	103.9	118.7	99.9	109.5	107.3	121.6	99.8	107.9	106.5	121.7	94.6	102.0	101.4	117.7	142.4	146.1	144.0	143.1	143.0	146.2	144.0	143.3	143.0	146.3	144.2	143.7	143.1	145.9	144.5	143.9	146.3		kN
Line 1 Bend Moment (End A)	251.0	231.4	219.1	184.6	326.3	297.0	289.3	245.1	334.2	294.8	294.6	255.2	208.2	170.9	171.4	144.1	47.9	36.1	37.6	38.4	68.1	57.0	61.4	58.6	77.0	67.8	70.6	69.0	76.9	74.7	74.9	74.7	334.2		kNm
Line 2 Bend Moment (End A)	248.8	232.1	217.2	185.2	323.6	297.6	287.0	243.4	332.0	295.4	292.4	252.5	207.8	170.2	170.6	142.6	72.7	61.3	66.4	62.6	71.2	59.8	63.7	60.6	79.6	70.3	72.5	70.5	77.1	75.3	75.6	74.8	332.0		kNm
Line 1 Shear Force (End A)	63.7	59.1	56.3	46.3	84.5	77.3	75.4	62.5	88.2	78.2	77.9	66.0	53.0	43.3	43.4	36.4	12.6	9.7	10.9	10.8	17.9	14.9	16.5	15.5	20.2	17.9	18.8	18.0	20.1	18.5	18.4	18.8	88.2		kN
Line 2 Shear Force (End A)	63.0	59.4	55.6	46.4	83.7	77.3	74.6	62.6	87.5	78.2	77.1	65.2	53.0	43.2	43.1	36.0	18.9	16.0	17.7	16.1	18.7	15.8	17.1	15.8	20.8	18.6	19.3	18.2	20.3	18.5	18.5	18.8	87.5		kN
Line 1 Effective Tension Max (Rubber)	172.7	157.3	162.2	151.6	167.9	154.5	158.6	148.9	166.7	153.5	158.2	147.0	172.2	160.9	163.0	152.2	134.4	131.3	133.9	133.9	133.9	130.8	133.1	133.6	133.2	130.2	132.5	132.9	132.0	129.4	131.3	131.4	172.7		kN
Line 2 Effective Tension Max (Rubber)	171.6	157.5	161.9	151.0	166.8	153.8	158.3	148.4	165.6	153.8	157.9	146.6	171.0	161.2	162.6	151.8	133.9	130.9	133.6	134.4	134.1	131.0	133.7	134.1	133.4	130.4	133.1	133.4	132.2	129.2	131.9	131.9	171.6		kN
Line 1 Effective Tension Max (HDPE)	84.8	77.6	81.2	74.5	81.6	77.2	79.1	73.8	80.3	76.6	78.5	71.9	83.6	79.3	81.0	74.3	66.8	65.4	65.6	66.0	66.8	65.7	65.4	66.0	66.7	65.4	65.1	65.5	66.2	64.7	64.6	64.9	84.8		kN
Line 2 Effective Tension Max (HDPE)	84.1	77.0	81.0	74.0	80.9	76.8	79.0	73.3	79.6	77.2	78.4	71.5	82.7	79.9	80.7	74.2	67.9	67.1	66.2	67.0	67.7	66.6	66.1	66.7	67.3	66.3	65.8	66.2	66.7	65.6	65.3	65.6	84.1		kN
Line 1 Curvature (Rubber)	0.093	0.085	0.081	0.069	0.119	0.108	0.105	0.090	0.121	0.106	0.106	0.093	0.077	0.064	0.064	0.054	0.017	0.013	0.013	0.013	0.025	0.021	0.022	0.022	0.028	0.025	0.026	0.026	0.029	0.028	0.028	0.028	0.1207	8.28	m
Line 2 Curvature (Rubber)	0.092	0.086	0.080	0.069	0.118	0.108	0.105	0.089	0.120	0.107	0.106	0.092	0.077	0.063	0.064	0.053	0.027	0.023	0.024	0.023	0.026	0.022	0.023	0.023	0.029	0.026	0.026	0.026	0.029	0.028	0.029	0.028	0.1201	8.33	m
Line 1 Curvature (HDPE)	0.007	0.007	0.006	0.006	0.009	0.008	0.008	0.007	0.008	0.007	0.007	0.006	0.007	0.006	0.006	0.005	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.0086	116.73	m
Line 2 Curvature (HDPE)	0.007	0.007	0.006	0.006	0.008	0.008	0.008	0.007	0.008	0.007	0.007	0.006	0.007	0.006	0.006	0.005	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.0085	117.73	m

DESCRIPTION	LOAD CASE (M Prefix)																																Max		
	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192			
Line 1 End Force (End A) Max	130.7	129.0	130.5	130.3	132.0	130.1	131.4	131.7	132.2	130.5	131.3	131.5	132.2	130.3	131.5	131.8	130.2	129.0	130.0	129.7	129.5	126.9	129.2	128.9	130.9	127.8	130.5	130.2	133.2	130.2	132.9	132.9	133.2		kN
Line 2 End Force (End A) Max	131.0	129.0	131.2	130.9	132.3	130.1	132.0	132.2	133.6	131.2	133.0	133.3	132.5	130.3	132.2	132.4	130.3	128.9	130.5	130.4	129.7	126.8	129.8	129.4	131.1	128.1	131.1	130.7	133.4	130.4	133.4	133.5	133.6		kN
Line 1 End Force (End A) Min	143.8	146.4	145.2	144.9	144.1	146.7	145.7	145.2	144.3	146.6	145.4	144.9	144.1	146.7	145.7	145.2	143.6	146.1	145.0	144.7	143.0	146.2	144.8	144.2	142.8	146.2	144.3	143.9	142.7	146.3	144.2	143.9	146.7		kN
Line 2 End Force (End A) Min	143.4	145.8	144.5	144.5	143.8	146.2	145.0	144.9	143.8	146.3	145.1	144.4	143.8	146.2	145.0	144.9	143.3	145.6	144.3	144.3	142.6	145.7	144.3	143.5	142.4	146.1	144.0	143.1	142.4	145.8	143.7	143.1	146.3		kN
Line 1 Bend Moment (End A)	97.5	96.5	98.5	96.4	88.7	78.2	81.3	81.2	86.1	79.4	82.9	81.7	83.7	73.0	76.1	76.0	104.7	108.6	105.6	105.1	122.5	123.3	122.7	122.5	133.2	128.6	126.5	129.7	91.3	82.9	87.2	88.8	133.2		kNm
Line 2 Bend Moment (End A)	98.3	96.8	99.6	96.5	90.8	80.7	83.5	82.6	61.1	46.8	49.9	49.6	85.6	75.5	78.3	77.5	106.1	108.4	106.1	105.3	122.1	123.3	122.9	122.5	135.5	129.6	127.8	129.8	93.5	84.4	88.2	89.4	135.5		kNm
Line 1 Shear Force (End A)	27.1	25.1	25.2	25.6	25.9	21.6	21.8	22.7	24.7	21.3	21.6	22.3	24.3	20.1	20.3	21.1	28.2	26.9	26.4	27.4	31.6	30.7	30.6	30.7	34.4	32.9	33.2	34.3	23.6	20.9	22.9	23.2	34.4		kN
Line 2 Shear Force (End A)	27.4	25.2	25.5	25.7	26.5	22.2	22.3	23.1	18.2	13.1	13.4	14.2	25.0	20.7	20.8	21.5	28.6	26.8	26.6	27.3	31.6	30.7	30.4	30.6	34.9	33.1	33.7	34.4	24.0	21.3	23.3	23.5	34.9		kN
Line 1 Effective Tension Max (Rubber)	130.7	129.0	130.5	130.3	132.0	130.1	131.4	131.7	132.2	130.5	131.3	131.5	132.2	130.3	131.5	131.8	130.2	129.0	130.0	129.7	129.5	126.9	129.2	128.9	130.9	127.8	130.5	130.2	133.2	130.2	132.9	132.9	133.2		kN
Line 2 Effective Tension Max (Rubber)	131.0	129.0	131.2	130.9	132.3	130.1	132.0	132.2	133.6	131.2	133.0	133.3	132.5	130.3	132.2	132.4	130.3	128.9	130.5	130.4	129.7	126.8	129.8	129.4	131.1	128.1	131.1	130.7	133.4	130.4	133.4	133.5	133.6		kN
Line 1 Effective Tension Max (HDPE)	65.5	64.0	64.0	64.3	65.5	63.7	63.9	65.1	65.1	63.8	63.6	65.8	65.5	63.8	63.9	65.1	65.4	64.0	64.0	64.1	66.0	64.7	64.6	64.9	66.8	65.5	65.2	65.8	67.1	66.0	65.7	66.1	67.1		kN
Line 2 Effective Tension Max (HDPE)	66.0	64.9	64.7	64.9	65.8	64.5	64.5	65.2	66.4	65.1	64.9	65.9	65.8	64.5	64.6	65.2	65.9	64.8	64.6	64.8	66.5	65.6	65.3	65.6	67.5	66.4	65.8	66.4	68.0	66.9	66.3	66.7	68.0		kN
Line 1 Curvature (Rubber)	0.035	0.036	0.036	0.035	0.030	0.028	0.029	0.029	0.030	0.029	0.030	0.029	0.029	0.026	0.028	0.027	0.040	0.041	0.040	0.039	0.046	0.046	0.046	0.046	0.049	0.048	0.047	0.048	0.034	0.031	0.032	0.032	0.0495	20.21	m
Line 2 Curvature (Rubber)	0.036	0.036	0.037	0.036	0.031	0.029	0.030	0.029	0.021	0.018	0.018	0.017	0.029	0.027	0.028	0.027	0.040	0.041	0.040	0.040	0.046	0.046	0.046	0.046	0.050	0.048	0.047	0.048	0.035	0.032	0.032	0.032	0.0504	19.85	m
Line 1 Curvature (HDPE)	0.005	0.004	0.003	0.004	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.005	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.004	0.004	0.004	0.004	0.004	0.003	0.004	0.003	0.0047	213.10	m
Line 2 Curvature (HDPE)	0.005	0.004	0.004	0.004	0.005	0.003	0.003	0.003	0.004	0.003	0.003	0.003	0.005	0.003	0.003	0.003	0.005	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.0049	204.66	m

	LOAD CASE (M Prefix)																																Max		
DESCRIPTION	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212	213	214	215	216	217	218	219	220	221	222	223	224			
Line 1 End Force (End A) Max	134.9	140.0	133.4	136.7	134.8	140.6	132.8	136.9	135.1	140.5	133.0	137.5	135.3	139.8	133.3	137.8	135.4	139.2	133.8	137.5	135.6	138.8	134.0	137.4	135.1	138.3	134.0	136.4	134.7	138.4	133.4	135.6	140.6	kN	
Line 2 End Force (End A) Max	133.7	140.0	131.8	136.5	134.3	140.3	132.5	136.9	134.6	140.2	132.7	137.4	134.8	139.4	133.0	137.7	134.8	138.7	133.5	137.5	135.0	138.4	133.7	137.4	135.1	139.0	134.0	137.1	134.3	138.0	133.2	135.6	140.3	kN	
Line 1 End Force (End A) Min	140.4	133.6	141.8	139.2	140.0	133.4	141.4	138.8	139.6	133.5	141.2	138.7	139.3	133.5	140.8	138.5	139.3	133.6	140.9	139.1	139.9	133.8	141.5	139.6	140.0	134.2	140.9	139.9	140.5	134.3	141.9	140.2	141.9	kN	
Line 2 End Force (End A) Min	140.4	133.8	141.8	138.4	140.1	133.9	141.5	138.2	139.7	133.9	141.2	138.1	139.4	134.0	140.9	138.0	139.4	134.2	140.7	138.5	140.0	134.4	141.5	139.0	139.9	134.1	141.5	139.0	140.6	134.8	141.9	139.6	141.9	kN	
Line 1 Bend Moment (End A)	62.3	49.2	51.1	49.4	78.2	66.8	67.4	63.1	80.3	83.4	79.4	78.7	101.4	91.7	93.9	97.2	116.8	101.2	105.2	121.2	96.2	86.9	90.3	96.9	90.9	85.3	92.7	84.5	87.1	82.7	84.3	80.2	121.2	kNm	
Line 2 Bend Moment (End A)	85.8	66.9	69.6	69.8	80.7	67.5	69.5	64.9	81.8	83.8	80.3	79.1	102.5	92.0	94.6	98.4	118.7	102.2	105.9	122.5	98.3	88.6	92.4	98.8	68.4	60.6	61.2	55.9	89.9	84.4	85.7	81.6	122.5	kNm	
Line 1 Shear Force (End A)	15.6	11.3	12.2	11.8	20.4	16.1	18.1	16.1	21.4	20.9	21.1	20.8	23.8	21.9	22.3	24.0	28.0	24.9	26.6	30.4	26.6	22.1	24.3	24.9	25.7	22.4	24.4	23.0	25.5	22.8	23.0	22.4	30.4	kN	
Line 2 Shear Force (End A)	22.0	16.7	18.6	17.3	21.0	16.4	18.7	16.5	21.9	20.9	21.5	21.0	24.0	22.0	22.5	24.3	28.5	25.1	26.9	30.7	27.6	22.9	24.8	25.2	18.9	15.2	16.2	15.0	26.1	23.3	23.3	22.7	30.7	kN	
Line 1 Effective Tension Max (Rubber)	134.9	140.0	133.4	136.7	134.8	140.6	132.8	136.9	135.1	140.5	133.0	137.5	135.3	139.8	133.3	137.8	135.4	139.2	133.8	137.5	135.6	138.8	134.0	137.4	135.1	138.3	134.0	136.4	134.7	138.4	133.4	135.6	140.6	kN	
Line 2 Effective Tension Max (Rubber)	133.7	140.0	131.8	136.5	134.3	140.3	132.5	136.9	134.6	140.2	132.7	137.4	134.8	139.4	133.0	137.7	134.8	138.7	133.5	137.5	135.0	138.4	133.7	137.4	135.1	139.0	134.0	137.1	134.3	138.0	133.2	135.6	140.3	kN	
Line 1 Effective Tension Max (HDPE)	66.6	69.2	64.6	67.7	66.1	69.2	64.8	67.8	65.6	69.1	64.8	67.9	64.5	69.1	64.6	67.9	64.2	69.1	64.2	67.9	64.5	68.9	63.6	67.5	64.9	69.3	63.5	67.4	64.8	69.3	63.4	67.1	69.3	kN	
Line 2 Effective Tension Max (HDPE)	66.6	69.0	65.2	67.7	66.9	69.1	65.2	67.9	66.5	69.0	65.3	68.1	65.5	68.9	65.1	68.1	64.5	68.6	64.7	68.0	64.2	68.6	64.0	67.6	65.2	69.0	64.2	67.5	64.5	68.9	63.8	67.3	69.1	kN	
Line 1 Curvature (Rubber)	0.023	0.020	0.020	0.019	0.029	0.026	0.024	0.024	0.031	0.031	0.029	0.030	0.039	0.035	0.036	0.037	0.045	0.039	0.040	0.045	0.037	0.033	0.033	0.036	0.034	0.032	0.034	0.031	0.030	0.030	0.030	0.028	0.0451	22.17	m
Line 2 Curvature (Rubber)	0.032	0.026	0.027	0.027	0.030	0.026	0.025	0.024	0.031	0.031	0.029	0.030	0.040	0.035	0.036	0.037	0.046	0.039	0.041	0.046	0.037	0.033	0.034	0.036	0.027	0.024	0.022	0.021	0.031	0.030	0.031	0.029	0.0456	21.91	m
Line 1 Curvature (HDPE)	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.004	0.005	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.0050	198.87	m
Line 2 Curvature (HDPE)	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.003	0.004	0.005	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.005	0.004	0.004	0.004	0.0052	191.59	m

	LOAD CASE (M Prefix)																																Max		
DESCRIPTION	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256			
Line 1 End Force (End A) Max	131.6	136.6	130.7	132.9	129.6	135.3	129.6	131.9	130.2	136.7	131.0	133.5	132.9	139.4	132.1	135.1	175.1	172.4	169.1	164.0	175.4	171.6	169.7	163.1	175.0	170.8	169.9	162.6	174.0	169.5	169.7	161.8	175.4	kN	
Line 2 End Force (End A) Max	131.3	136.1	130.5	132.5	129.3	134.9	129.0	131.6	130.2	136.5	130.5	133.3	132.5	139.1	131.5	135.2	174.0	171.7	168.8	162.6	174.7	171.3	169.5	162.7	174.3	170.5	169.8	162.3	173.2	169.2	169.5	161.4	174.7	kN	
Line 1 End Force (End A) Min	140.9	134.3	142.4	141.0	141.6	134.4	142.7	141.0	141.5	134.3	142.7	140.7	140.7	133.5	142.1	139.4	101.3	102.6	109.0	114.7	101.2	102.4	108.5	114.5	101.4	102.8	108.2	114.4	101.2	103.4	107.8	113.7	142.7	kN	
Line 2 End Force (End A) Min	141.0	134.8	142.3	140.5	141.7	134.8	142.8	140.5	141.6	134.7	142.8	140.1	140.8	133.9	142.2	138.8	102.5	102.0	109.2	114.7	102.1	102.1	108.7	114.9	102.3	102.5	108.4	114.9	102.1	103.3	108.0	114.3	142.8	kN	
Line 1 Bend Moment (End A)	122.6	128.3	116.1	131.9	162.2	153.2	145.3	168.1	163.7	146.6	147.5	169.3	105.6	90.2	94.5	102.8	93.3	79.7	68.4	52.0	88.5	80.8	73.1	63.3	114.4	105.9	99.8	89.3	126.7	118.7	115.6	104.9	169.3	kNm	
Line 2 Bend Moment (End A)	120.8	127.8	115.4	130.8	162.7	152.0	144.7	167.6	165.1	147.4	148.5	169.9	107.7	91.9	95.9	104.1	101.7	90.8	80.2	62.5	88.1	81.7	73.6	64.2	113.4	106.7	99.8	89.9	126.4	120.2	116.0	105.5	169.9	kNm	
Line 1 Shear Force (End A)	30.6	32.1	29.9	32.3	40.2	38.8	36.0	40.9	41.8	36.7	37.2	42.1	25.9	22.0	22.6	24.4	20.5	18.4	15.3	10.6	22.4	19.3	18.6	17.3	29.6	26.6	25.9	23.7	32.5	29.9	29.6	27.2	42.1	kN	
Line 2 Shear Force (End A)	30.5	32.2	29.7	31.8	40.4	38.4	36.3	40.7	42.3	36.8	37.3	42.2	26.6	22.6	22.8	24.8	22.4	21.6	18.5	15.2	22.1	19.5	18.6	17.2	29.1	27.0	25.7	23.4	32.2	30.2	29.6	26.9	42.3	kN	
Line 1 Effective Tension Max (Rubber)	131.6	136.6	130.7	132.9	129.6	135.3	129.6	131.9	130.2	136.7	131.0	133.5	132.9	139.4	132.1	135.1	175.1	172.4	169.1	164.0	175.4	171.6	169.7	163.1	175.0	170.8	169.9	162.6	174.0	169.5	169.7	161.8	175.4	kN	
Line 2 Effective Tension Max (Rubber)	131.3	136.1	130.5	132.5	129.3	134.9	129.0	131.6	130.2	136.5	130.5	133.3	132.5	139.1	131.5	135.2	174.0	171.7	168.8	162.6	174.7	171.3	169.5	162.7	174.3	170.5	169.8	162.3	173.2	169.2	169.5	161.4	174.7	kN	
Line 1 Effective Tension Max (HDPE)	64.1	68.9	63.2	66.4	64.6	69.1	63.9	66.7	65.7	69.5	64.2	67.6	66.2	69.5	64.6	67.4	94.0	95.9	90.6	87.9	94.1	95.4	91.0	87.3	93.6	95.0	91.2	87.2	92.6	94.2	91.0	86.8	95.9	kN	
Line 2 Effective Tension Max (HDPE)	64.1	68.6	63.1	66.5	65.4	68.8	63.6	66.4	66.5	69.3	64.5	67.4	67.0	69.3	65.1	67.7	93.1	95.3	90.5	86.9	93.7	95.2	90.9	87.0	93.0	95.0	91.1	86.9	91.9	93.9	90.9	86.4	95.3	kN	
Line 1 Curvature (Rubber)	0.046	0.048	0.043	0.051	0.061	0.057	0.054	0.063	0.061	0.055	0.055	0.063	0.040	0.035	0.036	0.039	0.037	0.031	0.028	0.021	0.034	0.031	0.028	0.024	0.043	0.040	0.037	0.034	0.048	0.045	0.043	0.040	0.0634	15.76	m
Line 2 Curvature (Rubber)	0.046	0.048	0.043	0.050	0.061	0.056	0.054	0.063	0.061	0.055	0.055	0.063	0.041	0.036	0.037	0.040	0.041	0.035	0.032	0.025	0.033	0.032	0.028	0.024	0.042	0.041	0.037	0.034	0.047	0.045	0.043	0.040	0.0633	15.79	m
Line 1 Curvature (HDPE)	0.005	0.004	0.004	0.004	0.005	0.004	0.004	0.005	0.005	0.004	0.004	0.005	0.004	0.004	0.004	0.004	0.005	0.004	0.004	0.003	0.005	0.004	0.004	0.003	0.005	0.004	0.004	0.003	0.005	0.004	0.004	0.003	0.0053	190.44	m
Line 2 Curvature (HDPE)	0.005	0.004	0.004	0.004	0.005	0.004	0.004	0.005	0.005	0.005	0.005	0.005	0.005	0.004	0.004	0.004	0.005	0.004	0.004	0.003	0.005	0.004	0.004	0.003	0.005	0.004	0.004	0.003	0.005	0.004	0.004	0.003	0.0054	184.95	m

	LOAD CASE (M Prefix)															
DESCRIPTION	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272
Line 1 End Force (End A) Max	173.3	168.6	169.3	161.5	173.8	169.7	168.9	162.1	173.6	170.2	168.3	162.6	173.9	170.8	168.4	162.9
Line 2 End Force (End A) Max	172.5	168.2	169.2	161.0	173.0	169.4	168.8	161.8	173.4	170.5	168.8	162.7	173.3	170.5	168.3	162.7
Line 1 End Force (End A) Min	100.9	104.3	107.8	113.8	100.6	104.3	108.0	113.2	101.0	104.6	108.3	113.2	101.7	104.2	109.1	113.5
Line 2 End Force (End A) Min	101.8	104.3	107.9	114.2	101.5	104.1	108.1	113.8	101.7	103.3	108.6	114.0	102.5	104.0	109.3	114.1
Line 1 Bend Moment (End A)	136.1	125.8	124.3	113.3	116.0	102.4	100.8	86.8	98.7	85.1	85.5	78.3	119.4	101.8	96.6	80.7
Line 2 Bend Moment (End A)	136.1	127.4	124.5	113.9	116.1	103.8	101.4	87.4	88.1	73.8	66.3	55.2	118.2	101.4	95.3	80.8
Line 1 Shear Force (End A)	35.6	32.3	32.3	28.8	29.6	26.2	26.1	21.9	24.2	21.3	21.7	20.1	29.1	25.5	23.4	20.1
Line 2 Shear Force (End A)	35.5	32.5	32.2	28.5	29.6	26.4	26.2	22.0	20.7	17.5	15.9	13.8	28.8	25.4	23.2	20.2
Line 1 Effective Tension Max (Rubber)	173.3	168.6	169.3	161.5	173.8	169.7	168.9	162.1	173.6	170.2	168.3	162.6	173.9	170.8	168.4	162.9
Line 2 Effective Tension Max (Rubber)	172.5	168.2	169.2	161.0	173.0	169.4	168.8	161.8	173.4	170.5	168.8	162.7	173.3	170.5	168.3	162.7
Line 1 Effective Tension Max (HDPE)	92.0	93.9	90.9	86.8	92.7	94.2	90.5	86.7	92.7	94.6	90.3	87.2	93.4	94.8	90.5	87.4
Line 2 Effective Tension Max (HDPE)	91.4	93.5	90.8	86.4	92.1	93.9	90.4	86.5	92.4	94.4	90.3	86.8	93.0	94.5	90.4	87.2
Line 1 Curvature (Rubber)	0.051	0.047	0.046	0.043	0.044	0.038	0.037	0.033	0.038	0.033	0.033	0.029	0.045	0.038	0.037	0.030
Line 2 Curvature (Rubber)	0.051	0.048	0.046	0.043	0.044	0.039	0.038	0.033	0.034	0.029	0.026	0.021	0.045	0.038	0.036	0.030
Line 1 Curvature (HDPE)	0.005	0.004	0.004	0.003	0.005	0.004	0.004	0.003	0.005	0.004	0.004	0.003	0.005	0.004	0.003	0.003
Line 2 Curvature (HDPE)	0.005	0.004	0.004	0.004	0.005	0.004	0.004	0.003	0.005	0.004	0.004	0.003	0.005	0.004	0.003	0.003

	LOAD CASE (M Prefix)																Max		
DESCRIPTION	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288			
Line 1 End Force (End A) Max	171.6	170.3	165.7	161.7	169.9	169.5	163.8	160.7	170.9	170.6	164.5	161.7	173.3	172.1	167.7	163.3	173.9	kN	
Line 2 End Force (End A) Max	171.0	170.1	165.6	161.3	169.3	169.5	163.9	160.5	170.3	170.6	164.5	161.5	172.6	172.0	167.6	163.1	173.4	kN	
Line 1 End Force (End A) Min	103.2	104.5	110.1	113.9	104.6	104.6	111.6	114.7	104.6	104.1	111.6	115.5	102.5	102.6	109.9	114.3	115.5	kN	
Line 2 End Force (End A) Min	104.0	104.2	110.3	114.4	105.3	104.2	111.9	115.2	105.4	103.7	111.9	116.0	103.3	102.3	110.1	114.9	116.0	kN	
Line 1 Bend Moment (End A)	173.4	158.6	147.0	131.8	220.2	198.2	187.7	168.9	216.0	188.8	182.3	160.5	139.7	121.1	114.5	88.6	220.2	kNm	
Line 2 Bend Moment (End A)	171.6	158.5	146.6	131.9	218.1	198.0	187.2	168.5	214.2	190.4	180.8	159.6	139.3	122.2	114.9	88.6	218.1	kNm	
Line 1 Shear Force (End A)	43.6	39.6	35.9	31.9	55.3	50.4	47.5	41.2	53.7	48.4	44.9	39.8	32.3	29.8	26.4	20.9	55.3	kN	
Line 2 Shear Force (End A)	43.1	39.6	35.8	32.0	54.7	50.3	47.3	41.1	53.1	48.7	44.8	39.6	32.1	30.1	26.6	21.3	54.7	kN	
Line 1 Effective Tension Max (Rubber)	171.6	170.3	165.7	161.7	169.9	169.5	163.8	160.7	170.9	170.6	164.5	161.7	173.3	172.1	167.7	163.3	173.9	kN	
Line 2 Effective Tension Max (Rubber)	171.0	170.1	165.6	161.3	169.3	169.5	163.9	160.5	170.3	170.6	164.5	161.5	172.6	172.0	167.6	163.1	173.4	kN	
Line 1 Effective Tension Max (HDPE)	92.6	95.6	89.5	87.1	91.6	95.6	88.9	86.9	91.6	95.8	89.0	87.5	92.8	95.7	89.9	87.9	95.8	kN	
Line 2 Effective Tension Max (HDPE)	92.2	95.4	89.4	86.9	91.2	95.5	88.8	86.8	91.2	95.7	89.0	87.3	92.3	95.5	89.8	87.7	95.7	kN	
Line 1 Curvature (Rubber)	0.065	0.059	0.056	0.050	0.082	0.073	0.070	0.063	0.080	0.070	0.069	0.060	0.054	0.046	0.045	0.035	0.0822	12.17	m
Line 2 Curvature (Rubber)	0.064	0.059	0.056	0.050	0.082	0.073	0.070	0.063	0.080	0.070	0.068	0.060	0.054	0.047	0.045	0.035	0.0815	12.27	m
Line 1 Curvature (HDPE)	0.005	0.005	0.004	0.004	0.006	0.005	0.005	0.005	0.006	0.005	0.005	0.004	0.005	0.004	0.004	0.004	0.0062	160.17	m
Line 2 Curvature (HDPE)	0.005	0.005	0.004	0.004	0.006	0.005	0.005	0.005	0.006	0.005	0.005	0.004	0.005	0.004	0.004	0.004	0.0062	160.81	m

APPENDIX D – ADDITIONAL ANALYSIS (P13966-RL-102)

EMSTEC GmbH
Gewerbering 8
22113 Oststeinbek
Germany
Tel.: +49 (0) 40 79686 345
Fax: +49 (0) 40 79686 702
info@emstec.net
sales@emstec.net
www.emstec.net

Rev	Date	By	Chk	App	Description
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Project:	**Ghana OCTP Development Project** **OCTP Offshore - FPSO**		
Client:	**YINSON**		
Title:	**Seawater Suction Hose System** **Technical Note – Additional Hydrodynamic Analysis**		
Doc No:	**P13966-RL-102**	Rev:	A

CONTENTS

1.0 INTRODUCTION

The Seawater Uptake System supplied for the Ghana OCTP Development FPSO consists of a 2-off 36"NB Seawater Uptake Hose Strings, ~98m in length, supported from the underside of the SW Intake Caissons by a fixed riser head arrangement.

To confirm the suitability of the Seawater Suction Hose string configuration and to determine the loads transmitted into the SW Intake Caissons, it was necessary to perform a hydrodynamic analysis of the Seawater Suction Hose system. This analysis was carried out using the Orcaflex software package, developed by Orcina Ltd (www.orcina.com) specifically for analysis of flexible lines in the offshore environment and the findings are reported in document : 1305-EM-51-R-CA-00002 [1].

At the request of the Client, document 1305-EM-51-R-CA-00002 [1] was reviewed by DNVGL who recommended that additional load cases were undertaken to obtain the statistical extreme values of the riser forces/displacements [2].

Additionally, the Client has since advised a Survival Condition for the vessel for consideration within the analysis [3].

This Technical Note documents the findings of the additional load cases as recommended by DNVGL and the Survival Condition as advised by the Client.

1.1 Executive Summary

Simulations were run for the critical load cases using a 3 hours irregular wave time domain analysis with 5 different seeds for the 100yr return total wave data.

The statistical extremes values of the relevant riser loads and displacement were obtained and compared to the original results presented in document 1305-EM-51-R-CA-00002 [1].

It showed that, for the input into the Riser Seat & Riser Head FEA, the statistical extreme values from the additional analysis were slightly less than those originally reported indicating that the original values were conservative.

The hose tension values for both the Rubber Hose and HDPE Section were slightly higher than those originally reported but still well within the allowable values.

The minimum bend radius values for the Rubber Hose and HDPE Sections were slightly higher than those originally reported indicating that the original values were conservative.

The same simulations were then re-run but with the Survival Conditions incorporated and the same loads and displacements extracted.

It showed that, for the input into the Riser Seat & Riser Head FEA, the statistical extreme values from the Survival Condition were approximately 40% higher than for the design condition but an approximation showed that resulting stresses are still within the allowable values.

The hose tension values for both the Rubber Hose and HDPE Section were slightly higher than those for the design condition but still well within the allowable values.

The minimum bend radius values for the Rubber Hose and HDPE Sections were slightly lower than those for the design condition but still within the allowable values.

2.0 ADDITIONAL HYDRODYNAMIC ANALYSIS

2.1 DNVGL Recommendations

With reference to [2], DNVGL made the following recommendations:

We recommend to carry out 3 hours irregular wave time domain analysis with at least 5 different seeds for each of the following cases:

- *Cases with maximum end force (e.g. effective tension, bending moment, shear loads) at riser head*
- *Cases with maximum hose tension and minimum bend radius (MBR)*
- *Cases with maximum HDPE tension and minimum bending radius (MBR)*

The statistical extreme value of relevant riser force/displacement shall be obtained from the resulted 3 hour time series

2.2 Survival Condition

Yinson advised that the only survival condition applicable is due to unintentional flooding of the tanks [3].

For this condition, the vessel will heel to a maximum of 15deg.

2.3 Critical Load Cases

With reference to section 2.1, the load cases indicated by DNVGL, hereinafter called 'critical load case', were identified from [1] as:

- *Cases with maximum end force (e.g. effective tension, bending moment, shear loads) at riser head*
  Critical Load Cases M113 & M137

- *Cases with maximum hose tension and minimum bend radius (MBR)*
  Critical Load Cases M113 & M137

- *Cases with maximum HDPE tension and minimum bending radius (MBR)*
  Critical Load Cases M133 & M282

2.4 Additional Load Cases

Each of the critical load cases was assigned 5 seeds within Orcaflex (each seed number producing a different wave time series from the JONSWAP spectra) as follows:

Seed Reference	Seed Number
Original Seed	12345
1	23456
2	34567
3	45678
4	56789
5	67890

Table 1: Seed Numbers

this created an additional 20 load cases as listed below:

Load Case	Critical Load Case	Seed	Load Case	Critical Load Case	Seed
113-1	113	23456	137-1	137	23456
113-2	113	34567	137-2	137	34567
113-3	113	45678	137-3	137	45678
113-4	113	56789	137-4	137	56789
113-5	113	67890	137-5	137	67890
133-1	133	23456	282-1	282	23456
133-2	133	34567	282-2	282	34567
133-3	133	45678	282-3	282	45678
133-4	133	56789	282-4	282	56789
133-5	133	67890	282-5	282	67890

Table 2: Additional Load Cases

2.5 Simulation Details

Each of the additional load cases presented in Table 2 was ran using 3 hours irregular wave time domain analysis for the 100yr return total wave data.

All other input data remained the same as that presented in document 1305-EM-51-R-CA-00002 [1].

The Survival Condition was then incorporated into each of the additional load cases presented in Table 2 and ran using 3 hours irregular wave time domain analysis for the 100yr return total wave data.

3.0 RESULTS

3.1 Additional Load Cases

The extreme values from load cases listed in Table 2 were extracted and the maximums for each seed of the applicable load case identified. The average of these values was calculated to determine the statistical extreme values and are presented below:

Description	Load/ Displacement	Load Case	Seed					Average Value
			1	2	3	4	5	
Riser Head Flange	Moment (kNm)	113	304.9	338.3	307.4	357.0	338.2	329.2
	Shear (kN)	113	82.7	88.6	81.6	96.2	89.5	87.7
	Tension* (kN)	113	144.7	127.1	137.9	137.8	135	136.5
Rubber Hose	Tension (kN)	137	216.1	222.8	210.7	234.2	222.3	221.2
	MBR (m)	113	9.21	8.14	9.02	7.83	8.16	8.47
HDPE Section	Tension (kN)	133	128.7	128.3	122.3	140.1	131.0	130.1
	MBR (m)	113	120.5	114.2	122.8	111.9	116.8	117.2

*Corresponding Tension at Maximum Bending Moment

Table 3: Additional Load Case Result Summary

3.2 Survival Condition

The extreme values from each of the Survival Condition load cases were extracted and the maximums for each seed of the applicable load case identified. The average of these values was calculated to determine the statistical extreme values and are presented below:

Description	Load/ Displacement	Load Case	Seed					Average Value
			1	2	3	4	5	
Riser Head Flange	Moment (kNm)	113	434.6	470.8	441.3	493.0	474.0	462.7
	Shear (kN)	113	113.1	117.8	112.6	127.9	121.7	118.6
	Tension* (kN)	113	123.9	101.0	113.6	109.8	105.1	110.7
Rubber Hose	Tension (kN)	137	207.9	222.3	205.5	225.9	216.8	215.7
	MBR (m)	113	6.32	5.71	6.15	5.55	5.7	5.87
HDPE Section	Tension (kN)	133	120.5	119.8	115.1	129.6	122.8	121
	MBR (m)	113	117.0	105.4	114.2	103.0	103.7	108.3

*Corresponding Tension at Maximum Bending Moment

Table 4: Survival Condition Load Case Result Summary

4.0 CONCLUSION

4.1 Additional Load Cases

4.1.1 Riser Head Flange

Table 5 below compares the loads at the Riser Head Flange from the critical load cases as presented in [1] against the additional load case average values given in Table 3.

Load	Critical Load Case	Additional Load Cases
Bending Moment (kNm)	334.20	329.20
Shear Force (kN)	88.17	87.70
Tension (kN)	178.08	136.5

Table 5: Comparison of Riser Head Flange Critical Load Cases v Additional Load Cases

The critical load case values indicated in Table 5 were used as the input values for the Riser Seat & Riser Head FEA [4] which, as can be seen, are slightly higher, and therefore more conservative, than those from the additional analysis.

Therefore, additional FEA of the Riser Seat & Riser Head is not required.

4.1.2 Rubber Hose

Table 6 below compares the load and displacement values of the Rubber Hose from the critical load cases as presented in [1] against the additional load case average values given in Table 3, and also indicates the allowable values:

Load/Displacement	Critical Load Case	Additional Load Cases	Allowable Value
Tension (kN)	178.08	221.2	4,946
Minimum Bend Radius (m)	8.28	8.47	3.6

Table 6: Comparison of Rubber Hose Critical Load Cases v Additional Load Cases

The tension value for the Rubber Hose is slightly higher than that originally reported but still well within the allowable values.

The minimum bend radius value for the Rubber Hose is slightly higher than that originally reported indicating that the original values were conservative.

Therefore, the Rubber Hose design remains **ACCEPTABLE.**

4.1.3 HDPE Section

Table 7 below compares the load and displacement values of the HDPE Section from the critical load cases as presented in [1] against the additional load case average values given in Table 3, and also indicates the allowable values:.

Load/Displacement	Critical Load Case	Additional Load Cases	Allowable Value
Tension (kN)	95.83	130.1	~4000
Minimum Bend Radius (m)	116.72	117.2	36.0

Table 7: Comparison of HDPE Section Hose Critical Load Cases v Additional Load Cases

The tension value for the HDPE Section is slightly higher than that originally reported but still well within the allowable values.

The minimum bend radius value for the HDPE Section is slightly higher than that originally reported indicating that the original values were conservative.

Therefore, the HDPE Section design remains **ACCEPTABLE**.

4.2 Survival Condition

4.2.1 Riser Head Flange

Table 8 below compares the loads at the Riser Head Flange from the critical load cases as presented in [1] against the Survival Condition load case average values given in Table 4.

Load	Critical Load Case	Survival Condition	Difference
Bending Moment (kNm)	334.20	462.7	+38%
Shear Force (kN)	88.17	118.6	+35%
Tension (kN)	178.08	110.7	-38%

Table 8: Comparison of Riser Head Flange Critical Load Cases v Additional Load Cases

The critical load case values indicated in Table 8 were used as the input values for the Riser Seat & Riser Head FEA [4]. The maximum stress from the FEA was identified as 85.5MPa in the Riser Head, caused primarily by the bending moment.

Using the Survival Condition bending moment value, an approximation of the increased stresses in the Riser Head can be made as follows:

From FEA [4]:

Max Stress = M x (y/I)   85.5Mpa = 334.2kNm x (y/I)   so (y/I) = 0.2558

For Survival Condition

Max Stress = M x (y/I)   Max Stress = 462.7 x 0.2558   **Max Stress = 118.3MPa**

This is well below allowable value of 284MPa, therefore additional FEA is not deemed necessary to demonstrate this.

4.2.2 Rubber Hose

Table 9 below compares the load and displacement values of the Rubber Hose from the Survival Condition presented in Table 4 against the allowable values:

Load/Displacement	Survival Conditions	Allowable Value
Tension (kN)	215.7	4,946
Minimum Bend Radius (m)	5.87	3.6

Table 9: Comparison of Rubber Hose Survival Condition v Allowable Values

The tension value and minimum bend radius value for the Rubber Hose is within the allowable values.

Therefore, the Rubber Hose design remains **ACCEPTABLE.**

4.2.3 HDPE Section

Table 10 below compares the load and displacement values of the HDPE Section from the Survival Condition presented in Table 4 against the allowable values:

Load/Displacement	Survival Condition	Allowable Value
Tension (kN)	121	~4000
Minimum Bend Radius (m)	108.3	36.0

Table 10: Comparison of HDPE Section Survival Condition v Allowable Values

The tension value and minimum bend radius value for the HDPE Section is within the allowable values.

Therefore, the HDPE Section design remains **ACCEPTABLE**.

5.0 REFERENCES

[1] Doc No.:1305-EM-51-R-CA-00002 Seawater Suction Hose System Hydrodynamic Analysis Report

[2] Doc No.: PP142957-001 Design Verification of Seawater Suction Hose System for Ghana OCTP FPSO

[3] e-mail: Nasir/Craig (07.10.15)

[4] Doc No.: 1305-EM-51-R-CA-00003 Structural Analysis Report

APPENDIX E – CLASH ANALYSIS (P13966-RL-103)

EMSTEC GmbH
Gewerbering 8
22113 Oststeinbek
Germany
Tel.: +49 (0) 40 79686 345
Fax: +49 (0) 40 79686 702
info@emstec.net
sales@emstec.net
www.emstec.net

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Rev	**Date**	**By**	**Chk**	**App**	**Description**

Project:	**Ghana OCTP Development Project** **OCTP Offshore - FPSO**		
Client:	**YINSON**		
Title:	**Seawater Suction Hose System** **Technical Note – Clash Analysis**		
Doc No:	**P13966-RL-103**	Rev:	A

CONTENTS

1.0 INTRODUCTION

The Seawater Uptake System supplied for the Ghana OCTP Development FPSO consists of a 2-off 36"NB Seawater Uptake Hose Strings, ~98m in length, supported from the underside of the SW Intake Caissons by a fixed riser head arrangement.

To confirm the suitability of the Seawater Suction Hose string configuration and to determine the loads transmitted into the SW Intake Caissons, it was necessary to perform a hydrodynamic analysis of the Seawater Suction Hose system. This analysis was carried out using the Orcaflex software package, developed by Orcina Ltd (www.orcina.com) specifically for analysis of flexible lines in the offshore environment and the findings are reported in document : 1305-EM-51-R-CA-00002 [1].

Section 2.1 of the Seawater Suction Hose Specification [2] specifies:

- Provide analysis and recommendation on minimum distance required between hoses to avoid clashes due to water currents and bending radii of hoses.

Using the simulations presented in [1], a clash analysis was undertaken, the findings of which are presented in this Technical Note.

1.1 Executive Summary

Clash data was extracted from the Hydrodynamic Analysis [1] for the extreme conditions 100yr return total wave data.

It was shown that under certain combination of Wave and Current direction, the hoses do clash (DNV refer to these events as collisions).

The possibility of clashing and the clash energy values recorded are presented, the levels of which are low and will not affect the integrity of the Seawater Intake Risers.

2.0 CLASH ANALYSIS

The simulations presented in the Hydrodynamic Analysis Report [1] were screened to identify load cases where clashing occurred.

It was found that clashing occurred where the current direction was from 0° or 180° in relation to the vessel centreline. This is as expected given that the 2-off Seawater Intake Risers (SWIR) are on the same longitudinal centreline, in which case the leading SWIR would create a wake and the trailing SWIR would react to the wake. This creates a 'shielding effect' whereby the displacement of the trailing SWIR is less than the leading SWIR which, if the current is of sufficient magnitude, can cause the two SWIR to come into contact.

The maximum clash energy value was extracted from each of the load cases where clashing occurred and the highest value found to be from load case 3.

A number of sensitivities were performed on load case 3 to validate the clash energy values.

3.0 RESULTS

The maximum Clash Energy value was recorded as: **0.0551kJ**.

The location of this contact was at the lower end of the Seawater Intake Risers between the HDPE sections.

4.0 DISCUSSION

4.1 Collisions

Reference is made to DNV-RP-F203 Riser Interference [3] Section 2.2.1 Design Principles which refers to two design strategies, namely:

-No Collision Allowed

-Collisions Allowed

No Collisions Allowed

This recommended practice suggests that collisions are not normally acceptable in a number of scenarios such as:

-in buoyancy sections-

-between Risers and Mooring Lines

-between Risers and Other Structures

-between and Risers and Unprotected External Lines.

In these situations sufficient spacing should be documented for all critical load cases including normal, extreme and accidental scenarios

Collisions Allowed

However, it does suggest that infrequent collisions may be allowed in other scenarios, such as temporary, accidental or extreme conditions, provided that the consequences are evaluated and found acceptable.

From the analysis undertaken, it is determined that the most likely possibility of clashing is when the current direction is 0° or 180° in relation to the vessel heading. As the vessel is moored at 30° North, these current directions translate as 30° or 210° in the metocean data.

From the metocean data [4] Section 8.3.1, the distribution shows that, for the surface current, the annual percentage for these current headings are 5.79% and 1.16% respectively. The analysis undertaken [1] considered 100 year current extremes, which for load case 3 has a current profile of >0.3m/s. Further examination of the current directional distribution shows that annual percentage for surface current velocities >0.3m/s for current headings of 30° and 210° are 1.88% and 0.01% respectively.

Furthermore, if the current direction varies by +/-10°, the 'shielding effect' is not as significant thereby lowering the risk of collisions further.

This suggests that the likelihood of the two Seawater Intake Risers coming into contact is low and infrequent which supports the justification that potential collisions between adjacent risers are allowed.

Nonetheless, there is a possibility of collisions occurring therefore consideration needs to be given to show that the structural integrity of the components is not affected by the temporary collisions, which would satisfy the recommendations of DNV-RP-F203 Riser Interference [3].

4.2 HDPE Section Clashing

From Analysis: Maximum Clash Energy = 0.0551 kJ (5.51J)

To put this clash energy value into perspective, the following relationship can be used:

Potential Energy = m.g.h

So, considering a mass of 1kg, it can be shown that: 5.51 = 1 x 9.81 x h

Therefore: h = 5.51 / 9.81 = 0.56m

The clash energy is therefore the equivalent of dropping a 1kg weight from0.56m onto the HDPE section which is negligible.

It should be noted that HDPE has good impact resistance with Impact Strengths of ~20kJ/m^2 @ 23°C.

4.3 Line Spacing

The minimum spacing between the Seawater Intake Risers in the current configuration is 4.7m. As described above, under certain temporary conditions, collisions may occur between adjacent risers, but it can be permitted if it can been shown that the potential clashing does not affect the structural integrity of the risers.

A further consideration for line spacing is transverse displacement that may occur due to the effects of Vortex Induced Vibration (VIV).

With reference to DNV-RP-F203 Riser Interference [3] Section 4.5, the maximum transverse displacement caused by VIV can be in the order of one pipe diameter per riser. Therefore, to avoid any potential clashing due to VIV, it is recommended to space the lines at least 2 x Riser Diameter apart. As the maximum line diameter is approx. 1.24m (at the flange joint) this would require a minimum spacing of 2.48m. This is less than the present proposed spacing of 4.7m and is therefore acceptable.

5.0 CONCLUSION

Considering the points discussed above, it is concluded that, although there is a possibility of the two Seawater Intake Risers clashing during operation, the likelihood and frequency of this is low. Furthermore, if the risers do clash, the clash energy is shown to be negligible and is not detrimental to the structural integrity of the components.

6.0 REFERENCES

[1] Doc No.:1305-EM-51-R-CA-00002 Seawater Suction Hose System Hydrodynamic Analysis Report

[2] Doc No.:1305-YP-51-R-SA-00001 Seawater Suction Hose Specification

[3] DNV-RP-F203: DNV Recommended Practice- Riser Interference

[4] 351400BGRB09411 Rev 00: Ghana OCTP Development Project - Metocean Design Basis

PROJECT Non Straddling Resources - FLNG KBR	FILE 4404YYBNRZ1907K_CDFE00_50.zip
PLANT LOCATION Offshore	TRANSMITTAL IN DATE 3/9/2015
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COMMENTS SHEET

Document Title	SEA WATER INTAKE RISERS – MECHANICAL CALCULATION NOTE
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Note: "COMPANY's approval of this document has to be deemed just as an authorization to proceed with the project execution.
CONTRACTOR is aware that COMPANY's approval is not relieving CONTRACTOR from any of its responsibilities in the performances required by the CONTRACT"

(*)

A	APPROVED
B	APPROVED WITH COMMENTS
C	NOT APPROVED

Comments:

DISCIPLINE	COMMENTS	CONTRACTOR'S REPLY (IF ANY)
CT Marine	No Comments Closed by: Halligan James Closed Date: 03/27/2015 10:36 AM	
CT Mechanical	Closed by: Kang Daehoon Closed Date: 04/08/2015 03:42 PM	
FT KBR Mechanical-Machinery-Piping	No Comments. Closed by: Caulfield Kevin Closed Date: 03/25/2015 04:10 PM	
FT KBR Naval (Focal Point)	1. Page 5, Table 3-1. Please change 'Maximum operating mean draft(moulded)' to 'Ballast Draft'. 2. Page 6, Sec. 2.2.1. Please add calculation details of Total Weight of Intake Riser in Air and Water. 3. Page 8, Sec. 2.3.1. Please clarity that the Frame 60 means the frame number of the FLNG.	1. Noted 2. Noted 3. Confirmed and noted.

	4. Page 8, Sec. 2.3.1. Please update drawing no. (P13939-DE-001) in line with assigned no. for the drawing.	4. Noted
	5. Page 14, Sec. 2.4.7. Please change KBR to KD.	5. Noted
	6. Page 14, Sec. 2.4.7. Please clarify which CD value was used for the analysis.	6. Drag co-efficients are addressed in Section 2.3.3
	7. Page 15, Sec. 3.1.2. Please clarify that the same seed number was used for all wave.	7. Confirmed and noted
	8. Page 19, Sec. 4. Please clarify the values in the tables are the maximum value of the time series results or statistic results.	8. Noted. Values are maximum from time series.
	9. Page 25, Sec. 5. Table 2.1 doesn't exist. Please add.	9. Should read Table 2-2, will be amended.
	10. Microsoft native file of the report shall be submitted according to the contract.	10. Noted
	11. Please attach native Orcaflex YML fine to the report.	11. Noted. Orcaflex file format is .dat
	Closed by: Kang Daehoon Closed Date: 04/08/2015 03:42 PM	

EMSTEC GmbH
Gewerbering 8
22113 Oststeinbek
Germany
Tel.: +49 (0) 40 79686 345
Fax: +49 (0) 40 79686 702
info@emstec.net
sales@emstec.net
www.emstec.net

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Project:	**Coral South Development FLNG**
Client:	**KBR**
Document Title:	**Seawater Intake Riser FEED - Hydrodynamic Analysis Report**
Emstec DocNo: / Client Doc No.:	**P13919-RL-001** / **4404YYBNRZ1907K**
Rev:	**01**

CONTENTS

1 INTRODUCTION

The Seawater Intake Riser System proposed for the Coral South Development FLNG consists of 4-off 36"NB Seawater Intake Risers, 135m in length, supported from the underside of the FLNG by a fixed riser head arrangement.

To confirm the suitability of the Seawater Intake Riser Hose string configuration and to determine the loads transmitted into the hull of the FLNG, it was necessary to perform a hydrodynamic analysis of the Seawater Intake Riser system. This analysis was carried out using a software package called OrcaFlex, developed by Orcina Ltd (www.orcina.com) specifically for analysis of flexible lines in the offshore environment.

This report has been prepared to outline the input data and analysis methodology used and to report the results and conclusions from the hydrodynamic analysis.

1.1 EXECUTIVE SUMMARY

Using the Orcaflex model provided by the Client, simulations of 10,800s were run for 100yr cyclonic wind, wave and current conditions for the permutation of directions specified by the Design Basis which equated to 8 load cases for the DESIGN CONDITION.

A secondary model was built using RAO data provided by the Client and, for both the BALLAST and FULL condition, simulations of 300s (each including a significant wave event) were run for 100yr cyclonic wave and current conditions for the permutation of directions specified by the Design Basis which equated to 64 load cases for the DESIGN CONDITON.

The most onerous load cases identified for the Primary and Secondary models were also ran for the SURVIVAL CONDITION.

It was shown that for the DESIGN CONDITION, the maximum hose tension and bend radius remain within acceptable limits during all simulated conditions.

For the SURVIVAL CONDTION it is shown that the hose string will remain intact but is likely to experience structural damage.

Maximum end tensions, bending moments and shear loads were obtained for use in the design of the riser head and caisson interface.

The results from the analysis confirm the suitability of the Seawater Intake Risers and provide the necessary input data for the Structural Analysis of the riser head arrangement.

1.2 METHODOLOGY

Refer to Appendix A for the methodology applied for the Hydrodynamic Analysis.

2 INPUT DATA

2.1 VESSEL DATA

2.1.1 FLNG Particulars

The primary model for the Coral South Development FLNG was received from the Client as an Orcaflex data file (.dat) [1] and which included the vessel data.

The secondary model for the Coral South Development FLNG was modelled in Orcaflex with the characteristics provided in [2] Table 3-1 and which are reproduced below:

Hull overall length	425.0m
Breadth moulded	68.0m
Depth moulded	36.2m
Camber	0.5m
Ballast Draft	15.2m

Ref. [2] Table 3-1 FLNG Particulars

2.1.2 Response Amplitude Operators (RAO)

The primary model for the Coral South Development FLNG was received from the Client as an Orcaflex data file (.dat) [1] and which included the vessel RAO data.

For the secondary model, a full set of vessel RAO's provided by the Client [3] were used and which included three environmental conditions, namely; 1yr RP Non Cyclonic, 100yr RP Cyclonic, and 10,000yr RP cyclonic, each with an RAO data set for the BALLAST and FULL draft conditions giving a total of six RAO Data sets.

For each loading condition, the COG / RAO origin was advised as [4]:

Load Case	Draft (m)	X (m forward of AP)	Y (m from CL, + to P)	Z (m AB)
Ballast	15.2	211.41	0	19.89
Full Load	16	211.26	0	22.695

Table 2.1.2 - Vessel COG/RAO Origin

2.2 SEAWATER INTAKE RISER HOSE DATA

Each Seawater Suction Hose string assembly model consists of:

Section	Qty per Riser	I/D (mm)	O/D (mm)	Section Length (m)	Mass in Air (kg)	Weight in Water (kg)	Axial Strength (kN)	Min. Bend Radius (mm)
Steel Riser Head	1	N/A	N/A	N/A	1900	1652	N/A	N/A
Hose Section	14	900	1060	9.7	4500	2083	~4946	3600
Steel Strainer	1	1040	1060	3.75	970	845	N/A	N/A
Flange Connections	14	N/A	N/A	N/A	150	130	N/A	N/A

Table 2.2 – Hose String Composition

2.2.1 Overall hose string properties

- Total Length of Intake Riser: 139.55m
- Total Weight of Intake Riser in Air:

Riser Head	1900kg	+
Hose Sections	14 x 4500kg	+
Strainer	970kg	+
Flange Connections	14 x 150kg	
Total:	**67,970 kg**	

- Total Weight of Intake Riser in Water:

Riser Head	1652kg	+
Hose Sections	14 x 2083kg	+
Strainer	845kg	+
Flange Connections	14 x 130kg	
Total:	**33,479 kg**	

The following flexible hose stiffness properties were used for the hydrodynamic analysis :

Bending Stiffness: 1,735 kN/m^2

Axial Stiffness: 12,000 kN,

Note: the above values can be used as a guideline and can be optimized to suit configuration.

2.2.2 Pressure Loss Characteristics

The Pressure Loss characteristics of the Seawater Intake Riser are shown below

Pressure Loss through Hose String

Enter Values in	*White Cells*	*only*
Length of Hose	135.8	*m*
Hose Bore	0.9	*m*
Hypochlorite Hose OD	0.076	*m*
Roughness	0.2	*mm*
Density of Fluid	1025	*kg/m^3*
Viscosity of Fluid	1.1063E-06	*m^2/s*
Flow Rate	6000	*m^3/hr*
Velocity	2.64	*m/s*
Hydraulic Diameter	0.824	
Relative Roughness	2.2E-04	
Reynolds No	1965262	
Friction Factor	0.0145	*Look up from Moody Tab*

Pressure Drop	7812	*Pa*	*Note 1*
(Hose)	0.08	*Bar*	
Strainer	0.04705	*Bar*	
Total (Hose + Strainer)	**0.12517**	***Bar***	

Notes:

1. Pressure Loss calculated using D'Arcy-Weisbach Equation

Fig. 1 – Pressure Loss Characteristics at Maximum Flow

Water Properties taken from [10] for the water temperature corresponding with the warmest water temperature (month 10) at 200m as provided in specified [5] Table 12-1

A pressure loss curve was developed for the Seawater Intake Riser and is presented below:

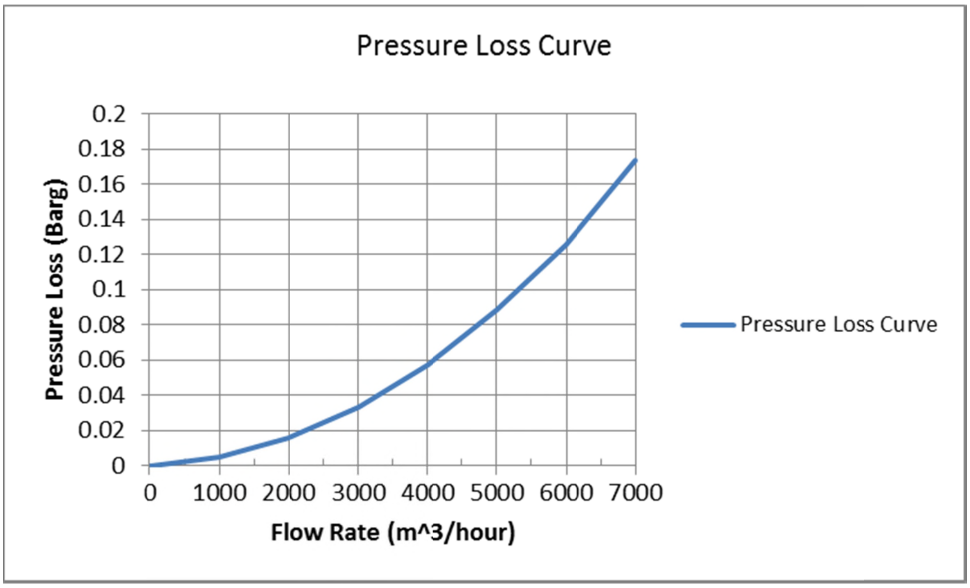

Fig. 2 – Pressure Loss Curve

2.3 SYSTEM CONFIGURATION

2.3.1 Seawater Intake Riser Locations

The Seawater Intake Risers assemblies are connected to the lower end of the Seawater Caissons at the locations provided in [2] Section 3.2.

The 4-off caissons are arranged in a single transverse row, 2.5m forward of FLNG Frame 60. The two inboard caissons are equi-spaced about the vessel centreline, 6.96m apart with the Port and Starboard outboard caissons spaced 7.13m from the inboard caissons. The lower edge of the caisson is at the Hull Bottom level (refer to drawing no. 4404YYBNRZ1927K [Emstec No.: P13919-DE-001] : General Arrangement)

This translates to the following coordinates relative to the vessel local origin, i.e. midships (x), on centerline (y) and Ballast draft line (z):

Seawater Intake Riser		Line 1	Line 2	Line 3	Line 4
Connection Location (from Vessel Origin)	x	-150.00m	-150.00m	-150.00m	-150.00m
	y	-10.61m	-3.48m	3.48m	10.61m
	z	-15.20m	-15.20m	-15.20m	-15.20m

Table 2.3.1 – Seawater Intake Riser Coordinates

A visual representation of the model in a static state is presented in Appendix B.

2.3.2 Seawater Intake Riser Assemblies

The flexible pipe string assemblies were modelled as flexible elements with sufficient nodal points to allow curvature. The strainer was modelled as a section of straight pipe whereas the riser head and flange connections were modelled as clump weights of appropriate mass and volume. The flange connections were modelled with a normal drag area equal to the protruding area of a 36”NB flange.

Damping is set to zero since, within broad limits, structural damping has little influence on the results of the hydrodynamic simulation unless the system is subject to very rapid variations in tension or bending. Additionally, such damping is negligible compared to the damping applied by hydrodynamic resistance in submarine hoses

2.3.3 Drag Coefficients

The normal drag coefficient (Cd) is dependent upon the Reynolds number (Re), which in turn is a function of the surface roughness and diameter of the hose, as well as the fluid flow velocity. Using the technique provided within ESDU 80025, the Cd values were determined for the corresponding Re number for the hose sections.

Surface roughness values used to calculate the Drag Coefficients were specified as:

Rubber Hose = 3mm (value similar to concrete given in [6] Table 6-1)

The Cd values were input into Orcaflex which calculates the Reynolds number and applies the corresponding Cd for any given fluid velocity.

The strainer value was set at Cd = 1.0 based upon drag coefficients for perforated cylinders as specified in [7] Figure 6.

Axial drag coefficient was set as a constant 0.008 for plain pipe.

The flange connections modelled as clump weights and a drag area equal to the protruding flange specified and an axial drag coefficient of 1.9 [6] Table E-1 applied for the vertical direction.

For marine growth covered hose sections (ref. Section 2.4.7), the surface roughness was specified as 20mm, which is within the values specified in [6] Table 6-1.

2.4 ENVIRONMENTAL DATA

The Design Basis [2] Table 5-2 (corrected by [12]), specifies the following environmental conditions to be considered for the listed conditions:

	Current	Waves	Wind
Design Condition	100 yr (cyclonic) RP	100 yr (cyclonic) RP	100 yr (cyclonic) RP
Survival Condition	10,000 yr (cyclonic) RP	10,000 yr (cyclonic) RP	10,000 yr (cyclonic) RP

Ref. [2] Table 5-2 Environment Conditions (including correction [12])

The metocean data provided by KBR [5] included the Current, Waves and Wind data for the listed conditions.

2.4.1 Direction Convention

The below direction convention is used:

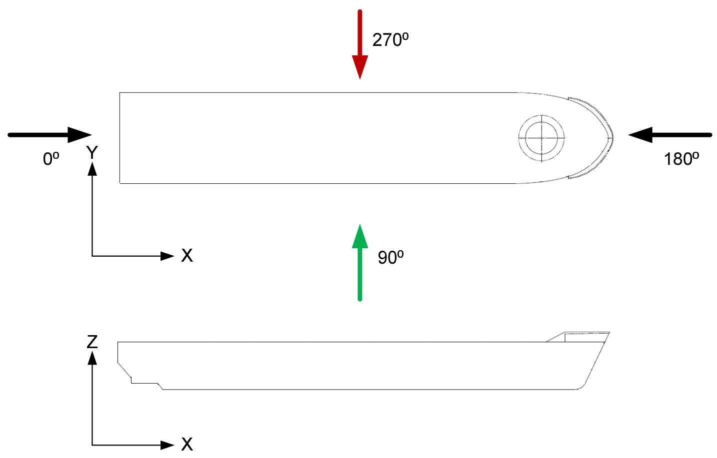

Fig. 3 – Direction Convention [4]

2.4.2 Current and Wave Directions

The Design Basis [2] Table 5-3 (corrected by [4]), specifies the following combinations of current and wave directions to be considered.

Current orientation	Waves orientation
90	270
180	135
180	180
180	225

Ref. [2] Table 5-3 Current and Wave Combinations (including correction [4])

2.4.3 Current

As per [2] table 5-2, the 100yr Cyclonic RP (Design) and 10,000yr Cyclonic RP (Survival) current conditions provided in [5] Tables 2-13 are considered and are reproduced:

Current velocity extremes (m/s)						
C1	Return period (years)					
% Water depth	20	100	200	500	1000	10000
0.3 (surface)	0.36	1.26	1.66	2.11	2.44	3.67
1	0.29	1.14	1.52	1.95	2.27	3.47
2	0.19	0.93	1.28	1.68	1.97	3.10
5	0.12	0.76	1.07	1.44	1.72	2.77
11	0.04	0.46	0.70	0.99	1.21	2.10
16	0.01	0.28	0.45	0.68	0.85	1.58
44	-	0.02	0.05	0.10	0.15	0.39
66	-	0.00	0.01	0.02	0.04	0.13
88	-	-	0.00	0.01	0.01	0.04
99 (4m abs)	-	-	0.00	0.00	0.00	0.02
99 (1m abs)	-	-	-	0.00	0.00	0.02

Ref. [5] Table 2-13 Omnidirectional Cyclonic Current Extremes at C1

2.4.4 Waves

As per [2] table 5-2, the 100yr Cyclonic RP (Design) and 10,000yr Cyclonic RP (Survival) wave conditions provided in [5] Tables 2-6 are considered and are reproduced below:

dir(°N)	100			10000		
	Hs(m)	Hmax(m)	Tp(s)	Hs(m)	Hmax(m)	Tp(s)
Omni	**14.16**	**24.68**	**13.75**	**20.43**	**35.39**	**15.20**
0	4.11*	7.34*	8.29*	4.11*	7.34*	8.29*
30	6.57	11.60	10.26	15.04	26.30	13.34
60	12.46	21.75	13.14	19.15	33.16	15.26
90	13.42	23.28	13.95	19.72	34.23	14.76
120	14.16	24.68	13.75	20.43	35.39	15.20
150	13.95	24.28	13.80	18.87	32.64	15.48
180	13.14	22.88	13.55	18.59	32.23	15.03
210	8.82	15.21	12.96	11.09	19.23	13.27
240	-	-	-	-	-	-
270	-	-	-	-	-	-
300	-	-	-	-	-	-
330	-	-	-			

Ref. [5] Table 2-6 Offshore location: wave cyclonic extremes

Note: Omnidirectional Values are used

It was further advised that:

"Where applying a wave heading of 90 or 270 degrees, in cyclonic cases, a significant wave height of 60% of the significant wave height at 180 degrees will be used" [8]

This applies to the following combination:

Current orientation	Waves orientation
90	270

For the 100yr Cyclonic Condition, the corresponding Tp was advised as 10.65s [9].

For the 10000yr Cyclonic Condition, the corresponding Tp was pro-rata'd as 11.77s .

2.4.5 Wave Spectra

As per [5] Section 7.6.3, during large storms (i.e. Design Condition and Survival Condition), the spectra can be represented by JONSWAP wind Sea spectra, therefore JONSWAP spectrum is considered for the analysis.

The γ coefficient for the spectral peakedness parameter for storm waves was set at 1.4 as per [13] Point 2.

2.4.6 Wind

As per [2] table 5-2, the 100yr Cyclonic RP (Design) and 10,000yr Cyclonic RP (Survival) wind speeds provided in [5] Tables 2-2 are considered and are reproduced below:

Return Period (years)	Ws (m/s)
20	27
100	36
200	40
500	42
1000	45
10000	56

Ref. [5] Table 2-2 Cyclonic extreme winds (offshore point 41.00°E 10.48°S) 10m–10minutes average

Wind was applied from the same direction as the waves and for the primary model only as this considers second order motions.

The secondary model considers first order motions only.

2.4.7 Marine Fouling

Marine Growth data provided by KD [11] was considered and is reproduced below:

"4.13 MARINE GROWTH

The climax marine growth thickness profile is estimated to be 100mm from +2m to -10m, decreasing linearly to 25mm at 65m, with no growth below 65m."

The density of the Marine Growth was assumed to be 1325kg/m^3 as recommend by [6] Section 6.7.4

3 HYDRODYNAMIC ANALYSIS SIMULATIONS

3.1 DESIGN CONDITION

3.1.1 Primary Model

The Primary Model utilised the Orcaflex model provided by the Client [1].

The Wave parameters were set to the maximum 100yr Cyclonic return conditions, heading set as a variable. The Current profile was set to the maximum 100yr return conditions and the direction set as a variable. The mean Wind Speed was set to the 100yr return conditions and the direction set as a variable.

The permutation of directions specified by the Design Basis [2] was applied.

A 10,800s JONSWAP wave packet was selected and a build up period of 500 seconds was defined prior to the main simulation to ensure that any sudden transients were avoided.

Simulations were ran for lines with and without Marine Growth.

Eight (8) combinations of the above were identified and are presented below:

Load Case	Current Direction	Waves Direction	Wind Direction	Marine Growth
PM 1	90	270	270	No
PM 2	180	135	135	No
PM 3	180	180	180	No
PM 4	180	225	225	No
PM 5	90	270	270	Yes
PM 6	180	135	135	Yes
PM 7	180	180	180	Yes
PM 8	180	225	225	Yes

Table 3.1.1 – Primary Model Load Case Combinations (Design Condition)

3.1.2 Secondary Model

The Primary Model detailed in Section 3.1.1 included second order vessel motions, consequently during analysis, the vessel drifted and tended to rotate into the direction of the Wave heading.

Therefore, a secondary model was built to consider the vessel with a fixed heading such that the wave and current directions were applied in relation to the vessel heading.

RAO data provided by the Client [3], for both the 100yr BALLAST and FULL condition, were selected.

The Wave parameters were set to the maximum 100yr Cyclonic return conditions, heading set as a variable. The Current profile was set to the maximum 100yr return conditions and the direction set as a variable. Wind was not applied as only the first order motions are considered.

Using the same seed number for all waves, a 300s JONSWAP wave packet was identified which included the Rise and Fall wave events for the maximum and minimum associated period (T_{ass}), and simulation period set so that the event occurred at the mid-point of the wave packet. A build up period of 8 seconds was defined prior to the main simulation to ensure that any sudden transients were avoided.

Simulations of 300s (each including a significant wave event) were run for 100yr cyclonic wave and current conditions for the permutation of directions specified by the Design Basis [2].

Simulations were ran for lines with and without Marine Growth.

Sixty Four (64) combinations of the above were identified and are presented below:

Load Case	Draught	Current Direction	Wave Direction	Wave Event	Marine Growth
SM 1	Ballast	90	270	T_{ass} Max Rise	No
SM 2	Ballast	90	270	T_{ass} Max Fall	No
SM 3	Ballast	90	270	T_{ass} Min Rise	No
SM 4	Ballast	90	270	T_{ass} Min Fall	No
SM 5	Ballast	180	135	T_{ass} Max Rise	No
SM 6	Ballast	180	135	T_{ass} Max Fall	No
SM 7	Ballast	180	135	T_{ass} Min Rise	No
SM 8	Ballast	180	135	T_{ass} Min Fall	No
SM 9	Ballast	180	180	T_{ass} Max Rise	No
SM 10	Ballast	180	180	T_{ass} Max Fall	No
SM 11	Ballast	180	180	T_{ass} Min Rise	No
SM 12	Ballast	180	180	T_{ass} Min Fall	No
SM 13	Ballast	180	225	T_{ass} Max Rise	No
SM 14	Ballast	180	225	T_{ass} Max Fall	No
SM 15	Ballast	180	225	T_{ass} Min Rise	No
SM 16	Ballast	180	225	T_{ass} Min Fall	No
SM 17	Full	90	270	T_{ass} Max Rise	No
SM 18	Full	90	270	T_{ass} Max Fall	No
SM 19	Full	90	270	T_{ass} Min Rise	No
SM 20	Full	90	270	T_{ass} Min Fall	No

Load Case	Draught	Current Direction	Wave Direction	Wave Event	Marine Growth
SM 21	Full	180	135	T_{ass} Max Rise	No
SM 22	Full	180	135	T_{ass} Max Fall	No
SM 23	Full	180	135	T_{ass} Min Rise	No
SM 24	Full	180	135	T_{ass} Min Fall	No
SM 25	Full	180	180	T_{ass} Max Rise	No
SM 26	Full	180	180	T_{ass} Max Fall	No
SM 27	Full	180	180	T_{ass} Min Rise	No
SM 28	Full	180	180	T_{ass} Min Fall	No
SM 29	Full	180	225	T_{ass} Max Rise	No
SM 30	Full	180	225	T_{ass} Max Fall	No
SM 31	Full	180	225	T_{ass} Min Rise	No
SM 32	Full	180	225	T_{ass} Min Fall	No
SM 33	Ballast	90	270	T_{ass} Max Rise	Yes
SM 34	Ballast	90	270	T_{ass} Max Fall	Yes
SM 35	Ballast	90	270	T_{ass} Min Rise	Yes
SM 36	Ballast	90	270	T_{ass} Min Fall	Yes
SM 37	Ballast	180	135	T_{ass} Max Rise	Yes
SM 38	Ballast	180	135	T_{ass} Max Fall	Yes
SM 39	Ballast	180	135	T_{ass} Min Rise	Yes
SM 40	Ballast	180	135	T_{ass} Min Fall	Yes
SM 41	Ballast	180	180	T_{ass} Max Rise	Yes
SM 42	Ballast	180	180	T_{ass} Max Fall	Yes
SM 43	Ballast	180	180	T_{ass} Min Rise	Yes
SM 44	Ballast	180	180	T_{ass} Min Fall	Yes
SM 45	Ballast	180	225	T_{ass} Max Rise	Yes
SM 46	Ballast	180	225	T_{ass} Max Fall	Yes
SM 47	Ballast	180	225	T_{ass} Min Rise	Yes
SM 48	Ballast	180	225	T_{ass} Min Fall	Yes
SM 49	Full	90	270	T_{ass} Max Rise	Yes
SM 50	Full	90	270	T_{ass} Max Fall	Yes
SM 51	Full	90	270	T_{ass} Min Rise	Yes
SM 52	Full	90	270	T_{ass} Min Fall	Yes
SM 53	Full	180	135	T_{ass} Max Rise	Yes
SM 54	Full	180	135	T_{ass} Max Fall	Yes
SM 55	Full	180	135	T_{ass} Min Rise	Yes
SM 56	Full	180	135	T_{ass} Min Fall	Yes
SM 57	Full	180	180	T_{ass} Max Rise	Yes
SM 58	Full	180	180	T_{ass} Max Fall	Yes
SM 59	Full	180	180	T_{ass} Min Rise	Yes
SM 60	Full	180	180	T_{ass} Min Fall	Yes
SM 61	Full	180	225	T_{ass} Max Rise	Yes
SM 62	Full	180	225	T_{ass} Max Fall	Yes
SM 63	Full	180	225	T_{ass} Min Rise	Yes
SM 64	Full	180	225	T_{ass} Min Fall	Yes

Table 3.1.2 – Secondary Model Load Case Combinations (Design Condition)

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3.2 SURVIVAL CONDITION

3.2.1 Primary Model

The Primary Model utilised the Orcaflex model provided by the Client [1].

The Wave parameters were set to the maximum 10,000yr Cyclonic return conditions, heading set as a variable. The Current profile was set to the maximum 10,000yr return conditions and the direction set as a variable. The mean Wind Speed was set to the 10,000yr return conditions and the direction set as a variable.

The permutation of directions specified by the Design Basis [2] was applied.

A 10,800s JONSWAP wave packet was selected and a build up period of 500 seconds was defined prior to the main simulation to ensure that any sudden transients were avoided.

Simulations were ran for lines with and without Marine Growth.

The most onerous load cases identified from the analysis of 3.1.1 was identified and used for the Survival Condition and are presented below:

Load Case	Current Direction	Waves Direction	Wind Direction	Marine Growth
PM 6	180	135	135	Yes
PM 8	180	225	225	Yes

Table 3.2.1 – Primary Model Load Case Combinations (Survival Condition)

3.2.2 Secondary Model

The Primary Model detailed in Section 3.2.1 included second order vessel motions, consequently during analysis, the vessel drifted and tended to rotate into the direction of the Wave heading.

Therefore, a secondary model was built to consider the vessel with a fixed heading such that the wave and current directions were applied in relation to the vessel heading.

RAO data provided by the Client [3], for both the 10,000yr BALLAST and FULL condition, were selected.

The Wave parameters were set to the maximum 10,000yr Cyclonic return conditions, heading set as a variable. The Current profile was set to the maximum 10,000yr return conditions and the direction set as a variable. Wind was not applied as only the first order motions are considered.

A 300s JONSWAP wave packet was identified which included the Rise and Fall wave events for the maximum and minimum associated period (T_{ass}), and simulation period set so that the event occurred at the mid-point of the wave packet. A build up period of 8 seconds was defined prior to the main simulation to ensure that any sudden transients were avoided.

The most onerous load cases identified from the analysis of 3.1.2 were identified and used for the Survival Condition

32 load cases from Section 3.1.2 were identified and are presented below:

Load Case	Draught	Current Direction	Wave Direction	Wave Event	Marine Growth
SM 33	Ballast	90	270	T_{ass} Max Rise	Yes
SM 34	Ballast	90	270	T_{ass} Max Fall	Yes
SM 35	Ballast	90	270	T_{ass} Min Rise	Yes
SM 36	Ballast	90	270	T_{ass} Min Fall	Yes
SM 37	Ballast	180	135	T_{ass} Max Rise	Yes
SM 38	Ballast	180	135	T_{ass} Max Fall	Yes
SM 39	Ballast	180	135	T_{ass} Min Rise	Yes
SM 40	Ballast	180	135	T_{ass} Min Fall	Yes
SM 41	Ballast	180	180	T_{ass} Max Rise	Yes
SM 42	Ballast	180	180	T_{ass} Max Fall	Yes
SM 43	Ballast	180	180	T_{ass} Min Rise	Yes
SM 44	Ballast	180	180	T_{ass} Min Fall	Yes
SM 45	Ballast	180	225	T_{ass} Max Rise	Yes
SM 46	Ballast	180	225	T_{ass} Max Fall	Yes
SM 47	Ballast	180	225	T_{ass} Min Rise	Yes
SM 48	Ballast	180	225	T_{ass} Min Fall	Yes
SM 49	Full	90	270	T_{ass} Max Rise	Yes
SM 50	Full	90	270	T_{ass} Max Fall	Yes
SM 51	Full	90	270	T_{ass} Min Rise	Yes
SM 52	Full	90	270	T_{ass} Min Fall	Yes
SM 53	Full	180	135	T_{ass} Max Rise	Yes
SM 54	Full	180	135	T_{ass} Max Fall	Yes
SM 55	Full	180	135	T_{ass} Min Rise	Yes
SM 56	Full	180	135	T_{ass} Min Fall	Yes
SM 57	Full	180	180	T_{ass} Max Rise	Yes
SM 58	Full	180	180	T_{ass} Max Fall	Yes
SM 59	Full	180	180	T_{ass} Min Rise	Yes
SM 60	Full	180	180	T_{ass} Min Fall	Yes
SM 61	Full	180	225	T_{ass} Max Rise	Yes
SM 62	Full	180	225	T_{ass} Max Fall	Yes
SM 63	Full	180	225	T_{ass} Min Rise	Yes
SM 64	Full	180	225	T_{ass} Min Fall	Yes

Table 3.2.2 – Secondary Model Load Case Combinations (Survival Condition)

4 RESULTS

The results of the Hydrodynamic Analyses were stored, evaluated and exported using the *Orca-Flex* post processing facilities. These results are summarised below and presented in more detail at Appendix C.

4.1 DESIGN CONDITION

Appendix C lists in full the maximum time series peak loads from each of the simulations.

This section identifies each of the worst case load magnitudes and the associated loads for both the Primary (PM) and Secondary (SM) Model. This data can be used for the design of the riser head and riser seat, however, it must be noted that these values are individual maximum values of the time series results encountered during each simulation and may not necessarily occur simultaneously and is therefore considered conservative.

The maximum hose excursions are also identified.

4.1.1 Maximum End Force at Riser Head

Load Case	Line No	Highest End Force (kN)	Corresponding worst:		
			Shear Load (kN)	Bend Moment (kNm)	Hose Tension (kN)
PM8	**1**	**565.9**	294.3	721.5	559.3
SM52	**4**	**860.3**	197.3	370.3	837.8

4.1.2 Maximum Hose Tension at Riser Head

Load Case	Line No	Highest Tension (kN)	Corresponding worst:		
			Shear Load (kN)	Bend Moment (kNm)	Bend Radius (m)
PM8	**1**	**559.3**	294.3	721.5	4.63
SM52	**4**	**837.8**	197.3	370.3	9.43

4.1.3 Maximum Bending Moment at Riser Head

Load Case	Line No	Highest Bending Moment (kN)	Corresponding worst:		
			Shear Load (kN)	End Force (kN)	Bend Radius (m)
PM6	**1**	**889.1**	313.6	556.2	3.65
SM40	**1**	**837.5**	301.0	734.7	3.8

4.1.4 Maximum Shear Load at Riser Head

Load Case	Line No	Highest Shear Load (kN)	Corresponding worst:		
			End Force (kN)	Bend Moment (kNm)	Bend Radius (m)
PM6	**4**	**319.4**	537.6	817.8	3.93
SM40	**1**	**301.0**	734.7	837.5	3.8

4.1.5 Minimum Bend Radius

Load Case	Line No	Bend Radius (m)	Corresponding worst:		
			Shear Load (kN)	Bend Moment (kNm)	End Force (kN)
PM6	**1**	**3.65**	313.6	889.1	556.2
SM40	**1**	**3.8**	301.0	837.5	734.7

4.1.6 Hose Excursions

Primary Model DESIGN CONDITION simulation PM7 (Wave Direction 180°/Current Direction 180° /with Marine Growth), was selected to extract the time history for the positions of End A (Hull Connection) and End B (Free End). The End A position was subtracted from the End B position to determine the relative excursion of the free end at each stage of the simulation.

Secondary Model DESIGN CONDITION simulation SM41 (Wave Direction 180°/Current Direction 180° /with Marine Growth), was selected to extract the time history for the positions of End A (Hull Connection) and End B (Free End). The End A position was subtracted from the End B position to determine the relative excursion of the free end at each stage of the simulation.

The maximum relative excursions were identified and are presented below:

	End B – Relative Excursion			
Load Case	**Line 1**	**Line 2**	**Line 3**	**Line 4**
PM7	54.98m	53.53m	52.16	50.77
SM41	21.76m	21.76m	21.76m	21.76m

Table 4.1.6 – Hose End B Relative Excursions

The below plots show the End B excursion pattern for Line 1 from the Primary Model and Secondary Model respectively:

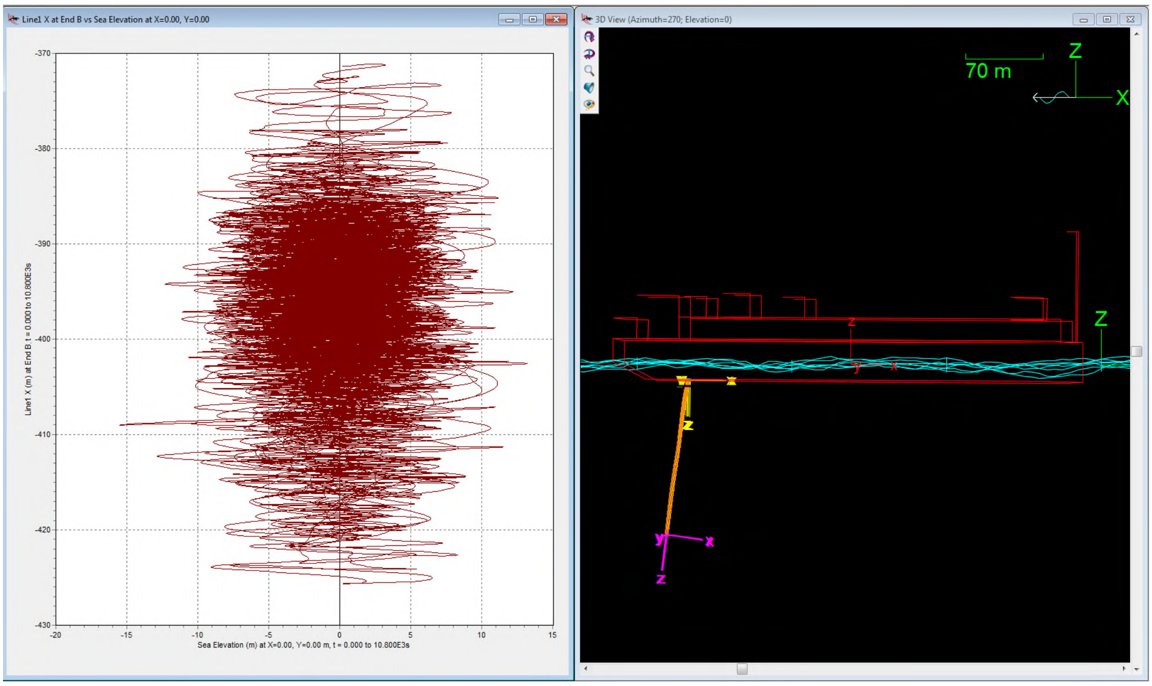


Fig. 4 -Primary Model - Hose End B Excursion Pattern (Line 1 - Load Case PM7)

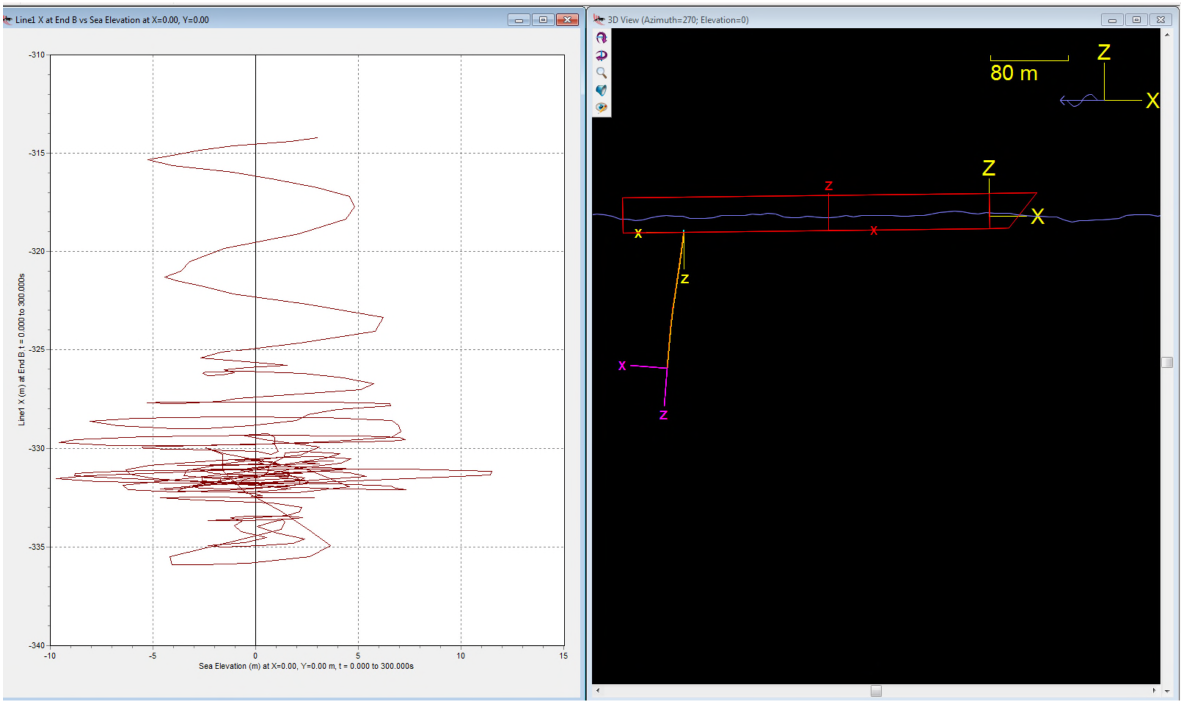


Fig. 5 -Secondary Model - Hose End B Excursion Pattern (Line 1 - Load Case SM41)

4.2 SURVIVAL CONDITION

Appendix C lists in full the maximum the peak loads from each of the simulations.

This section identifies each of the worst case load magnitudes and the associated loads for both the Primary and Secondary Model. This data can be used for verify the survival of the riser head and riser seat, however, it must be noted that these values are individual maximum values of the time series results encountered during each simulation and may not necessarily occur simultaneously and is therefore considered conservative.

4.2.1 Maximum End Force at Riser Head

Load Case	Line No	Highest End Force (kN)	Corresponding worst:		
			Shear Load (kN)	Bend Moment (kNm)	Hose Tension (kN)
PM8	**1**	**2437.5**	2208.8	3249.8	2290.1
SM35	**1**	**1602.8**	972.6	1537.5	1562.4

4.2.2 Maximum Hose Tension at Riser Head

Load Case	Line No	Highest Tension (kN)	Corresponding worst:		
			Shear Load (kN)	Bend Moment (kNm)	Bend Radius (m)
PM8	**1**	**2290.1**	2208.8	3249.8	1.06
SM35	**1**	**1562.4**	972.6	1537.5	2.28

4.2.3 Maximum Bending Moment at Riser Head

Load Case	Line No	Highest Bending Moment (kN)	Corresponding worst:		
			Shear Load (kN)	End Force (kN)	Bend Radius (m)
PM8	**4**	**3856.9**	2260.6	2262.1	0.91
SM37	**1**	**2567.9**	1257.3	1261.1	1.36

4.2.4 Maximum Shear Load at Riser Head

Load Case	Line No	Highest Shear Load (kN)	Corresponding worst:		
			End Force (kN)	Bend Moment (kNm)	Bend Radius (m)
PM8	**4**	**2260.6**	2262.1	3856.9	0.91
SM37	**1**	**1257.3**	1261.1	2567.9	1.36

4.2.5 Minimum Bend Radius

Load Case	Line No	Bend Radius (m)	Corresponding worst:		
			Shear Load (kN)	Bend Moment (kNm)	End Force (kN)
PM8	**4**	**0.91**	2260.6	3856.9	2262.1
SM37	**1**	**1.36**	1257.3	2567.9	1261.1

4.3 NATURAL FREQUENCY

The natural frequencies of the Seawater Intake Riser are extracted from the hydrodynamic model and are presented below.

No.	Mode Number	Period (s)	Frequency (Hz)	Mode Type
1	1	58.89	0.01698	Transverse
2	2	58.87	0.01699	Inline
3	3	25.28	0.03955	Inline
4	4	25.28	0.03956	Transverse
5	5	15.43	0.06480	Inline
6	6	15.43	0.06481	Transverse
7	7	10.64	0.09401	Inline
8	8	10.64	0.09401	Transverse
9	9	7.87	0.12703	Transverse
10	10	7.87	0.12704	Inline
11	11	6.12	0.16330	Inline
12	12	6.12	0.16331	Transverse

Fig. 6 – Seawater Intake Riser Natural Frequencies

5 CONCLUSION

From the results presented in Section 4.0, the following can be concluded:

5.1 DESIGN CONDITIONS ANALYSIS

5.1.1 Minimum Bend Radius

From Analysis, Hose Minimum Bend Radius (MBR) = **3.65 m**

From Table 2-2, Allowable Hose MBR = **3.6 m**

The induced hose bend radius does not infringe the hose MBR and is therefore ACCEPTABLE.

5.1.2 Maximum Hose Tension

From Analysis, Maximum Hose Tension = **837.8 kN**

From Table 2-2, Allowable Max Hose Tension = **4946 kN**

The induced hose tension does not exceed the maximum axial strength and is therefore ACCEPTABLE.

Therefore the Seawater Suction Hose is suitable for the configuration and environmental conditions that it will be subjected to during the life of the system.

5.2 SURVIVAL CONDITION ANALYSIS

5.2.1 Minimum Bend Radius

From Analysis, Hose Minimum Bend Radius (MBR) = **0.91 m**

From Table 2-2, Allowable Hose MBR = **3.6 m**

The Allowable Hose MBR is the value that can be accommodate by the hose without any permanent damage to the structure of the hose.

For the Survival Condition, the MBR of the hose to be further investigated/verified but it is expected that the hose would remain intact although it would most likely 'kink' causing permanent structural damage.

5.2.2 Maximum Hose Tension

From Analysis, Maximum Hose Tension = **2290.1 kN**

From Table 2-2, Allowable Max Hose Tension = **4946 kN**

The induced hose tension does not exceed the maximum axial strength and is therefore ACCEPTABLE.

The results presented in Section 4.0 can be used to verify the design of the Riser Head and Riser Seat Components, ref Section 6.0.

6 LOCAL FEA SWIR / HULL CONNECTION

Refer to Document P13919-RL-004: Hull Connection FEA Report

REFERENCES

[1] SWIR_100cyc_a60.dat – (received by e-mail: Panda/Craig 10/12/14)

[2] 4404YYBNRB1910K Rev 01: Seawater Intake Riser Design Basis and Scope of Work

[3] SWIR_RAOs.zip – (received by e-mail: Panda/Craig 24/11/14)

[4] e-mail: Wykeham/Craig (27/11/14)

[5] 440200FGRF02014 Rev 05: Meteocean Design Basis for FLNG (Coral)

[6] DNV-RP-C205 : DNV Recommended Practice – Environmental Conditions and Environmental Loads

[7] ESDU 80025 Mean forces, pressures and flow field velocities for circular cylindrical structures

[8] e-mail: Panda/Craig (09/12/14)

[9] Telecon: Wykeham/Craig (03/12/14 -11.30am)

[10] ITTC (2011) Recommended Procedures: Fresh Water and Seawater Properties

[11] e-mail: Wykeham/Craig (06/01/15)

[12] e-mail: Wykeham/Craig (22/01/15

[13] 4404GGBNRB00037 Rev 05: FLNG Technical Note, Additional Information on the Revised Meteocean Design Basis

APPENDICES

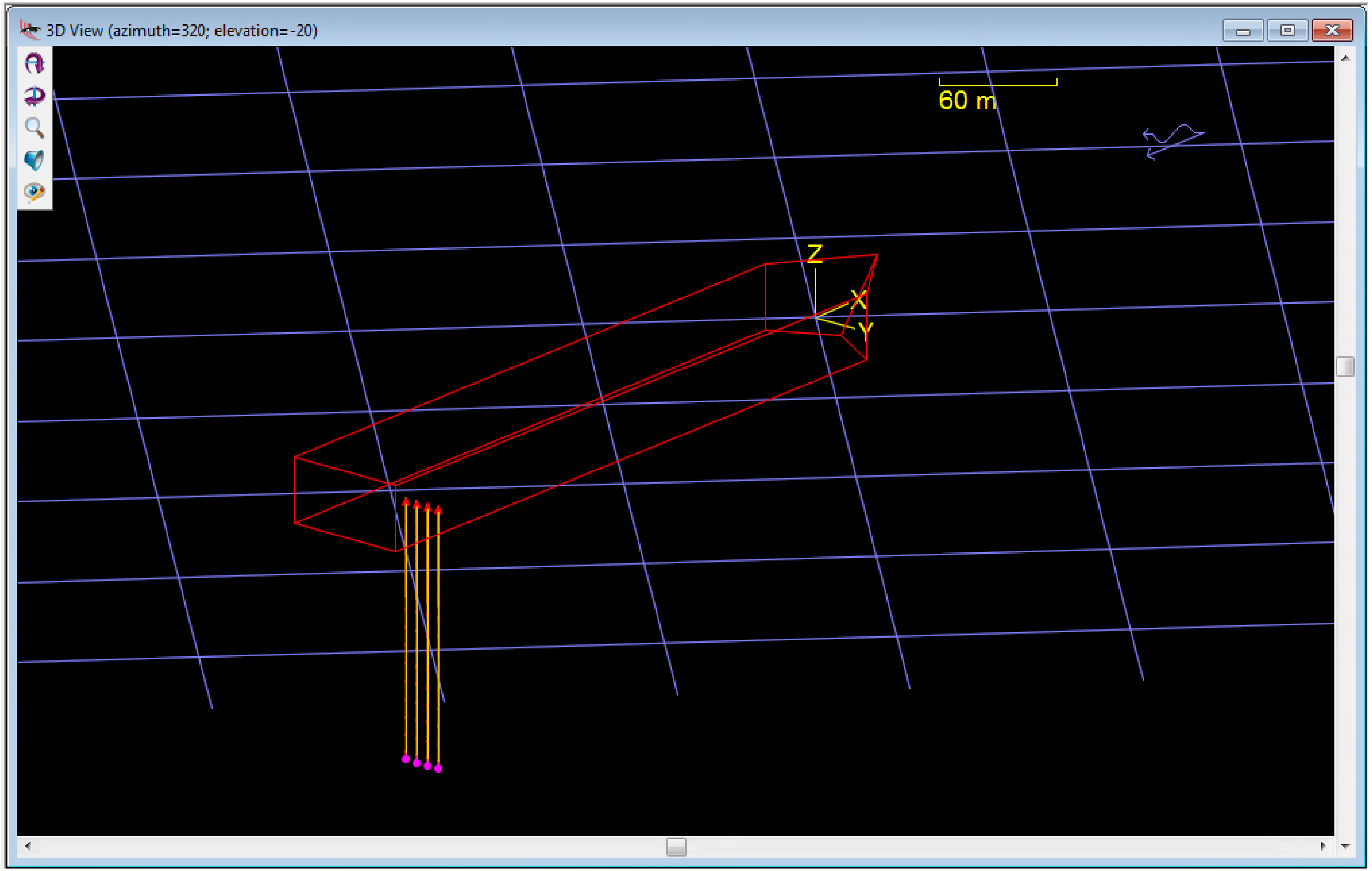
APPENDIX A – METHODOLOGY

Item	Description	References	Input Data	Process	Output	Acceptance Criteria
1	Hydrodynamic Analysis	[1] [2] [3]	Vessel RAO Data Meteocean Data Riser Properties	Build Model Establish Design & Survival Load Case Combinations Run Analyses Extract Results	Hose Maximum Tension Hose MBR Hose Displacement Clash Report Modal Analysis Hang Off Connection Loads & Moments	Hose allowable tension not exceed Hose MBR not exceed No interference with mooring lines Allowable Clash Energies are not exceed Input for VIV Screening Input for Hang Off Connection FEA
2	Hose Fatigue Analysis	[1] [4]	Vessel RAO Data Meteocean Data SN Data	Establish Hs / Tz Occurrences Define Fatigue Bins Run Orcaflex wave scatter tool Extract fatigue load cases Run Analyses Extract Results	Bending Moment & Tension ranges	Predicted fatigue of Hose Reinforcement Materials within S-N allowable
3	VIV	[5] [6]	Modal Analysis	Determine Vortex Shedding Frequencies	Vortex Shedding Frequency Range	Natural Frequency of Riser outside of Vortex Shedding Frequency Range – Low Risk
4	FEA of Hang Off Connection	[7] [8]	Hull / Caisson Structural Details Hang Off Connection Loads & Moments	Build Hang Off Connection Model Establish Boundary Conditions Run Analyses Extract Results	Maximum Stresses	Maximum Stresses do not exceed material allowable stresses.

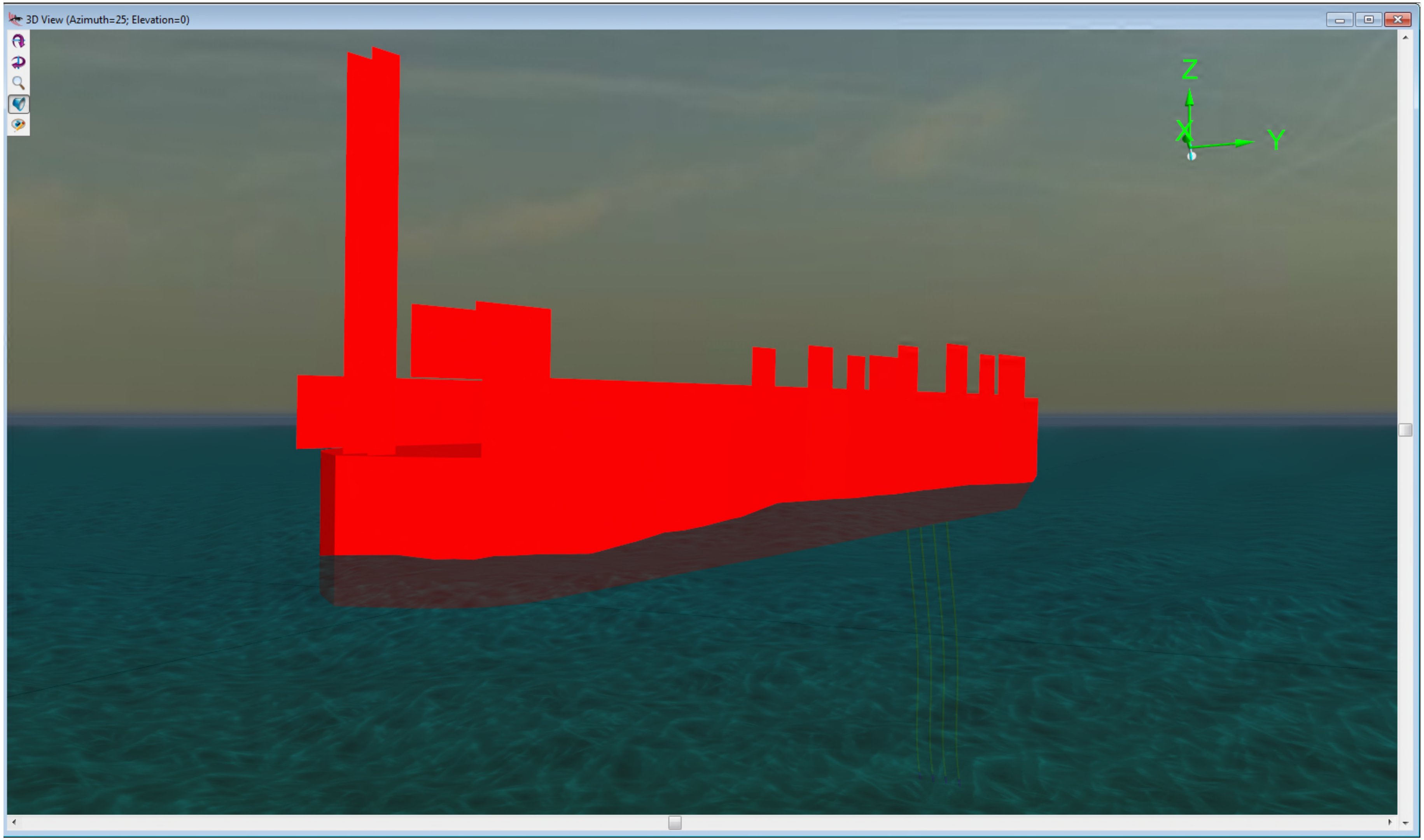
References:

[1] Orcaflex Software
[2] Seawater Intake Riser Design Basis and Scope of Work – 4404YYBNRB1910K
[3] Meteocean Design Basis for FLNG (CORAL) - 440200FGRF02014
[4] Specification for Bonded Flexible Pipe API 17K.
[5] Recommended Practice DNV-RP-C205 – Environmental Conditions and Environmental Loads
[6] Recommended Practice DNV-RP-F204 - Riser Fatigue
[7] Autodesk Inventor / ANSYS Software
[8] EUROCODE 3 - DIN EN 1993

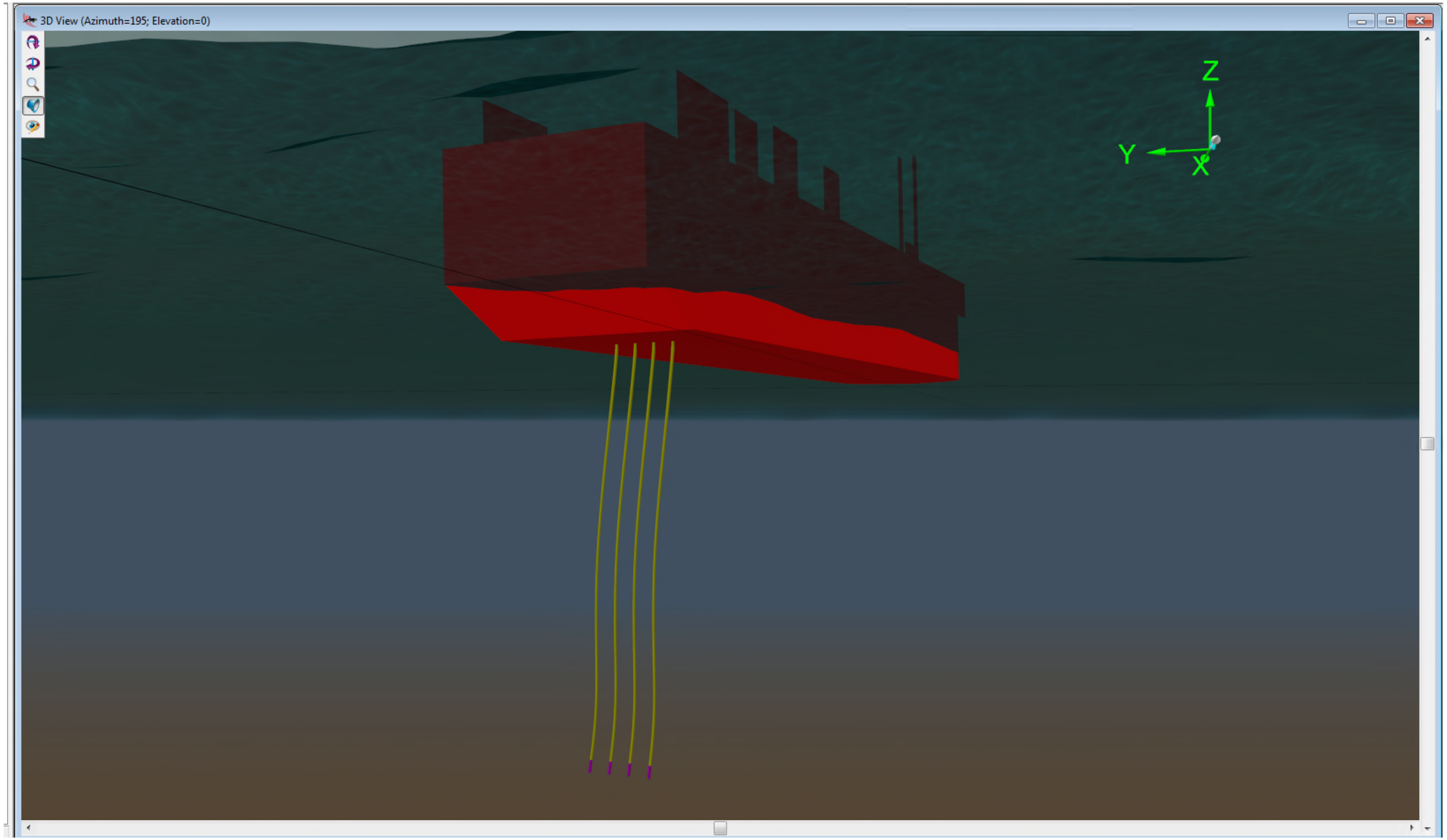
APPENDIX B – MODEL SCREEN SHOTS



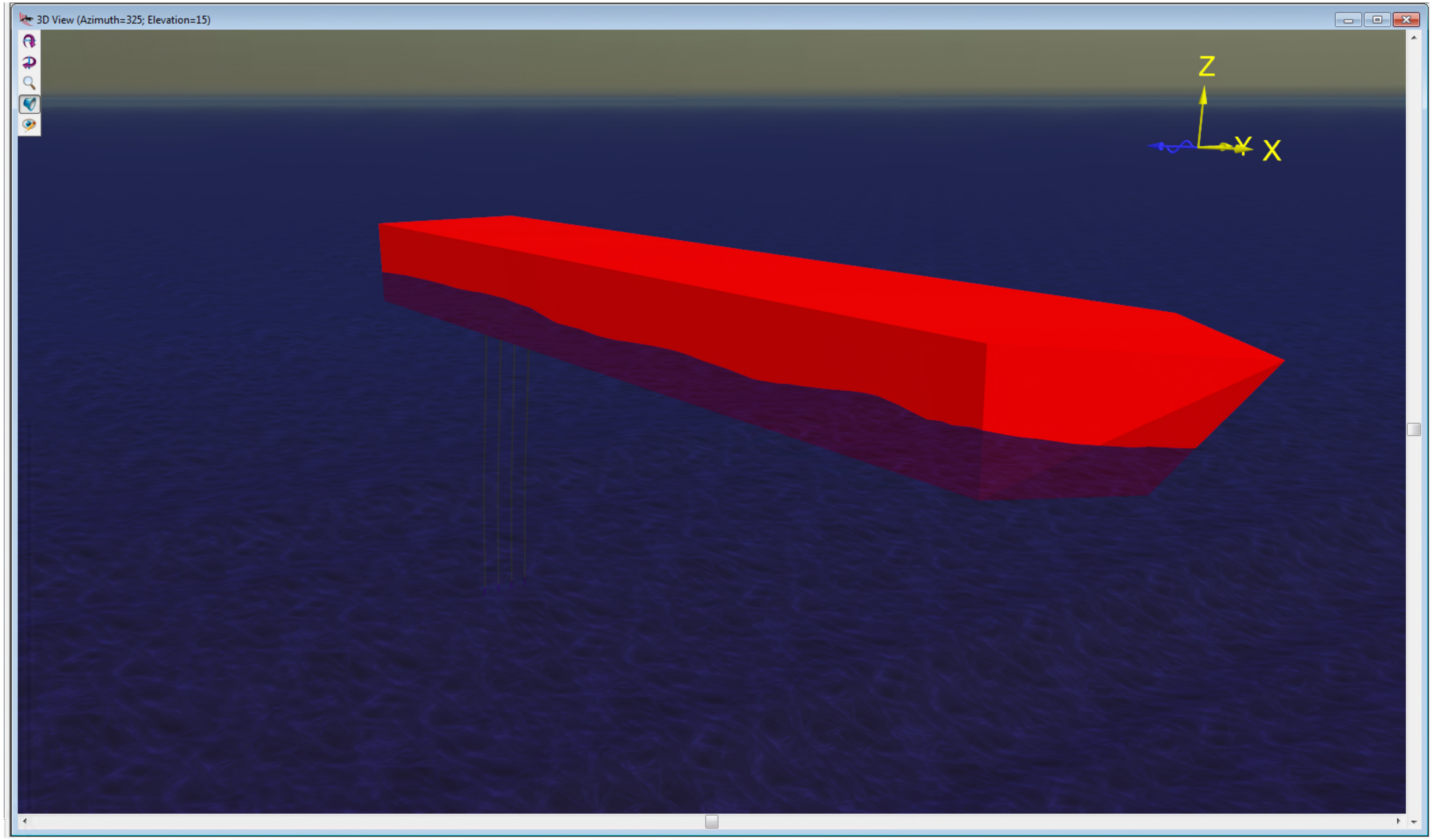
Secondary Model In Static Condition



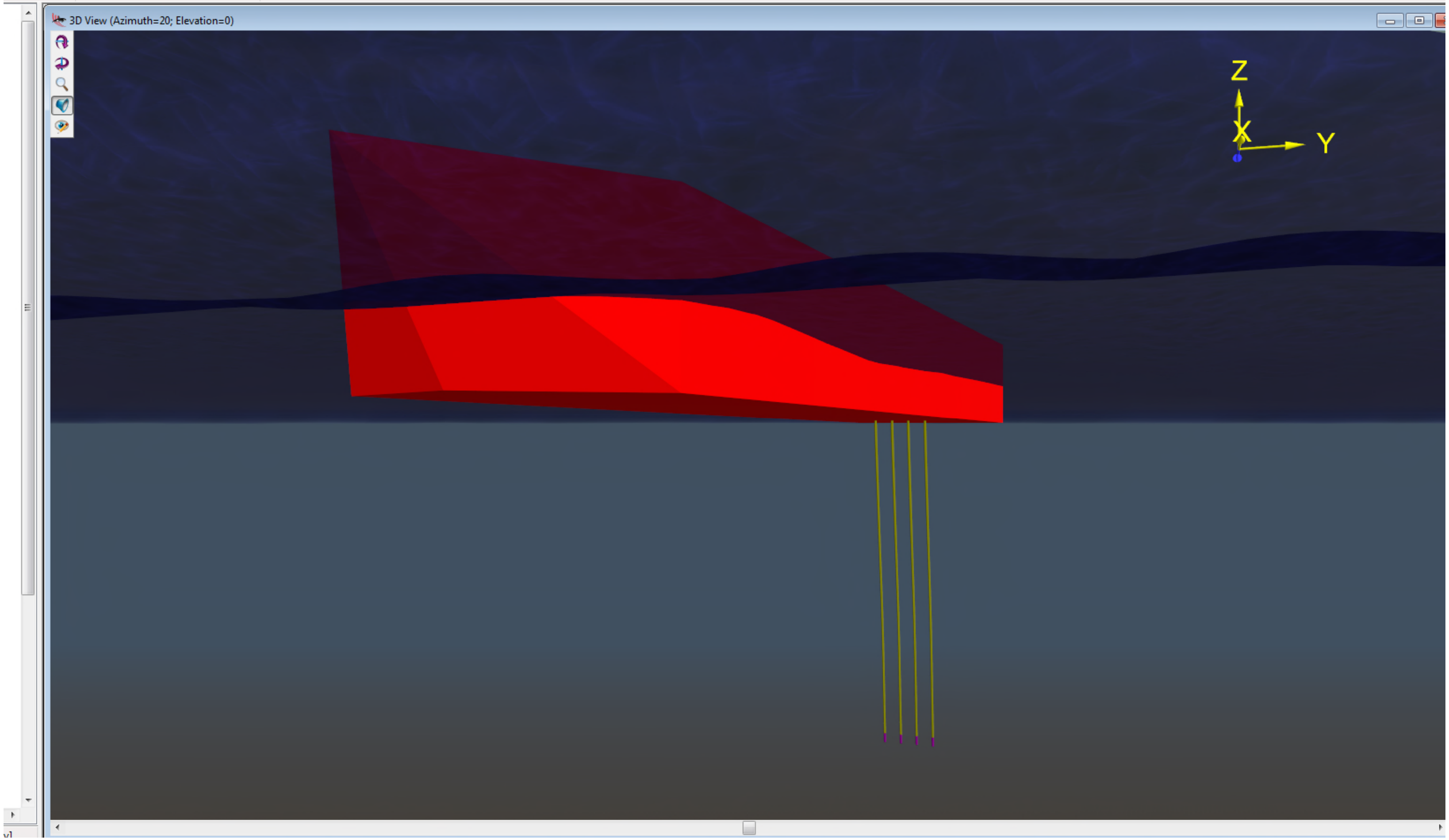
Primary Model



Primary Model



Secondary Model



Secondary Model

APPENDIX C – HYDRODYNAMIC ANALYSIS RESULTS

	LOAD CASE (PM)								Max		
DESCRIPTION	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**			
Line 1 End Force (End A) Max	427.8	507.2	503.1	518.8	472.0	556.2	557.5	565.9	565.9	kN	
Line 2 End Force (End A) Max	430.7	500.0	504.7	519.6	475.2	547.4	552.1	565.1	565.1	kN	
Line 3 End Force (End A) Max	432.3	490.8	510.4	517.5	477.2	537.7	555.1	563.0	563.0	kN	
Line 4 End Force (End A) Max	432.8	490.6	519.5	512.3	477.7	537.6	563.3	558.5	563.3	kN	
Line 1 End Force (End A) Min	236.9	127.4	142.7	142.1	266.3	137.7	139.3	155.8	127.4	kN	
Line 2 End Force (End A) Min	235.5	129.7	144.5	155.7	265.2	139.9	136.7	156.1	129.7	kN	
Line 3 End Force (End A) Min	234.4	131.2	146.6	153.2	264.1	137.3	136.1	154.6	131.2	kN	
Line 4 End Force (End A) Min	233.8	123.5	137.9	149.5	263.4	112.8	137.2	154.9	112.8	kN	
Line 1 Bend Moment (End A)	343.4	796.3	670.4	665.9	374.9	889.1	723.6	721.5	889.1	kNm	
Line 2 Bend Moment (End A)	352.9	757.0	690.2	677.3	385.1	860.2	740.5	731.6	860.2	kNm	
Line 3 Bend Moment (End A)	358.6	721.3	709.0	686.2	391.2	836.0	757.2	740.0	836.0	kNm	
Line 4 Bend Moment (End A)	360.1	690.2	727.3	693.4	392.6	817.8	774.3	745.9	817.8	kNm	
Line 1 Shear Force (End A)	131.2	258.2	249.4	260.9	148.3	313.6	280.5	294.3	313.6	kN	
Line 2 Shear Force (End A)	133.3	249.5	253.9	266.2	150.6	312.1	285.8	298.2	312.1	kN	
Line 3 Shear Force (End A)	134.3	244.2	267.0	270.8	151.6	314.0	294.8	302.1	314.0	kN	
Line 4 Shear Force (End A)	134.0	245.7	279.8	274.2	151.2	319.4	309.5	305.2	319.4	kN	
Line 1 Effective Tension Max	423.6	488.1	472.8	513.4	467.4	533.0	522.5	559.3	559.3	kN	
Line 2 Effective Tension Max	426.7	481.0	474.9	513.5	470.9	523.9	521.2	557.7	557.7	kN	
Line 3 Effective Tension Max	428.6	472.1	475.6	510.8	473.1	516.3	527.3	555.1	555.1	kN	
Line 4 Effective Tension Max	429.2	477.1	483.3	505.4	473.8	522.0	532.5	550.6	550.6	kN	
Line 1 Effective Tension Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kN	
Line 2 Effective Tension Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kN	
Line 3 Effective Tension Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kN	
Line 4 Effective Tension Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kN	
Line 1 Curvature	0.108	0.263	0.210	0.204	0.117	0.274	0.222	0.216	0.2740	3.7	m
Line 2 Curvature	0.111	0.250	0.216	0.206	0.120	0.274	0.227	0.219	0.2740	3.7	m
Line 3 Curvature	0.113	0.238	0.221	0.209	0.121	0.264	0.232	0.221	0.2638	3.8	m
Line 4 Curvature	0.114	0.226	0.226	0.215	0.122	0.254	0.237	0.223	0.2544	3.9	m

PRIMARY MODEL - DESIGN CONDITION RESULTS

	LOAD CASE (SM)																																Max
DESCRIPTION	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	
Line 1 End Force (End A) Max	752.3	752.7	663.9	752.7	566.6	566.6	648.7	658.1	416.4	459.8	484.2	424.9	560.8	530.4	664.2	674.8	729.4	731.5	637.4	732.3	550.2	544.3	635.3	675.1	414.3	452.8	488.0	423.2	557.9	535.8	658.7	657.8	752.7 kN
Line 2 End Force (End A) Max	755.2	754.5	663.9	754.5	561.2	561.2	652.7	662.5	416.4	459.8	484.2	424.9	558.0	531.1	657.6	668.1	739.4	740.9	640.7	742.2	553.1	540.3	642.2	668.1	414.3	452.8	488.0	423.2	555.8	537.3	650.0	662.5	755.2 kN
Line 3 End Force (End A) Max	778.3	777.0	675.0	777.0	558.0	558.0	657.6	668.1	416.4	459.8	484.2	424.9	561.2	533.3	652.7	662.5	773.2	773.7	659.1	775.0	555.8	537.3	650.0	662.5	414.3	452.8	488.0	423.2	553.1	540.3	642.2	668.1	778.3 kN
Line 4 End Force (End A) Max	790.2	789.6	677.6	789.6	560.8	560.8	664.2	674.8	416.4	459.8	484.2	424.9	566.6	536.6	648.7	658.1	804.3	805.7	674.1	804.8	557.9	535.8	658.7	657.8	414.3	452.8	488.0	423.2	550.2	544.3	635.3	675.1	805.7 kN
Line 1 End Force (End A) Min	3.7	1.5	7.6	1.5	152.5	152.5	149.5	124.0	226.2	215.8	199.7	194.3	171.6	128.2	72.0	85.4	1.6	1.5	34.9	2.8	160.2	140.1	124.6	119.5	227.8	217.2	203.1	200.6	168.5	134.8	56.6	94.7	1.5 kN
Line 2 End Force (End A) Min	2.5	1.4	28.1	1.4	160.8	160.8	134.7	111.4	226.2	215.8	199.7	194.3	170.0	130.8	76.9	97.0	0.8	0.8	42.9	1.7	162.4	138.6	120.2	115.4	227.8	217.2	203.1	200.6	164.9	136.7	113.4	103.6	0.8 kN
Line 3 End Force (End A) Min	2.9	2.6	49.2	2.6	170.0	170.0	76.9	97.0	226.2	215.8	199.7	194.3	160.8	133.0	134.7	111.4	2.9	2.7	52.2	2.8	164.9	136.7	113.4	103.6	227.8	217.2	203.1	200.6	162.4	138.6	120.2	115.4	2.6 kN
Line 4 End Force (End A) Min	13.0	12.5	50.9	12.5	171.6	171.6	72.0	85.4	226.2	215.8	199.7	194.3	152.5	135.0	149.5	124.0	5.7	3.0	45.3	5.0	168.5	134.8	56.6	94.7	227.8	217.2	203.1	200.6	160.2	140.1	124.6	119.5	3.0 kN
Line 1 Bend Moment (End A)	267.5	264.7	180.9	264.7	542.2	542.2	477.3	736.7	452.9	513.5	467.4	538.3	450.4	421.8	382.7	628.0	236.9	235.0	157.0	235.3	535.2	460.1	466.3	723.5	440.6	501.1	452.9	524.9	450.0	415.1	376.2	616.8	736.7 kNm
Line 2 Bend Moment (End A)	249.3	246.5	195.5	246.5	516.7	516.7	429.8	691.8	452.9	513.5	467.4	538.3	486.6	440.3	405.8	663.9	215.6	215.2	166.0	216.6	512.7	448.0	424.1	680.8	440.6	501.1	452.9	524.9	484.8	433.5	397.8	653.6	691.8 kNm
Line 3 Bend Moment (End A)	272.0	270.3	220.0	270.3	486.6	486.6	405.8	663.9	452.9	513.5	467.4	538.3	516.7	454.5	429.8	691.8	236.2	235.3	193.2	233.2	484.8	433.5	397.8	653.6	440.6	501.1	452.9	524.9	512.7	448.0	424.1	680.8	691.8 kNm
Line 4 Bend Moment (End A)	374.7	374.1	345.2	374.1	450.4	450.4	382.7	628.0	452.9	513.5	467.4	538.3	542.2	466.0	477.3	736.7	348.8	348.0	321.4	347.0	450.0	415.1	376.2	616.8	440.6	501.1	452.9	524.9	535.2	460.1	466.3	723.5	736.7 kNm
Line 1 Shear Force (End A)	122.3	122.0	86.8	122.0	196.6	196.6	190.5	261.7	186.9	203.6	192.6	224.7	156.2	167.9	152.4	224.8	103.0	103.0	71.0	103.2	196.7	183.8	185.3	258.7	181.3	197.2	185.5	218.0	156.9	165.7	149.0	221.2	261.7 kN
Line 2 Shear Force (End A)	123.3	122.3	94.4	122.3	185.2	185.2	175.3	256.3	186.9	203.6	192.6	224.7	172.0	175.9	162.6	243.1	105.2	105.1	79.5	105.5	185.8	179.4	170.9	252.3	181.3	197.2	185.5	218.0	172.7	173.7	158.8	239.2	256.3 kN
Line 3 Shear Force (End A)	143.1	142.1	109.1	142.1	172.0	172.0	162.6	243.1	186.9	203.6	192.6	224.7	185.2	181.3	175.3	256.3	123.8	123.3	95.0	122.2	172.7	173.7	158.8	239.2	181.3	197.2	185.5	218.0	185.8	179.4	170.9	252.3	256.3 kN
Line 4 Shear Force (End A)	198.2	197.7	172.2	197.7	156.2	156.2	152.4	224.8	186.9	203.6	192.6	224.7	196.6	185.0	190.5	261.7	185.6	185.1	160.3	184.5	156.9	165.7	149.0	221.2	181.3	197.2	185.5	218.0	196.7	183.8	185.3	258.7	261.7 kN
Line 1 Effective Tension Max	745.0	745.1	658.2	745.1	552.2	552.2	638.0	632.2	405.4	440.0	452.4	416.2	545.2	519.5	655.0	652.6	724.5	725.9	633.7	727.4	537.8	527.5	623.6	648.1	406.9	435.3	457.4	414.2	545.4	524.2	649.2	636.6	745.1 kN
Line 2 Effective Tension Max	745.8	744.9	656.6	744.9	547.2	547.2	642.8	638.2	405.4	440.0	452.4	416.2	542.1	519.2	648.2	645.1	732.6	733.6	635.5	735.5	540.8	525.7	631.5	643.1	406.9	435.3	457.4	414.2	543.5	524.5	640.0	639.6	745.8 kN
Line 3 Effective Tension Max	765.0	763.7	665.8	763.7	542.1	542.1	648.2	645.1	405.4	440.0	452.4	416.2	547.2	519.8	642.8	638.2	763.4	763.3	652.1	765.2	543.5	524.5	640.0	639.6	406.9	435.3	457.4	414.2	540.8	525.7	631.5	643.1	765.2 kN
Line 4 Effective Tension Max	764.7	764.0	654.0	764.0	545.2	545.2	655.0	652.6	405.4	440.0	452.4	416.2	552.2	521.2	638.0	632.2	782.7	782.4	653.9	783.6	545.4	524.2	649.2	636.6	406.9	435.3	457.4	414.2	537.8	527.5	623.6	648.1	783.6 kN
Line 1 Effective Tension Min	-106.4	-104.7	-36.3	-104.7	0.0	0.0	-3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-25.8	-5.4	-90.3	-89.1	-30.8	-88.9	0.0	0.0	-3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-25.0	-1.9	-106.4 kN
Line 2 Effective Tension Min	-81.0	-80.0	-31.9	-80.0	0.0	0.0	-9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-16.8	-1.3	-75.4	-74.4	-28.4	-73.8	0.0	0.0	-9.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-16.2	0.0	-81.0 kN
Line 3 Effective Tension Min	-48.6	-48.9	-27.8	-48.9	0.0	0.0	-16.8	-1.3	0.0	0.0	0.0	0.0	0.0	0.0	-9.6	0.0	-51.1	-51.3	-26.1	-50.5	0.0	0.0	-16.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-9.1	0.0	-51.3 kN
Line 4 Effective Tension Min	-35.3	-35.2	-23.1	-35.2	0.0	0.0	-25.8	-5.4	0.0	0.0	0.0	0.0	0.0	0.0	-3.1	0.0	-44.7	-44.9	-23.7	-45.4	0.0	0.0	-25.0	-1.9	0.0	0.0	0.0	0.0	0.0	0.0	-3.4	0.0	-45.4 kN
Line 1 Curvature	0.079	0.078	0.052	0.078	0.170	0.170	0.155	0.233	0.135	0.156	0.140	0.163	0.144	0.129	0.120	0.198	0.070	0.070	0.045	0.070	0.167	0.139	0.147	0.229	0.132	0.153	0.136	0.159	0.144	0.127	0.118	0.194	0.2330 4.3 m
Line 2 Curvature	0.071	0.070	0.056	0.070	0.163	0.163	0.139	0.221	0.135	0.156	0.140	0.163	0.155	0.133	0.128	0.208	0.062	0.061	0.048	0.062	0.161	0.136	0.135	0.217	0.132	0.153	0.136	0.159	0.154	0.131	0.126	0.204	0.2208 4.5 m
Line 3 Curvature	0.078	0.077	0.063	0.077	0.155	0.155	0.128	0.208	0.135	0.156	0.140	0.163	0.163	0.138	0.139	0.221	0.067	0.067	0.055	0.067	0.154	0.131	0.126	0.204	0.132	0.153	0.136	0.159	0.161	0.136	0.135	0.217	0.2208 4.5 m
Line 4 Curvature	0.107	0.107	0.099	0.107	0.144	0.144	0.120	0.198	0.135	0.156	0.140	0.163	0.170	0.141	0.155	0.233	0.100	0.099	0.092	0.099	0.144	0.127	0.118	0.194	0.132	0.153	0.136	0.159	0.167	0.139	0.147	0.229	0.2330 4.3 m

SECONDARY MODEL – DESIGN CONDITION RESULTS (SM1-SM32)

	LOAD CASE (SM)																																Max
DESCRIPTION	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	
Line 1 End Force (End A) Max	806.8	807.3	709.5	807.8	652.0	652.0	679.6	734.7	455.6	500.7	523.0	494.0	619.8	601.9	697.7	741.2	711.9	784.8	682.1	785.6	634.6	625.3	680.9	759.7	453.4	493.9	528.2	483.7	629.5	607.5	697.7	721.8	807.8 kN
Line 2 End Force (End A) Max	804.8	804.9	711.7	805.2	641.5	641.5	681.5	734.8	455.6	500.7	523.0	494.0	631.0	606.1	684.6	737.2	711.3	790.3	687.6	790.6	633.7	618.8	685.1	744.4	453.4	493.9	528.2	483.7	632.2	612.8	690.6	732.2	805.2 kN
Line 3 End Force (End A) Max	837.8	835.3	727.7	837.2	631.0	631.0	684.6	737.2	455.6	500.7	523.0	494.0	641.5	611.3	681.5	734.8	721.9	830.5	710.3	831.9	632.2	612.8	690.6	732.2	453.4	493.9	528.2	483.7	633.7	618.8	685.1	744.4	837.8 kN
Line 4 End Force (End A) Max	848.8	848.2	724.0	848.7	619.8	619.8	697.7	741.2	455.6	500.7	523.0	494.0	652.0	617.2	679.6	734.7	735.6	859.3	719.3	860.3	629.5	607.5	697.7	721.8	453.4	493.9	528.2	483.7	634.6	625.3	680.9	759.7	860.3 kN
Line 1 End Force (End A) Min	2.0	1.9	16.4	2.7	159.1	159.1	177.0	119.6	249.5	236.0	213.5	181.3	192.6	132.6	73.0	103.5	36.3	1.8	45.8	3.3	163.6	141.7	154.3	114.1	251.4	238.0	217.2	189.9	178.5	138.5	57.6	112.8	1.8 kN
Line 2 End Force (End A) Min	2.2	1.0	42.6	2.1	169.0	169.0	170.9	126.8	249.5	236.0	213.5	181.3	180.0	134.1	157.7	113.7	50.9	1.2	58.5	1.7	170.2	140.5	155.1	123.7	251.4	238.0	217.2	189.9	173.4	139.3	151.9	119.8	1.0 kN
Line 3 End Force (End A) Min	1.7	2.0	67.7	2.6	180.0	180.0	157.7	113.7	249.5	236.0	213.5	181.3	169.0	135.9	170.9	126.8	70.3	1.8	71.0	3.0	173.4	139.3	151.9	119.8	251.4	238.0	217.2	189.9	170.2	140.5	155.1	123.7	1.7 kN
Line 4 End Force (End A) Min	14.1	11.0	69.5	13.8	192.6	192.6	73.0	103.5	249.5	236.0	213.5	181.3	159.1	137.6	177.0	119.6	74.1	4.3	63.4	5.8	178.5	138.5	57.6	112.8	251.4	238.0	217.2	189.9	163.6	141.7	154.3	114.1	4.3 kN
Line 1 Bend Moment (End A)	250.3	250.1	182.1	249.6	602.2	602.2	530.3	837.5	504.4	575.1	521.6	609.1	497.6	468.5	419.8	707.2	165.5	216.3	159.2	214.6	596.5	510.1	521.8	823.5	490.2	560.9	505.3	593.2	496.7	460.6	413.3	694.4	837.5 kNm
Line 2 Bend Moment (End A)	243.5	247.3	208.9	245.3	573.3	573.3	475.3	785.0	504.4	575.1	521.6	609.1	539.0	489.0	446.3	749.1	173.5	208.2	177.9	206.7	569.8	497.2	471.5	771.8	490.2	560.9	505.3	593.2	537.1	481.3	438.4	737.9	785.0 kNm
Line 3 Bend Moment (End A)	284.3	289.7	234.7	284.8	539.0	539.0	446.3	749.1	504.4	575.1	521.6	609.1	573.3	504.4	475.3	785.0	197.2	255.0	205.5	255.4	537.1	481.3	438.4	737.9	490.2	560.9	505.3	593.2	569.8	497.2	471.5	771.8	785.0 kNm
Line 4 Bend Moment (End A)	397.9	398.5	373.8	397.9	497.6	497.6	419.8	707.2	504.4	575.1	521.6	609.1	602.2	516.5	530.3	837.5	318.9	369.4	348.5	370.3	496.7	460.6	413.3	694.4	490.2	560.9	505.3	593.2	596.5	510.1	521.8	823.5	837.5 kNm
Line 1 Shear Force (End A)	121.4	122.1	91.8	121.3	221.3	221.3	191.1	301.0	215.7	237.2	223.6	260.9	176.0	189.2	166.1	257.8	79.3	102.3	74.5	101.1	221.5	207.8	189.2	294.3	209.1	229.7	215.5	253.1	176.5	186.6	162.7	253.3	301.0 kN
Line 2 Shear Force (End A)	129.0	131.1	105.3	130.0	208.9	208.9	181.9	291.3	215.7	237.2	223.6	260.9	194.0	197.9	172.9	277.7	83.6	109.1	88.4	108.5	209.4	201.3	178.7	286.4	209.1	229.7	215.5	253.1	194.6	195.4	170.1	272.9	291.3 kN
Line 3 Shear Force (End A)	152.5	155.5	120.1	152.8	194.0	194.0	172.9	277.7	215.7	237.2	223.6	260.9	208.9	203.5	181.9	291.3	96.3	132.3	104.0	132.7	194.6	195.4	170.1	272.9	209.1	229.7	215.5	253.1	209.4	201.3	178.7	286.4	291.3 kN
Line 4 Shear Force (End A)	214.9	215.5	191.6	215.0	176.0	176.0	166.1	257.8	215.7	237.2	223.6	260.9	221.3	207.8	191.1	301.0	156.1	197.3	178.4	197.3	176.5	186.6	162.7	253.3	209.1	229.7	215.5	253.1	221.5	207.8	189.2	294.3	301.0 kN
Line 1 Effective Tension Max	799.1	799.7	703.2	799.9	638.0	638.0	677.9	708.0	446.7	490.2	499.7	490.5	606.6	590.9	694.2	718.1	708.4	779.2	678.0	780.1	623.0	611.0	674.0	731.9	446.2	484.3	507.8	480.4	617.5	596.2	694.6	699.3	799.9 kN
Line 2 Effective Tension Max	794.3	794.2	703.8	794.7	627.8	627.8	680.0	709.9	446.7	490.2	499.7	490.5	617.7	594.7	683.3	713.5	706.9	782.8	681.9	783.3	621.9	605.8	680.1	719.0	446.2	484.3	507.8	480.4	620.2	600.6	686.9	708.5	794.7 kN
Line 3 Effective Tension Max	822.4	820.4	717.7	821.9	617.7	617.7	683.3	713.5	446.7	490.2	499.7	490.5	627.8	599.0	680.0	709.9	715.9	819.4	702.6	820.6	620.2	600.6	686.9	708.5	446.2	484.3	507.8	480.4	621.9	605.8	680.1	719.0	822.4 kN
Line 4 Effective Tension Max	821.3	820.6	697.8	821.3	606.6	606.6	694.2	718.1	446.7	490.2	499.7	490.5	638.0	603.9	677.9	708.0	719.4	836.7	696.7	837.8	617.5	596.2	694.6	699.3	446.2	484.3	507.8	480.4	623.0	611.0	674.0	731.9	837.8 kN
Line 1 Effective Tension Min	-115.4	-115.7	-36.9	-114.2	0.0	0.0	-2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-20.0	-3.9	-6.5	-97.1	-31.4	-96.0	0.0	0.0	-3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-19.8	-1.5	-115.7 kN
Line 2 Effective Tension Min	-90.0	-88.3	-32.4	-88.1	0.0	0.0	-7.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-13.3	-0.6	-2.8	-80.9	-28.9	-80.7	0.0	0.0	-7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-13.1	0.0	-90.0 kN
Line 3 Effective Tension Min	-51.8	-52.1	-28.2	-51.5	0.0	0.0	-13.3	-0.6	0.0	0.0	0.0	0.0	0.0	0.0	-7.3	0.0	0.0	-54.0	-26.5	-53.5	0.0	0.0	-13.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-7.8	0.0	-54.0 kN
Line 4 Effective Tension Min	-38.4	-37.5	-23.5	-37.5	0.0	0.0	-20.0	-3.9	0.0	0.0	0.0	0.0	0.0	0.0	-2.5	0.0	0.0	-45.8	-25.3	-45.5	0.0	0.0	-19.8	-1.5	0.0	0.0	0.0	0.0	0.0	0.0	-3.4	0.0	-45.8 kN
Line 1 Curvature	0.072	0.071	0.052	0.071	0.188	0.188	0.167	0.263	0.148	0.171	0.153	0.181	0.158	0.141	0.131	0.221	0.047	0.063	0.045	0.062	0.186	0.154	0.164	0.259	0.145	0.168	0.149	0.176	0.157	0.139	0.129	0.217	0.2629 3.8 m
Line 2 Curvature	0.070	0.071	0.060	0.070	0.180	0.180	0.152	0.248	0.148	0.171	0.153	0.181	0.170	0.147	0.140	0.232	0.050	0.059	0.051	0.059	0.178	0.150	0.149	0.244	0.145	0.168	0.149	0.176	0.169	0.145	0.139	0.229	0.2484 4 m
Line 3 Curvature	0.081	0.083	0.067	0.081	0.170	0.170	0.140	0.232	0.148	0.171	0.153	0.181	0.180	0.152	0.152	0.248	0.056	0.073	0.059	0.073	0.169	0.145	0.139	0.229	0.145	0.168	0.149	0.176	0.178	0.150	0.149	0.244	0.2484 4 m
Line 4 Curvature	0.114	0.114	0.107	0.114	0.158	0.158	0.131	0.221	0.148	0.171	0.153	0.181	0.188	0.156	0.167	0.263	0.091	0.106	0.100	0.106	0.157	0.139	0.129	0.217	0.145	0.168	0.149	0.176	0.186	0.154	0.164	0.259	0.2629 3.8 m

SECONDARY MODEL – DESIGN CONDITION RESULTS (SM33-SM64)

	Load Case (PM)		Max		
DESCRIPTION	6	8			
Line 1 End Force (End A) Max	1885.9	2437.5	2437.5	kN	
Line 2 End Force (End A) Max	1900.3	2242.8	2242.8	kN	
Line 3 End Force (End A) Max	1925.0	2207.1	2207.1	kN	
Line 4 End Force (End A) Max	1964.6	2262.1	2262.1	kN	
Line 1 End Force (End A) Min	8.7	3.8	3.8	kN	
Line 2 End Force (End A) Min	16.9	15.4	15.4	kN	
Line 3 End Force (End A) Min	17.0	10.2	10.2	kN	
Line 4 End Force (End A) Min	3.1	5.8	3.1	kN	
Line 1 Bend Moment (End A)	3288.5	3249.8	3288.5	kNm	
Line 2 Bend Moment (End A)	3218.0	3401.1	3401.1	kNm	
Line 3 Bend Moment (End A)	3165.0	3598.2	3598.2	kNm	
Line 4 Bend Moment (End A)	3125.3	3856.9	3856.9	kNm	
Line 1 Shear Force (End A)	1884.2	2208.8	2208.8	kN	
Line 2 Shear Force (End A)	1891.4	2165.3	2165.3	kN	
Line 3 Shear Force (End A)	1903.6	2192.5	2192.5	kN	
Line 4 Shear Force (End A)	1927.7	2260.6	2260.6	kN	
Line 1 Effective Tension Max	1549.9	2290.1	2290.1	kN	
Line 2 Effective Tension Max	1588.3	2023.9	2023.9	kN	
Line 3 Effective Tension Max	1634.9	1920.3	1920.3	kN	
Line 4 Effective Tension Max	1692.9	1901.0	1901.0	kN	
Line 1 Effective Tension Min	-280.2	-429.6	-429.6	kN	
Line 2 Effective Tension Min	-306.8	-380.5	-380.5	kN	
Line 3 Effective Tension Min	-334.4	-381.5	-381.5	kN	
Line 4 Effective Tension Min	-363.6	-548.6	-548.6	kN	
Line 1 Curvature	0.940	0.929	0.9397	1.1	m
Line 2 Curvature	0.920	0.971	0.9715	1	m
Line 3 Curvature	0.905	1.028	1.0278	1	m
Line 4 Curvature	0.893	1.102	1.1016	0.9	m

PRIMARY MODEL - SURVIVAL CONDITION RESULTS

	LOAD CASE (SM)																																Max		
DESCRIPTION	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64			
Line 1 End Force (End A) Max	1490.9	1282.6	1602.8	1341.9	1261.1	1261.1	844.5	982.2	1054.7	1003.3	931.7	875.2	971.8	647.7	695.3	879.1	1429.6	1240.7	1479.5	1270.2	1230.0	765.8	821.7	955.3	1022.0	978.4	908.4	849.1	934.0	632.2	673.8	849.9	1602.8	kN	
Line 2 End Force (End A) Max	1365.4	1287.0	1456.8	1442.4	1169.8	1169.8	791.7	952.4	1054.7	1003.3	931.7	875.2	1074.8	687.3	739.2	919.7	1367.5	1262.7	1452.3	1402.6	1138.9	723.0	770.4	924.2	1022.0	978.4	908.4	849.1	1040.6	678.8	718.9	890.2	1456.8	kN	
Line 3 End Force (End A) Max	1404.5	1298.8	1480.7	1426.3	1074.8	1074.8	739.2	919.7	1054.7	1003.3	931.7	875.2	1169.8	732.7	791.7	952.4	1434.3	1305.7	1461.8	1414.3	1040.6	678.8	718.9	890.2	1022.0	978.4	908.4	849.1	1138.9	723.0	770.4	924.2	1480.7	kN	
Line 4 End Force (End A) Max	1263.8	1243.6	1376.2	1368.6	971.8	971.8	695.3	879.1	1054.7	1003.3	931.7	875.2	1261.1	776.7	844.5	982.2	1309.2	1259.4	1413.7	1377.7	934.0	632.2	673.8	849.9	1022.0	978.4	908.4	849.1	1230.0	765.8	821.7	955.3	1413.7	kN	
Line 1 End Force (End A) Min	17.4	7.3	3.6	18.7	180.7	180.7	157.7	150.1	121.0	107.0	107.4	128.7	163.7	193.5	192.0	168.1	14.2	8.1	7.5	18.4	160.7	122.1	167.8	132.5	125.6	112.8	108.2	133.5	192.6	193.2	174.2	169.1	3.6	kN	
Line 2 End Force (End A) Min	4.7	1.0	2.5	3.7	176.8	176.8	168.1	155.2	121.0	107.0	107.4	128.7	174.6	165.1	179.2	161.2	2.4	4.7	2.9	4.3	171.3	143.0	169.3	143.7	125.6	112.8	108.2	133.5	180.6	166.5	171.3	155.7	1.0	kN	
Line 3 End Force (End A) Min	1.4	3.3	2.7	2.7	174.6	174.6	179.2	161.2	121.0	107.0	107.4	128.7	176.8	142.5	168.1	155.2	3.1	2.3	7.4	2.3	180.6	166.5	171.3	155.7	125.6	112.8	108.2	133.5	171.3	143.0	169.3	143.7	1.4	kN	
Line 4 End Force (End A) Min	1.8	1.4	0.4	1.2	163.7	163.7	192.0	168.1	121.0	107.0	107.4	128.7	180.7	123.5	157.7	150.1	2.0	2.2	1.6	1.2	192.6	193.2	174.2	169.1	125.6	112.8	108.2	133.5	160.7	122.1	167.8	132.5	0.4	kN	
Line 1 Bend Moment (End A)	1625.2	1565.1	1537.5	1569.5	2567.9	2567.9	1778.8	2192.9	2226.9	1784.4	1852.8	1833.6	2092.2	1758.5	1582.3	1959.3	1544.6	1479.8	1511.3	1538.4	2557.0	1835.2	1755.4	2159.9	2176.8	1753.3	1823.4	1793.1	2046.0	1743.3	1566.1	1924.5	2567.9	kNm	
Line 2 Bend Moment (End A)	1517.5	1568.4	1519.7	1614.5	2424.0	2424.0	1714.6	2138.4	2226.9	1784.4	1852.8	1833.6	2266.3	1816.2	1639.9	2057.6	1485.3	1514.5	1511.4	1564.3	2404.4	1827.5	1685.7	2103.4	2176.8	1753.3	1823.4	1793.1	2234.5	1798.2	1608.6	2023.7	2424.0	kNm	
Line 3 Bend Moment (End A)	1646.5	1623.3	1678.3	1726.8	2266.3	2266.3	1639.9	2057.6	2226.9	1784.4	1852.8	1833.6	2424.0	1848.5	1714.6	2138.4	1662.9	1596.2	1675.2	1713.5	2234.5	1798.2	1608.6	2023.7	2176.8	1753.3	1823.4	1793.1	2404.4	1827.5	1685.7	2103.4	2424.0	kNm	
Line 4 Bend Moment (End A)	1662.8	1826.3	1818.0	1854.2	2092.2	2092.2	1582.3	1959.3	2226.9	1784.4	1852.8	1833.6	2567.9	1856.9	1778.8	2192.9	1681.9	1785.5	1821.6	1833.0	2046.0	1743.3	1566.1	1924.5	2176.8	1753.3	1823.4	1793.1	2557.0	1835.2	1755.4	2159.9	2567.9	kNm	
Line 1 Shear Force (End A)	963.6	911.7	972.6	912.2	1257.3	1257.3	799.7	966.1	1045.5	910.1	879.3	820.4	950.8	645.4	656.9	863.3	936.5	847.7	942.6	862.5	1227.0	722.7	776.8	939.8	1012.8	886.7	857.4	796.4	918.3	629.6	636.6	835.9	1257.3	kN	
Line 2 Shear Force (End A)	872.9	910.8	957.9	981.9	1162.9	1162.9	749.9	945.9	1045.5	910.1	879.3	820.4	1061.3	665.2	706.5	914.6	877.8	879.7	950.4	952.6	1132.4	683.9	729.2	917.0	1012.8	886.7	857.4	796.4	1027.5	648.3	683.5	885.9	1162.9	kN	
Line 3 Shear Force (End A)	1012.0	962.2	1026.9	1060.9	1061.3	1061.3	706.5	914.6	1045.5	910.1	879.3	820.4	1162.9	694.4	749.9	945.9	1029.0	950.6	1028.5	1049.2	1027.5	648.3	683.5	885.9	1012.8	886.7	857.4	796.4	1132.4	683.9	729.2	917.0	1162.9	kN	
Line 4 Shear Force (End A)	970.2	999.7	1085.6	1038.4	950.8	950.8	656.9	863.3	1045.5	910.1	879.3	820.4	1257.3	735.6	799.7	966.1	1000.1	979.5	1098.2	1057.2	918.3	629.6	636.6	835.9	1012.8	886.7	857.4	796.4	1227.0	722.7	776.8	939.8	1257.3	kN	
Line 1 Effective Tension Max	1421.2	1206.2	1562.4	1259.2	927.5	927.5	651.5	674.3	778.9	823.5	711.2	691.4	692.7	493.0	513.9	613.1	1357.6	1162.2	1398.5	1178.9	886.2	598.0	630.1	650.8	751.5	799.7	688.9	668.0	654.1	491.8	501.3	584.8	1562.4	kN	
Line 2 Effective Tension Max	1282.5	1191.4	1374.1	1353.7	853.4	853.4	606.5	657.3	778.9	823.5	711.2	691.4	776.1	522.6	560.9	638.4	1284.5	1169.6	1368.9	1313.8	814.7	559.2	587.7	632.2	751.5	799.7	688.9	668.0	737.5	522.6	545.1	611.2	1374.1	kN	
Line 3 Effective Tension Max	1309.5	1194.8	1440.1	1319.0	776.1	776.1	560.9	638.4	778.9	823.5	711.2	691.4	853.4	562.6	606.5	657.3	1339.3	1206.4	1421.8	1308.2	737.5	522.6	545.1	611.2	751.5	799.7	688.9	668.0	814.7	559.2	587.7	632.2	1440.1	kN	
Line 4 Effective Tension Max	1147.5	1112.7	1258.2	1247.1	692.7	692.7	513.9	613.1	778.9	823.5	711.2	691.4	927.5	603.7	651.5	674.3	1197.4	1137.5	1295.6	1258.8	654.1	491.8	501.3	584.8	751.5	799.7	688.9	668.0	886.2	598.0	630.1	650.8	1295.6	kN	
Line 1 Effective Tension Min	-286.8	-244.4	-349.1	-267.2	-71.4	-71.4	-34.3	-65.4	-57.5	0.0	-3.8	-19.7	-0.8	-63.6	-0.7	-12.3	-269.7	-228.7	-285.0	-247.2	-80.8	-97.2	-21.7	-63.6	-47.6	0.0	0.0	-16.6	0.0	-62.1	-4.9	-24.3	-349.1	kN	
Line 2 Effective Tension Min	-246.8	-221.4	-320.9	-242.9	-22.1	-22.1	-19.2	-49.0	-57.5	0.0	-3.8	-19.7	0.0	-76.8	-5.0	-30.0	-241.1	-212.6	-295.0	-229.7	-26.3	-88.8	-16.4	-47.1	-47.6	0.0	0.0	-16.6	0.0	-77.2	-10.7	-28.5	-320.9	kN	
Line 3 Effective Tension Min	-211.5	-208.8	-296.9	-214.5	0.0	0.0	-5.0	-30.0	-57.5	0.0	-3.8	-19.7	-22.1	-88.7	-19.2	-49.0	-214.9	-205.6	-278.5	-207.3	0.0	-77.2	-10.7	-28.5	-47.6	0.0	0.0	-16.6	-26.3	-88.8	-16.4	-47.1	-296.9	kN	
Line 4 Effective Tension Min	-224.3	-225.5	-277.0	-226.9	-0.8	-0.8	-0.7	-12.3	-57.5	0.0	-3.8	-19.7	-71.4	-99.4	-34.3	-65.4	-240.3	-232.4	-275.1	-227.5	0.0	-62.1	-4.9	-24.3	-47.6	0.0	0.0	-16.6	-80.8	-97.2	-21.7	-63.6	-277.0	kN	
Line 1 Curvature	0.464	0.449	0.439	0.458	0.734	0.734	0.510	0.627	0.636	0.510	0.531	0.529	0.598	0.538	0.485	0.560	0.445	0.442	0.432	0.448	0.731	0.568	0.509	0.617	0.622	0.501	0.524	0.519	0.585	0.537	0.481	0.550	0.7337	1.36	m
Line 2 Curvature	0.434	0.452	0.434	0.461	0.693	0.693	0.500	0.611	0.636	0.510	0.531	0.529	0.648	0.555	0.494	0.588	0.424	0.435	0.432	0.447	0.687	0.563	0.499	0.601	0.622	0.501	0.524	0.519	0.638	0.553	0.491	0.578	0.6926	1.44	m
Line 3 Curvature	0.470	0.464	0.480	0.493	0.648	0.648	0.494	0.588	0.636	0.510	0.531	0.529	0.693	0.566	0.500	0.611	0.475	0.456	0.479	0.490	0.638	0.553	0.491	0.578	0.622	0.501	0.524	0.519	0.687	0.563	0.499	0.601	0.6926	1.44	m
Line 4 Curvature	0.475	0.522	0.519	0.530	0.598	0.598	0.485	0.560	0.636	0.510	0.531	0.529	0.734	0.572	0.510	0.627	0.481	0.510	0.520	0.524	0.585	0.537	0.481	0.550	0.622	0.501	0.524	0.519	0.731	0.568	0.509	0.617	0.7337	1.36	m

SECONDARY MODEL – SURVIVAL CONDITION RESULTS (SM33-SM64)

EMSTEC GmbH
Gewerbering 8
22113 Oststeinbek
Germany
Tel.: +49 (0) 40 79686 345
Fax: +49 (0) 40 79686 702
info@emstec.net
sales@emstec.net
www.emstec.net

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Project:	**Coral South Development FLNG**
Client:	**KBR**
Document Title:	**Seawater Intake Riser FEED -** **Technical Note - Hydrodynamic Analysis**

Emstec DocNo: Client Doc No.:	**P13919-RL-100**	Rev:	**A**

CONTENTS

1 INTRODUCTION

The Seawater Intake Riser System proposed for the Coral South Development FLNG consists of 4-off 36"NB Seawater Intake Risers, 135m in length, supported from the underside of the FLNG by a fixed riser head arrangement.

To confirm the suitability of the Seawater Intake Riser Hose strings, it was necessary to perform a hydrodynamic analysis of the Seawater Intake Riser system. For details of the analysis refer to Document No. 4404YYBNRZ1907K (P13919-RL-001) Hydrodynamic Analysis Report [1], which was carried out using software package Orcaflex, developed by Orcina Ltd (www.orcina.com) specifically for analysis of flexible lines in the offshore environment.

Additional load cases to those originally specified have since been provided by KBR [2] for analysis.

This technical note supplements the Hydrodynamic Analysis Report [1] and has been prepared to report the findings from the analysis of these additional load cases as advised by KBR.

2 INPUT DATA

2.1 MODEL

The primary model, as detailed in [1], was used for the additional load cases.

2.2 SYSTEM CONFIGURATION

The seawater intake hose string configuration as detailed in [1], was used for the additional load cases.

2.3 ENVIRONMENTAL DATA – DESIGN CONDITION

The environmental data for the Design Condition as detailed in [1], was used for the additional load cases.

The additional load cases were advised as:

Case	Current	Wave	Wind	
A	0^{o}	0^{o}	45^{o}	Direction convention as per Orcaflex
B	180^{o}	0^{o}	45^{o}	Direction convention as per Orcaflex
C	180^{o}	0^{o}	135^{o}	Direction convention as per Orcaflex

Table 2.3 : Additional Load Cases provided for analysis [2]

The variables in table 2.3 were set in the primary model and a 10,800s JONSWAP wave packet was selected. A build up period of 500 seconds was defined prior to the main simulation to ensure that any sudden transients were avoided.

The analysis was then repeated for each of the above load cases using a different 'seed' for the JONSWAP wave pattern, so that an alternate random wave pattern was generated.

3 FINDINGS

It was found that during the analysis, there were some occurrences in the random wave profile where the vessel entered into a severe 'roll'.

The consequence of this was that the flexible hose strings did not respond with the same rotational velocity as the vessel, causing the top hoses in the string to incur a higher level of bending.

The outputs showed that the bending at these occurrences was approximately 3 x ID of the hose. Consequently the bending moment into the hull was also increased, when compared to the results presented in [1].

There were approximately 2-3 such occurrence in the simulations, Load Case C appearing to be the most onerous.

The tension in the hose was also increased when compared to the results presented in [1].

A comparison of the findings from the Initial Load Cases and the Additional Load Cases is presented below:

Analysis	Minimum Bend Radius	Bending Moment	Tension
Initial Load Cases	3.65m (ID x 4.0)	889.1kNm	860.3kN
Additional Load Cases	2.6m (ID x 2.9)	1238kNm	1146kN

Table 3: Comparison of Findings from Initial Load Cases and Additional Load Cases

4 DISCUSSIONS

Firstly, the increase in tension is of no concern as it is well within the hose axial strength of 4946kN. Similarly, the increase in bending moment is well below the bending moment reported for the survival condition (i.e. 3856kNm) and which can be accommodated by the Riser Seat / Riser Head.

However, the findings showed that the minimum bend radius (MBR) of the hose occasionally reduced to ~3 x ID during the additional analysis which is greater than the recommended allowable MBR of 4 x ID.

Two points should be noted in regard to this:

i) The proposed hose design can accommodate occasional occurrences of an MBR of 3 x ID without incurring permanent damage.
ii) The proposed hose design is bespoke for this application and can be amended to provide a higher stiffness value (EI) if required.

If the additional load cases where considered to be realistic and likely scenarios, Emstec would suggest that the hose stiffness is increased such that the MBR did not exceed 4 x ID of the hose.

The hose stiffness value used for the analysis is a nominal value for a full hose section and is determined using the technique provided by OCIMF [3]. In practice, the hose has built in steel nipples at either end which provides the hose end with a rigid length. The section of hose between the rigid end and the 'flexible' body of the hose is transitioned which creates a region with a higher stiffness. This transition is considered in the analysis.

REFERENCES

[1] Document No. 4404YYBNRZ1907K (P13919-RL-001) Hydrodynamic .Analysis Report

[2] E-mail (Panda / Craig – 10.03.15)

[3] Oil Companies International Marine Forum, 2009. *Guide to Manufacturing and Purchasing Hoses for Offshore Moorings*. Guideline. Edinburgh: Witherby Seamanship International

COMMENTS SHEET

Document Title	SEA WATER INTAKE RISERS – CLASH ANALYSIS NOTE
Company Document Number and Revision	4404YYBNRZ1905K - CD-FE - 00
Contractor Document Number and Revision	
Transmittal IN Number	IN-4404-KBR-ENI-01349
Transmittal OUT Number	OUT-4404-ENI-KBR-00287
Transmittal OUT Date	08/04/2015
Approval Status Code	B - APPROVED WITH COMMENTS
Eni Document Approver	FT KBR PE - Beresford-Lambert James

Note: "COMPANY's approval of this document has to be deemed just as an authorization to proceed with the project execution.
CONTRACTOR is aware that COMPANY's approval is not relieving CONTRACTOR from any of its responsibilities in the performances required by the CONTRACT"

(*)

A	APPROVED
B	APPROVED WITH COMMENTS
C	NOT APPROVED

Comments:

DISCIPLINE	COMMENTS	CONTRACTOR'S REPLY (IF ANY)
CT Marine	No Comments Closed by: Halligan James Closed Date: 03/27/2015 10:02 AM	
FT KBR Mechanical-Machinery-Piping	No Comments. Closed by: Caulfield Kevin Closed Date: 03/25/2015 11:35 AM	
FT KBR Naval (Focal Point)	1. Page 3, Sec. 3.3. Please change 'Return' to 'Return Period or RP'. 2. Page 4, Sec. 2. All data used for the clash should be represented in the report. Only referring the other document is not acceptable for	1. Noted 2. References to other documents are made so that data is not duplicated and that in the event of a revision, only one document needs to be revised, (also reducing the risk of conflicting data). Please reconsider, however, if required, all data can be included within the report.

	Vessel Data, SWIR and Environment Condition.	
	3. Page 6, Please change 'KBR' to 'KD'.	3. Noted
	4. Page 6, Sec. 2.4.6. Please clarify that what is the CD value used for marine foulding.	4. Noted. The Drag Coefficients are addressed in ref. Doc No. 4404YYBNRZ1907K (Hydrodynamic .Analysis Report) Section 2.3.3
	5. Please clarify that is reduced drag force due to shielding effects used for the analysis? If you consider it, the clash energies are likely to be increased.	5. The shielding effect is considered in Orcaflex using the WAKE function. Section 3.2.1 provides an explanation.
	6. Please clarify that which Contents Method of Orcaflex is used for the clash analysis.	6. Contents were considered as 'Free Flooding'
	7. Please clarify that API 17J is considered as reference/codes & regulations or not.	7. The proposed hose is a bonded flexible pipe. API 17J applies to unbonded flexible pipe and is therefore not applicable.
	8. Please attach native analysis input file (YNL file) to the report.	8. Noted. File format from Orcaflex is .dat
	9. Microsoft native file of the report shall be submitted according to the contract.	9. Noted
	10. Will full or model scale clash test be perform in order to validate the analysis results or get certificate in EPCE phase?	10. Emstec propose two approaches to validate the integrity of the hose structure. Firstly, we would investigate the effect of impact using the FE model established for this hose design and secondly, as a part of the hose qualification programme, we would propose incorporating an impact test whereby the prototype hose would be subject to an impact of the magnitude determined from the analysis.
	Closed by: Kang Daehoon Closed Date: 04/08/2015 03:41 PM	

EMSTEC GmbH
Gewerbering 8
22113 Oststeinbek
Germany
Tel.: +49 (0) 40 79686 345
Fax: +49 (0) 40 79686 702
info@emstec.net
sales@emstec.net
www.emstec.net

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01	15.04.15	IC	RR	BB	Issued for Design
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Project:	**Coral South Development FLNG**
Client:	**KBR**
Document Title:	**Seawater Intake Riser FEED - Clash Analysis Report**
Emstec DocNo: Client Doc No.:	**P13919-RL-002 4404YYBNRZ1905K**
Rev:	**01**

CONTENTS

1 INTRODUCTION

The Seawater Intake Riser System proposed for the Coral South Development FLNG consists of 4-off 36"NB Seawater Intake Risers, 135m in length, supported from the underside of the FLNG by a fixed riser head arrangement.

To assess the potential clashing of the Seawater Intake Riser Hose strings, it was necessary to perform a hydrodynamic analysis of the Seawater Intake Riser system. For details of the analysis refer to Document No. 4404YYBNRZ1907K (P13919-RL-001) Hydrodynamic .Analysis Report [1], which was carried out using software package Orcaflex, developed by Orcina Ltd (www.orcina.com) specifically for analysis of flexible lines in the offshore environment.

This report has been prepared to outline the clash data extracted from the analysis and any further considerations and to and report the results and conclusions.

1.1 EXECUTIVE SUMMARY

Clash data was extracted from the Hydrodynamic Analysis of the DESIGN CONDITION (100yr Return Period).

Further analysis was undertaken in relation to the NORMAL OPERATING CONDITION (1yr Return Period), and the Clash data extracted.

From both analyses, it was shown that under certain combination of Wave and Current direction, the hoses do clash (DNV refer to these events as collisions).

The clash force and energy values recorded are presented and, while further analysis would be required to quantify the impact of the clash values, a solution is proposed to ensure that the clashing does not damage the Sea Water Intake Riser components.

1.2 METHODOLOGY

Refer to Appendix A for the methodology applied for the Hydrodynamic Analysis.

2 INPUT DATA

2.1 VESSEL DATA

2.1.1 FLNG Particulars

The primary model for the Coral South Development FLNG was received from the Client as an Orcaflex data file (.dat) and which included the vessel data.

The secondary model for the Coral South Development FLNG was modelled in Orcaflex with the characteristics provided and which are reproduced below:

Hull overall length	425.0m
Breadth moulded	68.0m
Depth moulded	36.2m
Camber	0.5m
Ballast Draft	15.2m

Table 2.1.1 FLNG Particulars

2.1.2 Response Amplitude Operators (RAO)

The primary model for the Coral South Development FLNG was received from the Client as an Orcaflex data file (.dat) and which included the vessel RAO data.

For the secondary model, a full set of vessel RAO's provided by the Client were used and which included three environmental conditions, namely; 1yr RP Non Cyclonic, 100yr RP Cyclonic, and 10,000yr RP cyclonic, each with an RAO data set for the BALLAST and FULL draft conditions giving a total of six RAO Data sets.

For each loading condition, the COG / RAO origin was advised as:

Load Case	Draft (m)	X (m forward of AP)	Y (m from CL, + to P)	Z (m AB)
Ballast	15.2	211.41	0	19.89
Full Load	16	211.26	0	22.695

Table 2.1.2 - Vessel COG/RAO Origin

Refer to Doc No. 4404YYBNRZ1907K (Hydrodynamic .Analysis Report) [1] Section 2.1

2.2 SEAWATER INTAKE RISER HOSE DATA

Each Seawater Suction Hose string assembly model consists of:

Section	Qty per Riser	I/D (mm)	O/D (mm)	Section Length (m)	Mass in Air (kg)	Weight in Water (kg)	Axial Strength (kN)	Min. Bend Radius (mm)
Steel Riser Head	1	N/A	N/A	N/A	1900	1652	N/A	N/A
Hose Section	14	900	1060	9.7	4500	2083	~4946	3600
Steel Strainer	1	1040	1060	3.75	970	845	N/A	N/A
Flange Connections	14	N/A	N/A	N/A	150	130	N/A	N/A

Table 2.2 – Hose String Composition

2.2.1 Overall hose string properties

- Total Length of Intake Riser: 139.55m
- Total Weight of Intake Riser in Air:

Riser Head	1900kg	+
Hose Sections	14 x 4500kg	+
Strainer	970kg	+
Flange Connections	14 x 150kg	
Total:	**67,970 kg**	

- Total Weight of Intake Riser in Water:

Riser Head	1652kg	+
Hose Sections	14 x 2083kg	+
Strainer	845kg	+
Flange Connections	14 x 130kg	
Total:	**33,479 kg**	

The following flexible hose stiffness properties were used for the hydrodynamic analysis :

Bending Stiffness: 1,735 kN/m^2

Axial Stiffness: 12,000 kN,

Note: the above values can be used as a guideline and can be optimized to suit configuration.

Refer to Doc No. 4404YYBNRZ1907K (Hydrodynamic .Analysis Report) [1] Section 2.2

2.3 SYSTEM CONFIGURATION

2.3.1 Seawater Intake Riser Locations

The Seawater Intake Risers assemblies are connected to the lower end of the Seawater Caissons at the below locations.

The 4-off caissons are arranged in a single transverse row, 2.5m forward of FLNG Frame 60. The two inboard caissons are equi-spaced about the vessel centreline, 6.96m apart with the Port and Starboard outboard caissons spaced 7.13m from the inboard caissons. The lower edge of the caisson is at the Hull Bottom level (refer to drawing no. 4404YYBNRZ1927K [Emstec No.: P13919-DE-001] : General Arrangement)

This translates to the following coordinates relative to the vessel local origin, i.e. midships (x), on centerline (y) and Ballast draft line (z):

Seawater Intake Riser		Line 1	Line 2	Line 3	Line 4
Connection Location (from Vessel Origin)	x	-150.00m	-150.00m	-150.00m	-150.00m
	y	-10.61m	-3.48m	3.48m	10.61m
	z	-15.20m	-15.20m	-15.20m	-15.20m

Table 2.3.1 – Seawater Intake Riser Coordinates

2.3.2 Seawater Intake Riser Assemblies

The flexible pipe string assemblies were modelled as flexible elements with sufficient nodal points to allow curvature. The strainer was modelled as a section of straight pipe whereas the riser head and flange connections were modelled as clump weights of appropriate mass and volume. The flange connections were modelled with a normal drag area equal to the protruding area of a 36"NB flange.

Damping is set to zero since, within broad limits, structural damping has little influence on the results of the hydrodynamic simulation unless the system is subject to very rapid variations in tension or bending. Additionally, such damping is negligible compared to the damping applied by hydrodynamic resistance in submarine hoses

2.3.3 Drag Coefficients

The normal drag coefficient (Cd) is dependent upon the Reynolds number (Re), which in turn is a function of the surface roughness and diameter of the hose, as well as the fluid flow velocity. Using the technique provided within ESDU 80025, the Cd values were determined for the corresponding Re number for the hose sections.

Surface roughness values used to calculate the Drag Coefficients were specified as:

Rubber Hose = 3mm (value similar to concrete given in [6] Table 6-1)

The Cd values were input into Orcaflex which calculates the Reynolds number and applies the corresponding Cd for any given fluid velocity.

The strainer value was set at Cd = 1.0 based upon drag coefficients for perforated cylinders as specified in [8] Figure 6.

Axial drag coefficient was set as a constant 0.008 for plain pipe.

The flange connections modelled as clump weights and a drag area equal to the protruding flange specified and an axial drag coefficient of 1.9 [6] Table E-1 applied for the vertical direction.

For marine growth covered hose sections (ref. Section 2.4.7), the surface roughness was specified as 20mm, which is within the values specified in [6] Table 6-1.

Refer to Doc No. 4404YYBNRZ1907K (Hydrodynamic .Analysis Report) [1] Section 2.3

2.4 ENVIRONMENTAL DATA – DESIGN CONDITION

The Design Basis, specifies the following environmental conditions to be considered for the listed conditions:

	Current	Waves	Wind
Design Condition	100 yr (cyclonic) RP	100 yr (cyclonic) RP	100 yr (cyclonic) RP
Survival Condition	10,000 yr (cyclonic) RP	10,000 yr (cyclonic) RP	10,000 yr (cyclonic) RP

Table 2.4: Environment Conditions

The metocean data provided by KD included the Current, Waves and Wind data for the listed conditions.

2.4.1 Direction Convention

The below direction convention is used:

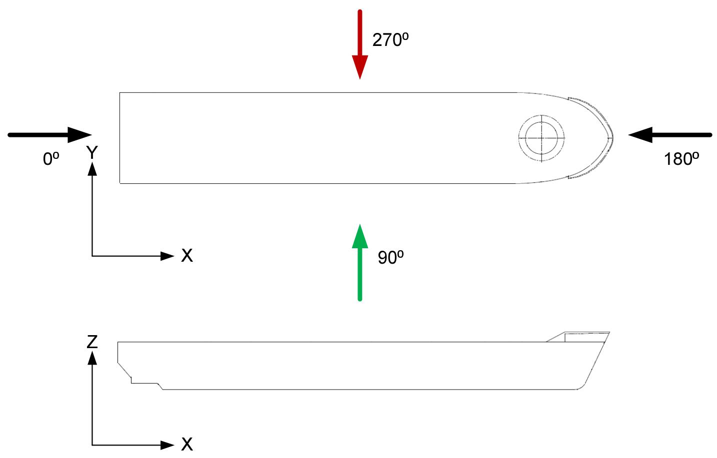


Fig. 3 – Direction Convention

2.4.2 Current and Wave Directions

The Design Basis , specifies the following combinations of current and wave directions to be considered.

Current orientation	Waves orientation
90	270
180	135
180	180
180	225

Table 2.4.2 Current and Wave Combinations

2.4.3 Current

The 100yr Cyclonic RP (Design) current conditions are considered and are reproduced:

Current velocity extremes (m/s)						
C1	Return period (years)					
% Water depth	20	100	200	500	1000	10000
0.3 (surface)	0.36	1.26	1.66	2.11	2.44	3.67
1	0.29	1.14	1.52	1.95	2.27	3.47
2	0.19	0.93	1.28	1.68	1.97	3.10
5	0.12	0.76	1.07	1.44	1.72	2.77
11	0.04	0.46	0.70	0.99	1.21	2.10
16	0.01	0.28	0.45	0.68	0.85	1.58
44	-	0.02	0.05	0.10	0.15	0.39
66	-	0.00	0.01	0.02	0.04	0.13
88	-	-	0.00	0.01	0.01	0.04
99 (4m abs)	-	-	0.00	0.00	0.00	0.02
99 (1m abs)	-	-	-	0.00	0.00	0.02

Table 2.4.3 Omnidirectional Cyclonic Current Extremes at C1

2.4.4 Waves

The 100yr Cyclonic RP (Design) wave conditions are considered and are reproduced below:

dir(°N)	100		
	Hs(m)	Hmax(m)	Tp(s)
Omni	**14.16**	**24.68**	**13.75**
0	4.11*	7.34*	8.29*
30	6.57	11.60	10.26
60	12.46	21.75	13.14
90	13.42	23.28	13.95
120	14.16	24.68	13.75
150	13.95	24.28	13.80
180	13.14	22.88	13.55
210	8.82	15.21	12.96
240	-	-	-
270	-	-	-
300	-	-	-
330	-	-	-

Table 2.4.4 Offshore location: wave cyclonic extremes

Note: Omnidirectional Values are used

It was further advised that:

"Where applying a wave heading of 90 or 270 degrees, in cyclonic cases, a significant wave height of 60% of the significant wave height at 180 degrees will be used"

This applies to the following combination:

Current orientation	Waves orientation
90	270

For the 100yr Cyclonic Condition, the corresponding Tp was advised as 10.65s .

2.4.5 Wave Spectra

During large storms (i.e. Design Condition and Survival Condition), the spectra can be represented by JONSWAP wind Sea spectra, therefore JONSWAP spectrum is considered for the analysis.

The γ coefficient for the spectral peakedness parameter for storm waves was set at 1.4.

2.4.6 Wind

The 100yr Cyclonic RP (Design) wind speeds considered and are reproduced below:

Return Period (years)	Ws (m/s)
20	27
100	36
200	40
500	42
1000	45
10000	56

Table 2.4.6 Cyclonic extreme winds (offshore point 41.00°E 10.48°S) 10m–10minutes average

Wind was applied from the same direction as the waves and for the primary model only as this considers second order motions.

The secondary model considers first order motions only.

2.4.7 Marine Fouling

Marine Growth data provided by KD [5] was considered and is reproduced below:

"4.13 MARINE GROWTH

The climax marine growth thickness profile is estimated to be 100mm from +2m to -10m, decreasing linearly to 25mm at 65m, with no growth below 65m."

The density of the Marine Growth was assumed to be 1325kg/m^3 as recommend by [6] Section 6.7.4

Refer to Doc No. 4404YYBNRZ1907K (Hydrodynamic .Analysis Report) [1] Section 2.4

2.5 ENVIRONMENTAL DATA – NORMAL OPERATING CONDITION

In addition to the DESIGN CONDITION, a further condition was considered to for the Clash Analysis which considered the NORMAL OPERATING CONDITION of the vessel. The NORMAL OPERATING CONDITION data is presented below.

2.5.1 Current and Wave Directions

The current and wave combination that incurred clashing is shown in the below extract from the Design Basis [2] Table 5-3 (corrected by [4]):

Current orientation	Waves orientation
90	270

Ref. [2] Extract from Table 5-3 Current and Wave Combinations (including correction [4])

2.5.2 Current

For the NORMAL OPERATING CONDITION, the 1yr Non Cyclonic RP extreme current profile provided in [5] Tables 2-8 are considered and are reproduced:

Return Period 1 Year											
Level	% Water depth	0.3 (surface)	1	2	5	11	16	44	66	88	99 (4m abs)
L10	0.3 (surface)	1.79	1.65	1.21	0.87	0.39	0.28	0.16	0.12	0.07	0.05
L9	1	1.69	1.74	1.27	0.91	0.4	0.29	0.17	0.12	0.07	0.05
L8	2	1.13	1.18	1.48	1.05	0.43	0.31	0.17	0.13	0.07	0.05
L7	5	0.89	0.93	1.17	1.32	0.5	0.34	0.19	0.13	0.07	0.05
L6	11	0.49	0.52	0.65	0.68	0.82	0.51	0.24	0.15	0.07	0.05
L5	16	0.42	0.45	0.57	0.58	0.64	0.72	0.32	0.18	0.07	0.05
L4	44	0.34	0.36	0.46	0.44	0.4	0.42	0.69	0.33	0.07	0.05
L3	66	0.33	0.35	0.44	0.42	0.36	0.36	0.55	0.56	0.08	0.05
L2	88	0.29	0.31	0.39	0.36	0.24	0.22	0.16	0.14	0.36	0.06
L1	99 (4m abs)	0.29	0.31	0.39	0.36	0.24	0.22	0.16	0.14	0.12	0.3

Ref. [5] Table 2-8 1 year current extremes profile

2.5.3 Waves

For the NORMAL OPERATING CONDITION, the 1yr Non Cyclonic total wave extremes provided in [5] Tables 2-3 are considered and are reproduced:

		1				
Dir (°N)	%	Hs(m)	Hmax(m)	Tp(s)	Tp5%(s)	Tp95%(s)
Omnidir	100.00	4.26	7.45	9.72	8.14	11.98
0	2.68	2.87	5.02	9.28	7.60	11.55
30	10.75	2.40	4.19	9.52	7.60	12.11
60	10.89	2.06	3.57	10.32	7.56	14.25
90	19.95	2.89	5.02	10.36	8.62	12.58
120	24.09	3.39	5.91	9.73	8.07	11.99
150	27.28	4.05	7.08	9.65	7.86	12.34
180	4.16	4.12	7.19	9.84	8.20	12.18
210	0.04	n.a	n.a	n.a	n.a	n.a
240	0.06	2.06	3.62	8.79	5.23	16.51
270	0.04	n.a	n.a	n.a	n.a	n.a
300	0.01	n.a	n.a	n.a	n.a	n.a
330	0.05	n.a	n.a	n.a	n.a	n.a

Ref. [5] Table 2-3 Offshore location: total sea: directional non-cyclonic wave extremes

Note: Omnidirectional Values are used

2.5.4 Wave Spectra

As per [5] Section 7.6.3, the wave spectra for the total sea is selected in accordance with equation 7-18 [5]:

Hs = 4.26m
Tp = 9.72s

And Tp/SQRT(Hs) = 9.72/SQRT(4.26) = 4.71 Eq.7-18[5]

4.71 < 5.4 therefore Wind Sea Spectra is selected.

The spectra can be represented by JONSWAP wind Sea spectra, therefore JONSWAP spectrum is considered for the analysis.

To determine the y coefficient for the spectral peakedness parameter for Wind Sea Spectra, equation 7-14 {where 3.6< Tp/SQRT(Hs)<5} [5] is considered.

1yr Return Period Condition – NORMAL OPERATING CONDITION

Hs = 4.26m

Tp = 9.72s

And : y = exp{5.75 –(1.15Tp/SQRT[Hs])} Eq.7-14[5]

y = exp{5.75 –(1.15 *9.72/SQRT[4.26])}

y = 1.397

2.5.5 Marine Fouling

Marine Growth data provided by KD [5] was considered and is reproduced below:

"4.13 MARINE GROWTH

The climax marine growth thickness profile is estimated to be 100mm from +2m to -10m, decreasing linearly to 25mm at 65m, with no growth below 65m."

The density of the Marine Growth was assumed to be 1325kg/m^3 as recommend by [6] Section 6.7.4

3 HYDRODYNAMIC ANALYSIS SIMULATIONS

3.1 DESIGN CONDITION

Refer to Doc No. 4404YYBNRZ1907K (Hydrodynamic .Analysis Report) [1] Section 3.1 for the DESIGN CONDITION Load Cases.

Because the primary model considered second order motions, the vessel tended to rotate into the direction of the wave. As the current was acting in the same (or opposite) direction to the wave, the risers moved in line with the vessel centreline and not transversely towards each other, therefore, there were no clashes in these simulations. The secondary model was such that the current was ‘forced’ to act transversely causing the leading hose to create a wake and the subsequent hose to react to the wake, hence ‘clashing’ is more likely to occur.

And as clashing is most likely in a BEAM SEA condition, only the BEAM SEA combination of load cases from the secondary model (with Marine Growth) are considered for the Clash Analysis, which are:

Load Case	Draught	Current Direction	Wave Direction	Wave Event	Marine Growth
SM 33	Ballast	90	270	T_{ass} Max Rise	Yes
SM 34	Ballast	90	270	T_{ass} Max Fall	Yes
SM 35	Ballast	90	270	T_{ass} Min Rise	Yes
SM 36	Ballast	90	270	T_{ass} Min Fall	Yes
SM 49	Full	90	270	T_{ass} Max Rise	Yes
SM 50	Full	90	270	T_{ass} Max Fall	Yes
SM 51	Full	90	270	T_{ass} Min Rise	Yes
SM 52	Full	90	270	T_{ass} Min Fall	Yes

3.2 NORMAL OPERATING CONDITION

3.2.1 Secondary Model

The secondary model as described in Doc No. 4404YYBNRZ1907K (Hydrodynamic .Analysis Report) [1] Section 3.1.2, was built to consider the vessel with a fixed heading such that the wave and current directions were applied in relation to the vessel heading.

RAO data provided by the Client [3], for both the 1yr BALLAST and FULL condition, were selected.

The Wave parameters were set to the 1 year Non Cyclonic Total Wave Extremes, and the heading set as a variable. The Current profile was set to the 1 year Non Cyclonic return period conditions and the direction set as a variable. Wind was not applied as only the first order motions are considered.

The Seawater Intake Risers were set to REACT TO WAKE with the leading string set to create a wake, the HUSE wake model was selected.

A 300s JONSWAP wave packet was identified which included the Rise and Fall wave events for the maximum and minimum associated period (T_{ass}), and simulation period set so that the event occurred at the mid-point of the wave packet. A build up period of 8 seconds was defined prior to the main simulation to ensure that any sudden transients were avoided.

As clashing is most likely in a BEAM SEA condition, only the BEAM SEA combination of load cases are considered for the Clash Analysis.

8 load cases were identified and are presented below:

Load Case	Draught	Current Direction	Wave Direction	Wave Event	Marine Growth
CM 1	Ballast	90	270	T_{ass} Max Rise	Yes
CM 2	Ballast	90	270	T_{ass} Max Fall	Yes
CM 3	Ballast	90	270	T_{ass} Min Rise	Yes
CM 4	Ballast	90	270	T_{ass} Min Fall	Yes
CM 5	Full	90	270	T_{ass} Max Rise	Yes
CM 6	Full	90	270	T_{ass} Max Fall	Yes
CM 7	Full	90	270	T_{ass} Min Rise	Yes
CM 8	Full	90	270	T_{ass} Min Fall	Yes

Table 3.2.1 – Clash Model Load Case Combinations (Normal Operating Condition)

4 RESULTS

The results of the Hydrodynamic Analyses were stored, evaluated and exported using the *Orca-Flex* post processing facilities. These results are summarised below and presented in more detail at Appendix C.

The two conditions considered for the Clash Analysis were the DESIGN CONDITION and the NORMAL OPERATING CONDITION. Both conditions showed clashes, and the values are reported in the following sections.

4.1 DESIGN CONDITION

Appendix C lists in full the maximum the peak loads from each of the simulations.

This section identifies each of the worst case load magnitudes and the associated clash energy for the load cases considered.

Note: To simplify the numerical model, the current velocities are ramped up at the beginning of the simulation, however, the rate of ramping is nominal and not necessarily representative of an actual current acceleration. Therefore, the initial 30s of the simulation is not considered in the results as this includes the initial impact due to this accelerating current.

4.1.1 Maximum Clash Force

Load Case: SM51 **Line: 4**

Component	Clash Force (kN)	Associated Values		
		Clash Energy (kJ)	Clash Velocity (m/s)	Distance from Hull Connection (m)
Flexible Hose	12.87	0.0165	0.2463	127.6
Strainer	29.1	0.0635	0.4149	139.31

4.1.2 Maximum Clash Energy

Load Case: SM34 **Line: 4**

Component	Clash Energy (kJ)	Associated Values		
		Clash Force (kN)	Clash Velocity (m/s)	Distance from Hull Connection (m)
Flexible Hose	0.00762	8.72	0.17	113.1
Strainer	0.0768	27.68	0.319	139.31

4.2 NORMAL OPERATING CONDITION

Appendix C lists in full the maximum the peak loads from each of the simulations.

This section identifies each of the worst case load magnitudes and the associated clash energy for the load cases considered.

Note: To simplify the numerical model, the current velocities are ramped up at the beginning of the simulation, however, the rate of ramping is nominal and not necessarily representative of an actual current acceleration. Therefore, the initial 30s of the simulation is not considered in the results as this includes the initial impact due to this accelerating current.

4.2.1 Maximum Clash Force

Load Case: CM7 **Line: 4**

Component	Clash Force (kN)	Associated Values		
		Clash Energy (kJ)	Clash Velocity (m/s)	Distance from Hull Connection (m)
Flexible Hose	2.387	0.00057	0.045	72.2
Strainer	12.477	0.01886	0.147	139.31

4.2.2 Maximum Clash Energy

Load Case: CM3 **Line: 4**

Component	Clash Energy (kJ)	Associated Values		
		Clash Force (kN)	Clash Velocity (m/s)	Distance from Hull Connection (m)
Flexible Hose	0.00055	2.35	0.0431	76.69
Strainer	0.01904	11.32	0.1495	139.31

5 CONCLUSION

5.1 DISCUSSION

Reference is made to DNV-RP-F203 Riser Interference [7].Section 2.2.1 Design Principles refers to two design strategies, namely:

-No Collision Allowed

-Collisions Allowed

No Collisions Allowed

This recommended practice suggests that collisions are not normally acceptable in a number of scenarios such as:

-in buoyancy sections-

-between Risers and Mooring Lines

-between Risers and Other Structures

-between and Risers and Unprotected External Lines.

In these situations sufficient spacing should be documented for all critical load cases including normal, extreme and accidental scenarios

Collisions Allowed

However, it does suggest that infrequent collisions may be allowed in other scenarios, such as temporary, accidental or extreme conditions, provided that the consequences are evaluated and found acceptable.

The highest values (DESIGN CONDITION) are presented for discussion as this is the worst case. From the analyses undertaken, the load cases where clashing has been shown to occur is in the BEAM SEA condition with the current acting at 90° to the vessel centerline, and hence in line with the Seawater Intake Riser centerlines. Furthermore, the current velocities analysed that induced the clashing were the 1yr extreme and 100yr cyclonic currents. A sensitivity analysis was ran where the same currents was set acting at 80° to the vessel centerline and clashing was found not to occur.

Therefore, given that the likelihood of the current acting between 80°-100° from the vessel centerline is both minimal and temporary, and given that the current velocities required to induce clashing at this range of headings are the 1yr extreme and 100yr cyclonic currents are also minimal and temporary, this supports the justification that potential collisions between adjacent risers are allowed.

The frequency of clashing can be extracted from the analysis but this may not prove to be a true measure of occurrence. Because the current is ‘forced’ to act transversely for this analysis, the leading hose begins to make intermittent contact with the next riser and will continue to do so, so long as the current direction and velocity is unchanged. The temporary aspect of the clashing is that it will only occur when the current direction is within a certain range (80°-100°) and at a certain velocity, the probability of both making the likelihood of clashing remote and temporary.

Consequently, if it can be demonstrated that the structural integrity of the components is not affected by the temporary collisions, then this would satisfy the recommendations of DNV-RP-F203 Riser Interference [7].

Post Analysis Note:

Further sensitivity studies of the clash analysis have suggested that the following reported clash energies are consistent and realistic, however, the reported clash forces may be conservative to be further investigated at EPCIC stage.

5.2 FLEXIBLE HOSE CLASHING

From Analysis: Maximum Clash Force = 12.87 kN

From Analysis: Maximum Clash Energy = 0.0165 kJ

The above values relate to Rubber to Rubber collisions and as Rubber has good energy absorption properties, the outer cover of the flexible hose strings will act as a damper and dissipate the energy.

The acceptance criteria in terms of allowable clash forces and energy does not appear to be a readily available property for the materials. Instead, it appears to be dependent upon the shape of the object and the contact area, which we believe will require additional analysis.

However, the values shown are not expected to affect the structural integrity of the hose, however, further analysis is recommended to quantify and verify this.

5.3 STRAINER CLASHING

From Analysis: Maximum Clash Force = 29.1 kN

From Analysis: Maximum Clash Energy = 0.0768 kJ

The above values relate to Strainer to Strainer collisions

The acceptance criteria in terms of allowable clash forces and energy does not appear to be a readily available property for the materials. Instead, it appears to be dependent upon the shape of the object and the contact area, which we believe will require additional analysis.

Further analysis is recommended to quantify the impact of the strainer to strainer collisions, however, to avoid any potential damage caused by this, the following solution is proposed:

The length of each alternating hose string is increased by 5-10m such that the positions of the adjacent strainers are staggered. This would ensure that in the event of any clashing, the strainer would collided with an adjacent rubber hose section. If necessary, the outer cover of the adjacent rubber hose section could be increased to provided additional energy absorption.

Note that this arrangement has been installed on a previous project supplied by Emstec.

5.4 LINE SPACING

The minimum spacing between the Seawater Intake Risers in the current configuration is 6.96m. As described above, under certain temporary conditions, collisions may occur between adjacent risers, but it can be permitted if it can been shown that the potential clashing does not affect the structural integrity of the risers.

A further consideration for line spacing is transverse displacement that may occur due to the effects of Vortex Induced Vibration (VIV).

With reference to DNV-RP-F203 Riser Interference [7] Section 4.5, the maximum transverse displacement caused by VIV can be in the order of one pipe diameter per riser. Therefore, to avoid any potential clashing due to VIV, it is recommended to space the lines at least 2 x Riser Diameter apart. As the maximum line diameter is approx. 1.1m (at the flange joint) this would require a minimum spacing of 2.2m. This is less than the present proposed spacing of 6.96m and is therefore acceptable.

REFERENCES

[1] Document No. 4404YYBNRZ1907K (P13919-RL-001) Hydrodynamic .Analysis Report

[2] 4404YYBNRB1910K Rev 01: Seawater Intake Riser Design Basis and Scope of Work

[3] SWIR_RAOs.zip – (received by e-mail: Panda/Craig 24/11/14)

[4] e-mail: Wykeham/Craig (27/11/14)

[5] 440200FGRF02014 Rev 05: Meteocean Design Basis for FLNG (Coral)

[6] DNV-RP-C205: DNV Recommended Practice – Environmental Conditions and Environmental Loads

[7] DNV-RP-F203: DNV Recommended Practice- Riser Interference

[8] ESDU 80025 Mean forces, pressures and flow field velocities for circular cylindrical structures

APPENDICES

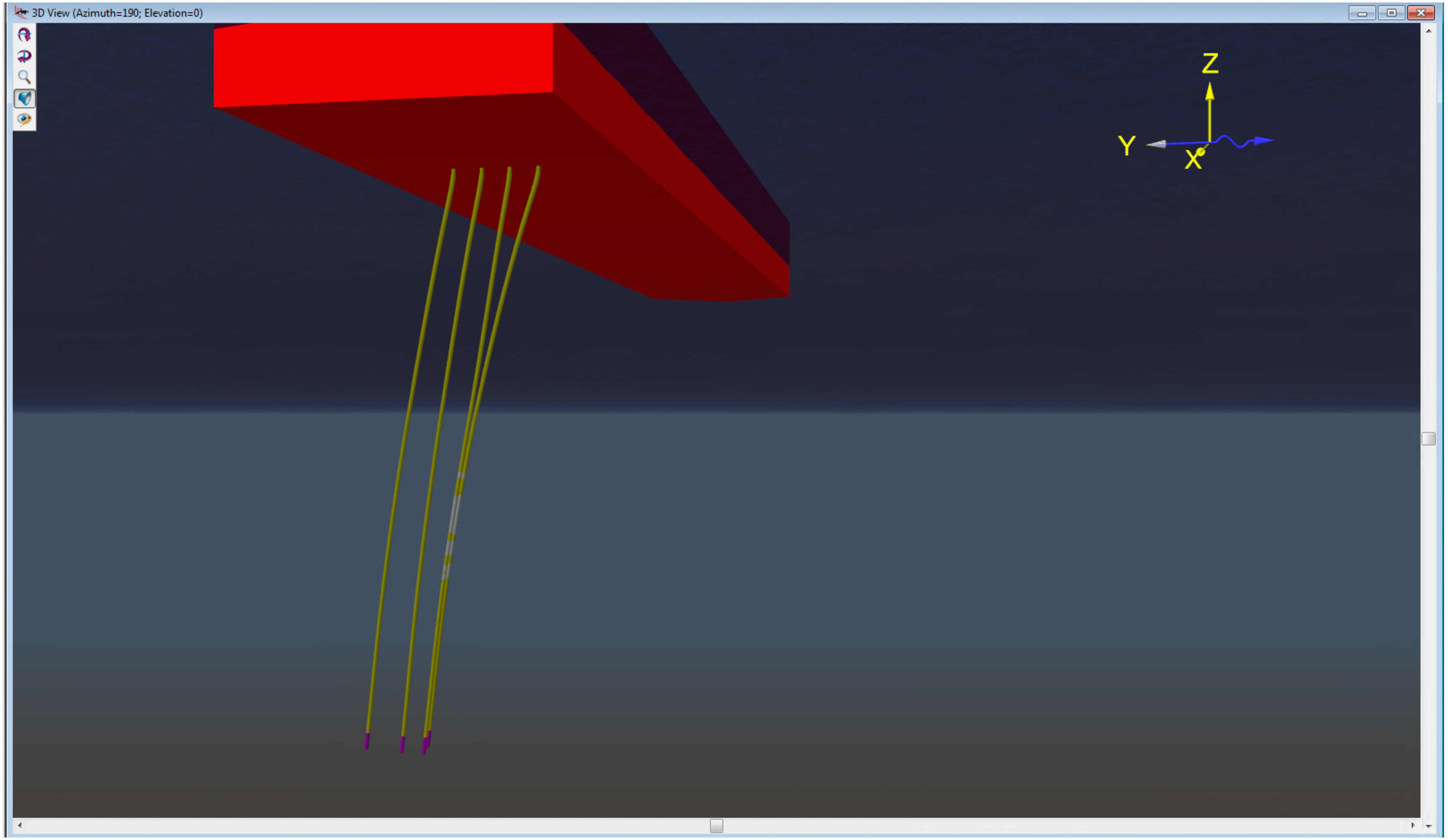
APPENDIX A – METHODOLOGY

Item	Description	References	Input Data	Process	Output	Acceptance Criteria
1	Hydrodynamic Analysis	[1] [2] [3]	Vessel RAO Data Meteocean Data Riser Properties	Build Model Establish Design & Survival Load Case Combinations Run Analyses Extract Results	Hose Maximum Tension Hose MBR Hose Displacement Clash Report Modal Analysis Hang Off Connection Loads & Moments	Hose allowable tension not exceed Hose MBR not exceed No interference with mooring lines Allowable Clash Energies are not exceed Input for VIV Screening Input for Hang Off Connection FEA
2	Hose Fatigue Analysis	[1] [4]	Vessel RAO Data Meteocean Data SN Data	Establish Hs / Tz Occurrences Define Fatigue Bins Run Orcaflex wave scatter tool Extract fatigue load cases Run Analyses Extract Results	Bending Moment & Tension ranges	Predicted fatigue of Hose Reinforcement Materials within S-N allowable
3	VIV	[5] [6]	Modal Analysis	Determine Vortex Shedding Frequencies	Vortex Shedding Frequency Range	Natural Frequency of Riser outside of Vortex Shedding Frequency Range – Low Risk
4	FEA of Hang Off Connection	[7] [8]	Hull / Caisson Structural Details Hang Off Connection Loads & Moments	Build Hang Off Connection Model Establish Boundary Conditions Run Analyses Extract Results	Maximum Stresses	Maximum Stresses do not exceed material allowable stresses.

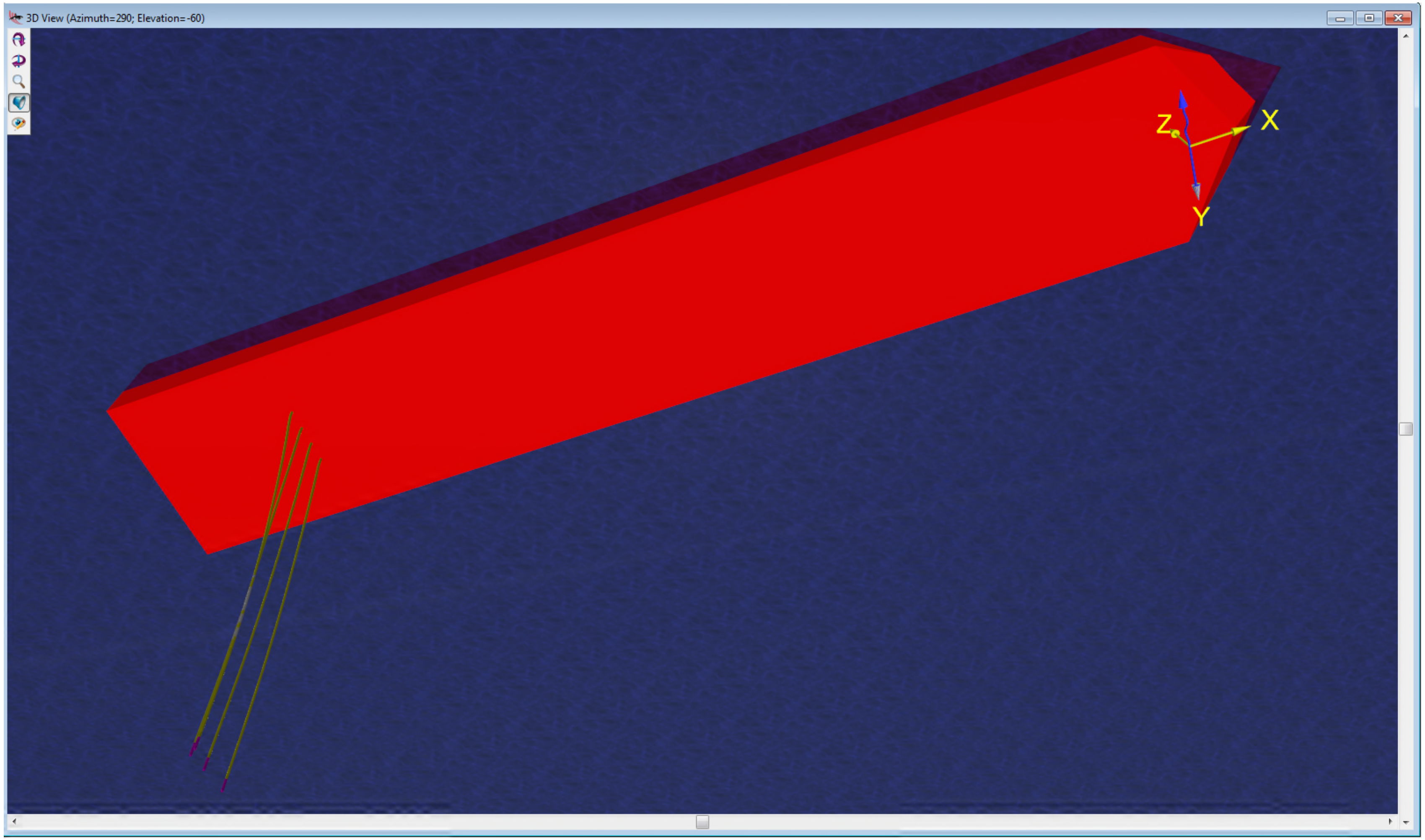
References:

[1] Orcaflex Software
[2] Seawater Intake Riser Design Basis and Scope of Work – 4404YYBNRB1910K
[3] Meteocean Design Basis for FLNG (CORAL) - 440200FGRF02014
[4] Specification for Bonded Flexible Pipe API 17K.
[5] Recommended Practice DNV-RP-C205 – Environmental Conditions and Environmental Loads
[6] Recommended Practice DNV-RP-F204 - Riser Fatigue
[7] Autodesk Inventor / ANSYS Software
[8] EUROCODE 3 - DIN EN 1993

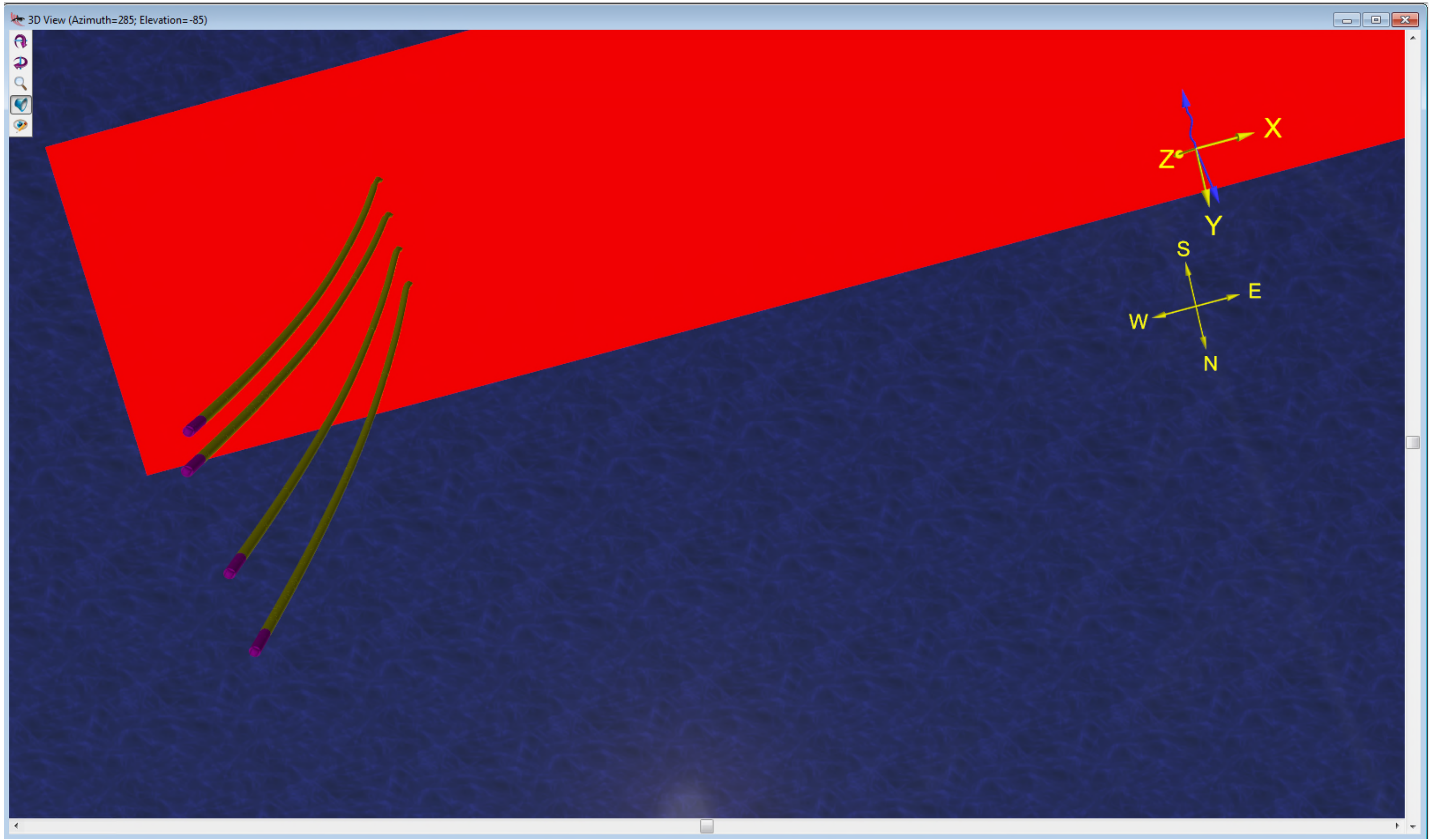
APPENDIX B – MODEL SCREEN SHOTS



Normal Operating Condition (Current at 90° to Vessel CL) : Clash Occurring



Normal Operating Condition (Current at 90° to Vessel CL) : Clash Occurring



Normal Operating Condition (Sensitivity Case – Current at 80° to Vessel CL) : No Clashing

APPENDIX C – CLASH ANALYSIS RESULTS

	LOAD CASE (SM)								Max	
DESCRIPTION	33	34	35	36	49	50	51	52		
Line 1 Clash Force Max	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kN
Line 2 Clash Force Max	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kN
Line 3 Clash Force Max	5.8	14.5	18.8	5.2	17.6	14.4	20.6	4.9	20.6	kN
Line 4 Clash Force Max	9.4	27.7	29.1	9.9	26.1	25.8	29.1	8.5	29.1	kN
Line 1 Clash Energy Max	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	kJ
Line 2 Clash Energy Max	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	kJ
Line 3 Clash Energy Max	0.0068	0.0421	0.0355	0.0055	0.0622	0.0412	0.0425	0.0048	0.0622	kJ
Line 4 Clash Energy Max	0.0090	0.0768	0.0573	0.0098	0.0715	0.0676	0.0635	0.0074	0.0768	kJ

DESIGN CONDITION – CLASH ANALYSIS RESULTS

DESCRIPTION	LOAD CASE (CM) 1	2	3	4	5	6	7	8	Max	
Line 1 Clash Force Max	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	kN
Line 2 Clash Force Max	5.0	7.3	9.6	5.6	6.1	7.2	9.1	5.7	9.6	kN
Line 3 Clash Force Max	8.5	8.0	7.3	8.5	8.3	8.0	6.9	8.7	8.7	kN
Line 4 Clash Force Max	9.9	7.6	11.3	10.2	10.0	7.2	12.5	9.7	12.5	kN
Line 1 Clash Energy Max	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	kJ
Line 2 Clash Energy Max	0.0051	0.0107	0.0185	0.0062	0.0075	0.0104	0.0166	0.0065	0.0185	kJ
Line 3 Clash Energy Max	0.0073	0.0067	0.0053	0.0073	0.0073	0.0064	0.0052	0.0075	0.0075	kJ
Line 4 Clash Energy Max	0.0098	0.0107	0.0190	0.0092	0.0105	0.0104	0.0189	0.0095	0.0190	kJ

NORMAL OPERATING CONDITION – CLASH ANALYSIS RESULTS

PROJECT Non Straddling Resources - FLNG KBR	FILE 4404YYBNRZ1906K_CDFE01_69.zip
PLANT LOCATION Offshore	TRANSMITTAL IN DATE 4/30/2015
CONTRACTOR KBR	PAGE 1 of 2

COMMENTS SHEET

Document Title	SEA WATER INTAKE RISERS – VIV ANALYSIS NOTE
Company Document Number and Revision	4404YYBNRZ1906K - CD-FE - 01
Contractor Document Number and Revision	
Transmittal IN Number	IN-4404-KBR-ENI-02535
Transmittal OUT Number	OUT-4404-ENI-KBR-00446
Transmittal OUT Date	13/05/2015
Approval Status Code	B - APPROVED WITH COMMENTS
Eni Document Approver	FT KBR PE - Beresford-Lambert James

Note: "COMPANY's approval of this document has to be deemed just as an authorization to proceed with the project execution.
CONTRACTOR is aware that COMPANY's approval is not relieving CONTRACTOR from any of its responsibilities in the performances required by the CONTRACT"

(*)

A	APPROVED
B	APPROVED WITH COMMENTS
C	NOT APPROVED

Comments:

DISCIPLINE	COMMENTS	CONTRACTOR'S REPLY (IF ANY)
CT Material and Corrosion	No comments Closed by: Renella Maria Closed Date: 05/06/2015 12:36 PM	
CT Piping	No Comments Closed by: Banham Paul Closed Date: 05/07/2015 01:08 PM	
CT Riser-Flowline-Subsea	Section 3, VIV Analysis Note: • Section 4.1 (Current Induced VIV) - the methodology used to derive that the likelihood of current induced VIV is low is not agreed. Current velocity of 1.79m/s, corresponding to 1 year return period, is extremely high and leads to high vortex shedding frequencies. Lower current velocities could lead to lower shedding frequencies, thus exciting the fundamental natural frequencies of the system, and should therefore be checked. Please update the document accordingly.	Noted. Theoretically, the current velocity can range from 0 – 1.79 m/s. Therefore, using the same technique, we propose: I) the theoretical effective velocity required to excite the fundamental frequency of the line is determined II) this theoretical effective velocity is assessed against the relevant current speed scatter data to assess likelihood of VIV at lower velocities.

	Closed by: Puliafito Marco Closed Date: 05/12/2015 06:18 PM	
CT Material and Corrosion (Focal Point)	No additional comments Closed by: Renella Maria Closed Date: 05/12/2015 06:20 PM	

EMSTEC GmbH
Gewerbering 8
22113 Oststeinbek
Germany
Tel.: +49 (0) 40 79686 345
Fax: +49 (0) 40 79686 702
info@emstec.net
sales@emstec.net
www.emstec.net

01	03.06.15	IC	RR	BB	Issued for Design
A	04.03.15	IC	RR	BB	Issued for Review and Comments
Rev	**Date**	**By**	**Chk**	**App**	**Description**

Project:	**Coral South Development FLNG**
Client:	**KBR**
Document Title:	**Seawater Intake Riser FEED -** **VIV Analysis Report**
Emstec DocNo: Client Doc No.:	**P13919-RL-003** **4404YYBNRZ1906K**
Rev:	**01**

CONTENTS

1 INTRODUCTION

The Seawater Intake Riser System proposed for the Coral South Development FLNG consists of 4-off 36"NB Seawater Intake Risers, 135m in length, supported from the underside of the FLNG by a fixed riser head arrangement.

To assess the likelihood of Vortex Induced Vibration(VIV) within the Seawater Intake Riser Hose strings, it was necessary to perform a hydrodynamic analysis of the Seawater Intake Riser system. For details of the analysis refer to Document No. 4404YYBNRZ1907K (P13919-RL-001) Hydrodynamic Analysis Report [1], which was carried out using software package Orcaflex, developed by Orcina Ltd (www.orcina.com) specifically for analysis of flexible lines in the offshore environment.

This report has been prepared to assess the likelihood VIV from data extracted from the analysis and to and report the results and conclusions.

1.1 EXECUTIVE SUMMARY

A modal analysis of the Seawater Intake Riser was performed using Orcaflex to determine the natural frequencies of the line.

The Vortex Shedding Frequencies for the configuration were determined and compared against the natural frequency of the Sea Water Intake Riser.

The fundamental frequency of the Sea Water Intake Riser was outside the range of Vortex Shedding Frequencies, therefore it is concluded that the risk of current induced VIV is **LOW**.

The theoretical effective velocity required to place the natural frequency of the riser within the vortex shedding frequency range was determined and assessed against the relevant current distribution data, the occurrence of which was also found to be **LOW**.

The Reduced Velocity range of the Riser was also determined and compared against the Reduced Velocity range where wave induced VIV may occur.

The Reduced Velocity range was found to be outside the Reduced velocity range where vortex shedding may occur, therefore it is concluded that the risk of wave induced VIV is **LOW**.

1.2 METHODOLOGY

Refer to Appendix A for the methodology applied for the Hydrodynamic Analysis.

2 INPUT DATA

2.1 VESSEL DATA

Refer to Doc No. 4404YYBNRZ1907K (Hydrodynamic Analysis Report) [1] Section 2.1

2.2 SEAWATER INTAKE RISER HOSE DATA

Refer to Doc No. 4404YYBNRZ1907K (Hydrodynamic Analysis Report) [1] Section 2.2

2.3 SYSTEM CONFIGURATION

Refer to Doc No. 4404YYBNRZ1907K (Hydrodynamic Analysis Report) [1] Section 2.3

2.4 ENVIRONMENTAL DATA

Doc No. 4404YYBNRZ1907K (Hydrodynamic Analysis Report) [1] Section 2.4 considers the DESIGN CONDITION and SURVIVAL CONDITION Criteria for the Sea Water Intake Risers.

However, for the assessment of Vortex Induced Vibration, it is necessary to consider the current velocities associated with the NORMAL OPERATING CONDITION and which is presented below.

2.4.1 Direction Convention

The below direction convention is used:

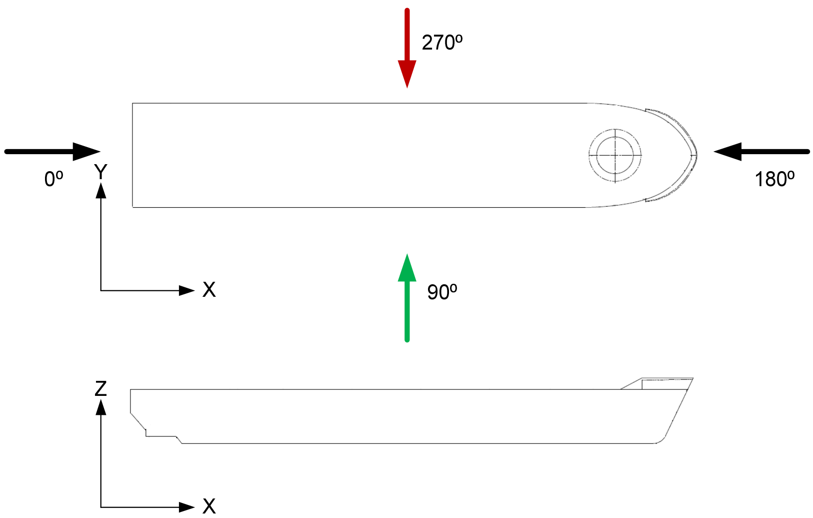


Fig. 3 – Direction Convention [2]

2.4.2 Current

For the NORMAL OPERATING CONDITION, the 1yr Non Cyclonic RP extreme current profile provided in [5] Tables 2-8 are considered and are reproduced:

Return Period 1 Year											
Level	% Water depth	0.3 (surface)	1	2	5	11	16	44	66	88	99 (4m abs)
L10	0.3 (surface)	1.79	1.65	1.21	0.87	0.39	0.28	0.16	0.12	0.07	0.05
L9	1	1.69	1.74	1.27	0.91	0.4	0.29	0.17	0.12	0.07	0.05
L8	2	1.13	1.18	1.48	1.05	0.43	0.31	0.17	0.13	0.07	0.05
L7	5	0.89	0.93	1.17	1.32	0.5	0.34	0.19	0.13	0.07	0.05
L6	11	0.49	0.52	0.65	0.68	0.82	0.51	0.24	0.15	0.07	0.05
L5	16	0.42	0.45	0.57	0.58	0.64	0.72	0.32	0.18	0.07	0.05
L4	44	0.34	0.36	0.46	0.44	0.4	0.42	0.69	0.33	0.07	0.05
L3	66	0.33	0.35	0.44	0.42	0.36	0.36	0.55	0.56	0.08	0.05
L2	88	0.29	0.31	0.39	0.36	0.24	0.22	0.16	0.14	0.36	0.06
L1	99 (4m abs)	0.29	0.31	0.39	0.36	0.24	0.22	0.16	0.14	0.12	0.3

Ref. [3] Table 2-8 1 year current extremes profile

2.4.3 Marine Fouling

Marine Growth data provided by KBR [4] was considered and is reproduced below:

"4.13 MARINE GROWTH

The climax marine growth thickness profile is estimated to be 100mm from +2m to -10m, decreasing linearly to 25mm at 65m, with no growth below 65m."

The density of the Marine Growth was assumed to be 1325kg/m^3 as recommend by [5] Section 6.7.4

3 VORTEX INDUCED VIBRATION

3.1 GENERAL

For the assessment of Vortex Induced Vibration, it is necessary to perform a Quasi-Static Analysis with consideration for the current velocities associated with the NORMAL OPERATING CONDITION.

Screening for VIV was undertaken using the techniques suggested by :

DNV-RP-C205 – DNV Recommended Practice – Environmental Conditions and Environmental Loads - October 2010 [5]

DNV-RP-F204 – DNV Recommended Practice - Riser Fatigue - October 2010 [6]

3.2 SEA WATER INTAKE RISER NATURAL FREQUENCIES

A Quasi-Static Analysis was undertaken in Orcaflex and a Modal Analysis performed to determine the natural frequencies of the Seawater Intake Riser (SWIR), the output of which is presented in Doc No. 4404YYBNRZ1907K (Hydrodynamic Analysis Report) [1] Section 4.3 and reproduced below.

No.	Mode Number	Period (s)	Frequency (Hz)	Mode Type
1	1	58.89	0.01698	Transverse
2	2	58.87	0.01699	Inline
3	3	25.28	0.03955	Inline
4	4	25.28	0.03956	Transverse
5	5	15.43	0.06480	Inline
6	6	15.43	0.06481	Transverse
7	7	10.64	0.09401	Inline
8	8	10.64	0.09401	Transverse
9	9	7.87	0.12703	Transverse
10	10	7.87	0.12704	Inline
11	11	6.12	0.16330	Inline
12	12	6.12	0.16331	Transverse

3.3 CURRENT INDUCED VIV

Using the VIV screening techniques presented in [5] & [6], the vortex shedding frequency (f_s) in relation to the Max 1 yr current velocities is calculated as follows:

$f_s = St * U_{eff} / D_h$ [6] Eq. 4.4

where: St = Strouhal Number
U_{eff} = Effective Velocity
D_h = Outside Diameter

From the hydrodynamic analysis, the Reynolds Number is in the range:

727,000 < Re < 2,081,778

And so **St = ~0.23** [5] fig 9-1

The Effective Velocity U_{eff} is the mean velocity over the excitation length, where the excitation length is the part of the riser where the velocity is 2/3 of the maximum velocity [6] Sect 4.1.2.

The maximum velocity at the top hose connection:

U_{max} = ~ 1.74m/s
so $U_{max2/3}$ = ~1.1588m/s

Depth at which current = $U_{max2/3}$ is approx. 125m, so excitation length is approx. 109m (>10% of Riser therefore OK [6] Sect 4.1.2 Guidance Note).

Therefore U_{eff} = 1.74 - (1.74-1.1588)/2 = 1.45m/s
U_{eff} = 1.45m/s

And **D_h = 1.06m**

Therefore fs = 0.23 * (1.45 / 1.06)
fs = 0.314 Hz

The frequency bands where the riser can be excited are calculated using a nominal value of 0.2 from the recommended frequency bandwidth parameter (i.e. 0.10-0.25) as follows:

Cross Flow Vortex Shedding Frequency (f_s^{CF}) = f_s (± 20%) [6] Eq. 4.5

f_s^{CF} = 0.251-0.377 Hz

In Line Vortex Shedding Frequency (f_s^{IL}) = 2*f_s (± 20%) [6] Eq. 4.6

f_s^{IL} = 0.502 – 0.754 Hz

Theoretical Effective Velocity to Excite Riser

As the current velocity can range from between 0 – 1 yr Return Velocity maximum, a further test is made to determine the effective velocity that would place the fundamental natural frequency of the line (Mode 1) within vortex shedding frequency range.

From Section 3.2, the fundamental natural frequency of the line (Mode 1) is 0.01698 Hz

Therefore, the effective current velocity that would place the fundamental natural frequency of the line (Mode 1) within vortex shedding frequency range is:

$f_s = St * U_{eff} / D_h$ [6] Eq. 4.4

so $U_{eff} = f_s * D_h / St$

$U_{eff} = 0.01698 * 1.06 / 0.23$

$U_{eff} =$ **0.0783 m/s**

3.4 WAVE INDUCED VIV

Using the VIV screening technique in [5] Sect. 9.7, the vortex shedding frequencies in relation to wave motion are assessed.

To determine if the flow is current dominated, the following test is used:

$$\alpha = u_c / (u_c + v_m)$$

where: u_c = instantaneous current velocity (m/s)

v_m = maximum relative velocity between wave motion and member (m/s)

From the hydrodynamic analysis, the sea velocity and riser velocity were extracted for each time step and subtracted to determine the relative velocity (v_m).

The above test was then performed to determine a value for **α** (ref. Appendix B)

From this test α = ~0.5 (<0.8 therefore flow is not current dominated and further screening is required)

For irregular waves (as per this analysis), the vortex shedding behave as for $K_C > 40$ [5] para 9.7.2.3. (where K_C is the Keulegan Carpenter Number).

For this condition, vortex shedding may occur when:

In line excitations: $1 < V_R < 3.5$ [5] para 9.7.3.3

Cross Flow excitation: $3 < V_R < 9$ [5] para 9.7.3.3

where V_R = Reduced Velocity

and $V_R = u / (f_n * D)$ [5] Sect 9.1.1

where: u=instantaneous flow velocity normal to member axis (m/s)
f_n = natural frequency of the member (Hz)
D = Diameter of the member (m)

Using the instantaneous flow velocity from the hydrodynamic analysis, the Reduced Velocity (V_R) was calculated for the fundamental natural frequency of the riser and found to be in the range :

$$\mathbf{51 < V_R < 148}$$

4 RESULTS

4.1 CURRENT INDUCED VIV

Maximum 1 yr Return Period Velocity

From Section 3.2, the fundamental natural frequency of the line (Mode 1) is **0.01698 Hz**

As shown in Section 3.3, the Vortex Shedding Frequencies of the line are calculated as:

Cross Flow Vortex Shedding Frequency **(f_s^{CF}) =** **0.251-0.377 Hz** **(>0.01698 Hz)**

In Line Vortex Shedding Frequency **(f_s^{IL}) =** **0.502 – 0.754 Hz** **(>0.01698 Hz)**

Both the Cross Flow and In Line Vortex Shedding Frequency range is outside of the Natural Frequency of the Riser indicating that the likelihood of Current Induced VIV is LOW.

Theoretical Effective Velocity to Excite Riser

The further test showed that the effective current velocity required to place the fundamental natural frequency of the line (Mode 1) within vortex shedding frequency range is **0.0783m/s**

As the excitation length is approx. 109m from the top connection, it can be estimated that the effective velocity acts on the mid-point on the excitation length, i.e. approx. 50m below sea level which corresponds to L8 of the current profile data.

This effective velocity value of 0.0783m/s (<0.1m/s) value is compared to the current distribution data at L8 provided within [3] and can be assessed as follows:

Dir	Current speed L8 (m/s)															
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	Total
0	0.32	0.76	0.82	0.74	1.24	0.49	0.20	0.08	0.05	0.01	0.01	0.00	0.00	0.00	0.00	4.71
30	0.15	0.20	0.16	0.05	0.16	0.08	0.00	0.02	0.16	0.08	0.00	0.00	0.00	0.00	0.00	1.07
60	0.12	0.11	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.36
90	0.12	0.17	0.17	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.47
120	0.13	0.15	0.11	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48
150	0.16	0.18	0.35	0.37	0.10	0.06	0.09	0.02	0.03	0.00	0.00	0.00	0.00	0.00	0.00	1.35
180	0.21	0.57	1.39	1.41	1.62	1.52	1.69	1.79	1.36	0.32	0.29	0.01	0.00	0.00	0.00	12.20
210	0.21	1.09	2.28	3.85	3.99	4.87	3.75	2.23	1.68	1.55	1.02	0.35	0.02	0.00	0.00	26.88
240	0.24	1.53	2.96	3.82	2.97	2.46	1.94	1.25	1.15	0.50	0.10	0.10	0.00	0.00	0.00	19.06
270	0.41	2.01	3.65	2.88	1.87	0.94	0.25	0.09	0.13	0.07	0.00	0.00	0.00	0.00	0.00	12.29
300	0.47	2.36	3.45	2.93	1.05	0.50	0.25	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.00	11.09
330	0.42	1.62	2.39	1.90	1.36	1.13	0.59	0.38	0.15	0.08	0.00	0.00	0.00	0.00	0.00	10.03
Total	2.97	10.76	17.85	18.07	14.37	12.07	8.76	5.90	4.73	2.62	1.43	0.47	0.02	0.00	0.00	100.00

Tab. 8-14 L8 - Current speed/direction scatter at 50m bsl at the station C1.

With reference to [3] Table 8-14 L8 (reproduced above), the percentage of occurrence for velocities upto 0.1m/s is 2.97% indicating a LOW risk of occurrence.

Also, it is noted that the Current Profile for Fatigue Analysis [3] Table 8-52 : 8-55 considers current values of >0.15m/s for the profile at 2% of the water depth (i.e. 50m BSL) which also suggests a LOW risk of occurrence.

4.2 WAVE INDUCED VIV

As shown in Section 3.4, the Reduced Velocity range for the Riser was calculated as:

$$51 < V_R < 148$$

The Reduced Velocity Range where Vortex Shedding may occur is stated as:

In line excitations: **$1 < V_R < 3.5$** (<**$51 < V_R < 148$)**

Cross Flow excitation: **$3 < V_R < 9$** (<**$51 < V_R < 148$)**

The Reduced Velocity range for the Riser is outside the Reduced Velocity Range for both the Cross Flow and In Line Excitations indicating that the likelihood of Wave Induced VIV is **LOW**

5 CONCLUSION

From the VIV screening assessment, it can be demonstrated that the risk of both Current Induced and Wave Induced Vortex Induced Vibration is LOW.

However, the referenced documents used for the VIV screening assessment are intended for Top Tensioned Risers and Steel Catenary Risers as opposed to free hanging flexible cantilevers.

Both Fujarra et al (2001) and Prastiano et al (2009) have undertaken research specifically for Flexible Free Hanging Cantilevers and further analyses of this work is recommended.

REFERENCES

[1] Document No. 4404YYBNRZ1907K (P13919-RL-001) Hydrodynamic .Analysis Report

[2] e-mail: Wykeham/Craig (27/11/14)

[3] 440200FGRF02014 Rev 05: Meteocean Design Basis for FLNG (Coral)

[4] e-mail: Wykeham/Craig (06/01/15)

[5] DNV-RP-C205: DNV Recommended Practice – Environmental Conditions and Environmental Loads

[6] DNV-RP-F204 – DNV Recommended Practice - Riser Fatigue - October 2010

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Fujarra, A.L.C., Pesce, C.P., Flemming, F. & Williamson, C.H.K., 2001. Vortex Induced Vibration of a Flexible Cantilever. *Journal of Fluids and Structures*, 15, pp.651-58.

Prastiano, R.W., Otsuka, K. & Ikeda, Y., 2009. Vortex Induced Vibration of a Flexible Free Hanging Circular Cantilever. *ITB Journal of Engineering Science*, 41(2), pp.111-25.

APPENDICES

APPENDIX A – METHODOLOGY

Item	Description	References	Input Data	Process	Output	Acceptance Criteria
1	Hydrodynamic Analysis	[1] [2] [3]	Vessel RAO Data Meteocean Data Riser Properties	Build Model Establish Design & Survival Load Case Combinations Run Analyses Extract Results	Hose Maximum Tension Hose MBR Hose Displacement Clash Report Modal Analysis Hang Off Connection Loads & Moments	Hose allowable tension not exceed Hose MBR not exceed No interference with mooring lines Allowable Clash Energies are not exceed Input for VIV Screening Input for Hang Off Connection FEA
2	Hose Fatigue Analysis	[1] [4]	Vessel RAO Data Meteocean Data SN Data	Establish Hs / Tz Occurrences Define Fatigue Bins Run Orcaflex wave scatter tool Extract fatigue load cases Run Analyses Extract Results	Bending Moment & Tension ranges	Predicted fatigue of Hose Reinforcement Materials within S-N allowable
3	VIV	[5] [6]	Modal Analysis	Determine Vortex Shedding Frequencies	Vortex Shedding Frequency Range	Natural Frequency of Riser outside of Vortex Shedding Frequency Range – Low Risk
4	FEA of Hang Off Connection	[7] [8]	Hull / Caisson Structural Details Hang Off Connection Loads & Moments	Build Hang Off Connection Model Establish Boundary Conditions Run Analyses Extract Results	Maximum Stresses	Maximum Stresses do not exceed material allowable stresses.

References:

[1] Orcaflex Software
[2] Seawater Intake Riser Design Basis and Scope of Work – 4404YYBNRB1910K
[3] Meteocean Design Basis for FLNG (CORAL) - 440200FGRF02014
[4] Specification for Bonded Flexible Pipe API 17K.
[5] Recommended Practice DNV-RP-C205 – Environmental Conditions and Environmental Loads
[6] Recommended Practice DNV-RP-F204 - Riser Fatigue
[7] Autodesk Inventor / ANSYS Software
[8] EUROCODE 3 - DIN EN 1993

APPENDIX B – VIV SCREENING

VIV SCREENING

Time (s)	Sea Velocity (m/s)	Riser Velocity (m/s)	Relative Velocity (m/s)	$\alpha = u_c/u_c+v_m$	Reduced Velocity ($V_R = u/f_n * D$)
0	-2.00	0.01	-2.01	0.50	-111.63
1	-2.18	0.00	-2.18	0.50	-121.31
2	-2.27	-0.02	-2.25	0.50	-124.87
3	-2.17	-0.04	-2.13	0.50	-118.54
4	-1.86	-0.04	-1.82	0.51	-100.91
5	-1.40	-0.03	-1.37	0.51	-76.28
6	-1.01	0.00	-1.00	0.50	-55.77
7	-0.90	0.03	-0.92	0.49	-51.27
8	-1.15	0.04	-1.20	0.49	-66.47
9	-1.67	0.04	-1.71	0.49	-94.79
10	-2.23	0.01	-2.24	0.50	-124.69
11	-2.62	-0.01	-2.61	0.50	-144.74
12	-2.65	-0.02	-2.63	0.50	-146.16
13	-2.29	-0.01	-2.28	0.50	-126.81
14	-1.71	0.00	-1.72	0.50	-95.41
15	-1.21	0.01	-1.22	0.50	-67.95
16	-1.01	0.00	-1.01	0.50	-56.27
17	-1.12	-0.01	-1.11	0.50	-61.54
18	-1.43	-0.02	-1.41	0.50	-78.29
19	-1.81	-0.01	-1.79	0.50	-99.63
20	-2.12	0.00	-2.12	0.50	-117.53
21	-2.22	0.01	-2.22	0.50	-123.62
22	-2.04	0.01	-2.05	0.50	-114.17
23	-1.70	0.01	-1.71	0.50	-95.20
24	-1.46	0.01	-1.46	0.50	-81.29
25	-1.53	0.00	-1.53	0.50	-85.22
26	-1.88	0.00	-1.89	0.50	-104.80
27	-2.19	0.00	-2.19	0.50	-121.66
28	-2.12	0.01	-2.12	0.50	-118.03
29	-1.70	0.00	-1.70	0.50	-94.50
30	-1.26	-0.01	-1.25	0.50	-69.26

Fundemental Frequency (fn)	0.01698	*Hz*
Diameter (D)	1.06	*m*

270	-1.87	0.06	-1.93	0.49	-107.49
271	-2.01	0.06	-2.06	0.49	-114.70
272	-2.06	0.03	-2.09	0.50	-115.93
273	-1.98	-0.01	-1.97	0.50	-109.61
274	-1.81	-0.04	-1.77	0.51	-98.44
275	-1.61	-0.04	-1.57	0.51	-87.31
276	-1.48	-0.03	-1.45	0.51	-80.60
277	-1.47	-0.01	-1.45	0.50	-80.69
278	-1.58	0.00	-1.58	0.50	-87.52
279	-1.76	0.00	-1.76	0.50	-97.53
280	-1.87	0.00	-1.87	0.50	-103.81
281	-1.82	0.00	-1.82	0.50	-101.28
282	-1.66	0.01	-1.68	0.50	-93.13
283	-1.58	0.02	-1.60	0.50	-88.85
284	-1.67	0.03	-1.69	0.50	-94.13
285	-1.87	0.03	-1.90	0.50	-105.44
286	-2.06	0.02	-2.07	0.50	-115.12
287	-2.13	0.00	-2.13	0.50	-118.15
288	-2.05	-0.02	-2.03	0.50	-112.95
289	-1.84	-0.04	-1.80	0.50	-100.03
290	-1.54	-0.04	-1.50	0.51	-83.22
291	-1.28	-0.03	-1.25	0.51	-69.60
292	-1.18	-0.01	-1.18	0.50	-65.48
293	-1.29	0.02	-1.31	0.50	-72.88
294	-1.57	0.04	-1.61	0.49	-89.25
295	-1.93	0.03	-1.96	0.50	-108.90
296	-2.23	0.01	-2.25	0.50	-124.93
297	-2.37	-0.01	-2.36	0.50	-131.11
298	-2.25	-0.02	-2.24	0.50	-124.19
299	-1.93	-0.02	-1.92	0.50	-106.42
			MAX	0.51	-51.27
			MIN	0.49	-148.66

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Feasibility Study of 500m Seawater Intake System
for
Statoil Petroleum AS

Progress Presentation Sept. 2014
by
B Brink & I Craig

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Background to Study

- Study Commissioned by Statoil (Mar 2014)
- KOM held at Rotvoll (April 2014)
  -Scope and Deliverables agreed
  -Proposed Layout of Report agreed
- Progress Meeting held at Rotvoll (June 2014)
  -Emstec presented the work undertaken up to the point of proposed concepts, including:
  State of the Art Technology for FPSO and FLNG
  Qualitative Assessment of Concepts and Layouts
  -Preferred Concept Agreed

2 x ~60"NB Flexible Pipe Strings - Seachest System

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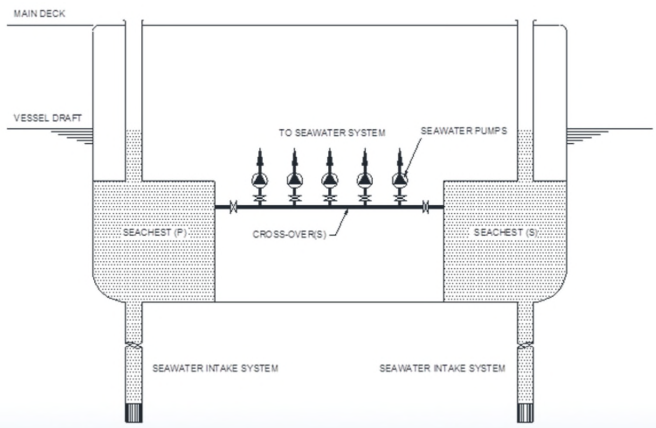
Preferred Concept



2 x ~60"NB Flexible Pipe Strings - Seachest System

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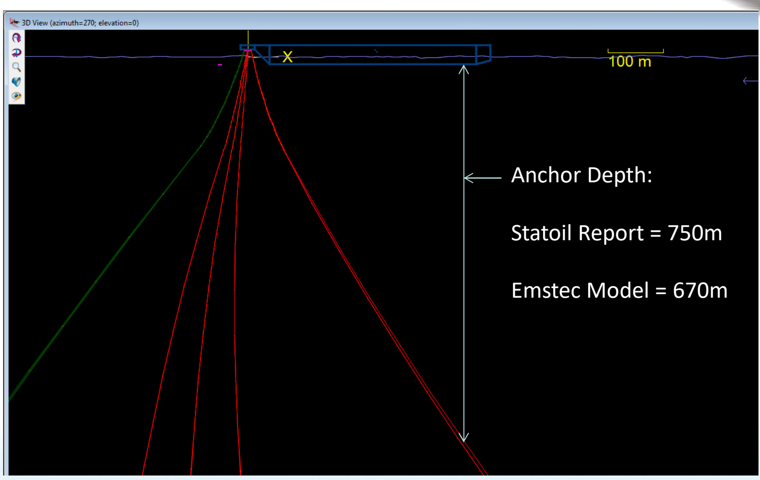
Mooring Line Configuration



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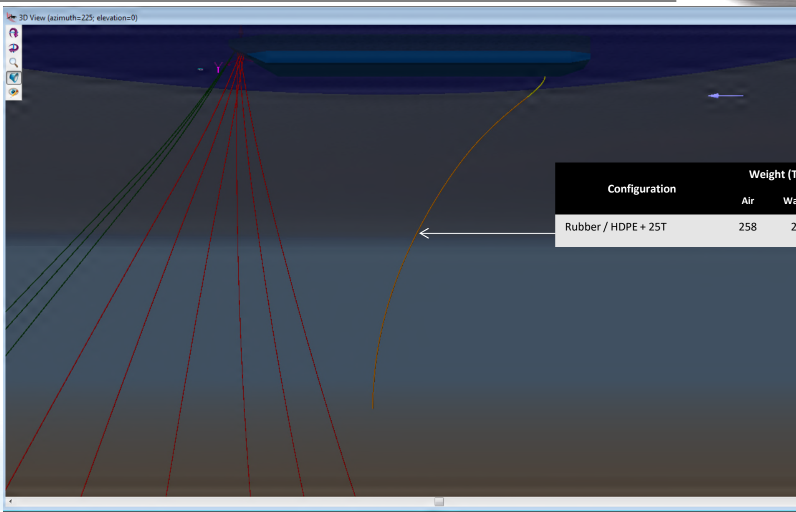
Flexible Pipe String Configuration



Configuration	Weight (Te) Air	Weight (Te) Water
Rubber / HDPE + 25T	258	22

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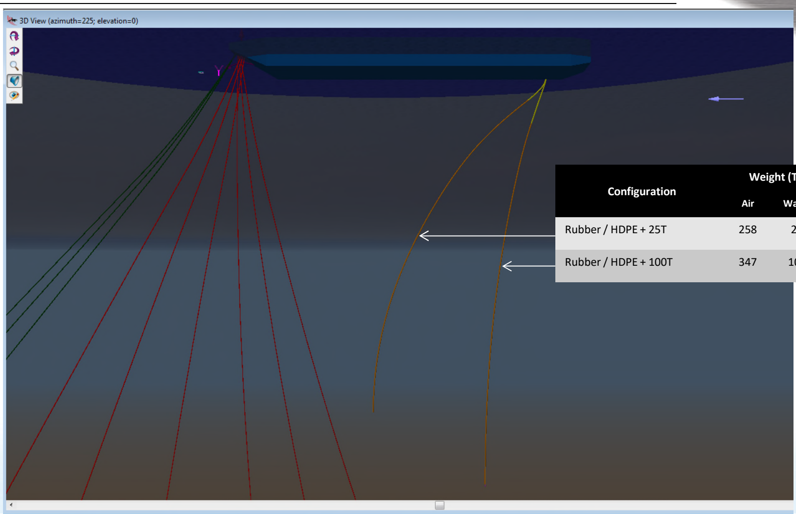
Flexible Pipe String Configuration



Configuration	Weight (Te) Air	Weight (Te) Water
Rubber / HDPE + 25T	258	22
Rubber / HDPE + 100T	347	106

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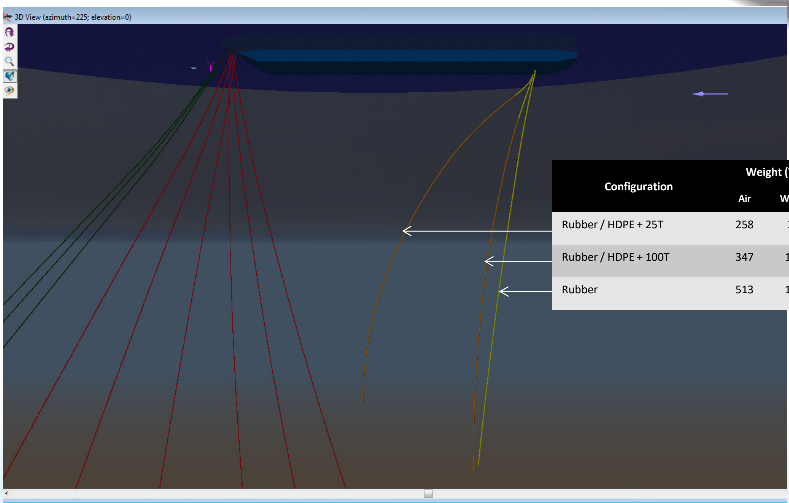
Flexible Pipe String Configuration



Configuration	Weight (Te) Air	Weight (Te) Water
Rubber / HDPE + 25T	258	22
Rubber / HDPE + 100T	347	106
Rubber	513	175

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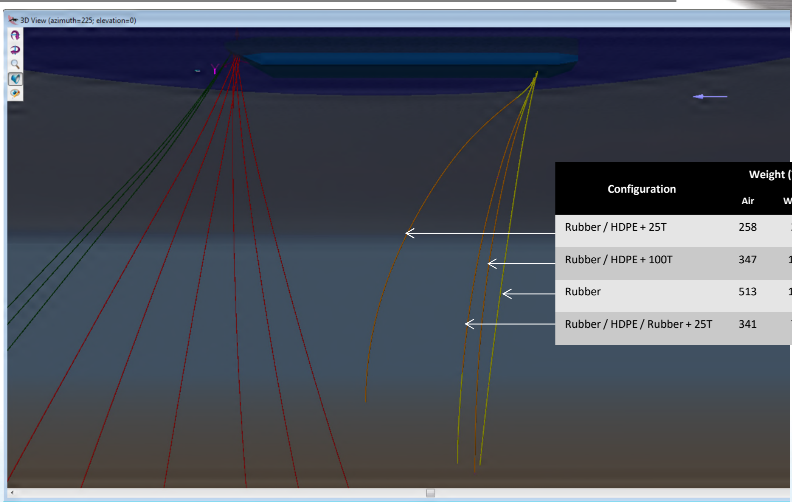
Flexible Pipe String Configuration



Configuration	Weight (Te) Air	Weight (Te) Water
Rubber / HDPE + 25T	258	22
Rubber / HDPE + 100T	347	106
Rubber	513	175
Rubber / HDPE / Rubber + 25T	341	75

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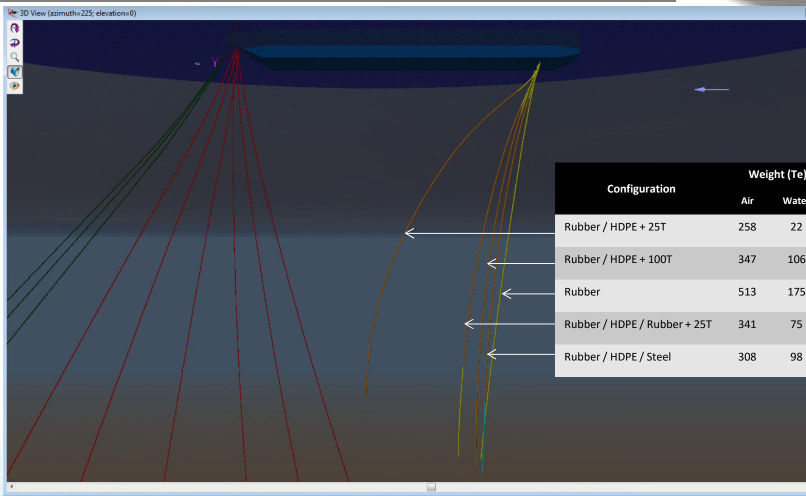
Flexible Pipe String Configuration



Configuration	Weight (Te) Air	Weight (Te) Water
Rubber / HDPE + 25T	258	22
Rubber / HDPE + 100T	347	106
Rubber	513	175
Rubber / HDPE / Rubber + 25T	341	75
Rubber / HDPE / Steel	308	98

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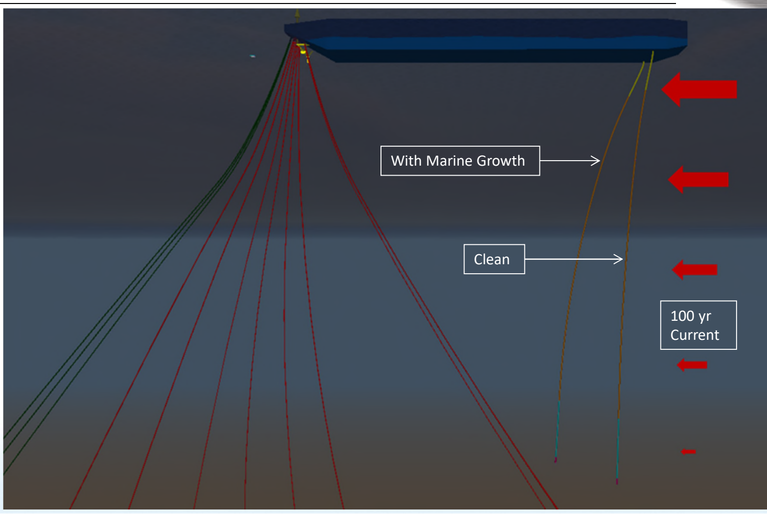
Marine Growth



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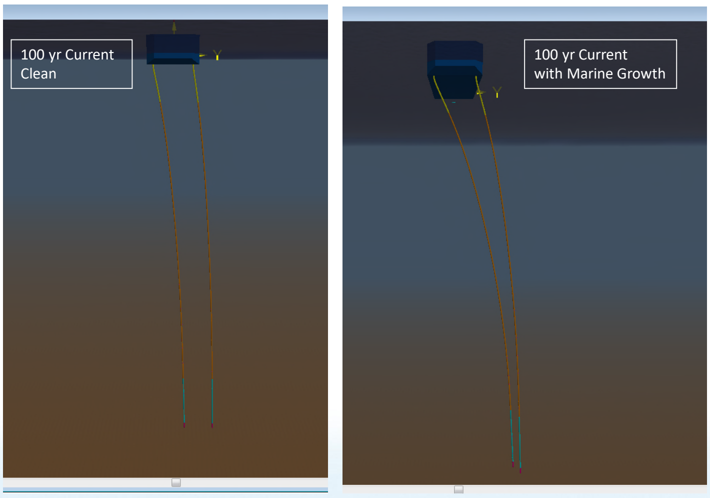
Flexible Pipe String – Wake Interaction / Clashing



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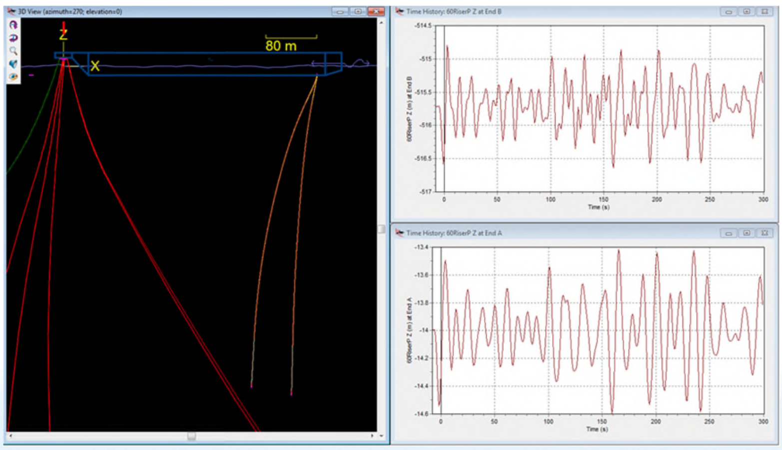
Flexible Pipe String – End Displacement

During 100yr Return Conditions:

Top End +/- 0.6m Lower End +/- 0.9m



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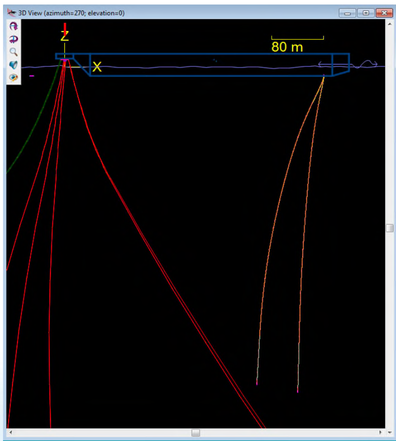
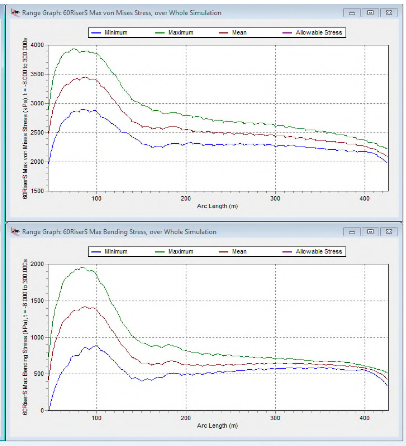
Flexible Pipe String – HDPE Stresses

During 100yr Return Conditions:

Bending Stress : <2N/mm2   Von Mises Stress: <4N/mm2





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Flexible Pipe String – Hydraulic Performance

Pressure Loss through Hose String

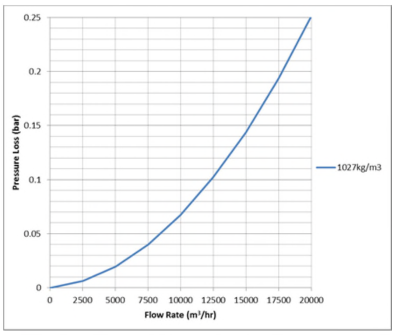
Enter Values in WHITE *cells only*

Section	Hose	HDPE	Steel	
Length of Hose	46	379.5	69	*m*
Outside Diameter	-	1600	1524	*mm*
Wall Thickness	-	61.2	19.05	*mm*
Inside Diameter	1500	1477.6	1485.9	*mm*
Roughness	0.2	0.0015	0.045	*mm*
Hypochlorite Hose OD	0			*mm*
Density of Fluid	1027.0			*kg/m^3*
Viscosity of Fluid	1.3604E-06			*m^2/s*
Flow Rate	17500			*m^3/hr*
Velocity	2.75	2.83	2.80	*m/s*
Hydraulic Diameter	1.500	1.478	1.486	*m*
Relative Roughness	1.3E-04	1.0E-06	3.0E-05	
Reynolds No	3033107	3079088	3061889	
Friction Factor	0.0131	0.0097	0.0109	*Look up from Moody Tab*

Pressure Drop per Section	1564	10314	2038	*Pa*	*Note 1*
	0.02	0.10	0.02	*Bar*	
Strainer	0.05459			*Bar*	
Total Pressure Loss	**0.19375**			*Bar*	

Notes:

1. Pressure Loss calculated using D'Arcy-Weisbach Equation



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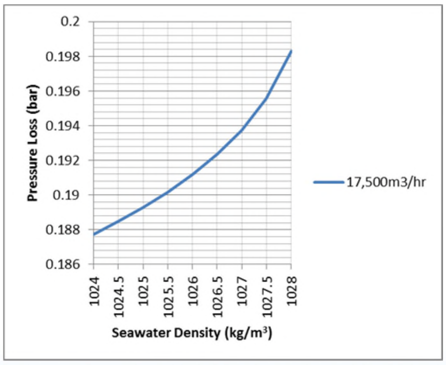
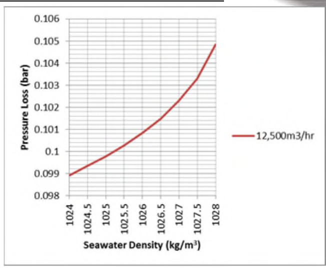
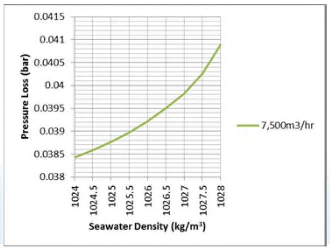
Flexible Pipe String – Hydraulic Performance

Sensitivity to Water Density







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Flexible Pipe String – Vortex Induced Vibration

Screening for VIV using DNV-RP-C205 & DNV-RP-F204

Modal Analysis using Orcaflex to determine natural frequency (fn) of Flexible Pipe String

Vortex Shedding Frequency (fs) determined using fs = S*V/D
(where: S = Strouhal No. / V = Velocity / D = diameter)

Where fn is within approx. +/-20% of fs, potential for VIV

fn (Mode 1) = 0.00585 Hz   fs = 0.046 – 0.07 Hz

Initial analysis indicates potential for VIV at higher modes (9 to 12) which would suggest 'low risk'

Further analysis recommended

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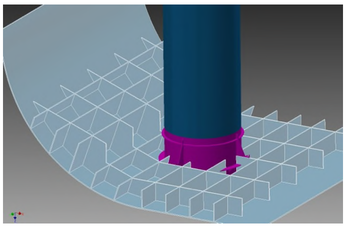
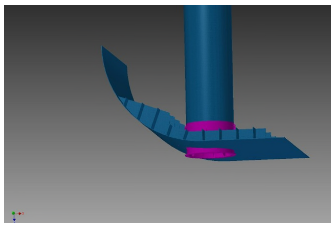
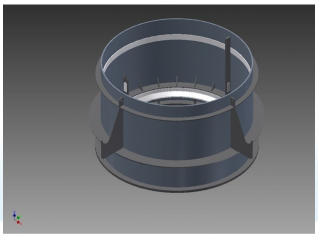
Structural Capacity

Typical Hang Off Structure used for Diverless installed systems:







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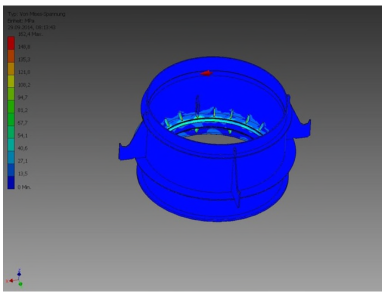
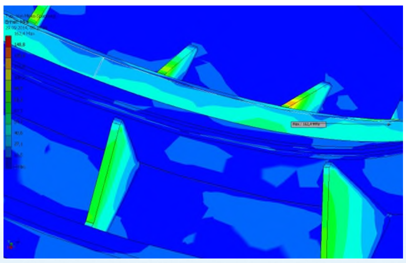
Structural Capacity

Typical Hang Off Structure FEA (Stresses ~163N/mm^2):





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Flexible Pipe String – Installation / Maintenance

Current proven installation procedure can be utilised

Depending upon capcity of vessel crane, alternatively, dedicated pull in winch may be considered

Estimated installation duration of 80-100 hours / hose string (subject to availability of vessel crane)

To avoid congestion in laydown areas, consideration may be given to assembly overboard of support vessel, then pulled into FLNG through caisson for Riser Head installation

Assembly onshore and tow out may be considered but subergence technique would need to be developed

Flexible Pipe String – Installation / Maintenance

System maintenance intervals dependent upon the environmental conditions, material selection, cathodic protection requirements, etc..

As a guideline, first visual inspection undertaken by ROV within 3-5 years of installation.

Subsequent inspections intervals dependent upon findings of first visual inspection

If removal is required, reverse operation of Installation Procedure is applicable

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Contact

EMSTEC GmbH

Gewerbering 8

D-22113 Oststeinbek

Tel.: +49 40 79 686 345
Fax: +49 40 79 686 702

E-mail: info@emstec.net
web: www.emstec.net

www.emstec.net

EMSTEC GmbH
Gewerbering 8
22113 Oststeinbek
Germany
Tel.: +49 (0) 40 79686 345
Fax: +49 (0) 40 79686 702
info@emstec.net

Rev	Date	By	Chk	App	Description
0	22.12.14	IC	BB		Issued as Final
B	19.11.14	IC	BB		Issued for Comments
A	17.06.14	IC			Preliminary Issue

Project:	Feasibility Study of 500m Seawater Intake System
Client:	Statoil Petroleum AS
Document Title:	Seawater Intake System: **Study**
Document No.:	4140506-RP-001
Rev:	0

TABLE OF CONTENTS

LIST OF FIGURES

1. EXECUTIVE SUMMARY

This report provides a state of the art review for Sea Water Intake Systems on board FPSO and FLNG vessels. It compares and contrasts the various layouts and concepts currently considered within the industry and then through qualitative assessment selects a preferred concept and configuration for further investigation and analysis.

The preferred concept consists of 2-off x 60”NB Seawater Intake Risers (1-off Port & 1-off Starboard) each connected to a sea chest which in turn have a cross-over line to facilitate the connection of the Sea Water Suction Pumps.

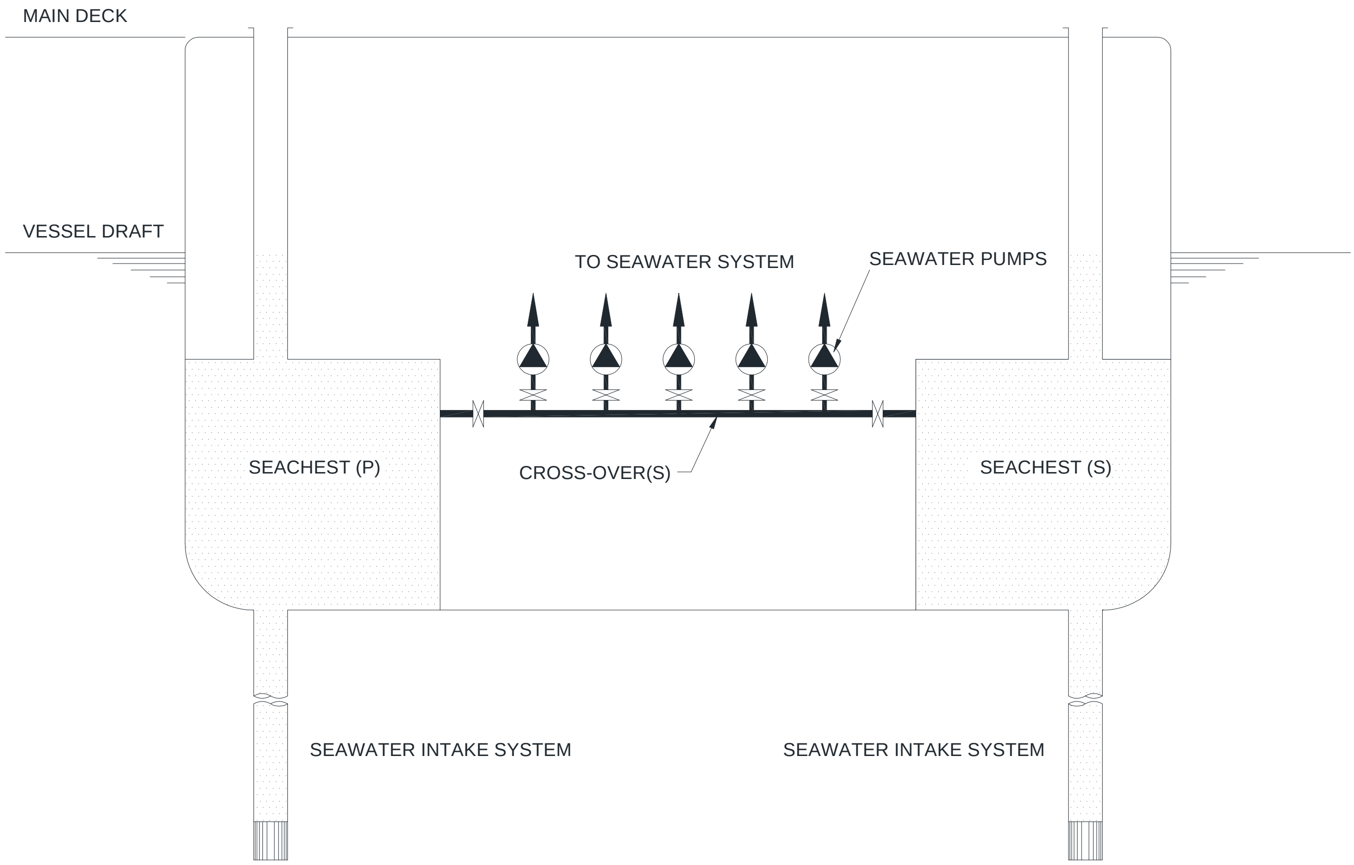

Fig. 1: Seachest Conceptual Arrangement

The selected configuration for each Seawater Intake Riser (SWIR) is an optimisation of function, stability, weight and cost and is a hybrid assembly consisting of flexible rubber hose sections at the upper end of the SWIR, HDPE pipe sections for the central part of the SWIR and steel pipe sections at the lower end of the SWIR (a General Arrangement is presented in Appendix C).

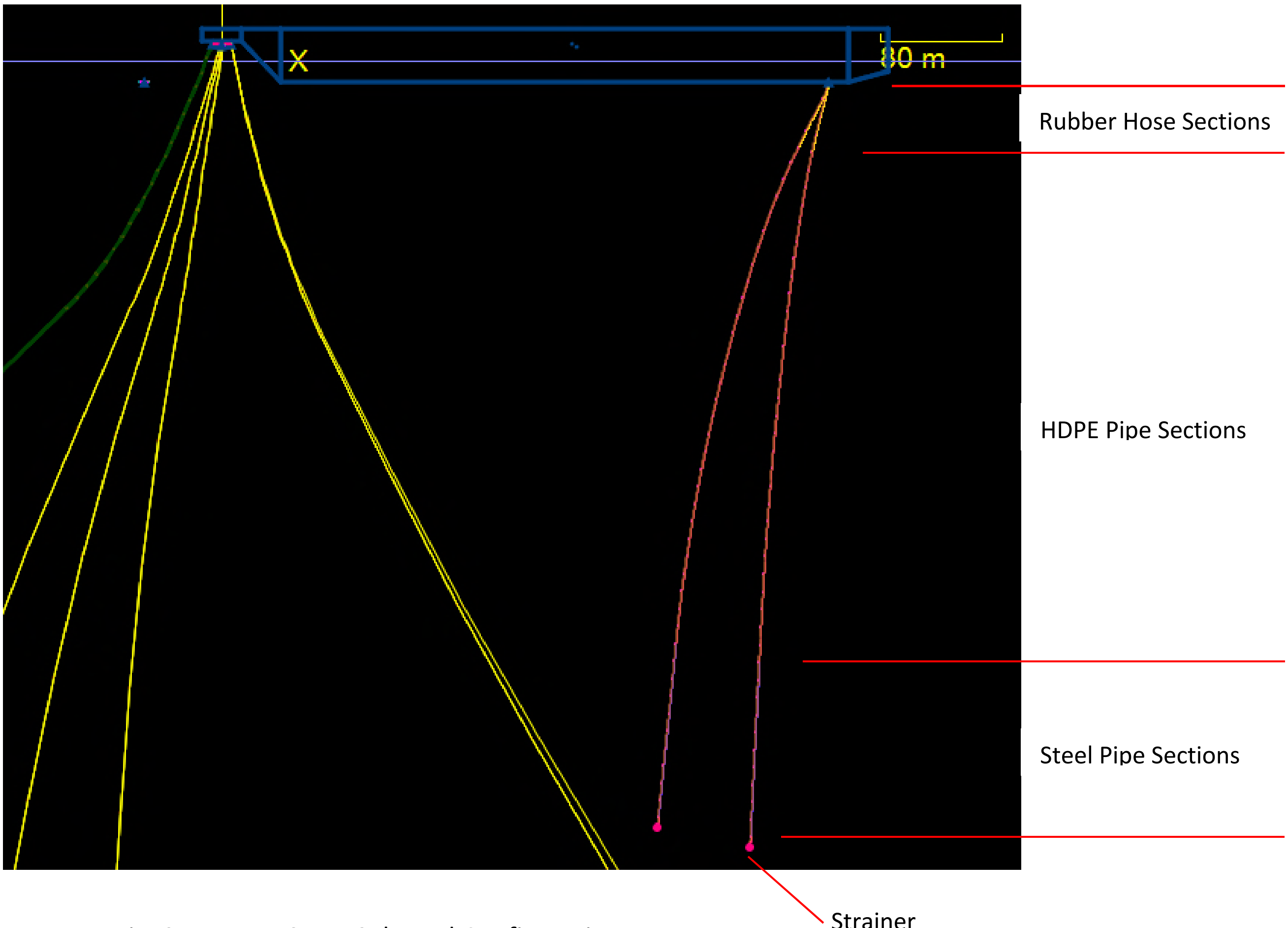

Fig. 2: SWIR Selected Configuration

The global performance of the selected concept and configuration in waves and ocean current is documented through hydrodynamic analysis with particular focus on current wake interaction, possible clashing of single pipe and vortex-induced vibrations (VIV). A detailed arrangement at the connection point is proposed in order to limit load effects into the hull of the vessel and the structural capacity of the arrangement is verified through FEA.

A hydraulic verification of the selected configuration is performed which includes a review of sensitivity to seawater density and also marine growth and a number of graphs are presented in respect of this.

An installation procedure is proposed and the maintenance and inspection requirements reviewed and presented.

A budgetary cost for the preferred concept is provided which indicates that the system CAPEX at €8,950,000 (excluding transportation and installation costs).

The main technical challenges identified by this study relate to the installation of the system. The current installation procedure employed by Emstec for their Diverless Installed System may be considered for the preferred concept, this procedure will typically will use the vessel crane. The maximum installation weight of the preferred concept is estimated at 128 tonnes, therefore, if the capacity of the vessel crane is insufficient, consideration may be given to a dedicated winch, although this would also necessitate a structure of sufficient capacity and height above the caisson to accommodate a sheave block.

Nonetheless, the report concludes that, with the proposed system, it is feasible to reach and import water from a depth of 500m. It further concludes that, subject to the mooring line configuration, the system can be extended to reach and import water from up to 800m depth.

The report recommends that further research is undertaken in a number of areas:

- **The likelihood and attachment resistance of marine growth to proposed materials and the effect on drag.**

  The marine growth profile considered for the study is a generic profile in as much as it does not consider the properties of the relevant substrates. It is recommended that further research is undertaken in respect of marine growth as the mitigation of marine growth may prove beneficial in terms of reduced drag, and thus loading into the hull, and also optimal friction losses through the internal bore of the SWIR.

- **Further investigation regarding the mechanisms and likelihood of VIV**

  The documents reference for the assessment of VIV [5] [10] are intended for Top Tensioned Risers and Steel Catenary Risers as opposed to free hanging flexible cantilevers. Both Fujarra et al (2001) and Prastiano et al (2009) have undertaken research specifically for Flexible Free Hanging Cantilevers and further analyses of this work is recommended.

- **Review of vessel motion and metocean data**

  With regard to vessel motion, the flexible pipe string shows a relatively small displacement. Further investigation with regard to RAO data and Metocean may be beneficial to validate this vessel motion.

  Also, a mooring analysis provided by Statoil [3] refers to the vertical clearance between the intended hose connection point and the mooring line as the 'anchor depth'. It further states that the 'anchor depth' achieved is in the region of 750m. However, using the particulars provided by this mooring analysis, it was possible to produce an Orcaflex model with an 'anchor depth' of approximately 670m and is therefore considered conservative, further investigation may clarify this discrepancy.

2. ABBREVIATIONS

CP	Cathodic Protection
FEA	Finite Element Analysis
FLNG	Floating Liquefied Natural Gas Vessel
FPSO	Floating Production Storage and Offloading Vessel
HDPE	High Density Polyethylene
LNG	Liquefied Natural Gas
MGPS	Marine Growth Protection System
VIV	Vortex Induced Vibration

3. INTRODUCTION

A crucial system for a floating LNG production unit (FLNG) is the seawater intake system. Due to cost, complexity and efficiency of the LNG liquefication process, it is very important to reach and import water of as low temperature as possible. The purpose of this study is to build technical confidence and prove system feasibility of a seawater riser intake system importing water from 500m water depth.

The seawater intake system comprises the riser pipes, the hang-off assembly with possible caisson pumps and the lower riser assembly with inflow equipment and strainers. Two important technical aspects are technical feasibility related to hydrodynamic behaviour and interaction of riser pipes as well as inflow and hydraulic performance.

This study includes the following activities:

- Brief summary on technology state-of-art for water intake systems for FPSOs and FLNGs.
- Propose and compare different seawater intake concepts and layouts. Perform a qualitative comparison based on selected criteria together with Statoil. The comparison is based on concepts consisting of single pipes vs possible bundled concepts and sea chest concepts vs caisson concepts. Proposition of a preferred concept for further assessment.
- Develop and document preferred riser pipe concepts, including: proposed design requirements, type and material properties.
- Proposed installation procedures.
- Document global performance in waves and ocean current. Particular focus on current wake interaction, possible clashing of single pipe and vortex-induced vibrations (VIV). Document pipe tension, curvature and motions. Proposed detailed arrangement at the top in order to limit load effects at the hang-off.
- Verification of hydraulic performance and sensitivity to marine growth and water density.
- Verification of structural capacity.
- Proposed maintenance requirements and possible change-out procedures.
- A brief technical description on the possibility of extending the water intake to 800m below the sea surface.

4. STATE OF THE ART TECHNOLOGY FOR FPSO AND FLNG

4.1. FPSO

As the onshore, shallow water and more easily accessible oil reserves become depleted, oil companies are taking oil exploration and production to deeper and less accessible locations. This has seen an emergence of floating oil production installations, often referred to as FPSO's (Floating Production Storage and Offloading), where the water depth makes a fixed leg platform impractical or where the reservoir location is too remote from a pipeline infrastructure. As the acronym suggests, an FPSO is a ship shape vessel that is moored to the seabed over the oil reservoir from which oil is delivered to the FPSO via flexible riser pipes. The oil is treated through an onboard process or 'production' facility and then stored in the tanks of the vessel. A sea going 'shuttle' tanker comes alongside and is connected to the FPSO, so that the stored oil can be transferred to the tanks of the shuttle tanker via an offloading system. The shuttle tanker then transports the oil onshore.

In many locations, particularly the warm water locations such as West Africa and Brazil, process engineers have found it beneficial to use cooler, cleaner and less oxygenated seawater from below sea level for the vessel's cooling, process, utility and water injection systems. This is achieved using a Seawater Intake System, the utilization of which is fairly recent in the industry, with the first systems being installed circa. 2000.

Each Seawater Intake System is field specific and is designed accordingly, subject to a hydrodynamic analysis which considers the vessel response characteristics, the field specific metocean data and extreme conditions and the flexible hose string properties, which are optimised to suit the required configuration.

A Seawater Intake System is effectively a number of flexible pipe sections suspended from the underside of the seawater caissons, or sea chests, which enable the seawater pumps, to draw seawater from below the surface depths. The length of the Seawater Intake System is field specific but to date, the maximum depths achieved have been approximately 120-130m. Consequently, the Seawater Intake System cannot be installed at the onshore location during the vessel construction and must be deployed once the vessel has been moored over the reservoir, which creates a number of limitations to the design of the Seawater Intake System, most notably the weight restriction. The Seawater Intake System is deployed in the same manner as drill string, that is, the first flexible pipe section is held in a vertical position while the next section is lowered into place by the onboard vessel crane and connected to the first section. The two connected sections are then lowered into the water by the vessel crane until the second section can be held to enable a third section to be connected, and so on until the desired length is achieved. It is desirable to utilise the onboard vessel crane for the installation (and recovery for maintenance and inspection) of the system as an external heavy lift crane is expensive to charter. Consequently, the capacity of the onboard vessel crane currently limits the diameter and/or quantity of flexible pipe sections that can be included in the hose string.

A typical configuration for a Seawater Intake System installed on an FPSO would consist of three 20”NB flexible pipe strings, with a flow rate of 2000m^3/hr per string. Each string would be fitted with fitted with a coarse strainer at the lower end to prevent the ingress of debris or sea life. A marine growth protection system (MGPS) is normally installed in the system which consists of a small bore sodium hypochlorite line within main seawater flexible pipe sections, to enable sodium hypochlorite to be injected into the seawater via a dispersion ring fitted inside the strainer.

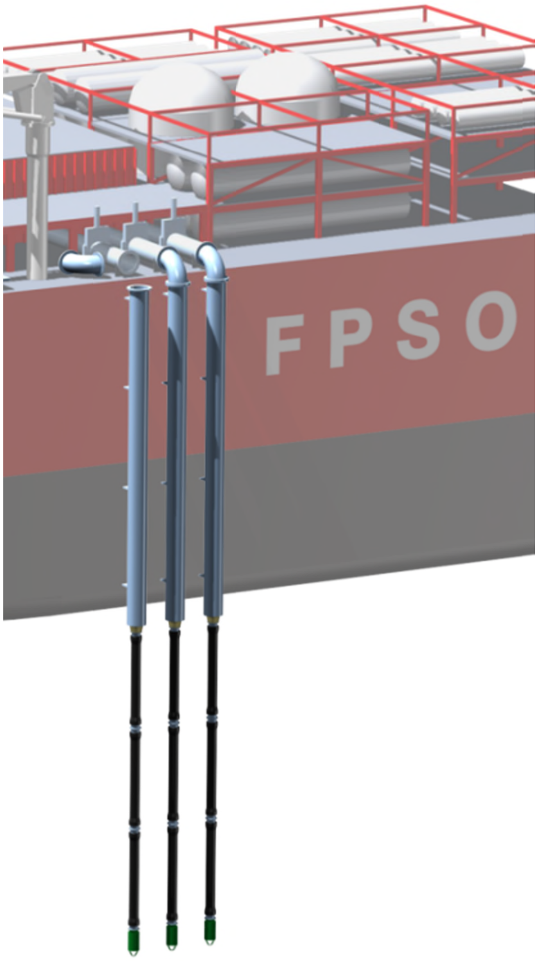

Fig. 3: Typical Seawater Intake System on an FPSO (External Caisson)

4.2. Typical Components of Seawater Intake System

The following is an outline description and the function of the components that generally constitute a Seawater Intake System.

4.2.1. Caisson Interface Structure (Riser Seat)

The Caisson Interface Structure (also referred to as the Riser Seat) forms an integral part of the caisson. It is welded to the vessel caisson and incorporates an internal female conical seat to mate with and centralize the riser head seat. The structure also includes an internal circumferential bearing ring that mates with the riser head bearing ring. To prevent the exposure of bare carbon steel at the mating faces, a super duplex machined surface is installed to each seat face.

Fig. 4: Caisson Interface Structure (Riser Seat)

4.2.2. Riser Head

The Riser Head provides an interface between the caisson interface structure and flexible pipe sections and includes a male conical seat to mate with the female conical seat within caisson interface structure, preventing downward and lateral movement. To prevent tilting, the Riser Head includes an external upper circumferential bearing ring which mates with the caisson interface structure internal circumferential bearing ring. The Riser Head has a flange connection to facilitate connection of the flexible hose sections and anti-rotational brackets that interlock with the caisson interface structure plus reinforced cut-outs for the engagement of the deployment and retrieval tool.

Fig. 5: Riser Head

4.2.3. Flexible Pipe Sections

The Flexible Pipe Sections are typically bonded rubber flexible hose sections that are designed specifically for this application and are connected together in a ‘string’ for the conveyance of seawater. The flexible hose properties are optimised to ensure that, during operation, the vessel motion and environmental conditions do not compromise the flexible hose design parameters, whilst minimising the loads and moments into the caisson structure. The ends of the flexible hose sections are flanged and hypochlorite hose supports are built in to the hose to secure and support the hypochlorite line.

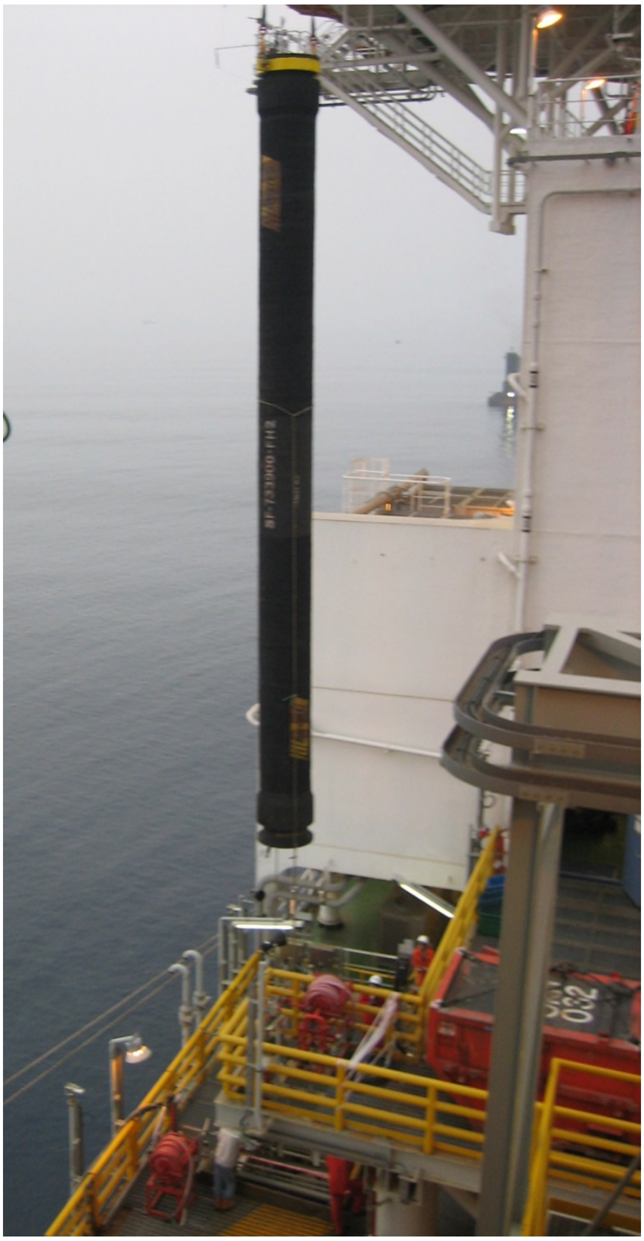

Fig. 6: Flexible Pipe Section

4.2.4. Hypochlorite Line

A hypochlorite delivery hose is normally installed to each seawater flexible pipe sections, and are connected to form a continuous flexible line from the caisson head to the strainer unit. The purpose is for the conveyance of sodium hypochlorite to intake strainer, enabling it to be injected into the seawater as it is drawn in. It should be noted that all wetted metallic parts within the hypochlorite system are manufactured from titanium, this be resistant to chemical attack from sodium hypochlorite.

Fig. 7: Hypochlorite Line

4.2.5. Strainer

A coarse strainer is connected to the lower end of the seawater flexible pipe string to prevent the ingress of large sea life or debris into the seawater system. The strainer includes a hypochlorite dispersion ring which enables sodium hypochlorite to be injected into the seawater as it is drawn into the system.

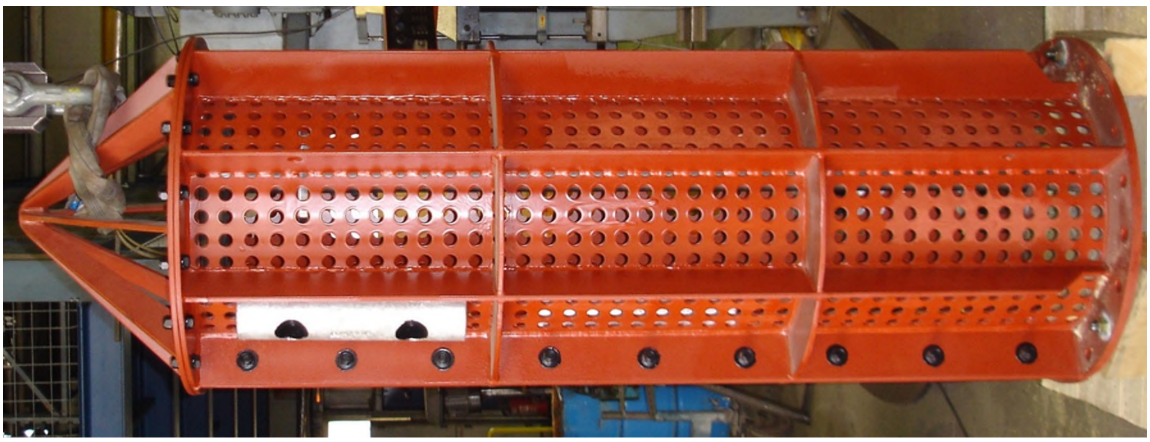

Fig. 8: Strainer

4.2.6. Studbolts & Nuts

The seawater flexible pipe sections are connected by means of studbolts complete with full nuts and lock nuts.

Fig. 9: Studbolts & Nuts

4.2.7. Cathodic Protection

Where required, sacrificial anodes are bolted to the metallic components in the system to provide cathodic protection to the system.

Fig. 10: Cathodic Protection

4.3. Variants to the Seawater Intake System

Since the introduction of Seawater Intake System, the design has been optimised based on feedback from the field and a number of variants are now commonly considered for each project:

4.3.1. Diverless & Diver Assisted Installation

A system designed for diverless installation is installed through a caisson and without the aid of divers. The caisson interface structure is supplied and pre-installed during the construction phase of the vessel and includes a load ring which forms the riser seat. The flexible pipe string is assembled and deployed through the caisson and lowered into place by a deployment tool which is hydraulically operated from deck level to activate the release mechanism of the tool once the assembly has been seated (the riser head installed to the top end of the flexible pipe string engages with the pre-installed riser seat structure) allowing the deployment tool to be retrieved through the caisson.

Refer to Appendix A for Installation Sequence for Diverless Installation System

A diver assisted system is assembled in a similar manner to the above except that it is assembled over the side of the vessel rather than through a caisson. Using the onboard vessel crane and a series of pull-in wires, the assembled flexible pipe string is lowered into the water over the side of the vessel and then pulled up to the underside of the caisson or sea chest connection. This connection is typically a bolted flange connection which needs to be made by divers.

Fig. 11: Assembled Flexible Pipe String being lowered overboard for a Diver Assisted Installation

Refer to Appendix B for Installation Sequence for Diver Assisted Installation System

4.3.2. Rubber Hose or HDPE Sections

Where the weight of the Seawater Intake System has become critical, alternative configurations have been installed utilising High Density Polyethylene (HDPE) sections. HDPE is virtually neutrally buoyant, so once submerged the crane hook load is relieved. Similarly, the installed weight of the system is also reduced. A typical configuration utilising HDPE will consist of a rubber top hose, as this is where the main loads and bending occurs, with the lower sections from HDPE. Due to the reduced weight of this configuration, a ballast weight is normally installed at the lower end of the hose string to provide stability. Additional advantages of HDPE are that, it has a smoother surface than rubber hose which improves the pressure loss characteristics of the system, also, due to the smooth surface, marine growth does not readily attach to the surface.

There are at least three such systems currently operational.

4.3.3. Single or Dual Hypochlorite Line

It has been reported that for a diver assisted installation currently in the field, a component installed by the divers did not function correctly, resulting in a loss of Sodium Hypochlorite into the sea water system. This event resulted in a build up of marine growth, which broke away and was pulverised by the seawater pumps and ingested into the cooling system, resulting in a costly shutdown due to blocked heat exchangers.

Consequently, due to the criticality of the system, it is becoming more common for projects to specify a dual hypochlorite line to provide redundancy for the system. The dual hypochlorite system consists of two completely independent hypochlorite lines and dispersion rings

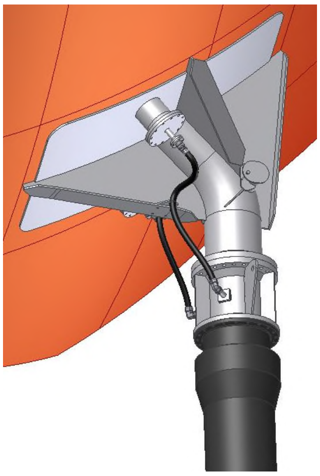

Fig. 12: Dual Internal Hypochlorite Line
(shown for Diver Assisted Installation)

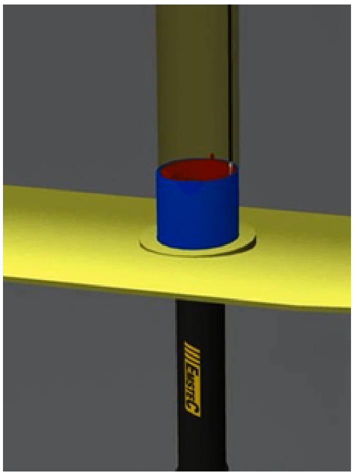

Fig. 13: Single Internal Hypochlorite Line
(shown for Diverless Installation)

4.3.4. External or Internal Hypochlorite Line

To enable the injection of Sodium Hypochlorite, a small bore hypochlorite line is commonly installed along the complete length of the flexible pipe string, terminating at the dispersion ring within the coarse strainer. When installed in a diverless system, the hypochlorite line is located inside the main seawater flexible pipe, fixed and supported at each hose flange connection, to protect it from potential damage during installation.

For a diver assisted system, the hypochlorite line can be installed either internally of externally. When installed externally, the hypochlorite line is generally fitted helically.

For diver assisted systems, a diver installed jumper hose connects the hypochlorite line to the vessel MGPS.

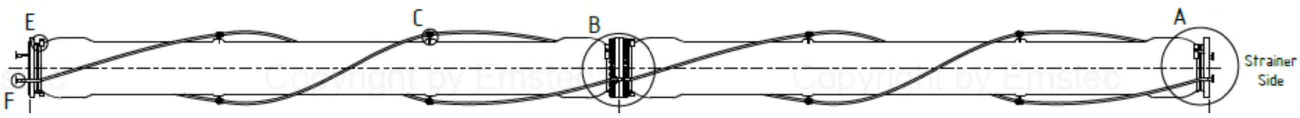

Fig. 14: External Hypochlorite Line Arrangement (Dual Line shown)

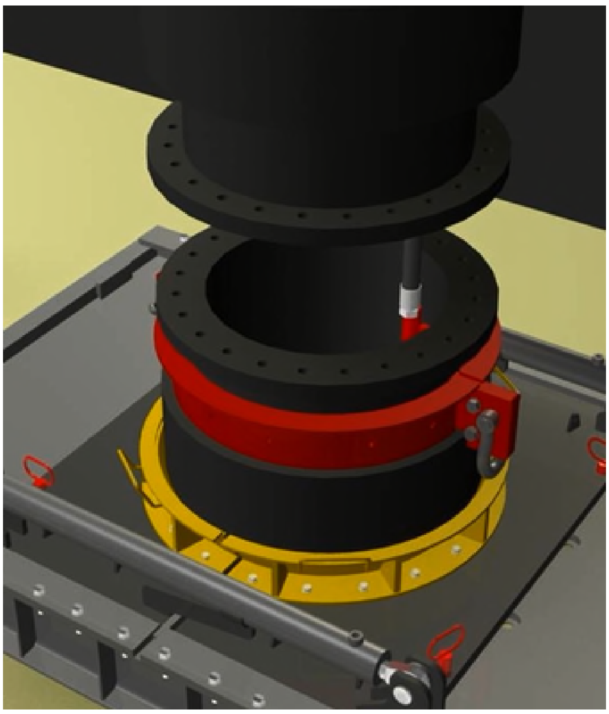

Fig. 15: Single Internal Hypochlorite Line (shown during installation)

4.3.5. Cathodic Protection and / or Corrosion Resistant Materials

Flexible rubber hose sections are fully encapsulate with rubber and as such do not have any exposed metallic components.

However, other metallic components within a system include, Riser Seat, Riser Head, Studbolts and Nuts and the Strainer, and typically, each of these components will be manufactured from Carbon Steel and coated with an appropriate subsea paint system. The strainer is often coated with an anti-fouling biocide release paint system to prevent marine growth and reduce the possibility of blockages. In addition to this, sacrificial anodes are fitted to provide cathodic protection (CP) for the submerged components, the exception usually being the riser seat which is connected to and protected by the vessel CP system.

For the metallic components within the system, there are a number of corrosion resistant materials currently in operation in the field. For example, the studbolts and nuts have been specified as Super Duplex on a number of projects and in one case titanium bolting was specified. This negates the requirement for sacrificial anodes thus reducing the potential maintenance requirements

Fig. 16: Flange Connection with Carbon Steel Studbolts & Nuts and Anodes

Fig. 17: Flange Connection with Super Duplex Studbolts & Nuts (No Anodes)

Similarly, the strainer has been specified as Super Duplex on previous projects, again negating the requirement for sacrificial anodes. The riser seat and riser head are not normally specified in a corrosion resistant material as the riser seat generally forms a part of the hull or caisson and the riser head, being the first component in the string, is more easily retrieved for maintenance and inspection. However, on one project, both the Riser Seat and Riser Head structures were specified and manufactured from 6Mo.

Although it is not known if any are currently in the field, there has recently been more interest in manufacturing the strainer from a copper alloy to prevent the attachment of marine growth.

All wetted components within the hypochlorite line are from titanium to resist the chemical attack of sodium hypochlorite.

4.3.6. Guide Bar or Orientation Pipes

To ensure that the hypochlorite line is not subjected to excessive loading during operation, it is necessary to prevent rotation of the installed hose string once deployed. This is achieved by incorporating anti-rotation brackets onto the Riser Head which engage with stop plates on the Riser Seat. Therefore, to ensure that the hypochlorite line and the ant-rotational brackets are correctly aligned during installation, there are two methods currently employed to achieve this.

A guide bar can be pre-installed along the full length of the caisson, the Riser Head and installation tools have a corresponding cut-out, similar to a keyway, so that, when deployed, the hose string cannot rotate and is seated in the correct orientation.

Alternatively, a set of orientation pipes can be provided with the installation tools. These pipes are connected to the deployment tool as is it is lowered into the caisson. A datum point is marked at the top of the caisson which corresponds to a datum point on the Riser Seat.

The orientation pipes are marked accordingly such that, during deployment, a torque can be applied (at the top of the caisson) to the suspended hose string to ensure that the Riser Head is correctly aligned with the Riser Seat.

Fig. 18: Installation using Guide Bar

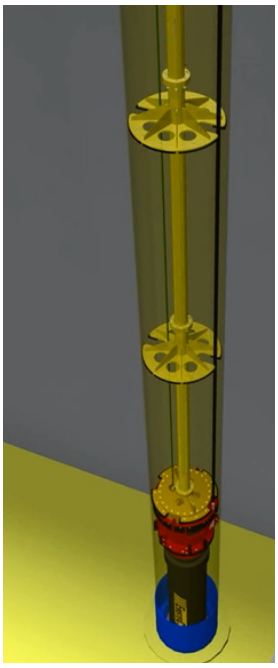

Fig. 19: Installation using Orientation Pipes

4.3.7. Installation Tooling

The installation tools that are supplied with the system have been optimised over the years. There has been a great focus on the safe handling of the equipment during installation and a number of safety features incorporated within the installation tools such as locking pins, positive spacers for hose connection. Where applicable installation tools are load tested and witnessed by a third party and a dedicated spreader beams are provided for handling hose sections

4.4. FLNG

Although none have yet been put into operation, a number of major oil and gas companies are developing Floating Liquefied Natural Gas (FLNG) vessels (Morgan, 2012). The function of an FLNG is to harvest natural gas from remote gas reservoirs and use its onboard processing facilities to liquefy the natural gas (LNG) and then store the LNG onboard the vessel until such time that it can be transported onshore via a sea going vessel, in the same way that a FPSO and Shuttle tanker operates for oil reserves.

An animation of such a vessel can be found at: http://www.youtube.com/watch?v=3FqhwJ22H4E (Prelude FLNG - Investors Handbook, 2012)

The FLNG onboard liquefication process requires extremely large volumes of seawater for the cooling systems. The volumes required are in the order of 35,000 - 50,000 m^3/hr which are approaching 10 times the amount utilised on FPSO's. Also, process engineers are seeking to take water from depths of up to 500m to obtain even cooler water. It has been estimated that the efficiency and / or production of the FLNG can be significantly improved by utilising water from these depths.

It is known that a number of studies have been undertaken in respect of sea water intake on FLNG vessel, but at time of writing there are no systems of this magnitude in operation.

These studies include the use of steel riser pipes installed in a bundle with the connection to the hull made by a flexible connection with an articulated internal load bearing component.

5. QUALITATIVE ASSESSMENT OF CONCEPTS AND LAYOUTS

5.1. Single Pipes

A single pipe configuration refers to a flexible pipe string, that is not joined to another pipe string or structure and is free to move independently. This configuration can be connected directly to a vessel caisson or intake from the underside of the vessel (by use of divers) or it can be installed from the topsides through a caisson and without the aid of divers. On an FPSO it is common to have up to 5-off single pipe configurations installed in line either longitudinally or transversely in relation to the vessel centreline.

Analysis has shown that, when multiple single pipe strings have been installed, they each behave similarly to both current and wave forces. However, there is a possible scenario, where a current with sufficient velocity is heading in line with the flexible pipe strings, has a wake generated by the leading string and the subsequent strings react to that wake and behave differently. Analysis has shown that in this scenario, there is a possibility that the strings can 'clash' with one another. However, analysis has also shown that the impact values are low and do not present a problem in respect of damage to the flexible pipe strings.

As it is an independent assembly, a single pipe configuration can be removed for inspection and maintenance without having to disturb another hose string.

5.2. Bundled Pipes

A bundled pipe configuration is one where multiple seawater intake pipes are connected to one another and / or a structure. The conceptual feature of the bundle is to ensure that each of the intake pipes moves in conjunction with the others and do not clash with one another, that is the wake effect is removed. It is known that a current project is developing a bundled concept for installation onto an FLNG vessel comprising of 8-off intake pipes and a central supporting structure.

The study for this project shows that, the initial installation of a bundled system requires that the support structure is installed from the underside of the vessel utilising a heavy lift crane. It also requires a temporary installation platform to assist with the deployment of the central supporting structure.

The seawater risers are then fed through caissons and through the openings in the bundle spacer structure. In this particular study, risers manufactured from steel are considered and are each connected to the hang off point by a rubber hose section. Within each of the rubber hose sections is a chain / articulated link which accommodates the tensile load of the bundle. Although this system is not yet in service, and consequently unproven, it is understood that scale model tests have been performed.

5.3. Caisson Arrangements

In offshore terminology, a caisson is an open tubular structure that is installed vertically from a position below the waterline of an installation to a position above the waterline. Caissons are commonly used for the intake of seawater by either installing a submersible pump within the caisson or by taking a branch from the caisson into an adjoining compartment where a centrifugal pump (or similar) can be connected.

Caissons can be installed either externally of internally, an external caisson being one that is attached to the outside of the vessel hull, whereas in internal caisson is one which is incorporated into the hull structure. An external caisson would normally accommodate a submersible pump whereas an internal caisson may utilise both configurations.

The type and location of caisson would normally be determined to suit the layout of the topsides process systems. In terms of design, the main difference is that, as an external caisson does not form part of the hull structure, and will not affect the watertight integrity of the vessel if damaged, it is not considered a ‘class’ item. An internal caisson does form a part of the vessel hull structure and is therefore would require class design approval.

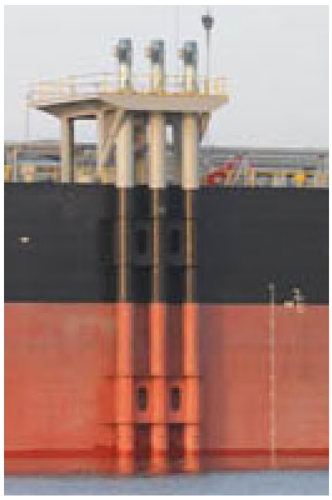

Fig. 20: Vessel fitted with Internal Caissons

Fig. 21: Vessel fitted with External Caissons

To provide system redundancy, a complete caisson, pump and intake string would be required and if the hose string needed to be retrieved for maintenance and inspection, then a submersible pump (if installed) would need to be removed first

5.4. Sea Chest Arrangements

Traditionally, a seachest is a small compartment incorporated into the hull of a sea going vessel that is open to the sea and provides an intake point for the seawater

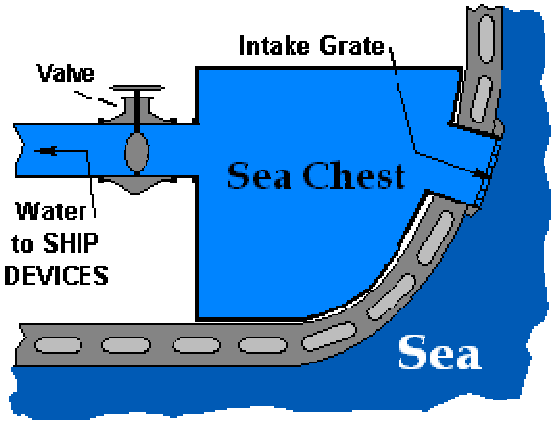

Fig. 22: Traditional Seachest Arrangement

However, on FPSO's this concept has been extended in a number of ways. Firstly, the traditional seachest may be fitted with an inlet pipe to accommodate a seawater intake system, as shown below.

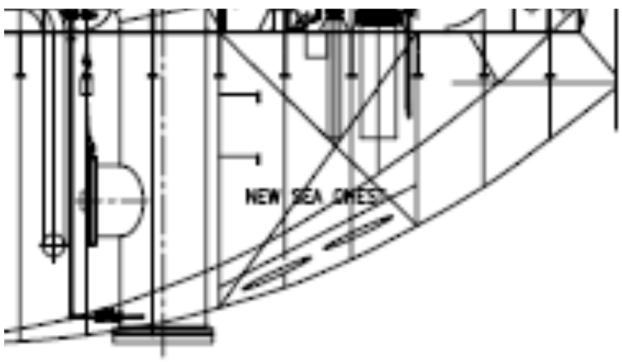

Fig. 23: Seachest with Intake Pipe

Alternatively, the seachest may be a much larger compartment that is flooded and provides sufficient volume to feed multiple seawater pumps, i.e. Firewater, Cooling, Ballast Water, etc. The pumps selected in this arrangement could be a series of submersible pumps arranged within the Seachest compartment or else centrifugal pumps (or similar) positioned outside the seachest connected to a outlet pipework.

This larger flooded compartment would also be fitted with an inlet pipe (or pipes) to enable the installation of a seawater intake system.

5.5. Discussion

In assessing the above concepts the first point to note is that, the bundled concept is as yet unproven (there are no known systems as such operating in the field), therefore neither the system performance nor the practicality of the installation philosophy can be assessed with any certainty. Furthermore, it is understood that the bundled concept has so far only been considered for 150m depth, but even at this length, the installation philosophy and the system maintenance appears complex. Alternate materials other than steel risers may be considered for a bundled arrangement but given that it is, as yet, untried and untested, it is not recommended that the bundled system is considered at this stage.

Conversely, it is believed that all systems currently operating in the field to date on FPSO vessels have adopted the single pipe concept. It is estimated that there are in excess of 50 vessels currently operating in the field with multiples of this type of arrangement installed where the maximum depth achieved to date is approximately 130m. There has been no feedback from the field to suggest that either the installation or the performance of such systems has been unsatisfactory and , although analysis has shown that under certain conditions, clashing may occur between multiple hose strings arranged in line, there are no known reports from the field indicating that this has either occurred and / or been problematic.

In terms of the caisson versus seachest concepts, the main criteria for preferred concept is the optimum pipework layout and pump selection to suit the vessel / topsides layout. Although not directly affecting the performance of the seawater intake system, the selected concept would need to be taken into consideration during design with regard to system installation.

For example, an external caisson is positioned outboard of the vessel and as such generally does not have any overhead restrictions, allowing the vessel crane to have free access for system installation. An internal caisson however, is located inboard and may be positioned below process modules thus restricting headroom for installation or, inversely, the process modules may have to be designed ‘around’ the caisson to enable access. Similarly, the caisson top may be positioned either at a machinery flat or within a tank space inside the hull of the vessel meaning access would need to be created by a series of openings and /or hatches. Nonetheless, whether the caissons are external or internal type, the practicality of the pipework layout favours the caissons to be arranged in line and thus the possibility of clashing under certain conditions.

A sea chest concept would generally consist of one or two hose strings, not necessarily arranged in line and thus minimising the possibility of line clashing. Furthermore, if two sea chests were considered (one port and one starboard), each with a Seawater Intake System, this would further separate the hose strings and reduce the chances of clashing even more.

It is from this assessment that two concepts are presented for consideration for further development as described in the next section.

6. DEVELOP AND DOCUMENT PREFERRED CONCEPTS

The required inflow of water to the LNG process has been specified as:

- 15,000 m3/hr – Low Flow Rate
- 35,000 m3/hr – High Flow Rate

Therefore, to provisionally quantify the requirements for the seawater intake system in terms of flexible pipe diameter versus quantity, a preliminary flow analysis has been performed and the summary presented in the below table:

Hose Bore		Hose X-Sect Area (m^2)	Seawater Velocity (m/s)	Flow Rate per String (m^3/hr)	Aprrox Press Loss* for 500m String (bar)	Qty Strings for High Flow Rate (35,000m^3/hr)	Qty Strings for Low Flow Rate (15,000m^3/hr)
NB	mm						
30	750	0.442	3.0	4771	0.45	8	4
32	800	0.503	3.0	5429	0.42	7	3
36	900	0.636	3.0	6871	0.37	6	3
40	1000	0.785	3.0	8482	0.32	5	2
48	1200	1.131	3.0	12215	0.26	3	2
60	1500	1.767	3.0	19085	0.19	2	1
					*excluding strainer		

To date, and unless specified otherwise, the general design parameters for hose size selection are a maximum velocity of 3m/s and a maximum pressure loss of 0.2barg.

Therefore, a value of 3m/s was used for the provisional analysis and the corresponding pressure loss evaluated accordingly (based on the properties of rubber hose). A more comprehensive pressure loss calculation will be undertaken later, nonetheless, it can be seen that the trend is that larger pipe diameters have a lower pressure loss.

Similarly, and although it is has not yet been quantified, due to the reduced surface area, the temperature loss through a single large pipe diameter is expected to be lower than the temperature loss through two smaller pipes carrying the equivalent volume.

As discussed in Section 5.5, two concepts are considered initially, namely: Caisson Concept and Seachest Concept.

6.1. Caisson Concept

At present, the largest submersible pump known to be readily available, has a design capacity of approx. 10,000m^3/hour. Therefore, for an arrangement using single pipes in individual caissons with submersible pumps, a 40"NB system would be the maximum line size available for selection, and which would require 5-off caissons to achieve the high flow rate. For the low flow rate, only 2-off caissons would be required.

As described earlier in the document, the caissons are generally arranged in sequence (externally or internally) with a set distance between them. This is to enable the seawater pipework arrangement and power supplies for the pumps to be more efficiently arranged. The consequence of this for the seawater intake system is that the flexible pipe strings are relatively close to one another and, under certain environmental conditions, may clash. Although previous analysis has shown that the clash forces experienced to date are not detrimental, it is preferred that clashing is avoided. For this arrangement, consideration may need to be given to clash prevention equipment.

The following diagram illustrates a typical arrangement using seawater caissons:

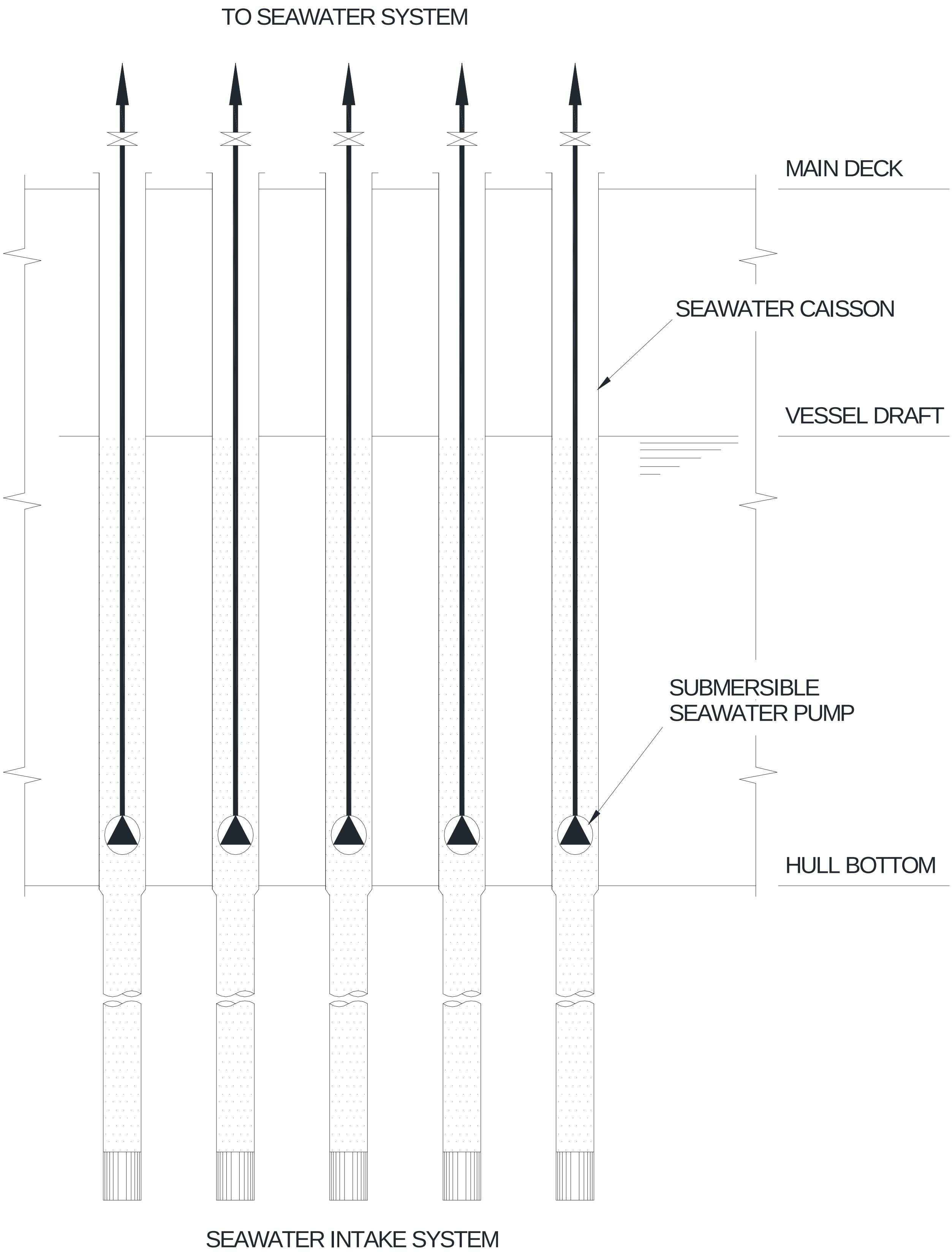

Fig. 24: Typical Caisson Arrangement

6.2. Seachest Concept

For a seachest arrangement, 2-off single pipes with a 60”NB line size could achieve the high flow rate whereas 1-off single pipe would be required to achieve the low flow rate.

To minimize the possibility of the two single pipes clashing, two seachests could be considered at the port and starboard extremities of the vessel. Extension of the seachest inlets to the Main Deck would enable the system to be installed from the topsides similar to the caisson arrangement.

The two seachests could be connected by a cross-over pipe, to which the required pumps could be connected, as shown in the diagram below:

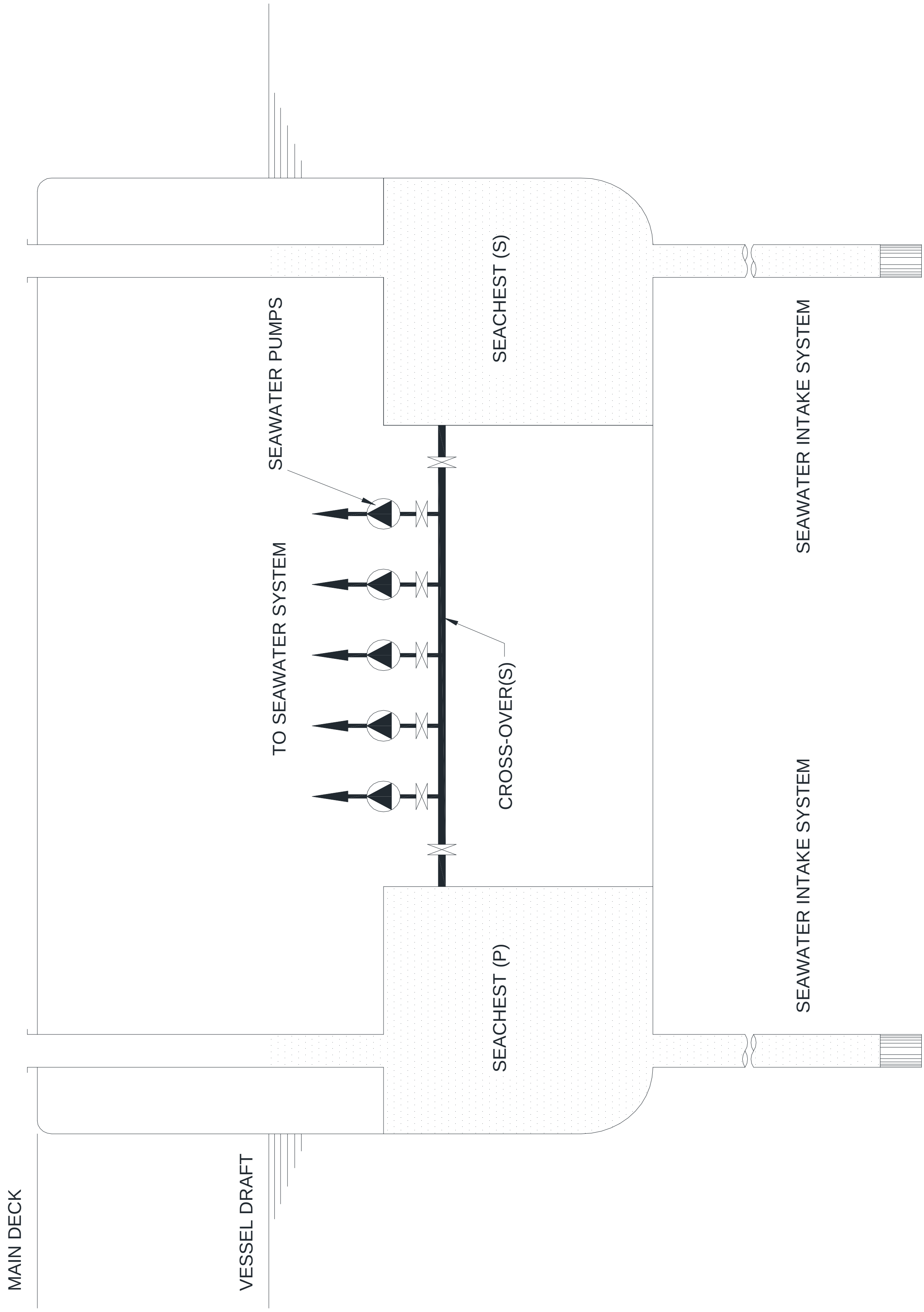

Fig. 25: Seachest Conceptual Arrangement

6.3. Preferred Concept

After reviewing and discussing the two options presented above, it was decided that the preferred option was that presented in Section 6.2:

- 2-off 60"NB x 500m Flexible Pipe Strings (1P &1S) – Seachest Concept

This feasibility study will proceed on this basis.

7. HYDRODYNAMIC ANALYSIS

7.1. Input Data

7.1.1. Vessel Data

The vessel data was received in the form of an Orcaflex data (.dat) file [1] and represented a vessel corresponding to a displacement of approximately 370,000m^3 and a length of approximately 425m.

The vessel RAO data was received in the form of a WAMIT output (.out) file [2] and included two sets of RAO data namely, Haskind and Diffraction. The data was imported into the above Orcaflex data file and the Haskind RAO selected.

7.1.2. Mooring Line Configuration

A report [3] was received [1] which detailed the mooring system optimisation to maximise the length of the seawater hoses.

The mooring lines were modelled into Orcaflex in accordance with the details provided in Sections, 2.3.2, 2.3.3 and 2.3.4 of this report [3].

Note that the report refers to the vertical clearance between the intended hose connection point and the mooring line as the 'anchor depth'. It further states that the 'anchor depth' achieved is in the region of 750m. However, using the particulars provided by the report, it was possible to produce an Orcaflex model with an 'anchor depth' of approximately 670m and is therefore considered conservative, although this may be examined further at a later date.

7.1.3. Environmental Data

The metocean data was received [1] in the form of a report [4].

7.1.3.1. Direction Convention

Wave: specified direction is FROM where the wave are coming

Current: specified direction is TO where the current is flowing

7.1.3.2. Return Periods

With reference to the Metocean Data [4], Section 1.3.4, the return periods are identified by the following Annual Probabilities of Exceedance:

Return Period	Annual Probability of Exceedance
1 year	0.63
10 year	10^{-1}
100 year	10^{-2}
10,000 year	10^{-4}

Environmental data will be referred to by 'Return Period' from hereonin.

7.1.3.3. Waves

As suggested within the Metocean Data [4], Section 3.4, for short term analysis, the wave data from Table 3.7 is used and reproduced below:

Table 3.7 Omni-directional extreme significant wave heights and corresponding spectral peak periods; mean values and 90 % confidence bands.

Annual probability of exceedance	Significant wave height H_S – (m)	Spectral peak period T_p – (s)		
		5 %	Mean	95 %
0.63	2.9	8.5	10.4	12.5
10^{-1}	3.8	9.4	11.1	12.9
10^{-2}	4.8	10.3	11.9	13.6
10^{-4}	6.7	11.6	13.2	14.8

The most consistent estimate for the q-annual probability load/response is obtained by performing a full long term analysis. For the area under consideration, it is recommended that this is done using a POT formulation of the long term response analysis. Time histories for environmental characteristics during storm can be provided. The long term analysis must account both for the variability of the maximum storm response and the long term variability of the storm severity. For early phase considerations, a short term analysis can possibly give results of sufficient accuracy. In case of a short term analysis, one shall select extreme H_S from Table 3.7 together with the most unfavourable period of the period band provided by the table. The duration of the sea state shall be taken as 3 hours, and the q-probability response can be estimated by the 90% value of the 3-hour extreme value distribution for the target response quantity.

The Torsethaugen frequency spectrum was selected as recommended in [4] Section 3.5.

A sensitivity study was carried out for the 100yr return (10^{-2}) wave to determine the worst case period between 10.3s and 13.6s as presented in [4] table 3.7. The associated Hmax was determined using the Orcina recommendation of:

Hmax = kHs[½ln(N)]^{½} *(where N = T/Tz & k = 0.9)*

and applied to 5 periods within the range.

The vessel accelerations at the hose connection point were extracted which showed that the most onerous period was the mean 11.9s which is used for all subsequent analysis.

A three hour wave profile was ran using the Hs and most onerous Tp value and four wave packets of 300s, each with a significant event at their midpoint, were identified ($Tass_{min}$ Rise, $Tass_{min}$ Fall, $Tass_{max}$ Rise, $Tass_{max}$ Fall) and the relevant time origin used for the analysis.

7.1.3.4. Current

The current profiles provided in [4] Table 4.22 were used and is reproduced below:

Table 4.22 Extreme current profiles at Block 2 Station C3.

	Annual probability of exceedance		
Water depth	0.63	10^{-1}	10^{-2}
m	cm/s	cm/s	cm/s
0	174	188	200
-47	158	171	182
-108	142	152	162
-147	89	94	98
-207	85	91	96
-307	83	89	95
-508	76	82	88
-748	66	72	78
-1008	64	71	77
-1410	40	44	48
-1982	28	31	34

The current profile for 100yr return (10^{-2}) was considered for the analysis

7.1.3.5. Extreme Condition

It was assumed that Wave and Current data of the same return period occur at the same time, although this is a pessimistic assumption as it is unlikely that they will coincide.

As the vessel is Turret Moored, it is assumed that it will be always be heading into the Waves, however, it is assumed that the current can be considered to be independent of the Wave Direction and is therefore modelled at 5 directions (assuming symmetry) around the vessel heading.

7.1.4. Flexible Pipe String Data

The following components are used to model the Flexible Pipe String:

Component	O/D *(mm)*	I/D *(mm)*	Section Length *(m)*	Mass in Air *(kg)*	Weight in Water *(kg)*	Axial Strength *(kN)*	Min. Bend Radius *(m)*
Steel Riser Head	n/a	n/a	n/a	2500	2,175	n/a	n/a
Hose Section	1760	1500	11.5	11,940	3,900	~20,900	6
HDPE Section	1600	1478	11.5	3,249	-227	~7,650	64
Steel Pipe	1524	1486	11.5	8,110	7,050	~25,000	1,200
Flange Connections	n/a	n/a	n/a	750	652	n/a	n/a
Steel Strainer	1855	1837	6.5	2640	2295	n/a	n/a

Table 8.1.4 – Flexible Pipe String Data

7.1.5. Flexible Pipe String Configuration

The selected configuration of the flexible pipe string (refer to Appendix C for General Arrangement) is based on an optimisation of a number of factors namely, function, stability, weight and cost.

7.1.5.1. Function

From experience with seawater intake systems, it is known that the most bending is induced at the upper end of the flexible pipe string. This is primarily due to the current profiles of the geographical region, which are highest at the surface and reduce with depth. Furthermore, the loads induced by the vessel motion are also absorbed at the upper end of the flexible pipe string. Consequently, it is common practice to install a stiffer, more robust hose section as the first hose(s) to accommodate the greater loads seen at the upper end of the flexible pipe string. Below the top hose, a less stiff hose is generally installed as there is less bending induced by the current and the loads incurred are lower. On a number of systems supplied into the field, these lower hoses have been manufactured from HDPE which is less flexible than a rubber hose but flexible enough to absorb the bending from the currents. On these systems, and due to the positive buoyancy of HDPE, it was necessary to add a ballast weight at the lower end of the flexible pipe string to ensure that the string maintains a positive load onto the riser seat and also to maintain the stability of the string in the ocean currents.

7.1.5.2. Stability

It is generally desirable to minimise the excursion of the free end of the flexible pipe string. This is due to a number of reasons, one of which is that, the further the excursion, the depth of the intake point decreases and the water temperature increases. A further benefit is to avoid any potential interference with mooring lines or other riser systems. It has also been shown that, the less the excursion is, the lower the bending moment into the hull at the upper end of the flexible pipe string but the greater the tension is which is advantageous both in preferred loading and greater positive tension at the riser seat seal.

A flexible pipe string from rubber hose sections generally has enough self weight to provide sufficient stability within the string. As described above the, systems in the field using HDPE sections have ballast weights installed at the lower end to provide this stability.

However, for the large bore and longer length seawater intake risers currently being considered for FLNG projects, the self weight of the rubber hose systems, and the required ballast weight of the rubber/HDPE system makes the installation of the system more challenging due to the increase in installation weight and the capacity of the onboard vessel crane

7.1.5.3. Weight

The lower the installed weight of the system (i.e. submerged weight), the lower the loads and moments induced into the hull are likely to be. Also, weight saving on any equipment package is advantageous to the global weight of the vessel.

Furthermore, and as discussed above, on FPSO vessels it has been normal practice to install the seawater intake risers utilising the onboard vessel crane. This has been achievable due to the comparative smaller bore and shorter length of the systems required by FPSO’s to that of FLNG vessels. As the diameter and length of the system increases, then so too does the installation weight. The installation weight is the maximum weight likely to be seen by the installation device and is generally the fully assembled flexible pipe string, at the point of deployment.

Therefore, to minimise the costs of a high capacity lifting device or an external crane barge for installation (and retrieval for maintenance/inspection), it is desirable to keep the installation weight as low as is reasonably practicable.

7.1.5.4. Cost

As with any equipment package, cost has to be a major consideration. A system where the cost outweighs the operational financial benefits of the system is not a realistic proposition. Similarly, during operation, it is desirable to recover the CAPEX of the system as quickly as possible. Therefore, the cost of the system is a contributing factor to the selected configuration.

7.1.5.5. Selected Configuration

Based on the above discussion, a number of configurations were considered and subject to a quasi-static analysis to determine the most optimum arrangement.

The selected configuration is tabulated below and is based on the following rationale;

Rubber hose sections are selected for the upper end of the hose string to absorb the main bending loads induced by the ocean currents and the vessel motion.

HDPE pipe sections are selected for the mainline part of the string, primarily to minimise the weight of the flexible pipe string. HDPE provides sufficient flexibility to accommodate the amount of bending seen at this part of the string.

Steel pipe is used for the lower section of the pipe string. The function of the steel pipe is to provide ballast and thus the stability to the system, while simultaneously adding to the length of the system. It was found by the quasi-static analysis, that sections of steel pipe provide the optimum stability in terms of weight versus free end excursion as opposed to, say a clump ballast weight at the lower or steel pipes sections interspersed along the length of the string.

In terms of weight, and as indicated above, HDPE has positivie buoyancy, therefore, the more HDPE sections that are used, the lower the installation and installed weight of the system.

With regard to cost, HDPE and Steel pipe sections are the least expensive elements therefore the fewer rubber hose sections employed, the more cost effective the system is

Therefore, the following flexible pipe configuration is considered for further analysis (refer to Appendix C for General Arrangement).

Component	Quantity	Length *(m)*	Weight in Air *(kg)*	Weight in Water *(kg)*
Steel Riser Head	1	-	2,500	2,175
Hose Section	4	46	47,760	15,600
HDPE Section	29	333.5	94,221	-6,496
Steel Pipe	10	115	81,100	70,500
Flange Connections	42	-	31,500	27,384
Steel Strainer	1	-	2,640	2,295
TOTAL		494.5	259,721	111,458

Table 8.1.5 – Flexible Pipe String Configuration

The flexible pipe string assemblies were modelled as flexible elements with sufficient nodal points to allow curvature. The strainer was modelled as a section of straight pipe whereas the riser head and flange connections were modelled as clump weights of appropriate mass and volume. The flange connections were modelled with a normal drag area equal to the protruding area of a 60”NB flange.

Damping is set to zero since, within broad limits, structural damping has little influence on the results of the hydrodynamic simulation unless the system is subject to very rapid variations in tension or bending. Additionally, such damping is negligible compared to the damping applied by hydrodynamic resistance in submarine hoses.

7.1.5.6. Drag Coefficients

The normal drag coefficient (Cd) is dependent upon the Reynolds number (Re), which in turn is a function of the surface roughness and diameter of the hose, as well as the fluid flow velocity. Using the technique provided within ESDU 80025, the Cd values were determined for the corresponding Re number for the various hose sections types.

Surface roughness values used to calculate the Drag Coefficients were specified as:

Rubber Hose	= 3mm	(value similar to concrete given in [5] Table 6-1)
HDPE Pipe	= 0.003mm	(ref. [6])
Steel Pipe	= 0.05mm	(ref [5] Table 6-1)

The Cd values were input into Orcaflex which calculates the Reynolds number and applies the corresponding Cd for any given fluid velocity.

The strainer value was set at Cd = 1.0 based upon drag coefficients for perforated cylinders as specified in [7] Figure 6.

Axial drag coefficient was set as a constant 0.008 for plain pipe.

The flange connections modelled as clump weights and a drag area equal to the protruding flange specified and an axial drag coefficient of 1.9 [5] Table applied for the vertical direction.

7.1.6. Marine Growth

Marine Growth data was provided within [5] Section 8, Table 8.1 and is reproduced below:

Table 8.1 Marine growth profile estimates. Data are obtained from [8].

Level	Thickness	Roughness	Weight in air	Weight in seawater
m below MSL	mm	mm	kg/m^2	kg/m^2
+2	100	50	9.5	3.2
-10	100	50	9.5	3.2
-65	25	18	2.4	0.8
Below -65	0	3	0.0	0.0

An additional model was developed to consider the effects of marine growth.

7.1.6.1. Further Research

Further research in respect of marine growth, identifies the mesapelagic zone, often referred to as the 'twilight' zone and operationally defined as the region between 200m-1000m depth of the world's oceans, is characterised by increased hydrostatic pressure, diminished light, high inorganic nutrient concentrations and episodic food supply (Robinson et al., 2010). A study by Robinson (2010) confirms that marine organisms exist at these depths and describes the known ecology within the twilight zone.

Direct correspondence with the prime author of the study, Dr Carol Robinson, also describes how marine growth attachment may occur at these depths:

"…there are definitely organisms living at 500m and most organisms prefer to be attached to something than floating around as often the thing they're attached to becomes a hot spot of food / prey. The first thing that will happen is the pipes will get covered with bacterial slime, then microzooplankton, then anything larger. I think as a rule of thumb, anything put into the sea will foul it just depends on the timescale. The timescale may also depend on which ocean at 500m since some waters have higher surface plankton productivity than others which rains down to the depths when the plankton die providing a food source for the organisms at depth."

This is further corroborated by Stanczak (2004), who describes that the growth of a biofilm can be such that it provides a foundation for the growth of seaweed, barnacles and other organisms although the conditions and substrate have a significant impact on the marine growth attachment. Lebret et al (2009) describes how biofilm attachment begins to occur within seconds or minutes of a substrate submersion into seawater.

Stanczak (2004) indicates certain types of biofilm favour a water velocity of 1m/s for maximum development but mussels will not occur at velocities greater than 2m/s.

Harder and Lee (2009) make reference to the Baier Curve which provides a generalised relationship between the surface energy of a material and its resistance to bio-adhesion. Lines (Dyne Technology, 2012) indicates that HDPE has a low surface energy and specifies a surface energy value consistent with weak bio-adhesion according to the Baier curve, and as such resists marine growth attachment.

7.1.6.2. Anti-Fouling Techniques

The techniques commonly used to prevent biofouling on the seawater intake systems are the injection of sodium hypochlorite into the seawater at the intake point and also foul release paint systems on the metallic components such as the strainer.

The philosophy is that the sodium hypochlorite is injected and mixed into the seawater at the intake point to kill any marine organisms prior to entry to the onboard seawater system. A further sodium hypochlorite injection point is generally provided at the intake to the submersible pump by the pump supplier to provide further anti-fouling measures. The sodium hypochlorite is injected either as a continuous dose or a higher shock dose.

As sodium hypochlorite has a higher SG than seawater, the limitation of this techniques is that, when injected at the intake point, i,e. the strainer, the sodium hypochlorite is only effective when the system is drawing in seawater. When the system is idle, the injected sodium hypochlorite will fall downwards out of the strainer. Furthermore, the sodium hypochlorite does not provide any anti-fouling benefits to the outer surface of the strainer.

The technique most commonly used for the metallic components such as the strainer is the use of polymeric foul-release paint systems such as PTFE based systems.

Foul-release paint systems differ from anti-fouling paint systems in as much as they do not contain biocides. Instead they provide the substrate with a slippery, low friction surface onto which fouling organisms have difficulty attaching (International Paint Ltd, 2010) and any which do will be loosely adhered and is removed from the surface by water movement or by its own weight (International Paint Ltd, 2014).

Whereas the biocide within an anti-fouling paint system depletes over a relatively short period, the foul-release paint does not have a depletion rate. A leading supplier of this type of paint system, International Paints, recently presented their latest product (Intersleek 1100SR) which has very good resistance to biofilm (slime) formation, and slime that does attach is washed off at very low water velocities. International also advised that, when applied, this system has a field life of +20years (the Shell Prelude Hull is protected by this system). Furthermore, the system is very flexible and can be applied to flexible substrates such a rubber hoses and HDPE.

The metallic material most effective against marine growth is copper and copper nickels such as CuPro 90/10, has been shown to release copper ions more slowly than pure copper.

7.1.6.3. Proposal for Anti-Fouling Philosophy

To synthesise the above, the following marine growth mitigation philosophy is proposed:

During the installation and pre-commissioning phase of the system, when the system is submerged but not operational, a biofilm may begin to form on the internal and external surfaces of the components.

A strainer fabricated from Copper Nickel would resist the formation of the biofilm during this phase. However, a carbon steel strainer coated with a fluoropolymer paint system, such as Intersleek 1100SR, would also resist biofilm formation and would be a more cost effective option. The HDPE components have a relatively low surface energy and would also resist the formation of the biofilm at this phase. Consideration may also be given to the application of a fluoropolymer paint system to the HDPE sections. The steel pipe and riser head would be coated internally and externally with a fluoropolymer paint system which would also resist the formation of the biofilm. The external surface of the flexible hose elements could be coated with a low surface energy material, such as polyurethane, or, again, fluoropolymer paint system to resist the attachment of marine growth. The internal bore of the HDPE and Rubber Hose elements may also be coated with a fluoropolymer paint system to resist biofilm formation and also improve pressure loss characteristics.

However, it is assumed that a biofilm may begin to form on the flexible pipe string elements.

The sodium hypochlorite injection point would be located at the upper end of the hose string, for example within the riser head. Prior to start up of the system, a shock dose of sodium hypochlorite would be injected into the intake riser which would gravitate downwards through the string attacking any biofilm that may have formed on the inside of the pipe sections. (It is known that one operator pours a solution of sodium hypochlorite directly into the caisson during idle periods to achieve this effect)

When the system is in operation, the water velocity through the hose string is generally between 2-3m/s which is higher than the preferred velocity for biofilm formation and also the velocity at which any biofilm is removed from a fluoropolymer coating. Any organisms within the seawater would be treated by the sodium hypochlorite injection at the riser head and also by the injection point at the pump intake system, thus protecting the onboard pipework. The flow velocity through the strainer is typically in the region of 0.5m/s which is within preferred velocities of biofilm formation, however, a strainer coated with a fluoropolymer system would resist formation and any biofilm formation would detach.

Over time, the external surface of the system may begin to allow marine growth formation, although this will be mitigated by the foul-release paint on each of the flexible pipe string elements. Regular inspection by ROV may be performed to assess the marine growth on the system, and if problematic, may be water jetted by ROV if a full system retrieval is not preferred.

The benefits of the above philosophy are that the optimum anti-fouling measures are applied, plus, as an internal hypochlorite line is not installed within the full length of the flexible pipe string, providing improved pressure loss characteristics and reduced weight. Furthermore, any possible degradation of the sodium hypochlorite hose over the life of the system, and the potential replacement costs are eliminated.

Any maintenance to the hypochlorite system would be at the upper end of the string which is more easily accessible and achievable without a full system retrieval.

7.1.7. Flexible Pipe String Co-ordinates

The Seawater Flexible Pipe String Assemblies are connected to the underside of the vessel hull at the following locations relative to the vessel origin, i.e.:

X = Turret Centreline

Y = Vessel Centreline

Z= Hull Bottom

Flexible Pipe String		Port	Starboard
Connection Location (from Vessel Origin)	X	-399m	-399m
	Y	25m	-25m
	Z	0 m	0 m

7.2. Analyses

7.2.1. Wake Interaction

For the load cases where the current was in line with the two flexible pipe strings, wake generation was applied to the leading line and reaction to wake applied to the trailing line. The wake model used was the Huse model within the Orcaflex software.

7.2.2. Line Clashing

The lines were given contact values within Orcaflex and selected for Clash Check. This enables the software to provide a clash report to identify clash locations, clash energy etc if applicable.

7.2.3. Vortex Induced Vibration

A modal analysis of the Flexible Pipe String was performed using Orcaflex to determine the natural frequencies of the line.

Screening for VIV was undertaken using the techniques suggested by :

DNV-RP-C205 – DNV Recommended Practice – Environmental Conditions and Environmental Loads - October 2010 [5]

DNV-RP-F204 – DNV Recommended Practice - Riser Fatigue - October 2010 [10]

7.2.4. Load Cases

The following load cases were considered for the analysis

Case	Marine Growth	Current Direction	Wave Event	Case	Marine Growth	Current Direction	Wave Event
1	No	0	$Tass_{min}$ Rise	21	Yes	0	$Tass_{min}$ Rise
2	No	0	$Tass_{min}$ Fall	22	Yes	0	$Tass_{min}$ Fall
3	No	0	$Tass_{max}$ Rise	23	Yes	0	$Tass_{max}$ Rise
4	No	0	$Tass_{max}$ Fall	24	Yes	0	$Tass_{max}$ Fall
5	No	45	$Tass_{min}$ Rise	25	Yes	45	$Tass_{min}$ Rise
6	No	45	$Tass_{min}$ Fall	26	Yes	45	$Tass_{min}$ Fall
7	No	45	$Tass_{max}$ Rise	27	Yes	45	$Tass_{max}$ Rise
8	No	45	$Tass_{max}$ Fall	28	Yes	45	$Tass_{max}$ Fall
9	No	90	$Tass_{min}$ Rise	29	Yes	90	$Tass_{min}$ Rise
10	No	90	$Tass_{min}$ Fall	30	Yes	90	$Tass_{min}$ Fall
11	No	90	$Tass_{max}$ Rise	31	Yes	90	$Tass_{max}$ Rise
12	No	90	$Tass_{max}$ Fall	32	Yes	90	$Tass_{max}$ Fall
13	No	135	$Tass_{min}$ Rise	33	Yes	135	$Tass_{min}$ Rise
14	No	135	$Tass_{min}$ Fall	34	Yes	135	$Tass_{min}$ Fall
15	No	135	$Tass_{max}$ Rise	35	Yes	135	$Tass_{max}$ Rise
16	No	135	$Tass_{max}$ Fall	36	Yes	135	$Tass_{max}$ Fall
17	No	180	$Tass_{min}$ Rise	37	Yes	180	$Tass_{min}$ Rise
18	No	180	$Tass_{min}$ Fall	38	Yes	180	$Tass_{min}$ Fall
19	No	180	$Tass_{max}$ Rise	39	Yes	180	$Tass_{max}$ Rise
20	No	180	$Tass_{max}$ Fall	40	Yes	180	$Tass_{max}$ Fall

Table 8.2.4 – Load Case Combinations

7.3. Results

The results of the Hydrodynamic Analyses were stored, evaluated and exported using the Orcaflex post processing facilities. These results are summarised below and presented in more detail at Appendix D.

7.3.1. Maximum End Force at Riser Head

Load Case 4 - Line S

Highest Force (kN)	**Corresponding worst:**		
	Shear Load (kN)	Bend Moment (kNm)	Hose Tension (kN)
1228.2	409.0	1352.6	1174.1

7.3.2. Maximum Hose Tension at Riser Head

Load Case 29 – Line P

Highest Tension (kN)	**Corresponding worst:**		
	Shear Load (kN)	Bend Moment (kNm)	End Force (kN)
1206.8	516.4	1817.4	1215.0

7.3.3. Maximum Bending Moment at Riser Head

Load Case 39 – Line S

Highest Bending Moment (kNm)	**Corresponding worst:**		
	Shear Load (kN)	End Force (kN)	Hose Tension (kN)
2201.4	624.5	1175.9	1064.1

7.3.4. Maximum Shear Load at Riser Head

Load Case 21 – Line P

Shear Load (kN)	**Corresponding worst:**		
	End Force (kN)	Bend Moment (kNm)	Hose Tension (kN)
631.8	1195.5	2171.8	1037.2

7.3.5. Minimum Bend Radius

Rubber Hose: 6.1m Load Case 39 –Line P
HDPE 322.4m Load Case 23–Line P

7.3.6. Wake Interaction

For the load cases where the current was in line with the two flexible pipe strings, wake generation was applied to the leading line and reaction to wake applied to the trailing line. With a 100 yr return current, there was no reported collisions between the risers although in the models including marine growth, the risers became close at the lower ends.

It should be noted that the DNV Recommended Practice, RP F203 Riser Interference [11], does permit collision in certain circumstance, e.g. extreme conditions, subject to the consequences being evaluated and found acceptable.

Further analysis may be required to establish under what conditions collisions may occur and to evaluate and document the consequences.

7.3.7. Line Clashing

The analysis has shown that the lines do not clash with one another with the selected arrangement and configuration. However, as described above, further analysis may be required to establish under what conditions collisions may occur and to evaluate and document the consequences.

7.3.8. Vortex Induced Vibration

The Modal Analysis output from Orcaflex provided the following natural frequencies of the line:

Modes Table | View | Loads Table | Loads Graph | VIV

No.	Mode Number	Period (s)	Frequency (Hz)	Mode Type
1	1	142.07	0.00704	Mostly Transverse
2	2	142.07	0.00704	Mostly Inline
3	3	50.66	0.01974	Mostly Inline
4	4	50.66	0.01974	Mostly Transverse
5	5	31.01	0.03224	Inline
6	6	31.01	0.03224	Transverse
7	7	20.94	0.04775	Mostly Inline
8	8	20.94	0.04775	Mostly Transverse
9	9	15.22	0.06568	Mostly Inline
10	10	15.22	0.06568	Mostly Transverse
11	11	11.76	0.08500	Mostly Inline
12	12	11.76	0.08500	Mostly Transverse

7.3.8.1. Current Induced VIV

Using the VIV screening techniques presented in [5] & [10], the vortex shedding frequencies (f_s) in relation to the 1 yr current velocities are calculated to be in the range of:

$f_s = St * U_{eff} / D_h$ where St = Strouhal Number = 0.2 [10] para 4.3
U_{eff} = Effective Velocity = 1.55m/s [10] para 4.3
D_h = Outside Diameter = 1.6m

$f_s = 0.2 * (1.55 / 1.6) = 0.19575$ Hz

Cross Flow Vortex Shedding Frequency (f_s^{CF}) = f_s (± 20%) = 0.155 – 0.2325Hz

In Line Vortex Shedding Frequency (f_s^{IL}) = $2*f_s$ (± 20%) = 0.31 – 0.465 Hz

The fundamental natural frequency of the line (Mode 1) is 0.00704 Hz which is below the calculated vortex shedding frequencies indicating that the risk of VIV is low.

However, the referenced documents are aimed at Top Tensioned Risers and Steel Catenary Risers as opposed to free hanging flexible cantilevers whereas both Fujarra et al (2001) and Prastiano et al (2009) have undertaken research specifically for Flexible Free Hanging Cantilevers and further analyses of this work is recommended.

7.3.8.2. Wave Induced VIV

Using the VIV screening technique in [10], the vortex shedding frequencies in relation to wave motion are assessed.

For irregular waves (as used in this analysis), shedding behaves as if Keulegan-Carpenter number (K_c) > 40.
For the condition, $K_c > 40$ resonant vibrations due to vortex shedding may occur when:

$$\mathbf{3 < V_R < 9}$$

where V_R = Reduced Velocity

$V_R = u / (fi*D)$ where u=instantaneous flow velocity normal to member axis (m/s)
fi = natural frequency of the member (Hz)
D = Diameter of the member (m)

So for this analysis, the flow velocities of 0.2m/s thru' 1.5m/s give V_R values of:

$V_R = 0.2 / (0.00704 * 1.6) = 26$
$V_R = 1.5 / (0.00704 * 1.6) = 133$

This is out of the range of **$3 < V_R < 9$** indicating that the risk of VIV is low.

7.4. Discussion

The summary results are shown above and a full set of results are presented in Appendix D, however, the following has been extracted for discussion:

The main concern regarding the stability of the flexible pipe string is the potential interference with the mooring lines. As the vessel is weather vaning, it is assumed to head into the wave direction, however, current can act independent of wave direction and could potentially come from the stern which would create the condition most likely to cause the flexible pipe string to interfere with the mooring lines.

The following screenshot illustrates the effect of marine growth on the flexible pipe string when subject to the 100yr conditions where the wave and current directions are opposed.. The marine growth profile was ‘generic’ in as much as it does not make allowance for the substrate that it is attaching to. For example, it is known that HDPE resists marine growth attachment and which may result in different drag factors considered for the hydrodynamic analysis.

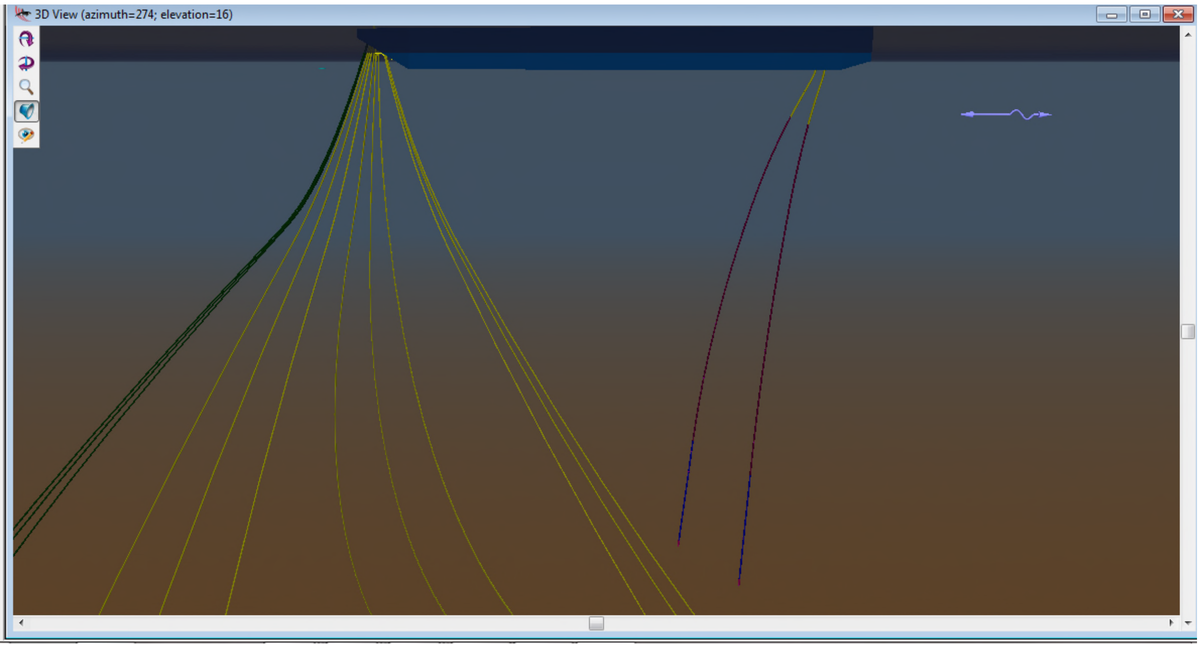

Fig. 26: 100yr Wave & Current - Port String ‘Clean’ / Starboard String ‘with Marine Growth’

Legend: Rubber Hose = Yellow

HDPE = Brown

Steel Pipe = Blue

Strainer = Purple

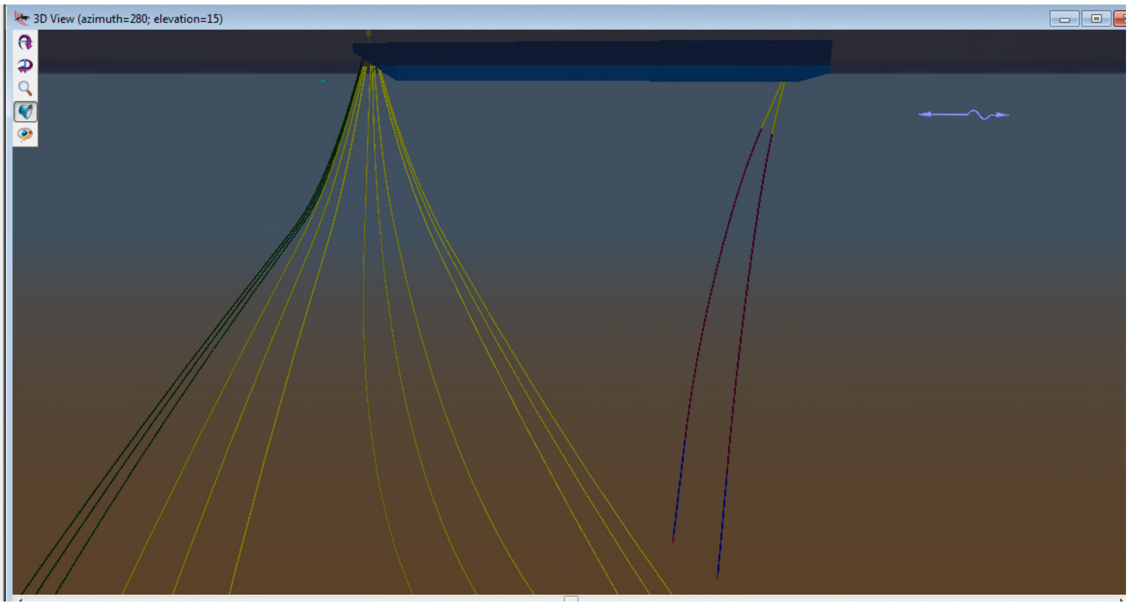

Fig. 27 : 1yr Wave & Current - Port String 'Clean' / Starboard String 'with Marine Growth'

With regard to vessel motion, the flexible pipe string shows a relatively small displacement.

The below image shows the relative movement of each end of the hose string when subjected to the 100 yr return conditions. It also illustrates that the suction depth is maintained at below 500m. Further investigation with regard to RAO data and Metocean may be beneficial to validate this vessel motion.

Top End (A) = +/- 1m

Lower End (B) = +/- 1.2m

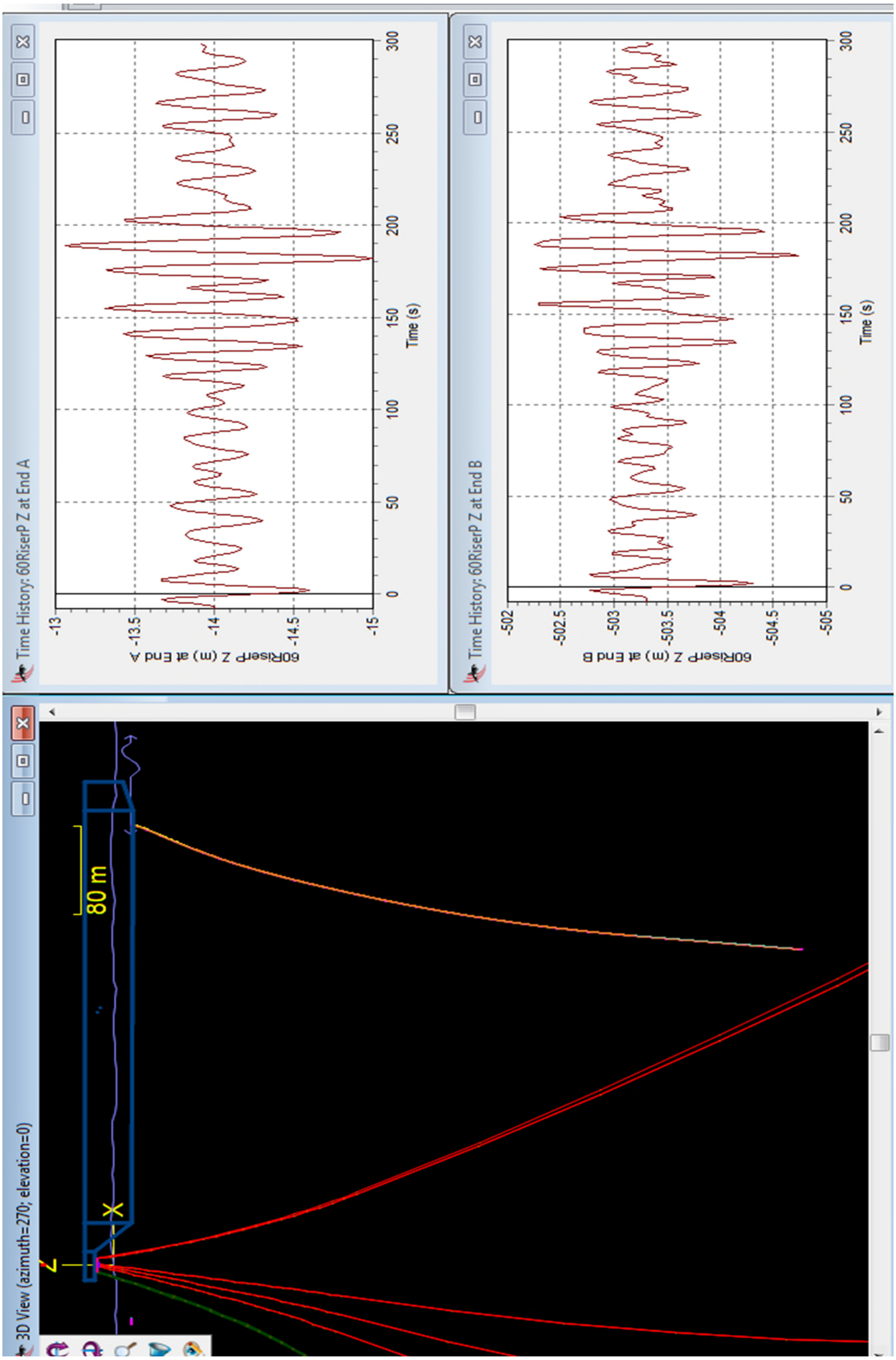

Fig. 28: End Displacement – 100-yr return

The material proposed for the main central section of the flexible pipe string is HDPE. HDPE wall thickness is defined by the SDR number which is the ratio between the wall thickness and the outside diameter. HDPE SDR26 was considered for this study which has the same SDR as systems currently operating in the field. Orcaflex can calculate the Bending Stress & Von Mises Stress in the HDPE which is ,~2N/mm^2 & ~5N/mm^2 respectively, as shown below (this for line with Marine Growth) and is within the documented yield strength of HDPE.

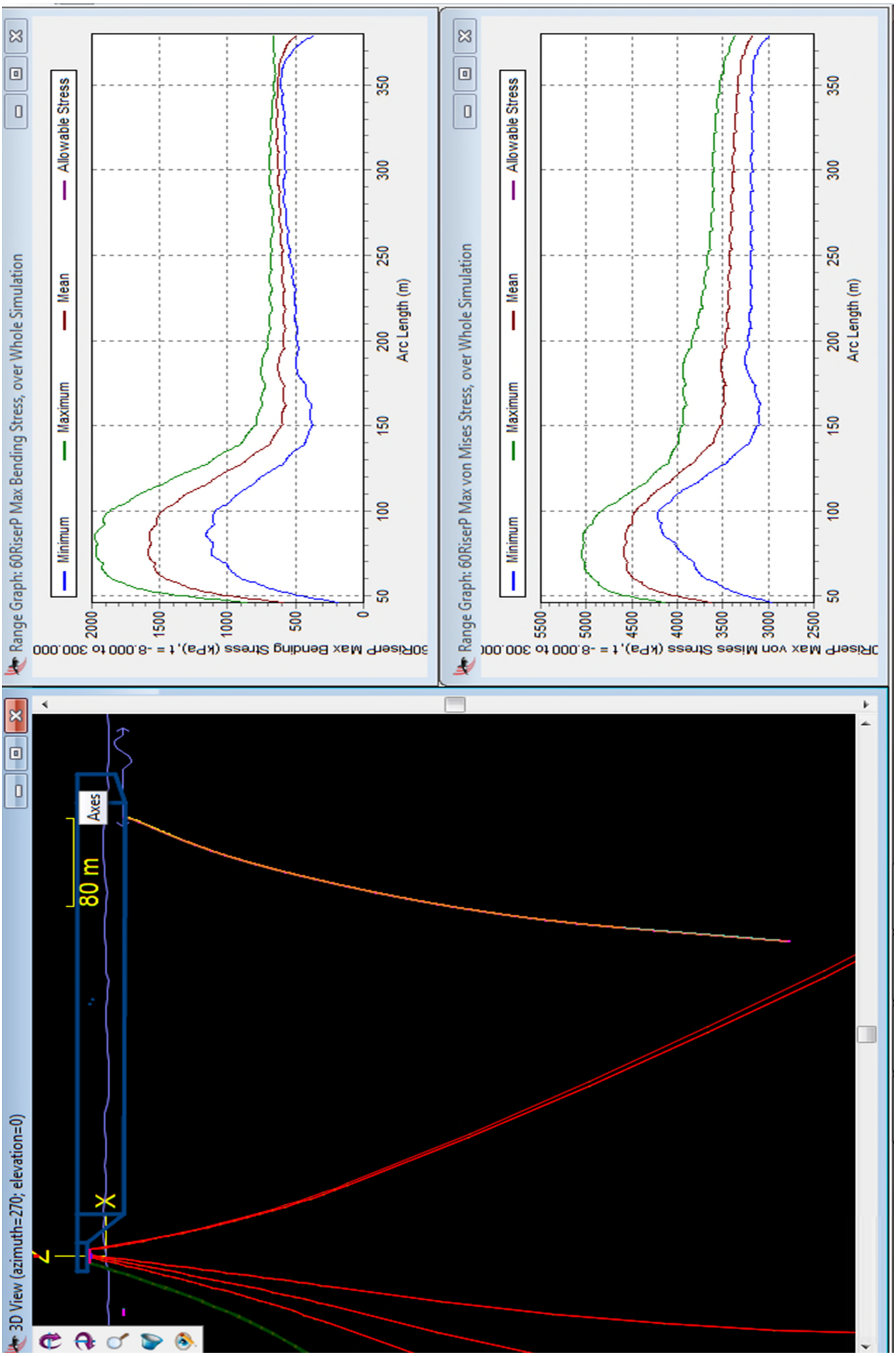

Fig. 29: Stress in HDPE Section – 100-yr return with Marine Growth

The following table highlights the effect of marine growth with respect to loads into the hull connection:

Load	Without Marine Growth*	With Marine Growth*
Tension (kN)	1228	1220
Bending Moment (kNm)	1418	2201
Shear Force (kN)	428	631

*Values are maximums and are not concurrent with each other.

7.5. Conclusion

In conclusion to this analysis, it has been demonstrated that, with the parameters and conditions under consideration, it is feasible to reach and import seawater from 500m using a flexible pipe string. The materials and elements considered for the flexible pipe string do not exceed their design parameters and the flexible pipe string is shown to not interfere with the mooring lines nor clash with one another. The likelihood of VIV is low risk.

However, it is recommended that the following areas are considered for further investigation:

- The likelihood and attachment resistance of marine growth to proposed materials and the effect on drag.
- Further investigation regarding the mechanisms and likelihood of VIV
- Review of vessel motion and metocean data

8. HYDRAULIC PERFORMANCE

8.1. Pressure Losses

A spreadsheet was prepared to calculate the pressure losses through the Flexible Pipe String using the D'arcy Weisbach equation. The strainer losses are taken from a CFD analysis of a Strainer. The Seawater properties for the following calculations were taken from [8] and which have been calculated in accordance with [9].

Pressure Loss through Hose String

Enter Values in WHITE *cells only*

Section	Hose	HDPE	Steel	
Length of Hose	46	333.5	115	*m*
Outside Diameter	-	1600	1524	*mm*
Wall Thickness	-	61.2	19.05	*mm*
Inside Diameter	1500	1477.6	1485.9	*mm*
Roughness	0.2	0.0015	0.045	*mm*
Hypochlorite Hose OD	0			*mm*
Density of Fluid	1027.0			*kg/m^3*
Viscosity of Fluid	1.3604E-06			*m^2/s*
Flow Rate	17500			*m^3/hr*
Velocity	2.75	2.83	2.80	*m/s*
Hydraulic Diameter	1.500	1.478	1.486	*m*
Relative Roughness	1.3E-04	1.0E-06	3.0E-05	
Reynolds No	3033107	3079088	3061889	
Friction Factor	0.0131	0.0097	0.0109	*Look up from Moody Tab*

Pressure Drop per Section	1564	9064	3396	*Pa*	*Note 1*
	0.02	0.09	0.03	*Bar*	
Strainer	0.05459			*Bar*	
Total Pressure Loss	**0.19483**			*Bar*	

Notes:

1. Pressure Loss calculated using D'Arcy-Weisbach Equation

Fig. 30: Pressure Loss Calculation – Standard Bore

This shows that the pressure loss through the flexible pipe string at maximum design flow rate is **0.19483 bar** which is within the general parameters generally considered for a seawater intake system.

With reference to the discussion in paragraphs 7.1.6.2 & 7.1.6.3, the application of Intersleek to the internal bore of the flexible pipe string reduces the roughness to a value similar to HDPE. Based on this potential characteristic, a further pressure loss calculation was undertaken to determine the benefits (if any) of this. The below illustration shows that there is a pressure loss reduction of approximately 4% at the maximum design flow rate.

Pressure Loss through Hose String

Enter Values in WHITE *cells only*

Section	Hose	HDPE	Steel	
Length of Hose	46	333.5	115	*m*
Outside Diameter	-	1600	1524	*mm*
Wall Thickness	-	61.2	19.05	*mm*
Inside Diameter	1500	1477.6	1485.9	*mm*
Roughness	0.0015	0.0015	0.0015	*mm*
Hypochlorite Hose OD	0			*mm*
Density of Fluid	1027.0			*kg/m^3*
Viscosity of Fluid	1.3604E-06			*m^2/s*
Flow Rate	17500			*m^3/hr*
Velocity	2.75	2.83	2.80	*m/s*
Hydraulic Diameter	1.500	1.478	1.486	*m*
Relative Roughness	1.0E-06	1.0E-06	1.0E-06	
Reynolds No	3033107	3079088	3061889	
Friction Factor	0.0098	0.0097	0.0097	*Look up from Moody Tab*

Pressure Drop per Section	1162	9064	3042	*Pa*	*Note 1*
	0.01	0.09	0.03	*Bar*	
Strainer	0.05459			*Bar*	
Total Pressure Loss	**0.18726**			*Bar*	

Notes:

1. Pressure Loss calculated using D'Arcy-Weisbach Equation

Fig. 31: Pressure Loss Calculation – Smooth Bore

The spreadsheet was used to produce the following Pressure Loss curve vs Flow Rate for Seawater density of 1027kg/m3 (Temp. 10°C)

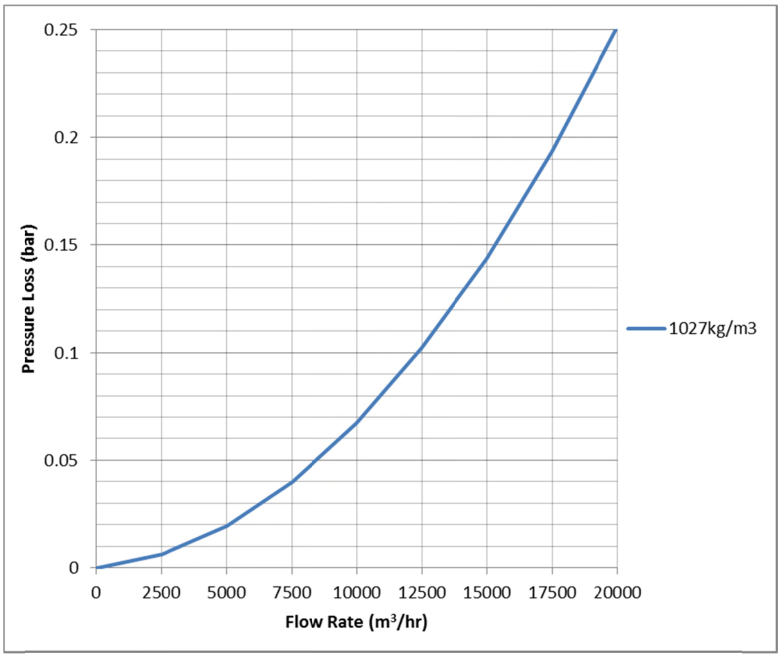

Fig. 32: Pressure Loss Curve

8.2. Sensitivity to Water Density

8.2.1. Pressure Losses through Flexible Pipe String

The spread sheet developed in Section 9.1 was then used to produce the following Pressure Loss Curve vs Water Density for Flow Rates of 17,500, 12,500 & 7,500 m^3/hr

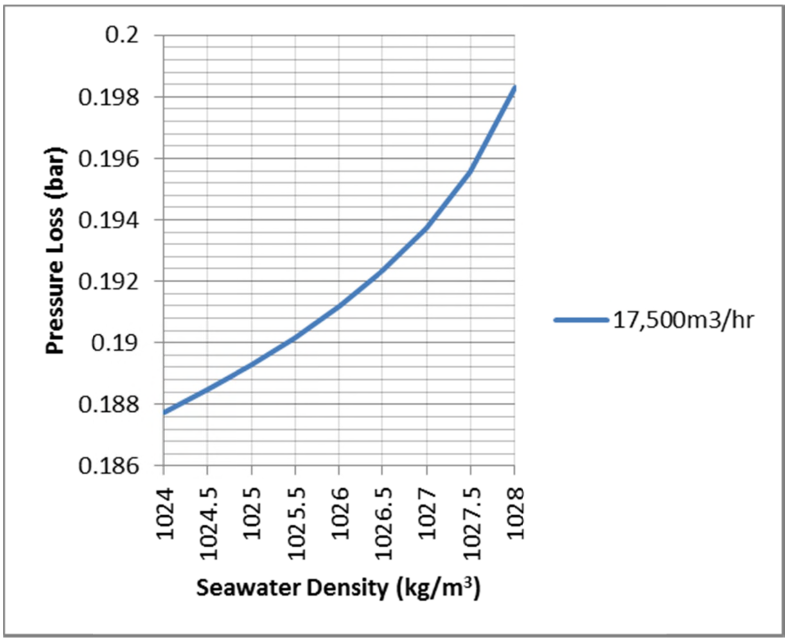

Fig. 33: Seawater Density sensitivity curve (17,500m^3/hr)

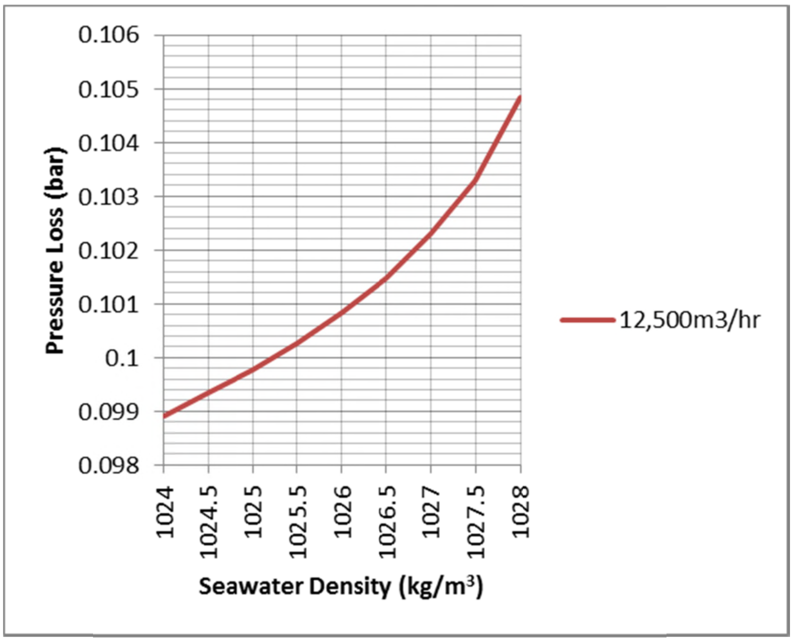

Fig. 34: Seawater Density sensitivity curve (12,500m^3/hr)

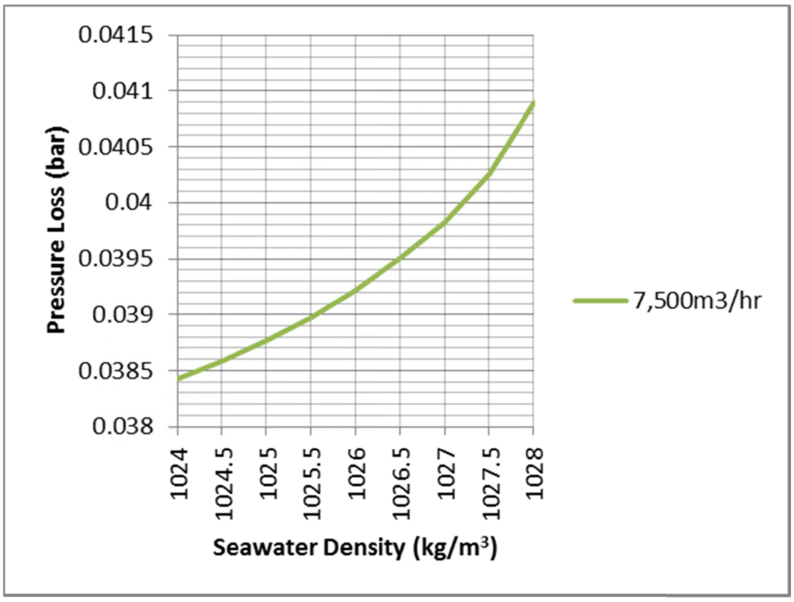

Fig. 35: Seawater Density sensitivity curve (7,500m^3/hr)

The seawater temperature and viscosities associated with the densities used to generate the above charts are as follows [8]:

Seawater Properties		
Density kg/m^3	*Temp °C*	*Viscosity m^2/s*
1024	22.9	9.82E-07
1024.5	21.1	1.02E-06
1025	19.3	1.07E-06
1025.5	17.3	1.12E-06
1026	15.1	1.19E-06
1026.5	12.7	1.26E-06
1027	10	1.36E-06
1027.5	6.7	1.50E-06
1028	2.2	1.72E-06

8.2.2. Static Head Differential

A further analysis of the sensitivity to seawater density was undertaken to determine the effect (if any) on the pressure differential between the water column inside the flexible pipe string and the 'outside' water column, and the likely effect on the drawdown.

To determine the 'outside' water column pressure, the monthly temperature profiles presented in [4] Table 9.1 were used to develop a spreadsheet. For each month and each depth increment, the average temperature was taken and the associated Seawater Density given in [8] was established. The static head pressure was then calculated for each depth increment and then summed up to provide the 'outside' water column pressure at the intake depth (i.e. -500m).

For the water column inside the flexible pipe, the seawater density for the temperature at the inlet depth (i.e. -500m) was taken from [8] and the static head pressure at the inlet depth calculated.

The two values were then subtracted to determine the Pressure Differential which indicated that the temperature profile for October gave the highest differential of 0.0763 bar, as shown below.

	OCTOBER			
Depth m	**Temp** °C	**Ave. Temp** °C	**Density** kg/m^3	**Pressure** Bar
0	26.28			
-10	26.2	26.24	1023.016	1.0036
-20	26.15	26.18	1023.048	1.0036
-30	25.98	26.07	1023.079	1.0036
-50	25.54	25.76	1023.172	2.0075
-75	25.02	25.28	1023.326	2.5097
-100	23.72	24.37	1023.599	2.5104
-125	22.01	22.87	1024.038	2.5115
-150	18.87	20.44	1024.704	2.5131
-200	16.1	17.49	1025.468	5.0299
-250	13.76	14.93	1026.043	5.0327
-300	12.31	13.04	1026.442	5.0347
-400	10.32	11.32	1026.769	10.0726
-500	8.77	9.55	1027.084	10.0757
Pressure Outside Column (Bar)				50.3086
Pressure Inside Column (Bar)				50.3848
Pressure Differential (Bar)				**0.0763**

Fig. 36: Pressure Differential of Outside and Inside Water Column due to Seawater Density

8.3. Sensitivity to Marine Growth

Table 8.1 provides marine growth profile estimates. Fouling is expected to occur throughout the year although growth will be greatest during the summer period when the water temperatures are highest. The extreme marine growth thickness profile is assumed to be 100 mm from +2 m to –10 m, decreasing linearly to 25 mm at -65 m, with no growth below -65 m. The roughness is defined as the average "peak to trough" distance in the growth.

Table 8.1 Marine growth profile estimates. Data are obtained from [8].

Level	Thickness	Roughness	Weight in air	Weight in seawater
m below MSL	mm	mm	kg/m^2	kg/m^2
+2	100	50	9.5	3.2
-10	100	50	9.5	3.2
-65	25	18	2.4	0.8
Below -65	0	3	0.0	0.0

If marine growth is expected to be critical for design, a systematic growth measurement program should be carried out.

As discussed in section 8.4, the marine growth profile in the above table was considered for the analysis. The drag factor of the flexible pipe string was set using the technique provided within ESDU 80025, for the corresponding Re number for the various pipe sections types and the effect of marine growth is significant in terms of stability and loads into the hull connection.

A further series of pressure loss calculations which assumed marine growth attached to the inside of the flexible pipe string. The above table specifies a roughness of 3mm for the marine growth roughness below 65m. As the seawater intake is below this level, a range of roughness values up to 3mm were considered and the findings are presented on the graph below

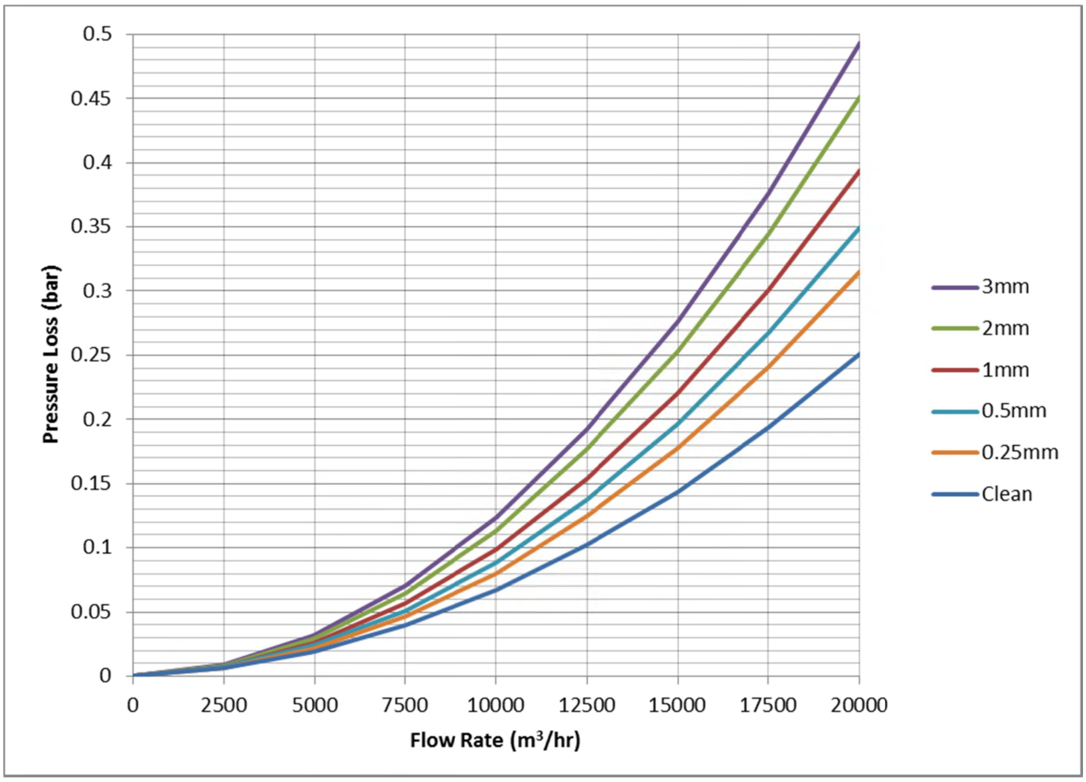

Fig. 37: Pressure Loss Curve and Sensitivity to Marine Growth Roughness

However, the data provided in the above table appears to be 'generic' and does not consider marine growth resistance of relevant substrate.

It is therefore recommended, and as suggested by the above extract, that further investigation is undertaken in the area as mitigation of marine growth may prove beneficial to the system.

9. STRUCTURAL CAPACITY

A model of the standard hang off arrangement normally considered by Emstec for a diverless installed system, was modelled for the dimensions of the Flexible Pipe String considered within the study, as shown in the below screenshots.

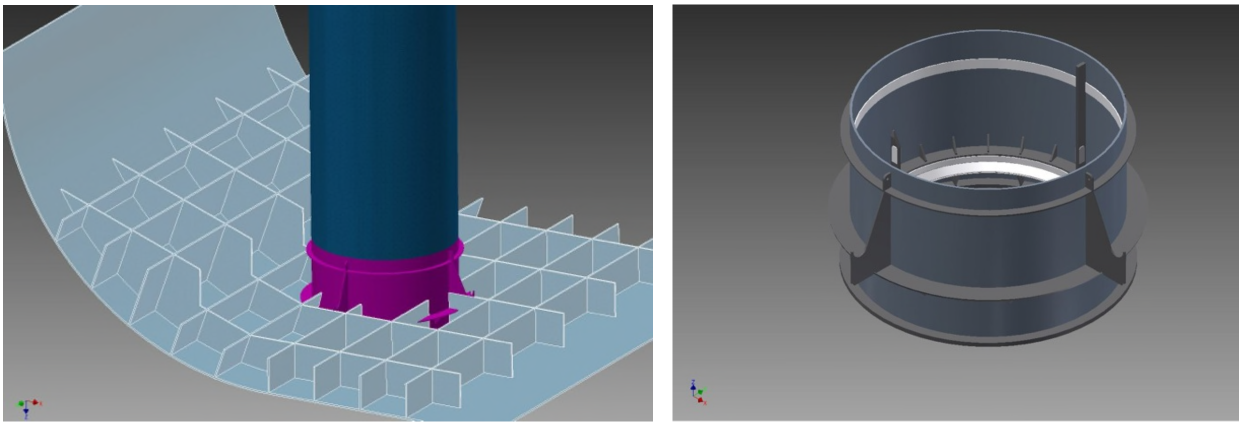

Fig. 38: Screenshots of Hang Off Structure

Using the output from the hydrodynamic analysis 100 yr return conditions, the Riser Seat was subject to an FEA to determine the magnitude of stresses likely to be incurred.

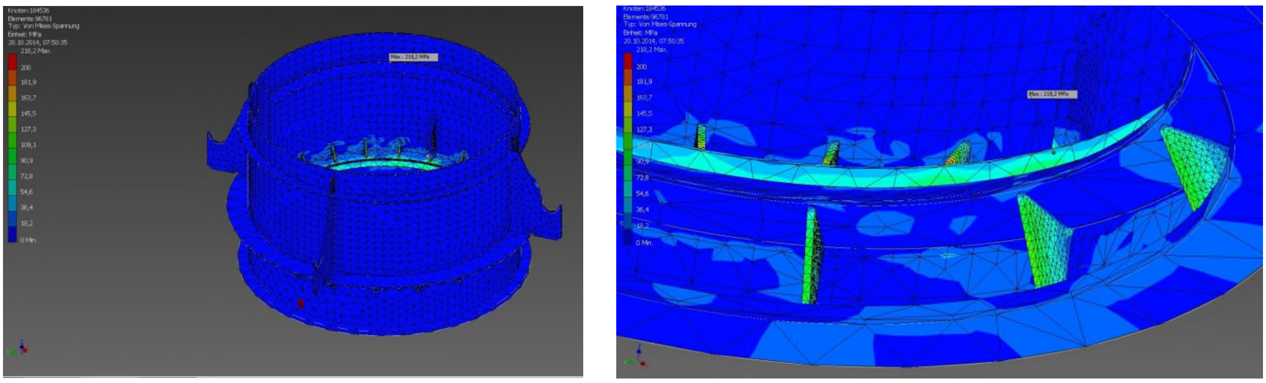

Fig. 39: Screenshots of Hang Off Structure FEA

The below screenshot indicates that, during the 100 yr extreme condition, the maximum stresses are in the region of 218N/mm^2, which is within the allowable stress range for the steel grade 355 that is generally used in the construction of these components.

This indicates that the arrangement currently in operation is suitable for the application considered by this study.

A more detailed analysis would be required to verify the interface connections when the hull structural details are available.

10. PROPOSED INSTALLATION PROCEDURES

The current installation procedure employed by Emstec for their Diverless Installed System may be considered for the preferred concept (refer to Emstec Installation Animation video file).

Typically, this procedure will use the vessel crane, the capacity of which is often the limiting factor in selecting the diameter/length of hose string.

The hose string configuration considered in the next section (Hydrodynamic Analysis) has a maximum installation weight in the region of 128 tonnes.

If the capacity of the vessel crane is insufficient for the installation weight, consideration may be given to a dedicated winch, although this would also necessitate a structure of sufficient capacity and height above the caisson to accommodate a sheave block.

From field experience, the estimated installation time for systems currently installed on FPSO's is calculated using 1 hour per bolted flange connection plus rig up and rig down time. For the diameter of hose string under consideration for this study, it may be reasonable to estimate 2 hour per flange connection, and given that there may be in excess of 40 hose sections per string, this could mean 80-100 hours to install each hose string. This is a reasonable estimate for actual time on task, however, in practice, the duration time is often dictated by the availability of the vessel crane, which during the start up and commissioning phase of the vessel is required for many other activities

A dedicated winch would avoid this reliance on the vessel crane. Alternatively, to avoid congestion of the laydown areas and crane usage during start up and commissioning phase of the project, consideration may be given to assembling the hose string over the side of a suitable support vessel. Once assembled, a pre-installed pull-in wire could be used to pull the hose string up the caisson where the Riser Head could be fitted on board the FLNG.

Another installation philosophy is the assembly of the flexible pipe string onshore and then towing the floating assembled string to the field. The main consideration for technique would be to ensure that the flexible pipe string can be submerged in a controlled manner without impeding the bend radius of the various sections. Once submerged and in the vertical orientation, the flexible pipe string could be pulled up the caisson and the Riser Head fitted on board the FLNG in the same manner as described above.

11. PROPOSED MAINTENANCE AND CHANGE OUT PROCEDURES

The system maintenance intervals generally depend upon the environmental conditions, material selection, cathodic protection requirements, etc.. However, as a guideline, it is recommended that the first visual inspection is undertaken by ROV within 3-5 years of installation. Subsequent inspections intervals dependent upon findings of first visual inspection.

Where a flexible pipe string is to be recovered, the reverse procedure to the installation can be applied. Upon recovery, typical maintenance would include:

- When recovered, each flexible hose section should be inspected. Marine growth should be removed by high pressure water blasting. The outside of the flexible hoses have to be checked for rubber cracks or outer damages. Damages of the rubber, as long as the reinforcement is not damaged, will have to be repaired by cold-vulcanising rubber compound.

- Each flexible hose section should be pressure tested in accordance with 'OCIMF Guidelines for the Handling, Storage, Inspection and Testing of Hoses in the Field' and results recorded accordingly.

- If the measured temporary or permanent elongation of the tested hose section exceeds the factory test by 2%, the hose shall be retired.

- Where the reinforcement of the hose section has been exposed to water, it will have to be inspected and assessed by a hose technician before being reinstalled.

- All other flexible pipe sections should be checked for damage and repaired if necessary

- the steel parts have to be checked for damages due to corrosion.

- the protective anodes, which protect the steel parts from corrosion, must be checked and replaced if necessary.

- the strainer shall be checked. Holes shall be checked and any blockages cleared. The strainer shall be cleaned by water blasting. The protective coating (if applicable) shall be checked and any damages recoated, anodes to be replaced as necessary.

- the hose string should then be re-assembled and deployed in accordance the installation procedure

12. REVIEW OF EXTENDING SYSTEM TO 800M

There are a number of considerations in extending the proposed system to 800m, most notably the potential clashing with the mooring lines and also the stresses induced into the HDPE sections of the flexible pipe string

As described in section 8.1.2, the anchor depth achieved within this report was approximately 670m whereas the anchor depth achieved within [3] is 750m.

However, assuming that further mooring analysis enables the anchor depth to be increased to in excess of 800m, then the flexible pipe string can be increased accordingly. The increase in length increases the area that drag can act upon the line, therefore two options were reviewed.

The first was to maintain the port side configuration as per the 500m riser and the second to increase the number of steel sections at the lower end of the starboard riser from 10-off to 16-off to add more stability.

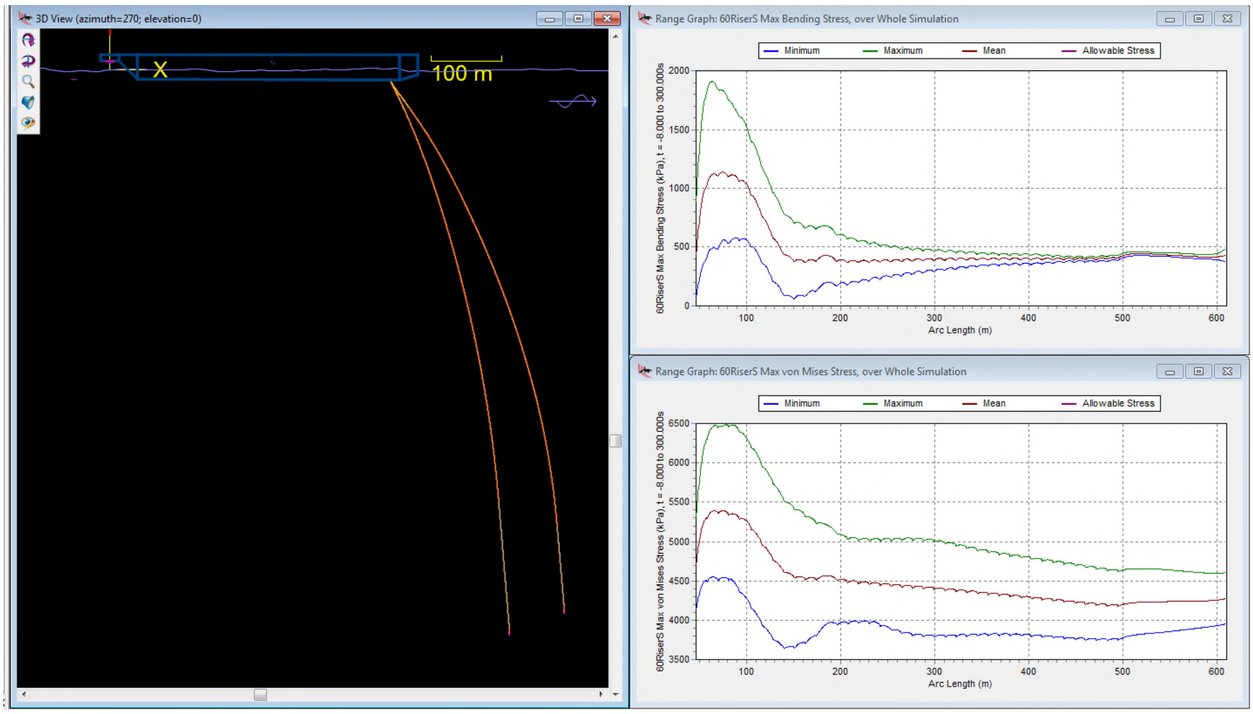

Fig. 40: 800m Riser - Stress in HDPE Section – 100-yr return with Marine Growth

As shown in the above figure, the provisional analysis indicates that, by adding the additional steel sections at the lower end of the riser, the stability is greatly improved without incurring significant increases to the HDPE stresses. The Bending Stress & Von Mises Stress in the HDPE which is ,~1.9N/mm^2 & ~6.5N/mm^2 respectively and remain within the documented yield strength of HDPE. Consideration should also be given to the increase in installation weight.

13. BUDGET COSTS

The budget cost for the 2-off 60"NB x 500m Seawater Intake Risers as proposed within this report is as follows:

ID	Description	Qty	Total Price
Seawater Intake Riser Package including:-			
A1	**Project Management**		
	• Project documentation • Technical support • Static and hydrodynamic analysis • Quality control • Testing and inspection	1	Included
A2	**2-off Hose String Assembly (60"NB x 500m)**		
	Caisson interface structure complete with integral riser seat.	2	Included
	Riser Head Assembly	2	Included
	Top Flexible hose section (60"NB x 11.5m)	8	Included
	Mainline Flexible hose section (60"NB x 11.5m)	58	Included
	Steel Pipe Section (60"NB x 11.5m)	20	Included
	Hypochlorite line and interface assembly	2	Included
	Suction strainer	2	Included
	Cathodic Protection (set for each hose string)	2	Included
	Bolts, Nuts and Gaskets for complete assembly (Carbon Steel)*	2	Included
	Backing Quadrants (set for each hose string)	2	Included
A3	**Installation Tools**		
	Lifting tool	2	Included
	Suspension tool	1	Included
	Safety tool	1	Included
	Deployment and retrieval tool	1	Included
A4	**Hose Handling Equipment**		
	Spreader beam	1	Included
	Hose blanking flanges	172	Included
A5	**Documentation Package**		
	• Manufacturing data book • Assembly and installation procedures • Operation and maintenance manual	1	Included
	TOTAL PRICE (€ EURO)		**8,950,000**

ID	Description	Qty	Total Price
OPTIONS			
B1	Same package as above except supplied with Super Duplex Bolting	2	Included
	TOTAL PRICE (€ EURO)		**10,850,000**

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[5] Recommended Practice DNV-RP-C205 – Environmental Conditions and Environmental Loads

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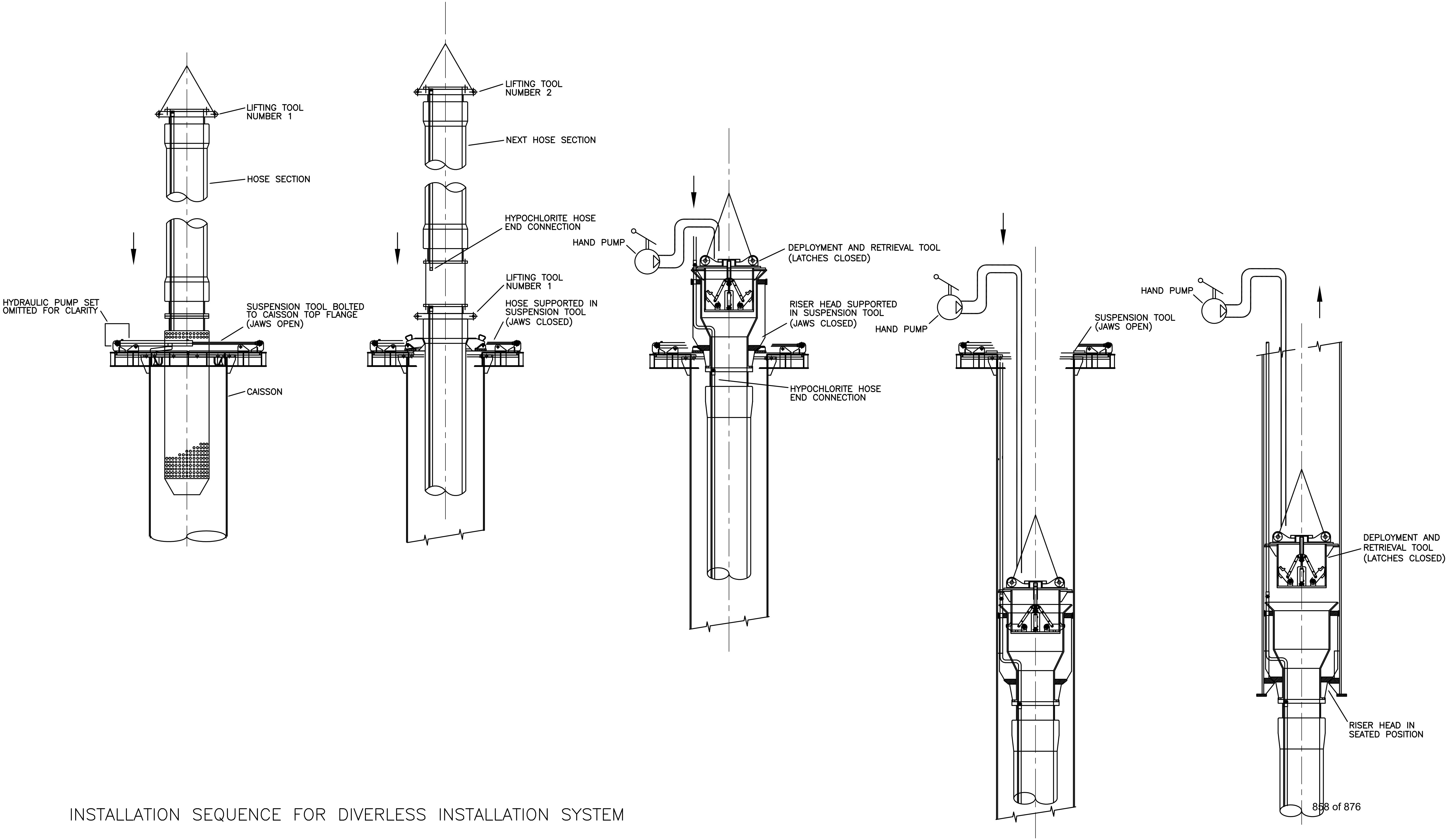
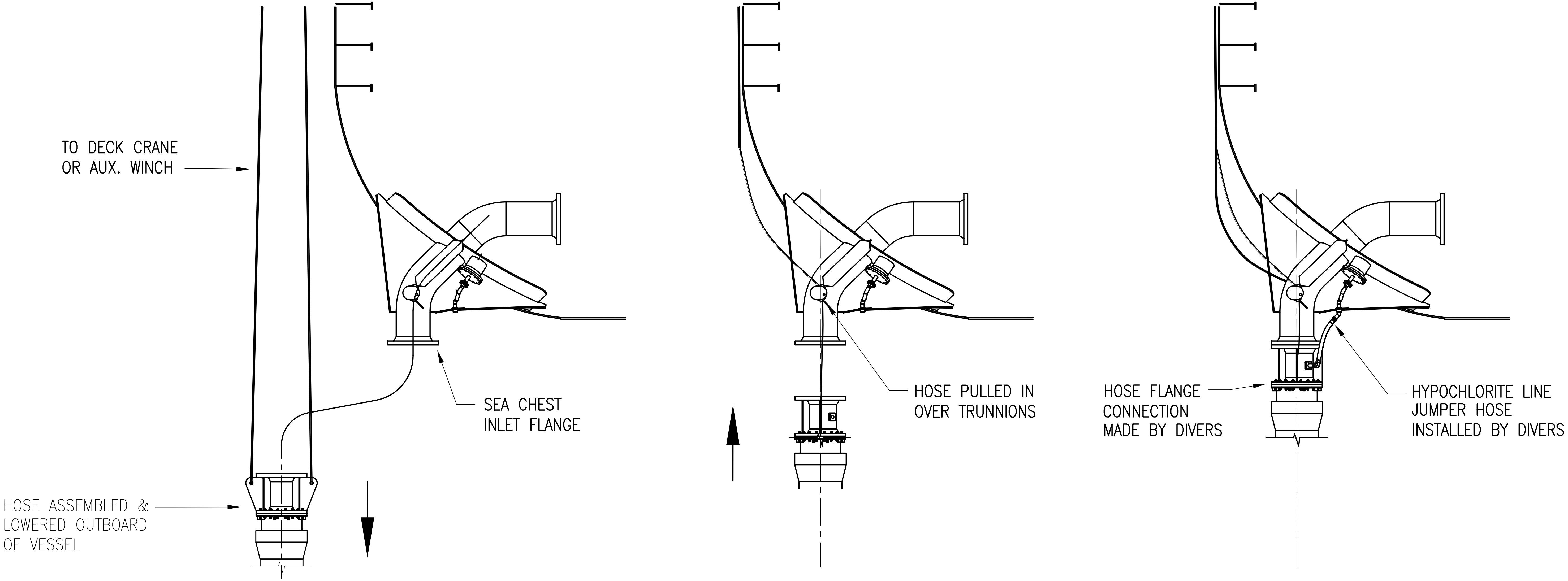
APPENDICES

APPENDIX A: INSTALLATION SEQUENCE FOR DIVERLESS INSTALLATION SYSTEM



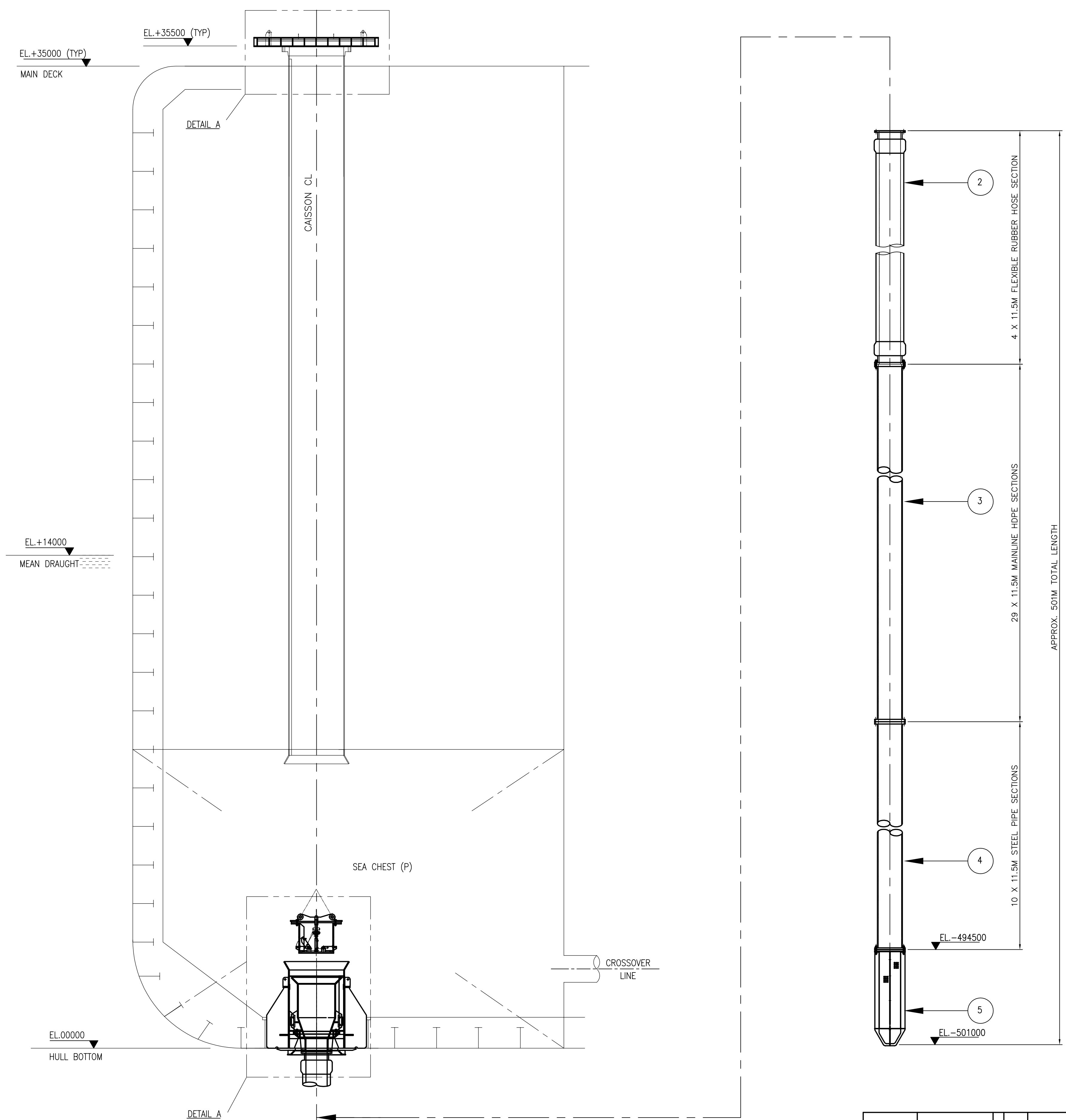
INSTALLATION SEQUENCE FOR DIVERLESS INSTALLATION SYSTEM

APPENDIX B: INSTALLATION SEQUENCE FOR DIVER ASSISTED INSTALLATION SYSTEM

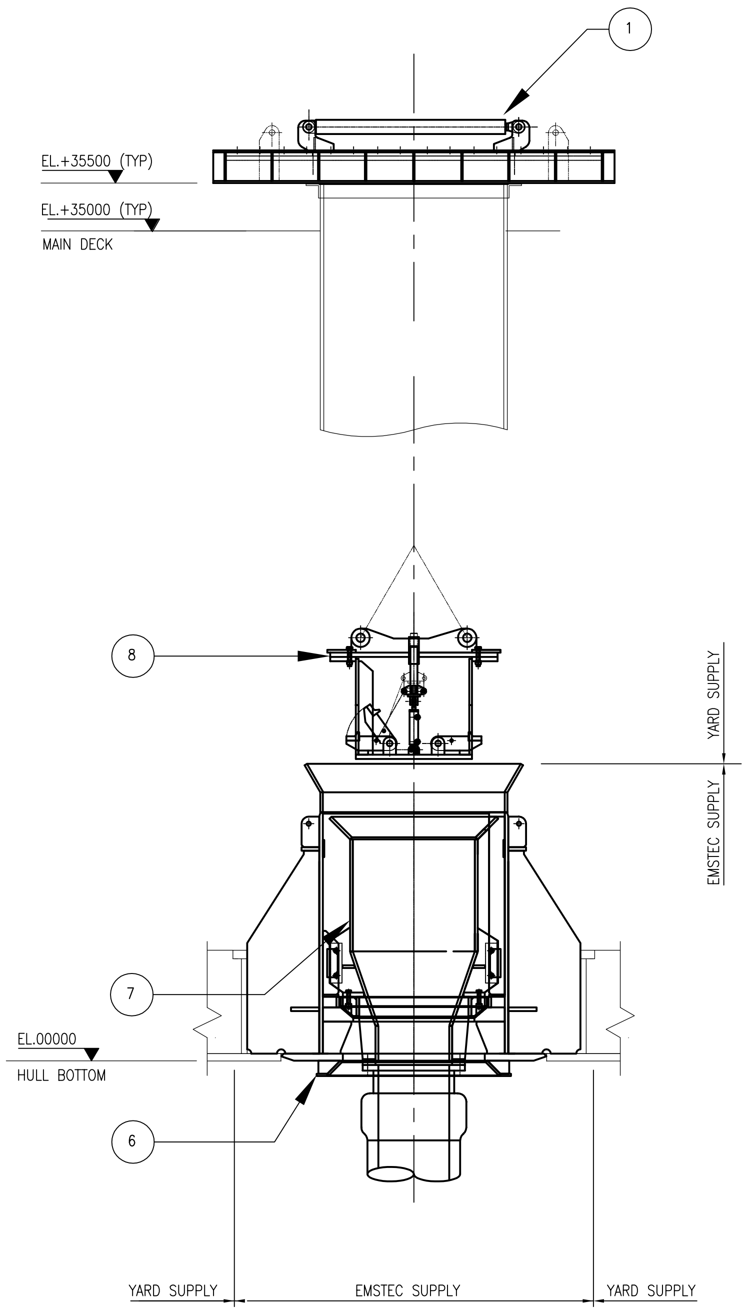


INSTALLATION SEQUENCE FOR DIVER ASSISTED INSTALLATION SYSTEM

APPENDIX C: PREFERRED CONCEPT – GENERAL ARRANGEMENT



PORT SIDE – LOOKING FORWARD
(STARBOARD OPPOSITE HAND)



DETAIL 'A'

NOTES:

1. ALL DIMENSIONS ARE IN mm (UNLESS OTHERWISE SPECIFIED)
2. * QUANTITIES FOR COMPLETE SYSTEM (P & S)

ITEM	QTY*	DESCRIPTION	EMSTEC REF.	UNIT WEIGHT
8	1	FISHING & RELEASE TOOL	TBC	TBC
7	2	RISER HEAD	TBC	TBC
6	2	RISER SEAT	TBC	TBC
5	2	STRAINER	TBC	TBC
4	20	STEEL PIPE SECTION 60"NB	TBC	TBC
3	58	HDPE MAINLINE SECTION 60"NB	TBC	TBC
2	8	TOP FLEXIBLE SUCTION HOSE 60"NB	TBC	TBC
1	1	HANG OFF TOOL	TBC	TBC

REV	DATE	ISSUED FOR	BY	CHK	APP.	DESCRIPTON
A	22.12.14	FOR INFORMATION	IC	AR	BB	FEASIBILITY STUDY

REVISIONS

DRAWING NUMBER	DRAWING TITLE

REFERENCE DRAWINGS

Project: GENERIC FLNG

Client: STATOIL

Client Drg No.

EMSTEC

Title: SEAWATER INTAKE SYSTEM GENERAL ARRANGEMENT DIVERLESS INSTALLATION

PROJECTION 3RD ANGLE
CAD DRAWING – DO NOT SCALE

Scale NTS | Sheet No. 1(1) | Mass Kg | Drg Size A1

Drawing No. 4140506-DE-001 | Rev No. A

APPENDIX D: HYDRODYNAMIC ANALYSIS RESULTS

	Load Case																				
Description	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**Max**
Line P End Force (End A)	1216.7	1202.1	1190.0	1227.5	1208.2	1198.6	1190.9	1225.7	1208.1	1191.1	1192.7	1222.1	1205.8	1186.3	1195.3	1218.0	1207.3	1183.4	1197.7	1215.8	**1227.5** *kN*
Line S End Force (End A)	1217.5	1201.8	1190.3	1228.2	1209.0	1198.2	1191.2	1226.4	1215.2	1197.3	1196.8	1228.1	1206.1	1185.9	1195.6	1218.7	1206.5	1183.0	1197.9	1216.5	**1228.2** *kN*
Line P Effective Tension (End A)	1152.1	1139.7	1151.0	1173.4	1151.5	1139.5	1149.0	1172.3	1158.0	1141.1	1142.5	1171.0	1159.4	1145.4	1146.0	1169.9	1168.0	1147.7	1152.6	1169.2	**1173.4** *kN*
Line S Effective Tension (End A)	1151.3	1139.3	1151.2	1174.1	1150.8	1139.1	1149.2	1173.0	1188.9	1169.9	1170.8	1201.4	1160.1	1145.0	1146.2	1170.6	1168.7	1147.4	1153.2	1169.9	**1201.4** *kN*
Line P Bend Moment (End A)	1393.9	1352.6	1401.6	1352.6	1335.9	1303.2	1339.1	1303.1	1215.2	1198.0	1183.5	1197.7	1299.7	1305.0	1350.1	1304.8	1363.2	1369.3	1417.9	1369.2	**1417.9** *kNm*
Line S Bend Moment (End A)	1393.8	1352.6	1401.8	1352.6	1335.7	1303.2	1339.2	1303.1	878.5	868.0	869.6	867.6	1299.5	1304.6	1350.2	1304.4	1362.9	1368.9	1418.0	1368.8	**1418.0** *kNm*
Line P Shear Force (End A)	428.3	409.1	419.9	409.1	406.0	390.5	398.4	390.5	361.5	353.1	349.3	353.0	387.0	374.8	401.3	374.8	408.5	395.5	422.7	395.5	**428.3** *kN*
Line S Shear Force (End A)	428.2	409.1	420.0	409.0	405.9	390.5	398.6	390.5	266.0	259.1	258.6	259.0	387.0	374.8	401.5	374.8	408.5	395.3	422.8	395.3	**428.2** *kN*
Line P Curvature (Rubber)	0.103	0.100	0.104	0.100	0.099	0.096	0.099	0.096	0.090	0.089	0.088	0.089	0.096	0.096	0.100	0.096	0.101	0.101	0.105	0.101	**9.5** *m*
Line S Curvature (Rubber)	0.103	0.100	0.104	0.100	0.099	0.096	0.099	0.096	0.065	0.064	0.064	0.064	0.096	0.096	0.100	0.096	0.101	0.101	0.105	0.101	**9.5** *m*
Line P Curvature (HDPE)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	**382.7** *m*
Line S Curvature (HDPE)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	**323.2** *m*

	Load Case																				
Description	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**Max**
Line P End Force (End A)	1195.5	1186.6	1175.6	1199.9	1190.2	1180.6	1169.8	1197.5	1215.0	1195.9	1197.5	1206.0	1181.8	1161.6	1170.4	1185.0	1186.1	1160.0	1175.8	1182.2	**1215.0** *kN*
Line S End Force (End A)	1196.2	1186.3	1176.1	1200.5	1190.9	1180.3	1170.3	1198.1	1215.1	1195.5	1194.8	1220.0	1181.1	1161.3	1170.6	1185.6	1185.4	1159.7	1175.9	1182.9	**1220.0** *kN*
Line P Effective Tension (End A)	1037.2	1029.4	1035.6	1055.5	1037.2	1028.7	1034.0	1054.5	1206.8	1171.3	1186.0	1144.7	1055.2	1038.4	1051.0	1052.0	1061.9	1043.7	1063.7	1051.8	**1206.8** *kN*
Line S Effective Tension (End A)	1036.9	1029.1	1035.7	1056.0	1036.5	1028.4	1034.2	1055.0	1206.4	1177.8	1188.8	1162.6	1055.9	1038.1	1051.5	1052.6	1062.5	1043.4	1064.1	1052.4	**1206.4** *kN*
Line P Bend Moment (End A)	2171.8	2118.7	2159.4	2118.7	2118.9	2081.3	2097.5	2081.2	1817.4	1832.4	1843.9	1807.8	2077.2	2065.8	2127.4	2065.7	2135.6	2136.7	2201.3	2136.6	**2201.3** *kNm*
Line S Bend Moment (End A)	2171.5	2118.4	2159.6	2118.3	2118.6	2080.9	2097.8	2080.8	1252.2	1262.6	1266.3	1251.8	2076.4	2065.2	2127.5	2065.1	2134.8	2136.1	2201.4	2136.0	**2201.4** *kNm*
Line P Shear Force (End A)	631.8	607.9	615.6	607.9	617.7	592.3	596.4	592.2	516.4	522.3	514.3	519.7	580.4	571.2	602.4	567.8	605.3	590.1	624.4	590.1	**631.8** *kN*
Line S Shear Force (End A)	631.6	607.6	615.9	607.6	617.6	592.0	596.6	592.0	366.1	368.2	360.8	369.7	580.2	571.0	602.6	567.8	605.4	590.2	624.5	590.1	**631.6** *kN*
Line P Curvature (Rubber)	0.161	0.157	0.160	0.157	0.157	0.154	0.155	0.154	0.134	0.135	0.136	0.134	0.154	0.153	0.157	0.153	0.158	0.158	0.163	0.158	**6.1** *m*
Line S Curvature (Rubber)	0.161	0.157	0.160	0.157	0.157	0.154	0.155	0.154	0.093	0.093	0.094	0.093	0.154	0.153	0.157	0.153	0.158	0.158	0.163	0.158	**6.1** *m*
Line P Curvature (HDPE)	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	**322.4** *m*
Line S Curvature (HDPE)	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002	0.003	0.003	0.002	0.003	0.003	0.003	0.003	0.003	**322.4** *m*

Section 12.0: Directorships

Techflow Marine – Objectives and Achievements

(The section numbers refer to a dossier documenting status of company at the point of my resignation and which is available for review)

The following is an outline of my objectives and achievements during my tenure as Director of Techflow Marine Ltd.

As a founding Director, the company was established in July 2005 and built from the ground, i.e. without a workforce, equipment, trade references, customer references, management systems, etc..

Five strategic objectives were set, namely:

- **Profitability**
- **Quality**
- **Health Safety & Environment**
- **Operational Excellence**
- **Longevity**

The following is a review of where the company stood on each of these objectives at the point of my resignation in May 2011:

Profitability

Section 1.0 of the enclosed dossier contains a copy of the company's audited accounts for each of the accounting periods to date, which can be summarised as follows:

Year End	Turnover	Profit Before Tax	Net Margin
31st July 2006	£1,215,738	£257,873	21.2%
31st July 2007	£3,010,140	£472,397	15.7%
31st July 2008	£7,268,287	£973,288	13.4%
31st Jan 2010*	£10,885,057	£1,550,204	14.2%
31st Jan 2011**	£4,384,240	£524,742	12.0%

* 18 month accounting period

** Draft accounts awaiting final sign off

Furthermore, in March 2010, a forensic accountant was commissioned to perform an independent analysis and valued the company at between £4m - £5.7m.

An extract from this report can be found in section 2.0 of the enclosed dossier.

Quality

A Quality Management System (QMS) was developed in accordance with ISO 9001:2008.

The QMS was implemented and received accreditation from Lloyds Register of Quality Assurance (LRQA) within the first six months of the company's formation. The certificate has since been renewed against ISO 9001:2008, and a recent focus visit by LRQA has demonstrated that the QMS is robust and well maintained.

A copy of the current certificate and focus visit report can be found in section 3.0 of the enclosed dossier.

Health Safety and Environment

A Health, Safety and Environment system (HSE) was established alongside the QMS. The company operated in an environmentally responsible manner since its formation and was kept in line with current legislation regarding disposal of waste etc. Furthermore, the company qualified and appointed an HSE Representative who currently holds a NEBOSH National Diploma.

The company is also a current member of the Achilles Joint Qualification System (JQS) which, together with a satisfactory QMS, requires that the company is able to demonstrate a satisfactory HSE system.

A copy of the Achilles JQS certificate and the HSE Representative qualification can be found in section 4.0 of the enclosed dossier.

Operational Excellence

The company worked towards providing operational excellence for customers, suppliers and employees alike. Whilst its financial performance provides an indicator of customer and supplier satisfaction, the company also strives towards employee satisfaction. Consequently, an Employee Opinion Survey (EOS) was undertaken by the appointed Human Resource provider, Right Hand HR (RHHR), to identify areas of improvement within the organisation in respect of this. The EOS results returned a positive response, and indicated that the current working environment was a good one with satisfied and motivated staff.

A copy of EOS results can be found in section 5.0 of the enclosed dossier.

Longevity

Whereas the company was still very much in its infancy, the current order book had a value of £9m, providing a firm base for the company's growth and sustainability.

A copy of the current order book can be found in section 6.0 of the enclosed dossier.

Finally, in the early part of 2009, the Directors undertook a strategic review of the company, the findings of which were presented to the employees in May 2009. At this time, the vision of the Directors was to 're-organise' and 'professionalise' the company during its growth from small to medium size company and to ensure that it continued to work towards and build upon its five strategic objectives.

A copy of this presentation can be found in section 7.0 of the enclosed dossier.

PROJECTS : PROCESSES : PEOPLE

The hands on application of expertise

SCROLL DOWN FOR MORE INFO

WELCOME TO HART CONSULTANCY

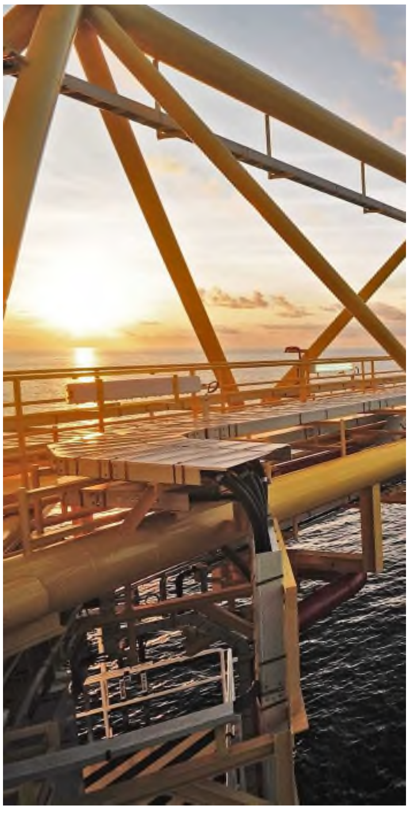
All good businesses, at different times, need to find additional expertise

This is sometimes due to the short supply of skill and / or experience and often occurs when timescales are short and expediting is required to ensure business delivery.

Read more

ABOUT HART CONSULTANCY

Within the company we explore how to match our client requirements with our expertise. If we haven't got the expertise you need we won't take your business. However we will help you make contact with our associate network of excellent professionals who may be able to provide the expertise you require. The company is led by two directors who each have over 30 years' experience in their respective fields, each being highly regarded within their own sectors for being down to earth, pragmatic and hardworking.



WHO WE ARE

Ian Craig - BEng (Hons) CEng MIET

Ian has over 30 years experience in the Offshore / Marine Oil & Gas industries at Design, Project Management and Director level, all acquired within internationally renowned engineering companies.

He possesses a broad technical knowledge and a comprehensive understanding of industry standards, practices and procedures, gained primarily from within engineering offices but has extensive experience within manufacturing facilities and on offshore installations.

Ian is registered with the Engineering Council as a Chartered Engineer and is a full member of the Institute of Engineering & Technology. He holds a first class BEng (Hons) Engineering from the University of Sunderland.

Maxine Craig - DProf, MSc, BA, DipN, RN, Cert Coach

Dr Maxine Craig is an Organisation Development leader with over 34 years of experience of organisational change. Organisation Development is the application of the behavioural sciences into the business environment. Maxine is a Visiting Professor (Leadership and Management) at Sunderland University , a board member of the Organisation Development Network for Europe and a Trustee at Teesside Hospice. Maxine has published a number of books and articles, a list of which can be found here.

In both 2013 and 2014 she was listed as a Top 50 Innovator by the Health Service Journal for her work with team performance. She specialises in the development of strategic, team and individual level interventions designed to support the creation of open and honest cultures. As an academic practitioner she works to bring the best available research and evidence into organisations, groups and communities to support business performance. She is a certified coach and psychometrician. She is passionate about helping groups and teams to flourish and achieve their best potential, whilst simultaneously delivering the desired business outcomes.

INTERESTED?
PLEASE CONTACT US

PROJECTS/PROCESSES

Introduction

With a well publicised shortage of experienced engineers, a lot of companies today are under pressure. No more so than in the Offshore / Marine Industry where safety is paramount, quality is essential yet budgets must be maintained and delivery schedules are become ever more challenging.

Today companies cannot always find the resource or expertise to deliver projects effectively, and as a result, suffer additional costs on projects through poor conception, planning, procurement and execution.

A range of services can be provided to facilitate successful project delivery, including Project Management, Technical Guidance, Expediting and Team Development Alternatively, these services can be used to provide expert support to client project teams.

So whatever your requirements, whether you wish to outsource the management of an engineering project or require additional expertise to compliment your internal resources, a service can be provided to fit your needs.

Project Management

- Review of RFQ Documentation
- Co-ordination / Preparation of Bid Documentation
- Co-ordinating / Attending Bid Clarification activities
- Contract Review
- Co-ordination /Attending Project Kick–off activities
- Client Liaison during execution of contract
- Progress reporting
- Assistance / coordination of Design Engineering & Project Engineering Activities
- Ensuring compliance with Industry Standards & Project Specifications
- Ensuring scheduled issue of Engineering Deliverable
- Monitor Project Schedule & Cost Control
- Contract Variation Control
- Placement & Expediting Sub Orders
- Liaising with and coordination of Vendors, Contractors, Site
- Interaction with overseas manufacturing facilities
- Co-ordination of 3rd Party Inspection
- Coordination and participation in Testing and Pre-commissioning activities
- Collation & preparation of Final Documentation
- Supervising Offshore Installation / Commissioning
- After sales coordination with Client

PROJECT INTERVENTION

No matter how well planned and executed, projects are rarely completed perfectly. Budgets and deadlines are missed, expectations are not fully met and small conflicts occur. Indeed, research suggests that 70% of projects fail to meet the objectives.

Some projects experience these to a minimal degree and the project goals and objectives are met. Unfortunately, others are troubled projects and experience these problems to a more significant degree. Examples include:

The project is trending +25% over budget Expectations are becoming unmet to the point where there is doubt as to the value of the solution The project team capability is becoming questionable and additional resources are not realigning the schedule Conflict within the team, or between client and vendor, is high and relationships are becoming dysfunctional Executives have lost interest and become unsupportive

It is never easy turning around a troubled project, but there are a number of services we can offer to help get them back on track: Validation of project problems and determination of intervention requirements Clarification of key issues and identifying root causes Capability assessment of project team Assist with preparation of turnaround plan Initiate management and reporting standards to establish execution structure Provide ongoing coaching to assist with the implementation of the turnaround plan

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EXPEDITING

We can provide your project with an expediting function or alternatively provide a range of services to assist an expediting team, including:

- Perform vendor capability
- Expediting purchase order acknowledgements and schedule commitments
- Verify achievability of vendor delivery schedule
- Vendor liaison to ensure the on-time delivery of the purchased materials and equipment
- Shop Inspections to verify quality and progress
- Expediting the submittal of vendor data/drawings as required to fulfil SDRL requirements
- Preparing and distribute equipment package progress reports to project personnel
- Providing technical/commercial opinion as to poor vendor performance
- Develop and provide practical and economical solutions for schedule realignment
- Facilitate meetings with project team to compare site need dates with scheduled delivery dates
- Co-ordinate 3rd party inspections and witness factory acceptance tests
- co-ordinate with logistics for delivery dates, collection locations, shipping documents and package dimensions etc
- Resolution of vendor contract variation claims

Specialist Consultancy

Due to the prominent emergence and accelerated development of offshore reserves utilising FPSO/FSU units, Fluid Transfer Systems and flexible pipe technology are used extensively within offshore oil and gas industry in a number of applications.

With 30+ years experience in the Offshore / Marine Oil & Gas industries at Design, Project Management and Director level within internationally renowned engineering companies, and having spent the previous 6 years as Technical Director of a leading supplier of Fluid Transfer Systems, Ian is able to offer the following services to support client operations in relation to selection and procurement of Fluid Transfer Systems:

- Independent advice regarding suitability of solution
- Technical Review and Evaluation of Bid Packages
- Commercial Analysis of Bid Packages
- Technical & Design Guidance for Fluid Transfer Systems
- Compliance with Industry Standards and Project Specifications
- Package Responsibility & Vendor Liaison
- Installation & Commissioning Supervision

Seawater Uptake Systems: provide a means of supplying cooler, cleaner and less oxygenated seawater from below sea level to the vessel's cooling, process, utility and water injection. With exploration now in deeper water and warmer climates, these systems are becoming invaluable for both oil and gas production vessels.

Offloading Systems: are a means for storage, deployment and recovery of flexible pipe for the transfer of crude oil or other media in dynamic applications, e.g.:

- Crude Oil Loading / Offloading
- Methanol Loading / Offloading

- Condensate Offloading
- Well Intervention / Work-Over Systems

Tandem Mooring Systems: complement Offloading Systems by providing a means for storage, deployment and recovery of the Mooring Hawser String, enabling safe and efficient tandem mooring operations between FPSO and Shuttle Tankers.

Hose Bunkering Stations: provide safe and efficient operation and storage of bulk loading hoses, for fluid or powder transfer operations, in many offshore applications, e.g.

- Drill Fluid / Powder Bunkering / Loading
- Potable Water / Diesel replenishment
- Seawater Delivery
- Methanol Bunkering

Breakaway Coupling Systems: are a safety feature which can complement each of the above systems by providing a controlled/safe means of disconnecting the flexible pipe in an unplanned or emergency release scenario, e.g.

- Bow Connector Couplings
- Quick Release Couplings
- Emergency Disconnect Couplings
- Weak-link Couplings