**NTNU – Trondheim**
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# Design and Analysis of Steel Catenary Riser Systems for Deep Waters

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Subsea Technology
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**NTNU**
**Norwegian University of Science and Technology**
*Department of Marine Technology*

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for
Master Student Thomas Buberg

# Design and Analysis of Steel Catenary Riser Systems for Deep Waters

*Dimensjonering og analyse av kjedelinje-stigerør i stål*

The marine riser is an important part in the oil and gas industry. Integrity and reliability of such structure is very important. Failure will lead to major loss and severe consequences.

Future production of oil and gas will to a large extent take place in water depths that exceed 1000m. This implies that design of the systems that connect the surface floater to the subsea structure must focus on different aspects of the environmental forces relative to more shallow waters.

The following subjects are to be addressed as part of this work:

1. The candidate shall give a brief description of the riser systems that are relevant for such large water depths. The description should comprise the following topics (i) Geometric configuration (Vertical, catenary, double-curved shapes) (ii) Materials (Steel, titanium, fiber composites, flexible pipes) (iii) End components (ball-joints, bending stiffeners)

2. The loads acting on the riser system is to be described, and methods for computation of load effects as function of position along the risers are presented. The loading mainly comprises (i) Loading from current and waves (ii) Loading due to vessel motion (iii) Loading due to top tension (iv) Self weight and buoyancy (v) Contact-forces from the seabed (vi) Loading due to internal pressure. A summary of relevant design codes and mechanical limit states for such systems is also to be given.

3. A static and dynamic response analysis is to be performed for a reference SCR-configuration. Subsequently, a more optimized SCR-configuration is identified by application of weight coating and buoyancy elements for different riser segments. A comparison of static and dynamic response properties for the two different configurations is also to be made.

4. Parametric studies with respect to input parameters such as vessel offset are subsequently performed for the optimized SCR-configuration to the extent that time allows.

The work scope may prove to be larger than initially anticipated. Subject to approval from the supervisor, topics may be deleted from the list above or reduced in extent.

In the thesis the candidate shall present his personal contribution to the resolution of problems within the scope of the thesis work. Theories and conclusions should be based on mathematical derivations and/or logic reasoning identifying the various steps in the deduction.

The candidate should utilise the existing possibilities for obtaining relevant literature.

The thesis should be organised in a rational manner to give a clear exposition of results, assessments, and conclusions. The text should be brief and to the point, with a clear language. Telegraphic language should be avoided.

The thesis shall contain the following elements: A text defining the scope, preface, list of contents, summary, main body of thesis, conclusions with recommendations for further work, list of symbols and acronyms, references and (optional) appendices. All figures, tables and equations shall be numbered.

The supervisor may require that the candidate, in an early stage of the work, present a written plan for the completion of the work.

The original contribution of the candidate and material taken from other sources shall be clearly defined. Work from other sources shall be properly referenced using an acknowledged referencing system.

The thesis shall be submitted electronically:
- Signed by the candidate
- The text defining the scope included
- Drawings and/or computer prints that cannot be bound should be organised in a separate folder.

Supervisor: Professor Bernt J. Leira

Deadline: June 10th 2014

Trondheim, January 15th 2014

Bernt J. Leira

# Abstract

The global growing demand of energy leads the oil and gas industry into deeper waters and harsher environments as current fields are being depleted. This results in need for more advanced technologies to ensure that the systems are able to cope with the increased environmental loads and vessel motions. A key to success when moving into these new environments, and the development of new fields, is advanced riser technology.

Steel catenary risers (SCRs) has emerged as a preferred solution for use in deepwater fields because of its simplicity in terms of engineering and construction in addition to its cost efficiency and flexibility in choice of host platform. However, the SCRs face challenges concerning large motions from the host platform and excessive bending moment at the touchdown point (TDP).

The first part of this thesis assesses different types of marine riser systems in terms of geometric shapes, and discusses various types of relevant materials for these systems. Furthermore, a more in-depth description of SCR systems is given.

The second part concentrates on the loads acting on the system and what software is used to analyze the SCR configurations in this thesis.

The third part of the thesis performs analysis on how a conventional 12-inch SCR responds to environmental loading at extreme North Sea values. The study shows that the conventional SCR is not suitable for the environments, and therefore an optimized SCR configuration is identified based on varying coating-weight along the riser.

Analysis is performed on the weight-distributed SCR configuration, and the two configurations are compared to each other.

The last part of the thesis consists of a sensitivity study on the weight-distributed SCR in terms of how different coating densities affect the system response. In addition, a sensitivity study is performed on how the number of elements used in the analysis affects the system.

The thesis concludes by the comparison of the two configurations that the weight-distributed SCR configuration has remarkable improvement in response values compared to the conventional SCR configuration in all areas analyzed, and that even with deep waters and harsh environments, suitable solutions are possible to achieve.

## Sammendrag

Den globale økende etterspørselen av energi fører olje- og gassindustrien til større vanndyp og tøffere miljøer etter hvert som nåværende felt tømmes. Dette resulterer i et behov for mer avansert teknologi for å sikre at systemene er i stand til å takle de økte miljøbelastninger og bevegelser fra plattformene. En nøkkel til å lykkes i disse nye omgivelsene, og i utviklingen av nye felt, er avansert stigerørsteknologi.

Kjedelinje-stigerør i stål har dukket opp som en foretrukket løsning for bruk i dypvannsfelt på grunn av sin enkelhet i form av prosjektering og fabrikasjon, samt kostnadseffektivitet og i tillegg fleksibilitet i valg av vertsplattform. Kjedelinje-stigerør står overfor utfordringer knyttet til store bevegelser fra vertsplattform og overdrevet bøyemoment ved nedslagspunktet.

Den første delen av denne avhandlingen beskriver ulike typer marine stigerørssystemer ved geometrisk form, og drøfter ulike typer relevant materiale for disse systemene. Videre er en mer dyptgående beskrivelse av kjedelinje-stigerør i stål gitt.

Den andre delen av oppgaven konsentrerer seg om de belastninger som virker på systemet, og hvilken programvare som blir brukt til analysene.

I den tredje delen av oppgaven utføres en analyse på hvordan et konvensjonelt 12-tommers kjedelinje-stigerør reagerer på miljølaster ved ekstreme nordsjø-verdier. Studien viser at det konvensjonelle kjedelinje-stigerørssystemet ikke er egnet for omgivelsene, og derfor utledes en ny og optimalisert konfigurasjon på grunnlag av varierende belegg-vekt langs stigerøret.

Analyser av den vekt-distribuerte konfigurasjonen blir så gjennomført, og de to konfigurasjonene blir sammenlignet med hverandre.

Den siste delen av oppgaven består av en sensitivitetsstudie på den vekt-distribuerte konfigurasjonen i forhold til hvordan ulike belegg tettheter påvirker systemet. I tillegg er et sensitivitetsstudie gjennomført med hensyn på hvordan antall elementer som benyttes i analysen påvirker systemet.

Rapporten konkluderer ved sammenligning av de to konfigurasjoner at den vekt-distribuerte konfigurasjonen har en bemerkelsesverdig forbedring i responsverdier sammenlignet med den konvensjonelle konfigurasjonen på alle områder som er analysert. Dette viser at selv med store vanndyp og værharde omgivelser er det mulig å lage egnede løsninger.

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# Preface

This report is the result of my Master Thesis written as a part of the curriculum spring 2014 at the Department of Marine Technology at the Norwegian University of Science and Technology. It is assumed that the person reading this thesis has some prior knowledge to the theories and terminology being applied.

I would like to thank my supervisor, Bernt J. Leira for good guidance as well as his ability to always be available when needed. I would also like to thank my fellow students at the Department of Marine Technology for academic discussions and also for all the extra-curricular activities.

Lastly, I wish to thank my parents for supporting and encouraging me through the full 5 years of my degree.

Trondheim, June 10, 2014

Thomas Buberg

Thomas Buberg

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## Abbreviations

| | |
|---|---|
| ABS | American Bureau of Shipping |
| ALS | Accidental Limit State |
| API | American Petroleum Institute |
| AR | Arbitrary Riser |
| BHR | Bundle Hybrid Riser |
| BS | British Standard |
| CPU | Central Processing Unit |
| CSA | Canadian Standards Association |
| DNV | Det Norske Veritas |
| DOF | Degree of Freedom |
| FEM | Finite Element Method |
| FLS | Fatigue Limit State |
| FPS | Floating, Production, Storage |
| FPU | Floating Production Unit |
| HSE | Health, Safety and Environment |
| ISO | International Organization for Standardization |
| NPD | Norwegian Petroleum Directorate |
| RAO | Response Amplitude Operator |
| SCR | Steel Catenary Riser |
| SHR | Single Hybrid Riser |
| SLS | Serviceability Limit State |
| TDP | Touchdown Point |
| TDZ | Touchdown Zone |
| TLP | Tension-Leg Platform |
| TTR | Top-Tensioned Riser |
| ULS | Ultimate Limit State |
| VIV | Vortex Induced Vibrations |

Other abbreviations used are explained throughout the thesis.

# 1 INTRODUCTION

## 1.1 Background

The petroleum industry is constantly evolving, and adapting into new environments involving deeper water depths. In recent years, the water depth of exploration and production activities has increased drastically, and new fields are discovered in deeper and deeper waters. As the water depth increases, both technological and economic challenges also increase. A key to success when moving into these new environments, and the development of new fields, is advanced riser technology.

As for deeper waters, the current trend is to use a FPS, rather than the fixed jacket structures that has been used in shallow waters. In addition to Spar, Semisubmersible and TLPs, the FPSO (Floating, Production, Storage and Offloading) system is now also deployed and used in deepwater scenarios. Regardless of which floater concept is used, there is always a need of a riser system for connection between the surface and subsea facilities.

Flexible risers, hybrid risers, top tensioned risers and steel catenary risers have all been used for deepwater fields. All these risers are described briefly in the report, except for the steel catenary riser, which is analyzed and described more in-depth.

*Steel catenary risers* (SCRs) are composed only from a simple steel pipe and require minimal subsea equipment, which makes it cheaper than other configurations. Earlier research shows that dynamic performance of a conventional steel catenary riser is limited. The suspended riser length along with significant heave and surge motions from the host platform creates excessive bending at the *Touch Down Point* (TDP). Stresses over a longer time period will also result in a low performance to fatigue damage.

To cope with these challenges, a fair amount of SCR configurations have been proposed, researched and developed. This report focuses on finding a better solution to a conventional SCR configuration.

## 1.2 Scope

Chapter 2 describes what a riser system is, different riser concepts due to difference in geometric shape (vertical, catenary, hybrid), riser components (flex joints, bending stiffeners etc.) and materials used in riser systems. In addition, some deepwater challenges for riser systems are presented.

Chapter 3 provides a more in-depth description of steel catenary risers. This includes description of components, different SCR configurations, installation methods and factors to consider when deciding which configuration to use.

Chapter 4 describes design codes that are used in riser design. The main purpose of the design codes is to make sure the SCR can withstand environmental, functional and accidental load effects throughout its lifetime, and to keep the failure probability below a certain value.

Chapter 5 gives the reader information about the analysis software being used in this thesis. The chapter includes how the software SIMA/RIFLEX is built up and how it works.

Chapter 6 provides methodology for the upcoming design and analyses chapters. The chapter describes how the static and dynamic analyses are performed, which sea-state is being used, current forces, etc.

Chapter 7 provides a response analysis for a conventional SCR system. Static tension, static bending, dynamic tension and dynamic bending are the analyses that are investigated.

Chapter 8 provides a response analysis for a weight-distributed SCR system. As in chapter 7, static tension, static bending, dynamic tension and dynamic bending are the analyses that are investigated.

Chapter 9 discusses a comparison study between the conventional SCR in chapter 7 and the weight-distributed SCR in chapter 8.

Chapter 10 discusses a sensitivity study performed on the weight-distributed SCR configuration. The sensitivity study examines how the coating densities can be changed, and how this affects the riser response. In addition, the study examines how the number of elements chosen in SIMA/RIFLEX affects the result of the riser response.

Chapter 11 provides a closing conclusion and recommendation for further work.

# 2 DEEPWATER RISER SYSTEM

## 2.1 Introduction

A riser system is basically the connection between the seabed and the floater on the surface. Risers are considered the most critical component in an offshore pipeline development, because of the dynamic loads and sour service conditions they need to withstand. The riser is a major factor for success in all the operational phases subsea. While drilling, the drill string is carried in and out through the riser, and the riser also serves as the return path for the drilling fluid. In addition to assist the drilling phase, the riser system is also included in workover-, production- and export phases. A riser can, similar to flow- and pipelines, transport production materials (e.g. injection fluids) and produced hydrocarbons.

A riser system is an assembly of components, which can include a tensioning system, buoyancy modules, etc. According to *American Petroleum Institute* (API), a riser system typically involve these elements:

- Riser (Metal- or flexible pipe)
- Bottom interface
- Top interface

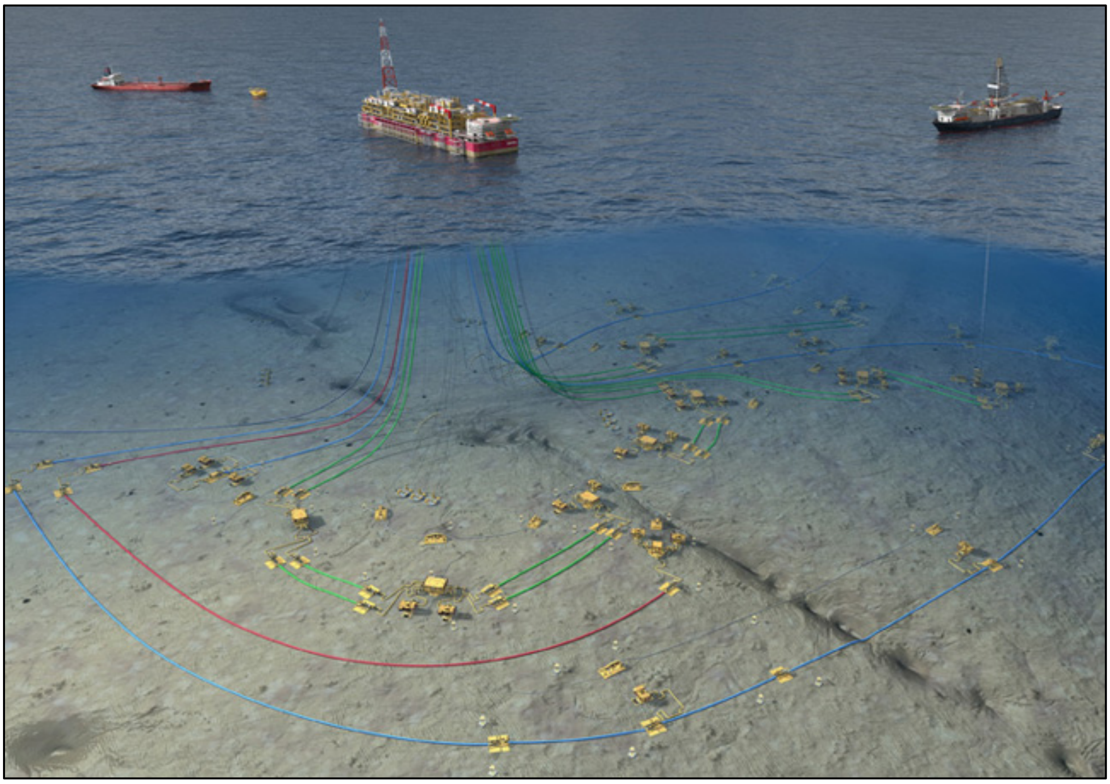

**Figure 2-1: Riser system (Rigzone)**

## 2.2 Riser systems

Oil- and gas fields vary in geology and environments, and these differences calls for different designs on the riser systems. In chapter 2.1, different tasks for risers are mentioned briefly. These different types of risers can be classified as the following (Larsen, C.M):

- Drilling riser – this type of riser is used when drilling new wells.
- Production riser –used for transporting the well stream from the seabed to the production facility at the platform.
- Workover riser – used for well operations and maintenance in a production well.
- Export riser – used for transporting processed oil or gas from the platform, and down to the pipelines.

The floater on the surface has to deal with different dynamic behaviors, and because of this, we also classify the riser systems by looking at the construction. These types of riser systems are discussed more in-depth in the following subchapters.

### 2.2.1 Compliant riser

The name "compliant" riser itself tells what type of system this is. The compliant risers are formed such that they can cope with the dynamic motions of the floater, without using additional equipment such as motion compensators or heave compensators. Compliant risers can again be divided into 6 different configurations (Bai and Bai, 2005). These configurations are shown in Figure 2-2. To decide which riser design is to be used; there are a number of factors playing their part. A static analysis will have to be carried out, as well as considering factors including global behavior, structural integrity, materials, costs, etc.

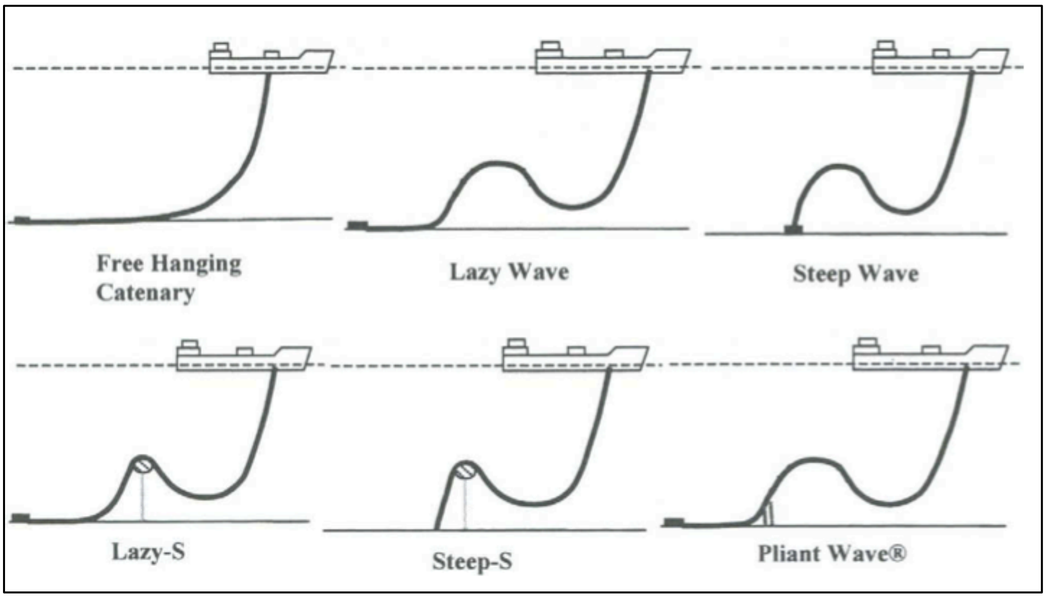

Figure 2-2: Compliant risers (Bai and Bai, 2005)

- *Free Hanging Catenary*: Free hanging catenary is usually the cheapest solution for a compliant riser configuration, and it is also the simplest. This configuration uses from none to minimal subsea infrastructure, and is fairly easy to install. When installing a free hanging catenary, the riser is just either lifted up from the seabed, or lowered down onto it. The negative aspect when lifting or lowering it down is the severe loading it is being exposed to due to vessel motions.

  As the water depth increase, so does the top tension, because of its weight/length. The most critical point on a catenary riser is the *Touch Down Point* (TDP). When the floater on top is moving, the surface motion is directly transferred to the TDP.

- *Pliant Wave*: From looking at Figure 2-2 we see that a pliant wave configuration is similar to the steep wave configuration. The difference is that on the pliant wave, the tension in the riser is transferred to an anchor. This anchor acts like a protection for the riser at the TDP. Another benefit with this configuration is that it is tied to the well beneath the floater, which means there is no need for an additional vessel when doing well intervention.

  This configuration requires complex subsea installations, and is normally therefore only used where other configurations are not viable.

- *Lazy- and Steep Wave*: This configuration is similar to Lazy and Steep S, but instead of a single buoy, buoyancy and weights are added along a longer length of the riser. Lazy wave requires minimal subsea infrastructure, and is therefore often preferred to steep wave configuration. Steep wave risers require a subsea base and a subsea bend stiffener.

  When placing the buoyancy modules onto the riser it is important to clamp them tightly to avoid slippage, but it is also important to not damage the external sheath, as this can cause water ingress to the annulus.

- *Lazy- and Steep S*: In this configuration, there is either added a fixed subsea buoy, or a buoyant buoy. A fixed buoy is fixed to a structure at the seabed. By adding these buoys, the top tension is reduced because you also reduce the free length of the riser. The TDP is also protected, as the buoy also absorbs the tension variation due to the movement.
  The S-configuration is usually only considered if catenary or wave configurations are possible, due to complex installation.

### 2.2.2 Top Tensioned riser

*Top tensioned risers* (TTRs) require a platform with good response characteristics such as Spar or TLPs. TTRs are equipped with a tensioning system to maintain acceptable vertical movement. The TTRs are normally designed to give direct access to the well, including a dry tree on the floater deck. Because of this, it is critical that it is able to resist tubing pressure, in case of a failure.

TTRs consists of (Cheng, Xu and, Stanton 2011):

- Riser joint
- BOP
- Tensioning system
- Guides
- Keel joint
- Stress joint and tieback connector
- Strakes, fairing, etc. to suppress the risk of VIV damage

The reason for the tensioning system is to constantly keep tension in the riser during service to avoid buckling and bending stresses due to surface motion or *Vortex Induced Vibrations* (VIV). Buoyancy cans, hydraulic tensioners and RAM tensioners are all examples of tensioning systems that are used.

In deep water, TTRs encounter problems. The riser tension increases, which again affects the size of the tensioning system and buoyancy requirements. This increase in size and scope usually makes the TTR configuration neither feasible nor economic.

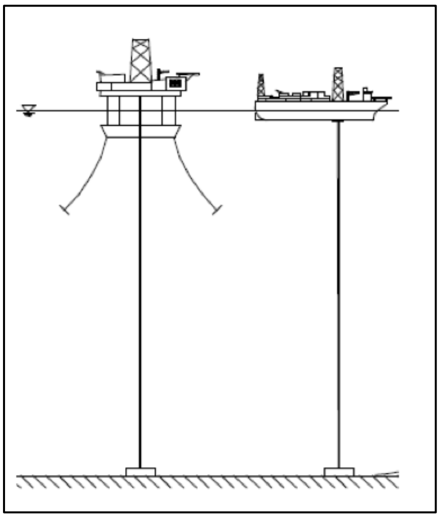

**Figure 2-3: Top tensioned riser system (DNV, 2010)**

### 2.2.3 Hybrid riser

There are two types of hybrid risers: *Single Hybrid Riser* (SHR) and *Bundled Hybrid Riser* (BHR).

The lower parts of the Hybrid risers are tensioned risers attached to the seabed by gravity and suction piles. Hybrid risers accommodate relative motion between a floater and the tensioned risers by connecting them with flexible pipes. The connection of the tensioned risers and the flexible pipes is done either directly using rigid gooseneck, or through fluid swivel bearing.

This configuration can use disconnectable turret and decoupled risers, which means the floater can move in case of extreme weather conditions, and leave the risers subsea. Because the tensioned riser is located at depths where there is less significant wave loading, hybrid risers can cope with harsh environments.

## 2.3 Riser components

A riser system consists of a number of components. These components help optimizing and improving the riser system. Some of the most used, and most important components are briefly described below:

- *Flex joints*: Flex joints can be found at the top region of SCRs, and its purpose is to minimize motion-induced stresses, bending stress and to resist internal pressure. It allows the riser system to rotate with minimum bending moment.
- *Stress joints*: Stiffer than flex joints, and generally used at lower pressure cases. Titanium is the ideal material because of its low modulus, high strength and excellent fatigue properties.
- *Ball joints*: Consists of a ball and a matching socket housing that join two pipe segments.
- *Keel joints*: Located at the point where the riser enters the bottom of a deep draft vessel. It is used to protect the riser against bending stresses due to vessel motion. Applied in TTRs.
- *Buoyancy modules*: Can appear as air cans or foam. Air cans are the central component of buoyancy based tensioning system and are typically used to provide top tension to risers in deep draft vessel applications. Foam is used to provide lift and reduce the submerged weight of the riser joints in deepwater applications (Bai and Bai, 2005).
- *Bending stiffeners and Bell mouths*: The top part of a flexible riser is a critical area, because it is prone to over-bending. Bending stiffeners and bell mouths are used in order to prevent this from happening. Bending stiffeners are normally made of polyurethane material, while the bell mouths are steel components (Bai and Bai, 2005).

- *Bending restrictor*: Used in order to limit bending on static pipelines. Normally located at the top and bottom connections. Made of hard plastic material, which restrains the riser tension, bending and shear loads. Provides mechanical locking to prevent over-bending.

## 2.4 Deepwater challenges

As the water depths where risers are being applied are growing, more challenges are applied to the design of the riser.

- *Hydrostatic pressure*: The external hydrostatic pressure increases as the water depth increases. If the external pressure becomes too high for the riser design, it will lead to a collapse failure. To cope with this challenge, larger wall thickness is a possibility, but this again creates other challenges on the riser design itself.
- *Increased riser weight*: When the riser must withstand higher external pressure, and the riser becomes longer with increased depth, the weight of the riser naturally becomes larger. This leads to an increase in top-tension force. Also, the cost of the riser will increase.
- *Current forces*: In deepwater, large current forces occurs. With large current speeds, Vortex-Induced Vibrations (VIV) is caused by the regular shedding of vortices in the wake behind the riser in steady current. By applying VIV-strakes along the riser to reduce the fatigue damage of the VIV, increased drag forces occur.
- *Vessel motions*: By pursuing deeper waters, the environmental challenges will become more significant. Vessel offset is one challenge. This causes high bending moment for the riser at the TDP.

## 2.5 Riser materials

Material selection for riser systems depends on a number of factors including internal and external environment, maximum and minimum temperatures, service life, loads, etc. On selection of materials, risers are divided into rigid risers and flexible risers.

For rigid pipes, alloys based on carbon steel are the dominant material. The requirements on steel quality differ from location to location, and characteristics of the steel (e.g. yield/tensile strength, modulus of elasticity) vary by which materials are included in the alloy. The most common steel alloy used in the offshore industry is stainless steel, which is a steel alloy with minimum 10,5% chromium content by mass (ISSF, 2012). Typical steel grades used for rigid pipes are X60, X65 and X70.

Certain stress-exposed areas can have alloys containing tin, aluminum and titanium due to their flexibility and low weight. Titanium is superior with its high strength and corrosion resistance, but it is an expensive material. For titanium to be used over large areas it would be a costly solution.

Flexible pipes are built up by several steel and composite layers as shown on Figure 2-4, to increase the flexibility. The pipes are classified into bonded and non-bonded. Bonded pipes are vulcanized (i.e. completely bonded together), while the non-bonded are free to move relative to each other. Because the flexible pipes are built up with different layers, there are number of opportunities to create different curvatures.

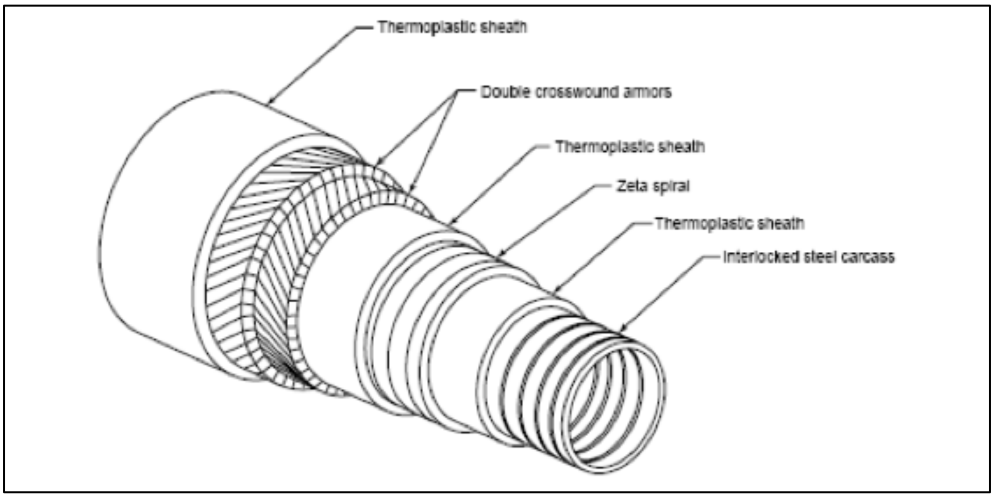

**Figure 2-4: Flexible pipe structure (API, 1998)**

# 3 STEEL CATENARY RISER

A *Steel Catenary Riser* (SCR) is a compliant riser. The name catenary simply originates from the catenary shape of the riser. In 1994, the first SCR was deployed to Shell's Auger Tension Leg Platform at 872m. Before it was applied to the Auger TLP, it was used as export lines (Sparks, 2007). Nowadays, the SCR technology has emerged as one of the top solutions for subsea field development in deepwater.

SCR is known to be economically attractive in terms of both installation and construction, and compared to flexible risers they are easier and cheaper to produce in longer and larger sections. Due to the material, they also have high resistance to the internal and external pressure they are exposed to at larger depths. The steel may also be modified to different alloys for increased strength capacity.

SCRs are more sensitive to dynamic motions when they are light in water (e.g. gas production/injection risers), and these risers are less resistant to fatigue.

## 3.1 SCR Components

The following subchapters will describe the different SCR components, both for Stability and load control and for fluid transfer.

### 3.1.1 Stability and load control

External forces and loads constantly affect the riser. Therefore, components have been developed to help keep it at bay. These components will be briefly described in the following.

- *Flex joint*: Figure 3-1 shows a flex joint. In order to reduce the bending moment at the top region of the SCR, flex joints are used. These joints consist of alternating layers of elastomeric materials and metal, which helps allow angular deflections at the top end of the riser.

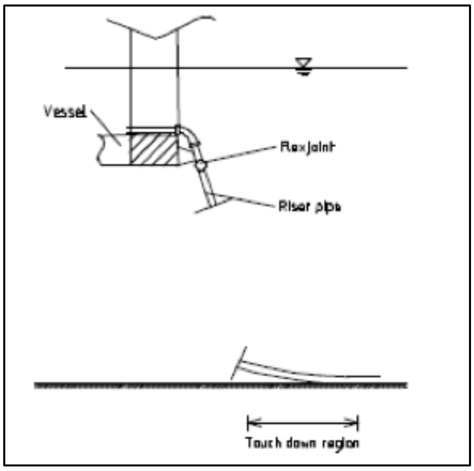

**Figure 3-1: Flex joint sketch (DNV, 2010)**

- *Stress joint*: Used to provide a transition member between rigidly fixed or stiffer sections of the riser and less stiff sections. Helps reduce local bending stress and at the same time provide flexibility at the riser end.
- *VIV*-strakes: As mentioned in chapter 2.3 the high current speeds at deeper water creates vortex-induced vibrations, and to help reduce the fatigue damage VIV-strakes are applied. Figure 3-2 shows an animation of what VIV-strakes may look like.

**Figure 3-2: VIV strakes (Offshore-mag, 2011)**

### 3.1.2 Fluid transfer

Two sections build up the SCR: The static flowline section, and the dynamic riser section. The static flowline section is the part of the riser ranging from the termination structure to the TDP, whilst the dynamic riser section is the part from the TDP and up to the floater. This section is the most force-affected by the two sections.

These sections are joined together to make up a complete riser. The different connection areas can be divided into:

- *End connectors*: Riser connection at the floater, and riser connection at the bottom-end on the seabed. Works as a fluid containment seal in both upper and lower end. The bottom end must be able to cope with loading from the SCR motion.
- *Riser coupling*: Connection between the different sections. Main purpose to provide a seal between the sections, and still not be a “weak-point”.

## 3.2 SCR Configurations

Selection of riser configuration can make a significant difference in achieving feasibility of the SCR application.

The three most used SCR configurations are:

- Free Hanging
- Lazy Wave
- Buoyancy-supported

### 3.2.1 Free Hanging SCR

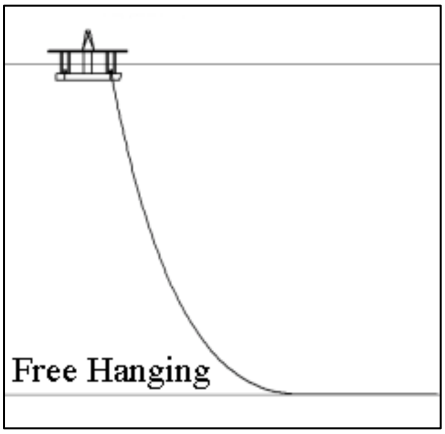

**Figure 3-3: Free Hanging SCR**

The Free Hanging SCR is the simplest and cheapest of the three configurations, and also the most widely used configuration (See figure 3-3). The free hanging catenary consists of a rigid pipe that is directly welded onto a static rigid pipeline a few hundred meters from the touchdown point (TDP), or via an anchored subsea structure. At the floater, the riser is connected via a flex- or stress joint.

The free hanging SCR is a subject to high fatigue damage at the top end, and at the TDP, because of its weight in free span and dynamic motions from the floater. The riser is also affected by VIV. To cope better with these vibrations, VIV-strakes are often installed on this configuration.

### 3.2.2 Weight Distributed SCR

To reduce the fatigue damage and excessive bending moment that occurs on free hanging SCRs, a weight-distribution concept has been developed. Figure 3-4 shows a sketch of how the weight-distribution concept works.

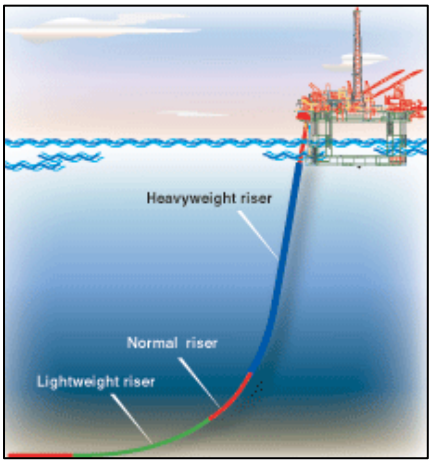

**Figure 3-4: Weight Distributed SCR concept (Karunakaran, 2006)**

The concept of this is to involve varying weight along the riser, with the lightest possible cross-section in the touchdown zone (TDZ). To achieve this, different density coatings are applied on the riser. By using a heavy cross-section at the straight part of the riser, the dynamics in this area is reduced. However, this may also increase the hang-off load and the dynamic axial stress closer to the hang-off.

To distribute the weight along the riser, two methods are used:

- External coating with varying density
- Clump weights along parts of the riser

More information about the weight-distributed SCR concept can be found in chapter 8.

### 3.2.3 Lazy Wave SCR

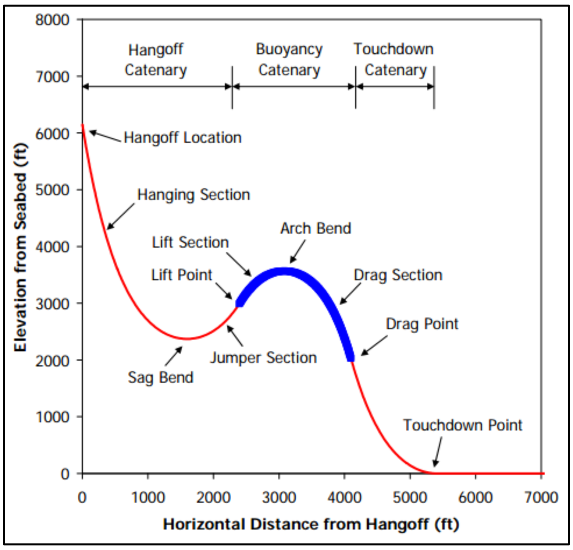

**Figure 3-5: Lazy Wave SCR (2H Offshore)**

Lazy wave SCR was first installed by Subsea 7 at Shell's BC-10 project in Brazil in 2009.

Because of the excessive fatigue damage on free hanging SCRs, new configurations are emerging, and one of these is the lazy wave. By adding buoyancy elements close to the TDP (Figure 3-5), the heave transmitted from the facility is reduced, and therefore, the stress and fatigue damage both at the TDP and the Top End is reduced.

This configuration requires mostly the same subsea installations as the free hanging, but because of the buoyancy elements it is more expensive.

### 3.2.4 Buoyancy-Supported SCR

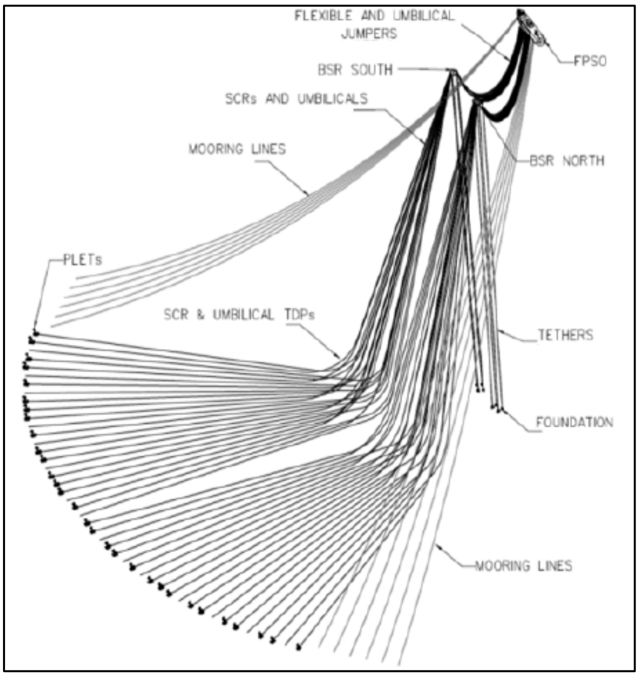

**Figure 3-6: Buoyancy Supported SCR system (Milne, G. Subsea 7, 2012)**

The BSR concept consists of a large sub-surface buoy, which is anchored to the seabed by tethers, shown in Figure 3-6. A more detailed picture of a sub-surface buoy is shown in Figure 3-7. The buoy supports multiple SCRs that are connected to the floater by non-bonded flexible jumpers.

This system absorbs the dynamics from the floater, resulting in almost no dynamic stresses on the SCRs, making them behave like a long free-spanning line with the major fatigue response coming from the VIV due to local currents. Since there is very little dynamic response on the SCRs, mechanical-lined pipe can be used for the SCR section, thereby optimizing the riser design.

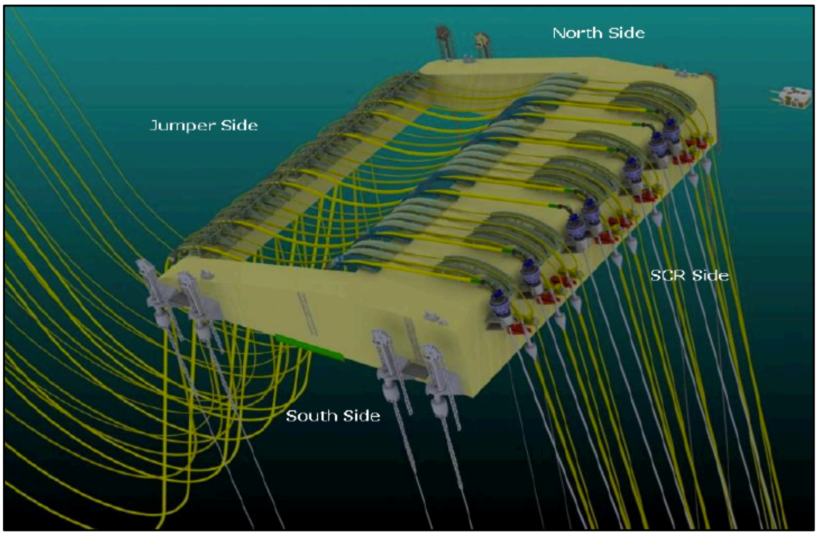

**Figure 3-7: Sub-surface buoy (Milne, G. Subsea 7, 2012)**

## 3.3 Determining factors in configuration design

When choosing what configuration to use, there are a number of factors to consider. This subchapter will describe these determining factors.

- *Water depth*: As mentioned in chapter 2.4, with increased water depth follows increased external pressure. With increased external pressure, the requirement of wall thickness becomes a driving parameter. Thicker wall thickness means that more material is being used, which again increase the weight of the riser, and enhanced cost of production.
- *Fatigue*: SCR configurations experience a significant issue with fatigue, because they are sensitive to floater motions and vortex-induced vibrations. Measures to prevent this happening will also lead to increased cost.
- *Field layout*: A field often consists of a number of risers; hence one must assure that it is enough space for these risers, so that they don’t clash into each other. On the other hand, too much space between them leads to a reduced number of allowable risers.
- *Welding*: Different riser configurations require different welding processes. A poorly implemented weld may cause a collapse failure. For S-lay and J-lay installations, the welding is done offshore, and the testing is therefore somehow limited. For a reel-lay installation, the welding is done onshore, and the fatigue testing of the weld can therefore be done easier.

## 3.4 SCR installation methods

SCRs can be installed using four different methods. These are:

- S-Lay
- J-Lay
- Reel lay
- Tow-out

### 3.4.1 S-Lay

When performing S-lay, the riser is eased off the vessel through a stinger as it moves forward (See Figure 3-8). The stinger helps supporting the pipe as it leaves the vessel to decrease tension and prevent buckling. Stingers can be up to 90 meters long, and most stingers are also able to adjust the size. The pipeline diameter can be from 8” to 40”. The riser curves downward (convex upward) when it leaves the stinger, and straightens up through the water until it curves upward in a sag-bend (convex downward) as it gets closer to the TDP. This installation method is the most common worldwide, and it is especially suited for shallower water. The offshore pipe-welding process is fast and efficient. For deepwater, this method becomes less and less used, because of the risk of damage to the pipe due to the high tension. A longer stinger can be used, but then again the stinger is vulnerable to wave and current forces.

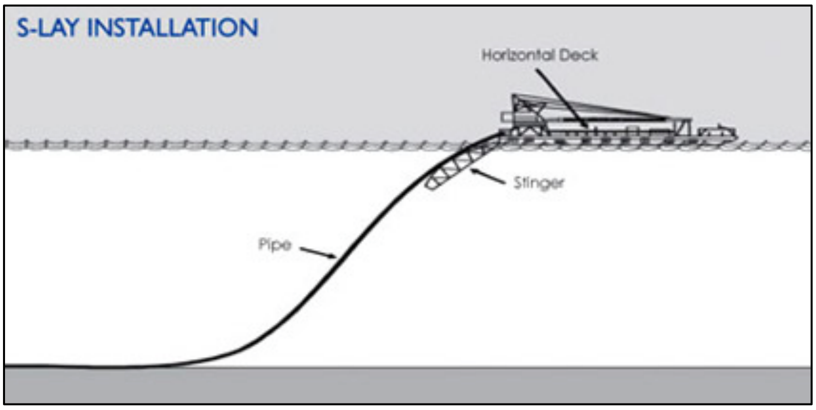

**Figure 3-8: S-lay installation (Rigzone)**

*Pros*:

- Widely used- very well known procedure
- Fast, efficient pipe welding offshore- high lay rate (100-500m/hr)
- No plastic deformation of pipeline

*Cons*:

- Experience difficulties on deep water because of very high tension on the riser

### 3.4.2 J-Lay

J-lay inserts the pipe in almost vertical position, to decrease the stress and tension on the pipes as it leaves the vessel. Pipeline diameter can vary from 8” to 30”. In the S-lay you experience a double curvature, which you don’t get with J-lay, hence the names J- and S-lay. The reduced stress allows J-lay to operate on deeper waters than S-lay, and it can also withstand more motion and underwater currents (Rigzone).

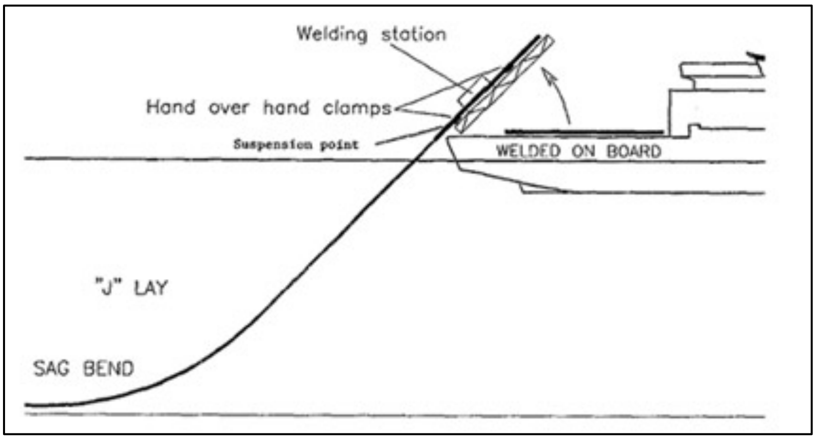

**Figure 3-9: J-Lay installation (Rigzone)**

*Pros*:

- Field proven for simple steel catenaries
- Required lower tension compared to S-lay
- Feasible for deep water (>1000m)
- No plastic deformation of pipeline

*Cons*:

- Laying speed 50-150m/hr compared to S-lay 100-500m/hr
- Top tension challenges

### 3.4.3 Reel Lay

The third method used when installing SCRs is the Reel Lay method. In this method, the pipe is first fabricated and welded together onshore, and then spooled onto the lay vessel. Figure 3-10 shows a sketch of the reel-lay equipment. When deploying it into the water, both S-lay and J-lay can be used. Welding and fabricating onshore reduce the installation cost. This method is often used on small to medium diameter pipes (4” – 18”).

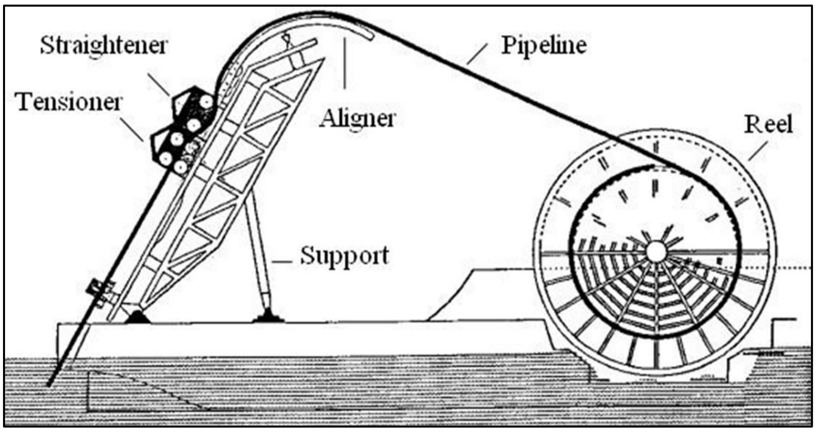

**Figure 3-10: Reel Lay equipment (Hu, Duan, Liu, 2012)**

*Pros*:

- Fast laying operation (600-1000m/hr)
- Efficient for short pipelines
- Pipelines welded onshore

*Cons*:

- Limited pipeline diameter
- Plastic deformation on pipeline (10-20%)
- Reel capacity 10-15km

### 3.4.4 Tow-Out

The fourth and final installation method is the tow-out method. In this method the pipe is towed out to its destination by tugboats. The method can be carried out in four different ways. *Surface towing* uses buoyancy modules along the pipe to keep it floating on the surface. When it reaches its destination the buoyancy modules are either flooded or removed, so that the pipe floats down to the bottom. *Mid-depth tow* includes less buoyancy modules; hence the pipe drops down to mid-water. *Off-bottom tow* uses both chains for added weight, and buoyancy modules that work against each other to keep the pipe just above the seabed. The last method is the *Bottom-tow*, which drags the pipe along the seabed (Hellestø, A.F, Karunakaran, D, Grytten, T, Gudmestad, O.T, 2007)

*Pros*:

- Less static stress
- Fast offshore operation (reduces cost of vessel etc.)
- No need for high spec vessels

*Cons*:

- Pipeline experience increased fatigue during towing
- Additional buoyancy modules increases cost
- Requires suitable launch location

# 4 DESIGN CODES

Design of SCR systems has to fulfill criteria set by different authorities and classification societies, depending on where it is to be deployed. Design codes such as ISO, API, NPD, HSE, BS, CSA, DNV and ABS are all examples of guidelines used when designing SCR systems.

The main purpose of the design codes is to make sure the SCR can withstand environmental, functional and accidental load effects throughout its lifetime, and to keep the failure probability below a certain value. According to DNV, the riser system including riser pipe and interfaces, details and components, shall be designed according to the following basic principles:

- The riser system shall satisfy functional and operational requirements as given in the design basis.
- The riser system shall be designed such that an unintended event does not escalate into an accident of significantly greater extent than the original event;
- Permit simple and reliable installation, retrieval, and be robust with respect to use;
- Provide adequate access for inspection, maintenance, replacement and repair;
- The riser joints and components shall be made such that fabrication can be accomplished in accordance with relevant recognized techniques and practice;
- Design of structural details and use of materials shall be done with the objective to minimize the effect of corrosion, erosion and wear;
- Riser mechanical components shall, as far as practicable, be designed “fail safe”. Consideration is to be given in the design to possible early detection of failure or redundancy for essential components, which cannot be designed according to this principle;
- The design should facilitate monitoring of its behavior in terms of tension, stresses, angles, vibrations, fatigue cracks, wear, abrasion, corrosion, etc.

To establish acceptance criteria there is two methods:

- *Working Stress Design* (WSD)
- *Load and Resistance Factor Design* (LRFD)

These two methods for establishing acceptance criteria are described in the following subchapters.

## 4.1 Load and Resistance Factor Design

The LRFD method separates the influence of uncertainties and variability originating from different causes by means of partial safety factors. The LRFD allows for a more flexible and optimal design with uniform safety level and is considered superior to the WSD method.

The code is divided into 4 limit states:

- *Serviceability Limit State (SLS):* requires that the riser must be able to remain in service and operate properly. Corresponds to criteria limiting or governing the normal use of the riser
- *Ultimate Limit State (ULS):* requires that the riser must remain intact and avoid rupture, but not necessary be able to operate. For operating conditions it corresponds to the maximum resistance to applied loads with $10^{-2}$ annual exceedence probability
- *Fatigue Limit State (FLS):* ULS from accumulated excessive fatigue crack growth or damage under cycling loading.
- *Accidental Limit State (ALS):* ULS due to accidental loads

### 4.1.1 Serviceability Limit State

SLS are most often associated with determination of acceptable limitations to normal operation. Exceeding a SLS shall not lead to failure and an ALS shall be defined in association with exceedence of SLS. According to DNV, 2010, there are some limits that have to be satisfied to be classified SLS:

- Risers shall not be subjected to excessive ovalisation and this shall be documented. Flattening due to bending together with the out-of-roundness tolerance from fabrication shall be limited to 3.0%.

$$\boldsymbol{f_0 = \frac{D_{max} - D_{min}}{D_o} \leq 0.03} \tag{4.1}$$

- During installation, weather limitation is to be set to avoid riser interference

### 4.1.2 Ultimate Limit State

This limit state provides design checks with emphasis on load-controlled conditions.

**Bursting**

To avoid bursting caused by overpressure in the pipe, all cross sections of the riser shall be designed to satisfy:

$$\boldsymbol{(p_{li} - p_e) \leq \frac{p_b(t_1)}{\gamma_m \cdot \gamma_{SC}}} \tag{4.2}$$

Where
$p_{li}$ = local incidental pressure
$p_c$ = external pressure

The burst resistance, $p_b$ is given by:

$$p_b(t) = \frac{2}{\sqrt{3}} \cdot \frac{2 \cdot t}{D-t} \cdot min\left(f_y; \frac{f_u}{1.15}\right) \tag{4.3}$$

**System Hoop Buckling (Collapse)**
Pipe members subjected to external overpressure shall be designed to satisfy the following condition (DNV, 2010):

$$(p_e - p_{min}) \leq \frac{p_c(t_1)}{\gamma_{SC} \cdot \gamma_m} \tag{4.4}$$

Where $p_{min}$ is minimum internal pressure. For water filled pipes, $p_{min} = p_e$.
From DNV-OS-F101 we find the elastic collapse pressure:

$$p_{el}(t) = \frac{2 \cdot E \cdot \left(\frac{t}{D}\right)^3}{1-\nu^2} \tag{4.5}$$

And the plastic collapse pressure is given by:

$$p_p(t) = 2 \cdot \frac{t}{D} \cdot f_y \cdot \alpha_{fab} \tag{4.6}$$

Where $\alpha_{fab}$ is a fabrication factor that can be found in Table 5-7, DNV-OS-F201.

**Propagating Buckling**
Local buckling may occur on the pipe due to system failure. This local buckle will propagate until external pressure drops due to change in pipe properties. To ensure that a possible local buckle remains local, and does not lead to successive hoop buckling (collapse), a propagating buckling check is required:

$$(p_e - p_{min}) \leq \frac{p_{pr}}{\gamma_c \gamma_{SC} \gamma_m} \tag{4.7}$$

Here, $\gamma_c$ = 1.0 if no buckle propagation is allowed. If the buckle is allowed to travel a short distance, $\gamma_c$ = 0.9 may be used. Resistance against buckling propagation, $p_{pr}$, is given by:

$$p_{pr} = 35 \cdot f_y \cdot \alpha_{fab} \cdot \left(\frac{t_2}{D}\right)^{2.5} \tag{4.8}$$

**Combined Loading Criteria**
Pipe members subjected to bending moment, effective tension and net *internal* overpressure shall be designed to satisfy:

$$\{\gamma_{SC}\cdot\gamma_m\}\left\{\left(\frac{|M_d|}{M_k}\cdot\sqrt{1-\left(\frac{p_{ld}-p_c}{p_b(t_2)}\right)}\right)+\left(\frac{T_{ed}}{T_k}\right)^2\right\}+\left(\frac{p_{ld}-p_c}{p_b(t_2)}\right)^2\leq 1 \qquad (4.9)$$

$M_d$ = Design bending moment
$T_{ed}$ = Design effective tension
$p_{ld}$ = Local internal design pressure
$p_e$ = Local external pressure
$M_k = f_y \cdot \alpha_c \cdot (D-t_2)^2 \cdot t_2$ (Plastic bending moment resistance)
$T_k = f_y \cdot \alpha_c \cdot \pi \cdot (D-t_2)^2 \cdot t_2$ (Plastic axial force resistance)
$\alpha_c = (1-\beta)+\beta\cdot\frac{f_u}{f_y}$ (Strain hardening and wall thinning parameter)

Pipe members subjected to bending moment, effective tension and net *external* overpressure shall be designed to satisfy:

$$\{\gamma_{SC}\cdot\gamma_m\}^2\left\{\left(\frac{|M_d|}{M_k}\right)+\left(\frac{T_{ed}}{T_k}\right)^2\right\}^2+\{\gamma_{SC}\cdot\gamma_m\}^2\left(\frac{p_e-p_{min}}{p_c(t_2)}\right)^2\leq 1 \qquad (4.10)$$

As a minimum requirement, the riser pipes and connectors shall be designed for the potential modes of failure listed in Table 4-2.

### 4.1.3 Fatigue Limit State

The riser system shall have adequate safety against fatigue within the service life of the system, and the fatigue analysis shall consider all relevant cyclic loading effects including:

- First order wave effects
- Second order floater motions
- Thermal and pressure induced stress cycles
- Vortex induced vibrations
- Collisions

According to DNV, the fatigue assessment can be divided into two methods:

- Fatigue assessment using S-N curves
    - $D_{fat} \cdot DFF \leq 1.0$
    - $D_{fat}$ = Accumulated fatigue damage (Palmgren-Miner rule)
    - $DFF$ = Design fatigue factor (Table 5-9 DNV 2010)

- Fatigue assessment by crack propagation calculations
    - $\frac{N_{tot}}{N_{cg}} \cdot DFF \leq 1.0$
    - $N_{tot}$ = Total number of applied stress cycles during service or to in-service inspection

- $N_{cg}$ = Number of stress cycles necessary to increase the defect from the initial to the critical defect size
- $DFF$ = Design fatigue factor (Table 5-9 DNV 2010)

### 4.1.4 Accidental Limit State

The *accidental limit state* (ALS) is a limit state due to accidental loads or events. According to DNV, accidental loads shall be understood as loads to which the riser may be subjected in case of abnormal conditions, incorrect operation or technical failure.

Relevant failure criteria and accidental loads in terms of frequency of occurrence and magnitude shall be determined based on risk analyses and relevant accumulated experience, and accidental loads may be categorized into (DNV, 2010):

- Fires/explosions
- Impact/collisions (e.g. impact from dropped objects/anchors)
- Hook/snag loads (e.g. dragging anchor)
- Failure of support system (Heave system malfunction, loss of buoyancy etc.)
- Exceedence of incidental internal overpressure (Failure of well tubing, packers etc.)
- Environmental events (Earthquake, tsunami, iceberg)

**Table 4-1: Simplified design check for accidental loads**

| **Prob. of occurrence** | **Safety class low** | **Safety class normal** | **Safety class high** |
|---|---|---|---|
| **$>10^{-2}$** | Accidental loads may be regarded similar to environmental loads and may be evaluated similar to ULS design check. | | |
| **$10^{-2}$-$10^{-3}$** | To be evaluated on a case by case basis | | |
| **$10^{-3}$-$10^{-4}$** | $\gamma_c = 1.0$ | $\gamma_c = 1.0$ | $\gamma_c = 1.0$ |
| **$10^{-4}$-$10^{-5}$** | Accidental loads or events may be disregarded | $\gamma_c = 0.9$ | $\gamma_c = 0.9$ |
| **$10^{-5}$-$10^{-6}$** | | Accidental loads or events may be disregarded | $\gamma_c = 0.8$ |
| **$<10^{-6}$** | | | Accidental loads or events may be disregarded |

For all limit states, as a minimum requirement, the riser pipes and connectors shall be designed for the potential modes of failure listed in Table 4-2 on the next page.

**Table 4-2: Potential modes of failure**

| **Limit State Category** | **Limit state** | **Failure definition/ Comments** |
|---|---|---|
| SLS | Clearance | No contact between e.g. riser-riser, riser-mooring line, riser-hull, surface tree- floater deck, subsea tree-seabed, surface jumper- floater deck. |
| | Excessive angular response | Large angular deflections that are beyond the specified operational limits, e.g. inclination of flex joint or ball joint. |
| | Excessive top displacement | Large relative top displacements between riser and floater that are beyond the specified operational limits for top tensioned risers, e.g. stroke of telescope joint, slick joint and tensioner, coiled tubing, surface equipment and drill floor. Note that systems can be designed for exceeding displacement limits if the structural integrity is maintained. |
| | Mechanical function | Mechanical function of a connector during make-up/break-out. |
| ULS | Bursting | Membrane rupture of the pipe wall due to internal overpressure only |
| | Hoop buckling | Gross plastic deformation (crushing) and/or buckling (collapse) of the pipe cross section caused by external overpressure only. |
| | Propagating buckling | Propagating hoop buckling initiated by hoop buckling. |
| | Gross plastic deformation and local buckling | Gross plastic deformation (rupture/crushing) of the pipe cross-section in combination with any local buckling of pipe wall (wrinkling) due to bending moment, axial force and internal overpressure. |
| | Gross plastic deformation, local buckling and hoop buckling | Gross plastic deformation and hoop buckling of the pipe cross section and/or local buckling of the pipe wall due to the combined effect of external overpressure, effective tension and bending moment. |
| | Unstable fracture and gross plastic deformation | Unstable crack growth or rest ligament rupture or cross-section rupture of a cracked component. |
| | Liquid tightness | Leakage in the riser system including pipe and components. |
| | Global buckling | Overall column buckling (Euler buckling) due to axial compression (negative effective tension). |
| FLS | Fatigue failure | Excessive Miner fatigue damage or fatigue crack growth mainly due to environmental cyclic loading, directly or indirectly. Limiting size of fatigue cracks may be wall thickness (leakage) or critical crack size (unstable fracture/gross plastic deformation). |
| ALS | Same as ULS and SLS | Failure caused by accidental loads directly, or by normal loads after accidental events (damage conditions). |

## 4.2 Working Stress Design

The WSD format is included as a more easy-to-use conservative alternative to the LRFD method. The WSD have the same limit states as the LRFD, but accounts for the influence of uncertainty in only a single usage factor.

The general WSD design format can be expressed as:

$$\boldsymbol{g(S, R_k, \eta, t) \leq 1} \tag{4.11}$$

Where S is the total load effect, $R_k$ the resistance, $\eta$ the usage factor and g is the generalized load effect. For the WSD, all design load effects equals unity ($\gamma_F = \gamma_E = \gamma_A = \gamma_{SC} = \gamma_m = 1.0$. Instead, the basic usage factor shown in Table 4-3 applies.

**Table 4-3: Usage factor, WSD**

| **Safety Class** | **Low** | **Normal** | **High** |
|---|---|---|---|
| **Usage factor, $\eta$** | 0.83 | 0.79 | 0.75 |

Pipe members subjected to bending moment, effective tension and net *internal* overpressure shall be designed to satisfy:

$$\left\{\left(\frac{|M|}{M_k}\cdot\sqrt{1-\left(\frac{p_{ld}-p_e}{p_b(t_2)}\right)^2}\right)+\left(\frac{T_e}{T_k}\right)^2\right\}+\left(\frac{p_{ld}-p_e}{p_b(t_2)}\right)^2 \leq \eta^2 \tag{4.12}$$

Pipe members subjected to bending moment, effective tension and net *external* overpressure shall be designed to satisfy:

$$\left(\left(\frac{|M|}{M_k}\right)+\left(\frac{T_e}{T_k}\right)^2\right)^2+\left(\frac{p_e-p_{min}}{p_c(t_2)}\right)^2 \leq \eta^4 \tag{4.13}$$

# 5 SIMA/RIFLEX

## 5.1 Introduction

The RIFLEX program has been developed by MARINTEK and SINTEF in cooperation with the Norwegian University of Science and Technology (NTNU) as a joint industry project. BP Petroleum Development, Conoco Norway, Esso Norge, Norsk Hydro, Saga Petroleum and Statoil have all participated in developing the program.

RIFLEX was initially developed as a tool for analysis of flexible marine systems, but is as well suited for any type of slender structure, such as mooring lines, umbilicals, and also for steel pipeline and conventional risers. The program computes static and dynamic characteristics of the chosen structure (Ormberg and Passano, 2013).

Static analysis comprises:

- Equilibrium configuration
- Parameter variations of tension or position parameters, current velocity and direction

Dynamic analysis comprises:

- Eigenvalue analysis, natural frequencies and mode shapes
- Response to harmonic motion and wave excitation
- Response to irregular wave- and motion excitation

The program is based on nonlinear finite element formulation. The following key features are included:

- Flexible modeling of simple as well as complex systems
- Nonlinear time domain simulation of riser motions and forces
- Nonlinear cross section properties
- Generalized Morison type of load model. Simplified analysis options:
    - Static analyses, catenary approximations and linear time domain simulation
    - Frequency domain analysis

## 5.2 RIFLEX Modules

RIFLEX consists of modules communicating by a file system, as shown in Figure 5-1. Each of the different modules will be briefly described in the following (Ormberg and Passano, 2013).

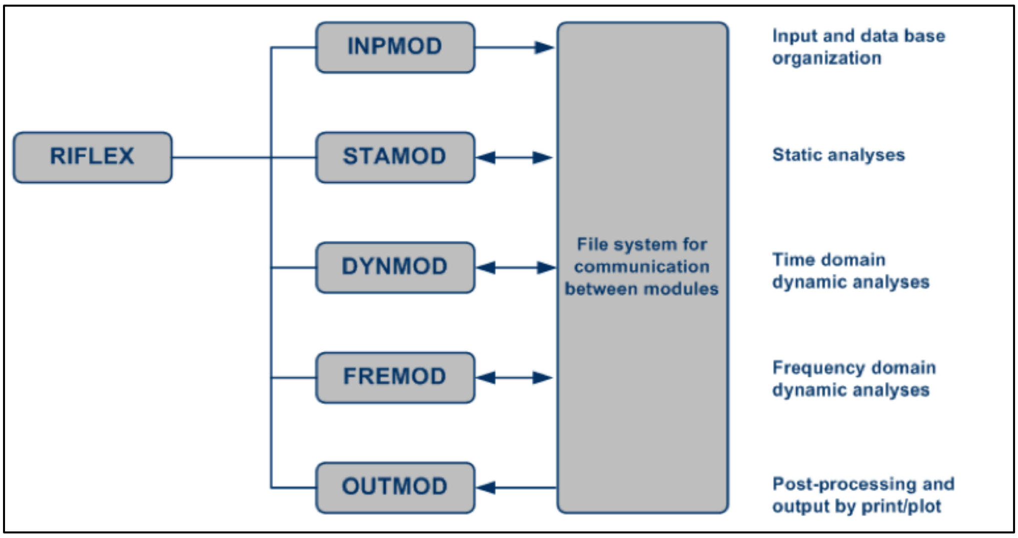

**Figure 5-1: Riflex modules (RIFLEX User Manual)**

- *INPMOD Module*: This module reads input data and organizes a database for use during subsequent analysis. Once the INPMOD has been run, the other modules can perform several analyses without rerunning of INPMOD, which is indicated by the one-way arrow in Figure 5-1.
- *STAMOD Module*: Performs several types of static analyses, based on system data given from INPMOD. Results may be used directly in parameter studies etc., and are also used to define the initial configuration for a succeeding dynamic analysis.
- *DYNMOD Module*: Carries out time domain dynamic analyses based on the final static configuration, environment data and data to define motions applied as forced displacements in the analysis. Several analyses might be performed without returning to either INP- or STAMOD. Response time series are stored on file for further post-processing by OUTMOD and PLOMOD.
- *FREMOD Module*: In this module, dynamic analyses performed in the frequency domain are performed. Works the same way as DYNMOD, but the module serves a computational advantage because of linear relationship between loads and response for the actual problem.
- *OUTMOD Module*: Performs post-processing of selected results generated by STA- and DYNMOD. Different options available for creating visual results of interest.
- *PLOMOD Module*: Interactive plotting module for graphic presentation of plots generated by OUTMOD. Animation tool is available for visualization of the dynamic behavior of the complete system.

## 5.3 Riser system modeling

System modeling starts with definition of the topology, and proceeds in increasing detail to line and component descriptions. There are two ways to model the riser system in SIMA. It is possible to specify a system with general topology (Arbitrary Riser system, AR), or by using commonly used configurations with well-defined standard topologies (Standard systems). Figure 5-2 shows the general procedure of modeling a system.

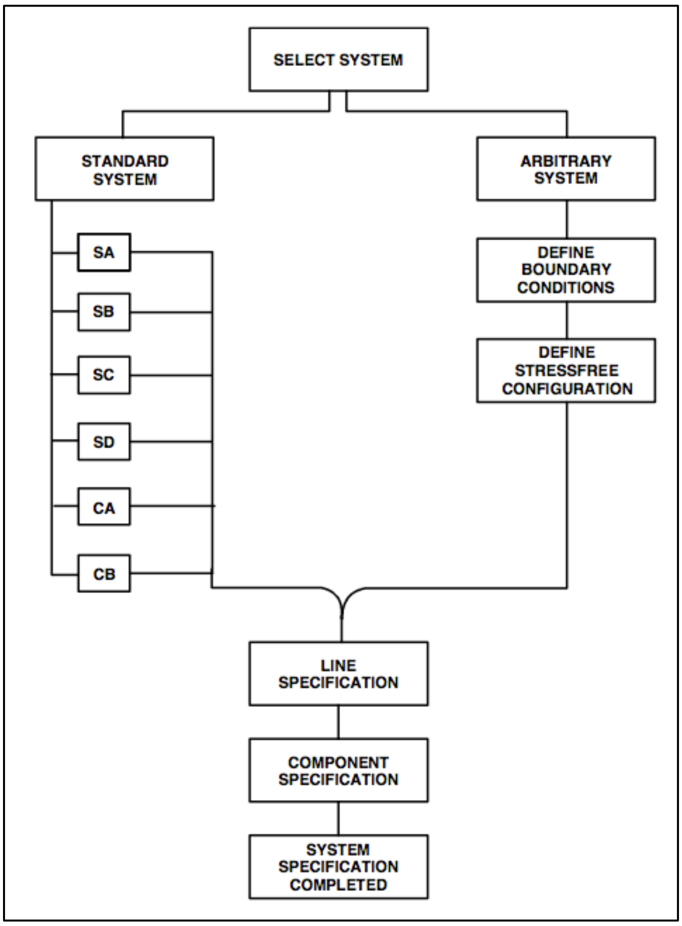

**Figure 5-2: System overview (RIFLEX User Manual)**

The system topology is basically described in terms of branching points and terminal points, denoted supernodes (Ormberg and Passano, 2013). Simple defined lines connect the supernodes. In other words, the system is uniquely determined by the connectivity between a number of defined supernodes and lines.

Supernodes are classified as free, fixed or prescribed depending on their boundary condition modeling. If all DOF's are free, the supernode is denoted free. Fixed supernodes are used for modeling supports at fixed structures, seafloor connection, etc., and is denoted fixed if one or several DOF's are fixed. Prescribed supernodes are usually used for modeling supports with forced dynamic motions.

A line is a linear structural element between two supernodes that is identified by a line type number. Because of this, a line type can be referred several times in the system topology description, which is convenient for modeling of systems with several identic segment properties (parallel coupled risers etc.). A sketch of the line and segment specification is shown in Figure 5-3.

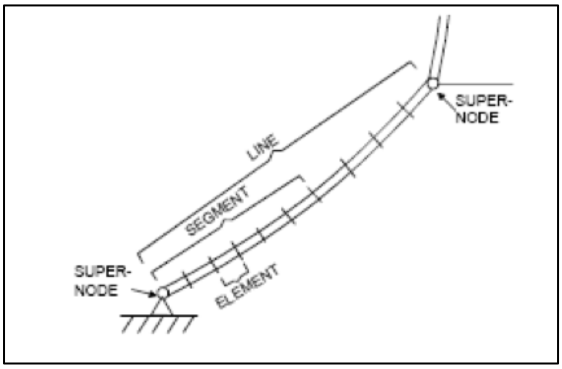

**Figure 5-3: Line and Segment definition (RIFLEX User Manual)**

Components represent the elementary description of the mechanical properties. The components that are available in present RIFLEX version can be divided into three groups:

- *Cross sectional components*: Specified in terms of axial, bending and torsional stiffness. The most relevant types are pipe cross-section (CRS0) and axi-symmetric cross section (CRS1). Other available cross section types are bi-symmetric (CRS2), and cross section for advanced modeling of floating, partly submerged structures (CRS3, CRS4, CRS5).
- *Nodal components*: Body for modeling of clump weight, buoys etc., and ball joint connector for modeling swivels, hinges, etc.
- *Special components*: Rollers for description of elastic contact forces between lines or tensioner component for modeling of tensioner mechanisms.

# 6 SCR DESIGN & ANALYSIS METHODOLOGY

This chapter describes in general what methods are being used in the following design and analysis studies of both the conventional free hanging SCR (Chapter 7), and the weight-distributed SCR (Chapter 8).

## 6.1 Degrees of Freedom

In the analyses, the riser and its components are divided into structural elements, which can be specified as either bars or beams. Beam element formulation is preferred in cases involving bending and torsion, and the bar element formulation is preferred for simplified systems. The bar element comprise 3 translational DOFs in each node, while the complete beam element consists of 14 DOFs. RIFLEX is used as the analysis program in this report, and this program deals with 12 DOFs, as warping torsion is neglected.

## 6.2 Strength analysis methods

DNV states that the purpose of a global riser system analyses is to describe the overall static and dynamic structural behavior by exposing the system to a stationary environmental loading condition. Relevant global response quantities can be grouped into:

- Resulting cross-sectional forces (eff. tension, bending moment, torsional moment)
- Global riser deflections (curvature, elongation, angular orientation)
- Global riser position (co-ordinates, distance to other structures, position of TDP, etc.)
- Support forces at termination to rigid structures

For global riser system analysis, the Finite Element (FE) approach is the approach used most often.

### 6.2.1 Static FE analysis

The purpose of the static analysis is to obtain static equilibrium due to static loading such as weight, current, buoyancy, for given locations of riser terminations to rigid structures. Before any dynamic- or eigenvalue analyses can be done, a static analysis has to be carried out. As mentioned, a FE approach is often used, and therefore it is convenient to separate the basic loading components into four groups:

- ***Volume forces***: Derived under the combined effect of self-weight, buoyancy and internal fluid pressure.
- ***Specified forces***: Additional forces applied to the riser system, e.g. top tension, which is applied to always keep the riser tensioned. For SCRs, the weight of the riser is enough to keep the riser tensioned, and additional tensioners are therefore not used.

- ***Prescribed displacements***: Final position of riser is found by applying prescribed displacements to specified positions.
- ***Displacement dependent forces***: In order to complete the static equilibrium, steady current forces are applied.

These load components is applied in load increments starting from an initial stress-free configuration, to obtain static riser configuration. The equilibrium is ensured by iteration at each load increment. Three methods for obtaining static equilibrium that will be described in the following is the *Euler-Cauchy Method*, the *Newton-Raphson Iteration Procedure* and a method combining these two, *combined method.*

Static equation governing structural problems are given in vector form as:

$$\boldsymbol{R}^s(\boldsymbol{r}) = \boldsymbol{R}^e(\boldsymbol{r}) \tag{6.1}$$

Where $\boldsymbol{R}^s$ is the internal reaction force vector, $\boldsymbol{R}^e$ represents the external forces. These vectors are functions of the nodal displacement vector $\boldsymbol{r}$ in FEA.

In linear structural problems, equation (6.1) can be simplified in terms of the stiffness matrix $\boldsymbol{K}$:

$$\begin{gathered}\boldsymbol{Kr} = \boldsymbol{R}^e \\ \boldsymbol{r} = \boldsymbol{K}^{-1}\boldsymbol{R}^e\end{gathered} \tag{6.2}$$

**Euler-Cauchy**

In most cases, equation (6.1) is impossible to solve analytically, and hence, the static equilibrium must be found in another way. One way is to apply incremental loading with equilibrium iteration. A well known incremental method is the *Euler-Cauchy method*. This method involves the incremental stiffness matrix, $\boldsymbol{K_I}$, calculated based on known displacements and stress condition (see Figure 6-1). In addition, a new load increment is applied. This load increment, and nodal displacement number (m+1) may be expressed as:

$$\begin{gathered}\Delta\boldsymbol{R}^e_{\boldsymbol{m+1}} = \boldsymbol{R}^e_{\boldsymbol{m+1}} - \boldsymbol{R}^e_{\boldsymbol{m}} \\ \Delta\boldsymbol{r}_{\boldsymbol{m+1}} = \boldsymbol{K_I}(\boldsymbol{r_m})^{-1}\Delta\boldsymbol{R}^e_{\boldsymbol{m+1}} \\ \boldsymbol{r}_{\boldsymbol{m+1}} = \boldsymbol{r_m} + \Delta\boldsymbol{r}_{\boldsymbol{m+1}}\end{gathered} \tag{6.3}$$

with m=0 as the initial condition.

This function is able to increment the load to a desired level, but will not be able to fulfill total equilibrium. To achieve sufficient equilibrium, we can add a term in the next load increment that accounts for the unbalanced force, $\boldsymbol{R_{eq}}$, between internal and external load:

$$\boldsymbol{R}_{\boldsymbol{eq}} = \boldsymbol{R}^{\boldsymbol{e}}(\boldsymbol{r}_{\boldsymbol{m}}) - \boldsymbol{R}^{\boldsymbol{s}}(\boldsymbol{r}_{\boldsymbol{m}})$$

$$\Delta\boldsymbol{r}_{\boldsymbol{m}+\boldsymbol{1}} = \boldsymbol{K}_{\boldsymbol{I}}(\boldsymbol{r}_{\boldsymbol{m}})^{-\boldsymbol{1}}\left[\Delta\boldsymbol{R}^{\boldsymbol{e}}_{\boldsymbol{m}+\boldsymbol{1}} + \boldsymbol{R}_{\boldsymbol{eq}}\right] \qquad (6.4)$$

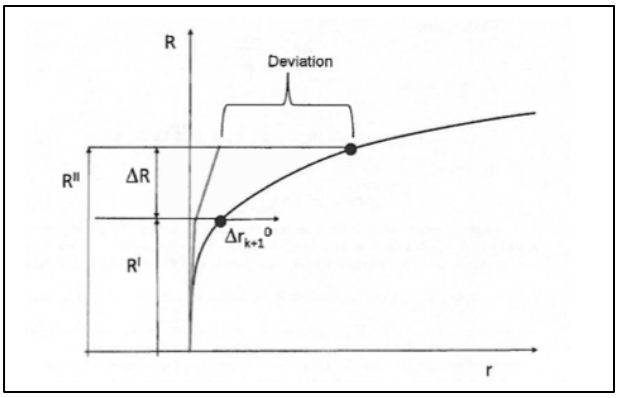

Figure 6-1: Euler-Cauchy (Moan, 2003)

### Newton-Raphson

Alternative to the *Euler-Cauchy*, one can use the *Newton-Raphson* iteration procedure to obtain static configuration. This method uses the following iterative algorithm:

$$\boldsymbol{r}_{\boldsymbol{m}+\boldsymbol{1}} - \boldsymbol{r}_{\boldsymbol{m}} = \Delta\boldsymbol{r}_{\boldsymbol{m}+\boldsymbol{1}} = \left[\boldsymbol{K}_{\boldsymbol{I}}^{-\boldsymbol{1}}(\boldsymbol{r}_{\boldsymbol{m}})(\boldsymbol{R}^{\boldsymbol{e}} - \boldsymbol{R}^{\boldsymbol{s}})\right] \qquad (6.5)$$

The method is illustrated in Figure 6-2.

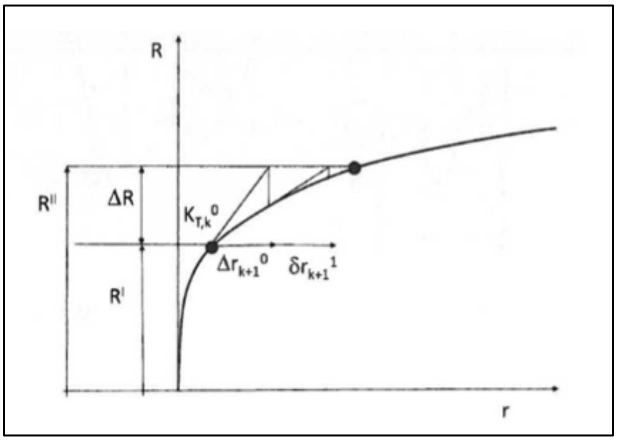

Figure 6-2: Newton-Raphson (Moan, 2003)

### Combined method

The third method used to achieve an adequate static solution is *combined methods.* This method starts by applying incremental loading, followed by iteration at subsequent load levels (i.e. combining the first two methods).

### 6.2.2 FE Eigenvalue analysis

To determine the eigenfrequencies- and modes of the riser system, eigenvalue analysis is used. Before starting the dynamic analysis, eigenvalue analysis is to be carried out in order to represent a fundamental check of the dynamic properties of the riser.

Eigenfrequencies for a free harmonic vibrating system can be found by solving:

$$[\boldsymbol{K} - \boldsymbol{\omega}^2 \boldsymbol{M}]\boldsymbol{r} = \boldsymbol{0} \tag{6.6}$$

By using eigenfrequencies calculated from this equation, one may evaluate the probability of resonance occurrence for given environmental conditions.

### 6.2.3 Dynamic analysis

SCR systems experience a lot of dynamic behavior, because of the forces from current, waves and wind. The dynamic analysis represents the riser response to this applied loading. The dynamic equilibrium equation fundamentally originates from D'Alemberts principle. This principle states that the sum of the differences between applied forces, $F_i$, and inertia forces, which is a source from mass of a particle, $m_i$, and the time derivatives of motion, $\ddot{u}_i$, is equal to zero.

$$\sum_k F_i - m_i \ddot{u}_i = 0 \tag{6.7}$$

However, in FE analyses, general formulation of an arbitrary dynamic system is described in terms of an equation containing matrices of mass, damping, stiffness, external loading and time derivatives of motion.

$$\boldsymbol{M}\ddot{\boldsymbol{r}}(t) + \boldsymbol{C}\dot{\boldsymbol{r}}(t) + \boldsymbol{K}\boldsymbol{r}(t) = \boldsymbol{Q}(t) \tag{6.8}$$

There are several different approaches to solve the dynamic equilibrium. In some cases, time domain may be enough to find the exact solution, but usually, the problem is solved using finite different method or other time incremental methods. The three most commonly used dynamic FE analysis techniques are the *nonlinear time domain analysis*, *linearized time domain analysis* and *frequency domain analysis* (DNV, 2010).

**Nonlinear time domain analysis**

The time domain method uses step-by-step integration in the time domain to solve the dynamic equilibrium, and can be approached in both linear and nonlinear analysis.

The *nonlinear time domain analysis* accounts for nonlinearities caused by large displacements, rotations and material behavior in the system. Nonlinear hydrodynamic loads are included and accurately calculated in time. Results may be used to evaluate whether the response deviate from being Gaussian distributed. Because of this, the method is a time consuming and CPU challenging method.

**Linearized time domain analysis**

This method is based on linearization of the dynamic equilibrium equations with regard to damping/inertia forces and stiffness at static equilibrium position. In other words, these matrices are kept constant throughout the analysis.

By linearizing the structural stiffness, and ignore variations in mass and damping, the linear method is far more efficient than the non-linear, and hence it is an attractive way to analyze riser systems.

**Frequency domain analysis**

In the frequency domain analysis, transforming relevant vectors into a complex representation helps us obtain dynamic equilibrium. We introduce Euler's identity:

$$e^{-i\omega t} = \cos(\omega t) + i\sin(\omega t) \tag{6.9}$$

This equation describes a vector rotating in the complex plane, and for a 1 DOF system, the load is written as:

$$Q(t) = Xe^{-i\omega t} \tag{6.10}$$

where $X$ is a complex number that describes the load in the frequency domain. By substituting $\boldsymbol{Q(t)}$ into equation (6.8) we get:

$$m\ddot{u} + c\dot{u} + ku = Xe^{-i\omega t} \tag{6.11}$$

where $\ddot{u}$ is the time derivatives. Rewriting (6.11) to harmonic form we get:

$$u = x(\omega)e^{-i\omega t} = H(\omega)Xe^{-i\omega t} \tag{6.12}$$

In this equation, we introduce the complex response function, $\boldsymbol{H(\omega)}$, which is given as:

$$H(\omega) = (-m\omega^2 + i\omega c + k)^{-1} \tag{6.13}$$

We also have:

$$X(\omega) = \frac{1}{2\pi}\int_{-\infty}^{\infty} Q(t)\, e^{-i\omega t} dt \tag{6.14}$$

The next step is to create an equation for these two, which yields the solution in the frequency domain:

$$x(\omega) = H(\omega)X(\omega) \tag{6.15}$$

By transforming this equation back to time domain, we have:

$$u(t) = \int_{-\infty}^{\infty} x(\omega)e^{-i\omega t}d\omega \tag{6.16}$$

## 6.3 Design parameters

### 6.3.1 Environmental data

As we all know, the environment changes across the globe, hence the environmental data differs from one location to another. This subchapter will describe environmental data for the North Sea, as this is what is being used in the analyses. General data:

- $\rho_{sw} = 1025kg/m^3$
- $Depth = 1000m$

**Waves**

Even though the riser is a submerged structure, surface waves are still a major source of dynamic forces acting on the riser. The waves create motion on the floater, which again translates to dynamic motions on the riser. Waves have irregular shape, length, height, and can be multidirectional.

Wave condition can either be described by a deterministic design, or by applying wave spectra. Most spectra are described in terms of significant wave height, $H_s$, spectral peak period, $T_p$, spectral shape and direction. For the North Sea, a 100-year return period is given as:

- $H_s = 15m$
- $T_p = 16s$

Several spectra are used in designing of offshore structures, and are used in different locations around the world. The most common are:

- ***Pierson-Moskowitz***: Originates from the idea that if the wind blow steadily for a long time over a large area, the waves will come into equilibrium with the wind. Assumes a deep sea and fully developed sea-state, which is a sea produced by winds blowing steadily over hundreds of miles for several days (Pierson and Moskowitz, 1964).

$$S(\omega) = \frac{\alpha g^2}{\omega^5} exp\left(-\beta\left(\frac{\omega_0}{\omega}\right)^4\right) \tag{6.17}$$

Written in terms of peak frequency, $\omega_0$, and the frequency correspond to the frequency at which the energy density spectrum peaks.

- ***Ochi-Hubble***: Allows two peaked spectra to be set up, which enables you to represent sea states that include both a local wind generated sea, and a remotely generated swell.

$$S(\omega) = \frac{1}{4}\sum_{j=1}^{2} \frac{H_{sj}^2 T_{pj}}{4\Gamma(\lambda_j)} \frac{(\lambda_j+0.25)^{\lambda_j}}{(T_{pj}f)^{4\lambda_j+1}} exp\left\{-\frac{\lambda_j+0.25}{(T_{pj}f)^4}\right\} \qquad (6.18)$$

This spectrum has 3 parameters for each wave system (significant wave height, spectral peak and the shape factor, $\lambda$.

- ***JONSWAP***: After analyzing data from the Joint North Sea Wave Observation Project (JONSWAP), Hasselmann et al. 1973 found that the wave spectrum is never fully developed. In order to improve the Pierson-Moskowitz, and extra factor was added. Hence, the JONSWAP is the Pierson-Moskowitz spectrum multiplied by an extra peak enhancement factor, $\gamma^r$.

$$S(\omega) = \frac{\alpha g^2}{\omega^5} exp\left(-\beta\left(\frac{\omega_0}{\omega}\right)^4\right)\gamma^r \qquad (6.19)$$

$$r = exp\left[-\frac{(\omega-\omega_o)^2}{2\sigma^2\omega_o^2}\right]$$

In other words, the spectrum is the same as the Pierson-Moskowitz, except that the waves continue to grow with distance.

As mentioned, the location of the field often decides which spectral model to use, and hence, the JONSWAP will be used in the analyses in this report.

**Current**

Riser systems are subject to significant loads from currents, as the riser structure itself is long and slender. The two main effects from current on the riser are hydrodynamic drag forces and vortex induced vibrations. Six contributions of currents make up the total (resulting) current, and these are (Faltinsen, 1990):

- Tidal current
- Local wind-generated current
- Stokes drift-generated current
- Ocean circulation
- Set-up phenomenon and storm surges

- Local density driven current

Currents vary in strength with depth, and are strongest at the surface. As the depth increase, the velocities decrease. Table X shows a typical 10-year return period for current velocities at various depths in the North Sea.

**Table 6-1: Current velocities**

| **Water depth (m)** | **Current velocity (m/s)** |
|---|---|
| 0 | 0.93 |
| 50 | 0.68 |
| 300 | 0.47 |
| 1000 | 0.00 |

### 6.3.2 Vessel motions

As mentioned in chapter 6.3.1, even though the riser is submerged, it is still affected by surface forces, as these creates motions on the floater that translates directly to the riser itself. Because catenary risers do not have tensioner systems, it relies on self-weight to keep the tension. Increased vertical motion gives reduced tension, which can cause buckling and instability.

Because the system is all connected, both the motion and offset of the floater constitute a source of static and dynamic loading on the riser. The main data needed for riser designs are (DNV, 2010):

- Static offset (mean offset due to wave, wind and current)
- Wave frequency motions (First order wave induced motions)
- Low frequency motions (Motions due to wind gust and second order wave forces)

For floater motion analysis one may either use coupled or de-coupled analysis. The main difference between the two is that the coupled analysis is considered to be more accurate, however, it requires excessive computational effort compared to the de-coupled analysis.

**Vessel type**

Traditionally, TLP has been used in combination with SCRs for water depths ranging from “mid” to deep waters. The low slow drift motion of the TLP has been the major reason for why it has been used for SCRs.

As the industry evolves and moves into deeper waters in search for new fields, Semi-Submersible platforms are more and more preferred. As the water depth increase, so does the length of the legs on the TLPs, which may cause design problems, and fixed structures are therefore not practical. By using Semi-Submersibles this problem is solved and hence preferred, even though the slow drift motion for Semi-Subs are around 10-15% of the water depth compared to TLPs who have up to 9% of the water depth. FPSO slow drift motions can be 20-30% of water depth depending on the mooring stiffness (Alderton and Thethi, 1998).

However, by using semi-subs a new design challenge appears, which is the vessel offset you get from this configuration. The SCR will experience high bending stress at the Touchdown-Zone if the vessel drifts toward the TDP, and on the other hand higher tension at the top if the vessel drifts too far away from the TDP.

In this report, a semi-submersible vessel will be used. Hence, Response Amplitude Operators (RAOs) for semi-submersibles are applied. This RAO is integrated into the model used in RIFLEX.

### 6.3.3 Internal fluid data

In order to calculate how forces and loads are acting on the riser, internal fluid plays its part. During the lifetime of a riser, the internal fluid changes. When installing, the pipe may either be filled with water, or be considered empty, and when the riser is in service phase, the internal fluid can be considered oil, gas, or both oil and gas.

This thesis focuses on the service/production phase. The density of crude oil is 750-1050kg/m$^3$, and in the analyses it is defined as 750kg/m$^3$.

### 6.3.4 Soil-riser interaction

Around the Touchdown-zone there will always be a soil-riser interaction that affects the riser because of the fluctuate motions of the riser. The soil-riser interaction is so complex that most simulations of risers and pipelines use simplified pipe/soil interaction models that are described in terms of non-linear elastic load/displacement curves.

The data used in the analyses is:

| | |
|---|---|
| Vertical soil stiffness: | 600kN/m$^2$ |
| Lateral soil stiffness: | 10kN/m$^2$ |

# 7 CONVENTIONAL FREE HANGING SCR ANALYSIS

In this chapter, static and dynamic analyses will be performed for a conventional/simple free hanging SCR, which is assumed installed in the North Sea. Current and wave parameters are set to 10- and 100-year respectively. In chapter 6.3.2 new challenges for SCRs applied to semi-subs are described. Because of this offset, analyses will be done for mean, far and near position.

## 7.1 Configuration description

In order to perform static and dynamic analysis, a configuration of the riser system must be created. The following subchapters will describe main input parameters in the configuration. The complete RIFLEX input file can be found in Appendix A.

### 7.1.1 Riser data

As mentioned in chapter 6.3.3, this report focuses on the production/service phase of the riser. For this phase, the risers typically are 8”-12” in diameter (Howells, 1995), and in this report a diameter of 12 inch will be used.

From chapter 2.5 we read that the most common steel alloy used in the offshore industry is stainless steel, which is a steel alloy with minimum 10.5% chromium content by mass (ISSF, 2012), and that typical steel grades used are X60, X65 and X70. The selected steel grade to be used is X65 carbon steel with density 7850kg/m$^3$, Young’s modulus 207000 MPa and Yield stress at 20° C is 448MPa.

In addition to the riser itself, a coating is applied on the outside, which makes up an outer diameter. According to Karunakaran et al, in reel-lay installation the coating thickness is limited to 100mm, and this will be used. The density of the coating is 900kg/m$^3$.

Wall thickness of the riser has to be designed in order to withstand collapse and burst criteria, including corrosion allowance. Two different cross sections are being used, with different wall thickness. The cross sections have 12” and 10” wall thickness. The length of the riser is 2400m.

Riser data overview:

- Density steel: 7850kg/m$^3$ ($\rho_{steel}$)
- Steel grade: X65
- Steel Young’s modulus: 207000 MPa
- Steel yield stress: 448 MPa
- Inner diameter: 12”
- Coating thickness: 100mm
- Coating density: 900kg/m$^3$ ($\rho_{coating}$)
- Wall thickness: 12” and 10”
- Riser length: 2400m

### 7.1.2 Environmental data

Most of the environmental data is described in Chapter 6.3.1; therefore this chapter only provides an overview of the data:

- Water depth: 1000m
- Density seawater: 1025kg/m$^3$ ($\rho_{sw}$)
- Density internal fluid: 750kg/m$^3$ ($\rho_{oil}$)
- Significant wave height*: 15m
- Spectral peak period: 16s
- Wave model: Irregular
- Wave spectrum: JONSWAP
- Current velocity at surface: 0.93m/s
- Seabed: Flat bottom

### 7.1.3 Vessel

The vessel to be used is a *Semi-Submersible Floating Production Unit* (FPU). The RAOs of a semi-sub is extracted from resource files in SIMA, and applied to all steps of the design analyses.

Semi-submersibles consist of a platform-type deck supported by pontoon-type columns that are submerged in the water. The concept of partially submerging the rig helps the structure to cope better with roll and pitch.

### 7.1.4 Structural modeling

The riser is considered a simple free hanging SCR. This subchapter describes modeling properties for the riser in SIMA.

**Supernodes**

Two supernodes are the end points of the riser. The Bottom-node is fixed to the seabed (connected to a flow line), and the Floater-node is fixed to the Semi-submersible.

**Segments**

In SIMA, the riser is to be divided into segments in order to perform finite element analysis (See chapter 5 for more information). The segments are again divided into elements, and the size of these elements may vary along different parts of the riser, as some areas may be more critical than others, and too long elements may cause instability in the results. However, in this report the elements are exactly 5 meter regardless of where on the riser they are, as this size is small enough for it to give proper results in any part of the riser.

## 7.2 Static Analysis

The static analyses performed are the riser xz configuration, static effective tension and static bending moment. To understand what the offset of the semisubmersible does with the riser and the forces affecting it, both 40 meter offset and 100 meter offset will be investigated in the static analysis.

- Offset 1: 40m offset in both positive and negative x-direction
- Offset 2: 100m offset in both positive and negative x-direction

### 7.2.1 Static XZ configuration

First off in the static analysis is to investigate the Static XZ Configuration for all three offset configurations; far, mean and near.

**Offset 1**

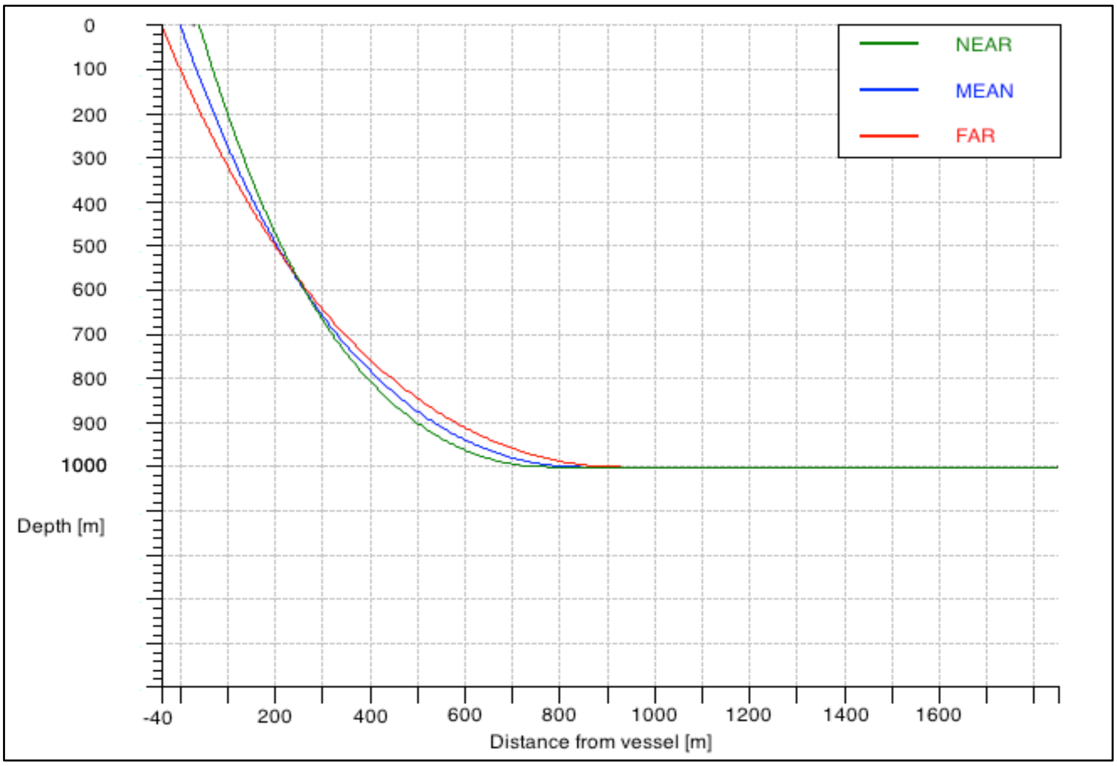

**Figure 7-1: Static configuration offset 1**

Already with an offset of 40 meter, we notice that it has significant impact on the configuration. The TDP changes drastically, which cause different dynamic behavior for the three different cases. For the near case, the bending moment becomes higher. For the far case the bending moment becomes lower, however, the top tension increase because the weight and free span of the riser is higher. This will be more explained in chapter 7.2.2 and 7.2.3.

**Offset 2**

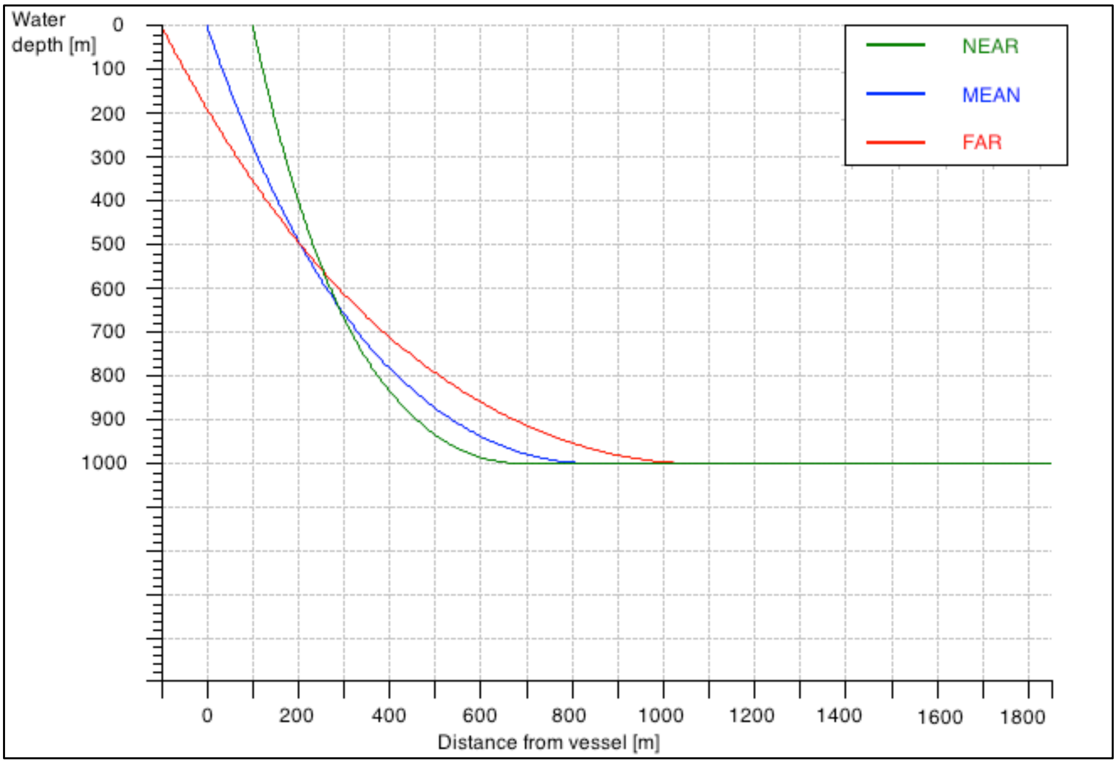

**Figure 7-2: Static configuration offset 2**

Figure 7-2 shows more clearly how significant the offset is to the riser configuration. The far case has a TDP at 1000m in the x-direction from the vessel, while the near case has a TDP at 650m in x-direction from the vessel, comparing to Figure 7-1 where the TDP is at 850m for the far case and 700m for the near case. Notice that the near case has a much sharper bend on it; hence the bending moment will increase, and that the effective tension will increase for the far case, as the free span of the riser becomes much larger.

Higher offset will occur more often in deep waters than in shallow waters, and by comparing Figure 7-1 and Figure 7-2 we notice the importance of having respect for this offset, as values increase drastically.

### 7.2.2 Static effective tension

The next analysis performed is the static effective tension, which presents the tension in the riser due to its self-weight in free span.

**Offset 1**

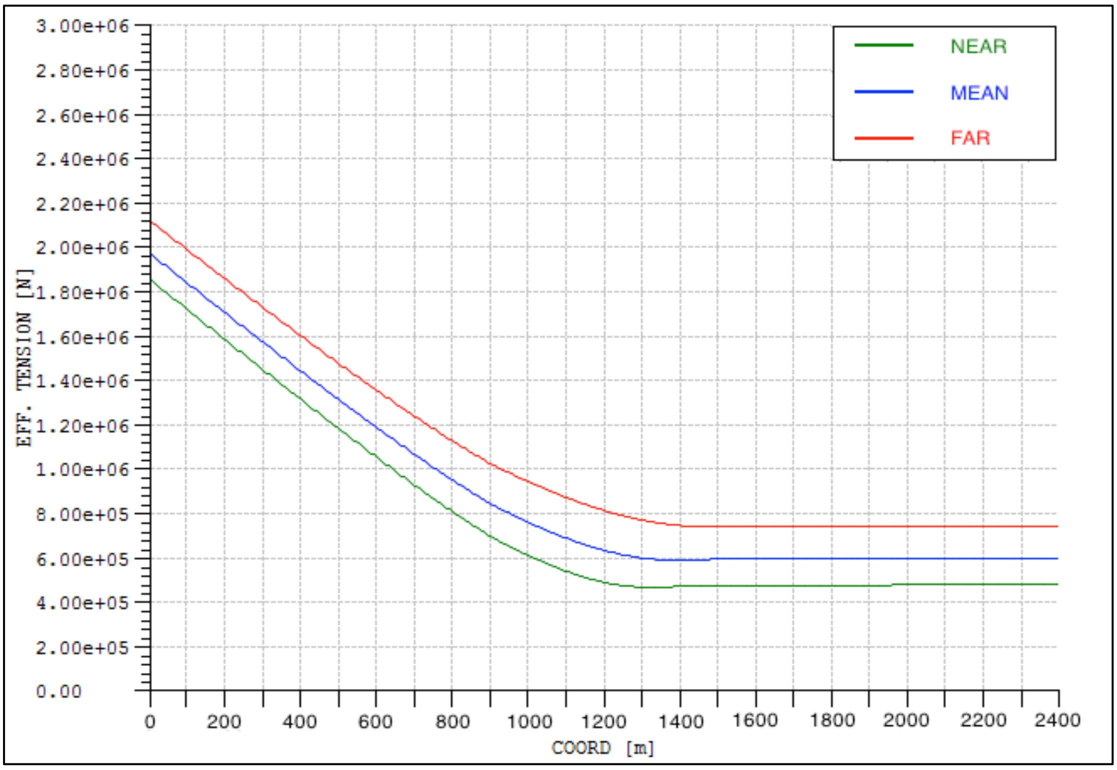

**Figure 7-3: Static effective tension offset 1**

Because the effective tension is based on the free span, the riser with the biggest offset has the highest tension. The tension is highest at the top-end of the riser, as this is where the riser is being "stretched".

**Table 7-1: Static effective tension max values in kN, offset 1**

| Load case | Mean | Near | Far |
|---|---|---|---|
| **Max tension [kN]** | 1930 | 1810 | 2070 |

**Offset 2**

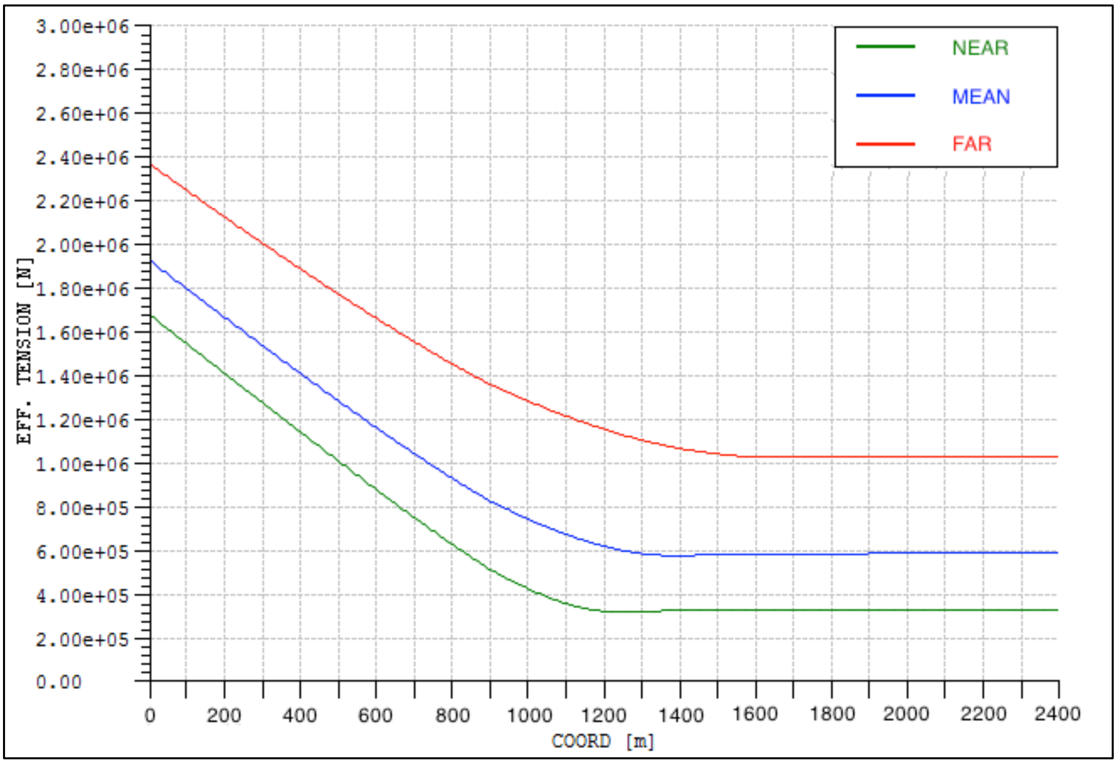

**Figure 7-4: Static effective tension offset 2**

With 100m offset, notice that the value of the tension for the far case has a bigger difference from offset 1 than the others. The mean tension is, because it has the same position, the same. The near case on the other hand is not decreasing with the same amount as the far case is increasing. The reason for this is because the far case gets a larger suspended riser length than the near case gets decreased suspended length, which can be seen by comparing Figure 7-1 and Figure 7-2.

**Table 7-2: Static effective tension max values in kN, offset 2**

| Load case | Mean | Near | Far |
|---|---|---|---|
| **Max tension [kN]** | 1930 | 1680 | 2370 |

### 7.2.3 Static bending moment

Bending moment characterizes the behavior of a slender structural element subjected to an external load.

**Offset 1**

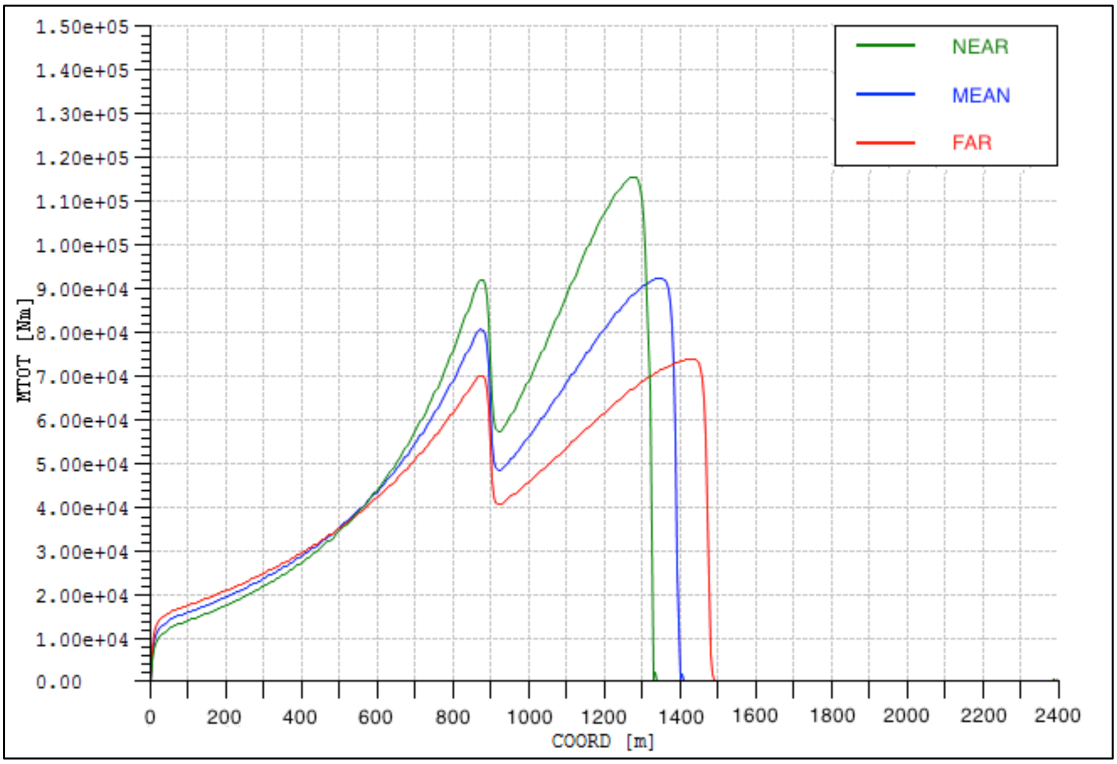

**Figure 7-5: Static bending moment offset 1**

In contrast to the effective tension, the bending moment is highest for the near case, and lowest for the far case. Because the distance from the semisubmersible to the TDP is shortest for the near case, the bending moment is highest. The closer the semisubmersible is to the TDP, the sharper will the bend be. A sharp bend leads to a higher bending moment.

The bending moment is increasing steadily until the wall thickness of the riser is changed, and then drops down before starting to increase towards the TDP. After TDP it drops to zero when interacting with the soil. This shows that the bending moment is not only concentrated at TDP.

**Table 7-3: Static bending moment max values in kNm, offset 1**

| Load case | Mean | Near | Far |
|---|---|---|---|
| Max bending moment [kNm] | 92.47 | 115.6 | 73.93 |

**Offset 2**

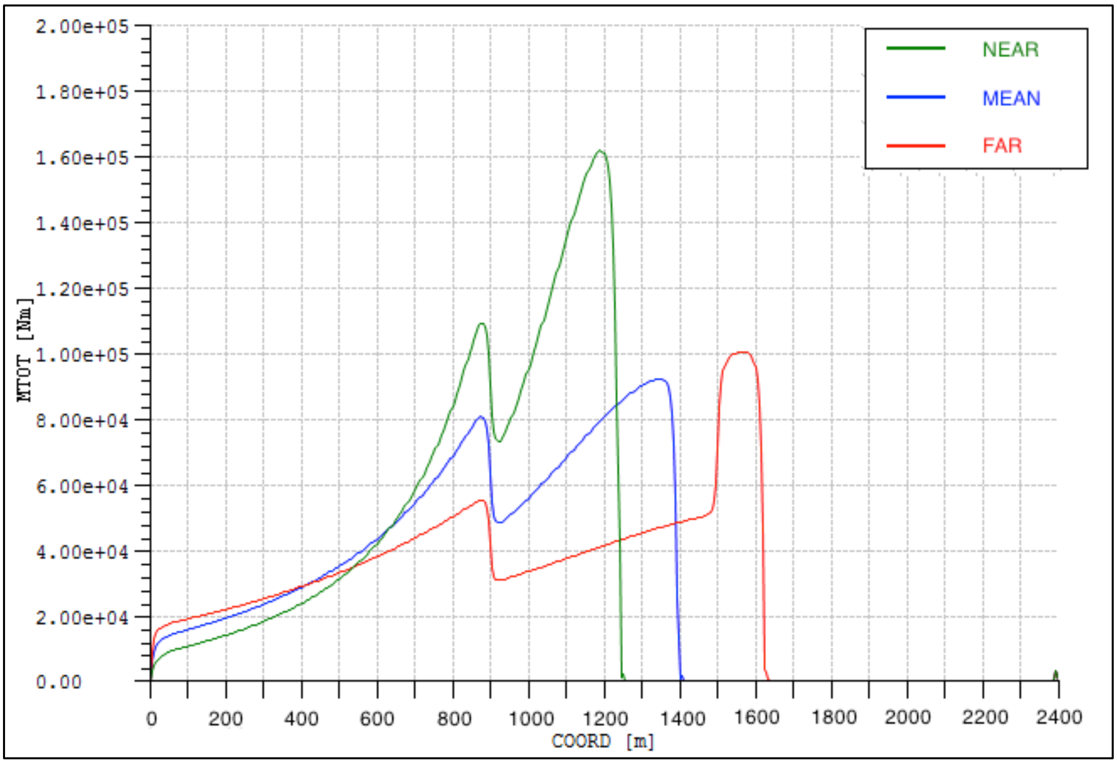

**Figure 7-6: Static bending moment offset 2**

By comparing Figure 7-6 and Figure 7-5 with Figure 7-4 and Figure 7-3, we notice that the same reaction happens; the case with the highest value increase more than the case with the lowest value decrease. The far case has a steadily increasing bending moment until it closes in on TDP, where it has a concentrated bending moment before dropping to zero.

**Table 7-4: Static bending moment max values in kNm, offset 2**

| Load case | Mean | Near | Far |
|---|---|---|---|
| **Max bending moment [kNm]** | 92.47 | 162 | 100.5 |

## 7.3 Dynamic Analysis

The dynamic analysis of the system is performed by a nonlinear time domain analysis with irregular waves. The most interesting analyses are the dynamic tension and the dynamic bending moment; hence these will be further investigated. The dynamic analysis will not investigate in both offsets as done in the static analysis, as the effect of this is shown.

We know from the static analysis that the tension is largest in the far load case, and that the bending moment is largest for the near load case. Therefore, the dynamic tension will concentrate on the far load case, and the dynamic bending will concentrate on the near load case.

### 7.3.1 Dynamic tension

From the static analysis we notice that the tension is highest at the far case, and therefore this case will be investigated.

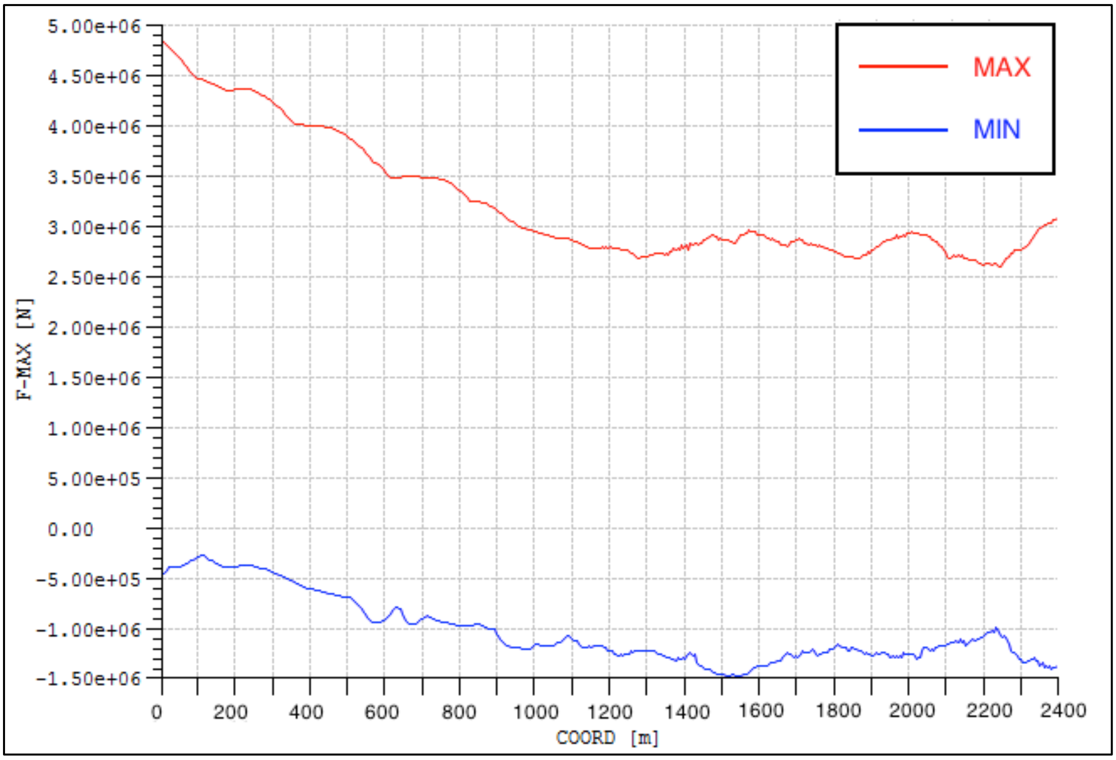

**Figure 7-7: Dynamic tension, far load case**

The most important information that can be obtained from Figure 7-7 is that the minimum tension is negative. When the tension is negative, compression occurs. Compression is not wanted; hence the configuration of the riser must be changed in order to avoid this. The max value for the tension can be read as 4810kN, and is found at the top-end of the riser.

### 7.3.2 Dynamic bending moment

The bending moment is highest at the near load case, because of its sharp bend near the TDP. Therefore, this case will be investigated.

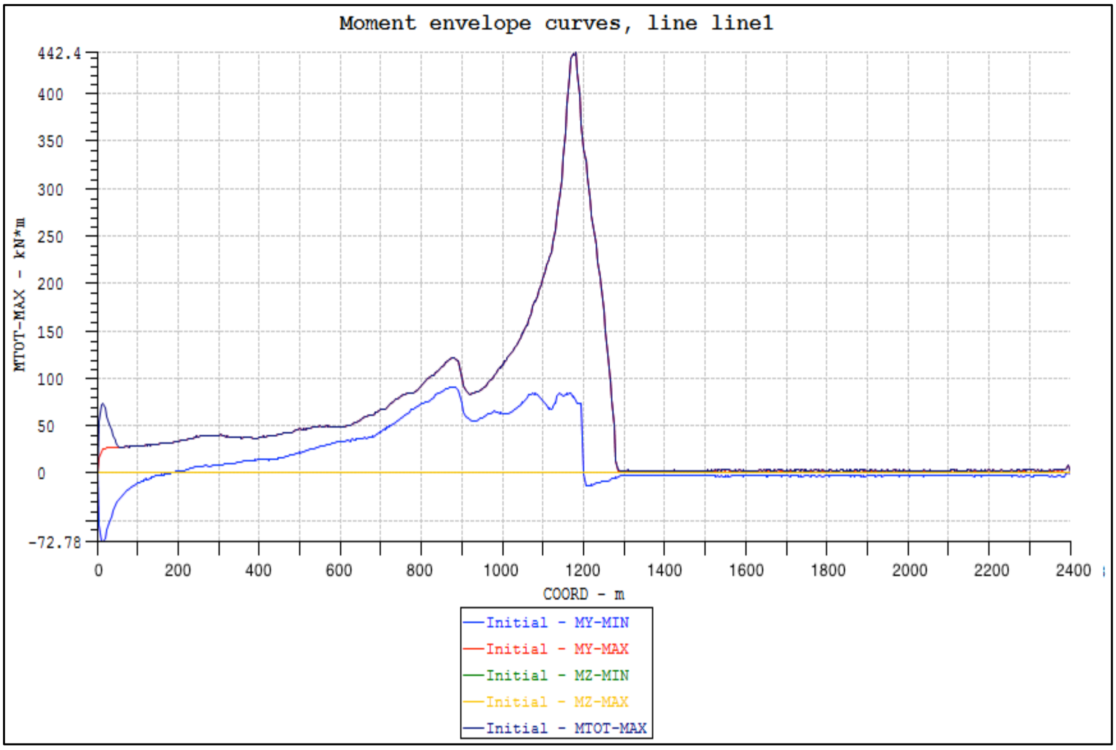

**Figure 7-8: Dynamic bending moment, near load case**

From Figure 7-8 it can be seen that the bending moment is 442.4kNm, and that it is mainly concentrated around the TDP. The bending moment steadily increase until the cross-section is changed, where it has a small drop before increasing towards the TDP, and then drops rapidly.

# 8 WEIGHT-DISTRIBUTED SCR ANALYSIS

In this chapter, static and dynamic analyses will be performed for a weight-distributed SCR configuration, which is assumed installed in the North Sea. Current and wave parameters are set to 10- and 100-year respectively. In chapter 6.3.2 new challenges for SCRs applied to semi-subs are described. Because of this offset, analyses will be done for mean, far and near position.

In chapter 3.2.2 it is mentioned that there are two methods used to distribute the weight along the riser:

- External coating with varying density
- Clump weights along the riser

This study will only concentrate on external coating with varying density as this concept uses available materials and technology, and is the simpler of the two in terms of fabrication. In addition, more technology research is needed for clump weights to avoid sliding and high local stresses.

## 8.1 Coating

First and foremost, the coating is applied to pipelines and risers in order to prevent corrosion, to prevent the pipe from damages during installation and to increase flow assurance and efficiency. In addition, the coating can also be used with varying density to distribute the weight, and there are different types of coating used in the industry including rubber coating, multilayer polypropylene, and polyethylene.

In this thesis, the coating is divided into four sections:

- Lightweight
- Normal weight
- Light Heavyweight
- Heavyweight

Heavy weight sections can be made from qualified coating, and during the Demo2000 project, Vikoweight coating from Trelleborg Viking was qualified for offshore use with a density equal to 3000kg/m$^3$ [Karunakaran, 2005]. This coating is rubber based.

Lightweight coating can be made from multi-layer technology to fulfill various functional requirements. Typical multi-layer technology is shown in Figure 8-1. In the Bonga project at 1200m this multi-layer PP coating was used with a density of 680kg/m$^3$.

## 8.2 Configuration description

In order to perform static and dynamic analysis, a configuration of the riser system must be created. The following subchapters will describe main input parameters in the configuration. The complete RIFLEX input file can be found in Appendix A.

### 8.2.1 Riser data

The riser data is the same as the conventional riser in chapter 7 for most parameters. The exception is the coating density, which is varied, and the different densities are as follows:

- Lightweight: 600kg/m$^3$
- Normal weight: 900kg/m$^3$
- Light Heavyweight: 1700kg/m$^3$
- Heavyweight: 2500kg/m$^3$

The remaining riser data is the same as in chapter 7, and provided in the overview below:

- Density steel: 7850kg/m$^3$ ($\rho_{steel}$)
- Steel grade: X65
- Steel Young's modulus: 207000 MPa
- Steel yield stress: 448 MPa
- Inner diameter: 12”
- Wall thickness: 12” and 10”
- Riser length: 2400m

### 8.2.2 Environmental Data

Most of the environmental data is described in Chapter 6.3.1; therefore this chapter only provides an overview of the data:

- Water depth: 1000m
- Density seawater: 1025kg/m$^3$ ($\rho_{sw}$)
- Density internal fluid: 750kg/m$^3$ ($\rho_{oil}$)
- Significant wave height: 15m
- Spectral peak period: 16s
- Wave model: Irregular
- Wave spectrum: JONSWAP
- Current velocity at surface: 0.93m/s
- Seabed: Flat bottom

### 8.2.3 Vessel

The vessel will be the same as in chapter 7, i.e. the vessel to be used is a *Semi-Submersible Floating Production Unit* (FPU). The RAOs of a semi-sub is extracted from resource files in SIMA, and applied to all steps of the design analyses.

Semi-submersibles consist of a platform-type deck supported by pontoon-type columns that are submerged in the water. The concept of partially submerging the rig helps the structure to cope better with roll and pitch.

### 8.2.4 Structural Modeling

The riser is considered a free hanging catenary riser, however, the build-up is different than in chapter 7, as the various segments will have different coatings applied. The supernodes are defined as in chapter 7.

**Segments**

Five segments that make up a total of 2400m build up the riser. Each segment consists of one element per 5 meter, which gives the riser a total of 480 elements.

Table 8-1 shows the breakdown of the segments with segment number 1 being the top end of the riser, and segment 5 the bottom end of the riser. The table also shows which coating density belongs to which part of the riser.

**Table 8-1: Segment breakdown**

| Segment number | Segment length | Coating density | Elements |
|---|---|---|---|
| **1** | 170 | Normal | 34 |
| **2** | 780 | Heavy | 156 |
| **3** | 100 | Light Heavy | 20 |
| **4** | 360 | Light | 72 |
| **5** | 990 | Normal | 198 |

*N.B. Comments concerning the analyses in this chapter are presented in chapter 9, where it is compared against the conventional SCR configuration from chapter 7.*

## 8.3 Static Analysis

The static analyses performed are the riser xz configuration, static effective tension and static bending moment. As in chapter 7, both 40 meter- and 100 meter offset will be investigated in the static analysis, which gives:

- Offset 1: 40m offset in both positive (Near case) and negative (Far case) x-direction
- Offset 2: 100m offset in both positive (Near case) and negative (Far case) x-direction

### 8.3.1 Static XZ configuration

Static XZ configuration is used to show how the riser is in static position.

**Offset 1**

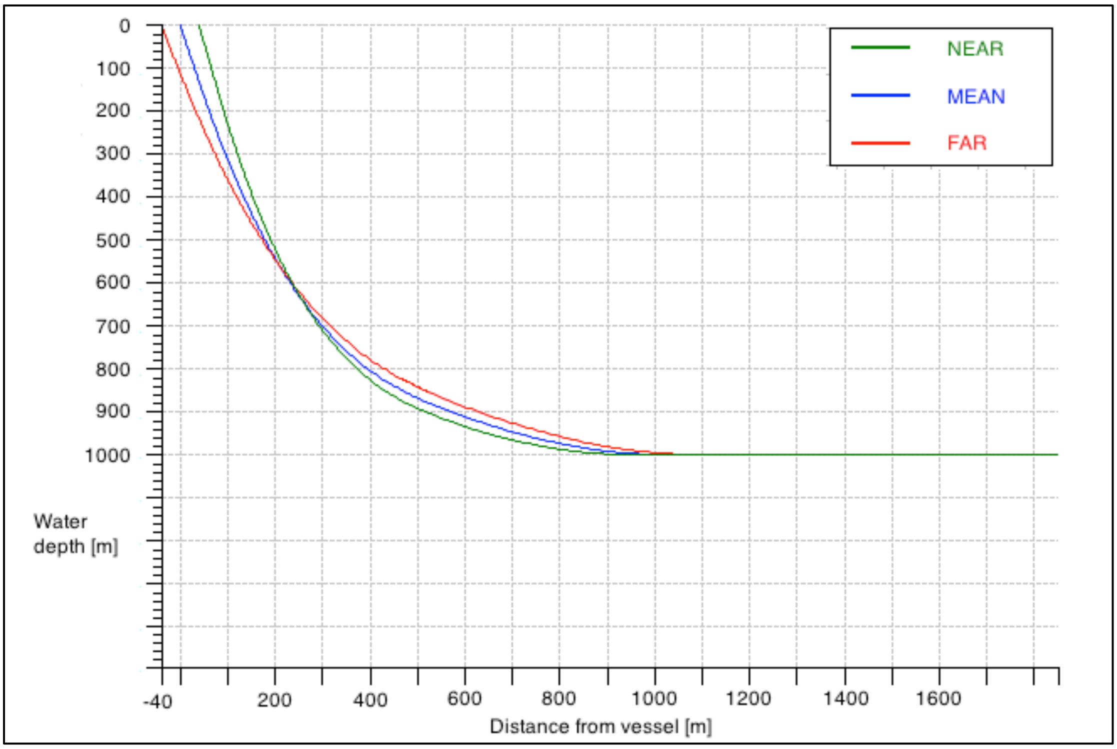

Figure 8-1: Static XZ configuration offset 1

**Offset 2**

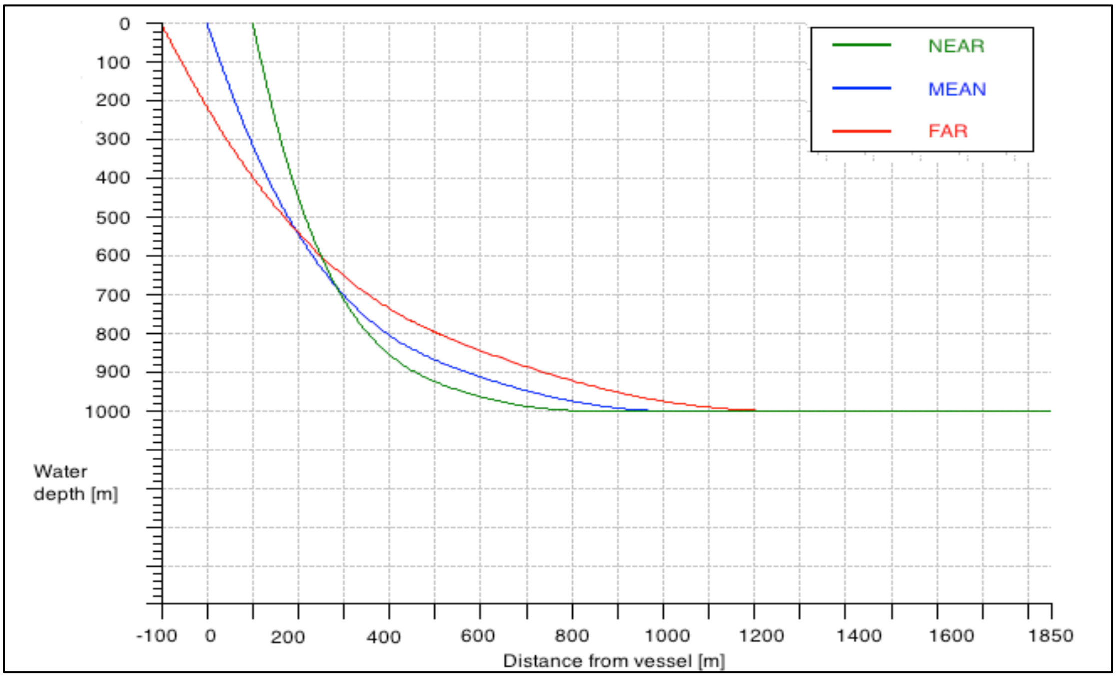

Figure 8-2: Static XZ configuration offset 2

### 8.3.2 Static effective tension

Static effective tension presents the tension in the riser, mainly according to the suspended riser length and its weight.

**Offset 1**

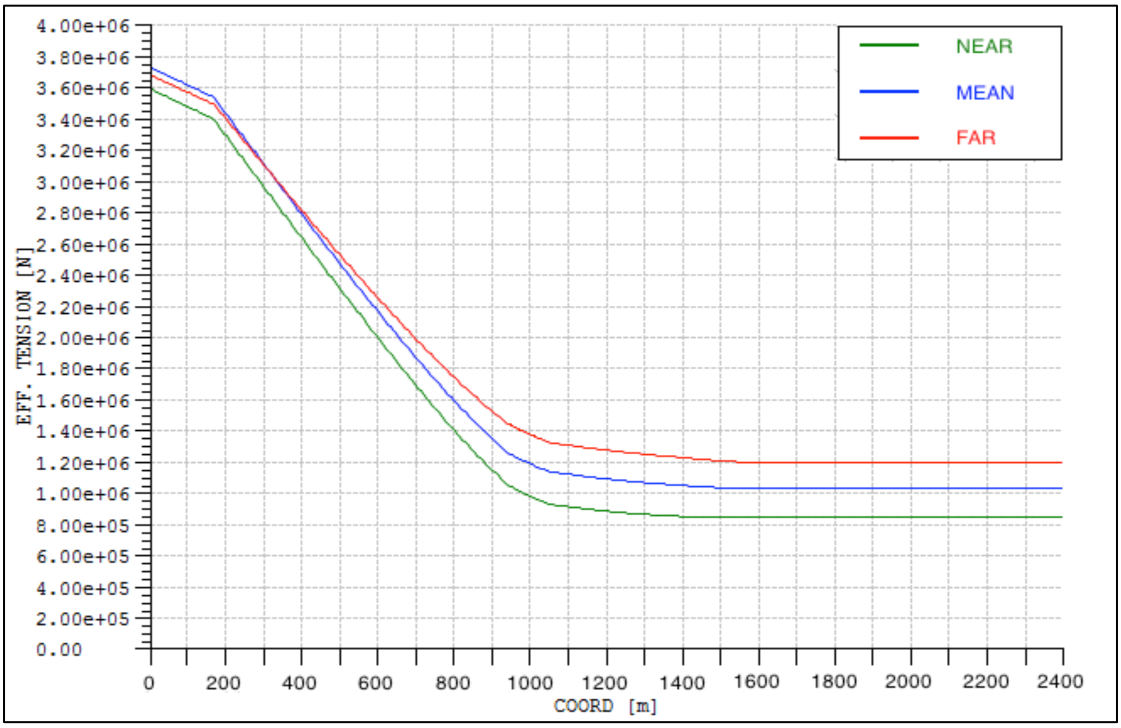

Figure 8-3: Static tension offset 1

**Offset 2**

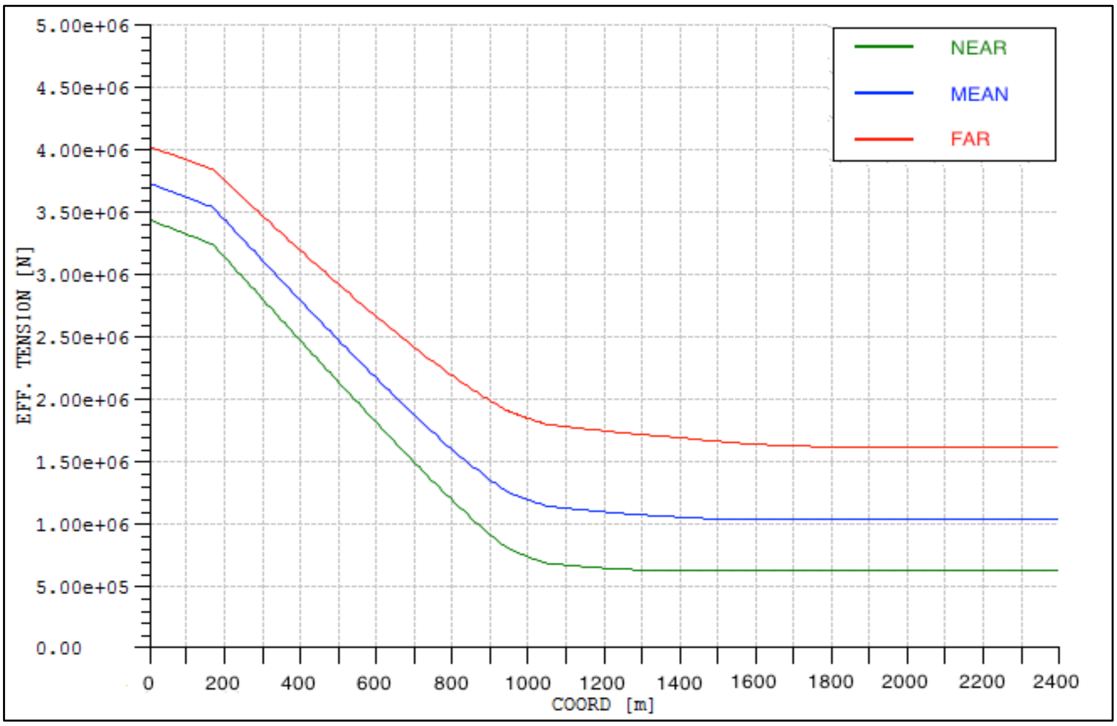

Figure 8-4: Static tension offset 2

### 8.3.3 Static bending moment

**Offset 1**

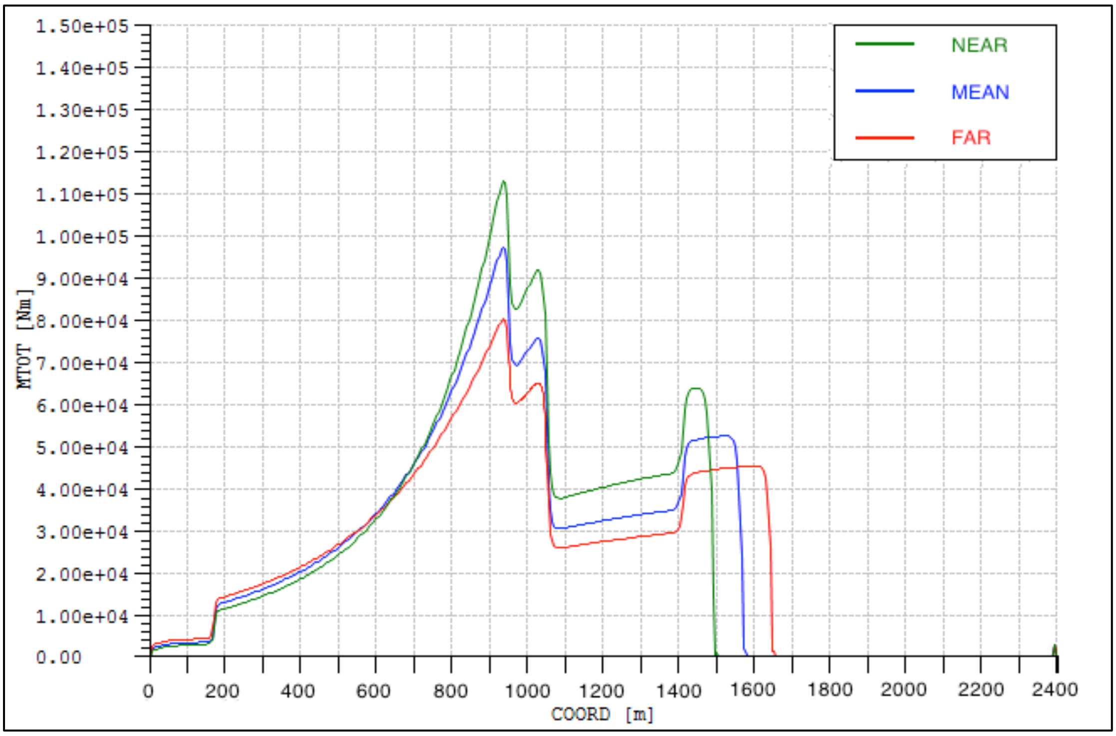

Figure 8-5: Static bending moment offset 1

**Offset 2**

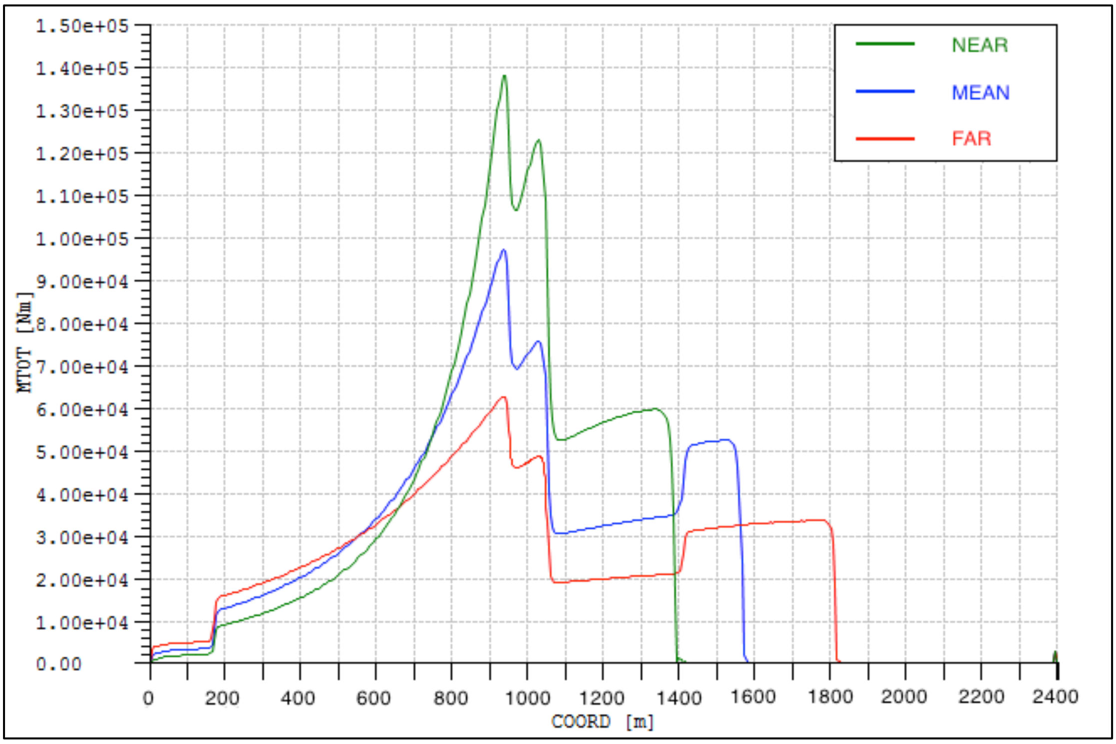

Figure 8-6: Static bending moment offset 2

Max values for the static analysis is given in Table 8-2 below:

**Table 8-2: Max values for static analysis**

| Offset | Max static tension [kN] | Max static bending moment [kNm] |
|---|---|---|
| **1** | 3730 | 112 |
| **2** | 4000 | 138 |

## 8.4 Dynamic analysis

The interesting plots from the dynamic analysis can be found in the dynamic tension and the dynamic bending moment.

The static analysis gives a good indication that the stress is highest at the far load case, and that the bending is highest at the near load case. Therefore, these load cases will be investigated.

### 8.4.1 Dynamic tension

Figure 8-4 and Figure 8-5 shows that the tension is most significant at the far load case.

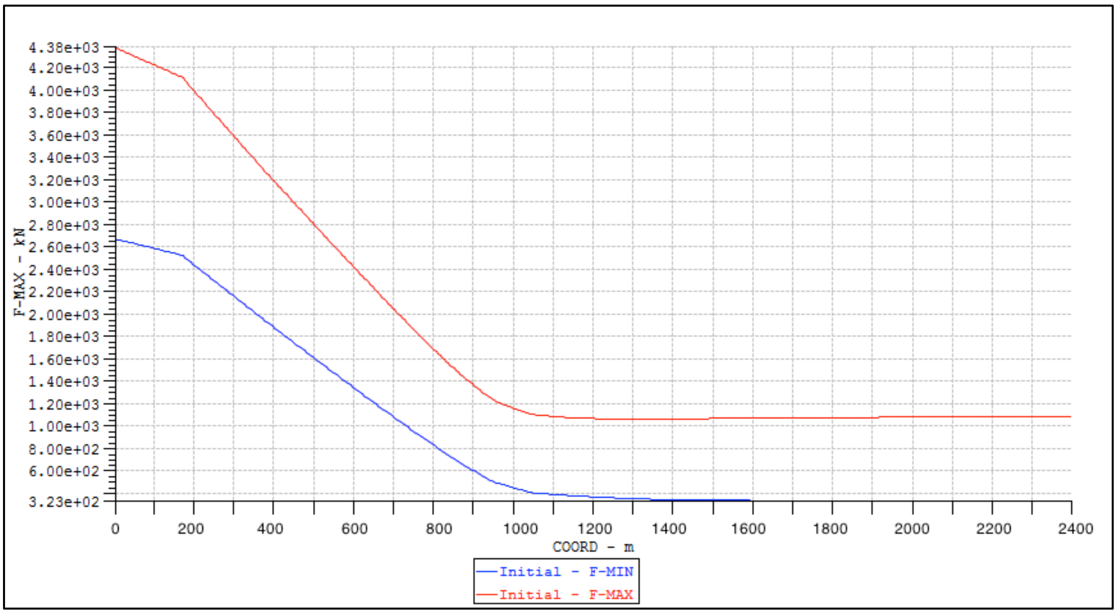

**Figure 8-7: Dynamic tension, far load case**

### 8.4.2 Dynamic bending moment

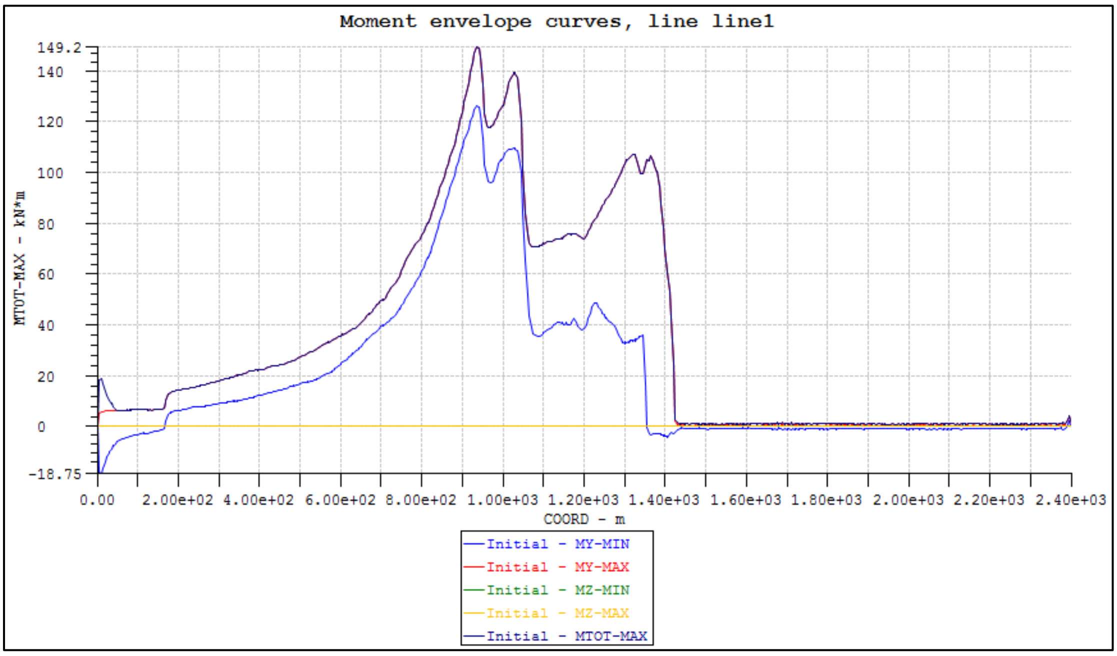

Figure 8-8: Dynamic bending moment, near load case

# 9 CONVENTIONAL SCR AND WEIGHT-DISTRIBUTED SCR COMPARISON

This chapter focuses on comparison between the two riser configurations, to see how the weight-distributed SCR acts compared to the conventional SCR.

The following comparison is done at 100m offset, and it has the same setup as the previous analyses, i.e. divided into:

- Static XZ configuration
- Static effective tension
- Static bending moment
- Dynamic tension
- Dynamic bending

In addition, the comparison will also take a look at the displacement along the riser in the different configurations.

In the following figures legend there is the abbreviations WD and CONV, where:

- WD = Weight-Distributed SCR case
- CONV = Conventional SCR case

## 9.1 Static XZ configuration

In the static configuration analyses, the far and near load cases for each configuration are compared to each other to see if the weight-distribution has any impact.

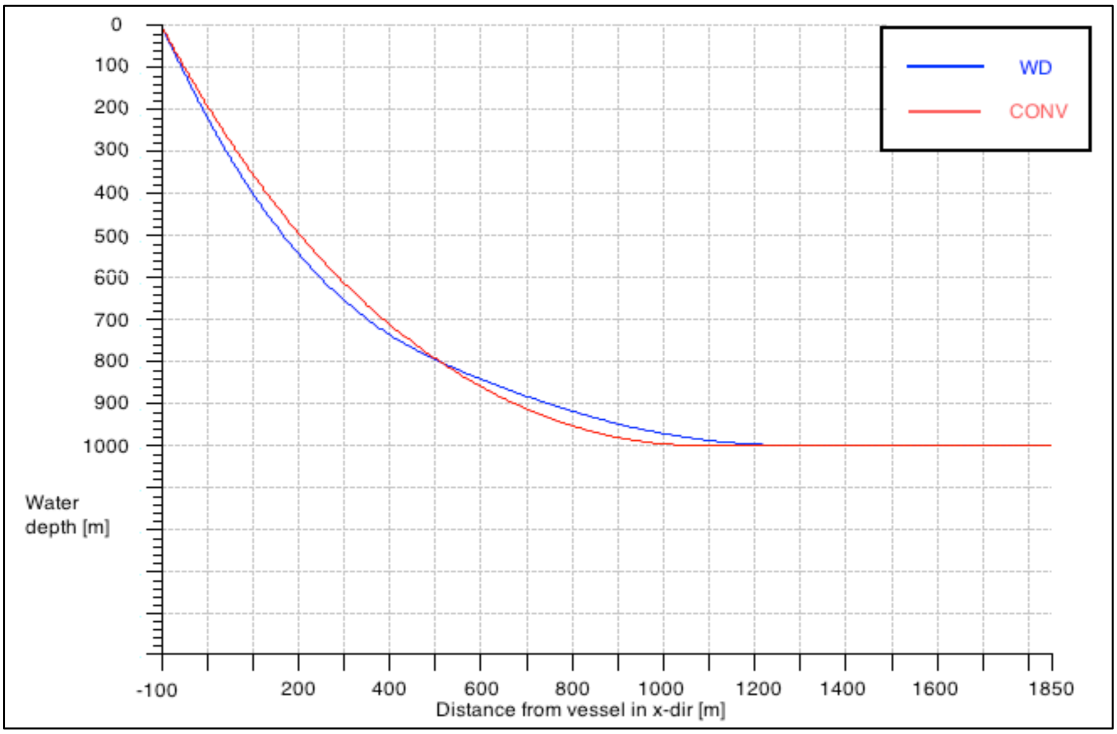

**Figure 9-1: Static configuration, far load case**

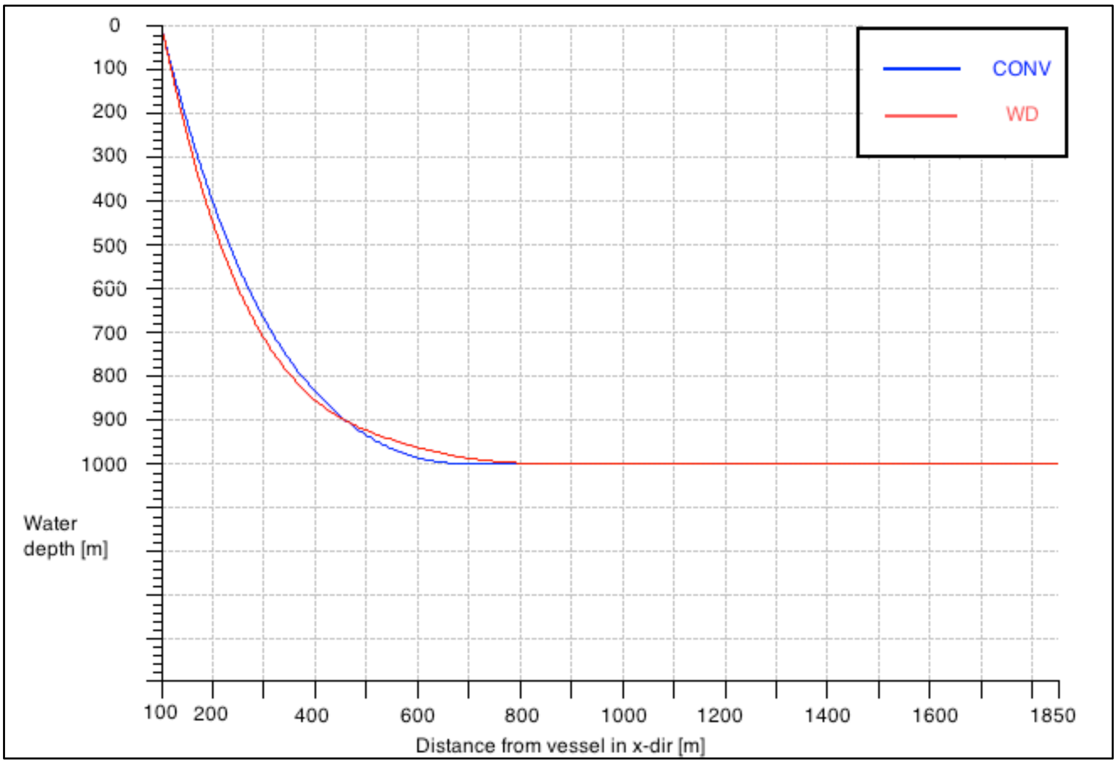

**Figure 9-2: Static configuration, near load case**

From Figure 9-1 and Figure 9-2 we notice that the change in the static configuration is similar in both load cases. Notice that the colors for the respective configurations have been changed from Figure 9-1. The weight-distributed riser is heavier in the earlier sections than the conventional riser; hence the weight-distributed riser has a more straight line downwards from the start.

When the weight-distributed riser changes to lighter coating weight, the bend is longer than the conventional, and the TDP for the weight-distributed risers ends up further from the riser than the conventional in both cases.

The riser-soil interaction is smoother in the weight-distributed configuration, which helps avoid excessive bending moment at the TDP.

## 9.2 Static tension

From chapter 7 and 8 we obtain information that the static effective tension is higher for the far load case than for the near load case. Therefore, the comparison for the static tension concentrates on the far load case.

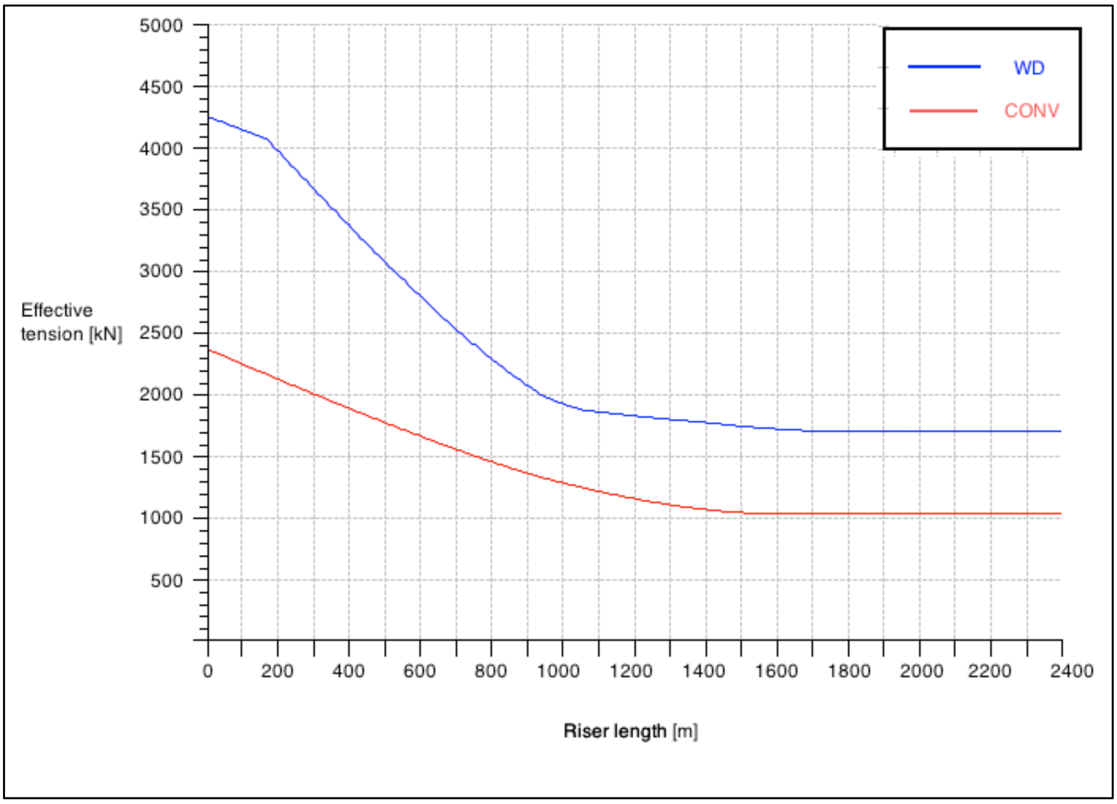

**Figure 9-3: Static tension, far load case**

The suspended riser length can explain the result from the static tension in Figure 9-3. We know from chapter 9.1 that the TDP for the weight-distributed riser appears further from the vessel than the conventional riser. In addition, the weight-distributed riser is heavier at the floater end, and therefore a larger static effective tension.

The tension on the weight-distributed riser drops from 4250kN to approximately 1700kN, while the tension on the conventional riser drops from 2370kN to 1000kN. This shows that the change in coating density has a significant effect on the change in maximum and minimum values for the riser.

**Table 9-1: Max/min values static effective tension**

| **Configuration** | **Max effective tension [kN]** | **Min effective tension [kN]** |
|---|---|---|
| **Weight-distributed** | 4250 | 1700 |
| **Conventional** | 2370 | 1000 |

## 9.3 Static bending moment

In contrast to the static effective tension, the static bending moment is highest at the near case, i.e. this case will be investigated in this section.

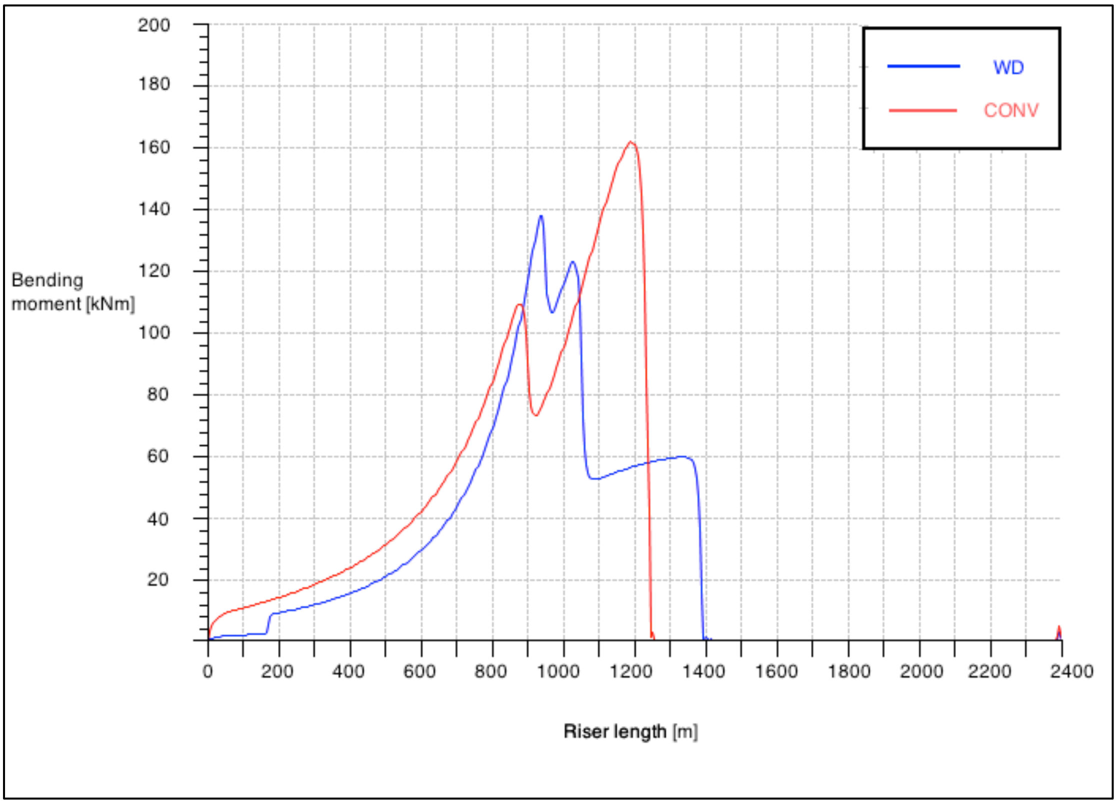

**Figure 9-4: Static bending moment, near load case**

The conventional riser has a steadily rising curve until the cross section changes, then drops and starts to rise again until it reaches TDP. After TDP, there is a sudden drop to zero.

For the weight-distributed there is a similar curve until the coating density changes from heavyweight to light heavyweight at 950m, and then drops. It reaches a new peak when it changes from light heavyweight to lightweight at 1050m. Notice that the slope becomes less steep after it changes to the lightweight coating.

Max values are given in Table 9-2 below:

**Table 9-2: Max values, static bending moment**

| Configuration | Max static bending moment [kNm] |
|---|---|
| **Weight-distributed** | 138.2 |
| **Conventional** | 162 |

## 9.4 Dynamic tension

The dynamic tension focuses on the far load case. Because negative dynamic tension leads to unwanted compression in the riser, both maximum and minimum values are investigated.

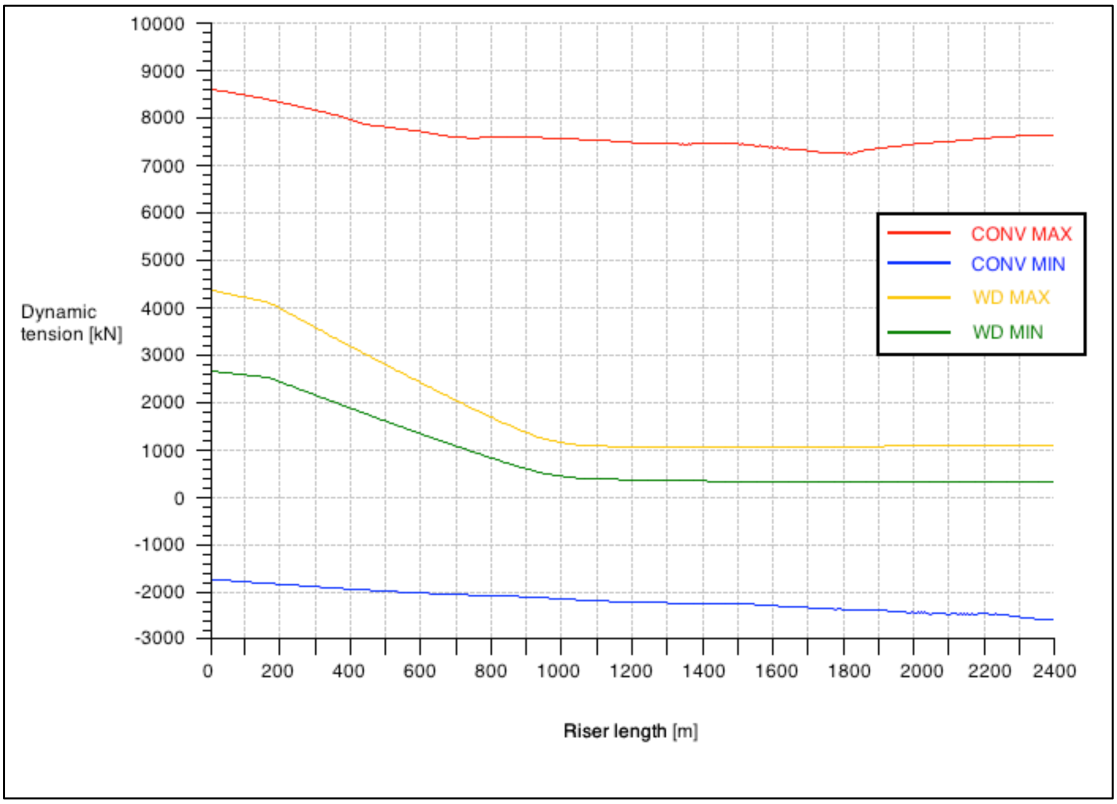

**Figure 9-5: Dynamic tension, far load case**

In dynamic tension, we notice a significant improvement from the conventional riser to the weight-distributed riser.

As shown in Figure 9-5, the maximum values for the conventional riser is relatively high (8610kN), and in addition the minimum values are negative, which leads to unwanted compression.

The weight-distributed riser has a lot lower maximum value (4380kN), and the minimum value is positive, i.e. no compression.

Maximum and minimum values are given in Table 9-3 below:

**Table 9-3: Max/min values dynamic tension**

| Configuration | Max dynamic tension [kN] | Min dynamic tension [kN] |
|---|---|---|
| **Weight-distributed** | 4380 | 323 |
| **Conventional** | 8610 | -2580 |

## 9.5 Dynamic bending moment

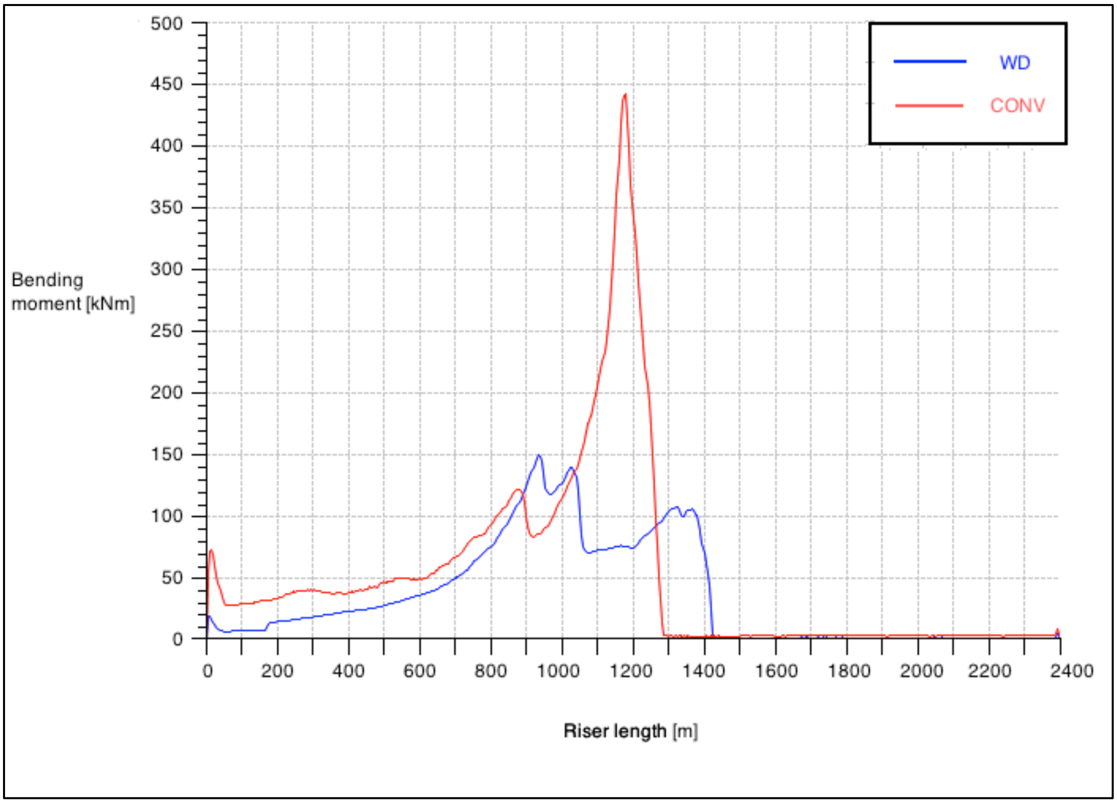

**Figure 9-6: Dynamic bending moment, near load case**

The weight-distributed riser configuration has a smoother approach to the TDP, which helps avoid excessive bending moment. This is clearly shown in Figure 9-6, where the dynamic bending moment for the conventional has a maximum value of 442.4kNm located at the TDP.

On the other hand, the dynamic bending moment for the weight-distributed has a maximum value of 149.2kNm, and it is more fairly distributed along the riser with peaks located where the coating density changes.

**Table 9-4: Maximum values, dynamic bending moment**

| **Configuration** | **Max dynamic bending moment [kNm]** |
|---|---|
| **Weight-distributed** | 149.2 |
| **Conventional** | 442.4 |

## 9.6 Displacement

The external forces acting on the riser creates displacement. Far load case creates the most displacement; hence this will be investigated.

### 9.6.1 Conventional SCR displacement

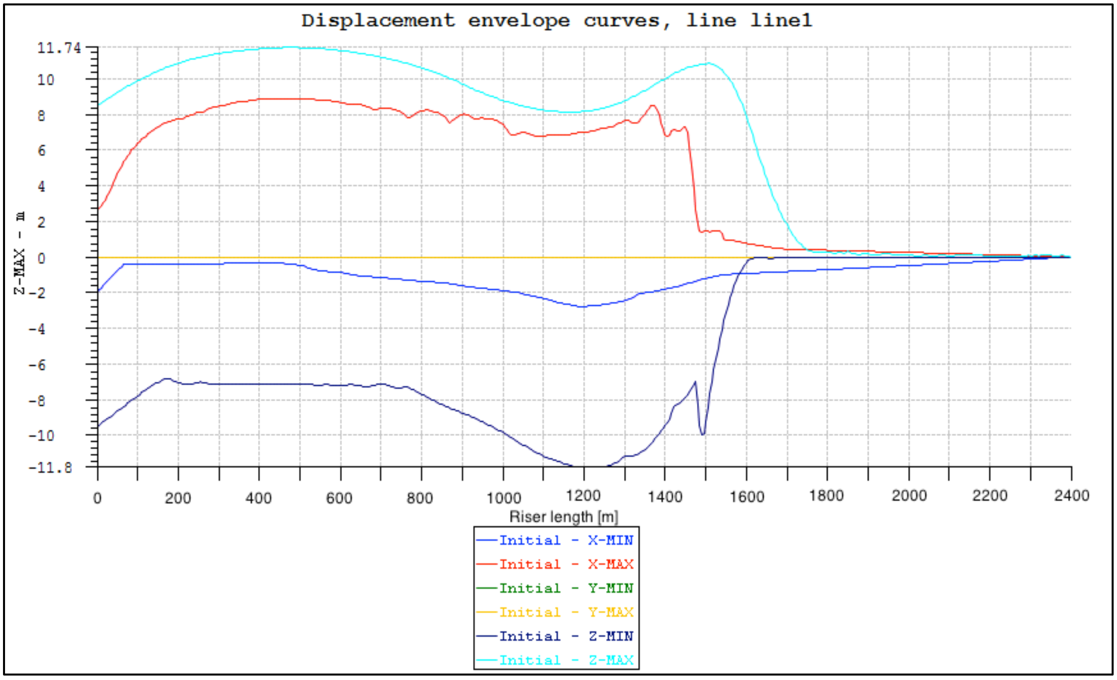

Figure 9-7: Conventional SCR displacement

### 9.6.2 Weight-distributed SCR displacement

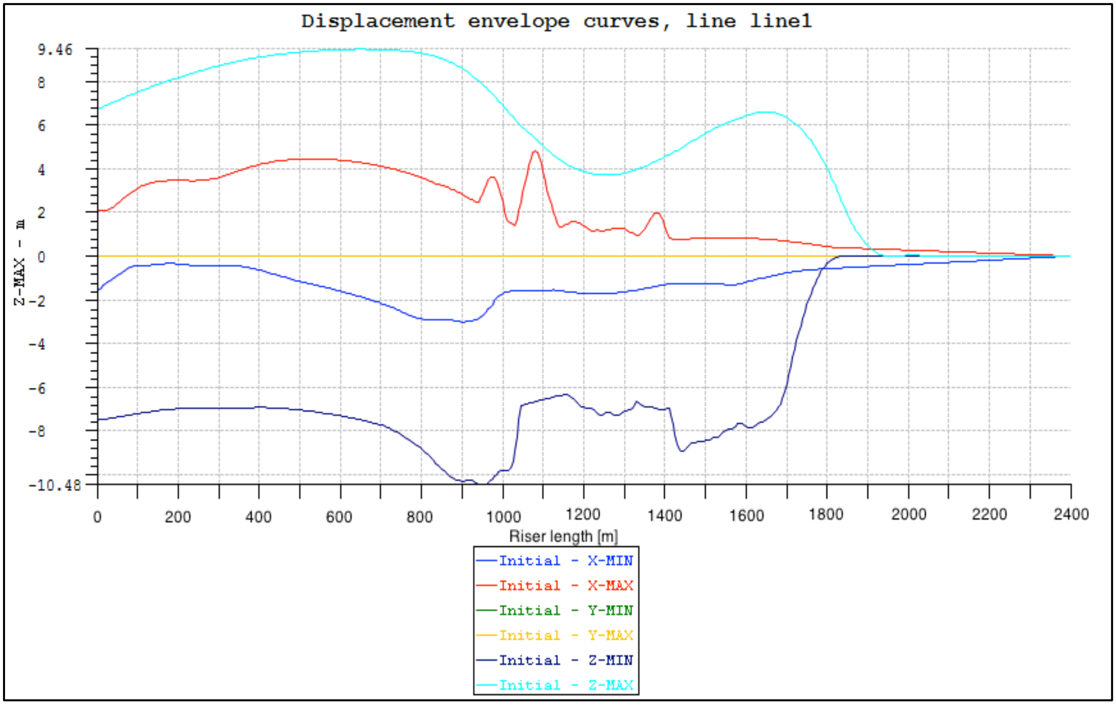

Figure 9-8: Weight-distributed SCR displacement

Displacements are in both cases highest in the z-direction, followed by the displacement in the x-direction. However, the highest z-value is the minimum value. The minimum values are simply displacement in the opposite way of the defined positive direction.

**Table 9-5: Max/min displacements**

| Configuration | Max displacement z-direction [m] | Min displacement z-direction [m] | Max displacement x-direction [m] | Min displacement x-direction [m] |
|---|---|---|---|---|
| **Weight-distributed** | 9.46 | -10.48 | 4.8 | -3.0 |
| **Conventional** | 11.74 | -11.8 | 9.0 | -3.0 |

By looking at Table 9-5 one may notice that the displacement decreases from the conventional to the weight-distributed configuration. The decrease is relatively small, except for the positive displacement in the x-direction.

## 9.7 Discussion

This chapter has shown that by modifying the conventional riser with various coating densities, its response to external forces improves significantly.

The static tension is initially higher for the weight-distributed, but the tension drops rapidly compared to the conventional configuration, and the value in itself is not critical.

The static bending is not critical for any of the configurations. However, the weight-distributed configuration has a lower static bending moment than the conventional, because of its smooth approach to the soil.

The dynamic analyses have bigger difference between the configurations. The dynamic tension is greatly improved both in terms of maximum and minimum values when using varying density along the riser. From having a high maximum tension, and in addition a negative minimum tension, which leads to compression in the pipeline, in the conventional configuration, to having a respectable maximum tension and a positive minimum tension in the weight-distributed configuration.

The dynamic bending also shows a significant improvement from the conventional to the weight-distributed configuration, going from 442.4kNm to 149.2kNm.

A more in depth and final conclusion is given in chapter 11.

# 10 WEIGHT-DISTRIBUTED SCR SENSITIVITY STUDY

The weight-distributed SCR configuration proved to be a great improvement compared to the conventional SCR configuration. This chapter focuses on how the weight-distributed configuration responds to different parameter variations. Vessel offset and its influence on the riser has been investigated in chapter 8, and will therefore not be investigated in this chapter.

The parameters that will be investigated are:

- Coating densities
- Element length

## 10.1 Coating densities

In this study, the different coating densities will be investigated, to see how changing them affects the riser system.

In the configuration in chapter 8, the different coating densities were:

- Lightweight: 600kg/m$^3$
- Normal weight: 900kg/m$^3$
- Light Heavyweight: 1700kg/m$^3$
- Heavyweight: 2700kg/m$^3$

By changing each of these densities and rerun analysis, results will show how the different coating densities can be changed to achieve other results than results from an initial run. Static effective tension and bending moment, as well as dynamic tension and bending moment will be investigated.

Other than the initial case, two additional configurations have been created. Table 10-1 below shows the values for each configuration.

**Table 10-1: Coating densities**

| Coating type | Configuration 1 (Chapter 8) | Configuration 2 | Configuration 3 |
|---|---|---|---|
| **Lightweight** | 600 kg/m$^3$ | 700 kg/m$^3$ | 700 kg/m$^3$ |
| **Normal weight** | 900 kg/m$^3$ | 900 kg/m$^3$ | 900 kg/m$^3$ |
| **Light Heavyweight** | 1700 kg/m$^3$ | 1500 kg/m$^3$ | 1300 kg/m$^3$ |
| **Heavyweight** | 2700 kg/m$^3$ | 2300 kg/m$^3$ | 2100 kg/m$^3$ |
| **Total weight** | 5900 kg/m$^3$ | 5400 kg/m$^3$ | 5000 kg/m$^3$ |

*N.B. The total weight cannot be considered for the whole riser, as the different coating types are used at different lengths. It is just provided as an indicator.*

### 10.1.1 Analysis results

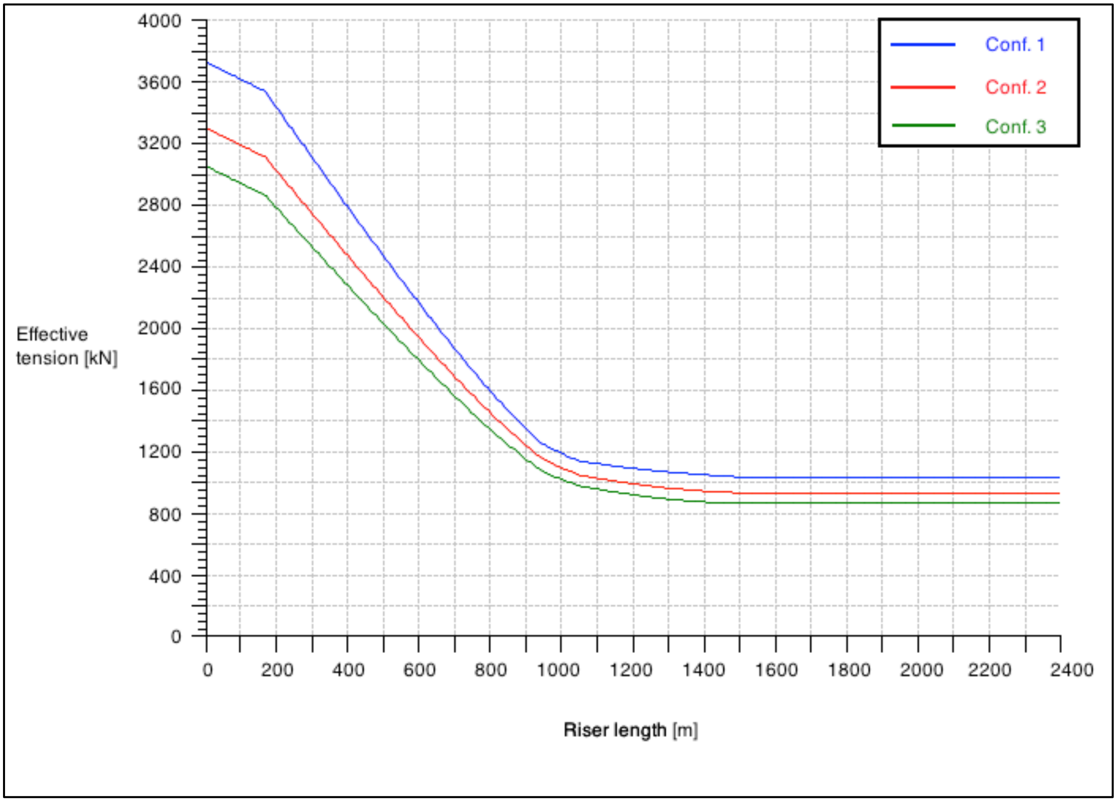

**Figure 10-1: Static effective tension for different coating densities**

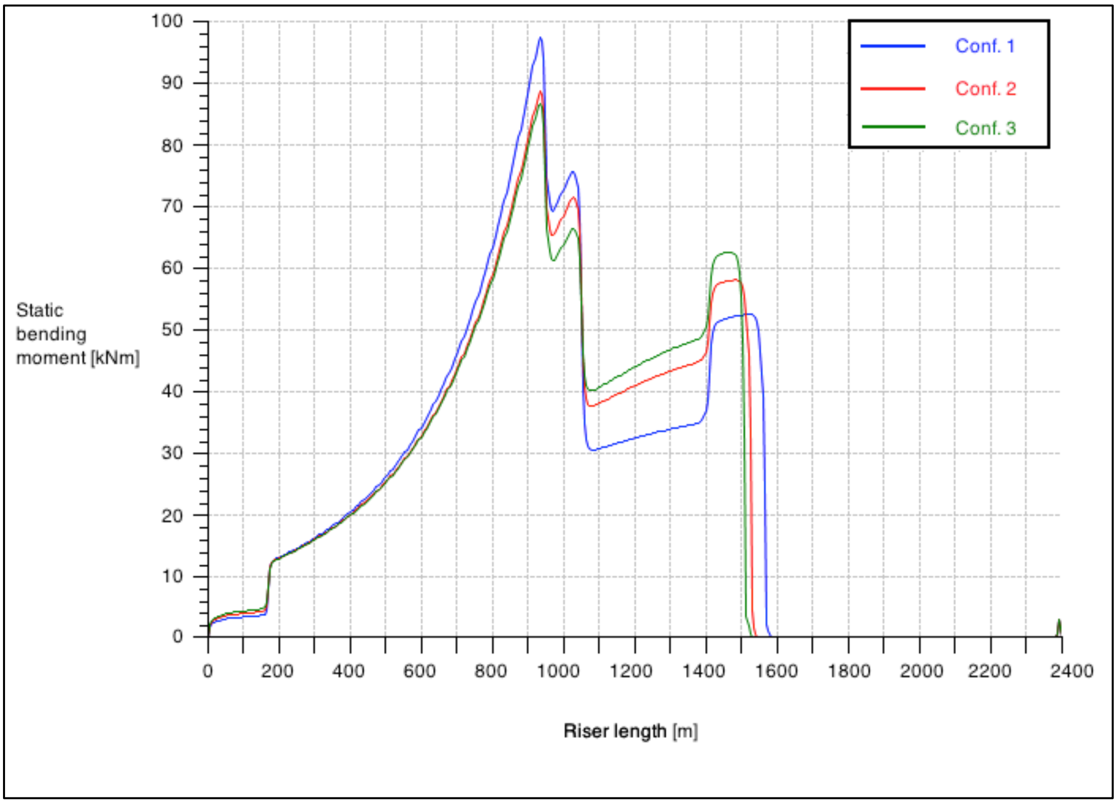

**Figure 10-2: Static bending moment for different coating densities**

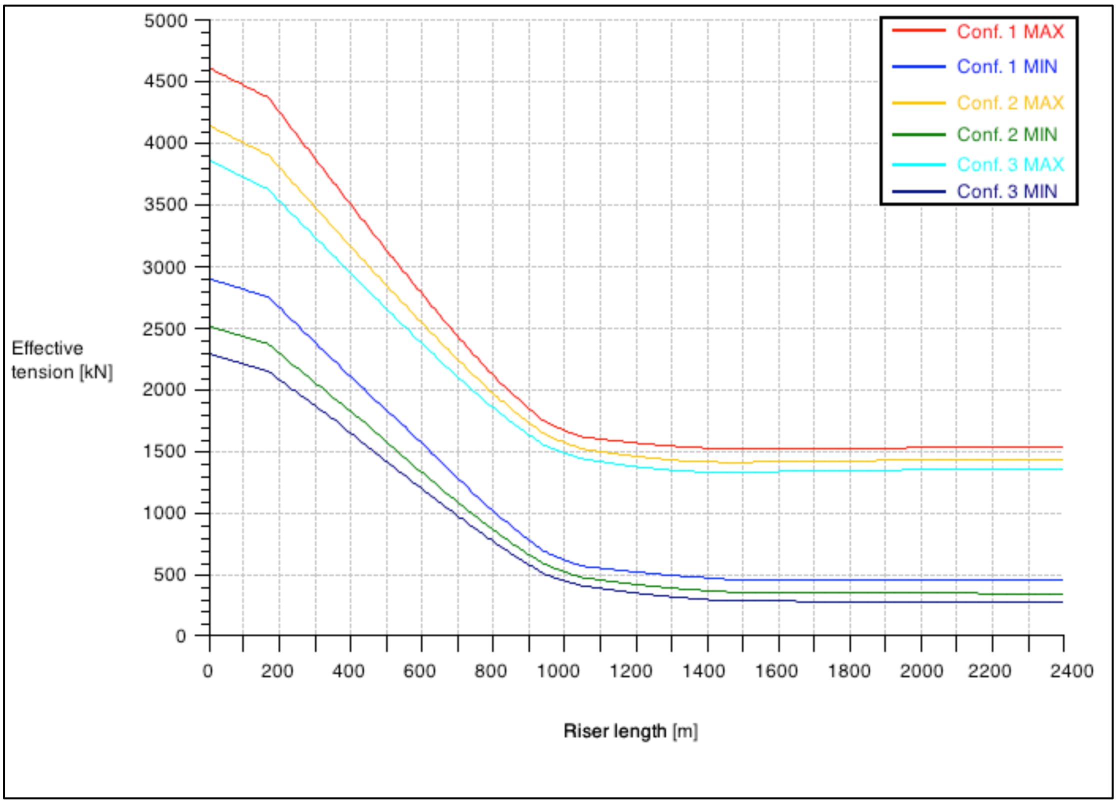

**Figure 10-3: Dynamic tension for different coating densities**

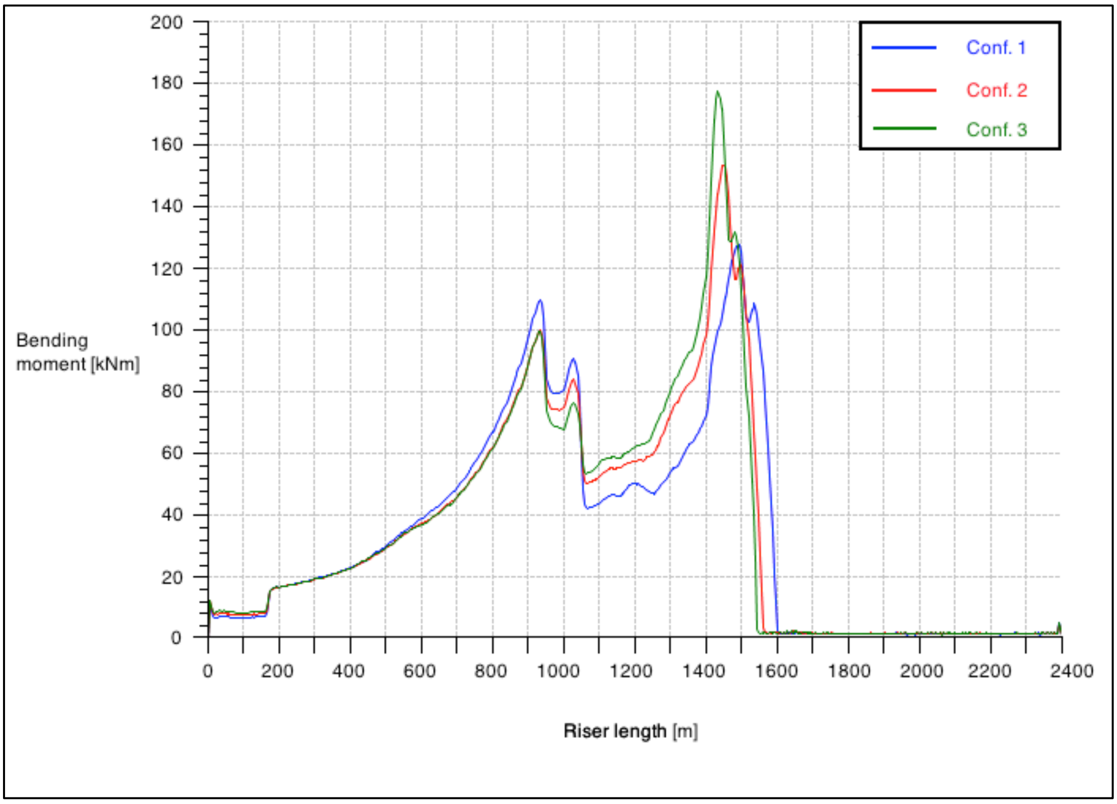

**Figure 10-4: Dynamic bending moment for different coating densities**

### 10.1.2 Analysis results discussion

***Static tension***: Because the weight is highest for configuration, second highest for configuration 2 and third highest for configuration 3, we get this outcome for the static tension analysis shown in Figure 10-1.

***Static bending moment***: In Figure 10-2 the static bending moment is presented. The initial configuration has a higher density for the heavyweight section, and a lower density for the lightweight section. This leads to a slightly higher bending moment at the end of the heavyweight section, and a slightly lower bending moment at the lightweight section.

***Dynamic tension***: For the dynamic tension shown in Figure 10-3, both maximum and minimum tension is investigated. In these analyses, none of the configurations has a negative value for the minimum tension. However, the trend shows that if the coating densities continue to decrease, the minimum tension will become of negative value, and compression in the pipe will occur.

***Dynamic bending moment***: Figure 10-4 shows the dynamic bending moment for the three configurations. The trend here shows that lighter coating densities leads to a fairly rapid increase in the bending moment around TDP.

### 10.1.3 Conclusion

From these analyses, the following conclusions can be drawn. The trend in various densities for the different coating classes shows that:

- If a weight-distributed SCR system is facing challenges with too high tension, lighter densities in the coating can be applied to cope with this to the extent that it does not create compression.
- On the other hand, if a weight-distributed SCR system is facing challenges with too high bending moment around the TDP, lighter coating densities in this area help avoiding it. Heavier density in the early section along with lighter density in the late section leads to a smoother approach for the riser when interacting with the soil.

## 10.2 Element length

When modeling the riser system in SIMA, the riser is defined as a line that is divided into segments which is again divided into elements (see chapter 5 for more information about SIMA/RIFLEX).

The length of the elements can vary, and this chapter investigates how the length of elements affects the result on the analysis.

Four configurations are being compared in order to achieve a trend for how the riser responds with different element lengths. The breakdown of the segment lengths, number of elements is shown in the tables below. Configuration 1 is the initial configuration used in chapter 8.

### 10.2.1 Segment and element breakdown

In Table 10-2 through 10-5 the breakdown of the number of elements for each configuration is described.

**Table 10-2: Initial configuration segment and element breakdown**

| Segment number | Segment length [m] | Elements |
|---|---|---|
| **1** | 170 | 34 |
| **2** | 780 | 156 |
| **3** | 100 | 20 |
| **4** | 360 | 72 |
| **5** | 990 | 198 |
| **TOTAL** | 2400 | 480 |

**Table 10-3: Configuration 2 segment and element breakdown**

| Segment number | Segment length [m] | Elements |
|---|---|---|
| **1** | 170 | 17 |
| **2** | 780 | 78 |
| **3** | 100 | 10 |
| **4** | 360 | 36 |
| **5** | 990 | 99 |
| **TOTAL** | 2400 | 240 |

**Table 10-4: Configuration 3 segment and element breakdown**

| Segment number | Segment length [m] | Elements |
|---|---|---|
| **1** | 170 | 9 |
| **2** | 780 | 39 |
| **3** | 100 | 5 |
| **4** | 360 | 18 |
| **5** | 990 | 49 |
| **TOTAL** | 2400 | 120 |

**Table 10-5: Configuration 4 segment and element breakdown**

| Segment number | Segment length [m] | Elements |
|---|---|---|
| **1** | 170 | 68 |
| **2** | 780 | 312 |
| **3** | 100 | 40 |
| **4** | 360 | 144 |
| **5** | 990 | 396 |
| **TOTAL** | 2400 | 960 |

### 10.2.2 Analysis results

Table 10-6 below shows the results for static tension, static bending moment, dynamic tension and dynamic bending moment.

**Table 10-6: Analysis results for configuration 1-4**

| Configuration | Static tension [kN] | Static bending [kNm] | Dynamic tension (max, min) [kN] | Dynamic bending [kNm] |
|---|---|---|---|---|
| **1** | 3730 | 97.52 | (4620, 451) | 127.8 |
| **2** | 3730 | 97.79 | (4610, 449) | 135.4 |
| **3** | 3720 | 99.16 | (4610, 444) | 162.1 |
| **4** | 3730 | 97.43 | (4620, 452) | 124.5 |

Furthermore, Figure 10-5 through 10-8 on the next pages shows graphs of each the individual analysis.

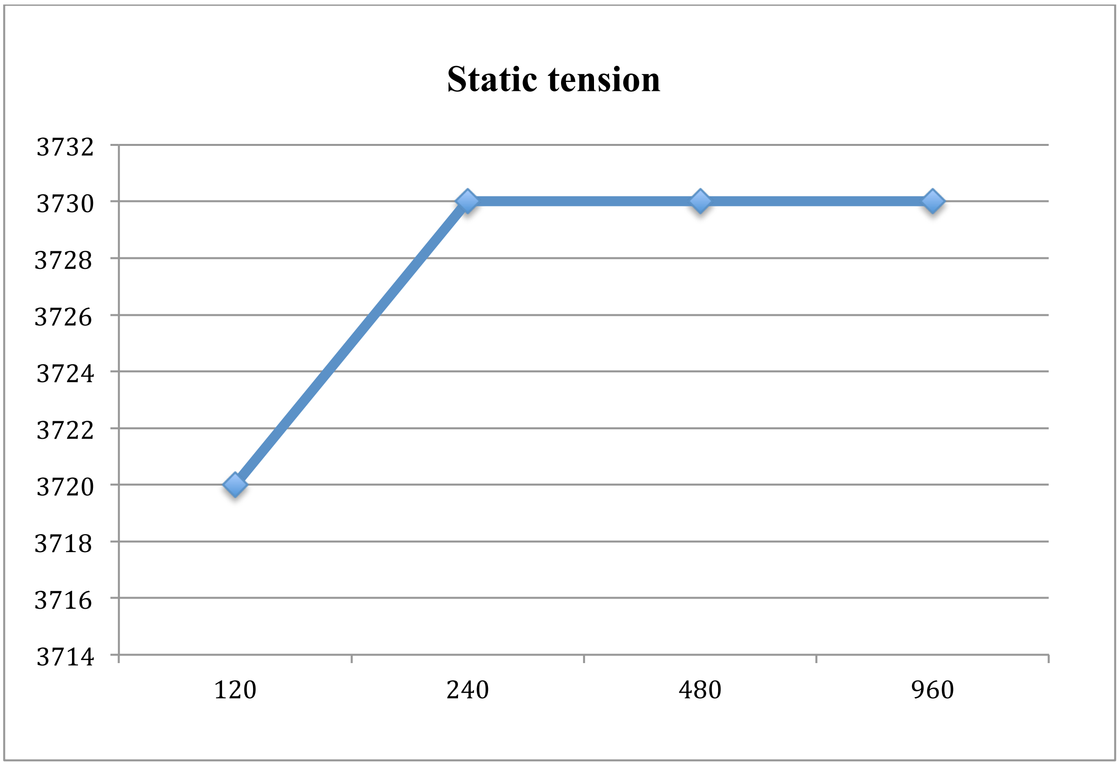

**Figure 10-5: Static tension vs number of elements**

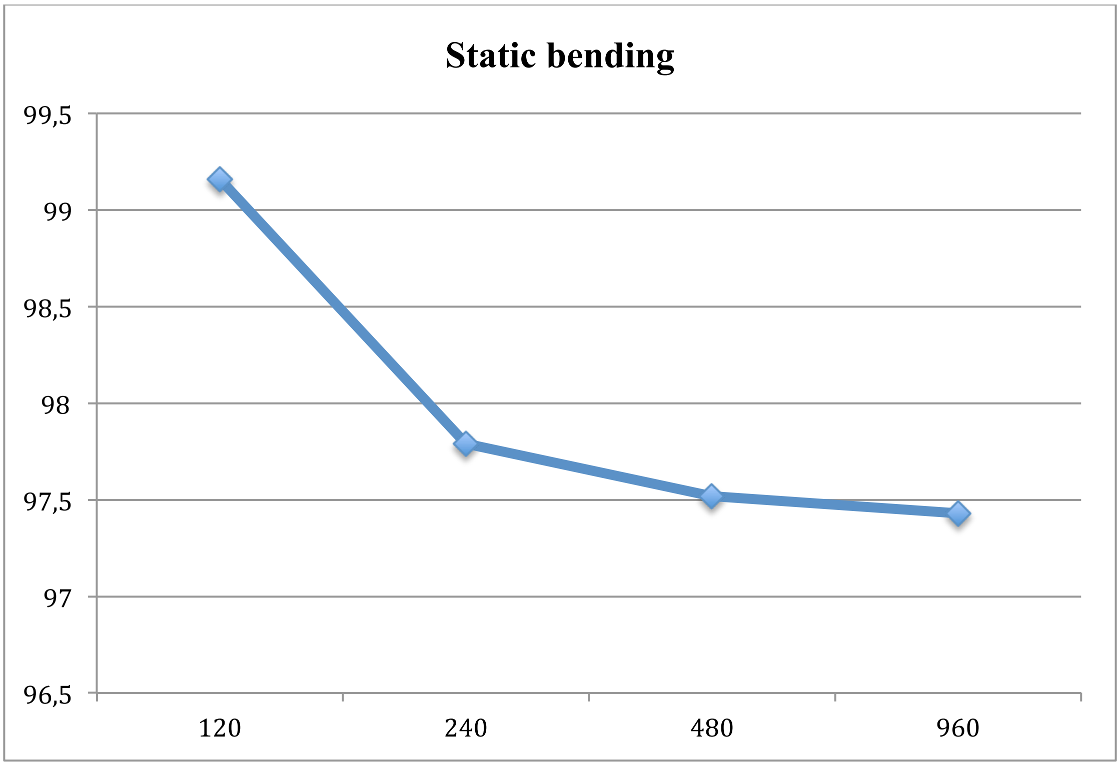

**Figure 10-6: Static bending vs number of elements**

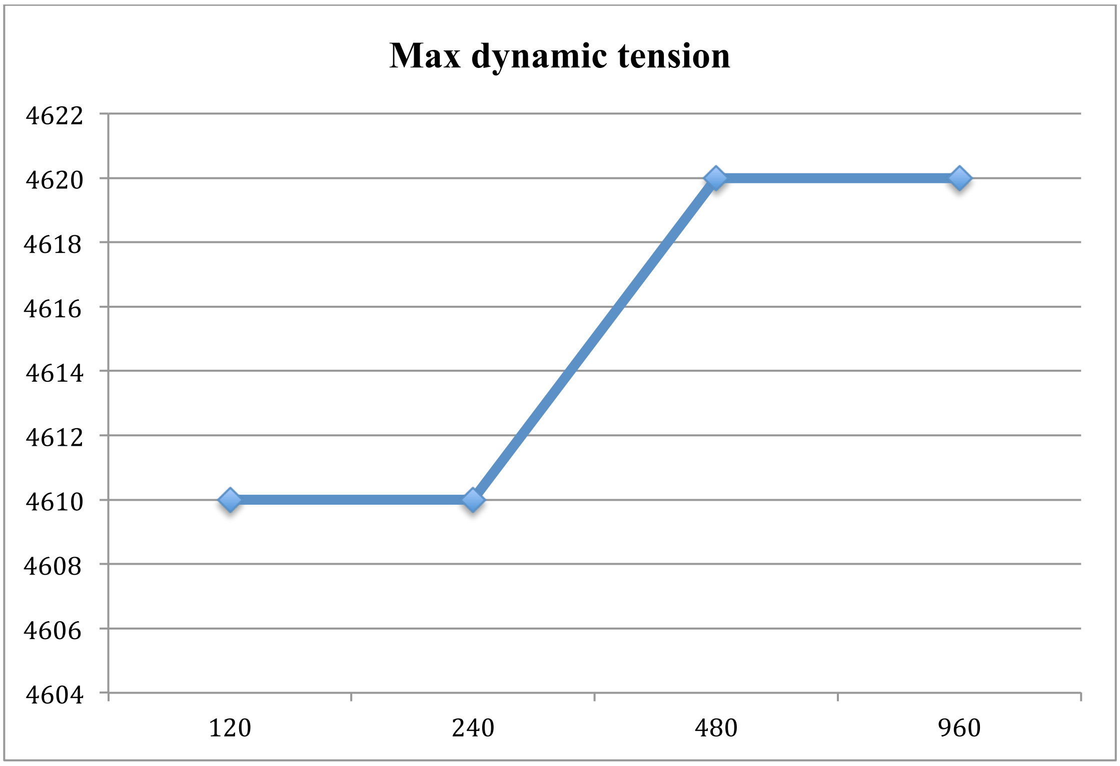

Figure 10-7: Max dynamic tension vs number of elements

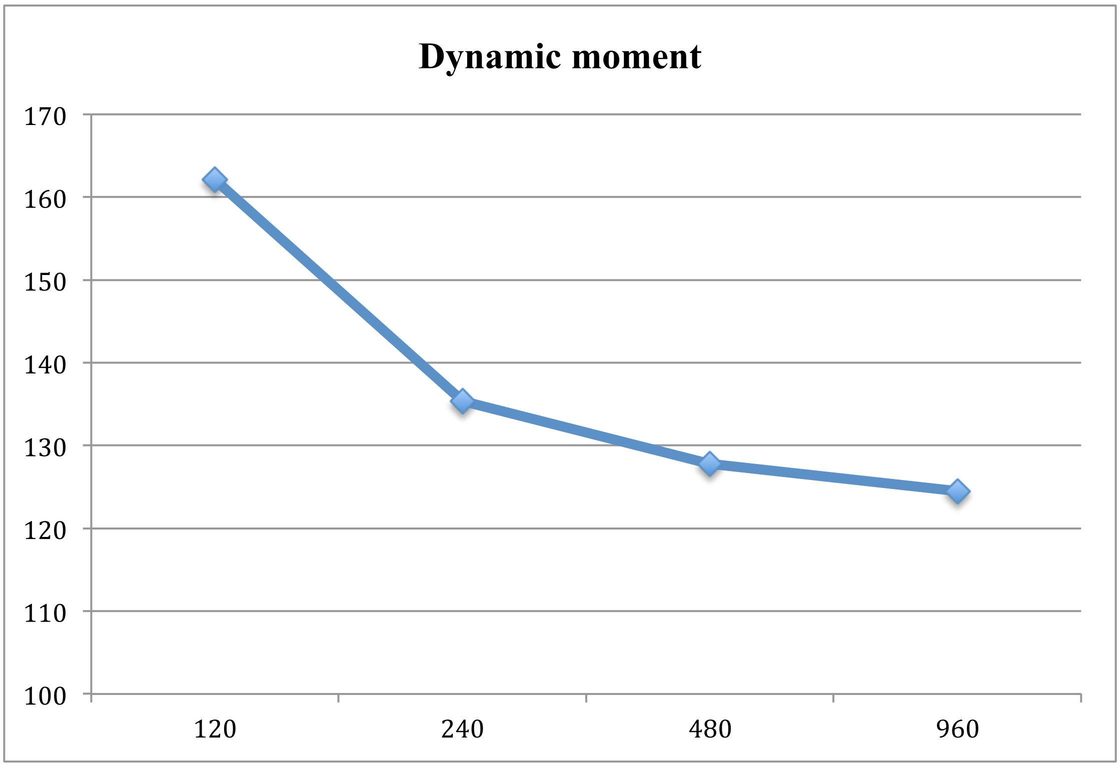

Figure 10-8: Dynamic moment vs number of elements

### 10.2.3 Analysis results discussion

***Static tension***: The difference in static tension is barely noticeable, with a deviation as small as 10kN from 120 elements to 960 elements. Ranging from 3720kN to 3730kN this makes it so small it is almost negligible.

***Static bending moment***: The static bending has a very small difference from 120 elements to 960 elements with its 1.73kNm in a scale ranging from 99.16kNm to 97.43kNm.

***Dynamic tension***: The dynamic tension is, as the static tension, almost negligible with a difference of only 10kN in a range of 4610kN to 4620kN.

***Dynamic bending moment***: As opposed to the other three analyses, the change in dynamic bending moment is not negligible. The difference is in this case 37.6kNm from 162.1kNm at 120 elements to 124.5kNm at 960 elements.

### 10.2.4 Conclusion

The trend regarding element length seems to be that an increased number of elements in this case give a lower bending moment, both in static and dynamic analyses.

On the other hand, the static tension is increasing with increased number of elements, but with a very small margin.

More elements will essentially get a more accurate solution than fewer elements. In a perfect world there could be one element per millimeter of the riser. However, this would be too computational demanding and time consuming in most cases. Therefore, the number of elements must in most cases have a minimum limitation to achieve sufficient computer efficiency without impairing the accuracy in any way. This thesis is using one element per 5 meter of the riser, which gives a total of 480 elements. By looking at the results, the deviation in results compared to 2.5 meter per element (960 total) is very small compared to the computational effort and time used. Hence, the total number of elements is by far acceptable in this thesis.

# 11 CLOSING CONCLUSION AND RECOMMENDATION

## 11.1 Conclusion

The development in the industry creates a natural development in technical solutions, including marine riser systems. The result of this is a number of new riser concepts coming up the last years.

Future exploration of oil and gas will go into deeper waters and harsher environments as the exploration in shallower waters and milder environments have already been explored. SCRs emerge as a good candidate for these new environments, with its simplicity and cost efficiency as driving factors.

From chapter 7 we learned that the conventional SCR have limitations for deep waters and harsh environments. High tension, bending moment and displacements can be observed from the analyses. With a conventional riser, the bending moment becomes excessive because of its lack of ability to distribute the bending moment along the riser, i.e. the bending moment is concentrated at the TDP.

To cope with the challenges the conventional SCR is facing, different configurations are being proposed, researched and developed. One of these is a weight-distributed SCR system. Instead of using buoys along the touchdown area as the Lazy Wave configuration, negative buoyancy is created by increasing the weight at the straight part of the riser, and decreasing the weight around the TDP.

Chapter 8 and 9 shows us that the weight-distributed SCR configuration is a promising solution to the problems conventional SCR configuration experience. By decreasing the weight near the TDP, the riser gets a smoother approach to the soil, and hence decreasing the bending moment significantly compared to the conventional SCR configuration.

The tension response is a result of the weight and suspended riser length, and therefore the static tension might be higher for the weight-distributed than the conventional, depending on how long the heavy and light segments are compared to the weight of the conventional riser. However, the maximum bending moment is in most cases the governing design parameter because the riser has greater capacity to withstand axial loads than lateral loads. As the comparison shows, the weight-distributed configuration has a significantly lower bending moment than the conventional configuration. The weight-distributed bending moment has a better distribution of the moment than the conventional, where the bending moment is concentrated around the TDP.

Sensitivity study has been performed on coating density and element length. The study of different coating densities shows how the riser can be modified if it is facing challenges with either too high tension or too high bending moment. If the problem is tension, lighter densities can be applied to the extent that it does not create compression. If the problem is concerning too high bending moment around the TDP, lighter coating density in this area help avoiding it.

The second sensitivity study, regarding element size, looks at how the riser responds when the defined element size in SIMA/RIFLEX is changed. This study shows that the element size used in the thesis is by far acceptable. The more elements used, the more accurate the analysis become, however, too many elements demand too much computational effort and is very time consuming. This fact makes it a balance act in order to find an acceptable element size for the analysis to be accurate, and at the same time not too CPU- and time demanding.

To summarize, the weight-distributed SCR concept improves the SCR response in all areas analyzed, and is rising up to be a very well suited concept for riser configurations in deep waters and harsh environments. This shows that even with deeper waters and harsher environments, suitable solutions are possible to achieve through innovative thinking.

## 11.2 Recommendation for further work

- Perform coupled analysis instead of de-coupled analysis. This method is considered to be more accurate, but demands a lot more computational effort and is much more time consuming. However, this is the next step for the analysis.
- Perform analyses for a configuration with clump weights, and compare it to coating-distributed configuration.
- Perform fatigue analysis due to VIV, soil-riser interaction, etc.
- Perform analysis in different simulation software (e.g. SIMA/RIFLEX, Orcaflex), and compare the two.
- Perform analysis for other RAO’s than semisubmersibles.

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# APPENDIX A: MASTER THESIS POSTER

Please see attached ZIP-file.

# APPENDIX B: RIFLEX INPUT FILES

Only the INPMOD files are presented in this appendix. All other RIFLEX files can be accessed from the digital attached zip-file named “Master thesis.stask”.

## INPMOD: CONVENTIONAL SCR NEAR POSITION

```
'**************************************************************************
**
 INPMOD IDENTIFICATION TEXT 4.0
'**************************************************************************
**
'--------------------------------------------------------------------
 UNIT NAMES SPECIFICATION
'--------------------------------------------------------------------
'ut ul um uf grav gcons
 s  m  Mg kN /     1.0000000
'**************************************************************************
**
 NEW SINGLE RISER
'**************************************************************************
**
'atyps idris
 AR    ARSYS
'**************************************************************************
**
 ARBITRARY SYSTEM AR
'**************************************************************************
**
'nsnod nlin nsnfix nves nricon nspr nack
 2    1   2      1    0      0    0

'ibtang zbot          ibot3d
 1      -1000.0000000 0

'stfbot     stfaxi    stflat     friaxi    frilat    dambot    damaxi    damlat
 600.0000000 0.0000000 10.0000000 0.0000000 0.5000000 0.0000000 0.0000000
0.0000000

'B 6.5: LINE TOPOLOGY DEFINITION
'lineid lintyp-id snod1-id snod2-id
 line1  ltyp1     Floa31   Bott16

'FIXED NODES
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 Bott16  0    1  1  1  0   0   0   GLOBAL NO

'x0         y0       z0           x1          y1        z1           rot       dir
 2120.7150000 0.0000000 -1000.0000000 1850.0000000 0.0000000 -1000.0000000
0.0000000 0.0000000
```

```
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 Floa31  1    1  1  1  0   0   1   GLOBAL NO

'x0        y0       z0       x1         y1       z1       rot      dir
 -61.0270000 0.0000000 0.0000000 100.0000000 0.0000000 0.0000000 0.0000000
0.0000000

'FREE NODES
'ives idwftr xg        yg       zg       dirx
 1    Seaf   40.0000000 0.0000000 0.0000000 0.0000000

'B.10 Line and segment specification
'*************************************************************
**
 NEW LINE DATA
'*************************************************************
**
'lintyp-id nseg ncmpty2 flutyp iaddtwi

 ltyp1     5    0       crudbe 0

'crstyp   ncmpty1 exwtyp nelseg slgth       nstrps nstrpd slgth0      isoity

 cs12inch 0       0      30     150.0000000 3      5      150.0000000 0

 cs12inch 0       0      150    750.0000000 3      5      750.0000000 0

 cs10inch 0       0      80     400.0000000 3      5      400.0000000 0

 cs10inch 0       0      40     200.0000000 3      5      200.0000000 0

 cs12inch 0       0      180    900.0000000 3      5      900.0000000 0

'*************************************************************
**
 NEW COMPONENT CRS0
'*************************************************************
**

'cmptyp-id temp       alpha     beta
 cs12inch  20.0000000 0.0000000 0.0000000

'diast      thst         densst    thex      densex    r-extcnt  r-intcnt
 -0.3048000 2.5400000e-02 7.8500000 0.1000000 0.9000000 0.0000000 0.0000000

'matkind emod         gmod
 1       2.0700000e+08 8.0000000e+07

'cqx      cqy      cax      cay      clx      cly      icode d
```

```
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb           ycurmx
 1.0000000e-03 1.0000000

'**********************************************************************
**
 NEW COMPONENT CRS0
'**********************************************************************
**

'cmptyp-id temp       alpha     beta
 cs10inch  20.0000000 0.0000000 0.0000000

'diast      thst          densst    thex          densex     r-extcnt  r-intcnt
 -0.2540000 2.5000000e-02 7.8500000 8.0000000e-02 0.9000000 0.0000000
0.0000000

'matkind emod          gmod
 1       2.0700000e+08 8.0000000e+07

'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4710000

'tb           ycurmx
 1.0000000e-03 1.0000000

'**********************************************************************
**
 NEW COMPONENT FLUID
'**********************************************************************
**

'cmptyp-id
 crudbe
'rhoi      vveli     pressi     dpress    idir
 0.7500000 0.0000000 20.0000000 0.0000000 2

'**********************************************************************
**
 SUPPORT VESSEL IDENTIFICATION
'**********************************************************************
**
'idhftr
 Seaf
'------------------------------------------------------------------
 HFTRANSFER REFERENCE POSITION
'------------------------------------------------------------------
```

```
'zg
 0.0000000
'-------------------------------------------------------------------
 HFTRANSFER CONTROL DATA
'-------------------------------------------------------------------

'ndhftr nwhftr isymhf itypin
9     30    1     2
'-------------------------------------------------------------------
'-------------------------------------------------------------------
WAVE DIRECTIONS
'-------------------------------------------------------------------
'ihead head

 1     0.0000000
 2     30.0000000
 3     60.0000000
 4     90.0000000
 5     120.0000000
 6     135.0000000
 7     150.0000000
 8     165.0000000
 9     180.0000000

'-------------------------------------------------------------------
'*****************************************************************
**
ENVIRONMENT IDENTIFICATION
'*****************************************************************
**
'idenv

 ENV
'-------------------------------------------------------------------
 WATERDEPTH AND WAVETYPE
'-------------------------------------------------------------------

'wdepth       noirw norw ncusta nwista
 1000.0000000 1     0    1      0

'-------------------------------------------------------------------
ENVIRONMENT CONSTANTS
'-------------------------------------------------------------------

'airden       watden    wakivi    airkivi
1.3000000e-03 1.0250000 1.0000000 1.8800000e-06
'-------------------------------------------------------------------

 NEW IRREGULAR SEASTATE
```

```
'--------------------------------------------------------------------
'nirwc iwasp1 iwadr1 iwasp2 iwadr2
 1    3     0     0     0
'--------------------------------------------------------------------
 WAVE SPECTRUM WIND
'--------------------------------------------------------------------
'omega     alfa          beta gamma siga sigb
 0.5000000 8.0000000e-03 /    /     /    /
'--------------------------------------------------------------------
 DIRECTION PARAMETERS
'--------------------------------------------------------------------
'wadr1     expo1
 0.0000000 2.0000000
'--------------------------------------------------------------------
 NEW CURRENT STATE
'--------------------------------------------------------------------
'icusta nculev l_ext
 1      4      0
'curlev    curdir    curvel
 0.0000000 0.0000000 0.9300000
 -50.0000000 0.0000000 0.6800000
 -300.0000000 0.0000000 0.4700000
 -1000.0000000 0.0000000 0.0000000
'**********************************************************************
**
 END
'**********************************************************************
**
```

## INPMOD: CONVENTIONAL SCR MEAN POSITION

```
'**********************************************************************
**
 INPMOD IDENTIFICATION TEXT 4.0
'**********************************************************************
**
'------------------------------------------------------------------
 UNIT NAMES SPECIFICATION
'------------------------------------------------------------------
'ut ul um uf grav gcons
 s  m  Mg kN /    1.0000000
'**********************************************************************
**
 NEW SINGLE RISER
'**********************************************************************
**
'atyps idris
 AR    ARSYS

'**********************************************************************
**
 ARBITRARY SYSTEM AR
'**********************************************************************
**
'nsnod nlin nsnfix nves nricon nspr nack
 2    1   2     1    0     0    0

'ibtang zbot          ibot3d
 1      -1000.0000000 0

'stfbot     stfaxi    stflat    friaxi    frilat    dambot    damaxi    damlat
 600.0000000 0.0000000 10.0000000 0.0000000 0.5000000 0.0000000 0.0000000
0.0000000

'B 6.5: LINE TOPOLOGY DEFINITION
'lineid lintyp-id snod1-id snod2-id
 line1  ltyp1     Floa31   Bott16

'FIXED NODES
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 Bott16  0    1  1  1  0   0   0   GLOBAL NO

'x0          y0        z0            x1           y1        z1            rot       dir
 2120.7150000 0.0000000 -1000.0000000 1850.0000000 0.0000000 -1000.0000000
0.0000000 0.0000000

'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 Floa31  1    1  1  1  0   0   1   GLOBAL NO
```

```
'x0        y0       z0       x1       y1       z1       rot       dir
 -61.0270000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000
0.0000000

'FREE NODES
'ives idwftr xg        yg       zg       dirx
 1    Seaf   40.0000000 0.0000000 0.0000000 0.0000000

'B.10 Line and segment specification
'**********************************************************************
**
 NEW LINE DATA
'**********************************************************************
**
'lintyp-id nseg ncmpty2 flutyp iaddtwi
 ltyp1     5    0       crudbe 0

'crstyp   ncmpty1 exwtyp nelseg slgth       nstrps nstrpd slgth0      isoity

 cs12inch 0       0      30     150.0000000 3      5      150.0000000 0

 cs12inch 0       0      150    750.0000000 3      5      750.0000000 0

 cs10inch 0       0      80     400.0000000 3      5      400.0000000 0

 cs10inch 0       0      40     200.0000000 3      5      200.0000000 0

 cs12inch 0       0      180    900.0000000 3      5      900.0000000 0

'**********************************************************************
**
 NEW COMPONENT CRS0
'**********************************************************************
**
'cmptyp-id temp       alpha     beta
cs12inch  20.0000000 0.0000000 0.0000000

'diast     thst         densst    thex      densex    r-extcnt  r-intcnt
 -0.3048000 2.5400000e-02 7.8500000 0.1000000 0.9000000 0.0000000 0.0000000

'matkind emod          gmod
 1       2.0700000e+08 8.0000000e+07

'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb            ycurmx
 1.0000000e-03 1.0000000
```

```
'***************************************************************************
**
 NEW COMPONENT CRS0
'***************************************************************************
**
'cmptyp-id temp      alpha     beta
 cs10inch  20.0000000 0.0000000 0.0000000

'diast     thst          densst    thex         densex    r-extcnt  r-intcnt
 -0.2540000 2.5000000e-02 7.8500000 8.0000000e-02 0.9000000 0.0000000
0.0000000

'matkind emod          gmod
 1       2.0700000e+08 8.0000000e+07

'cqx      cqy       cax       cay       clx       cly       icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4300000

'tb           ycurmx

 1.0000000e-03 1.0000000

'***************************************************************************
**
 NEW COMPONENT FLUID
'***************************************************************************
**
'cmptyp-id
crudbe
'rhoi     vveli    pressi        dpress    idir
0.7500000 0.0000000 20000.0000000 0.0000000 2

'***************************************************************************
**
SUPPORT VESSEL IDENTIFICATION
'***************************************************************************
**
'idhftr
Seaf

'--------------------------------------------------------------------
 HFTRANSFER REFERENCE POSITION
'--------------------------------------------------------------------
'zg
 0.0000000
'--------------------------------------------------------------------
 HFTRANSFER CONTROL DATA
'--------------------------------------------------------------------
'ndhftr nwhftr isymhf itypin
```

```
 9    30    1     2
'-----------------------------------------------------------------------
 WAVE DIRECTIONS
'-----------------------------------------------------------------------
'ihead head
 1     0.0000000
 2     30.0000000
 3     60.0000000
 4     90.0000000
 5     120.0000000
 6     135.0000000
 7     150.0000000
 8     165.0000000
 9     180.0000000

'************************************************************************
**
 ENVIRONMENT IDENTIFICATION
'************************************************************************
**
'idenv
 ENV

'-----------------------------------------------------------------------
 WATERDEPTH AND WAVETYPE
'-----------------------------------------------------------------------
'wdepth       noirw norw ncusta nwista
 1000.0000000 1     0    1      0
'-----------------------------------------------------------------------
 ENVIRONMENT CONSTANTS
'-----------------------------------------------------------------------
'airden        watden    wakivi    airkivi
 1.3000000e-03 1.0250000 1.0000000 1.8800000e-06
'-----------------------------------------------------------------------
 NEW IRREGULAR SEASTATE
'-----------------------------------------------------------------------
'nirwc iwasp1 iwadr1 iwasp2 iwadr2
 1     3      0      0      0
'-----------------------------------------------------------------------
 WAVE SPECTRUM WIND
'-----------------------------------------------------------------------
'omega     alfa          beta gamma siga sigb
 0.5000000 8.0000000e-03 /    /     /    /
'-----------------------------------------------------------------------
 DIRECTION PARAMETERS
'-----------------------------------------------------------------------
'wadr1     expo1
 0.0000000 2.0000000
'-----------------------------------------------------------------------
```

```
 NEW CURRENT STATE
'----------------------------------------------------------------------
'icusta nculev l_ext
 1      4      0

'curlev    curdir    curvel
 0.0000000 0.0000000 0.9300000
 -50.0000000 0.0000000 0.6800000
 -300.0000000 0.0000000 0.4700000
 -1000.0000000 0.0000000 0.0000000

'********************************************************************
**
 END
'********************************************************************
**
```

## INPMOD: CONVENTIONAL SCR FAR POSITION

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'****************************************************************************
**
INPMOD IDENTIFICATION TEXT 4.0
'****************************************************************************
**
'------------------------------------------------------------------------------
 UNIT NAMES SPECIFICATION
'------------------------------------------------------------------------------
'ut ul um uf grav gcons
 s  m  Mg kN /    1.0000000
'****************************************************************************
**
 NEW SINGLE RISER
'****************************************************************************
**
'atyps idris
 AR    ARSYS
'****************************************************************************
**
 ARBITRARY SYSTEM AR
'****************************************************************************
**
'nsnod nlin nsnfix nves nricon nspr nack
 2    1   2     1   0     0    0

'ibtang zbot         ibot3d
 1      -1000.0000000 0

'stfbot     stfaxi    stflat    friaxi    frilat    dambot    damaxi    damlat
 600.0000000 0.0000000 10.0000000 0.0000000 0.5000000 0.0000000 0.0000000
0.0000000

'B 6.5: LINE TOPOLOGY DEFINITION
'lineid lintyp-id snod1-id snod2-id
 line1  ltyp1     Floa31   Bott16

'FIXED NODES
'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 Bott16  0    1  1  1  0   0   0   GLOBAL NO

'x0          y0        z0           x1          y1        z1           rot       dir
 2120.7150000 0.0000000 -1000.0000000 1850.0000000 0.0000000 -1000.0000000
0.0000000 0.0000000

'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 Floa31  1    1  1  1  0   0   1   GLOBAL NO

'x0         y0        z0        x1          y1        z1        rot       dir
```

```
 -61.0270000 0.0000000 0.0000000 -100.0000000 0.0000000 0.0000000 0.0000000
0.0000000

'FREE NODES
'ives idwftr xg        yg        zg        dirx
 1    Seaf   40.0000000 0.0000000 0.0000000 0.0000000

'B.10 Line and segment specification

'*******************************************************************
**
 NEW LINE DATA
'*******************************************************************
**
'lintyp-id nseg ncmpty2 flutyp iaddtwi
 ltyp1     5    0       crudbe 0

'crstyp   ncmpty1 exwtyp nelseg slgth       nstrps nstrpd slgth0      isoity

 cs12inch 0       0      30     150.0000000 3      5      150.0000000 0

 cs12inch 0       0      150    750.0000000 3      5      750.0000000 0

 cs10inch 0       0      80     400.0000000 3      5      400.0000000 0

 cs10inch 0       0      40     200.0000000 3      5      200.0000000 0

 cs12inch 0       0      180    900.0000000 3      5      900.0000000 0

'*******************************************************************
**
NEW COMPONENT CRS0
'*******************************************************************
**
'cmptyp-id temp       alpha     beta
 cs12inch  20.0000000 0.0000000 0.0000000

'diast      thst           densst    thex       densex    r-extcnt  r-intcnt
 -0.3048000 2.5400000e-02 7.8500000 0.1000000 0.9000000 0.0000000 0.0000000

'matkind emod          gmod
 1       2.0700000e+08 8.0000000e+07

'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb            ycurmx
 1.0000000e-03 1.0000000
```

```
'*******************************************************************
**
 NEW COMPONENT CRS0
'*******************************************************************
**

'cmptyp-id temp       alpha     beta
cs10inch  20.0000000 0.0000000 0.0000000

'diast      thst          densst    thex          densex     r-extcnt  r-intcnt
 -0.2540000 2.5000000e-02 7.8500000 8.0000000e-02 0.9000000 0.0000000
0.0000000

'matkind emod          gmod
 1       2.0700000e+08 8.0000000e+07

'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4710000

'tb            ycurmx
 1.0000000e-03 1.0000000

'*******************************************************************
**
 NEW COMPONENT FLUID
'*******************************************************************
**
'cmptyp-id
 crudbe

'rhoi      vveli     pressi     dpress    idir
 0.7500000 0.0000000 20.0000000 0.0000000 2
'*******************************************************************
**
 SUPPORT VESSEL IDENTIFICATION
'*******************************************************************
**
'idhftr
 Seaf

'---------------------------------------------------------------------
 HFTRANSFER REFERENCE POSITION
'---------------------------------------------------------------------
'zg
 0.0000000
'---------------------------------------------------------------------
 HFTRANSFER CONTROL DATA
'---------------------------------------------------------------------
```

```
'ndhftr nwhftr isymhf itypin
 9      30     1      2
'-------------------------------------------------------------------
 WAVE DIRECTIONS
'-------------------------------------------------------------------
'ihead head
 1      0.0000000
 2      30.0000000
 3      60.0000000
 4      90.0000000
 5      120.0000000
 6      135.0000000
 7      150.0000000
 8      165.0000000
 9      180.0000000
'*********************************************************************
**
 ENVIRONMENT IDENTIFICATION
'*********************************************************************
**
'idenv
 ENV
'-------------------------------------------------------------------
 WATERDEPTH AND WAVETYPE
'-------------------------------------------------------------------
'wdepth       noirw norw ncusta nwista
 1000.0000000 1     0    1      0
'-------------------------------------------------------------------
 ENVIRONMENT CONSTANTS
'-------------------------------------------------------------------
'airden        watden    wakivi    airkivi
 1.3000000e-03 1.0250000 1.0000000 1.8800000e-06
'-------------------------------------------------------------------
 NEW IRREGULAR SEASTATE
'-------------------------------------------------------------------
'nirwc iwasp1 iwadr1 iwasp2 iwadr2
 1     3      0      0      0
'-------------------------------------------------------------------
 WAVE SPECTRUM WIND
'-------------------------------------------------------------------
'omega     alfa          beta gamma siga sigb
 0.5000000 8.0000000e-03 /    /     /    /
'-------------------------------------------------------------------
 DIRECTION PARAMETERS
'-------------------------------------------------------------------
'wadr1     expo1
 0.0000000 2.0000000
'-------------------------------------------------------------------
 NEW CURRENT STATE
```

```
'------------------------------------------------------------------------------
'icusta nculev l_ext
 1      4      0

'curlev    curdir    curvel
 0.0000000 0.0000000 0.9300000
 -50.0000000 0.0000000 0.6800000
 -300.0000000 0.0000000 0.4700000
 -1000.0000000 0.0000000 0.0000000
'************************************************************************
**
 END
'************************************************************************
**
```

# INPMOD: WEIGHT-DISTRIBUTED SCR NEAR POSITION

```
'************************************************************************
**
 INPMOD IDENTIFICATION TEXT 4.0
'************************************************************************
**
'--------------------------------------------------------------------------------
 UNIT NAMES SPECIFICATION
'--------------------------------------------------------------------------------
'ut ul um uf grav gcons
 s  m  Mg kN /    1.0000000
'************************************************************************
**
 NEW SINGLE RISER
'************************************************************************
**
'atyps idris
 AR    ARSYS
'************************************************************************
**
ARBITRARY SYSTEM AR
'************************************************************************
**
'nsnod nlin nsnfix nves nricon nspr nack
 2    1   2     1   0      0    0

'ibtang zbot          ibot3d
 1      -1000.0000000 0

'stfbot     stfaxi    stflat    friaxi    frilat    dambot    damaxi    damlat
 600.0000000 0.0000000 10.0000000 0.0000000 0.5000000 0.0000000 0.0000000
0.0000000

'B 6.5: LINE TOPOLOGY DEFINITION
'lineid lintyp-id snod1-id snod2-id
 line1  ltyp1     Floa31   Bott16

'FIXED NODES

'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 Bott16  0    1  1  1  0   0   0   GLOBAL NO

'x0          y0       z0           x1           y1       z1           rot      dir
 2120.7150000 0.0000000 -1000.0000000 1850.0000000 0.0000000 -1000.0000000
0.0000000 0.0000000

'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 Floa31  1    1  1  1  0   0   0   GLOBAL NO
```

```
'x0         y0       z0       x1         y1       z1       rot       dir
 -61.0270000 0.0000000 0.0000000 100.0000000 0.0000000 0.0000000 0.0000000
0.0000000

'FREE NODES

'ives idwftr xg        yg       zg        dirx
 1    Seaf   40.0000000 0.0000000 0.0000000 0.0000000

'B.10 Line and segment specification
'**********************************************************************
**
 NEW LINE DATA
'**********************************************************************
**

'lintyp-id nseg ncmpty2 flutyp iaddtwi
 ltyp1     5    0       crudbe 0

'crstyp ncmpty1 exwtyp nelseg slgth       nstrps nstrpd slgth0      isoity

 Normca 0       0      34     170.0000000 3      5      170.0000000 0

 Heave9 0       0      156    780.0000000 3      5      780.0000000 0

 Lighcc 0       0      20     100.0000000 3      5      100.0000000 0

 Ligh76 0       0      72     360.0000000 3      5      360.0000000 0

 Normca 0       0      198    990.0000000 3      5      990.0000000 0

'**********************************************************************
**
 NEW COMPONENT CRS0
'**********************************************************************
**
'cmptyp-id temp       alpha     beta
 Ligh76    20.0000000 0.0000000 0.0000000

'diast      thst         densst    thex      densex    r-extcnt  r-intcnt
 -0.2540000 2.5400000e-02 7.8500000 0.1000000 0.6000000 0.0000000 0.0000000

'matkind emod          gmod
 1       2.0700000e+08 8.0000000e+07

'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb          ycurmx
```

```
 1.0000000e-03 1.0000000
'*****************************************************************************
**
 NEW COMPONENT CRS0
'*****************************************************************************
**
'cmptyp-id temp      alpha     beta
 Normca    20.0000000 0.0000000 0.0000000

'diast     thst         densst    thex      densex    r-extcnt  r-intcnt
 -0.2540000 2.5400000e-02 7.8500000 0.1000000 0.9000000 0.0000000 0.0000000

'matkind emod          gmod
 1       2.0700000e+08 8.0000000e+07

'cqx      cqy       cax       cay       clx       cly       icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb           ycurmx
 1.0000000e-03 1.0000000
'*****************************************************************************
**
 NEW COMPONENT CRS0
'*****************************************************************************
**

'cmptyp-id temp      alpha     beta
 Lighcc    20.0000000 0.0000000 0.0000000

'diast     thst         densst    thex      densex    r-extcnt  r-intcnt
 -0.2540000 2.5400000e-02 7.8500000 0.1000000 1.7000000 0.0000000 0.0000000

'matkind emod          gmod
 1       2.0700000e+08 8.0000000e+07

'cqx      cqy       cax       cay       clx       cly       icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb           ycurmx
 1.0000000e-03 1.0000000
'*****************************************************************************
**
 NEW COMPONENT CRS0
'*****************************************************************************
**
'cmptyp-id temp      alpha     beta
 Heave9    20.0000000 0.0000000 0.0000000

'diast     thst         densst    thex      densex    r-extcnt  r-intcnt
```

```
 -0.2540000 2.5400000e-02 7.8500000 0.1000000 2.7000000 0.0000000 0.0000000

'matkind emod         gmod
 1       2.0700000e+08 8.0000000e+07

'cqx      cqy      cax      cay      clx      cly      icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb            ycurmx
 1.0000000e-03 1.0000000
'************************************************************************
**
 NEW COMPONENT FLUID
'************************************************************************
**
'cmptyp-id
 crudbe

'rhoi     vveli    pressi       dpress   idir
 0.7500000 0.0000000 20000.0000000 0.0000000 2
'************************************************************************
**
 SUPPORT VESSEL IDENTIFICATION
'************************************************************************
**
'idhftr
 Seaf
'--------------------------------------------------------------------
 HFTRANSFER REFERENCE POSITION
'--------------------------------------------------------------------
'zg
 0.0000000
'--------------------------------------------------------------------
 HFTRANSFER CONTROL DATA
'--------------------------------------------------------------------
'ndhftr nwhftr isymhf itypin
 9     30     1     2
'--------------------------------------------------------------------
 WAVE DIRECTIONS
'--------------------------------------------------------------------
'ihead head
 1     0.0000000
 2     30.0000000
 3     60.0000000
 4     90.0000000
 5     120.0000000
 6     135.0000000
 7     150.0000000
 8     165.0000000
```

```
 9     180.0000000

'***************************************************************
**
 ENVIRONMENT IDENTIFICATION
'***************************************************************
**
'idenv
 ENV
'-----------------------------------------------------------------------
 WATERDEPTH AND WAVETYPE
'-----------------------------------------------------------------------
'wdepth       noirw norw ncusta nwista
 1000.0000000 1     0    1      0
'-----------------------------------------------------------------------
 ENVIRONMENT CONSTANTS
'-----------------------------------------------------------------------
'airden        watden    wakivi    airkivi
 1.3000000e-03 1.0250000 1.0000000 1.8800000e-06
'-----------------------------------------------------------------------
 NEW IRREGULAR SEASTATE
'-----------------------------------------------------------------------
'nirwc iwasp1 iwadr1 iwasp2 iwadr2
 1     3      0      0      0
'-----------------------------------------------------------------------
 WAVE SPECTRUM WIND
'-----------------------------------------------------------------------
'omega     alfa          beta gamma siga sigb
 0.5000000 5.0000000e-03 /    /     /    /
'-----------------------------------------------------------------------
 DIRECTION PARAMETERS
'-----------------------------------------------------------------------
'wadr1     expo1
 0.0000000 2.0000000
'-----------------------------------------------------------------------
 NEW CURRENT STATE
'-----------------------------------------------------------------------
'icusta nculev l_ext
 1      4      0
'curlev    curdir    curvel
 0.0000000 0.0000000 0.9300000
 -50.0000000 0.0000000 0.6800000
 -300.0000000 0.0000000 0.4700000
 -1000.0000000 0.0000000 0.0000000
'***************************************************************
**
 END
'***************************************************************
**
```

## INPMOD: WEIGHT-DISTRIBUTED SCR MEAN POSITION

```
'**********************************************************************
**
 INPMOD IDENTIFICATION TEXT 4.0
'**********************************************************************
**
'----------------------------------------------------------------------
 UNIT NAMES SPECIFICATION
'----------------------------------------------------------------------
'ut ul um uf grav gcons
 s  m  Mg kN /    1.0000000
'**********************************************************************
**
 NEW SINGLE RISER
'**********************************************************************
**
'atyps idris
 AR    ARSYS
'**********************************************************************
**
 ARBITRARY SYSTEM AR
'**********************************************************************
**
'nsnod nlin nsnfix nves nricon nspr nack
 2    1   2     1   0      0    0

'ibtang zbot          ibot3d
 1      -1000.0000000 0

'stfbot     stfaxi    stflat    friaxi    frilat    dambot    damaxi    damlat
 600.0000000 0.0000000 10.0000000 0.0000000 0.5000000 0.0000000 0.0000000
0.0000000

'B 6.5: LINE TOPOLOGY DEFINITION

'lineid lintyp-id snod1-id snod2-id
 line1  ltyp1     Floa31   Bott16

'FIXED NODES

'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 Bott16  0    1  1  1  0    0    0   GLOBAL NO

'x0          y0        z0            x1           y1        z1            rot       dir
 2120.7150000 0.0000000 -1000.0000000 1850.0000000 0.0000000 -1000.0000000
0.0000000 0.0000000

'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 Floa31  1    1  1  1  0    0    0   GLOBAL NO
```

```
'x0        y0       z0       x1       y1       z1       rot       dir
 -61.0270000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000
0.0000000

'FREE NODES

'ives idwftr xg        yg       zg       dirx
 1    Seaf   40.0000000 0.0000000 0.0000000 0.0000000

'B.10 Line and segment specification
'************************************************************************
**
 NEW LINE DATA
'************************************************************************
**
'lintyp-id nseg ncmpty2 flutyp iaddtwi
 ltyp1     5    0       crudbe 0

'crstyp ncmpty1 exwtyp nelseg slgth       nstrps nstrpd slgth0      isoity

 Normca 0       0      34     170.0000000 3      5      170.0000000 0

 Heave9 0       0      156    780.0000000 3      5      780.0000000 0

 Lighcc 0       0      20     100.0000000 3      5      100.0000000 0

 Ligh76 0       0      72     360.0000000 3      5      360.0000000 0

 Normca 0       0      198    990.0000000 3      5      990.0000000 0

'************************************************************************
**
 NEW COMPONENT CRS0
'************************************************************************
**
'cmptyp-id temp       alpha     beta
 Ligh76    20.0000000 0.0000000 0.0000000

'diast     thst         densst    thex      densex    r-extcnt  r-intcnt
 -0.2540000 2.5400000e-02 7.8500000 0.1000000 0.6000000 0.0000000 0.0000000

'matkind emod          gmod
 1       2.0700000e+08 8.0000000e+07

'cqx       cqy       cax       cay       clx       cly       icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb          ycurmx
```

```
 1.0000000e-03 1.0000000
'**********************************************************************
**
 NEW COMPONENT CRS0
'**********************************************************************
**
'cmptyp-id temp      alpha     beta
 Normca    20.0000000 0.0000000 0.0000000

'diast     thst        densst    thex      densex    r-extcnt  r-intcnt
 -0.2540000 2.5400000e-02 7.8500000 0.1000000 0.9000000 0.0000000 0.0000000

'matkind emod          gmod
 1       2.0700000e+08 8.0000000e+07

'cqx      cqy      cax      cay      clx      cly      icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb            ycurmx
 1.0000000e-03 1.0000000
'**********************************************************************
**
 NEW COMPONENT CRS0
'**********************************************************************
**
'cmptyp-id temp      alpha     beta
 Lighcc    20.0000000 0.0000000 0.0000000

'diast     thst        densst    thex      densex    r-extcnt  r-intcnt
 -0.2540000 2.5400000e-02 7.8500000 0.1000000 1.7000000 0.0000000 0.0000000

'matkind emod          gmod
 1       2.0700000e+08 8.0000000e+07

'cqx      cqy      cax      cay      clx      cly      icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb            ycurmx
 1.0000000e-03 1.0000000
'**********************************************************************
**
 NEW COMPONENT CRS0
'**********************************************************************
**
'cmptyp-id temp      alpha     beta
 Heave9    20.0000000 0.0000000 0.0000000

'diast     thst        densst    thex      densex    r-extcnt  r-intcnt
 -0.2540000 2.5400000e-02 7.8500000 0.1000000 2.7000000 0.0000000 0.0000000
```

```
'matkind emod        gmod
 1       2.0700000e+08 8.0000000e+07

'cqx      cqy       cax       cay       clx       cly       icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb            ycurmx
 1.0000000e-03 1.0000000
'************************************************************************
**
 NEW COMPONENT FLUID
'************************************************************************
**
'cmptyp-id
 crudbe

'rhoi      vveli     pressi        dpress    idir
 0.7500000 0.0000000 20000.0000000 0.0000000 2
'************************************************************************
**
 SUPPORT VESSEL IDENTIFICATION
'************************************************************************
**
'idhftr
 Seaf
'--------------------------------------------------------------------
 HFTRANSFER REFERENCE POSITION
'--------------------------------------------------------------------
'zg
 0.0000000
'--------------------------------------------------------------------
 HFTRANSFER CONTROL DATA
'--------------------------------------------------------------------
'ndhftr nwhftr isymhf itypin
 9      30     1      2
'--------------------------------------------------------------------
 WAVE DIRECTIONS
'--------------------------------------------------------------------
'ihead head
 1      0.0000000
 2      30.0000000
 3      60.0000000
 4      90.0000000
 5      120.0000000
 6      135.0000000
 7      150.0000000
 8      165.0000000
 9      180.0000000
```

```
'******************************************************************
**
 ENVIRONMENT IDENTIFICATION
'******************************************************************
**
'idenv
 ENV
'------------------------------------------------------------------
 WATERDEPTH AND WAVETYPE
'------------------------------------------------------------------
'wdepth       noirw norw ncusta nwista
 1000.0000000 1     0    1      0
'------------------------------------------------------------------
 ENVIRONMENT CONSTANTS
'------------------------------------------------------------------
'airden       watden    wakivi    airkivi
 1.3000000e-03 1.0250000 1.0000000 1.8800000e-06
'------------------------------------------------------------------
 NEW IRREGULAR SEASTATE
'------------------------------------------------------------------
'nirwc iwasp1 iwadr1 iwasp2 iwadr2
 1     3      0      0      0
'------------------------------------------------------------------
 WAVE SPECTRUM WIND
'------------------------------------------------------------------
'omega     alfa          beta gamma siga sigb
 0.5000000 5.0000000e-03 /    /     /    /
'------------------------------------------------------------------
 DIRECTION PARAMETERS
'------------------------------------------------------------------
'wadr1     expo1
 0.0000000 2.0000000
'------------------------------------------------------------------
 NEW CURRENT STATE
'------------------------------------------------------------------
'icusta nculev l_ext
 1      4      0

'curlev    curdir    curvel
 0.0000000 0.0000000 0.9300000
 -50.0000000 0.0000000 0.6800000
 -300.0000000 0.0000000 0.4700000
 -1000.0000000 0.0000000 0.0000000
'******************************************************************
**
 END
'******************************************************************
**
```

## INPMOD: WEIGHT-DISTRIBUTED SCR FAR POSITION

```
'******************************************************************
**
 INPMOD IDENTIFICATION TEXT 4.0
'******************************************************************
**
'-----------------------------------------------------------------
 UNIT NAMES SPECIFICATION
'-----------------------------------------------------------------
'ut ul um uf grav gcons
 s  m  Mg kN /    1.0000000
'******************************************************************
**
 NEW SINGLE RISER
'******************************************************************
**
'atyps idris
 AR    ARSYS
'******************************************************************
**
 ARBITRARY SYSTEM AR
'******************************************************************
**
'nsnod nlin nsnfix nves nricon nspr nack
 2    1   2     1   0      0    0

'ibtang zbot          ibot3d
 1      -1000.0000000 0

'stfbot     stfaxi    stflat    friaxi    frilat    dambot    damaxi    damlat
 600.0000000 0.0000000 10.0000000 0.0000000 0.5000000 0.0000000 0.0000000
0.0000000

'B 6.5: LINE TOPOLOGY DEFINITION

'lineid lintyp-id snod1-id snod2-id
 line1  ltyp1     Floa31   Bott16

'FIXED NODES

'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 Bott16  0    1  1  1  0   0   0   GLOBAL NO

'x0          y0        z0            x1          y1        z1           rot       dir
 2120.7150000 0.0000000 -1000.0000000 1850.0000000 0.0000000 -1000.0000000
0.0000000 0.0000000

'snod-id ipos ix iy iz irx iry irz chcoo  chupro
 Floa31  1    1  1  1  0   0   0   GLOBAL NO
```

```
'x0        y0       z0       x1         y1       z1       rot      dir
 -61.0270000 0.0000000 0.0000000 -100.0000000 0.0000000 0.0000000 0.0000000
0.0000000

'FREE NODES

'ives idwftr xg        yg       zg       dirx
 1    Seaf   40.0000000 0.0000000 0.0000000 0.0000000

'B.10 Line and segment specification
'*****************************************************************************
**
 NEW LINE DATA
'*****************************************************************************
**
'lintyp-id nseg ncmpty2 flutyp iaddtwi
 ltyp1     5    0       crudbe 0

'crstyp ncmpty1 exwtyp nelseg slgth       nstrps nstrpd slgth0      isoity
 Normca 0       0      34     170.0000000 3      5      170.0000000 0

 Heave9 0       0      156    780.0000000 3      5      780.0000000 0

 Lighcc 0       0      20     100.0000000 3      5      100.0000000 0

 Ligh76 0       0      72     360.0000000 3      5      360.0000000 0

 Normca 0       0      198    990.0000000 3      5      990.0000000 0
'*****************************************************************************
**
 NEW COMPONENT CRS0
'*****************************************************************************
**
'cmptyp-id temp       alpha     beta
 Ligh76    20.0000000 0.0000000 0.0000000

'diast     thst         densst    thex      densex    r-extcnt  r-intcnt
 -0.2540000 2.5400000e-02 7.8500000 0.1000000 0.6000000 0.0000000 0.0000000

'matkind emod          gmod
 1       2.0700000e+08 8.0000000e+07

'cqx      cqy       cax       cay       clx       cly       icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb            ycurmx
 1.0000000e-03 1.0000000
'*****************************************************************************
**
```

```
 NEW COMPONENT CRS0
'************************************************************************
**
'cmptyp-id temp       alpha    beta
 Normca    20.0000000 0.0000000 0.0000000

'diast     thst        densst   thex     densex    r-extcnt  r-intcnt
 -0.2540000 2.5400000e-02 7.8500000 0.1000000 0.9000000 0.0000000 0.0000000

'matkind emod          gmod
 1       2.0700000e+08 8.0000000e+07

'cqx      cqy      cax      cay      clx      cly      icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb            ycurmx
 1.0000000e-03 1.0000000
'************************************************************************
**
 NEW COMPONENT CRS0
'************************************************************************
**
'cmptyp-id temp       alpha    beta
 Lighcc    20.0000000 0.0000000 0.0000000

'diast     thst        densst   thex     densex    r-extcnt  r-intcnt
 -0.2540000 2.5400000e-02 7.8500000 0.1000000 1.7000000 0.0000000 0.0000000

'matkind emod          gmod
 1       2.0700000e+08 8.0000000e+07

'cqx      cqy      cax      cay      clx      cly      icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb            ycurmx
 1.0000000e-03 1.0000000
'************************************************************************
**
 NEW COMPONENT CRS0
'************************************************************************
**
'cmptyp-id temp       alpha    beta
 Heave9    20.0000000 0.0000000 0.0000000

'diast     thst        densst   thex     densex    r-extcnt  r-intcnt
 -0.2540000 2.5400000e-02 7.8500000 0.1000000 2.7000000 0.0000000 0.0000000

'matkind emod          gmod
```

```
 1      2.0700000e+08 8.0000000e+07

'cqx      cqy      cax      cay      clx      cly      icode d
 0.0000000 1.0000000 0.0000000 1.0000000 0.0000000 0.0000000 2     0.4302000

'tb           ycurmx
 1.0000000e-03 1.0000000
'************************************************************************
**
 NEW COMPONENT FLUID
'************************************************************************
**
'cmptyp-id
 crudbe

'rhoi     vveli     pressi       dpress    idir
 0.7500000 0.0000000 20000.0000000 0.0000000 2
'************************************************************************
**
 SUPPORT VESSEL IDENTIFICATION
'************************************************************************
**
'idhftr
 Seaf
'----------------------------------------------------------------------------
 HFTRANSFER REFERENCE POSITION
'----------------------------------------------------------------------------
'zg
 0.0000000
'----------------------------------------------------------------------------
 HFTRANSFER CONTROL DATA
'----------------------------------------------------------------------------
'ndhftr nwhftr isymhf itypin
 9     30     1     2
'----------------------------------------------------------------------------
 WAVE DIRECTIONS
'----------------------------------------------------------------------------
'ihead head
 1     0.0000000
 2     30.0000000
 3     60.0000000
 4     90.0000000
 5     120.0000000
 6     135.0000000
 7     150.0000000
 8     165.0000000
 9     180.0000000
'************************************************************************
**
```

```
 ENVIRONMENT IDENTIFICATION
'**********************************************************************
**
'idenv
 ENV
'----------------------------------------------------------------------
 WATERDEPTH AND WAVETYPE
'----------------------------------------------------------------------
'wdepth       noirw norw ncusta nwista
 1000.0000000 1     0    1      0
'----------------------------------------------------------------------
 ENVIRONMENT CONSTANTS
'----------------------------------------------------------------------
'airden        watden    wakivi    airkivi
 1.3000000e-03 1.0250000 1.0000000 1.8800000e-06
'----------------------------------------------------------------------
 NEW IRREGULAR SEASTATE
'----------------------------------------------------------------------
'nirwc iwasp1 iwadr1 iwasp2 iwadr2
 1     3      0      0      0
'----------------------------------------------------------------------
 WAVE SPECTRUM WIND
'----------------------------------------------------------------------
'omega     alfa          beta gamma siga sigb
 0.5000000 5.0000000e-03 /    /     /    /
'----------------------------------------------------------------------
 DIRECTION PARAMETERS
'----------------------------------------------------------------------
'wadr1     expo1
 0.0000000 2.0000000
'----------------------------------------------------------------------
 NEW CURRENT STATE
'----------------------------------------------------------------------
'icusta nculev l_ext
 1      4      0

'curlev    curdir    curvel
 0.0000000 0.0000000 0.9300000
 -50.0000000 0.0000000 0.6800000
 -300.0000000 0.0000000 0.4700000
 -1000.0000000 0.0000000 0.0000000
'**********************************************************************
**
 END
'**********************************************************************
**
```