

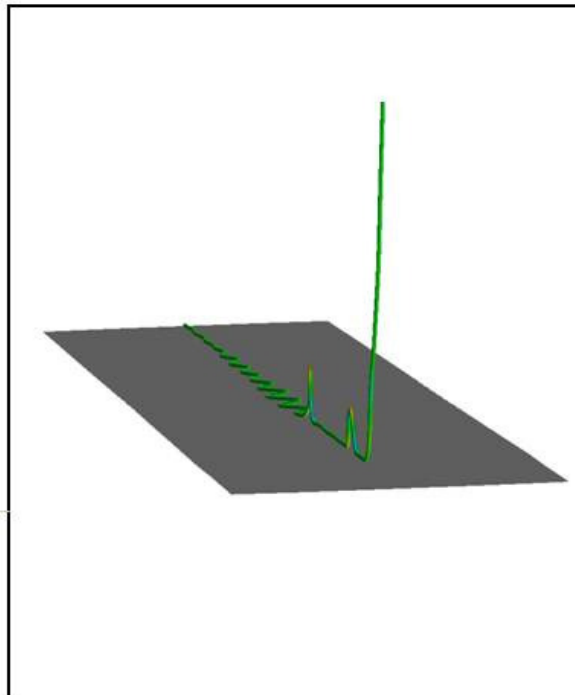
Master's thesis

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Simulation of dynamic umbilical installation effects

Trondheim, Spring 2010



THESIS WORK SPRING 2010

for

Stud. tech. Karl Erik Holum

Simulation of dynamic umbilical installation effects

Simulering av dynamiske effekter under kabelinstallasjon

The background for this study is a request from the industry related to the need of installing long length umbilicals utilizing large capacity vessels designed for installation of steel pipelines. In this way the umbilical installation can be performed without splicing, increasing the overall reliability of the umbilical.

In this project, the installation vessel Apache operated by Technip is to be studied. The umbilical is entering the seawater at the stern of the vessel. This means significant pitch induced heave motions of the umbilical. Since the umbilical has limited submerged weight it is dynamic sensitive. This may lead to compression at the touch down point (TDP) which is the major issue in this work.

The project work is to be carried out as follows:

1. Literature study, including non-linear finite element methods with focus on the methods applied in computer programs such as OFFPIPE, RIFLEX and SIMLA. The candidate is to list available programs for dynamic analysis of the lay operation. The literature study is also to include models for describing the pipe soil interaction in clay and sand soils and umbilical technology in general.
2. Define a lay scenario in terms of water depth, vessel geometry, vessel RAO, umbilical properties, hydrodynamic coefficients, environmental conditions and pipe-soil interaction parameters.
3. Establish a model in RIFLEX and SIMLA and study the structural response at different environmental conditions (regular wave and at least 10 sea states) and different apparent weight ratios ($((\text{dry weight in kg})/(\text{external area} \cdot \text{water density}))$, $1 = \text{neutral buoyant} = 0$ submerged weight).
4. Compare the curvature and axial force envelopes obtained from the two programs and also evaluate the results with regard to umbilical failure (minimum curvature radius).
5. Conclusions and recommendations for further work

The work scope may prove to be larger than initially anticipated. Subject to approval from the supervisors, 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.

Thesis format

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 numerated.

The supervisors may require that the candidate, in an early stage of the work, presents 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.

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Thesis supervisors

Prof. Svein Sævik

Deadline: June 14, 2010

Trondheim, February 2, 2010

Svein Sævik

Preface

This report is the result of a master's thesis by student Karl Erik Holum at the Norwegian University of Science and Technology, spring 2010. The thesis is a continuation of the work done in the project thesis during the fall of 2009, and it is performed as a part of my M.Sc. degree in marine technology, with specialization in marine hydrodynamics.

The main purpose of this thesis is to analyze the compressions at the touch down point for umbilicals due to dynamic installation effects, and to compare the obtained results from two computer programs, SIMLA and RIFLEX. Similar models have been made in both programs, and analyses have been run and compared for 20 sea states.

I would like to thank my advisor, Prof. Svein Sævik at the Department of Marine Technology, NTNU, and Kjetil Gjølstdal and Johan Kristian Bø at Technip for their continues support throughout the entire process. I would also like to thank MARINTEK for help with installation, information about the programs and the license of RIFLEX and SIMLA.

Trondheim, June 21th, 2010.

Karl Erik Holum
Stud.

Summary

The background for this study is a request from Technip related to the need of installing of long length umbilicals utilizing large capacity vessels designed for installation of steel pipelines. The installation vessel, Apache, operated by Technip, has for this reason been studied.

Two computer programs developed by Marintek, SIMLA and RIFLEX, have been used for this study. A literature study has taken place on the background theories of the programs. They are both based on the finite element method, and they analyze given problems very similarly. Nevertheless, one main difference was found, and that difference is in how they solve the dynamic time domain analyses. RIFLEX uses a Newmark β -method, while SIMLA uses HHT α -method.

A lay scenario and 20 sea states have been defined and modeled in both RIFLEX and SIMLA. The chosen lay scenario is at 360 meters water depth. The seabed is completely flat, thus no free spans will affect the result. All sea states are regular waves with wave propagation run directly against the course of the vessel. The umbilical is a thin and light weight umbilical with a diameter of only 9 cm.

Both static and dynamic analyses have been run for all sea states. Results from all sea states have been thoroughly studied and described. It was found that for this lay scenario, RIFLEX run the analyses more than twice as fast as SIMLA.

The static results are close to being identical for both programs, showing that the modeling must be correct considering the overall arrangement and orientations for the lay scenario, and considering the umbilical data like size, weights and the different stiffness properties.

The dynamic results show that for all results for sea states without compression, the two programs are quite similar. It is shown that RIFLEX also at this stage shows larger values than SIMLA, but the curvature of the plots are very similar. There is a big change of the RIFLEX results for the sea states where there are induced compressions at the touch down point. The compression seems to trigger a variable which makes irrational results for all contact elements of the umbilical and the sea bed. Many peaks can be observed, which is illogical.

SIMLA handles the compression very well, and do still return stable and smooth graphs as a result. As well as the smooth and reliable graphs, the end results from SIMLA are for all sea states smaller than for RIFLEX. This would in a real life project allow installations in heavier sea with use of SIMLA. A run in SIMLA was experienced as a much slower than RIFLEX.

All in all, it has been observed large differences in the dynamic results, especially for the load conditions inducing compression. There is one known modeling error, there might be more, and there is one main difference in the way the programs do dynamic analyses. It is reasonable to believe that the HHT α -method used in SIMLA are the reason for the smoother and more reliable graphs.

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1 Introduction

1.1 Background

Technip has stated that in some of their in-house analyses of umbilical installations, unexpected compression at the touch down point has been a result for some sea states.

It is believed that these results do not describe the actual installation correctly. These results define the sea states for when the installations can be carried out. Stating that there will be too large compression at the touch down point, leading to big bending moments and buckling, when the actual compression is smaller, will stop installations unnecessarily. As a delay of an installation is very expensive, it is naturally an unwanted situation to experience a delay due to incorrect compression analysis.

1.2 Scope

The scope of this thesis is mainly to establish models of a chosen lay scenario in RIFLEX and in SIMLA, and study the different structural responses at different environmental conditions. Furthermore, it is important to do a literature study to first of all get a general wide understanding of the installation scenario. Secondly, it is important to get a better understand of the differences of the programs. This is done by a study of the background theory for both programs. Both programs are based on the finite element method, and the lay scenario including a slender marine structure, will the encounter many nonlinear effect. Thus the nonlinear finite element method is central.

1.3 Thesis structure

Abstract	Gives an introduction to the world of the umbilical, and lists programs which are suitable for detailed analyses of umbilical systems.
Nonlinear Finite Element Analyses	Was meant to describe the basic methods applied in both RIFLEX and SIMLA.
Modeling	This chapter provides an overveiw of how to use RIFLEX and SIMLA. A short description of the input and output files are given.
Differences SIMLA/RIFLEX	This chapter gives a detailed description of the main difference of the two programs.
Lay scenario	The lay scenario is defined in detail.
Results	All results are given. Static, dynamic and maximum values are described
Conclusion	Thoughts, trends and observations of the results are discussed.

2 Abstract

2.1 Umbilical

Pipelines and umbilicals are key elements in subsea infrastructure for energy transport. A subsea umbilical is an essential link normally used to control subsea structures from a platform or a vessel. It is normally an assembly of many components, which makes it possible to support many systems with only one cable. The assembly may be hydraulic hoses for hydraulic control of subsea wells, electrical cables or optical fibres for data transmission, communication and electrical power.

Deepwater engineering always strive to go deeper, and research is now underway for designing umbilical depths to 4000 meters (*ref.1*).

2.1.1 Examples installations

The examples are installations by Nexans Norway (www.offshore-technology.com):

- **SNØVHVIT, NORWAY:** Five umbilicals containing electric power supply cables, fibre optic cables, hydraulic tubes for controlling and injection of chemicals. The lengths vary from 29 km to 145 km.
- **Ormen Lange, Norway:** Three umbilicals supply hydraulic fluid, electrical power and fibre optic signals required to operate the subsea production systems at 850m water depth.
- **Dolphin, Middle East:** Two umbilicals with respective lengths of 90km and 75km, will supply corrosion inhibitor, hydrate inhibitor and diesel fuel to two platforms, as well as facilitating communication via a fibre optic element.
- **Thunder Horse, Mexico:** BP's Thunder Horse is one of the largest oilfields discovered in the Gulf of Mexico. Nexans delivered 120km steel tube umbilicals to this field in 2005. The umbilicals are installed in maximum water depth of 1,890m.
- **Nakika, Gulf of Mexico:** Ten umbilicals of total length 135 km interlink six oil fields. The umbilicals supply hydraulic control, chemical injection, transfer of electrical power, and communication signals.

2.1.2 Example types

The following show the wide specter of umbilicals used (www.umf.as):

- Subsea Production Umbilicals
- Flying Leads and Jumper Umbilicals
- Intervention Umbilicals
- Workover Umbilicals
- Subsea Isolation Valve Umbilicals
- Blowout Preventer Umbilicals
- Subsea Power Umbilicals
- Pile-Driving Umbilicals Jacket Submergence Umbilicals
- Topsides Wellhead Control Umbilicals

2.2 Build up

All umbilicals are specifically designed for each and every project, and therefore it is difficult to specify exactly how an umbilical is built. The same for all umbilicals is that there are that there is some kind of energy transport in the center. This could be one, or plenty different signal cables or hoses. Depending of the size of the energy transport, the depth and the other loads the umbilical will have to endure, the protection layers are designed.

There might be

- Insulating layers
- Layers for buoyancy purposes
- Layers which endure inner or/and outer pressure
- Steel layers to control compression, tension and torsion

The following pictures show examples of umbilicals (www.xvision.no; www.xvision.no):



Figure 1: Cross section of an umbilical

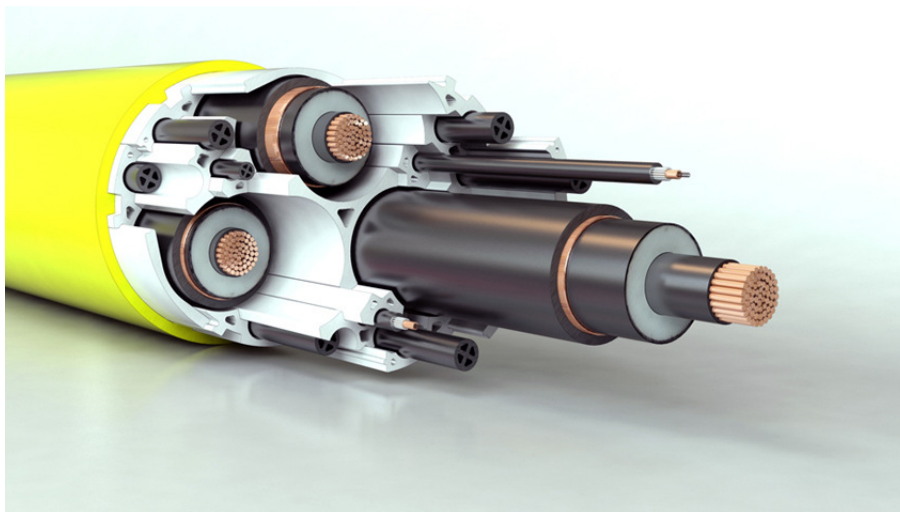


Figure 2: Umbilical

2.3 Umbilical installation procedure

2.3.1.1 Onshore preparations

DNV offshore standard, OS-F101, is the most updated standard on design and installation of offshore pipelines, and it covers among others the following issues to be considered prior to:

- Pre-installation route survey
- Seabed preparation
- Pipeline and cable crossing
- Shore approach

During laying operation the standard requires that several critical parameters are surveilled by instrumentation. Among these parameters are:

- Pipeline tension
- Reaction loads on first and last roller in stinger
- Vessel position
- Vessel motion
- Environmental conditions

Planning of marine operations shall be according to the *fail safe* principles, i.e. the handled object shall remain in a stable and controlled condition if a failure should occur (Nielsen, 2007).

During the planning of an installation, many detailed static and dynamic analyses are performed in order to determine the weather conditions under which the operation may take place. This is the operational weather window. Weather windows may either be established for the whole operation, or different weather windows may be established for different phases of the operation, e.g., depending on water depth, bottom conditions or prevailing current along the route. To allow these weather windows to be established, representative conditions must be chosen for each part of the route.

If the weather deteriorates during the operation so that forecasted weather conditions are not within the weather window, the operation must be halted until the weather conditions improve. Considering the day rates for laying barges, the increased costs may be significant. A delay may also be detrimental to the total project.

During the design process, detailed analyses are performed to determine for which weather conditions the umbilical will tolerate installation (Passano, 2008).

The use of envelope curves during dynamic analyses will show, among other things, maximum handling tension and minimum bending radius for the chosen time series. By comparing the maximum values from the envelope curves with the known maximum handling tension and minimum bending radius the umbilical can endure, the engineer can see if the sea state chosen in the dynamic analyses was approved.

2.3.1.2 Load out

Apache transits to an umbilical manufacturer's site and moors stern to quay. The umbilical laydown end is transferred over to Apache's main reel and seafastened. Monitoring devices are then connected to the termination head to enable monitoring of hydraulic lines pressure and electrical lines continuity throughout spooling umbilical from shore storage to Apache main reel. Spooling is performed using a catenary between vessel and quay to level out velocity variation between onshore umbilical handling arrangement and vessel reel. After the umbilical initiation head has seafastened on the vessel, a post load out test is performed. This is to verify that no incidents have occurred during the spooling (Holen, 2010).

2.3.1.3 Installation

Apache transits to field and performs dynamic positioning trials. Preparations are initiated, like verification of suitable weather window for the actual installation task. The initiation head, which is the last termination head arriving onboard during load out, is deployed and lowered towards the seabed. An initiation wire, typically 30m long, in front of the initiation head is hooked up to the seabed initiation point as soon as reach is enabled.

Umbilical lay catenary is then established through the process of stepwise paying out umbilical while vessel is stepped away from the initiation point. A WROV is at seabed observing the initiation point, the initiation head landing and the forming of the catenary ensuring no MBR exceedance. The umbilical laying is then performed by extracting the umbilical stepwise and moving the vessel accordingly along curves resulting in an umbilical landing along preset route at the seabed. WROV observes the travelling umbilical TDP and sends position data and video back to the installation vessel control room.

During the laying Apache longitudinal axis will be held in the lay catenary plane i.e. tangent to the seabed umbilical turns despite incoming weather / wave loads, directions and magnitude inside the approved weather window criteria.

To finalize the installation the monitoring system is disconnected, the umbilical lay down head is released from Apache's reel and deployed. It is then lowered and landed in the dedicated position using an A&R winch wire (Holen, 2010).

2.4 FEM based computer programs

There are many FEM based computer programs on the market, other than SIMLA and RIFLEX. This is a brief overview of some of the other programs that might be used for analysis of lay operations. All the information below is found on the respective home pages for the companies who have developed the programs. Since the companies are trying to sell the products on the home pages, all the information is believed to be superficial, but somewhat true. Most programs are based on an easy-to-use graphical user interface, which is not incorporated in SIMLA and RIFLEX.

OrcaFlex

Orcaflex (www.orcina.com) is a program developed by Orcina, and is the world's leading software package for the design and analysis of offshore marine systems. This is the standard program for Technips pipe laying analyses.

OrcaLay

OrcaLay (www.orcina.com) is also a program developed by Orcina, and is a second generation pipe lay optimization software tool

OFFPIPE

OFFPIPE (www.offpipe.com) has been developed specifically for the modeling and structural analysis of nonlinear problems encountered in the installation and operation of offshore pipelines.

PipeLay

PipeLay (www.mcs.com) is the state-of-the-art software application for offshore pipeline installation analysis. The program has been developed from the ground up as a specialized engineering tool to provide a comprehensive and modern solution to the analysis requirements of offshore pipeline installation. It incorporates a familiar user interface and a range of productivity-enhancing features. PipeLay is specialized for the following:

- J-Lay
- S-Lay
- Reeled installation

Flexcom

Flexcom (www.mcs.com) is the leading nonlinear finite element against third party software and model tests. It is used all over the world by oil companies, flexible pipe and equipment manufacturers, contractors and consultants, and has been widely validated. Here are some of the systems Flexcom is able to analyze:

- Flexible Risers
- Rigid Risers
- Catenary Risers
- Hybrid Risers
- Mooring Systems

DeepLines

DeepLines (www.principia.fr) has been developed to provide engineering and oil companies with an integrated tool to design and optimize their riser, flowline and mooring systems for shallow to deepwater offshore projects. Some applications are:

- All flexible risers, umbilicals, and floating hoses configurations,
- Rigid production (SCR) and drilling risers,
- Hybrid riser concepts,
- Mooring lines (catenary, taut, synthetic,...) and multi-bodies offshore systems,
- Pipeline and flowline laying and stability,

3 Nonlinear Finite Element Analyses

In this chapter a very brief introduction of nonlinear finite element method is given. Both SIMLA and RIFLEX are based on this method. Due to lack of time, or due to other time consuming parts of this project, this chapter is incomplete.

Linear analysis can be used by assuming small displacements and for linear and elastic materials. As this is not the case for umbilical installations, the modeling of umbilical installation effects is more complex. Nonlinear effects have to be introduced (Moan, 2003).

3.1 Nonlinearities

Several nonlinearities are important to consider for dynamic analyses of slender marine structures (Moan, 2003; Fylling, 1995):

- Geometrical nonlinearity
- Material nonlinearity
- Nonlinear boundary conditions
- Nonlinear hydrodynamic loading
- Nonlinear time domains
- Nonlinear cross section properties

3.1.1 Geometrical nonlinearity

For small displacements, the equilibrium equations can be established with reference to the initial configuration. Loads are then assumed to be acting similarly on the structure throughout the whole analysis. For large displacements, the geometry will change and the load is carried differently throughout the analyses. In this case non linear effects occur.

3.1.2 Material nonlinearity

The linear relationship between stress and strain is based Hooks' law and only describes the elastic behavior of the material

$$\text{Hooke's law: } \varepsilon = \frac{\sigma}{E}$$

A material is defined as nonlinear if the stress-strain relation varies due to change in the modulus of elasticity. In other words, nonlinearity will describe what happens when the stress reaches and exceeds yield stress. The material behavior after this occurs varies with the type of material, but normally combines a hardening of the material with a permanent deformation.

3.1.3 Non linear boundary condition

Displacements can lead to change in the boundary condition if contact with other elements changes the configuration.

3.1.4 Nonlinear hydrodynamic loading

Hydrodynamic loading is described by the Morison equation expressed by relative velocities, /12/:

$$dF = \rho\pi \frac{D^2}{4} C_M a_1 + \frac{\rho}{2} C_D D |u|u$$

Where

dF	- Total load of a strip
ρ	- Density of sea water
C_M	- Mass coefficient
C_D	- drag coefficient
D	- Umbilical diameter
a_1	- Acceleration at the midpoint of a strip
u	- Undisturbed fluid velocity

3.1.5 Nonlinear time domains

Non linear time domain accounts for non linear damping and stiffness in the dynamic equilibrium equation (Langen, 1979):

$$M\ddot{r} + C\dot{r} + Kr = Q(t)$$

Where

M, C, K are the mass, damping and stiffness respectively
 \ddot{r}, \dot{r} and r are the acceleration, velocity and displacement respectively
 $Q(t)$ is the time varying external load

Nonlinear time domain will be studied more in Chapter 6.

3.1.6 Non linear cross section

Non linear cross section properties have to be accounted for, due to the numerous variations of umbilical cross section arrangements that exist. The cross section can include hydraulic lines, signal cables and internal pipes all in one umbilical, which linear theory cannot describe in detail. Instead an average nonlinear relationship is used for the entire cross section.

3.2 Basics of the finite element method

A structural analysis is based on three principles for both linear and nonlinear finite element method.

- Equilibrium in terms of stresses
- Kinematic compatibility in terms of strains
- Constitutive equations – Stress/strain relationship.

The compatibility requirement for a beam assures that adjacent cross-sections get the same deformation and that the material is continuous when it deforms. This is fulfilled by describing the displacements with continuous interpolation functions and ensuring that the strain is finite at the element boundaries (Moan, 2003).

Equilibrium is expressed by means of the Principle of Virtual Displacements. This principle states that the work performed by the constant true internal stresses and the constant external forces is zero when the structure is exposed to a virtual displacement field which satisfies the boundary conditions. The principle is valid if the stresses and external forces represent an equilibrium state (Sævik S. , SIMLA - Theory Manual, 2003).

3.3 Lagrange Formulation

When the finite element method is formulated it is common to distinguish between:

Updated Lagrangian formulation

Total Lagrangian formulation

The difference between them is the choice of reference configuration. In a total Lagrangian formulation, all static and kinematic variables are referred back to the initial configuration, while in the updated formulation these are referred to the last obtained equilibrium configuration, i.e. the current configuration.

Both formulations have been successfully used in many non-linear problems (Sævik S. , SIMLA - Theory Manual, 2008).

4 Modeling

It has been established a basic model in RIFLEX and SIMLA for structural response analyses. This chapter introduces some basic information about the use of the programs. Both programs are based on finite element modeling.

4.1 SIMLA

SIMLA is a computer program for simulation of umbilical structures. The development was started based on a request from Norsk Hydro in September 2000 related to simulating pipeline installation of the Ormen Lange Pipelines.

SIMLA allows for both nonlinear static and dynamic analysis. In both cases the time domain is used to describe the load histories and the analysis sequence (Sævik S. Ø., 2009).

4.1.1 Input file

A text editor program called FlexEdit has been used to make an input file, prefix.sif, for SIMLA. In this input file everything needed for a static and dynamic analysis is defined:

- Lay scenario (RAOs, environmental data, umbilical data, material data)
- Geometry, element and nodal arrangements (Coordinates, orientations, boundary conditions)
- Time control
- Load history
- Types of results and how the results are stored

The input file used in the analyses is given as appendix A and is called apacheegen.sif.

The analysis can be run by SIMLA through FlexEdit, but a more time efficient method was found. SIMLA was copied to a local hard drive on a remote desktop, and this enabled eight parallel runs at the same time due to the computers eight core processor. During the whole process of this thesis, all analyses were done multiple times. In SIMLA, one run of a dynamic analysis over 200 seconds would take about 40 minutes. With that in mind, it is easy to see that use of the remote desktop saved many days work.

4.1.2 Output file

The required results found by SIMLA are saved in an output file, prefix.raf. This output file has in this project work been used in two ways. The file can be read directly by a program called XPOST, or it can be processed further in SIMVIS.

4.1.2.1 XPOST

XPOST is a post processing program of the SIMLA output file prefix.raf. No results in this report have been gathered from XPOST. The program has only been used for visualization purposes

Figure 6: Lay scenario is exported from XPOST. It shows an overview of the whole lay scenario. As quite self-explanatory, we can see the defined blue sea, the umbilical in red and the seabed in green.

4.1.2.2 SIMVIS

SIMVIS is a program run after SIMLA has completed a successful run. SIMVIS requires another input file, prefix.spi. The input file used in the analyses is given as appendix B, and is called apacheegen.spi.

SIMVIS processes the output file prefix.raf, to make new output files, prefix.mpf. The new output files are read by MATRIXPLOT.

Similar to SIMLA, SIMVIS can be run through FlexEdit or on a remote desktop. The output file prefix.raf generated by SIMLA is a very large file. To run SIMVIS is a quick process, but if run on the remote desktop, a vast amount of time is saved avoiding copying large files over the network.

4.1.2.3 MATRIXPLOT

MatrixPlot is a utility for plotting of matrix data, typically related to structural engineering applications. It reads the output files, prefix.mpf, from SIMVIS, and shows all results from the analyses as plots or tables. To change all plots in MatrixPlot to the preferred format for the report, and to find the right results, was a very time consuming process. Due to the enormous amount of data generated in this project work, scripts were made in Matlab to gather all necessary information from the prefix.mpf files instead. MatrixPlot was only used during the modeling of the umbilical installation to ensure right results.

4.2 RIFLEX

RIFLEX is quite similar to SIMLA in the way that RIFLEX only runs input files and save results to output files. It is not possible to do the actual modeling or visualization in RIFLEX.

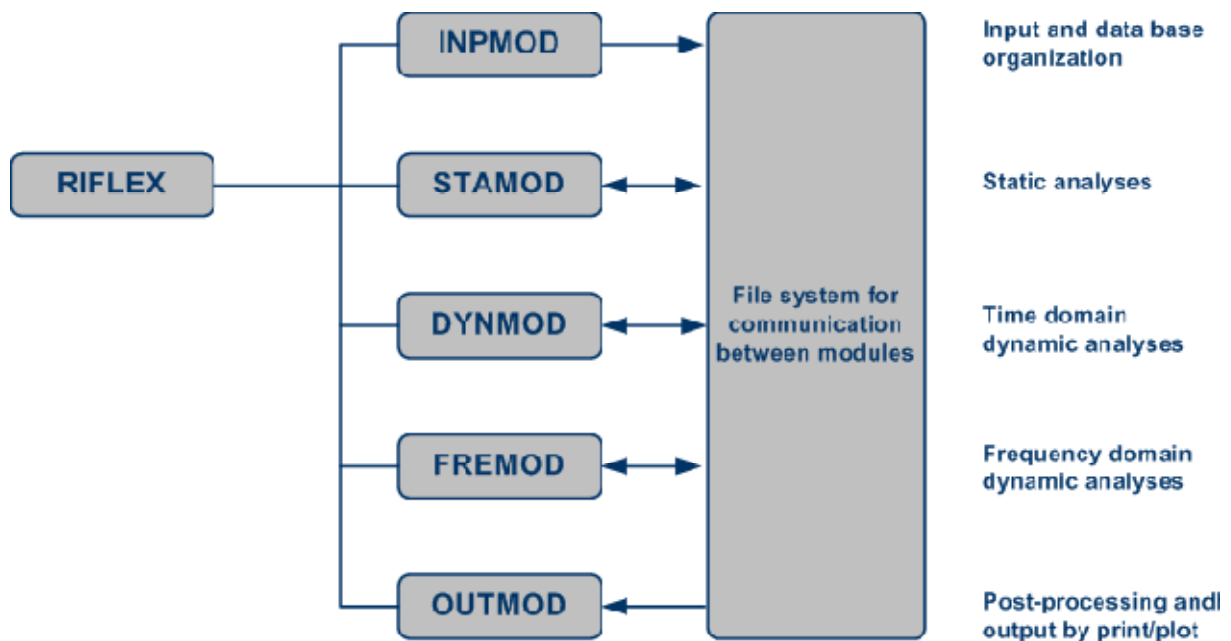


Figure 3: RIFLEX overview

4.2.1 Input files

As a difference to *SIMLA*, *RIFLEX* needs more than one input file to do the same analysis. In this way *RIFLEX* can run parts of the analyses separately. All input files are run by *RIFLEX* in the order which they are described:

4.2.1.1 *Inpmod*

Prefix_inpmod.inp defines the lay scenario and the finite element formulations:

- Geometric data - e.g. umbilical, seabed, vessel
- Material properties
- Loads – e.g. waves, current, wind

The input file used in this project is called *Apache_inpmod.inp*, and it is given in appendix C

4.2.2 *Stamod*

Prefix_stamod.inp defines the static analysis configurations (*RIFLEX* - User Manual, 2008)

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

The input file used in this project is called *Apache_stamod.inp*, and it is given in appendix C.

4.2.3 *Dynmod*

Prefix_dynmod.inp defines the dynamic analysis configurations (*RIFLEX* - User Manual, 2008). The user has the option of using frequency domain dynamic analyses or time domain:

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

The input file used in this project is called *Apache_dynmod.inp*, and it is given in appendix C

Fremod and *Outmod* have not been used in this project work.

The input files are opened in *RIFLEX* and run in *RIFLEX*. *RIFLEX* is not implemented into a text editor program like *SIMLA*. On the other hand, there are *RIFLEX* input file formats made for TextPad which makes the input files easier to read and edit by the user, but the input files are not run through TextPad.

RIFLEX was also used on a remote desktop to save time, but the difference was not as big as for *SIMLA*. A full analysis in *RIFLEX*, including the *inpmod*, *stamod* and *dynmod* analyses, did not take more than about 15 minutes.

4.2.4 Output files

The output files from RIFLEX are given directly as static and dynamic result files on a prefix.mpf file format. This is the same file format as the output from SIMVIS. The results can be read by RIFLEX itself showing the results as plots and tables. RIFLEX uses MatrixPlot to show these results, and just as for the SIMVIS results, results were only viewed in RIFLEX during the modeling and set up. To find the right results effectively, and to change the plots to the preferred format, scripts were made in Matlab to gather all necessary information from the prefix.mpf files.

4.3 Known modeling errors

To compare the results in SIMLA and RIFLEX, it is important that the modeling is done as identically as possible in both programs. The differences in the results are meant to be because of calculational differences. Differences in the model will in a way spoil the whole idea of the analyses comparisons.

4.3.1 Buoyancy

There were some problems with the results from RIFLEX during the buoyancy calculations. Knowing that the umbilical length, the location of the touch down point, weight, diameter and the ramp angle was the exact same for both models in RILFEX and SIMLA, the static tension results should be identical. This was not the case. RIFLEX showed a lower tension than SIMLA, which was because of how RIFLEX calculates the buoyancy. This information is believed not to be given in the RIFLEX theory manual. The solution was to alter the umbilical diameter used for buoyancy calculation in RIFLEX to get the same static tension as in SIMLA. The umbilical diameter used for other calculations, stayed the same.

The reason for this error is believed to be because of the uniform cross section used in the analyses. Normally the umbilical used in the analyses will have internal voids and/or other variations over the cross section.

The solution to this error is believed to make the RIFLEX and RIFLEX models more similar, even though the diameter was changed in RIFLEX from what was used in SIMLA.

4.3.2 Boundary conditions

There is an error in the modeling of the boundary conditions. In SIMLA, all rotations have been enabled, while in RIFLEX, rotations have been restrained. This is an error throughout all the analyses, and the result of this error has not been evaluated properly. Without going into detail, it is reasonable to say that restraining rotations lead to higher tensions and bending moments.

5 Differences SIMLA/RIFLEX

The main difference between SIMLA and RIFLEX is how they solve the dynamic time domain analyses. The dynamic equilibrium of a spatial discretized finite element system model can in general be expressed as:

$$\mathbf{R}^I(\mathbf{r}, \ddot{\mathbf{r}}, t) + \mathbf{R}^D(\mathbf{r}, \dot{\mathbf{r}}, t) + \mathbf{R}^S(\mathbf{r}, t) = \mathbf{R}^E(\mathbf{r}, \dot{\mathbf{r}}, t)$$

Where \mathbf{R}^I - inertia force vector

\mathbf{R}^D - damping force vector

\mathbf{R}^S - internal structural reaction force vector

\mathbf{R}^E - external force vector

$\mathbf{r}, \dot{\mathbf{r}}, \ddot{\mathbf{r}}$ - structural displacement, velocity and acceleration vectors

The dynamic equilibrium equation is solved by numerical time integration. RIFLEX uses the well known Newmark- β method, while SIMLA uses a HHT- α method proposed by Hilbert, Hughes and Taylor.

Nonlinear dynamic problems cannot be solved by modal superposition and therefore direct time integration of the equation of motion is necessary. This can either be performed by an explicit method or an implicit method. The difference in these methods is what information the displacement at the next time step is based on. The explicit method uses information from the current and the previous time steps, while the implicit method uses information from the next time step and the current. Both the Newmark- β and the HHT- α methods are implicit methods (SIMLA TM, 2008).

5.1 Newmark β -method

This method is a step by step numerical integration of the dynamic equilibrium equations which include the Wilson θ -method considering a constant time step throughout the analysis.

The methods apply the following relations between displacements, velocity and acceleration vectors at time t and $t + \Delta\tau$:

$$\begin{aligned}\dot{\mathbf{r}}_{t+\Delta\tau} &= \dot{\mathbf{r}}_t + (1 - \gamma)\ddot{\mathbf{r}}_t\Delta\tau + \gamma\ddot{\mathbf{r}}_{t+\Delta\tau}\Delta\tau \\ \mathbf{r}_{t+\Delta\tau} &= \mathbf{r}_t + \dot{\mathbf{r}}_t\Delta\tau + \left(\frac{1}{2} - \beta\right)\ddot{\mathbf{r}}_t(\Delta\tau)^2 + \beta\ddot{\mathbf{r}}_{t+\Delta\tau}(\Delta\tau)^2\end{aligned}$$

Where $\Delta\tau = \Delta\theta, \theta \geq 1.0$

γ, β and θ are parameters in the integration methods defining the functional change in displacement, velocity and acceleration vectors over the time step Δt . The input files for RIFLEX lets the user decide the values of the different parameters. The Newmark β -method covers five integration methods depended on different β -values between 0 and 1:

- Central Difference method
- Fox-Goodwins method
- Linear acceleration method
- Constant average acceleration method
- Wilson θ -method

For all analyses in this report γ, β and θ was set to default values at $\frac{1}{2}, \frac{1}{4}$ and 1, respectively.

5.2 HHT- α method

The HHT- α method used in SIMLA uses an incremental time integration scheme. SIMLA uses the same relations between displacements, velocity and acceleration vectors as RIFLEX, given in formula in section 5.1. The difference is that the HHT- α method modifies the dynamic equilibrium equation for the finite element system. The following is a rewrite of the dynamic equilibrium equation as used in the Newmark β -method:

$$\mathbf{M}\ddot{\mathbf{r}} + \mathbf{C}\dot{\mathbf{r}} + \mathbf{R}^S = \mathbf{R}^E$$

This is the modified dynamic equilibrium equation with the implementation of α :

$$\mathbf{M}\ddot{\mathbf{r}}_{k+1} + (1 + \alpha)\mathbf{C}\dot{\mathbf{r}}_{k+1} - \alpha\mathbf{C}\dot{\mathbf{r}}_k + (1 + \alpha)\mathbf{R}_{k+1}^S - \alpha\mathbf{R}_k^S = (1 + \alpha)\mathbf{R}_{k+1}^E - \alpha\mathbf{R}_k^E$$

Where k+1 - refers to next time step
k - refers to current time step
 \mathbf{M} - Mass matrix
 \mathbf{C} - Damping matrix

By setting $\alpha = 0$, $\gamma = 1/2$ and $\beta = 1/4$, the Newmark β -method with constant average acceleration is obtained.

All analyses in SIMLA were done with $\alpha = 0.05$, $\gamma = \frac{1}{2}(1 - 2\alpha)$ and $\beta = (1 - \alpha)^2$.

5.3 Effects of Newmark β and HHT α

In dynamic analyses the response of high frequency modes is of little interest and are described with less accuracy than the lower modes. Therefore it is desirable to remove these modes and at the same time describe the lower modes with good accuracy. It can be shown that increasing the damping ratio or introducing Rayleigh-damping in the Newmark β -method will damp out mainly the medium modes, leaving lower and higher modes almost unaffected. Higher modes can however be damped out by numerical damping. In the Newmark β -method numerical damping can be introduced at the cost of reducing the accuracy from 2nd order to 1st order. The drawback of reduced accuracy can

however be eliminated by applying the implicit HHT α -method. The HHT α -method will damp out high frequency modes and at the same time retain 2nd order accuracy (SIMLA TM, 2008).

6 Lay scenario

All environmental data in the different input files run by SIMLA and RIFLEX are modeled as identical possible, but there might be some differences. As SIMLA calculates the coordinates of the touchdown point, RIFLEX require the coordinates as input parameters. To make the models as similar as possible, the touchdown point calculated by SIMLA has been used as input parameters to the RIFLEX model.

6.1 Environment data

6.1.1 Apache

Apache is a pipe lay vessel owned and operated by Technip, hence all data about Apache is given by Technip.

Given data is for a load condition, recognized by Technip as LC8, where the reel load is 1000 tons and the ramp angle is 60 degrees.

Parameters		
Length between perpendiculars	121,920	m
Breadth moulded	23,340	m
Depth	8,690	m
Mean Draft, Tm	5,030	m
Metacentric Height, GM_{fluid}	2,330	m
Long Centre of Gravity, LCG	60,600	m
Vert Centre of Gravity, KG	9,330	m
Tran Centre of Gravity, TCG	0,000	m

Table 1: Apache parameters

Orientation of the CoG for Apache
LCG is measured positive forward from aft perpendicular
KG is measured positive up from vessel's keel
TCG is measured positive to port from vessel's centerline

Table 2: Orientation of the CoG for Apache

Although all the parameters in LC8 are based on a ramp angle of 60 degrees, a different ramp angle has been used in the analyses. To ensure a static bottom tension of 15 kN, the ramp angle has been adjusted to 68.53 degrees. In theory, Apache would experience a change of the center of gravity (CoG) because of this, and then again the response amplitude operators (RaOs) would change, but this fact is neglected due to the assumption of a very small change.

From the drawings of Apache, coordinates for the umbilical outlet on the vessel have been measured with respect to CoG and the sea surface. The drawing is not given as an appendix due to an inadequate format of the drawing.

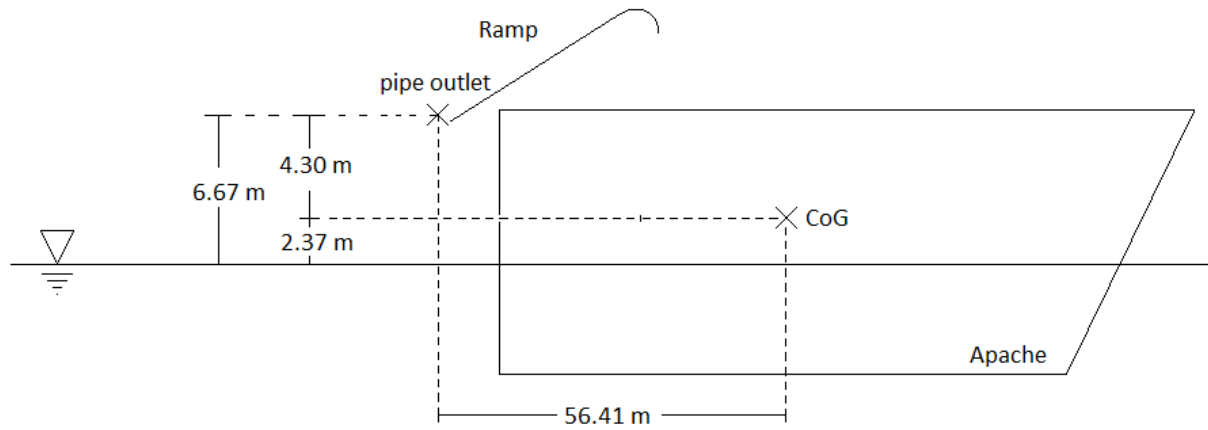


Figure 4: Lay arrangement of Apache

6.1.1.1 Response amplitude operators

The response amplitude operators, RAO's, were given in Microsoft excel format, *.xls, by Technip. The file format had to be changed for the programs to be able to read them.

6.1.2 Seabed

The modeled seabed is completely flat, i.e. no humps or any kinds of free span possibilities where the umbilical touches. This ensures that all contact forces between the umbilical and the seabed are evenly distributed. The depth is set to 360 meters. The friction is set to zero in all direction. The stiffness of the sea bed is defined to let the umbilical sink 1 mm into the soil during static analyses.

6.1.3 Sea states

Due to the importance of the pitch induced forces, only head sea is assumed to be of any interest. The chosen sea states are therefore described by regular waves with wave propagation run directly against the course of the vessel. All the chosen combinations of significant wave height and the wave period describe typical northern sea conditions. The following sea states have been analyzed:

Sea state	Hs [m]	Tp [s]
1	2.66	8.35
2	3	8.35
3	3	9.30
4	3.33	9.30
5	3.66	9.30
6	4	9.30
7	4	10.05
8	4.33	10.05
9	4.66	10.05
10	5	10.05
11	5	10.60
12	5.33	10.60
13	5.66	10.60
14	6	10.60
15	6	11.05
16	6.33	11.05
17	6.66	11.05
18	7	11.05
19	7	11.40
20	7.33	11.40

Table 3: Sea states

In SIMLA the analysis time control is based on seconds, while in RIFLEX it is based on wave periods. The analyses are set to 200 seconds in SIMLA, and 22 wave periods in RIFLEX.

All results will refer to these sea states as sea state 1 to 20. In all analyses, the only difference is the sea state.

6.1.4 Umbilical data

The chosen umbilical is given by Technip and is a standard sized umbilical.

Umbilical data		
Outer diameter	90	mm
Weight in air	12,7	kg/m
Weight in sea	7,2	kg/m
Axial stiffness	115	MN
Bend Stiffness	11	kNm ²
Torsional stiffness	7,6	kNm ²
MBR of umbilical (storage, displacement controlled)	2,9	m

Table 4: Umbilical data

Endurance limits for the umbilical		
Minimum Bending Radius , elastic limit	5	m
Maximum Handling Tension	160	kN

Table 5: Umbilical tolerance

Regarding umbilical elastic capacity for installation condition (bending radius at different tensions), is shown in the below Figure. The Figure is based on 15 MPa tube pressure.

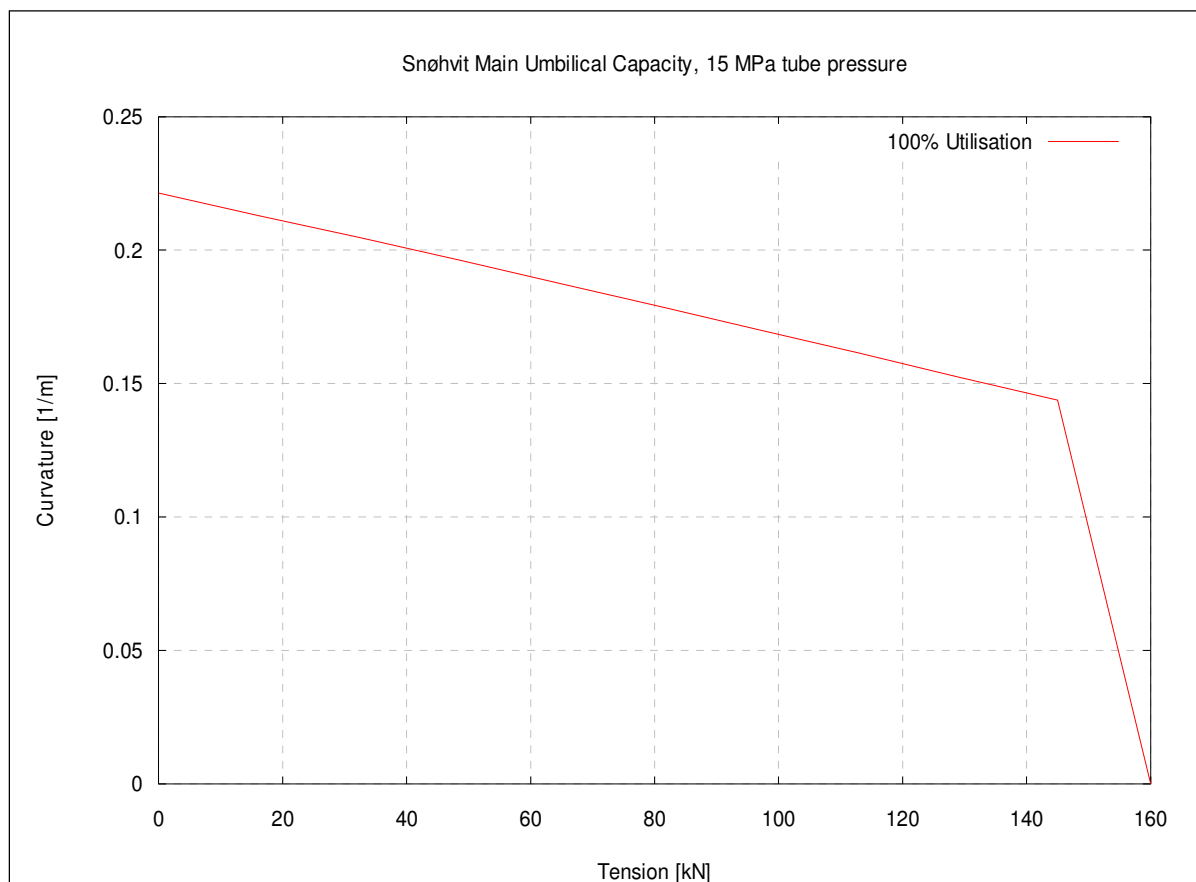


Figure 5: Umbilical capacity

Figure 6 shows the whole installation configuration. The green part is the sea bed, the blue part is the sea surface, and the red line is the famous umbilical.

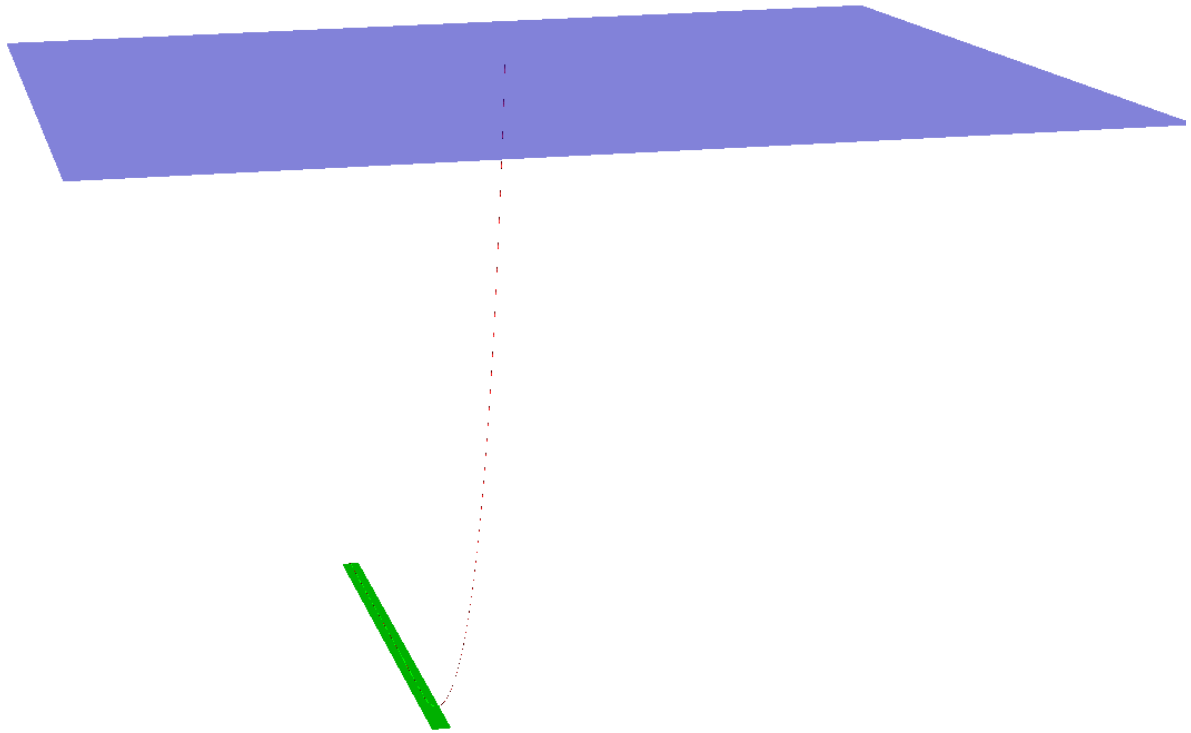


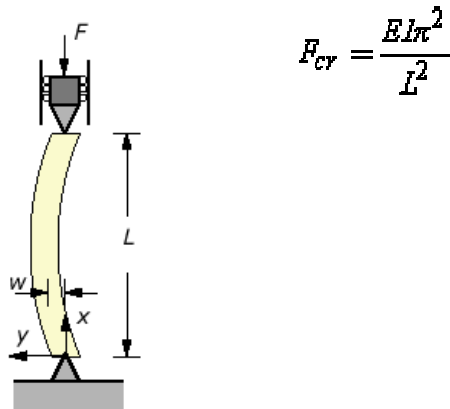
Figure 6: Lay scenario

6.2 Modeling of the umbilical

The cross-sectional build up of the umbilical has no importance in the analyses. The umbilical is therefore looked upon as an evenly distributed material through the whole cross section. There are no empty spaces, pipe in pipe or an inner flow of any kind.

6.2.1 Euler's formula

The umbilical is 850 meters long and is divided into 880 identical elements. This gives an element length of 0,966 meters. One criteria for the element length is to ensure that there is no internal buckling for an element during the analysis. The critical buckling load is given by Euler's formula (www.efunda.com).



Simply supported column subjected to axial load F Figure 7: Euler buckling

Which in this case mean,

$$\text{Critical compression} = \frac{\text{Bending stiffness} \times \pi^2}{\text{Element length}^2}$$

For an element length of 0,966 meters and a bending stiffness of 11 kNm², the critical compression for element buckling is then found to be 116 kN. This is by far higher than the maximum compression found by any of the two programs, and it proves the element length to be adequate. The elements have two nodes each, one on each end.

6.2.2 Hydrodynamic coefficients

The umbilical's cross-section is perfectly circular and is assumed to have the following hydrodynamic coefficients:

Hydrodynamic coefficients	
Radial drag coefficient	0,8
Tangential drag coefficient	0,1
Radial added mass coefficient	2
Tangential added mass coefficient	0,2

Table 6: Hydrodynamic coefficients

7 Results

The results from all analyses can be separated into one dynamic and one static part. The static results are the same for all analyses. The different sea states only have an effect on the dynamic results.

7.1 Static results

The static results describe the initial configuration of the installation procedure. The parameters that have been compared in SIMLA and RIFLEX are:

- XZ-configuration
- Bottom tension
- Bending moment
- Curvature

7.1.1 XZ-configuration

The x-direction is in the longitudinal direction, while the z-direction is the vertical direction. This is how the installations initial configuration looks like from the side. As seen in the graph, the configuration is close to identical.

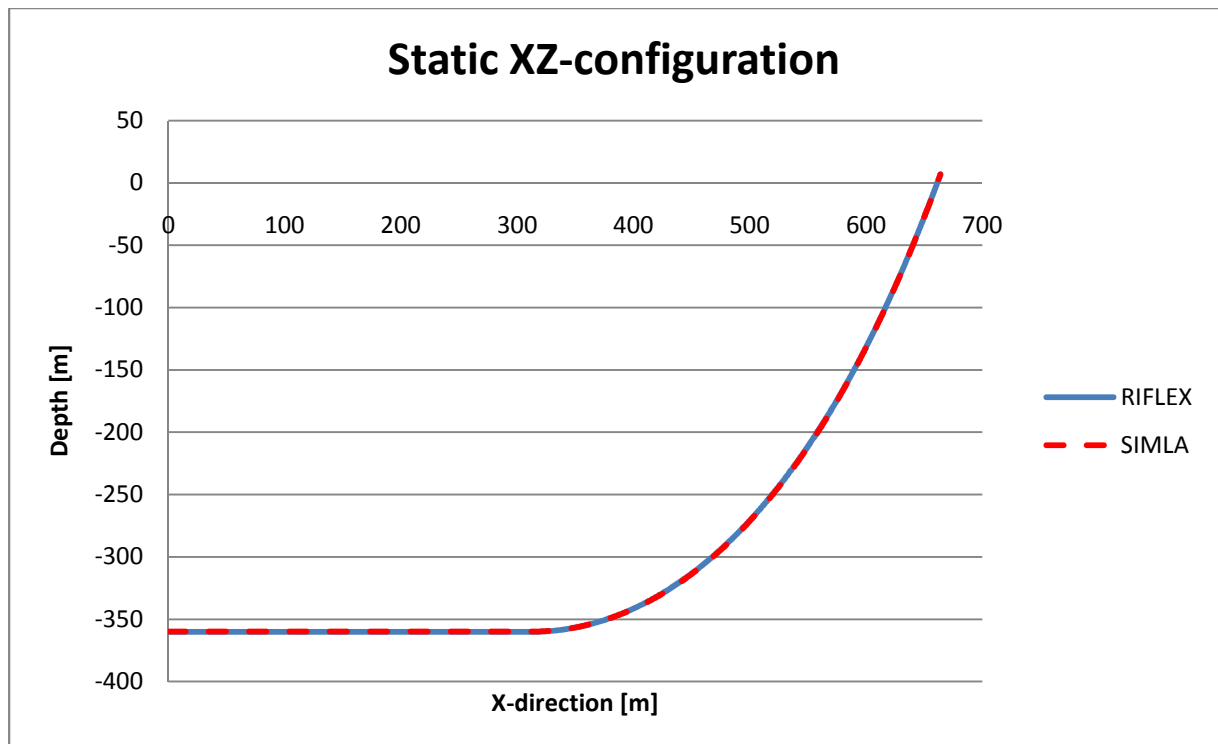


Figure 8: Static XZ-configuration

One interesting observation is, even though the soil stiffness is exactly the same in both programs, there is a small difference in the z-direction. The depth in RIFLEX is 360,0007 meters, while in SIMLA the depth is 359,956 meters. This is a difference of 4,47 cm.

7.1.2 Static tension

In SIMLA, an iteration process was done to find the ramp angle which induced a bottom tension of about 15 kN. It was found that the a ramp angel of 68,5 degrees from the horizontal plane resulted in a bottom tension of 14876 N. The same ramp angle was then used in RIFLEX, and it showed that the bottom tension in RIFLEX is 84 N higher. In RIFLEX the bottom tension is 14963 N.

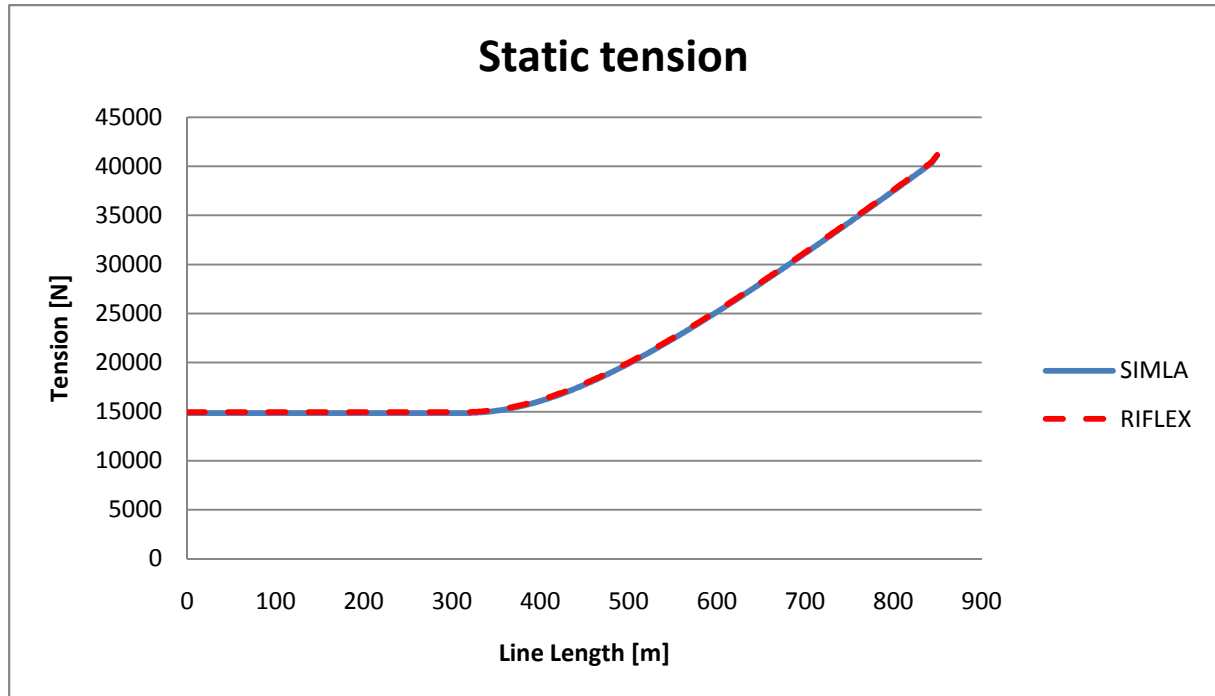


Figure 9: Static tension

At the top end attached to the vessel, RIFLEX shows a static tension of 41162,5 kN, while SIMLA shows about 41078,5 N. This difference is 87 N and it is quite stabile through the whole configuration.

7.1.3 Bending moment

The bending moment results from the static analyses are very similar. Max bending moment in the touch down area is 52,2 Nm in SIMLA, and 51,9 in RIFLEX. The result clearly shows differences in the connecting element between the umbilical and the vessel. In both RIFLEX and SIMLA the umbilical experience a similar extra bending moment close to the vessel, but in RIFLEX there is a big leap between the two last elements. This leap is in RIFLEX from 6,3 Nm to -48,0 Nm, while in SIMLA it is 11,3 Nm to 2,7 Nm. This shows that there is a difference in the connection element configurations.

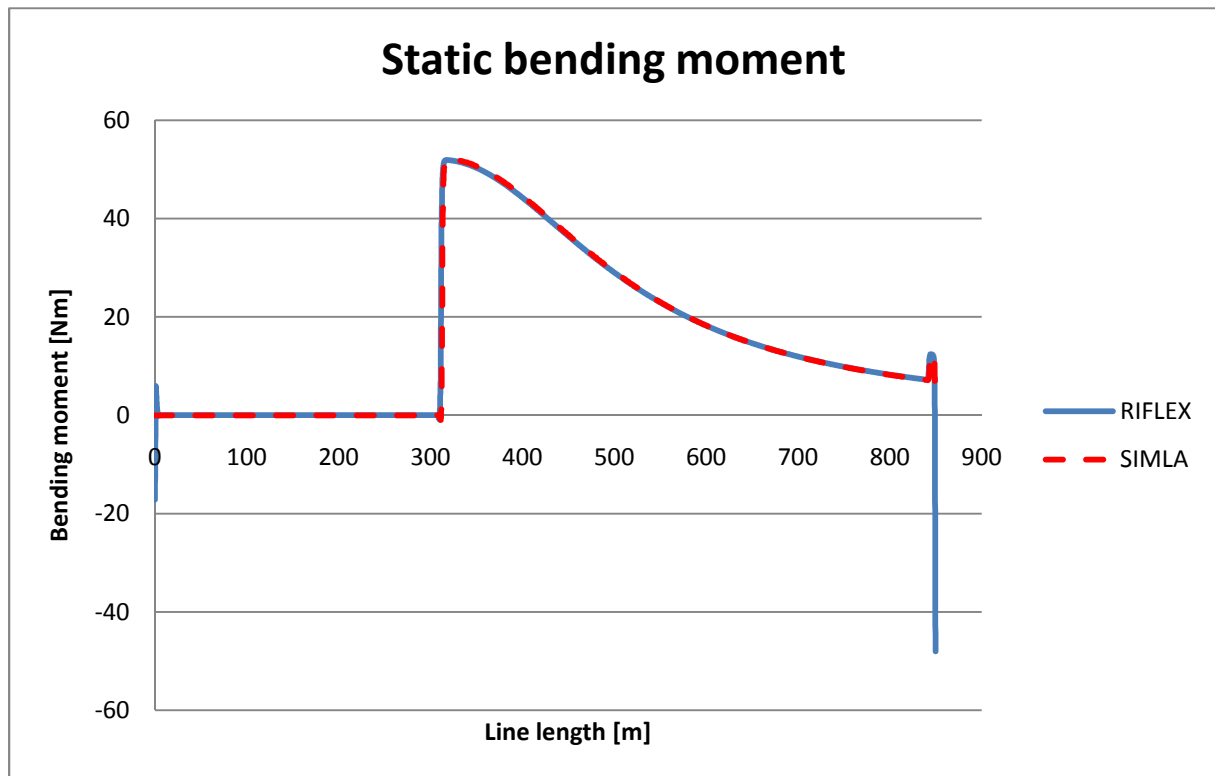


Figure 10: Static bending moment

7.1.4 Curvature

The curvature is an effect of the bending moment, hence the static curvature results reflects the static bending moment results. The curvature is almost identical all the way up to the vessel, but in RIFLEX a quite large curvature is shown at the connecting point compared to SIMLA. Apart from the connection point between the umbilical and the vessel, RIFLEX shows a maximum curvature of 0,00472 1/m, while SIMLA shows 0.00474 1/m. This gives a bending radius of 211,8 and 211 meters respectively, which is by far bigger than the critical 5 meter limit.

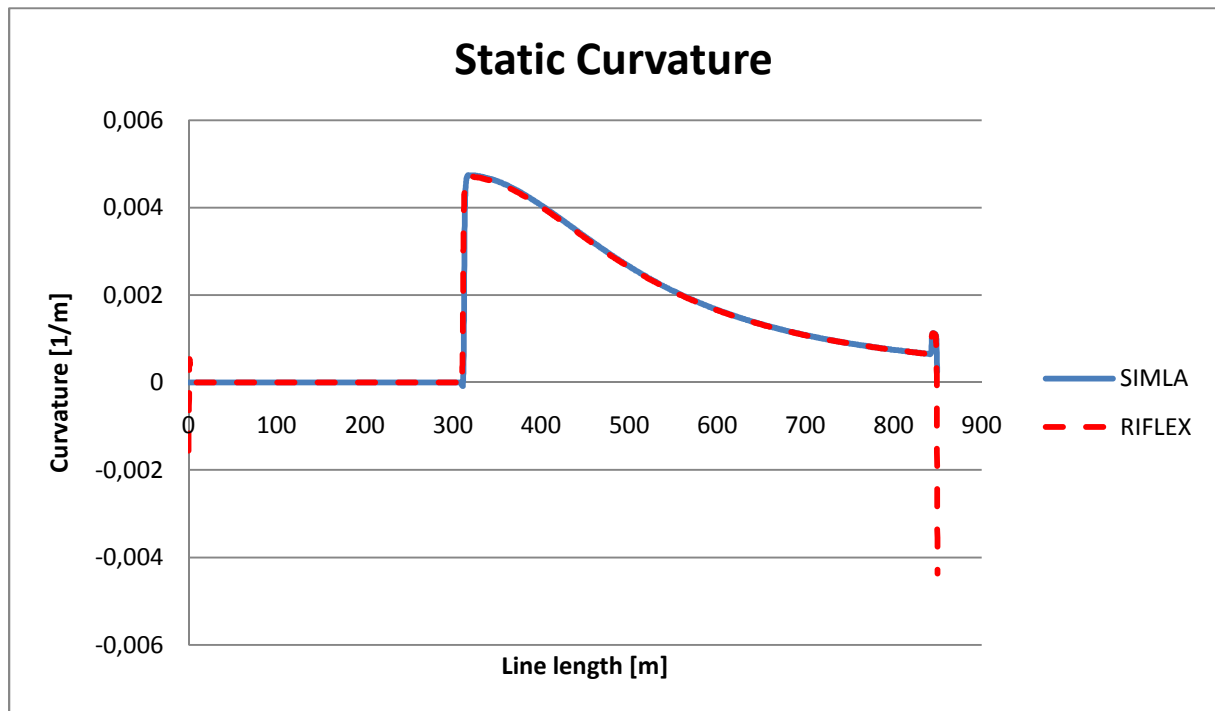


Figure 11: Static curvature

7.2 Dynamic results

The following dynamic results have been compared in the two programs:

- Displacement of connection point between vessel and umbilical
- Minimum/maximum force
- Bending moment
- Curvature

7.2.1 Envelope curves

The chosen outputs from the programs are envelope curves. The envelope curves show the maximum or the minimum result for each element over a time period.

The envelopes do not show when the maximum results take place. The maximum results for each element will probably not happen at the same time.

7.2.2 Sea state envelope results

In this part of the report results from 8 of the sea states will be compared and studied. The emphasis in this part will be to study the likeness of the graphs all over the line length. All maximum envelope values will be compared and studied later part of the report, thus it will not be essential in this part.

There are 20 sea states all in all, arranged with increasing wave heights and wave periods. The results given in this part of the report are mainly for the first 8 sea states. It is believed that the trends are shown already after 8 sea states. The last 12 sea states are based on large wave heights and long wave periods, giving large results for all envelope curves. These results are briefly mentioned to see how if the trends from the previous sea states are applicable for large induced forces.

7.2.2.1 Sea state 1

At this sea state the significant wave height is set to 2,66 meter, and the wave period is set to 8,35 seconds. The results are given as plots in Figure 14: Bending moment - Sea state 1 to Figure 15: Curvature - Sea state 1.

7.2.2.1.1 Envelope forces

The envelope curves for the forces show that there is tension from end to end of the umbilical at all times for both programs. The curvature of the plots are almost identical, but there is clearly a difference that shows almost constant higher maximum tension, and lower minimum tension for RIFLEX.

There is no compression or buckling in the touch down area.

7.2.2.1.2 Bending moment and curvature

It can be observed that in this sea state all results from both programs are far within the endurance limits of the umbilical. Both programs show peak values at the same places, but the peaks are not of the same size. There are noticeably higher RIFLEX values at the touch down point and at the connection point to the vessel. The rest of the umbilical length show very similar results. Apart from the connection point values for RIFLEX, the results are trustworthy from both programs.

7.2.2.1.3 Displacements

The displacement envelopes show only small differences. Both programs show that there is no movement on the seafloor up to the touch down point. There is a small difference at the touch down point, and then again, the catenary part of the umbilical is quite similar.

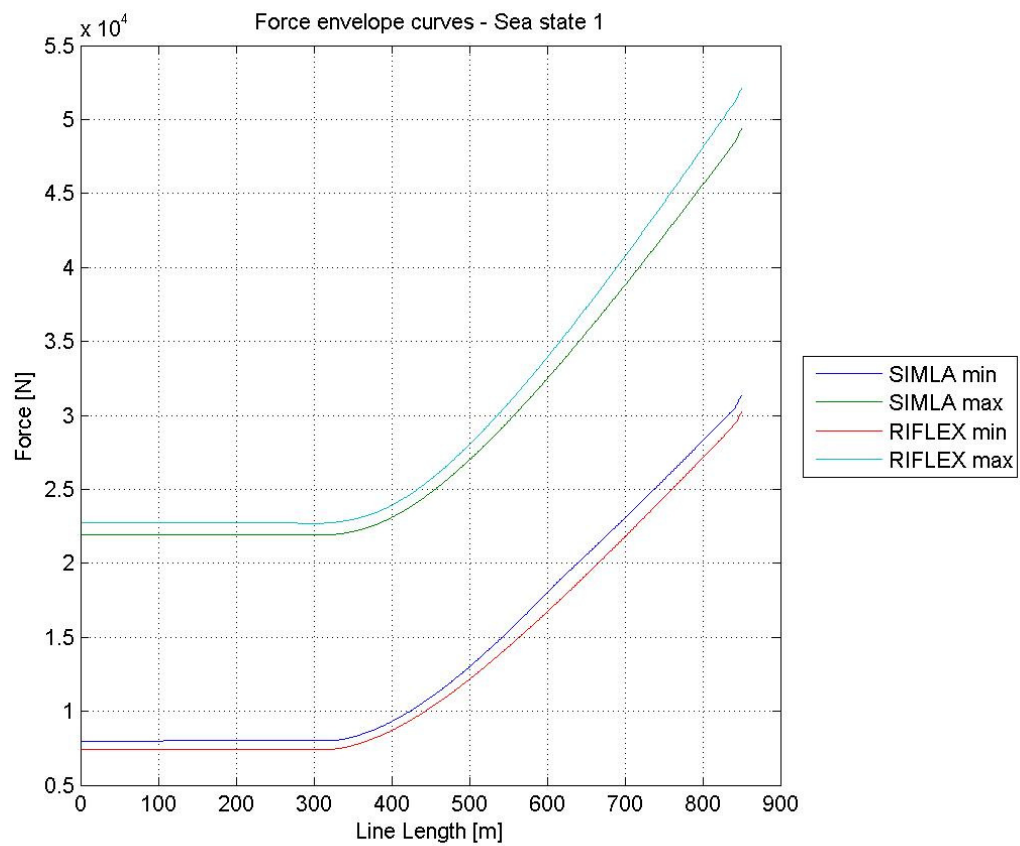


Figure 12: Forces - Sea state 1

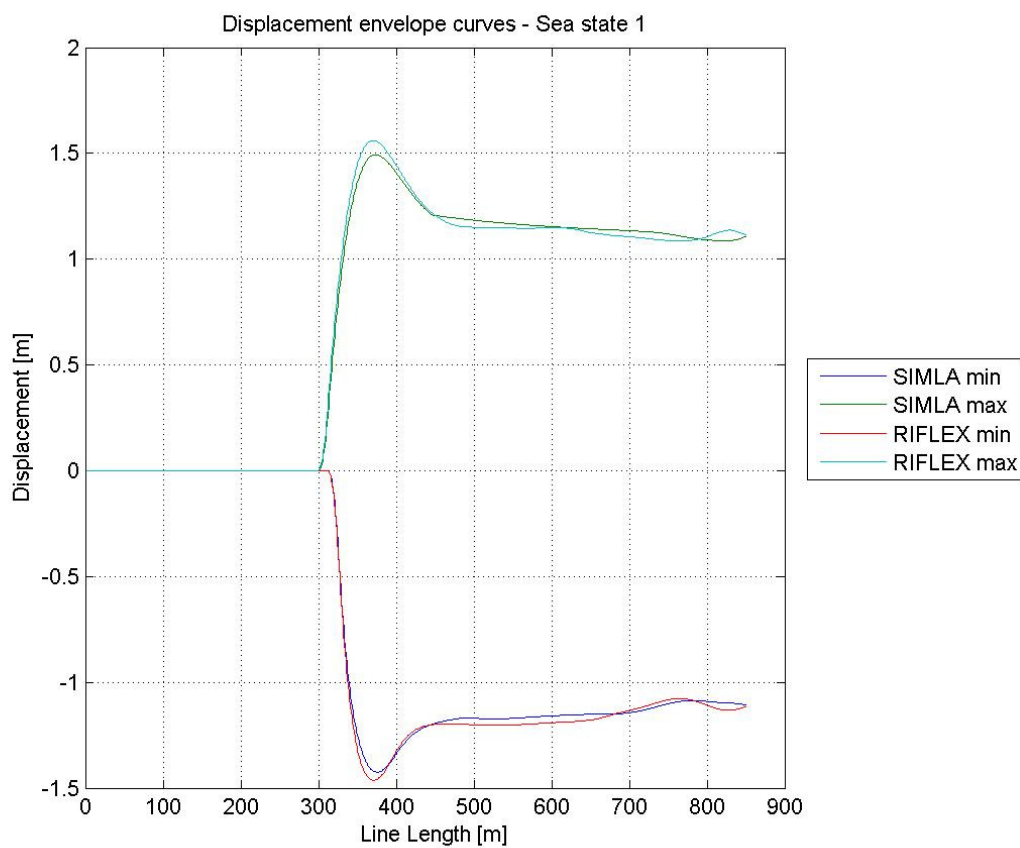


Figure 13: Displacements - Sea state 1

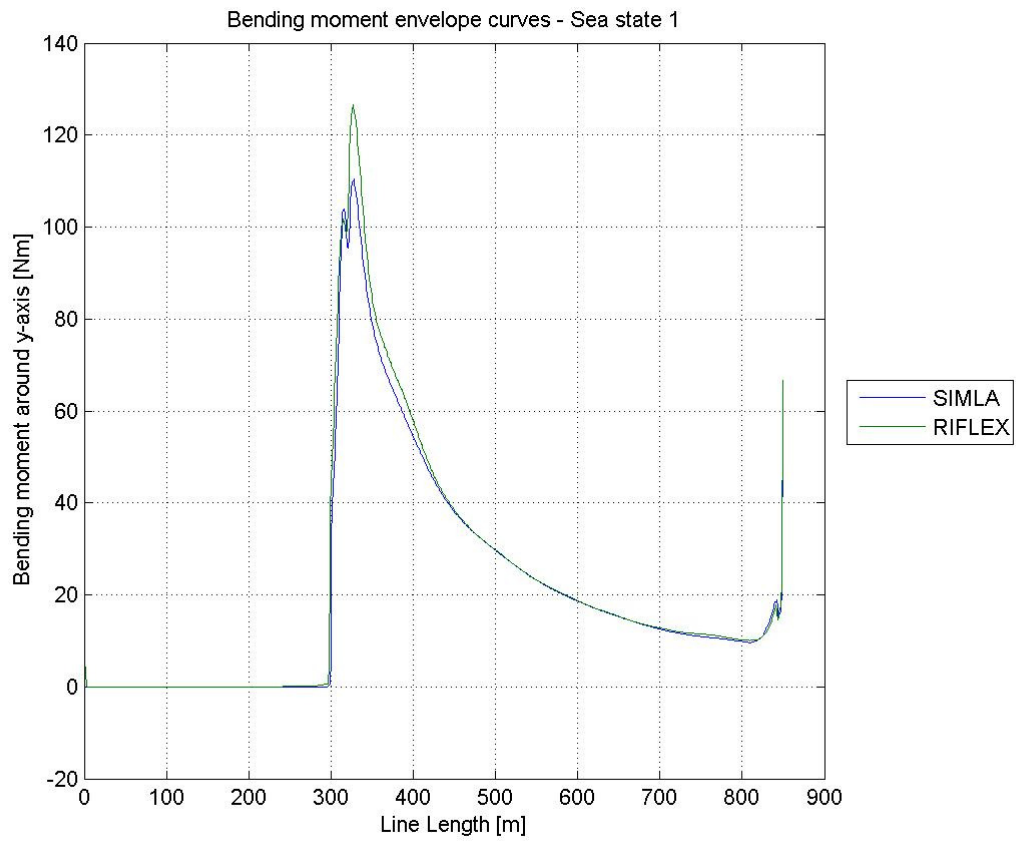


Figure 14: Bending moment - Sea state 1

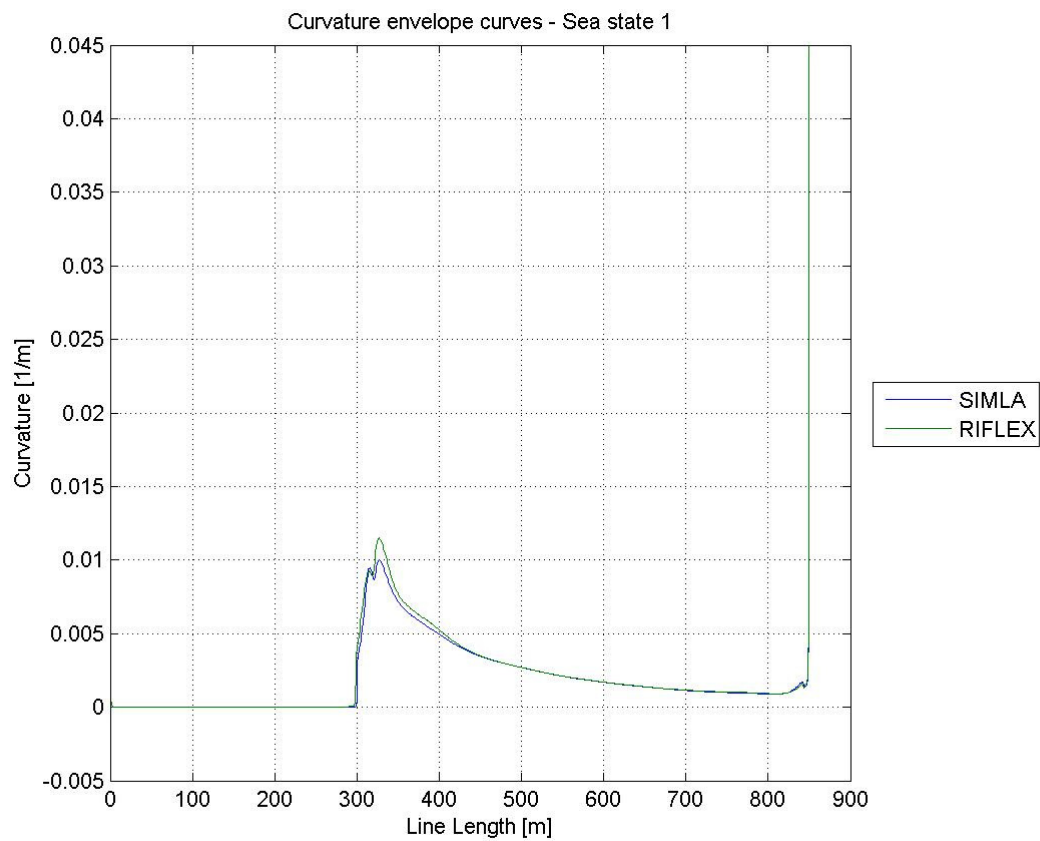


Figure 15: Curvature - Sea state 1

7.2.2.2 Sea state 2

At this sea state the significant wave height is set to 3 meters, and the wave period is set to 8,35 seconds. The results are given as plots in Figure 16: Forces - Sea state 2 to Figure 19: Curvature - Sea state 2.

7.2.2.2.1 Envelope force

As for sea state 1, the curvature of the envelope force plots are very similar, but there is clearly a difference that shows higher maximum, and lower minimum tension, for RIFLEX. The difference of about 1000 N is quite constant over the whole length of the umbilical. Both programs show that there is tension throughout the entire umbilical for the whole analysis.

There is no compression or buckling in the touch down area.

7.2.2.2.2 Bending moment and curvature

As for the bending moment and curvature in sea state 1, the results from both programs are by far within the endurance limits of the umbilical, and both programs show peak values at the same places. The difference at the touch down point is bigger than in sea state 1, but for the rest of the umbilical, the results are very similar.

7.2.2.2.3 Displacements

Both programs show that there is no movement on the seafloor up to the touch down point. There is a small difference at the touch down point, and then again, the results from the catenary part of the are quite similar.

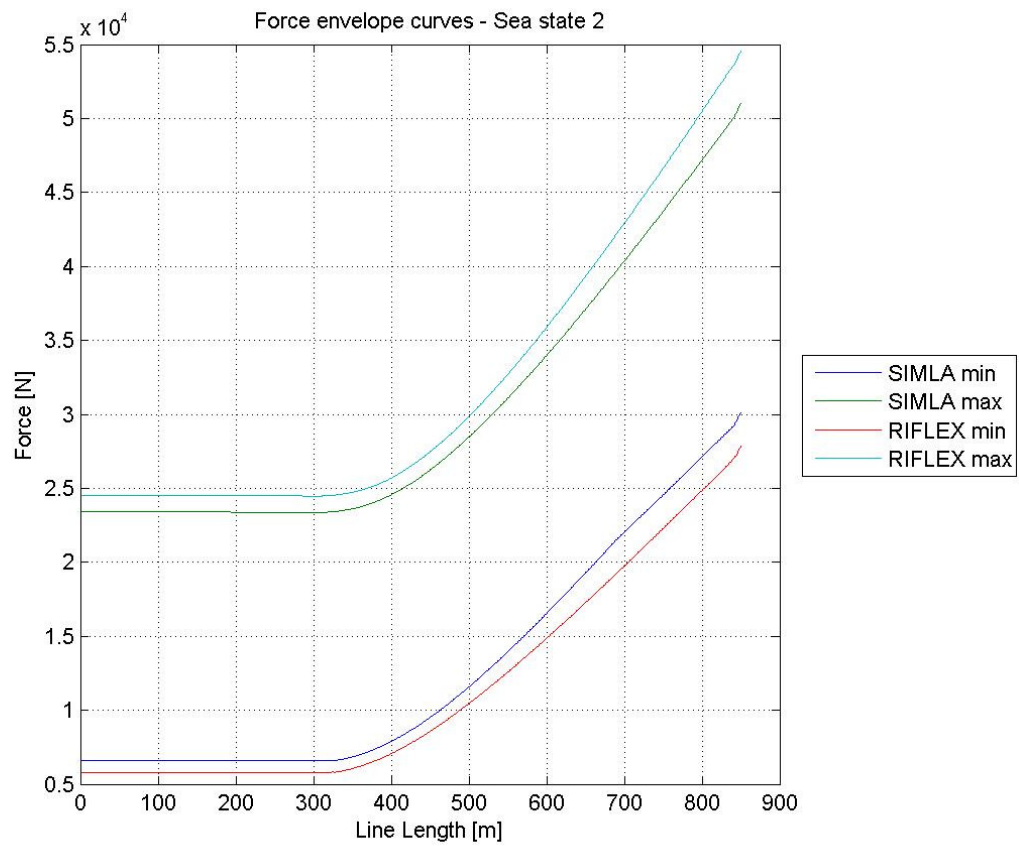


Figure 16: Forces - Sea state 2

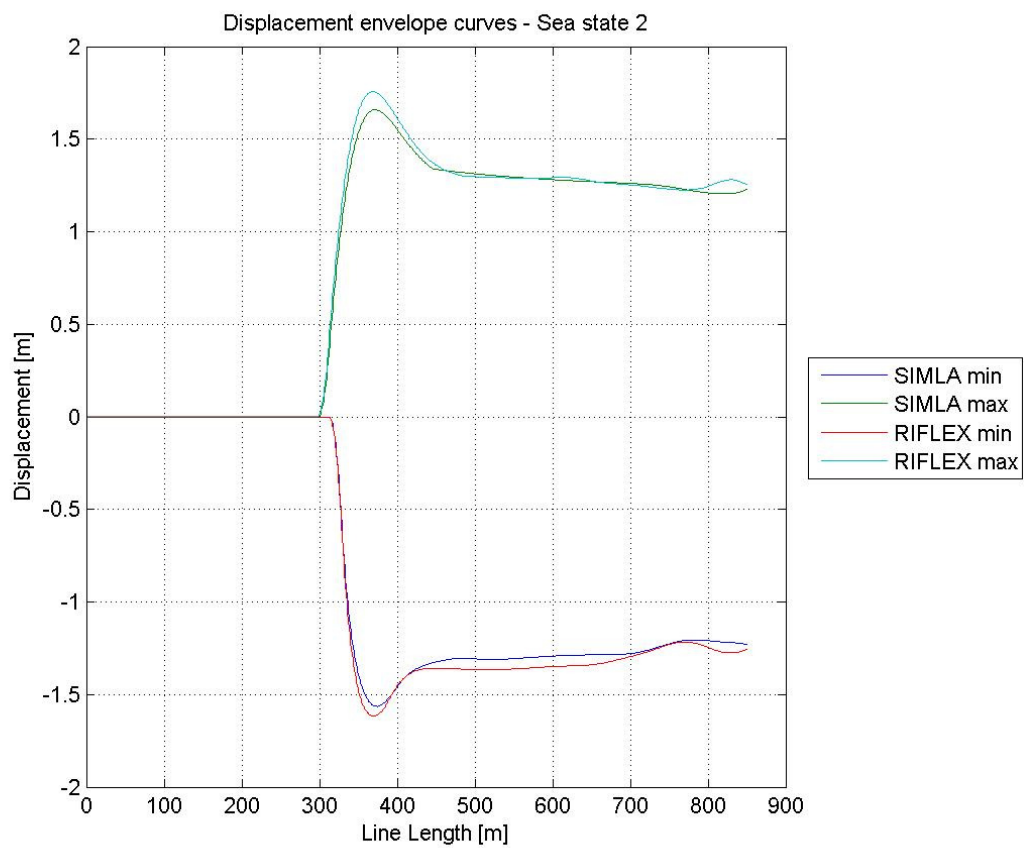


Figure 17: Displacement - Sea state 2

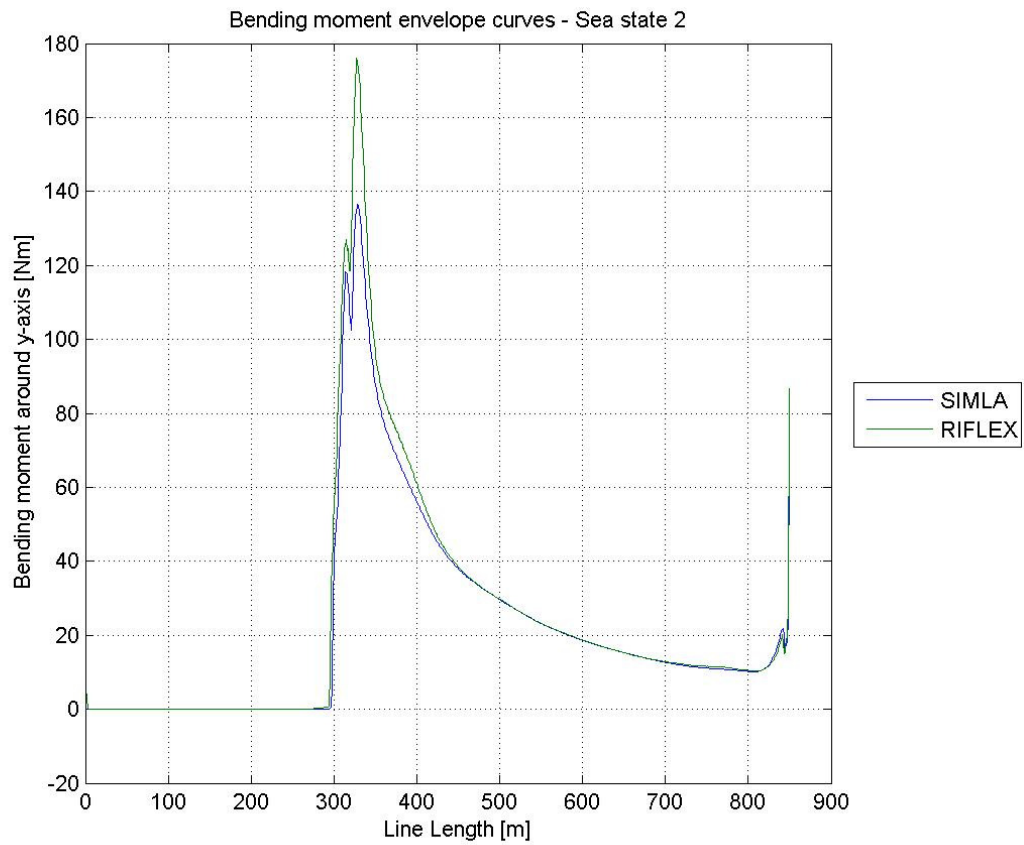


Figure 18: Bending moment - Sea state 2

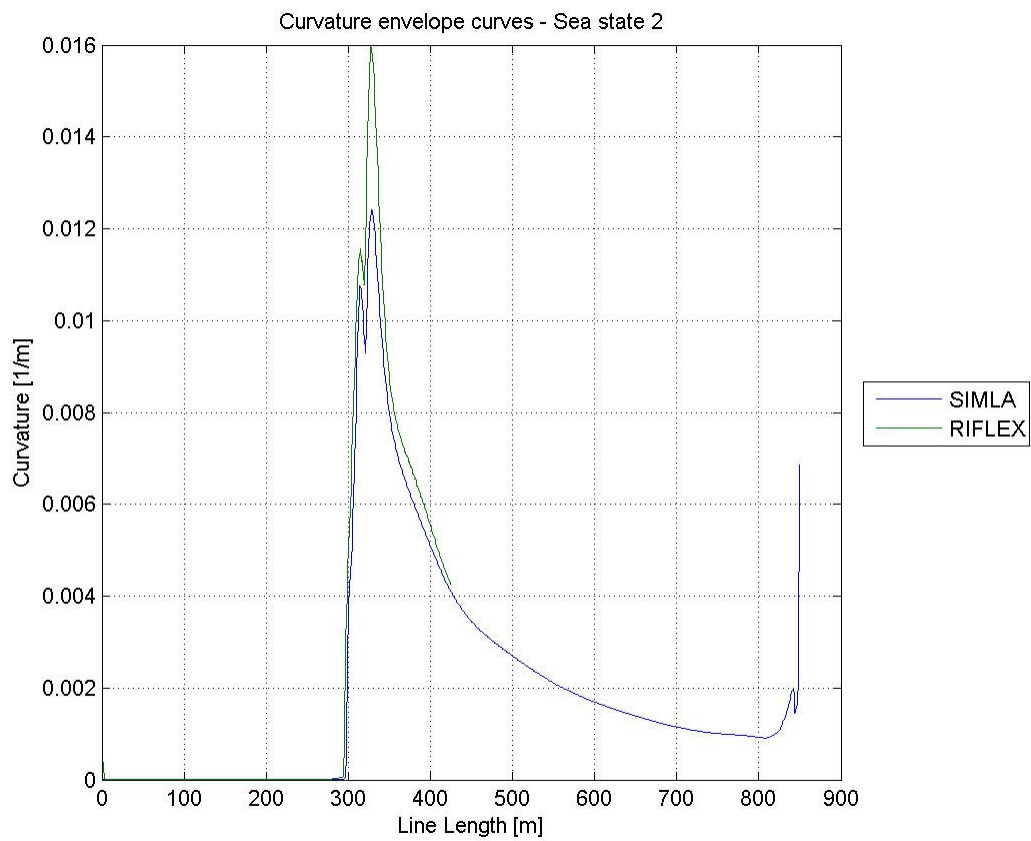


Figure 19: Curvature - Sea state 2

7.2.2.3 *Sea state 3*

At this sea state the significant wave height is set to 3 meters, and the wave period is set to 9,30 seconds. The results are given as plots in Figure 20: Forces - Sea state 3 to Figure 23: Curvature - Sea state 3.

7.2.2.3.1 *Envelope force*

It can be observed that the maximum tension is higher, and the minimum tension is lower, for RIFLEX than for SIMLA, but there is still no compression or buckling in the touch down area, or tension higher than the endurance for the umbilical.

7.2.2.3.2 *Bending moment and curvature*

The results are still very similar for both programs at the sea bed and at the catenary part of the umbilical, but there is also for this sea state a quite large difference at the touch down point and the connecting element. The envelope curvature at the touch down point is still very small.

7.2.2.3.3 *Displacements*

The displacement envelopes show only small differences. Both programs show that there is no movement on the seafloor and the catenary part of the umbilical. At the touch down point there is a small difference that is of no big practical importance for an installation.

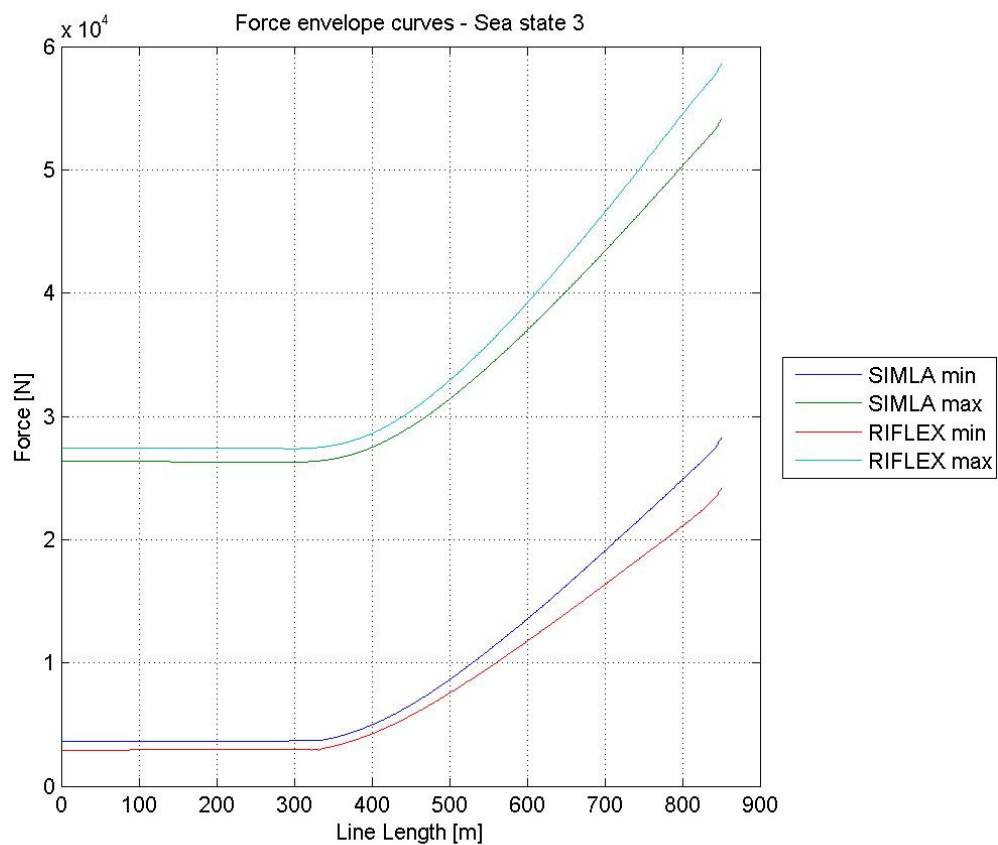


Figure 20: Forces - Sea state 3

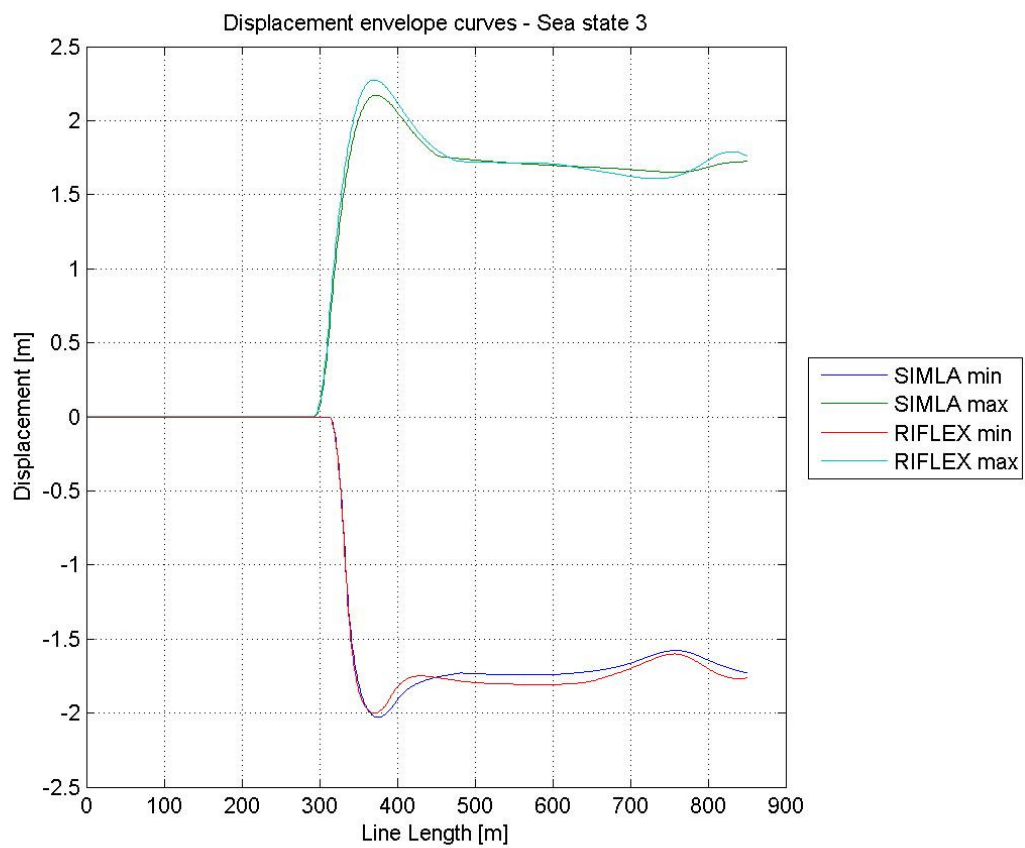


Figure 21: Displacements - Sea state 3

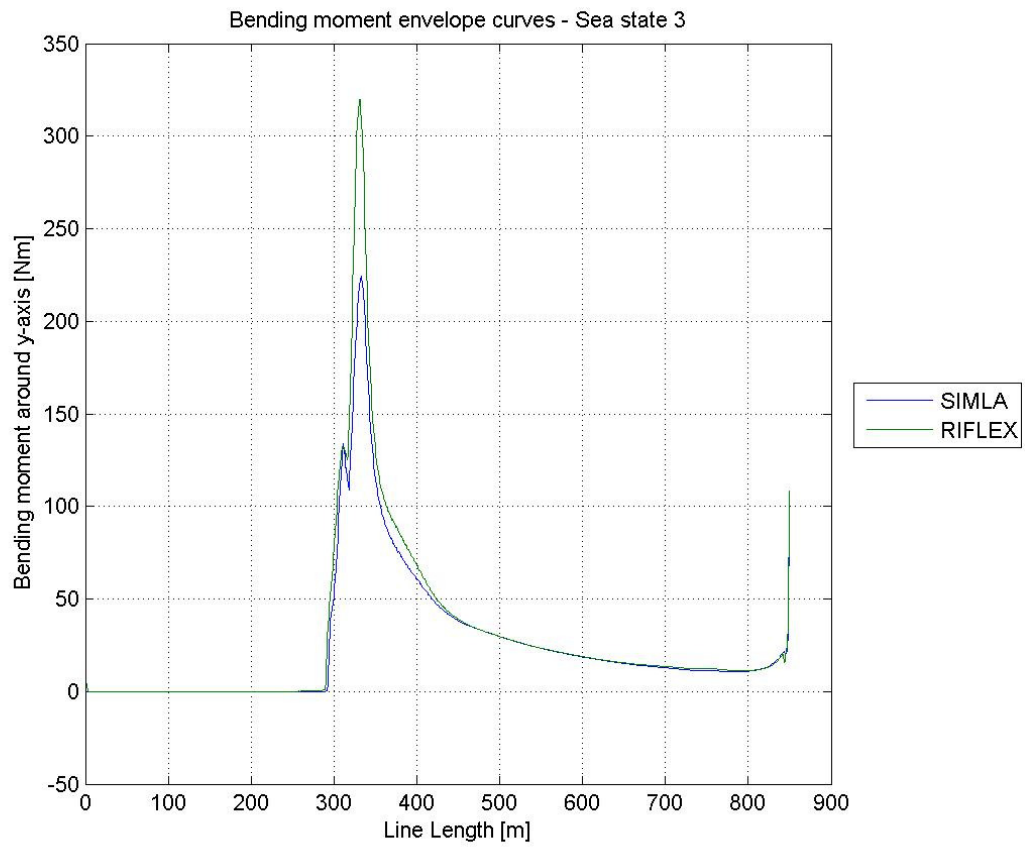


Figure 22: Bending moment - Sea state 3

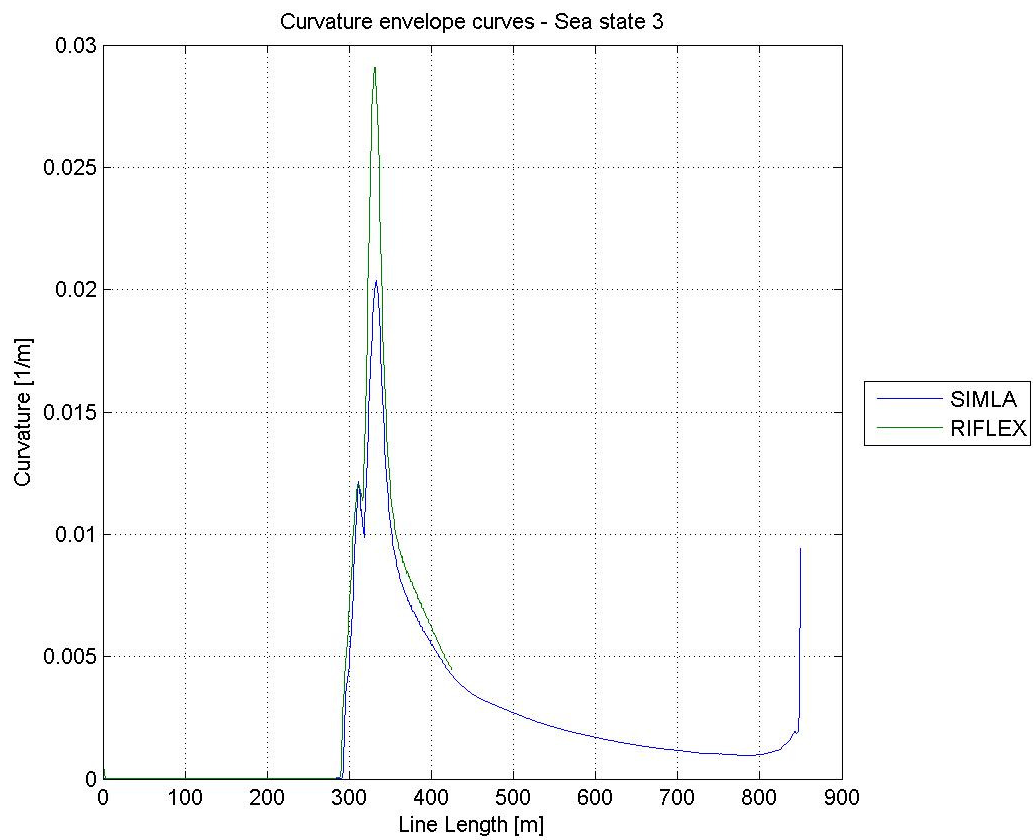


Figure 23: Curvature - Sea state 3

7.2.2.4 *Sea state 4*

At this sea state the significant wave height is set to 3,33 meters, and the wave period is set to 9,05 seconds. The results are given as plots in Figure 24: Forces - Sea state 4 to Figure 27: Curvature - Sea state 4.

7.2.2.4.1 *Envelope force*

The trends for this sea state are very similar as for sea state 3, but now the minimum bottom tension is getting very low. RIFLEX is closer to zero than SIMLA. The RIFLEX result also shows some kind of instability at the touch down point, showing a small minimum force peak where SIMLA has a smooth curve. The RIFLEX results are very close to showing compression at the touch down point.

7.2.2.4.2 *Bending moment and curvature*

The trends for sea state 4 are similar as for sea state 3, but the peaks are larger due to the higher significant wave height. The maximum curvature is about 25 percent of the umbilicals maximum tolerance.

7.2.2.4.3 *Displacements*

It can be observed that the trends from sea state 3 are valid for sea state 4 as well.

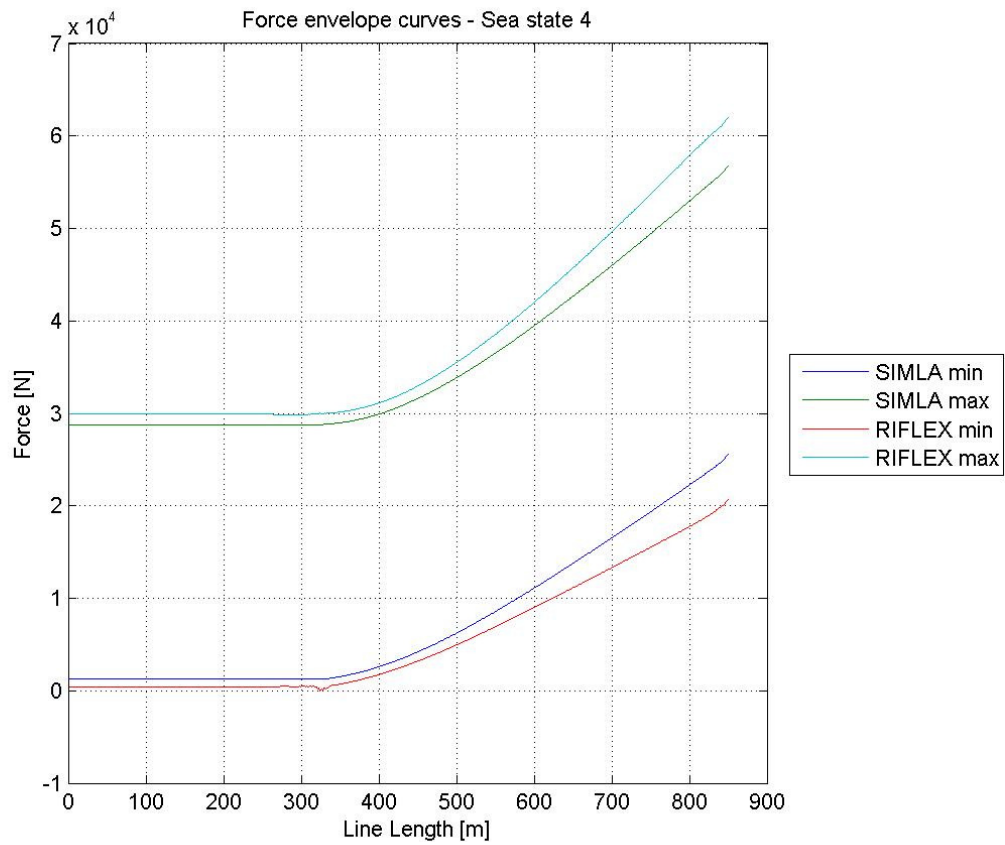


Figure 24: Forces - Sea state 4

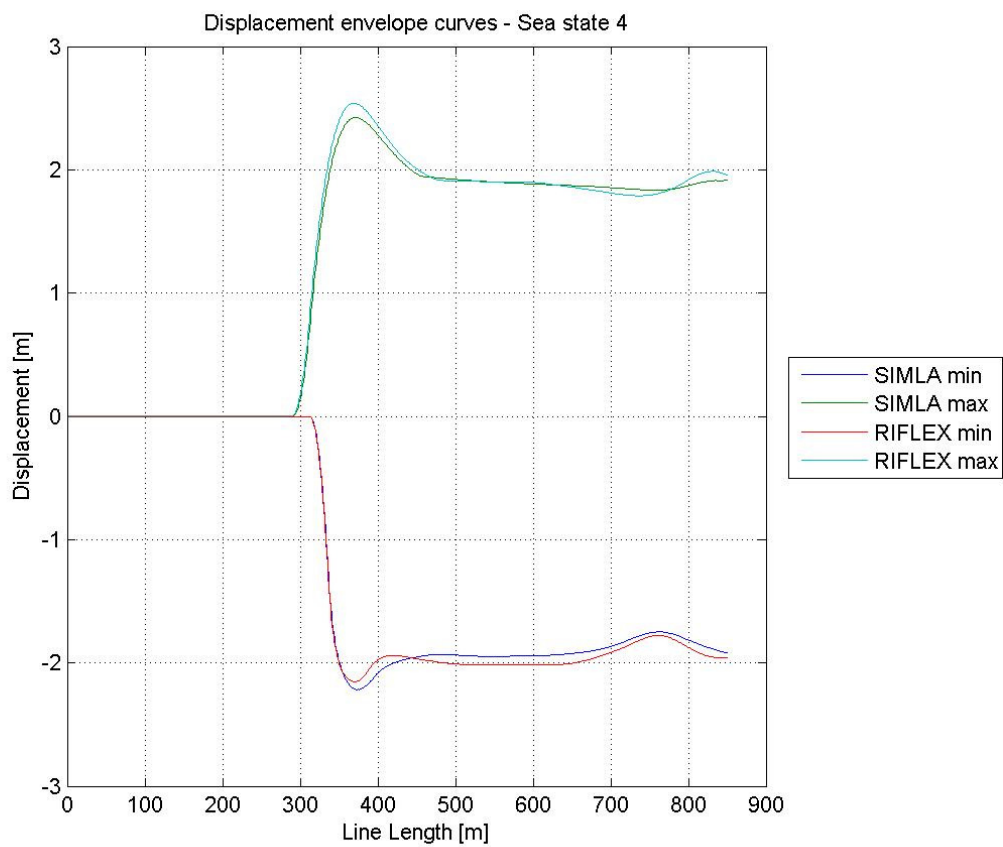


Figure 25: Displacements - Sea state 4

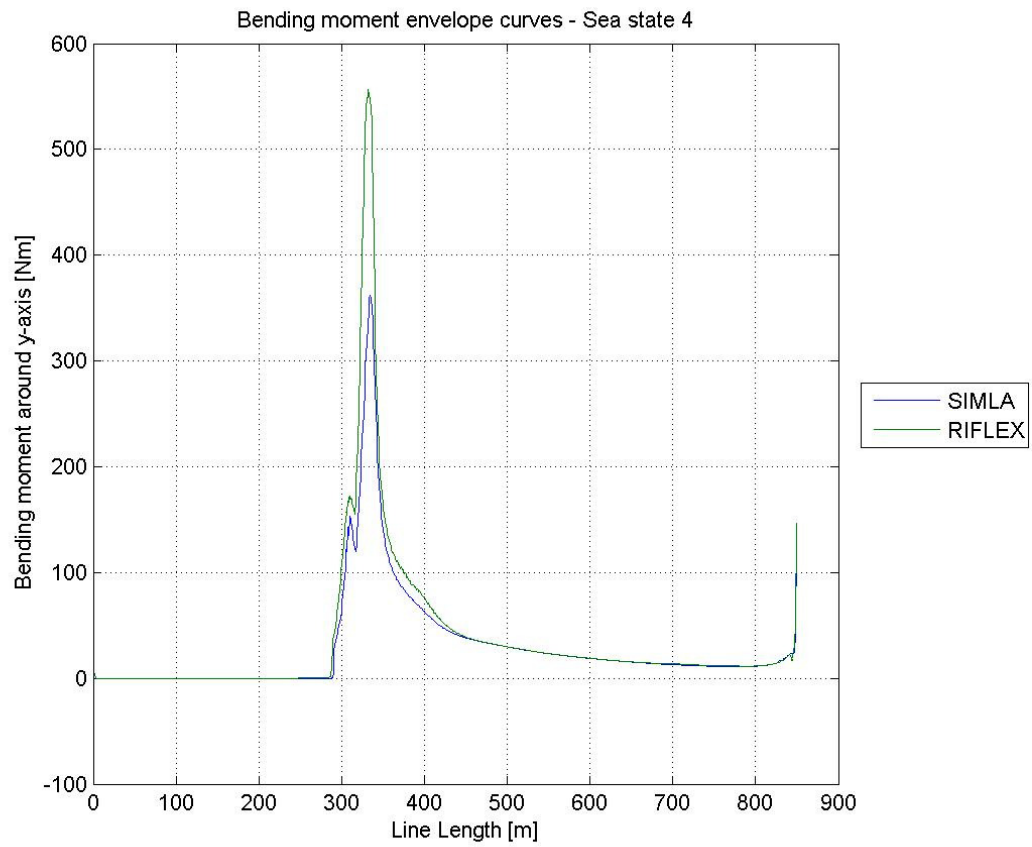


Figure 26: Bending moment - Sea state 4

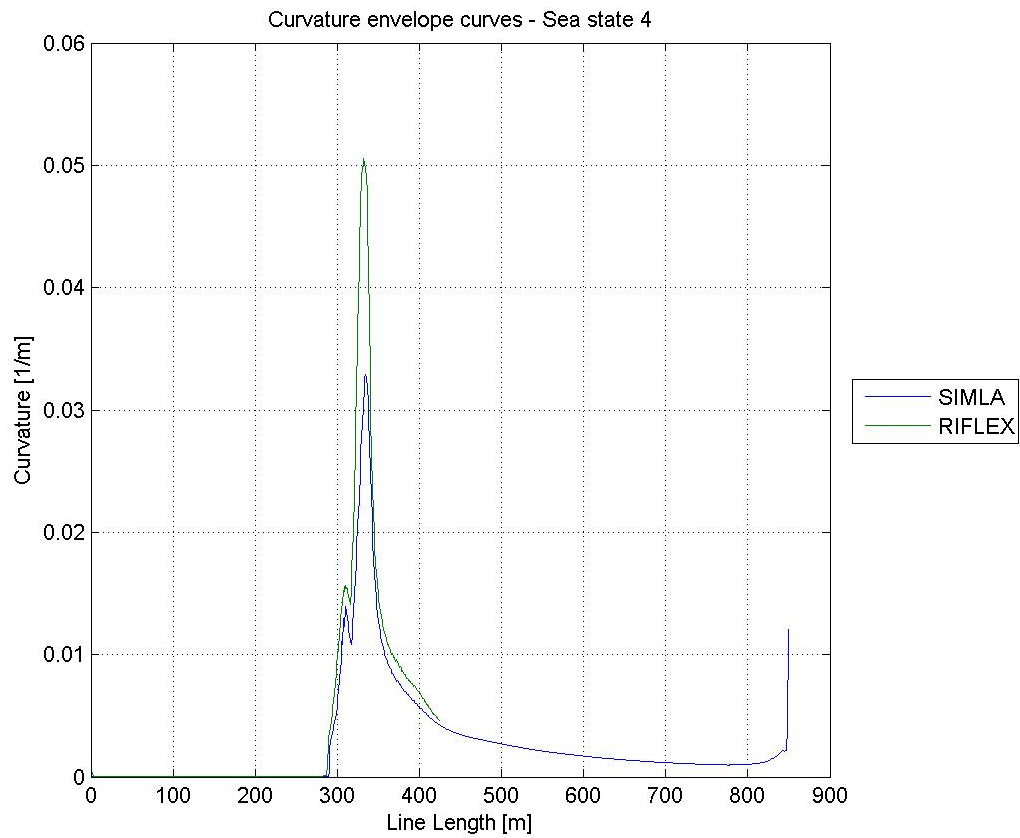


Figure 27: Curvature - Sea state 4

7.2.2.5 *Sea state 5*

Sea state 5 has a significant wave height set to 3,66 meters, and the wave period is set to 9,30 seconds. The results are given as plots in Figure 28: Forces - Sea state 5 to Figure 31: Curvature - Sea state 5.

7.2.2.5.1 *Envelope force*

In this sea state both programs show that compression at the touch down point occurs. Again, RIFLEX shows overall larger values than SIMLA, and RIFLEX has a local peak force at the touch down area which SIMLA do not have.

The compression is small for both programs and has not induced any vertical movements of the umbilical on the sea bed, except for the touch down point.

The maximum values are still well under the tolerated maximum tension of the umbilical.

7.2.2.5.2 *Bending moment and curvature*

Even though compression occurs, all bending moment and curvature trends in sea state 4 apply for this sea state as well.

7.2.2.5.3 *Displacements*

Even though compression occurs, displacement trends in sea state 4 apply for this sea state as well.

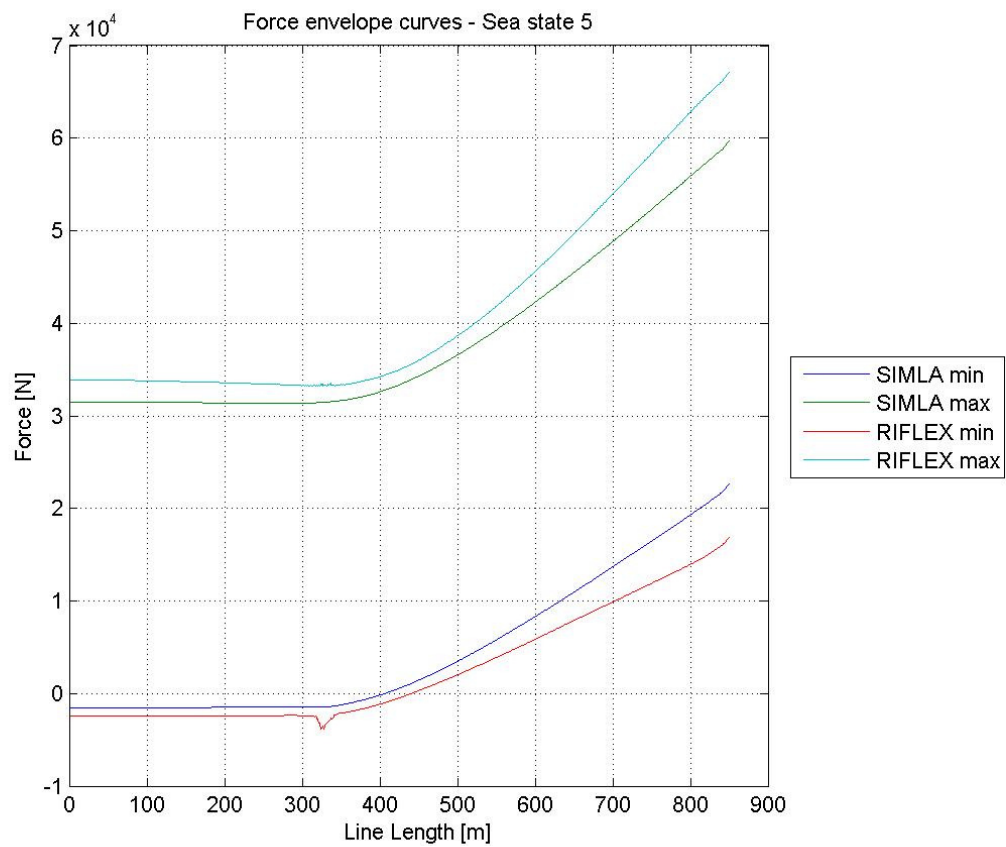


Figure 28: Forces - Sea state 5

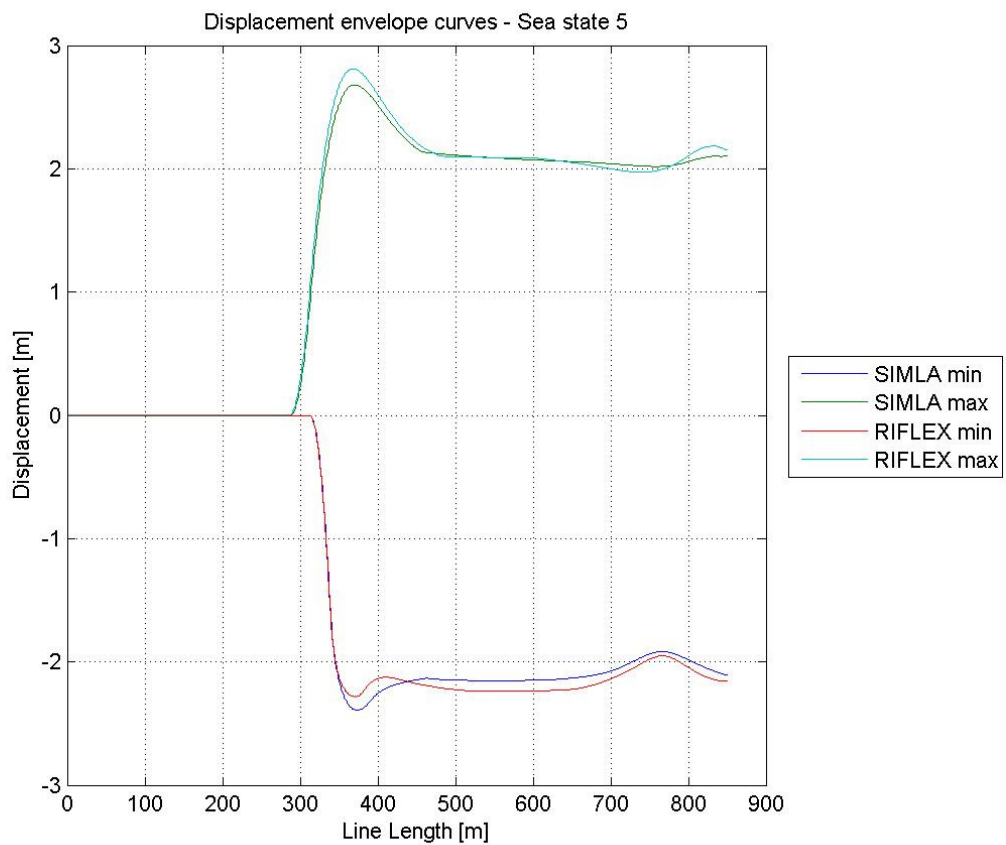


Figure 29: Displacements - Sea state 5

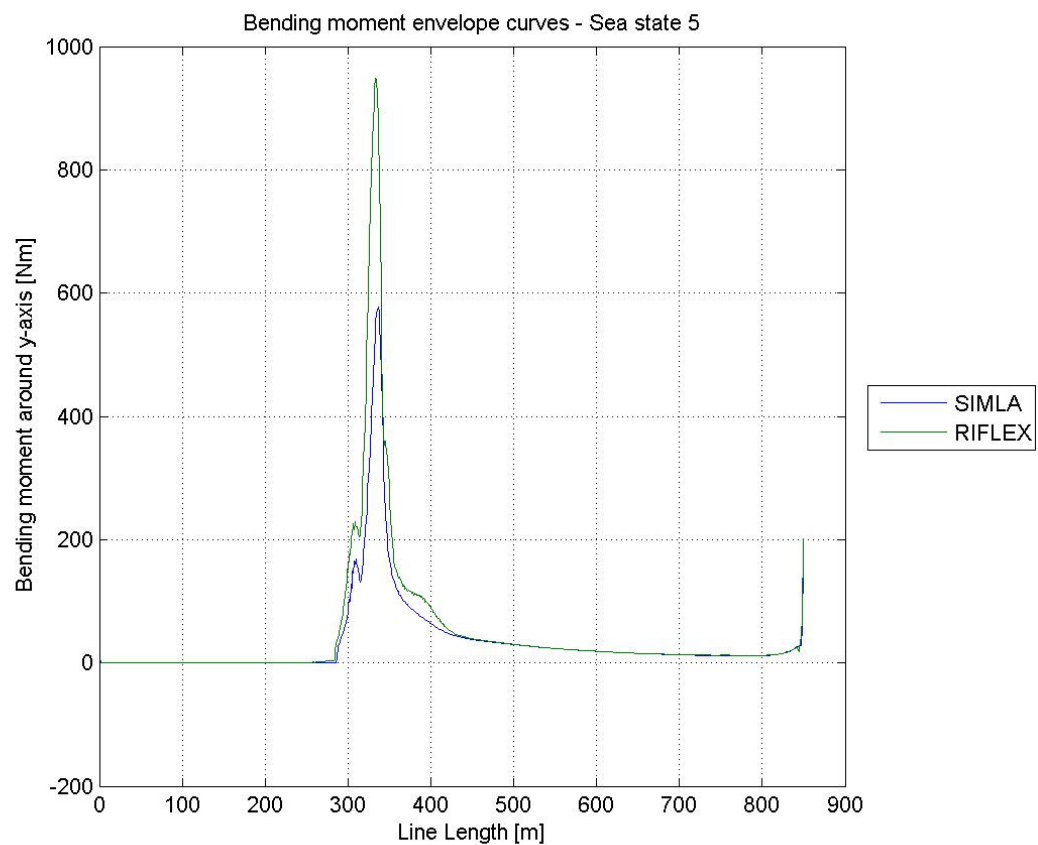


Figure 30: Bending moment - Sea state 5

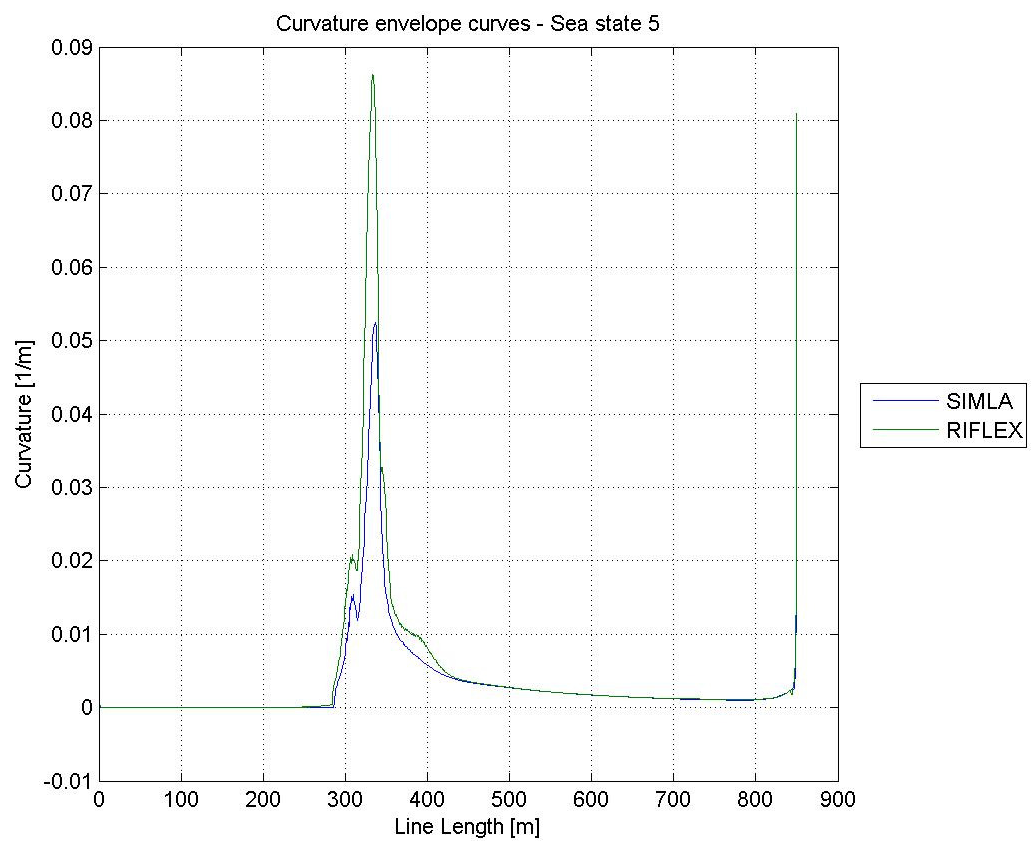


Figure 31: Curvature - Sea state 5

7.2.2.6 Sea state 6

At this sea state the significant wave height is set to 4 meter, and the wave period is set to 10,05 seconds. The results are given as plots in Figure 32: Forces - Sea state 6 to Figure 35: Curvature - Sea state 6.

7.2.2.6.1 Envelope force

There are big conflicting differences in this sea state. The SIMLA results show the same trend as for the sea state 5, showing stable compression at the sea bed. The RIFLEX results show many enormous local maximum and minimum peaks. The values of the peaks are up to 10 times as high as the SIMLA results, and are believed to be beyond any reasonable outcome of the analyses. Some of the maximum peaks are far beyond the endurance limit for the umbilical, which is 160 kN.

7.2.2.6.2 Bending moment and curvature

As for the forces of this sea state, there are immense differences. SIMLA shows stable bending moment and curvature, while RIFLEX show an instable result with bending moment all over the sea bed. The compression induced RIFLEX curvature at the seabed is within the tolerated bending radius for the umbilical. The results from the catenary part of the umbilical are quite similar.

7.2.2.6.3 Displacements

The compression and bending moments at the sea bed induce displacements of the umbilical in RIFLEX, while in SIMLA there are still no displacements. The displacements at the touch down point and at the catenary part are quite similar, reasonable and stable for both programs.

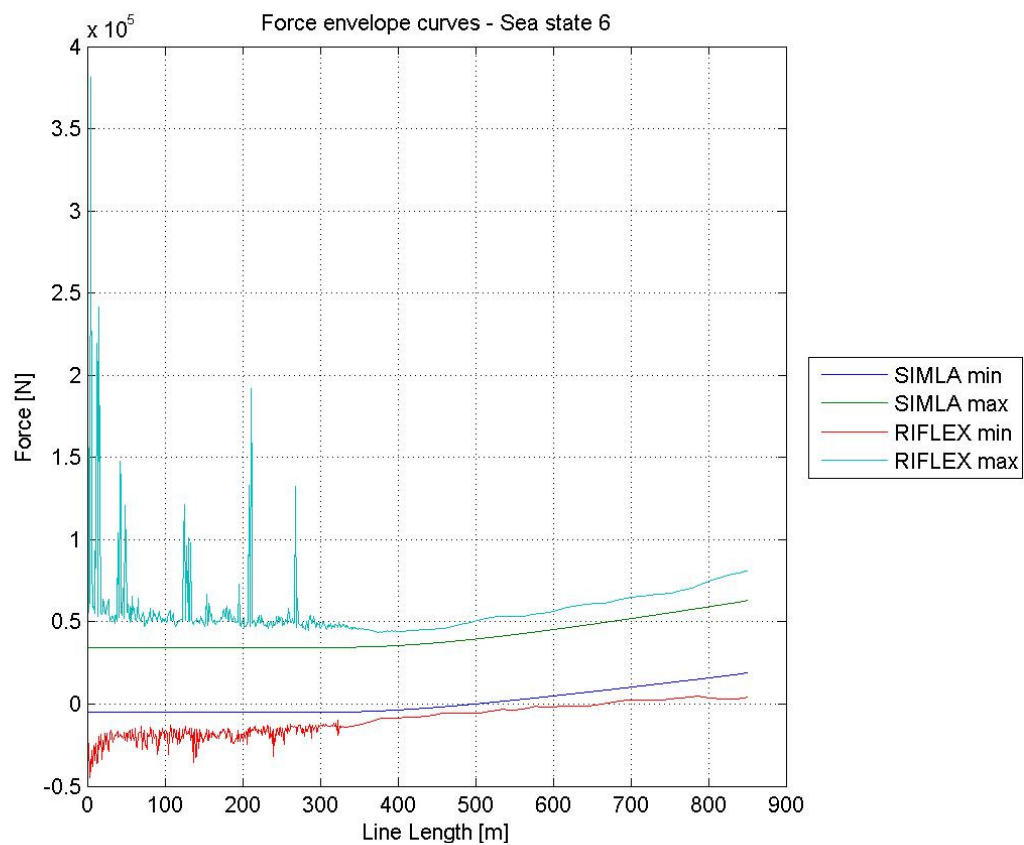


Figure 32: Forces - Sea state 6

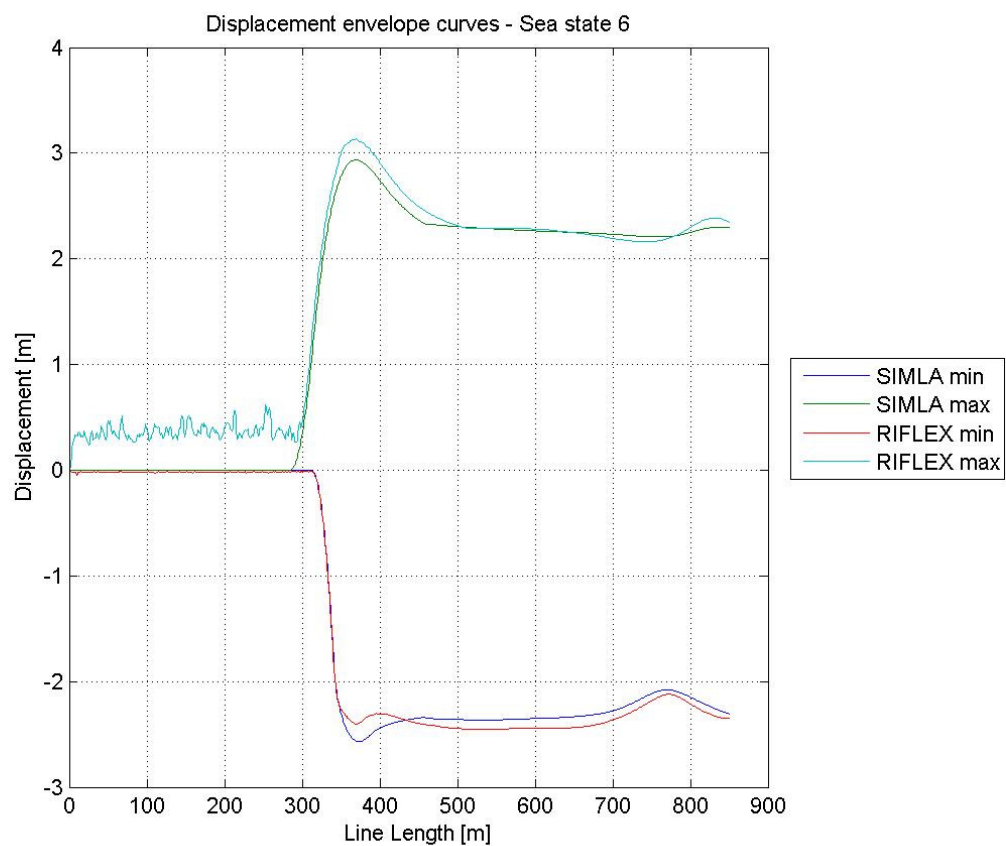


Figure 33: Displacements - Sea state 6

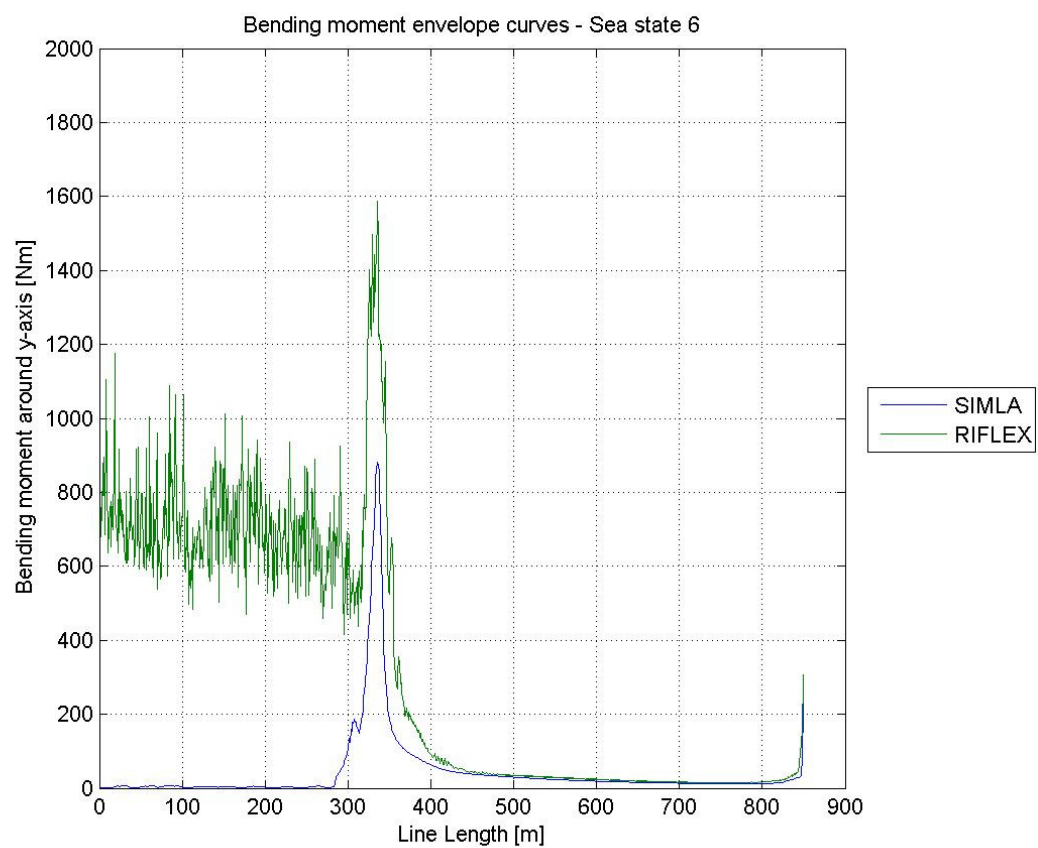


Figure 34: Bending moment - Sea state 6

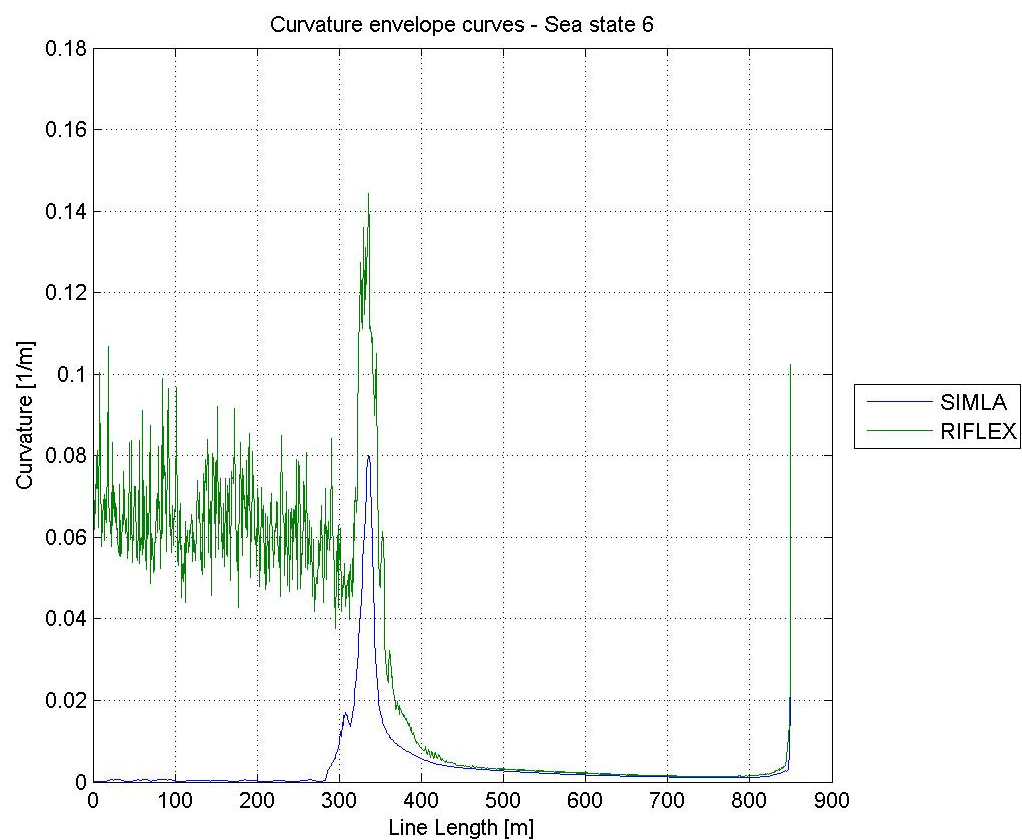


Figure 35: Curvature - Sea state 6

7.2.2.7 *Sea state 7*

At this sea state the significant wave height is set to 4,33 meters, and the wave period is set to 10,05 seconds. The results are given as plots in Figure 36: Forces - Sea state 7 to Figure 39: Curvature - Sea state 7.

7.2.2.7.1 *Envelope force*

The trends for sea state 6 describe the observations for this sea state well too. RIFLEX shows larger both minimum and maximum values, and the results are more irrational. SIMLA shows a stable compression of the bottom 500 meters of the umbilical, while RIFELX shows compression of the first 600 meters. The large maximum peaks shown in the RIFLEX results are higher than the tolerance limit.

7.2.2.7.2 *Bending moment and curvature*

The bending moment and curvature is largest at the touch down point for both programs, but also here RIFLEX shows large peaks and unstable results for the part of the umbilical which is on the sea bed. All results are still within the tolerance limits.

7.2.2.7.3 *Displacements*

Movements of the umbilical can be observed at the sea bed for the RIFLEX results, but SIMLA still show that the umbilical is unaffected on the sea bed. The results are quite similar for the touch down point and catenary parts of the results.

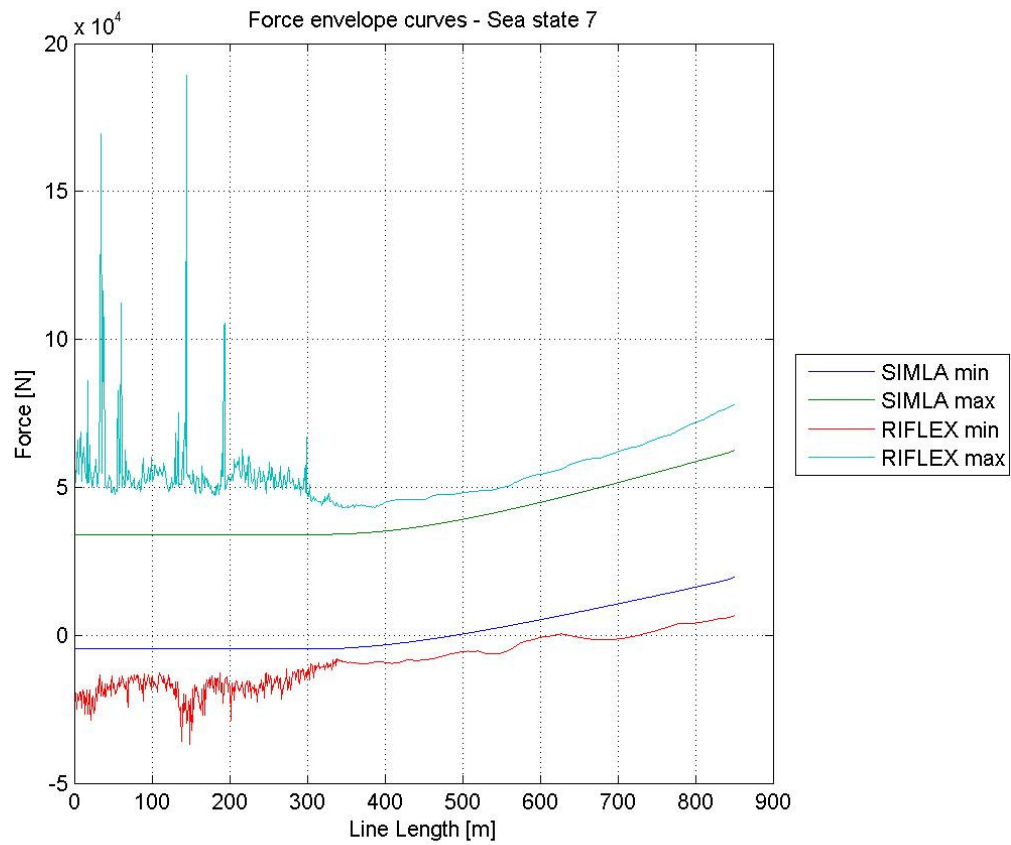


Figure 36: Forces - Sea state 7

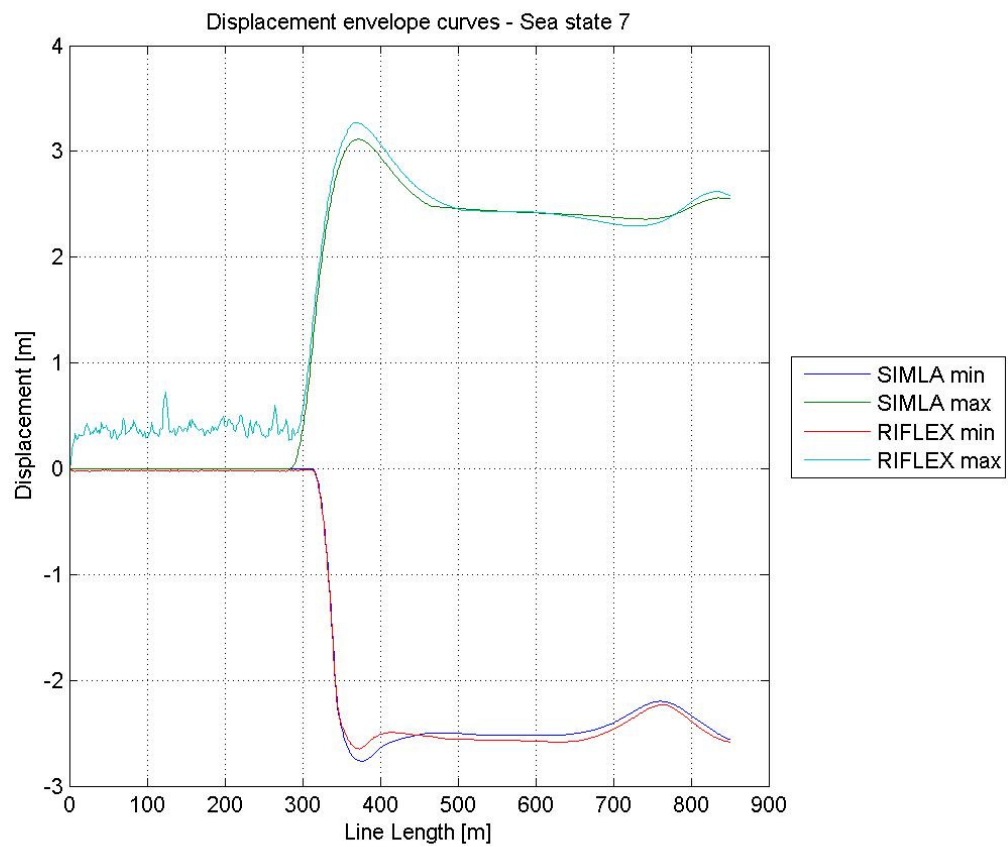


Figure 37: Displacements - Sea state 7

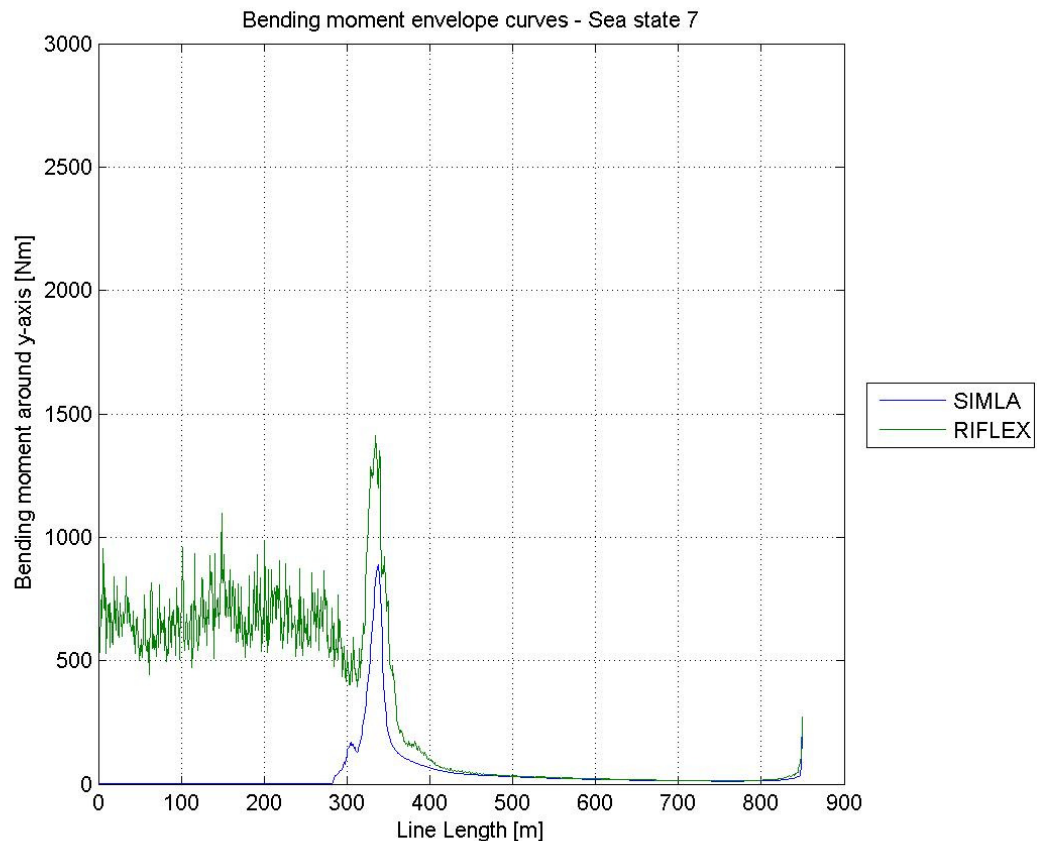


Figure 38: Bending moment - Sea state 7

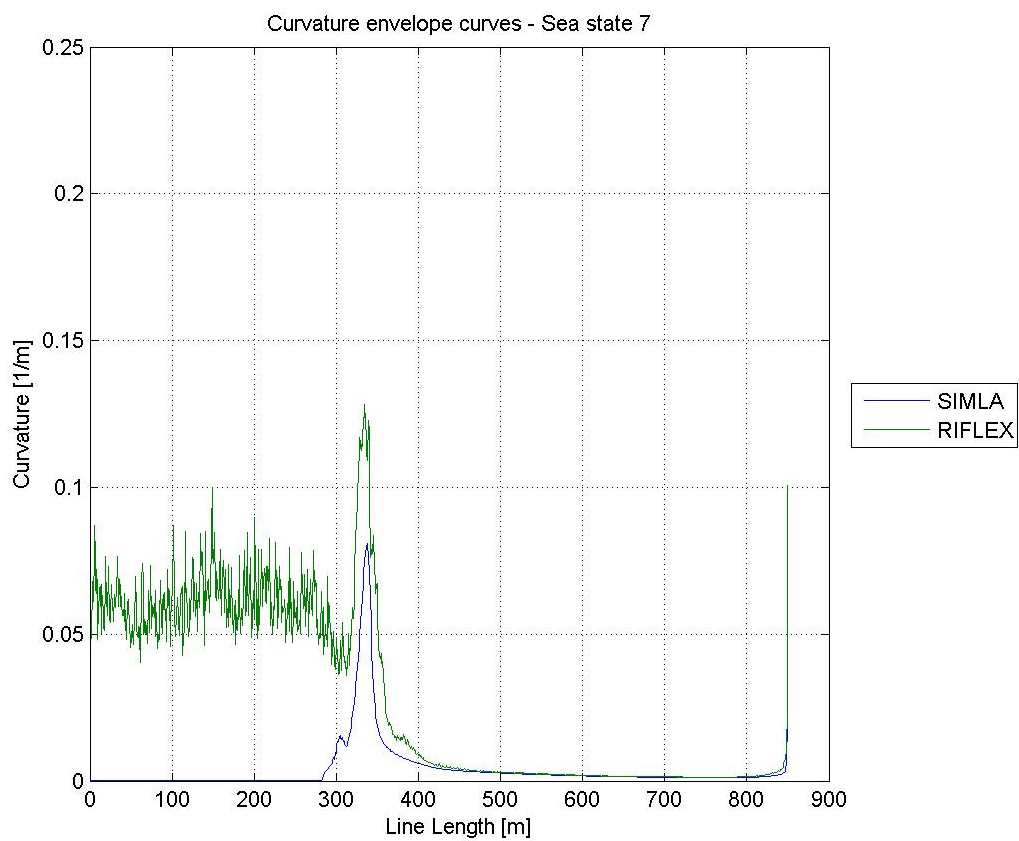


Figure 39: Curvature - Sea state 7

7.2.2.8 Sea state 8

At this sea state the significant wave height is set to 4,33 meter, and the wave period is set to 10,05 seconds. The results are given as plots in Figure 40: Forces - Sea state 8 to Figure 43: Curvature - Sea state 8.

7.2.2.8.1 Envelope force

The RIFLEX results are once again more dramatic than the SIMLA results. SIMLA shows smooth plots, while RIFLEX shows plots with disturbance peaks. SIMLA shows that compression occurs for the bottom 550 meters, while RIFLEX show compression for the bottom 650 meters.

7.2.2.8.2 Bending moment and curvature

Both programs show similar trends for the catenary part of the umbilical, but there are big differences for the rest. RIFLEX shows much higher values at the touch down point, and it shows a plot with a lot of disturbance for the part of the umbilical on the sea bed. SIMLA still show that there is not bending moment on the sea bed.

7.2.2.8.3 Displacements

Displacements of the umbilical can be observed at the sea bed for the RIFLEX results, but SIMLA still show that the umbilical is unaffected on the sea bed. These RIFLEX displacements are averaged at about half a meter. The results are quite similar for the touch down point and catenary parts of the results.

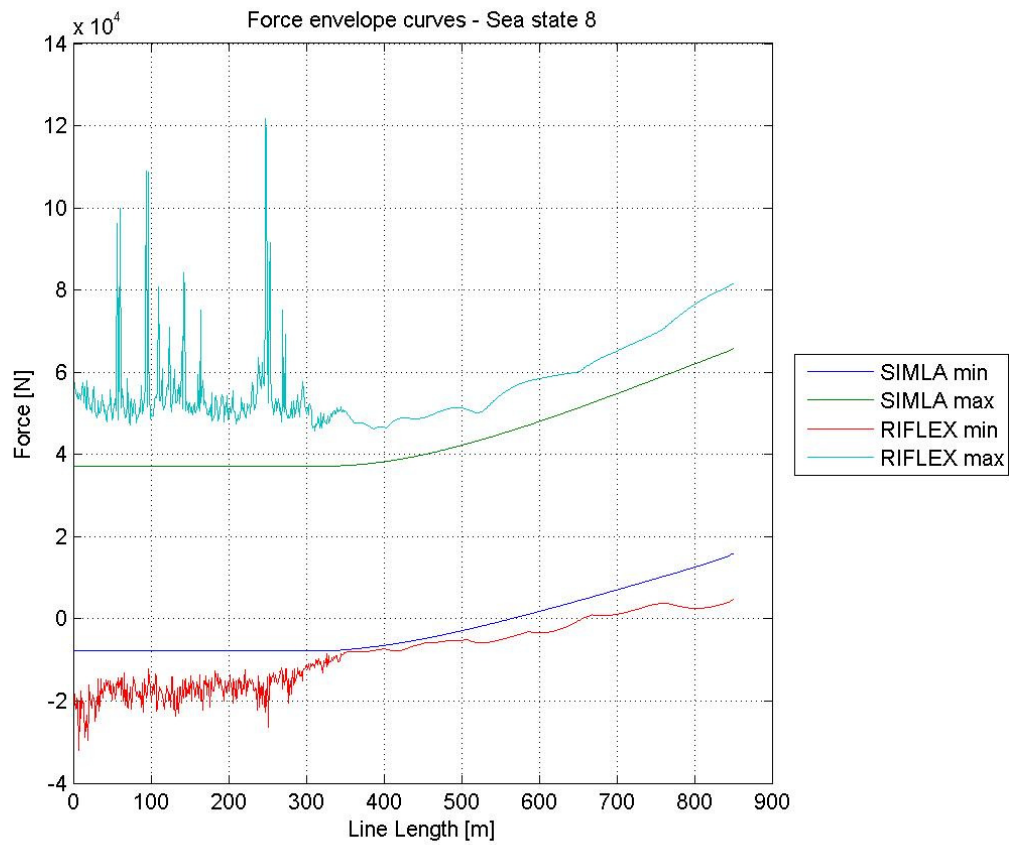


Figure 40: Forces - Sea state 8

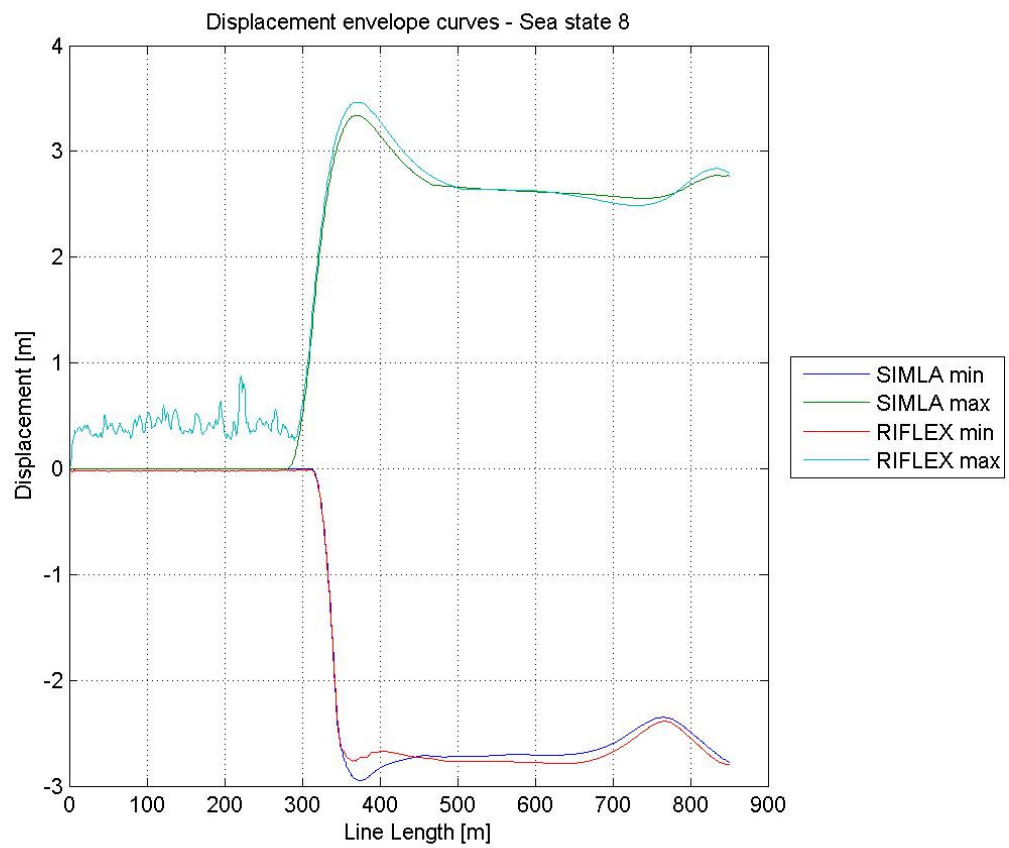


Figure 41: Displacements - Sea state 8

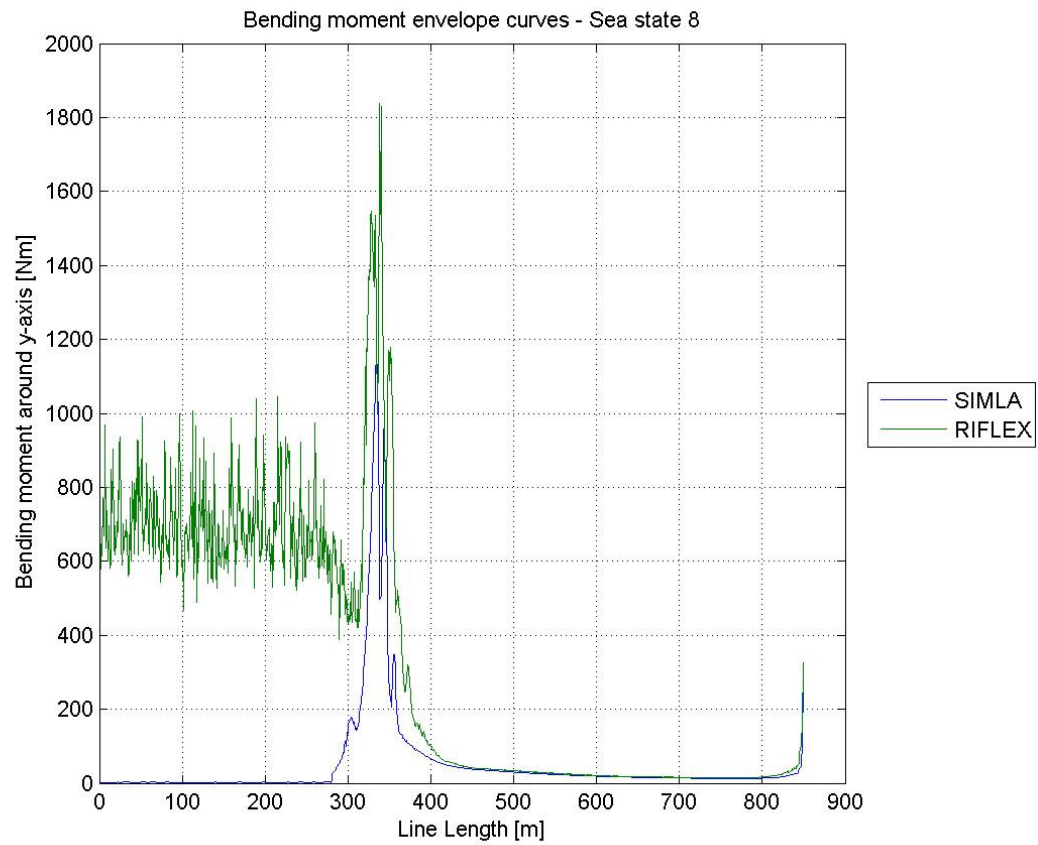


Figure 42: Bending moment - Sea state 8

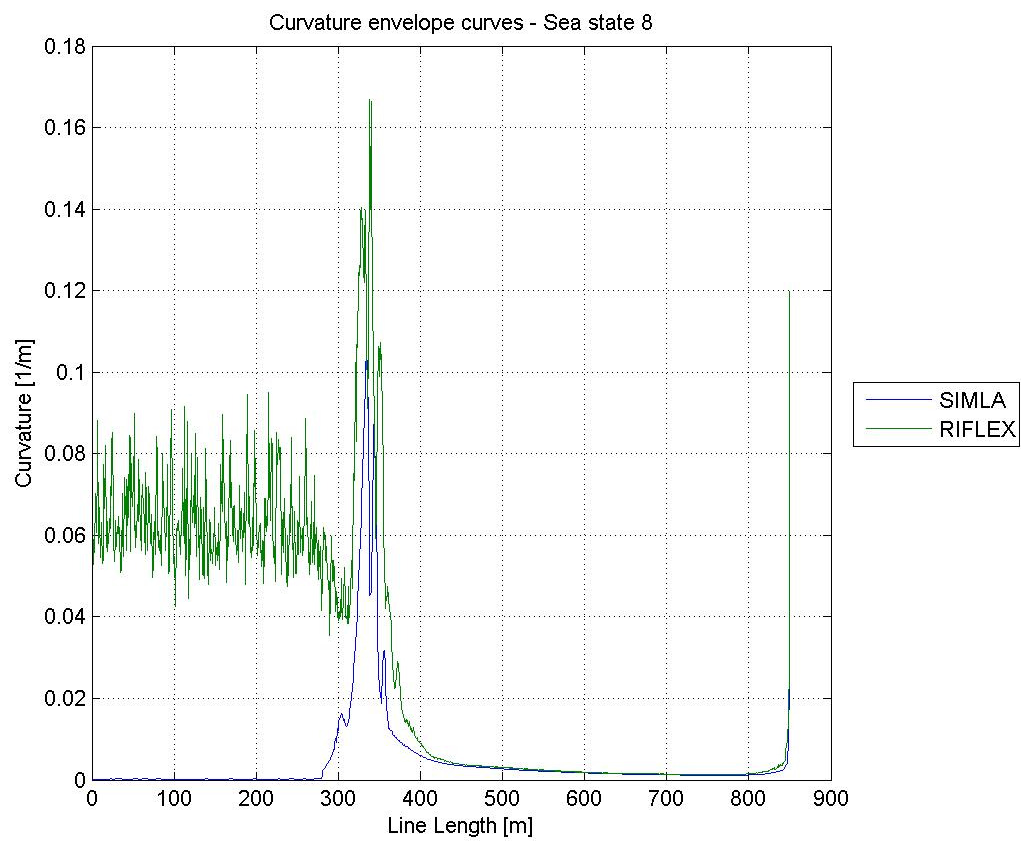


Figure 43: Curvature - Sea state 8

7.2.2.9 Sea state 9-20

Here follows a brief description of the last 12 sea states. All the results from sea state 9 to 20 are given as appendix D

7.2.2.9.1 Envelope forces

All plots from SIMLA are smooth and stable, without any indescribable peaks. The minimum values in SIMLA seem to converge to about 10 kN compression at the sea bed. The maximum values are far within the tolerance limits for the umbilical for all sea states.

RIFLEX show irrational results for most sea states. All of the 12 last sea states show enormous peaks, and for some of them, the peaks are higher than the tolerance limit for the umbilical. RIFLEX show large compressions all over the umbilical. One observation is that the compression at the touch down point is smaller than the compression along the sea bed. The compression at the touch down point do for some sea states happen to be smaller than for SIMLA.

RIFLEX exceeds the maximum allowed tension in 5 of the 12 last sea states.

7.2.2.9.2 Bending moment and curvature

The trends from the previous sea states apply for the last 12 sea states as well. The catenary parts of the results are similar for both programs. RIFLEX shows higher values at the touch down point, and there are big differences for the sea bed contact results. SIMLA show small values of maximum 50 Nm at the sea bottom for most sea states, while RIFLEX is has a quite consistent average of about 750 Nm.

For two of the sea states, number 16 and 18, SIMLA shows the same type of indescribable peaks as RIFLEX show.

For 11 out of the 12 sea states, RIFLEX exceeds the maximum curvature limit. SIMLA does not exceed this limit for any sea states.

7.2.2.9.3 Displacements

The trends from the previous sea states apply for most of the last 12 sea states as well. The displacements are quite similar for both the catenary part and the around the touch down point. SIMLA shows that the umbilical lays steady on the sea bed for most sea states, while RIFLEX show an average envelope displacement on the sea bed of about 0,5 meters for all sea states.

For two of the sea states, number 16 and 18, SIMLA shows the same type of indescribable peaks as RIFLEX show for the umbilical laying on the sea bed. Especially for sea state 18, the similarities are remarkably similar, even for the local peaks.

7.2.3 Maximum dynamic results

7.2.3.1 Displacement of connection point

This is a test to see if the induced motion of the top end of the umbilical is the same. For all sea states, the response amplitude operators for the vessel and the regular waves are the same for SIMLA and RIFLEX, and the motion of the top end of the umbilical should be identical. The results, on the other hand, show a small difference. For all sea states RIFLEX show a bigger movement then SIMLA. It varies from 0,14 % to 2,29 %, or from less than a cm to 3 cm, respectively.

Sea State	Maximum displacement positive z-direction [m]			Maximum displacement negative z-direction [m]		
	SIMLA	RIFLEX [m]	Difference	SIMLA [m]	RIFLEX [m]	Difference
1	1,106	1,114	0,72 %	-1,107	-1,114	-0,61 %
2	1,228	1,256	2,29 %	-1,229	-1,257	-2,20 %
3	1,727	1,763	2,08 %	-1,728	-1,764	-2,02 %
4	1,917	1,956	2,04 %	-1,918	-1,957	-1,97 %
5	2,107	2,150	2,06 %	-2,108	-2,151	-1,98 %
6	2,302	2,350	2,08 %	-2,304	-2,351	-2,00 %
7	2,559	2,583	0,96 %	-2,561	-2,584	-0,91 %
8	2,769	2,796	0,96 %	-2,772	-2,797	-0,90 %
9	2,980	3,009	0,97 %	-2,984	-3,011	-0,90 %
10	3,197	3,228	0,96 %	-3,201	-3,230	-0,89 %
11	3,319	3,329	0,32 %	-3,322	-3,331	-0,27 %
12	3,538	3,547	0,26 %	-3,541	-3,550	-0,25 %
13	3,756	3,767	0,29 %	-3,760	-3,769	-0,25 %
14	3,981	3,993	0,30 %	-3,985	-3,997	-0,30 %
15	3,996	4,018	0,55 %	-4,000	-4,019	-0,47 %
16	4,215	4,238	0,54 %	-4,219	-4,239	-0,47 %
17	4,436	4,458	0,51 %	-4,439	-4,459	-0,45 %
18	4,661	4,686	0,55 %	-4,664	-4,685	-0,44 %
19	4,693	4,698	0,12 %	-4,696	-4,699	-0,07 %
20	4,913	4,920	0,14 %	-4,916	-4,919	-0,06 %

Table 7: Maximum displacements

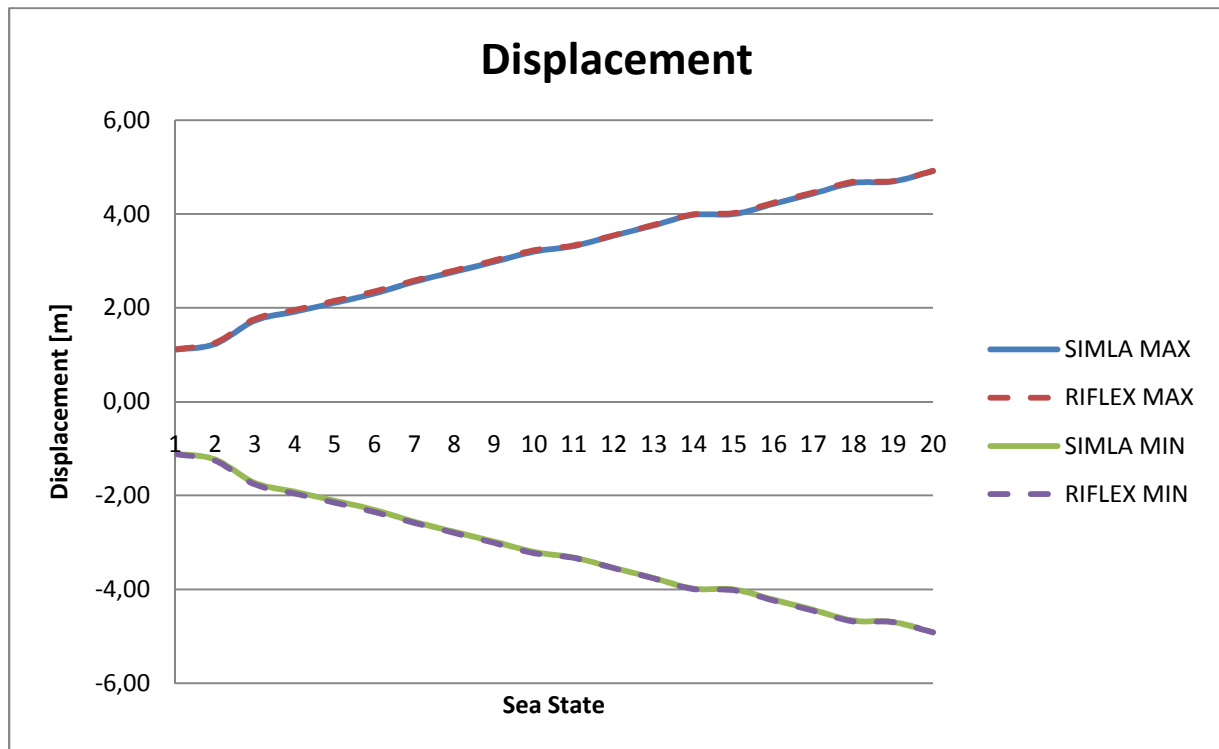


Figure 44: Maximum displacements

7.2.3.2 Dynamic force

The results of the analyses of the minimum and maximum forces are shown as envelope curves in both SIMLA and RIFLEX. Two important aspects have been compared:

1. To see if the minimum tension gets too low and results in compression at the touch down point.
2. Make sure the maximum tension of the load condition does not exceed the maximum handling tension for the umbilical.

7.2.3.2.1 Minimum Force

The minimum force was easily found in SIMLA due to the smoothness of the envelope curves. In RIFLEX the results varied a lot more due to the large peaks, as previously described. The following results include two different ways of interpreting the RIFLEX envelope curves. Table 8: Minimum forces - alternativ 1 is a comparison of SIMLA and the actual RIFLEX results that include the force peaks in the envelope curves. Table 9: Minimum forces - alternativ 2 is a comparison of the SIMLA results and the average of the minimum envelope force for the 300 first elements of the umbilical.

Either way the RIFLEX results are evaluated, RIFLEX show a bigger deviation from the static configuration than SIMLA for all sea states.

The results given in tables 8 and 9 are the resulting minimum forces and how big the variation is from the static configuration. The last column is the percentage of how much RIFLEX vary from the static configuration compared to how much SIMLA vary from the static configurations.

$$Difference [\%] = \frac{(SIMLA_{static} - SIMLA_{min}) - (RIFLEX_{static} - RIFLEX_{min})}{(RIFLEX_{static} - RIFLEX_{min})} \times 100$$

As seen in table 8 the results for sea state 1 to 5 differs from 7 to 13 %. For these sea states there are no large compressions in the umbilical. For sea state 6 to 20, the differences are substantial. For all these sea states there are large compressions, and the results in SIMLA and RIFLEX vary as much as 67 %.

Sea state	Minimum Force				
	SIMLA [N]	Variation [N]	RIFLEX [N]	Variation [N]	Difference [%]
1	7994	6882	7389	7574	9 %
2	6571	8305	5757	9206	10 %
3	3643	11233	2929	12034	7 %
4	1236	13639	-6	14970	9 %
5	-1520	16396	-3815	18778	13 %
6	-4954	19830	-44890	59853	67 %
7	-4592	19468	-36760	51723	62 %
8	-7830	22706	-32040	47003	52 %
9	-9315	24191	-38600	53563	55 %
10	-9924	24800	-32590	47553	48 %
11	-9388	24264	-33080	48043	49 %
12	-10451	25327	-33850	48813	48 %
13	-10565	25441	-36050	51013	50 %
14	-11703	26579	-37150	52113	49 %
15	-10413	25289	-36960	51923	51 %
16	-10670	25546	-43990	58953	57 %
17	-11956	26832	-39480	54443	51 %
18	-10871	25747	-37580	52543	51 %
19	-11873	26749	-33210	48173	44 %
20	-12356	27232	-31360	46323	41 %

Table 8: Minimum forces - alternativ 1

In table 9 where the results in RIFLEX are found as a average of the first 300 elements, the variations between the programs are smaller, but still quite big. Again, the differences are small for sea state 1 to 5, varying from 6 to 10 % where there are no, or only small, compressions. Sea states 6 to 20 have larger compressions, and then again have much larger variations, differing from 17 to 42 %.

Sea state	Min Force				
	Simla [N]	Variation [N]	RIFLEX (average) [N]	Variation [N]	Difference [%]
1	7994	6882	7402	7561	9 %
2	6571	8305	5772	9192	10 %
3	3643	11233	2952	12012	6 %
4	1236	13639	444	14519	6 %
5	-1520	16396	-2413	17377	6 %
6	-4954	19830	-19257	34221	42 %
7	-4592	19468	-18030	32993	41 %
8	-7830	22706	-17420	32383	30 %
9	-9315	24191	-18630	33594	28 %
10	-9924	24800	-17253	32216	23 %
11	-9388	24264	-17416	32379	25 %
12	-10451	25327	-18511	33475	24 %
13	-10565	25441	-18274	33237	23 %
14	-11703	26579	-17251	32215	17 %
15	-10413	25289	-18274	33238	24 %
16	-10670	25546	-18304	33267	23 %
17	-11956	26832	-18201	33164	19 %
18	-10871	25747	-18297	33261	23 %
19	-11873	26749	-17664	32628	18 %
20	-12356	27232	-17724	32688	17 %

Table 9: Minimum forces - alternativ 2

From the graphs, it is possible to see that there is a which occurs. Looking at the results from SIMLA, it can be seen that the graphs reach some kind of maximum compression at about 12 kN. Looking at the average results from RIFLEX, the maximum compression is about 18kN.

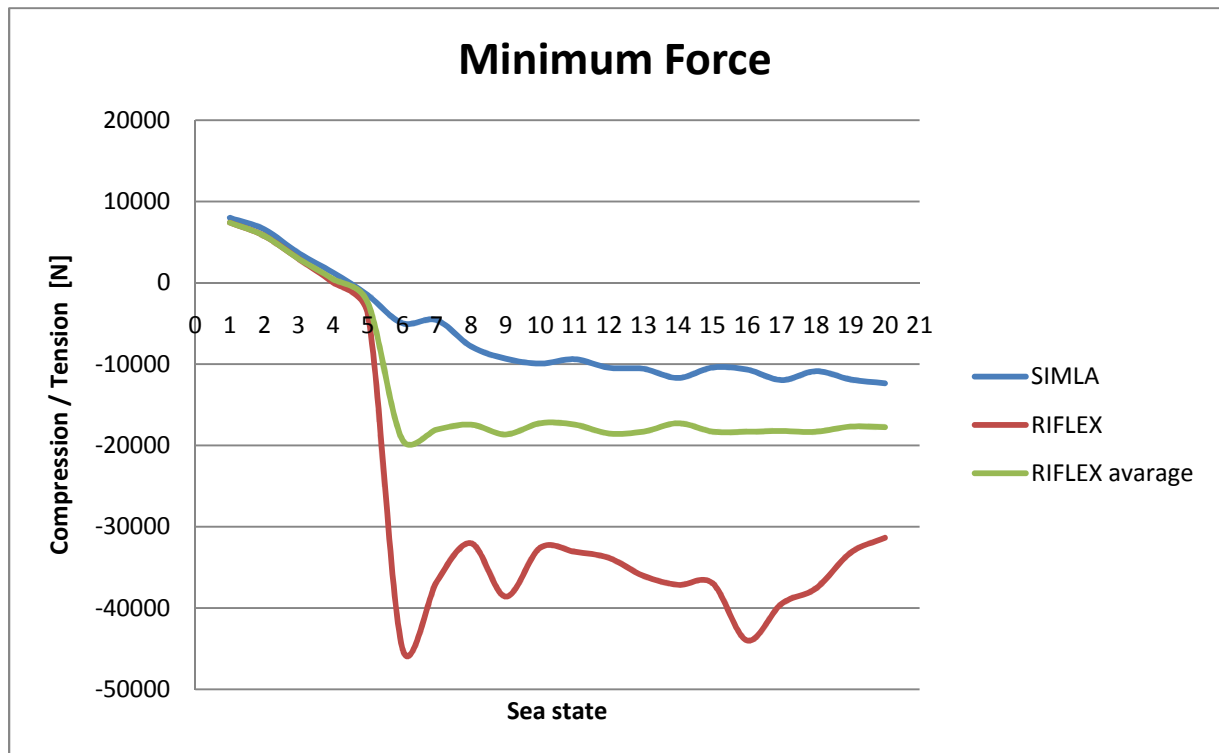


Figure 45: Minimum Forces

7.2.3.2.2 Maximum Force

The maximum force is for all sea states found at the connection point in SIMLA. RIFLEX shows large peaks of forces in the umbilical at the sea bottom. The peaks do exceed the connection point force at some sea states, but in this comparison this is neglected and the max force is assumed to be at the connection point in RIFLEX as well.

In difference from the previous static results and the dynamic displacements, RIFLEX and SIMLA show large differences in the max force envelopes. In sea state 1 to 5, the variations are from 7 to 14 %. There is a big leap up to sea state 6 where the difference is 27 %. From that sea state and up to sea state 20 the results differ between 24 and 34 %.

All results from both SIMLA and RIFLEX are within the umbilicals maximum tension limit.

Sea state	Max force				
	SIMLA [N]	Variation [N]	RIFLEX [N]	Variation [N]	Difference
1	49387	34511	52100	37137	7 %
2	51043	36167	54570	39607	9 %
3	54085	39209	58550	43587	10 %
4	56775	41899	62020	47057	11 %
5	59702	44826	67110	52147	14 %
6	62996	48121	80950	65987	27 %
7	62453	47577	77890	62927	24 %
8	65778	50902	81510	66547	24 %
9	69326	54450	87820	72857	25 %
10	73319	58443	95240	80277	27 %
11	70888	56012	90270	75307	26 %
12	74912	60036	98090	83127	28 %
13	78908	64032	107700	92737	31 %
14	82813	67937	117800	102837	34 %
15	78901	64025	104800	89837	29 %
16	82898	68022	115700	100737	32 %
17	86972	72097	117800	102837	30 %
18	91203	76327	131400	116437	34 %
19	87903	73027	123400	108437	33 %
20	91943	77067	130500	115537	33 %

Table 10: Maximum forces

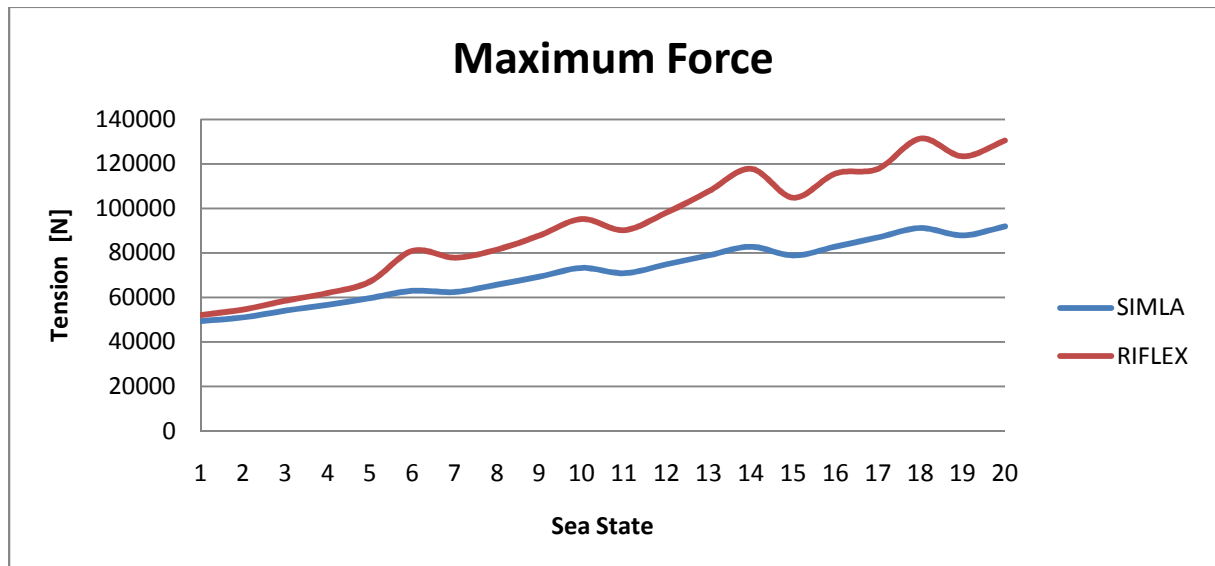


Figure 46: Maximum forces

7.2.3.3 Bending moment

The maximum bending moment results from the programs are given as envelope curves. The results given in the following table are the maximum values from each and every sea state. The bending moment results from RIFLEX and SIMLA differ a lot for all sea states. The percentage column in the table shows how much RIFLEX vary from the static configuration compared to how much SIMLA vary from the static configurations.

Sea state	Max Bending Moment		
	SIMLA [Nm]	RIFLEX [Nm]	Difference
1	111	127	21 %
2	137	176	32 %
3	224	320	36 %
4	362	557	39 %
5	577	949	41 %
6	882	1588	46 %
7	889	1413	39 %
8	1148	1837	39 %
9	1683	2023	17 %
10	1731	2256	24 %
11	1762	1987	12 %
12	1868	2304	19 %
13	1713	2449	31 %
14	1652	2508	35 %
15	1758	2373	27 %
16	2159	2538	15 %
17	1631	2681	40 %
18	2055	2695	24 %
19	1574	2710	43 %
20	1621	2711	41 %

Table 11: Maximum bending moments

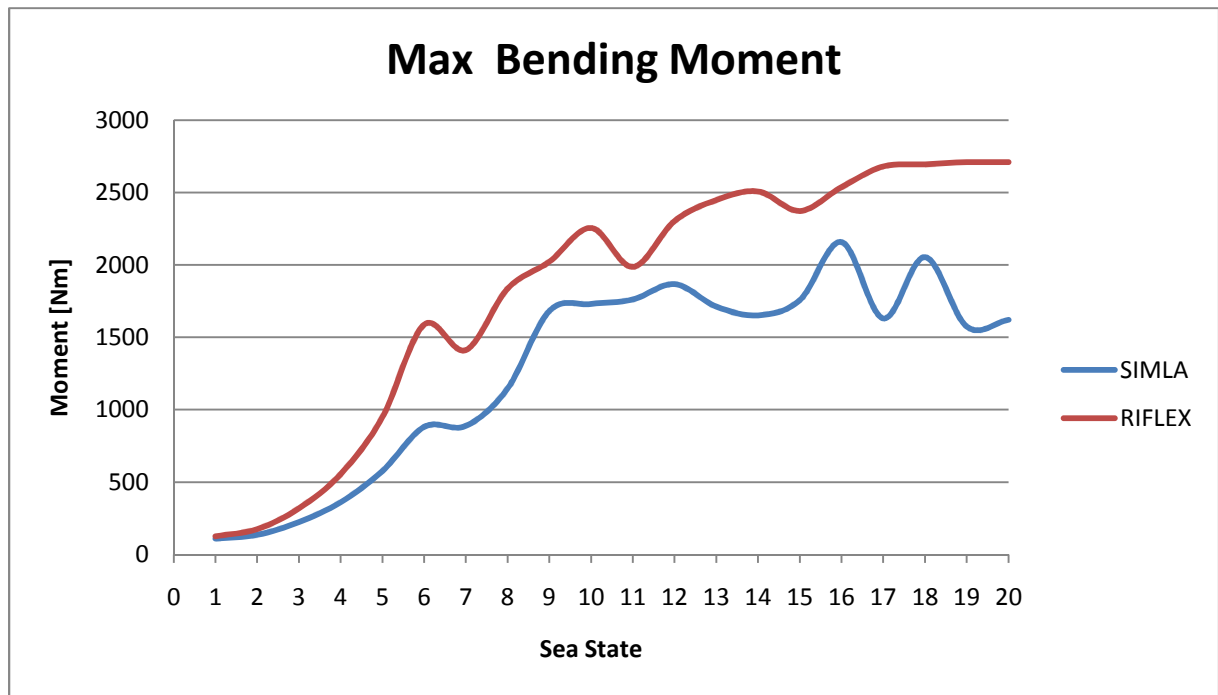


Figure 47: Maximum bending moments

7.2.3.4 Dynamic curvature

The curvature reflects the bending moment very well, and does also show large differences in the results from the two programs. The variation is from 12 to 46 % between the programs compared to the static configuration.

Sea state	Curvature		
	Simla [1/m]	RIFLEX [1/m]	Difference
1	0,010	0,012	21 %
2	0,012	0,016	32 %
3	0,020	0,029	36 %
4	0,033	0,051	39 %
5	0,052	0,086	41 %
6	0,080	0,145	46 %
7	0,081	0,128	38 %
8	0,104	0,167	39 %
9	0,153	0,184	17 %
10	0,157	0,205	24 %
11	0,160	0,181	12 %
12	0,170	0,219	23 %
13	0,156	0,223	31 %
14	0,150	0,228	35 %
15	0,160	0,234	32 %
16	0,196	0,238	18 %
17	0,148	0,258	43 %
18	0,187	0,258	28 %
19	0,143	0,254	45 %
20	0,147	0,259	44 %

Table 12: Maximum curvature

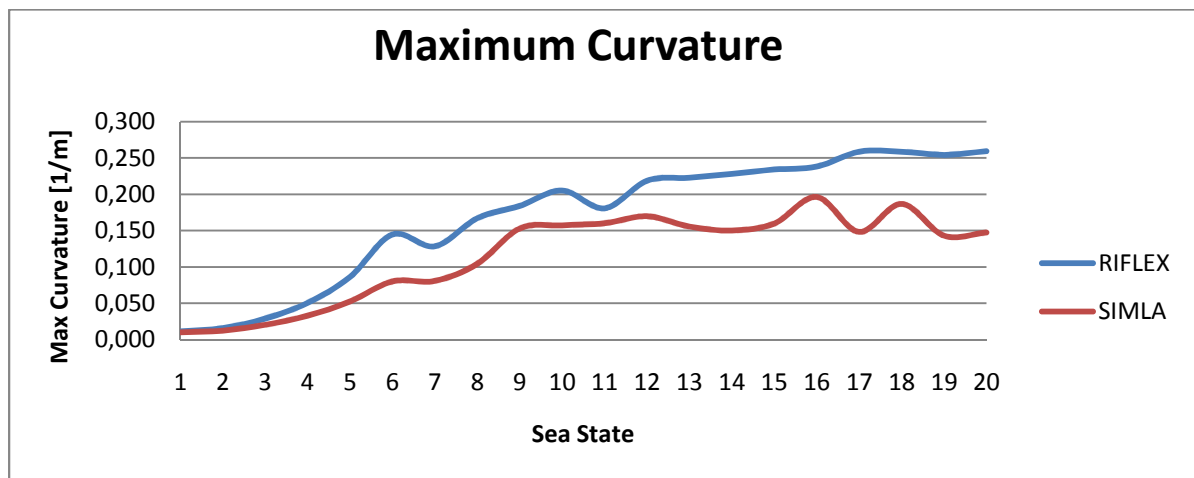


Figure 48: Maximum curvature

8 Conclusion

The main difference between SIMLA and RIFLEX is how they solve the dynamic time domain analyses. RIFLEX uses the well known Newmark- β method, while SIMLA uses a HHT- α method proposed by Hilbert, Hughes and Taylor. The HHT α -method is a spin off from the Newmark- β method, and it will damp out high frequency modes which the Newmark- β method cannot do.

8.1 Static results

The static results are close to being identical for both programs, showing that the modeling must be correct considering the overall arrangement and orientations for the lay scenario, and considering the umbilical data like the size, weights and the different stiffness properties.

It can clearly be seen in the static bending moment and the static curvature plots, Figure 10: Static bending moment and Figure 11: Static curvature, that there is a modeling error at both ends of the umbilical. In SIMLA rotations were free, while they were constrained in RIFLEX.

8.2 Dynamic results

For all results for sea states without compression, the two programs are quite similar. It is shown that RIFLEX also at this stage shows larger values than SIMLA, but the curvature of the plots are very similar.

There is a big change of the RIFLEX results for the sea states where there are induced compressions at the touch down point. This occur at sea state 6 and all the later sea states. The compression seems to trigger a variable which makes irrational results for all contact elements of the umbilical and the sea bed. Many peaks can be observed, which is illogical. In other words, RIFLEX is trying to say that an element, with less than a meters length, along the umbilical on the sea bed may have up to 8 times higher results than the neighboring element. Neighboring cells should have similar and consistent values along a line, specially a line laying on the sea bed. This is not the case for RIFLEX. With that in mind, it can be said that RIFLEX do not handle compression cases very well.

If the illogical peaks are seen as a disturbance that can be neglected, we can look upon the trends of the plots instead, and even then the results from SIMLA are noticeably smaller.

SIMLA handles the compression very well, and do still return stable and smooth graphs as a result. As well as the smooth and reliable graphs, the end results from SIMLA are for all sea states smaller than for RIFLEX. This would in a real life project allow installations in heavier sea with use of SIMLA. A run in SIMLA was experienced as a much slower than RIFLEX. RIFLEX was about 3 times faster for this model, which will save time and money during the analyses. On the other hand, when a vessel is chartered and ready, the cost of having to postpone an installation due to weather conditions RIFLEX rejects, is enormous. If the installation could proceed by doing the calculations in SIMLA instead, the money saved by the time efficient analyses in RIFLEX, would be neglectable.

The conclusions above are based on results that are known to be somewhat wrong. The dynamic effect of the rotational constrains are unknown, and all the RIFLEX values might be much higher than SIMLA just because of this.

The main difference in SIMLA and RIFLEX is how they solve the dynamic time domain analyses, and the big differences in the results are in the dynamic part. It cannot be proven that this is the reason for the large differences in the results, but it is reasonable to think it has an influence.

All in all, it has been observed large differences in the dynamic results, especially for the load conditions inducing compression. There is one known modeling error, there might be more, and there is one main difference in the way the programs do dynamic analyses. It is reasonable to believe that the HHT α -method used in SIMLA are the reason for the smoother and more reliable graphs.

8.3 Recommendations for future work

For a person who has never done umbilical installation analyses in his whole life, it was a very time consuming process to get familiarized with the programs. This has affected the time spent on the literature study of the thesis. Throughout this project, the theory regarding nonlinear finite element method and time domain analysis has been found to be very complex. More work on these elements could give a better understanding of the results gathered throughout the whole project.

Due to lack of time, only regular wave loads were analyzed, and the lay scenarios were unchanged for all analyses. Other elements that should be studied are current load effects, friction effects and other lay scenarios and umbilicals.

This thesis is based on a request from Technip. Initially, the request was that this study was to look upon some compression dilemmas due to some undesired results Technip had encountered in OrcaFlex and DeepLines. A natural part of the thesis should have been to compare the results from SIMLA and RIFLEX to the results of one of these programs. The thesis might have some interest as it is for Marintek, but the first priority for future work should be to extend the comparisons to another program which Technip use.

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1 Appendices

Appendix A

SIMLA – input file

Apacheegen.sif

```
#
Head    Umbilical installation analyses by Karl Erik Holum
#      mass length time
UNITS   1.0  1.0  1.0
#-----
# Control data:
#      maxit ndim  isolv npoint  ipri  conr  gacc  iproc
CONTROL 200  3    1   16    11  1e-5  9.81  autostart
#      ie1pip ie2pip incpip nrolls  icaten ivsnod
#      1    880  1    0    1    881
#      tens0 depang freeb rampan  rample stirad kp
#      0    1.196 6.67 0    0.0  0.0  667
#      seabedgrp  stingergrp  vesselgrp vessel  cog node
#      seabed    none        vessel_apache  3001
#
#      imass alfa1 alfa2 alfa
DYNCONT 1    0.0  0.095 -0.05
#      type      Scaling factor Result list
VISRES  integration  1          SIGMA-XX STRAIN-XX VCONFOR-Y VCONFOR-Z
#      TYPE  EL1  EL2  ELNOD  DOF  TIME0 [START STOP]
ENVRES_N  1    1    880  1    1
ENVRES_N  1    1    880  2    1
ENVRES_N  1    1    880  3    1
#
ENVRES_E  1    1    880  1    4    1
ENVRES_E  1    1    880  1    5    1
ENVRES_E  1    1    880  1    6    1
ENVRES_E  2    1    880  2    1    1
ENVRES_E  2    1    880  2    2    1
ENVRES_E  2    1    880  2    3    1
ENVRES_E  2    1    880  1    4    1
ENVRES_E  2    1    880  1    5    1
ENVRES_E  2    1    880  1    6    1
ENVRES_E  3    1    880  1    1    1
ENVRES_E  3    1    880  1    2    1
ENVRES_E  3    1    880  1    3    1
ENVRES_E  4    1    880  1    1    1
ENVRES_E  4    1    880  1    2    1
ENVRES_E  4    1    880  1    3    1
#-----
# Analysis time control:
#
#      t  dt  dtvi  dtdy  dt0  type  hla? STEPTYPE ITERCO ITCRIT MAXIT MAXDIV CONR
TIMECO  1.  1.0  1.0  1.0  1.0  200.0 STATIC NOHLA AUTO  none ALL 300 4  1e-5
TIMECO  200. 0.10 1.0  0.2  200.0 DYNAMIC NOHLA AUTO  none ALL 15 4  1e-5
#-----
# Nocoor input:
```

```

#
# - Coordinates of all Nodes - Umbilica - CoG - sea surface
# (need to be fixed in 1 and 2 directions)
#      NODE  XCOR  YCOR  ZCOR
NOCOOR  coordinates  1    0.0  0    6.67
          881  850.00  0    6.67
NOCOOR  coordinates  3001  906.409  0    4.30
NOCOOR  coordinates  2101  550    -200  0
          2121  1050  -200  0
#      N  NODINC  XINC  YINC  ZINC
repeat  11  21    0.0  40.0  0.0
#-----
# Element connectivity and properties - Mesh
#      groupname  elty  material  ID  n1  n2  n3  n4
ELCON  umbili    pipe31  umbmat   1   1   2
REPEAT  880  1    1
ELCON  vessel_apache  spring137  vessel_apache  3000  3001  881
#-----
#Elecc data:
#      type  elno  end    ex    ey  ez
ELECC  beam  3000  1     -56.409  0    2.37
# - Contact elements seabed/pipe:
ELCON  seabed    cont126  bedmat   1001  1
REPEAT  400  1    1
ELCON  surface    sea150  seamat   2101  2101  2102  2123  2122
REPEAT  20  1    1
REPEAT  10  20  21
#-----
# Element orientation
#
#      elid  x    y    z
ELORIENT  COORDINATES  1    0    1000  6.67
          880  0    1000  6.67
ELORIENT  EULERANGLE  3000  0    0    0
ELORIENT  EULERANGLE  1001  0    0    0
          1400  0    0    0
#-----
# Element property input:
#
#      ELGRP  CABLE  RCD  TCD  rcd  cdt  RMADD  TMADD  MD  MS  ODP  ODW  RKS
ELPROP  umbili  pipe  0.045  0.0346  0.8  0.1  2.0  0.2  12.7  7.2  0.09  0.09  0
#      name  type    TX  TY  TZ  RX  RY  RZ
ELPROP  vessel_apache  genspring  1  1  1  1  1  1
#-----
# Contact Surface data
#
#      name      data file  nlines  kp  x0  y0  fi  route id
COSURFPR  bedmat  "levold.txt"  1  0  0  0  0  100
#      route id  kp1  kp2  matname
COSUPR  100    -100000  600000  soil
#-----

```

```

# Contact interface data:
#
#      groupn mname slave-name   is1  isn   tx   ty   tz   gt1 gt2
CONTINT   seabed umbili seabed    1   401  1000.1 1000.1 1.0 10 1.0
CONTINT   surface surface umbili

#-----
# LOAD INPUT
#
# External pressure-hist gravity-hist:
PELOAD   100      100
#      seagrps type Waveid hist  x0  y0  phi T   H   D  Phase
WAVELO   surface REGULAR 100  200  0.0 0.0  3.14 11.40 7.33 360 0
#      no  type depth curr  fi
CURLOAD  100  global 0   0.30 1.57
          -50  0.20 1.57
          -360 0.10 1.57
          -3600 0.10 1.57
#      name      x1  y1  x2  y2  icur ihist
SEALO    surface -3e6 -3e6 15e6 15e6 100 300
#
#
#-----
# Boundary condition data
#
#      Loc  node  dir
BONCON   GLOBAL 1   1
BONCON   GLOBAL 1   2
BONCON   GLOBAL 1   3

BONCON   GLOBAL 2101 1
REPEAT    231  1
BONCON   GLOBAL 2101 2
REPEAT    231  1

#-----
# CONSTRAINT INPUT:
#
#      NODID dof  mnod  XANG  YANG  XANG ex  ey  ez
CONSTR   PDISP SPECIAL 881  1  3001  0  0  0 -56.409 0  2.37
CONSTR   PDISP SPECIAL 881  2  3001  0  0  0 -56.409 0  2.37
CONSTR   PDISP SPECIAL 881  3  3001  0  0  0 -56.409 0  2.37
CONSTR   PDISP SPECIAL 881  4  3001  0  0  0 -56.409 0  2.37
CONSTR   PDISP SPECIAL 881  5  3001  0  0  0 -56.409 0  2.37
CONSTR   PDISP SPECIAL 881  6  3001  0  0  0 -56.409 0  2.37
#      head  waveid
CONSTR   PDISP RAO  3001  1  0  100  surge
CONSTR   PDISP RAO  3001  2  0  100  sway
CONSTR   PDISP RAO  3001  3  0  100  heave
CONSTR   PDISP RAO  3001  4  0  100  roll
CONSTR   PDISP RAO  3001  5  0  100  pitch
CONSTR   PDISP RAO  3001  6  0  100  yaw

```

```

#                                waveid
CONSTR  PDISP WAVE  2101  3   100
REPEAT  231  1
#-----
# History data
#
#      no  t1  fac
THIST   100  0  1.0
        1000 1.0
#      NO  START STOP  RAMPTYPE  FAC
THIST_R  200  1   5   rampcos    1.0
THIST_R  300  1   5   rampcos    0.0
#-----
# RAO definitions:
#
READTRF  Apache.rao  SIM
#-----
# Material data:
#
#      name type poiss talfa tecond heatc beta ea  eiy eiz git  em  gm
MATERIAL umbmat linear 0.3  1.17e-5 50   800  0  115e6 11e3 11e3 7.6e3 2e11 8e10
#      name type density
MATERIAL seamat sea  1026.0
#      name type mux  muy  xname yname zname
MATERIAL soil  contact 0.5  1.0  soilx soily soilz
#      ihar eps  sigma
MATERIAL soilx epcurve 1  0  0
                0.005 1
                100.00 1
MATERIAL soily epcurve 1  0  0
                0.1  1
                100.00 1
MATERIAL soilz hycurve -10000 -1e9
                10000 1e9
#      name      type      apr1  spr2  spr3  spr4  spr5  spr6
MATERIAL vessel_apache genspring  surgesp yawsp heavesp rollsp pitchsp swaysp
#
MATERIAL surgesp epcurve 1
                0.00 0.0
                1.00 0.05
                23.00 0.20
MATERIAL surgesp hycurve -1000 0
                1000 0
MATERIAL yawsp hycurve -1000 0
                1000 0
MATERIAL heavesp hycurve -1000 0
                1000 0
MATERIAL rollsp hycurve -1000 0
                1000 0
MATERIAL pitchsp hycurve -1000 0
                1000 0
MATERIAL swaysp hycurve -1000 0

```

Appendix B

SIMVIS input file

Apacheegen.spi

```
# global nodal plot
#   .raf prefix  .mpf prefix      Legend x      x-res.  Legend y      y-res.  Node 1 Node 2 X-
fac Y-fac
GNPLOT "Apacheegen"  "apacheegen-xz"  "X-coordinate (m)" X-COR  "Z-coordinate (m)"  Z-
COR  1  881 1 1
# global element plot
#   .raf prefix  .mpf prefix      Legend x      x-res.  Legend y      y-res.  El1 El2 X-fac Y-fac
GLPLOT "Apacheegen"  "apacheegen-axial-force" "S-coordinate(m)" E-COR  "Axial force (kN)"
ELFORCE-X 1 880 1 1e3
GLPLOT "Apacheegen"  "apacheegen-moment"  "S-coordinate(m)" E-COR  "Moment (kNm)"
ELMOM-Y 1 880 1 1e3
GLPLOT "Apacheegen"  "apacheegen-curvatur" "S-coordinate(m)" X-COR  "Curvature (1/m)"
ELCUR-Y 1 880 1 1
#   RAFPRE      MPFPRE      XRES      XSCL  YSCL
ENPLOT "Apacheegen"  "envelopes"      E-COR      1 1
```

Appendix C

RIFLEX input files

Inpmod-file

```
'-----
'A1
'-----
      INPMod IDENTification TEXT   3.6
'-----
'A1.2 Identification text, three input lines
      Analysis of dynamic installation effects by Karl Erik Holum
      Inpmod-run
      Having fun
'=====
'A2
      UNIT NAME SPECIFICATION
'-----
'      UT      UL      UM      UF      GRAV  GCONS
      s        m        kg      N        9.81    1
'=====
'B1
      NEW SINGLE RISER
'-----
'B1.2 Selection of riser type and identifier
'      ATYPS IDRIS
      SB      Umbilical
'-----
      SINGLE RISER SB
'B3.2 NSNOD IBTANG
      2        1
'      ILINTY ISNOD1 ISNOD2
      1        1        2
'      ZL      XU      ZU      ALFL  ALFU  ZA      XA
      -360  664    6.67  0        21.47
'      STFBOT      STFAXI      STFLAT      FRIAXI      FRILAT      DAMBOT
      DAMAXI      DAMLAT
      1e5
'      IVES  IDWFTR      XG      YG      ZG      DIRX
      1      Apache      720.409      0      4.30  0.0
'
'-----
'B10 Line and segment specification
'-----
      NEW LINE DATA
'-----
'B10.2 Line specification
'      ILINTY      NSEG  ICNLTY      IFLUTY
      1      1      /      /
'-----
'B10.3 Segment specification
'      ICMPTY      ICN1TY      IEXWTY      NELSEG      SLGTH      NSTRPS*
NSTRPD*      SLGTH0*      ISOITY*
      1      0      0      880      850
'=====
'C
      NEW COMPONENT CRS1
'-----
'C2.2 Component type number
'      ICMPTY      TEMP  ALPHA      BETA
      1      /      /      /
```

```

'-----
'C2.3 Mass and volume
'   AMS   AE           AI   RGYR   AST           WST           DST   THST
'   R-EXTCNT R-INTCNT
'   12.7  5.365E-3    0     3.18E-3 6.36E-3   7.157E-05  0.09  0.045 /
/
'-----
'C2.4 Stiffness properties
'   IEA   IEJ   IGT   IPRESS* IMF*       HARPAR*
'   1     1     1
'-----
'C2.5 Axial stiffness
'   EA
'   115E+6
'-----
'C2.7 Bending stiffness
'   EJY   MF
'   11e3  /
'-----
'C2.11 Torsion stiffness
'   GT-   GT+
'   7.6e3 7.6e3
'-----
'C2.12 Hydrodynamic force coefficients
'   CQX   CQY   CAX   CAY   CLX   CLY   ICODE D
'   0.1   0.8   0.2   2.0   0     0     2     0.09
'-----
'C2.13 Capacity parameter
'   TB   YCURMX
'   160e3 0.25
'=====
'D
'   ENVIRONMENT IDENTIFICATION
'   Miljø
'-----
'D1.3 IDENV
'   Hurdalsjøen
'-----
'D2 Water depth and wave indicator
'   WATERDEPTH AND WAVETYPE
'-----
'D2.2 Water depth and control parameters.
'   WDEPTH NOIRW NORW NCUSTA
'   360    0     1     1
'-----
'D3
'   ENVIRONMENT CONSTANTS
'-----
'D3.1 Data group identifier,
'   AIRDEN WATDEN WAKIVI
'   /      /      /
'-----
'D5
'   REGULAR WAVE DATA
'-----
'D5.2
'   INRWC      AMPLIT      PERIOD      WAVDIR
'   1          1.330 8.35 180
'   1          1.500 8.35 180
'   1          1.500 9.30 180
'   1          1.665 9.30 180

```

```
'      1      1.830 9.30 180
'      1      2.000 9.30 180
'      1      2.000 10.05 180
'      1      2.165 10.05 180
'      1      2.330 10.05 180
'      1      2.500 10.05 180
'      1      2.500 10.60 180
'      1      2.665 10.60 180
'      1      2.830 10.60 180
'      1      3.000 10.60 180
'      1      3.000 11.05 180
'      1      3.165 11.05 180
'      1      3.330 11.05 180
'      1      3.500 11.05 180
'      1      3.500 11.40 180
'      1      3.665 11.40 180
```

```
'D6
```

```
      NEW CURRENT STATE
'      ICUSTA      NCULEV      L_EXT
      1      3      0
'      CURLEV      CURDIR      CURVEL
      -0.1  90      0
      -50   90      0
      -360  90      0
```

```
'=====
'E      SUPPORT VESSEL DATA
```

```
'-----
      TRANSFER FUNCTION FILE
```

```
'-----
'E1.2 File name
```

```
'      CHFTRA
      semi_42000.tra
```

```
'-----
      END
```


Stamod-file

```
'-----
      STAMOD CONTROL INFORMATION   3.6
'-----

'A1.2 Heading
Static analysis of Umbilical instalation configuration

'-----

'A1.3 Options and print switches
'      IRUNCO      IDRIS      IANAL      IPRDAT      IPRCAT      IPRFEM
      IPFORM      IPRNOR      IFILFM IFILCO
      1      Umbili      1      2      1      1
'-----

'A2.1 Data group identifier,
      RUN IDENTIFICATION
'-----

'A2.2 Data set identifier for results
'      IDRES
      Stat
'-----

'A3   Identifier of environment data
      ENVIRONMENT REFERENCE IDENTIFIER
'-----

'A3.2 IDENV
      Hurdalsjøen
'-----

'A4   Export of element responses
'      STORE VISUALISATION RESPONSES
'=====
'
'=====

'B1   Definition of subsequent input
      STATIC CONDITION INPUT
'-----

'B1.2      External, static loads
'      NLCOMP      ICURIN      CURFAC      LCONS      ISOLVR
      0      0      1      1      1
'-----

'B2
      COMPUTATIONAL PROCEDURE
'-----

'B2.2 AMETH
      FEM
'-----

'B6
      FEM ANALYSIS PARAMETERS
'-----

'B7.1.1      Data group identifier,
      LOAD GROUP DATA
'-----

'B7.1.2      Load group incrementation and iteration parameters,
'      NSTEP      MAXIT      RACU
      250      500
'-----

'B7.1.3      Load types to be activated, one line for each load type to be
'      activated within the load group
'      LOTYPE      ISPEC
      VOLU /
'-----

      LOAD GROUP DATA
```

```
      250    500
      DISP  /
',-----
      LOAD GROUP DATA
      250    500
      CURR   /
END
```

Dynmod-file

```
'-----
      DYNMOD CONTROL INFORMATION 3.6
      Dynamyc analysis of umbilical installation

'-----
'A1.3 IRUNCO      IANAL      IDRIS      IDENV      IDSTAT      IDIRR
      IDRES
      ANAL  Regular      Umbilic      Hurdal      Stat  motion      data
'-----

      STATIC LOAD CONDITION
'A2.2 SCALVF      SCALSF      SCALCF
      /      /      /
'-----

      REGULAR WAVE ANALYSIS
'C1.2 NPER  NSTPPR      IRWCN      IMOTD
      22    100    1      1
'-----

      REGULAR WAVE LOADING
'C2.2 IWTFP      ISURF      IUPPOS
      1      2      2
'-----

      REGWAVE PRINT OPTIONS
'C4.2 NPREND      NPRENF      NPRENC
      1      1      1
'-----

      TIME DOMAIN PROCEDURE
'E1.2 ITDMET      INEWIL      IDISST      IFORST      ICURST      ISTRST
      2      1      1      1      1      0
'-----

      BETIN      GAMMA      TETHA      A1      A2      A1T      A1TO      A1B      A2T
      A2TO  A2B
      /      /      1      /      /      /      /      /      /
'      INDINT      INDHYD      MAXHIT      EPSHYD      TRAMP      INDREL
      ICONRE      ISTEPR      LDAMP
      /      /      10      /      /      /      /
'-----

      NONLINEAR INTEGRATION PROCEDURE
'E2.2 ITFREQ      ISOLIT      MAXIT      DACCU      ICOCOD      IVARST
      ITSTAT
      /      /      /      /      /      /
'-----

      DISPLACEMENT RESPONSE STORAGE
'E10.2 IDISP      NODISP      IDISFM      CFNDIS
      1      3      1
'E10.2.2 ILIN      ISEG      INOD
      1      1      1
      1      1      300
      1      1      350
'-----

      FORCE RESPONSE STORAGE
'E11.2 IFOR      NOFORC      IFORFM      CFNFOR      IELTFM
      1      3      1      /      /
'E11.2.2 ILIN      ISEG      INOD
      1      1      1
      1      1      300
      1      1      350
'-----

      CURVATURE RESPONSE STORAGE
'E12.2.1 ICURV      NOCURV      ICURFM      CFNCUR
```

```

      1      3      1      /
'E12.2.2 ILIN      ISEG INOD
      1      1      1
      1      1      300
      1      1      350
'-----
      ENVELOPE CURVE SPECIFICATION
'E13.2.1 IENVD      IENVF      IENVC      TENVS      TENVE      NPREND
      NPRENF      NPRENC      IFILMP
      1      1      1      0      1E+6      1
      1      1      4
'-----
      STROKE RESPONSE STORAGE
'E14.2      ISTRO      INODST      IOPSTR      SETLEN      XRSTRO
      YRSTRO      NLIST      ILIN1 ... ILIN nlist
'-----
      STORE VISUALISATION RESPONSES
'R15.2      TCONDS      TCONDE      DELT      CHFORM
'      /      /      /      /
END

```

Appendix D

All envelope results for sea state 9-20

Bending moment envelope curves

Curvature envelope curves

Displacement envelope curves

Force envelope curves

