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Tie-in Spools

A Verification Study

Master Thesis by Espen Sletteboe

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Summary

Within the Oil industry, subsea pipelines are used to transport hydrocarbons from one location to another. After the installation of a subsea pipeline, the final connection between the pipeline ant the interconnecting facilities are done by using tie-in spools. In principle, tie-in spools serve two purposes. First, it needs to provide an interface that bridges the inaccuracies associated with offshore pipeline installation. Inaccuracies related to pipeline installation are numerous, but can be related to the existing seabed infrastructure, orientation/position of the tie-in facilities with respect to pipeline installation vessel, bathymetry & soil accuracy of data among others. These factors cause the tie-in spool to be measured, fabricated and installed after the pipeline has been laid in order to make up the connection. Secondly, the tie-in spool needs to be a flexible element as pipelines expands during operational conditions because of heat and pressure differences between installation and operational stages. By the tie-in spool being flexible, the forces in connectors are reduced in order to ensure safe transportation of hydrocarbons. These key requirements can have significant impact of the overall cost of a project as they will affect all necessary operations related to tie-in spools.

This report assesses key requirements related to tie-in spools by a detailed review about issues related to the design, fabrication, installation and operation of tie-in spools. By presenting details from the design of an actual installed tie-in spool in the southern North Sea this is sought achieved. By presenting a tie-in spool and its important design parameters, load steps that it is subjected to, and the results from loading analysis it is wanted to educate about the importance of tie-in spools.

A modification of the tie-in spool where done to develop a simple technique to quickly assess the preliminary design/configuration of a tie-in spool based on bending moment capacity of the associated connector. The design parameters, such as pipeline expansion, where extracted from the presented tie-in analysis. Four different analysis methods where used in order to give recommendations on which method are most suited for spool piece analysis. By comparing results with the actual installed spool, calculated results showed that three methods can be suited for simplified spool piece analysis.

In order to qualify one of the analysis methods, a downscaled tie-in spool was manufactured based on the modified spool. By innovative use of simple mechanical equipment, the tie-in spool was applied pipeline expansion via a winch. The bending moment in the connector where measured using an adjustable torque wrench. Measured bending moment was compared to the analysis methods and by comparison it was evident that numbers did not correlate. Due to this, no further recommendation on suitable analysis method could be given. A search for possible error sources contributing to no correlation was conducted. It is also proposed further development of experiment.

Preface

This thesis is part of my education of achieving a master's degree in Offshore Technology - marine and subsea, at the University of Stavanger during the spring 2012. The thesis has been developed and written in co-operation with BP Norway, who also provided me office facilities. BP also provided access to technical information throughout the process of writing this thesis. Practical experiments were conducted at Tengesdal in Bjerkreim.

During the process of developing this report, the undersigned has learnt some interesting new things about himself. Individually work is something that really requires strict discipline, structure and a plan. Lack of one, or more, of these have led to a lot of frustration throughout the spring. However, because of good supervisor, advisors and other helpful people, it was possible to write this thesis. Those that I am grateful to are:

- Eiliv Janssen, my faculty supervisor from the University of Stavanger. He has been helpful by giving advice on how the thesis should be set up structurally. And also by motivating me through regular meetings throughout the spring.
- Gordon Marshall, my external supervisor from BP. Although he was highly involved in other projects within BP during the spring, he could always fit me into his schedule. He has guided me technically, by being well experienced. He has also put me in contact with relevant people in the industry via his broad professional network.
- Ove Tobias Gudmestad, professor at the University of Stavanger. His experience and presence has been helpful throughout the spring. He has given advice on hydrodynamic calculations and how to approach the experimental part in the thesis. I would also like to thank him for visiting the test site.
- Odd Harald Sletteboe, my dad. He has been very important in the process of writing this thesis. Trough out the spring he has been an important person to discuss with. He is also the one who initiated contact with Aker Egersund, who fabricated the tie-in spools for the test. I would also like to thank him for providing me necessary equipment for the experimental part of the thesis.
- Ninni Takle, my fiancé. She has been a psychologist, chef and friend throughout the spring.
- Sveinung Rasmussen and Erlend Revheim, for being good fellow students throughout the spring and while studying at University of Stavanger. Thank you for interesting conversations.
- Family members; my mom, brother and sisters, for being supportive and helpful throughout the spring 2012.
- Employees at BP for being interested and willing to discuss various aspects of the thesis.

Stavanger, 15.06.2012

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Espen Sletteboe

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Nomenclatures

ASD	Allowable Stress Design
FAT	Factory Acceptance Test
HCCS	Horizontal Clamp Connection System
Hub	- "Refer to the ends of interconnecting pipelines which are joined to the subsea assets by hub connectors. Hubs are connectors that are closed together and sealed using external hydraulic pressure rams: these are of modern design and were developed to deep water ROB-aided installation. For the purposes of this document we will refer to all connectors as hubs." (International Marine Contractors Association, 2012)
ITA	Inline Termination Assembly
PLET	Pipeline End Termination
PP	Polypropylene
RAO	Response Amplitude Operator
ROV	Remotely Operated Vehicle
SIT	System Integration Test
SMTS	Specified Minimum Tensile Strength
SMYS	Specified Minimum Yield Strength
VFG	Valhall Flank Gas Lift
WP	Wellhead Platform

1 Introduction

1.1 Background & motivation

Within the Oil Industry subsea pipelines are used to transport hydrocarbons from one location to another. These pipelines can be "inter-field lines" that transport hydrocarbons from subsea facilities or between platform installations. Or major "trunk" lines that bring hydrocarbons from the Platform based process hubs to onshore facilities for subsequent refining.

After the installation of an offshore pipeline, the final connection of the pipeline ends to the associated facilities are made using by using tie-in spools. The facilities a pipeline can tie into are numerous; however typical facilities are defined as follows:

- A platform/jacket structure
- A subsea manifold/template
- Subsea Wells
- Floating Production Units

Essentially spoolpieces are short sections of pipeline that:

- Provide an interface between the pipeline and its connection point that bridges the inaccuracies associated with pipeline installation. For a tie-in spool to serve as intended, it needs to satisfy numerous different criteria. Principally it needs to make up the connection between the pipeline and the interconnecting part. For pipelines that are transporting hydrocarbons it is crucial that the connections are sealed. Containment of hydrocarbons is crucial to reduce the risk of pollution and ensuring safe transportation of hydrocarbons. Tie-in spools are measured, fabricated and installed after the pipeline has been laid. Mechanisms related to these operations, makes the tie-in spool a key piece of equipment in offshore field developments

- Allow the pipeline to expand during operation but also allow these pipeline expansion forces to be dissipated/reduced at the associated connection point. The tie-in spool also needs to be a flexible element. Pipelines expand because of temperature and pressure differences between installation and operational conditions. This expansion may be in the order of several meters. Depending on how the pipeline is constrained, expansion may cause the pipeline to buckle or by it extending in axial direction. The expansion is taken up by deflection of the tie-in spool. Simultaneously as the pipeline expands, forces are induced into the tie-in spool and the connector. Making sure that induced loads are below material and connector limitations is critical in design of tie-in spools.

These key requirements can have a significant impact on the overall cost of a project. A too conservative design means an oversized tie-in spool. A too large tie-in spool increases the use of materials, hampers the manufacturing process and more importantly may limit the number of vessels that can install the spools resulting in a requirement for large costly heavy lift vessels or separate two vessels to transport the spools.

Modern analysis of tie-in spools is performed by sophisticated and advanced software tools. A good understanding of modern tie-in spool analysis can reduces the risk of a costly over-conservative design. Any misunderstanding of results can lead to unnecessary gold plating of tie in spools and thus are exposed to the cost increases of having a too conservative design.

The reliance on complex analysis tools can lead to this, as misunderstandings in how to/or how certain design parameters are applied can sometimes be lost within the complex interfaces and data files associated with these analysis tools. In addition, not all design engineers have the practical ability to assess the correctness of a spool design.

With this in mind the author sought to use this Thesis to develop a simple technique to allow the preliminary design/configuration of a tie-in spool to be quickly assessed but could be benchmarked against more sophisticated analysis tools.

1.2 Purpose and Scope

Processes related to pipeline design and installation is well described by literature. However, the final connection of pipelines is often a forgotten theme and seems almost like an "industry secret".

As stated in the previous section, to keep costs related to pipelines at a minimum, an understanding of the challenges and mechanisms related to design of tie-in spools is necessary. A conservative design is directly proportional to cost.

When laying down the end of a pipeline, the final touchdown point for the pipeline end (or "target box") is critical as this determines the tie-in spool lengths. The location of a Target Box is dictated by a number of components, but is principally influenced by:

- Existing seabed infrastructure
- Orientation/position of the tie-in facilities with respect to the pipeline installation vessel
- Seabed bathymetry
- Soil conditions

The ability of a design engineer to quickly develop and assess a preliminary spool piece configuration based on pipeline end positions in early engineering phases, can improve cost savings by not over dimensioning the tie-in spool.

Thus, the purpose of this thesis is to:

- Research and gather information about tie-in spools and report on their function/purpose.
- Identify and describe relevant stages of tie-in spool design with a study of considerations related to design, fabrication, installation and operation.
- Present details on the design of an actual installed tie-in spool in the southern North Sea.
  - Analysis method adopted
  - Design parameters to be considered
  - Loading steps that the tie-in spool is subjected to.
  - Results from loading.
- Using a modified tie-in spool arrangement based on the industry example, develop simple method of calculating maximum bending moments in a spool and benchmark the results against the original analysis.
- Perform spoolpiece displacement tests on a downscaled version tie-in spool to obtain bending moment envelopes for varying spoolpiece leg lengths and compare the results obtained with results using theoretical methods
- Draw conclusion and make recommendations

1.3 Structure of the Report

This thesis deals with a subject that rarely gets brought up in learning contexts. Available literature on tie-in spools is limited, and seems forgotten in a world full of pipelines. This Thesis has therefore been structured accordingly, as there has been a need for a comprehensive literature review before any analytical tasks were investigated or conducted. Thus, the structure of the Thesis is described and seen on the illustrations below.

Part I - Introductional	
Chapter 2 - Tie-in Spools and their function	Chapter 3 - Industry Example

Because of the lack of literature on tie-in spools, there has been a desire to create a document that addresses this. Therefore, relevant information on tie-in spool gained through the literature study, have been presented as a general overall introduction.

As a part of the literature study, a real industry example has been studied. This addresses a typical tie-in spool project conducted in the southern North Sea at the Valhall complex as part of the VFG Project. Details of the tie-in spool are presented together with the design basis. There are details what software was used to perform the design. In addition, the results from the analyses are presented. Only reaction forces in the connectors, based on operational conditions, are shown as these are used in the analytical section.

Part II - Case Studies	
Chapter 4 - Case Study	Chapter 5 - Experimental Study

Using a modified tie-in spool arrangement based on the industry example, the spool has been analysed by three simple theoretical methods and one finite element software tool. Pipe soil interaction has been excluded based on calculated hydrodynamic lift force. The results from the four methods were then compared with the results from the industry example. The purpose of this was to develop simple method of calculating maximum bending moments in a spool.

Due to differences in the results obtained from the four theoretical methods, a series of practical experiments have been conducted. The modified theoretical tie-in spool were downscaled by a factor of 5 and analysed theoretically using all four methods. Theoretical reaction forces in the connectors were compared with practical results achieved from the experiment. A reeled winch was used to simulate pipeline expansion and the reaction forces were measured using an adjustable torque wrench. Based on comparisons of theoretical and experimental results, a search for mechanical error sources in the test equipment was also conducted. Conclusion have been drawn on this assessment and recommendations made for further development.

Each chapter is described by including a short introduction at the beginning. Most major calculations performed in relation to the thesis are referred to and included in the Appendixes. Conclusions related to part II are drawn throughout the report, but it is tried to summarize these at the end of each chapter.

Part I – Intro to theoretical and practical case studies

Part I includes two chapters. First is an introduction to the use purpose of tie-in spools. Second, a real industry example is presented including a tie-in spool analysis.

2 Pipelines, Tie-in Spools and Their Functions

This chapter includes relevant information about the need, use and design of tie-in spools. Different design considerations, connector types are reviewed and discussed.

2.1 Pipelines in General

To define a pipeline one can say that it is a pressure vessel designed to transport a product from one location to another. Pipelines are used for a numerous of different applications in offshore developments. Figure 2-1 show some of the most important application areas where pipelines are used.

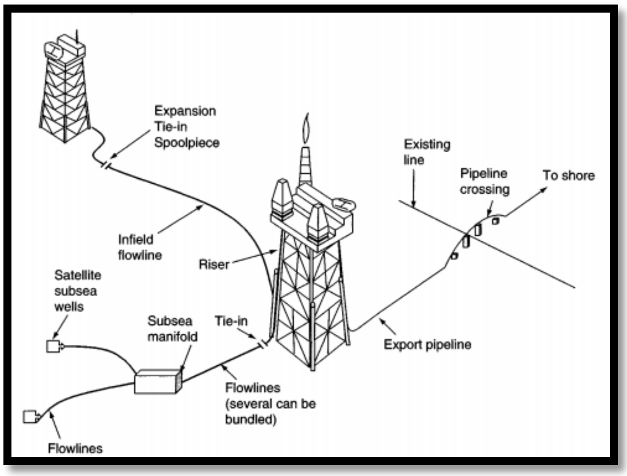


FIGURE 2-1 OFFSHORE PIPELINES (GUO, SONG, CHACKO, & GHALAMBOR, 2005)

A typical offshore development consists of flowlines, infield flowlines and export pipelines. (Guo, Song, Chacko, & Ghalambor, 2005). Umbilical's for control and operation of subsea equipment are also installed. Significant variations in pipe size are seen between offshore projects. Depending on the medium to be transported, desired flow rate and pressure characteristics, pipeline size varies significantly.

Depending on the field layout and location, lengths of pipelines may vary from just a few hundred meters to a several hundred kilometres. Export pipelines may be in the order of several hundred kilometres. The 44 inch gas pipeline, Langeled is 1166 kilometres long and is the world's longest subsea pipeline (GASSCO, 2012).

2.2 Subsea Pipe Laying Methods

Vessels laying pipelines are purpose built. Depending on the seawater depth, pipeline material and geometric attributes such as pipeline diameter and thickness, some methods are more or less favourable.

S-lay is a common method of laying pipelines in intermediate to shallow waters. The pipes are welded together horizontally on board the lay vessel. The pipe segments are welded together continuously as the pipeline is lowered into sea, making the s-lay method is a quick and efficient. This process requires a large deck space to house conveyor units, non-destructive inspection and coating departments among others. A stinger is mounted at the stern of the vessel to keep control of stress distribution in the pipeline as it is it lowered in an S shape down to the seabed. The method is suitable for most diameter pipelines. Constant tension in the pipeline is required in order to prevent pipeline buckling. This is achieved by the vessels thrusters. (Chakrabarti, 2005)

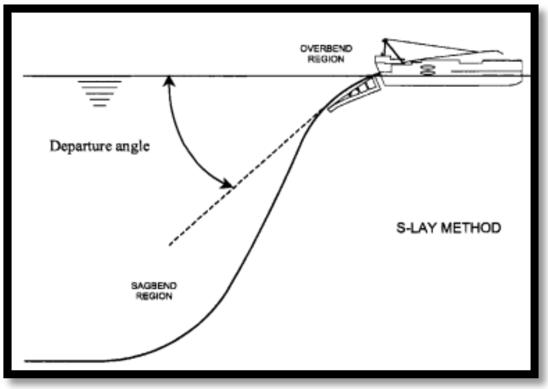


FIGURE 2-2 S-LAY METHOD (CHAKRABARTI, 2005)

The J-lay method is used to lay pipelines in deep to ultra-deep water. The pipe segments are by this method welded together in a vertical position. The pipe is lowered down to seabed vertically and there is no need for having a stinger. The method is suitable for all diameters. The departure angle is adjustable on most vessels, which in principle means that the j-lay vessel can be used also in shallow waters such as the S-Lay method.

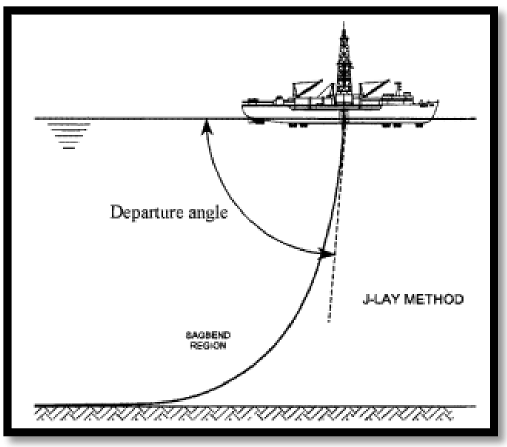


FIGURE 2-3 J-LAY METHOD (CHAKRABARTI, 2005)

Reel- Lay is a fast pipe laying method for relatively small diameter pipelines compared to S and J-lay methods. Sections or the entire pipeline length can be made in advance onshore, making expensive offshore welding unnecessary. The vessel then reel the entire length onto a large drum on board the vessel. The pipe is plastically deformed during this process and is straightened using purpose build straightening tools. The reel lay method provides a quick and cost effective method for laying pipes.

FIGURE 2-4 SUBSEA 7'S REEL LAY VESSEL SEVEN NAVICA (ENGINEER LIVE, 2012)

In addition to these three methods is a towing method. Similar as for the reel- lay method, long pipeline sections can be made in advance onshore. By towing the pipeline from the onshore to the offshore location, this provides a quick installation method. However, the tow method is very susceptible to bad weather. Large waves may cause the pipe to buckle.

2.3 Pipeline Expansion

When a pipeline is laid it holds the same temperature as the surrounding sea water. However, when operational conditions are reached, the temperature usually increases. Depending on the purpose of the pipeline this temperature may be in the order of hundreds of degrees. This causes the pipe to expand in axial and radial direction because of the atoms within the material requires larger space. The equation

$$\Delta L = \alpha * L_0 * \Delta T$$

is used to illustrate this. Shortly explained is that the total expansion of a material is based on the linear expansion coefficient α, the original length L_0 and the difference in temperature ΔT. The linear expansion coefficient is dependent on the material used in the system.

As a side step, thermal expansion is also a major concern in bridge building. Bridges often are made out of steel and some are very long in distance. You have probably wondered why most bridges have the thing seen on Figure 2-5 installed.

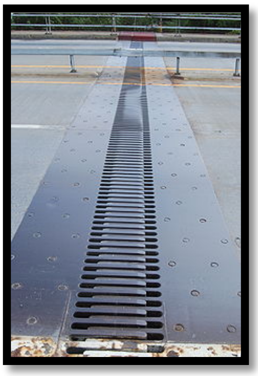


FIGURE 2-5 EXPANSION JOINT ON A BRIDGE (WIKIMEDIA FOUNDATION, 2012)

The expansion joints are there for a purpose. Each bridge has two of these installed, one on the entrance and one on the exit. At very hot days they allow the bridge to move freely in between the expansion joints. By absorption of the thermal expansion, cars can drive safely over the bridge.

The exact same principle is adopted for pipelines; pipeline expansion is taken up by expansion loops or tie-in spools. It is very important to keep in mind is that; many pipelines are transporting highly polluting and explosive hydrocarbons. Any leak may result in a nature disaster.

2.4 Pipeline Route Selection and Approach Considerations

When the end of a pipeline is laid down on the seabed it is practically impossible to achieve a position accuracy that is high enough. There are numerous of factors that affect the level of accuracy and some of these mechanisms are described below.

Uncertainties related to seabed bathymetry are governed by the accuracy of technique/methods used to obtain the data. Field specific attributes are important to take into consideration, as seabed subsidence may occur. At specific fields on the Norwegian Continental shelf, the subsidence is in the order of several metres.

Positioning capabilities of the lay vessel also affects the final accuracy of the pipeline touchdown point. Lay vessels are mostly equipped with dynamic position (DP) systems which results in excellent manoeuvrable capabilities of the vessels. By use of thrusters, no anchors are necessary for maintaining a specific position. DP systems include complex control systems and as a consequence: DP systems are very susceptible to breakdown of these and thus loss of position.

When approaching existing facilities, physical constraints such as the presence of platforms, drilling jackets, semi-submersibles and other vessels, may affect the accuracy. In addition to physical constraints above the sea level, there might as well be constraints below the sea level, on the seabed. Constraints on the seabed might be old pipelines, anchors and solid waste in the form of scrap metal or drill cuttings.

2.5 Pipeline End Terminations

Based on the above discussion on route selection and approach considerations, the location of both the first pipeline end termination (PLET) on the sea bed can be chosen to some extent. In order to achieve certain accuracy, the PLET is placed within a target box.

FIGURE 2-6 PIPELINE END TERMINATION - PLET (BP NORWAY, 2012)

The target box is marked off on the seabed and it is slightly larger than the geometric footprint of the PLET. It is also is reflecting the accuracy of the laying vessel. Above a typical reeled lay is about to start with the PLET soon to be deployed into water. With the PLET situated on the sea bed, it is time to introduce the tie-in spool. To make up the final connection between the PLET and interconnecting part, a tie-in spool is used.

The most important mechanisms to why tie-in spools are needed are now introduced. These mechanisms are inaccuracy of final location of the pipeline and expansion of the pipeline.

2.6 Tie-in Spools

A tie- in spool is a special purpose piece of pipe of piece that is measured, fabricated and installed after the PLET has been laid. As stressed in the previous sections, the tie-in spool needs to satisfy numerous criteria's. The most important criteria are to ensure safe transportation of hydrocarbons while it is subjected to pipeline expansion.

Tight seals between flanges/connectors are of highest importance when pressurized, explosive hydrocarbons are to be transported. Without tight seals there is a risk of having leaks that may lead to pollution. To achieve tight seals, tie-in spools are designed flexible by allowing it to deflect, thus reducing forces in flanges/connectors. Deflection is achieved by using bends that can take various configurations.

As a rough categorization, tie-in spools can be configured in two different ways. Figure 2-7 shows a horizontal tie-in spool while Figure 2-8 shows a vertical tie-in spool.

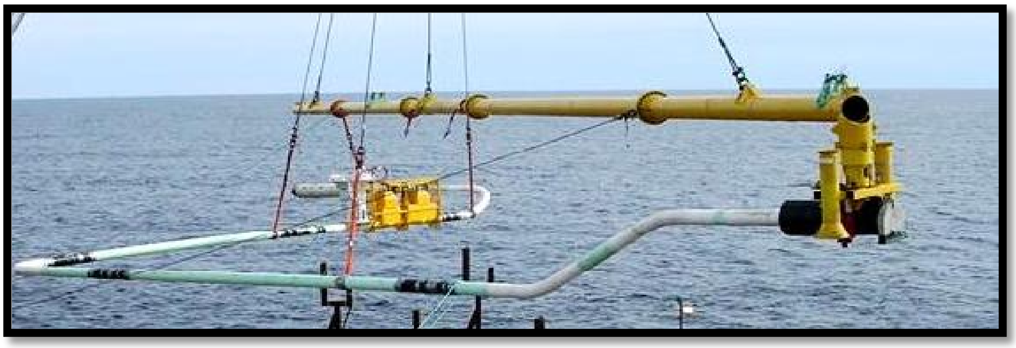


FIGURE 2-7 HORIZONTAL TIE-IN SPOOL (IKM GROUP, 2012)

Tie-in spools are equipped with connectors on each end. Many different connector types are developed and well proven. By looking at the installation sequence, connector types can also be categorized in two ways, i.e. vertical or horizontal.

FIGURE 2-8 VERTICAL TIE-IN SPOOL (INTECSEA, 2012)

To summarize, horizontal tie-in spools are most commonly equipped with horizontal connector types, while vertical tie-in spools are equipped with vertical connector types. Connector types are elaborated about in chapter 0. In the next section, design considerations related to choice of tie-in spool configuration is discussed.

2.7 Design Considerations of Tie-in Spools

When selecting the orientation of tie-in spools there are numerous different issues to consider, such as environmental, installation and operational conditions. Considerations related to horizontal or vertical oriented design of tie-in spool are roughly divided into five categories. These are:

- General
- Fabrication
- Connector
- Installation
- Operational

Design considerations are discussed with reference to the report "Advanced deepwater Spool Piece Design" by (Chan, Mylonas, & McKinnon, 2008) and to the report "Deepwater Tie-ins of Rigid Lines: Horizontal spools or Vertical Jumpers" by (Corbetta & Cox, 1999). A rough weighing has been done by marking issues that are positive with a green colour and highly negative with a red colour.

2.7.1 General

General considerations, relates to aspects that fall out of the other categories. However, general issues are, as important, as any other and may be decisive in the selections of spool orientation.

TABLE 2-1 GENERAL DESIGN CONSIDERATIONS

Issue	Horizontal Tie-in Spool	Vertical Tie-in Spool
Seabed footprint	Bends required for flexibility is occupying significant seabed areas. Consequently taking up space for other equipment.	Little seabed occupied as all bends are in vertical planes.
Flowline lay route	Lay route maybe need re-routing if much seabed space is occupied by existing equipment.	Vertical oriented, can be placed closer to objects located on seabed
Trawl ability	Horizontal connectors are generally not tall. Combined with seabed pipe gives a lower risk of snagging.	Higher risk of snagging because of tall structures because of vertical connectors.
Multibore design	No significant difference. Depending on connector type, horizontal connector can accommodate multibore designs.	No significant difference. Depending on connector type.
Metrology accuracy	Medium level of accuracy required, as installation can elastically deform the tie-in spool.	High level, as there is no opportunity to correct spool during the tie-in operation.

2.7.2 Fabrication

Considerations related to fabrication of tie-in spools are size, weight, complexity of the spool, i.e. number of bends. Considerations related to coating systems are also important.

TABLE 2-2 FABRICATION DESIGN CONSIDERATIONS

Issue	Horizontal Tie-in Spool	Vertical Tie-in Spool
Size and weight	Large footprint, but most work on low levels. Low risk	Small footprint, scaffolding most probably needed.
Complex Geometry	Generally fewer bends associated with horizontal spools. Time savings.	Generally more bends are related to vertical spool. Complex geometry.
Stands for fabrication	Lightweight, because stands does not need to accommodate for weight of tool, inboard test hub is not required.	Many structures are required as well as tilting functionality of hub.

2.7.3 Connector Systems

Considerations related to choice of connector can be seen Table 2-3. However industry practice normally has vertical tie-in spools equipped with collet type connectors. As the industry has moved into deep-waters, diverless connector systems have been developed. For shallow waters, the industry has in the recent years put focus on using diverless systems as well. From a HSE perspective, the use of diverless systems is favourable.

TABLE 2-3 CONNECTOR DESIGN CONSIDERATIONS

Issue	Horizontal Tie-in Spool	Vertical Tie-in Spool
Connector type	Mostly flanged type connectors.	Mostly collet type connectors.
Complexity	Simple and low complexity. Low weight compared to vertical connector.	Collet connectors are complex. High weight.
Cost	Medium/High	High
Seal damage	Low, as connecting depends on a lot of sequenced activities.	Connection is done in one operation, increasing risk for damaging seal.
Inboard porch size on structures.	Extra length and weight required for the horizontal landing structure.	Very compact arrangement.
Loading (Torsional)	Can take large loads	Can take small loads.
Divers/Diverless	Divers/Diverless	Diverless

By technology development, more and more sophisticated tie-in operation tools are made available. This enables the opportunity to use horizontal spools for deep water tie-ins

2.7.3.1 *Connector loading*

When selecting a connector type there are two main drivers that are important to consider. These are the ability to make up misalignments and the ability to handle induced forces. Misalignments in angular and linear directions due to inaccuracy will occur as in any other system and it is important that the connector can make up these misalignments. The connector's ability to handle induced forces and moments are important in order to maintain a perfectly tight seal.

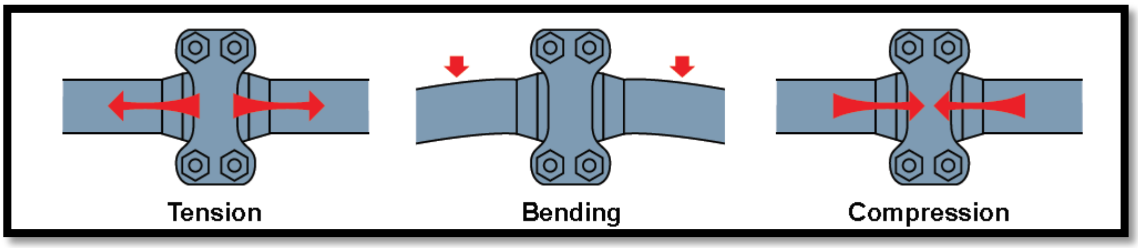


FIGURE 2-9 LOADS ON CONNECTORS (OCEANEERING, 2012)

Figure 2-9 illustrates the most important loadings that a typical connector will have to withstand. In addition to tension, compression and bending forces is important that any bolted flange connection can withstand torsion.

All connectors used for tie-in spool applications needs to go through an extensive qualification programme in order to achieve correct certificates. Connectors need to be tested for all loading types that it might be subjected to.

FIGURE 2-10 TESTING RIG OF A CONNECTOR (GE ENERGY, 2012)

Figure 2-10 shows a large test rig, where a typical bolted connection is tested for bending moment. Large hydraulic cylinders are mounted on each side of the connector and induce a known moment into the connector. By leak testing it afterwards, the sealing capability is revealed. By further testing capacity charts of the connectors can be established.

Table 2-4 shows 5 connectors and their respective capacities. For better understanding of the used axis orientation, it is referred to Figure 2-11.

TABLE 2-4 SOME CONNECTOR CAPACITIES

Diameter / Location	Connector Location	Load Case	Forces(kN)		Moments (kNm)	
			F_z	$\sqrt{F_y^2 + F_x^2}$	M_z	$\sqrt{M_y^2 + M_x^2}$
8" HCCS	PLET	Operational		3000		345
10" Manifold – FTA*	Manifold	Operational	40	30	60	200
	PLET		40	30	60	200
6" Manifold – Well*	Manifold	Operational	120	70	40	150
	Well		120	70	40	150
10" Manifold – ITA*	Manifold	Operational	40	30	60	200
	ITA		40	30	60	200
12" FTA – FTA*	PLET	Operational	70	50	60	250
	PLET		70	50	60	250

*These are estimated maximum capacities and there may be a trade of between forces and moments (Chan, Mylonas, & McKinnon, 2008).

Typically connectors are designed to fulfil specific requirements assigned to each specific development project. The connectors listed in Table 2-4 must only be taken as examples of connector capacities.

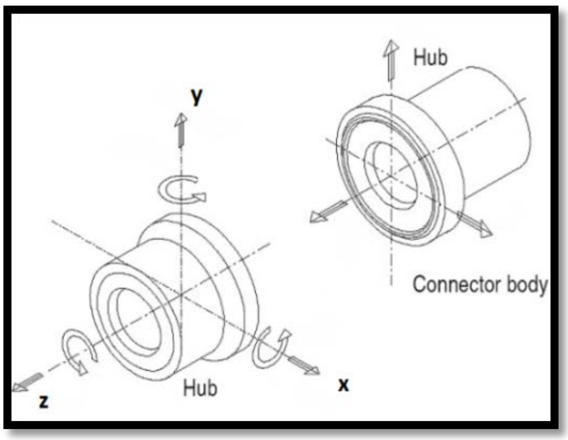


FIGURE 2-11 AXIS ILLUSTRATION

The illustration shows that each hub has 6 possible degrees of freedom. These are the axial direction, z, and the corresponding perpendiculars, x & y, that make up a Cartesian coordinate system three.

In the following some of the most used connection principles are introduced.

2.7.3.2 *Bolted Flange*

A bolted flange connection utilizes a metal gasket which is compressed to seal between two flanges. The bolts axis has the same orientation as the pipeline. When the bolts are tightened the metal gasket is deformed between the two flanges. The gasket allows the flanged connection to have some initial misalignment, but it is very vulnerable to rotational misalignment about z-axis due to the flanges respective bolt hole orientation.

FIGURE 2-12 BOLTED FLANGE CONNECTION (BOLT SCIENCE, 2012)

This connection is most commonly used for shallow water depths, where divers can make up the connection. Special ROV operated tools can also make up bolted flange connections, but these are heavy and require a lot of tooling to be run from the installation vessel. Bolted flange connections are well proven, both topsides and subsea, but it time consuming to tighten all bolts.

2.7.3.3 *Clamp Connector*

The clamp connector utilizes the same principle as the bolted flange connector. A gasket is placed between two flanges which are forced together inside the clamp, which is then closed by a torque tool. Because of fewer bolts to tighten the clamp connector is in general faster to make up than a bolted flange connection. Rotational misalignment about z-axis is not an issue for this type of connections because of no bolt holes that need to be aligned. Initial misalignment allowance is in general lower compared to bolted flange connections. A typical manually clamp connector is shown below.

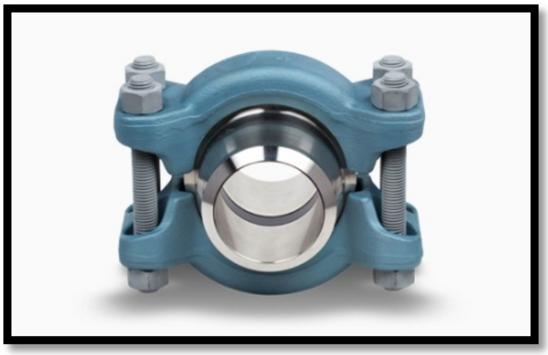


FIGURE 2-13 MANUAL PIPE CLAMP CONNECTION (VECTOR TECHNOLOGY GROUP, 2012)

The clamp grabs around the flange on each side and forces them together. In between, there is placed a sealing gasket which works as for the bolted flange connection system. The clamps bolts are placed perpendicular to the z axis; they are not connected to the piping structure, which means that rotational misalignment is not an issue when installing clamp connectors.

Often, for subsea applications, clamp connectors are favoured because of fewer bolts to tighten which directly affects the cost of the entire operation.

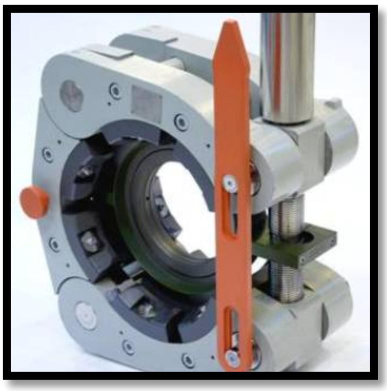


FIGURE 2-14 ROV OPERATED PIPE CLAMP CONNECTION (AKER SOLUTIONS, 2012)

The design of ROV operated clamp connectors differs from typical manual ones. The principle is the same, but instead of having bolts placed on each side of the pipe, one of the sides is a hinge, while the other one is a bolt. The layout of this is seen above

2.7.3.4 *Collet Connector*

For vertical connector types, the collet connector design is very frequent used. The collet connector is made up of a body and a hub. On the hub, individual collets are mounted in a circular pattern. Outside of the collets, a cam ring slides axially along the collets length to either lock or unlock the device. The seal is made by compression of a metal gasket between the body and the hub. A vertical oriented spool with a collet connector is shown below. The collet connector has the ability to align hubs that are misaligned. And misalignment in rotation about z-axis is generally not an issue for collet connectors.

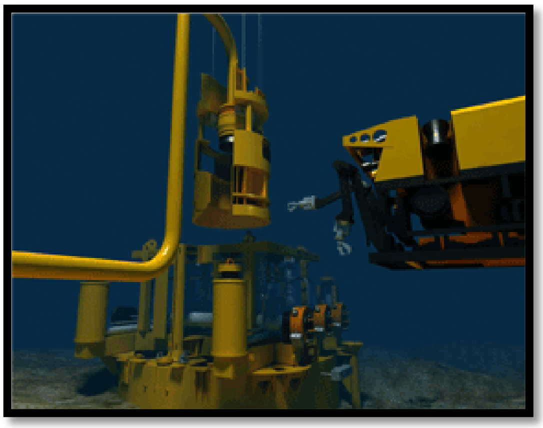


FIGURE 2-15 COLLET CONNECTOR (FMC TECHNOLOGIES, 2012)

2.7.4 Installation

There are large differences in equipment requirements, depending on the orientation of the spool. Vertical spools are generally faster to install, however they are also dependant on obtaining a favourable sea-state during installation. And vice versa, horizontal spools takes more time, but do not have as strict requirements to sea-state

TABLE 2-5 INSTALLATION DESIGN CONSIDERATIONS

Issue	Horizontal Tie-in Spool	Vertical Tie-in Spool
Load out	Simple seafastening. Large deck space may be needed if spool has irregular shape.	Seafastening requires tall structures.
Tie-in equipment need	Complex. Reliance on ROV if no possibility to use divers.	Simple. No reliance on ROV operated task except operation.
Installation time	Long.	Quick installation and fast connection
Installation vessel requirement	Relatively low specification vessel, but with large deck space for spool	Relatively high specification vessel with good RAO's
Weather dependence	Low	High

2.7.5 Operational

Some operational considerations are seen in Table 2-6.

TABLE 2-6 OPERATIONAL DESIGN CONSIDERATIONS

Issue	Horizontal Tie-in Spool	Vertical Tie-in Spool
Seal change	Simple. As it is only to push back connector and replace seal	Heavy lifting vessel might be required to lift spool up. Dependant on connector brand.
Flow Assurance	Horizontal bores eases flow assurance	Vertical bores induces risk of build-up of slugs.
Maintenance	No significant difference	No significant difference
Pigging ability	Can be equipped with 5D bends	Can be equipped with 5D bends. Pigging is however complex.

Via a weighting process performed by Giovanni Corbetta and David S. Sox [1], it is clear that there is no significant advantage in technical ranking gained by choosing horizontal spools before vertical spools. Both technologies have been used with success before.

2.7.6 Subsea Metrology - Measuring tie-in spools

Once the pipeline is laid on the seafloor, there is a gap between the PLET and the tie-in structure. Specialists will then do a metrology survey in order to establish dimensions for the tie-in spool. The results from the metrology survey are then used by pipeline engineers that design a spool that will connect the two hubs together.

The objective of a subsea metrology survey is to establish the two hubs positions relative to each other. One will also obtain bathymetric information in order to determine the spool route. Accuracy is a key word when doing metrology as the two hubs faces need so seal perfectly in order to get a safe transportation of hydrocarbons.

The most important deliverables from a subsea metrology report is:

- Horizontal position of the hubs
- Vertical Position of the hubs
- Depth of seabed along the intended spool route
- Attitude of the hubs
- Spool azimuth
- Angle of the spool approach.

Common metrology methods are by use of taut wire, long baseline acoustics or by use of inertial navigation systems. They are all briefly discussed in the following subsections by reference to the report "Guidance on Subsea Metrology" published by International Marine Contractors Association.

2.7.6.1 *Long Baseline Acoustic Metrology – LBL acoustic*

Long baseline acoustic (LBL) metrology is a widely used technique. The technique uses equipment that is highly accessible and well proven. Transponders communicate with each other by sending and receiving sound waves, thus by knowing the exact speed of sound in water for the specific place, one obtains the range between the two hubs. The principle is shown in Figure 2-16. A pressure survey is needed to determine the hubs depths and attitudes relative to each other.

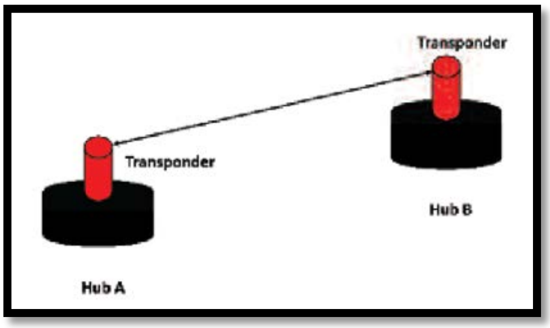


FIGURE 2-16 LONG BASELINE METROLOGY (INTERNATIONAL MARINE CONTRACTORS ASSOCIATION, 2012)

The method is highly adaptable and can be performed in the matter of hours and also allows for a transponder to be placed on the PLET and tie-in structure beforehand. Drawbacks for this method are that there is a lot of equipment to handle, both topside and subsea. Subsea noise is also a consideration as these methods rely on sound waves. Too much noise will disturb these waves and consequently lead to inaccuracy of the final metrology report. Some sources of subsea noise are nearby standby and support vessels, drilling activities and other subsea operations that might create sound.

2.7.6.2 *Taut Wire Metrology*

The taut wire method was the first subsea metrology method employed by divers. The technology consists of two separate plates with a protractor on each. The plates are accurate mounted above each hub, either by a stabbing mechanism or by bolts. A wire coiled up on a drum mounted on one of the plates is reeled out to be connected to the other plate on the second hub. The wire is then tightened with a hand cranked winch. The diver will perform all measurements needed in order to establish a metrology report that is usable for fabricating the tie-in spool. The protractor plates are shown in Figure 2-17 Contractor Plates for Taut Wire Metrology (International Marine Contractors Association, 2012).

Figure 2-17 Contractor Plates for Taut Wire Metrology (International Marine Contractors Association, 2012)

Compared with the LBL acoustic method, the amount of equipment need is very small. Together with a fast deployment time the taut wire method is very efficient for shallow waters where the use of divers is possible. However, the method requires that no physical obstacles are in between the two hubs. In addition the manual readings more or less depend upon the observational abilities of the diver and the visibility. The taut wire technology has also been adapted to fit ROV operated systems and by this, one can neglect limitation with regard to water depth.

2.7.6.3 *Inertial Navigation Systems - INS*

By use of accelerometers and gyroscopes, mounted in a device, one can measure the acceleration in X, Y and Z directions as well as the angular velocities. An INS metrology procedure starts at a reference point, which is one of the hubs. The INS device is then moved to the second hub and by mathematically processing one can then determine the final position of the second hub .The device is handled and powered by a ROV and the entire metrology operation is relatively fast. The INS device is a self-contained unit, which means that it does not rely on other assisting systems. High Tech navigation systems used on submarines has in the recent years been made available for civilian operations; this contributes to make INS metrology systems more and more accurate.

The operation time which is directly related to cost, is relatively small compared to other systems. No direct “line of sight” between the two hubs is necessary, as any obstacle can be flown around. It is quite immune to subsea noise.

Drawback of INS is that without external reference points it is subjected to cumulative errors. This means that if there is a small error in the measured accelerations, the integration will then give wrong answer when the final position is to be determined and also the hub face angular position. However, by future development and refinement, the INS system has the potential to become the most preferred metrology system.

2.7.6.4 *Other metrology methods*

Digital taut wire is a further development of the taut wire technology. Digital sensors are fitted on the measuring unit providing more accurate measurements and are thus mitigating the "human effect" as in the conventional taut wire.

Photogrammetry is a method which is based upon two or more photos which is taken along the planned spool route. A high quality camera is mounted on a ROV which sweeps over the area where the spool is to be installed. By use of measuring bars and reflective markers placed on the seabed, the images are processed by suitable software to create a three dimensional model of the hubs position and the seabed bathymetry. There is a potential of achieving high accuracy by use of photogrammetric metrology methods, however, the method is dependent upon good visibility and requires special trained personnel.

2.8 Installation of Tie-in Spools

Depending on the tie-in spools size, spools are generally transported offshore by the installation vessel itself or by towing it on a barge. The spools are then lifted off the deck of the transportation vessel using a vessel based crane.

The main limitation for installing a spoolpiece is the overboarding of the spool into the splash zone. This operation usually requires a very benign seastate with low winds. If there are many spools to be installed on a particular development, these might be placed on the seafloor in a wet storage area during a period of good weather. The spools can then be retrieved from this position and installed as the installation seastate is usually higher than that required for overboarding

A too rough seastate can delay spool piece installations. Installation method of tie-in spools is dependent upon tie-in spool orientation. Description of installation methods for tie-in spools and aspects related to marine operations is an entire study in itself and has therefor been excluded from this report. However, it is referred to section 3.4 for an explanation of a horizontal tie-in spool installation.

Prior to the installation of the spool it is important to monitor weather conditions. Each installation vessel has its own response amplitude operator (RAO) and this can in many cases be a showstopper. If the seastate at the time of installation is unfavourable, then the entire installation might be put on hold or it has to wait on weather. This is a costly affair, since the vessel is mobilized with all necessary crew and equipment.

3 Industry example – The Valhall Case

Within this section reference is made to a “live” field development example of a typical spoolpiece used on a shallow water development. Further work in this thesis will use this industry example as a relevant reference for comparisons.

3.1 Valhall Flanks Gas Lift Project

The Valhall field is located in block 2/8 in the southern North Sea. The field was discovered in 1975 and have been producing since 1982. It is operated by BP Norway. Since the discovery, 8 platforms have been installed on the field. Six of these platforms are located in the centre, in addition to two flank platforms that are located north and south of the Valhall complex. This is seen on Figure 3-1 below. The water depth is approximately 70 metres and is constantly increasing due to compaction of limestone reservoir.

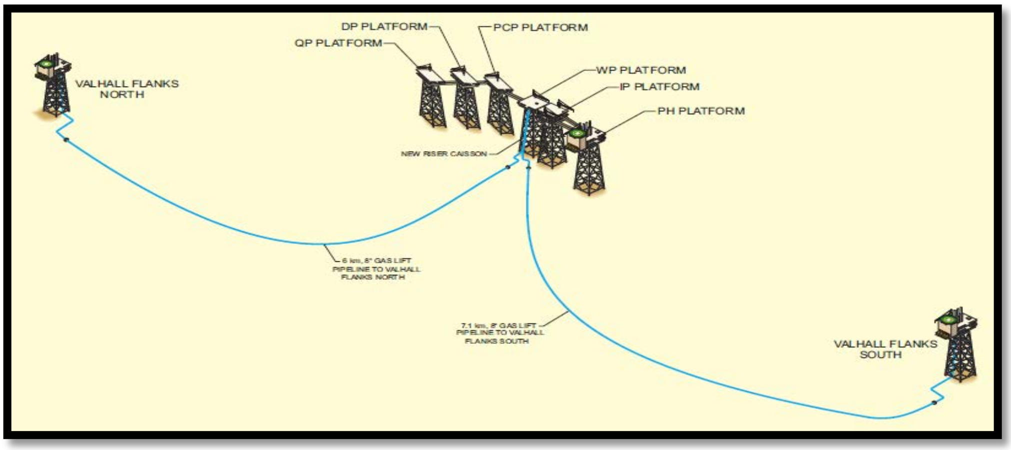


FIGURE 3-1 VALHALL FLANKS GAS LIFT, SCHEMATIC OVERVIEW (BP NORWAY, 2012)

As the reservoir at Valhall in being produced, energy stored within the reservoir has been reduced, although water injection to maintain this began in 2004. At the flank platforms, severe lifting problems of the wellstream from the 16 production wells were experienced in 2005.

In order to increase the production from the Valhall field, BP decided to outfit 15 wells at each flank platform with gas lift. Gas lift reduces the density of the well stream, and consequently increases the production.

Dry export gas from the production facilities at the Valhall centre, is exported from the WP platform to each flank via 8 inch pipelines. The wellhead platform (WP) is located in the centre of the Valhall complex as displayed on Figure 3-1. At Valhall Flank South (VFS) the gas is distributed from a manifold to each of the 15 wells that have been modified to accept gas for gaslift.

This report assesses one of the tie-in spools associated with the pipeline going from the WP-platform to VFS. The selected tie-in spool is the one that ties the pipeline to the WP-platform.

3.2 Tie-in Spool Presentation

In order to absorb axial expansion from the gas pipeline and to reduce forces that connectors are subjected to, a tie-in spool is installed. A plan view of the gas lift pipeline is presented in Figure 3-2. The pipeline was configured with pipeline end termination units. The presence of the PLET allows the pipeline to expand axially by not constraining the pipe in this direction. Forces and moments induced by pipeline expansion are absorbed by deflection of the tie-in spool.

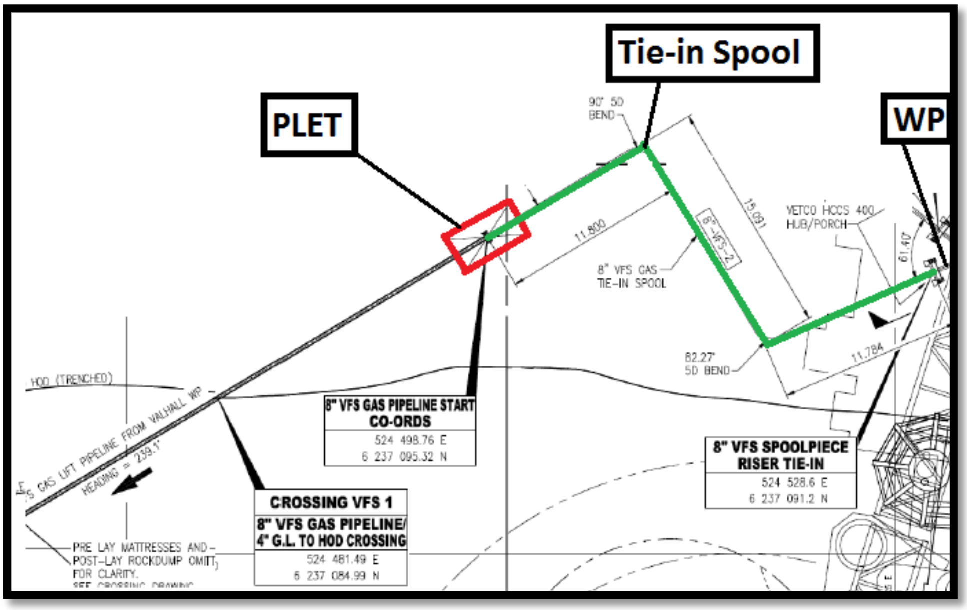


FIGURE 3-2 BIRDS VIEW: PLET & TIE-IN SPOOL

An 8 inch tie-in spool with as illustrated on Figure 3-3 was installed. This particular spool was categorized somewhere in between a Z-spool and L-spool configuration. With bends of about 90 degrees is it is assumed that a comparison with an L-shaped spool is the most reasonable. For a detailed ISO drawing, it is referred to appendix H.

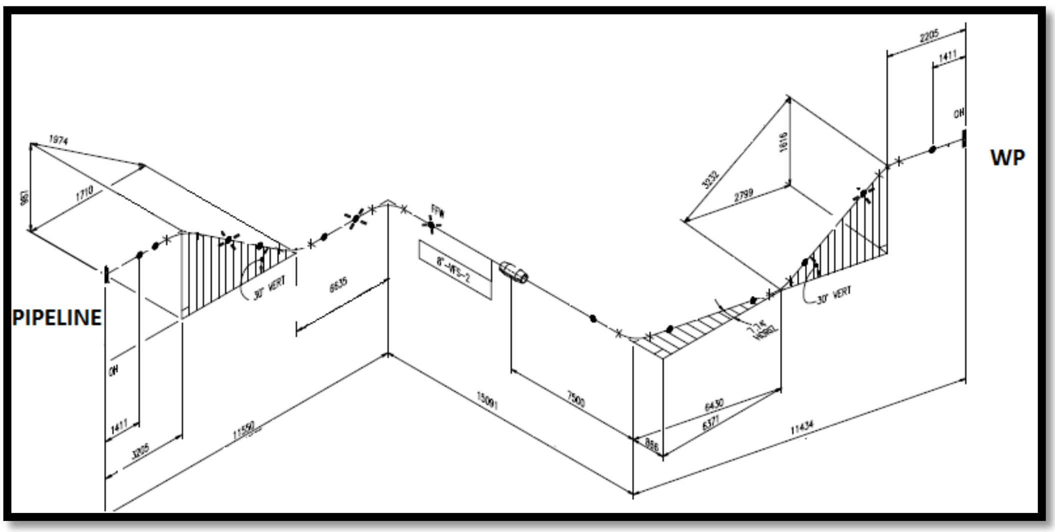


FIGURE 3-3 ISOMETRIC VIEW OF TIE-IN SPOOL

When installed, the spool is only supported by interaction with the seabed. At the ends, or hubs, one can see that the geometry changes from being oriented in one plane, to a multi plane orientation. This geometric change, which often is referred to as goosenecks, is used simply because of it is required for the installation. Raising the hub a distance above sea seabed facilitates space for tooling and guidance systems used for installation of the spool.

The material grade is DNV SML 450 which has a SMYS of 450 MPa at a temperature of 20 degree Celsius. Other material data can be seen Table 3-1 Tie-In Spool Material Data. There is a need for pigging of the pipeline and it is important to notice that all bends in the tie-in spool needs to have a radius that equal 5 times the pipeline diameter. Pigging for pre-commissioning installation issues and operational issues such as flow assurance is necessary for the spool to work as intended.

TABLE 3-1 TIE-IN SPOOL MATERIAL DATA (BP NORWAY AS, 2008)

Item	Unit	Value
Nominal Pipeline Outer Diameter	mm	219.1
Wall Thickness	mm	12.7
Pipeline inner Diameter	mm	193.7
Material Grade		DNV SML 450 I
Young's Modulus	GPa	207
Density	Kg/m^3	7850
SMYS @ 20 ^{0}C	MPa	450
SMYS @ 80 ^{0}C	MPa	432
Spool Bend Radius	mm	5 x OD

3.3 Connection system

The connection system used on the Valhall Flanks Gas lift project was supplied by VetcoGray. It is referred to as HCCS, Horizontal Clamp Connection System. The total connection system consists of two main parts, the inboard part and the outboard part. Tie-in spools are generally outfitted with the outboard part of the connection system, this because guiding systems are designed in a way that this is the most convenient way of installing. This can be seen on the spool presented in section 3.2. The tie-in spool is fitted with two outboard hubs. The inboard porch structure is fitted on the PLET and on the caisson that is placed on the WP Platform.

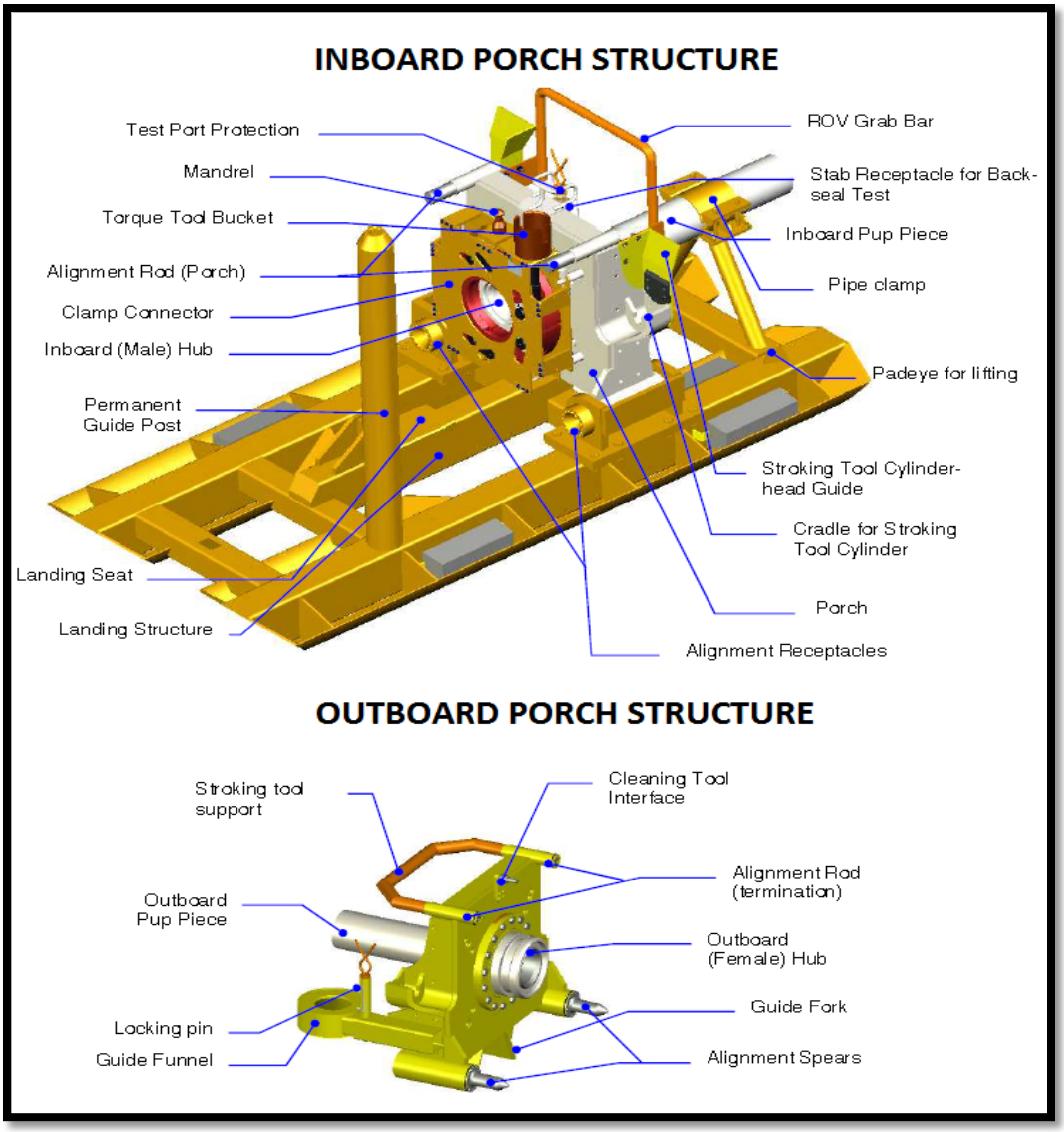


FIGURE 3-4 INBOARD AND OUTBOARD PORCHES FOR HCCS (BP NORWAY, 2012)

The clamp connector is mounted on the inboard porch since this is the most robust structure of the HCCS system. The inboard porch provides guiding systems to align the two hubs so that they are ready for stroking and clamping the two hubs together. The main processes of tie-in spool installation will now be described in the following chapter, with reference to the above illustration.

3.3.1 Connector Capacity

The capacity of VetcoGrays HCCS 400 used on VFG is seen in the chart below. Tie in spools are mainly installed to absorb pipeline expansion and to reduce loads on the HCCS400 connector. Other loadings are loads from waves and currents, trawl impacts, dropped object loading among others.

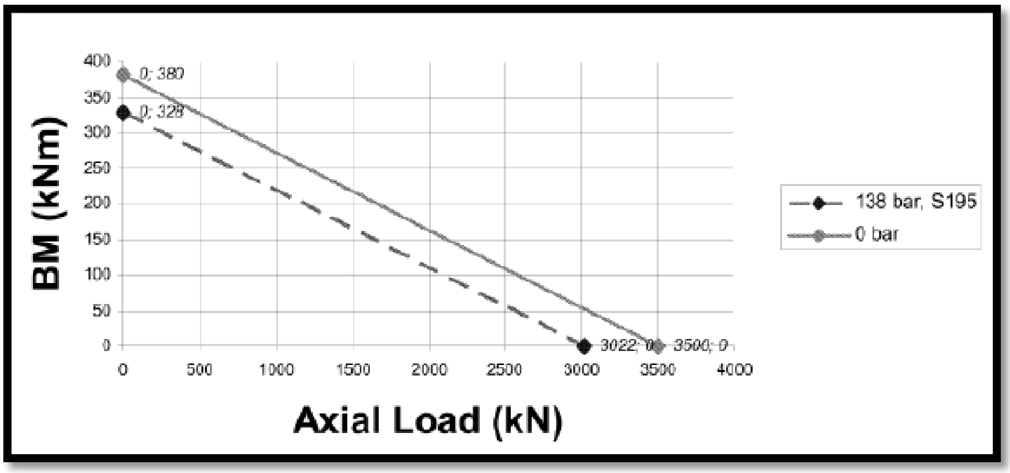


FIGURE 3-5 CAPACITY CHART HCCS CONNECTOR (BP NORWAY, 2012)

As seen on Figure 3-5, there will be a trade-off between bending moment and axial force and it also dependant on internal pressure.

3.4 Tie-in Sequence for The Spool

Prior to the tie-in operation there is a significant amount of equipment required to be mobilized to the associate spool installation vessel. Excluding the installation vessel itself, some of the most important tooling required for tie-in is as follows:

- Working class ROV
- Observation ROV's
- Stroking tools
- Torque tools
- Hub inspection cameras
- Tool deployment basket
- Gaskets
- Seals

All this equipment will have to be subject to an extensive onshore factory acceptance test (FAT) and system integration tests (SIT). FAT will test each single piece of equipment and check if it is working correctly. SIT will put the entire system together and check if the entire system works as intended. For the SIT, an imaginary installation site is built using the same connector and equipment as in the "real" case. In addition to this, crews to operate all necessary equipment are needed in order for the tie-in to be conducted.

3.4.1 Tie-in sequence

Once deployed through the splash zone, the spool was lowered to 5 metres above the seabed. The installation vessel was then manoeuvred until the spool was in the correct position above the alignment porches.

The spool was landed on the inboard porch that in this case was connected to ta riser attached to the WP jacket structure. The vertical guide post seen on the inboard porch provides a visible target and a rigid element to aim for. The spool is lowered so that the guide post is aligned with a guide hole fitted on the outboard porch. An ROV is utilized to manoeuvre the spool into position and guide these systems together.

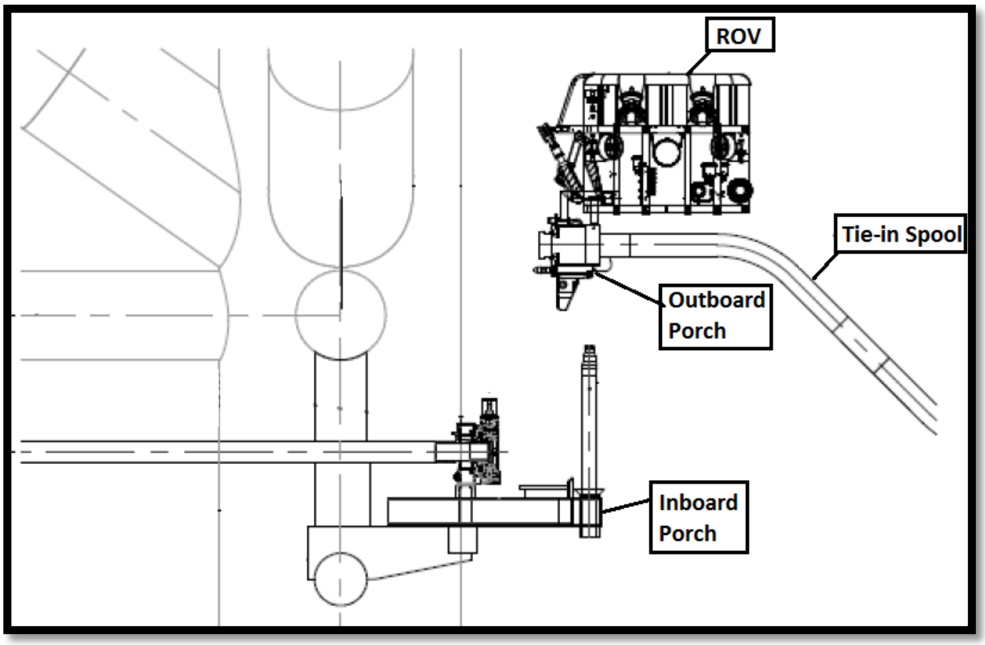


FIGURE 3-6 LANDING TIE-IN SPOOL

On the opposite side of the spool, the landing procedure is essentially a mirror image. The outboard porch sitting on the other end of the spool is landed on the inboard porch that is placed on the PLET. Both guide posts needs to hit the guide holes at the same time. Landing one end of the spool and thereafter landing the second one is not possible because of rotational misalignment.

Once the spool is landed on the respective inboard porches there is a gap between the hubs. The function of the gap is necessary in order to provide space for tooling and is needed on both ends of the spool. Required gap for easy tooling varies but is typically in the order of 350 mm, depending on the pipe dimension this will increase. Removal and replacement of seals and gaskets are needed to avoid seawater ingress and leakages when the hubs are clamped together.

Once the gasket is in place a purpose built stroking tool is used to stroke the two hubs together. The stroking tool is attached to prebuilt cradles on the inboard and outboard porches. Hydraulic power from the ROV is supplied to the stroking tool which forces the hubs together. Tie in to the most robust structure is done first, which in this context was the WP platform.

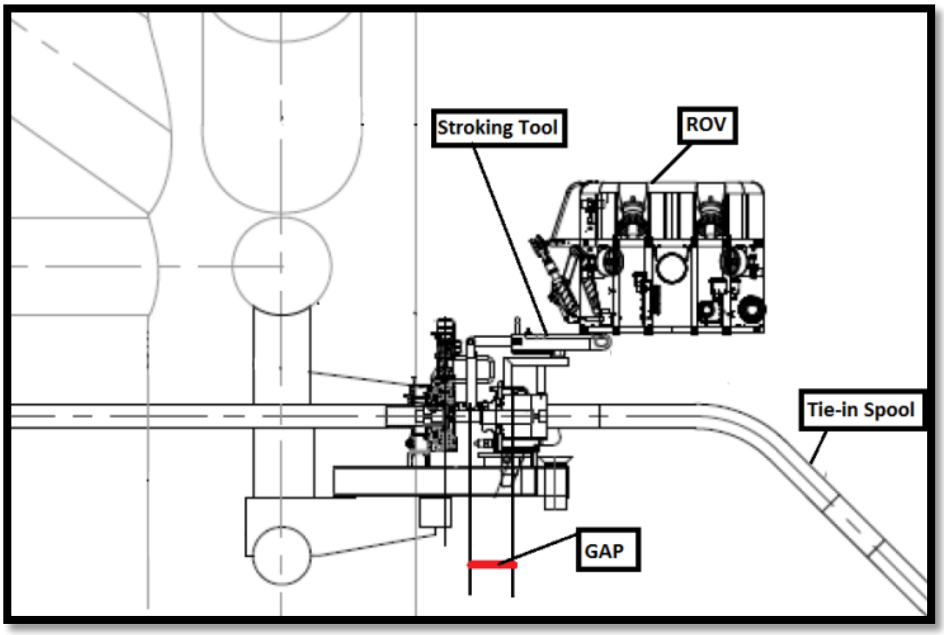


FIGURE 3-7 STROKING TIE-IN SPOOL

In order to achieve a pressure tight connection between the two hubs it is necessary to inspect and clean all sealing faces on the hubs before the hubs are stroked together. Purpose made seals is installed. After stoking, the ROV then operates a torque tool which is used to tighten the clamp connector.

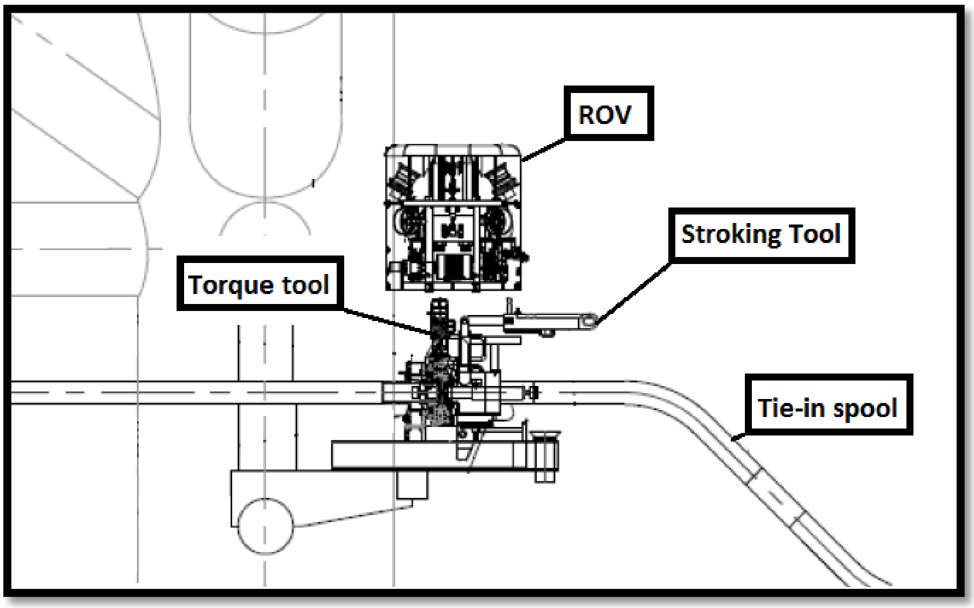


FIGURE 3-8 CLAMPING TIE-IN SPOOL

3.4.2 Caisson on WP

The inboard porches on the WP side sit inside a protection frame on the bottom of an 80 metres long caisson. The caisson is mounted on the side of WP jacket structure. The size of this protection frame is about 5 metres tall and 6 meters wide, making it a huge structure.

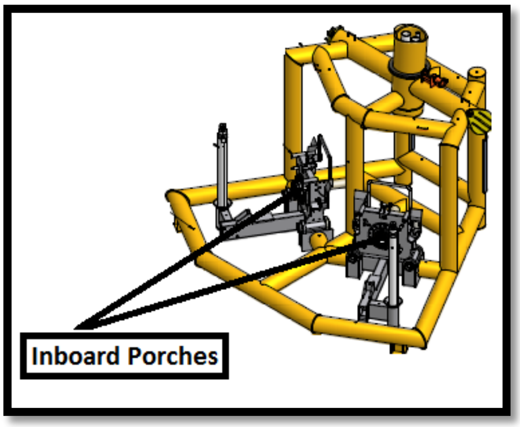


FIGURE 3-9 INBOARD PORCHES INSIDE PROTECTION FRAME

3.5 Basis of Design for Industry Example

The North Sea is characterized as a harsh environment with respect to waves and currents. Due to the fairly shallow water depth at Valhall, the wave's velocity profiles penetrate all the way to the bottom. The following subchapters present the various design parameters that have to be considered during the design of a spool piece. Only the most important parameters have been presented in this section.

The principle design code for all Norwegian sector projects is DNV-OS-F101; Submarine Pipeline Systems.

3.5.1 Operating and Material Data

Prior to designing pipelines and tie-in spools it is necessary to define the operating conditions. Operating conditions are important in the selection of material and determining the required wall thickness of the pipeline. The density of the contents to be transported is also important, as this will influence the on-bottom stability of the pipeline. For the Valhall VFG spool the operational parameters presented in Table 3-2 where used:

TABLE 3-2 SELECTION OF IMPORTANT OPERATING CONDITIONS (BP NORWAY AS, 2008)

Item	Unit	Value
Content		Dry Gas
Contents density	kg/m^3	0.81
Design Pressure (at LAT)	barg	143
Min. / (Max. Design Temperature)	^0C	-20/(+80)
Operating Temperature	^0C	+49

Another main important operating parameter is the temperature profile along the pipeline. This is necessary to know, as this will determine the magnitude of pipeline expansion at each end. Typically the supply end, defined as the hot end, has a higher temperature and thus will expand more. Figure 3-10 shows the temperature profile along the pipeline from the WP-platform to VFS platform

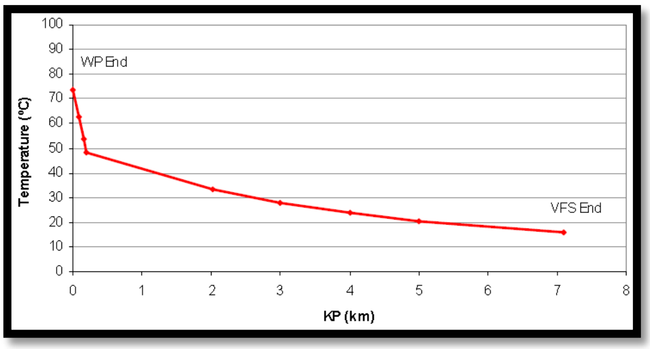


FIGURE 3-10 TEMPERATURE PROFILE ALONG PIPELINE (BP NORWAY AS, 2008)

It is evident from this graph that the sea causes a significant reduction of temperature along the pipeline as the VFG pipeline is not insulated. It is important to notice that other temperature profile on other locations may vary from this. If changes to the temperature profile are required, various pipe insulation methods can be adopted in order to achieve this.

The piping dimensions required to fulfil flow assurance, mechanical strength and material selection considerations are presented in Table 3-3. It is important to note as the medium transported is dry gas. Consequently there is no requirement for CRA materials or any corrosion allowances.

TABLE 3-3 PIPING DIMENSIONS AND MATERIAL SELECTIONS (BP NORWAY AS, 2008)

Item	Unit	Value
Nominal Pipeline Outer Diameter	mm	219.1
Wall Thickness	mm	12.7
Pipeline inner Diameter	mm	193.7
Material Grade		DNV SML 450 I
Material type		Carbon steel
Internal Corrosion allowance	mm	0

Regular inspections of the pipeline and tie-in spools by pigs to are necessary. Failure modes of the pipes are local and global buckling damages, corrosion and as well as phenomena's that prevents flow assurance. Pigs used for pipeline inspection and cleaning purposes need a certain radius in order to pass through. If the radius is less than five times the diameter, there is a possibility that the pig can't pass. When manufacturing bends, they tend to thin in the bending process. This value is set to 10 percentages of the wall-thickness.

3.5.2 Coating

Coating is applied in order to achieve:

- Protection for external corrosion
- Protection from accidental loads
- Insulation

For the VFG pipeline, a 3 layer polypropylene (PP) system has been used.

TABLE 3-4 COATING PROPERTIES (BP NORWAY AS, 2008)

Material	Thickness (mm)	Density (kg/m^3)	Thermal Conductivity (W/mK)
3 Layer PP	3	900	0.22

3.5.3 Environmental Data

Environmental conditions are a key component to be considered during the design. Environmental conditions can be described as:

- Waves
- Currents
- Seabed topography
- Geotechnical conditions
- Seismic conditions
- Reservoir compaction
- Marine growth

3.5.3.1 *Waves (Omni directional)*

As mentioned in the introduction of this subchapter, the southern part of the North Sea is to be regarded as shallow to intermediate waters with respect to waves. Compared to deep water, the momentum of the waves extends all the way to the seabed in shallow waters. And consequently the loading induced by water particles velocity increases.

Table 3-5 Waves Omnidirectional Values (BP Norway AS, 2008)

Return Period (years)	Significant waveheight (H_s) (m)	Zero-Up Crossing period (T_z) (s)	Spectral Wave Period (T_{01}) (s)	Peak Spectral wave period (T_P) (m)	Maximum Wave Height (H_{max}) (m)	Period of Maximum Wave (T_{max}) (s)	Maximum Wave Crest (CR_{max}) (MWL, m)
1 Year	9.6	9.9	10.7	13.0	17.3	12.4	10.9
10 Year	11.7	10.9	11.8	14.3	21.3	13.5	13.5
100 Year	13.8	11.9	12.9	15.5	25.2	14.4	16.2

3.5.3.2 *Currents (Omni directional)*

Fatigue of material on subsea installations[1] are of high concern when planning for a design life of 40 years. Assessing hydrodynamic forces and vibrations that are induced by currents are extremely important in order to maintain a high integrity in a subsea network.

Table 3-6 Omnidirectional Current (BP Norway AS, 2008)

Return Period (years)	Total Design Seabed Current (m/s)
1	0.45
10	0.55
100	0.75

These values must be used together with a scaling factor, since the current is not the same from every direction. Scaling factors are statistically determined. With the below table as a reference it is seen that the current will have its fastest velocity from a North West direction

[1] Subsea Installations: Pipeline, tie-in spools, PLETS, X-mas threes, Manifolds. Anything installed on the seafloor.

TABLE 3-7 CURRENT SCALING FACTORS (BP NORWAY AS, 2008)

Direction From	N	NE	E	SE	S	SW	W	NW
Scaling Factor	0.9	0.81	0.80	0.70	0.72	0.74	0.90	1.0

To assess proper current velocities in analyses it is important for a tie-in spool design to know the exact orientation of the spool.

3.5.3.3 *Geotechnical conditions*

Pipe soil interaction is a crucial mechanism in analysis of tie-in spools. It is necessary to in detail investigate the specific soil properties at each tie-in location. This is because the pipe soil interaction reliefs the resulting forces in the connectors. Comprehensive cone penetration testing on different locations is necessary to cover the entire installation area. Seabed properties may vary a lot with distance away from offshore installations. This is because of waste in the form of old drill cuttings may be located on the seabed.

TABLE 3-8 SOIL PROPERTIES (BP NORWAY AS, 2008)

Item	Minimum Value	Average Value	Max Value
Submerged unit weight of soil	9.8 kN/m^3	9.9 kN/m^3	10.0 kN/m^3
Soil Internal friction Angle	24	28	32
Axial pipe/soil Friction coefficient	0.4	0.4	0.4
Lateral friction coefficient	0.4	0.4	0.4

The most important parameters with respect to soil are the submerged weight and frictional coefficients. Friction forces in axial and lateral directions helps constraining the pipe by adding support to it. It is therefore necessary to reveal these values so that these can be included in the tie-in analyses.

At Valhall the surrounding soil is generally made up of layers of sand which is dense. This layer of sand extends 18 meter below the mudline.

3.5.3.4 *Marine Growth*

Marine growth is another design issue which needs to be assessed. When marine growth is established the hydrodynamic profile in terms of increased diameter of the associated member becomes larger and hence loads from waves and currents increases. Table 3-9 presents marine growth rates per year, with reference to average sea level.

TABLE 3-9 MARINE GROWTH (BP NORWAY AS, 2008)

Height	Growth
Above +2.35 m	0 mm
+2.35 m to -20 m	80 mm
-20 m to -40 m	50 mm
-40 m to seabed	25 mm

3.5.3.5 *Reservoir Compaction*

A special feature at the Valhall field is that the reservoir compacts as its being produced. The subsidence is estimated to 0.25 metres per year and with a design life of 40 years[2] this can prove to be a significant challenge. Current water depth is 74.6 metres.

TABLE 3-10 DESIGN WATER DEPTH (BP NORWAY AS, 2008)

Item	Unit	Value
WP	m	74.6

3.5.3.6 *Seismic conditions*

No seismic considerations are considered at Valhall.

[2] Counting from 2009

3.6 ANSYS model

The parameters defined in the previous section were used as input parameters to design the VFG spool by use of ANSYS software. The ANSYS software is a complex finite element programme that has a complex user interface that requires experienced users. The spool was modelled and built up with the same geometry as it is designed from the metrology report. It is applied the same material properties as in the basis of design.

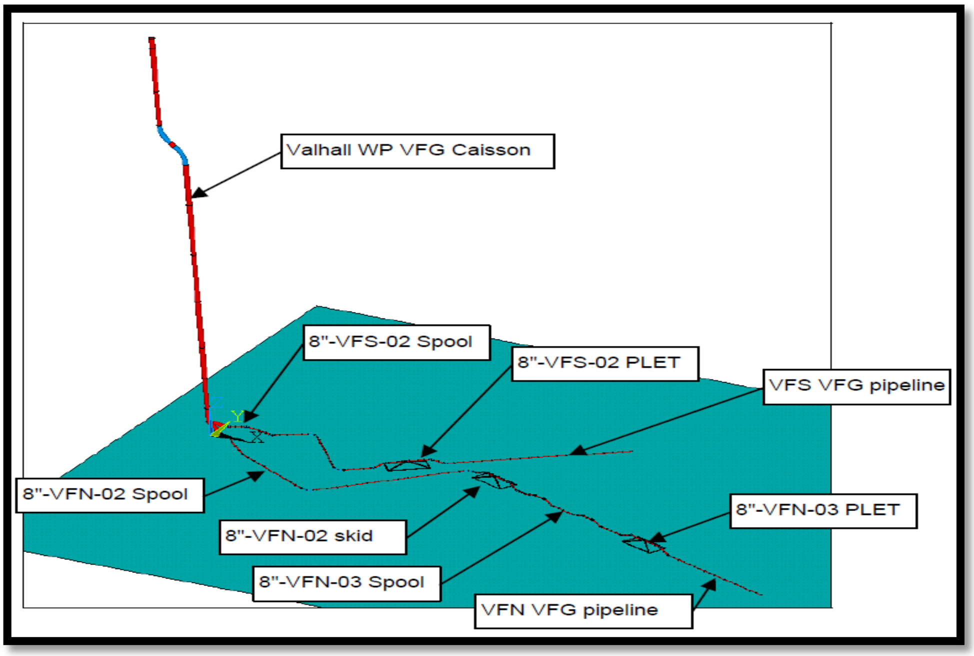


FIGURE 3-11 ANSYS MODEL (BP NORWAY, 2012)

The model consists of the tie-in spools for flank south and flank north together with the WP Caisson and the PLETS for the pipelines from each flank platform. By applying displacements, pressure, currents, waves and soil friction to the tie-in spool, many series of different load cases are run. The different load steps that are applied to the tie-in spool are in the next chapter described.

3.7 Tie-in Spool Loading

This chapter presents the various load cases that requires to be analysed to ensure the spool is correctly designed for installation and operational loads. The tie-in analysis is divided into load steps which is seen is Table 3-11. The load steps are run in series in the ANSYS software. From the software tool, the results are also presented in an individual format; a result is assigned to each load case. Input parameters to the loading are based on the previous mentioned basis of design.

3.7.1 Load Cases

All the different load steps that a tie-in spool analysis needs to take into consideration are listed below in Table 3-11. The sequence of loading may differ for the nine different steps, but not that severe as some of them are based on a previous load one.

TABLE 3-11 LOAD STEPS PERFORMED IN ANSYS

Load Step	Description	Content	Internal Pressure	Temperature
1	Apply Submerged Weight	Water	Hydrostatic	Ambient
2	First Tie-in	Water	Hydrostatic	Ambient
3	Second Tie-in	Water	Hydrostatic	Ambient
4	Pressure test (Positive pressure test)	Water	Test pressure: P_d*1.05*γ_{inc}	Ambient
5	Remove pressure and water (Negative pressure test)	Water	No pressure	Ambient
6	Add operating temperature	In-service content	Design Pressure: p_d	Design Temp
7	Add Wave loading	In-service content	Design Pressure: p_d	Design Temp
8	Pipeline Expansion	In-service content	Design Pressure: p_d	Design Temp
9	Pipeline contraction	In-service content	Design Pressure: p_d	Design Temp

Step 1:

A typical tie-in spool analysis starts when the spool is landed on the inboard porches, ref Figure 3-7 on page 26. At step 1, the only loads acting on the tie-in spool are the submerged weight of the spool. Operational content cannot be added to the system as the hubs are not connected yet. The tie-in spool is filled with water in order to allow for cap removal by balancing hydrodynamic pressure differences. At this point, the contents temperature is equal to the ambient surrounding water.

Step 2 & 3:

Further on, for step 2 and 3, the two connections are tied in. Normally the first tie-in is made to the most robust structure in the system. In this context, tie-in to the caisson at the WP-platform is done first. Still, no internal pressure is added as the content is water. The system is still cold or at ambient temperature.

Step 4

At the stage two connections are considered to be complete and the pipeline is effectively sealed from the outside surrounding water. To check for leaks, Load step 4 is applied to test the tie-in spool and sealing systems according to DNV requirements. The internal pressure is raised to a level of 1.05 times the design pressure. In addition an incidental factor equal to 1.10 is added. The pressure test medium is water. If the pipe is designed correctly, then it should withstand the pressure test.

Step 5

The next step (5) of loading is to remove water from the pipe, and as a consequence, the internal pressure drops. As the pressure difference between internal and external are large, collapse of the pipe walls is now checked. If an unwanted shutdown should occur, then this scenario is likely to happen. Now the tie-in spool is pressure tested positively and negatively respectively. If both tests are passed, then the tie-in spool characterized as pressure tight. From now on, all further tests are conducted with internal pressure at design level.

Step 6

The remaining steps, is to design the spool for the operating conditions. This is done in order to monitor reactions from the spool once it is installed and reaches its design temperature. It is important to notice that at this point of testing, “in-service content” have been added to the system. “In-service content” is for this industry example taken as gas.

Step 7

As load step number 7, hydrodynamic loading is added. Hydrodynamic loads like lift-, drag- and inertia forces are applied to the tie-in spool. It is important to put effort into investigating environmental parameters. Hydrodynamic loads can, especially for shallow water developments, prove to be significant. If any freespans, one has to check piping for vortex induced vibrations. Implementation of VIV reducing mechanisms may be mounted onto the tie-in spool.

Step 8

To simulate the operating conditions, the pipelines expansion is added to the tie-in spool as load step 8. As stressed before in this thesis, one of the main purposes of a tie-in spools is to absorb, by flexing, the expansion from the pipeline. The pipeline expansion introduces a numerous of loadings, all which have to be taken up by the connectors and pipes. In addition to forces taken up by the connectors, pipe soil interaction will relief these forces by absorbing the tie-in spools movement.

Step 9

As a final load step (9), pipeline contraction is added to the tie-in spool. Looking at the sequence of loading, it is obvious that the setup is designed in a logic way.

3.7.2 Tolerances and uncertainties

In addition, tolerances related to metrology and fabrication needs to be taken into consideration. Combinations of the different tolerances results in four different load combinations in wherein the 9 load steps need to be run. Also, two combinations of waves and currents need to be taken into consideration. In total this gives 8 unique load cases that need to be analysed. These are:

TABLE 3-12 LOAD CASES

Case	Waves & Current Direction	Metrology & Fabrication tolerance	Pipe Soil Interaction
Case 1	North	Maximum Stretch	Maximum Contact
Case 2	North	Maximum Stretch	Minimum Contact
Case 3	North	Minimum Stretch	Maximum Contact
Case 4	North	Minimum Stretch	Minimum Contact
Case 5	South	Maximum Stretch	Maximum Contact
Case 6	South	Maximum Stretch	Minimum Contact
Case 7	South	Minimum Stretch	Maximum Contact
Case 8	South	Minimum Stretch	Minimum Contact

Initially, the eight different cases may seem a bit confusing. But, in principle it is just variation of parameters related to uncertainties about waves & current directions, tolerances related to metrology and fabrication and uncertainties about pipe soil interaction. By varying them, eight different cases are made.

3.8 Code Check for Industry Example

The purpose of a tie-in analysis is to check all elements[3] within the tie-in spool against pre-defined code requirements. In addition the checking the capacity of the piping it is crucial to ensure that the connector loads is within pre-defined specified limits.

DNV-OS-F101 Submarine Pipeline systems, gives recommendations and guidelines in the design of submarine pipelines. In industrial projects, this code is used as a reference that sets criteria's that need to be fulfilled in order for the tie-in spool to meet regulatory requirements.

The objective of DNV-OS-F101 is to (Det Norske Veritas - DNV, 2000):

- Provide an international acceptable standard of safety fir submarine pipeline systems by defining minimum requirements for the design, materials, fabrication, installation, testing, commissioning, operation, repair, re-qualification and abandonment.
- Serve as a technical reference document in contractual matters between purchaser and contractor
- Serve as a guideline for designers, purchasers and contractors.

For code checks of tie-in spools it divided into two parts. Straight pipes and bends need to be checked separately. These two code checks are discussed in the following.

3.8.1 Straight pipe elements

Straight pipes are checked against local buckling with combined loading criteria. It is referred to section 5 D505 in DNV-OS-F101 for further detail. The utilization of a straight pipe element is calculated according to the below equation.

$$\gamma_{SC} \times \gamma_m \left(\frac{S_d}{\alpha_c \times S_p}\right)^2 + \gamma_{SC} \times \gamma_m \left(\frac{M_d}{\alpha_c \times M_p}\sqrt{1-(\frac{\Delta p_d}{\alpha_c \times p_b})^2}\right) + \left(\frac{\Delta p_d}{\alpha_c \times p_b}\right)^2 \leq 1.0 \qquad \text{Equation 3-1}$$

Where:

γ_{SC} - Safety class resistance factor [-]
γ_M - Material resistance factor [-]
S_d - Axial force design [N]
α_C - Flow stress parameter [-]
S_P - Axial plastic capacity [N]
M_d - Moment design [Nm]
M_P - Moment plastic [Nm]
Δp_d - Design pressure [MPa]
p_b - Burst pressure [MPa]

The way the equation works is that, induced loads are compared/divided by the plastic resistance for compressive and tensile strength, plastic bending moment capacity and burst pressure. By inserting of axial forces, bending moments and pressures into Equation 3-1, one seeks to obtain a value which is less than one. In which case, the loading is acceptable and the code check is accepted. If a value is more than one, the loading is not accepted and the spool design needs to be revised.

[3] Elements: sections of straight pipe and bends

3.8.2 Bends

Similar as for straight pipe elements all bends within a spool needs to be checked and verified against a code. Code check for bends are done according to ASD buckling check in section 12 F1200 in DNV-OS-F101. This can be done as a preliminary check for local buckling in bends.

In Equation 3-2 equivalent stress is compared to the yield stress which is multiplied with a usage factor η that is dependent upon safety class of the system. The usage factor is dependent on which kind of state the system is in.

$$\sigma_e \leq \eta \times f_y \qquad \text{Equation 3-2}$$

Where:

σ_e - Equivalent Stress [MPa]
η - Usage Factor [-]
f_y - Yield Stress [MPa]

For calculation of the equivalent stress it is referred to Von Mises equation for pipelines. The equivalent stress is based on hoop-, longitudinal- and tangential shear stress. Figure 3-12 shows the moments that can occur in a bend. A typical tie-in spool is oriented in three planes which makes the capacity analysis a complex affair.

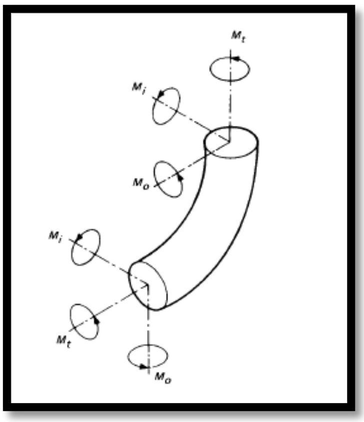


FIGURE 3-12 MOMENTS IN A BEND (ASME, 2010)

In addition to equivalent stress also the longitudinal stress of a bend needs to be checked. Similar as for the equation for equivalent stress, Equation 3-3 is built up in the same way. By comparing longitudinal stress to allowable yield stress multiplied with a usage factor. According to the convention used in Figure 3-12, longitudinal stresses arise from in-plane bending moments which have the notation M_i.

$$\sigma_l \leq \eta \times f_y \qquad \text{Equation 3-3}$$

Where:

σ_l - Longitudinal Stress [MPa]
η - Usage Factor [-]
f_y - Yield Stress [MPa]

Usage factor η, is determined according to Table 3-13 below. Depending on the safety class[4], the value of η can be selected.

TABLE 3-13 USAGE FACTORS FOR EQUIVALENT STRESS CHECK (DET NORSKE VERITAS - DNV, 2000)

Safety class	Low	Normal	High
η	1,00	0,90	0,80

Safety class low corresponds to conditions where the risk of human injuries, environmental pollution is low. Normally, during installation of tie-in spools, a low safety class is used. At the opposite, a high safety class implies high risk of human injuries and environmental pollution. Safety class high is normally selected for operating conditions.

[4] *Safety Class: In relation to pipelines; a concept adopted to classify the significance of the pipeline system with respect to the consequence of failure* (Det Norske Veritas - DNV, 2000).

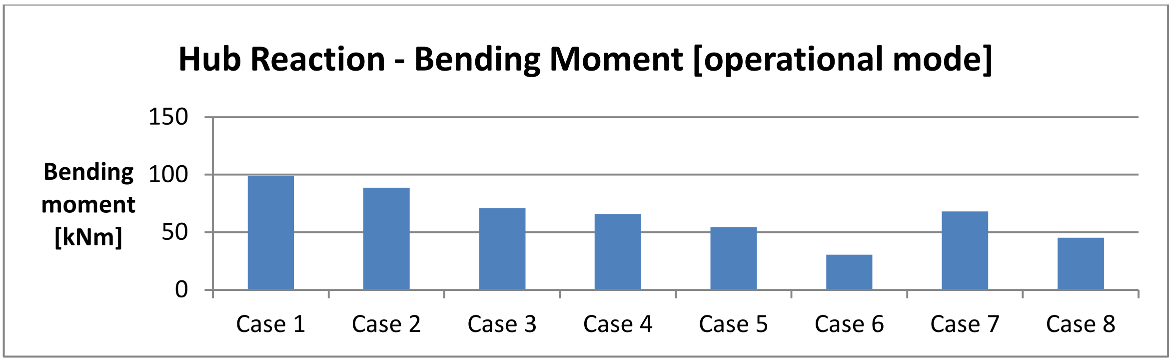
3.9 Results from Tie-in Analysis

Table 3-14 presents the maximum forces and moments applied to the hub at the WP riser interface during operational conditions, load step 8, for each of the individual tolerance related load cases. Reaction forces in other load steps can be found in appendix F. These reaction forces will serve as number of comparison for the modified case in chapter 4.1. The resulting bending moment for each case described in Table 3-12 is seen in the right column.

TABLE 3-14 HUB REACTIONS FOR TIE-IN SPOOL

	Node	Elem	Step	F_X	F_Y	F_Z	M_X	M_Y	M_Z	AxialF [kN]	BendM [kNm]
Case 1[5]	760	747	18	-7016.3	21945.5	16658.8	31963.3	19122.5	-96736.3	-7.0	98.6
Case 2	760	747	18	-5839.4	20737.5	14823.7	30079.9	5972.6	-88593.4	-5.8	88.8
Case 3	760	747	18	-8880.4	21069	16427.1	31694.4	21230.6	-67632.7	-8.9	70.9
Case 4	760	747	18	-7984.6	20583.1	14535.3	30065	-4389.9	-65639	-8.0	65.8
Case 5	760	747	18	-16021.4	-3401.6	18879.3	2563.5	46233.7	28523	-16.0	54.3
Case 6	760	747	18	-15231	-3256.7	16901.1	6429.1	16296	25809.8	-15.2	30.5
Case 7	760	747	18	-18755.8	-2590.8	18748.7	4622.5	49842.5	46410.2	-18.8	68.1
Case 8	760	747	18	-18149.8	-2189.4	16485.7	8873.9	17233.9	41842.4	-18.1	45.3

Figure 2-11 Axis Illustration, can be used to get a proper understanding of the axes used in the analysis.



GRAPH 3-1 OPERATIONAL MODE - HUB REACTION FORCES

It is seen in Graph 3-1 and Table 3-14, that, when varying waves, currents, metrology, fabrication and pipe soil interaction the results are spread. The above presented results are only valid for operational conditions and there are 8 more load steps to be analysed. In addition to hub reactions, the utilization factors also need to be assed. For the purpose of this thesis it is decided to omit them.

[5] See chapter Load Cases3.7.1- Load Cases for explanation of load steps 1-8

Part II – Theoretical and practical case studies

Part II includes two chapters. Chapter 4 includes a theoretical case cases study. Chapter 5 includes a practical case study with an experiment that is based on chapter 4.

4 Theoretical Case Study

Based on the previous industry example derived in chapter 0, a case study is conducted. The objective of the case study is to find a simplified and quick method that can determine the minimum spool lengths required for the connector forces to be within acceptable limits. No specific connector type is selected. The case study checks for operational case where pipeline expansion is present. A return period of 100 year environmental conditions is applied.

4.1 Modified Spool

The 8” tie-in spool used on the industry example is used as a reference. A simplification has been made to the original spool by removing the goosenecks. Roughly, the geometric shape of the original spool has been kept. The bends are 90 degrees. To make it more convenient, the lengths of the legs have been changed to whole digits.

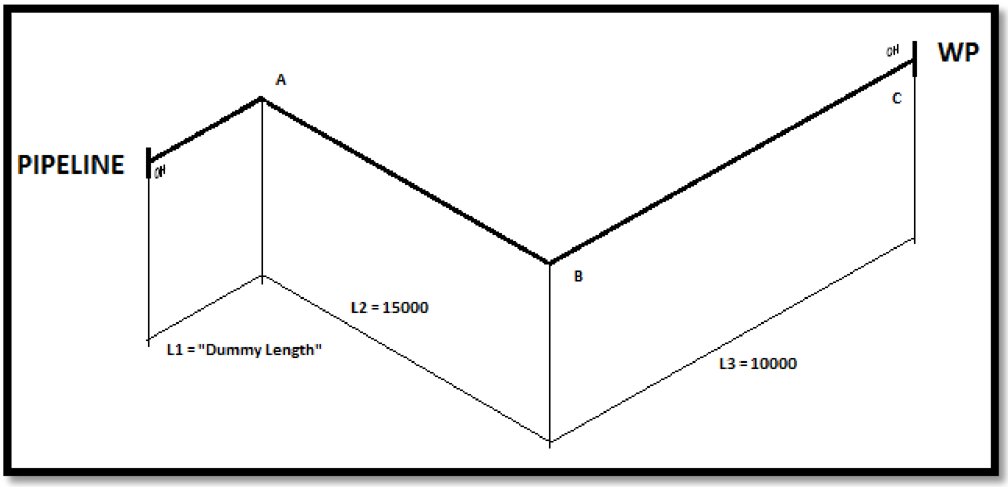


FIGURE 4-1 TIE-IN SPOOL FOR CASE STUDY

4.2 Basis of Design for Theoretical Case Study

The design basis in chapter used for the VFG project in chapter 3.5 is used. Only certain excerpts used for the case study are described in this section.

4.2.1 Dimensions & Material properties

The same dimensions that are used on the 8" industry example on the VFG project are used in this case study. The most important excerpts are seen below.

4.2.1.1 *Spool Cross-Sectional Dimensions*

TABLE 4-1 PIPING DIMENSIONS AND MATERIAL SELECTIONS FOR CASE STUDY (BP NORWAY AS, 2008)

Item	Unit	Value
Nominal Pipeline Outer Diameter	mm	219.1
Wall Thickness	mm	12.7
Pipeline inner Diameter	mm	193.7

4.2.1.2 *Material Data*

Important design parameters associated with the material grade are hereunder listed.

TABLE 4-2 MATERIAL PROPERTIES CASE STUDY (BP NORWAY AS, 2008)

Steel Grade	Young's Modulus (GPa)	Density (kg/m^3)	Poisson's Ratio
DNV SML 450 I	207	7850	0.3

4.2.1.3 *Coating*

Coating is included as it increases the overall diameter of the tie-in spool. This layer is 3 mm thick.

TABLE 4-3 COATING PROPERTIES CASE STUDY (BP NORWAY AS, 2008)

Material	Thickness (mm)	Density (kg/m^3)
3 layer polypropylene	3	900

4.2.2 Environmental

The most relevant environmental conditions relevant for this case study are listed in the following.

4.2.2.1 *Environmental Data*

TABLE 4-4 SEAWATER PROPERTIES CASE STUDY (BP NORWAY AS, 2008)

Item	Unit	Value
Sea Water Density	kg/m^3	1025

4.2.2.2 *Currents (Omni directional)*

TABLE 4-5 OMNIDIRECTIONAL CURRENT CASE STUDY (BP NORWAY AS, 2008)

Return Period (years)	Total Design Seabed Current (m/s)
100	0.75

TABLE 4-6 CURRENT SCALING FACTORS CASE STUDY (BP NORWAY AS, 2008)

Direction From	N	NE	E	SE	S	SW	W	NW
Scaling Factor	0.9	0.81	0.80	0.70	0.72	0.74	0.90	1.0

4.2.2.3 *Waves (Omni directional)*

TABLE 4-7 WAVES OMNIDIRECTIONAL VALUES CASE STUDY (BP NORWAY AS, 2008)

Return Period (years)	Significant waveheight (H_s) (m)	Zero-Up Crossing period (T_z) (s)	Spectral Wave Period (T_{01}) (s)	Peak Spectral wave period (T_P) (m)	Maximum Wave Height (H_{max}) (m)	Period of Maximum Wave (T_{max}) (s)	Maximum Wave Crest (CR_{max}) (MWL, m)
10 Year	11.7	10.9	11.8	14.3	21.3	13.5	13.5

4.2.2.4 *Soil Properties:*

TABLE 4-8 SOIL PROPERTIES CASE STUDY (BP NORWAY AS, 2008)

Item	Max Value
Submerged unit weight of soil	10.0 kN/m^3
Soil Internal friction Angle	32
Axial pipe/soil Friction coefficient	0.4
Lateral friction coefficient	0.4

4.2.3 Operating conditions

TABLE 4-9 PIPELINE EXPANSION AT OPERATING CONDITIONS (BP NORWAY AS, 2008)

Item	Unit	Value
Pipeline Expansion	mm	1500

4.3 Hydrodynamic Forces

Hydrodynamic loading that the tie-in spool will experience is in this chapter presented. Based on the load case that is: tied-in operational, a return period of 100 years is applied.

In section 2.2 of DNV-RP-F109 it is stated that the load cases that needs to be considered is:

- 100-year return condition for waves combined with the 10-year return condition for current.
- 10-year return condition for waves combined with the 100-year return condition for current.

From the design basis values for 100 year current and 10 year waves are extracted. These can be seen in the tables below.

TABLE 4-10 OMNIDIRECTIONAL CURRENT CASE STUDY

Return Period (years)	Design Seabed Current (m/s)
100	0.70

For currents, no directional scaling of direction is applied, which in principle implies that the seabed current is applied perpendicular[6] to the tie-in spool length L2.

TABLE 4-11 WAVES OMNIDIRECTIONAL VALUES CASE STUDY

Return Period (years)	Significant waveheight (H_s) (m)	Zero-Up Crossing period (T_z) (s)
10 Year	11.7	11.8

As for waves, the direction is also applied perpendicular to the tie-in spool. Waves are applied in the same directions as for the current. By doing this, summation of the current velocity and horizontal component of the waves is possible.

[6] Perpendicular to L2.

4.3.1 Horizontal water Particle Velocity

By use of the velocity potential for intermediate water, the horizontal water particle velocity in intermediate water is as seen in Equation 4-1. To describe intermediate water with respect to waves one can say that the velocity profile doesn't have enough water depth to fade away and consequently objects on the seabed are exposed to high velocities. Or opposite, for deep water, the water depth is deep enough in order for the waves to fade away into the deep.

$$U(z,t,x) = \frac{\xi_0 \times k \times g}{\omega}\left[\frac{\cosh k \times (z+d)}{\cosh(k \times d)}\right] \times \sin(\omega \times t - k \times x) \qquad \text{Equation 4-1}$$

Where:

U	- Horizontal water particle velocity [m/s]
ξ_0	- Wave Amplitude [m]
k	- Wave number [m^{-1}]
g	- Acceleration of gravity [m/s^2]
w	- Wave frequency [s^{-1}]
z	- Water depth [m]
d	- Total water depth [m]
t	- Time [s]
x	- Location [m]

The equation can be split into three parts and has three variables. The first part is made up of wave specific parameters like wave amplitude, wave number and the wave frequency. The middle part of the equation enables it for variations into depth. The last, sine part, gives the equation two more variables, which is time and location. The sine part has maximum value of 1, so, this is set equal to one. For hydrodynamic loading, only maximum values are wanted.

4.3.2 Hydrodynamic Lift force

The modified Morisons Equation by DNV-RP-F109, section 3, is used to calculate lift force. Equation 4-2 calculates a resulting force per unit length of pipe. To find the total resulting force one must then multiply with the leg length of the spool.

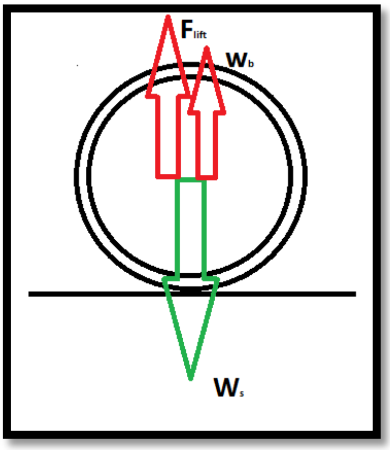


FIGURE 4-2 FORCES INFLUENCING VERTICAL STABILITY OF PIPE

Figure 4-2 shows the main forces influencing the vertical stability of a pipeline. Vertical related forces are submerged weight, buoyancy and lift force.

$$F_{lift} = \frac{1}{2} \times r_{totz} \times \rho_w \times D_{oc} \times C_z \times (U + V_c)^2 \qquad \text{Equation 4-2}$$

Where:
F_{lift} - Lift Force [N/m]
r_{totz} - Reduction factor [-]
ρ_w - Density of water [kg/m^3]
D_{oc} - Outer diameter pipe [m]
C_z - Peak vertical load coefficient [-]
U - Horizontal water particle velocity [m/s]
V_c - Current velocity [m/s]

Use of the equation is relatively straight forward with a brief description of the parameters included. A reduction factor r_{totz} is included to take into account burial of the tie-in spool. For further description of this, it is referred to the section 0. The constants ρ_w and D_{oc} are density of water and outer diameter of pipeline respectively. C_z are a peak vertical load coefficient that are dependent upon ratio between current and wave velocities (Equation 4-4) and the Keulegan-Carpenter Number (Equation 4-4). How to determined C_z, explained in the following. The last two parameters, wave and current velocity are added and then squared.

A load reduction factor can be taken into account because of pipe soil interaction. For further discussion it referred to chapter 0 which discusses the parameters included in Equation 4-3.

$$r_{totz} = r_{permz} \times r_{penz} \times r_{tz} \qquad \text{Equation 4-3}$$

4.3.2.1 *Vertical Peak Load Coefficient*

In determining the vertical peak load coefficient C_x, it is referred to the table below. Table 3-10 in DNV-RP-F109 have empirically determined the C_z –value based on two parameters. These parameters are the Keulegan-Carpenter Number, K-C number, and the current/wave ratio, respectively Equation 4-4 and Equation 4-5.

C_Z^*		K^*										
		≤2.5	5	10	20	30	40	50	60	70	100	≥140
M^*	0.0	5.00	5.00	4.85	3.21	2.55	2.26	2.01	1.81	1.63	1.26	1.05
	0.1	3.87	4.08	4.23	2.87	2.15	1.77	1.55	1.41	1.31	1.11	0.97
	0.2	3.16	3.45	3.74	2.60	1.86	1.45	1.26	1.16	1.09	1.00	0.90
	0.3	3.01	3.25	3.53	2.14	1.52	1.26	1.10	1.01	0.99	0.95	0.90
	0.4	2.87	3.08	3.35	1.82	1.29	1.11	0.98	0.90	0.90	0.90	0.90
	0.6	2.21	2.36	2.59	1.59	1.20	1.03	0.92	0.90	0.90	0.90	0.90
	0.8	1.53	1.61	1.80	1.18	1.05	0.97	0.92	0.90	0.90	0.90	0.90
	1.0	1.05	1.13	1.28	1.12	0.99	0.91	0.90	0.90	0.90	0.90	0.90
	2.0	0.96	1.03	1.05	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	5.0	0.91	0.92	0.93	0.91	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	10	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90

FIGURE 4-3 PEAK VERTICAL LOAD COEFFICIENTS (DET NORSKE VERITAS - DNV, 2010)

In order to determine $C_{z,}$ K^* and M^* needs to be calculated.

Parameters that go into the dimensionless Keulegan-Carpenter number is the horizontal water velocity U (from Equation 4-1), the period of oscillation T_s and the outer diameter of the pipe.

$$K_{kc} = \frac{U \times T_s}{D_{oc}} \qquad \text{Equation 4-4}$$

Generally, small values of K-C indicate that inertia forces will dominate, whilst drag/lift force will dominate for large K-C numbers.

The ratio between current and wave velocity indicates that for large wave velocities, the value of M_R will become smaller. By pondering one can think of the total induced water velocity increases its momentum by the wave velocity being higher than the current velocity. And consequently the value of C_z increases:

$$M_R = \frac{V_C}{U} \qquad \text{Equation 4-5}$$

4.3.2.2 ***Discussion on reduction parameter r_{totz}***

This parameter takes into consideration load reduction due to pipe soil interaction. Unique in-situ effects applies and proper investigation of these is important in order to assign correct values. These investigations are done by purpose mobilized ROV's.

The total reduction consists of three independent parameters which in the following are described.

4.3.2.2.1 Reduction due to permeable seabed r_{perm}

By having a permeable seabed, the vertical load will be reduced due to water being allowed to pass underneath the pipe. DNV-RP-F109 states:

"If the vertical hydrodynamic load used in an analysis is based on load coefficients derived from the assumption of a non-permeable seabed, the following load reduction applies; r_{perm}= 0.7"

In the development of velocity potential that Equation 4-1 is just a derivation of, it is assumed that the seabed is impermeable. For special interest on how the velocity potential is derived, it is referred to books regarding fluid flow- and dynamics. A value of 0.7 is assigned to this parameter.

4.3.2.2.2 Reduction due to penetration r_{pen}

A load reduction based on the tie-in spool penetration of the soil is included. To illustrate the mechanism one can think of a complete buried pipeline. It won't be subjected to any hydrodynamic loading. Figure 4-4 Illustrates soil penetration where z_p can be calculated based on input variables that are unique for each offshore location.

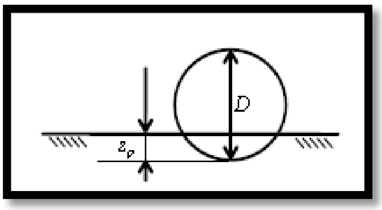


FIGURE 4-4 DEFINITION OF PENETRATION (DET NORSKE VERITAS - DNV, 2010)

Soil variations within offshore fields are also very possible, especially for field where drill cuttings have been disposed to sea. A prohibition of disposal of drill cuttings in the North Sea were introduced in 1993. (Norwegian Petroleum Directorate, 2012) However, old drill cuttings are on many offshore sites left, lying on the seabed.

FIGURE 4-5 ROV SURVEY CLOSE TO TIE-IN LOCATION SHOWING POROUS SOIL

Figure 4-5 shows a ROV in operation very close to the caisson at the WP-platform at Valhall, where the tie-in spool is located. The circular rod is made of plastic and has a diameter of 20mm. The distance between the black markings is about 250 mm.

It shows a very porous surface where the rod is forced straight through by a propeller thrust force of just 7 kg. How far out the drill cuttings stretch out from the well slots is not known. The location definitions included in appendix G and Figure 4-5 shows a survey at location 6. It indicates that there is a probability of drill cuttings having reached outside the jacket structure. Because of the above discussion, the value of soil penetration due to pipe movement is set to 40 mm

The initial soil penetration is calculated by assuming maximum pipe weight and no up-lift force. The pipe may be assumed filled with water, i.e. during pressure test, order to achieve maximum pipe weight. It is referred to appendix A for calculation. The value found to be 1.9 mm

For soil penetration due to pipe movement there is no good guide on how to decide this. It is recommended to perform a survey to check the specific soil condition at the offshore site.

Total seabed penetration z_p is calculated by summing the initial soil penetration and soil penetration due to pipe movement. The total value of seabed penetration z_p is found to be 41.9 mm

4.3.2.2.3 Reduction due to trenching r_{tr}

No trenching of the tie-in spool is done. This value is therefore set equal to one.

4.3.2.3 *Calculated Lift Force*

Based on the above discussed equations and parameters, a value for hydrodynamic lift force is obtained. For a conservative calculation, it is assumed that the attack angle of induced waves and currents are perpendicular to the leg length L2. The calculation itself can be found in appendix A. 100 year conditions, 10 year wave and 100 year current give:

$$F_{lift} = 251{,}37 \frac{N}{m}$$

4.3.3 Equivalent Weight of Tie-in Spool

Calculated submerged weight in operating condition is 252,634 N/m. By subtracting lift the lift force we obtain the resulting equivalent weight W_R, of the tie-in spool:

$$W_R = W_S - F_{Lift} = (252{,}634 - 251{,}37)\frac{N}{m} = 1{,}27 \frac{N}{m}$$

A resulting equivalent weight of 1.27 N/m means that, in practice, that the tie-in spool is close to weightless. By choosing the second 100 year load case to be 100 year wave and 10 year current, the horizontal water velocity will increase. Consequently, also the lift force and resulting equivalent weight will increase, making the tie-in spool want to float up. Keeping in mind that the connectors have a certain load capacity in z-direction[7], it is believed hold the tie-in spool in place.

By the above statements, it is decided to exclude soil resistance in the calculation of bending moments in the connectors.

4.3.4 Drag (& Inertia) Forces

Factors influencing the lateral stability of a pipe are the resulting equivalent weight and the amount of loading induced by waves and currents. The equivalent weight multiplied with a friction factor works opposite of the induced hydrodynamic loads. Figure 4-6 shows the main forces influencing lateral stability of a pipeline.

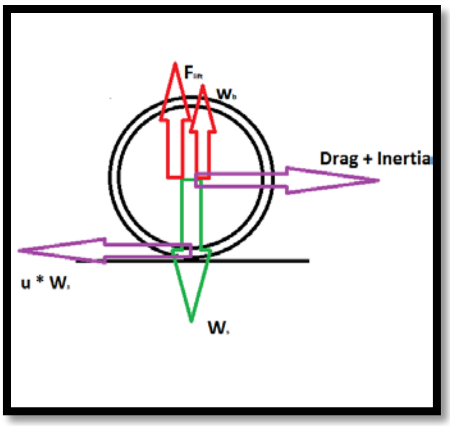


FIGURE 4-6 FORCES INFLUENCING LATERAL STABILITY OF PIPE

[7] Z-direction: Same direction as for the lift force.

For values of Keulegan-Carpenter larger than 45 the drag force is dominant (Delft University of Technology, 2012). The Keulegan-Carpenter number is for calculated to be 66.76 and inertia forces have then been excluded in the calculation of hydrodynamic horizontal loading.

Similar as for lift force, the drag force is calculated according to DNV-RP-F109. The equation for horizontal force is seen in Equation 4-6 and by comparing with Equation 4-2 similarity is seen.

$$F_{drag} = \frac{1}{2} \times r_{toty} \times \rho_w \times D_{oc} \times C_y \times (U + V_c)^2 \qquad \text{Equation 4-6}$$

Where:

F_{drag} - Drag Force [N/m]
r_{toty} - Reduction factor [-]
ρ_w - Density of water [kg/m^3]
D_{oc} - Outer diameter pipe [m]
C_y - Peak horizontal load coefficient [-]
U - Horizontal water particle velocity [m/s]
V_c - Current velocity [m/s]

A reduction factor, r_{toty}, takes care of soil penetrations issues. Peak horizontal load coefficient, C_y, is determined in the same way as for the peak vertical load coefficient C_z used in lift force calculations. The value of C_y is determined according to table 3-9 in DNV-RP-F109 based on flow characteristic parameters such as the Keulegan-Carpenter number and the "current to wave" ratio.

4.3.4.1 *Calculated Drag Force*

Based on the above discussed equation for drag force calculation and input parameters that are defined in the basis of design, the drag force is calculated to be:

$$F_{lift} = 274{,}41 \frac{N}{m}$$

Similar as for lift force, it is for conservative reasons, assumed that the induced waves and currents have an attack angle that is perpendicular to the leg length L2. Drag force is applied as a uniformly distributed load on the tie-in spool.

4.4 Theoretical Methods

Four different methods have been used to calculate the resulting force in the connector in point C in Figure 4-7. Frictional effects from soil are excluded based on the previous discussed hydrodynamic loading chapter. To simplify this assessment, emphasis has been put on using as simple theoretical methods as possible in order in order to reveal bending moment at the connector at point C seen on Figure 4-7.

The methods are:

- Built-in Cantilever
- Rigid Frame
- Elementary Beam Method
- Focus Software

The tie-in spool is treated without soil interaction and the pipeline expansion is denoted by letter d and is set to 1500 millimetres.

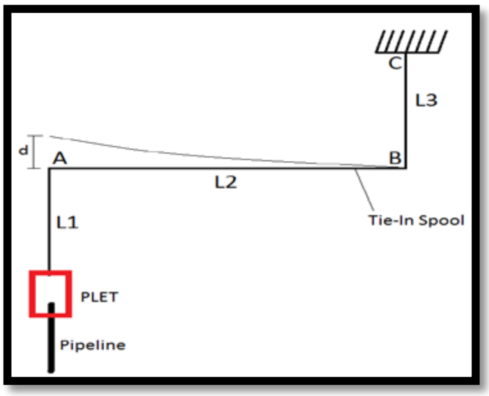


FIGURE 4-7 OVERVIEW OF TIE-IN SPOOL USED IN CASE STUDY

4.4.1 Built-in Cantilever

By use of standard equations related to deflection of built in cantilevers, the forces in point C is calculated. By splitting the spool in each bend and assuming that in split, the cantilevers are built-in, the resulting force is calculated. By not allowing bends to move and assuming a built-in mechanism, the transferal of forces is maximized. This because of the forces calculated are simply just transferred to the next member.

The equation for deflection of a built in cantilever is as follows:

$$d = \frac{P \times L2^3}{3 \times E \times I} \qquad \text{Equation 4-7}$$

Where:

d - Pipeline Expansion [m]
P - Force causing the deflection [N]
L2 - Length of pipe L2 [m]
E - Young's Modulus [MPa]
I - Area Moment of inertia [m^4]

By re-organizing Equation 4-7 and multiplying with the length L2, the bending moment in point C is:

$$M_C = d \times \frac{3 \times E \times I}{L2^3} \times L2 \qquad \text{Equation 4-8}$$

Where:
M_C - Bending moment in point C [Nm]
L2 - Length of pipe L2 [m]

4.4.2 Rigid Frame

The tie-in spool is made up of 90 degree bends which makes it possible to analyse it as a rigid frame structure. By removal of the goosenecks, only in-plane deformations and bending moments are considered.

By treating the straight pipes in the tie-in spool as individual cantilever beams one can, by matching of the slopes and deflections in each curvature change; treat it as a rigid frame. The members must have a uniform cross-section with a principal axis lying in the plane of bending. Chapter 8.4 of "Roark's formulas for stress and strain" by (Young, Bydynas, & Sadegh, 2012) lists some assumptions that are assumed in the development of formulae. First of is the assumption of that the beams are long in proportion to its depth. Secondly the beam is not disproportionately wide and that the maximum stress does not exceed the proportional. The tie-in spool meets all these requirements.

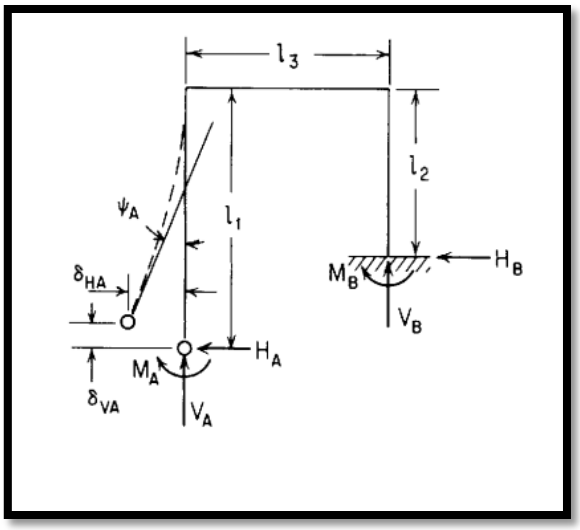


FIGURE 4-8 IN-PLANE LOADING OF ELASTIC FRAME (YOUNG, BYDYNAS, & SADEGH, 2012)

Figure 4-8 shows the initial setup of the rigid frame. Point B is fixed and hence is assumed to be the connector. To make it look more like our tie-in spool we want to change the length of member l_1, for the frame to make a Z- or an L-spool configuration. Being aware of that, when changing the sign of l_1 one also have to change the sign of three variables associated with the member l_2. This is the bending stiffness E*I, the length itself and the distance where any load is applied. By knowing this, the selection of formulae proves to be a valuable tool for the spool piece analysis performed in this thesis.

Equation 4-10, Equation 4-9 and Equation 4-11 below are deformation equations valid for point A in Figure 4-8. One or all of these equations may be used in order to solve a problem. For each equation, a loading function can be applied to create movement in any wanted direction in point A. In practice means, this implies that one need to know the effect of loading which creates reaction. Different loading functions have been derived in a way that it is convenient to apply by inserting them into the deformation equations. Frame constants, denoted C_{ij}[8], are calculated by inserting frame lengths, material properties and area moment of inertia. Vertical deflection is in our case supposed to be pipeline expansion which is parallel to the member l_2. In addition other deflection effects are not considered. By this, only parameters in Equation 4-9, vertical deflection is explained in detail.

Vertical Deflection at A:

$$\delta_{VA} = C_{VH} \times H_A + C_{VV} \times V_A + C_{VM} \times M_A - LF_V \qquad \text{Equation 4-9}$$

Where:

δ_{VA} - Vertical deflection at A [m]
C_{ij} - Frame constant (ij) [s^2/kg , 1/N , 1/Nm]
H_A - Horizontal Force at A [N]
V_A - Vertical Force at A [N]
M_A - Moment at A [Nm]
LF_V - Loading Function Vertical [m]

The same principles are yields for horizontal and angular rotation.

Horizontal Deflection at A:

$$\delta_{HA} = C_{HH} \times H_A + C_{HV} \times V_A + C_{HM} \times M_A - LF_H \qquad \text{Equation 4-10}$$

Angular rotation at A

$$\psi_A = C_{MH} \times H_A + C_{MV} \times V_A + C_{MM} \times M_A - LF_M \qquad \text{Equation 4-11}$$

Loading function LF_v

To simulate pipeline expansion, the most relevant loading type is selected from table 8.2 by in “Roark’s formulas for stress and strain” by (Young, Bydynas, & Sadegh, 2012). Figure 4-9 shows a loading type with a concentrated load on the horizontal member. The distance from the left where the concentrated load attacks can be adjusted to any wanted distance.

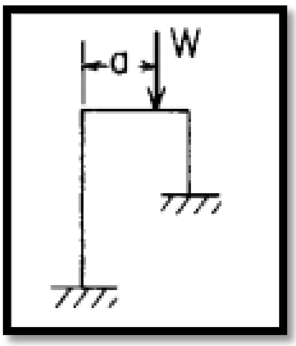


FIGURE 4-9 PIPELINE EXPANSION LOADING FUNCTION (YOUNG, BYDYNAS, & SADEGH, 2012)

[8] Where i and j can take values V and H, Vertically and Horizontally respectively

This loading type has the following vertical loading function:

$$LF_V = W\left(C_{VV} + a \times C_{VM} + \frac{a^3}{6 \times E_3 \times I_3}\right) \qquad \text{Equation 4-12}$$

Where

LF_V	- Loading function vertical
W	- Vertical Load [N]
C_{ij}	- Frame constant (ij) [s^2/kg , 1/N , 1/Nm]
a	- Distance from vertical edge [m]
E_3	- Young's modulus of 3rd member [MPa]
I_3	- Moment of inertia of 3rd member [m^4]

4.4.3 Elementary Beam Method

The rigid frame method originates from the development of the elementary beam method. Inclusion of the elementary beam method is done as a check of the rigid frame method.

The elementary beam method is developed by combining known equations for both simply-supported and built-in cantilevers. The actual frame or system to be analysed can be split into a system made of elementary beams by applying correct boundary conditions in each split.

4.4.4 Focus Construction

The software tool Focus Construction[9] performs statically analyses of two or three dimensional constructions. The graphically user friendly interface provides good visual control when designing constructions, applying boundary conditions and loads to any model.

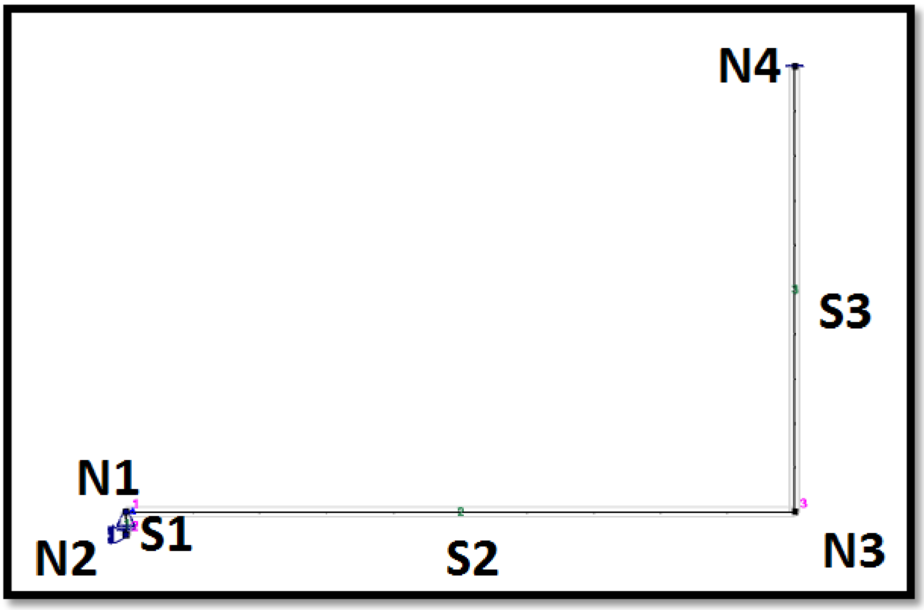


FIGURE 4-10 TIE-IN SPOOL MODELLED IN FOCUS CONSTRUCTION

[9] Developed by Focus Software AS (Focus Software AS, 2012)

Figure 4-10 shows the tie-in spool modelled in Focus Construction. The first thing that was done was to define the material according to the design basis. As the dropdown list of cross-sections didn't include correct cross-section, a new definition correct cross-section was done according to the design basis. The pipe segments are placed between user defined nodes.

Node 1, located at the left bottom corner is given an initial displacement equal to the pipeline expansion.

A displacement parallel to pipe segment 3 (leg length L3) is achieved by adding segment 1 to the model. By adding this segment, a node for placement of the guide boundary condition of node 2 is achieved. A parallel displacement of node 1 to pipe segment 3 is then achieved.

Node 4 is applied a build in boundary condition to illustrate the fully restrained inboard hub at the WP caisson. By having this setup, statically linear analyses are performed.

4.4.5 Bending Moment Induced by Drag Force

Drag force is applied as a uniformly distributed load perpendicular to the leg length L2 as seen in Figure 4-11. By treating leg L2 as a built-in cantilever the bending moment in point B is calculated. The bending moment in point B is simply transferred to the point C which is the connector at the WP-platform.

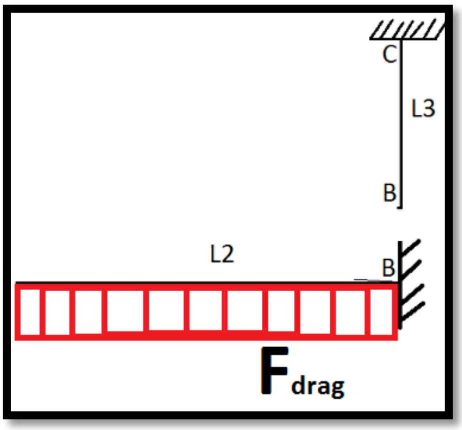


FIGURE 4-11 DRAG FORCE APPLIED ON TIE-IN SPOOL

By assuming a built-in cantilever beam, no forces are lost and thus, this is a conservative method for applying drag force on the tie-in spool. Calculated bending moment in the connector, from this method, is calculated separately and must be added manually, to each method used for calculating bending moment due to pipeline expansion.

The calculation can be found in its entirety in appendix D. Calculated bending moment induced by drag force is:

$$M_{Cdrag} = 13{,}72\ kNm$$

4.5 Results

Based on the four different methods elaborated in the previous section, the bending moment in the connector has been calculated. This chapter presents the final results based on a pipeline expansion of 1500 mm, without drag force applied. The calculation can be seen in its entirety in appendix B.a and for the method Focus Construction in appendix C.a. Table 4-12 lists the calculated bending moments:

TABLE 4-12 CALCULATED BENDING MOMENTS BASED ON INDUSTRY EXAMPLE

Method	Resulting Bending Moment in Connector [kNm]
Built-in Cantilever	182,32
Rigid Frame	60,74
Elementary Beam Method	60,75
Focus Construction	86,46

Not surprisingly, the “Rigid frame-” and the “Elementary Beam-” method provide the exact same numbers. This is in line with what is discussed in section 0. It is seen that the “Built in Cantilever” method provides numbers which is more than twice as high as number two on the list “Focus Construction”. Results from the built-in cantilever method are not discarded as these numbers provides values which are to be regarded as maximum values.

When comparing numbers from the analysis done on the original tie-in spool, it is obvious that the simplification that’s been done, with placing the spool in one plane, can be justified. Calculated numbers on the case spool is in the order of magnitude as for the analyses on the original tie-in spool.

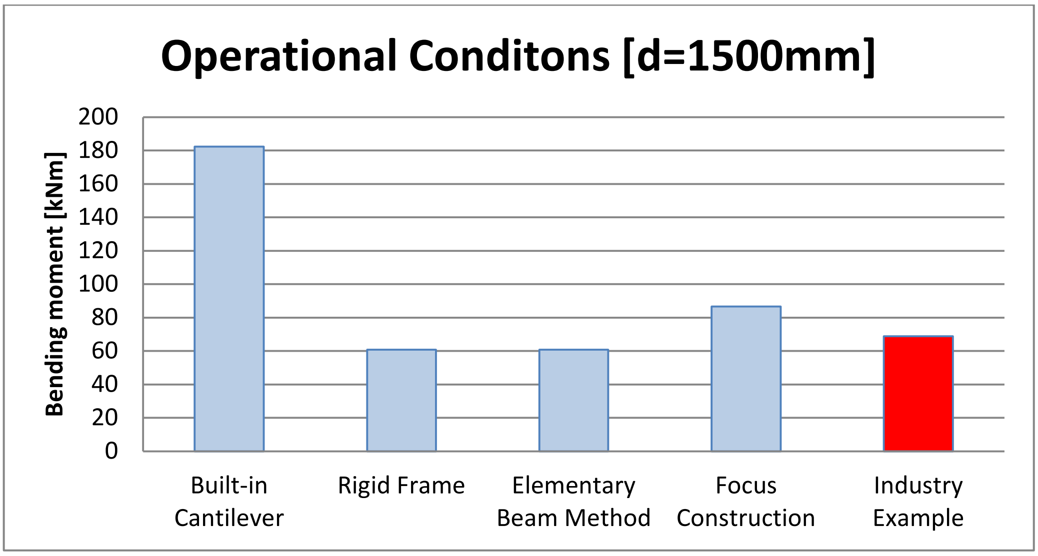
Table 4-13 shows the connector loads from the tie-in analysis performed by the ANSYS software tool in operational conditions. Case 4 corresponds to the condition where current & waves are applied from the north, fabrication tolerances has been set to a minimum and minimum soil contact. All in all, a case which suits the simplified analysis performed in this thesis quite well.

TABLE 4-13 NUMBERS FROM INDUSTRY EXAMPLE USED TO COMPARE AGAINST

	Node	Elem	Step	F_X	F_Y	F_Z	M_X	M_Y	M_Z	AxialF [kN]	BendM [kNm]
Case 4	760	747	18	-7984.6	20583.1	14535.3	30065	-4389.9	-65639	-8.0	65.8

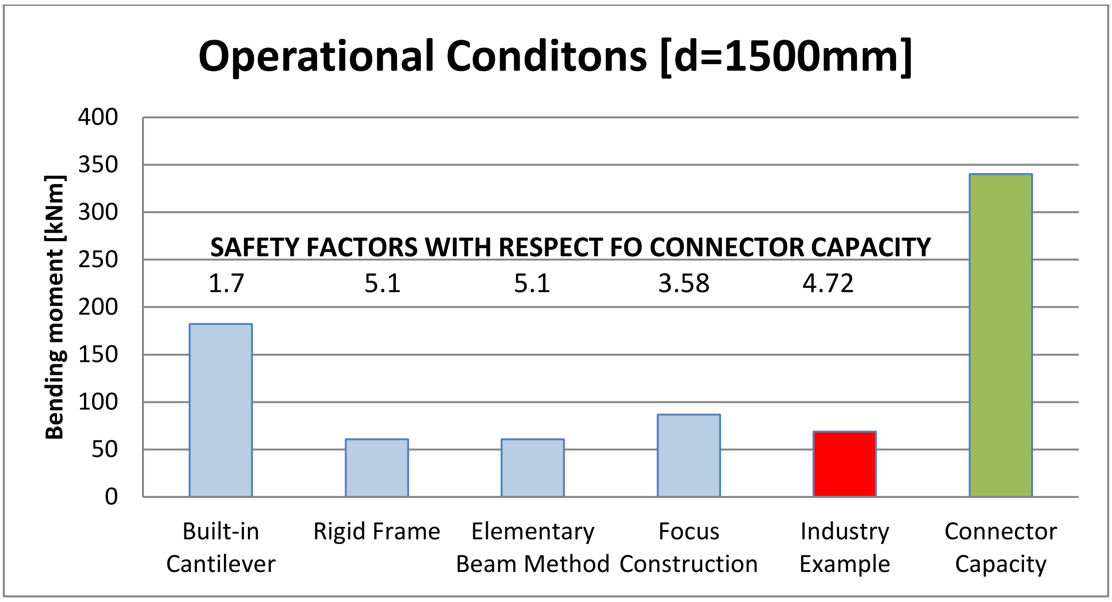
Since the original tie-in spool is outfitted with goosenecks, the resulting bending moment has a direction which is out of the horizontal plane. The tie-in spool analysed in the case study has no goosenecks and it is therefore more reasonable to compare numbers with the bending moment in the horizontal plane. In-plane bending moment M_z takes value 65.63 kNm, which is just slightly lower than the total resulting bending moment of 65.8 kNm.

Schematic comparison of the calculated results and the industry example illustrates that the numbers is not far of each other. Except from the Built-in Cantilever method, the three other methods prove to be good tools for roughly calculating bending moment due to pipeline expansion, even if drag force isn't applied.



GRAPH 4-1 OVERVIEW OF CALCULATED BENDING MOMENT CASE STUDY

The connector used on the VFG project has a maximum capacity of about 380 kNm with internal pressure of 0 bars. This is only when subjected to zero axial force. At operating conditions, this capacity reduces to about 340 bars due to increased internal pressure. The connector capacity at operational conditions is included in Graph 4-2 together with the calculated results.



GRAPH 4-2 OVERVIEW OF BENDING MOMENTS WITH INCLUDED CONNECTOR CAPACITY

It is seen in Graph 4-2 that with respect to connector capacity, the spool piece design is conservative for most methods. A rough safety factor has been calculated by dividing the connector capacity on the actual calculated numbers. The results are seen in Graph 4-2.

Based on varying results between the four different methods, a practical case study is conducted to find the most applicable method. This is done in chapter 5.

5 Practical case study

This chapter includes a practical test conducted on a downscaled tie-in spool. The spool has the same geometric shape as the spool in chapter 4. By use of simple mechanical tools, the resulting bending moment induced by pipeline expansion is measured in the connector. The purpose of the experiment is to give recommendations on which theoretical method used in chapter 4 that works best for analysing tie-in spools. This is done by comparing theoretical results with experimental results. Notation used earlier in the thesis is kept also for the experiment.

5.1 Presentation of Tie-in Spool Used in Experiment

The tie-in spool was manufactured at Aker Egersund based on rough sketch and a relatively short notice. Figure 5-1 shows the tie-in spool used in the test in addition to a special made slide used for measuring torque.

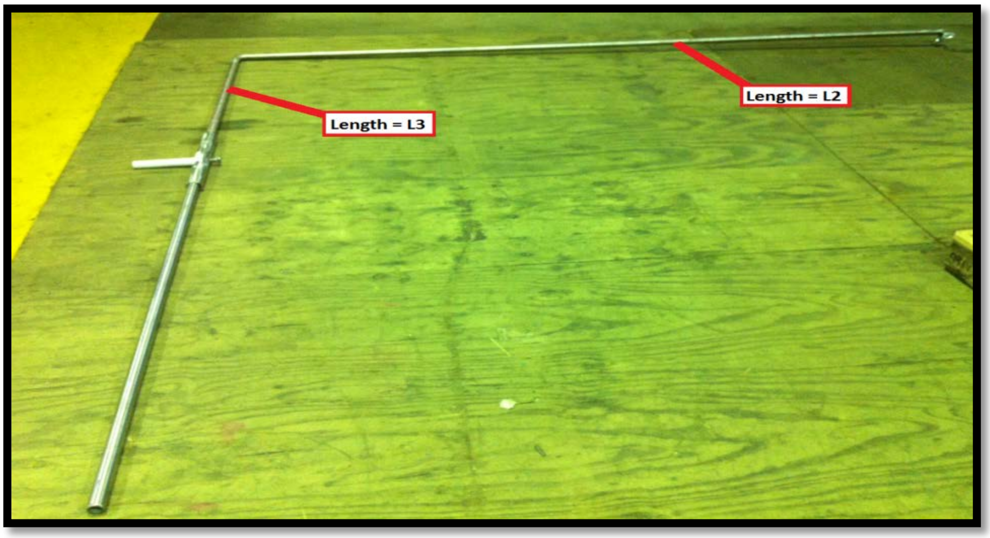


FIGURE 5-1 TIE-IN SPOOL USED IN TEST

The 1” tie-in spool is made duplex material and has one 90 degree elbow together with two legs of lengths 3 meter each. In one of the ends, two eyebolts have been welded on. One of the eyebolts provides an anchor for attaching the wire while the second eyebolts serve as guidance purposes.

5.1.1 Dimensions

By the below table, the cross sectional dimensions of the tie-in spool are presented.

TABLE 5-1 DIMENSIONS FOR TIE-IN SPOOL USED IN TEST

Item	Unit	Value
Nominal Pipeline Outer Diameter	mm	33.4
Wall Thickness	mm	4.55
Pipeline inner Diameter	mm	24.3
Elbow radius (LR[10])	mm	1.5*33.4 mm = 50,1mm

5.1.2 Material properties

The spool is made of duplex material. Consequently giving the material good mechanical strength combined with good ductility, impact toughness and fatigue life. Material certificates for pipe and bend is found in appendix I.

TABLE 5-2 MATERIAL PROPERTIES S31803 DUPLEX MATERIAL

Steel Grade	Young's Modulus (GPa)	SMYS (MPa)
S31803 Duplex	200	450

5.2 General Arrangement of Test Rig

Figure 5-2 shows the setup of the test rig. A porch is used as a solid foundation.

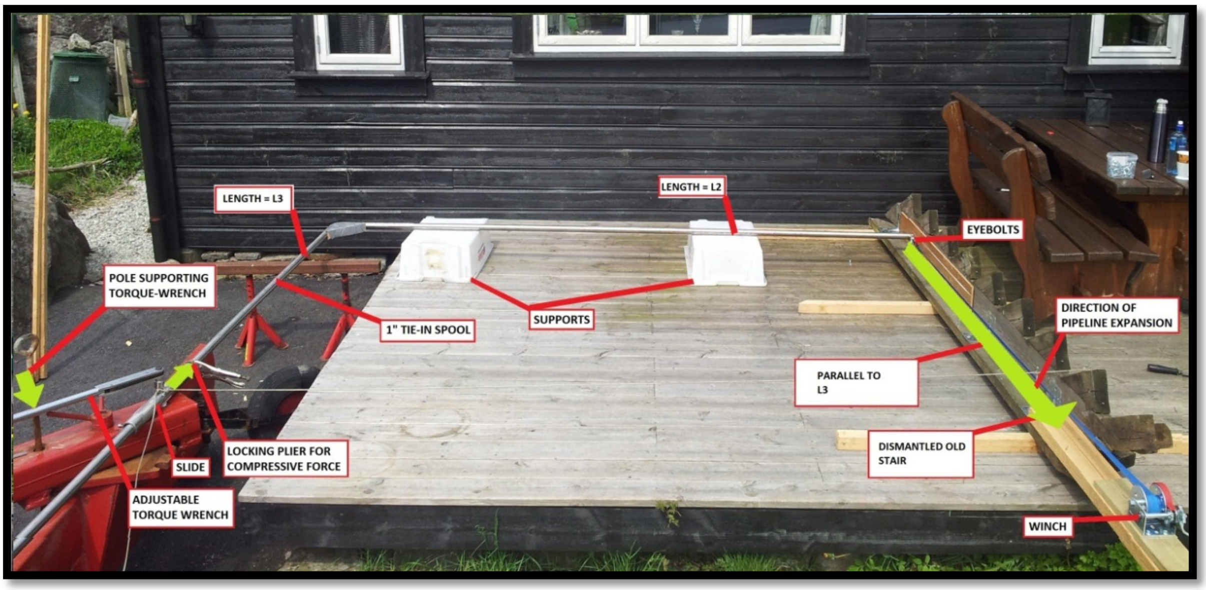


FIGURE 5-2 GENERAL ARRANGEMENT TEST RIG

Equipment and tooling used in the experiment is in the following described.

[10] LR – Long radius (1.5* Outer Diameter)

5.2.1 Connector – Slide & locking plier

The connector consists of a pipe with inner diameter a little bit larger than the 1 inch tie-in spool. By having this design, the length of the pipe is adjustable. To lock the L3 length at desired length a locking plier is clamped onto pipe. The locking plier also makes sure that the tie-in spool is held in position while applying pipeline expansion.

FIGURE 5-3 SLIDE & LOCKING PLIER

The slide is outfitted with a round steel rod which is not seen in Figure 5-3. The steel rod together with the scraper blade serves as a rotational centre. In the centre of this rotation, on the top of the slide, a bolt is welded onto the slide. This bolt provides an anchor point for attaching the measuring device, the adjustable torque wrench. This takes us to the next thing of equipment.

5.2.2 Measuring Device – Adjustable Torque Wrench

The key piece of equipment in this test is the adjustable torque wrench. The way this toque wrench works is by giving a signal when a pre-defined level of torque is reached. This is achieved by deflection of an inbuilt adjustable spring hitting some kind of bell. A clear distinct sound can be heard when the pre-defined level is reached.

FIGURE 5-4 ADJUSTABLE TORQUE WRENCH

Whilst most torque wrench is used by applying torque to a bolt, this test utilizes the torque wrench in the exact opposite way. By restraining the torque wrench, rotation of the bolt is applied via rotation of the slide together with the tie-in spool. The adjustable torque wrench is seen from above in Figure 5-4 and can be adjusted from 70 Nm to 330 Nm. According to the manufacturer, Britool, it is accurate to ±4%.

5.2.3 Pipeline Expansion – Winch

To simulate pipeline expansion a manually reeled winch is used. Coiled up on the winch is a tie-down strap able to take 400 kg. The winch is outfitted with a locking mechanism, which means that while doing measurement, the tie-in spool is held in position.

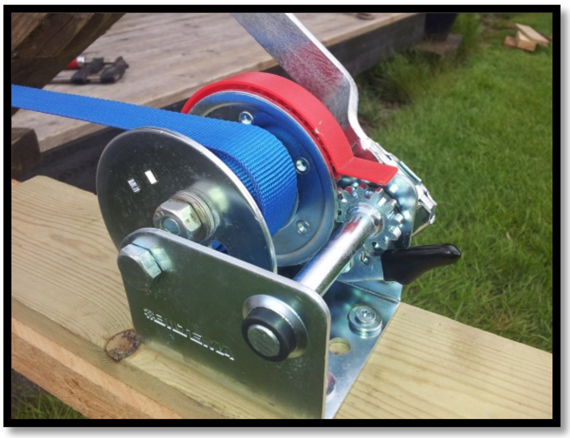


FIGURE 5-5 PIPELINE EXPANSION - WINCH

The winch is attached to the guiding system which is made of a dismantled old stair.

5.2.4 Inboard Porch – Scraper Blade

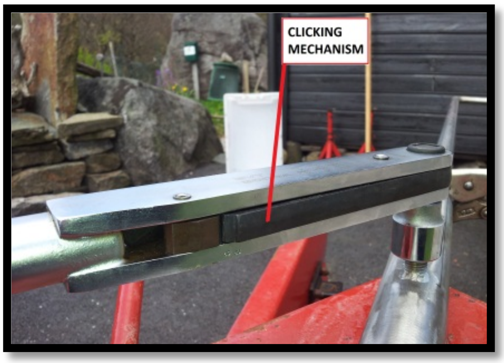
On the back of a John Deere tractor a scraper blade is attached. The scraper blade together with the tractor provides a solid foundation for constraining the tie-in spool. On the top of it, a hole can be seen. This serves as a mating point for the slide and as a rotational centre.

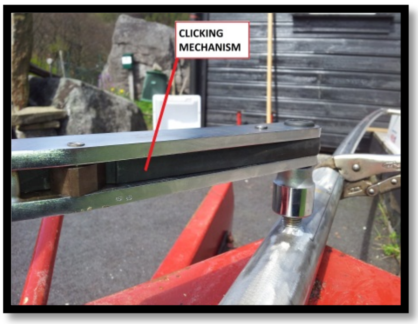
FIGURE 5-6 INBOARD PORCH SCRAPER BLADE

When installing the scraper blade it is crucial that the top surface is aligned in a perfectly parallel to the horizontal plane. This was achieved by supporting the scraper blade at necessary points to level it. This was done by plywood.

5.3 Test Procedure

The purpose of this section is to describe the test procedure by use of description of photos taken during the process of testing. A video illustrating the same can be found in the CD version.

Step 1. The starting position is where the lower eyebolt is placed adjacent to the tape measure. The pipeline deflection is read of by looking in the same direction as on the picture.	 
Step 2. At this point, the torque wrench is unloaded. This can be seen by the clicking mechanism being positioned the way it is. In this position the torque wrench is unloaded, i.e. no expansion is applied, but it is pre-set to a torque determined by the operator.	
Step 3. In unloaded conditions, the straight pipe elements are seen in the current position. It is seen that no deformation is applied to the tie-in spool.	 

Step 4. Pipeline expansion is then applied to the tie-in spool via the winch. Expansion is then applied until the torque wrench gives a clicking signal. The torque wrench clicks when a pre-defined level of torque is achieved, which means that a certain level of pipeline expansion is achieved. For illustrational purposes, the pipeline expansion is about 80 cm. One could think of this giving a bending moment of, let us say 150 Nm	
Step 5. Simultaneously with step number 4, the clicking mechanism moves inward in the torque wrench. As this happens, the wrench gives out a loud audible signal By also comparing step #2 and #5 it is seen that the pipe in behind deforms quite radically.	
Step 6.0 Photos showing deformation of the tie-in spool. At this point, the pipeline expansion and torque was registered is a logging sheet enclosed in appendix E.	 
Step 6.1 End position	
Step 7. By unreeling the winch, i.e. letting the tie-in spool spring back to its original position, the procedure is run in the exact same sequence multiple times.	

5.4 Test Results

The presentation of the test results are done by use of plotted graphs. Based on the manually logged results, graphs have been made. Results were logged continuously, by manually registration, in a sheet during the process of testing. The manual registration sheet is included in its entirety in appendix E.

The length L3[11] has been varied to three different lengths, 2.0, 1.75 and 1.5 meters respectively. The results for each specific length are presented by having their own chapter in the coming sections. Each specific test series is denoted:

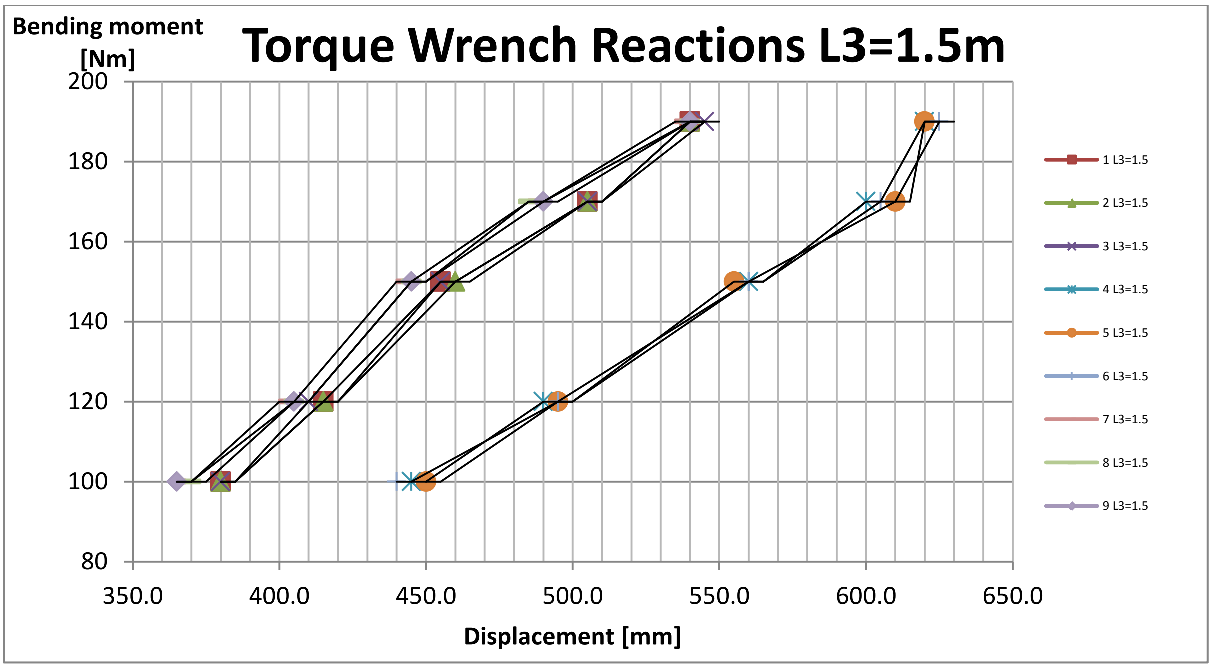
X L3= Y, where X is the specific number of test series and Y is the length of the spool leg L3.

In total, 9 datasets have been registered for each variation of the length L3. By having 5 datapoints for each dataset, a total of 135 registrations have been done.

The adjustable torque wrench was set to 5 different levels. These levels were 100, 120 150, 170 and 190 Nm. At a certain reached torque level, displacement/expansion is read off.

5.4.1 L3 = 1.5 metres

For the shortest variation of the length L3, a linear increasing bending moment is seen. Three datasets are located to the right on Graph 5-1. This means that, more displacement have been necessary to activate the torque wrench.



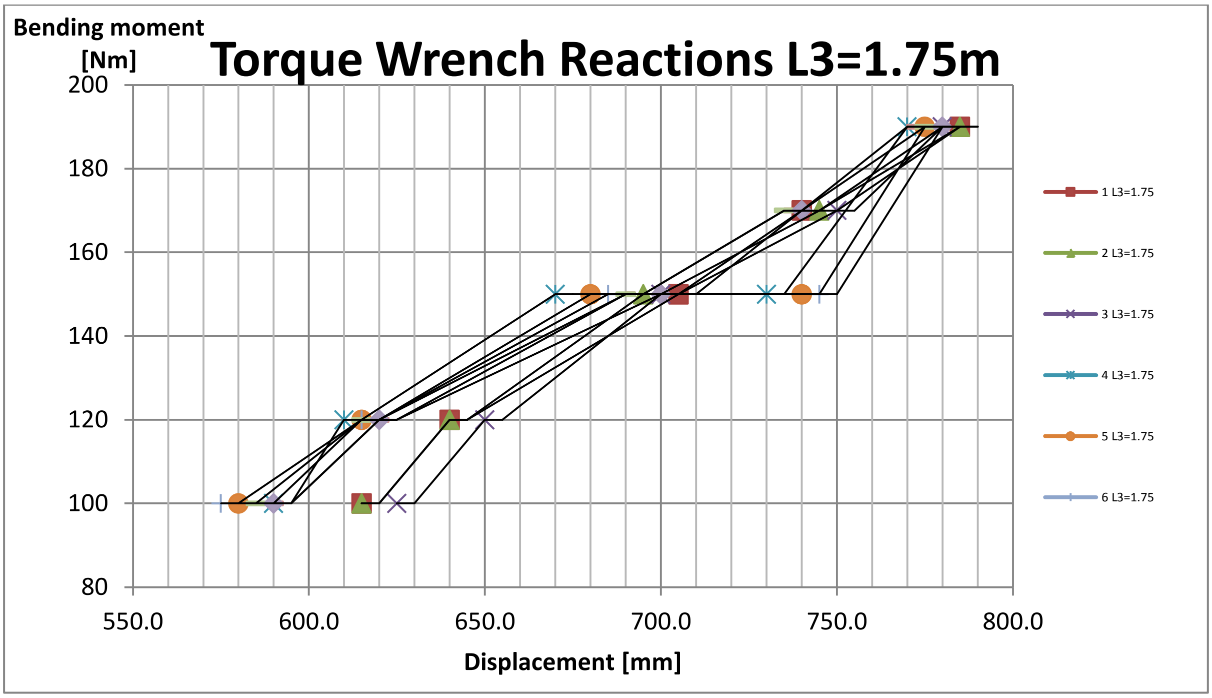
Graph 5-1 L3 = 1.5 Metres

This discrepancy is justified with the tape measure being placed incorrectly. By moving the three datasets about 70 mm to the left it is seen that they correlate good with the rest of the datasets.

[11] The pipe closest to to the torque-wrench.

5.4.2 L3 = 1.75 metres

For the middle variation of L3, a linear increasing slope is seen. The numbers tend to spread in the lower region of measured bending moment. At 100 Nm a spread of about 50 mm can be seen in Graph 5-2.

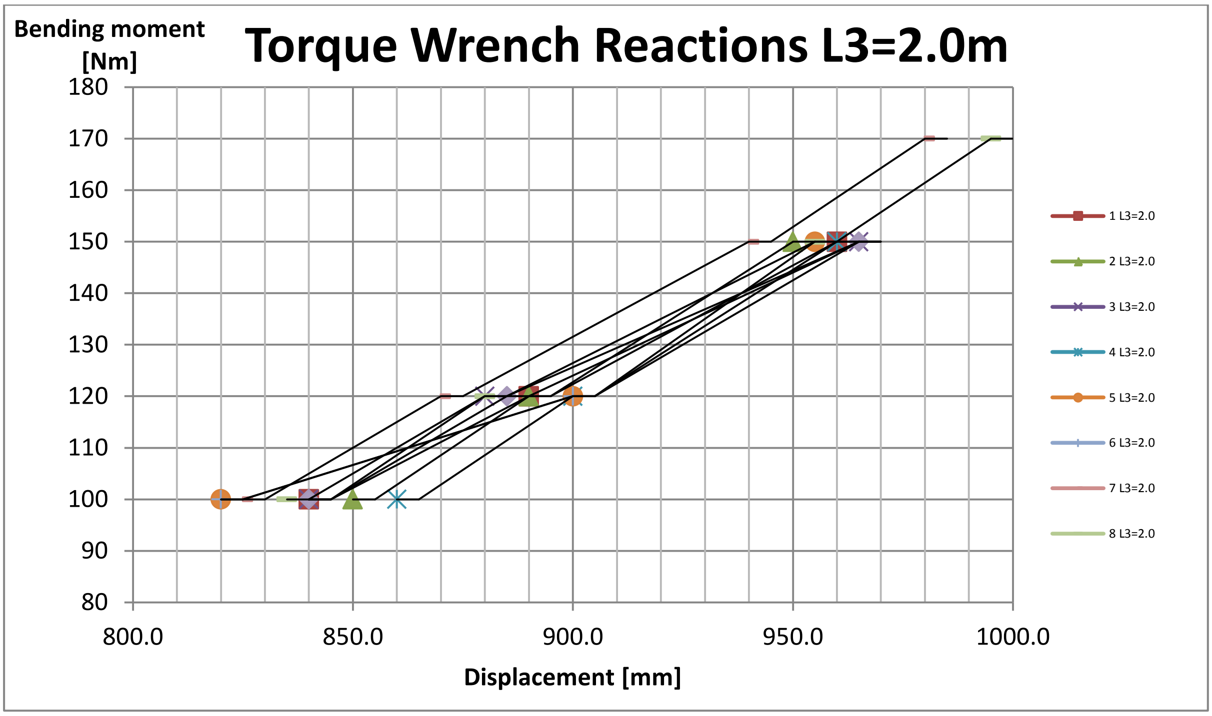


GRAPH 5-2 L3 = 1.75 METRES

With increasing displacement, the trend is a reduction in the spread between measured numbers. At 190 Nm, the spreading is about 20 mm which is said to be quite good.

5.4.3 L3 = 2.0 metres

For the maximum length of L3 equal 2.0 meters the results show a consistent system. The trend with having a relatively large spread in the low levels of measurements continues. Similar as for L3 equal 1.75 meter, is that the spread decay with increasing bending moment.



GRAPH 5-3 L3 = 2.0 METRES

As seen on the graph, relatively large displacements where needed in order to get reactions in the torque wrench. The upper limit of measurements is 170 Nm and here only two measurements were conducted. The reason for this was the risk of plastically deforming the tie-in spool. It was crucial during the testing process to avoid plastic deformation of the tie-in spool, as this would ruin the entire test.

By comparing the respective relative slopes for each variation of L3 it is seen that this decreases with increasing length of L3.

Slope for L3 equal to 1.5 metres: $a_{1.5m} = \frac{(540-375)}{(190-100)} = \frac{165}{90} = 0{,}546$

Slope for L3 equal to 1.75 metres: $a_{1.75m} = \frac{(775-595)}{(190-100)} = \frac{180}{90} = 0{,}5$

Slope for L3 equal to 2.0 metres: $a_{2{,}0m} = \frac{(960-840)}{(150-100)} = \frac{120}{50} = 0{,}41$

This means that the tie-in spool is becoming more and more flexible as more length is added to L3. This is indeed, exactly what was expected.

5.5 Comparison of Test and Theory

The registered data from the practical test is in the following compared to the three theoretical methods. Since the rigid frame and elementary beam method are equal with respect to numbers, they are plotted as one. Bending moment has been calculated with pipeline expansion of 0, 300, 500, 700 and 900 for three different lengths of L3. The different lengths of L3 are 1.5, 1.75 and 2.0 metres. Test results and theoretical results are plotted in the same graphs.

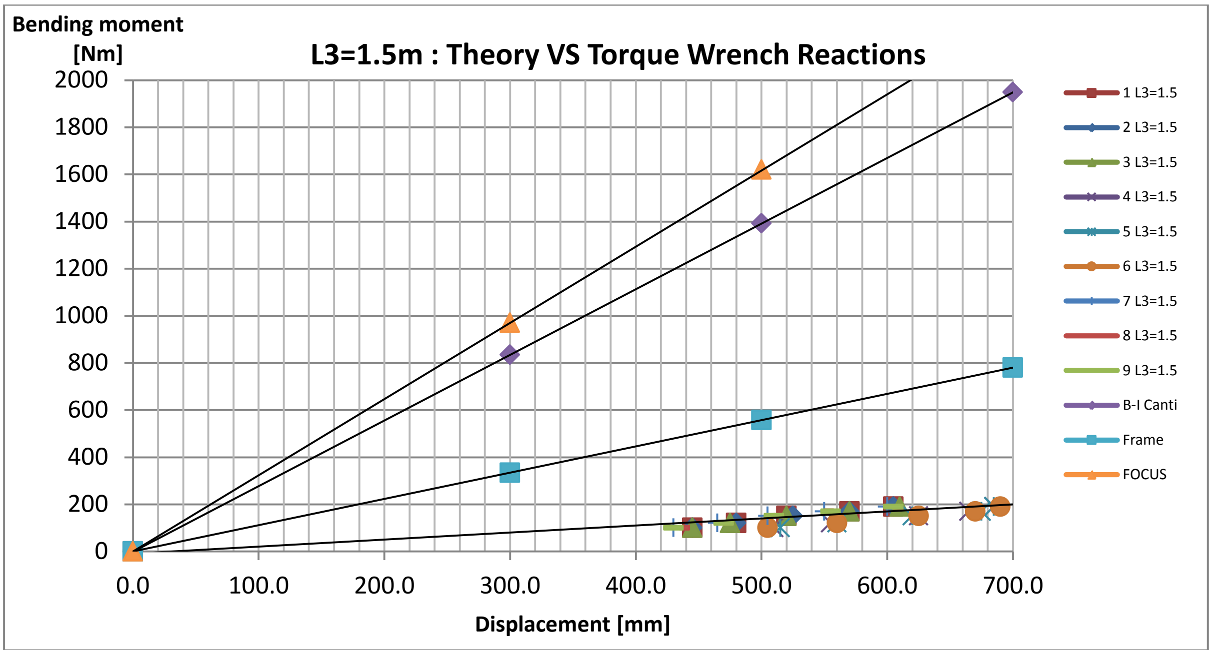
5.5.1 L3 = 1.5 metres

Based on bending moments that are calculated and included in appendix B.b, the numbers have been inserted into Table 5-3. Numbers from Focus Construction have been extracted from reports made by the software. These reports are also included in appendix C.b,c,d.

TABLE 5-3 L3 = 1.5M BENDING MOMENTS FROM THEORY

Displacement [mm]	Built-in Cantilever [Nm]	Rigid Frame[Nm]	FOCUS Construction[Nm]
0	0	0	0
300	835,5	334	970
500	1392	556	1620
700	1949	779	2260
900	2506	1003	2910

The numbers from Table 5-3 are plotted in Graph 5-4 together with the actual test results valid for L3 = 1.5 metres.



GRAPH 5-4 THEORY VS TEST RESULTS L3 = 1.5 METRES

By a quick comparison, it is seen that the measured results do not correlate with theoretical values.

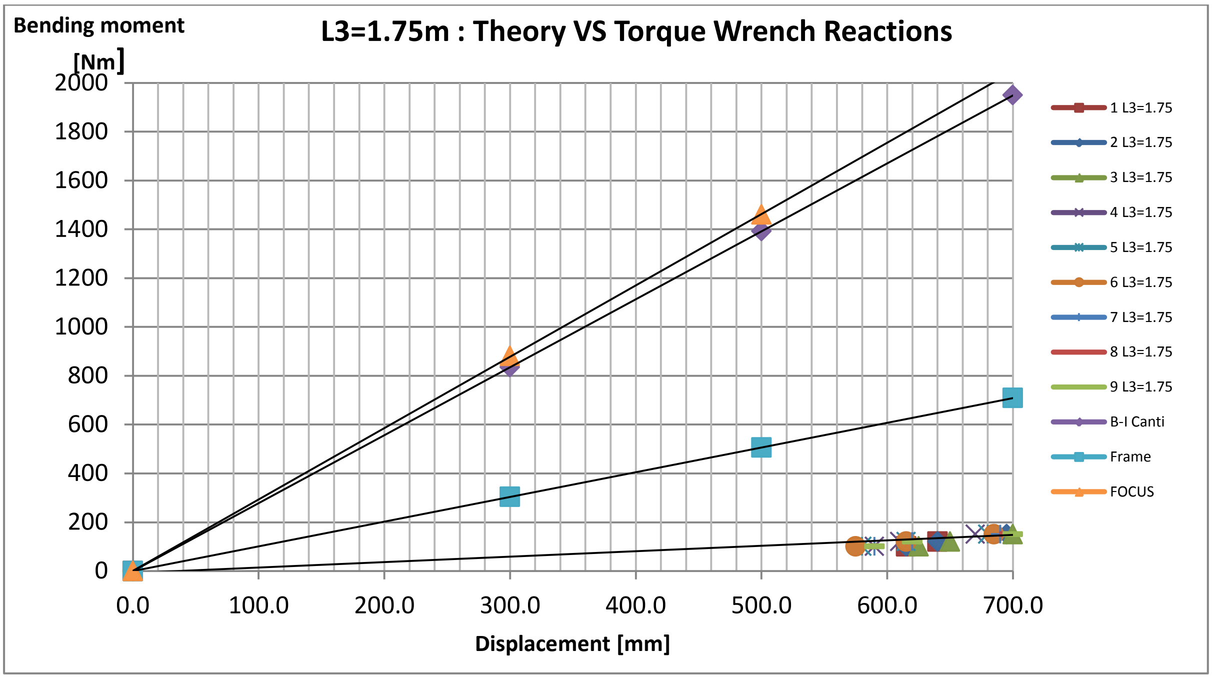
5.5.2 L3 = 1.75 metres

Table 5-4 shows calculated bending moments with L3 equal to 1.75 meters and pipeline expansion of 0, 300, 500, 500 and 900 mm respectively.

TABLE 5-4 L3 = 1.75M BENDING MOMENTS FROM THEORY

Displacement [mm]	Built-in Cantilever[Nm]	Rigid Frame[Nm]	FOCUS Construction[Nm]
0	0	0	0
300	835,5	304	880
500	1392	506	1460
700	1949	709	2050
900	2506	911	2630

The numbers from Table 5-4 is plotted in Graph 5-5 together with the actual test results.



GRAPH 5-5 THEORY VS TEST RESULTS L3 = 1.75 METRES

By comparing numbers, it is obvious that the number do not correlate. It is seen that the results from the rigid frame method and Focus Construction reduces. This is in line with expectation of that the tie-in spool becoming more flexible as more length is added to the pipe L3.

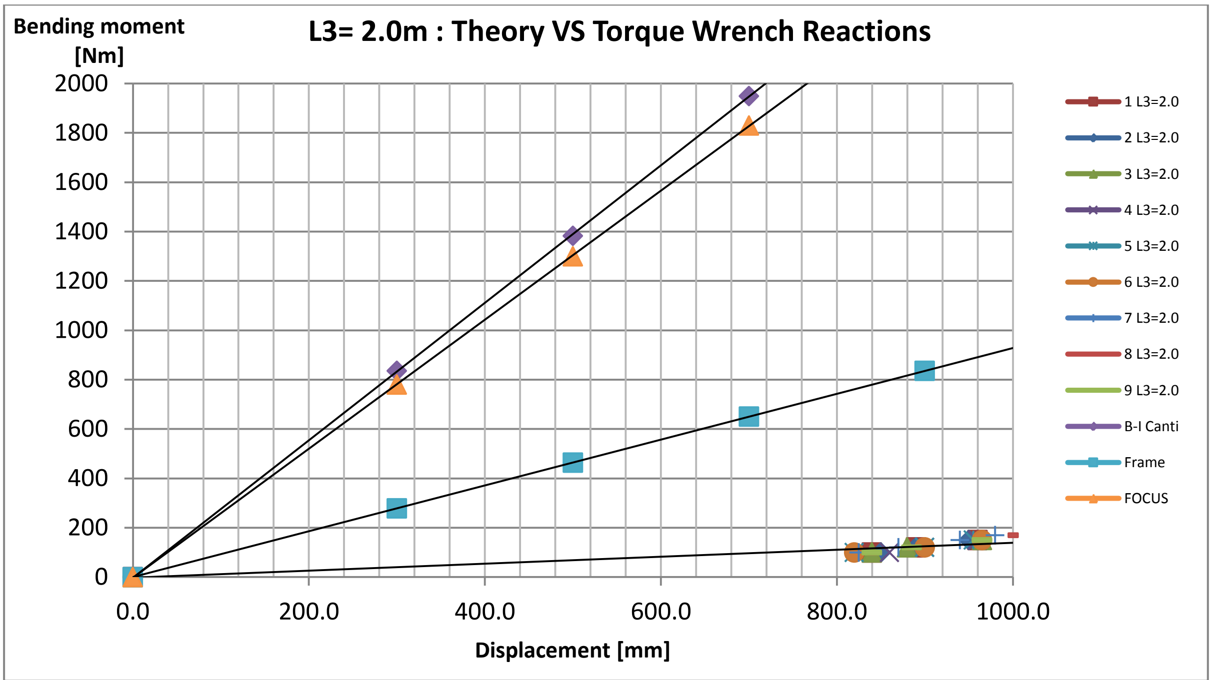
5.5.3 L3 = 2.0 metres

Table 5-5 shows calculated bending moments with L3 equal to 2.0 meters and pipeline expansion of 0, 300, 500, 500 and 900 mm respectively.

TABLE 5-5 L3 = 2.0M BENDING MOMENTS FROM THEORY

Displacement [mm]	Built-in Cantilever[Nm]	Rigid Frame[Nm]	FOCUS Construction[Nm]
0	0	0	0
300	835,5	278	780
500	1392	464	1300
700	1949	650	1830
900	2506	835	2350

The numbers from Table 5-5 is plotted in Graph 5-6 together with the actual test results for L3 equal to 2 metres.



GRAPH 5-6 THEORY VS TEST RESULTS L3 = 2.0 METRES

Similar as for the two previous versions of L3, the 2 meter version shows the same signs. No correlation is seen. There are some signs of that the frame and Focus methods, tends to reduce. This reduction is however, very small and not very visible.

5.6 Discussion on Results from Experiment

Throughout the previous section 5.5, the test results have been compared against theoretical solutions and a software tool and discussed separately there. Three different tests have been performed by variations of the length L3. This particular section includes a discussion about all three variations of L3. By gathering them, a general discussion about discrepancies between bending moment measured by the test and theoretical values are done.

If one isolates the results from the test away from other methods it is obvious that some linearity is seen. Especially when L3 was set to 1.5 metres, results shows a very consistent system being very close to linear. By increasing the length L3, to 1.75 and 2.0 metres respectively, it was seen that the linearity of results still was present. However, by increasing L3, larger discrepancies were seen between each test series. This indicates that the tie-in spool gets more and more flexible by increasing L3 and that it might have influence on the test equipment. It was seen throughout the testing process that the natural "spring-back" effect, caused by elasticity was fading away with increasing L3. During the testing process, the crew involved, was in an optimistic mood. This was because of consistency between each test series.

However, when comparing numbers with actually calculated results it is seen that no correlation with these numbers are present. No yield effects of the tie-in spool have been taken into consideration when the calculation of bending moment was performed. By doing this, the graphs show a bending moment that increases linearly to infinity with increasing pipeline expansion. This is not the case, as the 90 degree bend most probably would fail by buckling, far below this.

It is seen that results, from all test, are located in the bottom right corner, on each graph. This means that large displacement/pipeline expansion was required to get small reactions in the torque wrench. In addition to this, registered results from the torque wrench are way below theoretical methods. Comparisons become very difficult, because of the large discrepancies between numbers.

By comparing numbers related to L3 equal to 1.5 metres the large discrepancies are illustrated. At a displacement of 500 mm the following bending moments are read off from Graph 5-4and inserted into Table 5-6.

TABLE 5-6 DIFFERENCES BETWEEN TEST AND THEORETICAL RESULTS

Method	Value [Nm]	Difference [Nm]
Average test results	175	0
Rigid frame	556	381
Built-in Cantilever	1392	1217
Focus Construction	1620	1445

By comparing numbers and seeing the large differences, it becomes obvious that comparison has limited value.

It is worth mentioning that for L3 equal to 2.0 metres, the maximum applied displacement was as big as 995 mm. The industry example, presented in section 0 has a maximum displacement of 1500 mm. By knowing that tie downscaled version is about 5 times smaller geometric size than this, the test showed some interesting features.

The material used in the test has about the same elastic modulus as the material used in the industry example. However, the D/t value is not the same between the test and industry example. While the industry example has a D/t value of 17.25, the D/t value for the test is 7.34. This indicates that the duplex pipe used in the test should have behaved stiffer and not allow for such relatively large displacements without inducing more bending moment into the torque wrench.

Except from the unfavourable results, the test showed illustratively the flexural capability of the tie-in spool. Trough out the process of testing, plastically deformation of the tie-in spool was always a fear. Very large values of pipeline expansion were induced, but the tie-in spool showed no signs of plastic deformation after the test were done. Compared to the industry example where the tie-in spool is about 5 times larger, the undersigned was impressed by the flexural capability of the downscaled version.

The decision to exclude pipe soil interaction was on the basis of 100 year design, with 100 year and 10 year return periods for current and waves respectively. However, the decision to exclude this interaction should be investigated in more detail. One could argue that some of the discrepancies can be explained by frictional effects that are unknown in the experiment. Friction along the pipe-supports is anyhow believed to be neglect able.

5.7 Evaluation of Equipment Used in Experiment

Due to lack of correlation between calculated and measured numbers, an investigation of error sources is conducted. Measured numbers are far too low in order for them to have any validity. It has been set focus on mechanical equipment, mechanisms and solutions on how to measure the bending moment. Why the claim for these objects to contribute into low measured numbers, are in the following elaborated about and explained.

5.7.1 Adjustable Torque Wrench

Initially when planning of the test was started, the intention was to use electronic sensors to measure bending moment. Because of lack of available equipment and complications during planning, the choice of using an adjustable torque wrench taken. Manually registration of the data collected from testing seemed at that point a good idea.

After and during the test some findings related to the wrench were seen and observed.

5.7.1.1 *Play between bolt and wrench*

Between the bolt on the top of the slide and the socket there is in unloaded condition some play. This play is illustrated below and is measured to be about 190 mm at the end where the red adjustable handle is.

FIGURE 5-7 PLAY BETWEEN BOLT AND WRENCH

Although this play is quite substantial, it is taken care of by adjusting the guide vanes into a position where the torque wrench hits the guide post to the left on picture above. By doing this, the play is removed and the tie-in spool is more or less locked in position.

5.7.1.2 *Activation Play*

In order for the torque wrench to react, a certain rotation is required. This rotation is induced by pipeline expansion and increases with increasing expansion. In low levels of pipeline expansion it was seen sometimes that this rotation weren't enough to initiate activation of the torque wrench.

FIGURE 5-8 ACTIVATION PLAY TORQUE WRENCH

The activation play is shown in Figure 5-8 and it is seen that relatively large movements of the tie-in spool is required in order to activate the clicking mechanism inside the torque wrench. Most of the test series was run by manipulating the torque wrench. By manipulation, it is meant that the clicking mechanism was balanced at a point right below the activation point. By doing this a smaller value of rotation was required.

5.7.2 Slide

Two different error sources related to the slide have been identified. These mechanisms are believed to be the main contributions to why the test results show no correlation with theory.

5.7.2.1 *Bolt*

The bolt that is welded onto the slide, showed during the process of testing signs of fatigue or at least weaknesses by giving in. The material properties of the bolt in not known, but the dimension of the bolt is M14 and is approximately 20 mm from the weld bed to the top of the nut.

FIGURE 5-9 BOLT DIMENSIONS ON SLIDE

To improve design it might be a good idea to reduce the length of the bolt. This is in order to increase the torsional capacity of the bolt and therefore having a less flexible system being able to capture all movements.

5.7.2.2 *Steel rod friction*

Although the top surface and the rotational hole practically were soaked in PTFE lubricant, friction is believed to be the main error source. PTFE or Teflon lubricant is used to reduce friction between two relatively moving surfaces. Other usage areas are as top cover on frying pans and as lubricant for bicycle chains.

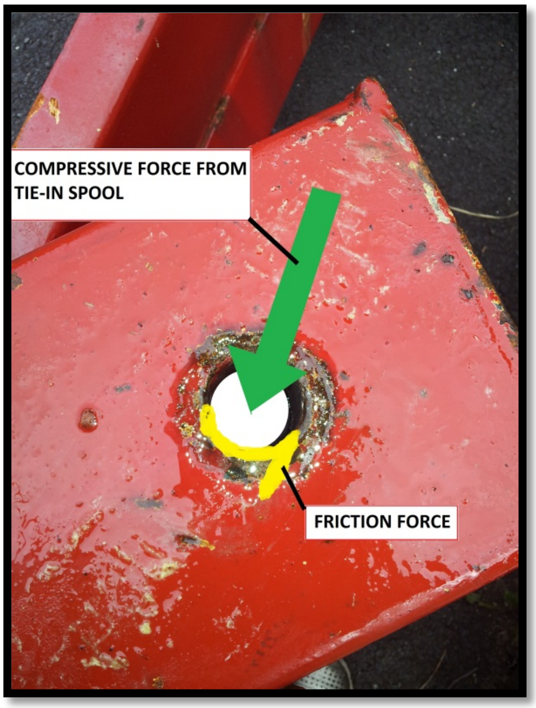


FIGURE 5-10 STEEL ROD FRICTION AND LUBRICANT

With increasing pipeline expansion, the compressive force from the steel rod inside the hole in the scraper blade increases. Figure 5-10 shows a sketch of what is happening. The white circle illustrates the steel rod from the slide. As the compressive force increases, the friction force which acts opposite of wanted rotational direction increases. Due to the shiny surface because of much lubrication, enough reduction of frictional force is not achieved. This is because of a too rough surface inside the hole in the scraper blade.

By not allowing for free rotation of the slide, a very high portion of bending moment is believed to be taken up by this interaction of materials. And consequently, the reactions in the adjustable torque wrench are reduced.

5.8 Suggestions to Further Development of Experiment

This section discusses further development of the test rig. The need for making the test rig itself, more sophisticated is justified by the discussion in section 5.7. The use of mainly rough mechanical equipment and parts is believed to negatively affect the actual measured results. Suggestions for further development are described by using the scraper blade as a reference. However, the related mechanisms that led bad measurements are believed to be as important, if other alternatives to the scraper blade were used.

Benefits of electronic measurements are that continuous logging of data is possible. By correctly calibration of the electronic components involved the results is believed to be more accurate than by manual registrations. Manually plotted coordinates could have been changed out with continuous graphs.

5.8.1 Adjustable Torque Wrench - Alternatives

The use of a torque wrench seemed initially to be a clever idea, but this was actually not the first choice in the selection of measuring equipment. Initially it was wanted to measure bending moment electronically by using one of the two methods below. The two different methods are elaborated briefly about in the following.

5.8.1.1 *Torque transducer*

HBM, a company which specializes on sensors to software, was contacted regarding the selection of appropriate torque transducer. The intended use of the torque transducer, T22, was to mount this on the top of the slide. The T22 transducer can be used for both rotational and stationary measurements. It could easily have been fitted to the slide, by use of special made bellow couplings.

FIGURE 5-11 TORQUE TRANSDUCER (HBM, 2012)

The T22, including couplings, can be mounted in any position, i.e. horizontal or vertical. Eight different versions of the T22 are available. It is recommended to select the largest one which can measure bending moments of up to 1000 Nm.

5.8.1.2 *Equilibrium principle*

Instead of using a purpose built torque transducer, the second choice was to use the equilibrium principle. By using a simple load cell placed at a certain distance away from the rotational centre, the bending moment could have been calculated.

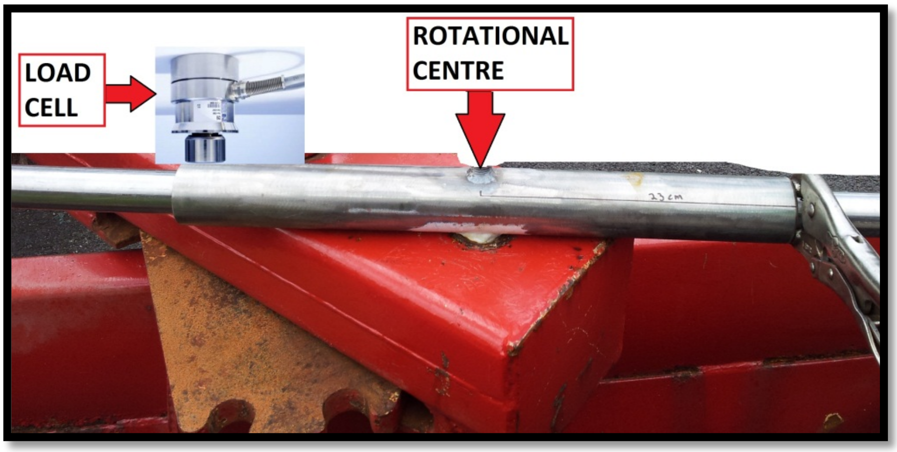


FIGURE 5-12 LOAD CELL PRINCIPLE

Above in Figure 5-12 the load cell principle is shown. By letting the tie-in spool being allowed to freely rotate, the compressive force is measured at a certain distance away from the rotational centre. Compressive load cells are standard equipment at most laboratories. It is easy to process data from them and continuous measurements can be saved electronically.

5.8.2 Slide - Modifications

Modifications on the slide must mainly be done in order to secure friction free rotation of the slide. A metal to metal interface is probably not the best solution for this application.

By outfitting the steel rod with radial bearings, issues related to friction between rod and scraper blade could have been omitted. A radial bearing is seen below.

FIGURE 5-13 RADIAL BEARING FOR STEEL ROD (ENCO, 2012)

Due to high compressive forces the selection of bearing type must be analysed in detail. This is because of radial bearings are designed for specific axial and radial loads.

6 Concluding Words

This thesis is divided into two parts.

The first part comprises a comprehensive introduction to tie-in spools. This is done in order to introduce important aspects related to the purpose, design and installation of tie-in spools. Different design considerations related to tie-in spools have been discussed and weighted by use of colour coding. In addition, methods for measuring tie-in spools and different connector systems have been studied.

A real industry example has been presented. This is done to show how modern tie- in spool analyses is conducted. The example includes the presentation of a tie-in spool with included connectors, how it is tied-in and how it is analysed. The design basis used, are said to be relevant for other offshore fields in the southern North Sea. The resulting connector forces that are based on pipeline expansion are presented. These results serves as comparison for the case studies conducted in part two of the thesis.

Part two includes two sections. The first part includes a case study on a tie-in spool, where connector forces are checked based on pipeline expansion. Pipeline expansion is applied due to operational conditions in addition to 100 year environmental loading. The tie-in spool analysed is modified from the industry example and is analysed by excerpts of the design basis in the industry example. Four different methods are used for analysing and comparison of results shows that three methods are good for calculating bending moment in the connector. There where however some differences between the methods of analysis and a no specific analyse method is recommended before any others. To find out which methods that are the best, an experiment on a downscaled tie-in spool where conducted.

A downscaled version of the tie-in spool was manufactured and analysed by applying pipeline expansion. Reaction forces in the connectors were measured by use of manual registrations from an adjustable torque wrench. Numbers from the test itself shows a consistent linear system. But, these numbers where compared against theoretical methods and large discrepancies were found. Limited correlation between results achieved from experiment and theory is explained by the test equipment being too mechanical and too rough. A search for possible error sources was conducted. Suggestions for further development of the test rig have been explained. Based on the test, no methods of analyses could be recommended. For visibility purposes, the experiment where concluded as a success.

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APPENDIX

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Note: Due to significant amount of appendix pages, only the results after each series of deflection are presented.

A

Sheet for calculation of hydrodynamic lift force:

Input Parameters:

Pipe Diameter: $D_{op} := 219.1mm = 0.219m$

Pipe thickness $t_p := 12.7mm = 0.013m$

Coating thickness $t_c := 3mm = 3 \times 10^{-3} m$

Density pipe material $\rho_p := 7850 \frac{kg}{m^3}$

Density coating material $\rho_c := 900 \frac{kg}{m^3}$

Density content material $\rho_{content} := 0.81 \frac{kg}{m^3}$

E - modolus of elasticity $E := 207GPa = 2.07 \times 10^{11} Pa$

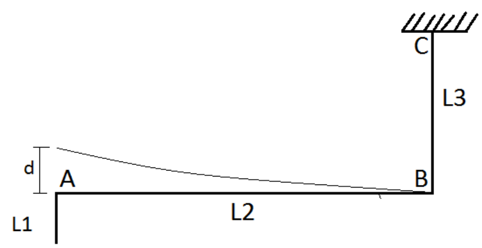
Density of water $\rho_w := 1025 \frac{kg}{m^3}$

Lengths of pipes - Input

On the PLET side: $L_1 := -1m$

Spool length $L_3 := 15m$

On WP side $L_2 := 10m$



Minor output values:

Diameter inner pipe $D_{ip} := D_{op} - 2 \cdot t_p = 193.7 \cdot mm$

Diameter inner coating $D_{ic} := D_{op} = 219.1 \cdot mm$

Diameter outer coating $D_{oc} := D_{ic} + 2 \cdot t_c = 225.1 \cdot mm$

Annulus area $A_a := \left(\frac{\pi}{4}\right) \cdot D_{ip}^{2} = 2.947 \times 10^{4} \cdot mm^{2}$

Area pipe $A_p := \left(\frac{\pi}{4}\right) \cdot \left(D_{op}^{2} - D_{ip}^{2}\right) = 8.235 \times 10^{3} \cdot mm^{2}$

Area coating $A_c := \left(\frac{\pi}{4}\right) \cdot \left(D_{oc}^{2} - D_{ic}^{2}\right) = 2.093 \times 10^{3} \cdot mm^{2}$

Area All: $A_{all} := A_a + A_p + A_c = 3.98 \times 10^{4} \cdot mm^{2}$

Moment of inertia pipe: $I_p := \left(\frac{\pi}{64}\right) \cdot \left(D_{op}^{4} - D_{ip}^{4}\right) = 4.402 \times 10^{-5} m^{4}$

Equivalent Weights:

Equivalent weight pipe	$w_p := A_p \cdot \rho_p = 64.645 \frac{kg}{m}$	$W_p := w_p \cdot g = 633.948 \cdot \frac{N}{m}$
Equivalent weight coating	$w_c := A_c \cdot \rho_c = 1.884 \frac{kg}{m}$	$W_c := w_c \cdot g = 18.475 \cdot \frac{N}{m}$
Equivalent weight content	$w_{cont} := A_a \cdot \rho_{content} = 0.024 \frac{kg}{m}$	$W_{cont} := w_{cont} \cdot g = 0.234 \cdot \frac{N}{m}$
Total equivalent weight:	$w_e := w_p + w_c + w_{cont} = 66.552 \frac{kg}{m}$	$W_e := w_e \cdot g = 652.657 \cdot \frac{N}{m}$
Bouyancy:	$w_b := A_{all} \cdot \rho_w = 40.791 \frac{kg}{m}$	$W_b := w_b \cdot g = 400.023 \cdot \frac{N}{m}$
Submerged Weight:	$w_s := w_e - w_b = 25.761 \frac{kg}{m}$	$W_s := w_s \cdot g = 252.634 \cdot \frac{N}{m}$

Calculation of Hydrodynamic Lift force

Input values:

Water Depth	$d := 73.8m$
Current velocity (100 year return period)	$V_c := 0.7 \frac{m}{s}$
Waves (10 year conditions)	$H_s := 11.7m$
	$T_s := 11.8s$

Deep Water Check:

Criteria:
(That need to be fulfilled in order for wave velocity profile to be in deep water)

$$\frac{d}{L_{deep}} > 0.5$$

Dispersion relation for deep water: $L_{deep} := \left(\frac{g}{2 \cdot \pi}\right) \cdot T_s^{\,2} = 217.323\,m$

Criteria check $\frac{d}{L_{deep}} = 0.34$

NO DEEPWATER

Since criteria for deepwater is not fulfilled we then need to check for intermediate water.

Intermediate Water Check:

Critera:
(That needs to be fullfilled in order for waves to be in intermediate water)

$$\frac{1}{20} < \frac{d}{L_{intermediate}} < \frac{1}{2}$$

$l_{intermediate1}$ is in principle the same as $l_{intermediate}$.
Need this to calculate exact value of $L_{intermediate}$

$$l_{intermediate1} := 211.925\text{m}$$

Dispersion relation for intermediate water:

$$L_{intermediate} := \left(\frac{g}{2\cdot\pi}\right)\cdot T_s{}^2\cdot\tanh\left(2\frac{\pi}{l_{intermediate1}}\cdot d\right)$$

$$L_{intermediate} = 211.925\,\text{m}$$

Criteria check

$$\frac{1}{20} = 0.05 \qquad \frac{d}{L_{intermediate}} = 0.348 \qquad \frac{1}{2} = 0.5$$

$$\frac{1}{20} < \frac{d}{L_{intermediate}} < \frac{1}{2}$$

WE ARE IN INTERMEDIATE WATER

Since we are in intermediate water the horizontal velocity profile of the wave particles are as follows:

$$U := \left(\frac{\zeta_0\cdot k\cdot g}{\omega}\right)\left(\frac{\cosh(k(z+d))}{\cosh(k\cdot d)}\right)\cdot\sin(\omega\cdot t - k\cdot x)$$

Wave amplitude $\zeta_0 := \frac{1.8}{2}\cdot H_s = 10.53\,\text{m}$

$$k := \frac{2\pi}{L_{intermediate}} = 0.03\frac{1}{\text{m}} \qquad \omega := \frac{2\pi}{T_s} = 0.532\frac{1}{\text{s}} \qquad z := -d - \frac{D_{oc}}{2} = -73.913\,\text{m}$$

Inserting all constants and setting sine equal to one gives us the horizontal velocity induced by waves at depth equal to the centre of the spool:

$$U := \left(\frac{\zeta_0\cdot k\cdot g}{\omega}\right)\left[\frac{\cosh[k\cdot(z+d)]}{\cosh(k\cdot d)}\right] = 1.274\cdot\frac{\text{m}}{\text{s}}$$

Morrisons Equation
(for finding lift force induced by current and waves)
by DNV-RP-F101. Assuming 90 degree attack-angle

$$F_{lift} := r_{totz} \frac{1}{2} \rho_w \cdot D_{oc} \cdot C_z \cdot (U + V_c)^2$$

Input values

Density Water: $\rho_w = 1.025 \times 10^3 \frac{kg}{m^3}$

Diameter outer coating: $D_{oc} = 225.1 \cdot mm$

Wave velocity: $U = 1.274 \frac{m}{s}$

Current velocity: $V_c = 0.7 \frac{m}{s}$

Friction factor $\mu := 0.4$

Submerged soil weight $\gamma_s := 10000 \frac{kg}{m^3}$

Submerged weight of pipe: $W_s = 252.634 \cdot \frac{N}{m}$

r_{totz} Reduction parameter due to pipe soil interaction:

Load reduction due to permeable seabed $r_{permz} := 0.7$

$z_p := 41.903mm$

Load reduction due to penetration $r_{penz} := 1 - 1.3 \cdot \left[\left(\frac{z_p}{D_{oc}} \right) - 0.1 \right] = 0.888$

$D_{oc} = 0.225\,m$

Pipe penetration $\mathbf{z_p}$ is based on two parameters:

1. Initial penetration z_{pi}

DNV RP F101 p19:
Maximum pipe weight (e.g. water fillled during the system pressure test) and zero uplift force can be assumed in the calculation of χ_s for initial penetration $\mathbf{z_{pi}}$ on sand.

Submerged soil weight: $\gamma_s = 1 \times 10^4 \frac{kg}{n^3}$

Water weight: $W_w := A_a \cdot \rho_w \cdot g = 296.206 \cdot \frac{N}{m}$

$$\chi_{swater} := \frac{\gamma_s \cdot D_{oc}^{\ 2}}{(W_s + W_w) \cdot \frac{1}{g}} = 9.054$$

$$z_{pi} := 0.037 \cdot \chi_{swater}^{\ -0.67} \cdot D_{oc} = 1.903 \cdot mm$$

2. Penetratrion due to pipe movement z_{pm} $z_{pm} := 40mm$

Evalutated to this due to separate discussion inside report

Total pipe penetration z_p $z_{p1} := z_{pi} + z_{pm} = 41.903 \cdot mm$

Load reduction due to trenching $r_{trz} := 1$ No trenching

Total load reduction factor $r_{totz} := r_{permz} \cdot r_{penz} \cdot r_{trz} = 0.622$

C_z Found from table 3-10 from DNV-RP-F109

Keulegan-Carpenter number $K_{kc} := \frac{U \cdot T_s}{D_{oc}} = 66.759$

Ratio between current and wave velocities $M_R := \frac{V_c}{U} = 0.55$

From table 3-10 we read out C_z to be: $C_z := 0.90$

Lift Force: Inserting values into Morrisons Equation -

$$F_{lift} := r_{totz} \frac{1}{2} \rho_w \cdot D_{oc} \cdot C_z \cdot (U + V_c)^2$$

$r_{totz} = 0.622$ $C_z = 0.9$

$\rho_w = 1.025 \times 10^3 \frac{kg}{m^3}$ $(U + V_c)^2 = 3.895 \frac{m^2}{s^2}$

$D_{oc} = 0.225\,m$

$$F_z := r_{totz} \frac{1}{2} \rho_w \cdot D_{oc} \cdot C_z \cdot (U + V_c)^2 = 251.364 \cdot \frac{N}{m}$$

Remaing "downward" force W_R then becomes:

$W_s = 252.634 \cdot \frac{N}{m}$

$$W_R := W_s - F_z = 1.27 \cdot \frac{N}{m}$$

B.a

Calculation sheet for L-spool:

Input Parameters:

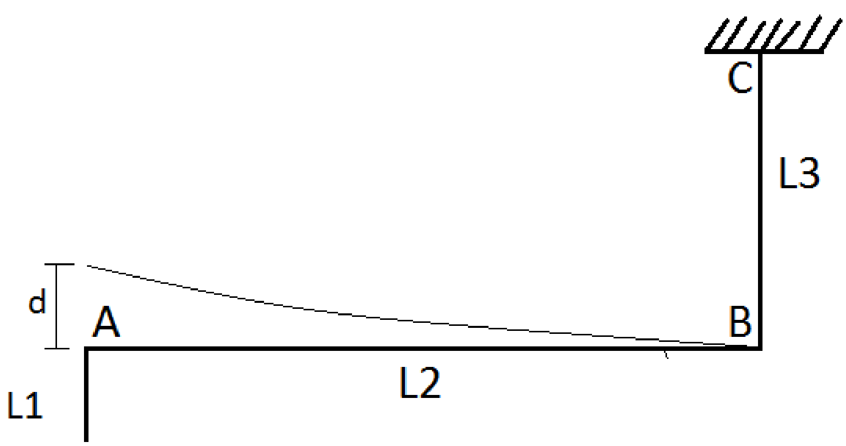
Pipe Diameter:	$D_{op} := 219.1mm = 0.219m$
Pipe thickness	$t_p := 12.7mm = 0.013m$
Coating thickness	$t_c := 3mm = 3 \times 10^{-3}\ m$
Density pipe material	$\rho_p := 7850 \frac{kg}{m^3}$
Density coating material	$\rho_c := 900 \frac{kg}{m^3}$
Density content material	$\rho_{content} := 0.81 \frac{kg}{m^3}$
E - modolus of elasticity	$E := 207GPa = 2.07 \times 10^{11}\ Pa$ $E_1 := E = 2.07 \times 10^{11}\ Pa$
Density of water	$\rho_w := 1025 \frac{kg}{m^3}$

Pipeline Expansion

Pipeline deflection:	$\delta_d := 1.5m$

Lengths of pipes - Input

On the PLET side:	$L_1 := -1m$ "dummy length"
Spool length	$L_3 := 15m$
On WP side	$L_2 := 10m$



Minor output values:

Diameter inner pipe	$D_{ip} := D_{op} - 2 \cdot t_p = 193.7 \cdot mm$
Diameter inner coating	$D_{ic} := D_{op} = 219.1 \cdot mm$
Diameter outer coating	$D_{oc} := D_{ic} + 2 \cdot t_c = 225.1 \cdot mm$
Annulus area	$A_a := \left(\frac{\pi}{4}\right) \cdot D_{ip}^{\ 2} = 2.947 \times 10^4 \cdot mm^2$
Area pipe	$A_p := \left(\frac{\pi}{4}\right) \cdot \left(D_{op}^{\ 2} - D_{ip}^{\ 2}\right) = 8.235 \times 10^3 \cdot mm^2$
Area coating	$A_c := \left(\frac{\pi}{4}\right) \cdot \left(D_{oc}^{\ 2} - D_{ic}^{\ 2}\right) = 2.093 \times 10^3 \cdot mm^2$
Area All:	$A_{all} := A_a + A_p + A_c = 3.98 \times 10^4 \cdot mm^2$
Moment of inertia pipe	$I_p := \left(\frac{\pi}{64}\right) \cdot \left(D_{op}^{\ 4} - D_{ip}^{\ 4}\right) = 4.402 \times 10^{-5} m^4$

Equivalent Weights:

Equivalent weight pipe	$w_p := A_p \cdot \rho_p = 64.645 \frac{kg}{m}$	$W_p := w_p \cdot g = 633.948 \cdot \frac{N}{m}$
Equivalent weight coating	$w_c := A_c \cdot \rho_c = 1.884 \frac{kg}{m}$	$W_c := w_c \cdot g = 18.475 \cdot \frac{N}{m}$
Equivalent weight content	$w_{cont} := A_a \cdot \rho_{content} = 0.024 \frac{kg}{m}$	$W_{cont} := w_{cont} \cdot g = 0.234 \cdot \frac{N}{m}$
Total equivalent weight:	$w_e := w_p + w_c + w_{cont} = 66.552 \frac{kg}{m}$	$W_e := w_e \cdot g = 652.657 \cdot \frac{N}{m}$
Bouyancy:	$w_b := A_{all} \cdot \rho_w = 40.791 \frac{kg}{m}$	$W_b := w_b \cdot g = 400.023 \cdot \frac{N}{m}$

Method 1. Build-in Cantiliver

Input Values:

Pipeline deflection $\delta_a := \delta_d = 1.5\,m$

Output values:

Force that corresponds to pipeline expansion δ_a: $P_A := \delta_a \cdot \frac{3E \cdot I_p}{L_3^{\,3}} = 12.149 \cdot kN$

Forces in bend at B

Force in B: $F_B := P_A = 1.215 \times 10^4\,N$

Bending moment in B $M_B := P_A \cdot L_3 = 182.236\,N \cdot km$

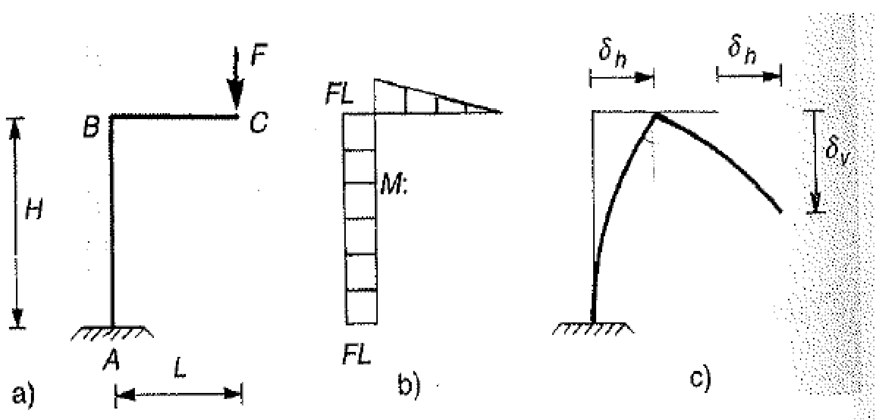
Forces at "tie in point"/clamp connection at platform

Force in C (compressive) $V_{C1} := F_B = 12.149 \cdot kN$

Bending moment in C $M_{C1} := M_B = 182.236\,N \cdot km$

Method 2. Elementary Beam Method

By setting the rotation in point B equal to eachother we obtain the following equation for the deflection in vertical direction:



$$\delta_V := \left(\frac{F_L \cdot L_3^{\,2} \cdot L_2}{3 \cdot E_1 \cdot I_p}\right) \cdot \left(3 + \frac{L_3}{L_2}\right) \qquad \delta_V := \delta_a = 1.5\,m$$

Rearranging the above equation wrt to F_L gives:

$$F_L := \delta_a \cdot \left(\frac{3 \cdot E_1 \cdot I_p}{L_3^{\,2} \cdot L_2}\right) \cdot \frac{1}{\left(3 + \frac{L_3}{L_2}\right)} = 4.05 \cdot kN$$

<u>Forces at "tie in point"/clamp connection at platform</u>

Force in C (compressive) $V_{C2} := F_L = 4.05 \cdot kN$

Bending moment in C $M_{C2} := V_{C2} \cdot L_3 = 60.745\,m \cdot kN$

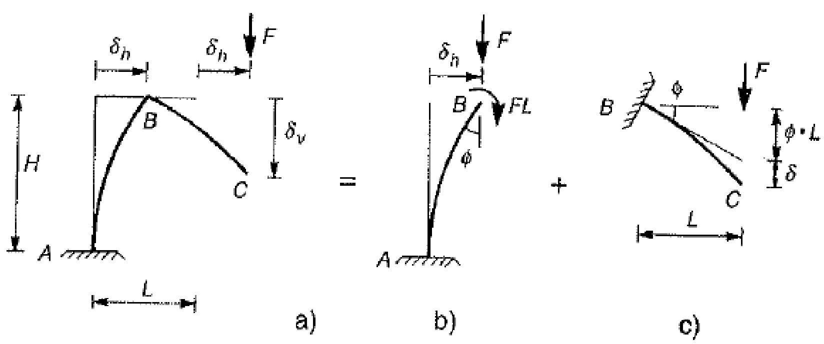


Fig. 20.6 Ramme ABC delt i to elementære kragbjelker AB og BC

Method 3. Portal by Roark's

Constants.

Length from end to "load" $a := 0m$

$$C_{HH} := \left(\frac{L_1^{\,3}}{3\cdot E_1\cdot I_p}\right) + \left[\frac{L_1^{\,3} - \left(L_1 - L_2\right)^3}{3\cdot E_1\cdot I_p}\right] + \frac{L_1^{\,2}\cdot L_3}{E_1\cdot I_p} = 5.026 \times 10^{-5}\,\frac{s^2}{kg}$$

$$C_{HV} := \left(\frac{L_2\cdot L_3}{2\cdot E_1\cdot I_p}\right)\left(2\cdot L_1 - L_2\right) + \frac{L_1\cdot L_3^{\,2}}{2\cdot E_1\cdot I_p} = -1.111 \times 10^{-4}\,\frac{s^2}{kg} \qquad C_{VH} := C_{HV}$$

$$C_{HM} := \left(\frac{L_1^{\,2}}{2\cdot E_1\cdot I_p}\right) + \left(\frac{L_2}{2\cdot E_1\cdot I_p}\right)\cdot\left(2\cdot L_1 - L_2\right) + \frac{L_1\cdot L_3}{E_1\cdot I_p} = -8.176 \times 10^{-6}\,\frac{1}{N} \qquad C_{MH} := C_{HM}$$

$$C_{VV} := \left(\frac{L_2\cdot L_3^{\,2}}{E_1\cdot I_p}\right) + \left(\frac{L_3^{\,3}}{3\cdot E_1\cdot I_p}\right) = 3.704 \times 10^{-4}\,\frac{s^2}{kg}$$

$$C_{VM} := \left(\frac{L_2\cdot L_3}{E_1\cdot I_p}\right) + \left(\frac{L_3^{\,2}}{2\cdot E_1\cdot I_p}\right) = 2.881 \times 10^{-5}\,\frac{1}{N} \qquad C_{MV} := C_{VM}$$

$$C_{MM} := \left(\frac{L_1}{E_1\cdot I_p}\right) + \left(\frac{L_2}{E_1\cdot I_p}\right) + \left(\frac{L_3}{E_1\cdot I_p}\right) = 2.634 \times 10^{-6}\,\frac{1}{J}$$

Forces in A (Pipeline end Termnial - PLET):

$H_A := 0$

$V_A := W_L$

$M_A := 0$

Deformation equations:

Horizontal deflection at A: δ_H $\qquad \delta_H := C_{HH}\cdot H_A + C_{HV}\cdot V_A + C_{HM}\cdot M_A - LF_H$

Vertical deflection at A: δ_V $\qquad \delta_V := C_{VH}\cdot H_A + C_{VV}\cdot V_A + C_{VM}\cdot M_A - LF_V$

Angular rotation at A: ψ_A $\qquad \psi_A := C_{MH}\cdot H_A + C_{MV}\cdot V_A + C_{MM}\cdot M_A - L_{FM}$

Calculating Reaction forces without pipe/soil interaction

Since H_A=0 & M_A=0 the equation for vertical deflection at A reduces to

$$LF_V := -\delta_V = \blacksquare \cdot 1.5m$$

Load function vertical: $$LF_V := W_L \cdot \left(C_{VV} - a \cdot C_{VM} + \frac{a^3}{6 \cdot E_3 \cdot I_p} \right)$$

Where W_L is set equal to V_A (which is the force from the pipeline expansion) and a is equal to zero. $$LF_V := V_A \cdot C_{VV}$$

The equation for vertical deflection then becomes:

$$\delta_{VA} := -\left(V_A \cdot C_{VV}\right) = \blacksquare \cdot 1.5m$$

Re-organizing wrt V_A gives and by use of $\delta_{VA} := 1.5m$:

$$V_A := \frac{-\delta_{VA}}{C_{VV}} = -4.05 \cdot kN$$ Force from pipeline expansion on tie-in spool

Forces at "tie in point"/clamp connection at platform

Force in C (compressive) $V_{C3} := \left|V_A\right| = 4.05 \cdot kN$

Bending moment in C $M_{C3} := \left|V_A\right| \cdot L_3 = 60.745\, m \cdot kN$

Method 4. FOCUS Software

See other analysis report in Appendix . Only results are presented here.

Forces at "tie in point"/clamp connection at platform

Force in C (compressive) $V_{C4} := 9.9kN$

Bending moment in C $M_{C4} := 86.57kN \cdot 1m = 86.57\, N \cdot km$

RESULTS FROM THE FOUR DIFFERENT METHODS:

1.Buildt-in Cantiliver

$V_{C1} = 12.149 \cdot kN$

$M_{C1} = 182.236\ N \cdot km$

2. Elementary Beam Method:

$V_{C2} = 4.05 \cdot kN$

$M_{C2} = 60.745\ m \cdot kN$

3. Portal By Roarks

$V_{C3} = 4.05 \cdot kN$

$M_{C3} = 60.745\ N \cdot km$

I.E We se that the Elementary beam method (2) & the Portal method (3) provides the same anwers. Which is "in-line" with theory.

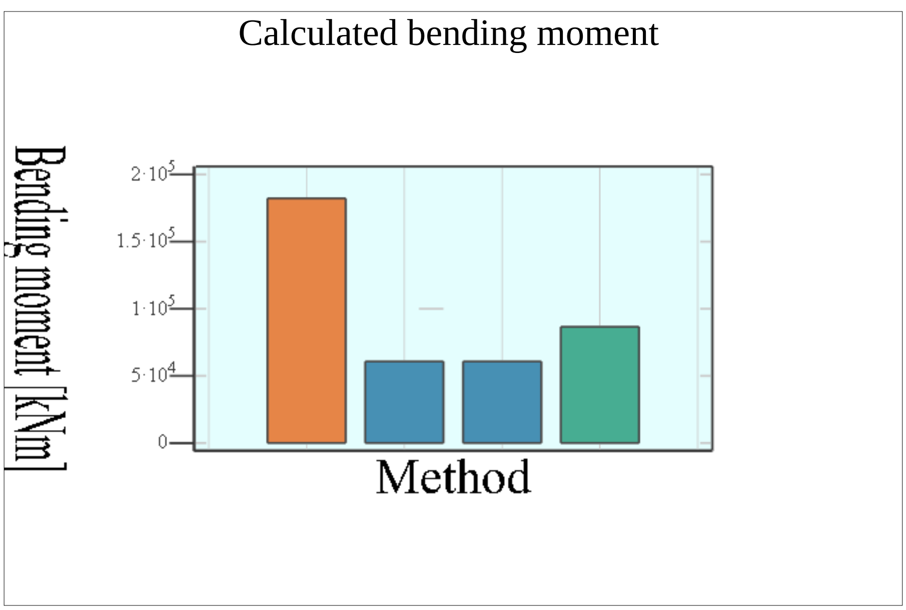
4. FOCUS Software:

$V_{C4} = 9.9 \cdot kN$

$M_{C4} = 86.57\ N \cdot km$

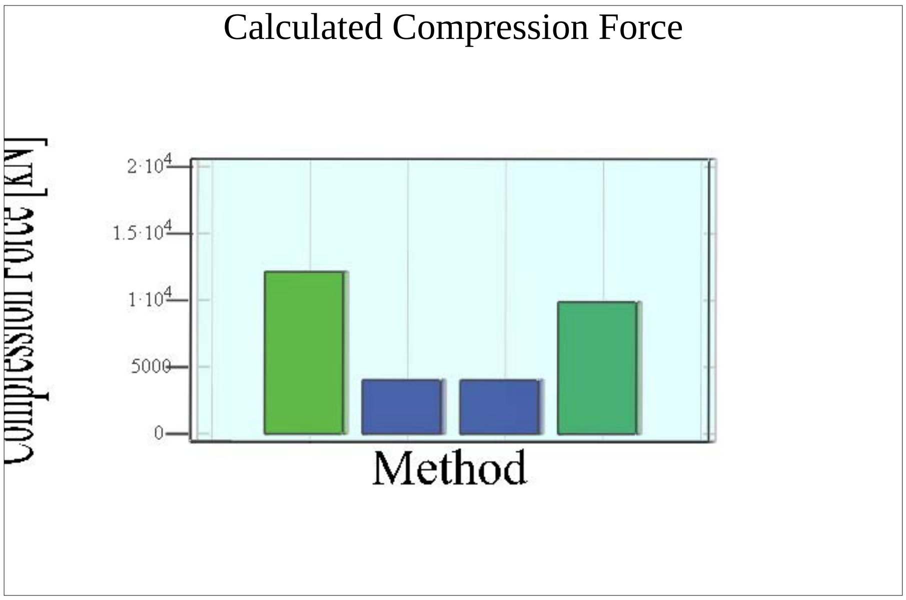
Bending moment in tie-in point due to pipeline expansion

$$M_C := \begin{pmatrix} M_{C1} \\ M_{C2} \\ M_{C3} \\ M_{C4} \end{pmatrix} = \begin{pmatrix} 182.236 \\ 60.745 \\ 60.745 \\ 86.57 \end{pmatrix} N \cdot km$$



Compression forces in tie-in point due to Pipeline expansion

$$V_C := \begin{pmatrix} V_{C1} \\ V_{C2} \\ V_{C3} \\ V_{C4} \end{pmatrix} = \begin{pmatrix} 12.149 \\ 4.05 \\ 4.05 \\ 9.9 \end{pmatrix} \cdot kN$$



B.b.1

Calculation sheet for L-spool
L3 = 1.5 metres

Input Parameters:

Pipe Diameter:	$D_{op} := 33.4mm = 0.033m$
Pipe thickness	$t_p := 4.55mm = 4.55 \times 10^{-3} m$
Coating thickness	$t_c := 0mm = 0$
Density pipe material	$\rho_p := 7850 \frac{kg}{m^3}$
Density coating material	$\rho_c := 900 \frac{kg}{m^3}$
Density content material	$\rho_{content} := 0.81 \frac{kg}{m^3}$
E - modolus of elasticity	$E := 190GPa = 1.9 \times 10^{11} Pa$
Density of water	$\rho_w := 1025 \frac{kg}{m^3}$

$E_1 := E = 1.9 \times 10^{11} Pa$

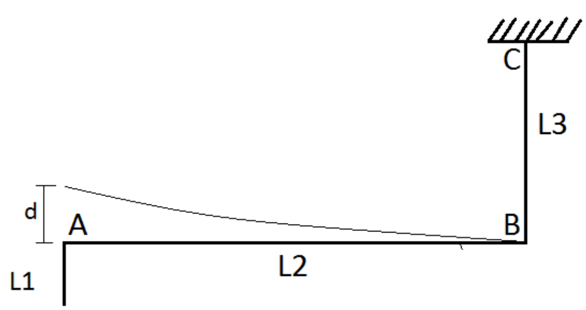
Pipeline Expansion

Pipeline deflection:

$$\delta_d := \begin{pmatrix} 0 \\ 0.30 \\ 0.5 \\ 0.7 \\ 0.9 \end{pmatrix} m$$

Lengths of pipes - Input

On the PLET side:	$L_1 := -1m$	"dummy length"
Spool length	$L_3 := 1.5m$	
On WP side	$L_2 := 3m$	



Minor output values:

Diameter inner pipe	$D_{ip} := D_{op} - 2 \cdot t_p = 24.3 \cdot mm$
Diameter inner coating	$D_{ic} := D_{op} = 33.4 \cdot mm$
Diameter outer coating	$D_{oc} := D_{ic} + 2 \cdot t_c = 33.4 \cdot mm$
Annulus area	$A_a := \left(\frac{\pi}{4}\right) \cdot D_{ip}^2 = 463.77 \cdot mm^2$
Area pipe	$A_p := \left(\frac{\pi}{4}\right) \cdot \left(D_{op}^2 - D_{ip}^2\right) = 412.389 \cdot mm^2$
Area coating	$A_c := \left(\frac{\pi}{4}\right) \cdot \left(D_{oc}^2 - D_{ic}^2\right) = 0 \cdot mm^2$
Area All:	$A_{all} := A_a + A_p + A_c = 876.159 \cdot mm^2$
Moment of inertia pipe	$I_p := \left(\frac{\pi}{64}\right) \cdot \left(D_{op}^4 - D_{ip}^4\right) = 4.397 \times 10^{-8} m^4$

Equivalent Weights:

Equivalent weight pipe	$w_p := A_p \cdot \rho_p = 3.237 \frac{kg}{m}$	$W_p := w_p \cdot g = 31.747 \cdot \frac{N}{m}$
Equivalent weight coating	$w_c := A_c \cdot \rho_c = 0 \frac{kg}{m}$	$W_c := w_c \cdot g = 0 \cdot \frac{N}{m}$
Equivalent weight conten	$w_{cont} := A_a \cdot \rho_{content} = 3.757 \times 10^{-4} \frac{kg}{m}$	$W_{cont} := w_{cont} \cdot g = 3.684 \times 10^{-3} \cdot \frac{N}{m}$
Total equivalent weight:	$w_e := w_p + w_c + w_{cont} = 3.238 \frac{kg}{m}$	$W_e := w_e \cdot g = 31.75 \cdot \frac{N}{m}$
Bouyancy:	$w_b := A_{all} \cdot \rho_w = 0.898 \frac{kg}{m}$	$W_b := w_b \cdot g = 8.807 \cdot \frac{N}{m}$

Method 1. Build-in Cantilever

Input Values:

Pipeline deflection $\delta_a := \delta_d = \begin{pmatrix} 0 \\ 0.3 \\ 0.5 \\ 0.7 \\ 0.9 \end{pmatrix} m$

Output values:

Force that corresponds to pipeline expansion δ_a: $P_A := \delta_a \cdot \frac{3E \cdot I_p}{{L_2}^3} = \begin{pmatrix} 0 \\ 0.278 \\ 0.464 \\ 0.65 \\ 0.835 \end{pmatrix} \cdot kN$

Forces in bend at B

Force in B: $F_B := P_A = \begin{pmatrix} 0 \\ 278.491 \\ 464.152 \\ 649.812 \\ 835.473 \end{pmatrix} N$

Bending moment in B $M_B := P_A \cdot L_2 = \begin{pmatrix} 0 \\ 0.835 \\ 1.392 \\ 1.949 \\ 2.506 \end{pmatrix} N \cdot km$

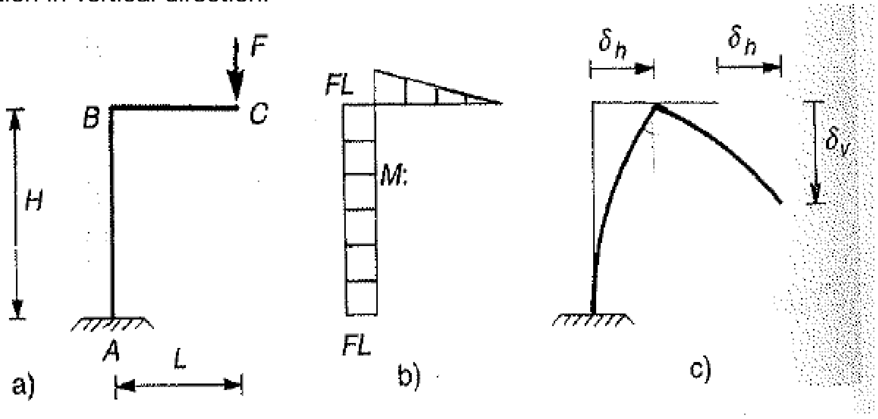
Forces at "tie in point"/clamp connection at platform

Force in C (compressive) $V_{C1} := F_B = \begin{pmatrix} 0 \\ 0.278 \\ 0.464 \\ 0.65 \\ 0.835 \end{pmatrix} \cdot kN$

Bending moment in C $M_{C1} := M_B = \begin{pmatrix} 0 \\ 835.473 \\ 1.392 \times 10^3 \\ 1.949 \times 10^3 \\ 2.506 \times 10^3 \end{pmatrix} N \cdot m$

Method 2. Elementary Beam Method

By setting the rotation in point B equal to eachother we obtain the following equation for the deflection in vertical direction:



$$\delta_V := \left(\frac{F_L \cdot L_2^{\,2} \cdot L_3}{3 \cdot E_1 \cdot I_p}\right) \cdot \left(3 + \frac{L_2}{L_3}\right) \qquad \delta_V := \delta_a = \begin{pmatrix} 0 \\ 0.3 \\ 0.5 \\ 0.7 \\ 0.9 \end{pmatrix} m$$

Rearranging the above equation wrt to F_L

$$F_L := \delta_a \cdot \left(\frac{3 \cdot E_1 \cdot I_p}{L_2^{\,2} \cdot L_3}\right) \cdot \frac{1}{\left(3 + \frac{L_2}{L_3}\right)} = \begin{pmatrix} 0 \\ 0.111 \\ 0.186 \\ 0.26 \\ 0.334 \end{pmatrix} \cdot kN$$

Forces at "tie in point"/clamp connection at platform

Force in C (compressive)

$$V_{C2} := F_L = \begin{pmatrix} 0 \\ 0.111 \\ 0.186 \\ 0.26 \\ 0.334 \end{pmatrix} \cdot kN$$

Bending moment in C

$$M_{C2} := V_{C2} \cdot L_2 = \begin{pmatrix} 0 \\ 334.189 \\ 556.982 \\ 779.775 \\ 1.003 \times 10^3 \end{pmatrix} m \cdot N$$

Method 3. Rigid Frame

Frame Constants

Length from end to "load" $a := 0m$

$$C_{HH} := \left(\frac{L_1^{\,3}}{3 \cdot E_1 \cdot I_p}\right) + \left[\frac{L_1^{\,3} - (L_1 - L_3)^3}{3 \cdot E_1 \cdot I_p}\right] + \frac{L_1^{\,2} \cdot L_2}{E_1 \cdot I_p} = 9.027 \times 10^{-4} \frac{s^2}{kg}$$

$$C_{HV} := \left(\frac{L_3 \cdot L_2}{2 \cdot E_1 \cdot I_p}\right)(2 \cdot L_1 - L_3) + \frac{L_1 \cdot L_2^{\,2}}{2 \cdot E_1 \cdot I_p} = -1.481 \times 10^{-3} \frac{s^2}{kg} \qquad C_{VH} := C_{HV}$$

$$C_{HM} := \left(\frac{L_1^{\,2}}{2 \cdot E_1 \cdot I_p}\right) + \left(\frac{L_3}{2 \cdot E_1 \cdot I_p}\right) \cdot (2 \cdot L_1 - L_2) + \frac{L_1 \cdot L_2}{E_1 \cdot I_p} = -7.481 \times 10^{-4} \frac{1}{N} \qquad C_{MH} := C_{HM}$$

$$C_{VV} := \left(\frac{L_3 \cdot L_2^{\,2}}{E_1 \cdot I_p}\right) + \left(\frac{L_2^{\,3}}{3 \cdot E_1 \cdot I_p}\right) = 2.693 \times 10^{-3} \frac{s^2}{kg}$$

$$C_{VM} := \left(\frac{L_3 \cdot L_2}{E_1 \cdot I_p}\right) + \left(\frac{L_2^{\,2}}{2 \cdot E_1 \cdot I_p}\right) = 1.077 \times 10^{-3} \frac{1}{N} \qquad C_{MV} := C_{VM}$$

$$C_{MM} := \left(\frac{L_1}{E_1 \cdot I_p}\right) + \left(\frac{L_3}{E_1 \cdot I_p}\right) + \left(\frac{L_2}{E_1 \cdot I_p}\right) = 4.189 \times 10^{-4} \frac{1}{J}$$

Forces in A (Pipeline end Termnial - PLET):

$H_A := 0$

$V_A := W_L$

$M_A := 0$

Deformation equations:

Horizontal deflection at A: δ_H $\qquad \delta_H := C_{HH} \cdot H_A + C_{HV} \cdot V_A + C_{HM} \cdot M_A - LF_H$

Vertical deflection at A: δ_V $\qquad \delta_V := C_{VH} \cdot H_A + C_{VV} \cdot V_A + C_{VM} \cdot M_A - LF_V$

Angular rotation at A: ψ_A $\qquad \psi_A := C_{MH} \cdot H_A + C_{MV} \cdot V_A + C_{MM} \cdot M_A - L_{FM}$

Calculating Reaction forces without pipe/soil interaction

Since H_A=0 & M_A=0 the equation for vertical deflection at A reduces to

$$LF_V := -\delta_V = \blacksquare \cdot 1.5m$$

Load function vertical: $$LF_V := W_L \cdot \left(C_{VV} - a \cdot C_{VM} + \frac{a^3}{6 \cdot E_3 \cdot I_p} \right)$$

Where W_L is set equal to V_A (which is the force from the pipeline expansion) and a is equal to zero. $$LF_V := V_A \cdot C_{VV}$$

The equation for vertical deflection then becomes:

$$\delta_{VA} := -(V_A \cdot C_{VV}) = \blacksquare \cdot 0.3m$$

Re-organizing wrt V_A gives and by use of : $$\delta_{VA} := \delta_d = \begin{pmatrix} 0 \\ 0.3 \\ 0.5 \\ 0.7 \\ 0.9 \end{pmatrix} m$$

$$V_A := \frac{\delta_{VA}}{C_{VV}} = \begin{pmatrix} 0 \\ 111.396 \\ 185.661 \\ 259.925 \\ 334.189 \end{pmatrix} \cdot N$$ Force from pipeline expansion on tie-in spool

Forces at "tie in point"/clamp connection at platform:

Force in C (compressive) $$V_{C3} := V_A = \begin{pmatrix} 0 \\ 0.111 \\ 0.186 \\ 0.26 \\ 0.334 \end{pmatrix} \cdot kN$$

Bending moment in C $$M_{C3} := V_A \cdot L_2 = \begin{pmatrix} 0 \\ 334.189 \\ 556.982 \\ 779.775 \\ 1.003 \times 10^3 \end{pmatrix} m \cdot N$$

Method 4. FOCUS Construction

See other analysis report in Appendix . Only results are presented here.

Forces at "tie in point"/clamp connection at platform

Force in C (compressive)

$$V_{C4} := \begin{pmatrix} 0 \\ 600 \\ 1000 \\ 1410 \\ 1810 \end{pmatrix} N$$

Values are updated from separate analyses in Focus Construction

Bending moment in C

$$M_{C4} := \begin{pmatrix} 0 \\ 970 \\ 1620 \\ 2260 \\ 2910 \end{pmatrix} N \cdot m$$

RESULTS FROM THE FOUR DIFFERENT METHODS:

Calculated bending moments based on pipeline expansion δ_d:

$$\delta_d = \begin{pmatrix} 0 \\ 300 \\ 500 \\ 700 \\ 900 \end{pmatrix} \cdot mm$$

1. Buildt-in Cantilever

Axial Force: $V_{C1} = \begin{pmatrix} 0 \\ 278.491 \\ 464.152 \\ 649.812 \\ 835.473 \end{pmatrix} \cdot N$

Bending Moment: $M_{C1} = \begin{pmatrix} 0 \\ 835.473 \\ 1.392 \times 10^3 \\ 1.949 \times 10^3 \\ 2.506 \times 10^3 \end{pmatrix} N \cdot m$

2. Elementary Beam Method

Axial Force: $V_{C2} = \begin{pmatrix} 0 \\ 111.396 \\ 185.661 \\ 259.925 \\ 334.189 \end{pmatrix} \cdot N$

Bending Moment: $M_{C2} = \begin{pmatrix} 0 \\ 334.189 \\ 556.982 \\ 779.775 \\ 1.003 \times 10^3 \end{pmatrix} N \cdot m$

3. Rigid Frame

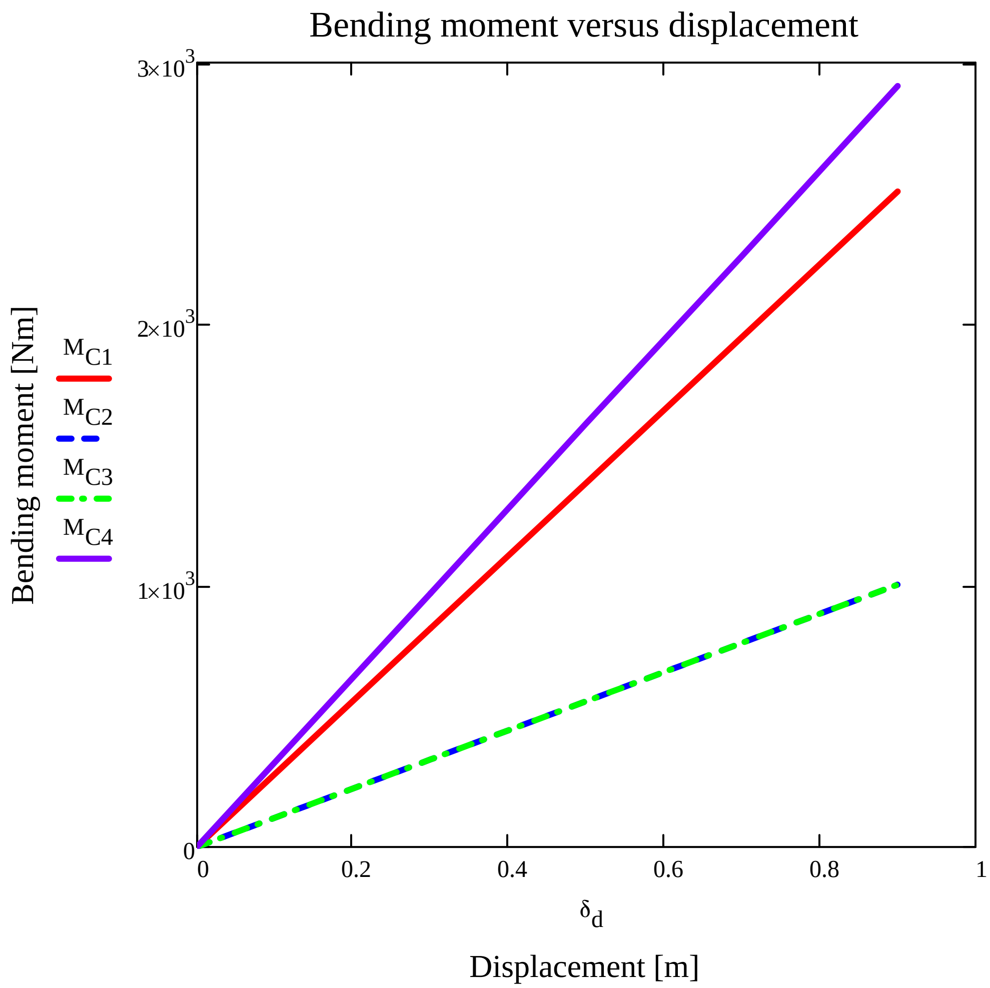
Axial Force: $V_{C3} = \begin{pmatrix} 0 \\ 111.396 \\ 185.661 \\ 259.925 \\ 334.189 \end{pmatrix} \cdot N$

Bending Moment: $M_{C3} = \begin{pmatrix} 0 \\ 334.189 \\ 556.982 \\ 779.775 \\ 1.003 \times 10^3 \end{pmatrix} N \cdot m$

4. FOCUS Construction

Axial Force: $V_{C4} = \begin{pmatrix} 0 \\ 600 \\ 1 \times 10^3 \\ 1.41 \times 10^3 \\ 1.81 \times 10^3 \end{pmatrix} N$

Bending Moment: $M_{C4} = \begin{pmatrix} 0 \\ 970 \\ 1.62 \times 10^3 \\ 2.26 \times 10^3 \\ 2.91 \times 10^3 \end{pmatrix} N \cdot m$



Bending moment versus displacement
Bending moment [Nm]
3×10^3
2×10^3
1×10^3
0
M_C1
M_C2
M_C3
M_C4
0
0.2
0.4
0.6
0.8
1
δ_d
Displacement [m]

B.b.2

Calculation sheet for L-spool
L3 = 1.75 metres

Input Parameters:

Pipe Diameter: $D_{op} := 33.4mm = 0.033m$

Pipe thickness $t_p := 4.55mm = 4.55 \times 10^{-3} m$

Coating thickness $t_c := 0mm = 0$

Density pipe material $\rho_p := 7850 \frac{kg}{m^3}$

Density coating material $\rho_c := 900 \frac{kg}{m^3}$

Density content material $\rho_{content} := 0.81 \frac{kg}{m^3}$

E - modolus of elasticity $E := 190GPa = 1.9 \times 10^{11} Pa$ $E_1 := E = 1.9 \times 10^{11} Pa$

Density of water $\rho_w := 1025 \frac{kg}{m^3}$

Pipeline Expansion

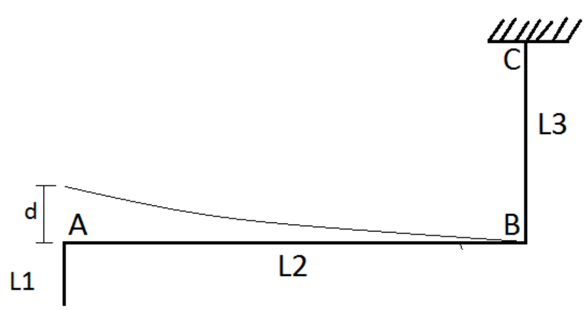
Pipeline deflection: $\delta_d := \begin{pmatrix} 0 \\ 0.30 \\ 0.5 \\ 0.7 \\ 0.9 \end{pmatrix} m$

Lengths of pipes - Input

On the PLET side: $L_1 := -1m$ "dummy length"

Spool length $L_3 := 1.75m$

On WP side $L_2 := 3m$



RESULTS FROM THE FOUR DIFFERENT METHODS:

Calculated bending moments based on pipeline expansion δ_d:

$$\delta_d = \begin{pmatrix} 0 \\ 300 \\ 500 \\ 700 \\ 900 \end{pmatrix} \cdot mm$$

1. Buildt-in Cantilever

Axial Force:

$$V_{C1} = \begin{pmatrix} 0 \\ 278.491 \\ 464.152 \\ 649.812 \\ 835.473 \end{pmatrix} \cdot N$$

Bending Moment:

$$M_{C1} = \begin{pmatrix} 0 \\ 835.473 \\ 1.392 \times 10^{3} \\ 1.949 \times 10^{3} \\ 2.506 \times 10^{3} \end{pmatrix} N \cdot m$$

2. Elementary Beam Method

Axial Force:

$$V_{C2} = \begin{pmatrix} 0 \\ 101.269 \\ 168.782 \\ 236.295 \\ 303.808 \end{pmatrix} \cdot N$$

Bending Moment:

$$M_{C2} = \begin{pmatrix} 0 \\ 303.808 \\ 506.347 \\ 708.886 \\ 911.425 \end{pmatrix} N \cdot m$$

3. Rigid Frame

Axial Force:

$$V_{C3} = \begin{pmatrix} 0 \\ 101.269 \\ 168.782 \\ 236.295 \\ 303.808 \end{pmatrix} \cdot N$$

Bending Moment:

$$M_{C3} = \begin{pmatrix} 0 \\ 303.808 \\ 506.347 \\ 708.886 \\ 911.425 \end{pmatrix} N \cdot m$$

4. FOCUS Construction

Axial Force:

$$V_{C4} = \begin{pmatrix} 0 \\ 520 \\ 870 \\ 1.22 \times 10^{3} \\ 1.56 \times 10^{3} \end{pmatrix} N$$

Bending Moment:

$$M_{C4} = \begin{pmatrix} 0 \\ 880 \\ 1.46 \times 10^{3} \\ 2.05 \times 10^{3} \\ 2.63 \times 10^{3} \end{pmatrix} N \cdot m$$

B.b.3

Calculation sheet for L-spool
L3 = 2.0 metres

Input Parameters:

Pipe Diameter:	$D_{op} := 33.4mm = 0.033\ m$
Pipe thickness	$t_p := 4.55mm = 4.55 \times 10^{-3}\ m$
Coating thickness	$t_c := 0mm = 0$
Density pipe material	$\rho_p := 7850 \frac{kg}{m^3}$
Density coating material	$\rho_c := 900 \frac{kg}{m^3}$
Density content material	$\rho_{content} := 0.81 \frac{kg}{m^3}$
E - modolus of elasticity	$E := 190GPa = 1.9 \times 10^{11}\ Pa$
Density of water	$\rho_w := 1025 \frac{kg}{m^3}$

$E_1 := E = 1.9 \times 10^{11}\ Pa$

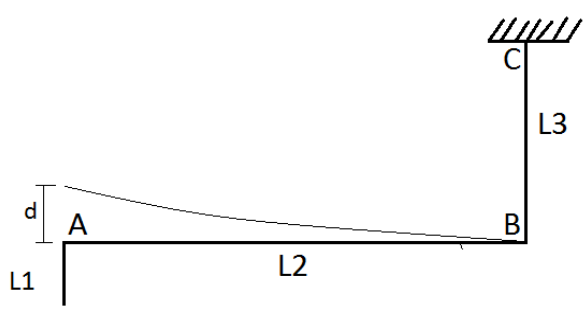
Pipeline Expansion

Pipeline deflection:

$$\delta_d := \begin{pmatrix} 0 \\ 0.30 \\ 0.5 \\ 0.7 \\ 0.9 \end{pmatrix} m$$

Lengths of pipes - Input

On the PLET side:	$L_1 := -1m$ "dummy length"
Spool length	$L_3 := 2.0m$
On WP side	$L_2 := 3m$



RESULTS FROM THE FOUR DIFFERENT METHODS:

Calculated bending moments based on pipeline expansion δ_d:

$$\delta_d = \begin{pmatrix} 0 \\ 300 \\ 500 \\ 700 \\ 900 \end{pmatrix} \cdot mm$$

1. Buildt-in Cantilever

Axial Force:

$$V_{C1} = \begin{pmatrix} 0 \\ 278.491 \\ 464.152 \\ 649.812 \\ 835.473 \end{pmatrix} \cdot N$$

Bending Moment:

$$M_{C1} = \begin{pmatrix} 0 \\ 835.473 \\ 1.392 \times 10^3 \\ 1.949 \times 10^3 \\ 2.506 \times 10^3 \end{pmatrix} N \cdot m$$

2. Elementary Beam Method

Axial Force:

$$V_{C2} = \begin{pmatrix} 0 \\ 92.83 \\ 154.717 \\ 216.604 \\ 278.491 \end{pmatrix} \cdot N$$

Bending Moment:

$$M_{C2} = \begin{pmatrix} 0 \\ 278.491 \\ 464.152 \\ 649.812 \\ 835.473 \end{pmatrix} N \cdot m$$

3. Rigid Frame

Axial Force:

$$V_{C3} = \begin{pmatrix} 0 \\ 92.83 \\ 154.717 \\ 216.604 \\ 278.491 \end{pmatrix} \cdot N$$

Bending Moment:

$$M_{C3} = \begin{pmatrix} 0 \\ 278.491 \\ 464.152 \\ 649.812 \\ 835.473 \end{pmatrix} N \cdot m$$

4. FOCUS Construction

Axial Force:

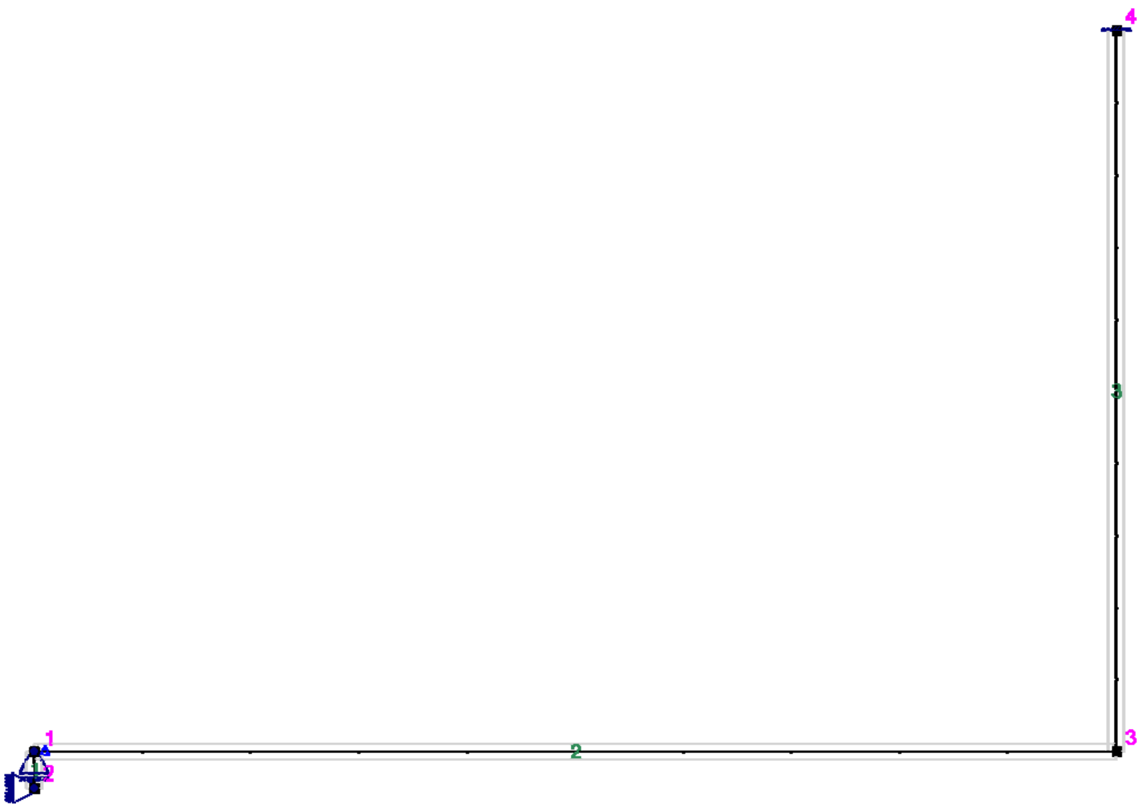
$$V_{C4} = \begin{pmatrix} 0 \\ 460 \\ 760 \\ 1.06 \times 10^3 \\ 1.37 \times 10^3 \end{pmatrix} N$$

Bending Moment:

$$M_{C4} = \begin{pmatrix} 0 \\ 780 \\ 1.3 \times 10^3 \\ 1.83 \times 10^3 \\ 2.35 \times 10^3 \end{pmatrix} N \cdot m$$

C.a

1. KONSTRUKSJONSMODELL OG LASTER



1.1. KNUTEPUNKTSDATA

Nr.	X [mm]	Z [mm]
1	0	0
2	0	-500
3	15000	0
4	15000	10000

1.2. TVERRSNITTSDATA

Nr.	Navn	Parametre	
1	Tie-In spool 8"	A [mm^2]	8235
		Ix [mm^4]	8,8037e+007
		Iy [mm^4]	4,4018e+007
		Iz [mm^4]	4,4018e+007
		Total vekt [kN]	16,48

1.3. MATERIALDATA

1 **Stål DNV SML 450 I** Material: Stål

Fasthetsklasse: S450

Varmeutv.koeff.: 1,20e-005 °C^-1 Tyngdetetthet: 78,50 kN/m^3

E-modul: 2,0700e+005 N/mm^2 G-modul: 8,1000e+004 N/mm^2

1.4. SEGMENTDATA

Seg Nr.	Kn.pkt 1	Kn.pkt 2	Tvsn 1	Tvsn 2	Material
1	1	2	Tie-In spool 8"	Tie-In spool 8"	Stål DNV SML 450 I
2	1	3	Tie-In spool 8"	Tie-In spool 8"	Stål DNV SML 450 I
3	3	4	Tie-In spool 8"	Tie-In spool 8"	Stål DNV SML 450 I

1.4.1. SEGMENTDATA EN 1993

Seg. nr.	Gamma_M0	Gamma_M1	L_ky [mm]	L_kz [mm]	L_eff [mm]
1	1,05	1,05	500	500	500
2	1,05	1,05	15000	15000	15000
3	1,05	1,05	10000	10000	10000

1.5. RANDBETINGELSER

Seg Nr.	X [mm]	Z [mm]	Frih.gr. X	Z	RotY
1	0	-500	F		
1	0	0		1500,0	
3	15000	10000	F	F	F

Forklaring til frihetsgrader: F = fastholdt, (blank) = fri
Tall betyr foreskreven forskyvning [mm]

1.7. LASTTILFELLER

1.8. LASTKOMBINASJON

Beregning utført for lastkombinasjon
(1) Lastkombinasjon 1500

Grensetilstand: Brudd

1,00 * <Foreskrevne forskyvninger>

2. STATISKE BEREGNINGER

2.1. KNUTEPUNKTSRESULTATER

2.1.1. Forskyvninger

Nr.	u [mm]	w [mm]	rotY [°]
1	65,6	1500,0	7,5
2	0,0	1500,0	7,5
3	65,4	0,1	1,6
4	0,0	0,0	0,0

2.1.2. Residualkrefter

Nr.	Rx [kN]	Rz [kN]	My [kN·m]
1	0,00	9,89	0,00
2	22,36	0,00	0,00
3	0,00	0,00	0,00
4	-22,36	-9,89	86,46

2.2. OPPLEGGSKREFTER

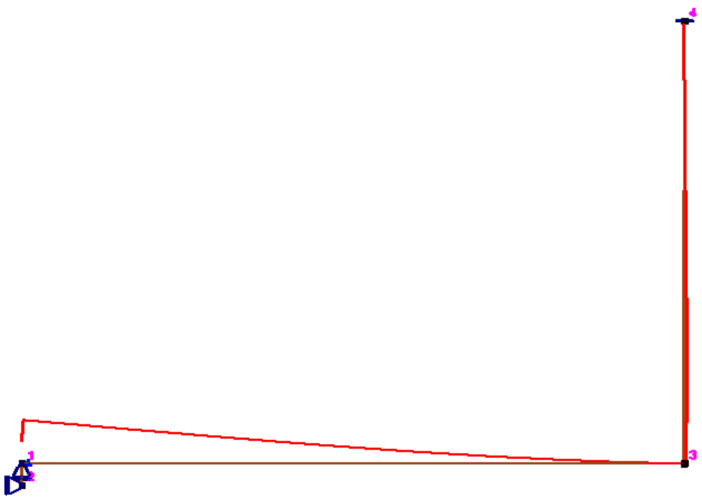
Seg Nr.	X [mm]	Z [mm]	Rx [kN]	Rz [kN]	My [kN·m]
1	0	-500	22,36	0,00	0,00
1	0	0	0,00	9,89	0,00
3	15000	10000	-22,36	-9,89	86,46
	Sum		0,00	0,00	

2.3. SEGMENTRESULTATER

Seg Nr.	Snitt mm	My [kN·m]	N [kN]	Vz [kN]	u [mm]	w [mm]
1	0	11,18	0,00	-22,36	65,6	1500,0
2	15000	-137,14	-22,36	-9,89	65,4	0,1
3	0	-137,14	-9,89	22,36	65,4	0,1

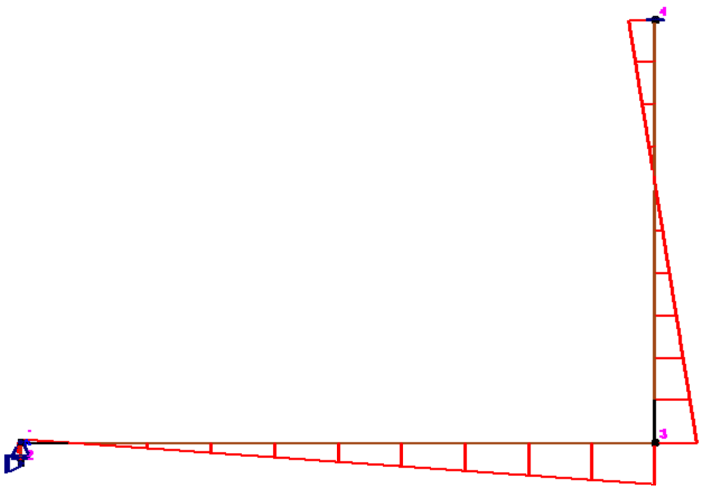
2.4. STATISKE RESULTATER GRAFISK

2.4.1. Forskyvning



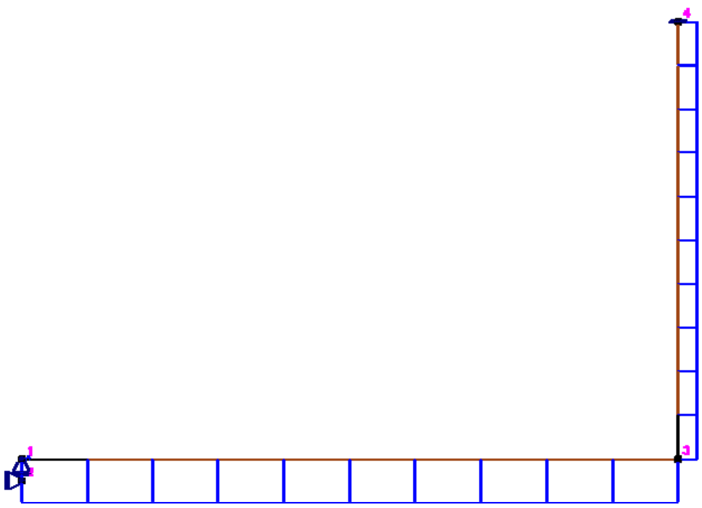
Største forskyvning: 1501,4 mm

2.4.2. Moment



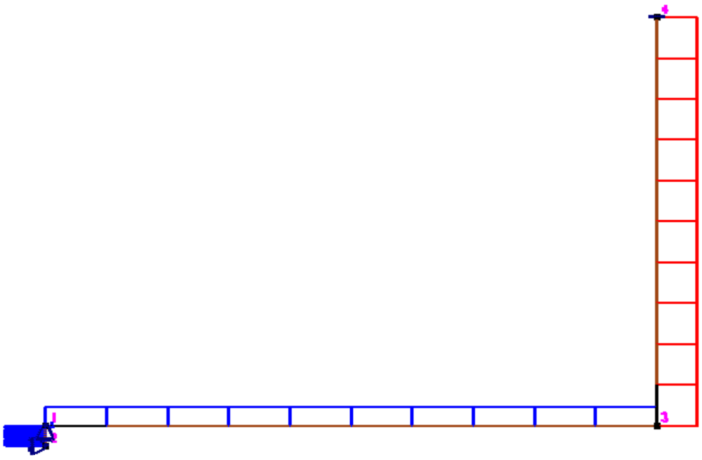
Største moment: 137,14 kN·m

2.4.3 Aksialkraft



Største aksialkraft: -22,36 kN

2.4.4. Skjærkraft



Største skjærkraft: 22,36 kN

3. KAPASITETSKONTROLL

3.1. UTNYTTELSESGRAD EN 1993

Seg. nr.	Snitt [mm]	Pl.tv	Pl.stab	El.tv	El.stab	Info
1	0	0,05	0,05	0,07	0,07	EN 1993-1-1 6.2.8 (bøyning og skjær)
2	15000	0,61	0,60	0,82	0,81	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)
3	0	0,61	0,60	0,82	0,81	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)

3.2. KAPASITETSKART

Største kapasitetsutnyttelse: 63,10 % (EN 1993-1-1 6.3.3 Ligning (6.62))

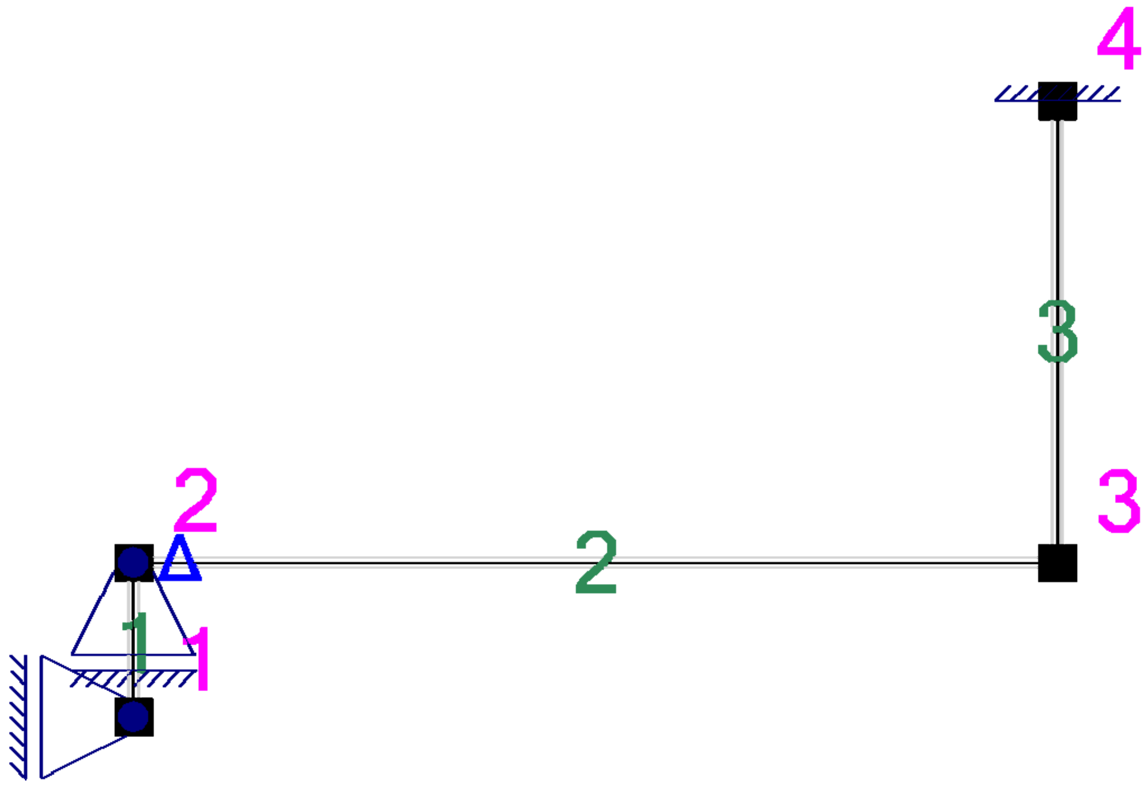
C.b.1

Prosjekttittel: Downscaled Spool [Displacement = 900mm]

Beregning utført: 24.05.2012 13:38:37

Focus Konstruksjon 2012

1. KONSTRUKSJONSMODELL OG LASTER



1.1. KNUTEPUNKTSDATA

Nr.	X [mm]	Z [mm]
1	0	-500
2	0	0
3	3000	0
4	3000	1500

1.2. TVERRSNITTSDATA

Nr.	Navn	Parametre	
1	1" S31803 Downscaled Version	A [mm^2]	409
		Ix [mm^4]	8,7378e+004
		Iy [mm^4]	4,3689e+004
		Iz [mm^4]	4,3689e+004
		Total vekt [kN]	0,16

1.3. MATERIALDATA

1 **Stål S31803** Material: Stål

Fasthetsklasse: Egendefinert

Varmeutv.koeff.: 1,20e-005 °C^-1 Tyngdetetthet: 78,05 kN/m^3

E-modul: 2,0000e+005 N/mm^2   G-modul: 8,1000e+004 N/mm^2

Karakteristiske fasthetsparametre:

f_y = 575,00 N/mm^2 for godstykkelse <= 40,0 mm
f_y = 575,00 N/mm^2 for godstykkelse <= 80,0 mm
f_y = 575,00 N/mm^2 for godstykkelse > 80,0 mm

1.4. SEGMENTDATA

Seg Nr.	Kn.pkt 1	Kn.pkt 2	Tvsn 1	Tvsn 2	Material
1	1	2	1" S31803 Downscaled Version	1" S31803 Downscaled Version	Stål S31803
2	2	3	1" S31803 Downscaled Version	1" S31803 Downscaled Version	Stål S31803
3	3	4	1" S31803 Downscaled Version	1" S31803 Downscaled Version	Stål S31803

1.4.1. SEGMENTDATA EN 1993

Seg. nr.	Gamma_M0	Gamma_M1	L_ky [mm]	L_kz [mm]	L_eff [mm]
1	1,05	1,05	500	500	500
2	1,05	1,05	3000	3000	3000
3	1,05	1,05	1500	1500	1500

1.5. RANDBETINGELSER

Seg Nr.	X [mm]	Z [mm]	Frih.gr. X	Z	RotY
3	3000	1500	F	F	F
1	0	-500	F		
1	0	0		900,0	

Forklaring til frihetsgrader: F = fastholdt, (blank) = fri
Tall betyr foreskreven forskyvning [mm]

1.7. LASTTILFELLER

1.8. LASTKOMBINASJON

Beregning utført for lastkombinasjon
(1) Lastkombinasjon 900
Grensetilstand: Brudd

1,00 * <Foreskrevne forskyvninger>

2. STATISKE BEREGNINGER

2.1. KNUTEPUNKTSRESULTATER

2.1.1. Forskyvninger

Nr.	u [mm]	w [mm]	rotY [°]
1	0,0	900,0	11,1
2	106,5	900,0	14,5
3	106,3	0,0	2,1
4	0,0	0,0	0,0

2.1.2. Residualkrefter

Nr.	Rx [kN]	Rz [kN]	My [kN·m]
1	4,17	0,00	0,00
2	0,00	1,81	0,00
3	0,00	0,00	0,00
4	-4,17	-1,81	2,91

2.2. OPPLEGGSKREFTER

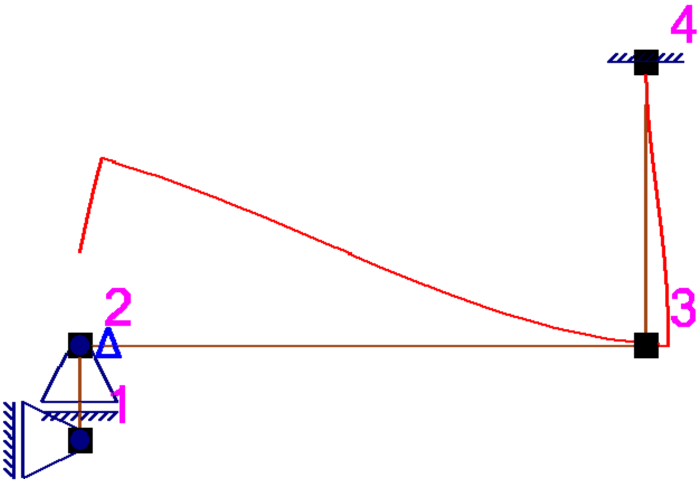
Seg Nr.	X [mm]	Z [mm]	Rx [kN]	Rz [kN]	My [kN·m]
3	3000	1500	-4,17	-1,81	2,91
1	0	-500	4,17	0,00	0,00
1	0	0	0,00	1,81	0,00
	Sum		0,00	0,00	

2.3. SEGMENTRESULTATER

Seg Nr.	Snitt mm	My [kN·m]	N [kN]	Vz [kN]	u [mm]	w [mm]
1	0	0,00	0,00	4,17	0,0	900,0
	500	2,08	0,00	4,17	106,5	900,0
	500	2,08	0,00	4,17	106,5	900,0
2	0	2,08	-4,17	-1,81	106,5	900,0
	3000	-3,34	-4,17	-1,81	106,3	0,0
	3000	-3,34	-4,17	-1,81	106,3	0,0
3	0	-3,34	-1,81	4,17	106,3	0,0
	0	-3,34	-1,81	4,17	106,3	0,0
	1500	2,91	-1,81	4,17	0,0	0,0

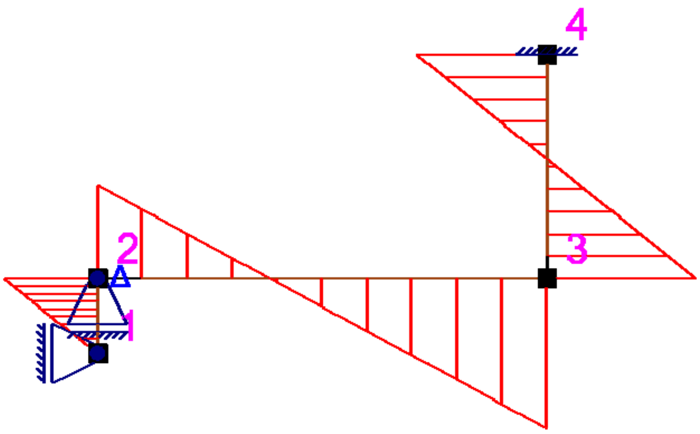
2.4. STATISKE RESULTATER GRAFISK

2.4.1. Forskyvning



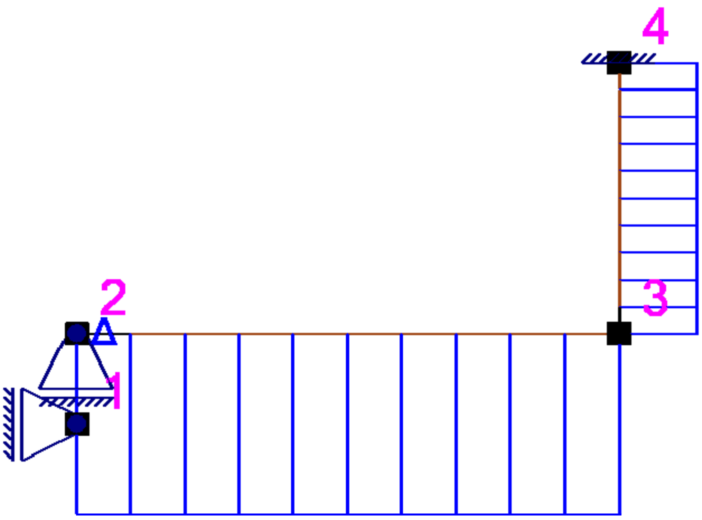
Største forskyvning: 906,3 mm

2.4.2. Moment



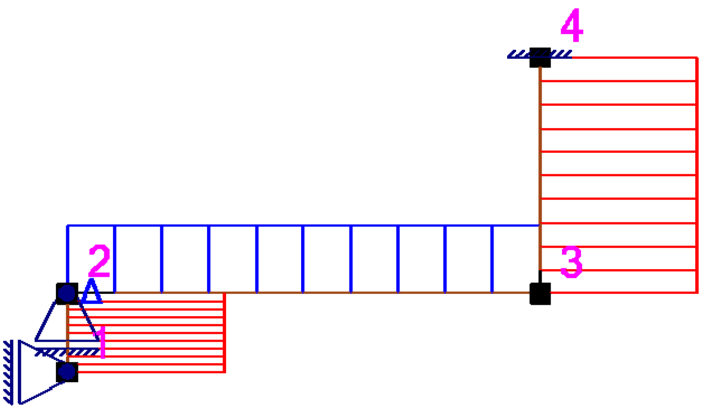
Største moment: 3,34 kN·m

2.4.3 Aksialkraft



Største aksialkraft: -4,17 kN

2.4.4. Skjærkraft



Største skjærkraft: 4,17 kN

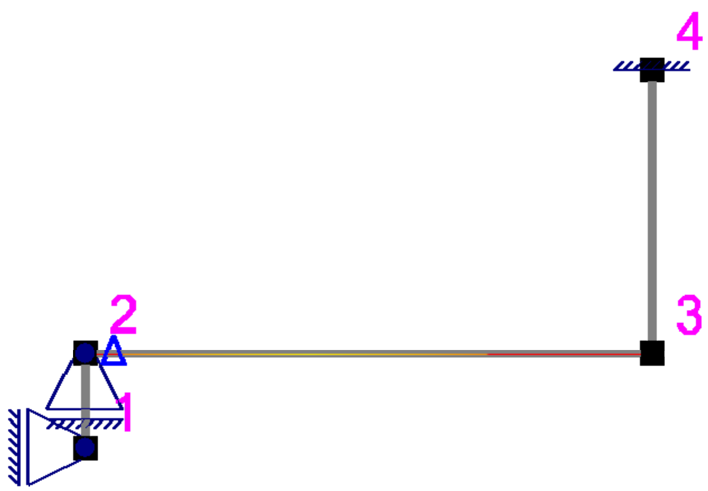
3. KAPASITETSKONTROLL

3.1. UTNYTTELSESGRAD EN 1993

Seg. nr.	Snitt [mm]	Pl.tv	Pl.stab	El.tv	El.stab	Info
1	0	0,05	0,00	0,06	0,00	EN 1993-1-1 6.2.6 om z-aksen
	50	0,10	0,10	0,15	0,15	EN 1993-1-1 6.2.8 (bøyning og skjær)
	100	0,20	0,20	0,29	0,29	EN 1993-1-1 6.2.8 (bøyning og skjær)
	150	0,30	0,30	0,44	0,44	EN 1993-1-1 6.2.8 (bøyning og skjær)
	200	0,40	0,40	0,58	0,58	EN 1993-1-1 6.2.8 (bøyning og skjær)
	250	0,50	0,50	0,73	0,73	EN 1993-1-1 6.2.8 (bøyning og skjær)
	300	0,60	0,60	0,87	0,87	EN 1993-1-1 6.2.8 (bøyning og skjær)
	350	0,70	0,70	1,02	1,02	EN 1993-1-1 6.2.8 (bøyning og skjær)
	400	0,80	0,80	1,16	1,16	EN 1993-1-1 6.2.8 (bøyning og skjær)
	450	0,90	0,90	1,31	1,31	EN 1993-1-1 6.2.8 (bøyning og skjær)

Seg. nr.	Snitt [mm]	Pl.tv	Pl.stab	El.tv	El.stab	Info
	500	1,01	1,00	1,45	1,45	EN 1993-1-1 6.2.8 (bøyning og skjær)
2	0	1,05	1,57	1,47	1,95	EN 1993-1-1 6.3.3 Ligning (6.61)
	300	0,76	1,29	1,09	1,57	EN 1993-1-1 6.3.3 Ligning (6.61)
	600	0,50	0,90	0,72	1,09	EN 1993-1-1 6.3.3 Ligning (6.61)
	900	0,24	0,67	0,34	0,75	EN 1993-1-1 6.3.3 Ligning (6.61)
	1200	0,06	0,51	0,08	0,53	EN 1993-1-1 6.3.3 Ligning (6.61)
	1500	0,32	0,74	0,46	0,86	EN 1993-1-1 6.3.3 Ligning (6.61)
	1800	0,58	0,97	0,84	1,19	EN 1993-1-1 6.3.3 Ligning (6.61)
	2100	0,84	1,38	1,21	1,69	EN 1993-1-1 6.3.3 Ligning (6.61)
	2400	1,22	1,66	1,59	2,08	EN 1993-1-1 6.3.3 Ligning (6.61)
	2700	1,87	1,95	1,97	2,46	EN 1993-1-1 6.3.3 Ligning (6.61)
	3000	2,65	2,23	2,35	2,85	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)
3	0	2,62	1,68	2,34	2,40	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)
	150	1,73	1,37	1,90	1,96	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)
	300	1,03	1,07	1,47	1,52	EN 1993-1-1 6.3.3 Ligning (6.61)
	450	0,71	0,77	1,03	1,08	EN 1993-1-1 6.3.3 Ligning (6.61)
	600	0,41	0,46	0,59	0,64	EN 1993-1-1 6.3.3 Ligning (6.61)
	750	0,11	0,16	0,16	0,21	EN 1993-1-1 6.3.3 Ligning (6.61)
	900	0,21	0,25	0,29	0,34	EN 1993-1-1 6.3.3 Ligning (6.61)
	1050	0,51	0,56	0,73	0,78	EN 1993-1-1 6.3.3 Ligning (6.61)
	1200	0,81	0,86	1,17	1,22	EN 1993-1-1 6.3.3 Ligning (6.61)
	1350	1,23	1,16	1,60	1,66	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)
	1500	1,99	1,47	2,04	2,10	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)

3.2. KAPASITETSKART



Største kapasitetsutnyttelse: 265,08 % (EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft))

INNHOLDSFORTEGNELSE

1. KONSTRUKSJONSMODELL OG LASTER SIDE: 1
1.1. KNUTEPUNKTSDATA SIDE: 1
1.2. TVERRSNITTSDATA SIDE: 1
1.3. MATERIALDATA SIDE: 1
1.4. SEGMENTDATA SIDE: 2
1.4.1. SEGMENTDATA EN 1993 SIDE: 2
1.5. RANDBETINGELSER SIDE: 2
1.7. LASTTILFELLER SIDE: 2
1.8. LASTKOMBINASJON SIDE: 2
2. STATISKE BEREGNINGER SIDE: 2
2.1. KNUTEPUNKTSRESULTATER SIDE: 2
2.1.1. Forskyvninger SIDE: 3
2.1.2. Residualkrefter SIDE: 3
2.2. OPPLEGGSKREFTER SIDE: 3
2.3. SEGMENTRESULTATER SIDE: 3
2.4. STATISKE RESULTATER GRAFISK SIDE: 3
2.4.1. Forskyvning SIDE: 3
2.4.2. Moment SIDE: 4
2.4.3 Aksialkraft SIDE: 4
2.4.4. Skjærkraft SIDE: 5
3. KAPASITETSKONTROLL SIDE: 5
3.1. UTNYTTELSESGRAD EN 1993 SIDE: 5
3.2. KAPASITETSKART SIDE: 6

C.b.2

Prosjekttittel: Downscaled Spool [Displacement = 700mm]

Beregning utført: 24.05.2012 13:36:17

Focus Konstruksjon 2012

2.1.1. Forskyvninger

Nr.	u [mm]	w [mm]	rotY [°]
1	0,0	700,0	8,6
2	82,8	700,0	11,3
3	82,7	0,0	1,6
4	0,0	0,0	0,0

2.1.2. Residualkrefter

Nr.	Rx [kN]	Rz [kN]	My [kN·m]
1	3,24	0,00	0,00
2	0,00	1,41	0,00
3	0,00	0,00	0,00
4	-3,24	-1,41	2,26

2.2. OPPLEGGSKREFTER

Seg Nr.	X [mm]	Z [mm]	Rx [kN]	Rz [kN]	My [kN·m]
3	3000	1500	-3,24	-1,41	2,26
1	0	-500	3,24	0,00	0,00
1	0	0	0,00	1,41	0,00
	Sum		0,00	0,00	

2.3. SEGMENTRESULTATER

Seg Nr.	Snitt mm	My [kN·m]	N [kN]	Vz [kN]	u [mm]	w [mm]
1	0	0,00	0,00	3,24	0,0	700,0
	500	1,62	0,00	3,24	82,8	700,0
	500	1,62	0,00	3,24	82,8	700,0
2	0	1,62	-3,24	-1,41	82,8	700,0
	3000	-2,60	-3,24	-1,41	82,7	0,0
	3000	-2,60	-3,24	-1,41	82,7	0,0
3	0	-2,60	-1,41	3,24	82,7	0,0
	0	-2,60	-1,41	3,24	82,7	0,0
	1500	2,26	-1,41	3,24	0,0	0,0

2.4. STATISKE RESULTATER GRAFISK

2.4.1. Forskyvning

C.b.3

Prosjekttittel: Downscaled Spool [Displacement = 500mm]

Beregning utført: 24.05.2012 13:25:48

Focus Konstruksjon 2012

2.1.1. Forskyvninger

Nr.	u [mm]	w [mm]	rotY [°]
1	59,2	500,0	8,0
2	0,0	500,0	6,1
3	59,1	0,0	1,2
4	0,0	0,0	0,0

2.1.2. Residualkrefter

Nr.	Rx [kN]	Rz [kN]	My [kN·m]
1	0,00	1,00	0,00
2	2,31	0,00	0,00
3	0,00	0,00	0,00
4	-2,31	-1,00	1,62

2.2. OPPLEGGSKREFTER

Seg Nr.	X [mm]	Z [mm]	Rx [kN]	Rz [kN]	My [kN·m]
1	0	-500	2,31	0,00	0,00
1	0	0	0,00	1,00	0,00
3	3000	1500	-2,31	-1,00	1,62
	Sum		0,00	0,00	

2.3. SEGMENTRESULTATER

Seg Nr.	Snitt mm	My [kN·m]	N [kN]	Vz [kN]	u [mm]	w [mm]
1	0	1,16	0,00	-2,31	59,2	500,0
	0	1,16	0,00	-2,31	59,2	500,0
	500	0,00	0,00	-2,31	0,0	500,0
2	0	1,16	-2,31	-1,00	59,2	500,0
	3000	-1,86	-2,31	-1,00	59,1	0,0
	3000	-1,86	-2,31	-1,00	59,1	0,0
3	0	-1,86	-1,00	2,31	59,1	0,0
	0	-1,86	-1,00	2,31	59,1	0,0
	1500	1,62	-1,00	2,31	0,0	0,0

2.4. STATISKE RESULTATER GRAFISK

2.4.1. Forskyvning

C.b.4

Prosjekttittel: Downscaled Spool [Displacement = 300mm]

Beregning utført: 24.05.2012 13:23:44

Focus Konstruksjon 2012

2.1.1. Forskyvninger

Nr.	u [mm]	w [mm]	rotY [°]
1	35,5	300,0	4,8
2	0,0	300,0	3,7
3	35,4	0,0	0,7
4	0,0	0,0	0,0

2.1.2. Residualkrefter

Nr.	Rx [kN]	Rz [kN]	My [kN·m]
1	0,00	0,60	0,00
2	1,39	0,00	0,00
3	0,00	0,00	0,00
4	-1,39	-0,60	0,97

2.2. OPPLEGGSKREFTER

Seg Nr.	X [mm]	Z [mm]	Rx [kN]	Rz [kN]	My [kN·m]
1	0	-500	1,39	0,00	0,00
1	0	0	0,00	0,60	0,00
3	3000	1500	-1,39	-0,60	0,97
	Sum		0,00	0,00	

2.3. SEGMENTRESULTATER

Seg Nr.	Snitt mm	My [kN·m]	N [kN]	Vz [kN]	u [mm]	w [mm]
1	0	0,69	0,00	-1,39	35,5	300,0
	0	0,69	0,00	-1,39	35,5	300,0
	500	0,00	0,00	-1,39	0,0	300,0
2	0	0,69	-1,39	-0,60	35,5	300,0
	3000	-1,11	-1,39	-0,60	35,4	0,0
	3000	-1,11	-1,39	-0,60	35,4	0,0
3	0	-1,11	-0,60	1,39	35,4	0,0
	0	-1,11	-0,60	1,39	35,4	0,0
	1500	0,97	-0,60	1,39	0,0	0,0

2.4. STATISKE RESULTATER GRAFISK

2.4.1. Forskyvning

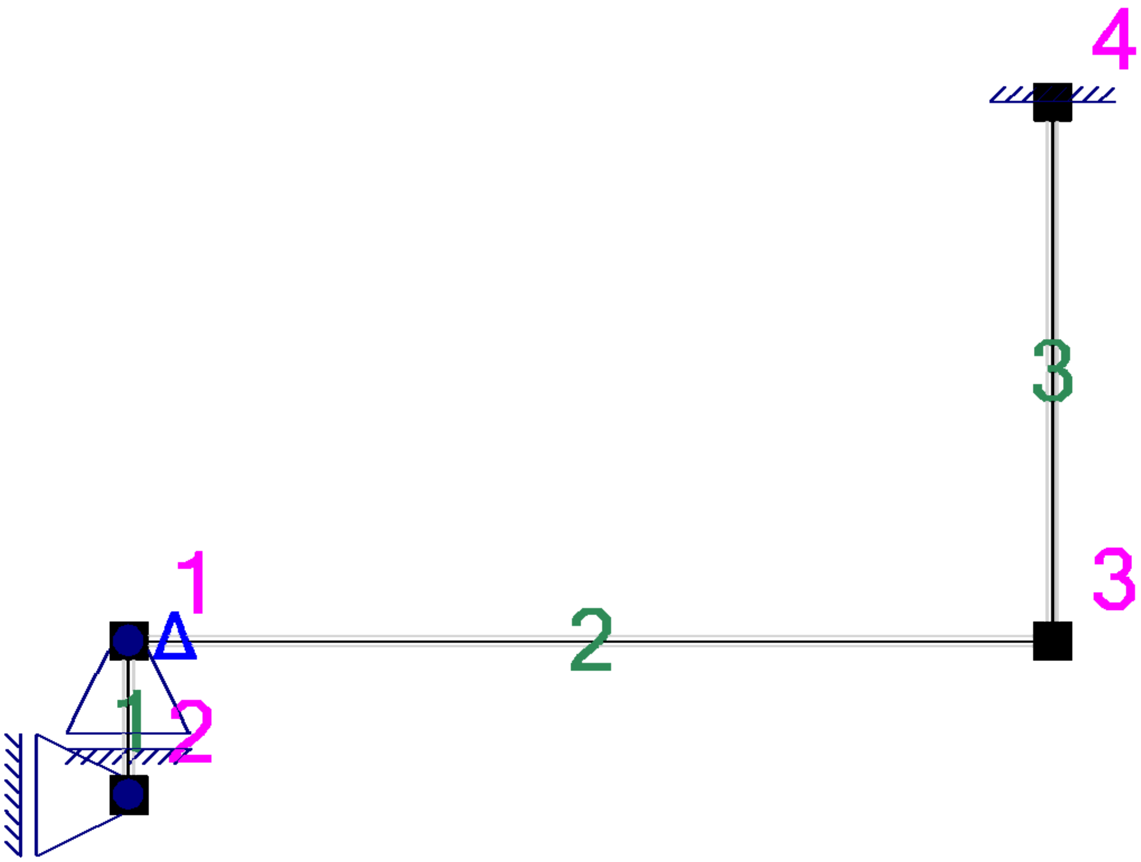
C.c.1

Prosjekttittel: Downscaled Spool [Displacement = 900mm]

Beregning utført: 24.05.2012 13:17:19

Focus Konstruksjon 2012

1. KONSTRUKSJONSMODELL OG LASTER



1.1. KNUTEPUNKTSDATA

Nr.	X [mm]	Z [mm]
1	0	0
2	0	-500
3	3000	0
4	3000	1750

1.2. TVERRSNITTSDATA

Nr.	Navn	Parametre	
1	1" S31803 Downscaled Version	A [mm^2]	409
		Ix [mm^4]	8,7378e+004
		Iy [mm^4]	4,3689e+004
		Iz [mm^4]	4,3689e+004
		Total vekt [kN]	0,17

1.3. MATERIALDATA

1 **Stål S31803** Material: Stål

Fasthetsklasse: Egendefinert

Varmeutv.koeff.: 1,20e-005 °C^-1 Tyngdetetthet: 78,05 kN/m^3

E-modul: 2,0000e+005 N/mm^2 G-modul: 8,1000e+004 N/mm^2

Karakteristiske fasthetsparametre:

f_y = 575,00 N/mm^2 for godstykkelse <= 40,0 mm
f_y = 575,00 N/mm^2 for godstykkelse <= 80,0 mm
f_y = 575,00 N/mm^2 for godstykkelse > 80,0 mm

1.4. SEGMENTDATA

Seg Nr.	Kn.pkt 1	Kn.pkt 2	Tvsn 1	Tvsn 2	Material
1	1	2	1" S31803 Downscaled Version	1" S31803 Downscaled Version	Stål S31803
2	1	3	1" S31803 Downscaled Version	1" S31803 Downscaled Version	Stål S31803
3	3	4	1" S31803 Downscaled Version	1" S31803 Downscaled Version	Stål S31803

1.4.1. SEGMENTDATA EN 1993

Seg. nr.	Gamma_M0	Gamma_M1	L_ky [mm]	L_kz [mm]	L_eff [mm]
1	1,05	1,05	500	500	500
2	1,05	1,05	3000	3000	3000
3	1,05	1,05	1750	1750	1750

1.5. RANDBETINGELSER

Seg Nr.	X [mm]	Z [mm]	Frih.gr. X	Z	RotY
1	0	-500	F		
1	0	0		900,0	
3	3000	1750	F	F	F

Forklaring til frihetsgrader: F = fastholdt, (blank) = fri
Tall betyr foreskreven forskyvning [mm]

1.7. LASTTILFELLER

1.8. LASTKOMBINASJON

Beregning utført for lastkombinasjon
(1) Lastkombinasjon 900

Grensetilstand: Brudd

1,00 * <Foreskrevne forskyvninger>

2. STATISKE BEREGNINGER

2.1. KNUTEPUNKTSRESULTATER

2.1.1. Forskyvninger

Nr.	u [mm]	w [mm]	rotY [°]
1	129,0	900,0	16,6
2	0,0	900,0	13,9
3	128,8	0,0	2,5
4	0,0	0,0	0,0

2.1.2. Residualkrefter

Nr.	Rx [kN]	Rz [kN]	My [kN·m]
1	0,00	1,56	0,00
2	3,25	0,00	0,00
3	0,00	0,00	0,00
4	-3,25	-1,56	2,63

2.2. OPPLEGGSKREFTER

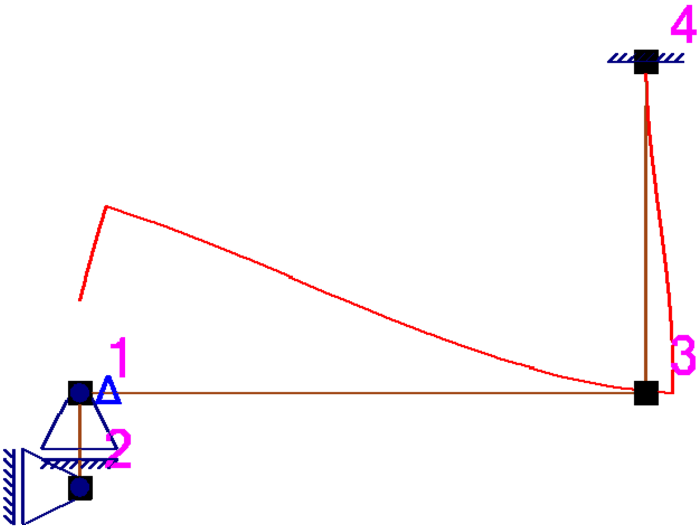
Seg Nr.	X [mm]	Z [mm]	Rx [kN]	Rz [kN]	My [kN·m]
1	0	-500	3,25	0,00	0,00
1	0	0	0,00	1,56	0,00
3	3000	1750	-3,25	-1,56	2,63
	Sum		0,00	0,00	

2.3. SEGMENTRESULTATER

Seg Nr.	Snitt mm	My [kN·m]	N [kN]	Vz [kN]	u [mm]	w [mm]
1	0	1,63	0,00	-3,25	129,0	900,0
	0	1,63	0,00	-3,25	129,0	900,0
	500	0,00	0,00	-3,25	0,0	900,0
2	0	1,63	-3,25	-1,56	129,0	900,0
	3000	-3,06	-3,25	-1,56	128,8	0,0
	3000	-3,06	-3,25	-1,56	128,8	0,0
3	0	-3,06	-1,56	3,25	128,8	0,0
	0	-3,06	-1,56	3,25	128,8	0,0
	1750	2,63	-1,56	3,25	0,0	0,0

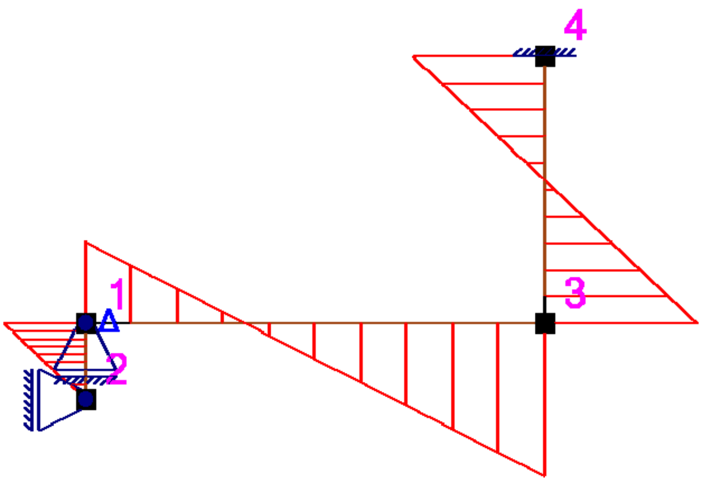
2.4. STATISKE RESULTATER GRAFISK

2.4.1. Forskyvning



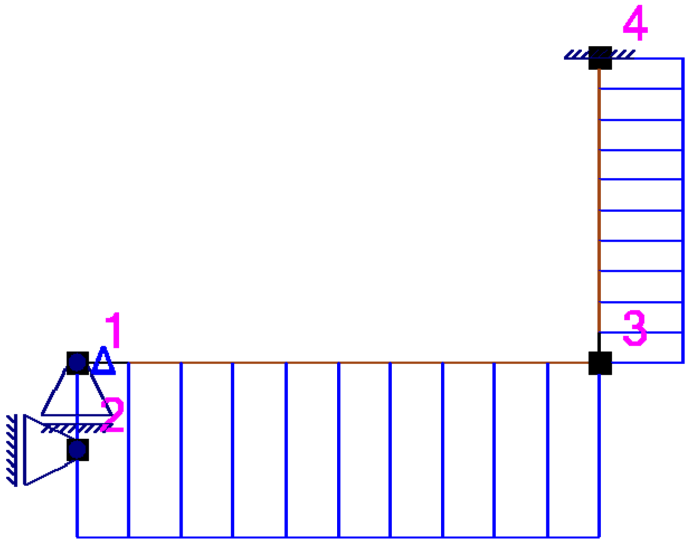
Største forskyvning: 909,2 mm

2.4.2. Moment



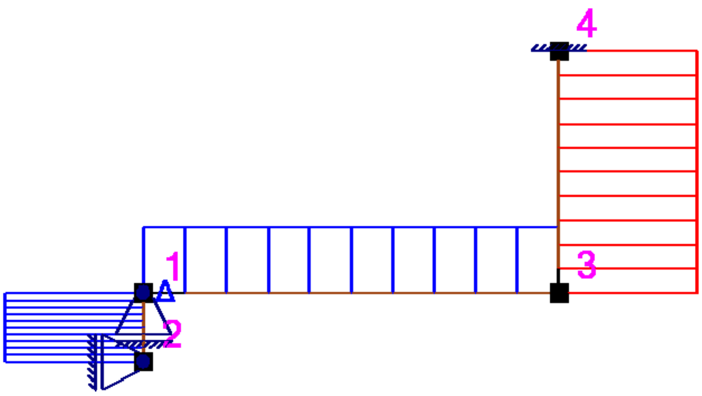
Største moment: 3,06 kN·m

2.4.3 Aksialkraft



Største aksialkraft: -3,25 kN

2.4.4. Skjærkraft



Største skjærkraft: 3,25 kN

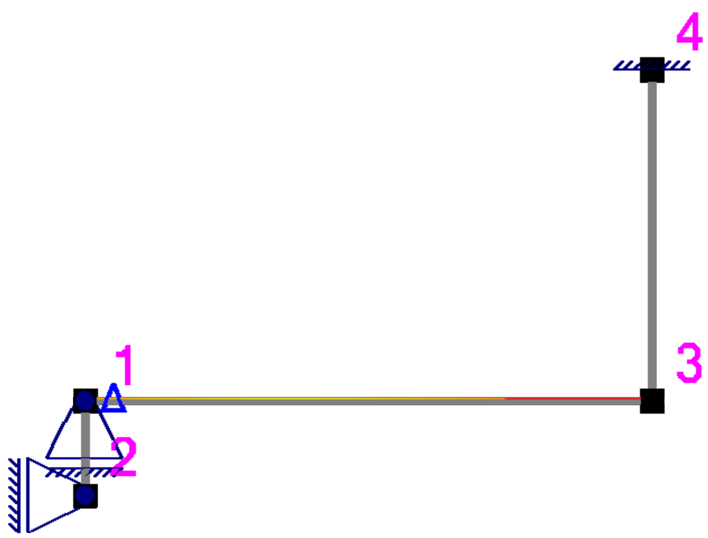
3. KAPASITETSKONTROLL

3.1. UTNYTTELSESGRAD EN 1993

Seg. nr.	Snitt [mm]	Pl.tv	Pl.stab	El.tv	El.stab	Info
1	0	0,78	0,78	1,14	1,14	EN 1993-1-1 6.2.8 (bøyning og skjær)
	50	0,71	0,71	1,02	1,02	EN 1993-1-1 6.2.8 (bøyning og skjær)
	100	0,63	0,63	0,91	0,91	EN 1993-1-1 6.2.8 (bøyning og skjær)
	150	0,55	0,55	0,79	0,79	EN 1993-1-1 6.2.8 (bøyning og skjær)
	200	0,47	0,47	0,68	0,68	EN 1993-1-1 6.2.8 (bøyning og skjær)
	250	0,39	0,39	0,57	0,57	EN 1993-1-1 6.2.8 (bøyning og skjær)
	300	0,31	0,31	0,45	0,45	EN 1993-1-1 6.2.8 (bøyning og skjær)
	350	0,24	0,24	0,34	0,34	EN 1993-1-1 6.2.8 (bøyning og skjær)
	400	0,16	0,16	0,23	0,23	EN 1993-1-1 6.2.8 (bøyning og skjær)
	450	0,08	0,08	0,11	0,11	EN 1993-1-1 6.2.8 (bøyning og skjær)

Seg. nr.	Snitt [mm]	Pl.tv	Pl.stab	El.tv	El.stab	Info
	500	0,04	0,00	0,05	0,00	EN 1993-1-1 6.2.6 om z-aksen
2	0	0,80	0,98	1,15	1,32	EN 1993-1-1 6.3.2 Ligning (6.54) om y-aksen
	300	0,57	0,66	0,82	0,81	EN 1993-1-1 6.3.3 Ligning (6.61)
	600	0,35	0,54	0,50	0,62	EN 1993-1-1 6.3.3 Ligning (6.61)
	900	0,12	0,43	0,17	0,45	EN 1993-1-1 6.3.3 Ligning (6.61)
	1200	0,13	0,43	0,19	0,46	EN 1993-1-1 6.3.3 Ligning (6.61)
	1500	0,36	0,55	0,51	0,63	EN 1993-1-1 6.3.3 Ligning (6.61)
	1800	0,59	0,67	0,84	0,83	EN 1993-1-1 6.3.3 Ligning (6.61)
	2100	0,81	0,99	1,17	1,34	EN 1993-1-1 6.3.2 Ligning (6.54) om y-aksen
	2400	1,08	1,27	1,50	1,72	EN 1993-1-1 6.3.2 Ligning (6.54) om y-aksen
	2700	1,60	1,56	1,82	2,10	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)
	3000	2,22	1,84	2,15	2,48	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)
3	0	2,20	1,56	2,14	2,23	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)
	175	1,46	1,28	1,75	1,83	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)
	350	0,93	1,00	1,35	1,42	EN 1993-1-1 6.3.3 Ligning (6.61)
	525	0,66	0,72	0,95	1,02	EN 1993-1-1 6.3.3 Ligning (6.61)
	700	0,38	0,45	0,55	0,62	EN 1993-1-1 6.3.3 Ligning (6.61)
	875	0,11	0,17	0,16	0,21	EN 1993-1-1 6.3.3 Ligning (6.61)
	1050	0,18	0,24	0,26	0,31	EN 1993-1-1 6.3.3 Ligning (6.61)
	1225	0,45	0,51	0,65	0,72	EN 1993-1-1 6.3.3 Ligning (6.61)
	1400	0,73	0,79	1,05	1,12	EN 1993-1-1 6.3.3 Ligning (6.61)
	1575	1,00	1,07	1,45	1,52	EN 1993-1-1 6.3.3 Ligning (6.61)
	1750	1,63	1,35	1,84	1,93	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)

3.2. KAPASITETSKART



Største kapasitetsutnyttelse: 221,89 % (EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft))

INNHOLDSFORTEGNELSE

1. KONSTRUKSJONSMODELL OG LASTER SIDE: 1
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1.3. MATERIALDATA SIDE: 1
1.4. SEGMENTDATA SIDE: 2
1.4.1. SEGMENTDATA EN 1993 SIDE: 2
1.5. RANDBETINGELSER SIDE: 2
1.7. LASTTILFELLER SIDE: 2
1.8. LASTKOMBINASJON SIDE: 2
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C.c.2

Prosjekttittel: Downscaled Spool [Displacement = 700mm]

Beregning utført: 24.05.2012 13:19:47

Focus Konstruksjon 2012

2.1.1. Forskyvninger

Nr.	u [mm]	w [mm]	rotY [°]
1	100,3	700,0	12,9
2	0,0	700,0	10,8
3	100,2	0,0	1,9
4	0,0	0,0	0,0

2.1.2. Residualkrefter

Nr.	Rx [kN]	Rz [kN]	My [kN·m]
1	0,00	1,22	0,00
2	2,53	0,00	0,00
3	0,00	0,00	0,00
4	-2,53	-1,22	2,05

2.2. OPPLEGGSKREFTER

Seg Nr.	X [mm]	Z [mm]	Rx [kN]	Rz [kN]	My [kN·m]
1	0	-500	2,53	0,00	0,00
1	0	0	0,00	1,22	0,00
3	3000	1750	-2,53	-1,22	2,05
	Sum		0,00	0,00	

2.3. SEGMENTRESULTATER

Seg Nr.	Snitt mm	My [kN·m]	N [kN]	Vz [kN]	u [mm]	w [mm]
1	0	1,27	0,00	-2,53	100,3	700,0
	0	1,27	0,00	-2,53	100,3	700,0
	500	0,00	0,00	-2,53	0,0	700,0
2	0	1,27	-2,53	-1,22	100,3	700,0
	3000	-2,38	-2,53	-1,22	100,2	0,0
	3000	-2,38	-2,53	-1,22	100,2	0,0
3	0	-2,38	-1,22	2,53	100,2	0,0
	0	-2,38	-1,22	2,53	100,2	0,0
	1750	2,05	-1,22	2,53	0,0	0,0

2.4. STATISKE RESULTATER GRAFISK

2.4.1. Forskyvning

C.c.3

Prosjekttittel: Downscaled Spool [Displacement = 500mm]

Beregning utført: 24.05.2012 13:20:50

Focus Konstruksjon 2012

2.1.1. Forskyvninger

Nr.	u [mm]	w [mm]	rotY [°]
1	71,6	500,0	9,2
2	0,0	500,0	7,7
3	71,6	0,0	1,4
4	0,0	0,0	0,0

2.1.2. Residualkrefter

Nr.	Rx [kN]	Rz [kN]	My [kN·m]
1	0,00	0,87	0,00
2	1,81	0,00	0,00
3	0,00	0,00	0,00
4	-1,81	-0,87	1,46

2.2. OPPLEGGSKREFTER

Seg Nr.	X [mm]	Z [mm]	Rx [kN]	Rz [kN]	My [kN·m]
1	0	-500	1,81	0,00	0,00
1	0	0	0,00	0,87	0,00
3	3000	1750	-1,81	-0,87	1,46
	Sum		0,00	0,00	

2.3. SEGMENTRESULTATER

Seg Nr.	Snitt mm	My [kN·m]	N [kN]	Vz [kN]	u [mm]	w [mm]
1	0	0,90	0,00	-1,81	71,6	500,0
	0	0,90	0,00	-1,81	71,6	500,0
	500	0,00	0,00	-1,81	0,0	500,0
2	0	0,90	-1,81	-0,87	71,6	500,0
	3000	-1,70	-1,81	-0,87	71,6	0,0
	3000	-1,70	-1,81	-0,87	71,6	0,0
3	0	-1,70	-0,87	1,81	71,6	0,0
	0	-1,70	-0,87	1,81	71,6	0,0
	1750	1,46	-0,87	1,81	0,0	0,0

2.4. STATISKE RESULTATER GRAFISK

2.4.1. Forskyvning

C.c.4

Prosjekttittel: Downscaled Spool [Displacement = 300mm]

Beregning utført: 24.05.2012 13:21:43

Focus Konstruksjon 2012

2.1.1. Forskyvninger

Nr.	u [mm]	w [mm]	rotY [°]
1	43,0	300,0	5,5
2	0,0	300,0	4,6
3	42,9	0,0	0,8
4	0,0	0,0	0,0

2.1.2. Residualkrefter

Nr.	Rx [kN]	Rz [kN]	My [kN·m]
1	0,00	0,52	0,00
2	1,08	0,00	0,00
3	0,00	0,00	0,00
4	-1,08	-0,52	0,88

2.2. OPPLEGGSKREFTER

Seg Nr.	X [mm]	Z [mm]	Rx [kN]	Rz [kN]	My [kN·m]
1	0	-500	1,08	0,00	0,00
1	0	0	0,00	0,52	0,00
3	3000	1750	-1,08	-0,52	0,88
	Sum		0,00	0,00	

2.3. SEGMENTRESULTATER

Seg Nr.	Snitt mm	My [kN·m]	N [kN]	Vz [kN]	u [mm]	w [mm]
1	0	0,54	0,00	-1,08	43,0	300,0
	0	0,54	0,00	-1,08	43,0	300,0
	500	0,00	0,00	-1,08	0,0	300,0
2	0	0,54	-1,08	-0,52	43,0	300,0
	3000	-1,02	-1,08	-0,52	42,9	0,0
	3000	-1,02	-1,08	-0,52	42,9	0,0
3	0	-1,02	-0,52	1,08	42,9	0,0
	0	-1,02	-0,52	1,08	42,9	0,0
	1750	0,88	-0,52	1,08	0,0	0,0

2.4. STATISKE RESULTATER GRAFISK

2.4.1. Forskyvning

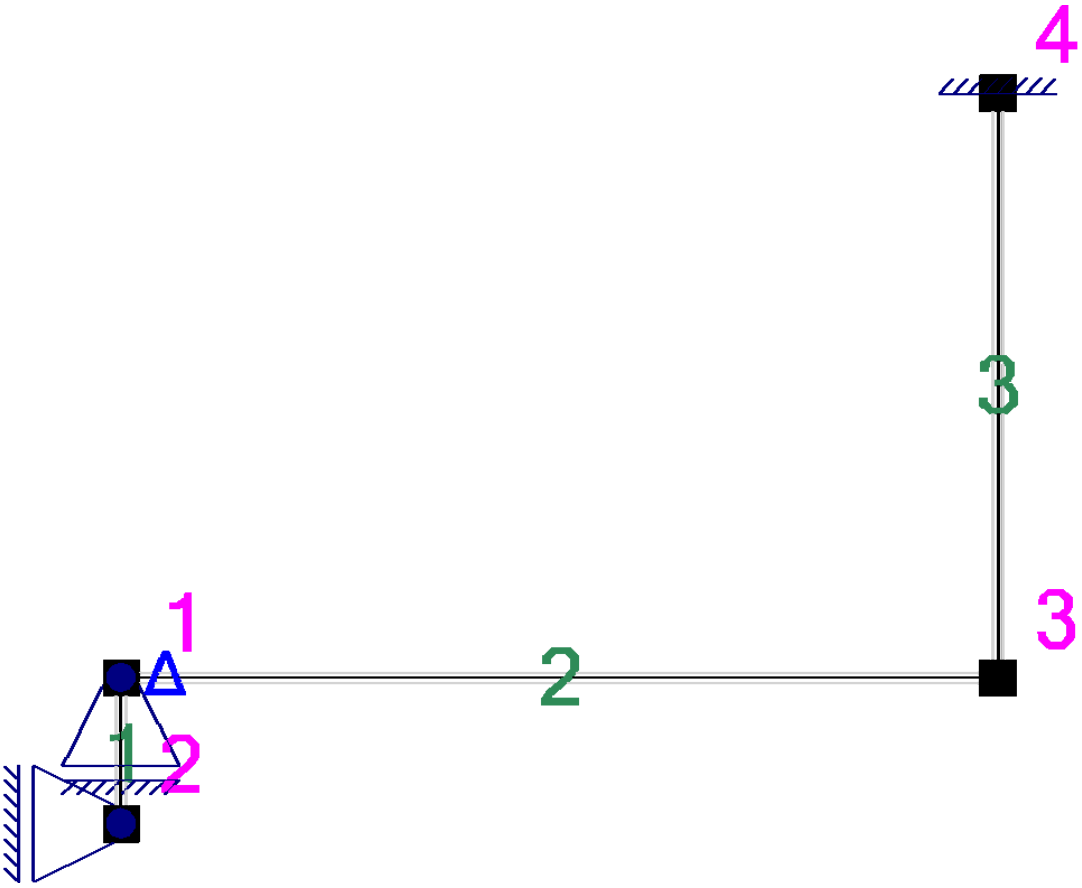
C.d.1

Prosjekttittel: Downscaled Spool [Displacement = 900mm]

Beregning utført: 24.05.2012 13:13:14

Focus Konstruksjon 2012

1. KONSTRUKSJONSMODELL OG LASTER



1.1. KNUTEPUNKTSDATA

Nr.	X [mm]	Z [mm]
1	0	0
2	0	-500
3	3000	0
4	3000	2000

1.2. TVERRSNITTSDATA

Nr.	Navn	Parametre	
1	1" S31803 Downscaled Ve	A [mm^2]	409
		Ix [mm^4]	8,7378e+004
		Iy [mm^4]	4,3689e+004
		Iz [mm^4]	4,3689e+004
		Total vekt [kN]	0,18

1.3. MATERIALDATA

1 **Stål S31803** Material: Stål

Fasthetsklasse: Egendefinert

Varmeutv.koeff.: 1,20e-005 °C^-1 Tyngdetetthet: 78,05 kN/m^3

E-modul: 2,0000e+005 N/mm^2   G-modul: 8,1000e+004 N/mm^2

Karakteristiske fasthetsparametre:

f_y = 575,00 N/mm^2 for godstykkelse <= 40,0 mm
f_y = 575,00 N/mm^2 for godstykkelse <= 80,0 mm
f_y = 575,00 N/mm^2 for godstykkelse > 80,0 mm

1.4. SEGMENTDATA

Seg Nr.	Kn.pkt 1	Kn.pkt 2	Tvsn 1	Tvsn 2	Material
1	1	2	1" S31803 Downscaled Version	1" S31803 Downscaled Version	Stål S31803
2	1	3	1" S31803 Downscaled Version	1" S31803 Downscaled Version	Stål S31803
3	3	4	1" S31803 Downscaled Version	1" S31803 Downscaled Version	Stål S31803

1.4.1. SEGMENTDATA EN 1993

Seg. nr.	Gamma_M0	Gamma_M1	L_ky [mm]	L_kz [mm]	L_eff [mm]
1	1,05	1,05	500	500	500
2	1,05	1,05	3000	3000	3000
3	1,05	1,05	2000	2000	2000

1.5. RANDBETINGELSER

Seg Nr.	X [mm]	Z [mm]	Frih.gr. X	Z	RotY
1	0	-500	F		
1	0	0		900,0	
3	3000	2000	F	F	F

Forklaring til frihetsgrader: F = fastholdt, (blank) = fri
Tall betyr foreskreven forskyvning [mm]

1.7. LASTTILFELLER

1.8. LASTKOMBINASJON

Beregning utført for lastkombinasjon
(1) Lastkombinasjon 900

Grensetilstand: Brudd

1,00 * <Foreskrevne forskyvninger>

2. STATISKE BEREGNINGER

2.1. KNUTEPUNKTSRESULTATER

2.1.1. Forskyvninger

Nr.	u [mm]	w [mm]	rotY [°]
1	144,3	900,0	17,9
2	0,0	900,0	15,8
3	144,2	0,0	3,0
4	0,0	0,0	0,0

2.1.2. Residualkrefter

Nr.	Rx [kN]	Rz [kN]	My [kN·m]
1	0,00	1,37	0,00
2	2,58	0,00	0,00
3	0,00	0,00	0,00
4	-2,58	-1,37	2,35

2.2. OPPLEGGSKREFTER

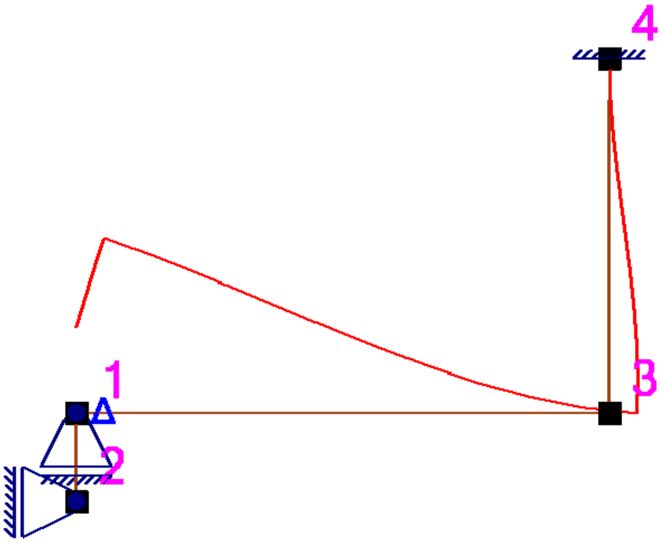
Seg Nr.	X [mm]	Z [mm]	Rx [kN]	Rz [kN]	My [kN·m]
1	0	-500	2,58	0,00	0,00
1	0	0	0,00	1,37	0,00
3	3000	2000	-2,58	-1,37	2,35
	Sum		0,00	0,00	

2.3. SEGMENTRESULTATER

Seg Nr.	Snitt mm	My [kN·m]	N [kN]	Vz [kN]	u [mm]	w [mm]
1	0	1,29	0,00	-2,58	144,3	900,0
	0	1,29	0,00	-2,58	144,3	900,0
	500	0,00	0,00	-2,58	0,0	900,0
2	0	1,29	-2,58	-1,37	144,3	900,0
	3000	-2,81	-2,58	-1,37	144,2	0,0
	3000	-2,81	-2,58	-1,37	144,2	0,0
3	0	-2,81	-1,37	2,58	144,2	0,0
	0	-2,81	-1,37	2,58	144,2	0,0
	2000	2,35	-1,37	2,58	0,0	0,0

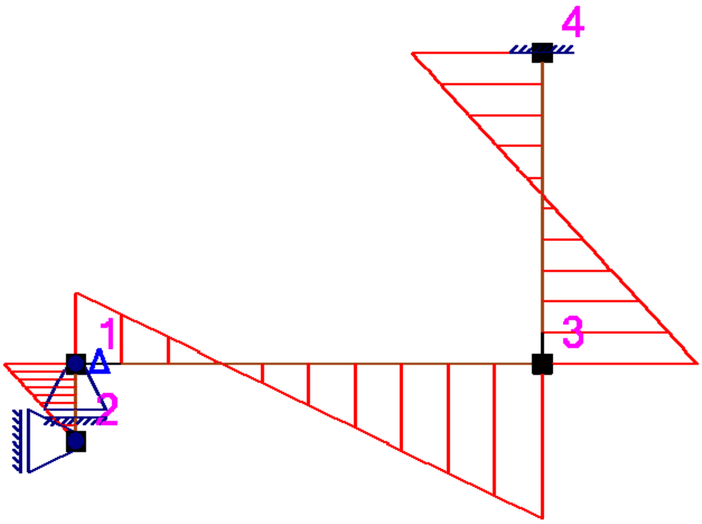
2.4. STATISKE RESULTATER GRAFISK

2.4.1. Forskyvning



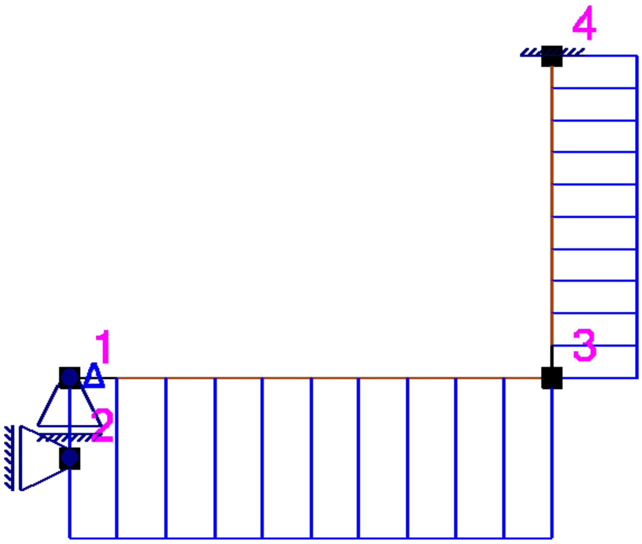
Største forskyvning: 911,5 mm

2.4.2. Moment



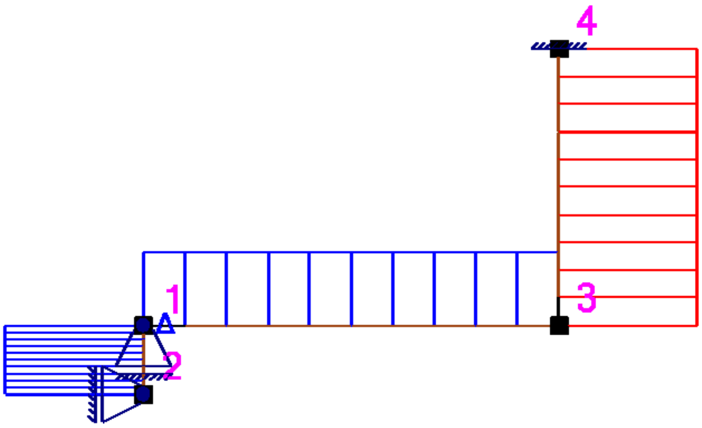
Største moment: 2,81 kN·m

2.4.3 Aksialkraft



Største aksialkraft: -2,58 kN

2.4.4. Skjærkraft



Største skjærkraft: 2,58 kN

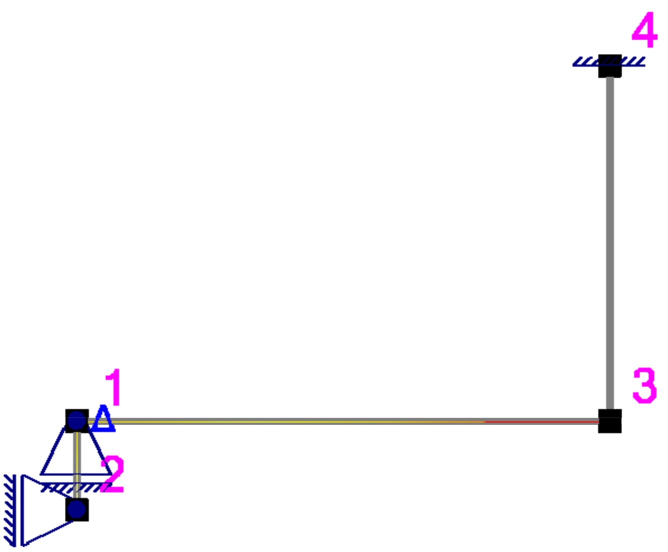
3. KAPASITETSKONTROLL

3.1. UTNYTTELSESGRAD EN 1993

Seg. nr.	Snitt [mm]	Pl.tv	Pl.stab	El.tv	El.stab	Info
1	0	0,62	0,62	0,90	0,90	EN 1993-1-1 6.2.8 (bøyning og skjær)
	50	0,56	0,56	0,81	0,81	EN 1993-1-1 6.2.8 (bøyning og skjær)
	100	0,50	0,50	0,72	0,72	EN 1993-1-1 6.2.8 (bøyning og skjær)
	150	0,43	0,43	0,63	0,63	EN 1993-1-1 6.2.8 (bøyning og skjær)
	200	0,37	0,37	0,54	0,54	EN 1993-1-1 6.2.8 (bøyning og skjær)
	250	0,31	0,31	0,45	0,45	EN 1993-1-1 6.2.8 (bøyning og skjær)
	300	0,25	0,25	0,36	0,36	EN 1993-1-1 6.2.8 (bøyning og skjær)
	350	0,19	0,19	0,27	0,27	EN 1993-1-1 6.2.8 (bøyning og skjær)
	400	0,12	0,12	0,18	0,18	EN 1993-1-1 6.2.8 (bøyning og skjær)
	450	0,06	0,06	0,09	0,09	EN 1993-1-1 6.2.8 (bøyning og skjær)

Seg. nr.	Snitt [mm]	Pl.tv	Pl.stab	El.tv	El.stab	Info
	500	0,03	0,00	0,04	0,00	EN 1993-1-1 6.2.6 om z-aksen
2	0	0,63	0,62	0,91	0,90	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)
	300	0,44	0,50	0,63	0,61	EN 1993-1-1 6.3.3 Ligning (6.61)
	600	0,24	0,41	0,34	0,46	EN 1993-1-1 6.3.3 Ligning (6.61)
	900	0,04	0,31	0,05	0,32	EN 1993-1-1 6.3.3 Ligning (6.61)
	1200	0,18	0,38	0,26	0,41	EN 1993-1-1 6.3.3 Ligning (6.61)
	1500	0,38	0,48	0,54	0,56	EN 1993-1-1 6.3.3 Ligning (6.61)
	1800	0,57	0,57	0,83	0,82	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)
	2100	0,77	0,95	1,11	1,28	EN 1993-1-1 6.3.2 Ligning (6.54) om y-aksen
	2400	0,97	1,19	1,40	1,61	EN 1993-1-1 6.3.2 Ligning (6.54) om y-aksen
	2700	1,36	1,44	1,68	1,94	EN 1993-1-1 6.3.2 Ligning (6.54) om y-aksen
	3000	1,86	1,69	1,97	2,27	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)
3	0	1,85	1,69	1,97	2,07	EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft)
	200	1,23	1,39	1,61	1,70	EN 1993-1-1 6.3.3 Ligning (6.61)
	400	0,86	0,94	1,25	1,34	EN 1993-1-1 6.3.3 Ligning (6.61)
	600	0,61	0,69	0,89	0,97	EN 1993-1-1 6.3.3 Ligning (6.61)
	800	0,37	0,44	0,53	0,60	EN 1993-1-1 6.3.3 Ligning (6.61)
	1000	0,12	0,18	0,17	0,23	EN 1993-1-1 6.3.3 Ligning (6.61)
	1200	0,14	0,21	0,21	0,27	EN 1993-1-1 6.3.3 Ligning (6.61)
	1400	0,39	0,47	0,57	0,64	EN 1993-1-1 6.3.3 Ligning (6.61)
	1600	0,64	0,72	0,93	1,01	EN 1993-1-1 6.3.3 Ligning (6.61)
	1800	0,89	0,97	1,29	1,38	EN 1993-1-1 6.3.3 Ligning (6.61)
	2000	1,29	1,42	1,65	1,74	EN 1993-1-1 6.3.3 Ligning (6.61)

3.2. KAPASITETSKART



Største kapasitetsutnyttelse: 186,15 % (EN 1993-1-1 6.2.10 (bøyning, skjær og aksialkraft))

INNHOLDSFORTEGNELSE

1. KONSTRUKSJONSMODELL OG LASTER SIDE: 1
1.1. KNUTEPUNKTSDATA SIDE: 1
1.2. TVERRSNITTSDATA SIDE: 1
1.3. MATERIALDATA SIDE: 1
1.4. SEGMENTDATA SIDE: 2
1.4.1. SEGMENTDATA EN 1993 SIDE: 2
1.5. RANDBETINGELSER SIDE: 2
1.7. LASTTILFELLER SIDE: 2
1.8. LASTKOMBINASJON SIDE: 2
2. STATISKE BEREGNINGER SIDE: 2
2.1. KNUTEPUNKTSRESULTATER SIDE: 2
2.1.1. Forskyvninger SIDE: 3
2.1.2. Residualkrefter SIDE: 3
2.2. OPPLEGGSKREFTER SIDE: 3
2.3. SEGMENTRESULTATER SIDE: 3
2.4. STATISKE RESULTATER GRAFISK SIDE: 3
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2.4.3 Aksialkraft SIDE: 4
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3.1. UTNYTTELSESGRAD EN 1993 SIDE: 5
3.2. KAPASITETSKART SIDE: 6

C.d.2

Prosjekttittel: Downscaled Spool [Displacement = 700mm]

Beregning utført: 24.05.2012 13:11:12

Focus Konstruksjon 2012

2.1.1. Forskyvninger

Nr.	u [mm]	w [mm]	rotY [°]
1	112,2	700,0	14,0
2	0,0	700,0	12,3
3	112,1	0,0	2,3
4	0,0	0,0	0,0

2.1.2. Residualkrefter

Nr.	Rx [kN]	Rz [kN]	My [kN·m]
1	0,00	1,06	0,00
2	2,00	0,00	0,00
3	0,00	0,00	0,00
4	-2,00	-1,06	1,83

2.2. OPPLEGGSKREFTER

Seg Nr.	X [mm]	Z [mm]	Rx [kN]	Rz [kN]	My [kN·m]
1	0	-500	2,00	0,00	0,00
1	0	0	0,00	1,06	0,00
3	3000	2000	-2,00	-1,06	1,83
	Sum		0,00	0,00	

2.3. SEGMENTRESULTATER

Seg Nr.	Snitt mm	My [kN·m]	N [kN]	Vz [kN]	u [mm]	w [mm]
1	0	1,00	0,00	-2,00	112,2	700,0
	0	1,00	0,00	-2,00	112,2	700,0
	500	0,00	0,00	-2,00	0,0	700,0
2	0	1,00	-2,00	-1,06	112,2	700,0
	3000	-2,18	-2,00	-1,06	112,1	0,0
	3000	-2,18	-2,00	-1,06	112,1	0,0
3	0	-2,18	-1,06	2,00	112,1	0,0
	0	-2,18	-1,06	2,00	112,1	0,0
	2000	1,83	-1,06	2,00	0,0	0,0

2.4. STATISKE RESULTATER GRAFISK

2.4.1. Forskyvning

C.d.3

Prosjekttittel: Downscaled Spool [Displacement = 500mm]

Beregning utført: 24.05.2012 13:08:19

Focus Konstruksjon 2012

2.1.1. Forskyvninger

Nr.	u [mm]	w [mm]	rotY [°]
1	80,1	500,0	10,0
2	0,0	500,0	8,8
3	80,1	0,0	1,7
4	0,0	0,0	0,0

2.1.2. Residualkrefter

Nr.	Rx [kN]	Rz [kN]	My [kN·m]
1	0,00	0,76	0,00
2	1,43	0,00	0,00
3	0,00	0,00	0,00
4	-1,43	-0,76	1,30

2.2. OPPLEGGSKREFTER

Seg Nr.	X [mm]	Z [mm]	Rx [kN]	Rz [kN]	My [kN·m]
1	0	-500	1,43	0,00	0,00
1	0	0	0,00	0,76	0,00
3	3000	2000	-1,43	-0,76	1,30
	Sum		0,00	0,00	

2.3. SEGMENTRESULTATER

Seg Nr.	Snitt mm	My [kN·m]	N [kN]	Vz [kN]	u [mm]	w [mm]
1	0	0,72	0,00	-1,43	80,1	500,0
	0	0,72	0,00	-1,43	80,1	500,0
	500	0,00	0,00	-1,43	0,0	500,0
2	0	0,72	-1,43	-0,76	80,1	500,0
	3000	-1,56	-1,43	-0,76	80,1	0,0
	3000	-1,56	-1,43	-0,76	80,1	0,0
3	0	-1,56	-0,76	1,43	80,1	0,0
	0	-1,56	-0,76	1,43	80,1	0,0
	2000	1,30	-0,76	1,43	0,0	0,0

2.4. STATISKE RESULTATER GRAFISK

2.4.1. Forskyvning

C.d.4

Prosjekttittel: Downscaled Spool [Displacement = 300mm]

Beregning utført: 24.05.2012 13:03:17

Focus Konstruksjon 2012

2.1.1. Forskyvninger

Nr.	u [mm]	w [mm]	rotY [°]
1	48,1	300,0	6,0
2	0,0	300,0	5,3
3	48,1	0,0	1,0
4	0,0	0,0	0,0

2.1.2. Residualkrefter

Nr.	Rx [kN]	Rz [kN]	My [kN·m]
1	0,00	0,46	0,00
2	0,86	0,00	0,00
3	0,00	0,00	0,00
4	-0,86	-0,46	0,78

2.2. OPPLEGGSKREFTER

Seg Nr.	X [mm]	Z [mm]	Rx [kN]	Rz [kN]	My [kN·m]
1	0	-500	0,86	0,00	0,00
1	0	0	0,00	0,46	0,00
3	3000	2000	-0,86	-0,46	0,78
	Sum		0,00	0,00	

2.3. SEGMENTRESULTATER

Seg Nr.	Snitt mm	My [kN·m]	N [kN]	Vz [kN]	u [mm]	w [mm]
1	0	0,43	0,00	-0,86	48,1	300,0
	0	0,43	0,00	-0,86	48,1	300,0
	500	0,00	0,00	-0,86	0,0	300,0
2	0	0,43	-0,86	-0,46	48,1	300,0
	3000	-0,94	-0,86	-0,46	48,1	0,0
	3000	-0,94	-0,86	-0,46	48,1	0,0
3	0	-0,94	-0,46	0,86	48,1	0,0
	0	-0,94	-0,46	0,86	48,1	0,0
	2000	0,78	-0,46	0,86	0,0	0,0

2.4. STATISKE RESULTATER GRAFISK

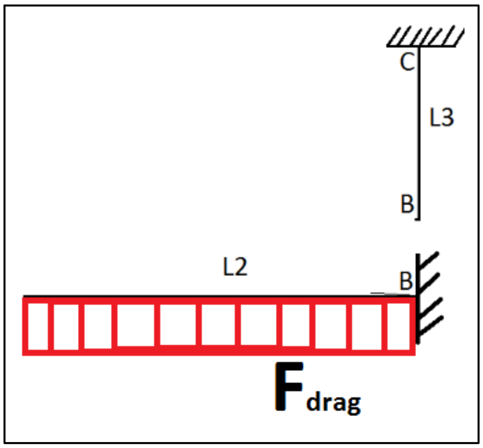
2.4.1. Forskyvning

D

Sheet for calculation of bending moment due to induced drag force:

Length L2 of tie-in spool: $L_2 := 10m$

Drag force calculated from hydrodynamic loading: $F_{drag} := 274.41 \cdot \frac{N}{m}$



Bending moment in B, due to drag force applied as a uniformly distributed load on cantilever beam: $M_{Bdrag} := \frac{F_{drag} \cdot (L_2)^2}{2} = 1.372 \times 10^4 \cdot N \cdot m$

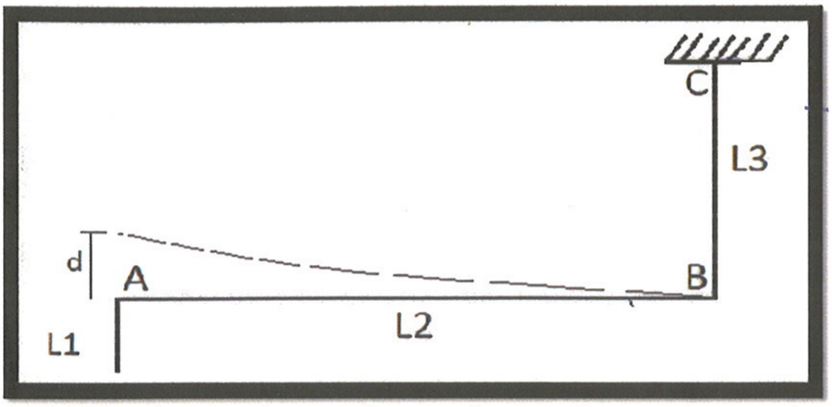
Bending moment in B transferred to connector in point C: $M_{Cdrag} := M_{Bdrag} = 1.372 \times 10^4 \cdot N \cdot m$

Bending moment in connector due to drag force: $M_{Cdrag} = 1.372 \times 10^4 \cdot N \cdot m$

E

Tie-in Spool Bending Test

Date:	12	05



Test 1

L1	0
L2	3
L3	1,5

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]	38	38	38	41,5	41,5	41	45,5	46	45,5	50,5	50,5
1Mc (Nm)	10	10	10	12	12	12	15	15	15	17	17

Test 2

L1	
L2	
L3	

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]	50,5	54	54	54,5							
2Mc (Nm)	17	19	19	19							

Test 3

L1	0
L2	3
L3	1,75

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]	61,5	61,5	62,5	64	64	65	70,5	69,5	70	74	74,5
3Mc (Nm)	10	10	10	12	12	12	15	15	15	17	17

Test 4

L1	
L2	
L3	

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]	75	76,5	74,5	78							
4Mc (Nm)	17	19	19	19							

Test 5

L1	0
L2	3
L3	2

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]	84	85	84	89	89	88	96	96	95	96,5	97
5Mc (Nm)	10	10	10	12	12	12	15	15	15	15	15

Test 6

L1	0
L2	3
L3	2

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]	86	82	82	90	90	90	96	95,5	96,5		
6Mc (Nm)	10	10	10	12	12	12	15	15	15	17	17

13/5-12

Test 7

L1	0
L2	3
L3	1,75

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]	59	58	57,5	61	61,5	61,1	67	68	68,5	73	74
7Mc (Nm)	10	10	10	12	12	12	15	15	15	17	17

Test 8

L1	
L2	
L3	

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]	74,5	77	77,5	78							
8Mc (Nm)	17	19	19	19	22	22	22				

Test 9

L1	0
L2	3
L3	1,5

	0 ✓	1	2	3	4	5	6	7	8	9	10
δ [mm]	44,5	45	44	49	49,5	49,5	56	55,5	56	60	61
9Mc (Nm)	10 ✓	10 ✓	10 ✓	12 ✓	12 ✓	12 ✓	15 ✓	15 ✓	15 ✓	17 ✓	17 ✓

Test 10

L1	
L2	
L3	

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]	60	62	63	62,5							
10Mc (Nm)	17 ✓	19 ✓	19	19							

Test 11

L1	
L2	
L3	

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]											
11Mc (Nm)											

Test 12

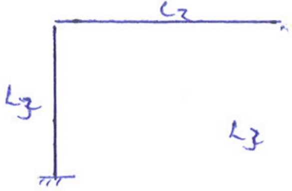
L1	
L2	
L3	

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]											
12Mc (Nm)											

Test 13

L1	
L2	
L3	

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]											
13Mc (Nm)											



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Test 14

L1	0
L2	3
L3	1,5

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]	36,5	37,0	36,5	40,0	40,5	40,5	44,0	44,5	44,5	48,5	48,5
14Mc (Nm)	10	10	10	12	12	12	15	15	15	17	17

Test 15

L1	0
L2	3
L3	

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]	49,0	53,5	54,0	54,0							
15Mc (Nm)	17	19	15"	19							

Test 16

L1	0
L2	3
L3	1,75

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]	59,0	58,0	59,0	62,0	61,5	62,0	69,0	69,0	70,0	73,5	73,5
16Mc (Nm)	10	10	10	12	12	12	15	15	15	17	17

Test 17

L1	0
L2	3
L3	1,75

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]	74,0	77,0	77,5	78							
17Mc (Nm)	17	19	15	19							

Test 18

L1	0
L2	3
L3	2,0

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]	82,5	83,5	84,0	87,0	88,0	88,5	94,0	95,5	96,5	98,0	99,5
18Mc (Nm)	10	10	10	12	12	12	15	15	15	17	17

Test 19

L1	0
L2	3
L3	2,0

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]											
19Mc (Nm)	17	19	19	19							

Test 20

L1	
L2	
L3	

	0	1	2	3	4	5	6	7	8	9	10
δ [mm]											
20Mc (Nm)											

F

Appendix 2

RESULTS FROM FE-ANALYSES

Results from analyses of VFG WP spools:

8"-VFN-02

WP end: Node 167 - HCCS400 tie-in system - SKID end: Node 168 - HCCS400 tie-in system

8"-VFN-03

SKID end: Node 168 - HCCS400 tie-in system - PLET end: Node 382 - HCCS400 tie-in system

8"-VFS-02

WP end: Node 760 - HCCS400 tie-in system - PLET end: Node 761 - HCCS400 tie-in system

Load sequence:

Load step 1	Displace Riser
Load step 2	Apply selfweight
Load step 3	Initiate connections
Load step 4	Do-first tie-in to PLET
Load step 5	Connect to PLET
Load step 6	Initiate connections
Load step 7	Do tie-in to riser
Load step 8	Connect to riser porch
Load step 9	Do second tie-in at skid/plet
Load step 10	Connect to skid/pelt
Load step 11	Apply mattress load
Load step 12	Hydrotest
Load step 13	Remove pressure
Load step 14	Add operating content and pressure
Load step 15	Add temperature
Load step 16	Add wave loading
Load step 17	Expansion
Load step 18	Wave loading + expansion

Load combinations:

Case 1	Omni wave/current from north + maximum stretch + maximum soil contact
Case 2	Omni wave/current from north + maximum stretch + minimum soil contact
Case 3	Omni wave/current from north + minimum stretch + maximum soil contact
Case 4	Omni wave/current from north + minimum stretch + minimum soil contact
Case 5	Omni wave/current from south + maximum stretch + maximum soil contact
Case 6	Omni wave/current from south + maximum stretch + minimum soil contact
Case 7	Omni wave/current from south + minimum stretch + maximum soil contact
Case 8	Omni wave/current from south + minimum stretch + minimum soil contact

HUB REACTION LISTING

STEP 10 = TIED IN
STEP 11 = HYDROTEST
STEP 15 = OPERATION
STEP 16 = WAVES+CURRENT - WITHOUT EXPANSION
STEP 18 = WAVES+CURRENT - WITH EXPANSION

Case 1

SPOOL ID: 8"-VFN-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
167	154	10	5708.6	4336.9	23662	3115.1	49339.4	-50424.9	5.7	70.5
167	154	11	5708.6	4336.9	23662	3115.1	49339.4	-50424.9	5.7	70.5
167	154	15	2664.9	3896.1	22930.2	2504.7	50929.7	-47593.5	2.7	69.7
167	154	16	-11153.3	15237.9	19677.9	10697.9	21074	-95476.7	-11.2	97.8
167	154	18	-15627.1	11036.6	18475.6	2394.2	13544.5	-66149.7	-15.6	67.5
168	155	10	6539.7	5955.9	21495.5	1319.6	26146.4	6420.7	6.5	26.9
168	155	11	6539.7	5955.9	21495.5	1319.6	26146.4	6420.7	6.5	26.9
168	155	15	3260.1	-64.2	20491.3	-1051.5	23981.7	24275.2	3.3	34.1
168	155	16	8568.2	-17925.3	14461.6	10243.5	-9488.9	107016.3	8.6	107.4
168	155	18	1442.5	-20605.8	13175.6	14018.6	-10449.2	64990.5	1.4	65.8

SPOOL ID: 8"-VFN-03

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
382	357	10	40250	2833.4	23706.1	-754.7	30066.2	-39956.1	40.3	50.0
382	357	11	40250	2833.4	23706.1	-754.7	30066.2	-39956.1	40.3	50.0
382	357	15	-16559.8	1047.2	20709.8	-1583.2	45165.5	-33978.3	-16.6	56.5
382	357	16	7936.2	-14321.9	20262	-8899.9	31252.1	43770.6	7.9	53.8
382	357	18	11206.5	-15117.6	18295	-9435.5	23276.2	55849.5	11.2	60.5

SPOOL ID: 8"-VFS-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
760	747	10	17842.7	-10955.3	25919.2	-8097.1	48257.9	32616.1	17.8	58.2
760	747	11	17842.7	-10955.3	25919.2	-8097.1	48257.9	32616.1	17.8	58.2
760	747	15	16532.1	-9867	25045.5	-6283.6	45679.4	27026.2	16.5	53.1
760	747	16	21817.7	3039.1	23570.1	5832.8	30181.1	-34193.9	21.8	45.6
760	747	18	-7016.3	21945.5	16658.8	31963.3	19122.5	-96736.3	-7.0	98.6
761	748	10	16038.4	-13262.3	23352	-3974.8	33267.3	20797.7	16.0	39.2
761	748	11	16038.4	-13262.3	23352	-3974.8	33267.3	20797.7	16.0	39.2
761	748	15	14912.8	-11900.5	22673.1	-3597.3	30276.2	16195.9	14.9	34.3
761	748	16	8467.5	-21701.9	21260.7	-9611.1	25736.2	58012	8.5	63.5
761	748	18	-16646	2205.6	15516.7	2496.7	11830.3	21237.9	-16.6	24.3

Case 2

SPOOL ID: 8"-VFN-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
167	154	10	6391.2	3989.5	21012.2	1631.2	13028.7	-48486.9	6.4	50.2
167	154	11	6391.2	3989.5	21012.2	1631.2	13028.7	-48486.9	6.4	50.2
167	154	15	1844.1	4352.7	19960.4	2354.2	13704.5	-50501.2	1.8	52.3
167	154	16	-10980.2	15357.6	15832.8	7444.8	-28470	-96584.2	-11.0	100.7
167	154	18	-16599.7	8798	15774.6	-3517.7	-22423	-32739.4	-16.6	39.7
168	155	10	5878.6	5573.5	16883.6	-298	-1320.4	9743.8	5.9	9.8
168	155	11	5878.6	5573.5	16883.6	-298	-1320.4	9743.8	5.9	9.8
168	155	15	1900.4	664.6	14746.5	-2561.2	-8400.2	23355.2	1.9	24.8
168	155	16	8078	-18637.1	10707	13116.3	-31289.4	107745	8.1	112.2
168	155	18	-31.9	-22737.2	10767.3	10750.6	-23798	65775.4	0.0	69.9

SPOOL ID: 8"-VFN-03

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
382	357	10	41580	2627.3	17450.9	-986	-29633.8	-38953.8	41.6	48.9
382	357	11	41580	2627.3	17450.9	-986	-29633.8	-38953.8	41.6	48.9
382	357	15	-25767.4	1251.5	10758.8	-1341.4	-26993.9	-35256.5	-25.8	44.4
382	357	16	1823	-12918.9	13201.4	-6934.1	-26066.3	31948.5	1.8	41.2
382	357	18	259.2	-14004.3	13148.2	-7823	-25253.6	51274.2	0.3	57.2

SPOOL ID: 8"-VFS-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
760	747	10	18694.9	-11747.3	22381.5	-9342.5	9896.7	37812.8	18.7	39.1
760	747	11	18694.9	-11747.3	22381.5	-9342.5	9896.7	37812.8	18.7	39.1
760	747	15	16503.1	-10045.2	21544.1	-7015.6	8908.5	28466.2	16.5	29.8
760	747	16	19522	5182.5	16992.4	10283.7	-29206.9	-46965.9	19.5	55.3
760	747	18	-5839.4	20737.5	14823.7	30079.9	-5972.6	-88593.4	-5.8	88.8
761	748	10	14711.8	-12414.8	17863.4	-128.3	-11289.5	14793.6	14.7	18.6
761	748	11	14711.8	-12414.8	17863.4	-128.3	-11289.5	14793.6	14.7	18.6
761	748	15	13005.1	-11199.9	16759.9	628.6	-15948.4	11152.3	13.0	19.5
761	748	16	6225.4	-19179.2	14641	-10190.2	-19152.7	54276.2	6.2	57.6
761	748	18	-15697.5	2036.3	12677.8	7527.1	-16610.9	23989.2	-15.7	29.2

Case 3

SPOOL ID: 8"-VFN-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
167	154	10	4069.9	1637.1	23546.4	2322.8	50571.3	-8418.8	4.1	51.3
167	154	11	4067	1638.5	23546.1	2325	50573.6	-8432.2	4.1	51.3
167	154	15	1055.2	1317.4	22847.4	1847.3	52488	-6440.8	1.1	52.9
167	154	16	-12569.7	13069.3	18284.7	7184.2	7516.6	-56628.3	-12.6	57.1
167	154	18	-17628.4	7649.9	18100.7	-1870.5	12337.3	-7834.5	-17.6	14.6
168	155	10	5871.8	6153.5	20862.7	4807.2	23004.6	6305.2	5.9	23.9
168	155	11	5855.9	6128.8	20861	4793.7	23008	6385.3	5.9	23.9
168	155	15	1399.7	-934.5	19485.9	1718.5	20725.8	27982.3	1.4	34.8
168	155	16	5314.2	-20649.1	13242.1	15061	-13437.8	111897.3	5.3	112.7
168	155	18	-1784.6	-23844	11775.6	14331.8	-14554.4	66338.4	-1.8	67.9

SPOOL ID: 8"-VFN-03

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
382	357	10	49092.2	-3189.1	23600.8	357.5	23054.5	41324.1	49.1	47.3
382	357	11	49087.5	-3188.9	23600.7	357	23056.6	41323.1	49.1	47.3
382	357	15	-11873.5	-1064.4	20715.9	1242.8	39976.8	34294.6	-11.9	52.7
382	357	16	2098.7	-16077.4	18862.9	-4786.3	27403.3	87144.1	2.1	91.4
382	357	18	2908.5	-16052.6	18188.9	-5118.3	25331.7	88836	2.9	92.4

SPOOL ID: 8"-VFS-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
760	747	10	16138.8	-14015.1	26000.2	-10760.2	51516.9	74452.5	16.1	90.5
760	747	11	16138.8	-14015.1	26000.2	-10760.1	51516.9	74452.5	16.1	90.5
760	747	15	14453.9	-12465.9	25079.2	-8493.2	49290.2	66523.5	14.5	82.8
760	747	16	16244.5	3908.5	22225.8	5351.8	30141.4	-17347.6	16.2	34.8
760	747	18	-8880.4	21069	16427.1	31694.4	21230.6	-67632.7	-8.9	70.9
761	748	10	13982.5	-15942.8	23304.8	-3525.8	33799.1	59048.1	14.0	68.0
761	748	11	13982.5	-15942.8	23304.8	-3525.8	33799	59048.1	14.0	68.0
761	748	15	12411.7	-14054.9	22312.3	-2736.2	28957.8	52096.7	12.4	59.6
761	748	16	2804.2	-19614.6	17022.3	-4082.9	4688.3	77485.5	2.8	77.6
761	748	18	-18822.3	1853.1	14676.1	4970.8	10022.5	44368.2	-18.8	45.5

Case 4

SPOOL ID: 8"-VFN-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
167	154	10	4901.1	1246.9	20771.6	1054.2	13113.3	-6147.1	4.9	14.5
167	154	11	4901	1246.9	20771.6	1054.2	13113.3	-6147.2	4.9	14.5
167	154	15	13.5	1703.1	19682.8	1911.7	14124.9	-8889.6	0.0	16.7
167	154	16	-12245.2	13459.3	15459.7	6383	-30575.7	-61905	-12.2	69.0
167	154	18	-17208.5	8048.1	15475.7	-2462.2	-24433	-12856	-17.2	27.6
168	155	10	5790.6	6239.5	16868.5	3117.6	-1837.3	8419.4	5.8	8.6
168	155	11	5790.6	6239.5	16868.5	3117.6	-1837.3	8419.4	5.8	8.6
168	155	15	1.3	-578.3	14344.6	-362.1	-8860	26741.2	0.0	28.2
168	155	16	5260	-21092.7	10875.1	14071.1	-28705.2	109155.4	5.3	112.9
168	155	18	-1238.4	-23926.3	10974.8	12170.3	-22200.2	65848.2	-1.2	69.5

SPOOL ID: 8"-VFN-03

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
382	357	10	41515.7	-2587.9	17437.2	424.2	-29665.3	38767	41.5	48.8
382	357	11	41515.7	-2587.9	17437.2	424.2	-29665.3	38767	41.5	48.8
382	357	15	-26739.7	-1208.6	10755.6	655.4	-26920.4	35290.4	-26.7	44.4
382	357	16	5875	-14426.4	14057.6	-3705.2	-23883.4	73193.1	5.9	77.0
382	357	18	3049.3	-14713.1	13820.9	-3948.2	-23481.8	73637.9	3.0	77.3

SPOOL ID: 8"-VFS-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
760	747	10	17099.1	-14830.2	22270.5	-12860.1	11234.2	79594.7	17.1	80.4
760	747	11	17099.1	-14830.2	22270.5	-12860.1	11234.2	79594.7	17.1	80.4
760	747	15	14686	-13033.9	21385.7	-10551.5	10455.8	70221.2	14.7	71.0
760	747	16	16367.6	4492	16208.8	10910.3	-30598.6	-21900.5	16.4	37.6
760	747	18	-7984.6	20583.1	14535.3	30065	-4389.9	-65639	-8.0	65.8
761	748	10	12354	-15218.9	17604.3	2006.5	-10633	54167.7	12.4	55.2
761	748	11	12354	-15218.9	17604.3	2006.5	-10633	54167.7	12.4	55.2
761	748	15	11267.1	-13196.2	17813.4	2951.9	-14919.5	47471.1	11.3	49.8
761	748	16	2990.1	-18683.2	14913.5	-7163.3	-14664.4	71589.3	3.0	73.1
761	748	18	-18083.8	2580.2	12354.2	11595.7	-16606.3	37652.2	-18.1	41.2

Case 5

SPOOL ID: 8"-VFN-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
167	154	10	5628.2	4269.2	23660.2	2957	49435	-49821.6	5.6	70.2
167	154	11	5628.2	4269.2	23660.2	2957	49435	-49821.6	5.6	70.2
167	154	15	2407.2	3815.3	22946.6	2335.7	51617.7	-47097.7	2.4	69.9
167	154	16	19289.9	-7517.5	18498	-15789.2	-20996.1	345.4	19.3	21.0
167	154	18	8887.6	-15193.5	17236.4	-28984.4	-18176.6	73752	8.9	76.0
168	155	10	6498	5826.9	21247.4	1592.1	24624.8	6672.9	6.5	25.5
168	155	11	6498	5826.9	21247.4	1592.1	24624.8	6672.9	6.5	25.5
168	155	15	2912.5	-355.8	20103.8	-734.5	22117.1	24846	2.9	33.3
168	155	16	3074.4	25304.4	14779.5	39125.7	-3411.3	-84839.2	3.1	84.9
168	155	18	-6736.6	17374.9	12696	36174.2	-5177.7	-107986.9	-6.7	108.1

SPOOL ID: 8"-VFN-03

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
382	357	10	49487.5	3138.2	23611.4	-547.8	22884.3	-40922.3	49.5	46.9
382	357	11	49487.5	3138.2	23611.4	-547.8	22884.3	-40922.3	49.5	46.9
382	357	15	-11300.8	1544.4	20844.1	-1387.9	39697.5	-34932.4	-11.3	52.9
382	357	16	-14886.3	15540.3	19014.9	9413.5	35114.8	-84327.7	-14.9	91.3
382	357	18	-43881.6	13700.7	17659.9	8643.6	47123.5	-74886.3	-43.9	88.5

SPOOL ID: 8"-VFS-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
760	747	10	17819	-10928.8	26003.4	-7578.6	48971.8	32441.6	17.8	58.7
760	747	11	17819	-10928.8	26003.4	-7578.6	48971.8	32441.6	17.8	58.7
760	747	15	16130.9	-9543.3	25097.3	-5420.5	46764.8	25443.5	16.1	53.2
760	747	16	8911.9	-20375.3	24405.1	-23165.3	52839.3	74005.9	8.9	90.9
760	747	18	-16021.4	-3401.6	18879.3	2563.5	46233.7	28523	-16.0	54.3
761	748	10	16043.7	-13224.6	23252.8	-4507.5	32201.3	20591.7	16.0	38.2
761	748	11	16043.7	-13224.6	23252.8	-4507.5	32201.3	20591.7	16.0	38.2
761	748	15	14710.4	-11028.6	22717.2	-3852.8	27738	14792.2	14.7	31.4
761	748	16	19440.7	239	15155.3	8224.6	-19779.3	-41447.5	19.4	45.9
761	748	18	-3734	19460.2	13242.5	16317.5	-10190.5	-59247	-3.7	60.1

Case 6

SPOOL ID: 8"-VFN-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
167	154	10	6322.2	3975.7	21003.2	1714.9	13053.1	-48404.7	6.3	50.1
167	154	11	6322.2	3975.7	21003.2	1714.9	13053.1	-48404.7	6.3	50.1
167	154	15	1800.1	4350.8	19960.6	2466.7	13714.3	-50517.1	1.8	52.3
167	154	16	19308.9	-7839.5	14098.4	-18603.1	-66834.7	5344.3	19.3	67.0
167	154	18	9534.9	-14850.6	13979.8	-29652.8	-55692.2	70520.4	9.5	89.9
168	155	10	6007.6	5561.6	16891.4	-538.2	-1329	10202.7	6.0	10.3
168	155	11	6007.6	5561.6	16891.4	-538.2	-1329	10202.7	6.0	10.3
168	155	15	1929.2	496.1	14699.5	-2836.8	-8415.1	23848.9	1.9	25.3
168	155	16	2710.1	24487.3	13110.6	37227	-14944	-83870.9	2.7	85.2
168	155	18	-6755.6	17108.6	13215.4	32393.2	-7220	-107891.2	-6.8	108.1

SPOOL ID: 8"-VFN-03

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
382	357	10	41633	2626.8	17449	-993.4	-29675.3	-38934.3	41.6	49.0
382	357	11	41633	2626.8	17449	-993.4	-29675.3	-38934.3	41.6	49.0
382	357	15	-25756.9	1207.9	10821.7	-1347.2	-27024.3	-35243	-25.8	44.4
382	357	16	-10395.9	13205.3	12807.4	7500.1	-23957	-62735.8	-10.4	67.2
382	357	18	-43822.9	10619.2	9407.7	5478.4	-22199.9	-47000.8	-43.8	52.0

SPOOL ID: 8"-VFS-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
760	747	10	18661.3	-11794.9	22373	-9474.8	9876.7	38162.1	18.7	39.4
760	747	11	18661.3	-11794.9	22373	-9474.8	9876.7	38162.1	18.7	39.4
760	747	15	16515.1	-10061.2	21542.5	-7105.3	8873.9	28564.4	16.5	29.9
760	747	16	9728.8	-20496.3	19680.7	-18555.7	-297.3	74657	9.7	74.7
760	747	18	-15231	-3256.7	16901.1	6429.1	16296	25809.8	-15.2	30.5
761	748	10	14749.1	-12367.3	17862.5	-110.3	-11324.6	14487.7	14.7	18.4
761	748	11	14749.1	-12367.3	17862.5	-110.3	-11324.6	14487.7	14.7	18.4
761	748	15	13040.6	-11169.2	16873.9	613.4	-15961.7	11148.2	13.0	19.5
761	748	16	20133.3	240	12695.1	4336	-41207.7	-41751.7	20.1	58.7
761	748	18	-2988.9	19243.3	12959.5	17495.4	-20153.2	-59284.9	-3.0	62.6

Case 7

SPOOL ID: 8"-VFN-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
167	154	10	4087.7	1624.7	23546.1	2187.3	50546.3	-8353.2	4.1	51.2
167	154	11	4086.3	1625.9	23546	2189.3	50547.4	-8364.9	4.1	51.2
167	154	15	1131.8	1303.8	22856.7	1711.7	52453.6	-6355.1	1.1	52.8
167	154	16	16851.1	-10594.2	17682.7	-19007.3	-26516.6	42773.1	16.9	50.3
167	154	18	6579.2	-17428.7	17366.9	-30089.2	-14994.4	107749.3	6.6	108.8
168	155	10	5862.4	6156	20862	4805.5	23001.2	6254.3	5.9	23.8
168	155	11	5847.4	6132.7	20860.5	4792.8	23004.3	6329.7	5.8	23.9
168	155	15	1415.7	-1260.9	19727.2	1771	20947.1	27497.4	1.4	34.6
168	155	16	398.7	22051.2	14541.9	40656.7	-2196.9	-73770.8	0.4	73.8
168	155	18	-9737.8	14600.6	13183.6	36680.1	-1463.3	-110856.3	-9.7	110.9

SPOOL ID: 8"-VFN-03

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
382	357	10	49121.1	-3189.5	23601.5	359	23044.2	41321.8	49.1	47.3
382	357	11	49116.7	-3189.3	23601.4	358.6	23046.2	41320.9	49.1	47.3
382	357	15	-11943.7	-1153.8	20567.4	1252.7	39844.7	34360	-11.9	52.6
382	357	16	-7710.7	15337.4	18798.2	13655	29717.8	-49730.1	-7.7	57.9
382	357	18	-51254.5	16566.6	17117	14498.4	46562	-60951.9	-51.3	76.7

SPOOL ID: 8"-VFS-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
760	747	10	16139.4	-14015.2	26000.3	-10759	51517.5	74456.4	16.1	90.5
760	747	11	16139.4	-14015.2	26000.3	-10759	51517.5	74456.4	16.1	90.5
760	747	15	14454	-12467.7	25079.3	-8494.7	49291.4	66539.9	14.5	82.8
760	747	16	7181.1	-22862.8	24827.6	-25209.1	58707.6	112536.1	7.2	126.9
760	747	18	-18755.8	-2590.8	18748.7	4622.5	49842.5	46410.2	-18.8	68.1
761	748	10	13971.8	-15946.9	23303	-3528.8	33795	59075.9	14.0	68.1
761	748	11	13971.8	-15946.9	23303	-3528.8	33795	59075.9	14.0	68.1
761	748	15	12410.9	-14057.8	22308.1	-2738.5	28949.3	52114.5	12.4	59.6
761	748	16	17714.2	-2299.1	15747.2	9272.6	-14765.7	-6761.1	17.7	16.2
761	748	18	-6425.5	20231.2	13230	19360.1	-7728.4	-45653.8	-6.4	46.3

Case 8

SPOOL ID: 8"-VFN-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
167	154	10	4937.8	1238.6	20777.7	1005.8	13111.9	-6085.9	4.9	14.5
167	154	11	4937.7	1238.6	20777.7	1005.8	13111.9	-6085.9	4.9	14.5
167	154	15	-3081.2	1679.1	19339	1906.9	16004.9	-9052.5	-3.1	18.4
167	154	16	17479.6	-10407.6	14163.9	-19921.3	-65356.3	41623.4	17.5	77.5
167	154	18	7157.3	-17231.7	14137.2	-30746.9	-52485.5	106297.3	7.2	118.5
168	155	10	5808.1	6254.6	16876.3	3121.2	-1811.4	8397.3	5.8	8.6
168	155	11	5808.6	6254.5	16876.4	3121.2	-1811.4	8397.6	5.8	8.6
168	155	15	290.7	-719.2	14330.5	-374.7	-8866.3	27322.6	0.3	28.7
168	155	16	1718.1	22284.1	13096.8	37575	-13762.5	-72163.9	1.7	73.5
168	155	18	-8995.5	14643.2	12926.6	32351.7	-6637.1	-109360.7	-9.0	109.6

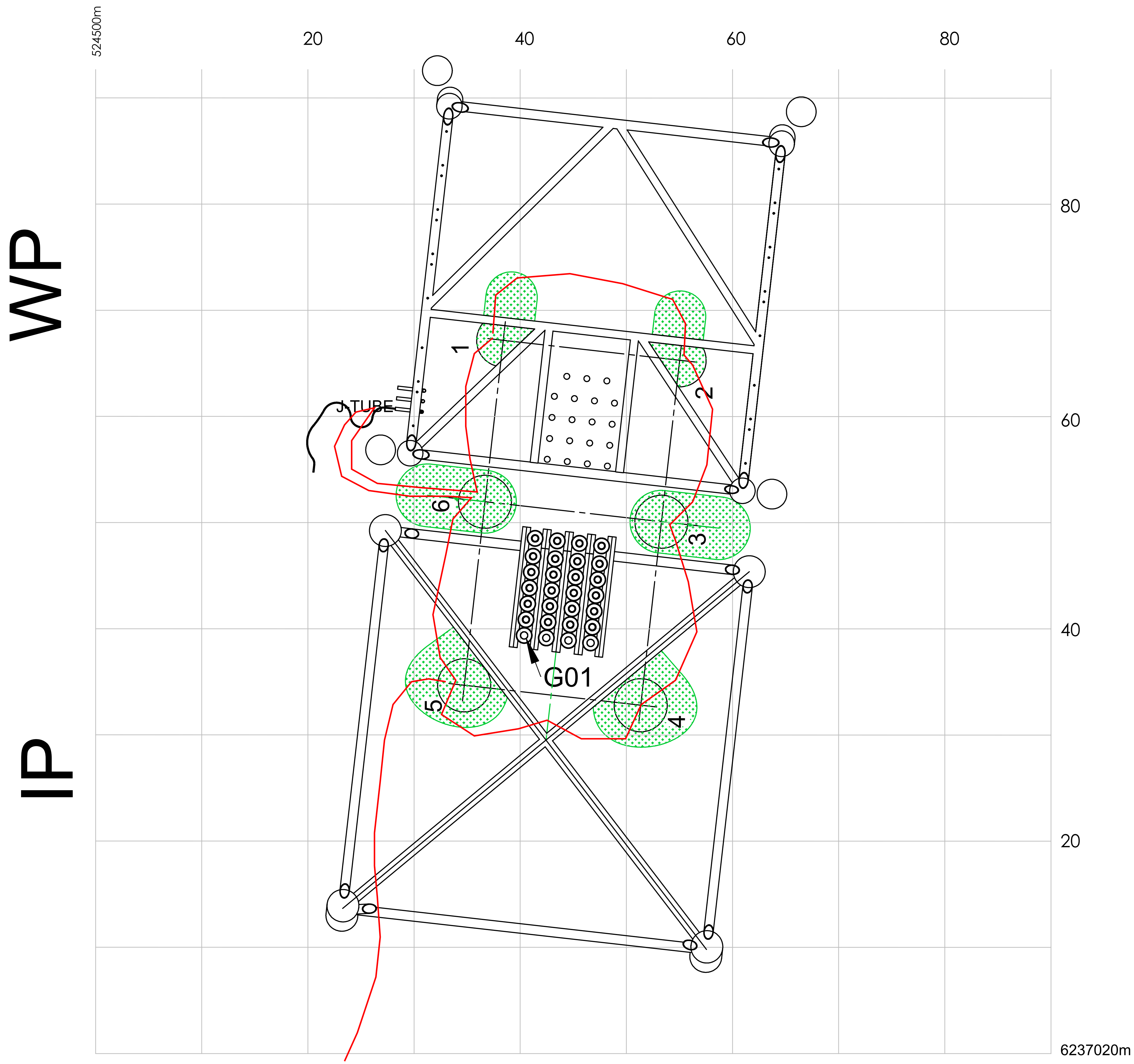
SPOOL ID: 8"-VFN-03

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
382	357	10	41536.4	-2589.9	17442.5	413.1	-29648.1	38771.4	41.5	48.8
382	357	11	41536.7	-2589.9	17442.6	413.1	-29648.1	38771.4	41.5	48.8
382	357	15	-26576.8	-1210.7	10864.8	632.7	-26856.6	35307.9	-26.6	44.4
382	357	16	-13506	13389.8	12236.9	11308.3	-25937.3	-38750.6	-13.5	46.6
382	357	18	-49616.4	12315.2	8429	10451.3	-23891	-40564.4	-49.6	47.1

SPOOL ID: 8"-VFS-02

NODE	ELEM	STEP	FX	FY	FZ	MX	MY	MZ	AxialF [kN]	BendM [kNm]
760	747	10	17093.6	-14832.8	22271.8	-12804.6	11256.9	79637.3	17.1	80.4
760	747	11	17093.6	-14832.8	22271.8	-12804.6	11256.9	79637.3	17.1	80.4
760	747	15	14683.2	-13038.7	21388.2	-10499.5	10550.3	70338.6	14.7	71.1
760	747	16	7777.2	-22911.7	19041.8	-20510	-2649.3	112987	7.8	113.0
760	747	18	-18149.8	-2189.4	16485.7	8873.9	17233.9	41842.4	-18.1	45.3
761	748	10	12359.4	-15200.6	17604.3	1973.6	-10643.9	54046.5	12.4	55.1
761	748	11	12359.4	-15200.6	17604.3	1973.6	-10643.9	54046.5	12.4	55.1
761	748	15	11228.4	-13024.7	17724.2	2908	-14950.4	47303.8	11.2	49.6
761	748	16	18194.9	-2170	12790.2	5238.3	-38476.4	-6995.2	18.2	39.1
761	748	18	-3528.7	21116.3	13032.9	21246.6	-16638.1	-46554.3	-3.5	49.4

G



Node No.:	Easting	Northing
1		
2		
3		
4		
5		
6		

PRELIMINARY

Unless otherwise specified tolerances to: **NS ISO 2768-1 Middels**	A3 SCALE: 1:400	**NORWEGIAN GEOTECHNICAL INSTITUTE** P.O.Box 3930 Ullevaal Stadion NO-0806 OSLO www.ngi.no Tel.:+47 22 02 30 00	F
FINISH:		REPLACE / REPLACE BY	
TITLE: **Vallhall, Nodes Survey**		DWG NO. 20110797_AR05	REV. **B**
MATERIAL:		ASSEMBLY Parts list	REV.
WEIGHT: gram VOLUME: 456115470443.93 cubic millimeter			

Rev. Nr.	Ref.	Modifications	Drawn	Date	Design Check	Date	Checked	Date	Approved	Date
		Original drawing	SHA	03.20.12	nn	xxx	nn	xxxx	nn	xxx

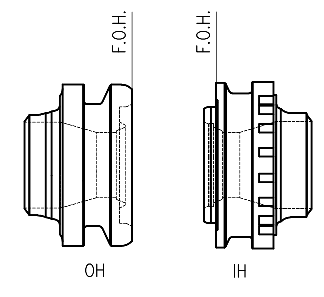
Department: Instrumentation

Project: Arrangement_20110797

SHEET 1 OF 1

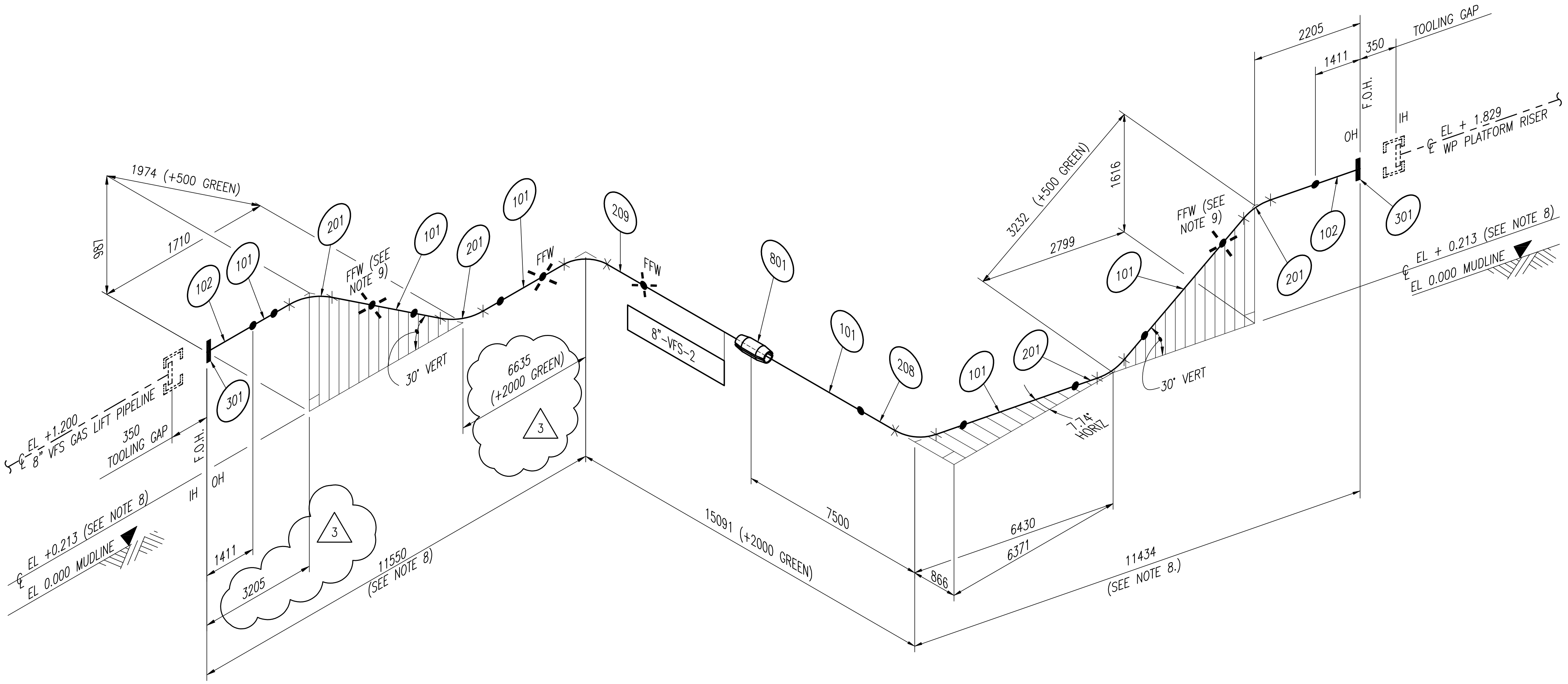
H

A1–H



LEGEND

FFW	– FIT FIELD WELD
(101)	– ITEM No.
8"–VFS–2	– SPOOL IDENT.
IH	– INBOARD HUB
OH	– OUTBOARD HUB
F.O.H.	– FACE OF HUB



MATERIAL LIST

ITEM	QTY.	DESCRIPTION	MATERIAL/COMMENTS
101	28.3m	LINEPIPE 219.1 O.D. x 12.7 WT c/w 3 LAYER PP	DNV SML 450 I
		EXTERNAL COATING TO VRD–JPG–J–0015	
		TOTAL COATING THICKNESS = 3.0mm	
102	2.3m	PUP PIECE 219.1 O.D. x 12.7 WT (VETCO)	DNV SML 450 I
201	4	PULLED BEND 30° 5D (1096 RAD) 8" NB x 12.7 WT	DNV SML 450 I
		c/w 500 LONG TANGENT ENDS, 3 LAYER PP	
		EXTERNAL COATING TO VRD–JPG–J–0015	
		TOTAL COATING THICKNESS = 3.0mm	
208	1	PULLED BEND 82.26° 5D (1096 RAD) 8" NB x 12.7 WT	DNV SML 450 I
		c/w 500 LONG TANGENT ENDS, 3 LAYER PP	
		EXTERNAL COATING TO VRD–JPG–J–0015	
		TOTAL COATING THICKNESS = 3.0mm	
209	1	PULLED BEND 90° 5D (1096 RAD) 8" NB x 12.7 WT	DNV SML 450 I
		c/w 500 LONG TANGENT ENDS, 3 LAYER PP	
		EXTERNAL COATING TO VRD–JPG–J–0015	
		TOTAL COATING THICKNESS = 3.0mm	
301	2	VETCO OUTBOARD HUB (OH) HCCS 400 TYP	
801	1	8" ANODE – TYPE 2 (39.0kg)	Al/Zn/In
		232mm ID x 500mm LONG x 45mm THICK	

NOTES

1. ALL DIMENSIONS ARE IN MILLIMETRES U.N.O.
2. ALL ELEVATIONS ARE IN METRES AND ARE RELATIVE TO :– MUDLINE (0.000)
3. PRIOR TO WELDING THE OUTBOARD TERMINATION ASSEMBLY ON TO THE SPOOL, THE TOP MARK ON THE HUB IS TO BE POSITIONED AT 12 O'CLOCK.
4. SPOOL TO BE FABRICATED IN ACCORDANCE WITH VRD–JPG–J–0020, SPECIFICATION FOR PIPELINE SPOOLPIECE FABRICATION.
5. ESTIMATED 8"–VFS–2 SPOOLPIECE PIPE WEIGHT = 2500 kg
6. VETCO OUTBOARD HUB (OH) HCCS 400 TYP SUBJECT TO VETCO DESIGN.
7. FOR TIE–IN OPERATIONS OF THE OUTBOARD HUBS 100mm CLEARANCE IS ADDED BETWEEN THE MUDLINE AND SPOOL CENTRELINE TO ENABLE THE DOCKING OF THE OUTBOARD HUB. THIS IS TO ENSURE THE SPOOL DOES NOT LAND ON THE SEABED BEFORE THE OUTBOARD CONNECTOR HAS DOCKED WITH THE INBOARD CONNECTOR ASSEMBLY.
8. SPOOL LENGTHS SHOWN ALLOW FOR THE TOOLING GAP REQUIREMENTS FOR VETCO HCCS SYSTEM FOR SPOOL TIE–IN OPERATIONS.
9. CONTRACTOR TO CONFIRM WHETHER FIELD WELD IS REQUIRED.
10. DIMENSIONS SHOWN ARE AS PER DESIGN. CONTRACTOR SHALL DETERMINE FINAL DIMENSIONS FROM FIELD METROLOGY.

METROLOGY SPOOL

J P KENNY

MATERIAL

DNV SML 450 I

DESIGN TEMPERATURE	: –20°C (+80)
DESIGN PRESSURE	: 143 barg (@ +20m)
TEST PRESSURE	: 165.2 barg (@ +20m)
CORROSION ALLOWANCE	: NA
RADIOGRAPHY	: 100%

CAD PRODUCED DRAWING – DO NOT CHANGE MANUALLY

REFERENCE DRAWINGS

JPK DRAWING No.	DRAWING TITLE
VRD–JPG–J–1011–002	8" ANODE – TYPE 2 (39.0 Kg) GENERAL ARRANGEMENT & DETAILS
FS–JPG–J–1020–001	8" VFS TIE–IN SPOOL SHEET 1 ISOMETRIC

REVISIONS

REV	DATE	REVISION	BY	CHK	ENG	PM	CLIENT
3	30.06.10	RE–ISSUED FOR CONSTRUCTION	GRM	TM	MJ	MJ	
2	10.03.10	RE–ISSUED FOR CONSTRUCTION	TM	GRM	MJ	SDH	
1	27.01.10	RE–ISSUED FOR CONSTRUCTION	GRM	TM	MJ	SDH	
0	05.03.09	ISSUED FOR CONSTRUCTION	TM	GRM	LSF	EH	
B	17.12.08	ISSUED FOR APPROVAL	TM	GRM	MJ	EH	
A	30.10.08	ISSUED FOR COMMENT	TM	DW	LSF	EH	

CLIENT: bp

PROJECT: BP VALHALL REDEVELOPMENT– FLANKS GAS–LIFT DETAILED DESIGN

TITLE: 8" VFS TIE–IN SPOOL SHEET 2 ISOMETRIC

DRAWN J.MURRAY	DATE 04.09.08	OFFICE 21	PROJECT No. 0008.15
CHECKED D.WARD	DATE 30.10.08	SCALE N.T.S.	JPK REF. 21–0008–15–U–0–020–02
ENG L.S.FAGERLAND	DATE 30.10.08	REGISTRATION CODES (AREA / SYSTEM / TYPE): UN 19 XN	DRAWING NUMBER: FS–JPG–J–1020–002
CLT. APP.	DATE	REV. 3	

PO :102746-BL743-001
SO :
Desc:1" S80S PIPE A790 UNS S31803 SMLS

Item :29
Heat :503892
Qty :6,91

ENERGY PIPING

1" PIPE

SANDVIK

CERTIFICATE

No. A/04-411396 Rev 00
Date 2004-12-21 Page 1/2

INSPECTION CERTIFICATE acc to
EN 10 204 3.1.B

STAVANGER RÖRHANDEL A/S
GAMLE FORUSVEI 53
4033 STAVANGER
NORWAY

INSPECTION STAMP
QA-TUBE

62721

Customer References

1-137000

Customer order
2004-08-23

120-08048 STAVANGER

Sandvik References

Order No. | Subs No. | ABSMT Dispatch note 09738/54

ABSMT No. 300-64653 | C.Code 03

Material description
SEAMLESS STAINLESS HOT FINISHED
PIPE

Steel making process
Electric furnace

Steel/material Designations

Sandvik	UNS
SAF 2205	S31803

Technical requirements
MDS SBD41 REV 2 (ASTM A-790-03)

EXTENT OF DELIVERY

It	Product designation	Heat	Lot	Pieces	Kg	M
04	XTSTE-SAF2205-1-SCH80 33.40 X 4.55	503892	18312	50	1120.0	345.77
			Total	50	1120.0	345.77

TEST RESULTS
Chemical composition (weight%)

Heat	C	Si	Mn	P	S	Cr	Ni	Mo
503892	0.014	0.46	0.77	0.018	0.0005	22.23	5.24	3.13

Heat	N
503892	0.187

Tensile test at room temperature

Lot	Yield strength N/mm2 Rp0.2	Tensile strength N/mm2 Rm	Elongation % 2"
18312	575	775	32

A/S Stavanger Rorhandel
Cert./QC Contr.
TOR S. KVALOY
Sign. 29/12.04

Quality assurance - Per Eriksson/ QA-manager Tube & Pipe
MTC Service / Certificates

Hardness test
According to NACE MR0175/ISO 15156-3:2003

Lot	Hardness HRC	
18312	21.0	21.0
	22.0	22.0

Ferrite
Tested according to ASTM E-562.

Lot	
18312	51.7

Corrosion test
According to ASTM G-48A, 25 degrees C for 24 hours.
No pitting corrosion found at 20x enlargement.

Lot	Specimen weight loss, g/m2/h
18312	0.00

Following controls/tests have been satisfactorily performed:
- The structure, examined at 400x magnifications is free from harmful amounts of intermetallic phases and precipitates.
- Flattening test according to ASTM A-530.
- PMI-test (100%).
- All tubes have been hydrostatic tested at 17 MPa, 5 seconds.
- Visual inspection and dimensional control.

Heat Treatment:
All tubes have been quickly cooled in water directly after extrusion.

The number of tests are based on the size of the manufacturing lot before cutting to finished lengths.

The delivered products comply with the specifications and requirements of the order.

The material is manufactured according to a Quality system, approved and registered to ISO 9001.

The certificate is produced with EDP and valid without signature.

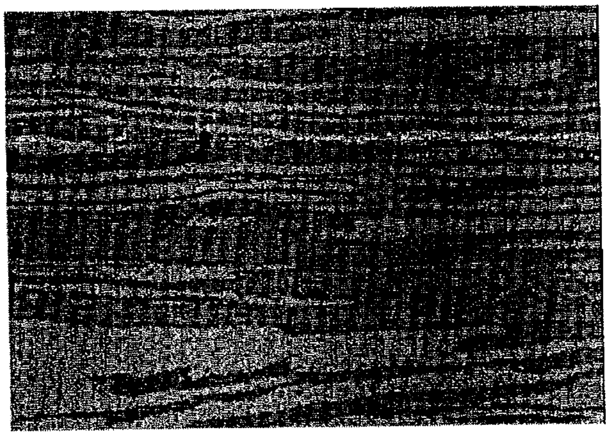
Cert.no: A/04-411396 Rev.00

SANDVIK

MICROSTRUCTURE EXAMINATION REPORT

Grade:	SAF 2205	**Test Procedure:**	10105/102 R1
Charge:	503892	**Surface Preperation:**	MURAKAMI
Lot.No:	18312-9	**Test Result:**	OK
Dim:	33,40X4,55	**Test Date:**	041214

Photo.no	Test,no	Magnification
A36249	107	X 400



SDPM:R.O

90° elbow

Customer: SCANDINAVIAN FITTINGS & FLANGES A/S
Order : 189488 - 12.03.2009
Descr. : ELBOWS 90° LR 1" SCH.80/S (LD073297 / 65)
Heat n°/Pcs. marking : 0174SAF9 Qtà/Qty:11 Posiz./Item n.: 65
Protocollo : CTCERC200900002589 * CERTIFIED TRUE COPY * Issued 22/04/09

raccortubi

TECNINOX s.r.l.

Stab. / Plant.: Via Don Spagnoli 5 - 29010 Sarmato (PC) - ITALIA
tel. (+39) 0523.887452-887991 - fax (+39) 0523.887687

Sede Operativa / Commercial Office:
RACCORTUBI S.p.A. - Viale De Gasperi, 194
20010 - Marcallo con Casone (MI) - ITALIA
tel. (+39) 02.976300.1 - fax. (+39) 02.90376337 - info@raccortubi.it

Lloyd's Register Quality Assurance ISO9001 — Quality System Certified

Certificato di collaudo d'officina tipo: EN 10204 3.1
Product test certificate Type: EN 10204 3.1
Certificat de Réception Type: EN 10204 3.1

Cliente *Customer/Client*	RACCORTUBI S.p.A.		
Ordine N. *P.O.N./Commande N.*	OS000207 S DEL 25/11/08		
Pos. N. *Item/Poste*	24	**Q.tà** *Q.ty/Q.té*	575

(*) Marcatura e cert. N. *Material Marking e Cert. N. Marquage du materiel*	0174SAF9	**Data:** *Date:*	02/04/2009
Descrizione *Description Description*	CURVE 90° LR 1" SCH.80/S		
Specifica *Specification Spécification*	BW FITTINGS TO ASTM/ASME SA/A815 UNS S31803-32205 DIMS/ENDS B16.9/25		

Materiale base/*Raw material/Materiel du depart*
Fabbricante/*Manufacturer/Fabriquant*: TUBACEX Cert. No.: 407679

Specifica *Specification/Specification*	Colata N. *Heat N. Couléé N.*	N. prova *Specimen N. Echantil. N.*	Snervamento *Yield strength Limite d'elasticité* N/mm²	Rottura *Tensile strength Resistance à la traction* N/mm²	Allungam. % *Elongation Allongement* 2"	Durezza *Hardness as per NACE MR01-75*	Durezza *Hardness Dureté HB*	Resilienza *Impact energy Resilience* Joules
SMLS PIPES TO ASTM A-790 UNS S31803	39692	933/03/09	519	750	29.4	HRC<28		

(Caratteristiche meccaniche / *Mechanical Properties/Caracteristiques Mechaniques*)

Analisi chimica %
Chemical composition/Composition chimique

Colata N. *Heat N. Couléé N.*	C	Si	Mn	P	S	Cr	Ni	Mo	N				PRE	FERRITE
39692	0,0150	0,4800	1,1600	0,0270	0,00050	22,4000	5,3500	3,2000	0,1605				35.528	44.73

SFF — COMPONENT MEETS THE REQ. IN PED 97/23 ANNEX I SECT. 4.3

Prove
Tests/Tests

Altri *Others Autres* **G-48 MET.A**

I dati dall'analisi chimica e delle prove meccaniche corrispondono al certificato del fabbricante del materiale base e/o dal laboratorio che ha effettuato le prove.
The chemical analysis and mechanical properties fully comply with the certificate issued by the raw material manufacturer and/or by the laboratory that carried out the tests.
L'analyse chimique et les caractéristique mécaniques sont en conformité au certificat émis par le producteur du materiel de base et/ou par la laboratoire qui a ecsécuté les tests.

Note/*Remarks/Notes*

MATERIAL CONFORMS TO NACE MR0175 ED.2002
- MECHANICAL TEST CARRIED OUT ON FINISHED FITTING
- LIQUID PENETRANT EXAMINATION ACCORDING TO ASME VIII Div 1 App B ON 10% OF FITTINGS: SATISFACTORY
- FITTINGS CAN SATISFACTORILY PASS THE INTERGRANULAR CORROSION TEST ACCORDING TO ASTM A 262 Pr E
- FOR SPECIAL TEST SEE SIDER TEST CERTIFICATES N.:3267/09-1735/09-1921/09
- HEAT TREATMENT SOAKING TIME FOR 20 MINUTES

(*) Material marked with certificate number as per relevant code.

Responsabile Controllo Qualità
Quality Control Manager
[signature]

Costruzione/*Manufacture/Méthode de fabrication*

Formato a freddo *Cold formed Formés à froid*	**Senza saldatura** *Seamless Sans soudure*

Ispezione/*Inspection/Inspéction*
— **Esame visivo e dimensionale: Buono**
Visual and dimensional test: Good
Examen visuel et dimensionel: Sans réclamation
— **Identificazione materiale** (100%)
Positive Material Identification
Analyse de controle du produit

Trattamento termico
Heat treatment/Traitement Thermique
Solubilizzazione a 1070°C
Solution Annealing at 1070°C, Water quenching
Hypertrempés à 1070°C

Guaranteed caracteristics (A.M. du 24.03.78)
Caracteristiques garanties pour Z2CN18-10 et Z2CND17-13

C ≤ 0.25%	Rm ≤ 760 N/mm²
S ≤ 0.05%	Rm(A-2) ≤ 10500 N/mm²
P ≤ 0.05%	A% sur 5,65 √So ≥ 16

Il materiale è stato fornito in conformità ai requisiti dell'ordine.
The material has been furnished in accordance with purchase order requirements.
Le matériel a eté trouvé conforme aux exigences.

Marchio di fabbrica
Trade Mark

Ispettore/*Inspector/Inspecteur*

PROJECT: Trym Subsea
CLIENT: AKER EGERSUND
CLIENT ART. CODE:
PRODUCT NO: 32636
Compliance with Client specification:
Signed: CA
SFF Q.C. - DEPT.

SIDER TEST S.r.l.
Mechanical Tests & Nondestructive Examinations

RAPPORTO DI PROVA No. 3267 / 09
TEST REPORT No.

Pag. 1 di 1 / *Sheet* 1 *of* 1

S.I.M. ST No.: 0728/09
F.C.P. ST No.: 0728/09 A / A

Sede legale ed amministrativa
Strada della Baraneila 1/B I-29015 C.S. Giovanni (PC)
P.IVA 01018540339
Tel. +39 0523 861 900 Fax +39 0523 842 903

Subcliente/*Subcustomer (SC)* Cliente/*Customer (C)*	TECNINOX SRL Via Don Spagnoli, 5 Sarmato (PC)
Ordine (SC) / *Order (SC)*	OS000207 S
Commessa (C) / *Job (C)*	159/08 08/2177
Posizione (SC / *Item (SC)*	24
Descrizione Prodotto / *Product Description*	ELBOWS 90° LR 1" SCH. 80S
Q.TA' / *Q.ty*	
Prova Nr. / *Test Nr.*	933/03/09
Colata / *Heat*	39692
Specifica (C) / *Specification (C)*	815S Rev.3 ASTM/ASME A/SA 815 Latest Ed.
Materiale / *Material*	UNS S31803 / S32205 ASTM/ASME A/SA 815

PROVA DI TRAZIONE — *TENSILE TEST*

Provino *Specimen*	Norma Costr. *Constr. Spec.*	Norma Esec. *Exec. Spec.*	Dimensioni *Dimensions* mm	Sezione *Section* mm2	Lungh. *Length* Lo mm	Dir *Dir*	Temp. *Temp.* °C	Limite di Snerv. *Yield Point* *(1) [1] [X] 0,2% [ ] 0,5% N/mm2 Min.	N Tot.	N/mm2	Limite di Snerv. Yield Point (1%) N Tot.	N/mm2	Carico di Rottura *Tensile Strength* N/mm2 Min-Max	N Tot.	N/mm2	Allungamento *Elongation* Min. %	mm	%	Strizione *Area Reduction* Min. %	Dimens. mm	Sez. mm2	Z %	S/R Max.
933/03/09	ASTM A 370-08a	ASTM A 370-08a	4,00 x 12,30	49,20	50,00	L	RT	450	25520	519			680/795	36900	750	25	64,68	29,4					

PROVA DI RESILIENZA — *IMPACT TEST*

Energia nominale *Nominal Energy* J = 295

Provino *Specimen*	Norma Costr. *Constr. Spec.*	Norma Esec. *Exec. Spec.*	Dimensioni *Dimensions* Size / Width / Length	Tipo *Type*	Dir *Dir*	Temp. *Temp.* °C	Locazione *Location*	Richiesto Min. J / J/cm²	Required Med. J / J/cm²	Valore singolo *Single value* J / J/cm²	Valore medio *Avg. Obtained* J / J/cm²	Area di Taglio *Shear Area* %	Espansione lat. > 0,38 mm *Lat. Expansion > 0,38 mm* mm

PROVA DI PIEGA — *BEND TEST*

Provino *Specimen*	Norma Costr. *Constr. Spec.*	Norma Esec. *Exec. Spec.*	Dimensioni *Dimensions* Wth. / Length / Width	Tipo *Type*	Dir *Dir*	Q.tà *Q.ty*	Angolo° *Angle°*	Ø Mandrino *Ø Former* Wt. / Ø	Distanza fra Appoggi *Distance between rollers* (Richiesta solo dalla EN 910)	Tipo e dimensioni delle imperfezioni osservate *Type and dimensions of imperfections observed*

*(1) LEGENDA: Determinazione dello snervamento (*Yield Strength Determination*)
1 Carico unitario di scostamento dalla proporzionalità (*Offset Method*)
2 Carico unitario limite di allungamento tota (*Extension-Under-Load Method*)
3 Diagramma autografico (*Autographic Diagram Method*)
4 Arresto della forza (*Half-of-the-Force Method*)
5 Velocità di deformazione (*Strain Rate Method*)

a) Si dichiara che il certificato riguarda solo campioni sottoposti a prova. *We declare that this report refers to the examined parts only.*
b) Si dichiara che il certificato non puo' essere riprodotto parzialmente, salvo nostra approvazione scritta. *We declare that this report cannot be partially reproduced without our written approval.*
c) Il campionamento dei provini viene eseguito dal Cliente. *Clients are in charge of sampling.*

NOTE *Remarks*

ESITO DELLE PROVE *RESULT OF TESTS*: CONFORME *SATISFACTORY*

Data Ingresso Materiale *Date of Arrival of Material*	Data Esecuzione Prove *Date of Testing*	Data Rapporto di prova *Test Report Date*	Ispettore *Inspector*	Ispettore *Inspector*	Cliente *Customer*	Operatore *Operator*	Responsabile Laboratorio *Laboratory Manager*
25/03/2009	31/03/2009	09/04/2009				FABRIZIO MANZINI SIDER TEST SRL	PAOLO TAMANI SIDER TEST Srl

Z:\QUALITA\DOCUMENTI_LABORATORIO\... R_TrResPiega_R02.xls of. 16/10/08

Customer: SCANDINAVIAN FITTINGS & FLANGES A/S
Order : 189488 - 12.03.2009
Descr. : ELBOWS 90° LR 1" SCH.80/S (LD073297 / 65)
Heat n°/Pcs. marking : 0174SAF9 Qtà/Qty:11 Posiz./Item n.: 65
Protocollo : CTCERC200900002589 * CERTIFIED TRUE COPY * Issued 22/04/09

raccortubi

SIDER TEST S.r.l. *Mechanical Tests & Nondestructive Examinations*	RAPPORTO DI PROVA No. / *TEST REPORT No.* 1735 / 09	Pag. 1 di 2 / *Sheet of*	S.I.M. ST No.: 0728/09 / F.C.P. ST No.: 0728/09 A/A	Sede legale ed amministrativa Strada della Bardonella 148 I-29015 C.S. Giovanni (PC) P.IVA [illegible] Tel. [illegible] Fax [illegible] [illegible] E-Mail [illegible]

Subcliente/Subcustomer (SC) / *Cliente/Customer (C)* TECNINOX SRL Via Don Spagnoli, 5 Sarmato (PC)	Ordine (SC) / *Order (SC)* OS000207 S	Commessa (C) / *Job (C)* 159/08 08/2177	Posizione (SC) / *Item (SC)* 24

Descrizione Prodotto / *Product Description* ELBOWS 90° LR 1" SCH. 80S	Q.TA' / *Q.ty*	Prova Nr. / *Test Nr.* 933/03/09	Colata / *Heat* 39692	Specifica (C) / *Specification (C)* Order Reqs.	Materiale / *Material* UNS S31803 / S32205 ASTM/ASME A/SA 815

CONTENUTO DI FERRITE *Ferritic Volume Fraction Test ASTM E 562* Norma lavorazione ed esecuzione / Construction and execution spec: *ASTM E 562-05e1 / ASTM E 562-05e1*

FORMULE USATE
(Formulas used)

Percentuale media di punti (Pp):
Average Percentage of Points (Pp):

$$Pp = 1/n \times \sum_{i=1}^{n} Pp(i)$$

Deviazione Standard (s):
Standard Deviation (s):

$$s = \left[\frac{1}{n-1} \sum_{i=1}^{n} (Pp(i) - Pp)^2 \right]^{1/2}$$

95% Intervallo di scarto (95% CI):
95% Confidence Interval (95%CI):

$$95\%CI = \frac{2.0 \times s}{(n-1)^{1/2}}$$

Errore (%):
Error (%):

$$\frac{95\%CI \times 100}{Pp}$$

Frazione di Volume (Vv%):
Volume Fraction (Vv %):

$$Vv = Pp \pm 95\%CI$$

RISULTATI (35% ÷ 55%)
Results (35% ÷ 55%)

Vv (% Frazione di volume della ferrite): / Vv (% Volume fraction of the constituent):	44,73 ± 1,08
% Errore (RA): / % Error (RA):	2,41
Nr. di campi per provino: / Nr. of fields for specimens:	30
Preparazione del provino: / Sample preparation:	KOH + Electrolytic
Orientamento della parte in esame: / Orientation of the tested part:	transversal
Ingrandimento: / Magnification:	500 X
Misura del reticolo: / Grid size:	40 mm. x 40 mm. 5 x 5 = 25 Points

% Frazione di volume della ferrite per ciascun campo esaminato
% Volume fraction of the costituent for each metallographic section

1	44	7	44	13	44	19	44	25	44
2	44	8	44	14	44	20	44	26	48
3	46	9	40	15	40	21	40	27	46
4	44	10	46	16	40	22	48	28	46
5	44	11	44	17	40	23	48	29	52
6	48	12	48	18	48	24	44	30	46

a) Si dichiara che il certificato riguarda solo campioni sottoposti a prova. *We declare that this report refers to the examined parts only.* c) Il campionamento dei provini viene eseguito dal Cliente. *Clients are in charge of sampling.*
b) Si dichiara che il certificato non puo' essere riprodotto parzialmente, salvo nostra approvazione scritta. *We declare that this report cannot be partially reproduced without our written approval*

NOTE / *Remarks*: FERRITE CONTENT BY FISCHER MP30 (%FE): 37.3 - 41.0 - 42.8
ESITO DELLE PROVE / *RESULT OF TESTS*

Data Ingresso Materiale / *Date of Arrival of Material*	Data Esecuzione Prove / *Date of Testing*	Data Rapporto di prova / *Test Report Date*	Ispettore / *Inspector*	Ispettore / *Inspector*	Cliente / *Customer*	Operatore / *Operator*	Responsabile Laboratorio / *Laboratory Manager*
25/03/2009	08/04/2009	09/04/2009				STEFANO ANTONELLI SIDER TEST SRL	PAOLO CAMANI SIDER TEST Srl

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Customer: SCANDINAVIAN FITTINGS & FLANGES A/S
Order : 189488 - 12.03.2009
Descr. : ELBOWS 90° LR 1" SCH.80/S (LD073297 / 65)
Heat n°/Pcs. marking : 0174SAF9 Qtà/Qty:11 Posiz./Item n.: 65
Protocollo : CTCERC200900002589 * CERTIFIED TRUE COPY * Issued 22/04/09

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SIDER TEST S.r.l.
Mechanical Tests & Nondestructive Examinations

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RAPPORTO DI PROVA No. / *TEST REPORT No.* 1735 / 09

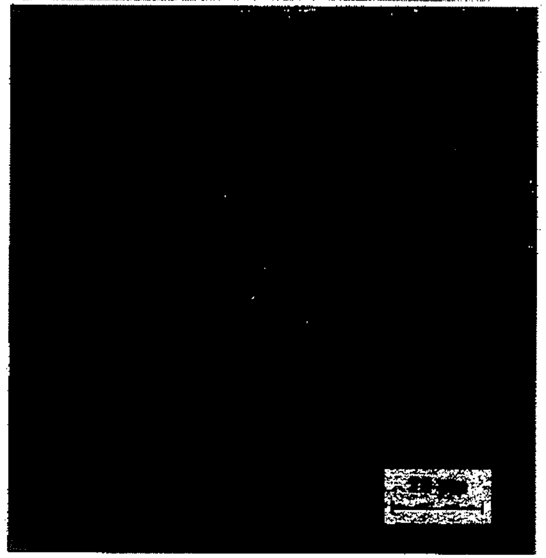
Pag. / *Sheet* 2 di / *of* 2

S.I.M. ST No.: 0728/09
F.C.P. ST No.: 0728/09 A/A

Subcliente/Subcustomer (SC) Cliente/Customer (C)	TECNINOX SRL Via Don Spagnoli, 5 Sarmato (PC)	Ordine (SC) / *Order (SC)*	OS000207 S	Commessa (C) / *Job (C)*	159/08 08/2177
				Posizione (SC / *Item (SC)*	24
Descrizione Prodotto / *Product Description*	ELBOWS 90° LR 1" SCH. 80S	Q.TA' / *Q.ty*		Prova Nr. / *Test Nr.*	933/03/09
Colata / *Heat*	39692	Specifica (C) / *Specification (C)*	Order Reqs.	Materiale / *Material*	UNS S31803 / S32205 ASTM/ASME A/SA 815

ESAME MICROGRAFICO *MICROGRAPHIC EXAMINATION* Norma lavorazione ed esecuzione / Construction and execution spec. ASTM E 3-01 / ASTM E 407-99

ATTACCO / Etching	KOH + Electrolytic
INGRANDIMENTI / Enlargement:	500 X
AREA CAMPIONE ESAMINATA / Area examined	WHOLE SECTION



SCALA 1.5 : 1

a) Si dichiara che il certificato riguarda solo campioni sottoposti a prova. *We declare that this report refers to the examined parts only.* c) Il campionamento del provini viene eseguito dal Cliente. *Clients are in charge of sampling.*
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NOTE / *Remarks*: STRUTTURA LIBERA DA PRECIPITAZIONI A BORDO GRANO E FASI INTERMETALLICHE / STRUCTURE FREE FROM GRAIN BOUNDARY CARBIDES AND INTERMETALLIC PHASES

ESITO DELLE PROVE / *RESULT OF TESTS*: CONFORME / *SATISFACTORY*

Data Ingresso Materiale / *Date of Arrival of Material*	Data Esecuzione Prove / *Date of Testing*	Data Rapporto di prova / *Test Report Date*	Ispettore / *Inspector*	Ispettore / *Inspector*	Cliente / *Customer*	Operatore / *Operator*	Responsabile Laboratorio / *Laboratory Manager*
25/03/2009	08/04/2009	09/04/2009				STEFANO ANTONELLI SIDER TEST SRL	PAOLO CAMANI SIDER TEST Srl

Customer: SCANDINAVIAN FITTINGS & FLANGES A/S
Order : 189488 - 12.03.2009
Descr. : ELBOWS 90° LR 1" SCH.80/S (LD073297 / 65)
Heat n°/Pcs. marking : 0174SAF9 Qtà/Qty:11 Posiz./Item n.: 65
Protocollo : CTCERC200900002589 * CERTIFIED TRUE COPY * Issued 22/04/09

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RAPPORTO DI PROVA No. / *TEST REPORT No.* 1921 / 09 — Pag. / *Sheet* 1 di / *of* 1 — S.I.M. ST No.: 0728/09 — F.C.P. ST No.: 0728/09 A / A

Subcliente/*Subcustomer (SC)* Cliente/*Customer (C)*: TECNINOX SRL Via Don Spagnoli, 5 Sarmato (PC)	Ordine (SC) / *Order (SC)*: OS000207 S	Commessa (C) / *Job (C)*: 159/08 08/2177	Posizione (SC) / *Item (SC)*: 24

Descrizione Prodotto / *Product Description*: ELBOWS 90° LR 1" SCH. 80S	Q.TA' / *Q.ty*	Prova Nr. / *Test Nr.*: 933/03/09	Colata / *Heat*: 39692	Specifica (C) / *Specification (C)*: Order Reqs.	Materiale / *Material*: UNS S31803 / S32205 ASTM/ASME A/SA 815

ASTM G 48 Metodo A — *Pitting Corrosion Test* — Norma lavorazione ed esecuzione / Construction and execution specifications. *ASTM G 48-03 / ASTM G 48-03*

Provino: / *Specimen:*	933/03/09
Dimensioni: / *Dimensions:*	44,3 x 20,8 x 4,7 mm
Area: / *Area:*	24,55 cm²
Temperatura di prova: / *Test temperature:*	25°C
Tempo di esposizione: / *Exposure time:*	24 Hours
Soluzione: / *Solution:*	$FeCl_3 \cdot 6H_2O$ 10% WATER SOLUTION

Peso iniziale (g): / *Initial weight (g):*	33,746
Peso finale (g): / *Final weight (g):*	33,745
Perdita di peso (g): / *Weight loss (g):*	0,001

NON SONO STATI RISCONTRATI DEI PIT NEL CAMPIONE IN ESAME A 20 X
NO PITS HAVE BEEN FOUND IN THE SPECIMEN TESTED AT 20 X

Media della profondità dei pit (micrometri): / *Average of pits depth (micrometers):*	0
Pit per cm2: / *Pit per cm2:*	0
Massima profondità dei pit (micrometri): / *Maximum pit depth (micrometers):*	0
Perdita della massa g/m2 / *Specimen mass loss g/m2*	0,40736

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NOTE / *Remarks*: WEIGHT LOSS SHALL NOT EXCEED 5 g/m2 — ESITO DELLE PROVE / *RESULT OF TESTS*: CONFORME / *SATISFACTORY*

Data Ingresso Materiale / *Date of Arrival of Material*	Data Esecuzione Prove / *Date of Testing*	Data Rapporto di prova / *Test Report Date*	Ispettore / *Inspector*	Ispettore / *Inspector*	Cliente / *Customer*	Operatore / *Operator*	Responsabile Laboratorio / *Laboratory Manager*
25/03/2009	31/03/2009	09/04/2009				STEFANO ANTONELLI SIDER TEST SRL	PAOLO AMANI SIDER TEST Srl

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Customer: SCANDINAVIAN FITTINGS & FLANGES A/S
Order : 189488 - 12.03.2009
Descr. : ELBOWS 90° LR 1" SCH.80/S (LD073297 / 65)
Heat n°/Pcs. marking : 0174SAF9 Qtà/Qty:11 Posiz./Item n.: 65
Protocollo : CTCERC200900002589 * CERTIFIED TRUE COPY * Issued 22/04/09

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N.	00002589
PAG. N. Sheet N.	1 / 1
DATA Date	22/04/2009

POSITIVE MATERIAL IDENTIFICATION

Cliente Customer:	SCANDINAVIAN FITTINGS & FLANGES A/S
Commessa Job N.	00000185
Ordine N. P.O. number:	189488 - 12.03.2009 PROJECT GJOA SEMI EPCH
Specifica d' esame Applicable Spec.	**Specifica d' esame** Applicable Spec.

Specifica cliente Customer specification

Il materiale sottoelencato e' stato sottoposto con esito favorevole al controllo P.M.I tramite apparecchiatura NITON XLT898 secondo specifica PO 40.

The under listed material have been satisfactory passed the P.M.I. test carried out with instruments NITON XLT898 in accordance with specification PO 40.

Note:
Notes: P.M.I. extension 100%

Pos. *Item*	Q.ta' *Q.ty*	U.M.	Descrizione *Description*	N° Colata/Marcatura Pz. *Heat N°/PCS. Marking*
			FITTINGS TO ASTM A-815 UNS S32760 DIM. ASME B16.9/B16.25	
57	1,00	NR	ELBOWS 90° LR 3/4" SCH.40/S (LD072036 / 57)	0037SA09
61	1,00	NR	ECC. REDS 4"x2" SCH.10/S (LD072165 / 61)	0035SA09
			BW FITTINGS TO ASTM/ASME SA/A-815 UNS S31803/32205 DIMS ENDS B16.9/28/25	
65	11,00	NR	ELBOWS 90° LR 1" SCH.80/S (LD073297 / 65)	0174SAF9

Operatore Qualificato *Qualified Operator*	Ente Terzo *Third Party Agency*	Cliente *Customer*	Raccortubi Q.A./Q.C.

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RACCORTUBI

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20121 Milano-Italia

Cap.Soc.€ 3.500.000 i.v.
C.F./P.IVA 00747640159
C.C.I.A.A. Milano N.384301
Iscr.Trib.Milano N.66820

Quality System Certified by Lloyd's Register. Cert. Number LRC 160065

STATEMENT

SCANDINAVIAN FITTINGS PROJECT GJOA SEMI EPCH
P.O.189488 – 12.03.09
Raccortubi Job : 0185
Material: ASTM A-815 UNS S32760-S31803/32205
BW FITTINGS

We certify that the fittings meet the requirements of above Order MDS- D 53 REV. 3 and MD-SBD43 Rev.04 specifications.
Material 100% P.M.I. tested.

Silvio Barbero
Quality Manager

Marcallo c/ Casone, 22/04/09