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ABSTRACT

The offshore oil industry has become a subsea industry. The majority of the offshore oil and gas fields developed in the world today are fully, or partially, subsea solutions. A subsea oil and gas field is totally dependent on subsea pipelines, and the reliability of the subsea pipelines is further fully dependent on proper subsea pipeline connections.

A subsea pipeline connection, whether it is a pipe-to-pipe connection or a pipe-to-structure connection, requires a structure for support towards the seabed. For a pipe-to-structure connection, the required support is maintained by the subsea facility which the pipeline is connected onto, while for a pipe-to-pipe connection, which is a stand-alone connection independent of a subsea facility, a purpose-built substructure provides the required support.

The PipeLine End Termination (PLET) is the required substructure for a pipe-to-pipe connection. The PLET is attached to the end of one of the pipelines involved in the connection. Normally the PLET is pre-attached to the pipeline end on the surface, and then the pipeline and the PLET are installed to seabed simultaneously. For pipelines of larger dimensions (approximately above 25 inches), this installation method is not suitable due to the size and the weight of the PLET. Consequently, the assembling of the PLET and the pipeline end takes place on the seabed after them being installed separately.

An “Open PLET” is a PLET structure designed for an assembly operation on the seabed. Current Open PLET systems comprises technical solutions which makes the subsea assembly operation challenging. These installation challenges are defined as follows:

- A difficult operation to position the Open PLET next to the pipeline prior to the subsea assembly operation due to the lack of a physical end stop feature.
- A difficult operation of lifting and shifting the heavy and rigid pipeline from the seabed to over the Open PLET prior to final engagement.
- A difficult operation where the vessel crane pulls the Open PLET on seabed to complete the integration of the pipeline.

A conceptual design of a new Open PLET system is in this thesis developed with the intention to reduce or eliminate these installation challenges.

In engineering design a concept is developed to be a basis for the detailed design of the product. The purpose in a conceptual design phase is to find and evaluate technical solutions which make the product fulfill the functional requirements.

The concept idea and the functional requirements for the new Open PLET system are in this thesis summarized in some "technical issues." The conceptual design then consists of the technical solutions to these issues.

The main technical solutions of the conceptual design are as follows:

- A longitudinal opening in the structure makes it possible to install the Open PLET straight over the pipeline instead of next to.
- A physical end stop feature facilitates proper positioning.
- The subsea assembly operation is accomplished by lifting the pipeline directly from the seabed to final position on the Open PLET. Guiding elements on the Open PLET positions the pipeline correctly.
- The pipeline is locked in final position by a mechanical locking mechanism which provides a vertical active locking direction.

A determining feature with the concept is the ability for the Open PLET to slide on the seabed. The sliding is required for aligning and guiding purposes, and to facilitate thermal expansion of the pipeline. The weight distribution over the Open PLET is found to be a vital factor for the sliding to occur. This weight distribution factor must be taken into account in the detailed design of the Open PLET.

The sliding feature is also considered as the major drawback of the concept solution. Uncertainty in the soil conditions on the seabed is the main reason as these conditions are determining with respect to the sliding capability. A consideration in further development of the concept is to eliminate the need for the Open PLET to slide on the seabed.

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Steinar Thorsen

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TERMS, DEFINITIONS & ABBREVIATIONS

Terms and definitions

Active locking direction	The locking direction of the locking mechanism.
Active Porch	Porch fixed to the skid. Pipeline and skid moves simultaneously.
Clamp connector	The locking mechanism in the connection. Interface towards outer geometries on the hubs.
Completion	The actual locking/clamping of a connection. Nowadays regarded as the last part of the connection operation when closing the clamp connector.
Connection	Short term for subsea pipeline connection.
Connection operation	The operation of completing a subsea pipeline connection. Normally includes a pull-in and a completion.
Connection point	The fixed end of a subsea pipeline connection. The physical position where the connection is completed.
Connection tool	Special designed tool for the connection operation. Carries out the pull-in operation in the HCCS.
Connection system	Collective term including all components involved and all tools required to complete a specific subsea pipeline connection.
HCCS	GE Oil & Gas connection system used with the Open PLET system.
Hub	Special designed segment at the end of the pipelines. Requires a clamp connector in the connection.
In-place	Operational condition for the Open PLET. Occurs when the installation and the connection are completed.
Landing operation	The part of the Open PLET installation when lowering from the installation vessel and landing on the seabed.
Lifting operation	The part of the Open PLET installation when lifting the pipeline end termination into position in the Porch.
Passive locking direction	The locking direction(s) which is a consequence of (or additional to) the active locking direction.
Passive Porch	Porch loose mounted on the skid. Enables the Porch to follow the pipeline movement independent of the skid.
Pipeline	Collective term which includes all kinds of flowlines, spools, jumpers and risers.
Porch	The fixed end of a connection. Special designed to fit in a connection system. Includes the pipeline end (hub) which is fixed to the Porch.
Pull-in	The physical repositioning and alignment of the termination from lay-down position to full hub contact at Porch. Regarded as the first part of a connection operation.
Sliding	Open PLET movement on the seabed.

Spool	Short segment of rigid pipeline. Designed to compensate the thermal expansion in pipelines. Often named "L-spool" or "Z-spool" due to the geometry.
Spool connection	The operation of completing a subsea pipeline connection when a spool is involved (ref. connection operation).
Subsea facility	Collective term for subsea structures such as Xmas trees, manifolds, templates, PLEMs, etc. (The PLET is not included in this term)
Substructure	Required supporting structure for a midline connection (pipe-to-pipe connection).
Technical solution	A particular design feature and/or functionality (how it works) which make the product fulfill a functional requirement.
Termination	The movable end of a connection. The end of a pipeline. Special designed to fit in a connection system.

Abbreviations

ANSYS WB	ANSYS WorkBench
CAD	Computer Aided Design
CoG	Center of Gravity
FE	Finite Element
FEM	Finite Element Method
GE	General Electric
HCCS	Horizontal Clamp Connection System
L	Load
LC	Load Case
MAS	Main Alignment Structure
N/A	Not Applicable
PLEM	Pipeline End Manifold
PLET	PipeLine End Termination
RAS	Rear Alignment Structure
SLS	Serviceability Limit Stat
UF	Utilization Factor
ULS	Ultimate Limit State

1 INTRODUCTION

The oil industry is big, world-wide and complex. It applies state of the art technology and a countless number of different components to solve the technical challenges that constantly occur as the industry develops. The intention in this chapter is to define in which segment of the oil industry the product examined in this thesis belongs to. Therefore a brief overview of the product will be presented.

1.1 FROM LAND TO SUBSEA

The oil is known for thousands of years. The people on earth got familiar with this substance as it was seeping up through the ground. Geographically, oil was first used in the Middle East and China. It was used for waterproofing boats and baskets, for painting and for lighting. Throughout centuries, in Asia, Europe and America, hand dug or primitive drilled holes in the ground was made to extract oil.

The inventions of the kerosene lamp in 1857 and the internal combustion engine in 1895 (and thereupon the first motor car in 1896) are two of many inventions which led to a world with an increasing need for oil. The industrial revolution at the end of the eighteenth century resulted in possibility for new technologies. The world demanded oil, the drilling technology developed; the result was the modern day oil wells.

The first modern oil wells were drilled in the middle of the nineteenth century in Asia, Europe and America. It then became possible to sell oil commercially. In the eighteen fifties and sixties the majority of the world oil production was in the Azerbaijan region in Asia. This changed towards the twentieth century when the oil rush in America made them become responsible for the majority of the world oil production [1, 2].

The first oil wells were on land, but due to the rapid growing demand for oil, oil companies began to explore for oil below seabed as well. The start of the offshore oil production adventure can be traced back to Summerland in California (US) as early as 1897. The first technology for offshore oil industry was a “pier and derrick” technique. Wooden piers were built from shoreline to about 400 meters out in the sea. Upon these piers wooden derricks were built for handling of the primitive non-rotational drilling equipment.

Stand-alone offshore platforms became the next step in the offshore adventure as the distance from shore increased. The first well drilled from a stand-alone offshore platform was in 1932, also in California. The first “out sight of land” oil-producing well was drilled in 1947 in the Gulf of Mexico [3, 4].

Offshore oil industry was established, and the technology developed rapidly as the distance to shore became longer and the oceans deeper. In addition to fixed platforms standing on the seabed, various types of floaters were developed, both platforms and vessels, for drilling and production. New technology for oil exploration, as geological research and exploration drilling, were important factors for the discovering of new oil reserves, all over the world. The constant developing drilling technology also made it possible to drill in multiple directions to reach more of the reservoir from a single point.

Offshore exploration drilling on the Norwegian continental shelf started in July 1966, and in 1969 the news were announced that the oil company Philips Petroleum had found one of the largest offshore oil reserves in the world. The field was called "Ekofisk," and the production started in 1971 [5].

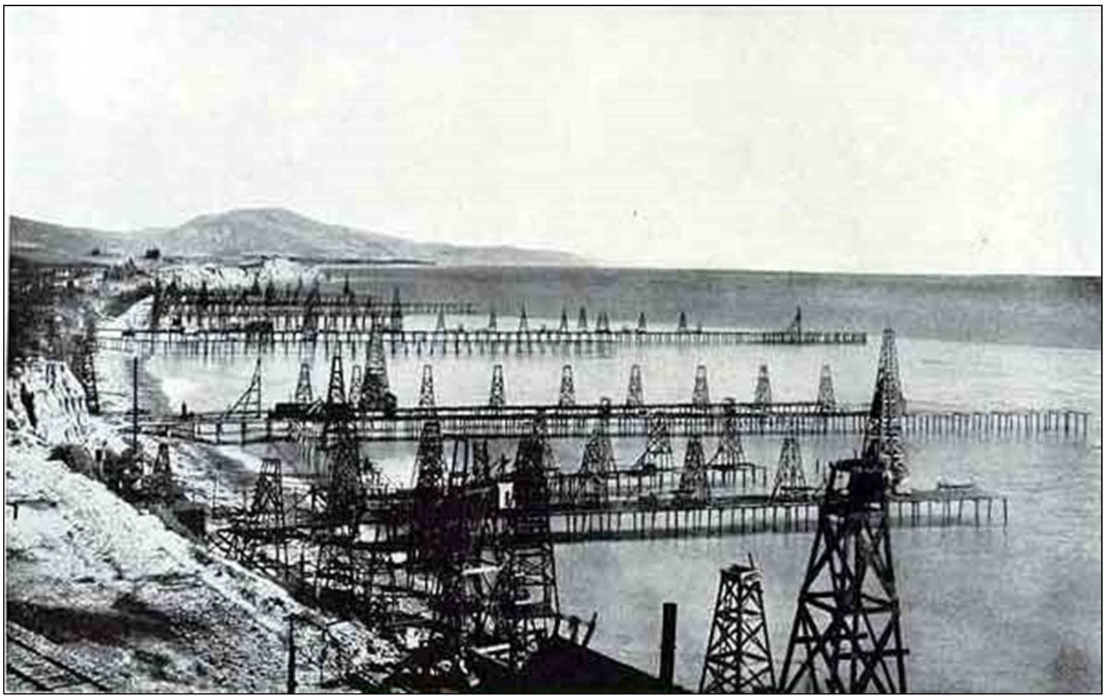


Figure 1.1 – Piers and derricks in Summerland, California, 1901 [4]

On top of every oil well, both on land and offshore, there is placed a so called "Xmas tree." It is basically an assembly of valves used to control the flow out of the well. The Xmas tree is a part of the primary barrier between the oil reservoir and the environment.

The first offshore oil-producing wells were surface completed wells, also called "platform wells." The Xmas tree was placed in dry environments upon the platform. If the Xmas tree is placed on the seabed, just on top of a drilled hole leading to the well, it is called a “subsea completed well”. A subsea Xmas tree was installed for the first time by Shell in the Gulf of Mexico in 1961 on a depth of 16 meters [6].

The basis for choosing a surface or a subsea completion involves factors as cost, technological possibilities, safety and reliability. A subsea completion has a lower recovery rate than a surface completion. If a surface completion is chosen on great depths, the riser (pipeline from seabed to platform) will be too long and heavy, and become a major risk with respect to a possible leakage. The ability to complete several subsea wells, integrate them into one system, and thereby reduce the amount of risers required, is a major advantage for a subsea completion. The functional reliability for the production equipment in dry environments is a major advantage for a surface completion.

1.2 SUBSEA PIPELINES

It exist basically two methods for transportation of liquids. Either you put the liquid in a tank, move the tank to the final destination, and empty the tank, or, you build a pipeline. When using a tank, the tank itself can be transported in several ways, most common by truck, rail or by ship. The first recorded ship that can be regarded as a conventional oil tanker was the sailing ship “Elizabeth Watts” carrying 224 tons of crude oil from Pennsylvania (US) to London in 1861 [1].

The use of pipelines for transportation of liquids can be traced back to the Antiquity. The first onshore pipeline for crude oil transportation was built in the United States in 1859 [7]. The use of subsea pipelines was first established in the twentieth century. In 1944 a fuel line was installed across the English Channel to supply allied troops during the Normandy landing. The first pipeline laid on the seabed was in the Mexican Gulf in 1954 [3].

The pipelines are the veins that keep an oil field alive. Produced oil and gas are transported through the pipelines from the well to the production facility. From the production facility service pipelines carries chemicals, hydraulics, and produced water and gas to the subsea facilities for operation and injection purposes. The production facility can be either a platform or an onshore facility. Large export pipelines are used for the transportation of the produced oil and gas from offshore location to shore. A pipeline, which is not working, due to various types of flow issues (slugging, hydrates, etc.) or mechanical leakage, can create problems influencing the whole oil field.

A typical subsea oil and gas field consists mainly of Xmas trees, manifolds, termination units and pipelines. The "central" in a subsea field is the manifold. It is the link between the subsea field and the production facility. The manifold consists of a network of pipes and valves for gathering and distribution of the production flow. By using a manifold, the number of pipelines required in a subsea field is reduces, and it allows for a single pipeline for transportation to the production facility.

The Xmas trees are (normally) placed on the seabed, acting like satellites around the manifold. The trees are connected to the manifold with a pipeline called "jumper" or "spool".

A termination unit can be called a "PLEM" or a "PLET." These units are connection points between two or several pipelines. The PipeLine End Termination (PLET) comprises a single pipeline connection only, while the PipeLine End Manifold (PLEM) is supporting two or more pipeline connections.

In the subsea industry, the "pipeline" is a collective term for flowlines (pipelines transporting fluids and/or gas), spools, jumpers and risers.

Figure 1.2 is a layout of a subsea field, and it is an example of how the various components can be configured with respect to each other.

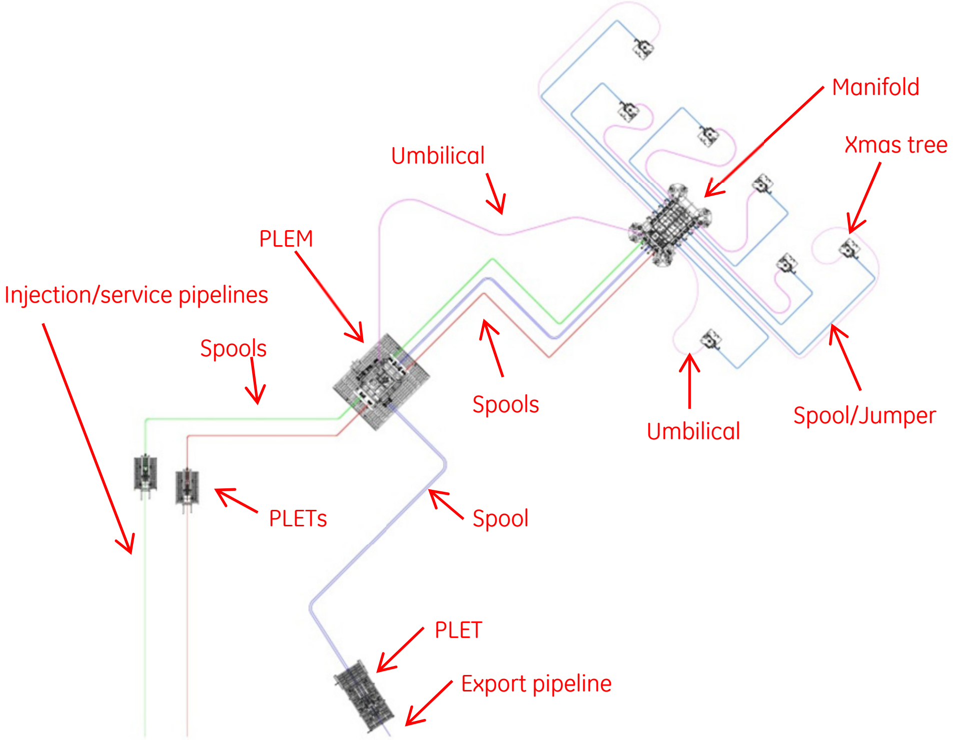


Figure 1.2 – Subsea field layout, example Gorgon field [8]

1.2.1 Subsea pipeline configuration

Almost unlimited possibilities exist with respect to subsea field configurations. The list of components and combinations to choose from is large. At the end, it is what the oil company wants, the features and functions of the subsea field, that decides how the field configuration and the solutions finally become.

For subsea field solutions, a distinction can be made between a “platform solution” and “subsea-to-shore solution.”

1.2.1.1 Platform solution

Per definition, in this context (thesis), a platform is all kinds of offshore surface units, like fixed platforms, floaters, FPSOs, etc. used in conjunction with offshore oil and gas production. If a subsea field is connected to a platform in such way that the produced oil and gas is transported to the platform for processing, it is called a platform solution. A common feature for this subsea solution is the riser which connects the subsea field to the platform.

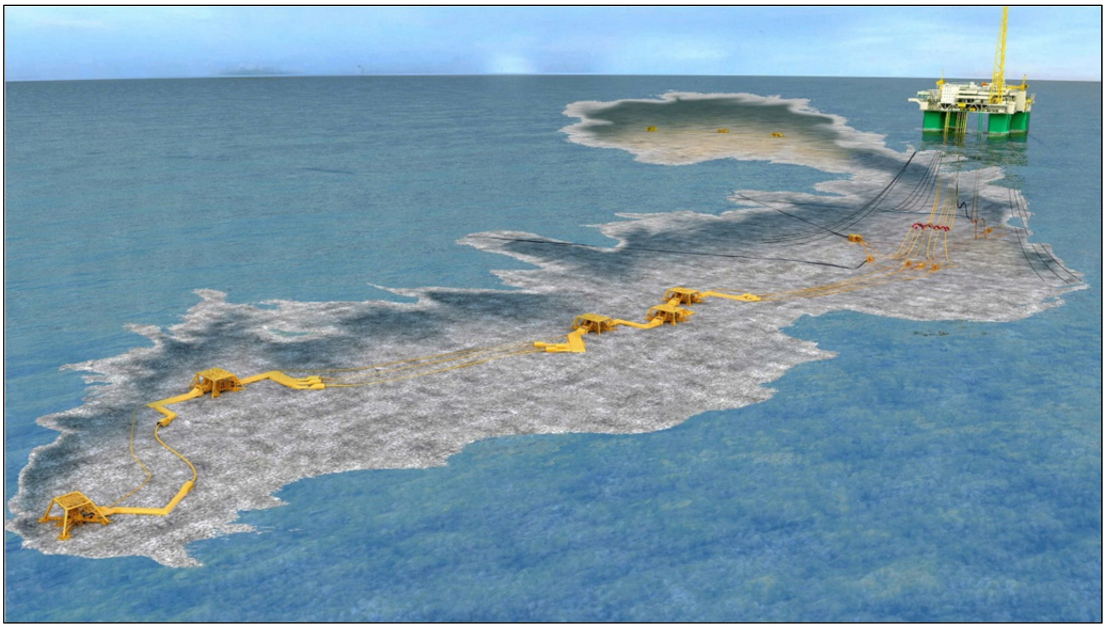


Figure 1.3 – Platform solution, example Gjøa field [9]

1.2.1.2 Subsea-to-shore solution

For this type of subsea solution, all produced oil and gas is transported (tie-back) to an onshore facility for processing. The transportation is in a long export flowline. The subsea fields “Snøhvit” and “Ormen Lange,” which are well known in Norway, comprise the subsea-to-shore solution.

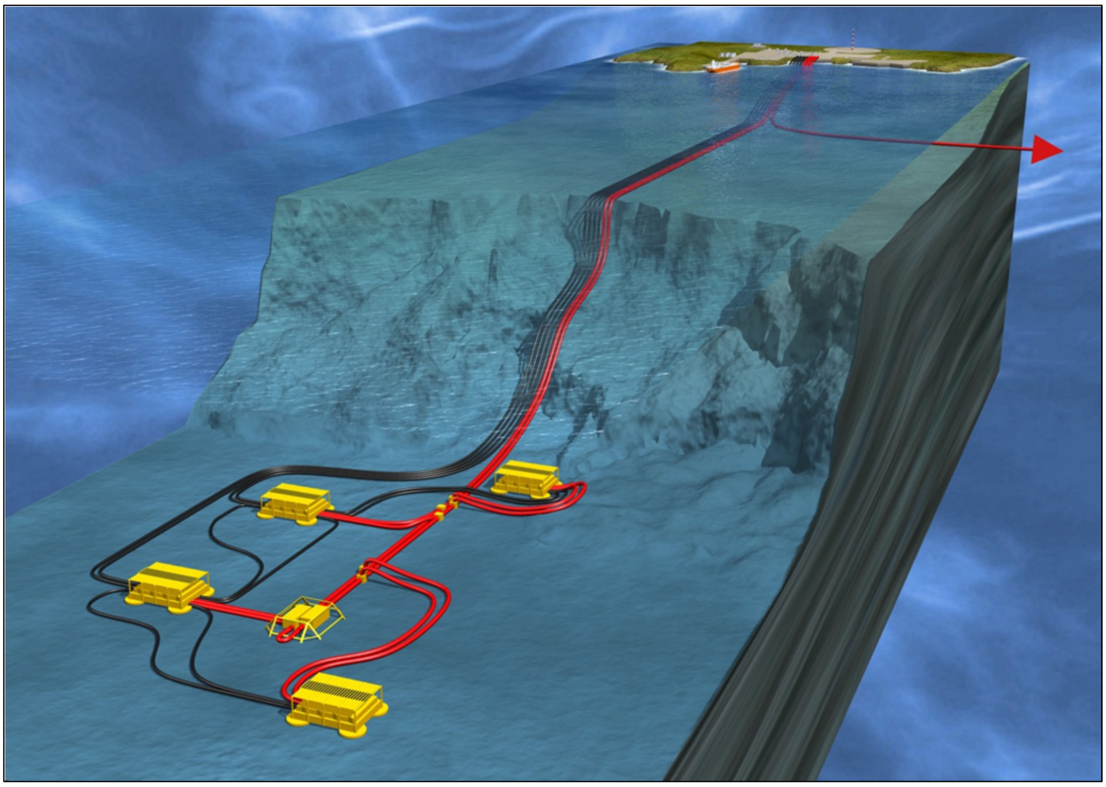


Figure 1.4 – Subsea-to-shore solution, example Ormen Lange field [10]

1.3 SUBSEA PIPELINE CONNECTIONS

Subsea pipeline connections can be differentiated between “pipe-to-pipe” connections and “pipe-to-structure” connections. Pipe-to-pipe connection is the definition when to pipelines are connected to operate as one pipeline, while pipe-to-structure connection is the definition when a pipeline is connected to a subsea facility such as a Xmas tree, a manifold or a PLEM.

If a long export flowline from shore is to be connected to a subsea facility, a spool is required between the flowline and the structure. The shape of the spool (L-shape or Z-shape) makes the spool compensate for thermal expansion in the flowline to avoid application of heavy loading directly into the connection point on the structure. The connection between a flowline and a spool is a very common subsea pipe-to-pipe connection.

1.3.1 History of subsea pipeline connection techniques

The methods for pipeline connections on land were proved successful. The first pipelines on land used in the oil industry were connected by screwed joints. Other techniques, like the use of welding, flanges, sleeves and mechanical connectors, were developed thereafter. When the pipelines moved to subsea (1954), a challenge occurred as the connection of pipelines should be completed in submerged environments. The first subsea wells (1961) were located in shallow water, so the appurtenant pipeline connections were completed by divers. The proven connection techniques used on land were the ones used subsea as well [11].

As the offshore industry developed, and the waters became deeper, the diver method reached its limits, and the technology needed to improve to deal with the deep water challenge of how to complete a subsea pipeline connection without using divers.

Deep waters, and the size and weight of the pipelines, made it more and more difficult and dangerous for divers to complete the connections. In addition, the most preferred connection technique on land was by welding, and welding is naturally much more difficult in wet environments.

One of the first technologies that developed to deal with these challenges was the use of a "one atmosphere connector chamber" (Figure 1.5). The technology was based on techniques developed in the nineteen fifties. A pipe-to-pipe connection or a pipe-to-structure connection is completed by means of conventional welding techniques in a manned chamber subsea. The chamber provided a dry, one atmosphere environment. Access to the chamber was attained by a lowering the personnel in a service capsule from a surface vessel to the subsea chamber. From the service capsule, the personnel entered the chamber to complete the connection [12].

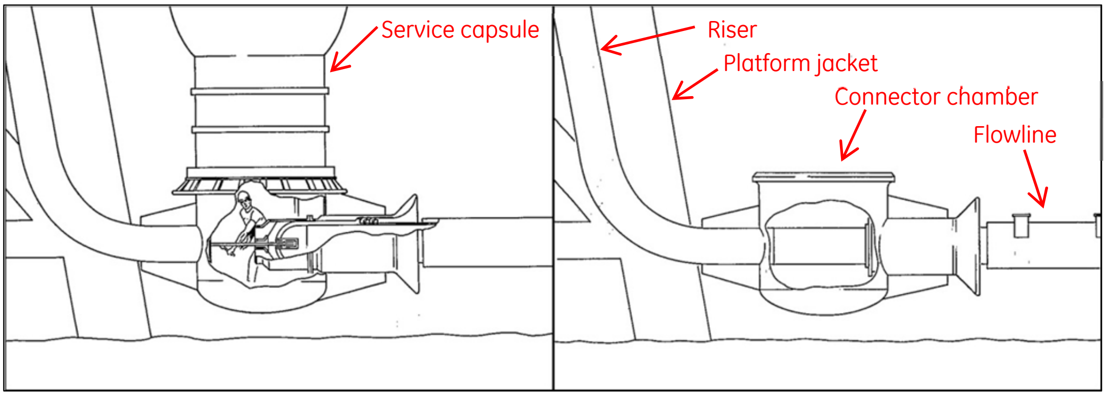


Figure 1.5 – One atmosphere connector chamber [12]

The subsea oil industry grew and developed at a fast pace. In the first decade of this industry, from its start in 1961, the arena was in the Mexican Gulf, but from the early seventies the North Sea became the major subsea technology arena [13].

The seventies is the decade when the diver is replaced with the Remotely Operated Vehicle (ROV) as an essential need with respect to subsea industry. The ROV is a small, unmanned submarine equipped with two-off manipulator arms for operational tasks, cameras for observation and hydraulic power supply for tooling. The ROV is controlled by “pilots” located on a surface vessel. The ROV is attached to the vessel with a long umbilical cable [14].

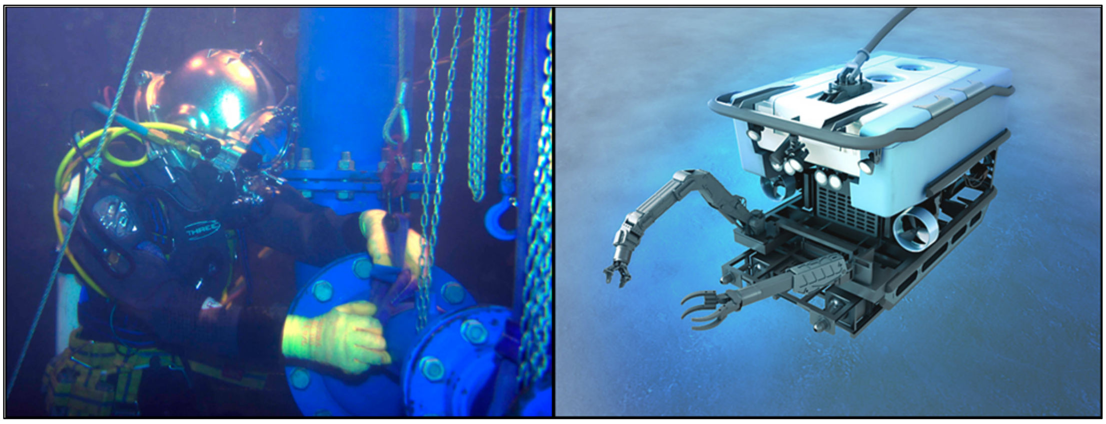


Figure 1.6 – Diver and ROV

To complete a connection of submerged pipelines without the use of divers, the mechanical clamp connector became of major importance. The clamp connector replaced the use of welded or flanged connections, connections which in subsea environments could be completed by divers only. The clamp connector is remotely operated by a ROV or a connection tool.

Figure 1.7 presents the features of a clamp connector. The clamp connector has interfaces towards the pipeline ends. The end of a pipeline connected by a clamp connector is called a “hub.” The two opposite hubs are connected by closing the clamp connector. The clamp connector is closed by rotating some stud bolts. The stud bolts are rotated by ROV operated torque motors. Between the hubs, a metal-to-metal seal contributes to get a sealed connection.

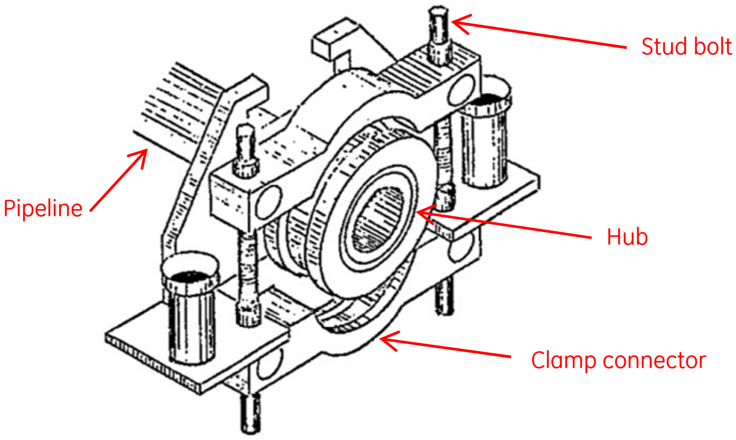


Figure 1.7 – Mechanical clamp connector [15]

Figure 1.8 shows a diverless operated connection tool. The first diverless connection techniques were controlled by use of underwater television cameras. No ROV was used. The flowline to be connected was installed in position close to the connection point on the subsea facility (pipe-to-structure connection). A special designed connection tool, which were hydraulically operated and directly controlled from a surface vessel, was then lowered from the vessel and landed upon the connection point. The connection was completed by installing a small spool piece (short pipeline) to close the gap between the flowline and the connection point. Small torque motors operated the two clamp connectors, and clamped the spool piece to the flowline and the connection point [15].

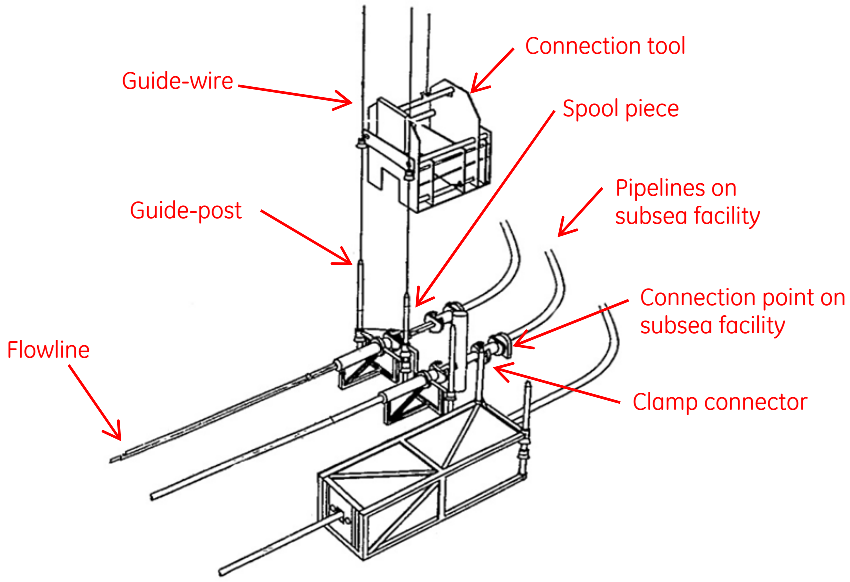


Figure 1.8 – Diverless operated connection tool [15]

The use of ROV increased in the subsea industry from the early nineteen eighties. The advantages were cost savings and improved safety. Towards the end of the last century the ROV technology fortified its position as an industry choice. Nowadays, most of the subsea pipeline connections are completed by use of a connection tool operated by a ROV. The ROV manipulator arms operate hydraulic valves on the tool, the ROV supplies the tool with hydraulic power, and by cameras on the ROV, the whole connection operation can be observed. The pipeline connection itself is clamped by a clamp connector [16].

Figure 1.9 (overleaf) shows a ROV operated connection tool.

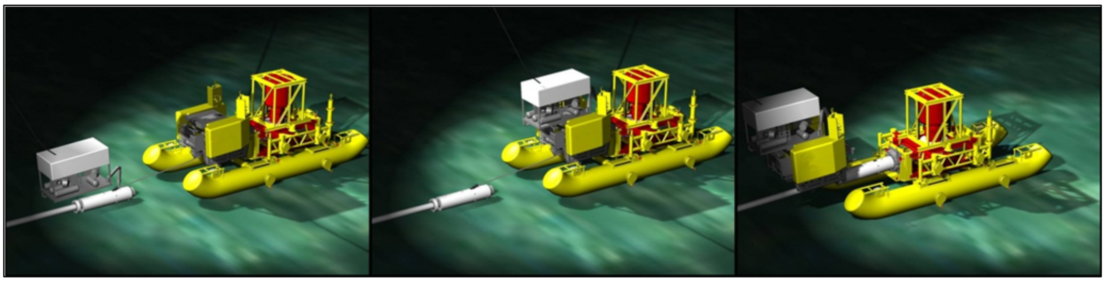


Figure 1.9 – ROV operated connection tool [8]

1.4 PIPELINE END TERMINATION (PLET)

A "pipe-to-pipe connection" can take place when a riser is connected to a subsea installed pipeline, or when an export flowline is connected to a spool. These types of connections, compared to the "pipe-to-structure connections," do not have a given substructure for support. For a pipe-to–structure connection, the Xmas tree, the manifold or the PLEM will provide the required support to the connection point, while a pipe-to-pipe connection requires a purpose-built substructure.

The PLET is the required substructure for a pipe-to-pipe connection. It provides the support for the connection point. Figure 1.10 is an example of a PLET. A detail description of PLET is given in section 2.3.

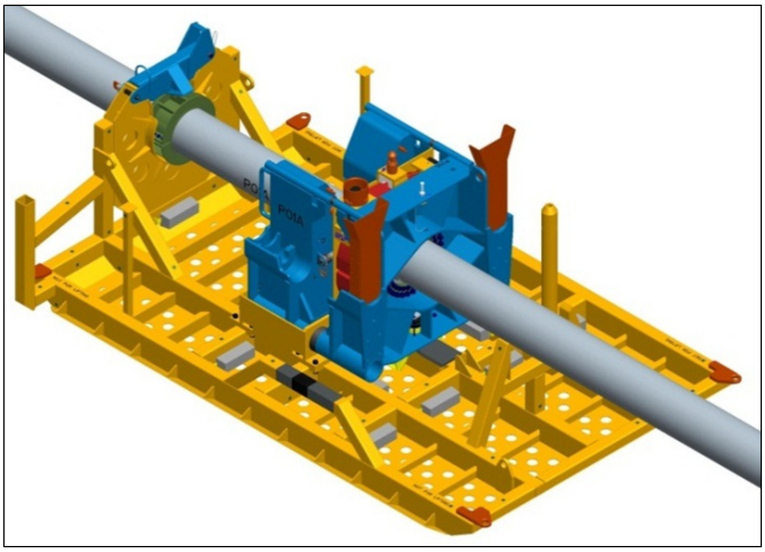


Figure 1.10 – PLET, example Skarv field

Figure 1.11 (overleaf) illustrates a difference between a platform solution and a subsea-to-shore solution with respect to the use of a PLET. For the subsea-to-shore solution, the PLET is positioned at the connection point between the export flowline and a spool as the flowline cannot be connected directly into the manifold. For the platform solution the PLET is positioned at the connection point between the riser and a spool as the riser cannot be connected directly into the manifold.

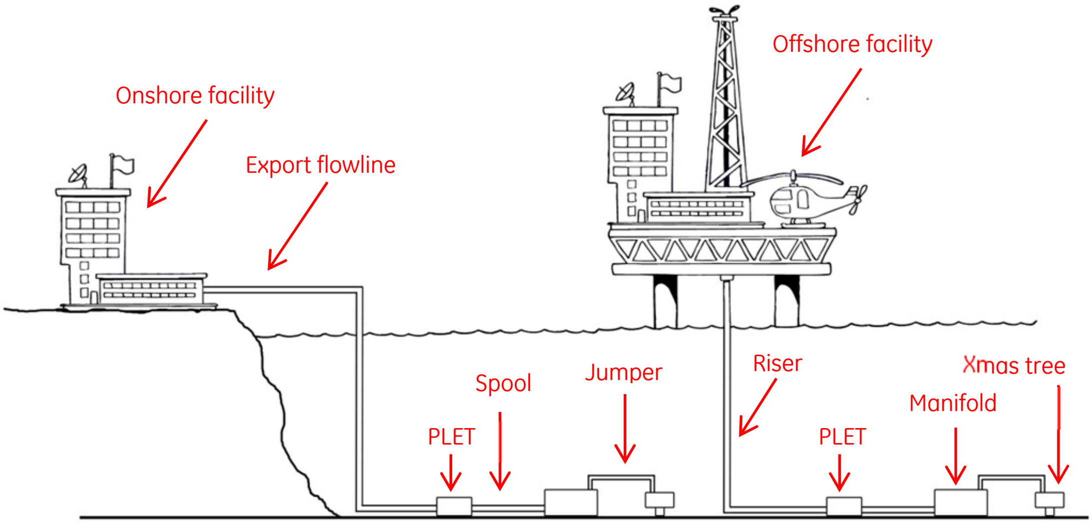


Figure 1.11 – Open PLET in subsea field configurations

Generally, a PLET is positioned where a flowline is connected to a spool. Most of the flowlines in a subsea field are rigid pipelines (section 2.1), and spools are then required between the flowlines and the connection points on the subsea facilities to compensate the thermal expansions in the flowlines (section 1.3).

Figure 1.12 shows how PLETs are used in a subsea field configuration. The red clouds indicate the positions.

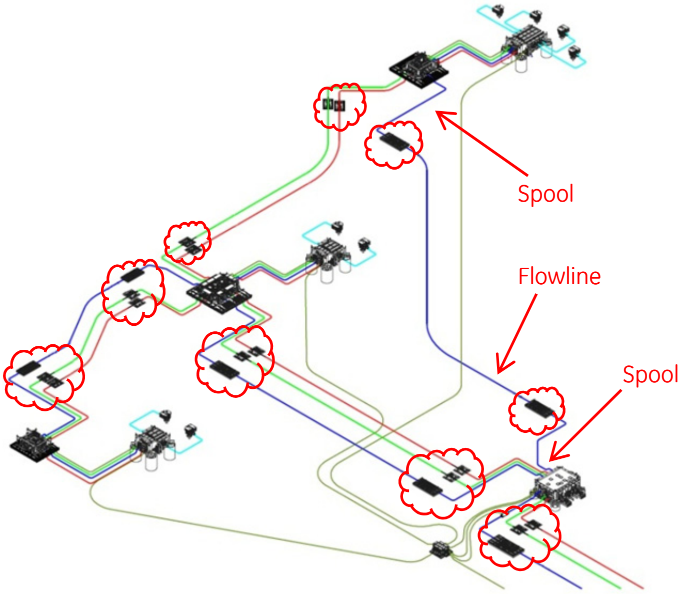


Figure 1.12 – PLETs in a subsea field, example Gorgon field [8]

1.5 THESIS OBJECTIVE

The PLET is generally installed subsea pre-attached to the pipeline end. The assembly consisting of the substructure and the pipeline end, is called “PipeLine End Termination” or “PLET”.

If the size of the pipeline or the substructure is large, it becomes not suitable to install them simultaneously as a completed PLET assembly. An “Open PLET” is a PLET assembly which requires to be assembled on the seabed after a separate installation of the pipeline and the substructure. This is due to the size and weight of the pipeline and or the substructure. The assembly operation on the seabed, to integrate the pipeline end on the substructure, is challenging. These challenges form the basis for this thesis.

Is it possible to reduce or eliminate the challenges of this subsea assembly operation?

A closer presentation of the current Open PLET system is given in section 2.3 and 2.4. A detailed description of the challenges mentioned above is given in section 2.6.5.

The example of an Open PLET system used in this thesis is currently in use by GE Oil & Gas. This Open PLET will be the basis for description of components and functions of the system. But above all, it will be the representative for the challenges that defines the problem that will be examined in this thesis.

1.5.1 Problem presentation

The subsea installation of the current Open PLET system, including the assembly operation, includes challenges which makes the operation complicated and time consuming (section 2.6.5). The installation method demands good preparations and planning, and is costly due to the time consumption.

The subsea installation of an Open PLET system is accomplished by an installation vessel. These vessels are very costly to operate; a day rate of about one million NOK is common. If an Open PLET system can be installed faster, significant savings is possible.

The main objective of this thesis is to develop a conceptual design for a new Open PLET system. The purpose is to reduce or eliminate the challenges with the current system. Based on the experience with the current system, an *idea* for a new Open PLET system has been developed within GE Oil & Gas, and this new idea will be a basis upon which the conceptual design shall be developed.

The new system shall meet some defined functional requirements, be designed according to defined design criteria and developed according to an industry norm that says “simple solutions”.

A design basis for the thesis can be found in section 2.6. A presentation of the concept idea for the new Open PLET system can be found in section 3.2.

A review of the conceptual design will be carried out. This review will first of all verify if the new Open PLET system is able to meet its functional requirements. Naturally, a comparison between the current and the new system will form a basis for the review.

1.5.2 Work phases

The thesis work comprises three main phases:

1. Context phase
2. Design phase
3. Review phase

1.5.2.1 Context phase

The first phase is the context phase. This is a presentation of relevant history and technology to place the Open PLET system in a context. Familiarization with the system is achieved by treating questions like what is it, where is it used and why? A detailed overview of the current Open PLET system is given with a presentation of components and functions. Relevant theory will be defined to give a basis for the following work phases.

This phase involves literature study, study of relevant GE Oil & Gas documents, putting information into systems, and definition of essential demarcations.

1.5.2.2 Design phase

A conceptual design describes how a new product will work and meet its requirements. It is the creation, exploration and representation of an idea. The research done and the information gathered, will in this phase be put together to develop a conceptual design. Verification of the new design will be done by evaluations and thereupon determined analysis.

This phase of the thesis is divided in three sub-phases: In the *concept selection* phase, ideas will be highlighted prior to final selection of the concept solution. In the *modeling* phase, the conceptual design shall be developed as a 3D model. In the *evaluation* phase important components will be analyzed to verify if they are meeting relevant requirements and criteria.

The design phase involves meetings with experienced offshore personnel (GE Oil & Gas personnel), selection of concept, development of 3D model, and essential analyses of important components.

1.5.2.3 Review phase

A review of the new concept will be carried out on the basis of a comparison between the current and the new system. The new system will be presented with respect to technical solutions and functions. Alternative solutions to the chosen design will be discussed.

This phase involves use of information from the context phase and the design phase.

1.5.3 Demarcations

The following demarcations are defined for the scope of the thesis:

- The Open PLET system dealt with in this thesis comprises a connection system called “HCCS” (section 2.5). No modifications will be executed on the HCCS with respect to the interface towards the Open PLET.

- Prior to installation of the Open PLET system, some requirements with respect to the seabed conditions and the lay-down position (angle) of the pipeline end termination must be fulfilled. This thesis will not include any work to define such pre-installation requirements.

- This thesis deals with a conceptual design. Consequently, optimization of the design on basis of the results from the evaluation phase (section 1.5.2.2) will not be done. The intention of the work in the evaluation phase is basically to support the results of the development of the conceptual design.

- In the evaluation phase, only static analyses of the components will be conducted. Even though the Open PLET system, during design life, will be subjected to dynamic forces, these evaluations will not be taken into account as this thesis concerns a conceptual design.

- No evaluation and consideration of materials will be done.

1.6 OUTLINE OF REPORT

Chapter 2 of this report presents the theory relevant for this thesis. Basic theory about subsea pipelines and subsea pipeline connections is followed by detailed descriptions of the current Open PLET system. The end of the chapter is the design basis where the functional requirements are listed together with important definitions. A part of the design basis is a presentation of the installation challenges with the current Open PLET.

Chapter 3 describes the concept selection process and the results of the 3D modeling. The concept selection is the process of defining all the technical solutions for the concept. The 3D model is presented along with relevant technical data.

Chapter 4 presents the results of the evaluation phase which involves analyses of important components of the design. In addition, an important feature (technical solution) of the conceptual design is verified by a hand calculation.

Chapter 5 is a review of the conceptual design. The technical solutions and the functions of the new system are presented. A review of the concept is then conducted to evaluate if the functional requirements are met, to discuss alternative solutions, and to compare the new concept with the current system.

Chapter 6 is a conclusion of the thesis and considerations regarding future work.

2 THEORY

2.1 SUBSEA PIPELINES

The most common way to fabricate a subsea pipeline is to weld a large number of pipe joints into each other on a special lay-vessel at the same time as the pipeline is lowered and installed on the seabed. Typical pipeline material is carbon steel or a type of alloy.

Pipelines are generally regarded as rigid or flexible. Rigid pipelines are made of steel and have limited bending capacity and flexibility. Export flowlines and spools are usually rigid pipelines. The rigid pipelines are generally less expensive than flexible pipelines.

Flexible pipelines are characterized by a low bending stiffness combined with high axial stiffness. The material is a composite material consisting of layers of metallic wires, polymers, textiles, tapes and lubricants. Flexible pipelines are of special benefit in use with floating production units, where wave motion exposed to the pipeline (riser) may be an issue. Flexible pipelines are able to work under extreme dynamic conditions, and they have relatively good insulating and chemical compatibility properties compared to rigid steel pipelines. Free hanging flexible pipelines, as for risers, are limited to water depths of about 2000 meters, dependent on the pipe diameter and the internal pressure. The first commercial flexible subsea pipeline was installed in 1968 [17].

2.1.1 Installation methods

Depending on the size and material of the pipeline, and the installation water depth, different techniques are used for subsea installation of pipelines [18].

2.1.1.1 S-lay

Pipe joints are welded to a pipeline on a lay-vessel. From the lay-vessel the pipeline appear as an S-curve to the seabed. S-lay is used for large, rigid pipelines with an inner diameter above 16 inches. The method is feasible to approximately 700 meter water depth.

2.1.1.2 J-lay

Pipe joints are welded to a pipeline on the lay-vessel. The welding is done with the pipe joints in vertical position. The pipeline enters the water in vertical direction, and it appears as a J-curve from the lay-vessel to the seabed. This method is feasible to at least 2000 meters water depth.

2.1.1.3 Reel-lay

The pipeline is manufactured onshore and spooled onto a large reel which is mounted on the deck of a vessel. The reel-lay method implies either S-lay or the J-lay method when lowering the pipeline. The maximum pipeline diameter is approximately 16 inches.

2.1.1.4 Towing

The pipeline is fabricated onshore and towed, either floating or submerged, by a surface vessel, to the offshore location.

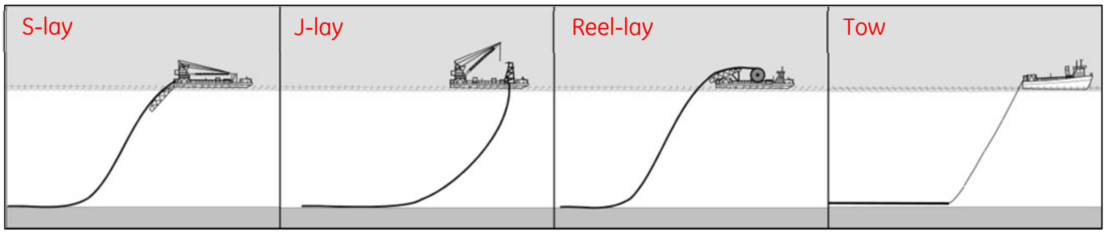


Figure 2.1 – Pipeline installation methods

Installation of spools and jumpers to a subsea field is done by an installation vessel (not lay-vessel). The spool or jumper is fabricated onshore, and is then transported by the vessel to the offshore location. From the vessel, the spool or jumper is installed to seabed by vessel crane.

Figure 2.2 is showing a typical installation vessel. The vessel is equipped with a large crane for lowering and installation of for example spools and PLETs to seabed. This is a reference when referring to a "vessel" in this report.

Figure 2.2 – Installation vessel [19]

2.2 SUBSEA PIPELINE CONNECTION

A "connection system" is a collective term for all components involved and all equipment (tools) required to complete a subsea pipeline connection. The design of a connection system with all its components and functions, are nowadays tailored for operation with the ROV. These systems often include a special designed connection tool. These tools execute a pull-in operation when aligning and mating the pipeline ends prior to closing of the clamp connector.

A subsea pipeline connection consists of a fixed end and a movable end. The fixed end is called a "Porch," and it is the connection point on a subsea facility. The Porch is a structure special designed to fit in a particular connection system. The Porch comprises one of the pipeline ends (hub), which is fixed to the Porch.

The movable end of the connection is called a "termination." The termination is the last part of a pipeline, and it is specially designed to fit a particular connection system. There are big variations in design of terminations, mainly due to the amount of connection systems and connection methods that exists (section 2.2.3), and the fact that almost every single connection system requires a unique termination design.

2.2.1 Connection system application

This is a brief overview of the steps in the completion of a typical subsea pipeline connection, including relevant terms and explanations:

1. Pre-installation of the Porch (fixed end). Installed with the Xmas tree, the manifold, the PLEM or the PLET.
2. Installation of the termination (movable end) close to the Porch. A gap exists between the pipeline ends (hubs).
3. Pull-in operation executed by a connection tool. Closes the gap between the hubs by pulling and aligning the termination to the Porch. The hub faces are mated.
4. Completion of the connection by closing the clamp connector. Operation carried out by a connection tool or the ROV.

2.2.2 Principle of a subsea pipeline connection

Figure 2.3 (overleaf) presents the principle of the locking method for a subsea pipeline connection. This is a common way of connecting subsea pipelines, and it is applicable for the majority of the connection systems. Following the presentation is a brief description of the components.

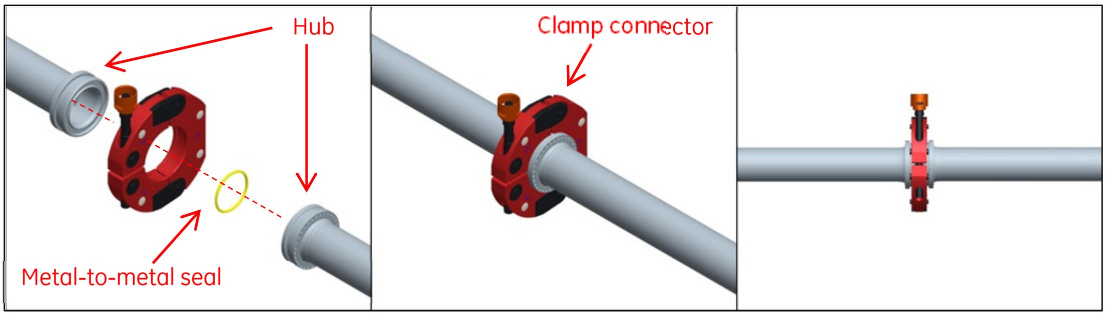


Figure 2.3 – Principle of a subsea pipeline connection

2.2.2.1 Hub

The end of the pipeline is a segment called "hub." The hub has an interface towards the hub on the opposite pipeline and to the clamp connector. Between the hubs, a metal-to-metal seal contributes to get a sealed connection. Due to the geometry, the hubs are called "male hub" and "female hub." The hubs are complicated parts involving stringent material properties and fine geometrical tolerances. The hub segment is a machined part which is welded to the pipeline.

2.2.2.2 Metal-to-metal seal

The metal-to-metal seal has an interface towards both the hubs. The interface on the hub is called "seal area." The seal design is considered a trade secret. Metal-to-metal seals are a field proven technology both onshore and offshore.

2.2.2.3 Clamp connector

The clamp connector is the mechanical component which acts as the locking mechanism in the connection. The clamp comprises segments with interfaces towards the outer geometries of the hubs in such way that the hubs are mated and clamped as the clamp connector is closing. The clamp connector is operated by turning a drive screw. This drive screw is operated by a torque tool.

2.2.3 Categorization

There are several ways to categorize a subsea pipeline connection. Some have become an industry standard, and are listed in codes and regulations, while some are more unstandardized, but widely used industry terms.

2.2.3.1 First end/second end/midline

Connections can be differentiated according to the sequence in which they occur in the offshore installation operation, like "first end" and "second end." It is natural to assume that each pipeline has only two connections, one in each end, but this is not always the case. If a connection between two respective pipelines makes them start to operate as one pipeline, the connection is defined as a “midline connection.” A midline connection is basically a stand-alone connection on the seabed compared with those in conjunction with a subsea facility [20].

2.2.3.2 Pull-in and connect/deploy-to-place and connect

For the “pull-in and connect method,” the pipeline termination is installed on the seabed close to the Porch. By a pull-in operation, the termination is aligned to the Porch, and the gap between the hubs is closed. The connection is then completed by closing the clamp connector [15, 21].

For the “deploy-to-place and connect method,” the pipeline termination is installed directly into position on the Porch so that no pull-in operation is required. Only a small gap between hub faces requires to be closed prior to closing of the clamp connector.

2.2.3.3 Horizontal/vertical

The connections can be differentiated with respect to orientation. Horizontal connections are accomplished with the pipeline termination in horizontal position. This method may require a pull-in operation, but horizontal systems comprising the deploy-to-place and connect method also exist.

For vertical connections, the termination is installed directly from the installation vessel onto the receiving hub (fixed end), which is positioned in vertical direction. This method does not require any pull-in capability.

2.2.3.4 Surface/subsea

A subsea pipeline connection can be differentiated in (surprisingly) “surface connections” and “subsea connections.” As the subsea operations throughout the years have become diverless, and fully remote controlled, the connections have naturally differentiated according to this trend as well. Surface connections are the connections completed on the surface, mainly on a vessel deck, prior to subsea installation. The pipeline is connected to the subsea facility, and the pipeline and the facility (e.g. Xmas tree) are installed to seabed simultaneously. The most common surface connection techniques are welded and flanged connections.

Subsea connections are the connections completed on the seabed. As the industry has become diverless, subsea connections by welding and flanges are more or less non-existing. Subsea connections are completed by remotely operated mechanical connectors, also called clamp connectors.

2.3 PLET

The PipeLine End Termination (PLET) is a substructure required in a midline connection (section 2.2.3.1). While the connection point on a subsea facility, the Porch, is supported to seabed by the facility itself, the midline connections are stand-alone units on the seabed, and therefore require their own substructure.

On basis of section 2.2.3, a PLET can generally be categorized as following:

- Midline connection
- Horizontal connection
- Pull-in and connect method
- Subsea connection

Section 2.3.1 and 2.3.2 presents two examples of PLETs designed by GE Oil & Gas. The main difference between the two is that they comprise different connection systems.

2.3.1 PLET example 1

Figure 2.4 shows the PLET (fixed end), the termination (movable end) and the configuration before and after the connection operation. The termination is landed *on the PLET*, close to the Porch. A ROV operated connection tool executes the pull-in operation by pulling the termination towards the Porch. A torque tool operated by the ROV closes the clamp connector.

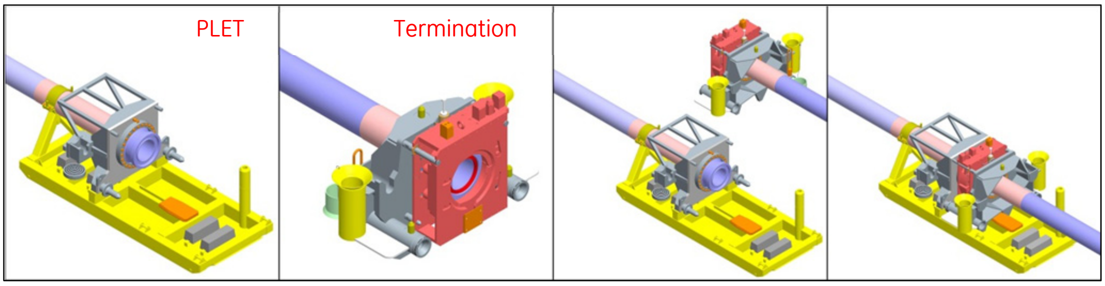


Figure 2.4 – PLET example 1

2.3.2 PLET example 2

Figure 2.5 (overleaf) shows the PLET (fixed end), the termination (movable end) and the configuration before and after the connection operation. The termination is landed *on the seabed* in proper distance from the Porch. A ROV operated connection tool lands on the Porch, attaches a rope to the termination, and executes the pull-in operation. The termination is aligned towards the Porch. Closing of the clamp connector is also executed by the same tool (integrated pull-in and connection tool [21]).

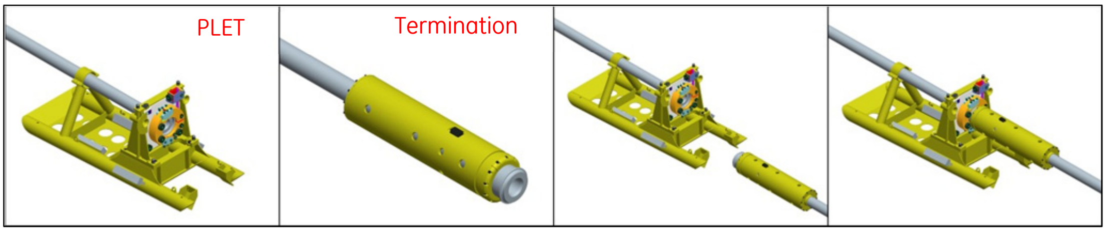


Figure 2.5 – PLET example 2

2.3.3 Open PLET

The PLET systems provided by GE Oil & Gas can roughly be differentiated as following:

1. Integrated structure PLET
2. Open structure PLET (Open PLET)

If the substructure is attached to the pipeline end prior to subsea installation, the PLET is called an "integrated structure PLET." Examples of integrated structure PLETs are given in section 2.3.1 and 2.3.2. This type of PLETs can be used for pipelines and substructures of limited sizes. When the pipeline dimensions become large, the size and the weight of the connection system components increase. A larger substructure is then required for support. The installation loads will then be too large to install the pipeline and the substructure simultaneously.

The ability for the seabed to carry the weight of the PLET is also vital with respect to the size of the substructure. If the soil has low carrying capacity, the bearing surface on the substructure has to increase.

For pipelines of larger dimensions (approximately above 25 inches), and or in situations where the seabed has relatively low carrying capacity, the required size of the substructure will result in the open structure PLET solution. The pipeline end and the substructure then have to be installed separately, and assembled on the seabed. This system is called "Open PLET."

The pipeline end used with the Open PLET system has to be specially designed due to the subsea assembly operation. In addition to the pipeline itself, and the hub, some alignment sleeves mounted on the pipeline are required to facilitate the integration with the substructure. This pipeline end is defined as "pipeline end termination," and it must not be mistaken with the termination (movable part) of the connection system. The pipeline end termination is the pipeline end used with an Open PLET system.

Substructure + pipeline end termination = Open PLET (= fixed end of connection system).

In this thesis, the term “Open PLET” is used for the substructure as well. In the industry it is common to use “Open PLET” for the substructure both with and without the pipeline end termination engaged.

Figure 2.6 is an illustration showing examples of the two types of PLET (Open PLET to the left). For the Open PLET the pipeline end and the substructure (yellow structure) are separable. The integrated structure PLET has a substructure (yellow and blue structure) which is pre-attached to the pipeline end.

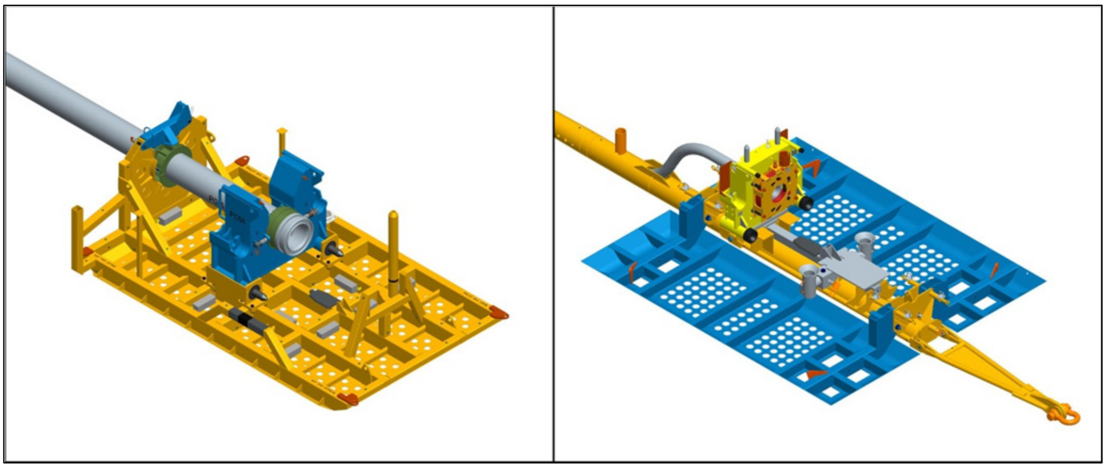


Figure 2.6 – Open structure PLET (left) and integrated structure PLET [8]

2.4 EQUIPMENT OVERVIEW

This section gives an overview of the current Open PLET system that is used as a reference in this thesis. Components and functions are presented in detail with intention to form a basis for the development of a new concept.

2.4.1 Open PLET

Figure 2.7 (overleaf) is an overview of an Open PLET delivered by GE Oil & Gas to the Skarv field in the North Sea. Following the presentation is a brief description of the main components.

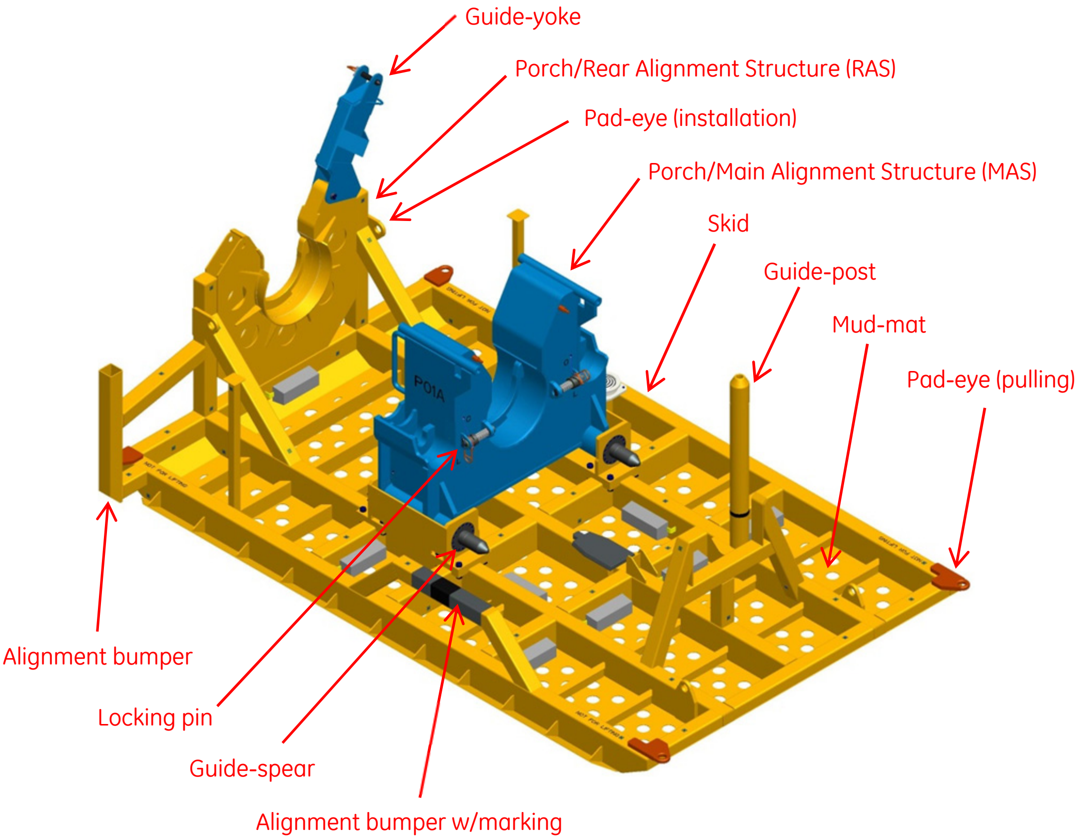


Figure 2.7 – Open PLET overview

Skid: The structural framework for the Open PLET. The Porch, mud-mat, guide-post and alignment bumpers are mounted on the skid. The skid must withstand all the loads exposed to the Open PLET during design life.

Mud-mat: Prevents the Open PLET from sinking into the mud/seabed. The perforation ensures water current through the structure. This gives better maneuverability during installation.

Porch: The Porch on the Open PLET is referred to as “Porch open” due to the ability to engage and disengage with the pipeline end termination after subsea installation. The Porch on the Open PLET can be regarded to consist of the two alignment structures, Porch = MAS+RAS. The RAS is required, because the clamping of the end termination to the Porch open is not as good as for a regular Porch (for the Porch open, the MAS alone provides insufficient pipeline clamping capability to deal with applied moment loads).

Main Alignment Structure (MAS): The structure has interfaces towards the pipeline end termination for guiding purpose and for clamping. It provides locking pins for locking of the pipeline end termination in axial direction.

Rear Alignment Structure (RAS): The structure has interfaces towards the pipeline end termination for guiding purpose and for clamping. The RAS provides a guide-yoke which facilitates guiding, alignment and locking of the pipeline end termination.

Alignment bumpers: The bumpers are used for alignment of the Open PLET towards the pipeline end termination during subsea installation. One of the bumpers provides a marking system to facilitate positioning of the Open PLET in axial direction.

Pad-eyes: One set of pad-eyes is used for the installation of Open PLET from vessel to seabed. The other set of pad-eyes is used for a pull operation at seabed when repositioning the Open PLET in axial direction.

2.4.2 Pipeline end termination

The pipeline end termination is the pipeline end used with the Open PLET system. The end termination provides an interface – the hub – towards the opposite pipeline hub, and it provides interfaces towards the Open PLET for guiding and alignment during installation.

Figure 2.8 is a presentation of the pipeline end termination used with the Open PLET presented in section 2.4.1. The figure is showing the end termination in "installation mode" which includes a Lay-down Clamp and a Lay-down Head. The clamp locks the Lay-down Head to the end termination. The purpose of the Lay-down Head is to protect the seal area on the hub during installation. Following the presentation is a brief description of the main components:

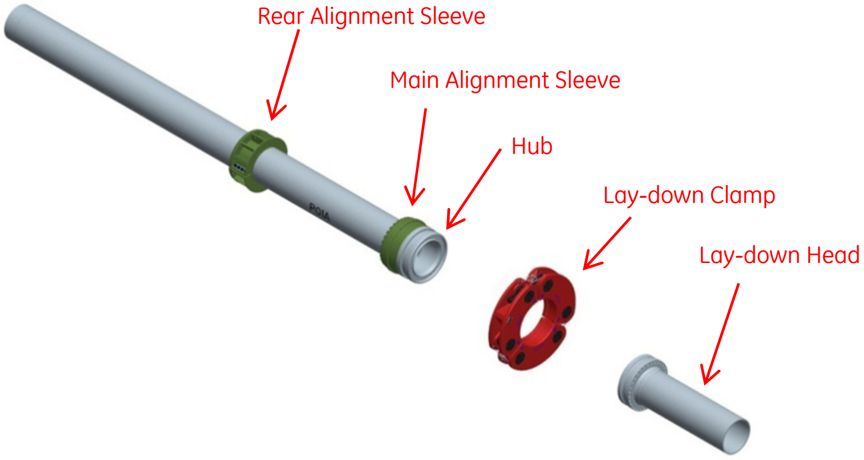


Figure 2.8 – Pipeline end termination, installation mode

Main Alignment Sleeve: This is the interface towards the MAS on the Open PLET. It is used for guiding and locking of the pipeline end termination in final position onto the Open PLET.

Rear Alignment Sleeve: This is the interface towards the RAS on the open PLET. It is used for guiding and locking of the pipeline end termination in final position onto the Open PLET.

Lay-down Head: The Lay-down head is connected to the pipeline end termination during lay-down of pipeline and installation of Open PLET. The Lay-down Head has means for protection of sealing area on the hub, and for support during installation of the pipeline end termination onto the Open PLET. The Lay-down Head is removed prior to spool connection.

Lay-down Clamp: Connects the Lay-down Head to the pipeline end termination. It has interfaces towards the hub on the pipeline end termination and the hub on the Lay-down Head. The clamp is operated by a ROV and removed prior to spool connection.

2.4.3 Installation and connection

The “Open PLET installation” is regarded as the operation of landing the Open PLET on the seabed and then assembling/installing the pipeline end termination on the Open PLET.

The opposite pipeline to be connected with the Open PLET is a rigid spool (can also be flexible). The termination is called “spool termination,” and it is special designed for the applicable connection system.

The “spool connection” is regarded as the operation of completing the subsea pipeline connection. This is accomplished by landing the spool on the Open PLET, pulling the spool termination towards the Porch, and closing the clamp connector.

2.4.3.1 Open PLET installation

Prior to installation of the Open PLET, the pipeline end termination is laid down on seabed by a lay-vessel. A preferred pipeline installation method when using the Open PLET system is the S-lay method (section 2.1.1.1) as the PLET systems in general are designed for this installation method [8]. Figure 2.9 (overleaf) is a sequential illustration of the Open PLET installation.

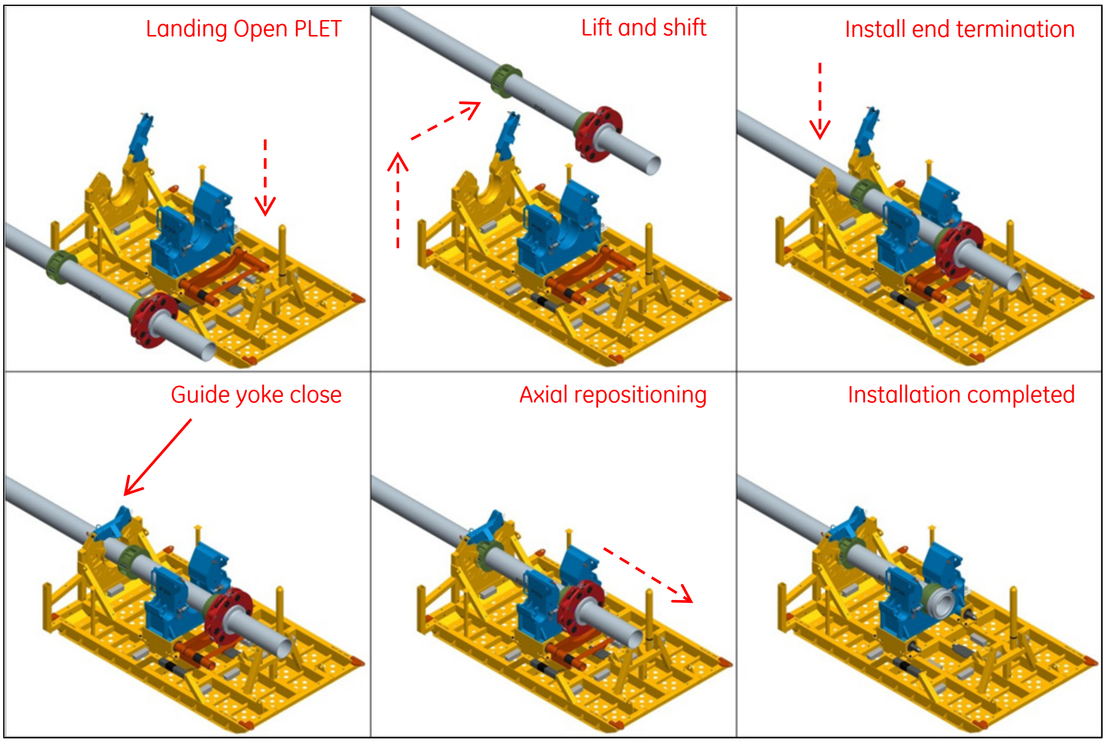


Figure 2.9 – Open PLET installation

The Open PLET is directly installed from the installation vessel to alongside the pipeline end termination on the seabed. Through the splash zone (water surface), and when lowering towards the seabed, the Open PLET is tilted 70° about horizontal direction for to minimize forces acting from waves and sea current. The alignment bumpers on the Open PLET, together with a marking system, facilitate adequate alignment with the pipeline end termination when landing on the seabed.

After landing the Open PLET, the pipeline end termination is by the installation vessel, lifted and shifted over the center of the Open PLET, and installed into the alignment structures (MAS, RAS). Lead-in chamfers on the alignment structures facilitate guiding of the end termination during this installation operation.

After the pipeline end termination is laid down on MAS and RAS, the Open PLET requires to be repositioned in axial direction to achieve proper integration and locking of the end termination to the Porch. This is executed by a pull operation and by means of pad-eyes located in the front of the skid. The alignment sleeves on the pipeline end termination facilitate the required guiding and alignment during the repositioning.

The pull operation is executed by the installation vessel. The crane is attached to the dedicated pad-eyes, and by help of clump weights in the crane wire, the vessel is able to pull the Open PLET in axial direction until the pipeline end termination achieves the final position in the Porch. Spring loaded locking pins locks the pipeline end termination in axial direction.

The subsea assembly operation is then completed and the Open PLET is installed subsea. Prior to the spool connection, the Lay-down Clamp must be removed along with the Lay-down Head.

2.4.3.2 Spool connection

The dimensions of the spool are first measured *after* installation of the Open PLET. This is because the actual location of the installed Open PLET is unpredictable prior to the installation. Subsea measurements have to be carried out to find the actual dimensions. On basis of these measurements the spool is fabricated. Figure 2.10 is a sequential illustration of the spool connection.

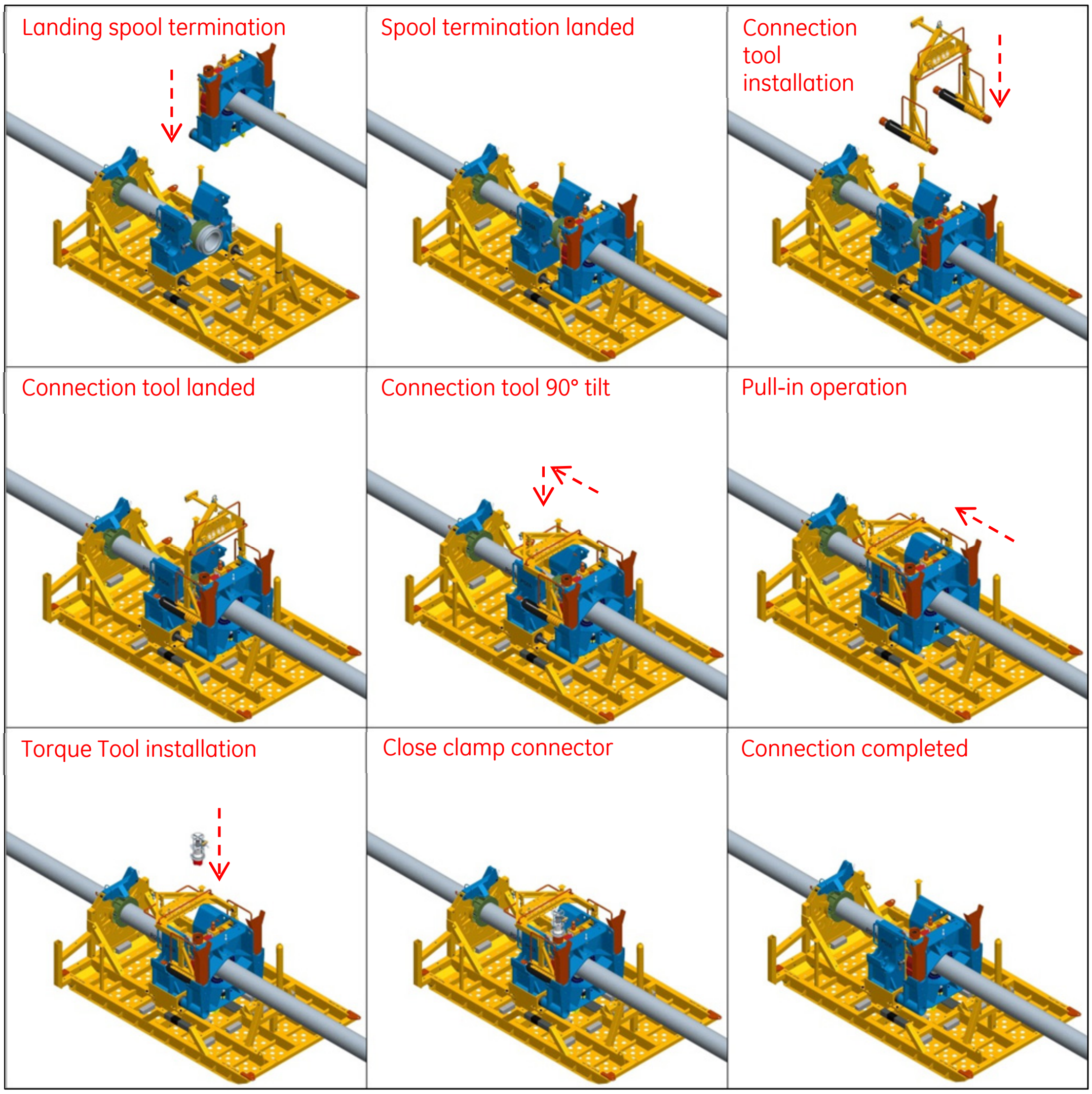


Figure 2.10 – Spool connection

With the Open PLET proper installed and the spool fabricated, the spool connection will begin (weeks or months after the Open PLET installation). The spool termination has interfaces towards the guide-post on the skid and the guide-spears on the Porch (section 2.4.1). The installation vessel lowers the spool and lands it onto the Open PLET using the guide-post for guiding during landing.

Prior to the connection operation, a series of small operations have to be executed to ensure proper sealing between the hubs. A cleaning tool is used for cleaning the seal area on both hubs. An inspection tool is used to verify the cleanliness of the seal area. A seal replacement tool is used for installation of the seal. All these tools are specially made for this connection system, and they are operated by the ROV. The application of such tools will not be covered in this thesis (section 1.5.3).

When the spool termination is in position on the Open PLET, a connection tool is installed in position (cradles) on the Porch and the spool termination. The connection tool comprises two cylinders capable of closing the gap between the hubs by pulling the spool termination towards the Porch. The ROV operates the connection tool.

The guide-spears on the Porch facilitate proper alignment of the spool termination during the pull-in operation. When the hub faces are mated, the pull-in is completed. While the connection tool still applies full pull force on the cylinders, a torque tool is installed for operation of the clamp connector. The torque tool closes the clamp connector and completes the connection. The torque tool and connection tool can then be retrieved to surface.

2.5 HORIZONTAL CLAMP CONNECTOR SYSTEM (HCCS)

The connection system used on the Open PLET is a GE Oil & Gas invented system called "Horizontal Clamp Connector System" (HCCS). This connection system comprises the "pull-in and connect method" (section 2.2.3.2). Figure 2.11 (overleaf) presents an overview of the HCCS.

The Porch is fixed to a substructure (PLET) which is pre-installed on the seabed. The termination (spool) is thereafter installed and landed upon the substructure. A special designed connection tool is then installed in dedicated positions on the Porch and the spool termination. By hydraulic cylinders, the tool provides the forces required to pull the spool termination towards the Porch and mate the hubs. A torque tool operated by the ROV activates the clamp connector – which is pre-installed on either the Porch or the spool termination – to complete the connection.

The spool termination, when installed on the substructure, must be positioned within some tolerances. The tolerances for the HCCS are defined for the axial, lateral, and vertical positions as well as the rotational positions about vertical, lateral and axial axes [8]. Typically, the rotational tolerances are ±1° about mentioned axes. The tolerances are required to ensure entrance for the guide-spears (into the guide-spear receptacles) during the pull-in, and to achieve a proper (sealed) connection. Consequently, to pay attention to these system requirements is of importance when designing an Open PLET.

The HCCS on the Open PLET in this thesis is a size 30 type. That means that the Porch will be designed for pipelines with an outer diameter up to 30 inches. The GE Oil & Gas designate this particular system "HCCS-30".

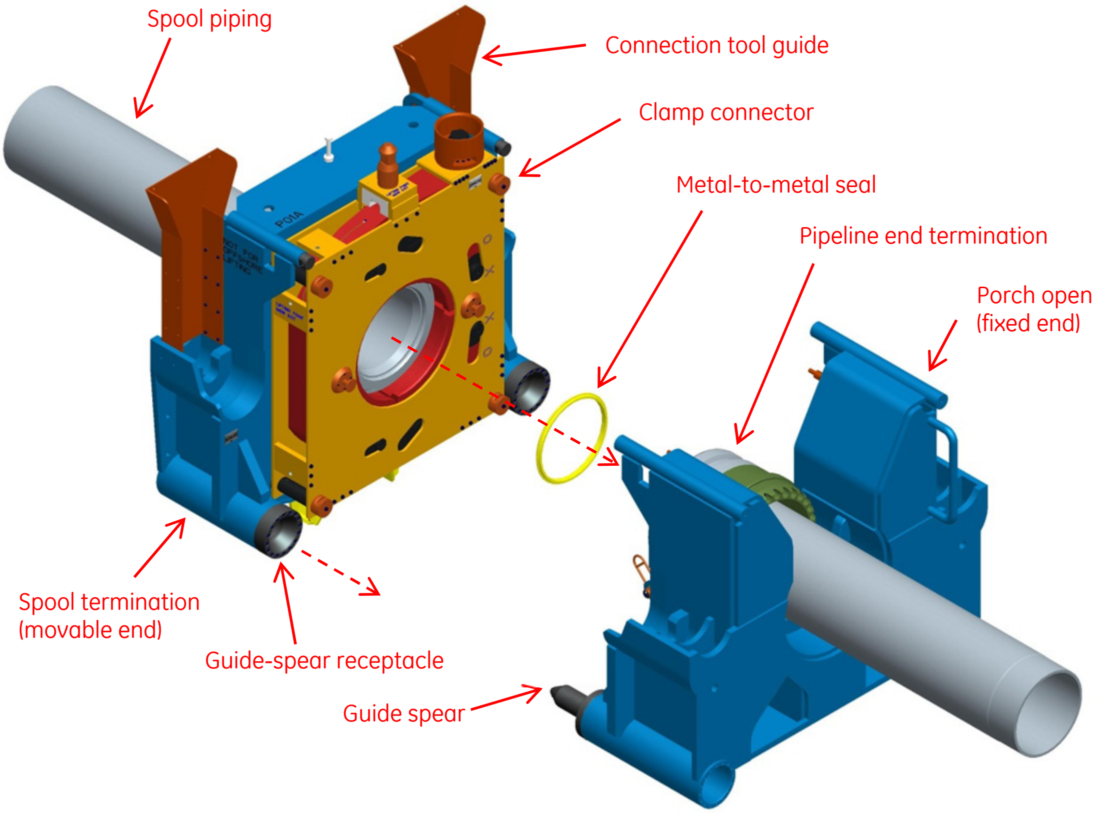


Figure 2.11 – HCCS overview

2.6 DESIGN BASIS

The Open PLET presented in section 2.4 will be a reference for the development of the concept for a new Open PLET system. In this section of the report, the requirements for the new system are defined, design goals are stated and the challenges with current Open PLET system are explained.

2.6.1 Functional requirements

The functional requirements, often called the "behavioral requirements," describe what the product shall be able to do. It is a list of "tasks" the product with its components shall be able complete in the different stages of the design life.

The main purpose for the Open PLET system is to be a substructure providing support to the pipeline end termination and the components of the applicable connection system. This includes the following requirements:

1. Support of pipeline end termination and connection system components.
2. Facilitate required interfaces for completing the connection.
3. Facilitate pipeline thermal expansion.

In addition, some more detailed requirements are applicable. Some requirements will apply to the whole system, while some applies to one or several of the components of the system. The requirements are defined on basis of GE Oil & Gas documentation [8].

2.6.1.1 General

For the new Open PLET system, the following functional requirements given in Table 2.1 are applicable.

Table 2.1 – Functional requirements, general

ITEM	REQUIREMENT DESCRIPTION
a.	Widest range of alignment and offset tolerances during installation and connection operation to reduce installation accuracies required.
b.	The connection operation shall be fully reversible at any stage of the installation.
c.	It shall be possible to "interrupt" a normal connection operation, place the system in safe condition and leave within sixty minutes (ex. due to weather conditions).
d.	Disconnection and reconnection shall be possible at any time during design life.
e.	Connection system shall be based on ROV assisted tools.
f.	Verification of ROV access for all tasks and all tooling needed.
g.	The system shall accommodate for thermal expansions in the pipeline.
h.	Installation of Open PLET shall be done after pipe-lay operation.
i.	Installation shall not require more than one ROV.
j.	Mud-mat shall be designed for self-embedment.

2.6.1.2 Skid

The skid will be one of the main components in the new system. Table 2.2 lists the functional requirements applicable for the skid.

Table 2.2 – Functional requirements, skid

ITEM	REQUIREMENT DESCRIPTION
a.	Sufficient structural stiffness between mud-mat elements to ensure satisfactory skid behavior during installation and in-place operation.
b.	Guiding means for guiding of skid towards the pipeline end termination in axial and lateral direction.
c.	Sliding on seabed capability.

2.6.1.3 Porch

The Porch will be one of the main components in the new system. Table 2.3 lists the functional requirements applicable for Porch.

Table 2.3 – Functional requirements, Porch

ITEM	REQUIREMENT DESCRIPTION
a.	Guiding means for vertical and axial positioning of the pipeline end termination.
b.	Locking mechanism for locking of the pipeline end termination in all directions.
c.	Possible to lock and unlock pipeline end termination from Porch at all times.
d.	Interface towards spool termination shall include means for guiding.

2.6.2 Design goals

A design goal describes how to make a better and more attractive product. It is not a defined requirement that the product *must* fulfill, but guidelines on how to make the product attractive.

Table 2.4 presents the design goals defined for the new Open PLET system. The goals are normal for GE Oil & Gas equipment and are based on industry experience.

Table 2.4 – Design goals

ITEM	GOAL	DESCRIPTION
a.	Simple solutions	Will give reduced engineering and fabrication cost as well as give better operational reliability.
b.	Robust equipment	Will ease the installation, because the product can withstand rougher handling. This is attractive to the customer and the installation contractor.
c.	Few details	Will minimize the possibility for installation error. This is due to a minimum of complicated mechanical components.

2.6.3 Regulations, codes and standards

The applicable standards for this thesis are defined and listed in Table 2.5. These standards contain some design requirements, and they provide details about how to design a product in order to meet those requirements.

Table 2.5 – Applicable standards

STANDARD	NAME
ISO 13628-1	Petroleum and natural gas industries – Design and operation of subsea production systems – Part 1: General requirements and recommendations
Eurocode 3	Design of steel structures – Part 1-1: General rules and rules for buildings
DNV-OS-C101	Design of offshore steel structures, general (LRFD method)
DNV-RMO	Rules for planning and execution of Marine Operations

2.6.4 Description of axes

This report will refer to the axes of the Open PLET. The direction and name of the axes are presented on Figure 2.12.

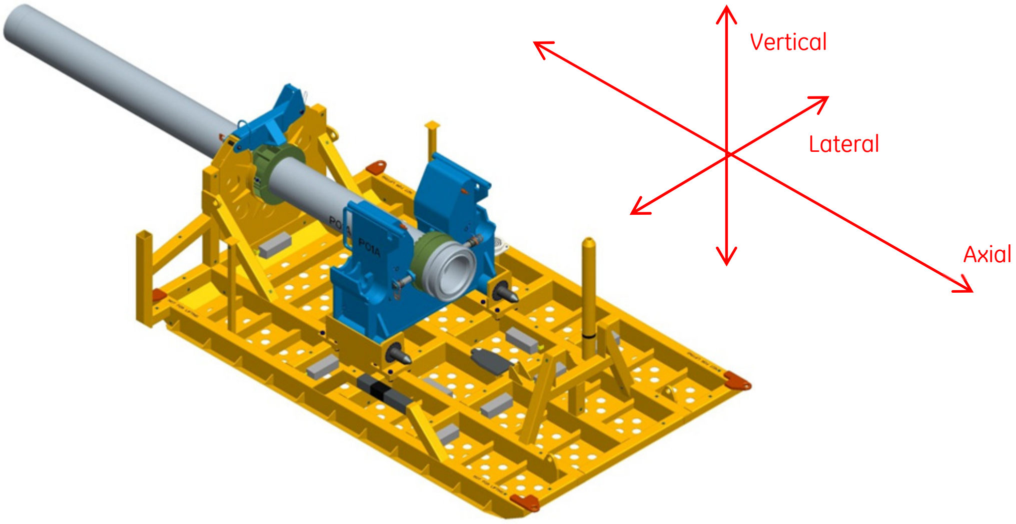


Figure 2.12 – Description of axis

2.6.5 Current Open PLET challenges

The *new* Open PLET system shall be developed on basis of the intention to reduce or eliminate some challenges with the *current* Open PLET system, challenges related to the offshore installation operation. Details about the challenges are described below in order of defined difficulty. The most difficult is presented first [22].

The presentation of the Open PLET installation in section 2.4.3.1 can be used as a reference to this section.

2.6.5.1 Pull operation

A complicated part of the installation is the pull operation of the skid. This involves pulling of the Open PLET on the seabed in axial direction to achieve proper integration of the pipeline end termination into the Porch. This operation is regarded as the most difficult part of the installation.

The pull operation is executed by attaching the vessel crane to the pad-eyes in front of the skid, and attaching some clump weights to the crane wire. The clump weights give the crane wire an approximate horizontal direction in front of skid. This is a complicated crane wire configuration, but it makes pulling of the skid possible.

Figure 2.13 (overleaf) illustrates the pull operation.

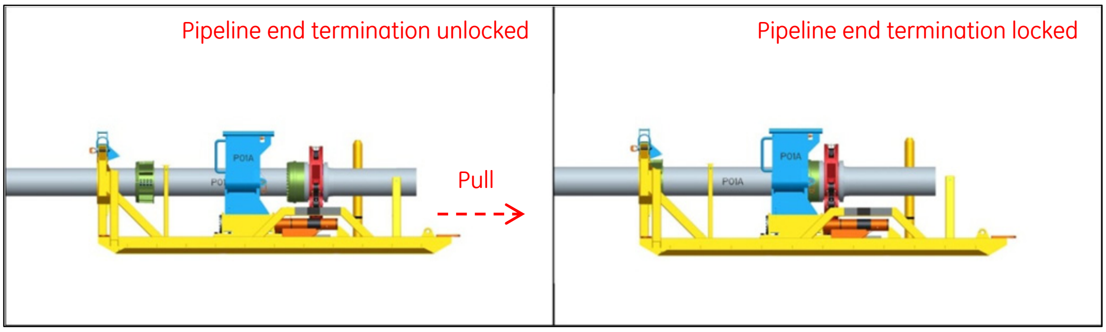


Figure 2.13 – Pull operation

2.6.5.2 Alignment next to the pipeline

Another complicated part of the installation is the alignment of the Open PLET in proper position next to the pipeline end termination. The skid has to be positioned and aligned within a tolerance to ensure proper installation of pipeline end termination. The marking and the alignment bumpers on the skid facilitate the positioning.

Regardless of the marking, the alignment bumpers, and the ROV to assist the operation, the positioning of the skid is challenging and time consuming. Water current affects the skid motion and the vessel crane has limitations in the accuracy. Also the lack of a physical end stop feature creates uncertainty with respect to achieve the required position. Figure 2.14 illustrates the tolerance requirements for the skid position next to the pipeline end termination.

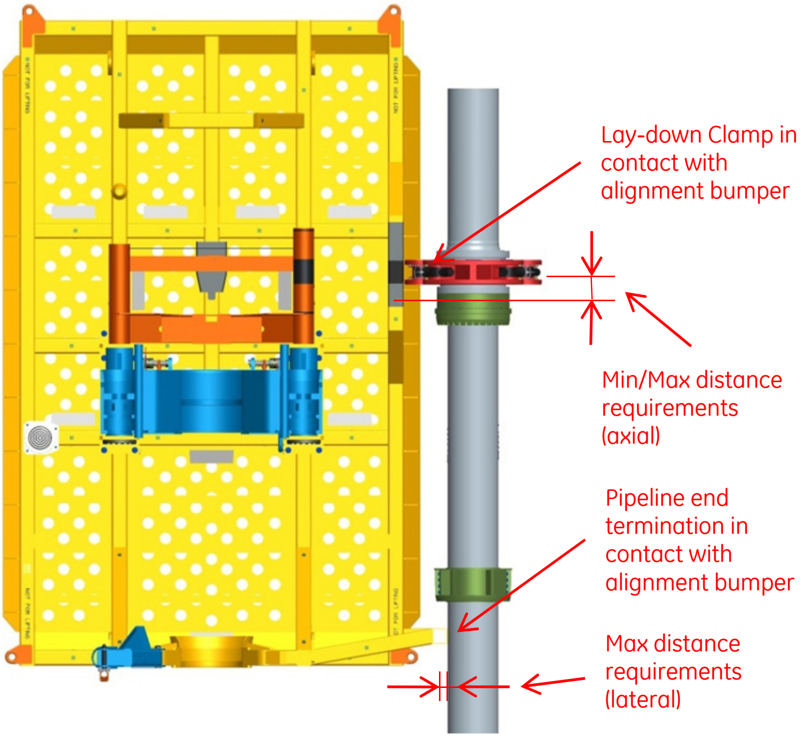


Figure 2.14 – Alignment tolerances

2.6.5.3 Lift and shift operation

The operation of lifting and shifting the pipeline end termination from seabed to over the Open PLET, and then landing the end termination onto the Porch, is experienced to be challenging. The pipeline equipment is heavy, and the length makes it stiff and unwieldy. This, combined with the need for accuracy in this phase of the installation, makes this complicated and time consuming.

Figure 2.15 illustrates the lift and shift operation.

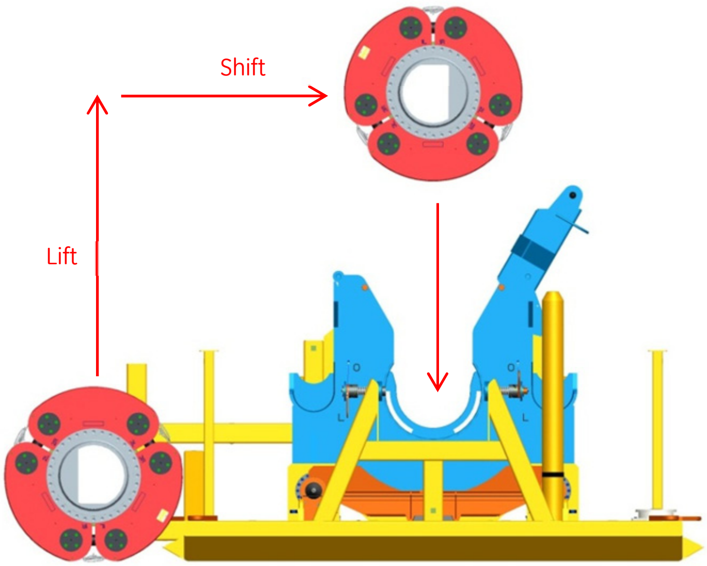


Figure 2.15 – Lift and shift operation

3 CONCEPTUAL DESIGN

"Make things as simple as possible, but not simpler."

Albert Einstein

"If you generate only one idea, it will probably be the best solution;
If you generate several ideas, then you will have an excellent solution."

GE Oil & Gas documentation

3.1 ABOUT CONCEPTUAL DESIGN

A conceptual design is the phase in the product development where an idea for a new product is developed by finding technical solutions that fulfills defined requirements of the product. This phase is completed prior to detailed design of the product, and it forms a basis upon which the detailed design is accomplished. The result of the conceptual design is a presentation of the product which includes all the technical solutions.

In engineering, product development concerns the total life-cycle of the product, from design and manufacturing to operation and scrapping. Engineering design is most commonly recognized as the development of products which provides a technical function. Engineering design consists mainly of two phases, the conceptual design phase and the detailed design phase. Figure 3.1 illustrates an example of a product life-cycle and how engineering design is related to this cycle.

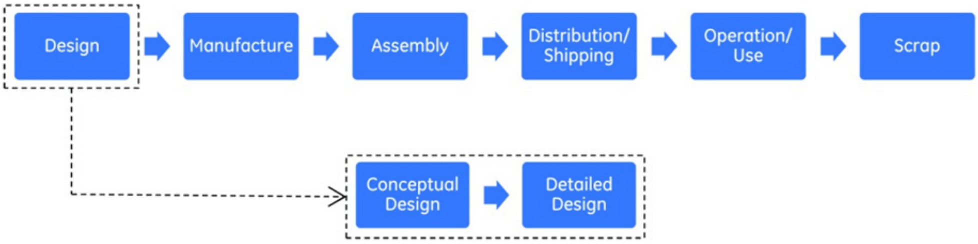


Figure 3.1 – Product life-cycle and engineering design [23]

The initiation of the conceptual design process is the recognition of a need. The need is then analyzed and translated into a statement which is referred to as the "product design specification." The design specification contains a set of requirements the product must satisfy, often recognized as functional requirements and physical requirements [23].

The recognized need that becomes the initiation of the conceptual design in this thesis has evolved as a result of experience and evaluation in use of an existing product. The particular need is a product improvement to eliminate some challenges experienced by use of the product (section 2.6.5). An idea for a new concept is invented by GE Oil & Gas. This idea deals with the recognized need, and forms the basis for the design specification for the new product.

3.2 CONCEPT IDEA

The concept idea for a new Open PLET system is invented by GE Oil & Gas, and this idea becomes the initiation for the conceptual design process in this thesis. The following presentation can be regarded as the basic design specification for the concept.

The idea is to make an Open PLET system where the skid has a longitudinal opening in the bottom that makes it possible to land the skid straight over the pipeline end termination, instead of next to the end termination as on the current system. With the skid landed on seabed over the pipeline end termination, the end termination can be lifted straight up from seabed to integration with Porch. The Porch for this new system will be an "inverted open" type compared with the current system, with a configuration of the Porch where the opening is facing downwards. The Porch shall provide means for locking of pipeline end termination in all directions.

Figure 3.2 (overleaf) is a sketch illustrating the idea for the new Open PLET system. With reference to this figure, this is an overview of the most important components:

- The skid (item 1) will have a longitudinal opening in the bottom to make it possible to land over the pipeline end termination (item 2). The stiffness between the two separate mud-mat elements must be ensured by a structural framework over the pipeline end termination.

- The Porch (item 9) will be an inverted open type with the opening facing downwards. Included in the Porch must be a locking mechanism which locks the pipeline end termination to the Open PLET in all directions.

- The PLET Integration Tool (item 6) must be developed if a pull operation of the skid or Porch (with respect to the end termination) is required to complete the integration of the end termination into the Porch.

- The Rear Alignment Structure (item 14) will have a geometry which facilitates guiding of the pipeline end termination in lateral and vertical direction. It must also be evaluated if the RAS should include a locking mechanism as well.

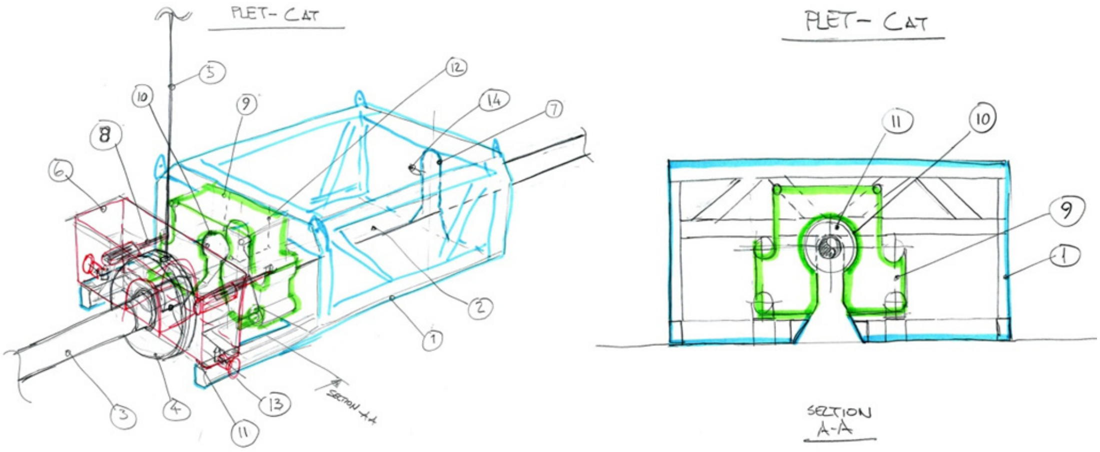


Figure 3.2 – The concept idea for the new Open PLET system [22]

3.3 CONCEPT SELECTION

In this concept selection phase (section 1.5.2.2) the goal is to find technical solutions for the new system. A technical solution is in this thesis defined as a particular design feature and/or functionality which makes the product able to fulfill a functional requirement. The technical solutions shall be chosen prior to 3D modeling of the concept.

According to the description given in section 3.2, the new Open PLET system may consist of three main components (the RAS is assumed to be a part of the skid):

1. Skid
2. Porch Inverted Open
3. PLET Integration Tool

The development and selection of the conceptual design comprises to solve a list of defined *technical issues* related to the system on basis of the concept idea. For every main component mentioned above, some technical issues are recognized, and all of them relates to the concept idea (section 3.2) and the functional requirements given in section 2.6.1. The *technical solutions* to be chosen must “solve” these technical issues to ensure the Open PLET system fulfills the defined specifications and the functional requirements.

The work process in this phase of the thesis basically involves generating a lot of ideas of how to solve the different technical issues, prior to finally selecting a concept which comprises the chosen technical solutions.

To facilitate the concept selection phase, some specific "tools" is used:

- The "Concept Breakdown Structure" presents the pre-defined technical issues related to each of the main components.
- The "Brainstorm Matrix" keeps track of which of the technical solution that belongs to which of the technical issues.
- The "Decision Matrix" evaluates the different proposed solution for to be able to select the best solution for the concept.

Figure 3.3 illustrates the work process for the concept selection phase. As shown, the result of this phase is a concept solution.

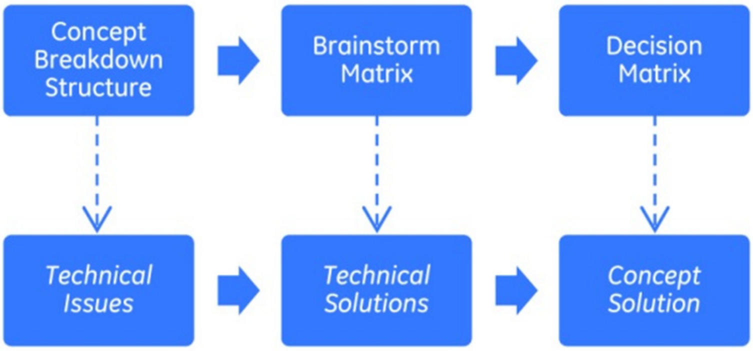


Figure 3.3 – Concept selection process

3.3.1 Concept Breakdown Structure

A diagram showing the pre-defined main components of the new Open PLET system, and thereupon the technical issues linked to each of the components, are in this thesis defined as the "Concept Breakdown Structure."

Figure 3.4 (overleaf) presents the Concept Breakdown Structure. The diagram shows the technical issues for each of the pre-defined main components. These technical issues are defined on basis of the concept idea and functional requirements given in section 2.6.1. A detailed description of the technical issues is given in section 3.4.

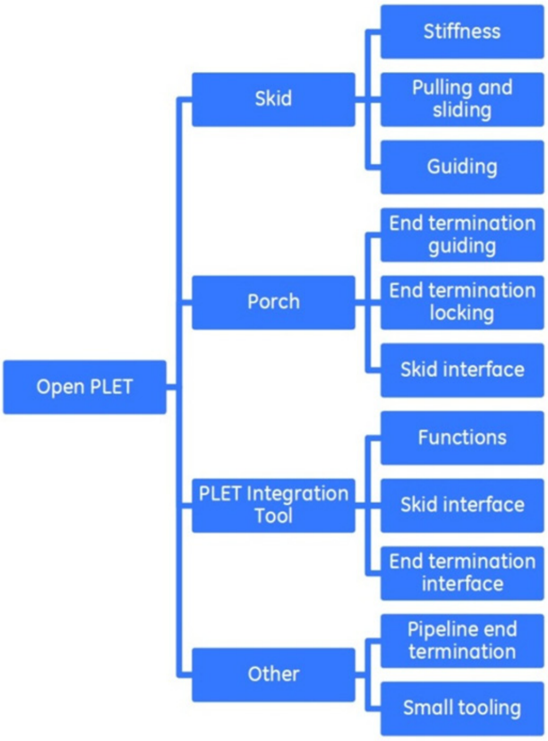
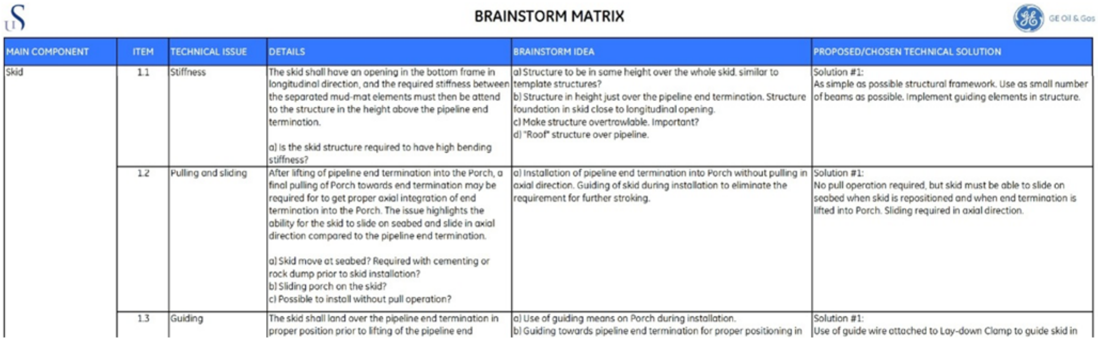


Figure 3.4 – Concept Breakdown Structure

3.3.2 Brainstorm Matrix

The Brainstorm Matrix is the tool for to keep track of the generated ideas during the concept selection phase. The matrix is based on the Concept Breakdown Structure. The proposed technical solutions for each of the technical issues are given in the rightmost column. Figure 3.5 illustrates the matrix. For the complete matrix, see appendix A1.



BRAINSTORM MATRIX

MAIN COMPONENT	ITEM	TECHNICAL ISSUE	DETAILS	BRAINSTORM IDEA	PROPOSED/CHOSEN TECHNICAL SOLUTION
Skid	1.1	Stiffness	The skid shall have an opening in the bottom frame in longitudinal direction, and the required stiffness between the separated mud-mat elements must then be attend to the structure in the height above the pipeline end termination. a) Is the skid structure required to have high bending stiffness?	a) Structure to be in same height over the whole skid. similar to template structures? b) Structure in height just over the pipeline end termination. Structure foundation in skid close to longitudinal opening. c) Make structure overtrowlable. Important? d) "Roof" structure over pipeline.	Solution #1: As simple as possible structural framework. Use as small number of beams as possible. Implement guiding elements in structure.
	1.2	Pulling and sliding	After lifting of pipeline end termination into the Porch, a final pulling of Porch towards end termination may be required for to get proper axial integration of end termination into the Porch. The issue highlights the ability for the skid to slide on seabed and slide in axial direction compared to the pipeline end termination. a) Skid move at seabed? Required with cementing or rock dump prior to skid installation? b) Sliding porch on the skid? c) Possible to install without pull operation?	a) Installation of pipeline end termination into Porch without pulling in axial direction. Guiding of skid during installation to eliminate the requirement for further stroking.	Solution #1: No pull operation required, but skid must be able to slide on seabed when skid is repositioned and when end termination is lifted into Porch. Sliding required in axial direction.
	1.3	Guiding	The skid shall land over the pipeline end termination in proper position prior to lifting of the pipeline end	a) Use of guiding means on Porch during installation. b) Guiding towards pipeline end termination for proper positioning in	Solution #1: Use of guide wire attached to Lay-down Clamp to guide skid in

Figure 3.5 – Brainstorm Matrix

3.3.3 Decision Matrix

To choose the best of the proposed technical solutions (from Brainstorm Matrix), a Decision Matrix is used. The matrix is a tool for comparison of the proposed technical solutions towards a set of defined criteria. A numerical evaluation scale rates each solution towards each criterion, and the solution with the highest score will be chosen [24].

The numerical scale will be:

- +1 = The solution gives an advantage with respect to the criterion
- 0 = The solution is considered to be average with respect to the criterion
- -1 = The solution gives a disadvantage with respect to the criterion

Table 3.1 is the general form of the Decision Matrix. The total points for each of the compared solutions are given in the bottom row.

Table 3.1 – Decision Matrix, general form

CRITERION	SOLUTION #1	SOLUTION #2
Simplicity		
Cost		
Time		
Accuracy		
Skill		
Size/weight		
Total points		

If for some reason the total points of the compared solutions are the same after the evaluation, the one with the best score on the simplicity criterion will be the chosen solution. This because "simple solutions" can be considered a normative design goal in the subsea industry, and the criterion reflects the principle of the concept idea for the new Open PLET system.

A detailed description of the evaluation criteria is presented below. All criteria reflect the design goals given in section 0.

3.3.3.1 Simplicity

The technical solution shall be simple, with few mechanical components and few details, to ensure a reliable operation and a minimum possibility for installation and operation error.

3.3.3.2 Cost

The cost is evaluated with respect to the whole product life-cycle. Engineering and development cost, fabrication cost and installation cost are the most important factors.

3.3.3.3 Time

The time criterion is mainly an evaluation towards offshore installation time, which means how the technical solution will affect the time required to install the Open PLET system subsea.

3.3.3.4 Accuracy

Evaluates which level of accuracy (tolerances) required when installing the system subsea.

3.3.3.5 Skill

Evaluates how the technical solution influences the difficulty of operating the Open PLET system, and consequently the skills required by the personnel execute the operation.

3.3.3.6 Size/weight

Each solution is evaluated with respect to how it influences the size and weight of the components involved in the system.

3.4 TECHNICAL ISSUES

The technical issues are listed in the Concept Breakdown Structure in section 3.3.1. Hereby follows a more detailed description of the issues.

3.4.1 Skid: Stiffness

The skid shall have an opening in the bottom frame in longitudinal direction, and the required stiffness between the separated mud-mat elements must then be attend to a framework in the height over the pipeline end termination.

3.4.2 Skid: Pulling and sliding

After lifting the pipeline end termination into the Porch, a final pulling of the skid with respect to the pipeline end termination may be required to get a proper axial integration of the end termination into the Porch (similar to pull operation, section 2.6.5.1). The issue highlights the ability for the skid to slide on the seabed in axial direction.

3.4.3 Skid: Guiding

The skid shall land over the pipeline end termination in proper position prior to lifting of the pipeline end termination. The skid structure must comprise means for guiding of skid in axial and lateral directions towards the pipeline end termination.

3.4.4 Porch: End termination guiding

Pipeline end termination shall be lifted in vertical direction from seabed into the Porch. The Porch must facilitate for guiding of end termination in axial and lateral direction.

3.4.5 Porch: End termination locking

A locking mechanism is required to keep pipeline end termination locked in position in the Porch. The locking mechanism may be a part of the Porch assembly, and it shall comprise interfaces towards the pipeline itself or the alignment sleeves on the end termination.

3.4.6 Porch: Skid interface

The Porch is the fixed end in the connection system. The Porch can be either fixed on skid, defined as "active Porch", or the Porch can be mounted able to slide upon skid following the pipeline movements, defined as "passive Porch". A passive Porch is still regarded as the fixed end of the connection.

3.4.7 PLET Integration Tool: Functions

The PLET Integration Tool shall have a function for pulling of skid in axial direction to fully integrate the pipeline end termination into the Porch.

3.4.8 PLET Integration Tool: Skid interface

The integration tool shall be landed and operated on the skid. The tool can be pre-installed on the skid, or it can be installed subsea on a later occasion.

3.4.9 PLET Integration Tool: End termination interface

The reactions during the pull operation may be between the Porch and the Lay-down Clamp. Consequently, the tool must then comprise interfaces towards those components.

3.4.10 Pipeline end termination

The design of the pipeline end termination shall facilitate guiding towards the Porch, and it shall comprise an interface to the locking mechanism. Alignment sleeves are probably required, but the need for a rear alignment sleeve can be evaluated.

3.4.11 Small tooling

Small tooling is not a part of this thesis (section 1.5.3), but some considerations might occur with respect to the small tooling.

3.5 TECHNICAL SOLUTIONS

When one technical solution is chosen, this might affect how the solutions for the rest of the technical issues will become. Consequently, some of the technical issues are of more importance than others with respect to the concept solution. Of all the technical issues presented in section 3.4, only the ones defined to be the most significant issues will therefore be evaluated by a Decision Matrix. The rest of the technical solutions are then defined upon the significant solutions.

The concept idea presented in section 3.2 already gives guidance to some technical solutions, although the intention was to just present the concept idea. However, all technical solutions in the concept shall be evaluated. The final concept solution then maybe includes some technical solutions that totally differ from some of the basics presented in the concept idea. However, the principles for the new Open PLET system will be safeguarded.

The technical solutions considered to have the biggest influence on the concept solution, and therefore are defined as the most significant technical solutions, are the “Porch: end termination locking” (section 3.4.5) and “Skid: Guiding” (section 3.4.3). The rest of the solutions will then be defined upon these solutions.

3.5.1 Porch: End termination locking

The most significant technical solution is evaluated to be how the pipeline end termination is locked in the Porch. This solution will create spin-off effects on how the solutions of almost all the other defined technical issues will become.

The pipeline end termination must be locked in axial and vertical direction. Lateral locking is ensured by the geometry of the interface between the end termination and the Porch. The two locking directions (axial and vertical) are related so that one can be regarded as the “active locking direction” and the other as the “passive locking direction”. If the pipeline end termination is locked in axial direction so that the vertical direction becomes locked as a consequence, the locking in axial direction will be the *active direction* and the locking in vertical direction will be the *passive direction*. The locking method for the current Open PLET system is axial active and vertical passive (section 2.4.3.1).

Two possible solutions for the end termination locking issue is the result from the Brain-storm Matrix.

3.5.1.1 Proposed solutions

Solution #1

The pipeline end termination is lifted from seabed to full vertical integration into the Porch. To get full axial integration, an axial pulling of the end termination towards the Porch is required. An alignment sleeve on the end termination will then enter the Porch, and the geometry on the Porch ensures the vertical locking. A locking mechanism completes the axial locking. The axial locking direction is then the active direction.

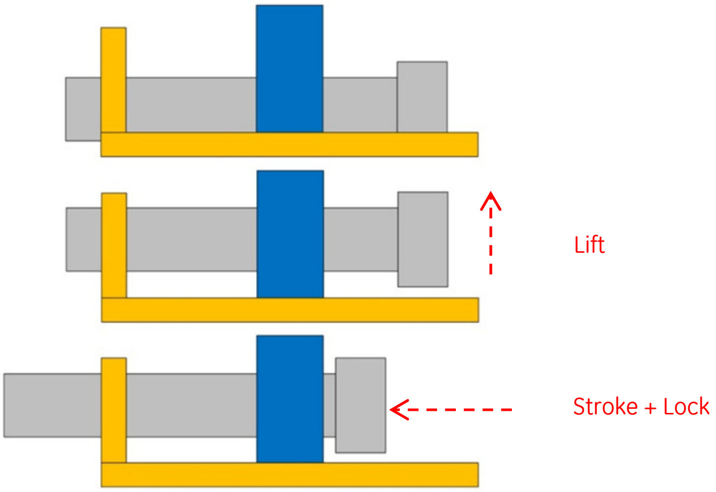


Figure 3.6 – Porch: End termination locking, solution #1

Solution #2

The pipeline end termination is lifted directly from seabed into the Porch. The end termination is fully integrated with the Porch after the vertical lifting, and consequently no pull operation is required. Thereafter, a locking mechanism will be activated to lock the end termination in vertical direction. The vertical locking direction is the active direction. The interface between the Porch and the end termination maintain the axial and lateral position of the end termination.

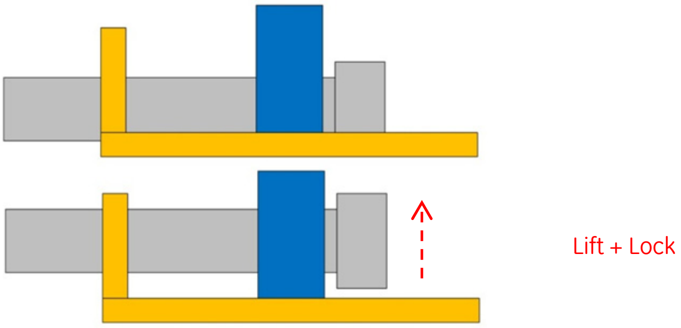


Figure 3.7 – Porch: End termination locking, solution #2

3.5.1.2 Decision Matrix evaluation

The proposed technical solutions presented in section 3.5.1.1 are evaluated in the Decision Matrix below.

Table 3.2 – Decision Matrix, Porch: End termination locking

CRITERION	SOLUTION #1	SOLUTION #2
Simplicity	-1	0
Cost	-1	0
Time	0	1
Accuracy	1	-1
Skill	-1	0
Size/weight	-1	0
Total points	**-3**	**0**

Solution #1

- This solution involves a pulling operation which implies either a sliding skid (active Porch) or a sliding Porch (passive Porch). A special designed tool (PLET Integration Tool) is required to execute the pull operation. Simplicity = -1.
- The required PLET Integration Tool increases the cost with respect to engineering and production. Cost = -1.
- This solution makes it possible to lock the pipeline end termination in the Porch within a fine tolerance with respect to vertical positioning. Accuracy = 1.
- The operation of a special designed integration tool, and the pull operation itself requires skilled personnel. Skill = -1.
- As the Open PLET system will be designed for large pipelines, the Open PLET system will become large. The additional size and weight of the integration tool increases the total size and weight of the system. Size/weight = -1.

Solution #2

- No pull operation is required, and the result is reduced installation time. Time = 1.
- As the vertical locking direction will be the active direction, some uncertainty exists with respect to the accuracy of the vertical positioning of the pipeline end termination. Accuracy = -1.

The total points in Table 3.2 show that the best solution will be solution #2.

3.5.1.3 Additional aspects

The chosen solution for locking of the pipeline end termination into Porch is the one which implies the vertical active locking direction. Hence, if the locking mechanism fails, the pipeline end termination will be unlocked in vertical direction (and fall onto seabed).

One consideration with respect to locking of the pipeline end termination is whether to have a locking mechanism positioned at both MAS and RAS (end termination locked in two positions), or if it is possible to make it a single locking mechanism positioned in one position only.

The pipeline end termination shall be fixed to the Porch, not possible to move or rotate in any direction with respect to the Porch. This can be done by locking the end termination in two positions, at the MAS and RAS, or by clamping the end termination at MAS only. A clamping at MAS only involves a locking mechanism that is required to withstand all moment forces from the end termination. This solution will make the design more complicated as the requirements for the locking mechanism will be much tougher. The final technical solution will consequently be a locking mechanism positioned at both MAS and RAS.

3.5.2 Skid: Guiding

Guiding of skid in axial and lateral direction when landing on seabed implies technical solutions that will have large influence on the final concept. The pipeline end termination will be designed according to the chosen solution in section 3.5.1, and the end termination design is important as it shall facilitate guiding of the skid as well.

Two possible solutions for the skid positioning is the result from the Brainstorm Matrix.

3.5.2.1 Proposed solutions

Solution #1

A guide-wire from the installation vessel is attached to the Lay-down Clamp prior to installation of the Open PLET. The Open PLET is then installed from installation vessel, and the axial position is maintained by the guide-wire. Prior to landing on the seabed, the ROV assists to get the proper lateral orientation. When the Open PLET is landed on the seabed no further repositioning is required.

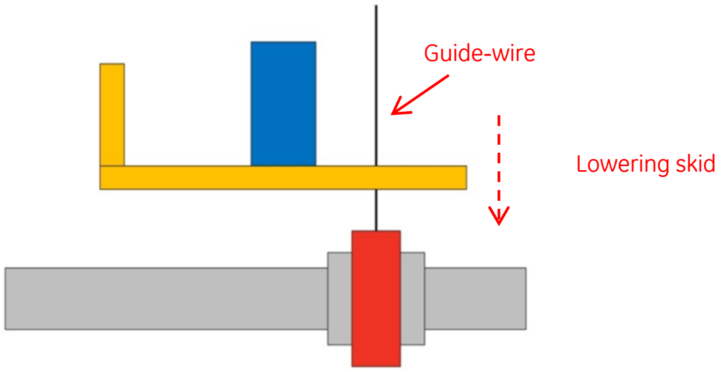


Figure 3.8 – Skid: Guiding, solution #1

Solution #2

The Open PLET is installed from installation vessel and landed over the pipeline end termination with proper lateral orientation due to the longitudinal opening on skid. The ROV assists this operation. The Open PLET must be positioned correctly to the Lay-down Clamp. After landing on the seabed, the Open PLET must be repositioned in axial direction. A guiding feature provides the physical end stop when it achieves contact with the Lay-down Clamp. The repositioning is conducted by the installation vessel as part of the installation operation.

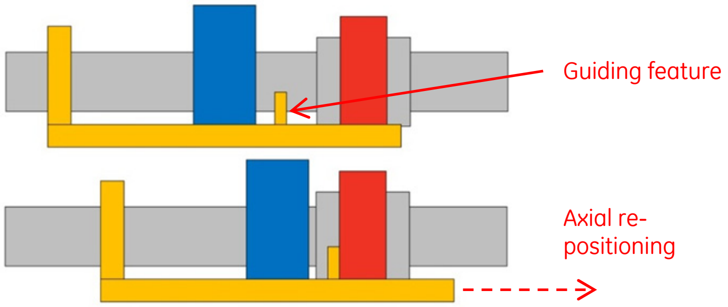


Figure 3.9 – Skid: Guiding, solution #2

3.5.2.2 Decision Matrix evaluation

The proposed technical solutions presented in section 3.5.2.1 are evaluated in the Decision Matrix below.

Table 3.3 – Decision Matrix, Skid: Guiding

CRITERION	SOLUTION #1	SOLUTION #2
Simplicity	-1	1
Cost	-1	0
Time	0	0
Accuracy	1	0
Skill	0	-1
Size/weight	0	0
Total points	**-1**	**0**

Solution #1

- Use of guide-wire is complicated as an operation for attaching the guide-wire to the Lay-down Clamp in subsea environments is required. Use of guide-wire is also limited to a certain water depth. Simplicity = -1.
- The development of a guide-wire locking mechanism (to Lay-down Clamp) implies a high cost as a new design as well as a redesign of Lay-down Clamp is required. Cost = -1.
- The use of guide-wire for guiding purposes makes it possible to land the Open PLET in a very accurate on the seabed. Accuracy = 1.

Solution #2

- Use of only the skid structure for guiding and positioning of the skid makes this a simple solution. Simplicity = 1.
- The repositioning of the Open PLET on seabed implies a challenging operation for the installation vessel, and skilled personnel are required. Skill = -1.

The total points in Table 3.3 show that the best solution will be solution #2.

3.5.3 Skid: Stiffness

The skid stiffness shall be ensured by use of a simple, but strong structural framework, with a small number of beams. Guiding elements shall be implemented in the framework.

3.5.4 Skid: Pulling and sliding

The chosen solution for locking of the end termination is the one that do not require a pull operation (section 3.5.1). But, the skid must be able to slide on the seabed due to the required axial repositioning and alignment of skid when lifting the end termination into the Porch. Sliding of skid on seabed in axial direction is also required to facilitate thermal expansion of the pipeline.

3.5.5 Porch: End termination guiding

Interfaces between the Porch and the alignment sleeve(s) on the pipeline end termination shall ensure guiding in axial and lateral direction during lifting of end termination. The skid shall also be slightly repositioned and aligned in axial direction during the lifting.

3.5.6 Porch: Skid interface

The chosen solution is an active Porch. This Porch is fixed to the skid by an interface less complicated than for a passive Porch. The method for attaching the Porch to the skid will be by using similar components as for the current Open PLET system. The active Porch is required for the chosen end termination locking solution, because both the MAS and RAS are positions for the locking mechanism (MAS should therefore not be movable compared to RAS). The active Porch solution also gives more predictability (than for passive Porch) with respect to the measurement prior to spool fabrication (section 2.4.3.2).

3.5.7 Pipeline end termination

Main alignment sleeve facilitates guiding of pipeline end termination for full integration into Porch. The main purpose for the sleeve will be the axial guiding of the Open PLET during lifting from seabed, and to maintain the axial and lateral position when end termination is locked in the Porch. Lateral and vertical guiding during lifting is maintained by lead-in chamfers on the Porch (MAS and RAS). The rear alignment sleeve is not required for the axial repositioning of the Open PLET, and therefore the sleeve itself is not required.

3.5.8 PLET Integration Tool

The chosen solution for end termination locking is the one that do not require a pull operation (section 3.5.1). Consequently, the requirement of a PLET Integration Tool vanishes. That also means that finding technical solutions for the tool is not applicable.

3.6 PRESENTATION OF DESIGN

This section presents the result of the modeling phase (section 1.5.2.2). In this section the conceptual design of the Open PLET system is presented and described. The functions, along with closer presentation of the technical solutions of the Open PLET, will be presented in section 5.1 of this report.

The 3D model of the design is made by use of the CAD software ProEngineer (WF3). All figures used in the presentation are generated from the 3D model.

The main components of the concept will be presented in detail in the following sections of this report. In addition to the main components, a multitude of other components are part of the design. Most of these components will be highlighted during the following presentations, but no further descriptions will be given as they are considered standard components in the industry.

The conceptual design is the result of putting together the chosen technical solution from the concept selection (section 3.3 and 3.5).

3.6.1 Main overview

Figure 3.10, Figure 3.11 (overleaf) and Figure 3.12 (overleaf) presents the conceptual design of the Open PLET system developed in this thesis.

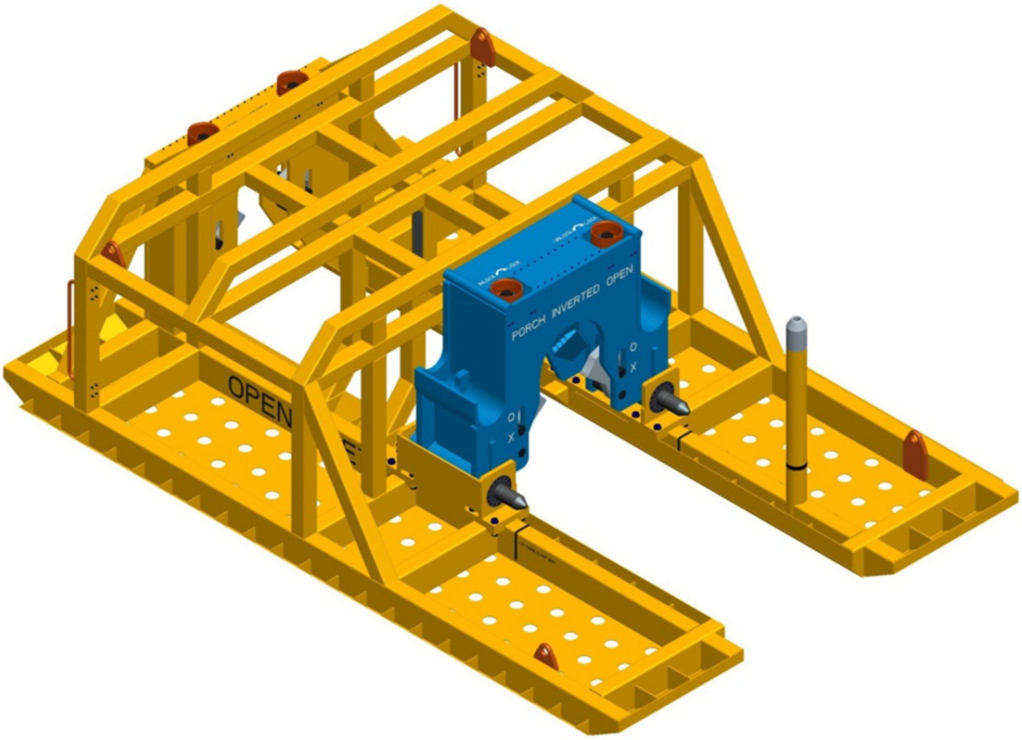


Figure 3.10 – Open PLET, iso-view front

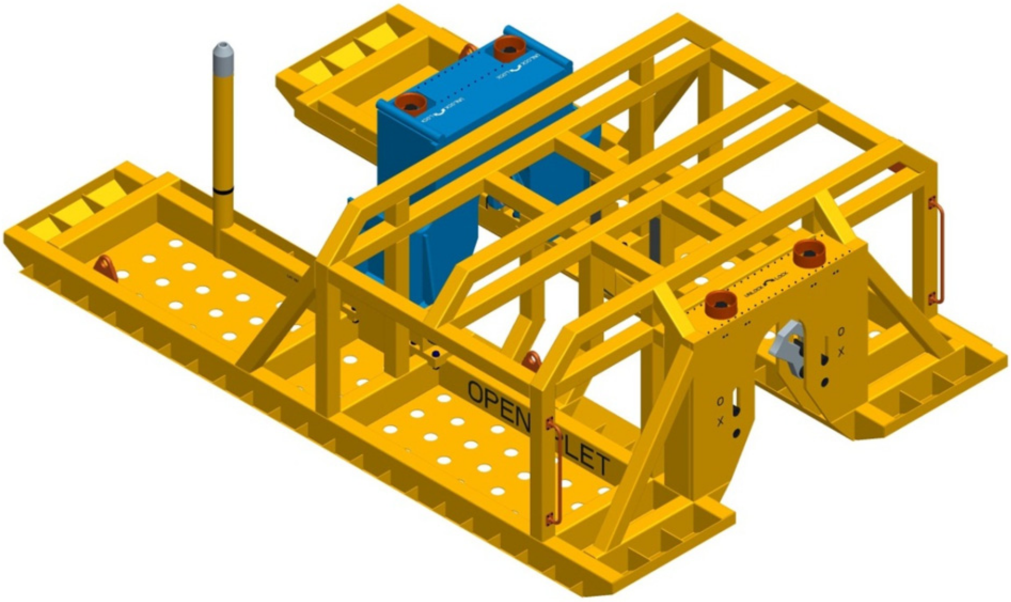


Figure 3.11 – Open PLET, iso-view back

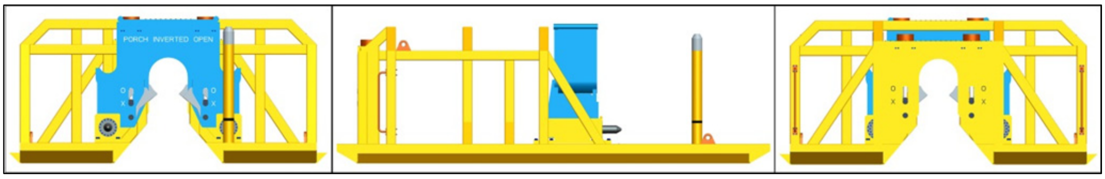


Figure 3.12 – Open PLET, front- side- and rear-view

The design consists of three main components:

1. Skid
2. Porch Inverted Open
3. Mechanical lock assembly

Figure 3.13 gives an overview of the location of the main components.

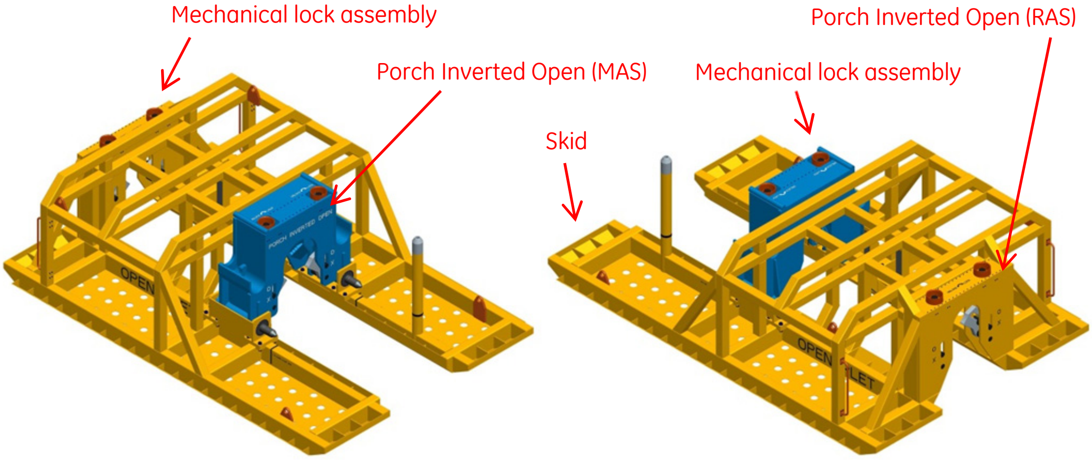


Figure 3.13 – Open PLET, main components

3.6.2 Skid

The skid consists of a bottom frame with a longitudinal opening in center position, a structural framework joining the two bottom frame elements and the Rear Alignment Structure (RAS).

Along the edges of the longitudinal opening, downward facing chamfers shall facilitate for guiding of the skid when landing over the pipeline end termination. Both the structural framework and the RAS have interfaces towards the pipeline end termination which are lead-in chamfers intended for guiding of the end termination to final position in the Porch. Rubber linings are attached to a guiding structure on the framework to protect the pipeline end termination from an unfavorable impact. The RAS provides interfaces for mounting of two mechanical lock assemblies. They are mounted by use of attachment plates (same as for the MAS, section 3.6.3).

The outer edges of the bottom frame are designed with chamfers. These are required to easier achieve sliding of skid on seabed in axial and lateral direction. The sliding occurs during installation of the Open PLET and in in-place operation due to thermal expansion of the pipeline.

In front of the structural framework the Porch Inverted Open (MAS) shall be mounted on mounting plates on the bottom frame. The guide-post facilitates for guiding of spool termination to proper position prior to spool connection. Lifting of skid is done by attaching a 4-part lifting sling to the lifting pad-eyes located in all four corners of the skid. ROV handles are intended to assist the lateral orientation of skid during installation.

The bottom frame is made by rectangular hollow section beams and plates. The plates with interface towards the seabed are the mud-mats. The structural framework is made by square hollow section beams. The RAS is made by plates. All material on the skid is S355 carbon steel.

3.6.2.1 Component overview

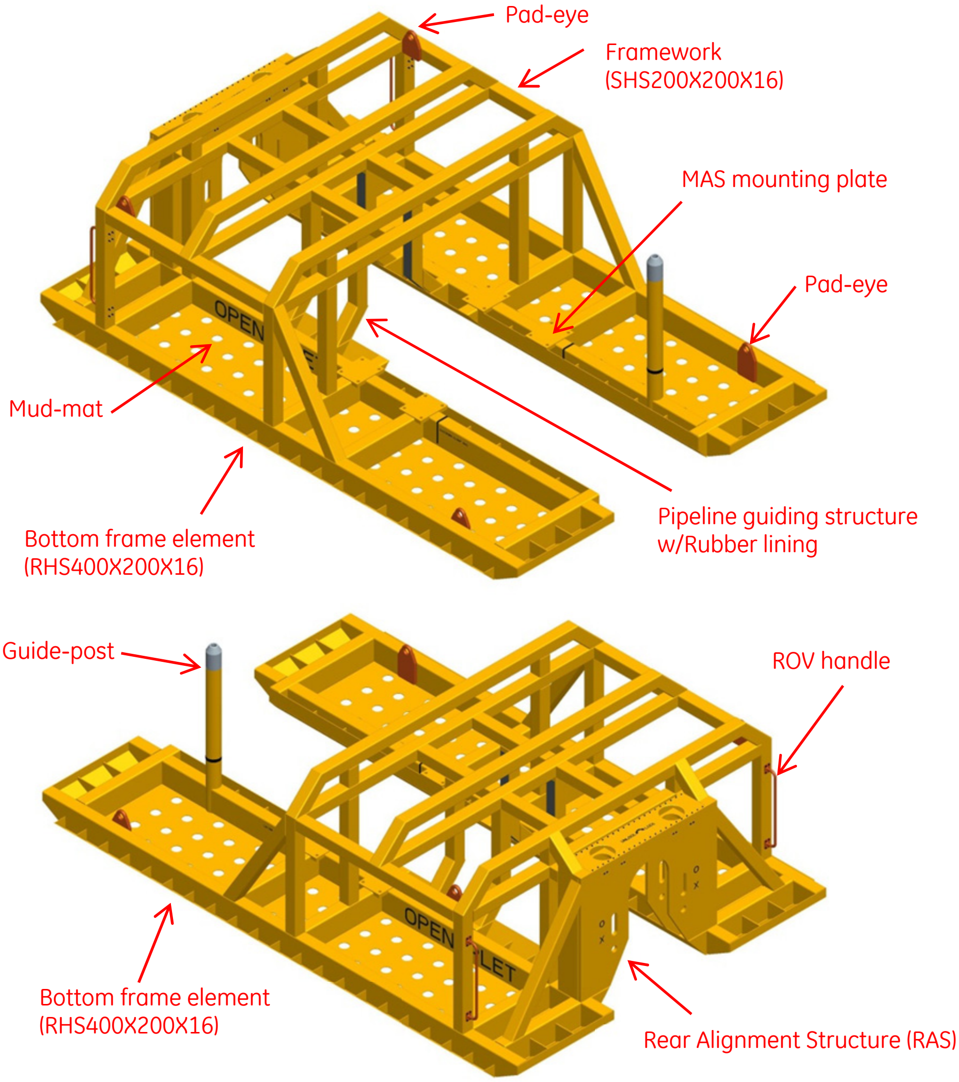


Figure 3.14 – Skid overview

Figure 3.15 (overleaf) is a side- and top-view of the skid showing some significant dimensions. The width of the longitudinal opening is designed on basis of the dimensions of the pipeline end termination and the Lay-down Clamp.

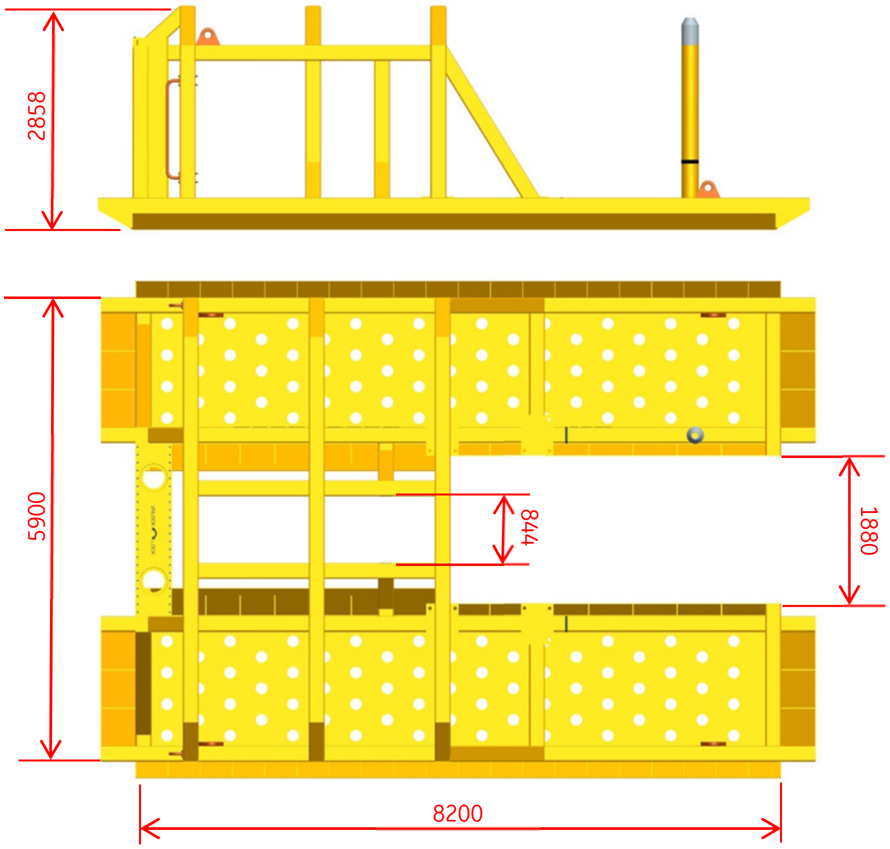


Figure 3.15 – Skid dimensions

3.6.2.2 Technical data

Table 3.4 – Technical data, skid

DESCRIPTION	DATA
Dimensions	Skid (L/W/H) = 8200mm / 5900mm / 2858mm Longitudinal opening width = 844mm / 1880mm
Weight	21832kg
Material	S355J2
Beams	Bottom frame elements = RHS400X200X16 Framework = SHS200X200X16
Plates	Bottom frame elements = 8mm / 15mm RAS = 15mm / 50mm
Interfaces	Pipeline end termination Mechanical lock assembly (RAS) Porch Inverted Open/Porch anchors HCCS spool termination Lifting sling/shackles (pad-eyes) ROV (handles)

3.6.3 Porch Inverted Open

Because of the downward facing opening, the Porch on the Open PLET is called "Porch Inverted Open." A "normal" open Porch has the opening facing upwards. The Porch on the Open PLET consists of MAS and RAS (section 2.4.1). This section covers the Main Alignment Structure (MAS). The RAS is presented as a part of the skid (section 3.6.2).

The Porch has an interface towards the skid, upon which it shall be mounted by bolts. The Porch anchors are required parts to complete this mounting. The Porch itself is attached to the Porch anchors by lock flanges in rear end and guide-spears in front. The guide-spears are not fixed to the Porch anchors as the interface provides for axial sliding.

The alignment sleeve on the pipeline end termination has interfaces towards the Porch for both axial guiding and final positioning. The sleeve impinges a "sliding face" on the Porch which forces the skid to slide axially compared to the end termination. This axial repositioning aligns the end termination properly into the Porch. A groove for the alignment sleeve keeps the end termination in proper axial position when fully integrated in the Porch.

The Porch provides interfaces for mounting of two-off mechanical lock assemblies. They are mounted by use of purpose-made attachment plates. The plates are attached to the structure by use of bolts. A removable top plate on the Porch gives proper access to the lock assembly.

The lower and upper alignment members are regarded as interfaces towards the HCCS spool termination. These members are the points of contact for the spool termination, and all alignment forces during the connection operation are distributed into Porch structure by these members.

The Porch Inverted Open is made by steel plates of various thicknesses. All material is defined as S355 carbon steel.

3.6.3.1 Component overview

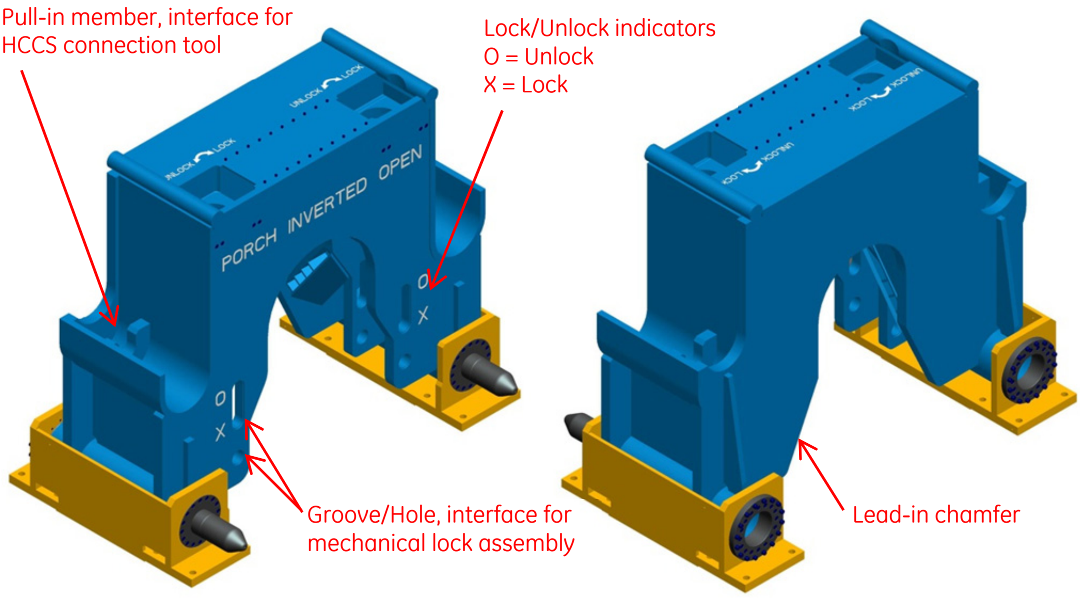


Figure 3.16 – Porch Inverted Open

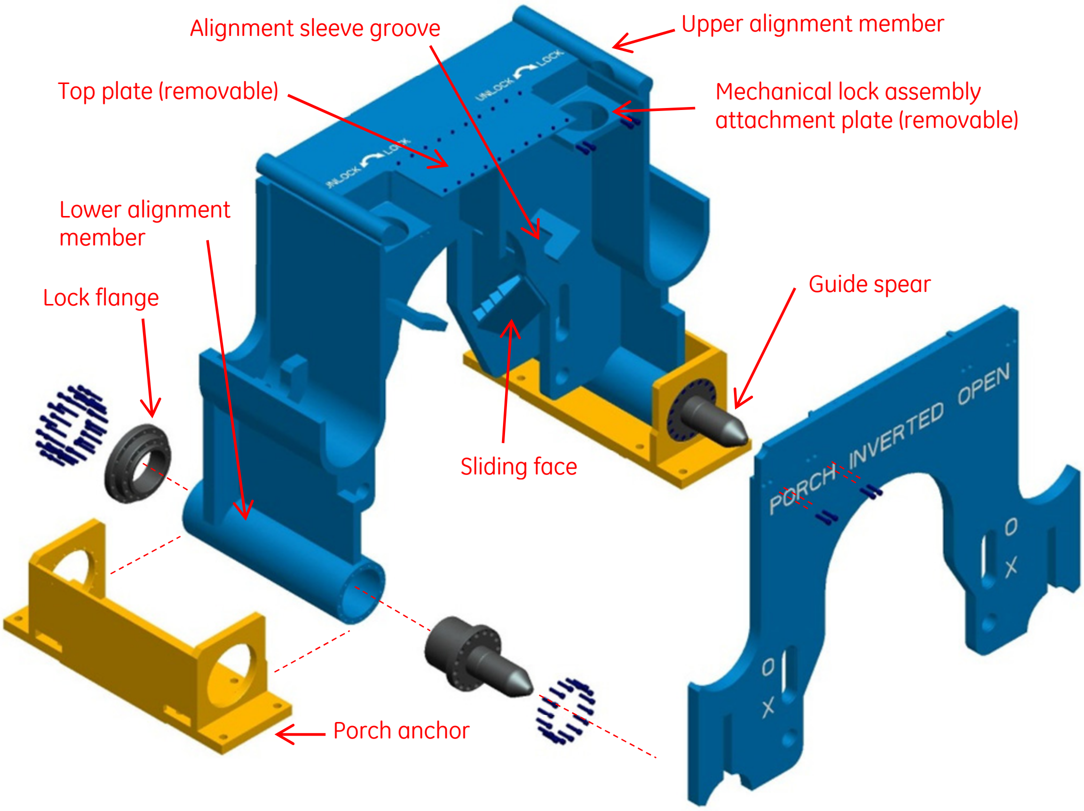


Figure 3.17 – Porch Inverted Open, exploded view

3.6.3.2 Technical data

Table 3.5 – Technical data, Porch Inverted Open

DESCRIPTION	DATA
Dimensions	Porch (L/W/H) = 1836mm / 2920mm / 2471mm
Weight	11372kg
Material	S355J2
Plates	Minimum thickness = 8mm Maximum thickness = 80mm
Interfaces	Skid Pipeline end termination w/alignment sleeve Mechanical lock assembly HCCS spool termination

3.6.4 Mechanical lock assembly

The mechanical lock assembly is the locking mechanism that keeps the pipeline end termination locked in the Porch. The Open PLET concept comprises four lock assemblies, two and two working together in two positions. There are two different versions of the lock assembly, one to be positioned at the MAS and one at the RAS. The first difference is the length of the threaded bar due to different heights between the MAS and the RAS. The second difference is the size of the lock-collar, because of a diameter difference on the interfaces. The alignment sleeve interface at MAS has a large diameter than the pipeline interface at RAS. However, the lock assembly components are the same on both versions.

The interfaces for the mechanical lock assembly are the Porch, the pipeline end termination and a torque tool. The lock assembly shall be mounted on both the MAS and the RAS in defined positions. At the MAS, the lock assembly interface is towards the alignment sleeve while at the RAS the interface is towards the pipeline itself.

The mechanical lock assembly is equipped with a torque tool bucket on top. It has a standard torque tool interface (torque tools are designed according to ISO standards). The torque tool rotates a threaded bar which is, in the bottom end, attached to the uppermost collar-bolt. The collar-bolts support and operate the lock-collar. The small space for assembling inside MAS and RAS requires the upper collar-bolt to consist of two/three parts (MAS/RAS). The trunnion part has a threaded hole which has an interface towards the threaded bar. The collar-bolts are assembled by use of standard

DIN/ISO threaded bolts, and they are held in axial position at MAS and RAS by small grooves with interfaces towards the end stoppers on the bolts.

A reaction arm is required to ensure the threaded bar is the rotating part during operation of the mechanical lock assembly. The reaction arm prevents the torque tool bucket to rotate along with the torque tool itself. The arm reacts towards the Porch structure.

The material for some of the components on the mechanical lock assembly would probably be other than regular S355 carbon steel if proper evaluated. But material considerations are not covered in this thesis, and all components are therefore defined with S355 carbon steel. This will not affect the purpose of the conceptual design.

3.6.4.1 Component overview

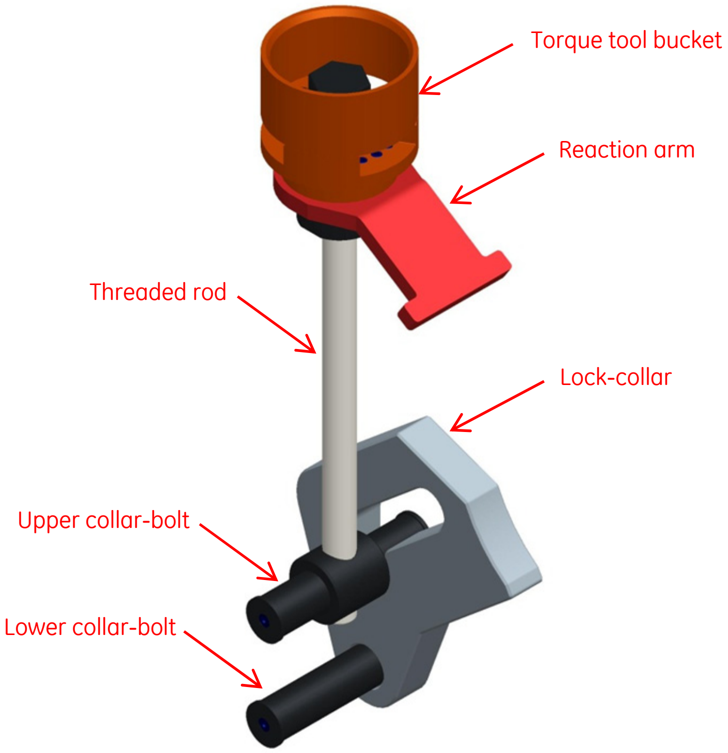


Figure 3.18 – Mechanical lock assembly

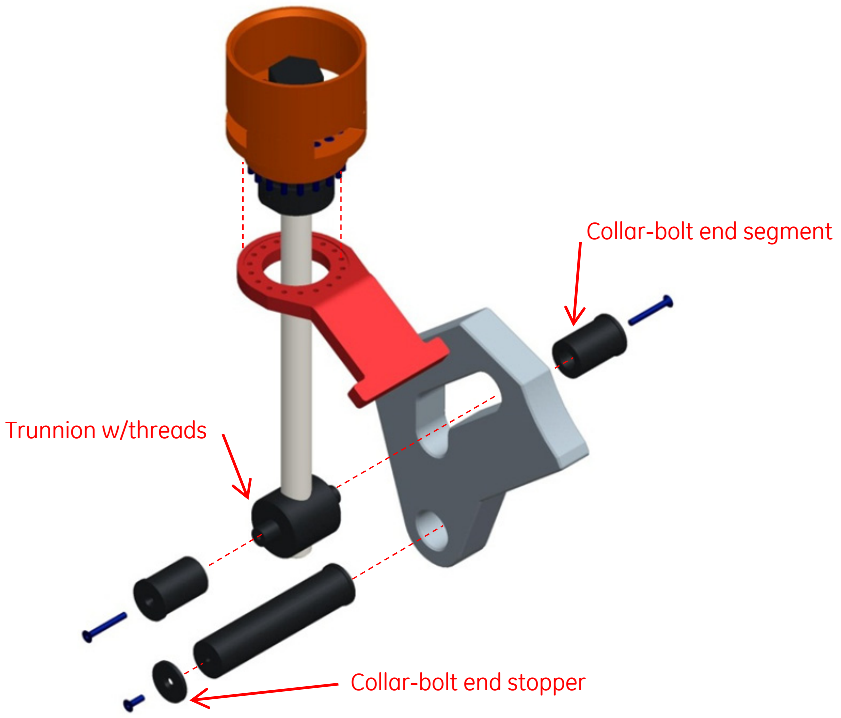


Figure 3.19 – Mechanical lock assembly, exploded view

3.6.4.2 Technical data

Table 3.6 – Technical data, mechanical lock assembly

DESCRIPTION	DATA
Dimensions	Threaded rod diameter = 75mm Collar-bolts diameter = 100mm Lock-collar thickness = 100mm
Material	S355J2
Interfaces	Torque Tool Pipeline end termination w/alignment sleeve Porch (MAS and RAS)

3.6.4.3 Mechanical lock assembly in Porch

Figure 3.20 shows the mechanical lock assembly mounted in the Porch.

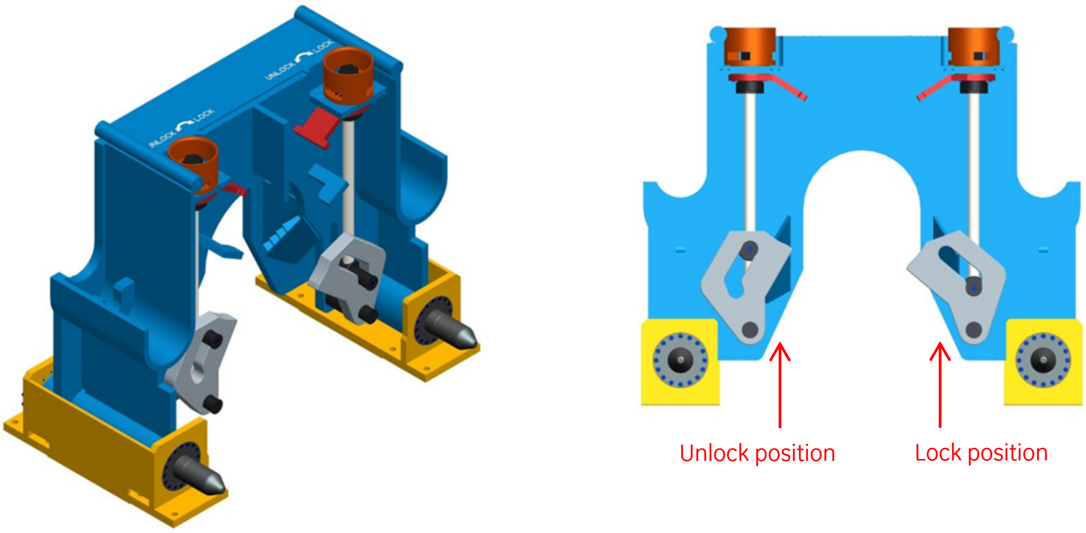


Figure 3.20 – Mechanical lock assembly in Porch

3.6.5 Pipeline end termination

The pipeline end termination is more or less the same for the Open PLET concept as for the end termination for the current Open PLET presented in section 2.4.2. Two major changes have been accomplished:

- Rear alignment sleeve is removed as it is not required (section 3.5.7).
- Main alignment sleeve has been modified to fit with the technical solutions and the Porch Inverted Open.

Figure 3.21 shows an exploded view of the pipeline end termination for the new concept.

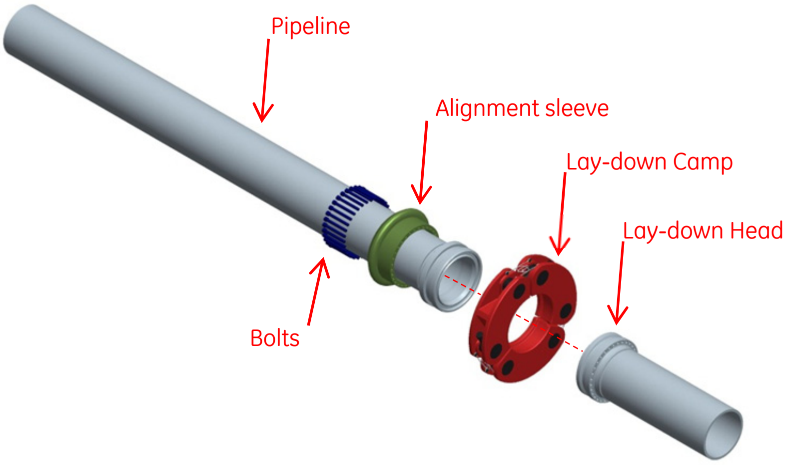


Figure 3.21 – Pipeline end termination, exploded view

Figure 3.22 shows the modified main alignment sleeve designed for this concept. The sleeve is bolted to the hub. It is designed to fulfill two main purposes:

1. Facilitate for sliding of Open PLET during installation. The extended collar on the sleeve has an interface towards the sliding face on the Porch (MAS).
2. Maintain axial position of pipeline end termination in locked position. The extended collar has an interface towards the "alignment sleeve groove" on the Porch (MAS).

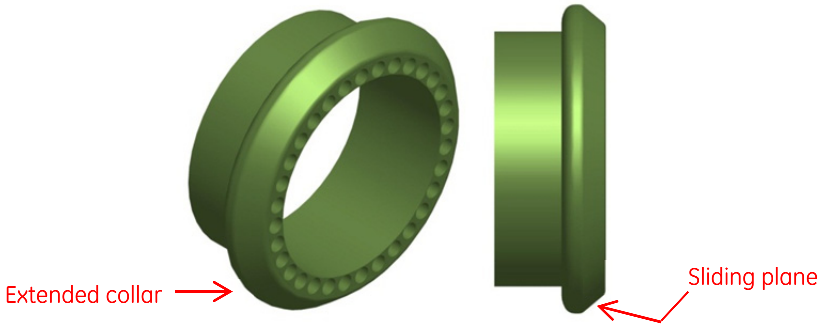


Figure 3.22 – Alignment sleeve

4 ANALYSIS

The purpose of the analysis in this thesis is to observe how the developed Open PLET system and its components respond under application of defined design loads, and thereupon evaluate and discuss the results. The distinction between a conceptual design and a detailed design will assert itself also here in the analysis. The purpose is not mainly to use the analysis to end up with a design which has the required structural integrity (such a goal belongs to the detail design phase). If some acceptance criteria are not met in the analysis, instead of doing redesign and optimization, the results are rather evaluated and discussed.

The intention with the analysis is to show that the conceptual design has the *potential* to achieve the required structural strength to withstand the loads and load conditions which the system is subjected to during design life. But, the eventual redesign and optimization needed to fulfill this requirement is supposed to be dealt with in the detail design phase. Another intention is to show that the technical solutions of the concept have the *potential* to be the final solutions for a detailed designed Open PLET system. It is assumed that optimization will be required in the detail design phase to fulfill that as well.

In the analysis, global responses of the Open PLET components are more important than local results. The focus will be on how the whole component reacts on the loads. Small regions or contacts with unwanted results will not be emphasized to any great extent.

4.1 EVALUATION OF COMPONENTS

Not all components of the Open PLET system are analyzed in this thesis. They are not relevant with respect to the level of details in a conceptual design. This section will give an evaluation of which components are considered important to be analyzed in the conceptual design phase.

4.1.1 Skid

The skid is an essential part of the Open PLET. It is the supporting structure for the connection system and it has important interfaces towards the pipeline end termination during installation. The stiffness between the two bottom frame elements shall be ensured by the structural framework between the elements. The analysis shall verify if the skid performs as intended, and that right choices of structural members have been made. The skid is considered to be an important component of the conceptual design.

4.1.2 Porch Inverted Open

The Porch Inverted Open is the supporting structure for the connection operation of the spool termination. It is also the point on the Open PLET where the pipeline end termination is locked in position. The Porch structure will undergo large loads and combinations of loads, especially during the spool connection. Various circumstances must be considered as a number of different load cases may occur. The analysis shall verify if the Porch is designed properly to meet all these requirements and load cases. Both the plate configurations and the plate thicknesses are vital for the result. The Porch Inverted Open is considered to be an important component of the conceptual design.

4.1.3 Mechanical lock assembly

The mechanical lock assembly is the mechanism which locks the pipeline end termination in position in a vertical active direction (section 3.5.1). The lock-collar and collar-bolts must withstand all the forces acting from the pipeline end termination in order to stop vertical movements (unlocking) of the end termination. This is maybe most important after completion of the spool connection, when the weights of both the pipeline end termination and the spool termination are acting on the lock assembly. The components of the mechanical lock assembly which are subjected to forces acting from the pipeline end termination are considered to be important parts of the conceptual design.

4.1.4 Non-important components

The following components are considered to not be important with respect to the conceptual design of the Open PLET system. These components will therefore not undergo analyses or calculations in this thesis, as the results will not influence the final conceptual design (will not influence the technical solutions).

4.1.4.1 Pad-eyes

Design and calculation of lifting points and pad-eyes will be done on basis of the center of gravity (CoG), the weight of the Open PLET and the interfaces towards the lifting sling. This information is possible to compute accurately in a detail design phase. Pad-eye design is based on the Open PLET design, not opposite, and it is therefore not important in a conceptual design phase.

4.1.4.2 Mud-mats

The size (thickness) and shape (number and size of holes) of the mud-mats on the Open PLET is calculated on basis of detailed information of the soil conditions on the seabed. Such information is field specific, and the calculations consequently belong to the detail design phase. Mud-mat design will not affect the conceptual design. The conclusion is that the mat-mat design is not of importance in the conceptual design phase.

4.1.4.3 Bolts

The Open PLET system comprises a number of bolts for fastening. These bolts are mainly subjected to tensile and shear forces. Some of the bolted connections are very critical, and the integrity of the bolts are consequently of high importance. But in this conceptual design phase calculation of bolts is not included, as they will not affect the technical solutions of the design.

4.1.4.4 Mechanical lock assembly

Some components of the mechanical lock assembly are considered important in the conceptual design phase (section 4.1.3). The torque tool bucket and the threaded rod on the assembly are used only for activation of the lock-collar, which is to change from “unlocked” to “locked” position, and opposite. They are considered as standard components and field proven technology, used on several GE Oil & Gas systems. The threaded rod will only transfer moment forces from the rotational movements of the torque tool to operate the upper collar-bolts. These forces will be of limited size. The design of these components is not of importance in the conceptual design phase.

4.1.4.5 Spool termination interface

The spool termination will land on the Open PLET by guidance of the guide-post. The interface between the skid and the spool termination shall facilitate proper positioning and sliding during the connection operation. This interface is highly important, but it will not affect the conceptual design and the technical solutions. Modifications of the HCCS are neither a part of the thesis scope (section 1.5.3)

4.2 BASIS FOR ANALYSES

4.2.1 General

The loads and load cases are defined on basis of industry norms as well as experience and documentation from similar equipment [8].

Analyses of the load cases concerning the skid are executed using the 3D structural analysis software STAAD.Pro (v8i). The Porch and the mechanical lock assembly are analyzed using the FEM software ANSYS Workbench (v13). In STAAD.Pro, the element model is defined by using the internal modeling interface. For the analyses in ANSYS WB, the element model is generated by an imported 3D model from ProEngineer.

Hand calculations will be carried out for components and load cases where use of the above mentioned software is not relevant.

Figure 4.1 presents the governing standards for the analyses. The division in the flowchart illustrates a distinction between analyses of load cases that involves lifting and non-lifting load cases.

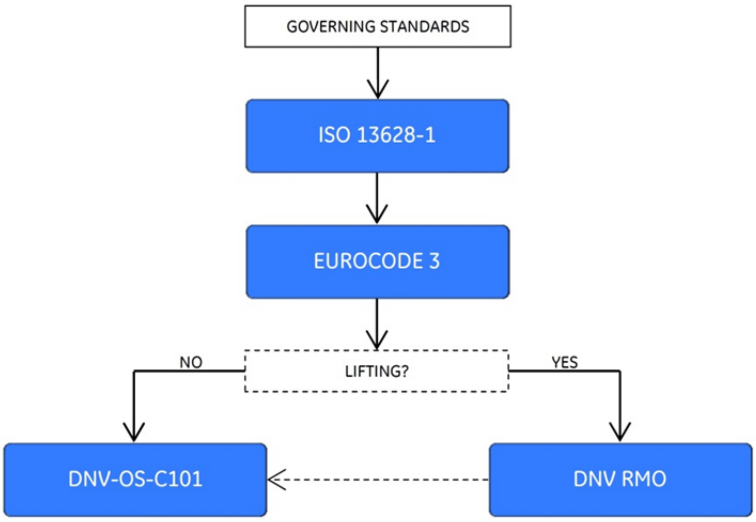


Figure 4.1 – Governing standards flowchart

4.2.2 Limit state

The analyses are carried out according to the "Load and Resistance Factor Design" (LRFD) method. In this method, uncertainties in loads and material resistance are represented by a load factor and a material factor. In the analyses, the structural performance of the components is described with reference to a "limit state". A limit state is defined as *"a state beyond which the structure no longer satisfies the requirements"* [25]. Limit states are in the standards divided into several categories where the Ultimate Limit State (ULS) has the strictest requirements. All analyses in this thesis are therefore carried out in ULS.

4.2.3 Material properties

All material is defined as S355 carbon steel according to EN 10025-2 [26]. A proper material selection is supposed to be done in the detail design phase. All data in Table 4.1 (overleaf) are given in accordance with Eurocode 3 [27] and EN 10025-2.

Table 4.1 – Material properties

DESCRIPTION	DATA
Steel grade	S355J2
Yield strength	355MPa ($t \leq 16mm$) 345MPa ($16mm < t \leq 40mm$) 335MPa ($40mm < t \leq 63mm$) 325MPa ($63mm < t \leq 80mm$) 315MPa ($80mm < t \leq 100mm$) 295MPa ($100mm < t \leq 150mm$)
Density	$7850kg/m^3$
Young`s modulus	210000MPa
Poisson ratio	0.3

4.2.4 Constants

Constants that are relevant for the analyses are presented in Table 4.2.

Table 4.2 – Constants

DESCRIPTION	SYMBOL	VALUE
Seawater density	ρ	$1025\ kg/m^3$
Friction, steel against steel	μ_{steel}	0.2(1)
Friction, steel against soil	μ_{soil}	1.0(1)
(1) The friction coefficient is defined on basis of GE Oil & Gas documentation concerning similar equipment [8].		

4.2.5 Weight of components

Weight and volume of components given in Table 4.3 is generated from the 3D model in ProEngineer.

Table 4.3 – Component weights

COMPONENT	VOLUME [m^3]	WEIGHT DRY [kg]	WEIGHT SUBMERGED [kg]
Skid	2.781	21832(1)	18981(2)
Porch	1.448	11372(1)	9888(2)
(1) Including the mechanical lock assemblies. (2) Calculation formula in section 4.2.5.1.			

4.2.5.1 Calculation of submerged weights

Calculation of submerged weights is executed according to the following formula:

$$\text{Weight submerged [kg]} = \text{Weight dry [kg]} - \rho \times \text{V}$$

Where

ρ = Seawater density

V = Volume of component

4.2.6 Loads

Table 4.4 lists the relevant loads applicable to the analyses.

Table 4.4 – Loads

LOAD NO.	LOAD DESCRIPTION	VALUE
L-01	Gravity load skid (dry)	214kN
L-02	Gravity load skid (submerged)	186kN
L-03	Gravity load Porch (dry)	112kN
L-04	Gravity load Porch (submerged)	97kN
L-05	Gravity load pipeline end termination (submerged)	350kN(1)
L-06	Gravity load spool termination (submerged)	145kN(1)
L-07	Axial load capacity	402kN(1)
L-08	Lateral load capacity	410kN(1)
L-09	Moment load capacity	3315kNm(1)
L-10	HCCS connection tool, hydraulic cylinder pull-force	1292kN(1)
(1) Value is defined on basis of GE Oil & Gas documentation concerning the equipment [8].		

4.2.7 Load cases

Table 4.5 (overleaf) lists the defined load cases. The load cases simulate situations and load combinations anticipated to occur during design life. The intention is that analyses of the load cases shall support and verify the chosen technical solution.

Table 4.5 – Load cases

LOAD CASE NO.	COMPONENT	DESCRIPTION	TOOL
LC-01	Skid	Lift onshore	STAAD.Pro
LC-02	Skid	Lift offshore	STAAD.Pro
LC-03	Skid	In-place	STAAD.Pro
LC-04	Porch	Spool connection, spool pull-in	ANSYS WB
LC-05	Porch	Spool connection, full hub contact	ANSYS WB
LC-06	Porch	Spool connection, single upper alignment member contact	ANSYS WB
LC-07	Porch	In-place, moment 45° from z-axis (lateral axis)	ANSYS WB
LC-08	Mechanical lock assembly	Collar-bolt shear calculation	Hand calculation
LC-09	Open PLET	Axial alignment during installation	Hand calculation

4.2.8 Overview of loads versus load cases

Table 4.6 lists which loads that are applicable to the different load cases.

Table 4.6 – Loads versus load cases

LOAD CASE NO.	LOAD NO.									
	L-01	L-02	L-03	L-04	L-05	L-06	L-07	L-08	L-09	L-10
LC-01	X		X							
LC-02	X		X							
LC-03		X		X	X	X				
LC-04					X	X				X
LC-05					X	X				X
LC-06					X	X				X
LC-07					X		X	X	X	
LC-08					X	X				
LC-09		X		X						

4.2.9 Load factors

4.2.9.1 ULS load factor, γ_f

This load factor is required due to uncertainties in the values of the applied loads. The load factor is defined according to DNV RMO (part 1, chapter 4, section 3.2.5) [28].

4.2.9.2 Skew load factor, γ_{SKL}

According to DNV RMO (part 2, chapter 5, section 2.3.1.1 and 2.3.2.5) [28], the skew load is defined as *"extra loading caused by equipment and fabrication tolerances and other uncertainties with respect to force distribution in the rigging arrangement"*. The skew load factor is applicable for load cases that involve lifting.

4.2.9.3 CoG shift factor, γ_{COG}

A CoG shift factor is, according to DNV RMO (part 1, chapter 3, section 3.5.3) [28], required due to a possible inaccuracy in positioning of the Centre of Gravity. The CoG shift factor is applicable for load cases that involve lifting.

4.2.9.4 Weight inaccuracy factor, γ_{ina}

Since the weight of most of the components is estimated using a 3D modeling computer software, and not by physical weighing, a weight inaccuracy factor is required according to DNV RMO (part 1, chapter 3, section 3.5.2) [28].

4.2.9.5 Consequence factor, γ_{con}

The consequence factor is intended to account for severe consequences of single element failures on the structure. The factor is applied according to DNV RMO (part 2, chapter 5, section 4.1.2) [28], and is applicable to load cases that involve lifting.

4.2.9.6 Dynamic amplification factor, γ_{DAF}

According to DNV RMO this is *"a factor accounting for the global dynamic effects normally experienced during lifting"*. There is a distinction between the amplification factor for onshore lifting and offshore lifting. The DAF factors are according to DNV RMO (part 2, chapter 5, section 2.2.2.4) [28].

Table 4.7 (overleaf) lists the values for the load factors applicable in the analyses.

Table 4.7 – Load factors

DESCRIPTION	SYMBOL	VALUE
ULS load factor	γ_f	1.30
Skew load factor	γ_{SKL}	1.25
CoG shift factor	γ_{COG}	1.05
Weight inaccuracy factor	γ_{ina}	1.05
Consequence factor	γ_{con}	1.15
Dynamic Amplification Factor, onshore	γ_{DAF_ON}	1.10
Dynamic Amplification Factor, offshore	γ_{DAF_OF}	1.30

4.2.10 Total load factors

The total load factor for each load case is calculated according to the following formula:

$$\gamma_{LC} = \gamma_f \times \gamma_{SKL} \times \gamma_{COG} \times \gamma_{ina} \times \gamma_{con} \times \gamma_{DAF}$$

The results are presented in Table 4.8.

Table 4.8 – Total load factors

LOAD CASE	SYMB.	γ_f	γ_{SKL}	γ_{COG}	γ_{ina}	γ_{con}	γ_{DAF_ON}	γ_{DAF_OF}	TOT.
LC-01	$\gamma_{LC\text{-}01}$	1.30	1.25	1.05	1.05	1.15	1.10	N/A	**2.27**
LC-02	$\gamma_{LC\text{-}02}$	1.30	1.25	1.05	1.05	1.15	N/A	1.30	**2.68**
LC-03	$\gamma_{LC\text{-}03}$	1.30	N/A	N/A	1.05	N/A	N/A	N/A	**1.37**
LC-04	$\gamma_{LC\text{-}04}$	1.30	N/A	N/A	1.05	N/A	N/A	N/A	**1.37**
LC-05	$\gamma_{LC\text{-}05}$	1.30	N/A	N/A	1.05	N/A	N/A	N/A	**1.37**
LC-06	$\gamma_{LC\text{-}06}$	1.30	N/A	N/A	1.05	N/A	N/A	N/A	**1.37**
LC-07	$\gamma_{LC\text{-}07}$	1.30	N/A	N/A	1.05	N/A	N/A	N/A	**1.37**
LC-08	$\gamma_{LC\text{-}08}$	1.30	N/A	N/A	1.05	N/A	N/A	N/A	**1.37**
LC-09	$\gamma_{LC\text{-}09}$	N/A	N/A	N/A	N/A	N/A	N/A	N/A	**1.00**

4.2.11 Material factors

The material factors are defined according to DNV-OS-C101 [25] for non-lifting load cases, and according to DNV RMO (part 1, chapter 4, section 4.1.3) [28] for load cases which involves lifting. The values are in ULS.

Table 4.9 gives the material factors applicable in the analyses.

Table 4.9 – Material factors

DESCRIPTION	SYMBOL	VALUE
ULS material factor, non-lifting	γ_{m_nl}	1.15
ULS material factor, lifting	γ_{m_l}	1.15

4.2.12 Acceptance criteria

4.2.12.1 Allowable stress

The stresses in the components shall be calculated as Von Mises equivalent stresses. The allowable stress is obtained by dividing the material yield strength (section 4.2.3) by the material factor for the relevant limit state (section 4.2.11). Table 4.10 shows the allowable stresses in ULS.

Table 4.10 – Allowable stresses

MATERIAL THICKNESS [mm]	MAX ALLOWABLE STRESS [MPa]
$t \leq 16$	309
$16 < t \leq 40$	300
$40 < t \leq 63$	291
$63 < t \leq 80$	283
$80 < t \leq 100$	274
$100 < t \leq 150$	257

For the bolt shear stress calculation (LC-08) the relation between shear stress and tensile stress is given by the following formula according to [29]:

$$\sigma = \sqrt{3(\tau)^2}$$

Where

$\sigma =$ tensile stress

$\tau =$ shear stress

The allowable equivalent stress and the related allowable shear stress are then given by:

$$\sigma \leq \sigma_{\text{all}} \rightarrow \tau_{\text{all}} = \frac{\sigma_{\text{all}}}{\sqrt{3}}$$

Where

σ_{all} = Allowable equivalent stress (Table 4.10)

τ_{all} = Allowable shear stress

4.2.12.2 Allowable deflections

Allowable vertical deflections on the skid members (beams) is defined according to DNV-OS-C101 (section 8) [25]. The limiting values are associated with the "*deflections which may prevent the intended operation of the equipment*" [25]. In the applicable standard the deflection criterion is given in SLS. But as the criterion, as stated, is associated with deflections which may prevent the intended operation of the equipment, it is considered fully applicable for the analyses in ULS. If the criterion is met in the ULS, it is also met in the SLS.

Table 4.11 gives the allowable deflections for the skid structure.

Table 4.11 – Allowable deflections, Skid

DESCRIPTION	ALLOWABLE DEFLECTION [mm]
Beams	L/300(1)
(1) L is the span of the beam	

The Porch shall undergo deflections so small that the integrity and alignment ability during the spool connection is maintained. For both the upper and the lower alignment members (section 3.6.3) there is a distinction whether both members are subjected to alignment forces or just a single member is subjected to the same forces. The alignment members are used to align the spool termination in proportion to the Porch. Alignment by use of both the lower alignment members is the most common.

The Porch is designed for the HCCS-30 (section 2.5). The allowable deflections are defined by GE Oil & Gas with respect to the HCCS-30. The values presented in Table 4.12 (overleaf) are the allowable deflections defined for the alignment members on the Porch in the HCCS.

Table 4.12 – Allowable deflections, Porch

DESCRIPTION	ALLOWABLE DEFLECTION [mm]
Upper alignment members, both	4.8(1)
Upper alignment member, one	7(1)
Lower alignment member, both	4.7(1)
Lower alignment member, one	8.1(1)
(1) Value is defined on basis of GE Oil & Gas documentation concerning the equipment [8].	

4.3 SKID ANALYSES

The skid analyses are accomplished by using the 3D structural analysis software STAAD.Pro (v8i). This version of the software calculates the Von Mises equivalent stresses and the deflections by analyzing the model according to standard NS3472. This standard is still applicable in this version of STAAD.Pro even though it is obsoleted and replaced by Eurocode 3. However, this has no impact on the results. The results for LC-01 to LC-03 are presented in a summary in section 4.3.5.

4.3.1 STAAD.Pro model

The STAAD.Pro element model consists of 72 nodes, 124 beams and 2 plates. The beams and plates are defined with properties (beam type, thickness, material, etc.) according to the design presented in section 3.6.2 and the info given in Table 4.1.

The skid is modeled in STAAD.Pro with dummy structures for the MAS and RAS to be able to apply loads to the model as realistic as possible. The top node on the MAS dummy and the center node on the RAS dummy are placed at the center axis of the pipeline end termination.

Figure 4.2 shows a 3D view of the model with the axes defined. These are the axes referred to in LC-01 to LC-03.

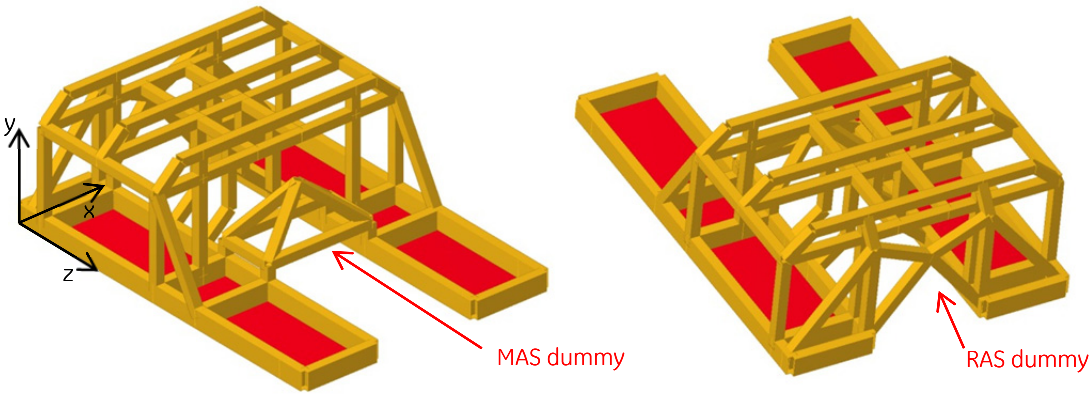


Figure 4.2 – STAAD.Pro element model

4.3.2 LC-01: Lifting onshore

The load case deals with skid lifted in dry environments onshore. Examples are lifting during fabrication and transportation. This is a horizontal lifting situation. The lifting slings in the model are in one end attached to the four pad-eyes on the skid, and in the other end to a lifting point. The lifting point is a "pinned" supported node with translation along all axes fixed and all moment directions released. The lifting point is positioned above the CoG of the element model so that the lifting sling angle is approximately 30° from vertical axis. The lifting slings are specified as "cables" transferring no compression. Figure 4.3 shows the setup for LC-01.

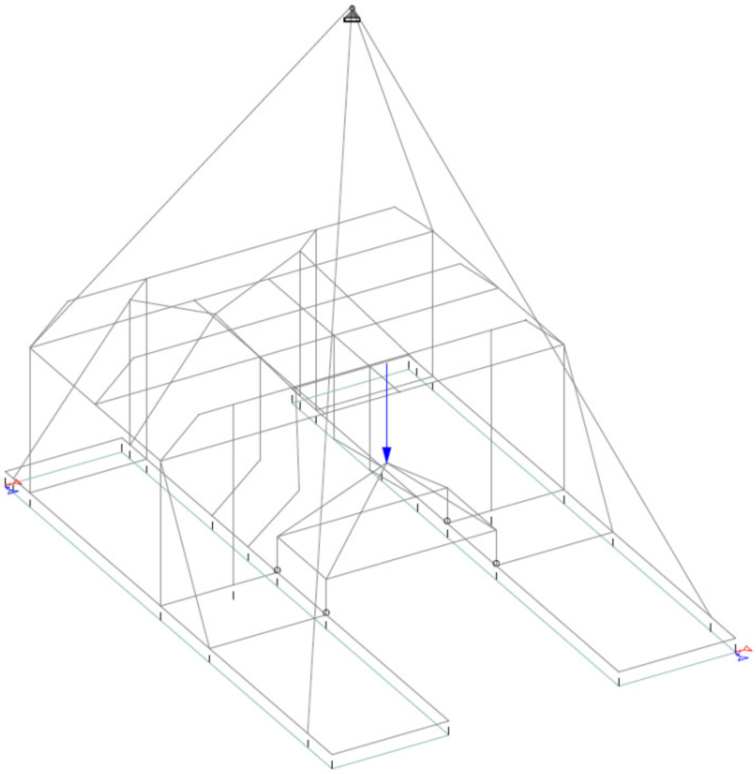


Figure 4.3 – LC-01 setup

4.3.2.1 Loads and supports

Table 4.13 (overleaf) shows the applied loads for this load case. The load factor $\gamma_{LC\text{-}01}$ = 2.27 (section 4.2.10) multiplied with the loads defined in Table 4.4 gives the applied values.

The self-weight of skid is automatically calculated in STAAD.Pro by a command. The command factor used is 2.27 ($\gamma_{LC\text{-}01}$) in negative *y*-direction.

Table 4.13 – Loads applied for LC-01

LOAD NO.	LOAD DESCRIPTION	APPLIED VALUE	COMMENTS
L-01	Gravity load skid (dry)	N/A	Calculated by STAAD.Pro. Command factor, Y = -2.27
L-03	Gravity load Porch (dry)	254kN	FY = -254kN

Table 4.14 shows the applied supports for this load case. Two weak spring supports are added at two bottom corner nodes to achieve stability. The spring stiffness *k* is set to 0.01kN/mm in x- and z-direction.

Table 4.14 – Supports for LC-01

SUPPORT	FX	FY	FZ	MX	MY	MZ
Lifting point	Fixed	Fixed	Fixed	Free	Free	Free
Bottom corners	*k* = 10N/mm	Free	*k* = 10N/mm	Free	Free	Free

4.3.3 LC-02: Lifting offshore

The load case deals with skid lifted in dry environments offshore prior to subsea installation. To reduce forces acting on skid when lowered through the splash zone, the Open PLET is angled to 70° about horizontal plane (section 2.4.3.1). The rear end (RAS end) of the structure is the lower end. The lifting slings in the model are in one end attached to the four pad-eyes on the skid, and in the other end to a spreader beam. The spreader beam is "pinned" supported in the middle with translation along all axes fixed and all moment directions released. The lifting point is positioned above the CoG of the element model. The lifting slings are specified as "cables" transferring no compression. Figure 4.4 (overleaf) shows the setup for LC-02.

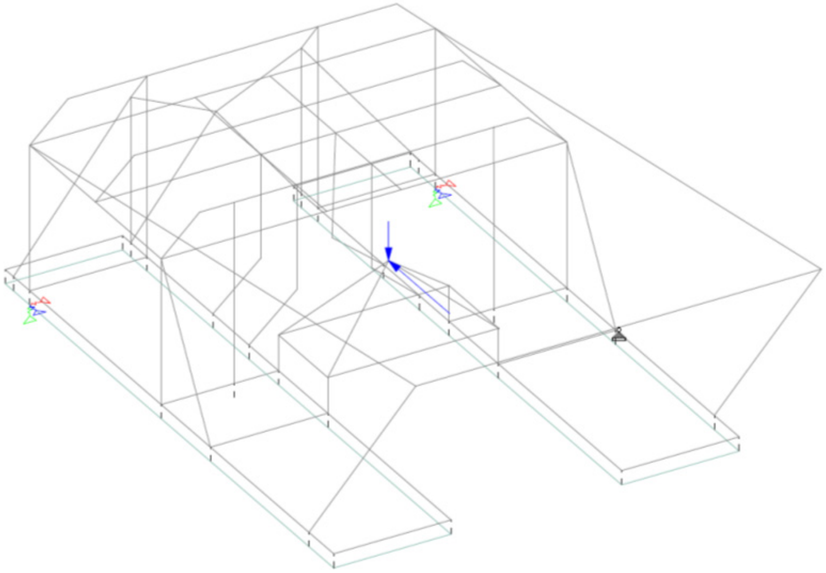


Figure 4.4 – LC-02 setup

4.3.3.1 Loads and supports

Table 4.15 shows the applied loads for this load case. The load factor γ_{LC-02} = 2.68 (section 4.2.10) multiplied with the loads defined in Table 4.4 gives the applied values.

Loads are applied to skid structure to simulate the angled lifting situation. For load number L-03 a 70° lifting angle gives 300kN x cos(70°) = 103kN in negative y-direction, and 300kN x sin(70°) = 282kN in negative z-direction.

The self-weight of skid is automatically calculated in STAAD.Pro by a command. The command factors used are 2.68 x cos(70°) = 0.92 in negative y-direction and 2.68 x sin(70°) = 2.52 in negative z-direction to simulate the angled lifting situation.

Table 4.15 – Loads applied for LC-02

LOAD NO.	LOAD DESCRIPTION	APPLIED VALUE	COMMENTS
L-01	Gravity load skid (dry)	N/A	Calculated in STAAD.Pro. Command factors, Y = -0.92 and Z = -2.52
L-03	Gravity load Porch (dry)	300kN	FY = -103kN, FZ = -282kN

Table 4.15 (overleaf) shows the applied supports for this load case. Two weak spring supports are added at two bottom nodes to achieve stability. The spring stiffness *k* is set to 0.01kN/mm in x-, y- and z-direction.

Table 4.16 – Supports for LC-02

SUPPORT	FX	FY	FZ	MX	MY	MZ
Lifting point	Fixed	Fixed	Fixed	Free	Free	Free
Bottom nodes	*k* = 10N/mm	*k* = 10N/mm	*k* = 10N/mm	Free	Free	Free

4.3.4 LC-03: In-place

The load case deals with skid installed on seabed in operational condition. The spool termination is connected to the Open PLET, so the weight of the spool termination including the clamp connector is applied to the skid along with the weight of the pipeline end termination. Figure 4.5 shows the setup for LC-03.

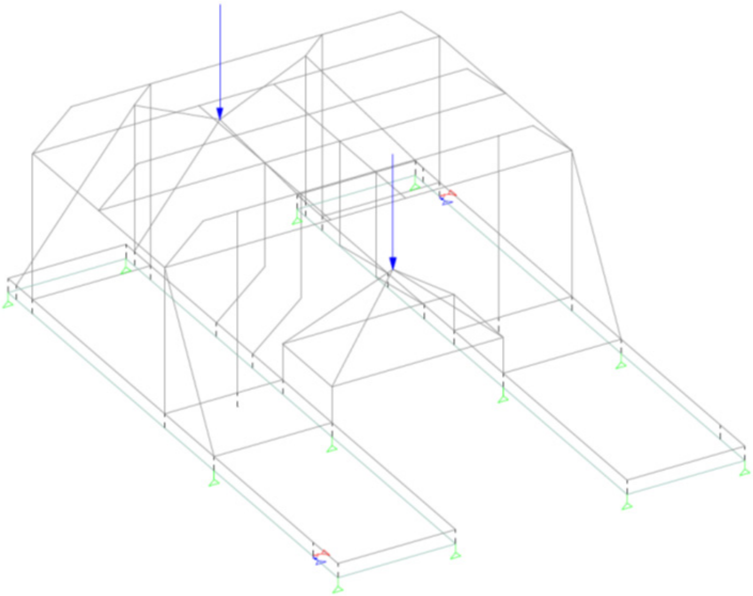


Figure 4.5 – LC-03 setup

4.3.4.1 Loads and supports

Table 4.17 (overleaf) shows the applied loads for this load case. The load factor $\gamma_{LC\text{-}03}$ = 1.37 (section 4.2.10) multiplied with the loads defined in Table 4.4 gives the applied values.

The gravity load of the pipeline end termination (L-05) is distributed 50% on MAS and 50% on RAS. All loads, including the self-weight, are in negative y-direction.

The self-weight of skid is automatically calculated in STAAD.Pro by a command. The submerged structure (0.87 times the weight of the dry structure, section 4.2.6) combined with the load factor $\gamma_{LC\text{-}03}$ = 1.37 gives the command factor used, which is 0.87 x 1.37 = 1.19.

Table 4.17 – Loads applied for LC-03

LOAD NO.	LOAD DESCRIPTION	APPLIED VALUE	COMMENTS
L-02	Gravity load skid (submerged)	N/A	Calculated in STAAD.Pro. Command factor, Y = -1.19
L-04	Gravity load Porch (submerged)	133kN	Applied on MAS
L-05	Gravity load pipeline termination (submerged)	480kN	Load applied 50% on MAS and 50% on RAS
L-06	Gravity load spool termination (submerged)	199kN	Applied on MAS

Table 4.18 shows the applied supports for this load case. The skid is supported at twelve bottom nodes fixed in *y*-direction. This simulates the in-place condition on seabed. Two weak spring supports are added at two bottom nodes to achieve stability. The spring stiffness *k* is set to 0.01kN/mm in x- and z-direction.

Table 4.18 – Supports for LC-03

SUPPORT	FX	FY	FZ	MX	MY	MZ
Lifting point	Fixed	Fixed	Fixed	Free	Free	Free
Bottom nodes	Free	Fixed	Free	Free	Free	Free
Bottom nodes	*k* = 10N/mm	Free	*k* = 10N/mm	Free	Free	Free

4.3.5 Results

Table 4.19 (overleaf) presents the results of the stress calculations for LC-01 to LC-03. The highest stressed beam members for every load case are presented by number. The maximum Von Mises equivalent stress in the respective load cases occurs in the emphasized members. A utilization factor is calculated on basis of the allowable stress (section 4.2.12.1). Figure 4.6 (overleaf) shows the relevant beam numbers on the element model.

Table 4.19 – STAAD.Pro results, Von Mises equivalent stresses

LOAD CASE	HIGHEST STRESSED BEAM NUMBER(S)	MAXIMUM VON MISES STRESS [MPa]	ALLOWABLE STRESS [MPa]	UTILIZATION FACTOR
LC-01	44, 45, 105, **106**, 122, **123**	165.1	309	0.53
LC-02	44, 45, 105, **106**, 122, **123**	97.2	309	0.31
LC-03	**75**, **76**, 112, 118	36.8	309	0.12

Table 4.20 presents the results of the deflection calculations for LC-01 to LC-03. The highest deflected beam members for every load case are presented by number. The maximum deflection in the respective load case occurs on the emphasized member(s). The allowable deflections are calculated by formula given in Table 4.11. A utilization factor is calculated on basis of the allowable deflection.

Table 4.20 – STAAD.Pro results, beam deflection

LOAD CASE	HIGHEST DEFLECTED BEAM NUMBER(S)	MAXIMUM DEFLECTION [mm]	ALLOWABLE DEFLECTION [mm]	BEAM LENGTH [mm]	UTILIZATION FACTOR
LC-01	44, 45, **106**, 113, 119, **123**	0.793	8	2400	0.10
LC-02	44, 45, **106**, **123**	0.566	8	2400	0.07
LC-03	**53**, 75, 76, 113, 119	0.347	12.2	3650	0.03

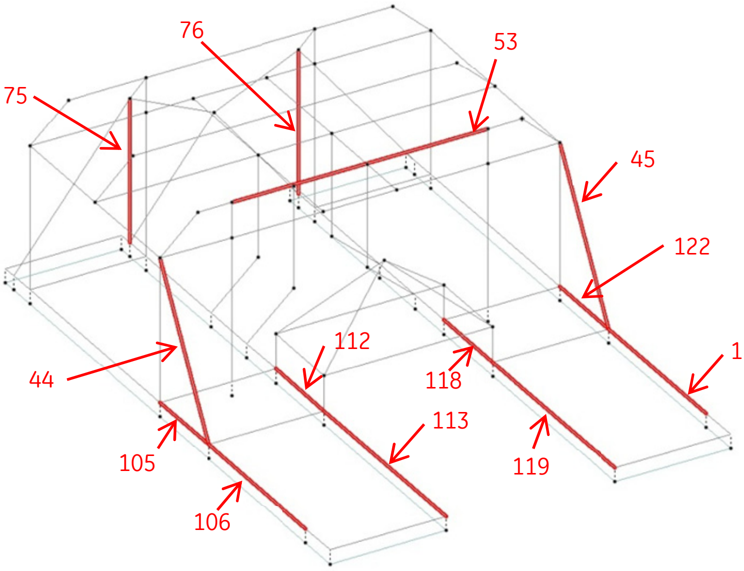


Figure 4.6 – STAAD.Pro element model, beam numbers

4.3.6 Discussion

The purpose of the skid analyses is first of all to observe if the structure has the strength and rigidity to maintain its integrity under applied loads. During installation and operation, the connection system (HCCS) on the Open PLET requires a stiff substructure with a minimum of deflections to ensure a proper (sealed) connection and stable in-place conditions. The tolerances are small, and a hub movement (Porch movement) relative to the opposite hub of just a couple of millimeters in vertical or lateral direction may obstruct the connection.

Highest equivalent stress is obtained in LC-01, during onshore lifting. The maximum UF is 0.53 on beam member 106 and 123. The calculated deflections can be considered very low with a maximum UF of 0.10. Maximum deflection is also obtained in LC-01 on the same beam members.

The skid gravity load (L-01) is in all load cases defined in STAAD.Pro by a given factor. The factor is applied on the element model itself. Consequently, components of the skid which are not a part of the element model in STAAD.Pro, like the ROV handles, the guide-post, the pad-eyes and some plates, are not included. The load factors are intended to compensate for the weight of these “missing” components.

A good margin on the allowable equivalent stress, and very small deflections, verifies that the skid structure is able to maintain its integrity and allows for proper functionality according to the requirements. The results also open the possibility for a redesign in the detail design phase. This conceptual design of the skid comprises a relatively complex framework of large beam members. A redesign should include optimization of the framework by reducing the number of beam members, reconfiguration of the framework and reducing the size of the members.

4.4 PORCH ANALYSES

The Porch analyses are accomplished by using the FEM software ANSYS Workbench (v.13). The finite element model (FE model) in the analyses is generated by importing (to ANSYS WB) the 3D model from ProEngineer. The transmittal file is a “.stp” file.

The methodology for the analyses is linear-elastic, and non-linear material properties are therefore not defined. If the equivalent stress in some regions is above yield stress it may be related to issues like stress singularities, contact stresses or stress concentrations. If such occurs is the analyses, the issue will only be pointed out.

The mechanical lock assembly is part of the Porch assembly in the analyses. The lock-collars and collar-bolts are required in the FE model for right distribution of forces from the pipeline end termination into the Porch structure.

The goal for the analyses is the global response of the Porch (global stresses) under applied loads. The results in small regions like holes, contact points, edges and corners are of no particular interest in this phase (conceptual design).

The results for LC-04 to LC-07 are presented in a summary in section 4.4.7.

4.4.1 Porch overview

This is a detailed presentation of the Porch assembly which will act as a reference for descriptions in the analyses. Right hand side of the Porch is defined when looking directly at the front of the Porch.

The Porch assembly includes the Porch anchors which are used for mounting the Porch onto the skid. These anchor brackets will be the fixed support in the analyses. A cylinder segment is also included to simulate the HCCS connection tool. The pipeline end termination is represented with the alignment sleeve only. The sleeve is the interface between the end termination and the Porch, and the only end termination component required in this assembly.

Figure 4.7 shows the Porch assembly used in LC-04 to LC-07. Table 4.21 (overleaf) presents the names of relevant members with reference to the figure.

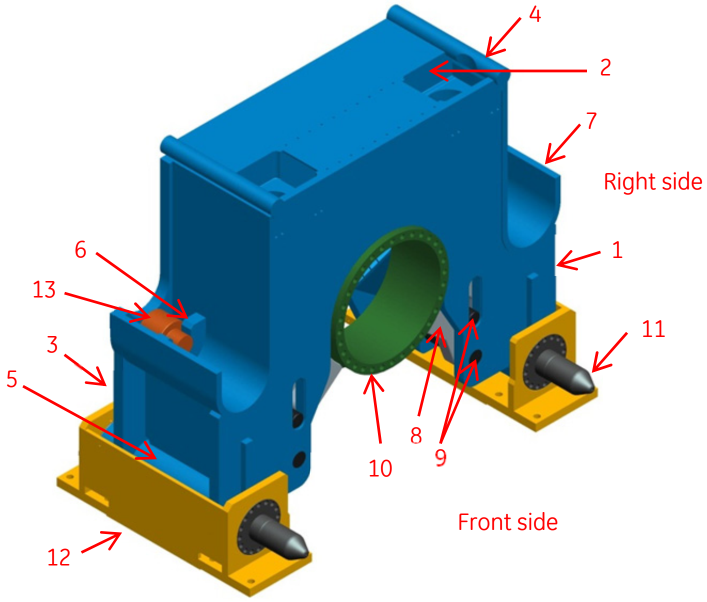


Figure 4.7 – Porch overview

Table 4.21 – Porch members

MEMBER NO.	MEMBER DESCRIPTION
1	Front member
2	Center member
3	Back member
4	Upper alignment member
5	Lower alignment member
6	Cylinder pull member
7	Cylinder cradle
8	Lock-collar
9	Collar-bolt
10	Alignment sleeve
11	Guide-spear
12	Porch anchor
13	HCCS connection tool cylinder

4.4.2 Finite Element model

Several of the plates on the FE model are reduced to shells (2D members) instead of solids (3D members). This is done to reduce the number of nodes and elements in the FE model. Figure 4.8 shows the meshed FE model with the axes referred to in LC-04 to LC-07.

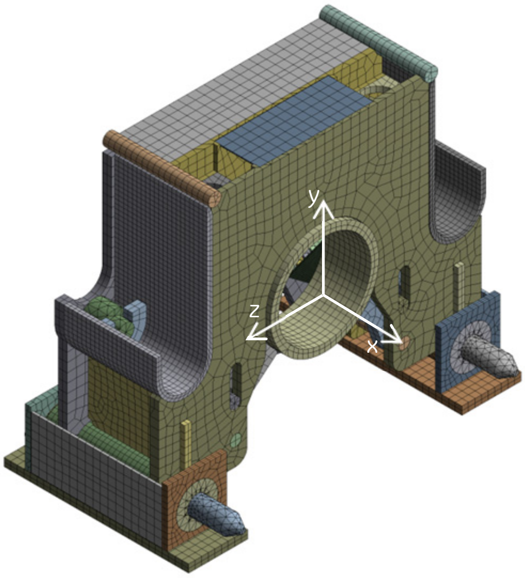


Figure 4.8 – FE model of Porch

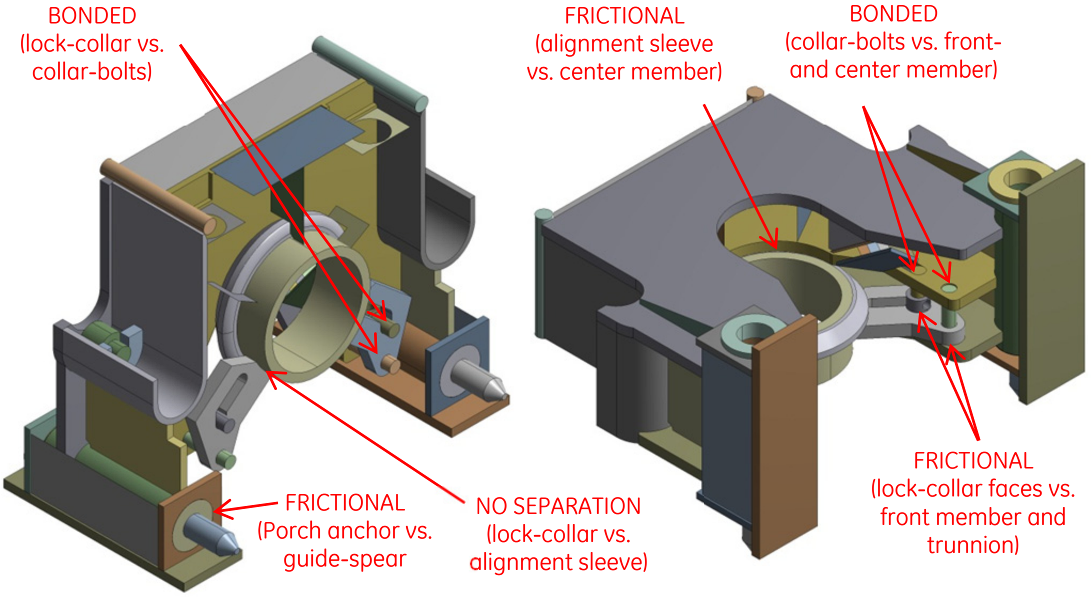
4.4.2.1 Mesh

To reduce the number of elements in the FE model, bolt holes, chamfers and rounded edges not required are removed. This might reduce the accuracy of the local results in the particular region, but it is done as the goal for the analyses is the global stresses and not local stresses at holes, corners and edges.

The mesh is generated by ANSYS WB on pre-defined input regarding element size. The 2D shell members have just one element in thickness, while all solid members (3D members) must have at least two elements in at least two directions to achieve a reliable solution.

4.4.2.2 Contacts

All contacts on the assembly that are similar to a welded or bolted connection are defined as “bonded contact.” Figure 4.9 shows the FE model with some significant contacts.



**Front member hidden for visual access*

Figure 4.9 – FE model, contacts

The alignment sleeve is defined with a “frictional contact” towards the face of the center member. The friction coefficient is set to 0.01 allowing for nearly free movement along the contact face. The movement in vertical direction is especially important for proper distribution of gravity loads from the pipeline end termination. Frictional contact with a small coefficient is chosen instead of frictionless contact, because it simulates better the reality (no contacts are totally frictionless), and the FE model also converges better with that choice. A "no separation contact" is defined towards the lock-collars. This contact is similar to bonded contact, but allows for frictionless sliding along the contact faces.

The contact between the lower alignment member and the Porch anchor – with sliding interface (guide-spear side) – is defined with frictional contact with a friction coefficient of 0.01.

The contacts between the lock-collar and the collar-bolts are defined as bonded contacts. Even though these contacts in reality can be considered frictional, and allow for free rotation, the bonded contact is set to achieve convergence easier. The bonded contact is also defined between the collar-bolts and the front and center member, even though these contacts as well, in reality can be considered frictional. This will lead to less accurate results in the contact regions, and will influence the global results. It affects the stress distribution in the relevant components, and it may conceal overstressed regions. However, these concerns are considered to not have a major influence on the concept solution. Consequently, this type of contact definition is evaluated to be ok.

The face boundaries between the lock-collar and front member, and lock-collar and upper collar-bolt, are defined with frictional contact and a friction coefficient of 0.01.

4.4.3 LC-04: Spool connection, spool pull-in

The load case simulates the Porch during pull-in of the spool termination. The load case situation occurs when the spool termination has entered the guide-spears on the Porch, but before full hub contact is achieved. All weight of the spool termination is then applied to the guide spears. The pipeline end termination is locked in the Porch. The connection tool cylinders have full pull-force applied. Figure 4.10 (overleaf) shows the setup for LC-04.

4.4.3.1 Loads and supports

Table 4.22 (overleaf) shows the applied loads for this load case. The load factor $\gamma_{LC\text{-}04}$ = 1.37 (section 4.2.10) multiplied with the loads defined in Table 4.4 gives the applied values.

The gravity load of the pipeline end termination (L-05) is distributed 50% on MAS and 50% on RAS. This is an approximate distribution based on the Open PLET design only. Consequently, 50% of L-05 is used in this load case. This way of applying L-05 will also be applicable for the load cases LC-05 to LC-07.

Table 4.22 – Loads applied for LC-04

LOAD NO.	LOAD DESCRIPTION	APPLIED VALUE	COMMENTS
L-05	Gravity load pipeline termination (submerged)	240kN	50% of L-05 used in this load case
L-06	Gravity load spool termination (submerged)	199kN	Applied on guide-spears
L-10	HCCS connection tool, hydraulic cylinder pull-force	1770kN	

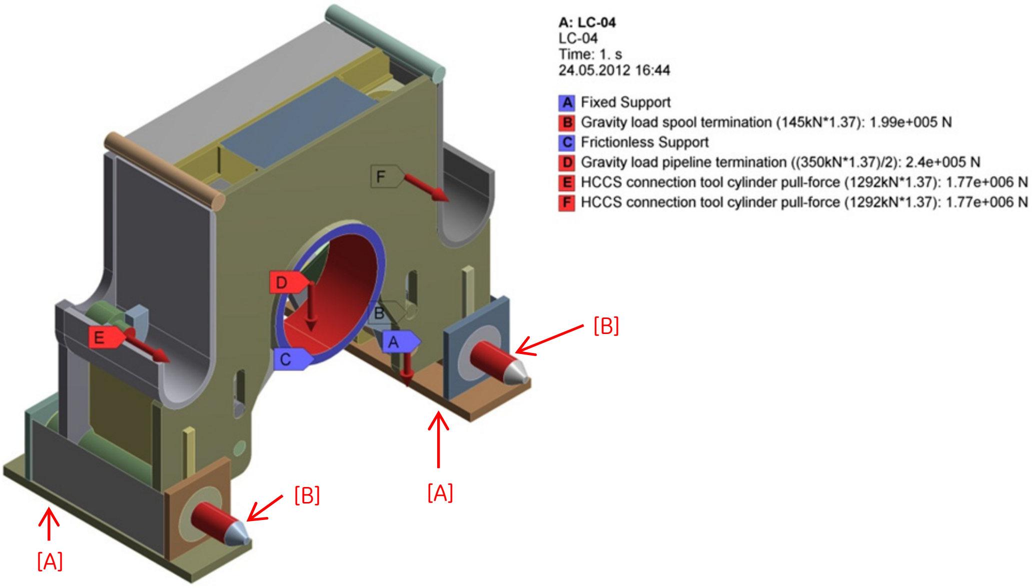


Figure 4.10 – LC-04, loads and supports

The Porch anchors are fixed on the bottom. A frictionless support is applied on the alignment sleeve to prevent movements in axial direction (x-direction). This simulates the fact that the pipeline end termination in reality is fixed in axial direction due to the friction between the pipeline and seabed. In this load case it is assumed that both lower alignment members participates in the alignment of the spool (ref. allowable deflections, section 4.2.12.2).

4.4.3.2 Results

Figure 4.11 shows the Von Mises equivalent stress distribution on the Porch assembly for LC-04. Red colored areas have stresses above 309MPa (section 4.2.12.1).

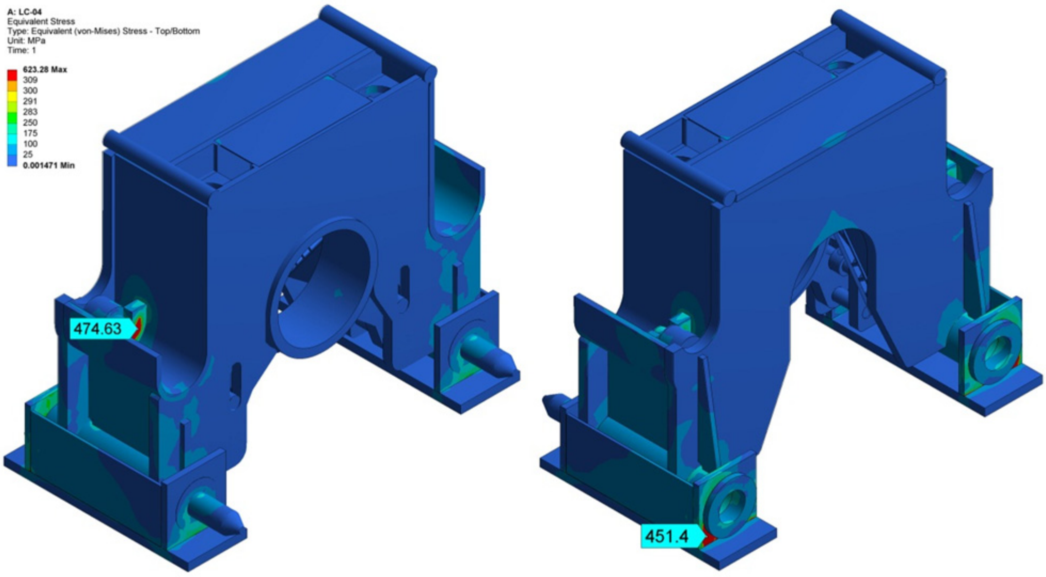


Figure 4.11 – LC-04, Von Mises equivalent stress distribution

The cylinder pull members (thickness 80mm) and a plate on both the Porch anchors (thickness 50mm) have red colored areas. The actual stresses are respectively about 475MPa and 450MPa, while the allowable stresses of these members are respectively 283MPa and 291MPa. Except from these members, the complete assembly have equivalent stresses below the allowable levels.

The legend on Figure 4.11 shows a maximum equivalent stress of 623MPa. This maximum stress is located at the contact boundary between the HCCS connection tool cylinder and cylinder pull member and may be a contact stress issue.

Figure 4.12 (overleaf) shows the total deformation distribution on the Porch assembly for LC-04.

The lower alignment members have an axial (x-direction) deflection of about 2.2mm. The allowable deflection is 4.7mm (section 4.2.12.2). Maximum deflection is on the top of the Porch (yellow area) with an axial deflection of about 5.8mm.

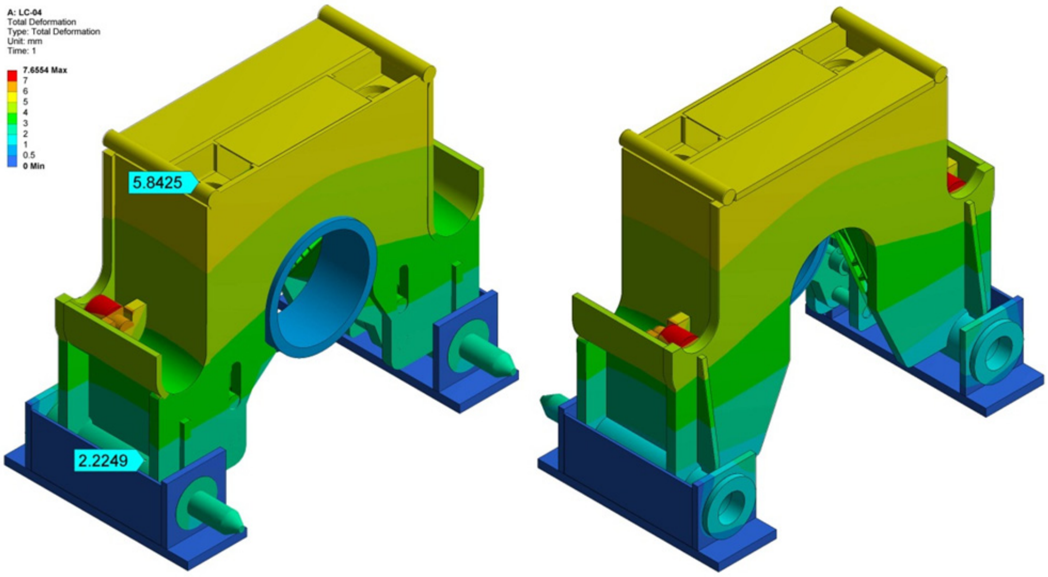


Figure 4.12 – LC-04, total deformation

4.4.4 LC-05: Spool connection, full hub contact

This load case simulates the Porch during pull-in of the spool termination. The load case situation occurs just after the clamp connector is closed, and all weight of spool termination is transmitted to the Porch by the connection. Spool termination is no longer in contact with the guide-spears. The connection tool cylinders still have full pull-force applied. Figure 4.13 (overleaf) shows the setup for LC-05.

4.4.4.1 Loads

Table 4.23 shows the applied loads for this load case. The load factor $\gamma_{LC\text{-}05} = 1.37$ (section 4.2.10) multiplied with the loads defined in Table 4.4 gives the applied values.

Table 4.23 – Loads applied for LC-05

LOAD NO.	LOAD DESCRIPTION	APPLIED VALUE	COMMENTS
L-05	Gravity load pipeline termination (submerged)	240kN	50% of L-05 used in this load case
L-06	Gravity load spool termination (submerged)	199kN	Applied on alignment sleeve inner walls
L-10	HCCS connection tool, hydraulic cylinder pull-force	1770kN	

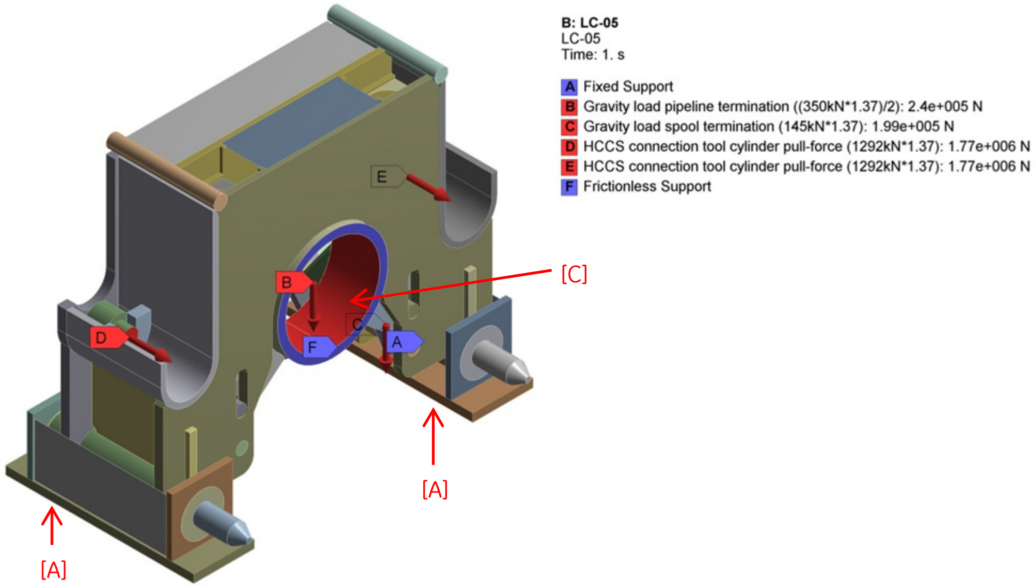


Figure 4.13 – LC-05, loads and supports

The Porch anchors are fixed on the bottom. The full hub contact is simulated by a frictionless support applied to the alignment sleeve (same support as in LC-04). The main difference from LC-04 is the application of the gravity load from the spool termination, which in this load case is applied on the alignment sleeve. In this load case it is assumed that both lower alignment members participates in the alignment of the spool (ref. allowable deflections, section 4.2.12.2).

4.4.4.2 Results

Figure 4.14 shows the Von Mises equivalent stress distribution on the Porch assembly for LC-05. Red colored areas have stresses above 309MPa (section 4.2.12.1).

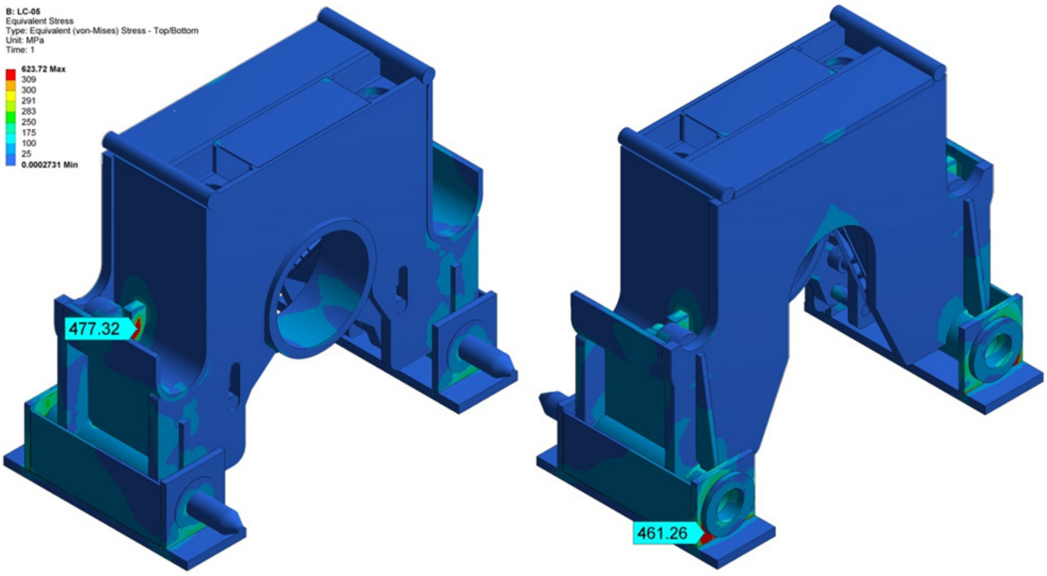


Figure 4.14 – LC-05, Von Mises equivalent stress distribution

The cylinder pull members (thickness 80mm) and a plate on both the Porch anchors (thickness 50mm) have red colored areas. The actual stresses are respectively about 475MPa and 460MPa, while the allowable stresses on these members are respectively 283MPa and 291MPa. Except from these areas, the complete assembly have equivalent stresses below the allowable levels.

The legend on Figure 4.14 shows a maximum equivalent stress of 624MPa. This maximum stress is located at the contact boundary between the HCCS connection tool cylinder and cylinder pull member, and may be a contact stress issue.

Figure 4.15 shows the total deformation distribution on the Porch assembly for LC-05.

The lower alignment members have an axial (x-direction) deflection of about 2.2mm. The allowable deflection is 4.7mm (section 4.2.12.2). Maximum deflection is on the top of the Porch (yellow area) with an axial deflection of 5.9mm.

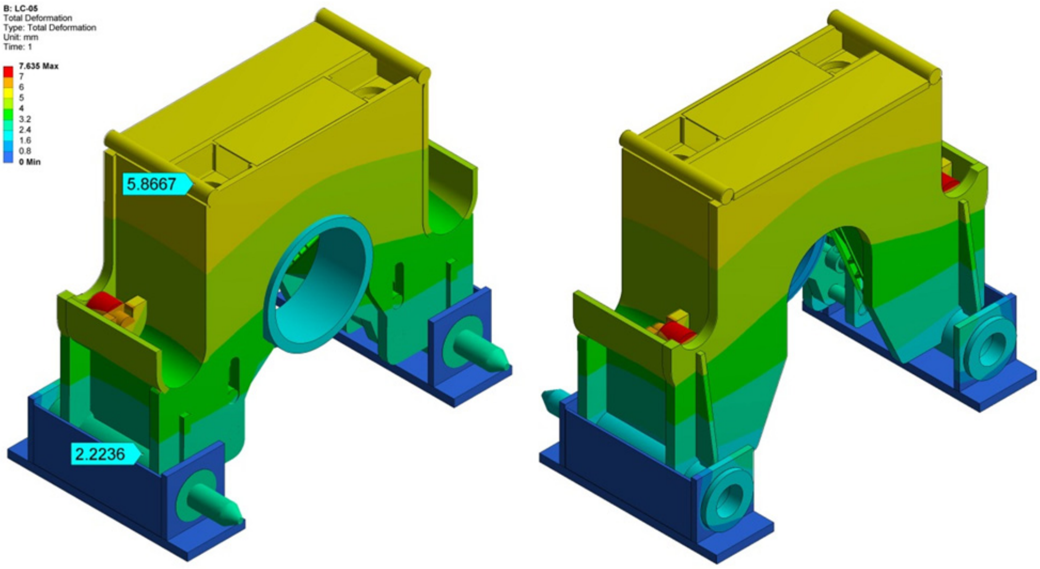


Figure 4.15 – LC-05, total deformation

4.4.5 LC-06: Spool connection, single upper alignment member contact

This load case simulates the Porch during pull-in of the spool termination. It is possible that the spool termination during pull-in will approach the Porch in an angled position with respect to the Porch. This load case simulates a scenario when the spool termination is angled with respect to the yz-plane (rotation about the y-axis and z-axis). This angled position leads to a situation where just one of the upper alignment members is in contact with the spool termination, and consequently all pull-in forces are transmitted through this alignment member during final alignment of the spool termination towards the Porch. This is defined as a worst-case scenario [8]. Figure 4.16 shows the setup for LC-06.

4.4.5.1 Loads

Table 4.24 shows the applied loads for this load case. The load factor $\gamma_{LC\text{-}06} = 1.37$ (section 4.2.10) multiplied with the loads defined in Table 4.4 gives the applied values.

Table 4.24 – Loads applied for LC-06

LOAD NO.	LOAD DESCRIPTION	APPLIED VALUE	COMMENTS
L-05	Gravity load pipeline termination (submerged)	240kN	50% of L-05 used in this load case
L-06	Gravity load spool termination (submerged)	199kN	Applied on guide-spears
L-10	HCCS connection tool, hydraulic cylinder pull-force	1770kN	

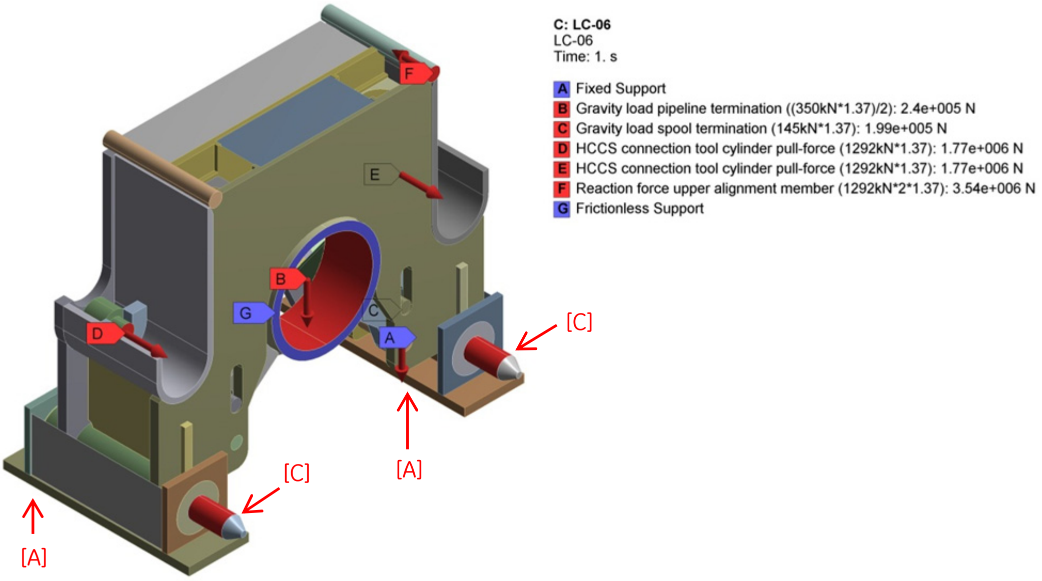


Figure 4.16 – LC-06, loads and supports

The Porch anchors are fixed on the bottom. A frictionless support is applied on the alignment sleeve to prevent movements in axial direction (similar to LC-04). A reaction force is applied to the upper right alignment member to simulate the spool termination single point of contact. The force size is the negative sum of the two HCCS connection tool cylinder pull-forces, 1292kN x 2 x 1.37 = 3540kN. In this load case only one of the upper alignment members participates in the alignment of the spool. This is considered a worste-case scenario (ref. allowable deflections, section 4.2.12.2).

4.4.5.2 Results

Figure 4.17 shows the Von Mises equivalent stress distribution on the Porch assembly for LC-06. Red colored areas have stresses above 309MPa (section 4.2.12.1).

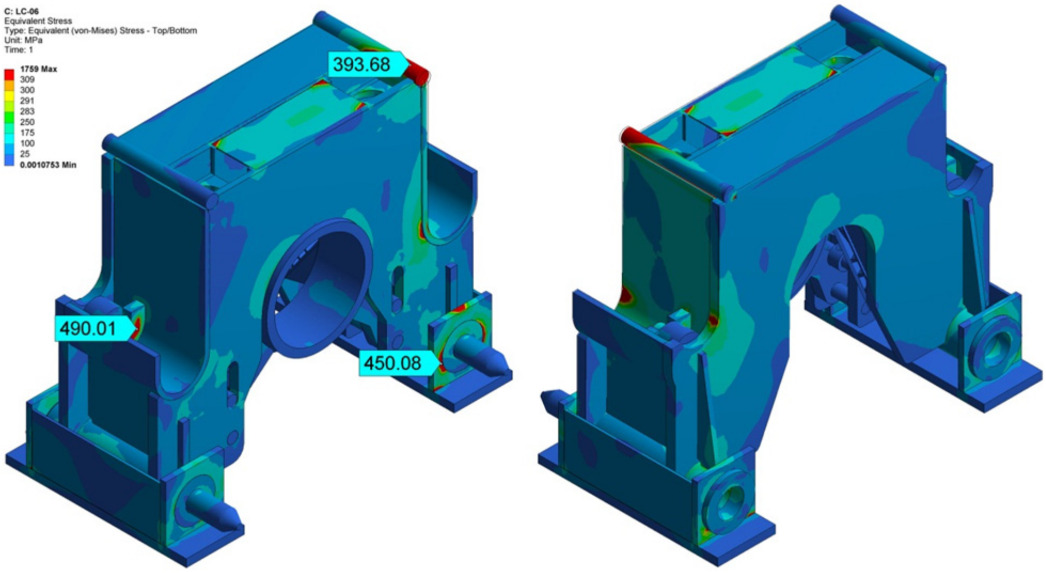


Figure 4.17 – LC-06, Von Mises equivalent stress distribution

The cylinder pull members (thickness 80mm), a plate on the Porch anchor (thickness 50mm) and the upper right alignment member (diameter 50mm) have red colored areas. The actual stresses on these members are respectively about 490MPa, 450MPa and 390MPa, while the allowable stresses on these members are respectively 283MPa, 291MPa and 291MPa. In addition, several small regions also have equivalent stresses above 309MPa. Except from these areas, the complete assembly have equivalent stresses below the allowable levels.

The legend on Figure 4.17 shows a maximum equivalent stress on 1759MPa. This maximum stress is located on the edge at the end of the high stressed upper alignment member (edge of contact face for applied load), and may be a stress singularity issue or a stress concentration issue.

Figure 4.18 (overleaf) shows the total deformation distribution on the Porch assembly for LC-06.

The upper right alignment member has an axial (x-direction) deflection of about 15.5mm. The allowable deflection is 7mm (section 4.2.12.2). The whole upper right side corner section of the Porch assembly has a relatively large deflection.

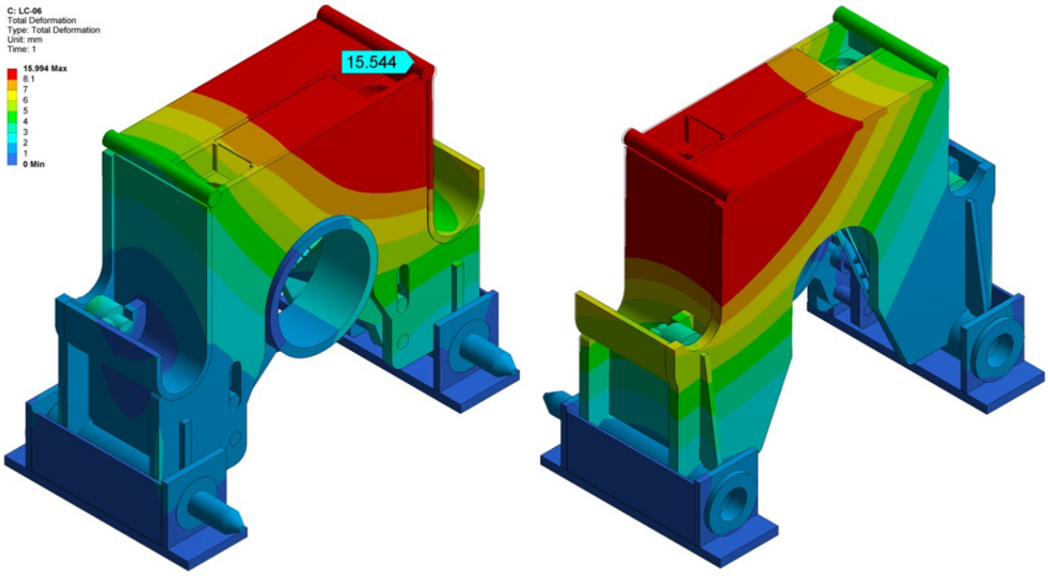


Figure 4.18 – LC-06, total deformation

4.4.6 LC-07: In-place, moment 45° from z-axis (lateral axis)

This load case simulates the Porch after completion of the spool connection. The load case simulates forces applied on the Porch from the spool termination during in-place operation. The loads from the spool termination come from the weight of the spool, thermal expansion of the spool pipe and vibrations and movements due to fluid flow. This load case includes a defined maximum moment load applied on the pipeline end termination hub 45° from the lateral z-axis. Figure 4.19 (overleaf) shows the setup for LC-07.

4.4.6.1 Loads and supports

Table 4.25 shows the applied loads for this load case. The load factor $\gamma_{LC\text{-}07}$ = 1.37 (section 4.2.10) multiplied with the loads defined in Table 4.4 gives the applied values.

Table 4.25 – Loads applied for LC-07

LOAD NO.	LOAD DESCRIPTION	APPLIED VALUE	COMMENTS
L-05	Gravity load pipeline termination (submerged)	240kN	50% of L-05 used in this load case
L-07	Axial load capacity	551kN	Applied on alignment sleeve face
L-08	Lateral load capacity	562kN	Applied on alignment sleeve inner walls
L-09	Moment load capacity	4542kNm	Applied 45° from z-axis

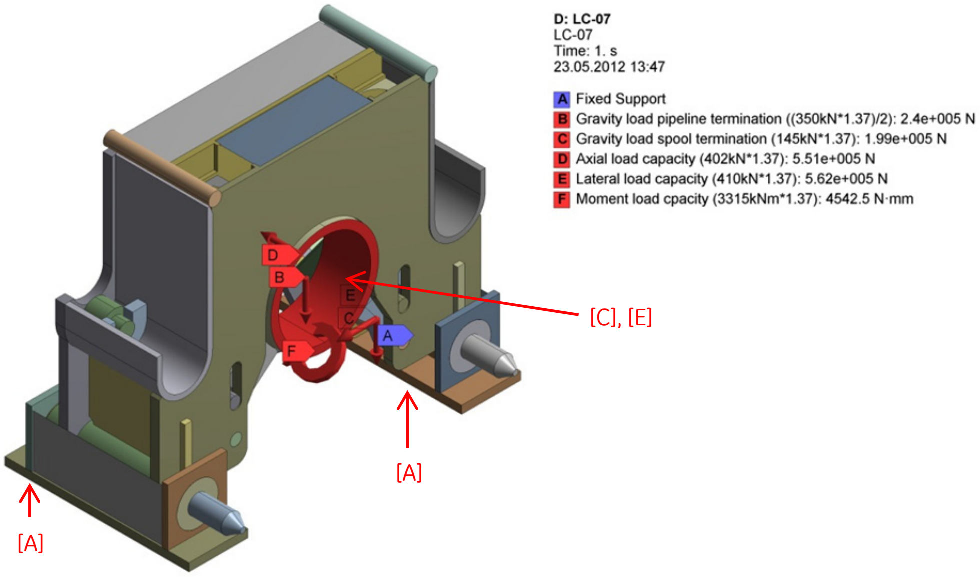


Figure 4.19 – LC-07, loads and supports

With reference to section 2.5, the Porch on this Open PLET system is a HCCS-30. The load values in Table 4.4 are taken from GE Oil & Gas documentation [8] concerning this particular Porch size. These loads are considered as the maximum loads that the Porch will be exposed to from the spool termination in an in-place situation.

The Porch anchors are fixed on the bottom. The loads L-08 and L-09 are in reality applied on the pipeline end termination hub. To simulate this situation, the loads on the FE model are applied on the face and the inside walls of the alignment sleeve. The moment load L-10 is also in reality applied to the pipeline end termination hub. In the FE model this load is applied on the face of the alignment sleeve. In this load case it is likely to assume that both lower alignment members participates in the alignment of the spool (ref. allowable deflections, section 4.2.12.2).

4.4.6.2 Results

Figure 4.20 shows the Von Mises equivalent stress distribution on the Porch assembly for LC-07. Red colored areas have stresses above 309MPa (section 4.2.12.1).

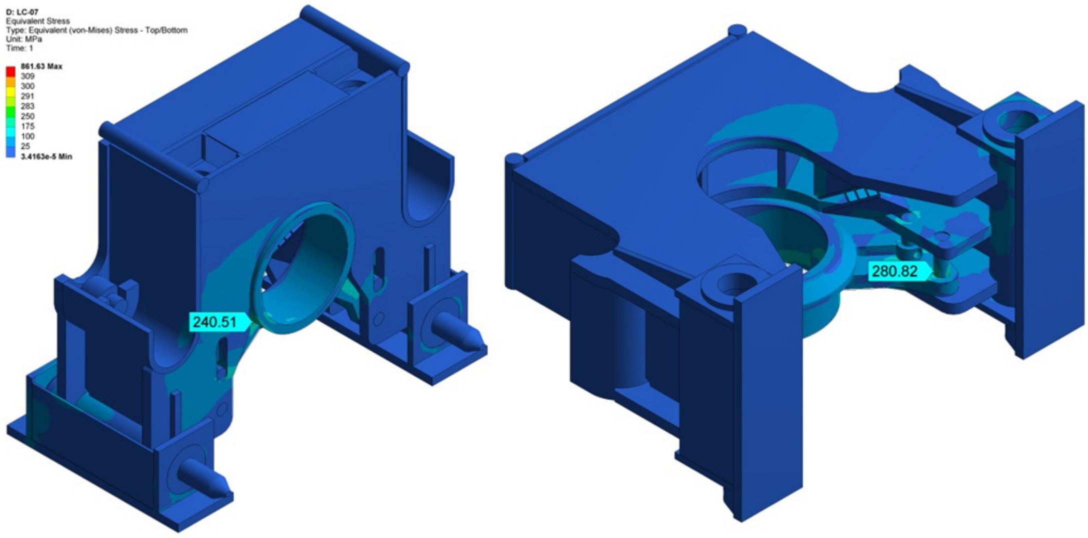


Figure 4.20 – LC-07, Von Mises equivalent stress distribution

The highest equivalent stress is achieved on the lock-collar and lower collar-bolt on the left side of the Porch. The maximum value is close to 280MPa on the surface of the collar-bolt. The equivalent stress on the lock-collar, positioned close to contact surface towards alignment sleeve, is about 240MPa. The allowable stress for these components is 274MPa. The complete assembly have equivalent stresses below the allowable level.

The legend on Figure 4.20 shows a maximum equivalent stress of 862MPa. This maximum stress is located at a corner of the plate called "sliding face" (section 3.6.3), and may be a stress singularity issue.

Figure 4.21 (overleaf) shows the total deformation distribution on the Porch assembly for LC-07.

The lock-collar (left side) has an axial (x-direction) deflection of about 5.8mm. That is the maximum deflection on the Porch (alignment sleeve has higher deflections, but it is not considered a part of the Porch). The lower alignment members have insignificant deflections.

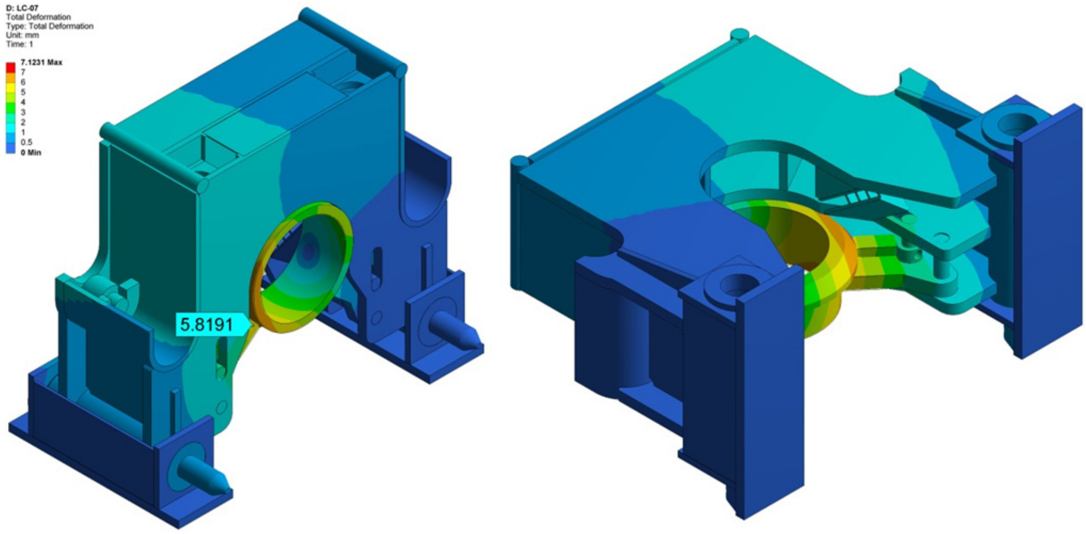


Figure 4.21 – LC-07, total deformation

4.4.7 Results

Table 4.26 presents the results of the equivalent stress calculations for LC-04 to LC-07. The Porch assembly members with the highest stresses are presented with the actual and allowable values. The actual values are found by using the "probe" function in ANSYS WB. A utilization factor is calculated on basis of the defined allowable stresses.

Table 4.26 – Porch analyses results, Von Mises equivalent stresses

LOAD CASE NO.	VON MISES EQUIVALENT STRESS			UTILIZATION FACTOR
	ACTUAL [MPa]	ALLOWABLE [MPa]	MEMBER	
LC-04	475	283	Pull-in members	1.67
	450	291	Porch anchors	1.54
LC-05	475	283	Pull-in members	1.67
	460	291	Porch anchors	1.58
LC-06	490	283	Pull-in members	1.73
	450	291	Porch anchor	1.54
	390	291	Upper alignment member (right side)	1.34
LC-07	281	274	Collar-bolt (lower)	1.03
	240	274	Lock-collar (left side)	0.88

Table 4.27 (overleaf) presents the results of the total deflection calculations for LC-04 to LC-07. The highest deflected Porch assembly members are presented with the actual and allowable values. A utilization factor is calculated on basis of the defined allowable deformations.

Table 4.27 – Porch analyses results, total deformation

LOAD CASE NO.	TOTAL DEFORMATION			UTILIZATION FACTOR
	ACTUAL [mm]	ALLOWABLE [mm]	MEMBER	
LC-04	2.2	4.7	Lower alignment members	0.47
	5.8	-	Upper alignment members	-
LC-05	2.2	4.7	Lower alignment members	0.47
	5.9	-	Upper alignment members	-
LC-06	15.5	7	Upper alignment member (right side)	2.21
LC-07	5.8	-	Lock-collar (left side)	-

4.4.8 Discussion

To ensure a proper spool connection, the structural strength of the Porch is extremely important. Only small deflections are allowed for, even under heavy loading, due to the tolerance requirements of the HCCS (section 2.5). The Porch is also the point for locking the pipeline end termination to the Open PLET, and consequently the Porch has to maintain its integrity when subjected to large weight loads.

LC-07 gives a result where only the collar-bolt has equivalent stress above allowable level. For LC-04 and LC-05, the pull members and the Porch anchors are not accepted. For LC-06, an upper alignment member is not accepted, in addition to the pull members and the Porch anchors. For LC-04, LC-05 and LC-07, all deflections are considered acceptable. For LC-06, a large deflection on the upper alignment member is not acceptable.

With respect to the results of the equivalent stress calculations, it is clearly that the pull members and the Porch anchors should be members of concern. In the load cases where full pull-force from connection tool is applied (LC-04 to LC-06) they are subjected to stresses above material yield level (355MPa).

For the Porch anchor, the regions of unaccepted stresses are relatively small and are located close to a contact boundary. By including all chamfers and rounds in the FE model, refine the mesh in the high stress regions, and increase the plate thickness, these issues may be dealt with.

The high stressed regions of the pull members cover roughly 50% of the members. By increasing the thickness of the member, the problem might solve. A redesign of the Porch, with reconfiguration of members for better distribution of the pull-forces, may be an additional or another solution.

The LC-06 simulates a worst-case scenario, and the upper alignment member is subjected to large forces. The equivalent stress and the total deformation of the member are above allowable levels. The whole Porch structure undergoes a large deflection in this load case. To deal with this issue, an optimization of the Porch assembly is probably required to increase the stiffness. Additional members, better configuration of members and increased plate thicknesses may be the options.

The input to these FEM analyses, like the mesh size, definition of contacts, and the way of application of loads and supports influences the results. Especially, if other types of contacts were defined to some of the significant boundaries, the results may have been different. With respect to section 4.4.2.2 and Figure 4.9, the following changes could have been considered:

- The bonded contacts between the lock-collar and the collar-bolts changed to “frictional.”
- The bonded contacts between the collar-bolts and the front- and center member changed to “frictional.”
- The no separation contact between the lock-collar and the alignment sleeve changed to “frictional.”

The above mentioned changes would presumably give another and more realistic results. However, as mentioned in section 4.4.2.2, the chosen contacts are intended to simplify the FE model to achieve solution convergence more easily. By applying the above mentioned changes, the FE model would require a more skilled setup to achieve a solution, a type of setup applicable in a detail design phase.

In the detail design phase of the Open PLET, an optimization of the Porch is required to deal with some high stressed regions, and members with unaccepted deflections. The optimization should presumably include reconfiguration of members, adding some members and increase the thickness of some members. A material review may also be worth considering to increasing the material strength on exposed members.

Despite some issues, the global response of the Porch reflected in the analyses verifies the conceptual design with respect to the technical solutions. The design of the Porch is considered to support the Open PLET concept solution.

4.5 MECHANICAL LOCK ASSEMBLY ANALYSIS

According to section 4.1.3, the lock-collars and collar-bolts of the mechanical lock assembly are the most critical components as they undergo heavy loading.

This section covers a shear stress calculation of the collar-bolts to verify the integrity under applied loads.

4.5.1 LC-08: Collar-bolt shear calculation

The loads applied on the lock-collars create shear stresses in the collar-bolts. This load case concerns how the collar-bolt reacts under application of the shear loads.

4.5.1.1 Loads

Table 4.28 shows the applied loads for this load case. The load factor $\gamma_{LC\text{-}08} = 1.37$ (section 4.2.10) multiplied with the loads defined in Table 4.4 gives the applied values.

Table 4.28 – Loads applied for LC-08

LOAD NO.	LOAD DESCRIPTION	APPLIED VALUE	COMMENTS
L-05	Gravity load pipeline termination	240kN	50% of L-05 used in this load case
L-06	Gravity load spool termination	199kN	Applied on alignment sleeve

The design shear load (V) used in the calculation is calculated on basis of loads L-05 and L-06. The calculation can be found in appendix A5.

4.5.1.2 Results

Table 4.29 shows the properties for the calculation.

Table 4.29 – LC-08 properties

DESCRIPTION	DATA
Collar-bolt diameter [D]	100mm
Allowable stress [σ_{all}]	274MPa
Shear load [V]	467kN

Collar-bolt cross section is given by:

$$A = \frac{\pi D^4}{4} = \frac{\pi \times (100\text{mm})^4}{4} = 7854\text{mm}^2$$

Collar-bolt shear area is twice the cross section, because the contact face towards the lock-collar has two edges. The actual shear stress is then given by:

$$\tau = \frac{V}{2A_s} = \frac{467000\mathrm{N}}{2 \times 7854\mathrm{mm}^2} = 29.7\mathrm{MPa}$$

Allowable shear stress (τ_{all}) is calculated from the formula given in section 4.2.12.1:

$$\tau_{all} = \frac{\sigma_{all}}{\sqrt{3}} = \frac{274\mathrm{MPa}}{\sqrt{3}} = 158.2\mathrm{MPa}$$

Collar-bolt shear stress calculation result:

$$\tau = 29.7\mathrm{MPa} < \tau_{all} = 158.2\mathrm{MPa} \rightarrow \mathrm{OK}$$

Utilization factor on collar-bolts:

$$\mathrm{UF} = \frac{\tau}{\tau_{all}} = \frac{29.7\mathrm{MPa}}{158.2\mathrm{MPa}} = 0.18$$

4.5.2 Discussion

Due to the applied contacts on the FE model (section 4.4.2.2), the results of the analysis in LC-04 to LC-07 is not reliable with respect to the lock-collar and collar-bolts. This is due to the bonded contact in the interface between the two. However, the results to a great extent indicate that both the lock-collar and the collar-bolts provide the structural strength required.

The shear stress calculation of the collar-bolt strengthened the case of a reliable design. The calculated shear stress was below the allowable shear stress, and it was demonstrated with a calculated utilization factor of 0.18. The collar-bolts are using less than 20% of their capacity.

The results make it possible for a redesign in the detail design phase. The diameter of the collar-bolts may be reduced as well as the thickness of the lock-collar. Both components may also be of a different material.

4.6 OPEN PLET ANALYSIS

4.6.1 LC-09: Axial alignment during installation

When installing the pipeline end termination into the Porch, an axial alignment of the Open PLET is required to integrate the end termination properly. The technical solution for this is that, when lifted from seabed into the Porch, the end termination has an interface towards the Porch, which facilitates for axial alignment by forcing the Open PLET to slide slightly on the seabed.

The load case deals with the axial alignment ability (ability to slide on the seabed) for the Open PLET with respect to some defined variables. Relevant figures and calculations are found on the calculation sheet in appendix A6 in this report.

4.6.1.1 Loads

Table 4.30 shows the applied loads for this load case. The load factor $\gamma_{LC\text{-}09}$ = 1.0 (section 4.2.10) multiplied with the loads defined in Table 4.4 gives the applied values. The load factor of 1.0 is used, because the purpose is to verify the relation between forces rather than verify the strength of the components.

Table 4.30 – Loads applied for LC-09

LOAD NO.	LOAD DESCRIPTION	APPLIED VALUE	COMMENTS
L-02	Gravity load skid (submerged)	186kN	
L-04	Gravity load Porch (submerged)	97kN	

4.6.1.2 Results

With respect to Figure 4.23 (overleaf), the total weight of the Open PLET (G) is (imaginary) applied to the CoG. The weight is then distributed to the Porch interface towards the pipeline end termination (point A) and the skid rear end interface towards the seabed (point B). The position of the CoG gives that 74% of the total weight is distributed to the Porch interface (G_A), and 26% to the skid rear end interface (G_B).

When referring to a weight distribution in this section, the percentage reflects how much of the total weight is applied at point A.

The Porch interface (ref. sliding face, section 3.6.3) is a 36° angled steel plate which will force the Open PLET to slide compared to the pipeline end termination when the end termination is lifted from the seabed. Figure 4.22 (overleaf) shows this “point A.” The load G_A is 74% of the total weight of the Open PLET, and it is applied on the end termination as the lifted end termination is lifting the Open PLET as well. The load S_A is the load component forcing the Open PLET to slide.

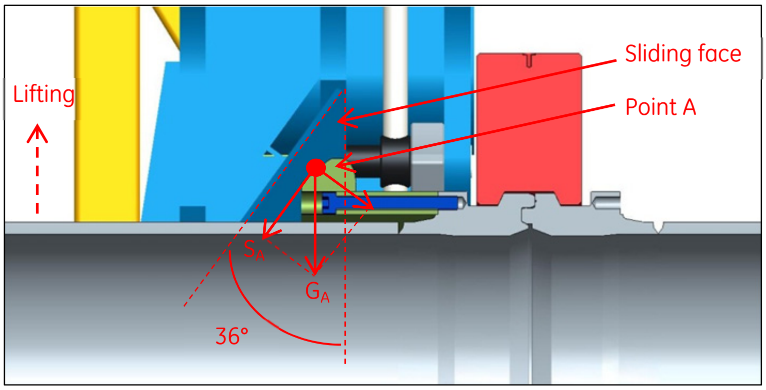


Figure 4.22 – Interface between Porch and pipeline end termination

At point A, a resultant force in axial direction ($F_{X,A}$) will force the Open PLET to slide, and at point B, a resultant force in axial direction ($F_{X,B}$) will prevent the Open PLET from sliding due to friction from seabed.

The total force in axial direction $F_{AXIAL} = F_{X,A} + F_{X,B}$. The Open PLET is assumed to slide if $F_{AXIAL} > 0$.

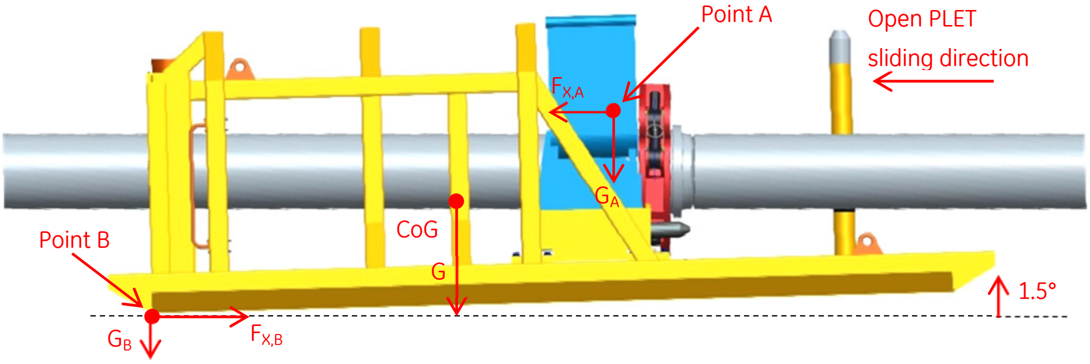


Figure 4.23 – LC-09, Open PLET axial alignment

The maximum lifting angle is found to be 1.5°. This angle is verified on the 3D model in ProEngineer. The limiting factor is the Lay-down Clamp which will collide with the Porch on larger lifting angles. If Open PLET is lifted above 1.5°, the Porch will be kind of squeezed to the pipeline end termination so no sliding occurs.

The sliding face plate is designed with an angle 36° (Figure 4.22) from vertical axis. This is a pre-defined angle. By the calculation sheet (appendix A6), the optimal angle is found. The optimal angle is the one that gives the highest total force (F_{AXIAL}), and the graph on Figure 4.24 shows that the optimal angle is approximately 41°.

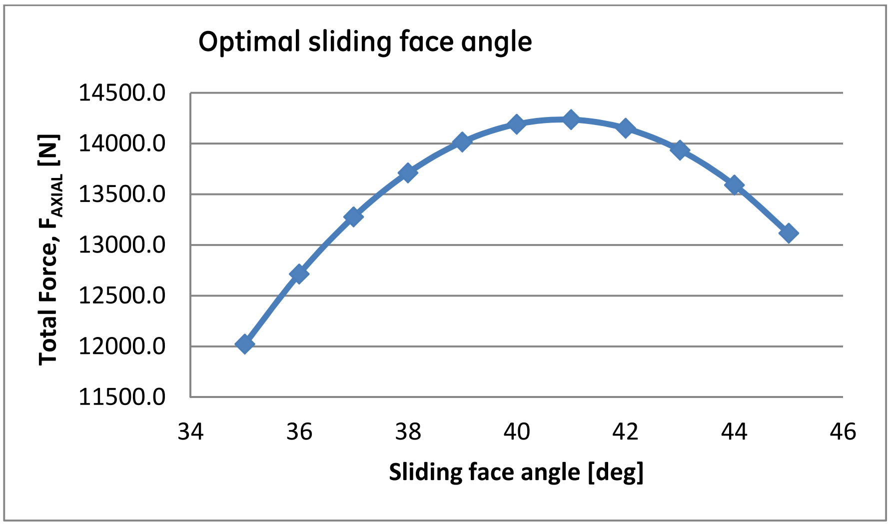


Figure 4.24 – Optimal sliding face angle

There are four variables considered important with respect to axial alignment (sliding) of the Open PLET:

- Lifting angle
- Weight distribution
- Friction coefficient point A
- Friction coefficient point B

Table 4.31 presents how the total force (F_{AXIAL}) changes when varying the above mentioned variables (calculated by varying the input data on the calculation sheet, appendix A6). The intention is to verify the sensitivity of the axial alignment ability with respect to the different variables.

Table 4.31 – LC-09 variables sensitivity

VARIABLE	VARIABLE CHANGE	TOTAL FORCE CHANGE	TOTAL FORCE CHANGE [%]
Lifting angle	1.5° → 0.5°	12714 → 11949	6.0
Weight distribution	74% → 73%	12714 → 8820.6	30.6
Friction coefficient point A	0.20 → 0.21	12714 → 12042.2	5.3
Friction coefficient point B	1.00 → 1.01	12714 → 11978.7	5.8

Figure 4.25 is a graph showing a friction coefficient (μ_{steel}) limit at point A for weight distributions in a range from 65% to 75%. The limit is the maximum coefficient possible for sliding to occur. The lifting angle is constantly at 1.5°, and the friction coefficient at point B (μ_{soil}) is constantly at 1.0.

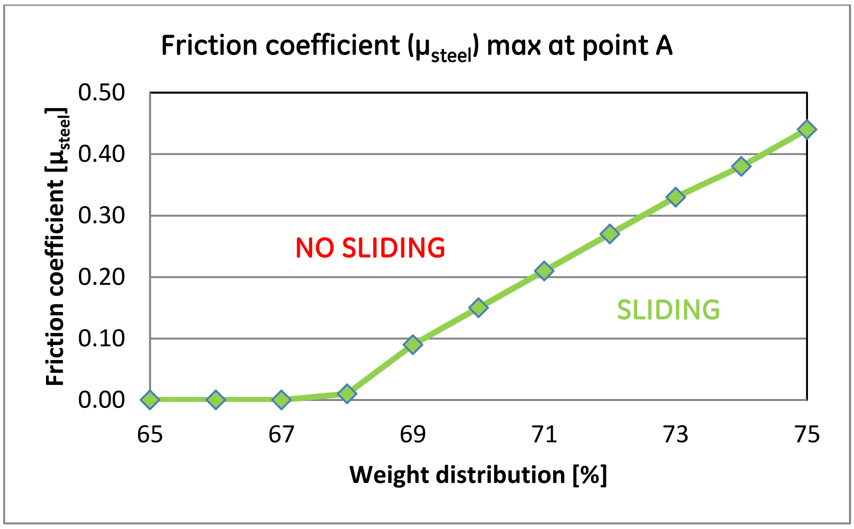


Figure 4.25 – Weight distribution vs. friction coefficient, point A

Figure 4.26 is a graph showing a friction coefficient (μ_{soil}) limit at point B for weight distributions in a range from 50% to 75%. The limit is the maximum coefficient possible for sliding to occur. The lifting angle is constantly at 1.5°, and the friction coefficient at point A (μ_{steel}) is constantly at 0.20.

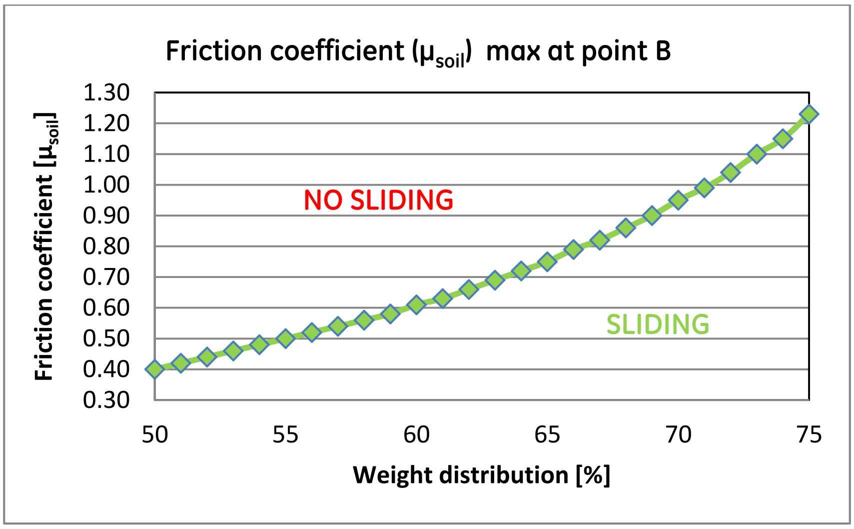


Figure 4.26 – Weight distribution vs. friction coefficient, point B

The graph for point A shows that the weight distribution must be at least 68% at point A to achieve sliding. Below 68% the Open PLET will not slide even though the friction coefficient at point A is zero (frictionless). This indicates that the weight distribution is probably more important than the friction coefficient at point A. With a weight distribution at 74%, this coefficient must be below 0.38 to achieve sliding.

The graph for point B shows that the Open PLET will slide at any weight distribution in the range 50% to 75% if the friction coefficient at point B is below the limit curve. However, at a 50% weight distribution, the maximum friction coefficient possible is $\mu_{soil} = 0.40$, which is a very improbable coefficient at point B (steel – soil friction). This friction coefficient will maybe have a lowest value of 0.90 (anticipated), which requires a weight distribution of at least 68%. With a weight distribution on 74%, this coefficient must be below 1.15 to achieve sliding.

With a 1.5° lifting angle, and the pre-defined friction coefficients (section 4.2.4), the weight distribution must be at least 71% at point A to achieve sliding.

4.6.2 Discussion

The lifting angle is the most predictable variable. It has a maximum limit of 1.5°, and it`s likely to assume that the Open PLET is lifted to this angle whenever installed. The lifting angle naturally affects the ability to achieve sliding (a lifting is required to achieve sliding at all). The lifting range is relatively small (0–1.5°), and the calculations (Table 4.31) show that this variable has a limited influence of the total force in x-direction.

The weight distribution should be calculated on basis of a physical weighing (after fabrication) of the Open PLET to get the most accurate values. The actual distribution is also dependent on the distance from the CoG to the point of attack for the pipeline end termination onto the sliding face on the Porch. This distance can vary approximately 140mm (verified on 3D model), and it causes an uncertainty in the actual weight distribution of 3% (calculated by formula presented on calculation sheet). However, the 74% distribution is a conservative assumption. The calculations (Table 4.31) show that the weight distribution is a sensitive variable with a high influence on the axial alignment ability.

The friction coefficient at point A reflects the steel against steel contact between the Porch and the pipeline end termination. The friction coefficient is relatively easy to predict within a limited range as the steel against steel contact is common in the industry. The calculations show that this variable is of medium influence with respect to the total force and the axial alignment ability.

The friction coefficient at point B reflects the steel against soil contact between the skid rear end and the seabed. The unpredictable condition of the soil (seabed) makes this variable perhaps the most difficult to define. It is common, prior to installation of an Open PLET, to prepare the seabed, often by rock dumping or cementing. Such foundation will make the friction coefficient more predictable. The calculations show that variations in this coefficient, similar to the coefficient at point A, are not as influencing as variations in the weight distribution.

Table 4.32 is a summary of the variables influencing the axial alignment ability of the Open PLET.

Table 4.32 – LC-09 variables summary

VARIABLE	ESTIMATION	INFLUENCE
Lift angle	Easy	Limited influence when varying within the defined lifting angle range.
Weight distribution	Medium	High influence. Small variations in distribution may conflicts the axial alignment ability.
Friction coefficient point A	Medium	Medium influence.
Friction coefficient point B	Hard	Medium influence.

Despite a limited influence on the axial alignment ability, it`s advantageous to be able to increase the lifting angle beyond the maximum of 1.5°. This small lifting angle range may cause the Open PLET to be vulnerable with respect to proper installation if landed on an uneven seabed where obstacles can stop the skid form sliding. The small lifting angle range may also make the actual installation of the Open PLET challenging. The design, as it is now, will require high accuracy in the lifting operation, because an angle above 1.5° will stop the Open PLET from sliding (Porch squeezed to the end termination). A larger lifting angle range will make the operation more reliable and less challenging. A redesign of the Porch is probably the best solution to increase the lifting angle.

The optimal axial alignment ability is achieved with a sliding face angle of 42°. A redesign of the sliding face in a detail design phase is advised.

Of the four variables influencing the sliding of the Open PLET, the most determine is the weight distribution over the system. Sufficient weight must be distributed to the Porch interface (point A). The weight distribution is also the most sensitive of the defined variables. Even small variations (uncertainties) cause significant changes in the total force. Consequently, the weight distribution will be a very important factor to take into account in the detail design of the Open PLET.

The technical solution of axial alignement by sliding on the seabed is one of the most fundamental principles characterizing this Open PLET, and the weight distribution is the most important factor with respect to the integrity of this particular technical solution (section 3.5.4).

5 REVIEW

The conceptual design of the Open PLET is developed on basis of a concept idea invented by GE Oil & Gas. In this thesis, this concept idea was brought into a concept selection phase where the Concept Breakdown Structure listed some technical issues to be solved, the Brainstorm Matrix kept track of generated ideas for technical solutions, and the Decision Matrix was used for selection of the final technical solutions of the concept.

The conceptual design consists of a list of selected and defined technical solutions. Table 5.1 presents a brief summary of these technical solutions.

Table 5.1 – Technical solutions of the conceptual design

TECHNICAL SOLUTION	REF. SECTION	DESCRIPTION
Porch: End termination locking	3.5.1	Lifting of end termination directly to final position in Porch. Vertical active locking of end termination by a locking mechanism.
Skid: Guiding	3.5.2	Guiding means for positioning of the skid over the pipeline end termination. Axial repositioning until contact with Lay-down Clamp.
Skid: Stiffness	3.5.3	Structural framework with guiding means.
Skid: Pulling and sliding	3.5.4	Sliding on seabed for axial repositioning, and to facilitate thermal expansion.
Porch: End termination guiding	3.5.5	Lead-in chamfers on Porch structure (MAS and RAS). Sliding face facilitates axial alignment.
Porch: Skid interface	3.5.6	Porch fixed on skid (active Porch).
Pipeline end termination	3.5.7	Alignment sleeve facilitates guiding and locking.

The concept selection phase mentioned above was one of three sub-phases in the design phase of the thesis (section 1.5.2.2). The two other sub-phases were the modeling phase, where the 3D model was developed, and the evaluation phase, where relevant analyses and calculations were accomplished.

5.1 PRESENTATION OF CONCEPT

An overview of the conceptual design is presented in section 3.6. The intention of the following section is to present the technical solutions and the functions that make the Open PLET fulfill the functional requirements given in section 2.6.1.

5.1.1 Open PLET installation

This section presents the landing (landing operation) of the Open PLET on the seabed, and the lifting (lifting operation) of the pipeline end termination from the seabed to integration with the Porch. Figure 5.1 (overleaf) is a sequential illustration of the Open PLET installation.

The Open PLET is lowered from installation vessel to seabed by crane and landed over the pre-installed (S-lay) pipeline end termination. When landing, it is important that the Open PLET is positioned correctly to the Lay-down Clamp (section 3.5.2). After landing on seabed, the Open PLET is still attached to the vessel crane. By slightly re-lifting from seabed, an axial repositioning is carried out so that the Porch achieves face contact with the Lay-down Clamp. This repositioning can be considered as a part of the landing operation.

The crane hook from the installation vessel is then disconnected from the Open PLET and reattached to lifting slings on the pipeline end termination (lifting slings are either pre-attached to the end termination, or attached by the ROV as part of this installation operation). The pipeline end termination is then lifted from seabed, and, by guiding means, integrated into the Porch. As part of this lifting operation an axial alignment takes place. The Open PLET slides on the seabed when the alignment sleeve interferes with the sliding face (section 3.6.3) on the Porch.

When the pipeline end termination is fully integrated into Porch, the vessel crane still keeps tension in the lifting slings. The tension shall not be released before the end termination is locked in position by the mechanical lock assemblies. While the tension still remains, the ROV applies a torque tool to operate the four lock assemblies and setting them to “locked” position. The tension in the lifting slings can then be released, the crane hook disconnected, and the Open PLET installation is completed.

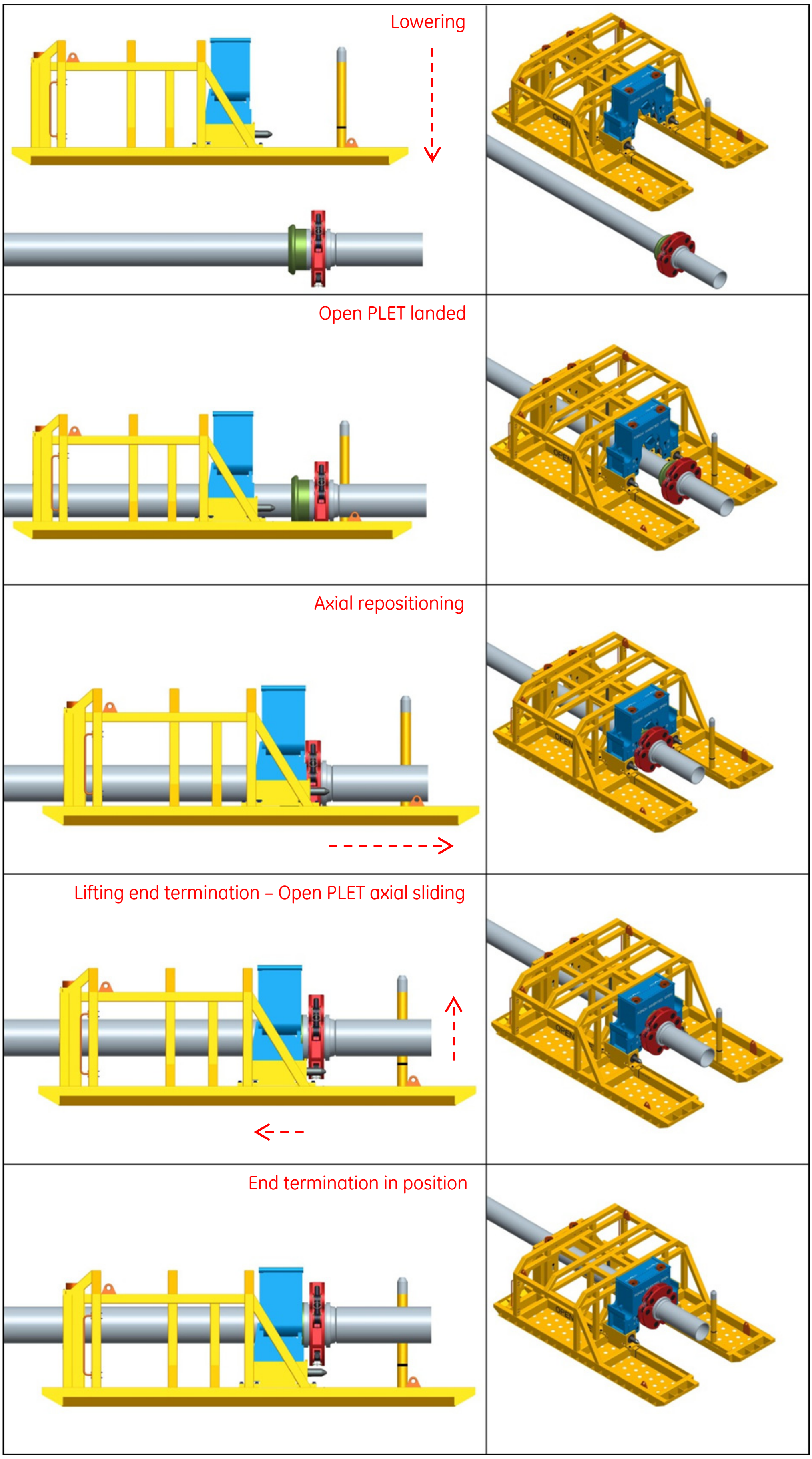


Figure 5.1 – Open PLET installation

5.1.2 Guiding solutions

This section presents the technical solutions for guiding. The guiding elements facilitate the positioning of the Open PLET towards the pipeline end termination when landing on the seabed, and the positioning of the end termination when lifting into the Porch. A distinction is made as the active guiding elements for the landing- and lifting operation are presented separately. Relevant marking (indicators) on the Open PLET will also be presented.

5.1.2.1 Landing of Open PLET

During the landing operation, the Open PLET is guided towards the pipeline end termination. With reference to Figure 5.2, the first guiding element (1) is the longitudinal opening with lead-in chamfers. This guiding element guides the Open PLET to a proper position prior to landing on seabed. To achieve the proper lateral orientation, the ROV can assist by using the ROV handles.

Second guiding element (2) is the “pipeline guiding structure” which is an integrated part of the structural framework (see Figure 3.14). This guiding element is activated in the last part of the landing operation, and it guides the Open PLET closer to the axial center of the end termination and adjusts the lateral orientation.

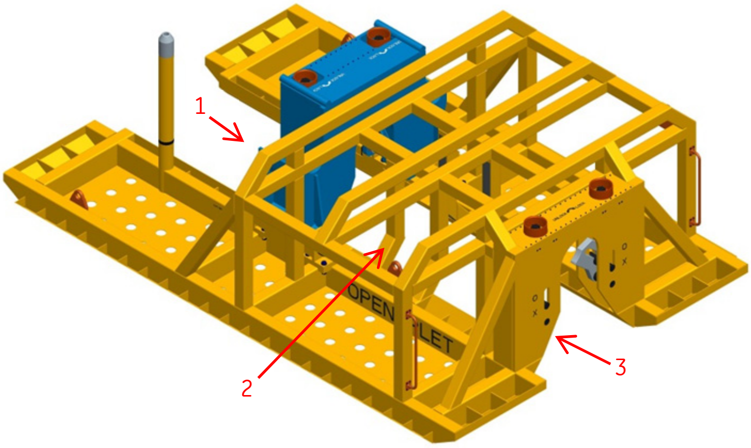


Figure 5.2 – Guiding elements

5.1.2.2 Lifting of pipeline end termination

During the lifting operation, the pipeline end termination is guided towards the Open PLET. With reference to Figure 5.2, the third guiding element (3) is the lead-in chamfers on the MAS and RAS. This guiding element is activated when the pipeline end termination is lifted from the seabed, and it guides the end termination in lateral direction towards the axial center of the Open PLET, and further to the final lateral position into the Porch. Both the MAS and RAS comprise this guiding element.

The alignment sleeve on the pipeline end termination will, when lifted from seabed, interfere with the sliding face on the Porch. The sliding face is the fourth guiding element, and this angled plate will force the Open PLET to slide on the seabed for axial alignment (section 4.6).

Figure 5.3 shows this fourth guiding element and how the end termination is lifted and guided into the Porch. The "sliding region" is the part of the lifting operation where the guiding element is active and contact between the alignment sleeve and the sliding face occurs. The axial alignment of the skid involves a repositioning of approximately 140mm in axial direction (Open PLET sliding direction). This is the last guiding element for guiding of the pipeline end termination to final position, fully integrated into the Porch.

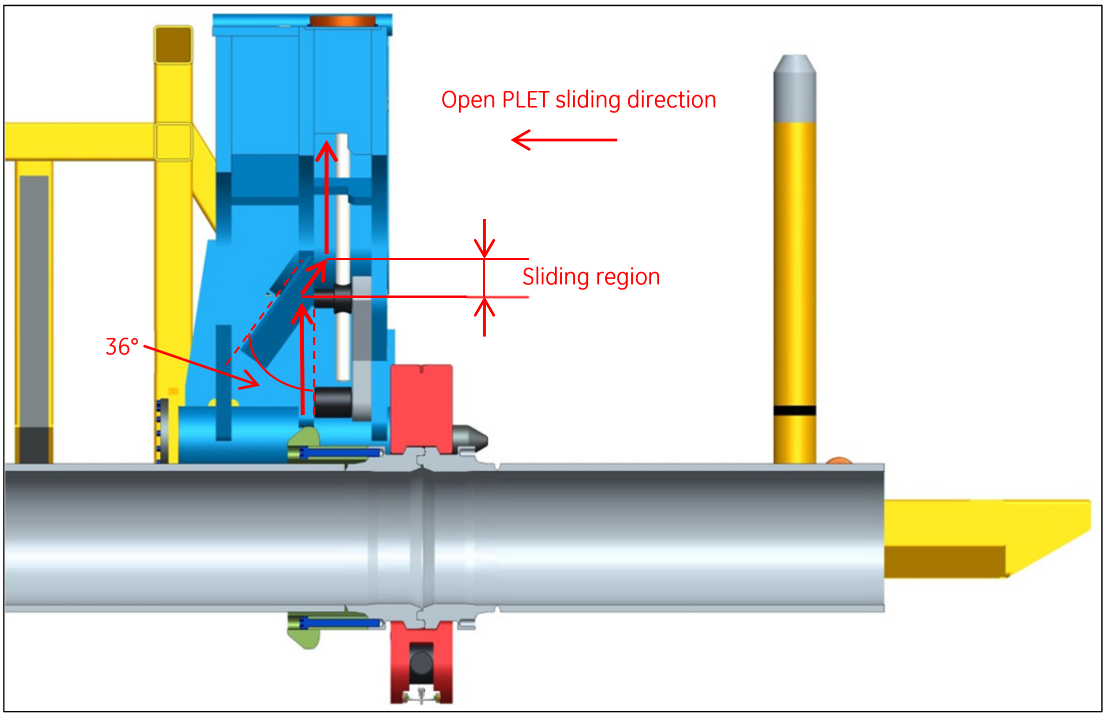


Figure 5.3 – Pipeline end termination guiding into Porch

5.1.2.3 Marking

A part of the landing operation is the axial repositioning of Open PLET (section 5.1.1). The Lay-down Clamp shall, prior to the lifting of the pipeline end termination, be positioned close to face contact with the Porch. This position is required to be within a maximum distance from the Porch. If positioned incorrectly, the end termination will not integrate properly into the Porch. Figure 5.4 (overleaf) shows the Lay-down Clamp in the maximum distance from Porch and the marking on the Open PLET indicating the maximum distance.

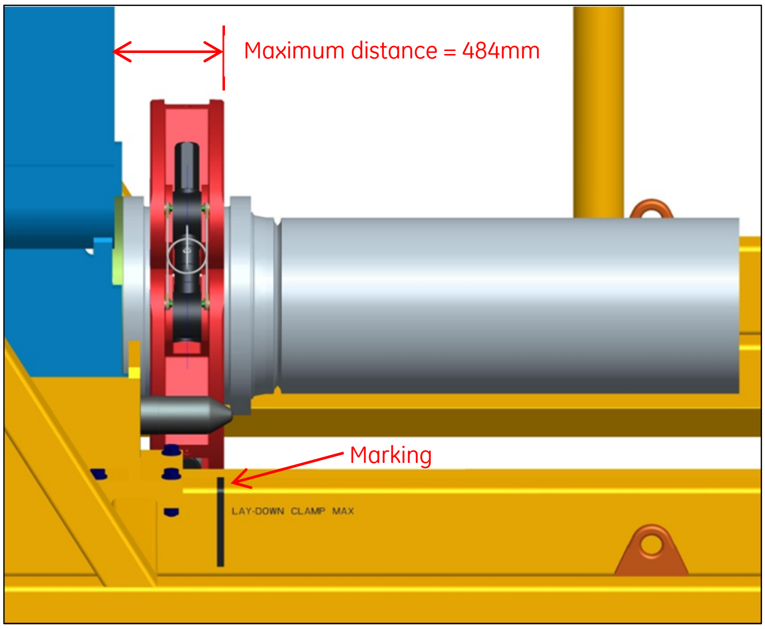


Figure 5.4 – Marking indicating lay-down clamp max position

5.1.3 Pipeline end termination locking to Porch

The pipeline end termination shall be locked in axial, lateral and vertical direction in the Porch. The vertical direction is regarded as the active direction (section 3.5.1). Figure 5.5 (overleaf) is a sequential illustration of how the pipeline end termination is lifted from the seabed into the Porch, and then locked in position by the mechanical lock assemblies.

The vertical locking direction is maintained by the mechanical lock assemblies. The pipeline end termination is lifted from the seabed into the Porch. While the vessel crane keeps tension in lifting slings, the ROV installs the torque tool in the torque bucket on one of the mechanical lock assemblies. The torque tool then operates the lock assembly to “locked” position by rotating the threaded bar in clock-wise direction (Figure 5.6 overleaf) so that the upper collar-bolt on the lock assembly achieves position “X.” The lock-collar will be in “locked” position, angled 20° from the “unlock” position (Figure 5.7 overleaf). The locking operation involves operation of all four lock assemblies to “locked” position. When all four are completed, the tension in lifting slings can be released.

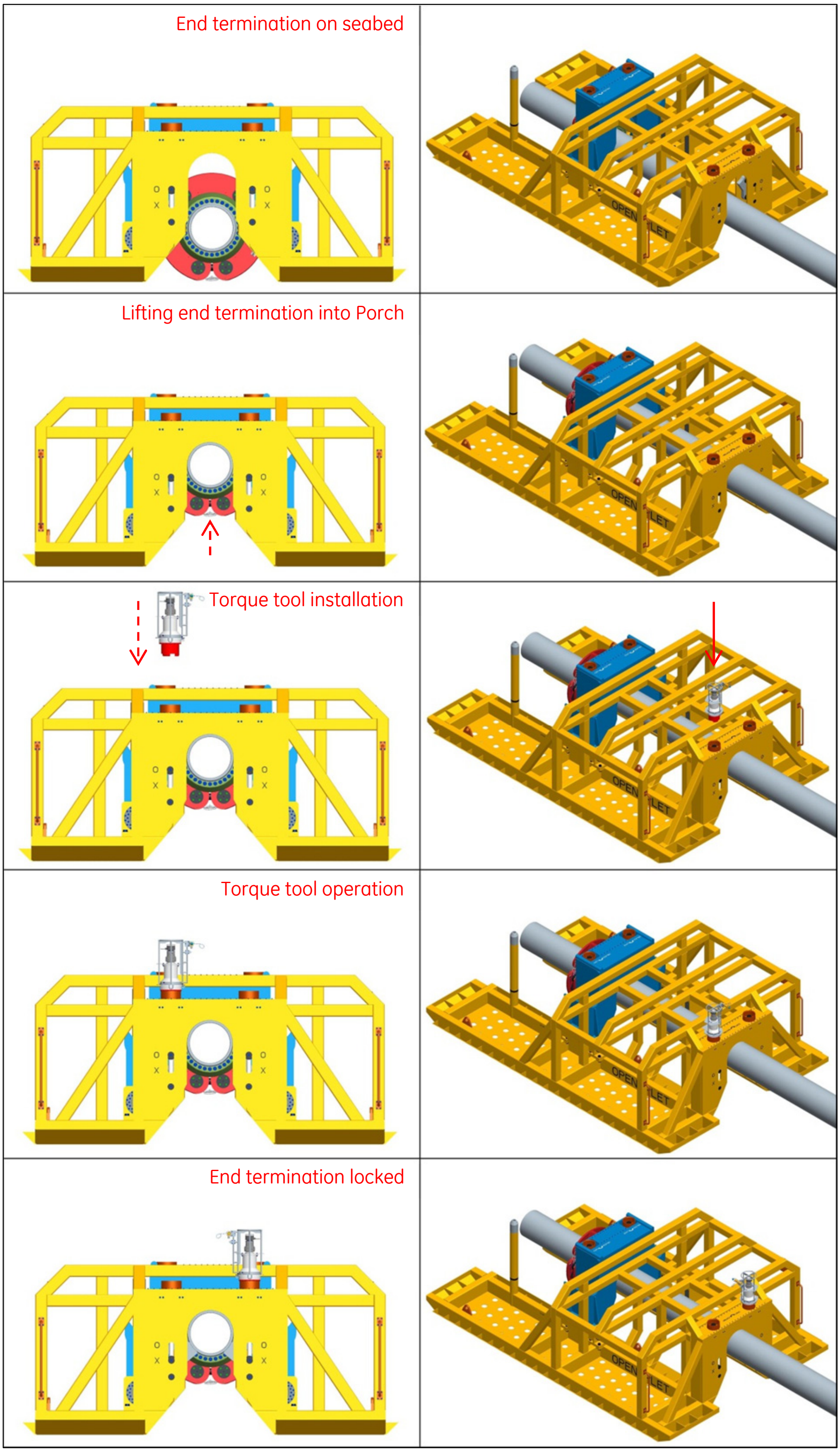


Figure 5.5 – Pipeline end termination locking to Porch

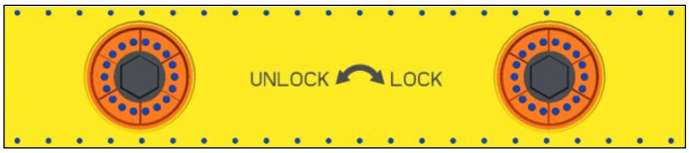


Figure 5.6 – Porch (RAS) torque tool indicator

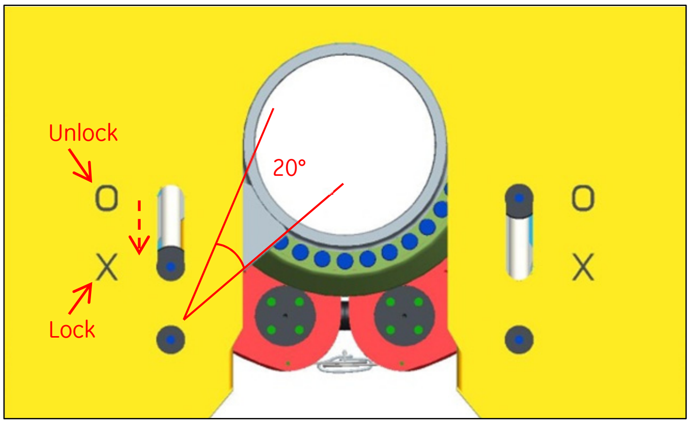


Figure 5.7 – Porch (RAS) locking indicators

The axial- and lateral locking directions are passive directions. These directions are maintained by the Porch structure. Figure 5.8 shows the pipeline end termination in final position in the Porch. The collar on the alignment sleeve (section 3.6.5) has entered into the alignment sleeve groove on the Porch. This groove allows for a free axial displacement of 10mm for the end termination.

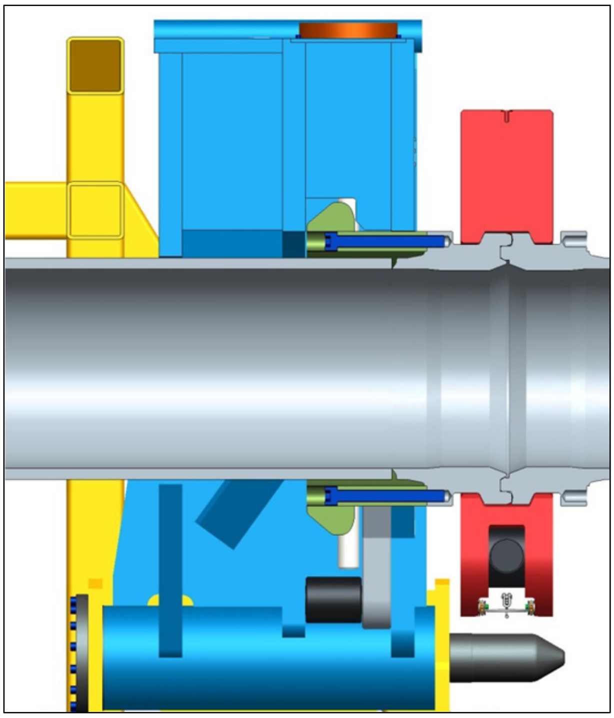


Figure 5.8 – Pipeline end termination fully integrated in Porch

5.1.4 Pre-installation requirements

Pre-installation requirements are the conditions required to install the Open PLET properly. The requirements presented in this section are given by tolerances, but other types of requirements may also be important. Pre-installation requirements are not part of the thesis scope (section 1.5.3), and consequently a brief overview is as follows.

5.1.4.1 Pipeline end termination on seabed

For proper landing of Open PLET on the seabed, and to be able to properly integrate the pipeline end termination in the Porch, the angle of the pipeline end termination with respect to the seabed has to be within a tolerance. A rough evaluation of the 3D model (ProEngineer) gives that the end termination must be installed within ±3° with respect to the seabed. Figure 5.9 shows the minimum and maximum angle defining the tolerance.

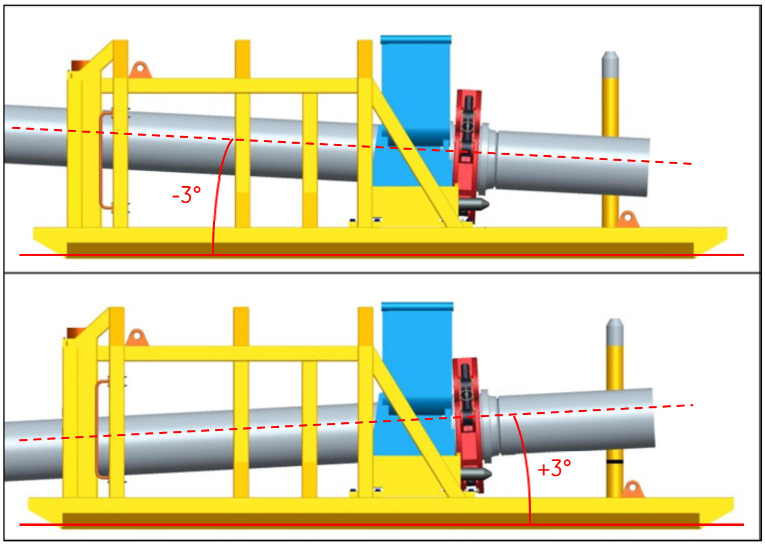


Figure 5.9 – Pipeline end termination tolerance towards seabed

5.1.4.2 Lateral rotation

Figure 5.10 (overleaf) shows the lateral rotation tolerance for landing of the Open PLET on the seabed. The possible misalignment from pipeline axis is ±7°. The lateral rotation of the Open PLET must be within this tolerance to achieve entering of the pipeline end termination in the longitudinal opening.

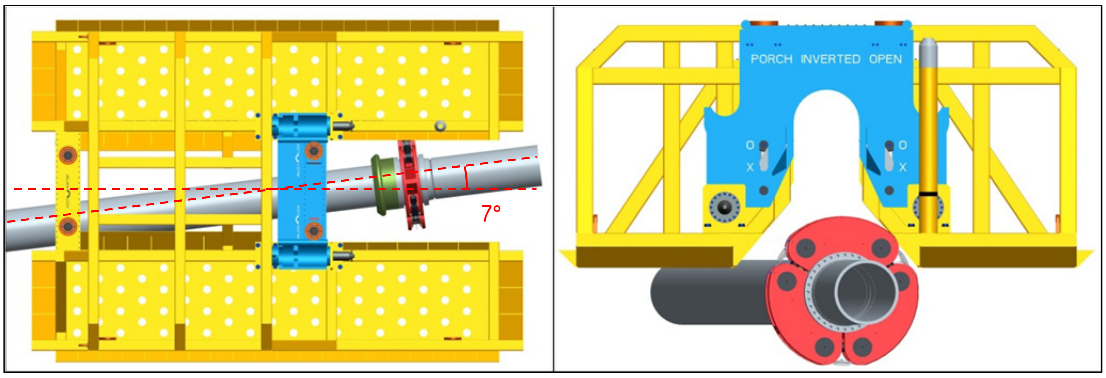


Figure 5.10 – Lateral rotation tolerance prior to landing

After the pipeline termination has entered the longitudinal opening, the pipeline guiding structure (section 3.6.2) will cause a maximum aberration of ±2.5° from the axial direction (Figure 5.11).

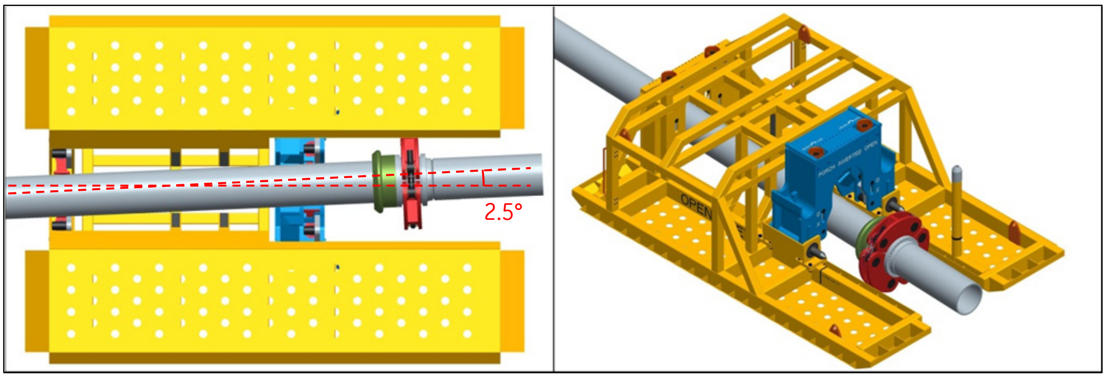


Figure 5.11 – Maximum lateral rotation after landing

5.1.5 Spool connection

Prior to the spool connection, the Lay-down Clamp and Lay-down Head are removed from the pipeline end termination. Figure 5.12 shows the Open PLET before and after spool connection.

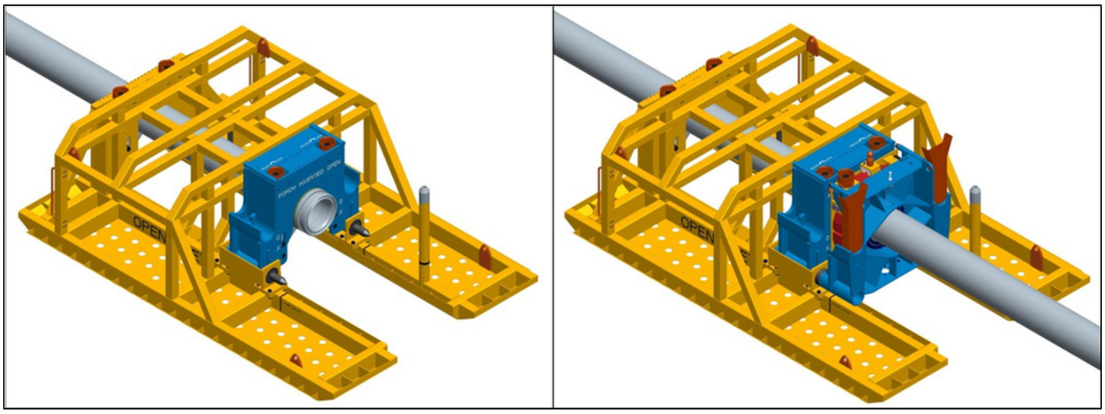


Figure 5.12 – Open PLET before and after spool connection

Figure 5.13 (overleaf) is a sequential presentation of the spool connection. The spool is lowered from the installation vessel and landed on the Open PLET. The guide-post facilitates the positioning during landing. When landed, the spool termination is ready for the connection operation.

The HCCS connection tool is installed from the installation vessel into positions (cradles) on the Porch and the spool termination. When landed, the tool is angled 90° over the Porch to gain access to ROV panel (operation panel). The ROV operates the connection tool, and by that, accomplishing the pull-in operation by pulling the spool termination towards the Porch until full contact between the two hub faces is achieved.

While the connection tool keeps full pull-force in the cylinders, the torque tool is installed in the torque tool bucket on the clamp connector. The torque tool is operated by a ROV, and the operation closes the clamp connector and completes the connection.

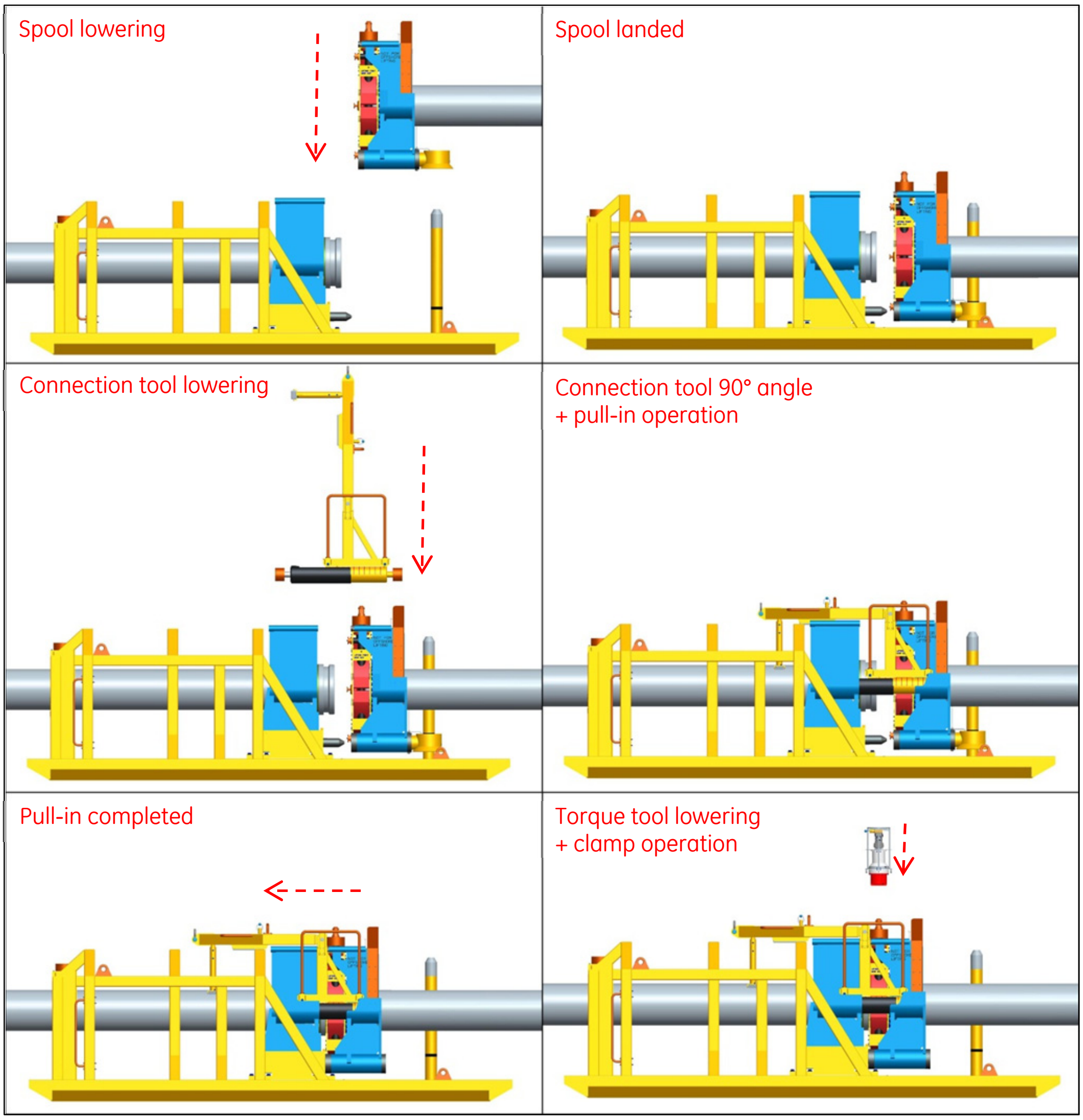


Figure 5.13 – Spool connection

5.1.6 In-place

When production fluid flows in the pipeline (flowline), a thermal expansion can occur due to the temperature of the fluid. The expansion can be as much as a couple of meters for a long pipeline. The Open PLET is designed with chamfers along the edges of the bottom frame to be able to slide on the seabed in axial and lateral direction. This sliding is intended to compensate for the expansion.

At any time, a disconnection of the spool termination is possible. This operation is accomplished by reversing the installation sequence presented in section 5.1.5. Disconnection and/or reconnection of the pipeline end termination are also possible at any time.

5.2 REVIEW OF CONCEPT

5.2.1 Design

The chosen technical solution for locking of the pipeline end termination to the Open PLET (section 3.5.1), which included a vertical active locking mechanism, made it possible to choose the technical solution of lifting the pipeline end termination directly to final position in the Porch. Consequently, an axial pulling of the skid is not required, and the complicated pull operation (section 2.6.5.1) is eliminated.

The current Open PLET system comprises a complicated operation for positioning of the skid next to the pipeline end termination (section 2.6.5.2). The new concept comprises the longitudinal opening and the pipeline guiding structure (section 5.1.2.1), which make it possible to land the skid directly over the end termination. Lateral orientation and alignment towards the pipeline end termination are consequently less complicated. The axial alignment is less complicated due to a physical end stop feature (the Porch, section 5.1.1) which facilitates the required axial repositioning.

When the landing operation is completed, the end termination is in position for it to be lifted directly into the Porch. Guiding of the end termination (section 3.5.5) when lifted from the seabed is accomplished by guiding elements on the Porch (section 5.1.2.2). The final axial alignment of Open PLET towards the end termination is accomplished as part of the lifting operation. Hence, the required and challenging lift and shift operation (section 2.6.5.3) on the current Open PLET system is eliminated.

The design of the skid allows for some lateral rotation when the skid is landed on seabed over the pipeline end termination (section 5.1.4.2). Prior to lifting of the end termination, it is important that the skid is in proper position as described in section 5.1.2.3. The design of the Porch must ensure that the alignment sleeve enters the Porch correctly if the end termination is lifted from the extreme positions mentioned (axial and rotational).

The Open PLET concept is designed in a conservative manner. The chosen elements (beams, plates, etc.) are similar (type, size) as on the current Open PLET, and the skid geometry is more or less basic framework comprising no unconventional solutions or methods. The Porch looks similar to the existing ones, just turned upside down, and the mechanical lock assembly comprises more or less well known subsea industry components. This method of designing is safe and reliable. The conceptual design presents new technology (technical solutions) with a recognizable appearance.

The “conservative design” makes the Open PLET become large and heavy. This conceptual design does not contribute to innovation with respect to reduce the amount of steel on subsea structures. A big challenge facing the subsea industry, as the size of the pipelines increases, is the required system components that are becoming almost oversized and unwieldy. New thinking is required to reduce the sizes.

5.2.2 Analyses

The purpose of the analysis in section 4 was to observe how the conceptual design responded under application of the design loads. The components of the Open PLET evaluated to be the most important is the skid, the Porch and the mechanical lock assembly.

The analyses of the skid revealed that the utilization of the structure is just about 50% of the capacity (section 4.3). Consequently, it is possible to reduce the size (and weight) of the skid, and the framework can be redesigned by removing and reconfiguring members. The good margin on the capacity analyses may also open for considering this skid design for larger pipelines. This Open PLET includes a HCCS-30 (section 2.5) with a pipeline size of maximum 30 inches. GE Oil & Gas holds a HCCS designed for pipeline sizes up to 42 inches. The Porch and spool termination for a HCCS-42 is larger and heavier than for the HCCS-30. It might be possible to consider a HCCS-42 with this skid design.

Utilization factors above 1.5 in the load cases involving the Porch reveal that the design is not optimized for the chosen technical solutions of the Porch. The Porch is probably the most critical component of the Open PLET as it combines strength to undergo heavy loading and at the same time accuracy by allowing for tight tolerances and small deflections. These requirements are of particular importance in the spool connection. Optimization is required, however, the technical solutions of the concept are considered possible with this Porch design.

Calculations of the Open PLET axial alignment ability, mathematically, confirmed that the required sliding of the skid on the seabed is achievable. However, some variables are of significant importance. The weight distribution over the Open PLET is calculated to be the most determine variable. A particular concern is the limited lifting angle range which allows for a maximum lifting angle of just 1.5°. This may cause challenges in the Open PLET installation, as a lifting angle above 1.5° will stop the sliding of the skid. A redesign of the lower region of the Porch is required to make more space for the Lay-down Clamp and consequently allow for a larger lifting angle.

5.2.3 Functional requirements and design goals

The functional requirements and the design goals for the Open PLET system are listed and defined in section 2.6.1.

The concept comprises technical solutions that enable fulfillment of the general requirements listed in section 2.6.1.1. Some of these requirements (amongst others) are, to support the pipeline end termination and the connection system, facilitate required interfaces for completing the connection and to facilitate pipeline thermal expansion. Special attention may be given to the requirement “a” in Table 2.1 about installation tolerances. This new concept, by the longitudinal opening, provides a large leeway during landing of skid. A minimum of accuracy is now required to install the Open PLET in proper position.

The skid is equipped with guiding elements that have interfaces towards the pipeline end termination (item “b,” Table 2.2). The lateral orientation of the skid is maintained by these elements. The interfaces towards the seabed, represented by the mud-mats and the chamfers on the skid bottom frame, enable the skid to slide on the seabed to facilitate repositioning and pipeline thermal expansion.

The Porch is designed with means for guiding of the pipeline end termination in axial and lateral direction (item “a,” Table 2.3). They are used when the end termination is lifted from the seabed into the Porch. The locking mechanism provides a vertical active lock to keep the pipeline end termination in position. This locking mechanism provides the ability to disengage the end termination at all times (item “b” and “c,” Table 2.3).

The design goals are given in section 0. The concept comprises simple solutions with respect to functionality during installation and in-place operation (section 5.1). The most complex part of the design is the locking mechanism which involves threaded components and mechanical movements. The locking mechanism is vulnerable with respect to corrosion and marine growth. Section 3.5.1 gives a detailed evaluation of why this technical solution was chosen, and the conclusion was that by choosing a relatively complex locking mechanism, the possibilities for simple, yet reliable solutions throughout the rest of the design were given.

The Open PLET has a robust design. The results of the analyses show a relatively small utilization factor for the skid, which is a basis for assuming that the structure is capable of rough handling. Expect from the locking mechanism, the concept is designed with few details, minimizing the possibility for installation and operation error (Table 2.4).

5.2.4 Comparison with existing system

The concept for a new Open PLET system designed in this thesis presents a new way of completing a subsea pipeline connection. The difference compared to the current Open PLET system is considerable in both design and functionality.

The major differences between the current Open PLET system presented in section 2.4 and the new Open PLET system is as follows:

- The new concept is installed straight over the pipeline end termination, while the current system is installed next to the end termination.
- The new concept comprises a Porch with the opening facing downwards, while the current system comprises a Porch with the opening upwards.
- The new concept enables a lifting of the pipeline end termination directly into the Porch, while the current system requires a lift and shift operation to install the end termination into the Porch.
- The new concept has a pipeline locking mechanism which is activated by use of a torque tool, while the current system requires a pull operation for locking of the end termination.
- The new concept comprises a skid structure which is a framework in the height over the pipeline end termination, while the current system comprises a structure at seabed level only.

5.2.4.1 Similarities

The new Open PLET is developed on basis of the current system, and as a natural consequence, some technical solutions and parts of the design are more or less similar.

Both systems have two alignment structures, the MAS and the RAS. These structures ensure a proper alignment and locking of the pipeline end termination. On both of the systems the MAS and RAS are equipped with guiding means (lead-in chamfers) required for proper guiding and alignment of end termination during installation.

The pipeline end termination requires to be locked in two positions with respect to the skid. The locking of the end termination is on both of the systems placed as an integrated part of the MAS and RAS. Locking in two positions is required to keep the end termination locked in a manner that ensures the integrity of the Open PLET, both with respect to strength and functionality (section 3.5.1.3).

A long pipeline, during in-place operation, may undergo a thermal expansion causing an elongation of several meters. One of the main requirements for the Open PLET system is to compensate this elongation. Both the old and the new system solve this issue by a skid structure capable of sliding on the seabed. The sliding is ensured by the mud-mats, which prevents the Open PLET from sinking or digging into seabed, and chamfers on the bottom frame.

Both of the systems comprise the “active Porch” (section 3.4.6) which is a Porch fixed on the skid. This type of Porch ensures that the Open PLET is aligned with the pipeline end termination at all times (the skid follows the movements of the end termination).

5.2.4.2 Skid installation (landing operation)

The installation of the current Open PLET system is challenging (section 2.6.5). The new Open PLET system comprises technical solutions which make the installation less challenging. During installation of the skid, the lateral and axial alignment is ensured by the use of guiding elements (section 5.1.2.1) on the skid structure. When landed, the skid has the proper lateral orientation, and the axial position is sufficient when the Lay-down Clamp is within the required tolerance defined by indicators on the skid (section 5.1.2.3).

5.2.4.3 Pipeline end termination installation (lifting operation)

The installation of the pipeline end termination is a challenging and time consuming operation with the current Open PLET system. The lift and shift operation of the end termination and the required pull operation are both difficult operations (section 2.6.5.1 and 2.6.5.3). The new Open PLET system enables a lifting of the pipeline end termination directly into the Porch with no need for lateral repositioning of the pipeline (shift operation) or pull operation.

5.2.4.4 Pipeline locking

The current Open PLET system includess an axial active locking of the pipeline end termination which is a simple and a reliable solution. The active mechanism is a spring loaded locking pin (section 2.4). The interface between the Porch and the end termination ensures a proper positioning in vertical direction.

The new Open PLET system includes a vertical active locking of the pipeline end termination. Hence, the components of the mechanical lock assembly are keeping the pipeline end termination in position by carrying the weight of the end termination. Compared to the current system, where the weight of the end termination is directly applied to the Porch, the new system is totally dependent on the integrity of the locking mechanism. Consequently, while the vertical position of the end termination on the current system is within a small tolerance, the new concept, due to the movable parts of the locking mechanism, is less accurate with respect to the final vertical position.

However, due to the choice of a vertical active locking mechanism, it became possible to lift the pipeline end termination directly into the Porch, which consequently eliminates the challenging pull operation (section 2.6.5.1).

5.2.4.5 Summary

The basis for the new concept was the installation challenges with the current system. Compared to the current system, the new concept provides a method for installation of the Open PLET which is less challenging, requires less accuracy and skill from the installation vessel (personnel), and potential reduces the installation time.

Table 5.2 shows a summary of the comparison of the new concept and the current system.

Table 5.2 – Comparison summary

DESCRIPTION	NEW CONCEPT	CURRENT SYSTEM
Skid installation	• Less time consuming due to alignment by use of guiding elements. • A minimum of positioning accuracy required to land the skid properly.	• Time consuming due to a complicated alignment operation. • Difficult positioning due to lack of a physical end stop feature.
Pipeline end termination installation	• Lift the pipeline end termination directly into Porch	• Lift and shift pipeline end termination before landing into Porch. • Pull operation required to get full integration with Porch.
Pipeline locking	• Vertical active locking which is activated during lifting operation. • Vertical position maintained by locking mechanism	• Axial active locking which is activated as a consequence of the pull operation. • Vertical position maintained by Porch structure.

5.2.5 Assumed further considerations

5.2.5.1 Pre-installation requirements

Section 5.1.4 gives a brief presentation of two important pre-installation requirements for the Open PLET. Another important requirement is the condition of the seabed. Prior to installation of the Open PLET, the seabed must be prepared by leveling the unevenness, and perhaps doing some cementing or rock dumping if the soil is not satisfactory. The angle of the seabed with respect to the horizontal plane is also of importance.

As these requirements are not part of the thesis scope, no further considerations are taken into account.

5.2.5.2 Spool interface towards skid

The conceptual design includes no technical solution for the interface between the skid and the spool termination. During the spool connection, the spool termination is landed on the skid and thereafter pulled towards the Porch in the pull-in operation. Hence, the interface shall enable for both lateral positioning and axial sliding. The design of this technical solution probably involves modifications on the spool termination in addition to the design of the interface on the skid. As modifications of the HCCS is not part of the thesis scope (section 1.5.3), this particular interface is not any further considered.

5.2.5.3 Removal of Lay-down Clamp

Prior to spool connection, the Lay-down Clamp and Lay-down Head is removed. The current Open PLET system offers a dedicated “cradle” to facilitate the clamp removal. This cradle is pre-installed on the guide-spears on the Porch, and consequently it also provides protection of the guide-spears during the Open PLET installation. The same type of pre-installed cradle is not possible with the new Open PLET as it will cross the longitudinal opening, and therefore will interfere with the pipeline end termination during the installation. A ROV installable cradle may be a possible solution as it can be installed separately from the Open PLET. However, the development of a technical solution for removal of the Lay-down Clamp is chosen not to be included in the scope of this thesis.

5.3 DISCUSSION

5.3.1 Advantages and disadvantages

Considerations and appreciations in this section are done with respect to some relevant topics to enhance potential advantages and disadvantages.

5.3.1.1 Conservative design

The conceptual design can be regarded as a conservative design (section 5.2.1). An advantage is the recognizable appearance of the design. The similarities with the current system (section 5.2.4.1), the use of familiar structural elements and some recognizable technical solutions will benefit further engineering, the production and the testing of the Open PLET.

As the new concept is based on a current Open PLET system an advantage will be that some of the technical solutions are “field proven technology.” As an example the sliding of the skid on the seabed to compensate for thermal expansion in the pipeline is proven to be a reliable solution.

The Open PLET system is a consequence of pipelines that becomes larger and larger (section 2.3.3). A trend in subsea engineering as the size of the pipelines increases is to scale small versions of relevant components (e.g. Porch, clamp connector, termination, etc.) to larger versions. A disadvantage is that the conservative design is based on this “scale method.” This way of designing large components should be changed as the pipeline sizes still increases. The scale method should be replaced by innovative thinking of how to reduce the amount of steel, the size and the weight of large subsea components.

The conservative design philosophy eliminated the use of a passive Porch (section 3.4.6 and 3.5.6). A passive Porch has an interface towards the skid which enables it to follow the movements of the pipeline independent of the skid. The skid can then be fixed to the seabed while the Open PLET is able to compensate for thermal expansion. The subsea industry is developing all over the world, and that means the Open PLET will be used on various soil conditions. The technical solutions which involve the skid sliding on the seabed are not reliable if the soil condition is bad (soft, muddy bottom). The axial alignment during installation and the sliding due to thermal expansion may not be possible in such conditions.

5.3.1.2 Open PLET installation

The new Open PLET concept comprises solutions on how to eliminate the installation challenges with the current Open PLET (section 2.6.5). The obvious advantage is the elimination of these challenges which leads to a less complicated installation and a reduced installation time. Requirements of the installation vessel and the personnel with respect to accuracy and skill are reduced, and the reduced installation time also reduces the installation cost.

The disadvantages with the chosen technical solutions are the required sliding of the skid on the seabed (axial repositioning (section 5.1.1), axial alignment (section 5.1.1) and thermal expansion (section 5.1.6) all require sliding). The ability to slide is totally dependent on the soil condition, and that dependency is regarded as a disadvantage.

The limited lifting angle range described in section 4.6 is also a disadvantage. The small range will probably cause installation challenges when lifting the pipeline end termination into the Porch.

5.3.1.3 Active Porch

The active Porch is required due to the chosen end termination locking solution (section 3.5.6). One advantage is the reliable locking of the end termination as it is locked in two positions (section 3.5.1.3). Another advantage is the good conditions for accurate measurements prior to spool fabrication (section 2.4.3.2), because the Porch is not movable (a passive Porch may move slightly when removing the Lay-down Clamp and the Lay-down Head as a lot of weight is removed).

The major disadvantage is that the active Porch will not be applicable with a skid fixed to the seabed (due to bad soil conditions). The installation of the pipeline end termination requires the axial alignment ability which is fulfilled by the skid sliding on the seabed, or by the Porch sliding on the skid (passive Porch).

5.3.1.4 Locking mechanism

The major advantage by the vertical active locking mechanism compared to the axial active, is the elimination of the challenging pull operation (section 2.6.5.1). This is achieved, because the vertical active locking mechanism makes it possible to lift the pipeline end termination directly to final position in the Porch.

The disadvantages with the chosen mechanism is the complexity of the mechanical lock assembly (section 3.6.4) due to several mechanical parts and the heavy loading applied directly onto the lock assembly. These factors reduce the reliability of the locking mechanism.

The movable parts of the mechanical lock assembly cause the final vertical position of the pipeline end termination to be less accurate. Also the required torque tool operation to operate the lock assembly is considered a disadvantage compared to the locking solution of the current Open PLET system.

5.3.1.5 Summary

Table 5.3 presents a brief summary of the advantages and disadvantages mentioned above. Additional considerations from the review section (section 5.2) and the rest of this report are included as well.

Table 5.3 – Advantages and disadvantages summary

DESCRIPTION	ADVANTAGE	DISADVANTAGE
Conservative design	• Recognizable appearance. • "Field proven" solutions. • Similarity to current system.	• Size and weight (scale method). • Elimination of passive Porch. • Lack of innovation with respect to increased pipeline sizes.
Open PLET installation	• Elimination of alignment operation (sec. 2.6.5.2). • Elimination of lift and shift operation (sec. 2.6.5.3). • Elimination of pull operation (sec. 2.6.5.1). • Less accuracy and skill required. • Reduced installation time (reduce cost).	• Dependent on sliding of the skid on the seabed. • Limited lifting angle range (section 4.6).
Active Porch	• Reliable locking of pipeline end termination. • Accurate measurements prior to spool fabrication.	• Not applicable if skid is fixed to seabed.
Locking mechanism	• Lifting of pipeline end termination directly into the Porch. • Elimination of pull operation (sec. 2.6.5.1).	• Complexity reduces the reliability. • Lock assembly subjected to heavy loading. • Accuracy of final vertical position. • Torque tool required.

5.3.2 Alternative solutions

The technical solutions in the new concept are chosen in the process described in section 3.3. In that process alternative technical solutions were considered prior to the concept selection. This section presents some alternatives to the chosen solutions.

5.3.2.1 Skid

The design of the skid presented in section 3.6.2 is a reference to this section. Some alternatives to the design are presented and discussed below:

- The width of the structural framework is dependent on the total width of the bottom frame, because it joins the bottom frame along the outer edges. An alternative can be a narrower design where the framework joins the bottom frame elements along the longitudinal opening. The framework will then have about the same width as the Porch. The advantage with this design is the possibility to vary the width of the bottom frame (for example due to the soil condition) without changing the design of the framework.

- An alternative design of the skid could be having a narrower bottom frame by reducing the width of the two bottom frame elements (if the soil condition allows). This could be done by keeping the framework unchanged by only reducing the framework width (eventually redesign the framework as described in previous alternative). A narrower design reduces the use of material (cost) and reduces the size and weight of the Open PLET. The goal must be to keep the size of the Open PLET at a minimum.

- Some subsea fields may not have good soil condition, which means the soil is soft and has low carrying capacity. The skid is not able to slide on such soil condition due to the required size (large bearing surface). The solution can be to install the skid on a *foundation* frame (also comprising a longitudinal opening). The foundation frame must be designed with the necessary width to avoid sinking into the soil, and it must be fixed to the seabed. It can either be pre-installed or installed pre-attached to the Open PLET. The skid will be able to slide upon the foundation frame. The advantage is the possibility to use the Open PLET (and the technical solutions that require sliding) on bad soil conditions as well.

5.3.2.2 Porch

The design of the Porch presented in section 3.6.3 is a reference to this section. Some alternatives to the design are presented and discussed below:

- The Porch is fixed to the skid (active Porch). An alternative would be the passive Porch which is able to follow the pipeline movements independent of the skid.

The skid can then be fixed to the seabed as the Porch itself compensates for the pipeline movements.

- The guide-spears on the Porch are used for guiding of the spool termination during spool connection (section 2.4.3). The guide-spears are vulnerable for impact, especially during the Open PLET installation (Lay-down Clamp may impinge on the guide-spears). An alternative can be a Porch designed with the guide-spear receptacles instead of the guide-spears (switch the guide-spear and the receptacle between the Porch and the spool termination, see section 2.5). The receptacles are less vulnerable and the need for guide-spear protection vanishes.

5.3.2.3 Mechanical lock assembly

The design of the mechanical lock assembly presented in section 3.6.4 is a reference to this section. Some alternatives to the design are presented and discussed below:

- An alternative locking mechanism is a frame (framework) to be slid under the pipeline end termination. This will comprise the vertical active locking direction as well. The frame is ROV operated and slides on the skid in lateral direction. Prior to Open PLET installation, the frame is set to "unlock" position which unblocks the longitudinal opening. When the pipeline end termination is lifted into the Porch, the ROV pushes (or pulls) the frame to "locked" position under the end termination. The advantage with this locking mechanism will be the reliability with respect to maintain the vertical position of the end termination. The disadvantages will be that it is potentially difficult to operate and that it can be hard to meet the required tolerances for the final vertical position of the end termination.

- An alternative is an axial active locking mechanism. This alternative involves a pull operation to proper integrate the pipeline end termination into the Porch (similar to current Open PLET system, section 2.4.3.1). Either the skid must be pulled with respect to the end termination, or, if applying a passive Porch, the Porch must be pulled with respect to the end termination. The pull operation requires hydraulic cylinder forces, for example applied by a PLET Integration Tool. The skid/Porch will have a "locked" and "unlocked" position. With the skid/Porch in unlocked position, the pipeline end termination is lifted from the seabed into the Porch. The skid/Porch is thereafter, by the hydraulic cylinders, axial pulled to locked position. The alignment sleeve enters the Porch, and the geometry on the Porch enables locking of the end termination in vertical direction.

5.3.2.4 Summary

Table 5.4 presents a brief summary of the alternative solutions mentioned above.

Table 5.4 – Alternative solutions summary

COMPONENT	ALTERNATIVE SOLUTION
Skid	• Framework width independent of bottom frame width. Framework joined to bottom frame along the longitudinal opening only. • Narrower design (if soil condition allows) to reduce size and weight. • Additional, fixed foundation frame which the skid can slide upon.
Porch	• Passive Porch instead of active Porch. • Guide-spears on spool termination and guide-spear receptacles on the Porch.
Mechanical lock assembly	• ROV operated frame to be slid in lateral direction under the pipeline end termination for locking in vertical direction. • Axial locking mechanism involving an axial pull operation accomplished by a PLET Integration Tool (hydraulic cylinders).

6 CONCLUSION

6.1 CONCLUSION

A subsea pipeline connection requires a structure for support towards the seabed. The Open PLET is a purpose-built substructure for a subsea pipe-to-pipe connection. Such connection is stand-alone compared to a pipe-to-structure connection, where a subsea facility provides the required support.

A "regular" PLET is pre-attached to the pipeline end on the surface, and then the PLET and the pipeline are installed on the seabed simultaneously. An Open PLET is required when the assembling to the pipeline end is required to take place on the seabed. The size and weight of the Open PLET, due to a large pipeline or not satisfactory seabed (soil) conditions, makes a simultaneous installation not suitable

The subsea assembly operation is challenging with current Open PLET systems. It is difficult and time consuming to install the Open PLET in proper position next to the pre-installed pipeline; it is challenging to lift and shift the heavy, rigid pipeline from the seabed to position on the Open PLET, and to achieve full integration of the pipeline on the Open PLET, a pulling of the Open PLET on the seabed is required.

The conceptual design of the new Open PLET system comprises technical solutions intended to reduce or eliminate the installation challenges with the current system. The new concept comprises a longitudinal opening in the bottom frame which enables a landing of the Open PLET straight over the pipeline. A guiding element consisting of a physical end stop provides a feature for reliable axial alignment prior to integration of the pipeline. The pipeline can be lifted directly from seabed into final position on the Open PLET. A guiding element consisting of an angled steel plate impinges on the pipeline, and forces the axial alignment of the Open PLET during the lifting operation. The pipeline is locked in final position by a mechanical locking mechanism which provides a vertical active locking direction.

The longitudinal opening in the bottom frame, along with the physical end stop feature, reduces the alignment challenges compared to the current Open PLET system. The ability to lift the pipeline from the seabed directly into final position on the Open PLET eliminates the need for a lift and shift operation, and by using a vertical active locking mechanism, the required pull operation of the current Open PLET is eliminated.

The main components of the new concept are the "skid," the "Porch" and the "mechanical lock assembly." The skid comprises the bottom frame and a structural framework. The analyses of the skid verified that the design, when subjected to the design loads, maintain its structural integrity. A redesign of the skid in a detail design phase, to reduce the size and weight, is possible due to a relative low UF.

The Porch in the new concept is referred to as "Porch Inverted Open" as the opening for engagement of the pipeline is facing downwards. The Porch is regarded as the fixed end of the connection, and it is subjected to heavy loads during the connection operation. The analyses revealed that, for a load case considered as a worst-case scenario, the Porch structure failed to achieve acceptable levels in stresses and deflections. However, the technical solutions of the concept are evaluated to be possible if the Porch, in a detail design phase, is redesigned and optimized.

A drawback with the new Open PLET is the mechanical lock assembly. The mechanical parts may cause operational errors, and the vertical active locking direction causes uncertainties with respect to the tolerances for the final vertical position of the pipeline. This technical solution can be considered as a compromise with respect to the design goals saying simple and robust solutions with few details. By applying this solution, the new concept was enabled to provide other technical solutions with great benefits compared to the current Open PLET system.

An important feature with the new concept is the ability to slide on the seabed. Such sliding is required for alignment and guiding purposes, and to facilitate thermal expansion in the pipeline. The calculations revealed that the weight distribution over the Open PLET is a vital factor for the sliding to occur when lifting the pipeline, and with that achieve axial alignment. The more weight distributed to the contact face (sliding plate) between the Open PLET and the pipeline, the more probable is the sliding. This weight distribution factor must be taken into account in a detail design of the Open PLET.

The major improvement on the new Open PLET system compared to the current system is the ability to land over the pipeline and thereupon lift the pipeline directly from the seabed to engagement and final position on the Open PLET. This thesis presents by a conceptual design the technical solutions making this possible.

6.2 FUTURE WORK

A conceptual design forms a basis for the detailed design. In this thesis the concept is presented, and by evaluation and analyses the technical solutions have been verified as feasible. By doing some redesign and optimization in a detail design phase, this new Open PLET system may be a welcome addition in the subsea industry.

The skid lifting angle when lifting the pipeline from the seabed into the Open PLET is of a limited range, and consequently a concern. If the skid is lifted above the maximum lifting angel, the installation of the Open PLET will be obstructed. This issue should be dealt with in further optimization of the concept.

The active Porch solution where the Porch is fixed to the skid can be considered a drawback. This solution results in an Open PLET system which requires the ability to slide on the seabed. This solution is vulnerable if the soil condition is not satisfactory. If optimizing the concept, a passive Porch solution should be considered. Such solution eliminates the sliding requirement, and widens the usage of the Open PLET.

The required sliding on the seabed is considered to be the major drawback of the new concept. The concept solution requires the sliding capability to fulfill the functional requirements for the Open PLET. If improving of the concept, the requirement of sliding should be replaced by technical solutions which allows for a skid fixed to the seabed.

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APPENDIX A1: BRAINSTORM MATRIX

BRAINSTORM MATRIX

MAIN COMPONENT	ITEM	TECHNICAL ISSUE	DETAILS	BRAINSTORM IDEA	PROPOSED/CHOSEN TECHNICAL SOLUTION
Skid	1.1	Stiffness	The skid shall have an opening in the bottom frame in longitudinal direction, and the required stiffness between the separated bottom frame elements must then be attend to the structure in the height above the pipeline end termination. a) Is the skid structure required to have high bending stiffness?	a) Structure to be in same height over the whole skid, similar to template structures? b) Structure in height just over the pipeline end termination. Structure foundation in skid close to longitudinal opening. c) Make structure overtrawlable. Important? d) "Roof" structure over pipeline.	Solution #1: As simple as possible structural framework. Use as small number of beams as possible. Implement guiding elements in structure.
	1.2	Pulling and sliding	After lifting of pipeline end termination into the Porch, a final pulling of Porch towards end termination may be required for to get proper axial integration of end termination into the Porch. The issue highlights the ability for the skid to slide on seabed and slide in axial direction compared to the pipeline end termination. a) Skid move at seabed? Required with cementing or rock dump prior to skid installation? b) Sliding Porch on the skid? c) Possible to install without pull operation?	a) Installation of pipeline end termination into Porch without pulling in axial direction. Guiding of skid during installation to eliminate the requirement for further pull operation.	Solution #1: No pull operation required, but skid must be able to slide on seabed when skid is repositioned and when end termination is lifted into Porch. Sliding required in axial direction.
	1.3	Guiding	The skid shall land over the pipeline end termination in proper position prior to lifting of the pipeline end termination. The skid structure must comprise means for guiding of skid in axial and lateral direction towards the pipeline end termination. a) How is skid positioned properly? b) What about guiding during landing? c) Special designed pipeline end termination with means for guiding of skid into place?	a) Use of guiding means on Porch during installation. b) Guiding towards pipeline end termination for proper positioning in axial direction. c) Use of Lay-down Clamp as guiding mean. d) Feature on skid for guiding in axial direction. e) Guide-wire attached to Lay-down Clamp to facilitate axial positioning.	Solution #1: Use of guide wire attached to Lay-down Clamp to guide skid in axial direction. Solution #2: Use of feature on skid to guide in axial direction. Guiding towards Lay-down Clamp. Axial repositioning of skid after landing performed by installation vessel.
Porch Inverted Open	2.1	End termination guiding	Pipeline end termination shall be lifted in vertical direction from seabed into the Porch. The Porch must facilitate for guiding of end termination in axial and lateral direction. a) Vertical guiding and alignment? b) Axial guiding and alignment? c) Axial movement of end termination required?	a) Alignment sleeves on pipeline end termination with interfaces towards Porch and with means for guiding in both vertical and axial direction. b) Porch geometry with lead-in chamfers to facilitate guiding. Interface towards alignment sleeves. c) "Big bags" under pipeline for elevation from the seabed and for to make the installation into Porch easier.	Solution #1: Interface between MAS/RAS structure and alignment sleeves on end termination will ensure guiding in axial and lateral direction. Skid must be repositioned in axial direction when lifting end termination.
	2.2	End termination locking	A locking mechanism is required to keep pipeline end termination locked in position in the Porch. The locking mechanism may be a part of the Porch assembly, and it has interfaces towards the pipeline itself or alignment sleeves on the end termination. a) Pipeline end termination structure required? b) Locking mechanism, how? c) ROV operated or integration tool operated?	a) ISO-mandrel for locking of end termination. Possible to use a threaded feature for to tighten the mandrel lock? b) Alignment sleeves on pipeline end termination with interfaces towards the locking mechanism on Porch.. c) Cam-ring and dogs to lock pipeline end termination vertically. d) Use toothed wheel mechanism with ROV handle to lock pipeline end termination to Porch. "Half moon" to lock pipeline from underneath. e) Locking of pipeline end termination in both MAS and RAS, or a possible solution where excluding the lock in RAS.	Solution #1: Lifting of pipeline end termination and thereafter axial pull operation to get full integration with Porch. Axial locking = active direction. Solution #2: Lifting of pipeline end termination to full integration with Porch without axial pull operation. Locking mechanism for lock in vertical direction. Vertical locking = active direction.
	2.3	Skid interface	The Porch is the fixed end of the connection system, but the Porch can be either fixed on skid, defined as "active Porch", or the Porch can be mounted able to slide upon skid following the pipeline movements, defined as "passive Porch". A passive Porch is still regarded as the fixed end of the connection.	a) Porch with MAS and RAS to be implemented in skid. b) An "active Porch" is a Porch fixed mounted to the skid. A "passive Porch" is a Porch loose mounted to the skid able to follow the rotation and expansion of the pipeline end termination.	Solution #1: An active Porch has a less complicated interface towards the skid and it gives predictable functionality to the Open PLET.

BRAINSTORM MATRIX

MAIN COMPONENT	ITEM	TECHNICAL ISSUE	DETAILS	BRAINSTORM IDEA	PROPOSED/CHOSEN TECHNICAL SOLUTION
PLET Integration Tool	3.1	Functions	The PLET Integration Tool shall have a function for pulling of skid in axial direction for to fully integrate the pipeline end termination into Porch. a) Use tool to replace HCCS connection tool?	a) One cylinder tool elevating the pipeline into Porch. b) Use of vessel crane to lift pipeline end termination to integration with Porch. Fine alignment adjusted after.	Not applicable due to chosen solution for item 2.2.
	3.2	Skid interface	The integration tool shall be landed and operated on the skid. The tool can be deployed subsea pre-installed on the skid, or it can be installed subsea on a later occasion. a) Landing on Porch or on structure?		Not applicable due to chosen solution for item 2.2.
	3.3	End terminaton interface	The reaction during the pulling operation may be between the Porch and the Lay-down Clamp. Consequently, the tool then has interfaces towards those components. a) Which type of locking mechanism to use? b) How many lifting points on pipeline termination?		Not applicable due to chosen solution for item 2.2.
Other	4.1	Pipeline end termination	The design of the pipeline end termination shall facilitate guiding towards the Porch and it shall comprise an interface to the locking mechanism. Alignment sleeves are probably required, but the need for a rear alignment sleeve can be evaluated. a) Keep termination as is today? b) "Clean" pipeline, just pipeline and hub? c) New end termination design to facilitate for guiding during skid landing operation and pipeline end termination lifting operation. New design can also provide means for locking of pipeline. Lock on termination?	a) Is the rear alignment sleeve required?	Solution #1: Rear alignment sleeve not required as the interface between main alignment sleeve and MAS completes the required axial repositioning of the Open PLET.
	4.2	Small tooling	Small tooling is not a part of this thesis, but some considerations might occur with respect to the small tooling. a) Is there any consideration that must be taken into account with respect to a conceptual design. b) Access for small tooling while integration tool is landed on PLET.	a) Important to ensure that the connection tool do not collide with the skid structure when installed on the Open PLET.	Solution #1: No modifications on the HCCS in this thesis. No further evaluation in use of the small tooling.

APPENDIX A2: STAAD.PRO EDITOR CODE (LC-01)

STAAD.PRO EDITOR CODE (LC-01)

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JOB NO LC-01
END JOB INFORMATION
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UNIT MMS KN
JOINT COORDINATES
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7 5700 0 0; 8 5700 0 8000; 9 0 0 600; 10 0 0 3800; 11 0 0 5000; 12 1650 0 600;
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65 2850 1703 200; 66 1650 703 3800; 67 1650 703 5000; 68 4050 703 3800;
69 4050 703 5000; 70 2850 1703 4400; 71 0 0 7400; 72 5700 0 7400;
73 2850 7735 3545;
MEMBER INCIDENCES
1 1 63; 2 3 59; 3 1 3; 4 2 4; 5 5 61; 6 7 64; 7 5 7; 8 6 8; 9 9 12; 10 10 27;
11 11 14; 12 15 18; 13 29 19; 14 17 20; 15 9 21; 16 10 22; 17 12 23; 18 15 24;
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107 71 2; 108 59 12; 109 12 55; 110 55 56; 111 56 13; 112 13 14; 113 14 4;
114 61 15; 115 15 57; 116 57 58; 117 58 16; 118 16 17; 119 17 6; 120 64 18;
121 18 19; 122 19 20; 123 20 72; 124 72 8;
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125 1 2 4 3; 126 5 6 8 7;
ELEMENT PROPERTY
125 126 THICKNESS 8
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ISOTROPIC STEEL
E 210
POISSON 0.3
DENSITY 7.85e-008
ALPHA 1.2e-005
DAMP 0.03
END DEFINE MATERIAL
MEMBER PROPERTY EUROPEAN
1 TO 14 63 64 103 TO 124 TABLE ST TUB40020016
15 TO 62 65 TO 92 95 TO 98 TABLE ST TUB20020012
MEMBER PROPERTY EUROPEAN
99 TO 102 PRIS YD 100
CONSTANTS
MATERIAL STEEL ALL
SUPPORTS
73 PINNED
1 8 FIXED BUT FY MX MY MZ KFX 0.01 KFZ 0.01
MEMBER CABLE
99 TO 102 TENSION 0
MEMBER OFFSET
1 TO 22 63 64 71 TO 76 83 TO 86 103 TO 124 START 0 200 0
1 TO 14 44 45 63 64 77 78 80 82 100 101 103 TO 124 END 0 200 0
MEMBER RELEASE
83 TO 86 START MX MY MZ
LOAD 1 LOADTYPE None  TITLE LC-01
SELFWEIGHT Y -2.27 LIST 1 TO 92 95 TO 126
JOINT LOAD
70 FY -254
PERFORM ANALYSIS PRINT STATICS CHECK
PARAMETER 1
CODE NS3472
BEAM 1 ALL
TRACK 2 ALL
FYLD 355 ALL
CHECK CODE ALL
FINISH
```

APPENDIX A3: STAAD.PRO EDITOR CODE (LC-02)

STAAD.PRO EDITOR CODE (LC-02)

```
STAAD SPACE
START JOB INFORMATION
ENGINEER DATE 01-May-12
JOB NO LC-02
END JOB INFORMATION
INPUT WIDTH 79
UNIT MMS KN
JOINT COORDINATES
1 0 0 0; 2 0 0 8000; 3 1650 0 0; 4 1650 0 8000; 5 4050 0 0; 6 4050 0 8000;
7 5700 0 0; 8 5700 0 8000; 9 0 0 600; 10 0 0 3800; 11 0 0 5000; 12 1650 0 600;
13 1650 0 3800; 14 1650 0 5000; 15 4050 0 600; 16 4050 0 3800; 17 4050 0 5000;
18 5700 0 600; 19 5700 0 3800; 20 5700 0 5000; 21 0 2250 600; 22 0 2250 3800;
23 1650 2250 600; 24 4050 2250 600; 25 5700 2250 3800; 26 5700 2250 600;
27 1025 0 3800; 28 1025 2250 3800; 29 4675 0 3800; 30 4675 2250 3800;
31 0 2250 2200; 32 5700 2250 2200; 33 2325 2250 600; 34 2325 2250 2200;
35 2325 2250 3800; 36 3375 2250 600; 37 3375 2250 2200; 38 3375 2250 3800;
39 540 2750 600; 40 540 2750 2200; 41 540 2750 3800; 42 5160 2750 600;
43 5160 2750 2200; 44 5160 2750 3800; 45 1650 2750 600; 46 1025 2750 3800;
47 4050 2750 600; 48 4675 2750 3800; 49 2325 2250 3080; 50 3375 2250 3080;
51 2325 790 2200; 52 3325 790 2200; 53 2325 790 3080; 54 3375 790 3080;
55 1650 0 2200; 56 1650 0 3080; 57 4050 0 2200; 58 4050 0 3080; 59 1650 0 200;
60 1650 2250 200; 61 4050 0 200; 62 4050 2250 200; 63 0 0 200; 64 5700 0 200;
65 2850 1703 200; 66 1650 703 3800; 67 1650 703 5000; 68 4050 703 3800;
69 4050 703 5000; 70 2850 1703 4400; 71 0 0 7400; 72 5700 0 7400;
73 2850 3560 10000; 74 0 3560 10000; 75 5700 3560 10000;
MEMBER INCIDENCES
1 1 63; 2 3 59; 3 1 3; 4 2 4; 5 5 61; 6 7 64; 7 5 7; 8 6 8; 9 9 12; 10 10 27;
11 11 14; 12 15 18; 13 29 19; 14 17 20; 15 9 21; 16 10 22; 17 12 23; 18 15 24;
19 18 26; 20 19 25; 21 27 28; 22 29 30; 23 21 23; 24 23 33; 25 24 26; 26 22 28;
27 28 35; 28 30 25; 29 21 31; 30 31 22; 31 26 32; 32 32 25; 33 33 36; 34 36 24;
35 35 38; 36 38 30; 37 33 34; 38 34 49; 39 36 37; 40 37 50; 41 31 34; 42 34 37;
43 37 32; 44 22 11; 45 25 20; 46 21 39; 47 39 45; 48 45 47; 49 47 42; 50 42 26;
51 22 41; 52 41 46; 53 46 48; 54 48 44; 55 44 25; 56 31 40; 57 40 43; 58 43 32;
59 23 45; 60 24 47; 61 28 46; 62 30 48; 63 27 13; 64 16 29; 65 49 35; 66 50 38;
67 34 51; 68 37 52; 69 49 53; 70 50 54; 71 55 51; 72 56 53; 73 57 52; 74 58 54;
75 59 60; 76 61 62; 77 60 63; 78 62 64; 79 65 60; 80 65 59; 81 65 62; 82 65 61;
83 13 66; 84 14 67; 85 16 68; 86 17 69; 87 70 66; 88 70 67; 89 70 68; 90 70 69;
91 60 45; 92 62 47; 95 66 67; 96 67 69; 97 68 69; 98 66 68; 99 74 21;
100 74 71; 101 75 72; 102 75 26; 103 63 9; 104 9 10; 105 10 11; 106 11 71;
107 71 2; 108 59 12; 109 12 55; 110 55 56; 111 56 13; 112 13 14; 113 14 4;
114 61 15; 115 15 57; 116 57 58; 117 58 16; 118 16 17; 119 17 6; 120 64 18;
121 18 19; 122 19 20; 123 20 72; 124 72 8; 127 74 73; 128 73 75;
ELEMENT INCIDENCES SHELL
125 1 2 4 3; 126 5 6 8 7;
ELEMENT PROPERTY
125 126 THICKNESS 8
DEFINE MATERIAL START
ISOTROPIC STEEL
E 210
POISSON 0.3
DENSITY 7.85e-008
ALPHA 1.2e-005
DAMP 0.03
END DEFINE MATERIAL
MEMBER PROPERTY EUROPEAN
1 TO 14 63 64 103 TO 124 TABLE ST TUB40020016
15 TO 62 65 TO 92 95 TO 98 TABLE ST TUB20020012
MEMBER PROPERTY EUROPEAN
99 TO 102 PRIS YD 100
MEMBER PROPERTY EUROPEAN
127 128 PRIS YD 500
CONSTANTS
MATERIAL STEEL ALL
SUPPORTS
73 PINNED
9 18 FIXED BUT MX MY MZ KFX 0.01 KFY 0.01 KFZ 0.01
MEMBER CABLE
99 TO 102 TENSION 0
MEMBER OFFSET
1 TO 22 63 64 71 TO 76 83 TO 86 103 TO 124 START 0 200 0
1 TO 14 44 45 63 64 77 78 80 82 100 101 103 TO 124 END 0 200 0
LOAD 1 LOADTYPE None  TITLE LC-02
SELFWEIGHT Y -0.92 LIST 1 TO 82 91 92 103 TO 126
SELFWEIGHT Z -2.52 LIST 1 TO 82 91 92 103 TO 126
JOINT LOAD
70 FY -103 FZ -282
PERFORM ANALYSIS PRINT STATICS CHECK
PARAMETER 1
CODE NS3472
BEAM 1 MEMB 1 TO 92 95 TO 124
TRACK 2 MEMB 1 TO 92 95 TO 124
FYLD 355 MEMB 1 TO 92 95 TO 124
CHECK CODE MEMB 1 TO 92 95 TO 124
FINISH
```

APPENDIX A4: STAAD.PRO EDITOR CODE (LC-03)

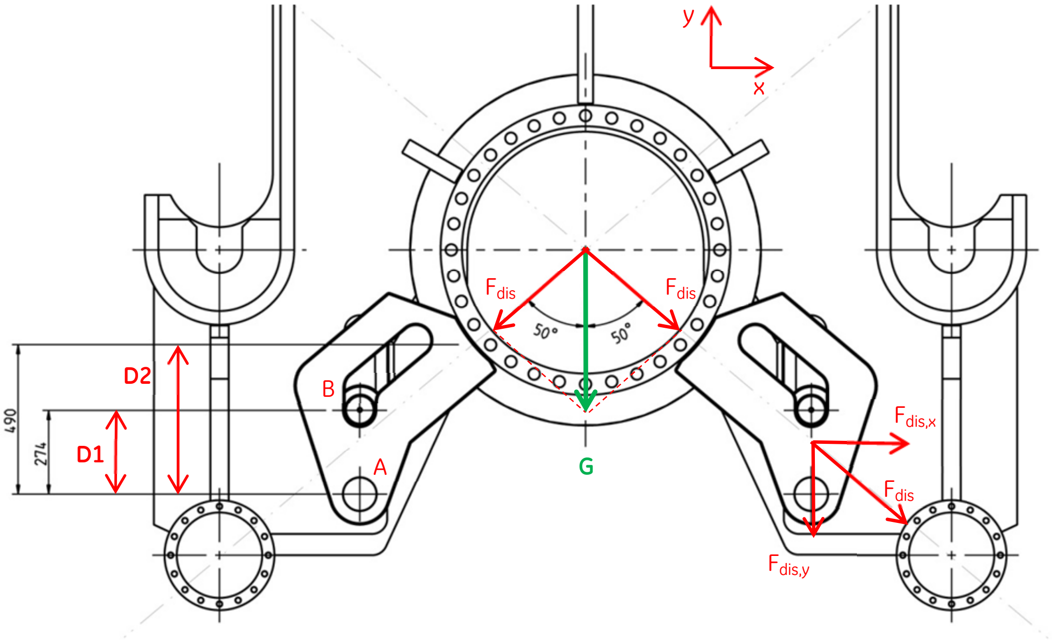
STAAD.PRO EDITOR CODE (LC-03)

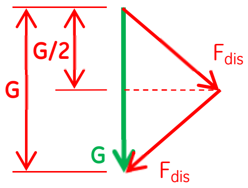
```
STAAD SPACE
START JOB INFORMATION
ENGINEER DATE 01-May-12
JOB NO LC-03
END JOB INFORMATION
INPUT WIDTH 79
UNIT MMS KN
JOINT COORDINATES
1 0 0 0; 2 0 0 8000; 3 1650 0 0; 4 1650 0 8000; 5 4050 0 0; 6 4050 0 8000;
7 5700 0 0; 8 5700 0 8000; 9 0 0 600; 10 0 0 3800; 11 0 0 5000; 12 1650 0 600;
13 1650 0 3800; 14 1650 0 5000; 15 4050 0 600; 16 4050 0 3800; 17 4050 0 5000;
18 5700 0 600; 19 5700 0 3800; 20 5700 0 5000; 21 0 2250 600; 22 0 2250 3800;
23 1650 2250 600; 24 4050 2250 600; 25 5700 2250 3800; 26 5700 2250 600;
27 1025 0 3800; 28 1025 2250 3800; 29 4675 0 3800; 30 4675 2250 3800;
31 0 2250 2200; 32 5700 2250 2200; 33 2325 2250 600; 34 2325 2250 2200;
35 2325 2250 3800; 36 3375 2250 600; 37 3375 2250 2200; 38 3375 2250 3800;
39 540 2750 600; 40 540 2750 2200; 41 540 2750 3800; 42 5160 2750 600;
43 5160 2750 2200; 44 5160 2750 3800; 45 1650 2750 600; 46 1025 2750 3800;
47 4050 2750 600; 48 4675 2750 3800; 49 2325 2250 3080; 50 3375 2250 3080;
51 2325 790 2200; 52 3375 790 2200; 53 2325 790 3080; 54 3375 790 3080;
55 1650 0 2200; 56 1650 0 3080; 57 4050 0 2200; 58 4050 0 3080; 59 1650 0 200;
60 1650 2250 200; 61 4050 0 200; 62 4050 2250 200; 63 0 0 200; 64 5700 0 200;
65 2850 1703 200; 66 1650 703 3800; 67 1650 703 5000; 68 4050 703 3800;
69 4050 703 5000; 70 2850 1703 4400; 71 0 0 7400; 72 5700 0 7400;
MEMBER INCIDENCES
1 1 63; 2 3 59; 3 1 3; 4 2 4; 5 5 61; 6 7 64; 7 5 7; 8 6 8; 9 9 12; 10 10 27;
11 11 14; 12 15 18; 13 29 19; 14 17 20; 15 9 21; 16 10 22; 17 12 23; 18 15 24;
19 18 26; 20 19 25; 21 27 28; 22 29 30; 23 21 23; 24 23 33; 25 24 26; 26 22 28;
27 28 35; 28 30 25; 29 21 31; 30 31 22; 31 26 32; 32 32 25; 33 33 36; 34 36 24;
35 35 38; 36 38 30; 37 33 34; 38 34 49; 39 36 37; 40 37 50; 41 31 34; 42 34 37;
43 37 32; 44 22 11; 45 25 20; 46 21 39; 47 39 45; 48 45 47; 49 47 42; 50 42 26;
51 22 41; 52 41 46; 53 46 48; 54 48 44; 55 44 25; 56 31 40; 57 40 43; 58 43 32;
59 23 45; 60 24 47; 61 28 46; 62 30 48; 63 27 13; 64 16 29; 65 49 35; 66 50 38;
67 34 51; 68 37 52; 69 49 53; 70 50 54; 71 55 51; 72 56 53; 73 57 52; 74 58 54;
75 59 60; 76 61 62; 77 60 63; 78 62 64; 79 65 60; 80 65 59; 81 65 62; 82 65 61;
83 13 66; 84 14 67; 85 16 68; 86 17 69; 87 70 66; 88 70 67; 89 70 68; 90 70 69;
91 60 45; 92 62 47; 95 66 67; 96 67 69; 97 68 69; 98 66 68; 103 63 9; 104 9 10;
105 10 11; 106 11 71; 107 71 2; 108 59 12; 109 12 55; 110 55 56; 111 56 13;
112 13 14; 113 14 4; 114 61 15; 115 15 57; 116 57 58; 117 58 16; 118 16 17;
119 17 6; 120 64 18; 121 18 19; 122 19 20; 123 20 72; 124 72 8;
ELEMENT INCIDENCES SHELL
125 1 2 4 3; 126 5 6 8 7;
ELEMENT PROPERTY
125 126 THICKNESS 8
DEFINE MATERIAL START
ISOTROPIC STEEL
E 210
POISSON 0.3
DENSITY 7.85e-008
ALPHA 1.2e-005
DAMP 0.03
END DEFINE MATERIAL
MEMBER PROPERTY EUROPEAN
1 TO 14 63 64 103 TO 124 TABLE ST TUB40020016
15 TO 62 65 TO 92 95 TO 98 TABLE ST TUB20020012
CONSTANTS
MATERIAL STEEL ALL
MEMBER OFFSET
1 TO 22 63 64 71 TO 76 83 TO 86 103 TO 124 START 0 200 0
1 TO 14 44 45 63 64 77 78 80 82 103 TO 124 END 0 200 0
SUPPORTS
1 TO 8 11 14 17 20 ENFORCED BUT FX FZ MX MY MZ
18 71 FIXED BUT FY MX MY MZ KFX 0.01 KFZ 0.01
LOAD 1 LOADTYPE None  TITLE LC-03
SELFWEIGHT Y -1.19 LIST 1 TO 82 91 92 103 TO 126
JOINT LOAD
70 FY -133
70 FY -199
70 FY -240
65 FY -240
PERFORM ANALYSIS PRINT STATICS CHECK
PARAMETER 1
CODE NS3472
BEAM 1 ALL
TRACK 2 ALL
FYLD 355 ALL
CHECK CODE ALL
FINISH
```

APPENDIX A5: DESIGN SHEAR LOAD CALCULATION (LC-08)

DESIGN SHEAR LOAD CALCULATION (LC-08)

Figures below shows how the loads L-05 and L-06 are distribution onto the lock-collars. The distribution angle of 50° simulates the point of attack from the alignment sleeve on the lock-collar. The point is set to be approximately in the center for the contact face arc on the lock-collar.





Total gravity load (G) is the sum of L-05 and L-06:

$$\mathrm{G} = 240\mathrm{kN} + 199\mathrm{kN} = 439\mathrm{kN}$$

Distributed forces (F_{dis}) into each of the lock-collars are given by:

$$\cos 50° = \frac{G/2}{F_{dis}} \rightarrow F_{dis} = \frac{G/2}{\cos 50°}$$

$$F_{dis} = \frac{G}{2\cos 50°} = 341\mathrm{kN}$$

Distributed force F_{dis} has components in x- and y-direction, and they are given by:

$$F_{dis,x} = F_{dis} \times \sin 50 = 261\mathrm{kN}$$

$$F_{dis,y} = F_{dis} \times \cos 50 = 219\mathrm{kN}$$

Forces in x-direction

The upper collar-bolt (B) can only withstand forces in x-direction. The force in collar-bolt is calculated by an equilibrium equation of moments about the lower collar-bolt (A):

$$\sum \vec{\mathrm{M}}_{\mathrm{A}} = 0 \ \rightarrow \left(\mathrm{F}_{\mathrm{dis,x}} \times \mathrm{D1}\right) + \left(\mathrm{F}_{\mathrm{B,x}} \times \mathrm{D2}\right) = 0$$

$$261\mathrm{kN} \times 490\mathrm{mm} = \ -\mathrm{F}_{\mathrm{B,x}} \times 274\mathrm{mm} \rightarrow \mathrm{F}_{\mathrm{B,x}} = \frac{127890\mathrm{kNmm}}{-274\mathrm{mm}} = -467\mathrm{kN}$$

The sum of forces in x-direction is zero, and the force in x-direction in point A ($F_{A,x}$) is then given by:

$$\sum \vec{\mathrm{F}}_{\mathrm{x}} = 0 \rightarrow \mathrm{F}_{\mathrm{dis,x}} + \mathrm{F}_{\mathrm{A,x}} + \mathrm{F}_{\mathrm{B,x}} = 0$$

$$261\mathrm{kN} + \mathrm{F}_{\mathrm{A,x}} - 467\mathrm{kN} = 0 \rightarrow \mathrm{F}_{\mathrm{A,x}} = 467\mathrm{kN} - 261\mathrm{kN} = 206\mathrm{kN}$$

Forces in y-direction

As the upper collar-bolt is not subjected to forces in y-direction, the force in y-direction in point A ($F_{A,y}$) is given by:

$$\sum \vec{\mathrm{F}}_{\mathrm{y}} = 0 \rightarrow \mathrm{F}_{\mathrm{dis,y}} + \mathrm{F}_{\mathrm{A,y}} = 0$$

$$-219 + \mathrm{F}_{\mathrm{A,y}} = 0 \rightarrow \mathrm{F}_{\mathrm{A,y}} = 219\mathrm{kN}$$

Total force on lower collar-bolt (A) and upper collar-bolt (B):

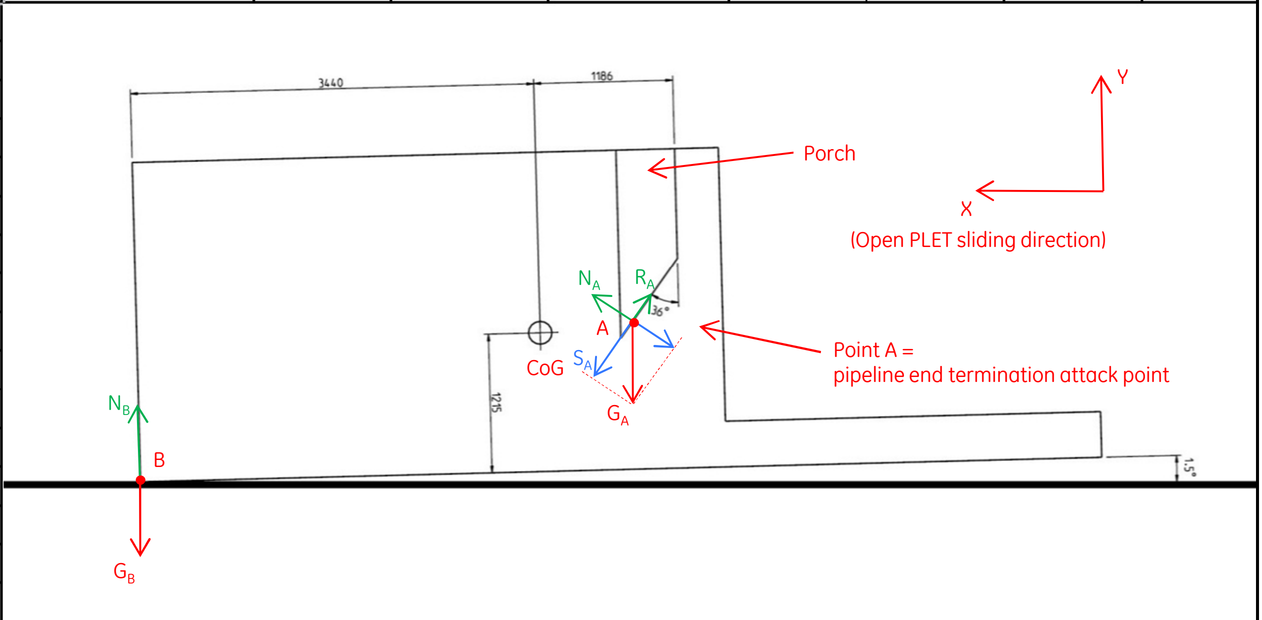
$$\mathrm{F}_{\mathrm{A}} = \sqrt{\left(\mathrm{F}_{\mathrm{A,x}}\right)^2 + \left(\mathrm{F}_{\mathrm{A,y}}\right)^2} = \sqrt{(206\mathrm{kN})^2 + (219\mathrm{kN})^2} = 301\mathrm{kN}$$

$$\mathrm{F}_{\mathrm{B}} = \mathrm{F}_{\mathrm{B,x}} = -467\mathrm{kN}$$

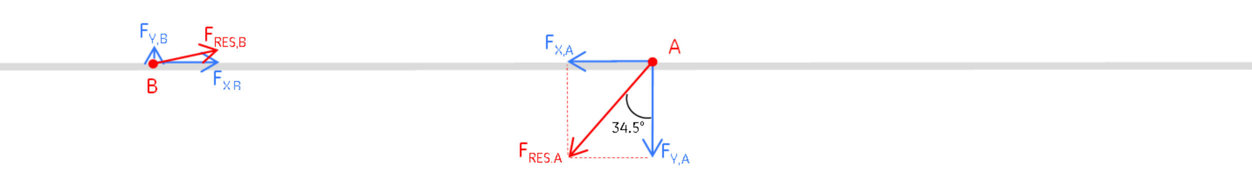
The design shear load (V) to be used in the calculation is V = $|F_B|$ = 467kN.

APPENDIX A6: CALCULATION SHEET (LC-09)

CALCULATION SHEET (LC-09)



	A	B	C	D	E	F	G	H
17	**INPUT DATA**							
18	Open Plet weight		283000	N	submerged weight (L-02 + L-04)			
19	Lifting angle		1.5	deg				
20	Sliding face angle (Porch)		36	deg				
21	Weight distribution		74.0	%	at point A, formula: ((3440/(1186+3440))*100)			
22	Friction coefficient	μ_{steel}	0.20		at point A, steel-steel			
23	Friction coefficient	μ_{soil}	1.00		at point A, steel-soil			
24								
25	- Lifting angle on 1.5° is the maximum possible angle. Angle is verified on 3D model in ProEngineer.							
26	- The Open PLET totalt weight is imaginary applied to the CoG and then distributed to point A and B. Weight distribution is calculated by use of the dimensions from CoG to points A and B (shown on figure above).							
27								
28	**POINT [A] CALCULATION**							
29	Description	Symbol	Value	Unit	Formula			Comments
30	Lift force	F_A	209 420.0	N	C18*(C21/100)			
31	Normal force	N_A	118 616.8	N	C30*(SIN(RADIANS(C20-C19)))			
32	Sliding force	S_A	172 588.5	N	C30*(COS(RADIANS(C20-C19)))			1
33	Friction force	R_A	23 723.4	N	C31*C22			2
34	Resultant force	$F_{RES,A}$	148 865.1	N	C32-C33			3
35								
36	**POINT [B] CALCULATION**							
37	Description	Symbol	Value	Unit	Formula			Comments
38	Gravity force	G_B	73 580.0	N	C18*(1-(C21/100))			
39	Normal force	N_B	73 554.8	N	C33*(COS(RADIANS(C19)))			
40	Sliding force	S_B	1 926.1	N	C33*(SIN(RADIANS(C19)))			4
41	Friction force	R_B	73 554.8	N	C39*C23			5
42	Resultant force	$F_{RES,B}$	-71 628.7	N	C40-C41			6



- The resultant force at point A indicates whether the Porch will slide on the pipeline end termination or not. A positive value means that the sliding force is higher than frictional force in the point, and sliding at the point occurs.
- The resultant force on point B simulates whether the Open PLET will slide on the seabed or not. A negatvie value means that the frictional force in the point is higher than the sliding force, and no sliding at the point occurs.

- The sum of the resultant force in x-direction ,$F_{X,A}$ + $F_{X,B}$, indicates whether the Open PLET will slide or not. If the value is positive, the Open PLET will slide because the resultant force in x-direction (= Open PLET sliding direction) at point A is higher than the resultant force in x-direction at point B.

	A	B	C	D	E	F	G	H
57	**RESULTANT FORCES IN X-DIRECTION**							
58	Description	Symbol	Value	Unit	Formula			Comments
59	Point A	$F_{X,A}$	84 318.1	N	C34*(COS(RADIANS(90-(C20-C19))))			7
60	Point B	$F_{X,B}$	-71 604.1	N	C42*(COS(RADIANS(C19)))			7
61	TOTAL	F_{AXIAL}	12 714.0	N	C59+C60			

SLIDING VERIFICATION

	A	B	C	D	E	F	G	H
65	**SLIDING VERIFICATION**							
66	Open PLET will slide?		**YES**		IF((C61)<0; "NO"; "YES")			

COMMENTS:

1. Sliding force at point A is forcing the Open PLET to slide when pipeline end termination is lifted. The force direction is 34.5° (36°-1.5°) from the y-axis in positive x- and negative y-direction.

2. Friction force acts between the Porch and the pipeline end termination. The force is a result of the weight of the Open Plet on the pipeline end termination. The force acts in direct opposite direction to the sliding force at point A.

3. Resultant force at point A are the sum of the sliding force and the friction force. The force direction is 34.5° (36°-1.5°) from the y-axis in positive x- and negative y-direction.

4. Sliding force at point B is forcing the Open PLET to slide when the skid is lifted from seabed (it is forcing the Open PLET to slide, but this force becomes very small compared to the friction force at point B for small lifting angles). The force direction is 1.5° from x-axis in positive x- and negative y-direction.

5. Friction force acts between the skid and the seabed. The force is a result of the weight of the Open PLET on the seabed. The force acts in direct opposite direction to the sliding force at point B.

6. Resultant force at point B is the sum of the sliding force and the friction force. The force direction is 1.5° from x-axis in negative x- and positive y-direction.

7. The resultant forces in x-direction are the forces in axial direction which determines if the Open PLET will slide or not. The forces are the x-components to the resultant forces at respectively point A and B.

CONSTANT FRICTION COEFFICIENT [μ_{steel}] = 0.15

		LIFTING ANGLE [deg]														
WEIGHT DISTRIB. [%]		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
	69	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	70	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩
	71	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	72	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	73	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	74	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	75	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

NO SLIDING

SLIDING

CONSTANT FRICTION COEFFICIENT [μ_{steel}] = 0.20

		LIFTING ANGLE [deg]														
WEIGHT DISTRIB. [%]		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
	69	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	70	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	71	🟥	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	72	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	73	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	74	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	75	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

NO SLIDING

SLIDING

CONSTANT FRICTION COEFFICIENT [μ_{steel}] = 0.25

		LIFTING ANGLE [deg]														
WEIGHT DISTRIB. [%]		0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5
	69	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	70	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	71	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	72	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	73	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	74	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	75	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

NO SLIDING

SLIDING

- The tables above show when sliding will occur (green areas) for three different friction coefficients at point A. The friction coefficient at point B is 1.00 for all three tables. The intention is to illustrate how a change in the friction coefficient affects the sliding situation. For example, when $\mu_{steel} = 0.20$, the weight distribution must be 71% (or higher) and the lifting angle at least 0.5° to achieve sliding.

- The table below (next page) shows when sliding occurs when varying the friction coefficient and the weight distribution at point A. The lifting angle is constantly 1.5°. For example, with a friction coefficient $\mu_{steel} = 0.25$, the weight distribution must be 72% or higher to achieve sliding.

- The graphs below (next page) show the maximum friction coefficients possible to achieve sliding for different weight distribtuions. The lifting angle is 1.5°. For the graph at point A, the friction coefficient at point B is 1.00, and for graph B the friction coefficient at point A is 0.20. For example, at point A, no sliding occurs with a weight

CONSTANT LIFTING ANGLE = 1.5°

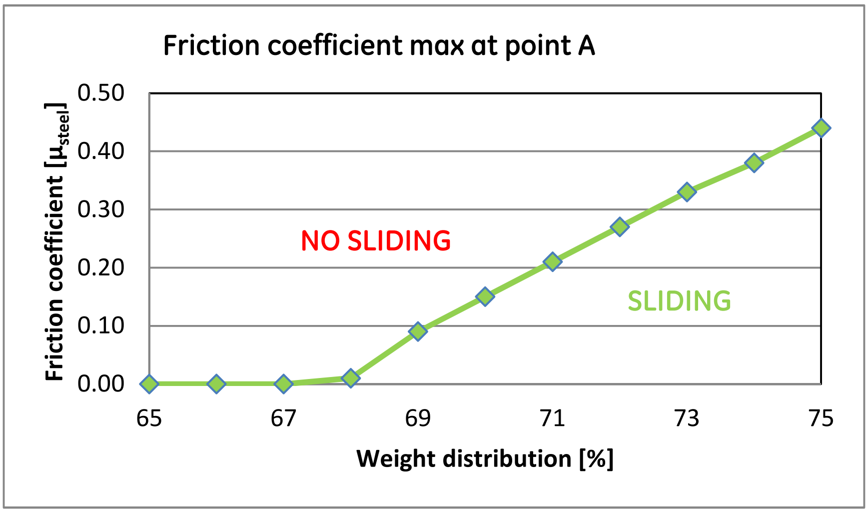
FRICTION COEFFICIENT [μ_{steel}] IN POINT A

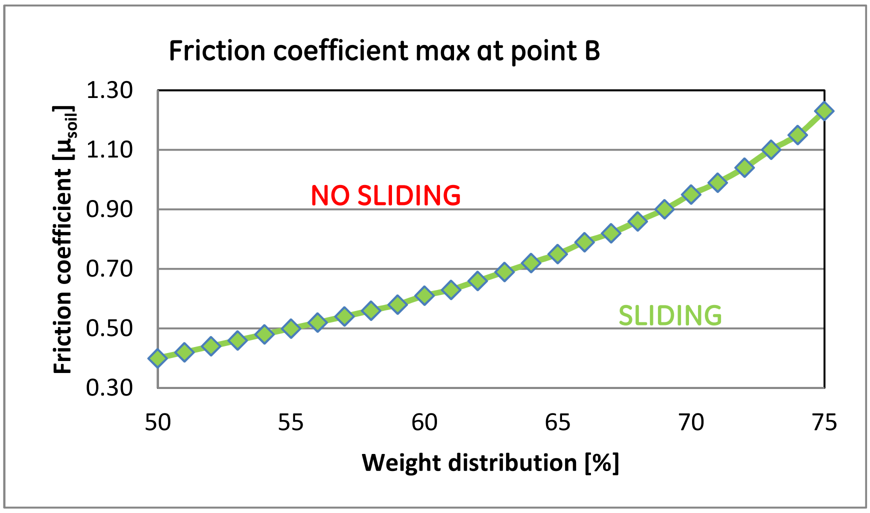
WEIGHT DISTRIBUTION [%]	0.15	0.16	0.17	0.18	0.19	0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.28	0.29
65	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
66	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
67	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
68	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
69	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
70	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
71	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
72	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥
73	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
74	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
75	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

🟥 NO SLIDING

🟩 SLIDING

WD	A	B
50	0	0.40
51	0	0.42
52	0	0.44
53	0	0.46
54	0	0.48
55	0	0.50
56	0	0.52
57	0	0.54
58	0	0.56
59	0	0.58
60	0	0.61
61	0	0.63
62	0	0.66
63	0	0.69
64	0	0.72
65	0	0.75
66	0	0.79
67	0	0.82
68	0	0.86
69	0.1	0.90
70	0.15	0.95
71	0.21	0.99
72	0.27	1.04
73	0.33	1.10
74	0.38	1.15
75	0.44	1.23





- The values in the table above is found by varying the weight distribution value and then the friction coefficient value at point A or B to find the respective limiting value. WD = Weight distribution, A = friction coefficient at point A ,and B = friction coefficient at point B.

SLIDING FACE ANGLE	TOTAL FORCE F_{AXIAL}
35	12022.6
36	12714.0
37	13277.2
38	13711.4
39	14016.1
40	14191.1
41	14236.0
42	14150.8
43	13935.6
44	13590.6
45	13116.4

- The graph below show the total force in x-direction for various sliding face angles. The optimal angle is the one which gives the highest totalt force.

- The values in the table to the left are found by varying the sliding face angle in the input data.