University of Stavanger

Faculty of Science and Technology

MASTER'S THESIS

Study program/ Specialization: Offshore Technology – Marine & Subsea Technology	Spring semester, 2012 Open
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Title of thesis: Investigation of Necessary Subsea Structure Modifications Prior to Installation of New Offloading System at Gullfaks	
Credits (ECTS): 30	
Key words: SPM, Offloading buoy, Gullfaks, subsea structure modification	Pages: 92 + enclosure: 35 Stavanger, 15.06.2012

Investigation of Necessary Subsea Structure Modifications Prior to Installation of New Offloading System at Gullfaks

Written by Erik Eide

Master Thesis, Spring 2012

Offshore Technology – Marine & Subsea Technology

University of Stavanger

Abstract

Due to the extension of the Gullfaks license, Statoil needs to perform several upgrades to systems to satisfy today's regulations. Today`s system consist of two large single point moored offloading buoys, SPM 1 and SPM 2. Statoil wishes to replace these with a new type of offloading system. The old system is just too expensive to maintain and will demand a comprehensive upgrade to meet the new regulations. The solution is to replace the existing system with a new system which is less expensive to maintain.

The existing offloading system consists roughly of a column from seabed to above sea surface, a connection plate and a subsea base structure. This thesis has focused on investigating necessary subsea structure modifications in order to use the existing base structure as interface for the new offloading system.

An investigation of the condition of the existing system has been performed, resulting in evaluations and recommendations regarding how to disconnect the connection plate and column from the base structure, and what measures must be taken in order to install a new system on the existing base.

The connection plate and column should be disconnected by a combination of ROV and diver assisted operations. The recommended solution is to use ROV in most cases due to economical and safety aspect of the operation. The disconnection will result in good connection possibilities for the new system, regarding both oil flow and locking mechanism. A riser base must be installed onto the base structure, working as an adapter between the base structure and the new offloading system.

The investigation revealed that extra sacrificial anodes need to be installed in order to restore sufficient cathodic protection of the structure. The result of a strength analysis performed in SolidWorks Simulation carried out on possible mounting points was very satisfactory and maximum stresses did not exceed 144,6 MPa with a safety factor of 1,5. The yield strength of the material is minimum 310 MPa.

The base structure is well suited for connecting a new system to the already existing infra-structure. However, this thesis only covers an investigation of what needs to be done. More detail planning and design and production of custom made tooling will be necessary in order to disconnect the connection plate and column.

Preface

This report is my master thesis of my master program in offshore technology at the University of Stavanger. The complexity of the thesis has made it challenging and most of the available documentation consisting of reports, procedures and drawings were created in 1986. Especially the hand written and extremely detailed drawings were demanding to understand at first. However, it has been an educational process giving me a good understanding of offshore offloading system and the complexity of performing modifications on older subsea structures.

This project was presented to me through my team leader in Oceaneering, Karl Kallevåg-Albrektsen. The many challenges and issues regarding subsea modifications to the offloading system sounded exciting. Contact was made to Øystein Kanestrøm at NCA, which established a contact with Stian Garlid at Statoil. Through varies meetings with my contacts in Statoil, NCA, Oceaneering and my faculty supervisor, Jonas Odland, the scope of work was formed.

The core aim of this thesis has been to investigate necessary subsea modifications prior installation of a new system on the existing base structure. A comprehensive pre-study was necessary to get a sufficient foundation for my work. My experience as a project engineer in the DTS Tooling department at Oceaneering has been of great benefit in order to use the SolidWorks CAD software and to understand the advantages and limitations of ROV`s.

I would like to thank both my supervisors, Karl Kallevåg-Albrektsen at Oceaneering AS and Professor II Jonas Odland at the University of Stavanger, and Øystein Kanestrøm at NCA, for providing me with useful ideas and constructive feedback throughout the period of my work. I would also like to thank Stian Garlid, platform technology engineer at Statoil, for assistance and for providing the technical documentation of the offloading system, and Jan Knut Fiskaa, principal service project engineer at National Oilwell Varco, for information regarding the APL offloading system. I will also like to thank Zenon Taushanis, senior project engineer at Oceaneering, for guidance for the strength analysis. Without their assistance this thesis could not have been written.

Oceaneering AS deserves an acknowledgment for giving me the opportunity and flexibility for studying for my master's degree through our study-agreement.

I will like to extend my gratitude to my wonderful girlfriend, Linn Underbakke. Thank you for reading through my thesis and correcting my grammar and spelling, and thank you for your invaluable support and encouragement during the past three years as I have been studying part-time beside full time work.

Stavanger, June 2012

……………………………….

Erik Eide

Abbreviations

The abbreviations used throughout this report are listed in the following table:

Abbreviations

APL	Advanced Production & Loading
Bbl.	Barrel
CAD	Computer-Aided Design
Condeep	Concrete deep water structure
CP	Cathodic Protection
DVD	Digital Video Disc
FEA	Finite Element Analysis
HAZ	Heat Affected Zone
HPU	Hydraulic Pressure Unit
I.D.	Inner Diameter
kN	Kilo Newton (= 1000 Newton)
MPa	Mega Pascal = N/mm^2
O.D.	Outer Diameter
OROV	Observation ROV
PSI	Pound per square inch
ROV	Remotely Operated Vehicle
Sm^3 o.e	Standard cubic meters oil equivalents
SPM	Single Point Mooring
WROV	Work ROV

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Appendix E	Verification of pre-stressed bolt length after cutting
Appendix F	Strength analysis for locking bolt housing

1. Introduction

1.1 Background for the thesis

In more than 25 years the Gullfaks field has supplied the marked with oil, gas and condensate from its reservoirs. The field was build out with three large, fully integrated, processing, drilling and accommodation platforms of the CONDEEP type, named Gullfaks A, B & C. Together, Gullfaks A and C have a total oil storage capacity close to four million barrels of oil.

The oil is transported from the storage tanks over to shuttle tankers through two single point moored offloading towers (Gullfaks SPM 1 & Gullfaks SPM 2).

Due to the size of the Gullfaks field with all of its belonging fields and wells, it is a significant piece of the subsea infrastructure in the Tampen area. The result of this is that even if the Gullfaks main field is in its tail phase of production, it is still desirable to upgrade the facilities in relation with extension of the Gullfaks license. The license has been extended from 2015 till 2030.

As part of this upgrade it will be necessary to upgrade the offloading system. Statoil is planning on removing both the Gullfaks SPM 1 and SPM 2, for the benefit of a new type of offloading system.

1.2 Objective

Regarding the removal of today`s system at Gullfaks, Statoil wishes to re-use parts of the existing structure. An opportunity is to disassemble the column from the subsea gravity base structure. The remaining structure can then be integrated to the new type offloading system.

The scope of work for this master thesis is to investigate what structure modifications that will be necessary on the existing structure of the SPM 1 prior to installation of a new type of offloading system at Gullfaks. This will mainly consist of how to disconnect the SPM column and what measures that needs to be taken before installation of a new system.

This work will in the first phase consist of a study of the SPM itself based on drawings and documentation from the engineering, building and installation phase. The thesis will then be continued with a study of the actual condition of the system after being in service since 1987 (SPM 2).

The foundation for this study is based on a survey executed in March 2012 by DeepOcean for Statoil AS. The scope of this survey was to inspect critical areas regarding the disconnection of the column. The survey was executed with an observation ROV.

Further, a study of the new planned offloading system is done. This is to determine the actual interfaces to the system and how it actually can be connected to the existing structure. Figure 1.1 and 1.2 illustrates the main differences between the old and the new system. Chapter 6 is dedicated to describe the new system in detail.

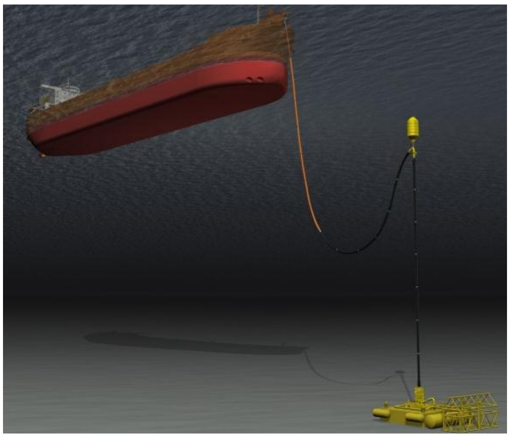


Figure 1.1: Alternative system from APL [1]

Figure 1.2: Present system at Gullfaks [2]

Based on these studies, a detailed investigation of how to disconnect the column from the base structure and necessary modifications to the structure will be carried out. The thesis will mainly focus on the anchoring and riser connection to the existing structure. It is highly desirable that the modifications necessary for installation of the new system is possible to accomplish with ROV, without any assistance from divers. This is due to the economic and safety aspect of the operation.

The first chapter in this thesis will give an introduction to the Gullfaks field, explaining the complexity of Gullfaks and the subsea infrastructure in the Tampen area. This introduction will give the answer to the question; why do Statoil wish to replace two offloading systems on a field in its tail production phase.

1.3 Limitations

This thesis presents a wide scope of work. To cover as many aspects of the task as possible, it affects the detailed level of the thesis. The thesis focuses more on what need to be done and less degree of detail on how to do it. The reason for this is that many of these modifications demands relatively demanding studies in themselves and does not correspond to the workload of a master thesis. Limitations taken in this thesis are presented in this section.

The focus where on the subsea base structure at which the SPM column is mounted at. A survey is presented on were to disconnect the column and how this can be done, but the marine operations associated with the removal are not part of the thesis.

The Gullfaks field has two offloading units, SPM 1 and SPM 2. These are close to identical and the descriptions of the system will therefore be applicable for both systems. Investigations of necessary modifications are based on the survey report of SPM 2.

One system is described as a potential alternative, delivered from APL. Other systems can be adapted to fit the subsea base structure, but this is not part of the thesis. APL delivered a similar system to replace the Statfjord SPM A and B, and there is a good chance that Statoil chooses the same type of system on the Gullfaks field.

In chapter 5 the disconnection of the column and the connection plate is discussed. The chapter compares ROV operations and diver assisted operations for the different stages of the removal operation. Due to the economic and safety aspects, ROV operations are in most cases preferred over diver operations in the North Sea over the last years. An economic evaluation to compare different options is not part of this thesis.

1.5 Software

For the modeling and strength analysis in this thesis, the 3D CAD software SolidWorks has been used. The simulation part of the Solid Works software is called SolidWorks Simulation.

SolidWorks is a three-dimensional parametric and function based CAD modeling- and analyzing program. SolidWorks Simulation is a design-analyzing tool which can execute analysis on complicated geometries based on the finite element analysis (FEA). This is a numerical technique for solving problems with partial differential equations. This is the most applied method used by engineers worldwide.

Prior any analysis of a geometrical model the following parameters must be defined in the program:

- Material properties
- Fixture of the model
- Loads

The model is then divided into small elements. This feature is called meshing. The different elements share common points which are called nodes. Response of the nodes in structural analysis is defined by three translations and three rotations. The deformation and stresses in the model is determined by adding all the solutions from the individual elements in a theoretical approach. [3]

The FEA simulation takes the following approaches:

- Linear material properties
    - Hooke`s law; The stresses are directly proportional with the strain
- The deformation is small enough to neglect change in stiffness which are caused by the load.
- The boundary conditions do not change when the load is applied. The load is constant in magnitude, direction and distribution.
- Von Mises stresses

2. Short description of Gullfaks

2.1 Introduction

This thesis will have its main focus on the Gullfaks offloading buoy structures, but due to the complexity of the Gullfaks field and the many associated fields, it is considered relevant to give an introduction of the fields to be able to understand the complexity and why Statoil is willing to replace both the offloading buoys on a field which is in its tail production.

2.2 Main field overview

The Gullfaks main field is located in the Norwegian sector in the Tampen area in the North Sea in block 34/10, about 160km west of Sognefjorden and 20 km south-west of the Statfjord field.

The field was discovered in 1978 and has been developed with three large fully integrated condeep processing, drilling and accommodation platforms, namely Gullfaks A, Gullfaks B and Gullfaks C. The water depth in the area varies from 130 to 220 meters.

Figure 2.1: Gullfaks field location [4]

On the 22 of December 1986 the field started producing on Gullfaks A, followed by Gullfaks B and Gullfaks C on 29 of February 1988 and 4 of November 1989, receptively. The Gullfaks field had its peak production in 1994 with total production of 33,99 mill Sm^3 o.e., and is now in its tail production phase with 6,1 Sm^3 o.e produced in 2011.

The total reserve estimates as of 12.02.2012 are 365,4 mill Sm3 of oil, 23 bill Sm^3 of gas and 2,8 mill tons of NGL. The remaining recoverable reserves are estimated to be 16,7 Sm^3 of oil. [5]

The Gullfaks main field was further developed with Gullfaks West in 1993 and Gullfaks Lunde in 1996. The Gullfaks West field is being drained with horizontal wells drilled from Gullfaks B and Gullfaks Lunde is being drained with wells drilled from Gullfaks C.

The recoverable factor on Gullfaks is 59 %, but the goal is to reach 62%. Horizontal and extended-reach wells, new completion and sand control technology, and water alternating gas (WAG) injection are all measures used to improve the recovery factor.

With the well drilled from Gullfaks A to Gulltopp (ref. figure 2.2), Statoil sat world record. This was the longest, most complicated well in Statoil`s history ever to be drilled from an offshore platform. Gulltopp came on stream in April 2010. Recoverable reserves are estimated to be 4 mill Sm^3 of oil and 500 mill Sm^3 of gas.

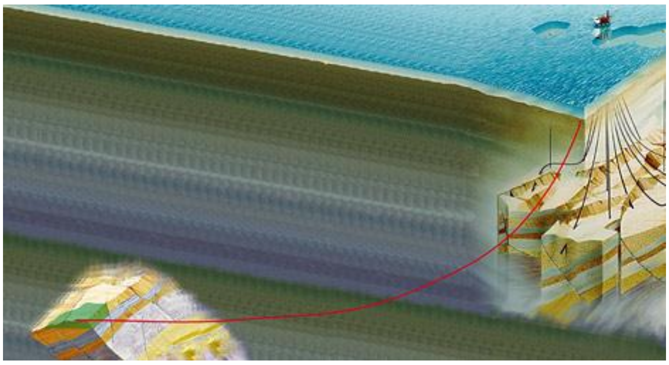


Figure 2.2: The Gullfaks A – Gulltopp well [6]

Statoil (70%) and Petoro (30%) are the only two license holders on Gullfaks, and this was the first time a purely domestic consortium had been awarded an offshore license. Statoil additionally operates the field [7].

The Gullfaks license expires in 2016, but currently efforts have been started with a goal to extend the life of Gullfaks towards 2030 with the possibility of further extension to 2040.

Reservoir specifications

The Gullfaks reservoirs consist of Middle Jurassic sandstones of the Brent Group, and Lower Jurassic and Upper Triassic sand stones of the Cook, Statfjord and Lunde Formations. The reservoirs lie from 1700 and down to 2000 meters below the sea level. [8]

The drive mechanisms for improved recovery from the Gullfaks field vary between the drainage areas, but water injection constitutes the main strategy. Gas and alternating water/gas injection are also used.

2.3 Gullfaks satellite fields

The Gullfaks satellite fields consist of Gullfaks South, Rimfaks, Gullveig and Skinfaks and are all included in the Gullfaks license. These are all developed with subsea wells remotely controlled from the Gullfaks A and C platforms. In addition the Gimle well is also tied back to the Gullfaks C platform. See figure 2.1 for field overview.

While the Gullfaks main field is now on decline with only 16,7 mill Sm^3 recoverable oil left in the reservoir, the Gullfaks satellite production is overall still at plateau with a production of 4 mill Sm^3 of oil and 4 bill $Sm^3$of gas per year. The total of recoverable oil reserves are estimated at 50 mill Sm^3 [9].

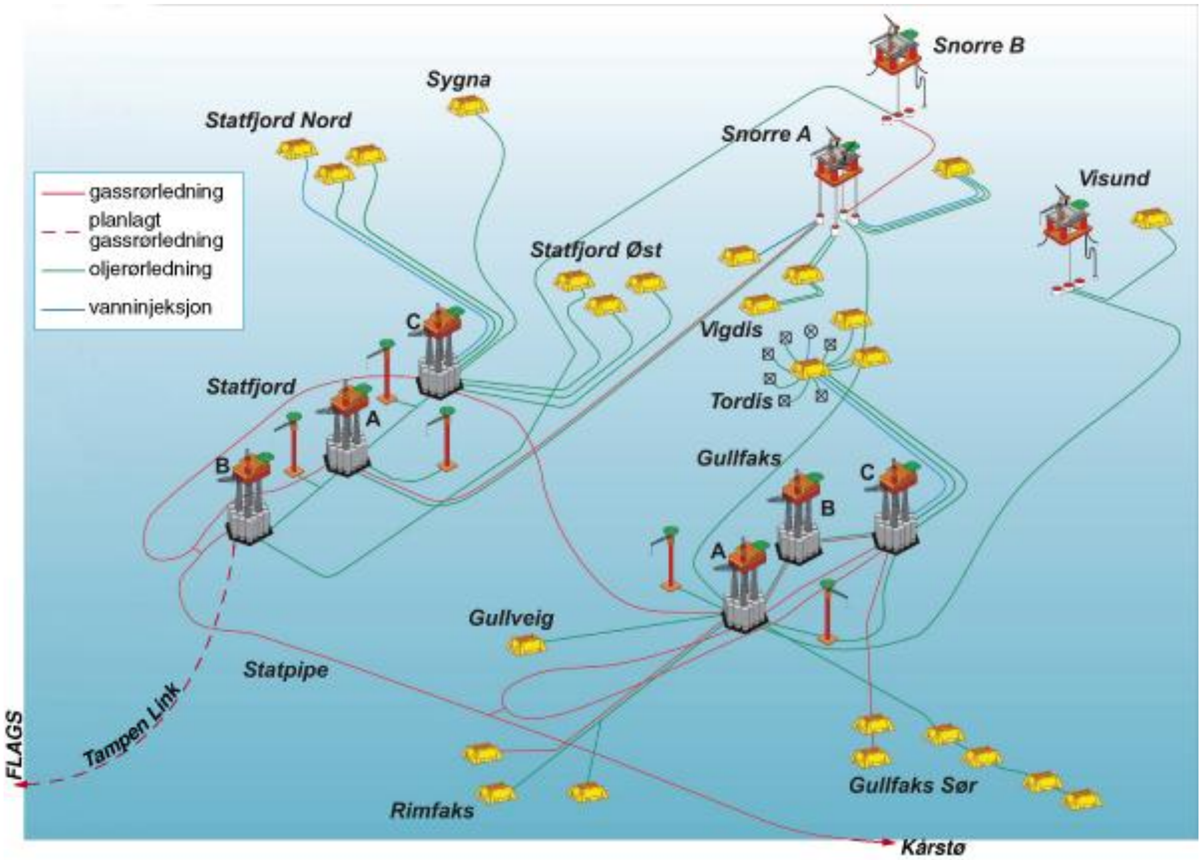


Figure 2.3: Overview of Gullfaks and close by fields in the Tampen area [10]

Gullfaks South

The Gullfaks South satellite field is developed with subsea production installations. Phase one of the developments came on stream in October 1998 and phase two came on stream in October 2001.

Production of oil and condensate, with reinjection of associated gas is covered in phase one, while phase two covers production and export of gas and liquids with subsea installations tied back to both Gullfaks A and C. [11]

Gullveig

The Gullveig satellite field is developed with a subsea template installed 11 kilometers west of Gullfaks. The installation is tied back via a flowline to the Gullfaks A platform. Gullveig came on stream on 10 October 1998 with oil production. [12]

Rimfaks

The Rimfaks field is developed with three subsea templates tied back to the Gullfaks A platform and started production of oil on 7 February 1999. [13]

Skinfaks

The Skinfaks field is developed with several smaller structures and a subsea production system tied back into existing x-mas trees on the Gullfaks South Satellite field. Production started on 27 January 2007. [14]

Gimle

The 7400 meter long Gimle oil well, which came on stream in 2006, is tied back to the Gullfaks C platform. The Gimle covers two licenses and does not have the same ownership structure as Gullfaks. A tie-back and processing contract has been established to handle this.

2.4 Other fields tied-back to Gullfaks

In addition to the satellites fields developed on the Gullfaks license, the three Gullfaks platforms also receive hydrocarbons from other close by fields, ref. figure 2.3.

Tordis

The Tordis main structure came on stream in 1994, but has been further developed with the Tordis East (1998), Borg (1999) and Tordis South East (2001) fields. These fields have all been developed with subsea installations, and the well stream is routed to Gullfaks C for processing, storage and export of oil and gas. [15]

Tordis was the world`s first full-scale commercial subsea separation, boosting and injection system (SSBI). With the SSBI system installation between the existing Tordis subsea field and Gullfaks C in 2007, Statoil expects to improve the Tordis field`s recovery factor from 49 % to 55 %. This is achieved by subsea water removal from the well stream and reinjection of the separated water in a water injection well, ref. figure 2.4.[16]

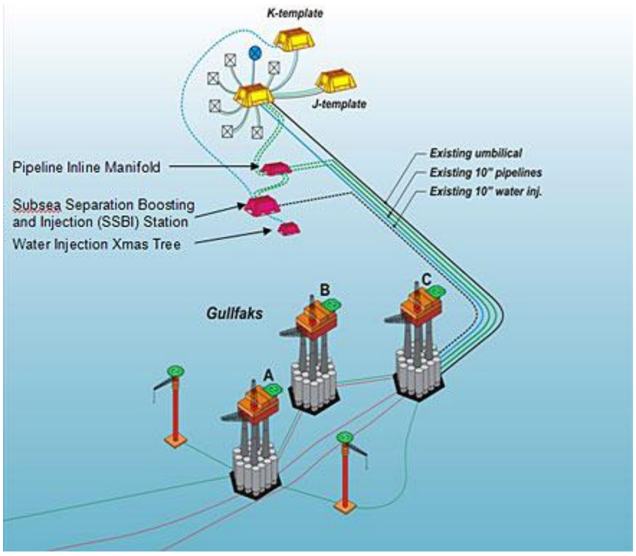


Figure 2.4: Tordis SSBI system [17]

Vigdis

Vigdis has been developed with subsea installations tied back to the Snorre A platform for processing of oil and gas. Stabilized oil is transported by a pipeline to Gullfaks A for storage and export, while the gas is being processed and transported from Snorre A. [18]

Visund

Visund is an oil and gas field developed with floating production, drilling and quarters platform and subsea wells tied back to the platform with flexible risers. The field came on stream in the spring of 1999 and the processed oil is piped to Gullfaks A for storage and export. Visund was further developed with a separate subsea development about 10km from the platform. [19]

2.5 Production, storage & transportation

The purpose of this section is to give an overview of the incoming oil to the Gullfaks platforms, and which platform that process and store oil from the different satellites and fields, ref. table 2.1 below. This is done due to the complexity of the Gullfaks fields. The SPM offloading buoy system will be further described in the next section.

The oil is offloaded from Gullfaks A and C to shuttle tankers from two offloading buoys, currently Gullfaks SPM 1 and SPM 2, while the associated processed gas is being transported to the Kårstø gas treatment plant, either directly through Statpipe or via Statfjord and Statpipe. Gullfaks SPM 1 and SPM 2 is planned replaced within 2016. In the picture below, Gullfaks A are shown with the Gullfaks B and Gullfaks C in the horizon.

Figure 2.5: The three Gullfaks coondeep platforms[20]

Gullfaks A is a drilling, production, accommodation and oil storage platform with a storage capacity of 1.950.000 bbl. All the produced gas from the Gullfaks South, Rimfaks and Gullveig is being re-injected to the Gullfaks field.

Gullfaks B is a drilling and accommodation platform with a simplified processing plant with only first stage separation. Oil and gas from Gullfaks B must therefore be transported to either Gullfaks A or Gullfaks C for further processing and storage. The Gullfaks B base is therefore not used for oil storage, but filled with water.

Gullfaks C is a drilling, production, accommodation and oil storage platform, with a storage capacity of 2.000.000 bbl., slightly larger the Gullfaks A.

From: To:	Gullfaks A	Gullfaks B	Gullfaks C
Gullfaks A	Processing, storage & offloading	-	-
Gullfaks B	Processing, storage & offloading	-	Processing, storage & offloading
Gullfaks C		-	Processing, storage & offloading
Gullfaks South Ph. one	Processing, storage & offloading	-	-
Gullfaks South Ph. two	Processing, storage & offloading	-	Processing, storage & offloading
Gullveig	Processing, storage & offloading	-	-
Rimfaks	Processing, storage & offloading	-	-
Skinfaks / Gullfaks South	Processing, storage & offloading	-	Processing, storage & offloading
Gimle	-	-	Processing, storage & offloading
Tordis	-	-	Processing, storage & offloading
Vigdis / Snorre A	Storage & offloading	-	-
Visund	Storage & offloading	-	-

Table 2.1: Production, storage and offloading overview for the Gullfaks field

The table above gives you an understanding of which fields and wells that are connected to the different Gullfaks platforms and what is done with the stream from the other fields. The left column represents the source from which the oil flows from, and the upper row represents the platforms the oil is transported too and

Regarding the oil stream, one can see that Gullfaks processes all the oil from the different fields, except from the Vigdis and Visund fields, where the oil is being processed at Snorre A and Visund, receptively. Gullfaks B has, as mentioned earlier, only first stage separation and the oil is transported to Gullfaks A or C for further processing.

3. Description of existing offloading system

3.1 Introduction

The stabilized oil stored in Gullfaks A and C is being loaded from the platform over to shuttle tankers through two offloading buoys. The offloading systems at Gullfaks consist of Gullfaks SPM 1 and Gullfaks SPM 2. Except from the oil flow on the base structure explained in section 3.3.2, the DFI from SPM 1 and SPM 2 are more or less the same.

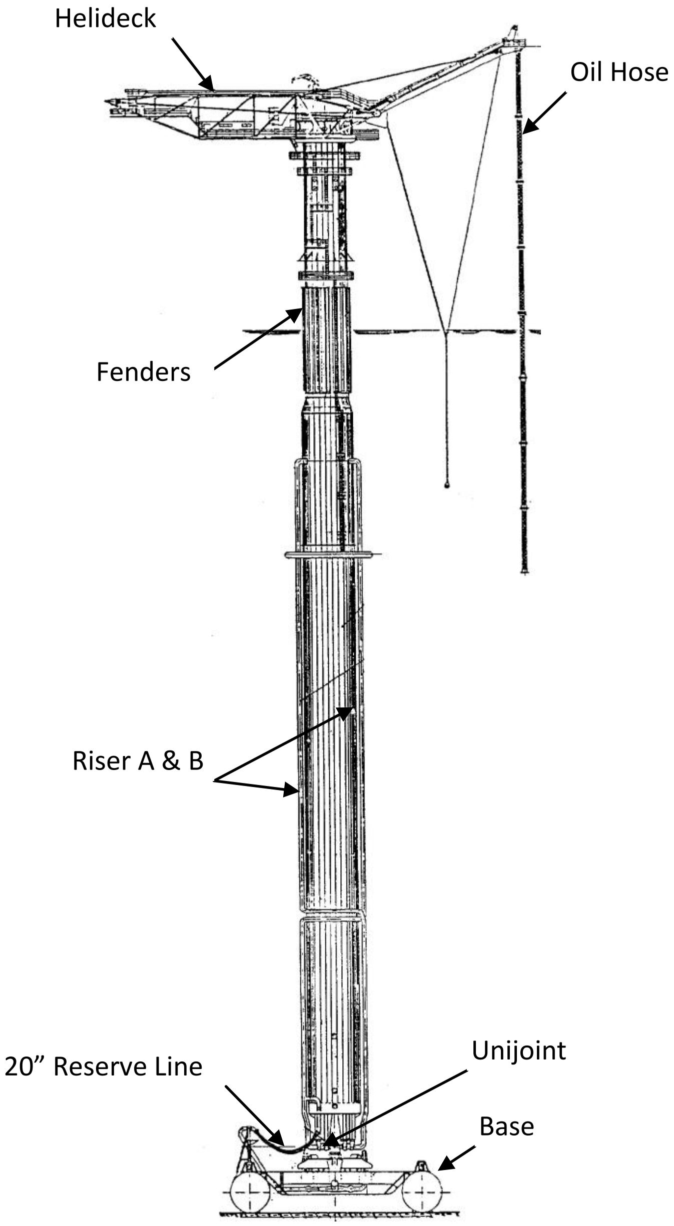


Figure 3.1: SPM illustration [21]

These systems consist of a vertical column attached to a gravity base structure at the seafloor and a small platform on top with helideck and shelter room for workers during maintenance work at the SPM. In between the column and the base structure there is a universal joint that allows the column to move in all directions in the horizontal plane, see figure 3.1. See appendix A for general arrangement drawing of Gullfaks SPM 1.

In this chapter the reason for changing the systems will be explained and the Gullfaks SPM systems will be described in detail. This is due to the following condition-study in chapter 4. The condition-study is part of the pre-study for determine which modifications that will be necessary before installing the new offloading system. Prior installation of a new system, the column has to be dismounted from the already existing structure.

3.2 Gullfaks SPM location & platform connection

The SPM 1 is only directly connected to the Gullfaks A platform, while the SPM 2 are connected to both Gullfaks A and Gullfaks C. If there should be any technical difficulties it is possible to route the crude oil from Gullfaks C past the SPM 2 to the SPM 1, although the crude oil must be transferred via Gullfaks A topside.

3.2.1 Geographical location of Gullfaks SPM 1 & 2

The *SPM 1* offloading buoy is located approximately 2,3 kilometers north-west of Gullfaks A. The water depth at the location is 136 meters [22].

The SPM 2 offloading buoy is located approximately 2,3 kilometers south-west of Gullfaks A. The water depth at the location is 136 meters [23].

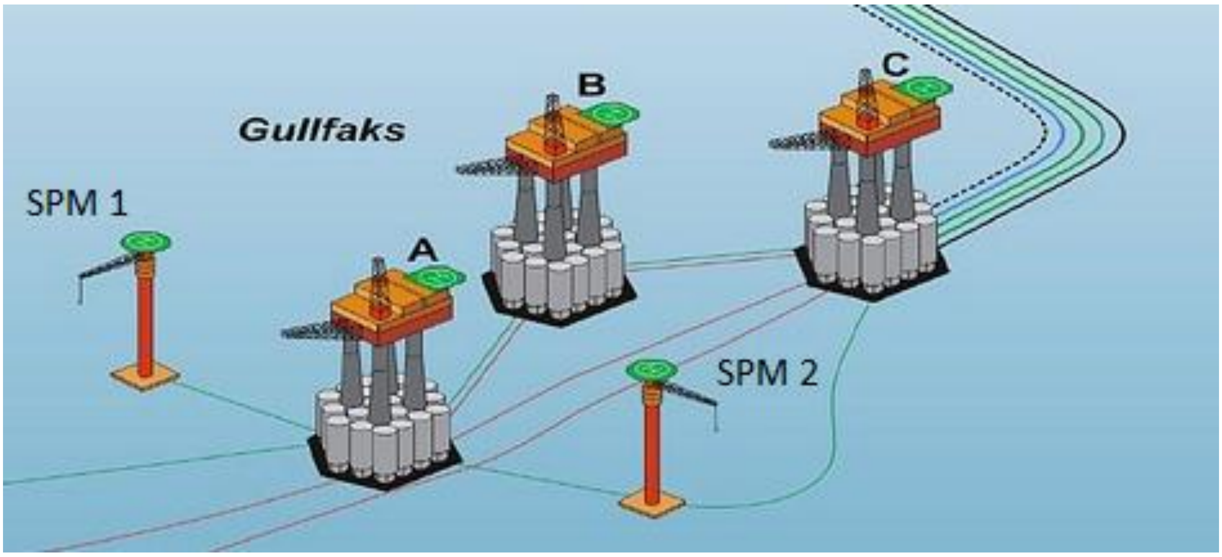


Figure 3.2: Gullfaks SPM location and flowline connection [24]

3.3 Gullfaks SPM function

3.3.1 Main function

The main function of the offloading buoys is to [25]:

- Be an anchoring point for shuttle tankers from 80.000 to 150.000 deadweight tonnage.
- Maintain an offloading capacity of 8520 m^3 oil pr. hour in sea states up to 5 meters significant wave height.
- Maintain a high offloading availability with a low degree of maintenance needed.

The actual capacity parameters are listed in the table below:

Capacity Parameters	
Design Oil Flow	10.000 m^3/hour
Maximum Oil Temperature	40 degree C
Design Pressure	32,3 BARG
Maximum Operational Pressure	22,5 BARG
Pressure drop, Base structure to shuttle tanker (maximum oil flow, oil temp of 8 °C, viscosity 35 es)	Approximately 4 BAR

Table 3.1 Capacity parameters

3.3.2 Main dimensions

The main dimensions are listed in the table below [26].

Main Dimensions[meter]			
Height (approximately):			
Total Height (Helideck to Seafloor)	172,8		
Height from sea level to helideck	47,3		
Rotating Head (approximately):	Length	Width	
Helideck	30	30	
Loading Boom	25	9	
Total	67,5	30	
Column Diameter	I.D	O.D	
	6,6 m	6,644-6,688	
	8,0	8,072-8,088	
Base	Length	Width	Height
Total	37,0	33,5	14
Weight	Net: 1449 t, Ballast: 3949 t		

Table 3.2 Main dimensions and weight

3.3.3 SPM offloading system

This system is identical on the SPM 1 and SPM 2. The crude oil is flowing in on the base structure through a 36” pipeline. On the base structure it is separated into 3 pipes. Two 24” pipe goes through each side of the universal joint and further up in the column, defined as riser A and B. The third pipe is a 20” reserve line with a flexible pipe bypassing the universal joint and into riser B.

The selection of which riser line to use is controlled by five hydraulic operated and two manually operated valves.

Riser A and B rises on the outside of the column up to approximately 20 meters below sea level. At this point they enter the column and continue further up to the swivel, where they are joined into one 34” pipe line. The pipe diameter is reduced to 24” after the swivel. Via a flexible hose, the pipe continues to the connection piece for the 20” offloading hose. This hose consists of eight of ten meters long hoses and ends up in the connection point in the shuttle tanker [27].

Figure 3.3: Offloading from SPM 2 to tanker [2]

SPM crude oil flow

The crude oil flow is the same in both SPM 1 and SPM 2. The only difference is that the SPM 1 is connected to Gullfaks A, while SPM 2 is connected to both Gullfaks A and Gullfaks B. Figure 3.4 below shows the crude oil piping arrangement with associated valves on Gullfaks SPM 1. Detailed drawing attached in appendix A, drawing number C001-L-A40-FB-001. All the valves on both SPM 1 and 2 can only be operated onboard the SPM`s themselves.

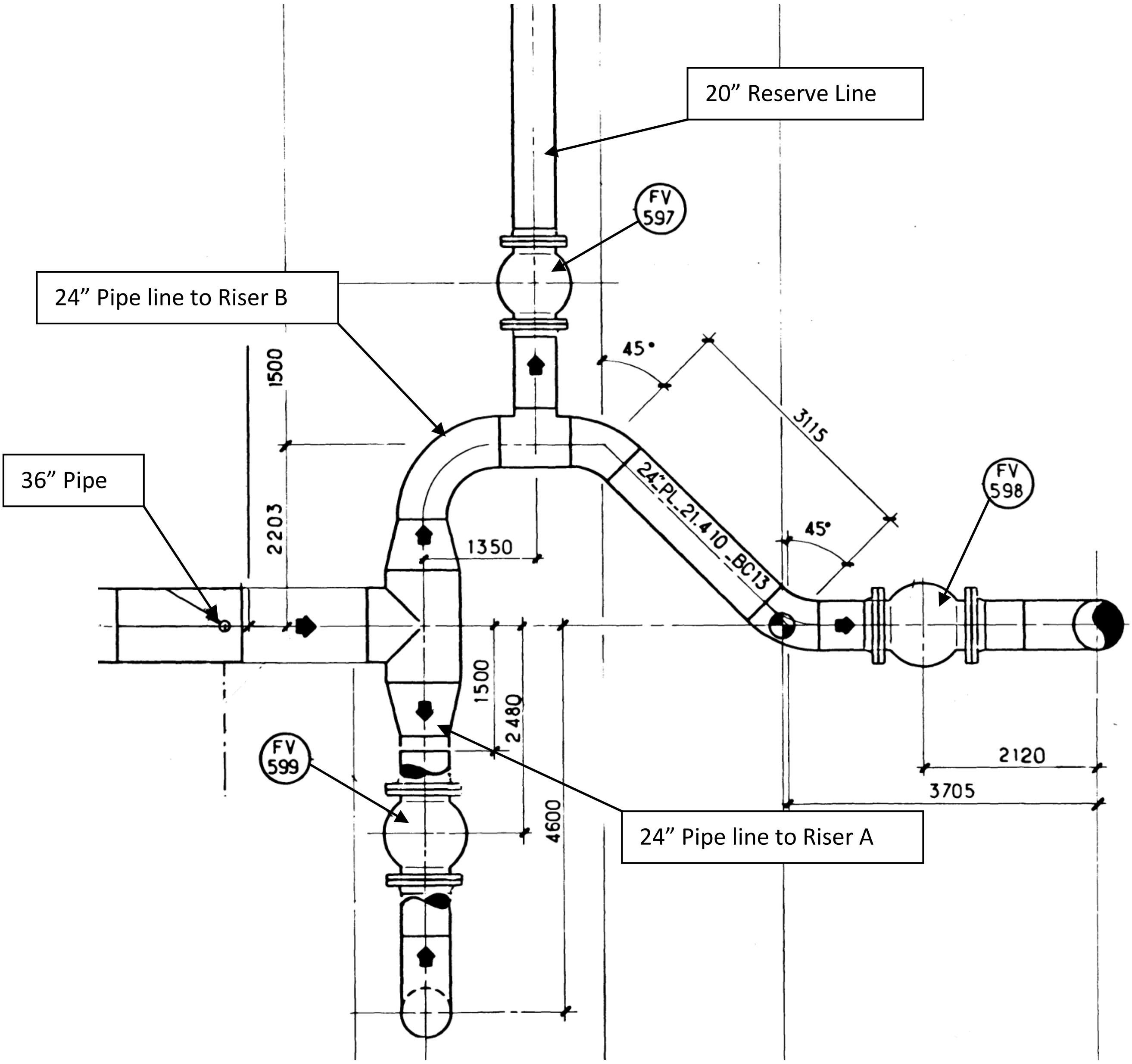


Figure 3.4: Crude oil piping on SPM 1

The result of the SPM 2 being connected to both Gullfaks A and Gullfaks B is that the crude oil can be directed from both the platforms. To be able to control the oil flow, two extra valves are necessary. Figure 3.5 shows the crude oil piping arrangement with associated valves on Gullfaks SPM 2. Detailed drawing attached in appendix A, drawing number C001-L-A90-FB-001.

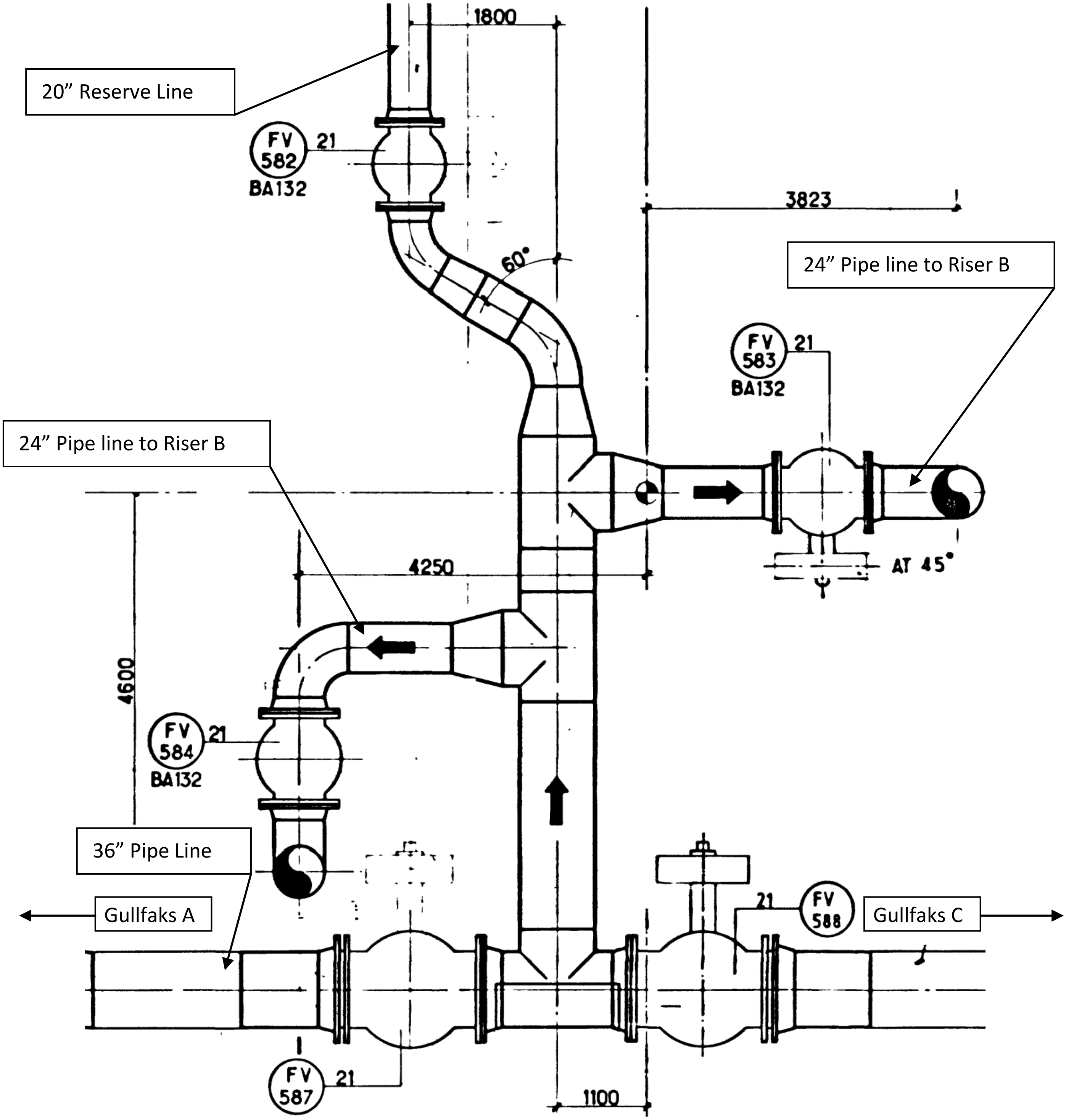


Figure 3.5: Crude oil piping on SPM 2

3.4 Structural components & mechanisms

To be able to actually install a new system, the old one needs to be removed. There are several ways to actually disconnect the tower from the base structure with ROV operated cutting equipment, but it is not certain that this will be the most optimal solution. An alternative solution is to disconnect the universal joint from the base structure. If this turns out to be possible, the old connection points can be re-used as an interface for the new system.

To be able to evaluate the different solutions for the connection of the new offloading system it is important to understand and identify the relevant components and associated mechanisms on the present system.

The SPM can be divided into the following main components:

- Rotating Head (Platform with helideck)
- Column
- Universal Joint
- Connection Plate
- Base Structure

The universal joint is connected to the connection plate with a locking mechanism at three points. To be able to disconnect the tower with the universal connector, the locking mechanism has to be identified and described in detail. The only documents available are some almost unreadable drawings from when the SPM was build. It is considered essential to get a detailed overview of the locking mechanism to be able to unlock it.

A short description will be given for the rotating head, the column and the universal joint, while a more extensive description will be given the connection plate and the base structure.

Rotating head

The rotating head can be described as the platform on top of the column. A swivel is installed, which makes it possible for the head to rotate 360 degrees. On top of the platform there is a helideck, and below the helideck there is a shelter room for workers during maintenance work on the SPM. It is also equipped with generators and lifting equipment [28].

Column

The column reaches from the universal joint and up to approximately 30 meters above the sea surface. Except for being the structural support for the platform and riser system during operation, the column has a ballast water system installed. The purpose of this system is to regulate the ballast water during launching, transportation, installation and demobilization and towing [29]. All valves are double block and in stainless steel. Pad eyes for towing are located approximately 35 meters below the sea level.

Universal joint

The universal joint consists of a cardan spider, four bearings and a total of four torque seals. The cardan spider transfers the structural loads between the two bearings and the bearings transfers the load from the column to the gravity base. The torque seals are in principal steel armed flexible pieces of hoses (rubber sleeves). On each side of the rubber sleeves there are vulcanized flanges with the same diameter as the risers.

The universal joint transfers all the forces acting on the column from environmental conditions and shuttle tankers and down to the base structure [30], but it also allows the column small movements in all directions in the horizontal plane. The universal joint is shown on figure 3.5. Detailed drawing attached in appendix A, drawing number C001-L-A30-MA-001.

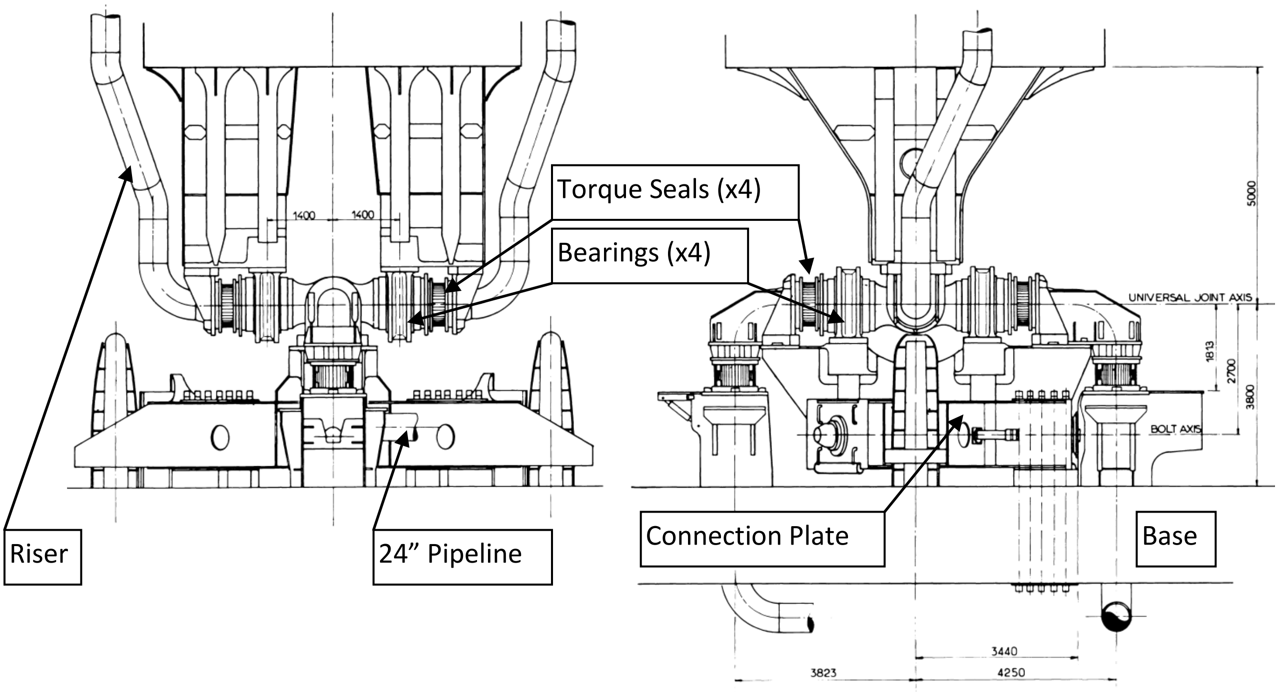


Figure 3.6: Drawing of the universal joint with rubber sleeves

The most relevant components regarding the necessary modifications prior to installation of the new offloading system are considered to be the connection plate with locking mechanism and the base structure. In section 3.4.1 and 3.4.2 the connection plate and the base structure, respectively, will be described in detail.

3.4.1 Connection plate with locking mechanism

In this thesis it is relevant to study the mechanism from the connection plate and down to the base structure. The mechanism from the column and down to the connection plate is not that relevant due to the fact that the column with the connection plate will be removed prior to the new installation. To be able to remove this it is the connection plate and the base structure that is of interest. In this section the connection plate and the locking mechanism will be described.

The connection plate is the structure between the universal joint and the base structure. This structure is equipped with the locking mechanism keeping the column attached to the base structure. The locking mechanism consists of the following elements:

- A total of 30 pre stressed foundation bolts attached to the base
- 3 of hydraulic driven locking bolts
- 3 of hydraulic driven safety locking bolts for the 3 locking bolts mentioned above
- 3 of safe pins for the above mentioned hydraulic driven safety lock

The pre stressed tension bolts were installed topside with the base and the connection plate in horizontal position, while the column floating in the water line, see figure 3.7.

The bolts are connected in the base structure with a pre stressed tension of 2000 kN. The three locking bolts are also locked in place in the base structure bolt housings [31].

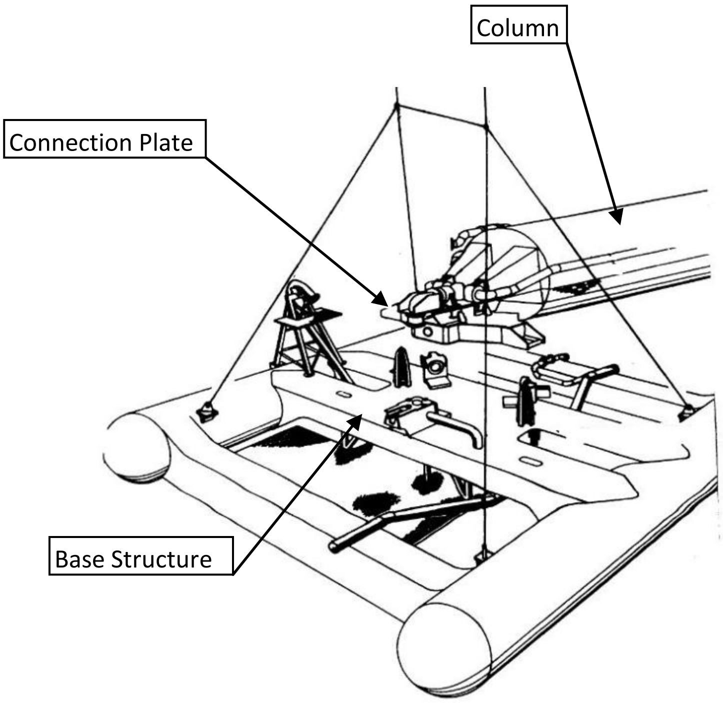


Figure 3.7: Mounting of connection plate and base structure in the water surface [32]

The connection system consisting of the foundation bolts, locking bolts, safety locking bolts and safety pin is shown in figure 3.8. Detailed drawing attached in appendix A, drawing number C001-L-A82-ME-001.

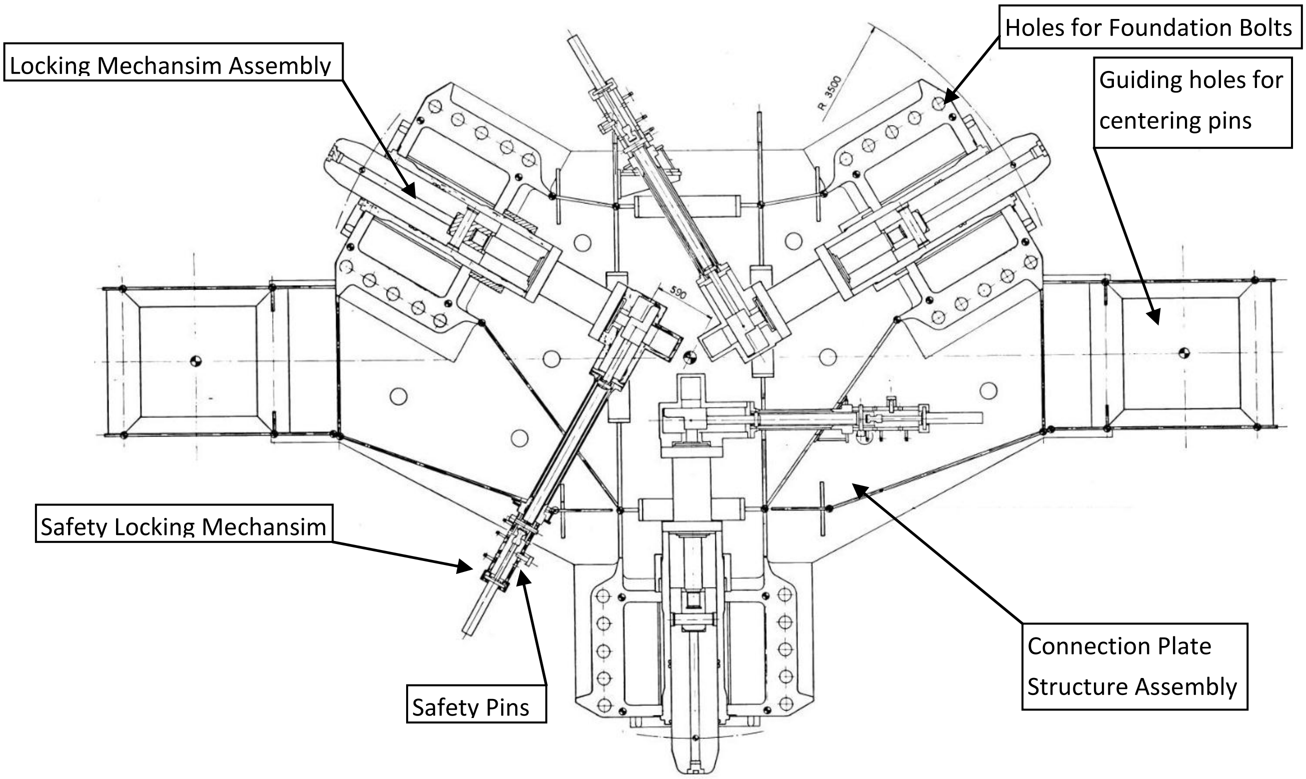


Figure 3.8: Connection plate structure and mechanical assembly

Main part of the locking mechanism consists of the bolt going into the bolt housing on the base structure and the foundation bolts. However, it is the foundation bolts that transfer the forces from the column to the base structure. The main locking bolt is practical a 2-way hydraulic cylinder, and can therefore be operated in both directions. Figure 3.9 shows the main locking bolt.

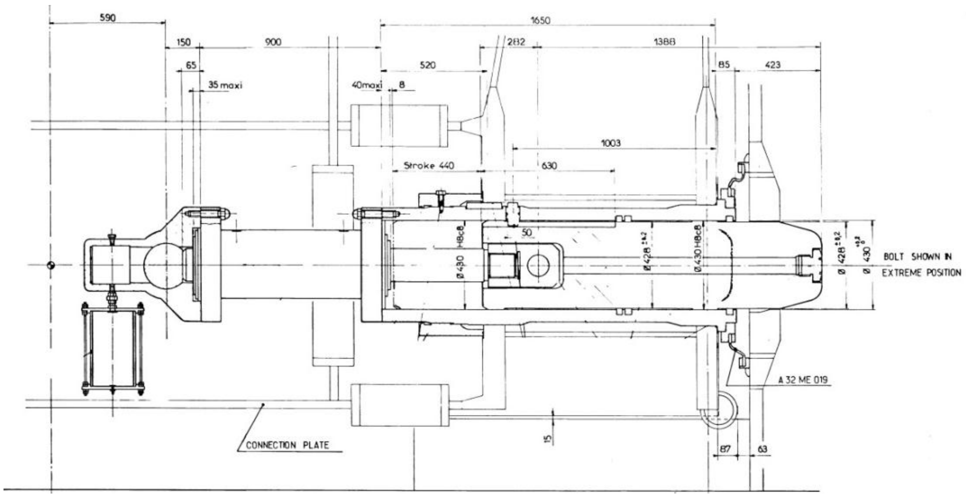


Figure 3.9: Locking bolt on the connection plate [33]

To secure the main bolts, there is a safety locking mechanism for each bolt. The safety locking mechanism is driven by a temporary installed 2-way hydraulic cylinder. An obstruction plate (safety lock) is pushed behind the main bolt, making it impossible for the bolt to move out from the bolt housing, ref. figure 3.10. Detailed drawing attached in Appendix A, drawing number C001-L-A32-MA-008.

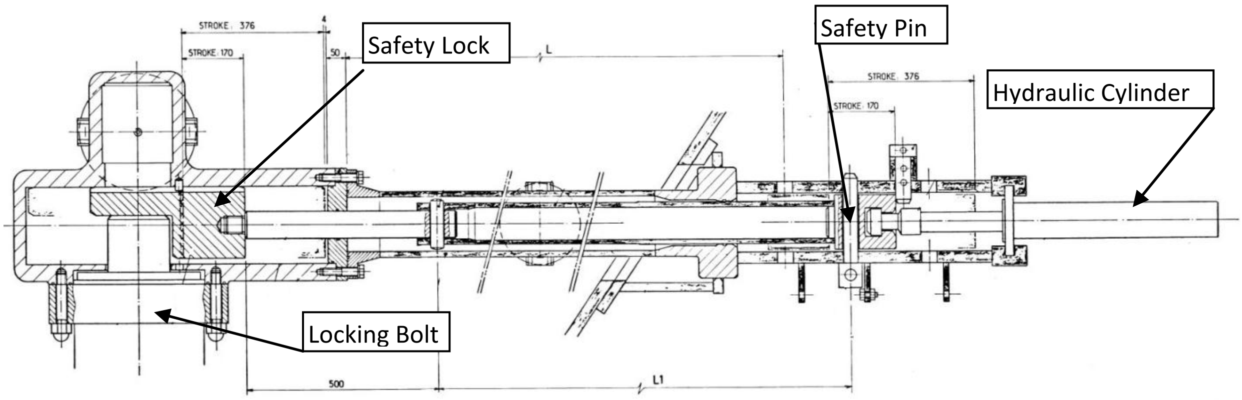


Figure 3.10: Safety locking mechanism

In addition, there is a small safety pin on the safety locking mechanism. This is fully mechanical.

To be able to get an easy disconnection of the connection plate from the base structure it is essential that these mechanisms still function properly. If anyone of these mechanisms should fail, it will be necessary with extensive ROV operations, probably with custom made tools for this particular situation.

In chapter 4, concerning the SPM condition, the condition of the locking mechanism will be evaluated. This will affect how the base structure can be re-used. An evaluation on how the forces have been acting on the structure must also be concidered. This is due to the risk of fatige damage where high loads has been applied on the structure over a long period of time. If the system still function, there will be a chance to be able to use already existing connection point as new anchoring points for the new offloading system.

3.4.2 Base structure

In this section the base structure itself will be described. As explained in the previous section, the connection plate is connected to the base structure, and it is this structure that it is desirable to re-use in relation with the new offloading system. It is therefore important to fully be able to understand the mechanisms on the base structure and which opportunities, regarding connection of the new system, they might give.

The locking mechanism was mainly described in the section regarding the connection plate. This chapter will therefore focus on the locking bolt housing and the three existing crude oil lines. Pictures from the building phase and drawings will be used to illustrate the base structure, and this will be essential to be able to fully understand pictures from the survey videos performed on the SPM.

These pictures will be presented in the next chapter regarding the survey of the SPM condition. However, a picture of the SPM during construction is presented below, ref. figure 3.11. The picture gives a general overview of the SPM in its full size. As a sidetrack, it is worth mention the HMS safety levels during construction. The pontoons have a diameter of approximately 6 meters, and yet, there are no temporary safety railings, neither on top of the pontoons nor on the stairways.

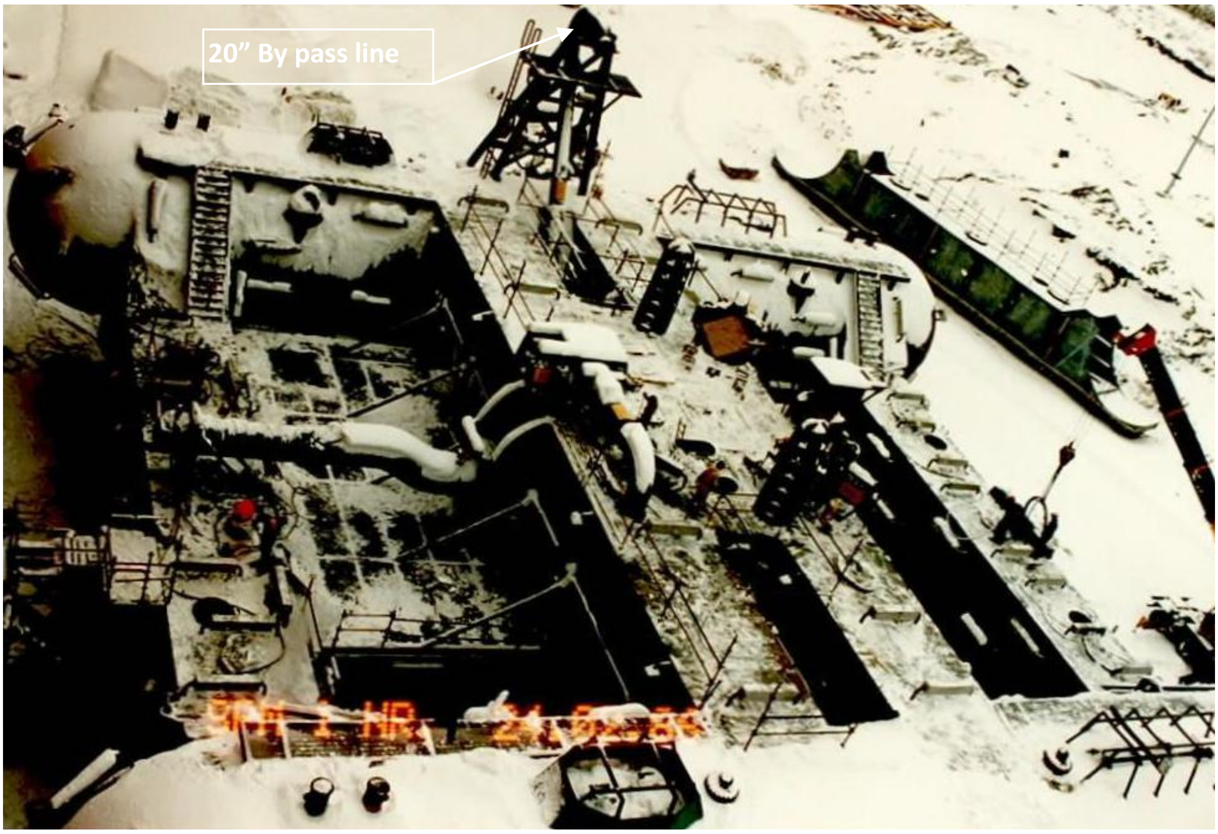


Figure 3.11: Picture of the SPM 1 base under construction [34]

In the other picture below, ref. figure 3.12, one can see different interfaces for the connection plate. The function of the centering pins was to guide the connection plate onto the base structure during assembly. There are a total of three bolt housings and a total of two connection points for the crude oil flow.

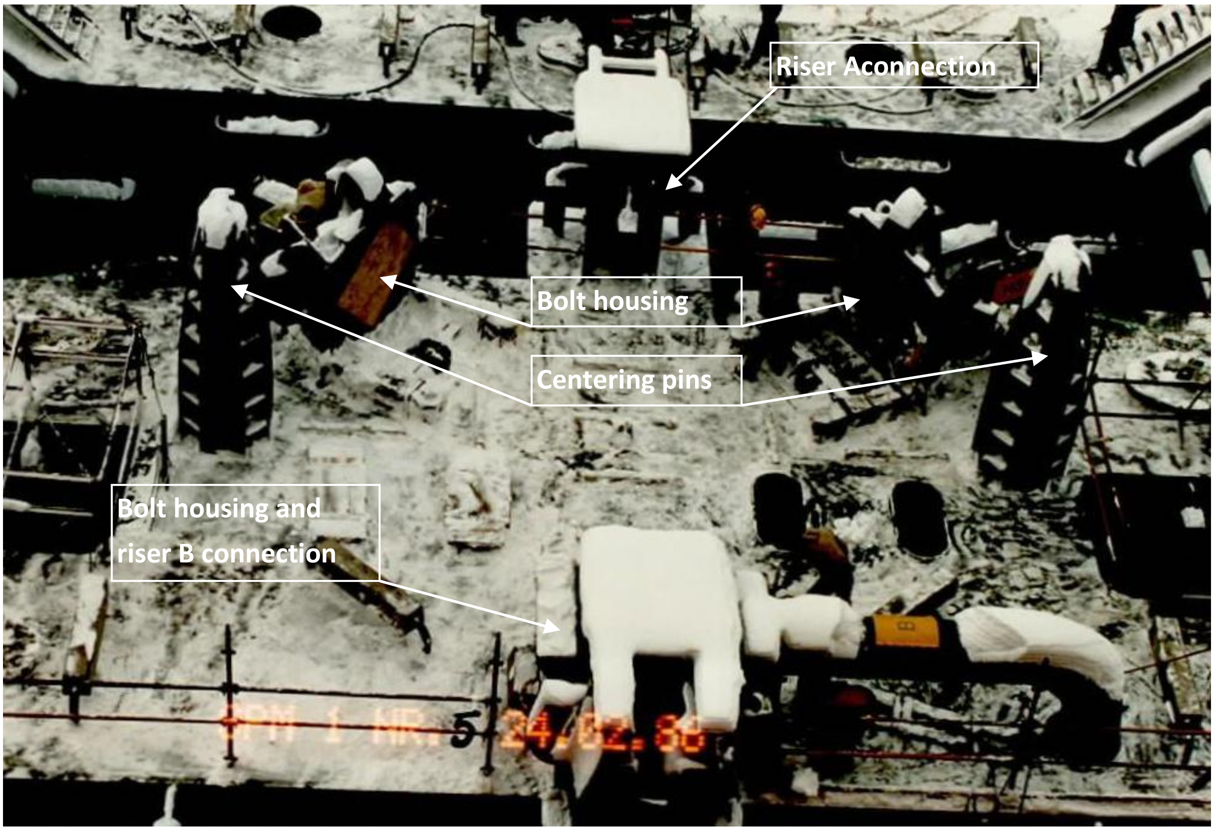


Fig 3.12: Centering pins, bolt housings and connection joints[34]

As one can see on the picture above, there is only four points for these connections. This means that there is one point which is designed to function both as crude oil flow connection and bolt housing.

The dual function bolt housing is called “Locking Bolt Housing and Connection Joint Support type 1”. The other one, with only the lock function is called “Locking Bolt Housing Type 2”.

Figure 3.13 below is an excerpt from drawing number C001-L-A40-NA-001 in appendix A, illustrating the base structure. One can see how the 36" line is routed into the SPM base, and then divided into two 24" pipelines. 24" lines end at the connection joint supports where there is a transitional link to the connection plate. The routing of the by-pass line is also shown.

The drawing shows an overview over the mechanisms that the connection point is mounted onto. The connection plate is mounted onto the base with 30 foundation bolts through the bolts holes. In addition, one can see the bolt housing, where the locking bolts are is pushed into.

It will be critical to get the connection plate disconnected without damaging potential locking points which can be re-used in the new connection. This will be covered in the chapter regarding the condition of the base structure.

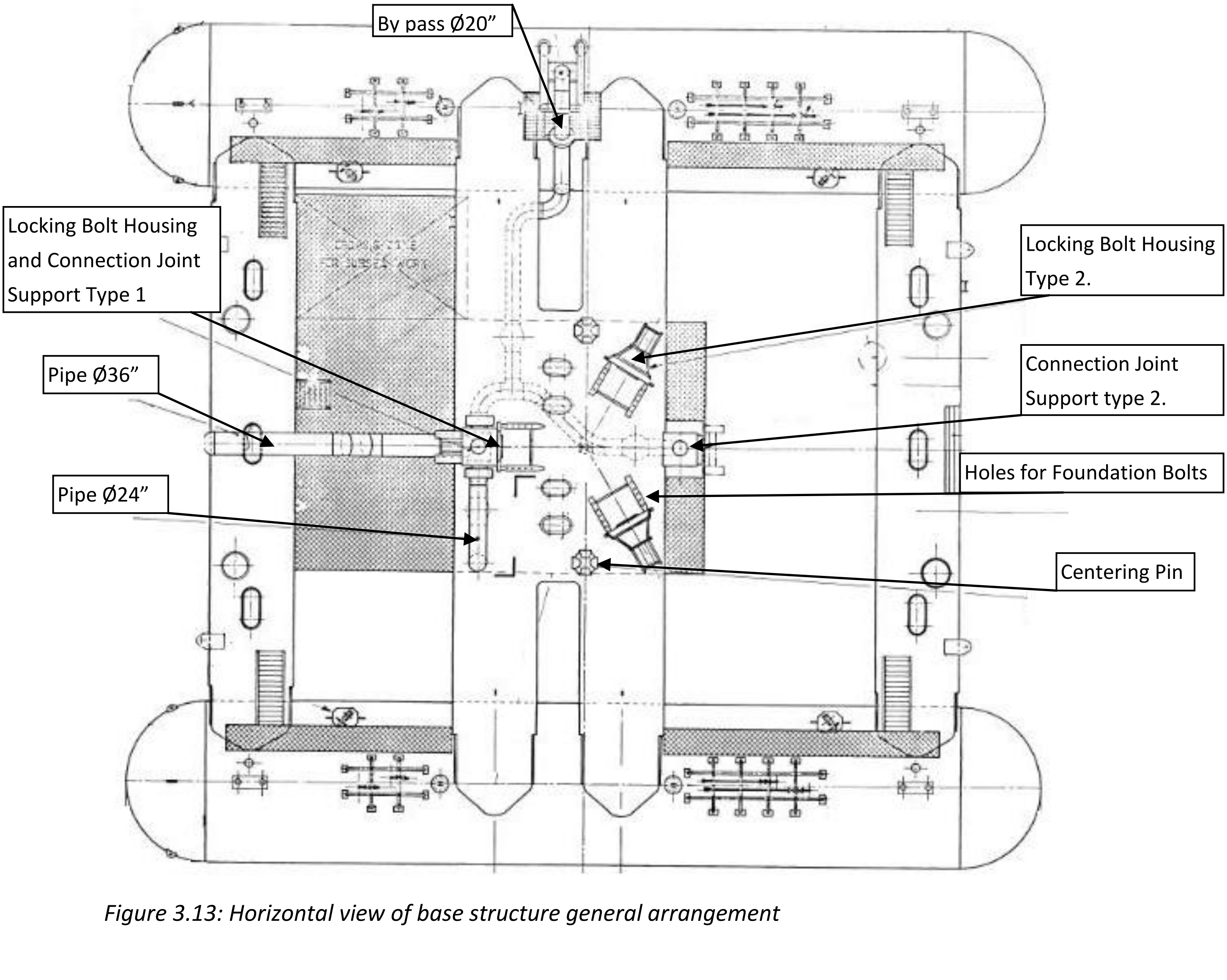


Figure 3.13: Horizontal view of base structure general arrangement

A section view of the above drawing is presented below, ref. fig. 3.14. Detailed drawing attached in appendix A, drawing number C001-L-A40-NA-002. The total height of the base structure, including the by-pass line structure, is 14,7 meters.

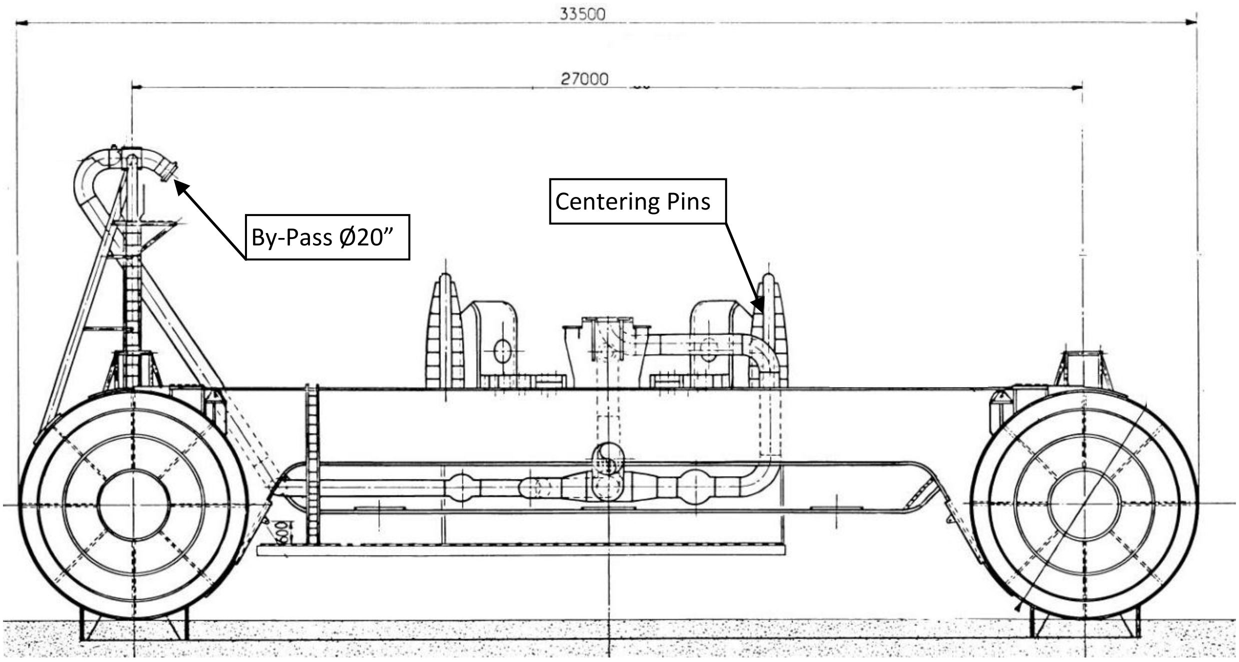


Figure 3.14: Section view from drawing C001-L-A40-NA-001, section B

Locking bolt housing and connection joint support type 1

The Locking Bolt Housing and Connection Joint Support type 1 is shown in the two figures below, ref. figure 3.15. The space behind where the locking bolts enter is sealed from the environment and is oil filled for corrosion protection.

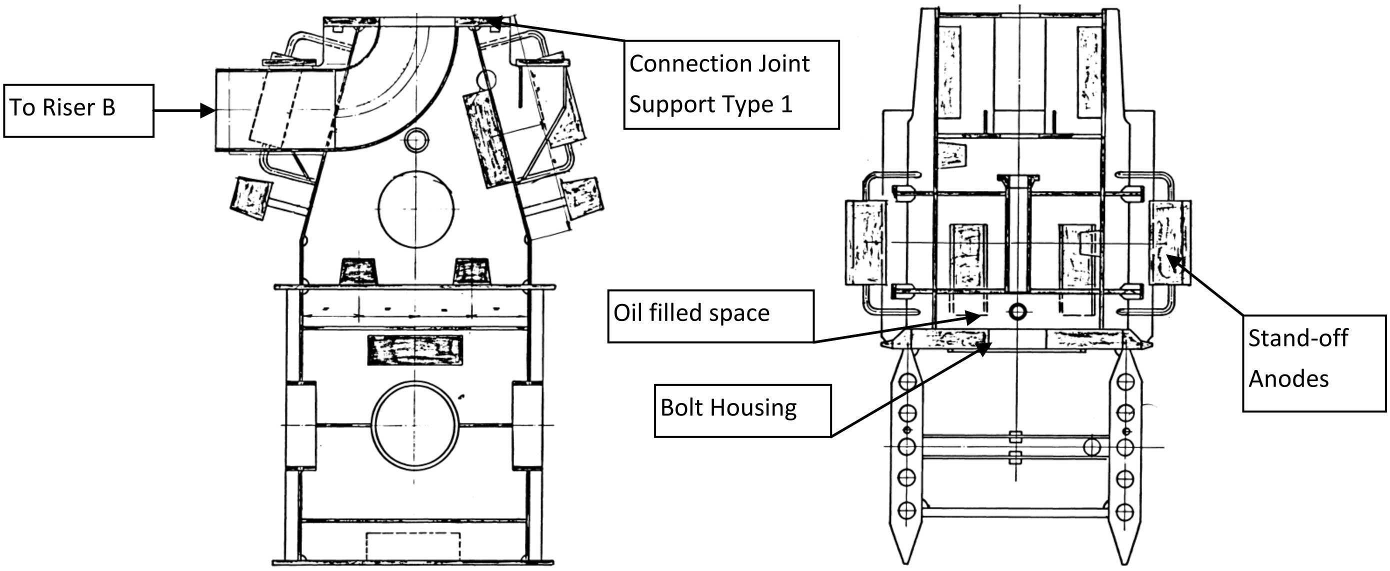


Figure 3.15: Locking bolt housing and connection Joint support type 1 [35]

In figure 3.16 one can see the connection between the locking bolt housing and connection joint support type 1.

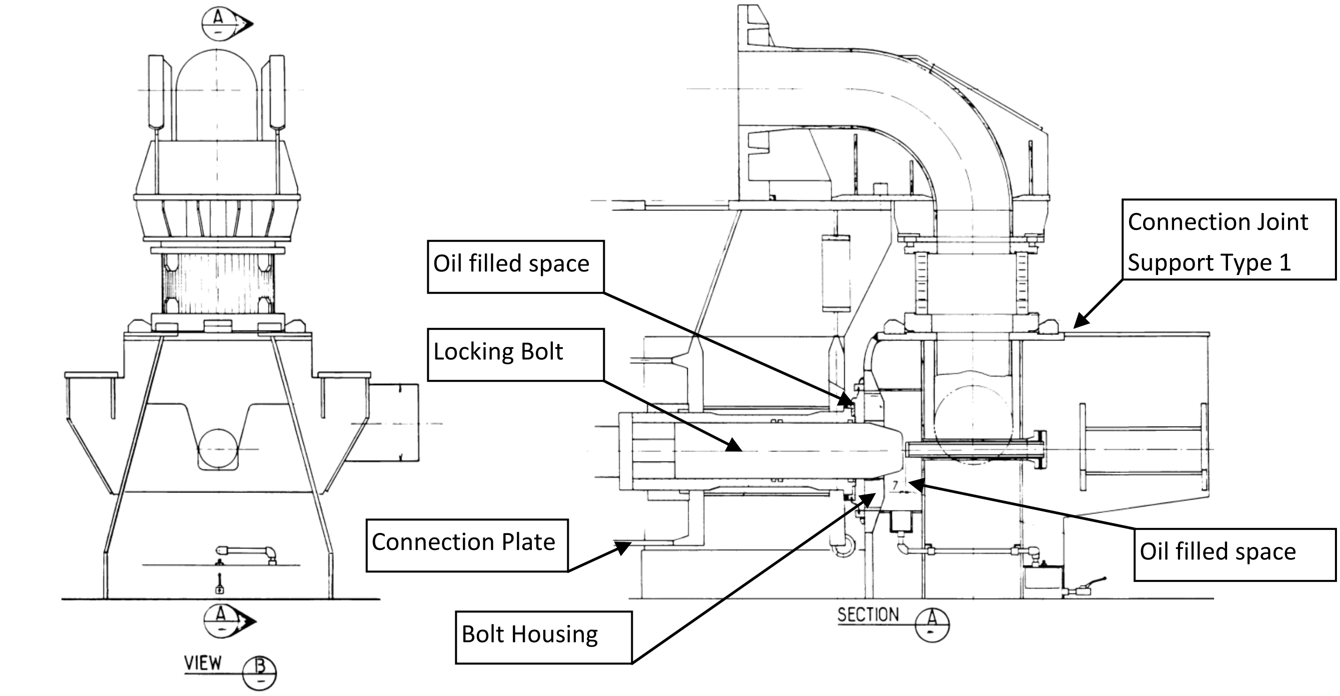


Figure 3.16: Connection sealing between base and connection plate [36]

Locking bolt housing type 2

Locking Bolt Housing Type 2 is shown in figure 3.17. There are two of these elements on the base structure. Its function is to lock the connection plate into position on the base structure.

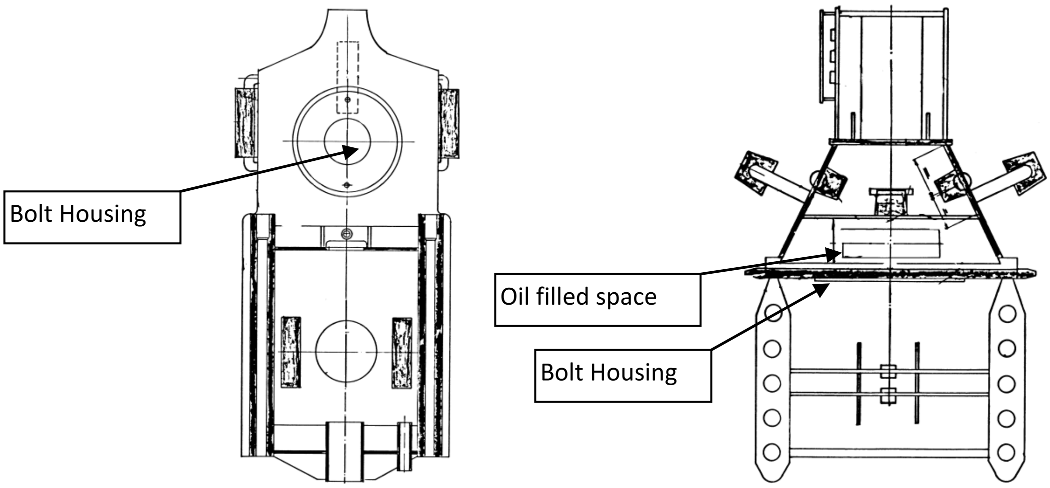


Figure 3.17: Locking bolt housing type 2 [37]

The drawings above are basically drawings over cathodic protection on the locking bolt housing, but these drawings illustrate a better overall illustration of the bolt housing. Detail drawing of the locking bolts can be found in appendix A with the following drawing numbers:

- C001-L-A93-NB-004, Base Structure Locking Bolt Housing Type 2
- C001-L-A93-NB-007, B.S. Locking Bolt Housing and Connection Joint Type 1

Connection joint support type 2

The connection joint support type 2 is connected to riser A on the column. Between the universal joint and the connection joint type 1 and 2 there is a rubber sealing, see figure 3.6.

The drawing below shows the connection joint support type 2, ref. figure 3.18. Detailed drawing attached in appendix A, drawing number C001-L-A43-NB-010.

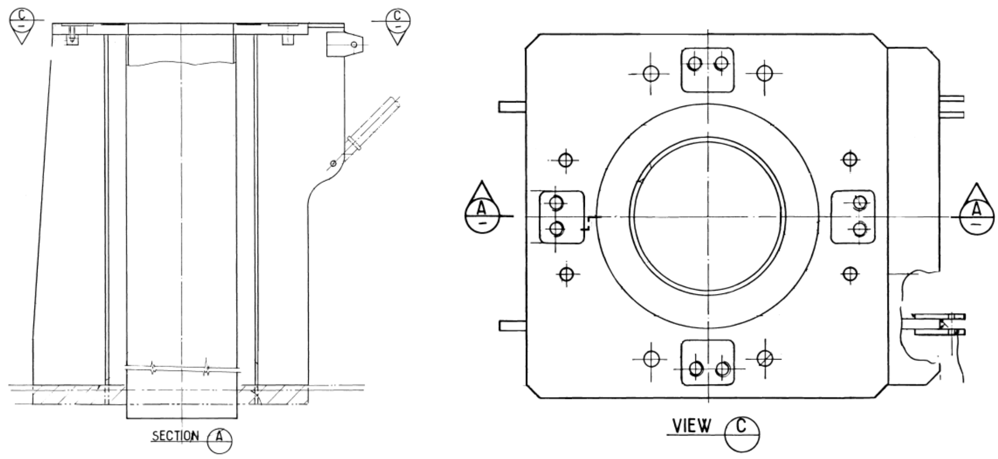


Figure 3.18: Base Structure Connection Joint Support Type 2

Pre-stressed bolts

There are a total of 30 pre-stressed bolts. Each locking bolt housing has 10 pre-stressed bolts, symmetrical distributed with five on each side. The pre-stressed bolts are 4280 millimeter long and have a maximum diameter of 90 millimeters. On the lower side of the bolt there is a washer and a nut, while on the upper side there is a washer, a nut and a counter nut. See appendix A, drawing number C001-L-A82-ME-025 for detailed drawing of the bolt.

The bolts are pre-tensioned with 2000 kN. This was achieved by use of a hydraulic bolt tightening equipment. This is why the bolt has two nuts, one regular nut and one counter nut just to seal off the bolt from sea water. The bolts are teflon coated.

Underneath the lower nut on the bolts there is installed a lifting frame for use if any bolts need to be replaced. There is installed one lifting frame for each Bolt Housing. The frames are powered with a hydraulic cylinder and the maximum stroke is 2060 millimeters.

The purpose of the lifting frame is to be used if a damaged bolt needs to be replaced. The lifting frame is parked up against to the foundation bolts when not used and is secured by two safety pins. These safety pins are again secured with a safety spike. If replacement of a bolt should be necessary, gratings below the base structure must be removed. This is because a bolt is more than 4 meters long and the height from the grating and up to the lifting frame is approximately 2 meters. When the lifting frame with a dismantled bolt is lower 2 meters, the bolt must be lifted with lifting bags from above the base structure. Then the lifting frame needs to be turned 90 degrees before the bolt can be fully lower down to the seabed[38].

The foundation bolt going through the connection plate and the bolt housing is shown below, ref. figure 3.19. Detailed drawing in appendix A, drawing number C001-L-A82-MA-009-01.

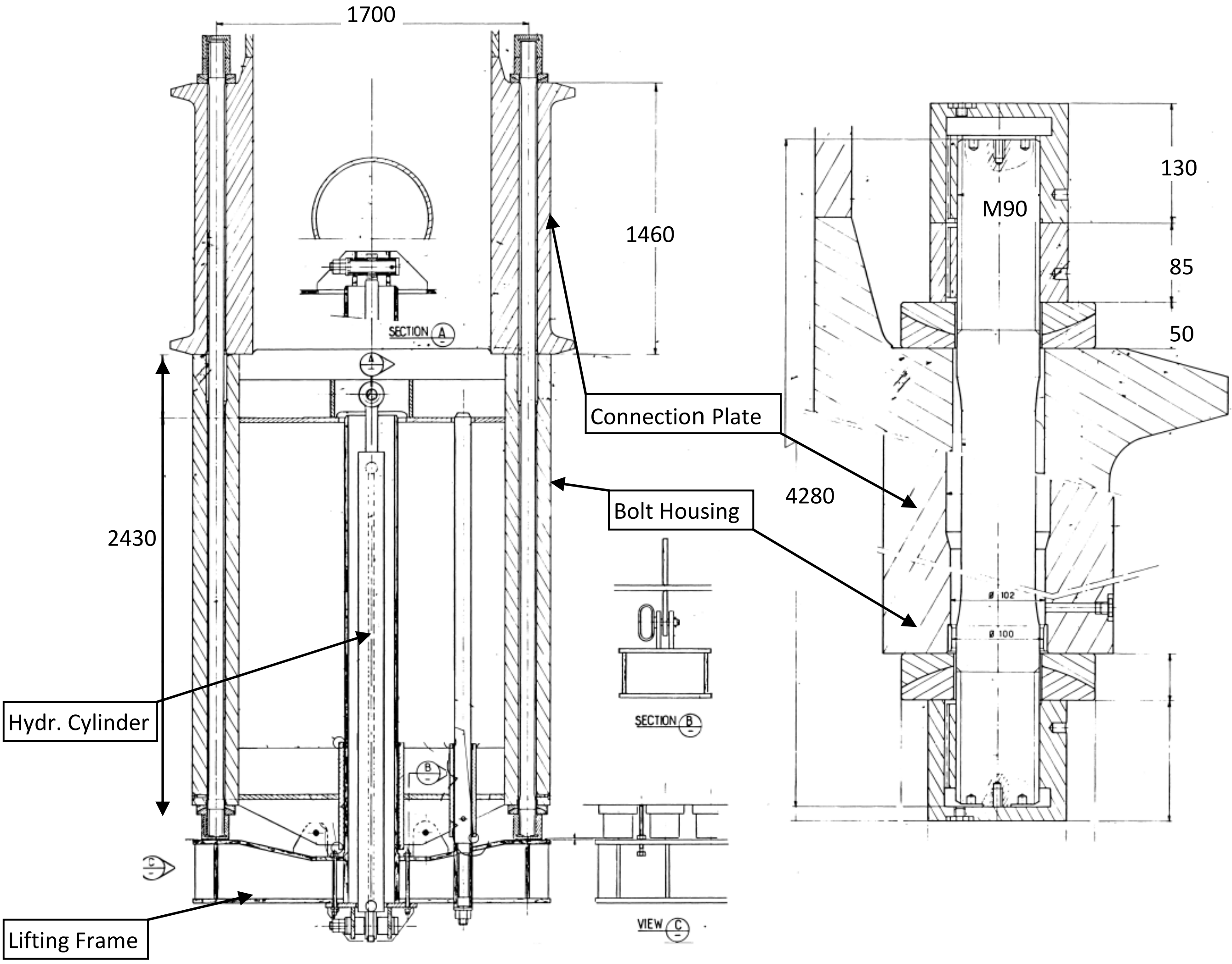


Figure 3.19: Foundation bolt assembly with lifting frame

3.5 SPM hydraulics

On board on the SPM there is a hydraulic power unit to run the hydraulic system. The hydraulic system will in this thesis be restricted to the system regarding the hydraulic actuators on the crude oil valves on the base structure and the hydraulic cylinders that operates the locking mechanism. The locking mechanisms consist of three large bolts which are pushed in place in the connection plate by the hydraulic cylinders.

Figure 3.20 below shows the hydraulic arrangement for the locking mechanism on SPM 2. Detailed Drawing attached in appendix A, drawing number C001-L-A82-LB-001.

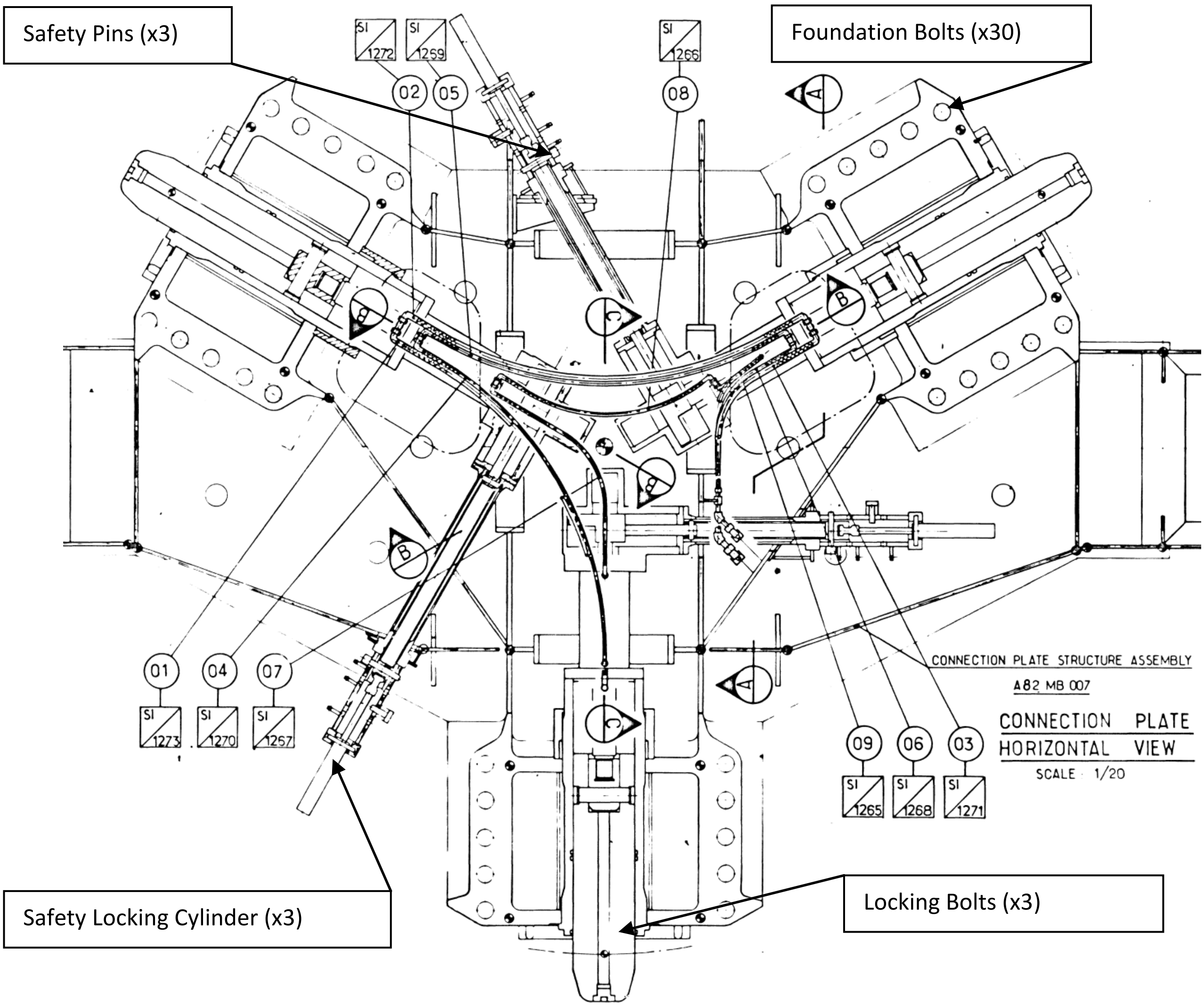


Figure 3.20: Hydraulic cylinders on locking mechanism

The hydraulic actuator system for the crude oil valves will be cut off when the column is disconnected from the base structure, but before that is done the locking mechanism needs to be released by use of the hydraulic cylinders. To release the cylinders, safety bolts needs to be removed first by use of an ROV. Then the safety pins need to be extracted. I have still not found any hydraulic lines on any schematic for this purpose. This will be further investigated on the SPM condition study.

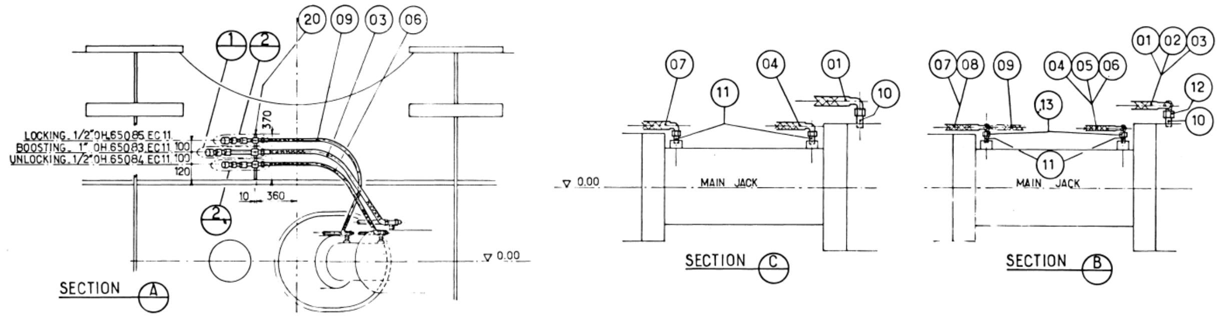


Figure 3.21: Hydraulic lines for locking cylinder

Figure 3.21 shows the different hydraulic lines connected to the locking mechanism cylinders. The unlocking lines should be easy to identify.

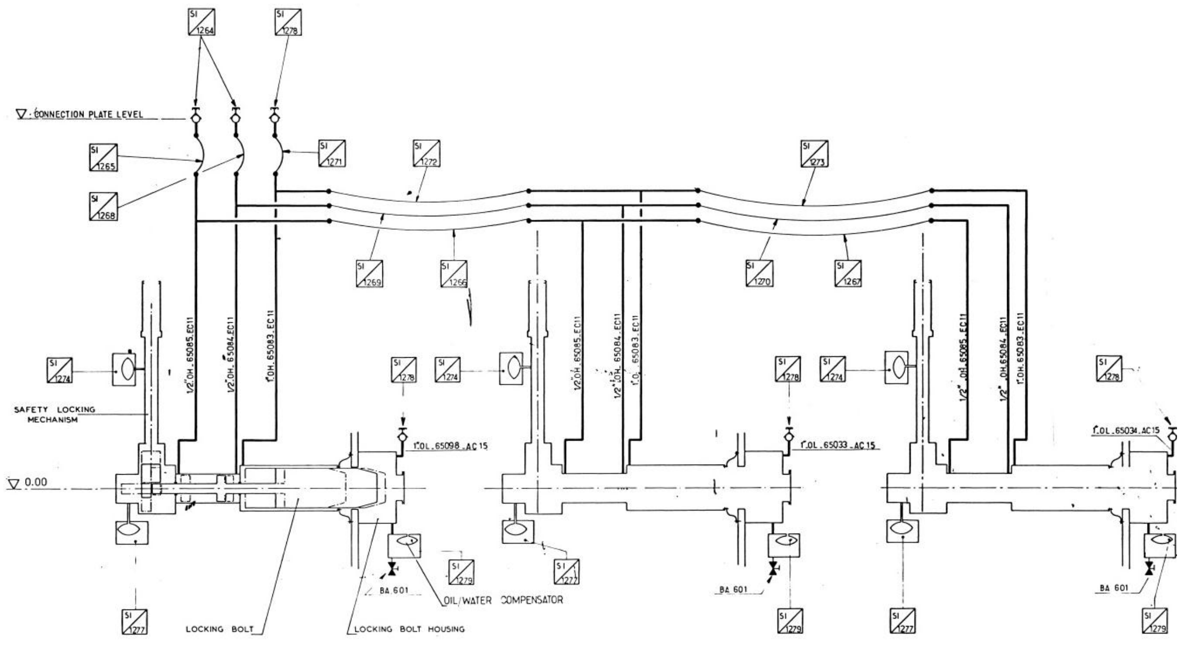


Figure 3.22: Hydraulic schematics for locking bolts

The three half (male) quick couplings S1-1264 and S1-1278 (and protective caps) are fitted to piping for flexible hoses connection, ref. drawing number C001-L-A80-LB-001in appendix A[39].

The crude oil valves are operated from the SPM platform through hydraulic lines going down to the crude oil valve actuators. Since Statoil wishes to be able to operate the valves through the new offloading system, the hydraulic lines must be connected to the new system.

To actually be able to do this without divers will require special made equipment for these connections. However, connection interfaces will be necessary to ensure proper function of the new connections.

The base structure and the column with the connection plate were fabricated separately. For this reason it is likely that there are some hydraulic connection points between the base structure and the connection plate.

There are unfortunately no documents available describing these connections. Assumptions must be made and uncertainties regarding this issue must be considered.

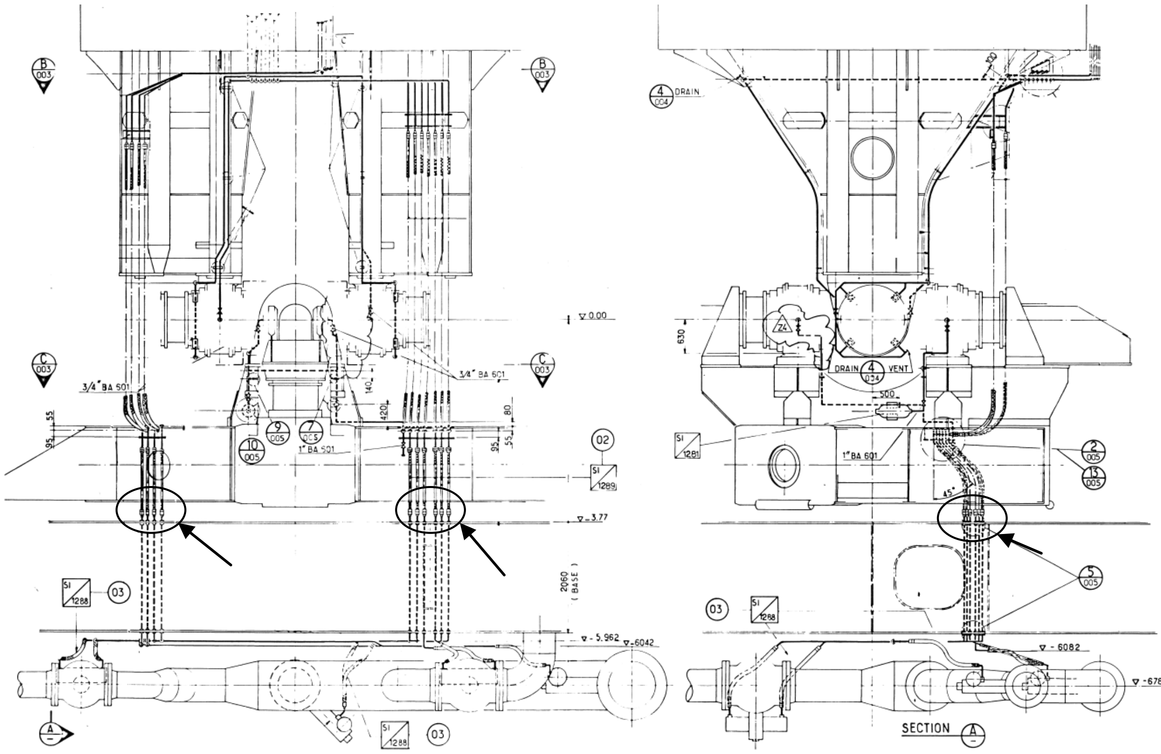


Figure 3.23: Crude Oil Valve Hydraulics [40]

3.6 Structural force distribution

In this section a brief description of the structural integrity will be given. This is relevant due to the possibility to use already existing mounting points. One of the most critical factors will be related to fatigue of construction in areas with high loads due to the helicopter and the environmental forces acting on the column. The main focus regarding forces will be on the base structure with respect to the areas concerning the bolt housing and the foundation bolts.

The net buoyancy forces acting on base structure due to the column buoyancy is approximately 22,6 tons according to calculations in Appendix C. According to a handwritten note in the DFI, these numbers are uncertain. The estimated buoyancy force in the note is 269,7 tons [41]. This must be further investigated prior any disconnection since it will be critical for the ballasting of the column. The new planned system will lead to a negative buoyancy force due to the weight of the riser base. The new net weight is estimated to be approximately 20-25 tons. This is based on previous similar riser bases changed on the Statfjord field.

3.6.1 Force contribution on existing structure

All forces accumulated from the platform and the column is transferred at the column bottom. The shear forces is transferred to thick vertical plates underneath the column bottom over to the horizontal flanges which forms the seat for the two bearings transferring the forces to the universal joint and the two brackets holding the torsion sealings in place [42].

The forces are then further transferred down to the connection plate by two bearings similar two bearings between the column and the universal joint. The forces are transferred down to the base structure through the connection plate by use of the foundation bolts. The main function for the three locking bolts is to position the connection plate. On this basis it is reasonable to believe that the locking bolt housing has not suffered severe fatigue damage. An evaluation of this will be presented in the chapter regarding necessary modifications [42].

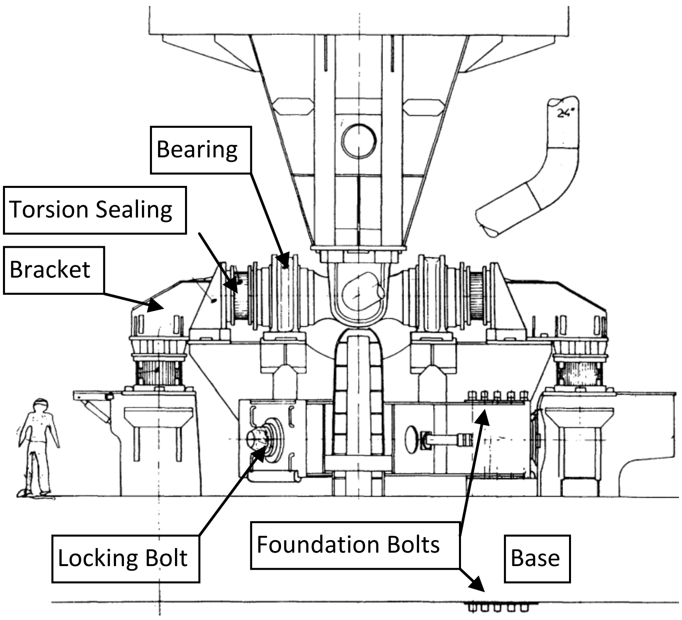


Figure 3.23: SPM force contribution [43]

3.6.2 Base structure

The base structure consists of two pontoons with beams in between. The base structure is modeled and strength calculated in three separate calculation reports. Unfortunately, they are stored in Statoil`s achieve, and will not be available before summer 2012. These documents are the following ones:

- Doc.no. C001-L-N-CE-401: Base Structure – Beams Calculation Note
- Doc.no. C001-L-N-CE-402: Base Structure – Lateral Floats-Calculation Note
- Doc.no. C001-L-N-CE-403: Locking Bolt Housing – Calculation note

In the second report, the connection between pontoons and cross-over beams are calculated.

In the third calculation report, C001-L-N-CE-403, the attachment of the locking bolts is calculated for the temporary transfer of forces from the column to the base via the three locking bolts. This is not the correct transfer method for permanent operation with the column attached. In that case the forces are transferred to the base structure via the pre-stressed bolts [44].

One of the two beams has two lock bolt housings attached to it while the other one has one lock bolt housing. The beams are welded onto the pontoons. The planned new system will not contribute to any buoyancy forces and the weight of the new system will have a net weight of approximately 20-25 tons. This is just a fracture compared to the weight of the base structure, which are 3949 tons. The strains on the welds will therefor decrease.

The steel material used in the base structure is Steel Grade 1 and 2 with a yield strength in the area 310-340 MPa, depending on the thickness. Steel grade 1 and 2 are for components which are critical for the structural integrity and which are exposed for large forces.

The locking bolt housing represents a very interesting area at which the new system can be attached to. This will be further investigated in chapter 7.

3.7 Reason for replacing offloading system

The replacement of the SPM 1 and 2 is a consequence of the license extension at Gullfaks. To be able to last out the planned extension period, the offloading systems is in need of comprehensive upgrades. The upgrades must also be in accordance to today`s regulations, and not the current regulations at the time the SPM was build.

To be able to meet the new regulations and to expand the design life of the SPM, there are mainly two options. The two options is one of the following alternatives

- Upgrade the SPM`s to today`s regulations
- Replace the SPM`s with a different type of offloading system

The necessary upgrades required to meet the new regulations will be expensive. It is also quite expensive to maintain the SPM`s as well. During offloading, the hydraulic actuators have to be operated from the SPM to open the valves. This results in regular helicopter flights to the SPM, either to operate the valves or for maintenance work.

Due to the technological development, these systems are also expired. They have their own mooring system for the tankers, and the column and the base are designed thereafter. Today the shuttle tankers are operated with dynamic positioning systems. The need for mooring systems from the tankers to the system does no longer exist. The maximum load the system needs to withstand is therefore determined by the fail safe load on new systems.

Regarding this issue, Statoil has carried out economic analysis on the different solutions, and the conclusion is that it is more economic in the long term to actually replace the old system with a new one. If possible, it is desirable to use the same base structure.

Another related problem with the SPM buoys is the possibility for collision between tankers and the buoy. The probability for such collisions has been reduced due to the development of better DP systems, but with a submerged buoy, this risk will be eliminated.

4. Condition of the existing offloading system

4.1 Introduction

Due to the workload of this thesis only one of the SPM will be investigated. SPM 2 has been chosen because this is the first system to be replaced as this is connected to both Gullfaks A and Gullfaks C platforms. So from her on and throughout this thesis all focus will be given to the SPM 2 system.

This study will reveal the true condition of the SPM and what measures that needs to be taken to actually be able to disconnect the column from the base structure. It is not easy to, or nearly impossible, to determine necessary modifications on the base structure before this work has been done. Connection of a new riser base will be discussed when this study is accomplished.

The most critical aspects that need to be investigated in this chapter are the condition and the accessibility to the following:

- Pre-stressed bolts (x30)
- Locking Bolt Hydraulics
- Safety Pin Hydraulics (x3) and safety spikes
- Connection Joints
- Crude Oil Valves and Hydraulics

The by-pass flange will be investigated due to the possibility to use this for connection to a potential riser base system.

The column will not be prioritized as this is not directly related to the connection mechanism of the structure. The focus will be given to the connection plate, base structure with the by-pass structure and the crude oil valves.

4.2 Column with platform

The marine operation regarding the removal and towing of the column is not covered in this thesis. But to actually be able to tug the column, the towing brackets must be intact. Three out of six brackets were inspected on the 2011 survey on the SPM 2.

Six towing brackets were found at depth of 35 meter below sea surface. All were 100 % covered in hard and soft marine growth consisting of mussels and sea grass. Three brackets were cleaned using high pressure water jetting [45]. Pictures before and after HP water jetting the bracket at 230° is shown below. The other two were found in similar condition.

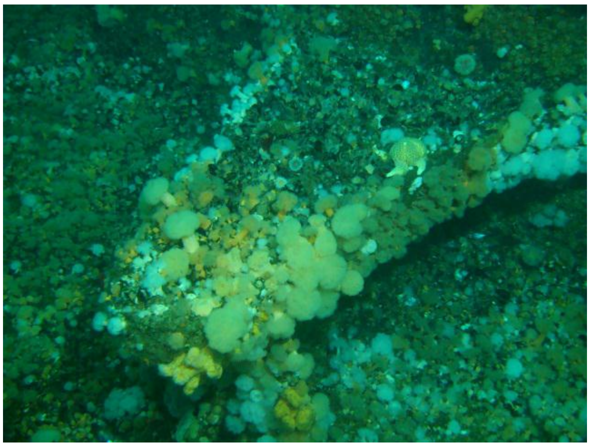
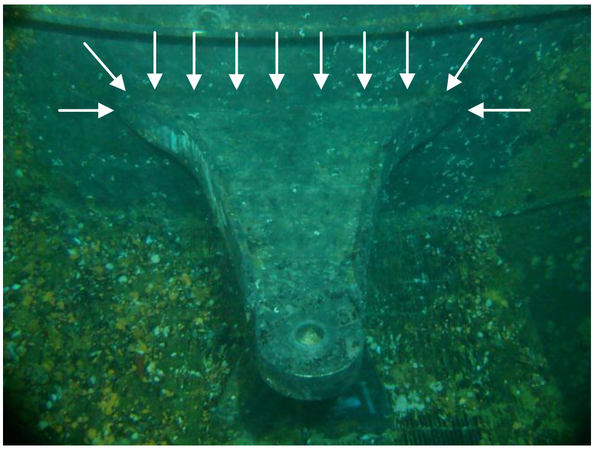
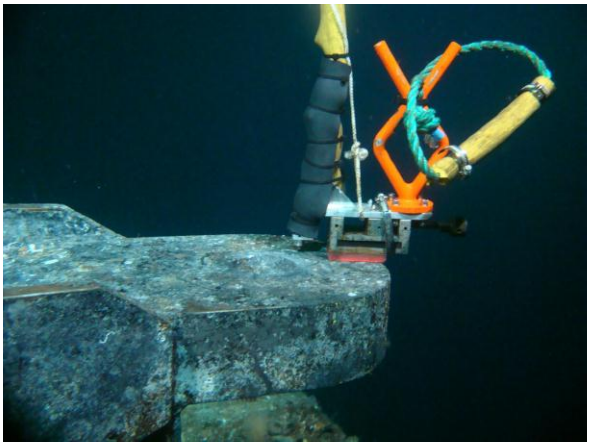
	

Figure 4.1: Before cleaning	Figure 4.2: After cleaning

NDT measurements on the welds (arrows on figure 4.2) and HAZ-area and ultrasonic thickness measurements were performed on the brackets in the following position: 110°, 230°& 350 °.

	
Figure 4.3: Eddy current measurements	Figure 4.4: Ultrasonic measurements

As one can see on the pictures the visual inspection of the towing brackets and corresponding welds shows little sign of corrosion, meaning fully cathodic protection. Eddy current measurements were performed on the brackets and none of the brackets shows any signs of surface defects, neither on the welds nor on the bracket itself.

The thickness of the brackets shall be approximately 110mm according to drawing C001-A22-NB-027. The results of the measurements were from 97mm to 100mm [46]. This is acceptable results and the column is ready to be towed when the disconnection has been made. Good planning and correct ballasting of the column will be critical for the operation.

4.3 Connection plate & base structure

The markings on the SPM do not correspond precisely to the markings on the drawing. Due to this deviation a new horizontal view of the base structure general arrangement will be presented with the corresponding markings of the SPM, ref. figure 4.5. The direction of the SPM is also shown on the figure. In this section the condition of the base structure and the connection plate will be investigated.

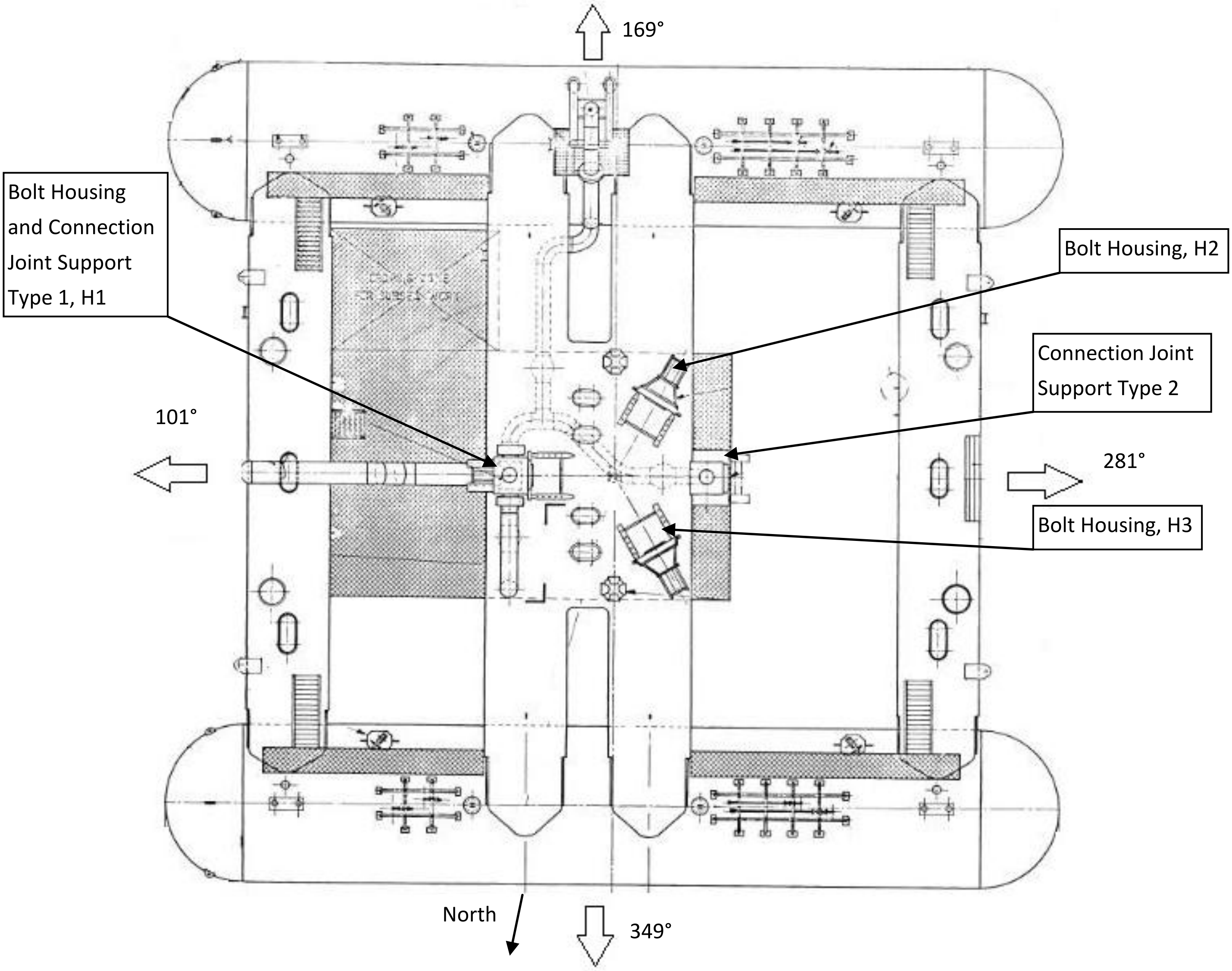


Figure 4.5: General arrangement with corresponding markings

The focus in this section will be given to the bolt housing, foundation bolts, locking bolt, safety pin, safety spikes and the connection joints.

4.3.1 Base structure general condition

The general condition of the base structure seems very good. There are no severe signs of corrosion and the anodes are evenly worn, ref. figure 4.6. The only place one can see more than average worn on the anodes is on the support structure of the by-pass line.

Fig 4.6: Pontoon with stand-off andoes

Figure 4.7: Loose anode on working platform

Some lose anodes are spotted on the working platform of the base structure and some scatterings. The grating was cleaned with HP water jetting and there is no sign of any damage.

There are a significantly amount of marine growth over the hole installation. Down at the base structure and the connection plate this is mostly soft marine growth. This can be cleaned either by multipurpose cleaning tool or with HP water jetting.

CP measurements have been performed and the structure is fully protected. However, it must be investigated that the protection will last throughout the base structure extended design life. It is recommended to do CP measurements on an annual basis. If the structure should be under protected, new anodes must be installed. This is an operation that can be performed with ROV and costume made stand-off anodes.

The bolt housing will be the most critical components on the base structure. These seem in good condition, and will be more thoroughly explained in the next section.

See DVD video file “As found survey” for video reference.

4.3.2 Bolt housing

There are a total of three bolt housings, named H1, H2 and H3. The bolt housing H1 also consist of the connection joint type 1, however, the connection joint is presented in its own section. Bolt housing is, as the name tells, the housing were the locking bolts in the connection plate enters the base structure. The locking bolt enters a sealed compartment in the bolt housing and between the bolt and the bolt housing there is a sealing keeping the entire bolt free for sea water. Some extra pictures are presented in section 4.3.2 with the intension to present an overview and not just close-up pictures of the mechanisms.

Bolt housing H1

Fig 4.8: North side of bolt bousing H1

Figure 4.9: Behind bolt housing with flange

On fig. 4.8 above one can see the left side of the bolt housing H1. No abnormalities can be observed. Figure 4.9 shows the bolt housing flange. All bolts are present and in good condition. On figure 4.10 one can see there is access behind the flange despite the connection joint.

Figure 4.10: Acess behind flange (from above)

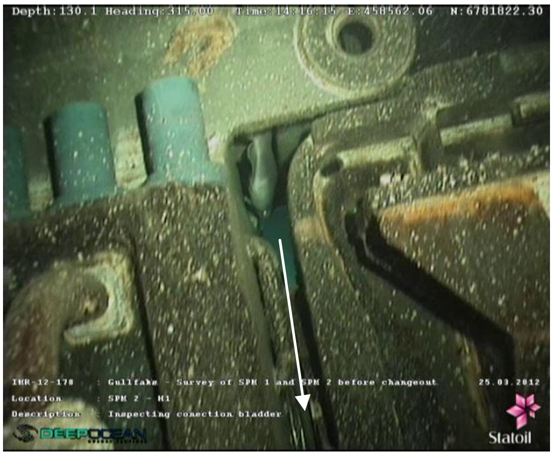


Figure 4.11: Connection bladder

Figure 4.11 shows the bladder connection between the bolt housing and the locking bolt assembly. The connection joint is connected to the riser above the bolt housing and the locking bolt assembly can`t be seen or accessed. The accessibility from the both sides is good and the gap between bolt locking assembly and bolt housing is estimated to be 80 millimeters.

If the hydraulic system to the locking bolt should fail or chosen not to be used, access for cutting tool is available from both sides. The survey video from this inspection can be found on the attached DVD with the following file name: “Bolt housing H1 inspection” and “Connection bladder H1 inspection”.

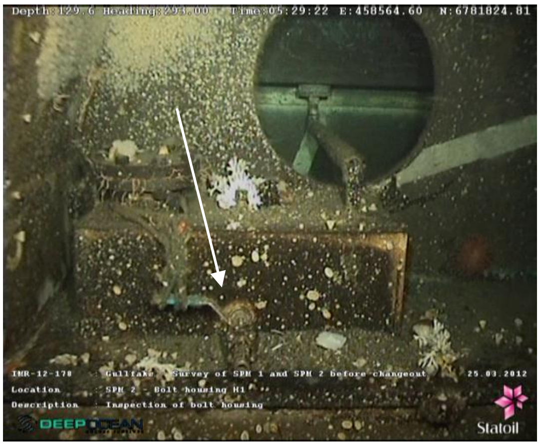


Figure 4.12: Bladder vent valve

Figure 4.13: Connection joint on top of housing

On the figure 4.10 one can see the bladder ventilation valve, which is an ordinary ball valve. This valve is connected to the bolt housing which share the same medium as in the bladder connection and the locking bolt assembly. The compartments are oil filled.

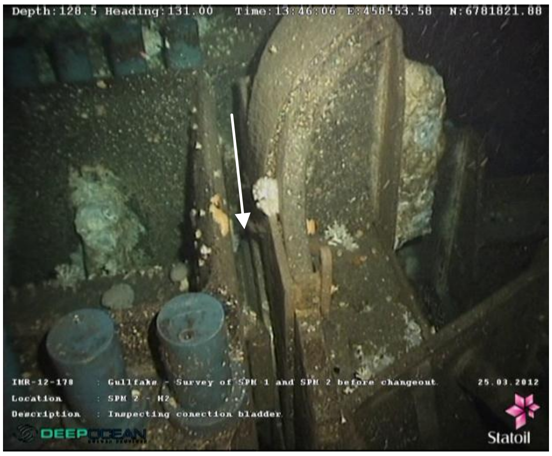
One can see that the valve is actually secured with a rope. The access to the bladder ventilation valve is good on all of the bolt housings.

Bolt housing H2

Fig 4.14: Side of bolt housing H1

Figure 4.15: Behind bolt housing with flange

On figure 4.14 and 4.15 no abnormalities can be observed and on the bolt housing flange all bolts are present and in good condition.

	
Figure 4.16: Flange access from above	Figure 4.17: Connection bladder

The H2 has no connection joint and therefore the accessibility is a little bit better here. There is possible access to the connection bladder from both sides and from above. However, it is worth mention that the accessibility from the right side (ref. figure 4.17) there is a structure close by where one of the centering pins is positioned. The access from this point will be handy if cutting of the locking bolts should be necessary.

The video from this inspection can be found on the attached DVD with the following file name: "Bolt housing H2 inspection" and "Connection bladder H2 inspection".

Bolt housing H3

	
Fig 4.18: Side of bolt housing H3	Figure 4.19: Behind bolt housing with flange

On figure 4.16 and 4.17 no abnormalities can be observed and on the bolt housing flange all bolts are present and in good condition.

Figure 4.20: Flange access from above

Figure 4.21: Connection bladder

As on the H2 bolt housing, the H3 has neither a connection joint and therefore the accessibility is a little better here than it is on the H1 bolt housing. The H3 bolt housing is also close to one of the centering pins and the accessibility is therefore slightly better from the left side.

The video from this inspection can be found on the attached DVD with the following file name: “Bolt housing H3 inspection” and “Connection bladder H3 inspection”.

4.3.3 Pre-stressed bolts and lifting frames

The foundation bolts transfers all the forces from the column and down to the base structure. There are a total of 30 bolts (90 x 4280mm) which are pre-stressed with 2000 kN. Access to the bolts and to the lifting frame beneath every bolt housing will be investigated.

H1 pre-stressed bolts and lifting frame

Figure 4.22 and 4.23 shows good accessibility to the H1 foundation bolts from both sides with a WROV. There are a total of 5 bolts on each side, all in very good condition. Some hydraulic hose can come in the way as we can see on the pictures.

Figure 4.22: Foundation bolts, north side

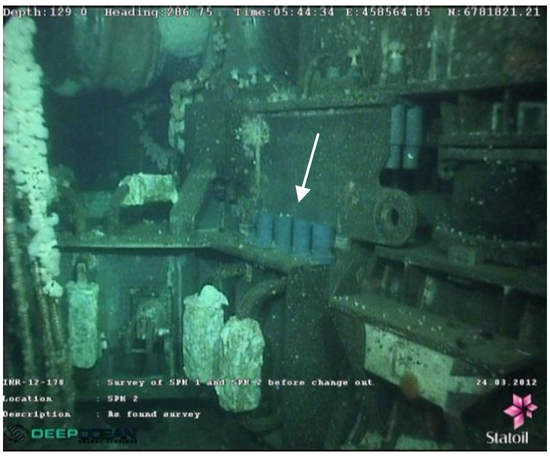


Figure 4.23: Foundation bolts, south side

The hydraulic hoses go to the hydraulic actuators controlling the crude oil valves on the SPM base structure. In figure 4.22 one can see the 24" pipe coming into the connection joint type 1, which leads to riser B.

Below the foundation bolts there is installed a lifting frame for the foundation bolts. If one of the bolts needed replacement, the frame is intendant to help a diver lowering the damaged bolt and to install a new one. However, such repairs have never been performed on the SPM. Access to the lifting frame is necessary if the bolts shall be removed from the bolt housing. To be able to operate the lifting frame hydraulics must be connected and the secure pin must be removed.

It will be impossible to operate a WROV inside the base structure and remove the secure pins and spikes. To be able to do this one is dependent on divers.

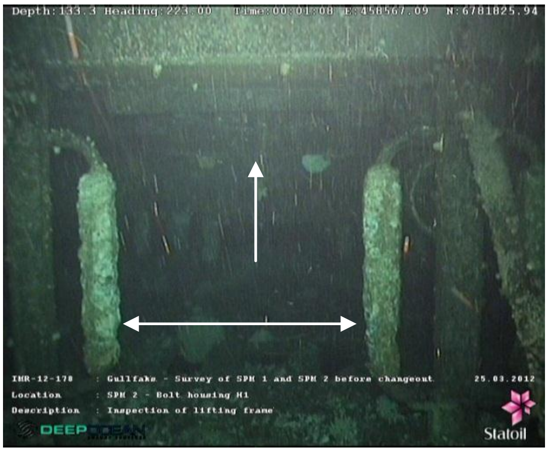


Figure 4.24: Accessibility in below the base

Figure 4.25: Lifting Frame and secure pins

On figure 4.24 one can see an arrow pointing at the lifting frame. Another arrow illustrates the opening between the two anodes. The height inside is approximately 2 meters and there is no room for a WROV to operate inside the base structure.

The survey video from these two inspections can be found on the attached DVD with the following file names: "Lifting frame H1 inspection" and "Bolt housing H1 inspection".

H2 pre-stressed bolts and lifting frame

All the foundation bolts can be easily accessed with a WROV. On the south east side of the H2 Bolt Housing there is a centering pin, ref. figure 4.27. Despite this, it will be no problem handling a normal sized WROV for cutting the foundation bolts.

Figure 4.26: Foundation Bolts North-West Side

Figure 4.27: Foundation Bolts South East Side

As for the H1 Bolt Housing, there is not much space underneath the base structure and a WROV will not be able to operate inside the base structure. The bolts seem to be in good condition.

Figure 4.28: Accessibility in below the base

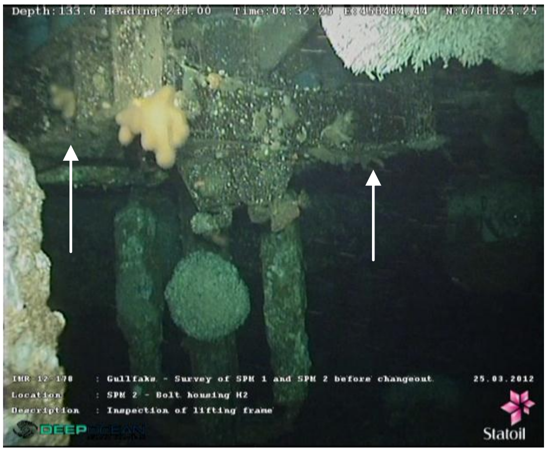


Figure 4.29: Lifting Frame and Secure Pins

The survey video from these to inspections can be found on the attached DVD with the following file names: “Lifting frame H2 inspection” and “Bolt housing H2 inspection”.

H3 pre-stressed bolts and lifting frame

Accessibility on the H3 is similar to the H2 accessibility. On the north east side of the H3 bolt housing there the other centering pin can be found.

Figure 4.30: Foundation Bolts North-East Side

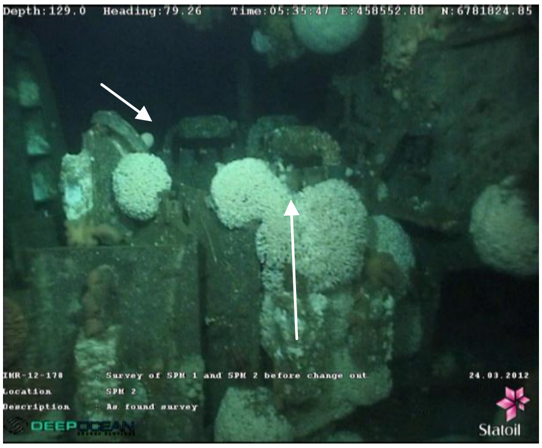


Figure 4.31: Foundation Bolts South-West Side

As for the H1 and H2 Bolt Housing, there is not much space underneath the base structure and a WROV will not be able to operate inside the base structure. The bolts seem to be in good condition.

Figure 4.32: Accessibility in below the base

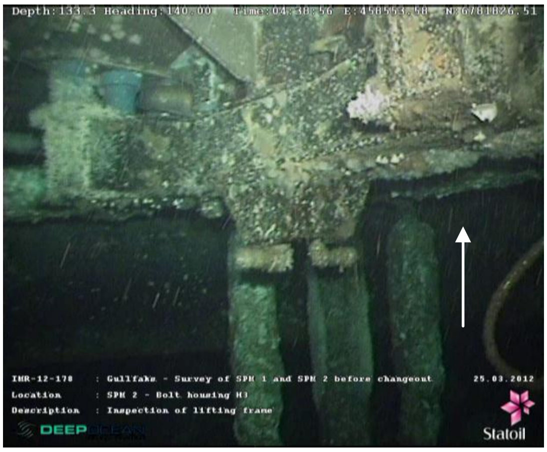


Figure 4.33: Lifting Frame and Secure Pins

The survey video from these to inspections can be found on the attached DVD with the following file names: "Lifting frame H3 inspection" and "Bolt housing H3 inspection".

4.3.4 Locking bolts and safety locking pins

The locking bolts are isolated from the environments and can`t be accessed or inspected. But to be able to retract the locking bolt, either the hydraulic line SI1268 (ref. figure 3.21) needs to be pressurized or the bolt can be pushed back by an override tool. Before any of this, locking pins must be retracted.

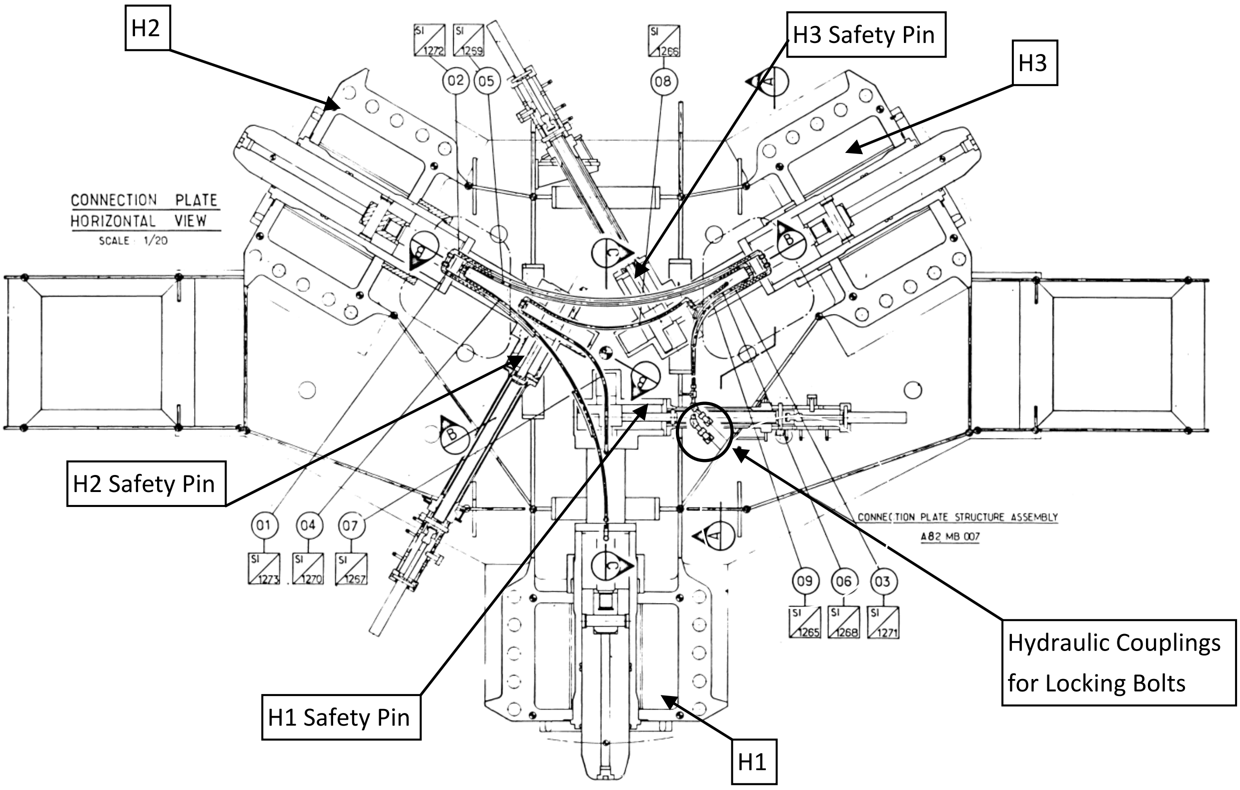


Figure 4.34: Locking Bolt and Safety Locking Pin Location

Figure 4.35: Location for Hydraulic Couplings

Figure 4.36: Locking Bolt Quck Couplings

It is possible to access to the couplings, but it can be a challenge operating them with a WROV, ref. figure 4.35 and 4.36.

H1 Safety locking pin

The H1 Safety Locking Pin is located between the H1 and the H3 Bolt Housing. As one can see on figure 4.34 there is no easy access to this. The survey videos confirm this, but there is a dedicated slot in the structure for access to the safety locking pin. In all documentation I have read there has been hydraulic cylinder to operate the safety pins. However, this is not the case due to the fact that there are no cylinders to be found. The safety pin is recently water jetted with high pressure and in good condition.

Figure 4.37: Slot for access to the safety pin

Figure 4.38: Safety pin and safety spike

In figure 4.38 one can see the safety spike where the left arrow points, which secures the safety pin. The right arrow points at the counter hold for the temporary hydraulic cylinder. A costume made cylinder which can be installed onto the safety pin slot must be designed to be able to retract it.

Reference video named “Locking pin H1” can be found on attached DVD.

H2 Safety locking pin

The H2 Safety Locking Pin is located between the H1 and H2 Bolt Housing. In contrast to the H1 Safety Locking Pin, the access to the H2 Safety Locking Pin is good. The safety locking pin is cleaned and seems to be in good condition.

Reference video named “Locking pin H2”can be found on attached DVD.

	
Figure 4.39: Acccess to H2 Safety Locking Pin	Figure 4.40: Close up

H3 Safety locking pin

The H3 Safety Locking Pin is located between the H2 and H3 Bolt Housing. Similar to the H2 Safety Locking Pin, the access to the H2 Safety Locking Pin is good. The safety locking pin is not cleaned, but seems to be in good condition.

	
Figure 4.41: Acccess to H3 Safety Locking Pin	Figure 4.42: Close up

Reference video, named “Locking pin H3”, can be found on attached DVD.

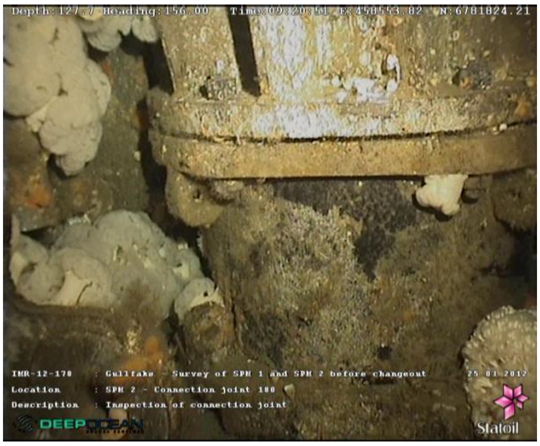
4.3.5 Connection joints

The two connection joints (type 1 and 2) can easily be accessed with a WROV. The rubber sleeves are in good condition and a leak test during loading to tanker was performed in June 2011. No leaks were observed.

In figure 4.43 and 4.44 one can see the Connection joint type 1. No abnormalities observed and one can see that the riser connection to the rubber sleeve is only fitted with a total of 4 bolts. No connections from the rubber sleeve to the top of the connection joint can`t be observed.

	
Figure 4.43: North side	Figure 4.44: South side

In figure 4.45 and 4.46 one can see the Connection joint type 2. As for the connection joint type 1, also this seems to be in good condition. This is also only fitted with 4 bolts. No connections from the rubber sleeve to the top of the connection joint can`t be observed.

	
Figure 4.45: South side	Figure 4.46: North side

Reference video, named “Connection joint type 1” and “Connection joint type 2”, can be found on attached DVD.

4.4 Crude oil valves

All the crude oil valves are located beneath the base structure and there is restricted access to them for a WROV. The crude oil valves are controlled by hydraulic actuators operated from the SPM platform.

During a survey in 2011 a leak inspection was performed during offloading to tanker and now leaks were observed. The crude oil valves seem to be in good condition.

The crude oil valves are not planned to be used in the new system, but they are indenting to be in constant open position. All necessary valves will be included in a riser base structure. Statoil wishes to use them as a backup solution. However, part of this thesis consists of looking at solutions for disconnection of the SPM and re-connection of a new offloading system without any use of divers.

It is also likely that the valves need to be closed during the change-out. This raises a dilemma due to the fact that the crude oil valves must be closed from the SPM platform and the hydraulic lines need to be cut when the connection plate is being disconnected.

The purpose of this section is to reveal the condition of crude oil valves and actuators. This is hereby done and as mentioned above, the conclusion is good, but there is restricted access.

As a result of the restricted access to the valves, other solutions must be considered. A possibility is investigating the hydraulic lines shown on figure 4.35 in section 4.3.4. From the drawing it looks like there are some hydraulic connection points between the base structure and the connection plate.

Since the valves will not be used on a regular basis and is just for extra safety precautions, it can be possible to develop a tool for connecting the hydraulic lines up to a permanent ROV panel. There are some uncertainties associated with this solution due to the fact that it might not be able to identify the crude oil hydraulic lines before the column is disconnected. A possible back-up solution is to connect the hydraulic actuators to a ROV panel with diver assistance.

4.5 By-pass structure

The flange on the by-pass structure is a possible interface connection to the new offloading system. The condition of this is therefore of great interest. On the overview pictures (figure 4.47) one can see that all the anodes on top of the structure are completely worn out. It is likely to believe miscalculations regarding cathodic protection in this area. Such calculations are often very complex and sometimes hard to predict. This has been seen many times in the offshore industry. Other than that, the structure seems to be in acceptable condition.

Figure 4.47: Upper part of By-Pass Structure

Figure 4.48: Upper part of By-Pass Strucutre

On the pictures below (fig. 4.49 and 4.50) one can see the flange where the flexible hose leading to the riser B is connected. All bolts are present and in good condition, but regarding the pipeline, heavy corrosion are observed on the top. Corrosion can also be found on the bolts on the flange. The corrosion is a direct result of the under protection, but the weight of the hose can contribute to some stress corrosion in the bend. Galvanic corrosion can also be an issue if the flange is higher rated in the galvanic series.

Figure 4.49: Flange from North

Figure 4.50: Flange from South

Reference video, named “By-pass structure”, can be found on attached DVD.

5. Disconnection of existing column

5.1 Introduction

Before any new installations can be installed onto the existing base structure, the existing column with the universal joint and connection plate needs to be disconnected. A suggestion for disconnection of the column with the universal joint and the connection plate is presented in this chapter. The suggestion is based on the results from the studies performed in chapter 3 and chapter 4 in this thesis.

A riser base structure must be designed regardless type of offloading system to be installed. The riser base will function as an adapter between the existing structure and new system. The objective to this chapter is to describe how the column can be disconnected in a way that eases any re-connection of a new structure.

This thesis focuses on use of ROV to the greatest extent possible. However, some stages of the operation might be more adapted to be executed by use of divers. In those cases where it can be beneficial to use divers, this will be presented as an alternative. The main reason for using ROVs rather than divers is for economical and safety reasons.

This chapter will start with a description of necessary preparation of the offloading system before starting the section regarding disconnection operations.

5.2 Preparation prior disconnection of Gullfaks SPM 2

Before any disconnection can take place, crude oil pipes must be flushed with water, specific valves needs to be closed and required barrier level need to be established.

5.2.1 Flushing of crude oil piping

Prior any disconnection one needs to ensure that environmental aspects of the operation are maintained. In this particular case it will be to make the disconnection without any discharges of oil to the environment.

Residues of oil in the crude oil piping can be cleaned to a certain level by flushing the piping. The Gullfaks A and C platforms have always a certain degree of ballast in its storage cells. This content will either consist of oil or water or a mixture of oil and water. Prior flushing, Gullfaks A`s loading cells must be free of oil.

While a tanker is connected to SPM 2 the offloading pumps at Gullfaks A must provide a sea water flow of 6000 m^3/h while flushing the two 24" pipes on the system. This is a flow rate suggested by Statoil. The purpose of the flushing is to achieve a required cleanliness of oil in the water. The requirement is less than 40 PPM hydrocarbons. Water measurements shall be taken from the tanker of water flushed through the SPM system.

A P&ID of the crude oil export system is to be found in appendix A, drawing number C001-D-000-PE-349-05. In table 5.1 valves relevant for the flushing of the SPM is described. There is one column showing valve position during flushing of the primary lines (Pos. Primary) and one column showing valve position during flushing of the by-pass line.

Name of Valve	Pos. Primary	Pos. By-Pass
FV 587	OPEN	OPEN
FV 588	CLOSED	CLOSED
FV 583	OPEN	CLOSED
FV 584	OPEN	CLOSED
FV 580	CLOSED	OPEN
FV 582	CLOSED	OPEN
FV 581	OPEN	CLOSED
HV 035	OPEN	OPEN
HV 036	OPEN	CLOSED

Table 5.1: Valve position during flushing

The by-pass line was not used during the leak test survey in 2011. For this reason it is difficult to ensure the condition of the hose. It is not recommended to use the same flow rate for this line. This is also a 20" line, which will result in a higher pressure by applying the same flow rate. A simple calculation for which flow rate to apply is recommended. This will not be performed in this thesis due to the work load of the thesis and scope of work.

5.2.2 Crude oil valve actuator and SPM hydraulic disconnection

When the system is flushed, some certain valves must be closed to ensure no water intrusion into the pipeline when the column is disconnected. There is also a requirement to maintain one of the Gullfaks loading systems operational at all times. Valve FV 587 and FV 588 can`t for this reason be closed. The barrier from the loading cells will be the other crude oil valves at the base structure as the second barrier and the platform loading valves functioning as the first barrier.

The valve positions on the base structure prior disconnection of the hydraulic system must be as followed:

Name of Valve	Pos. Primary
FV 587	OPEN
FV 588	OPEN
FV 582	CLOSED
FV 583	CLOSED
FV 584	CLOSED
FV 580	CLOSED

Table 5.2: Valve position prior hydraulic disconnection

When the crude oil valve actuators are set in correct position, the base structure hydraulics can be disconnected from the column and connection plate. This can either be done by use of divers or ROV. For economical and safety reasons it will usually be to prefer use of ROV over the use of divers.

Disconnection by use of divers versus use of ROV

At the connection plate one can see hydraulic couplings (ref. figure 4.35). There are such hydraulic couplings on each side of the H1 Bolt Housing. The greatest advantage with the use of a diver will be that when the disconnection is made, the lines can be blinded. A minimum of emissions to sea will take place.

One solution for disconnection of these lines by use of ROV will be cutting the lines with a cutting tool. Blinding the lines will not be possible by use of standard equipment. Small amounts of hydraulic oil may leak into the sea.

To be able to offload through the new offloading system, it will be of great advantage that the valves FV 587 and FV 588 can be operated from the riser base structure. If this is not possible, the loading system can only be directly used by one of the installation. One of the valves (FV 587 or FV 588) must in that case be closed to route the oil to the offloading system. To be able to load from the system which is not directly connected to the offloading system, the crude oil must be routed from one Gullfaks (A or B) installation to the other (A or B) via Gullfaks B topside.

The cutting point by use of ROV should be just above the area circled out in figure 3.23. There is a possibility that re-connection by ROV can be performed at this place by use of some simple costume made couplings.

5.2.3 Installation of hydraulic jacks on centering pins

Before any dismantling of the connection plate can take place, it is critical to secure the connection plate to the base structure. This needs to be done due to the buoyancy force from the column. If dismantling is started without securing the connection plate, the buoyancy force is held down by less and less bolts.

This problem is solved by using hydraulic jacks attached to the two centering pins. The jack uses the centering pin as back hold and then pushes the connection plate down in place. This solution will be used when disconnecting Statfjord C SPM. The same solution and equipment can be re-used on the Gullfaks SPM. The system is mounted by use of divers. There will still be stresses in the pre-stressed bolts, but the intension with the jack is to ensure that the connection plate and column remains stable during disconnection.

5.3 Disconnection of connection plate and column

The disconnection of the connection plate and column is achieved by mainly disconnecting the different locking mechanisms on the connection plate to the base structure. Some simple disconnections also had to be made to the crude oil flow line. This section will present a solution for disconnection of the existing offloading system. The solution presented takes into account that easy connection of the new system shall be possible.

The survey presented in chapter 4 reviewed the relevant mechanism necessary to dismantle to be able to disconnect the connection plate and the column. The following mechanisms that need to be dismantled are the following:

- Disconnection of crude oil flow lines
- Disconnection connection plate locking mechanism
    - Removal of safety spikes
    - Disconnection of safety pins
    - Disconnection of locking bolts
- Disconnection of pre-stressed bolts

Since the pre-stressed bolts are the mechanism designed to withstand the environmental forces onto the offloading system, it is reasonable to release the locking mechanism before removing the pre-stressed bolts. However, the hydraulic jack will keep the column in place even after the last pre-stressed bolt is removed.

5.3.1 Disconnection of crude oil flow lines

There are a total of three crude oil lines exiting the base structure and entering the column, the two primary lines and the by-pass line. All these three lines must be cut prior any disconnection of the column can continue. It is reasonable to start disconnecting these lines because there are no force transfers going through the bolts keeping the crude oil together.

Disconnection of primary lines

When first studying the video from the last survey, the most obvious way to disconnect the primary lines from the base structure was to cut the four bolts shown in figure 4.43-4.46. However, after a more thorough investigation of the videos, drawings and documentation, it appears that this connection is only secured by compression. The design ensures that when the column and the connection plate are connected to the base structure, the connection joints achieve compression.

In the pictures one can see four brackets attached on top of the bolt housing. The function of these brackets is probably to work as a guide during assembly and support when installed. Figure 3.16 and 3.17 shows the two connection joint types. No fasteners can be observed neither on the drawings nor the picture.

The conclusion for these two connections is actually that no work is needed to disconnect them. The connection joints will follow the column when the connection plate is disconnected.

Cutting of by-pass line

Unlike the primary lines, the by-pass line is fastened and needs to be cut to be able to disconnect it. To be able to install the new offloading system, one is depending on some suitable interfaces to make this connection. The by-pass line has a 13,5 meters flexible hose connected between the column and the by-pass line structure. The hose is connected to the by-pass structure with bolted 20" 300 PSI flanges.

In figure 4.47 one can see that the sacrificial anodes are totally worn out and the structure in this area suffers of cathodic under-protection. Figure 4.49 and 4.50 reveal many corroded bolts on the flange. There will be great risk associated with dismounting these bolts with regular hydraulic torque tools. This is a direct result of the cathodic under-protection.

A suitable disconnection point for this flow line will be at the flange. By cutting the bolts it will leave a nice surface with good possibilities for using this connection point as interface to the riser base structure. This work can be done by both divers and WROV. There is impeccable access to this location and it is recommended to perform this operation by use of a WROV. To ensure a safe disconnection and towing of the column it is recommended that the hose in its entirety is removed. This operation is not covered in the scope of work for this thesis.

As a conclusion to this disconnection it is recommended to cut the bolts on the flange. The cut must be made on the hose flange side to ensure no damage to flange on the by-pass line structure. The cutting can be made by a simple small cutting tool designed to be operated by a standard WROV.

5.3.2Disconnection of locking bolts

As described in chapter 3, there are a total of three locking mechanisms regarding the locking bolts. These are the following:

- Locking bolts, which actually locked the connection plate in position prior assembly
- Safety pins, which secures the locking bolts from retracting from the bolt housing
- Safety spikes, which secures the safety pins from retracting from the behind of the locking bolts.

A suggestion of how two disconnect these mechanisms is described in this section. The section is divided into three sub-sections, one for each mechanism.

Removal of safety spikes

To be able to retract the locking bolts, two safety mechanisms must be unlocked. These are the safety pins and the safety spikes, which secures the safety pins. As revealed in chapter 4, there are two safety spikes with good and one with poor accessibility for an ROV. Safety pin for the H2 and H3 bolt housings are good, but it will be difficult to operate tooling on the H1 bolt housing. A simple hydraulic actuation tool with a custom made extension bar would work, but the little safety spike make such tool a little too complicated.

It is recommended to get all the safety pins removed by use of a diver. There are many tasks which has advantages by use of divers. Many of these tasks can be accumulated and performed in one diving operation. A summary of which tasks that is recommended to execute by use of divers and when to do it is provided in section 5.4 in this chapter.

Retraction of safety pins

The safety pin must be retracted by a hydraulic safety pin. There are counter hold for the tool on the safety pin arrangement. The operation can be executed in the same operation as the diver removes the safety spikes. The safety pin condition on the H1 and H2 bolt housing seems to be in good condition (ref. figure 4.38 and 4.40) and it is likely to believe that this pin will retract by use of a hydraulic cylinder. The H3 bolt housing safety pin must be cleaned prior installation of the hydraulic cylinder, but regarding its condition, it is likely to believe that also this is in good condition since the other two were fine.

Disconnection of connection bladder

The connection bladder is the sealing for the oil filled area between the bolt lock housing and the connection plate locking bolt. The connection bladder is connected to a connection flange, which then is mounted onto the bolt lock housing with two of M20 bolts.

The oil inside the bolt housing should be drained by diver during the first diving operation. When the draining is completed, the two M20 bolts must be cut by use of a cutting tool. The result of this cut will be that the connection flange with the bladder will follow the connection plate when the column is removed.

The access in between the locking bolt housing and the connection plate is restricted. See figure 4.11 for reference. The width is approximately 235 mm and the distance into the M20 bolt is 32 cm from the side of the bolt housing. Figure 5.1 shows the connection flange connected to the bolt lock housing.

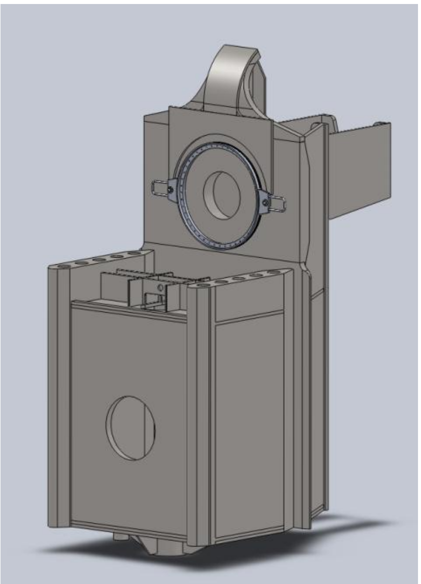


Figure 5.1: Bolt lock housing

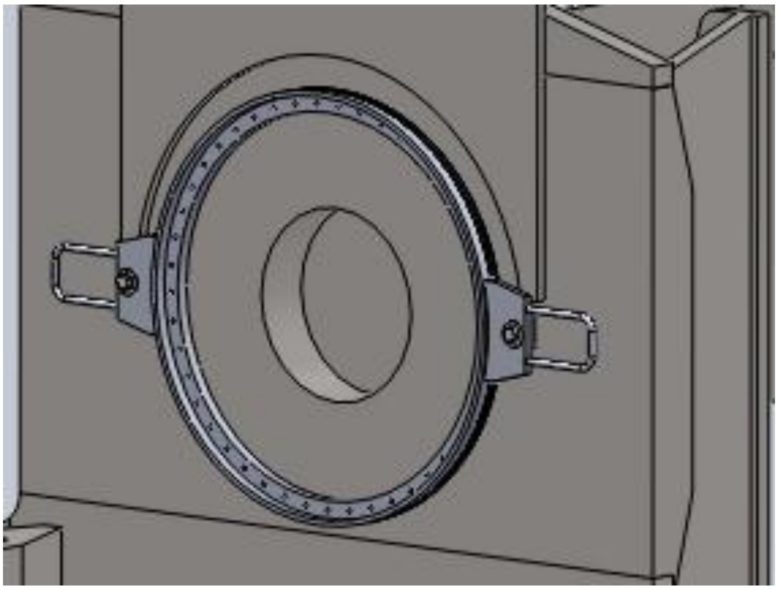


Figure 5.2: Connection bladder flange

Retracting locking bolts

There are two possible ways to retract the locking bolts. These are either to retract them by pressurizing the already existing hydraulic lines or push the locking bolts out of the locking bolt housings by use of an override jack.

It is recommended to drain as much fluid as possible from the connection bladder before disconnecting the column. The inside of the connection bladder is filled with oil which can be drain on the valve shown in figure 4.12. This valve is to be found beneath the bolt housings. The approximately amount of fluid that needs to be drained is 0,75 m^3 from each locking bolt housing. See appendix D for calculations.

The easiest way will be to use the already existing hydraulic lines. Override tool will then not be necessary to develop. But this is not an ROV friendly solution. The accessibility is not good for an ROV (ref. figure 4.35 and 4.36) and the hydraulic lines are only ½" sized with a blind cap. To retract all the cylinders after removing the safety pin, hydraulic line ½" OH65084EC11 (ref. figure 3.21) need to be pressurized. Before this line is pressurized it will be necessary to remove the blind cap from the extraction lines.

Because of the connection bladder between the connection plate and the bolt housing it will not be possible to ensure that the bolt is free from the bolt housing. A grinding tool can be used to cut open the connection bladder to visually verify the bolt to be out of the housing. The flanges shown in figure 4.15, 4.16 and 4.19 must be cut to be able to verify the bolt to be free from the bolt housing. All bolts are present and the condition look good so it is possible that these can be dismantled with a subsea torque wrench. However, cutting of the flange must be taken into account.

The other way to retract the locking bolts is more ROV friendly. The flanges must also in this case be removed, either dismantled or cut. If they can be easily dismantled, this is an operation a diver can perform during other operations. If this is not possible it is necessary to cut the flanges to get access to the bolts. There is adequate space for a WROV to install a cutting tool to cut the flanges.

Out from figure 3.16 it can seem like the bolt housings are designed such that the locking bolts can be retracted by use of an override jacking/actuator tool. This drawing shows how the flange and the locking bolt are aligned to make an easy override possible. In addition, there is a good support structure on the bolt housing which is ideal to install an override tool in. This is shown in figure 5.3.

The docking slot shown in this picture is identical for all the bolt housings. Before pressurizing an override tool to unlock the locking bolts, it is important that the hydraulic lines used to lock the locking bolts is opened. This needs to be done so the fluid trapped in the system has a way to flow. Otherwise the lines will burst. These lines have blind caps and are of the quick connector type. For this reason it is recommended to actually cut these lines. The amount of fluid in the system is very small and will not pose a danger for the environment. Chemicals can be injected near the emission to dissolve the oil.

Figure 5.3: Override-tool docking space

5.3.3 Disconnection of pre-stressed bolts

With a hydraulic jack securing the connection plate down to the base structure and the locking bolts removed, the pre-stressed bolts are ready to be removed.

To completely remove these bolts will demand an extensive operation with divers. The alternative to an extensive diver operation is cutting the bolts by use of WROV and custom made cutting equipment. These two alternatives will be described in this section.

Diver assisted bolt removal

The operation for removing the thirty bolts is extensive and it is not expected that this operation can be executed in one diving operation. Statoil estimates that removing these bolts will demand a total of three diving operations, one for each of the bolt housings. [47]

A Procedure for changing of damaged bolts was developed with the SPM documentation. This procedure can be found as Appendix C in this thesis. The parts in the procedure regarding dismantle of damaged bolt can be used as a method for dismantling the bolts. The main principles of the procedure will be described in this section.

Below the pre-stressed bolt lifting frame there is a grating that forms the working platform on the base structure. Welds needs to be cut and grating removed. The seafloor below the grating must be dredged to ensure a 4 meter gap between the grating and the seafloor. Hydraulic lines must be connected to the two quick-connections on the lifting jack.

The jack must be tested before proceeding. There are uncertainties associated with the function of the jack. The corrosive environment may have caused this jack not to work properly. If this occurs, the lifting frame must be removed and a new operation with special tooling designed for this task must be developed.

The diver rigs a lifting line attached to a buoyancy bag with a lifting capacity of 500 kg. The bag is attached to the SPM structure by use of rope or net and then filled with air until full lifting capacity is reached. [48]

Further, the diver must remove the top nuts on the pre-stressed bolts. Then a stretching tool must be installed onto the bolts where the top nuts where removed. All 30 bolts must be stretched simultaneously. This is achieved by installing tensioning tools onto each of the bolts. If this is not done, the tension in each remaining will increase until the rest of the bolts will reach the tensile strength and break. However, the tension will be reduced by use of the hydraulic jacks. In addition, ballast water can be added into the column to further reduce the tension in the bolts.

When the stretching tool and nut are removed, the bolts will rest in the lifting frame. Now, further there are two alternative. These two alternatives are either to leave them in the lifting frame or completely remove them. Regarding the new system, it will not be necessary to use these bolt holes for attaching the riser base structure. This will be described in chapter 7. For this reason it is recommended to leave the bolts in the lifting frame.

By use of the buoyancy bag and the lifting frame, the bolts is lowered two the seabed. The lifting frame can only be lowered 2 meters. So when this is reached, the bolt needs to be lifted out from the lifting frame. The frame is then turned 90° to allow the bolt to be completely lowered to the seabed. The bolt must then be removed from the seabed underneath the base structure.

The operation for completely removal of the pre-stressed bolts is described in detail in the change-out procedure found in Appendix C.

Cutting of bolts by use of ROV

Another alternative for removing the pre-stressed bolts will be to cut them by use of a WROV. There is good accessibility for an ROV with cutting equipment for this job. It will not be possible to remove the bolts completely only by use of the ROV, but there will be no problems with leaving the bolts in the lifting frame. The bolts can be cut be use of a special made hydraulic driven chop saw which can be attached to the bolt to ensure a stable operation.

The hydraulic jack installed on the centering pins will keep the connection plate in position when the bolts are gradually cut off. The tension in the remaining bolts during the cutting will increase. It is therefore important to lower the stresses in the bolts before cutting. This is achieved by use of the hydraulic jack. In addition, the column can be ballasted with water to ensure low enough stress.

When the bolts are cut, the hydraulic jacks and the ballasting system must be trimmed such that the connection plate goes clear of the connection bolts. When the column is removed, the bolts must be cut so they are flush with the bolt housing. The ROV can secure the bolt with the grabber arm (left arm) while the 7 function manipulator arm is cutting the bolt. The bolt can then be placed in a subsea basket. Figure 5.1 shows first the bolts after cut for connection plate removal and then bolt cut flush. The base structure is surrounding the locking bolt housing from the point where the arrows are shown in the picture to the right. This is valid for both the locking bolt housing types.

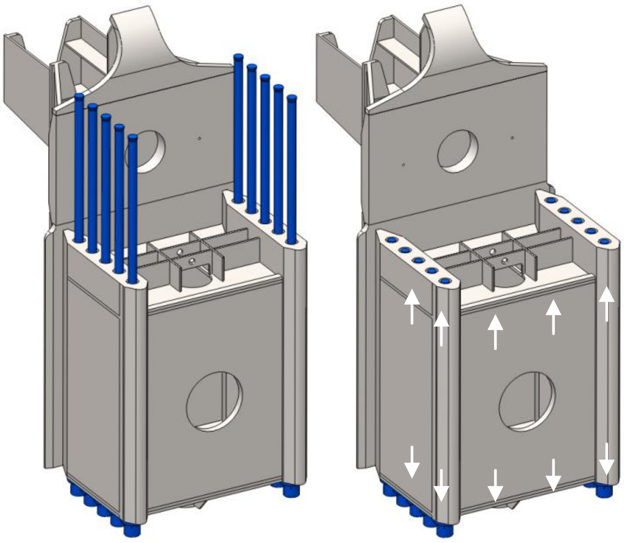


Figure 5.4: Pre-stressed bolts, alternative 1

An alternative (2) to cut the bolts flush with the locking bolt housing is to lower the lifting frame by use of diver in the first diving operation. The bolts will then fall down and be positioned partly in the lifting frame on the work platform grating and partly in the locking bolt housing, see figure 5.5. See appendix E for length verification.

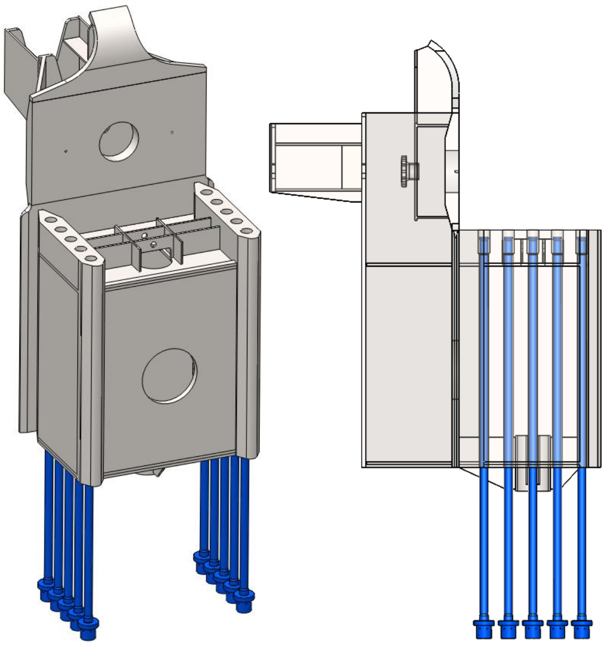


Figure 5.5: Pre-stressed bolts, alternative 2

Experience using the hydraulic jacks will be earned during the disconnection of the Statfjord C SPM. Another alternative method will be to jack the column up sufficiently to cut the bolts from below the connection plate before the column is removed. A disadvantage is that the bolts will fall out of the connection plate when it is removed.

5.4 Disconnection summary

After thoroughly examination the possibilities to disconnect the column from the base structure, the conclusion is that is can be best solved in a ROV / Diver operation. It will be extremely demanding to be able to disconnect this column only by use of ROV. This is due to the re-use of the base structure.

It is recommended to use divers to the following operations:

- Disconnection of the crude oil flow lines
- Remove safety spikes
- Retract safety pins
- Lower lifting frame
- Try release the bolt housing flange (if not succeeded, cut by ROV)

The scope of these operations would be very costly to execute by an ROV and custom made tooling. It is therefore assumed with great certainty that these operations will be less expensive by use of divers. The remaining operations are recommended performed by a WROV and suggested equipment.

When the pre-stressed bolts are removed, it is time for slowly disconnect the connection plate from the base structure by operating the hydraulic jacks installed on the centering pins. Further marine operations for removing the column is not described in this thesis. All necessary disconnection relevant for installation of the new offloading system has been covered and thereby the objective is achieved. Further, the necessary modifications prior installation of a new offloading system is described in chapter 7. Table 5.1 gives a short description and summary of suggested tooling.

Type of tool	Area of application	Tool status
Jacking Tool	Secure connection plate to base structure during disconnection.	Will be used during removal of Statfjord SPM C.
Safety pin extracting tool	Extracting the safety pins	Must be designed and produced.
Cutting tool	-Remove connection bladders -Disconnect bolt housing flanges	Simple existing hydraulic cutting tools can be used.
Locking bolt override tool	Extracting the locking bolts	Must be designed and produced.
Cutting tool	Cut pre-stressed bolts	Must be designed and produced to secure safe operation.
HPU	Operate lifting frame	HPU available from ROV
Suction tool	Collect oil in bolt housing compartments	Existing suction tools can be used.

Table 5.1: Suggested tooling

6. Description of APL offloading system

6.1 Introduction

The planned system to be installed is a system delivered from APL (Advanced Production & Loading) in Arendal. A similar type of system was installed on the Statfjord field in 1986 (Statfjord A OLS) and 1987 (Statfjord B OLS). These system then replaced the Statfjord SPM`s were the base structure were re-used. Some information about the Statfjord OLS will therefore be used to describe the system. The main difference will be the riser base structure due to the differences in the base structures on Gullfaks and Statfjord.

6.2 System principal

The new offloading system will consist of a riser base, which will function as an adapter between the existing base and the new offloading system, a vertical riser with a sub-surface buoy and offloading hose (flexible riser) from a gooseneck swivel connected to the sub-surface buoy.

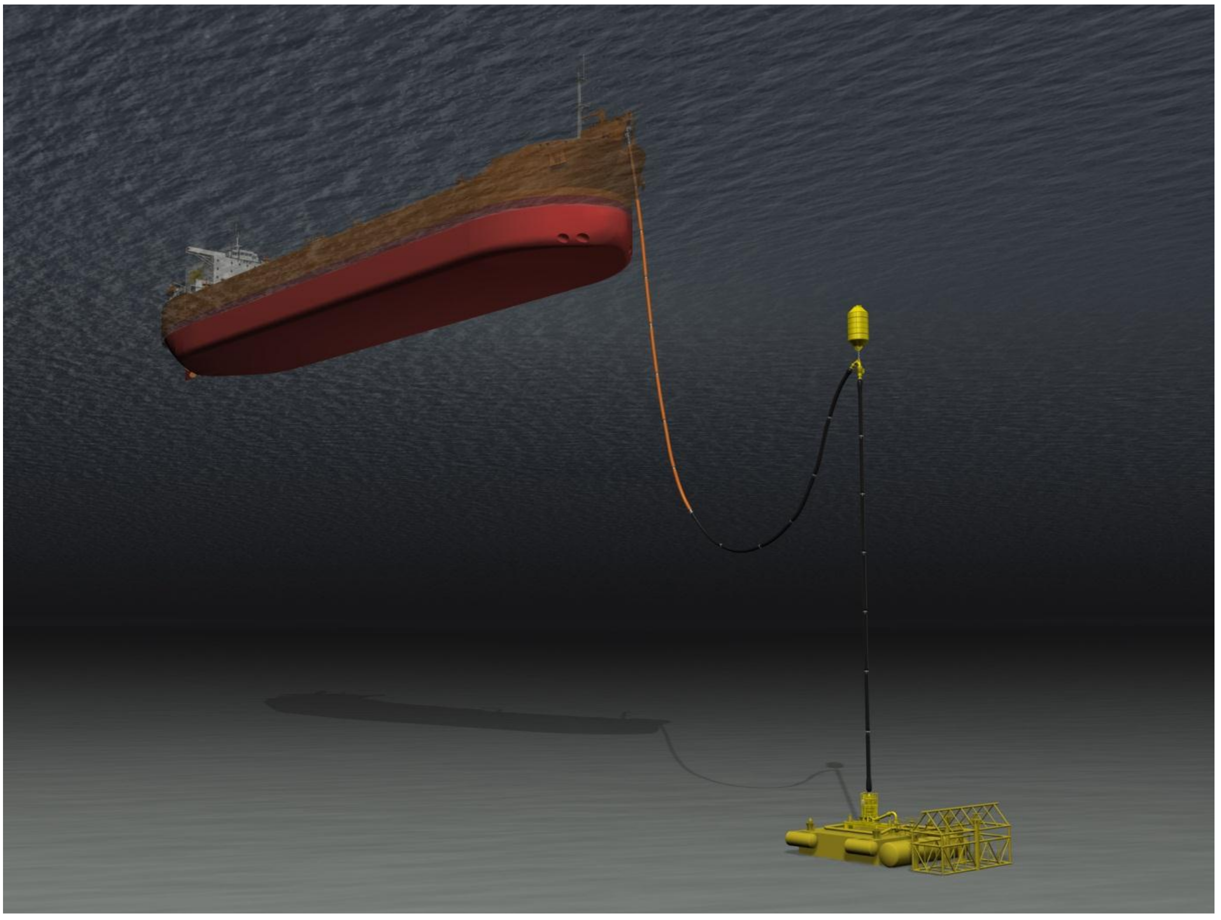


Figure 6.1: Illustration of *APL offloading system OLS B at Statfjord [1]*

The hose lies on the seafloor when not in use and is connected to a line with a floating element. The system connects to the tanker by pulling up the line with assistance by a support vessel. When tanking is completed the hose is laid back down onto the seabed. The only valve that needs to be operated on the system prior offloading through the system is the valve in the end of the flexible riser. This valve is operated onboard the tanker.

This system has no mooring capabilities so it is required that the tankers shall as minimum have DP class 2 installed. Before offloading can commence, a green line shall be established between the tanker and the installation. This is a logic based UHF link that shut down the loading pumps and closes the valves onboard the installation and tanker if the line brakes [49].

For installation of the new system, a rise base designed to fit the SPM 2 is first installed onto the SPM 2. This will be a steel structure with a weight of approximately 25-30 tons that will be installed as a separate marine operation. After installation of the riser base, the vertical riser with the riser foot, sub-surface buoy and flexible riser will be installed onto the riser base. This is ensured by an 18 ¾" connector system.

6.3 Riser base

The riser base will be designed after Statoil`s requirements regarding the locking mechanism needed to lock onto the existing base structure. How exactly the riser base can be connected to the existing structure will be discussed in chapter 7. The riser base will be the connection between the old system and the new riser system with the riser foot.

Figure 6.2 shows the riser foot used on the Statfjord OLS B offloading system. This system was locked down to the base structure with the existing locking mechanism on the base structure. This will not be the case for the base structure at Gullfaks. There are no locking mechanisms that can be activated for locking the riser foot to the structure. Another difference is numbers of possible locking bolts. The Gullfaks SPM`s have three lock bolt housings, while the Statfjord has four.

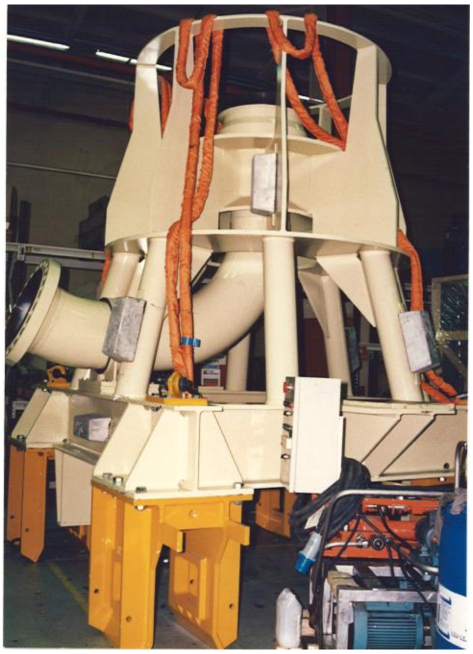


Figure 6.2: Statfjord OLS B riser foot [50]

The riser base to the base structure must be designed with locking mechanism integrated in the riser base design. In addition to the locking mechanism, the riser base shall include an ROV panel for controlling the already existing crude oil valves. A set of double block and bleed valves will also be integrated into the riser base design, also operated from the ROV panel integrated in the riser base.

The purpose of installing a double block and bleed valve is to be able to disconnect the riser system for maintenance work at shore. There will be no need for installing a temporary pressure cap onto the connector to maintain two barriers to 36" crude oil line. However, it will be necessary to clean the hub before reattaching the riser foot onto the riser base after maintenance. Figure 6.3 shows an excerpt from the system GA drawing, ref. appendix A drawing number 1531-APL-S-XS-BM-002.

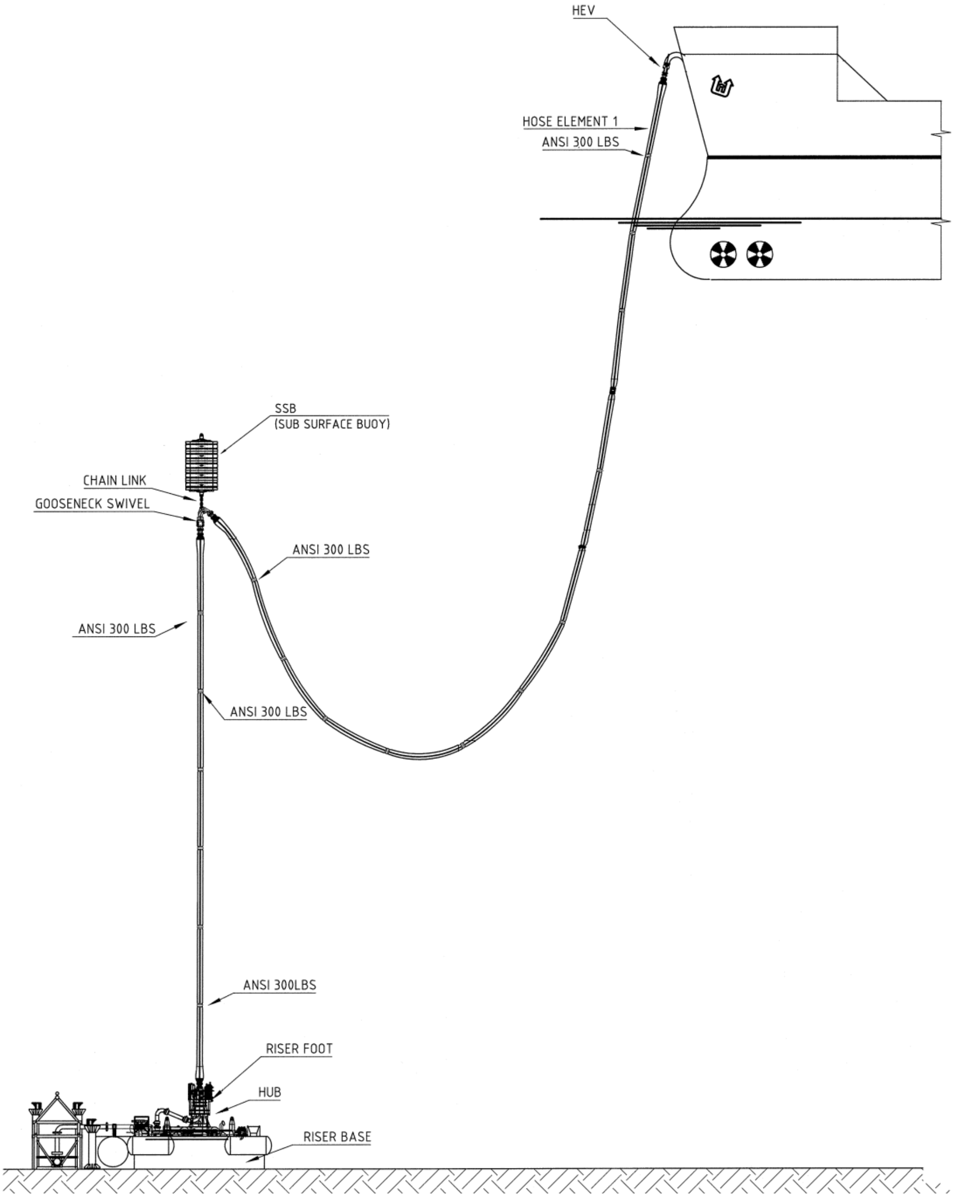


Figure 6.3: Excerpt from system GA drawing

6.4 Riser foot

The riser foot is located in the end of the vertical riser. The function of the riser foot is to ensure easy connection to the riser base hub and to accommodate an ESV, a hydraulic accumulator package and acoustic transponders. If an emergency should occur, the tanker can send an acoustic signal to the riser foot which will activate and close the emergency shutdown valve. The acoustic system does also send pressure readings to the tanker which makes it easy to keep track of the accumulator pressure. It is required that tankers operating the offloading system have this particular system installed.

The accumulator package can be charged by use of ROV with a HPU and a Hot-stab if the pressure drops below a given level. [51]

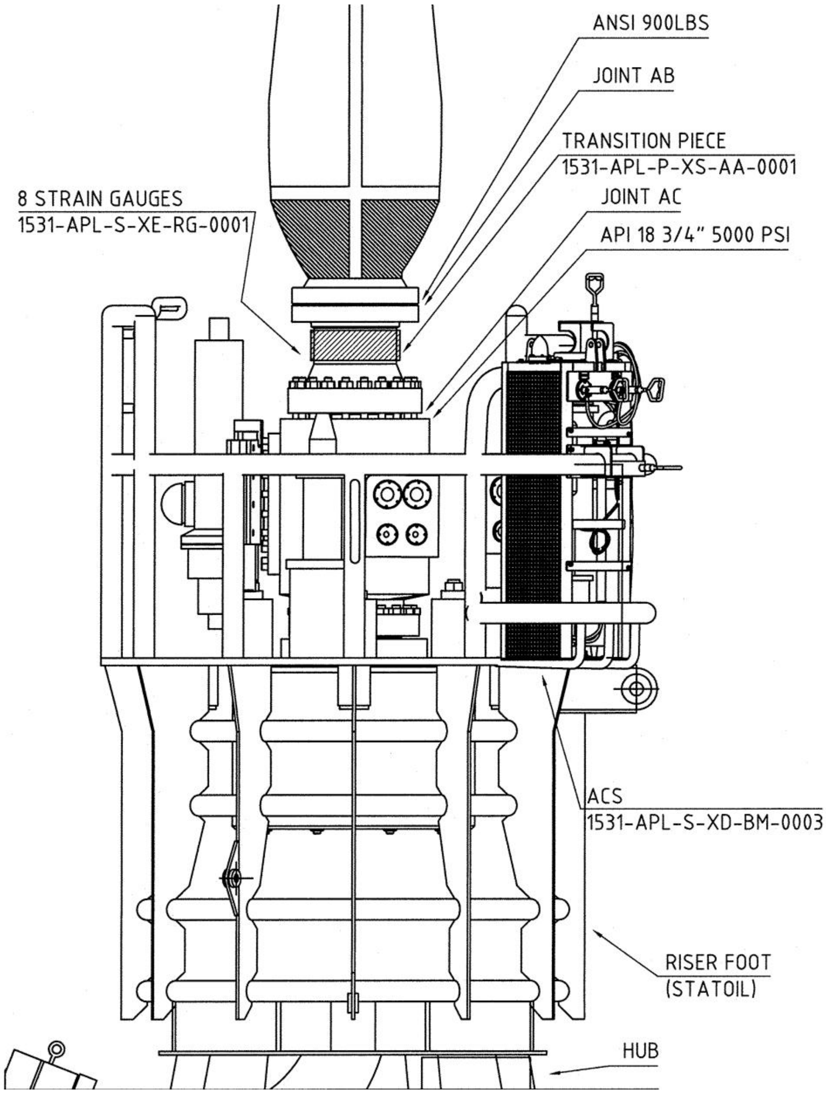


Figure 6.4: Riser foot connected onto riser base hub (excerpt from GA drawing)

6.5 Force contribution from new system to existing base

The force contribution from the new system to the existing base will be significantly smaller then forces from today`s column. The riser base structure that will be installed onto the existing base structure is estimated to weigh 25-30 tons. This is a number based on the experiences with the installation of the Statfjord OLS A and B in the end of the 80`s.

The buoyancy from the sub-surface buoy is approximately 5 tons, which result in a net gravity force of 20-25 tons acting on the base structure during normal conditions. The environmental forces acting on the vertical riser, the sub-surface buoy and the flexible riser can be neglected in conjunction with the base structure due to the weight of the riser base. These forces will not even come close to the gravity forces from the riser base.

However, extreme loading can occur as a result of system failure on tanker connected to the offloading system. This can be DP failure or engine failure on the tanker. This can result in tension in the flexible riser. The green line will in such case shut down offloading pumps and crude oil valves. The valve connected to the tanker bow will release if the tension exceeds 120 tons. The forces will for this reason not exceed 120 tons.

The new offloading system must for this reason be attached to the existing riser base structure such that the locking mechanism can withstand these forces.

An evaluation of this in particular will be presented in chapter 7 regarding necessary modifications prior installation of the new system.

7. Subsea structure modifications

7.1 Introduction

This chapter will investigate the modifications necessary to install the new offloading system onto the subsea base structure. Prior this installation, the removal of the column must be completed. This removal will result in three relatively clean interfaces available to connect the new system up against. These three interfaces are on top of the two connection joints and on the 20" by-pass lines flange.

The investigation will include multiple different areas. The thesis focuses on, and describes what need to be done, and due to the workload of the thesis, not in detail how to do this.

The following subjects will be studied in this chapter:

- Which line to use for connecting the new system up against the base structure
- Cathodic protection of the base structure
- Investigate if the lock bolt housing can be used for locking mechanism
    - Investigate how the lock bolt housing is attached to the base structure
    - Strength calculations for the lock bolt housing

An important part of the modification will be the design of the riser bases structure. This is not part of this thesis, but it will be investigated whether the bolt lock housing can be used to lock the riser base to the base structure or not. However, the riser base principle is described in chapter 6, including what functions that needs to be integrated in this.

7.2 Interfaces towards new offloading system

The interfaces towards the new offloading system will primarily consist of the crude oil flow interface and the interface for the base structure crude oil valves, meaning the hydraulics. This section will focus on both of these aspects of the interface connection.

7.2.1 Crude oil piping interface

There are a total of three possibilities for connecting the new riser system onto the existing base structure. These are, as mentioned above, either one of the connection joints or the by-pass line flange. During the investigation of the survey videos, it is clear that the flange is a very good point where an interface can be made. The flange gives very good accessibility for the connection operation and it will ensure a safe and secure connection.

The two connection joint on top of the bolt housing were secured only by compression from how the connection plate was assembled to the base structure. For this reason there are now good mounting opportunities on these. To make a connection to the new system at one of these areas would demand a special made locking cap which could secure the pipe to the connection joint. For this reason it is recommended to use the by-pass flange as connection point towards the new offloading system.

This connection is easiest accomplished with a diver operation. Simple torque tools for tightening the flange bolts are available to get safe connection. This connection can also be accomplished by use of a WROV, but it is recommended to design a tool with hydraulic bolt tensioning equipment integrated. Two half-moons can for instance be installed on each side of the flange with a plate instead of nuts on the opposite side then the tensioning tool.

However, a diver operation will be necessary in order to connect the hydraulic lines from the crude oil actuators to the integrated ROV panel on the riser base. Due to this, it is recommended that the flange connection is made by use of diver in the same diving operation.

To achieve a double barrier to the environment, it will be necessary to blind the primary lines A and B at the connection joints and blind caps must be designed for this purpose. With the blind caps installed on the connection joints, a double barrier will be obtained by permanently closing the valves FV 583 and FV 584. Valve FV 582 will be open at all times. As described in chapter 6, an acoustic emergency shutdown valve will be installed on the riser foot. This will be powered by hydraulic accumulators.

Regarding the cathodic protection, figure 4.47 shows completely worn out anodes on the by-pass structure. In order to use the by-pass line as primary line it will be critical to install sufficient cathodic protection in terms of stand-off anodes. Retrofit anodes can be designed to install subsea by use of ROV. Oceaneering AS has superior experience with such anodes and has in the past two years designed anodes for anchor line wire sockets and retrofit anodes to the Njord A platform.

7.2.2 Crude oil actuator hydraulics

To be able to control the valves on the base structure, the crude oil actuators must be connected to an ROV panel integrated on the riser base.

The SPM 2 offloading system can perform offloading directly from Gullfaks A and C, but one can say that SPM 2 is designated Gullfaks C and SPM 1 is designated Gullfaks A. However, the SPM 2 is the only offloading system that can perform direct offloading from both Gullfaks A and C. Alternatively, it is possible to route the crude oil between Gullfaks A and C via Gullfaks B topside.

The direct routing is regulated by the two valves FV 587 and FV 588. When offloading from Gullfaks C, valve FV 588 must be open while valve FV 587 is closed. The opposite when offloading directly from Gullfaks A, valve FV 587 open and valve FV 588 closed. It can be possible to leave both these valves in open position and during offloading the barrier will be the platform valve. It is still not decided whether to replace both SPM`s or only SPM 2 and removal of SPM 1.

It is desirable to be able to operate the valves on the SPM on Statoil behalf. All the valves must then be connected to the ROV panel. If using the by-pass line as the new primary line, valves FV 583 and FV584 should be closed permanently. In addition to the blind caps, one has the required double barrier to sea. Valve FV 582 must be permanently opened.

Since the valves must be closed before disconnecting the SPM column, they must be opened when the new offloading system is installed. Now, when these valves are opened, there are not large differences in scope of work from either opening the valves or connecting them up to the ROV panel. The extra cost for getting control over the valves is for this reason minimal.

7.2.3 Potential area for riser base installation

The potential area for a riser base installation is shown in figure 7.1. The riser base can be landed on the locking bolt housing given that the pre-stressed bolts are not interfering and are flush with the surface. The distance from the locking bolt housing to the center are 3475 mm. There are two stand-off anodes that can interfere with the riser base shown with the red arrow marked with the number 5. The riser base should be designed to fit inside the red markings. There will be no interface issues as long as the riser base is placed on the bolt housing, as shown in figure 7.2.

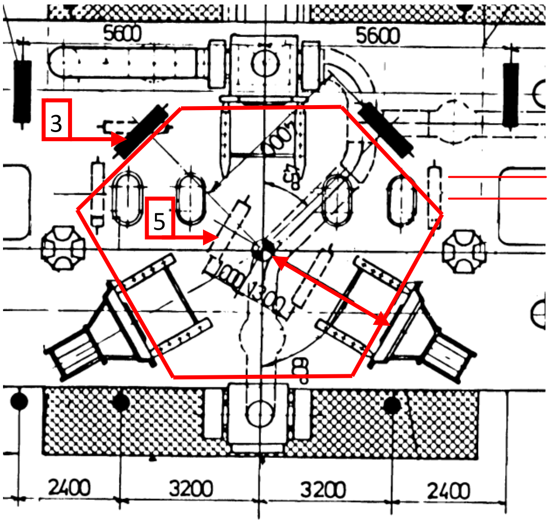


Figure 7.1: Area for riser base installation [52]

The by-pass structure is located to the right in figure 7.1 and the pipe connecting the riser base and the by-pass line is illustrated to the right as a potential solution at where there is enough space to connect the pipe.

There are possibilities to go beyond the marking, but these areas must go clear the two stand-off anodes. These two anodes are of the anode type 5. The anode marked with number five shows the anode type 3. Both anodes, figure 7.1 and 7.2 are shown on drawing C001-L-A42-RA-002 found in appendix A.

Figure 7.2 illustrates a section view of the base structure where the riser base be placed. This is shown by the red arrows. The spool for connecting the base structure to the riser base is also illustrated. To ease the installation it is a good solution to first install the spool with a vertical connector.

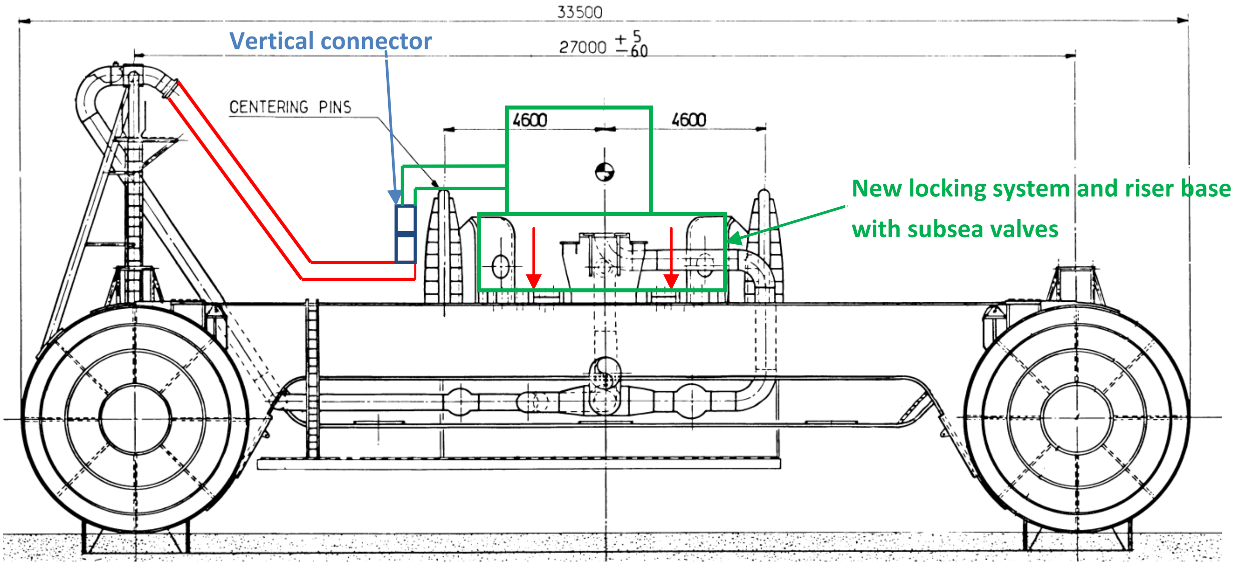


Figure 7.2: Riser base interface to existing structure

7.3 Cathodic protection

This section will focus on the cathodic protection of the base structure. A short introduction to cathodic protection is given before the base structure is described in section 7.3.2.

7.3.1 Short about cathodic protection

Cathodic protection (CP) is defined in DNV-RP-B401 as "electrochemical protection by decreasing the corrosion potential to a level at which the corrosion rate of the metal is significantly reduced".

The metal is forced down to a lower electrical potential in relation to its corrosion potential. The results in a lower anodic current density and the corrosion rate lower.

For galvanic anode CP systems, the anode of the electrochemical cell is a casting of an electrochemically active alloy, normally aluminum, zinc or magnesium based. The most common used for protection of subsea constrictions is the aluminum based alloy. The anode is the current source for the CP system and will be consumed. Consequently, it is often referred to as "sacrificial anode" as an alternative to "galvanic anode". For galvanic anodes on offshore structures, inspection and maintenance during operating can almost only be limited to periodic visual inspection of anode consumption. [53]

The main criteria for cathodic protection is that $E < E_b$, where E_b is a practical protection potential, mainly based on experience. For carbon steel in seawater E_b is usually -800mV against an Ag/AgCl/seawater reference electrode. The reactions are as following:

Anode: $Al \rightarrow Al^{3+}$

Cathode: $2H^+ + 2e^- \rightarrow H_2$ and

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

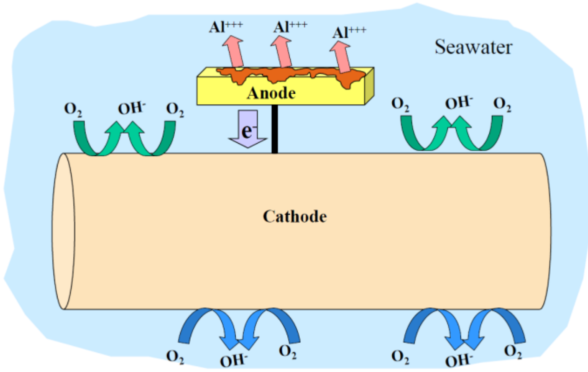


Figure 7.3: Cathodic protection with aluminum anode[54]

Whether there is enough current or not is therefore determined by measuring the potential of the steel against the standard reference electrode. Experience shows that if steel receives enough current to shift the potential to -0,8mV, the corrosion is essentially stopped. The most optimum potential seems to be between -950mV and -1000mV measured in against Ag/AgCl/seawater. [55]

7.3.2 Base structure cathodic protection

The condition of the base structure regarding corrosion seems to be very good. No significant corrosion has occurred and the anodes are evenly worn. Some of the stand-off anodes is broken and can be observed on the working platform of the base structure. This is due to fatigue at the mounting points. Drag forces due to shifting current results in force amplitudes which can lead to fatigue damage. This is not a critical problem, and it is only a fewer amount of anodes which are broken.

CP measuring of the entire column was performed during the 2011 survey. The measurements varied from -975mV to -1017mV [56].This is a very good result and confirms the base structure to be protected regarding corrosion. However, too few CP measurements have been performed on the base structure. On figure 4.47 one can see that the anodes are totally worn down on the by-pass structure. The result of this is that the area is suffering of cathodic under-production, hence the observed corrosion attacks.

For this reason it will be necessary to improve the cathodic protection at the by-pass structure by installing sacrificial anodes. CP calculations must be performed and anodes sufficient to last the design life must be installed. It is also recommended to perform periodic CP measurements to ensure the base structure to be fully protected at all times of the design life. The design life will initially be to 2030, but there is a possibility for this to be extended to 2040.

7.4 Assessment of structural integrity

In this section the bolt lock housing will be examined to determine whether the bolt lock housing can be used as a locking point for a riser base structure or not. There are some calculation notes from when the SPM was build, but these are not available in the period this report is written. Except from the cathodic protection, a strength analysis for how the new system is mounted and a fatigue risk evaluation will be necessary. This will be conducted in this section.

This section will investigate the possibility to connect the riser base to the base structure by locking the base structure onto the bolt lock housings. A strength analysis will be conducted for this purpose. The alternative to locking the riser base to the bolt lock housing is to mount it by use of new pre-stressed bolts. It will not be necessary with 30 pre-stressed bolts, but calculations should be performed to determine the correct amount of bolts necessary for withstanding the maximum force of 120 tons from the hose connected to tanker.

7.4.1 Fatigue evaluation

A fatigue calculation was performed prior building of the SPM 2, and most of the fatigue exposed areas are on the column. The force amplitude is largest at the top of the column, and decreases closer to the bottom.

However, it is the periodic forces acting on the base structure that will determine if the base structure is exposed for fatigue risks. The estimated buoyancy force from the column is approximately 226 tons. The net force from the new system will be approximately 20-25 tons. These forces are in opposite direction, but they are only a fraction of the initial forces.

Regarding fatigue, experience shows that there is a correlation between a materials tensile strength and its fatigue limit. For most cases, fatigue will not occur if the following criteria are satisfied [57]:

- $\sigma = 0{,}5R_m$ with bending
- $\sigma = 0{,}45R_m$ with axial loads
- $\sigma = 0{,}29R_m$ with torsion

These numbers needs to be checked with the calculation notes from the SPM 2. Unfortunately, these documents are not available at the moment, but they will be released from Statoil`s archive summer 2012.

The base structure consists of two pontoons with beams in between. The base structure is modeled and strength calculated in a total of three separate calculation reports:

- Doc.no. C001-L-N-CE-401: Base Structure – Beams Calculation Note
- Doc.no. C001-L-N-CE-402: Base Structure – Lateral Floats-Calculation Note
- Doc.no. C001-L-N-CE-403: Locking Bolt Housing – Calculation note

It is very likely to believe that fatigue will not occur with the new system installed. The documents mentioned above must be used to ensure that fatigue will not pose a risk to the structural integrity of the system. Strength calculations on the bolt locking housing will be performed in section 7.4.3. The DFI from the SPM 2 also implies that fatigue on the base structure will never be of any concern.

7.4.3 Strength analysis of locking bolt housing

The following section will present the strength analysis of the locking bolt housing. The model used for the simulation is based on the detailed locking bolt housing drawing. Drawing can be found in appendix A, drawing number C001-L-A93-NB-007.

There are two different types of locking bolt housings, as explained in chapter 3. It is assumed that the two locking bolt housings have the same strength properties. Only a model for the locking bolt housing type 2 is drawn in SolidWorks and analyzed. The analysis consists of checking for the strength when the locking bolt holes are used for securing a riser base to the base structure.

The locking bolt housings are welded to the base structure on several places. The welds were strong enough to resist the forces from the SPM column and will therefore be strong enough for the new riser system. The model fixture is defined with the fixed geometry at the places where the locking bolt housing is welded to the base structure. By fixed geometry means that these defined places are not allowed to move in any direction nor rotate. The fixed geometry is illustrated in figure 7.4. Detailed drawing of the locking bolt housing is attached in appendix A, drawing number C001-L-A42-NB-003 and C001-L-A42-NB-010.

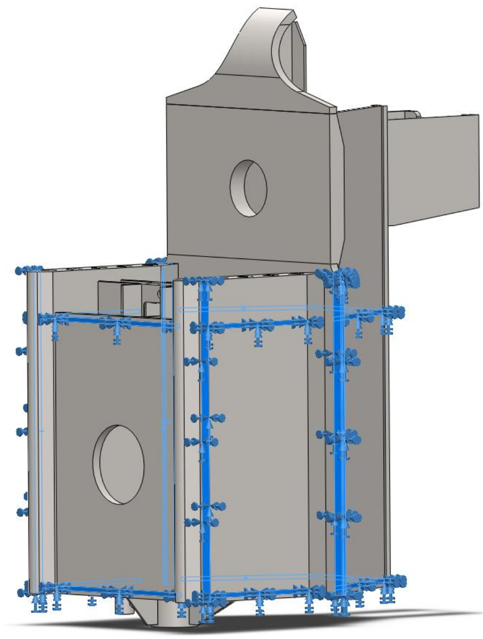


Figure 7.4: Fixed geometry

The load applied in the analysis is defined from the maximum load the system can experience. This is determined from load that will result the weakest link to break. The weakest link will be the valve connection onboard on the tanker and this will beak and shut the valve at a load of 120 tons. A load of 1.800 kN is applied in the simulations, resulting in a safety factor of just above 1.5.

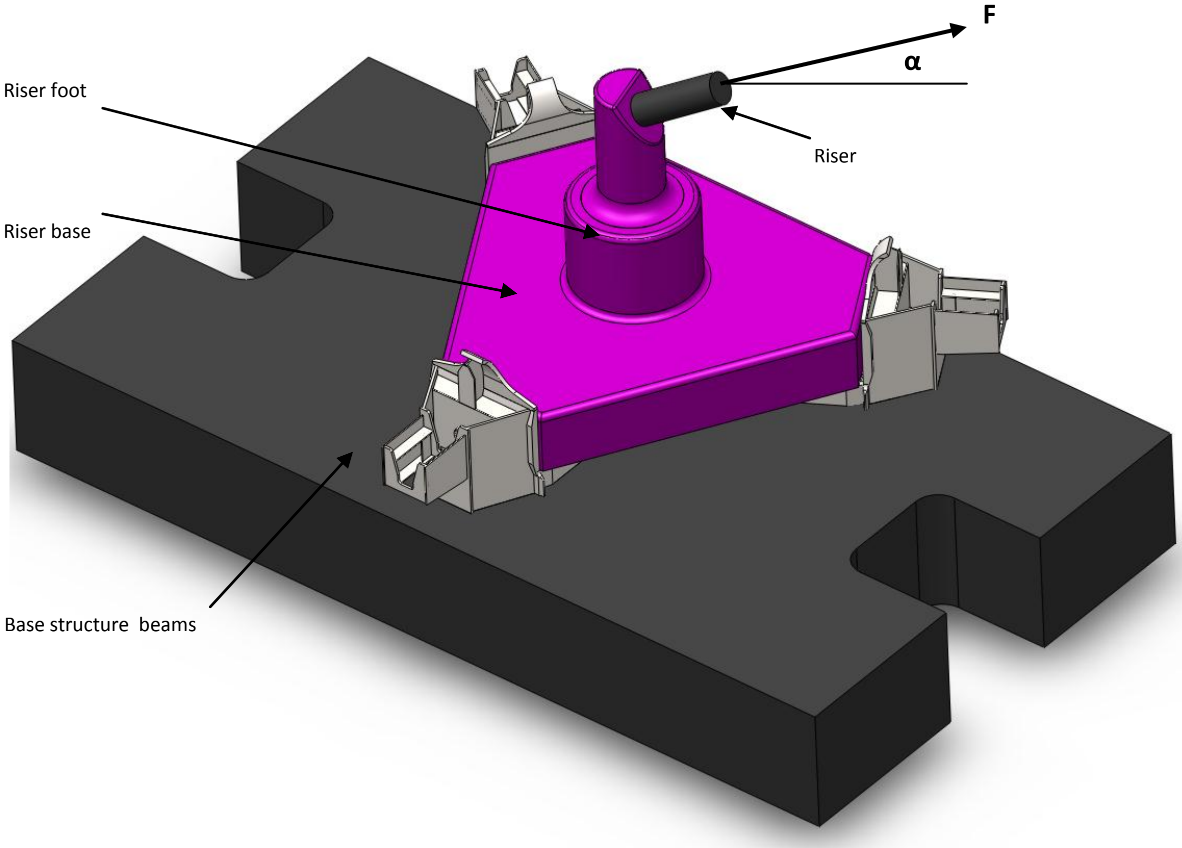


Figure 7.5: Illustration of offloading hose angle at maximum tension

Figure 7.5 illustrates the angle of the offloading hose if the ship drifts off and the hose is stretched out in its full length. This is not how the system will look. The solids are just to illustrate the force direction relative to the bolt housings. The angle α is estimated to be 33,5°. This is given a total length of 250 meters for the offloading hose from the riser foot. The force can act all the 360° around the riser base. The angles resulting in the highest stresses must be analyzed. Calculations attached in appendix F.

The material is defined in DFI as construction class 1, steel grade 1 or 2. This gives yield strength of minimum 310 MPa (depending on thickness) and a tensile strength of minimum 460 MPa. The E-modulus is not given, but it is assumed to be approximately 200 GPa. [58]

Finite element mesh

Figure 7.6 illustrates how the bolt housing where divided into elements for the SolidWorks Simulation analysis. The feature is called mesh, and the same mesh is used for all calculations in this thesis.

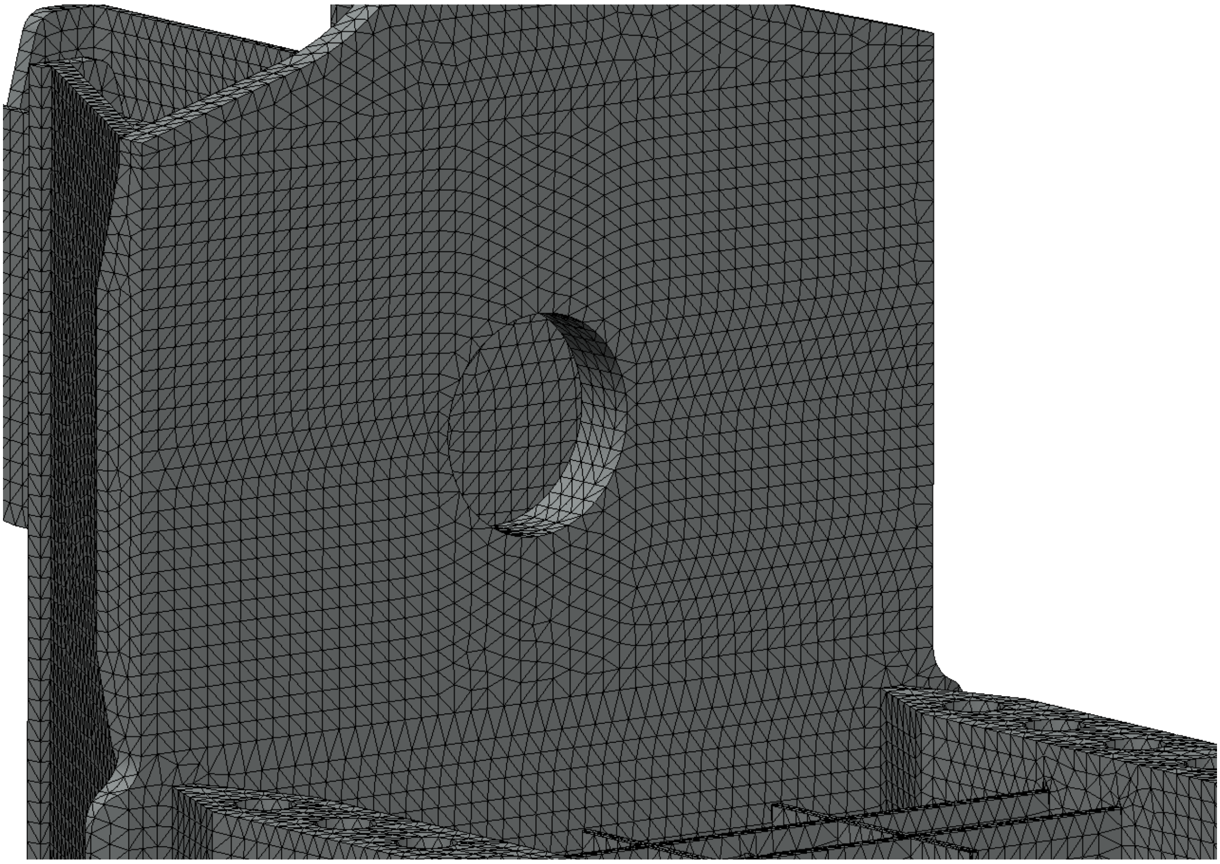


Figure 7.6: Mesh of locking bolt housing

The mesh details which are used in the element division are listed in table 7.1. The mesh division used is a self-defined mesh. The standard fine mesh was not fine enough and it was modified to the parameters listed in the table.

Mesh type:	Solid Mesh
Mesher used:	Custome (extra fine)
Element size:	46,4592 mm
Tolerance:	2,32296 mm
Mesh quality:	High
Number of nodes:	400475

Table7.1: Mesh Details

In order to determine the forces acting on the locking bolt housing, a part illustrating the riser base was modeled in SolidWorks. The model is a three legged pipe with a tube rising up from the center, virtual illustrating the riser base and riser foot connection. See figure 7.7 for a simplified riser base geometry.

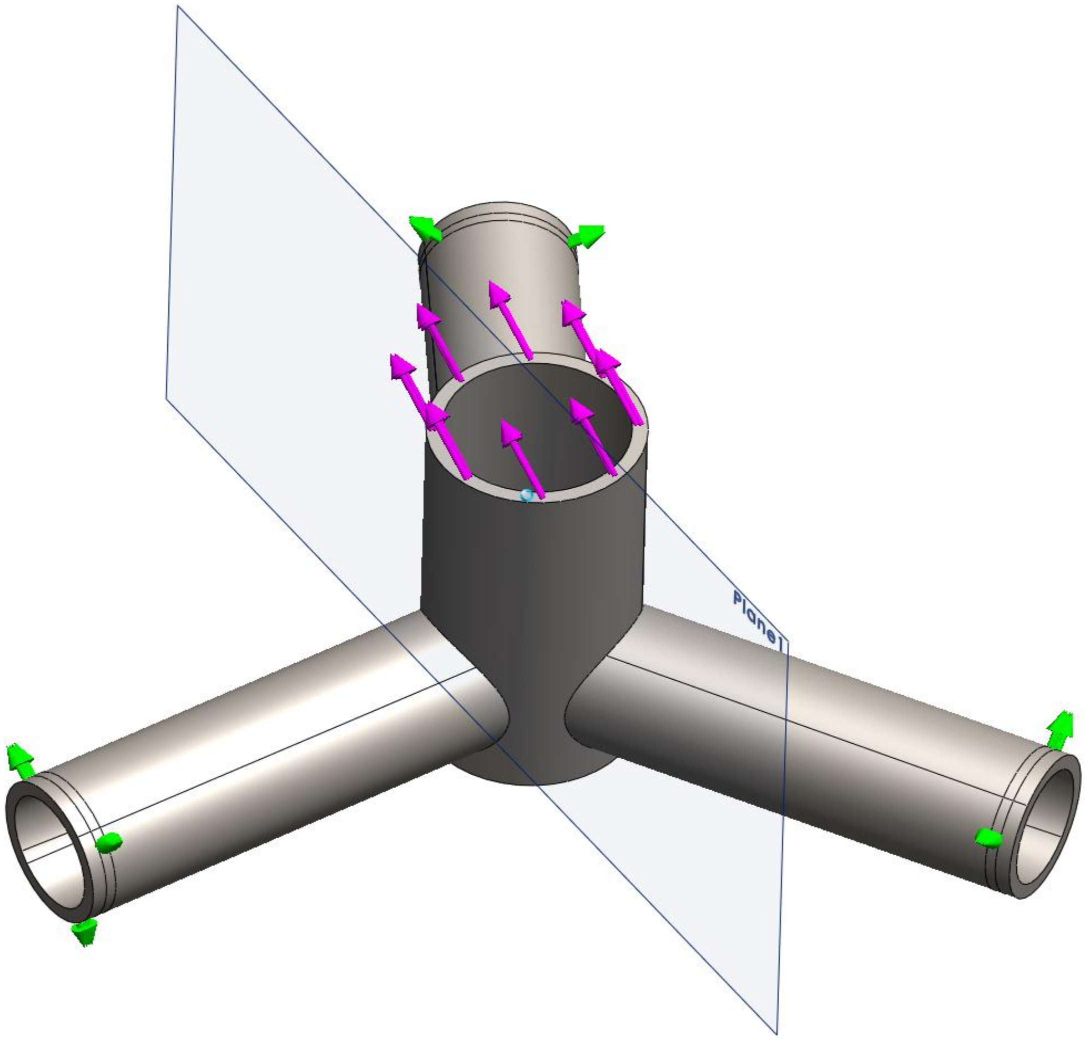


Figure 7.7: Virtual riser base for determining reaction forces

To be clear, this look nothing like the riser base will be looking like, but the geometry will help determining the forces acting in the reactions points. The pink arrows on the top indicate the action force on the geometry. Important parameters to this structure is the length from center of the geometry and out to the end of the cylinders. The length of the three legs is 3500 mm and the height of the center cylinder is assumed to be two meters. Reaction force from the action force is on a split line on each end of the legs, shown with the green arrows in figure 7.7. Local coordinates systems are also placed at these places to simplify the result force readout, ref. figure 7.8. The geometry is made cylindrical to reduce the number of nodes for calculation purposes. The reaction forces at the given areas will not be affected.

On each end there are green lines showing in which direction and were the geometry is fixed (figure 7.2). To get the right fixture, as locking a riser base to the three locking bolt housings by use of locking bolts, the geometry is free to move in axial direction and around itself, but locked in radial direction. This will give reaction forces in y and z direction (given the axial direction as the x-axis).

The angle β of the force acting on the riser base was changed around the geometry from 0° to 180° degrees with 15° degree intervals. The worst case will be further described in this section. Extended analysis is attached in appendix F.

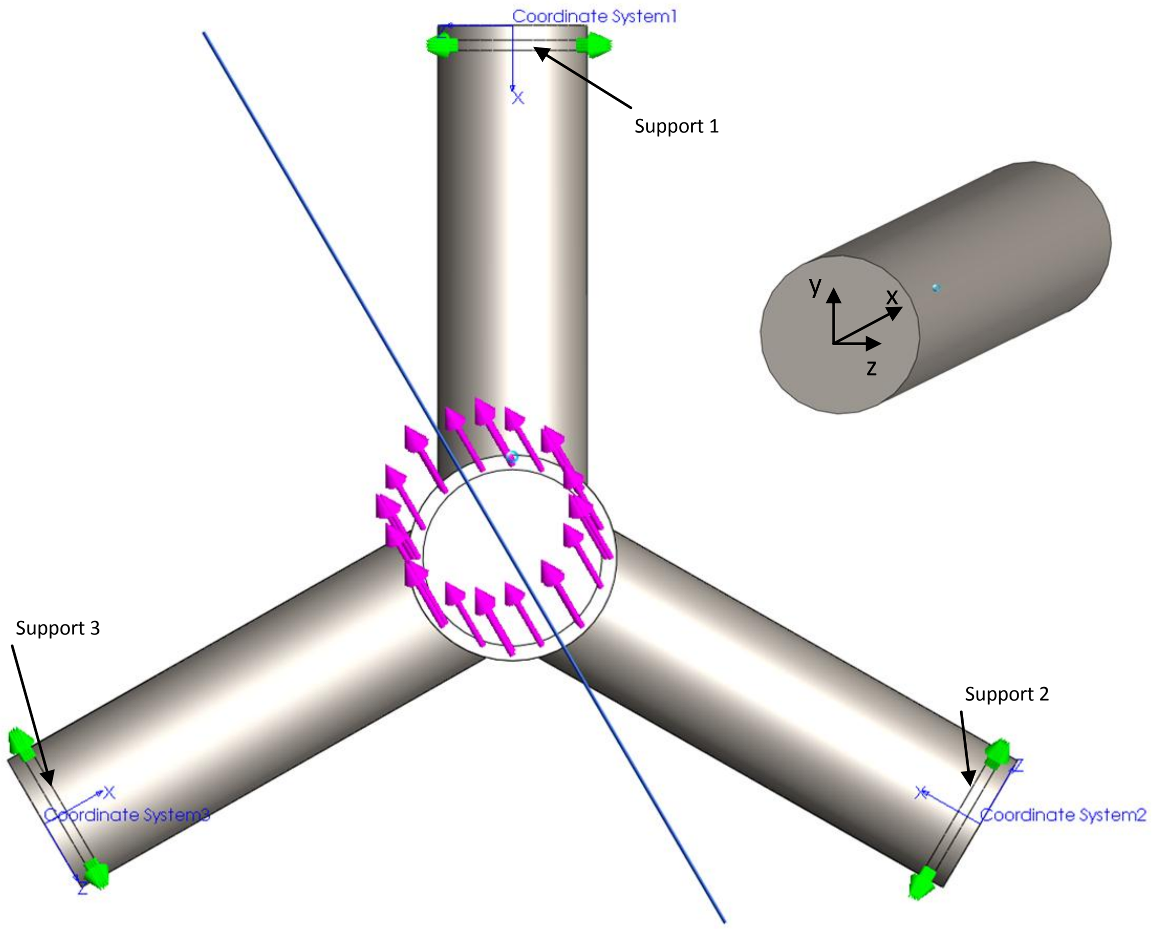


Figure 7.8: Angle of force and local coordinate system

The reaction forces found in the reaction points on the riser base geometry is used in the locking bolt housing model for the strength analysis. The worst case was found with an attack angle β of 105 degrees in the support 2 structure. The forces in the y-direction are -741 kN and 727 kN in the z-direction.

Figure 7.9 shows the stress distribution in the locking bolt housing for the 105 degrees attack angle in support 2. The distance from each of the bolt locking housings and into center and the angle between them are equal on all three and the support 2 is therefore a reference for at which angle the force is acting. The maximum stress is observed near a fixed area and the highest stresses can be observed on the edges. The edges are more rounded on the actual bolt housing. This will result in much lower stress concentrations as shown in figure 7.9. Stresses elsewhere are rather small.

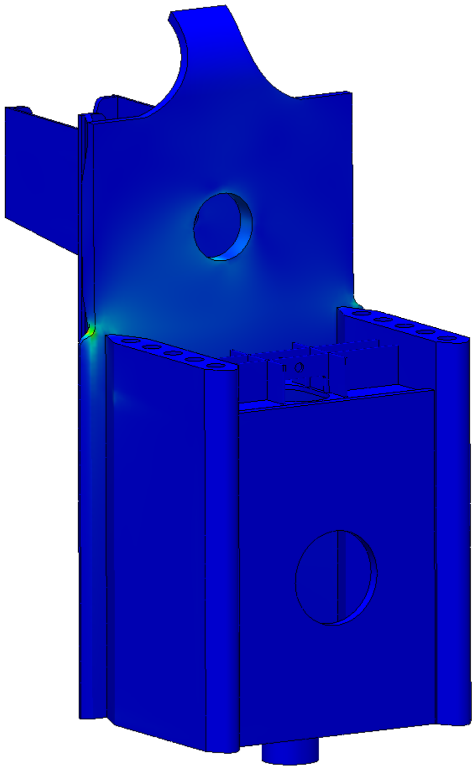


Figure 7.9: Stress distribution

An isolated clip (iso-clip) is made on the model on figure 7.10. The visible areas show where the stress is above 25 MPa and only 0,13 % of the volume are above this level. There are almost not any stresses higher than 25 MPa in the locking bolt hole. The stress concentrations are so small that they will not pose a threat for possible fracture.

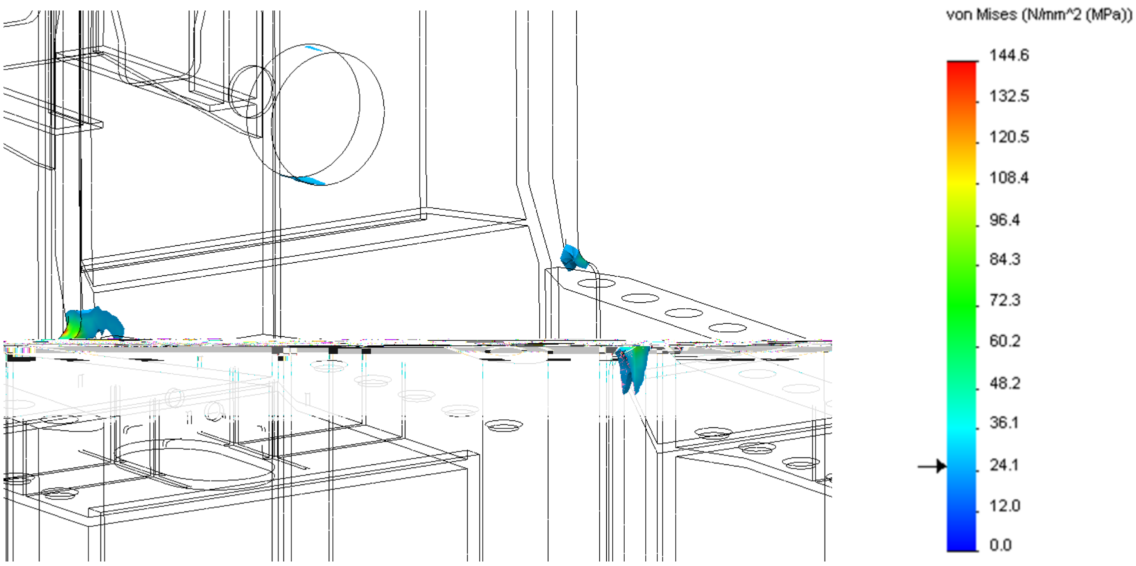


Figure 7.10: 25 MPa iso-clipping

8. Conclusions & Recommendations

8.1 Disconnection of existing column

The objective of this thesis was to identify necessary modifications on the existing offloading system in order to install a new system on the base structure. With this solution, the already existing base structure and interfaces towards Gullfaks can be re-used. In conjunction with the license extension it will be the most economical solution due to the cost related to upgrading the already existing system. The fact that the base structure can be used as an interface towards the new system will make the installation of the new system less demanding.

The pre-study in this thesis involved investigation and evaluation of the existing system. This was necessary to identify and reveal the opportunities and limitations of the existing base structure and to investigate how disconnection of the connection plate and column can be made.

The investigation revealed that the disconnection can hardly be performed only by use of ROV. However, it is recommended to execute the disconnection with as few diver operations as possible due to the economical aspect.

Before any disconnection can start, it is important to secure the connection plate and column so it stays steady during disconnection. This is achieved by use of hydraulic jacks connected to the centering pins.

The crude oil valves can be closed when the SPM column is still attached to the base structure. Prior the column disconnection, it is recommended that divers disconnect the hydraulic lines to the crude oil valve actuators. These can be connected to a ROV panel on the new riser base system. In the same diving operation it is recommended to get following operations done:

- Extract safety pins and safety spikes. A hydraulic override tool for the safety pins must be designed and produced.
- Lower lifting frame
- Disconnect bolt housing flanges and remove oil
- Extract locking bolts by pressurizing the extraction hydraulic lines

The three last points involve a risk of mechanisms to fail, but there are good alternative methods if any problems should occur. The lifting frame can be twisted 90° to go clear the pre-stressed bolts. If bolts on bolt housing flanges should be stuck, they can be cut be use of simple cutting tool and should the locking bolt hydraulics fail, these can be extracted by a custom made ROV operated override tool.

The most demanding operation regarding the disconnection will be the removal of the pre-stressed bolts. A complete removal will demand several comprehensive diving operations. It is therefore recommended to cut these bolts and leave them in the lowered lifting frame. The bolts will then not contribute to any interface problems to the riser base.

8.2 Subsea structure modifications

Regarding interface to new system it is recommended to use the by-pass flange for the connection towards the riser base. The reason is the good availability and mounting opportunities on the existing flange. When the old column and connection plate is removed, the crude oil interface on bolt housing A and B must be blinded. With the permanent closed base valves, this will ensure a double barrier to the environment. Blind caps must be designed for this purpose.

The condition of the base structure regarding corrosion seems to be very good. No significant corrosion has occurred and the anodes are evenly worn. The exception is on the by-pass structure. These anodes are totally worn down and corrosion on the structure and piping has occurred. Corrosion is at this time not severe and area can still be used as interface connection given that cathodic protection is reestablished. For this reason it will be necessary to improve the cathodic protection at the by-pass structure by installing sacrificial anodes. CP calculations must be performed and anodes sufficient to last the design life must be installed.

A riser base can be connected on the base structure and the system can be locked down to the base by use of the existing locking bolt housing. The forces acting on the new system during normal operation can be neglected since tankers will not be moored to the system. Tankers will keep position by DP. The weight of the riser base will exceed the buoyancy force of the subsurface buoy. Force amplitudes can be neglected due to their magnitude and fatigue will not be of concern for the base structure.

The worst scenario when it comes to forces will be a drifting ship connected to the offloading hose. However, the hose valve will disconnect and close when exceeding 120 tons. The strength calculations performed on the modeled locking bolt housing with a force of 1800 kN proves that the structural integrity will be intact even if such an event should occur. This means that pre-stressed bolts will not be necessary for the new system. The maximum stress at the locking bolt housing with the assumed force angle of attach is approximately 105 degrees from reference point shown in figure 7.3. The final length of the hose is not determined, so there are some uncertainties regarding the angle. Nevertheless, the locking bolt housing will still be over dimensioned for this purpose even with large angle deviation and different height of the force attacking the riser base. However, the three calculation notes that are being available this summer should be reviewed.

The riser base system that will be mounted onto the base structure should have an integrated ROV panel for operating the existing valves on the base structure. In addition, it should also have double block and bleed valves before the riser foot connection. This will make it easier for disconnecting the riser foot if this is in need of onshore maintenance work. The system can then be closed without use of the base structure valves.

The base structure is well suited for connecting a new system to the already existing infra-structure. However, it will be critical to maintain the cathodic protection to avoid further corrosion attacks. Periodic CP measurement is recommended to ensure that the system is not under-protected. The interval should be determined after a separate CP investigation is conducted.

It will not be necessary to use pre-stressed bolts in the locking bolt housing for securing a similar system as explained in chapter 6 in this thesis. As this investigation reveal, it will be both time and money saving leaving the bolts in the locking bolt housing after cutting.

8.3 Recommendations for further work

The removal of the existing column and the opportunities for re-using the base structure as interface point for a new offloading system is a comprehensive task and can off course not be covered by a master thesis alone. Working with this thesis has given me insight in interesting challenges that can be suited for other master thesis. This can for instance be:

- Planning the marine operation for removal of the connection plate and column. Preparations prior towing and towing itself will be important to describe before the column can be transported to scrapping site in Vats, Norway. Correct ballasting during disconnection will be important for a safe disconnection.
- Design of necessary tooling described in this thesis.
- Design of riser base with special focus on locking mechanism towards the base structure.

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Appendices

Appendix A: Drawing references

Appendix B: Video references

Appendix C: SPM buoyancy calculations

Appendix D: Locking bolt housing oil calculation

Appendix E: Verification of pre-stressed bolt length after cutting

Appendix F: Strength analysis

Appendix A

Drawing referances

Drawings attached in this appendix:

- C001-L-A30-MA-001
- C001-L-A32-MA-008
- C001-L-A40-FB-001
- C001-L-A40-NA-001
- C001-L-A40-NA-002
- C001-L-A42-NB-003
- C001-L-A42-NB-010
- C001-L-A42-RA-002
- C001-L-A43-NB-010
- C001-L-A80-LB-001
- C001-L-A82-LB-001
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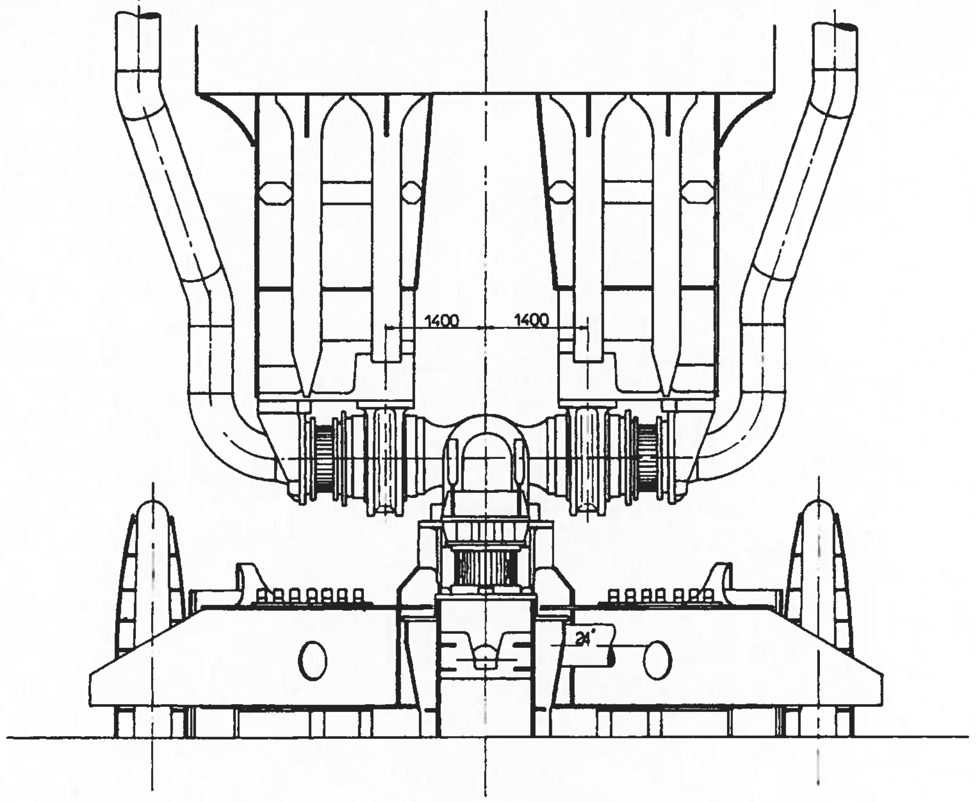

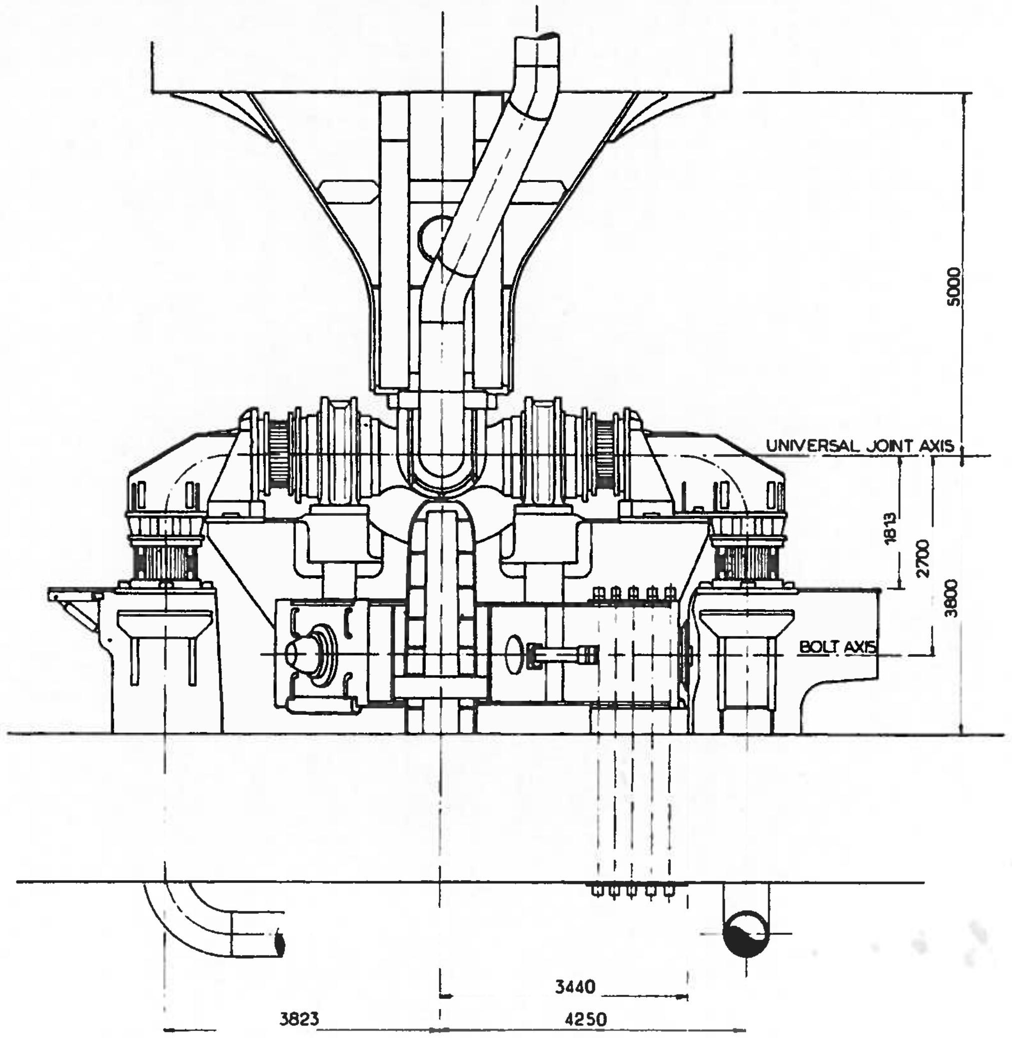

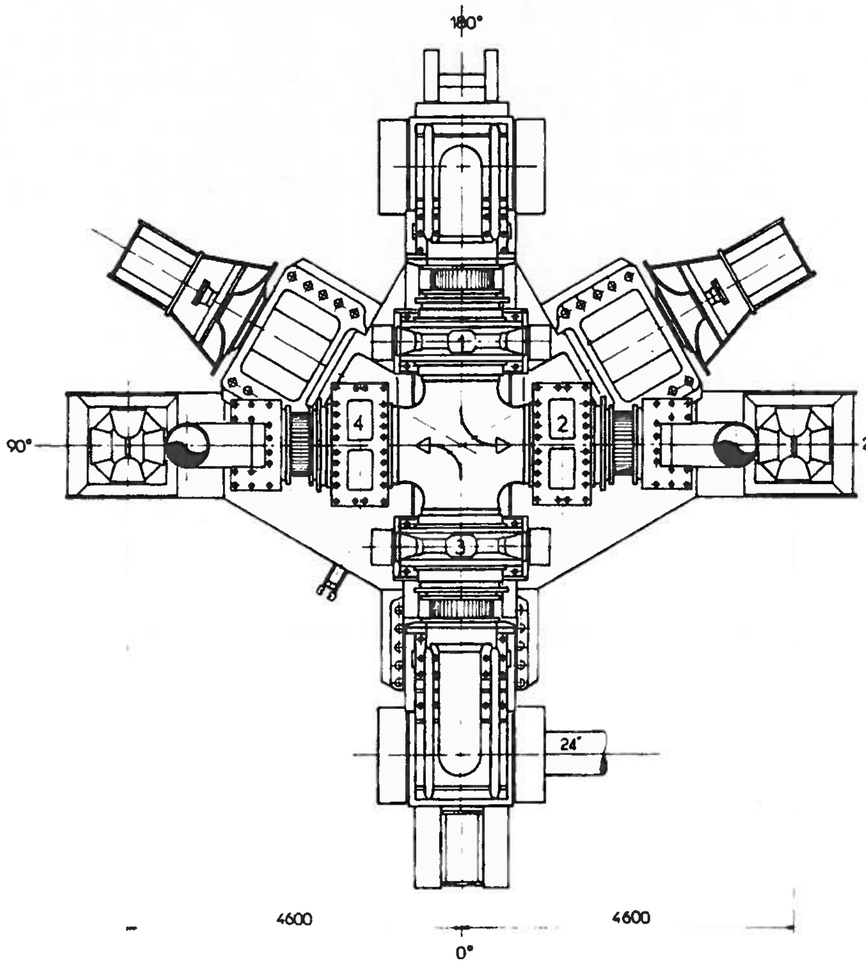

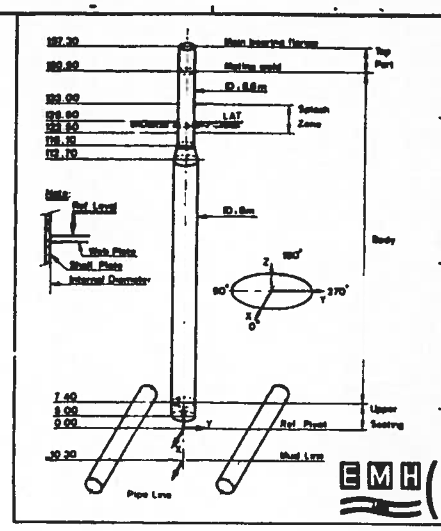

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GULLFAKS "A" SPM C - 90106

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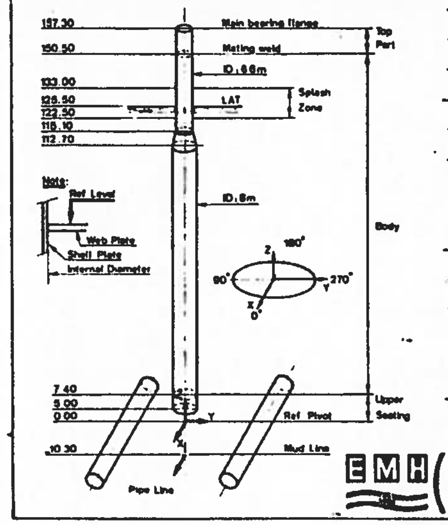

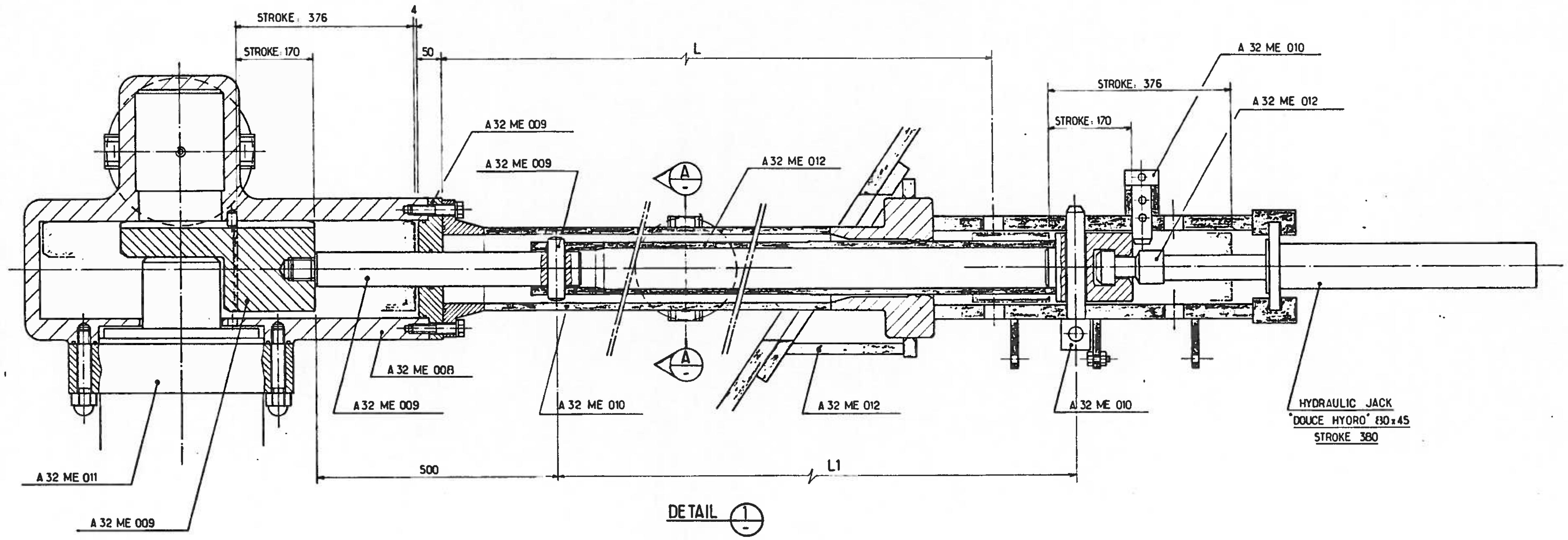

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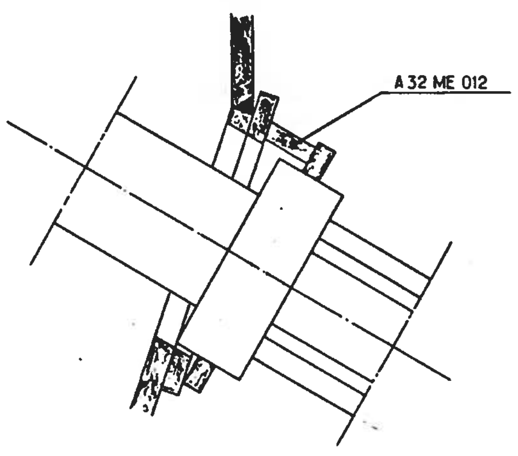

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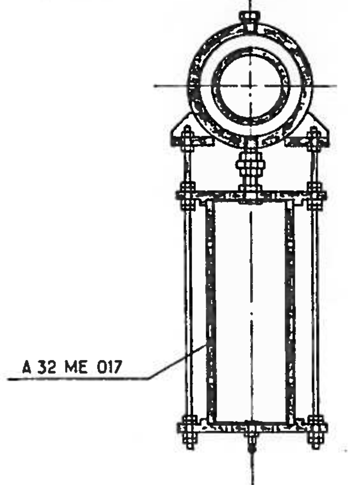
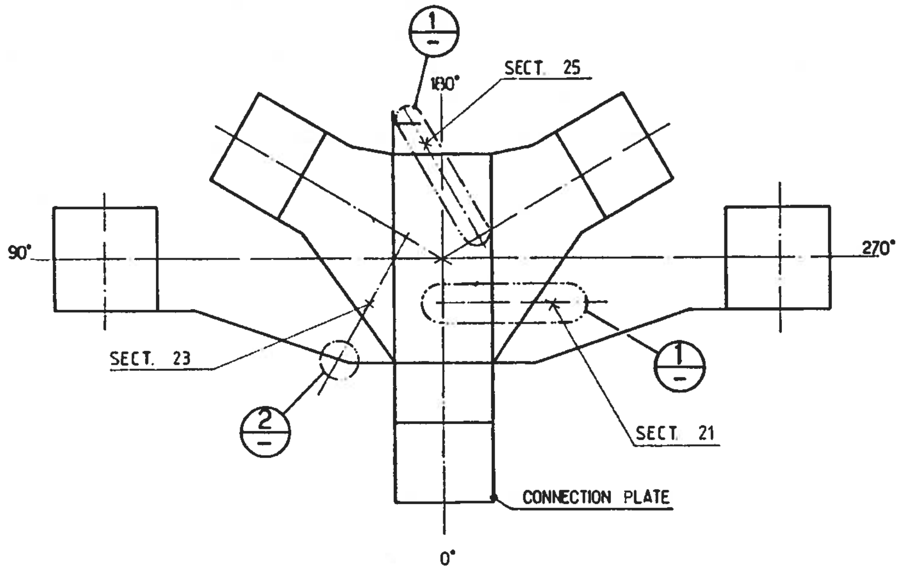


SECTION A



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REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
0	ISSUED FOR CONSTRUCTION	06.09.84	B. ch.	[illegible]	[illegible]	[illegible]
01 A	ISSUED FOR DETAIL ENG. COMPL.	16.05.84	B. ch.	[illegible]	[illegible]	[illegible]
01	ISSUED FOR APPR. DETAIL ENG. COMPL.					
01 A	ISSUED FOR BID	20.04.84	B. ch.			[illegible]
01	ISSUED FOR I.D.C	3.11.83	FCH	[illegible]	[illegible]	

W.P NO. 4.1.1.1
SYS. NO.
SCALE 1/5
MTO ☐ YES ☒ NO

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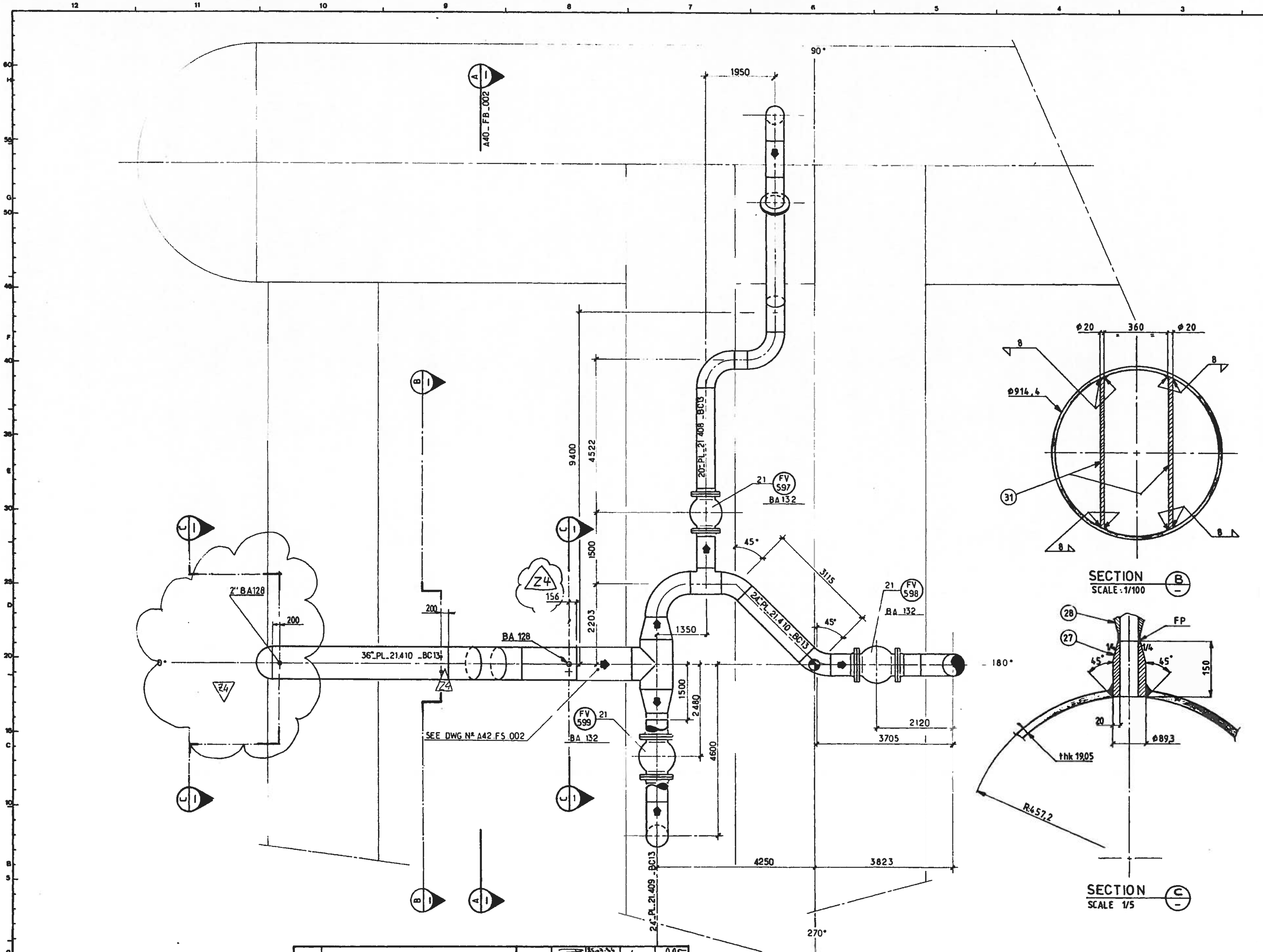
Contractor
ACN
Articulated Columns Norway A.S

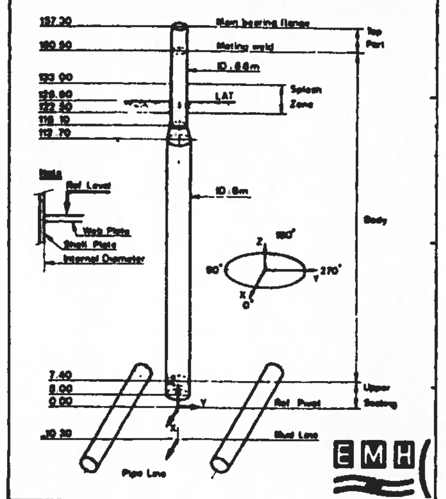
GULLFAKS "A" SPM C - 90106

TITLE:
CONNECTION SAFETY LOCKING MECHANISM

DRAWING NO.:

PROJECT NO.	CONTR.	AREA	DISC.	NUMBER	SHT.NO.	REV.
C001	L		A32	MA - 008	01	Z4





NOTE:
FOR SECTIONS B AND C :
NTD CLASS B C001.A.N.CG.509
WELDING PROCEDURE ACCORDING
TO C001.A.L.SP.501

FOR SUBSEA MARKINGS,
PAINTING AND RUBBER
COATING SEE DRG.A40 FB002 (Z4)

M.T.O Nº C001.L.F.AM.971

DRG. NO.	REFERENCE DRAWINGS
A42 FS 002	BASE C.O.PIPING SUPPORTS DETAILS 2
A40_FB_002	BASE_CRUDE OIL PIPING AND DETAILS
A00_FO_001	CRUDE OIL SYSTEM-DIAGRAM-

REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
Z4	AS BUILT	230786				
B	REISSUED FOR CONSTRUCTION	23.09.85	J-L. P.P.			
A	REISSUED FOR CONSTRUCTION	17.12.84	RL			
0	ISSUED FOR CONSTRUCTION	5.09.84	MR			
05A	ISSUED FOR DETAIL ENG. COMPL.	2708.84	MR			
04A	ISSUED FOR DETAIL ENG. COMPL.	BOURDY	27.7.84			

REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
03A	ISSUED FOR BID	20.04.84	B_ch_			
03 A	ISSUED FOR DETAIL ENG. COMPL.	26.1.84	BOURDY			
02 A	ISSUED FOR DETAIL ENG. COMPL.	13.12.83	BOURDY			
01	ISSUED FOR APPR. DETAIL ENG. COMPL.	26.10.83				
01	ISSUED FOR I.D.C	23.09.83	BOURDY			

W.P. NO. 4.1.1.1
SYS. NO.
SCALE 1/50
MTO ☐ YES ☒ NO

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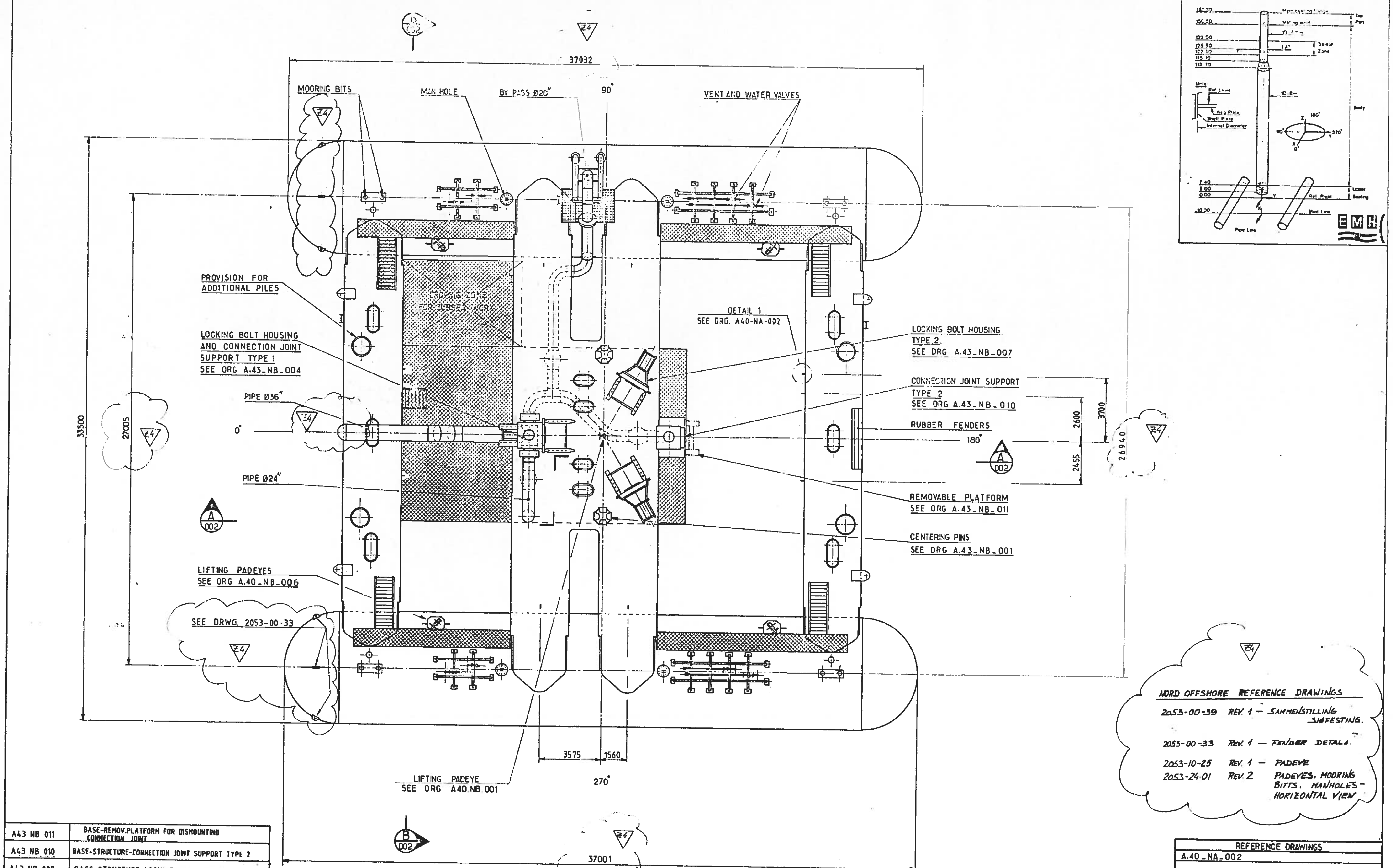
GULLFAKS "A" SPM C-9010

TITLE: BASE - CRUDE OIL PIPING-ARRANGEMENT

DRAWING NO.:	SHT.NO.	REV.
C001 - L - A40 - FB - 001	01	Z4

PROJECT NO. | CONTR. | AREA | DISC. | NUMBER | SHT.NO. | REV.

90 - 41



DRG. NO.	REFERENCE DRAWINGS
A43 NB 011	BASE-REMOV.PLATFORM FOR DISMOUNTING CONNECTION JOINT
A43 NB 010	BASE-STRUCTURE-CONNECTION JOINT SUPPORT TYPE 2
A43 NB 007	BASE-STRUCTURE-LOCKING BOLT HOUSING TYPE 2
A43 NB 001	BASE-STRUCTURE-CENTERING PINS
A43 NB 004	BASE-STRUC.-LOCK.BOLT HOUSING AND CONN.JOINT-TYPE 1
A40 NB 006	BASE-LIFTING PADEYES AND FENDER
A40 NB 001	BASE-LUGS-PADEYES AND MOORING BITS -HORIZONTAL VIEW
A 40 NA 002	BASE_GENERAL ARRANGEMENT SECTIONS

REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
Z4	AS BUILT	18.07.86	AAA			AAF
B	ISSUED FOR CONSTRUCTION	17.01.86				AAF
A	REISSUED FOR CONSTRUCTION	14.06.85	TR			AAF
0	ISSUED FOR CONSTRUCTION	5.09.84	MR			

REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
03A	ISSUED FOR DETAIL ENG. COMPL.	4.06.84	MR			
02A	ISSUED FOR BID	20.04.84	RC			
02A	ISSUED FOR DETAIL ENG. COMPL.	9.1.84	R.C			
01	ISSUED FOR APPR. DETAIL ENG. COMPL.	26.10.83				
01	ISSUED FOR LDC	22/08/83	B.ch.			

W.P. NO. 4.1.1.1
SYS. NO.
SCALE 1/100
MTO YES NO

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REFERENCE DRAWINGS
A.40_NA_002

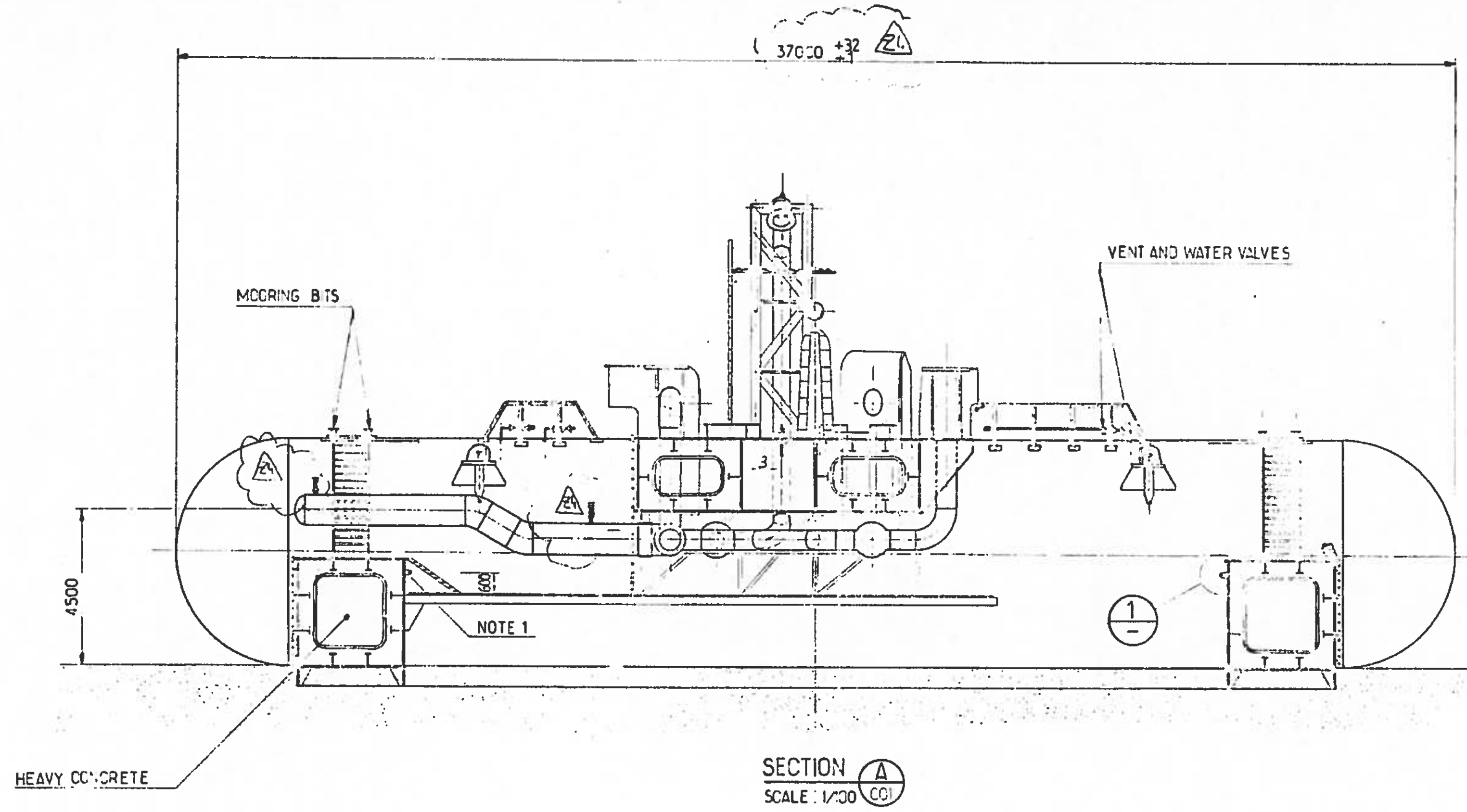
GULLFAKS "A" SPM C-90106

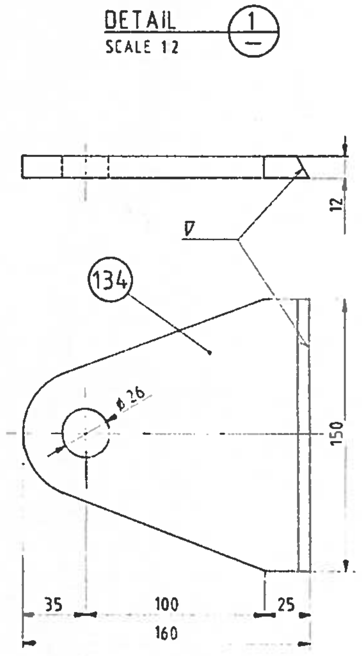
TITLE:

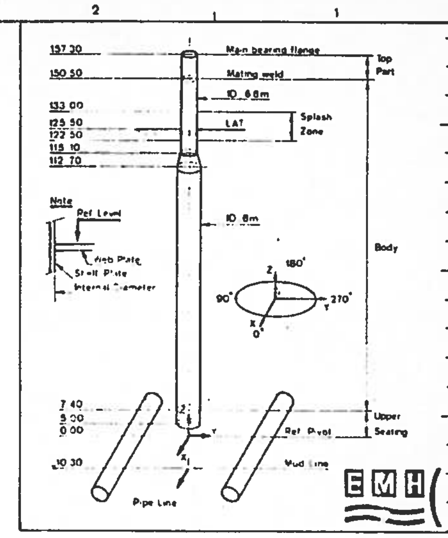
BASE_GENERAL ARRANGEMENT HORIZONTAL VIEW

DRAWING NO.: C001 - L - A40 - NA - 001 | SHT.NO. 01 | REV. Z4

86 - 6:



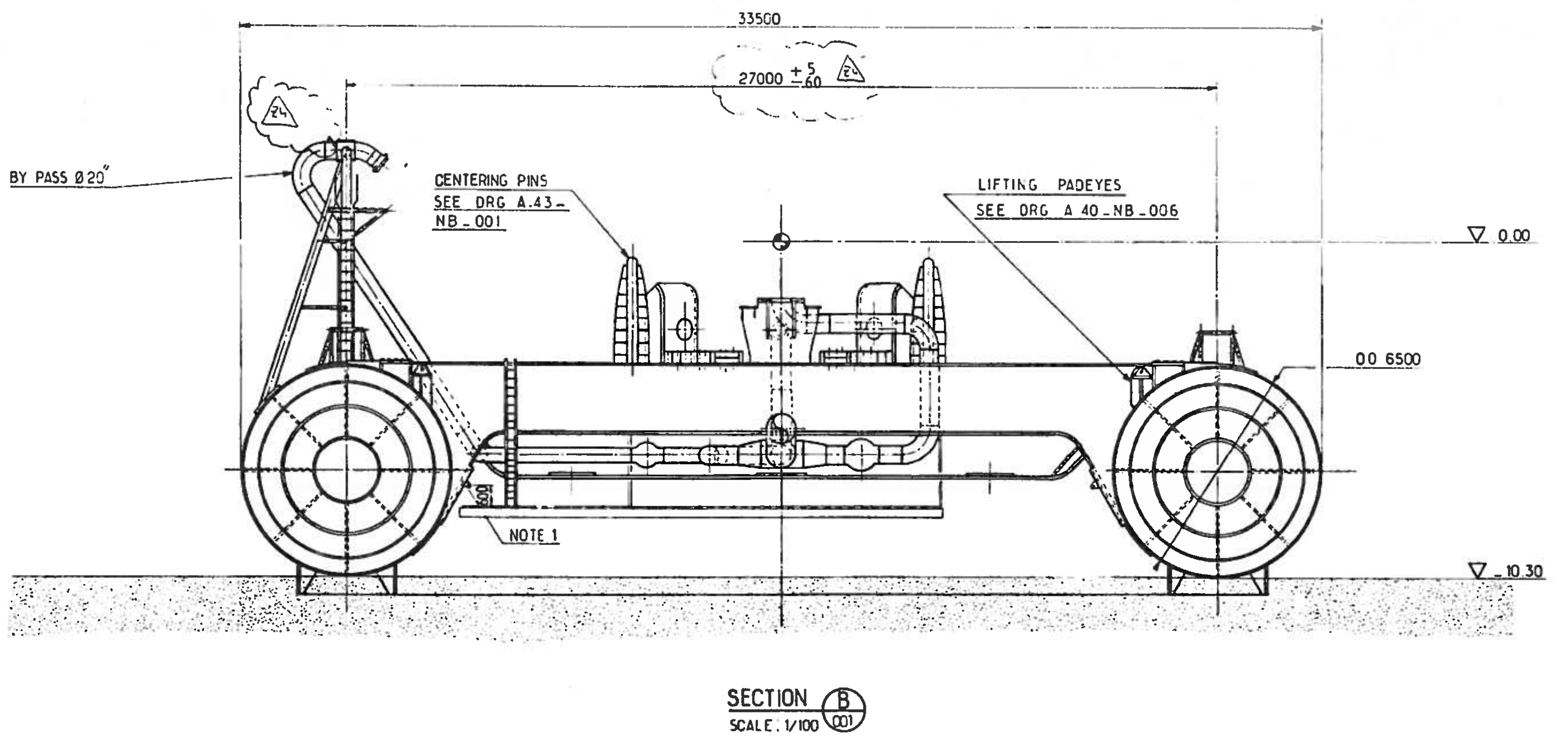




NOTE 1:

ALL PADEYES ARE IN VERTICAL POSITION AND CENTRE OF HOLE 600mm ABOVE GRATING.

ITEM 134: STEEL GRADE V
INSPECTION CATEGORY C



Z4

NORD OFFSHORE REFERENCE DRAWINGS
2053-00-35 REV. 1 — MIDLERTIDIG SUPPORT
2053-00-05 REV. 5 — PADEYE - BASE HORIZONTAL VIEW

M.T.O N° C001_L_N_AM_931

REFERENCE DRAWINGS
A-40-NA-001
A43-NB-001
A40-NB-006

DRG. NO.	REFERENCE DRAWINGS	REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
		Z4	AS BUILT	18.07.86				
		A	ISSUED FOR CONSTRUCTION	17.01.86				
A40 NA 001	BASE GENERAL ARRANGEMENT HORIZONTAL VIEW	0	ISSUED FOR CONSTRUCTION	06.09.84	B. ch.			

REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
03 A	ISSUED FOR DETAIL ENG. COMP.	4.06.84	MR			
02 A	ISSUED FOR BID	20.04.84	RC			
02 A	ISSUED FOR DETAIL ENG. COMPL.	9.1.84	R.C			
01	ISSUED FOR APPR. DETAIL ENG. COMPL.	26.10.83				
01	ISSUED FOR IDC	23/09/83	B. ch.			

W.P. NO. 4.1.1.1
SYS. NO.
SCALE 1/100
MTO ☐ YES ☒ NO

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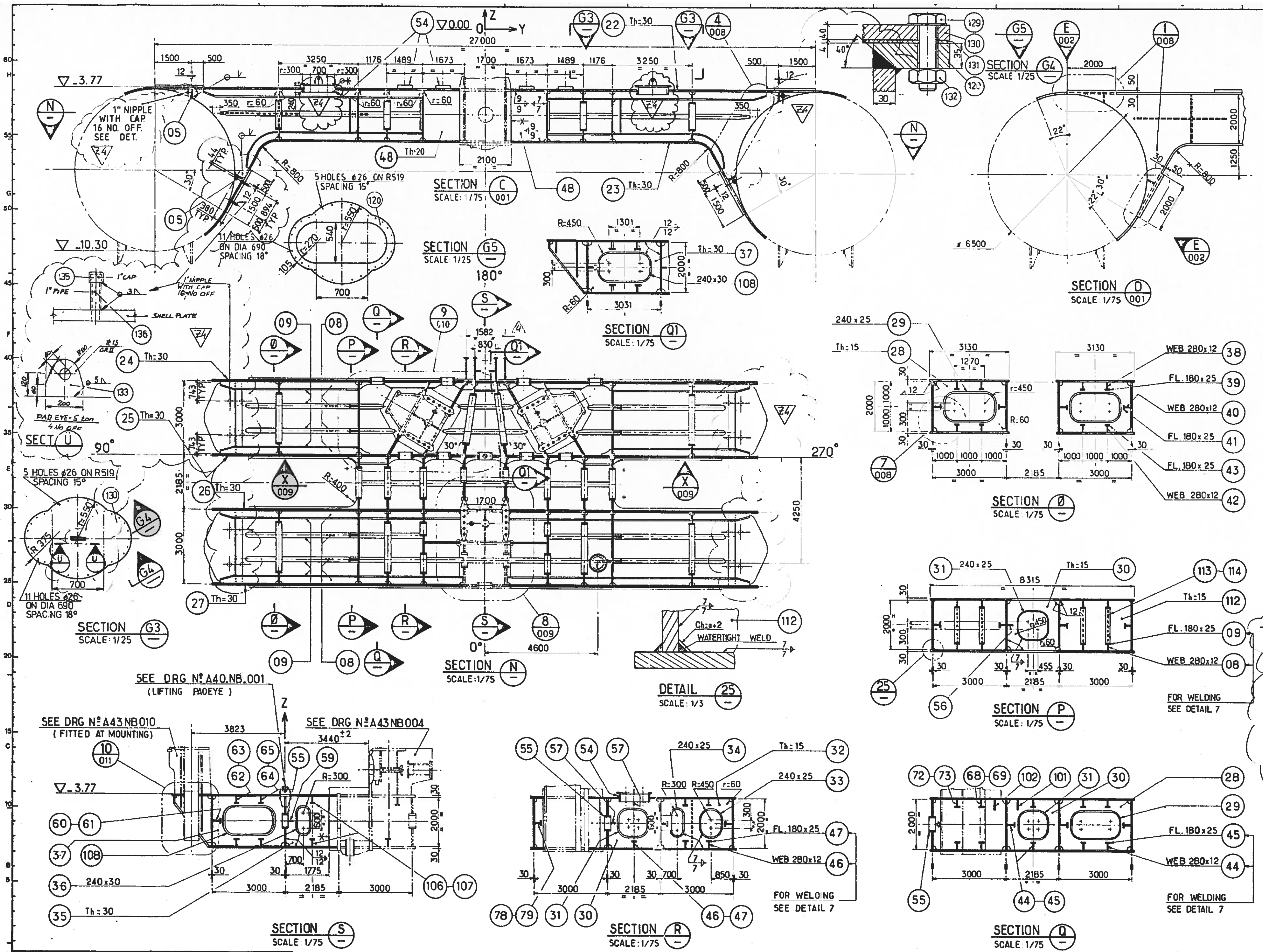
Contractor: ACN Articulated Columns Norway A.S

GULLFAKS "A" SPM C - 90106

TITLE: BASE GENERAL ARRANGEMENT SECTIONS

DRAWING NO: C001 - L - A40 - NA - 002 | SHT. NO. 01 | REV. Z4

86 - 64



NOTE
DESIGN CLASS 2
STEEL GRADE II
WELDS NDT B
UNLESS OTHERWISE SPECIFIED

NORD OFFSHORE REFERENCE DRAWINGS
2053-10-05 REV. 3 – SECTION 10 SECTION E-F
2053-10-04 REV. 6 – SECTION 10 SECTION C-D
2053-10-22 REV. 4 – SECTION 10 DETAILS 6
2053-10-07 REV. 5 – SECTION 10 SECTION H-I

M.T.O Nº C001-L-N-AM-334

REFERENCE DRAWINGS
A42-NB-008
A42-NB-009
A42-NB-010
A42-NB-011
A40-NB-001
A43 NB 010
A43 NB 004

DRG. NO.	REFERENCE DRAWINGS
A42 NB-011	BASE STRUCTURE – DETAILS 4
A42 NB-010	BASE STRUCTURE – DETAILS 3
A42 NB-009	BASE STRUCTURE – DETAILS 2
A42 NB-008	BASE STRUCTURE – DETAILS 1
A42 NB-002	BASE STRUCTURE – SECTIONS 1
A42 NB-001	BASE STRUCTURE – HORIZONTAL VIEW

REV.	REASON FOR ISSUE	DATE
Z4	AS BUILT	16.07.86
C	ISSUED FOR CONSTRUCTION	13.01.86
B	ISSUED FOR CONSTRUCTION	4.12.85
A	REISSUED FOR CONSTRUCTION	
0	ISSUED FOR CONSTRUCTION	06.09.84
04 A	ISSUED FOR DETAIL ENG. COMP	4.06.84
03A	ISSUED FOR BID	20.04.84
03A	ISSUED FOR DETAIL ENG COMPL.	06.02.84
02	ISSUED FOR APPR DETAIL ENG COMPL.	18.11.83
01	ISSUED FOR I.D.C	26.09.83

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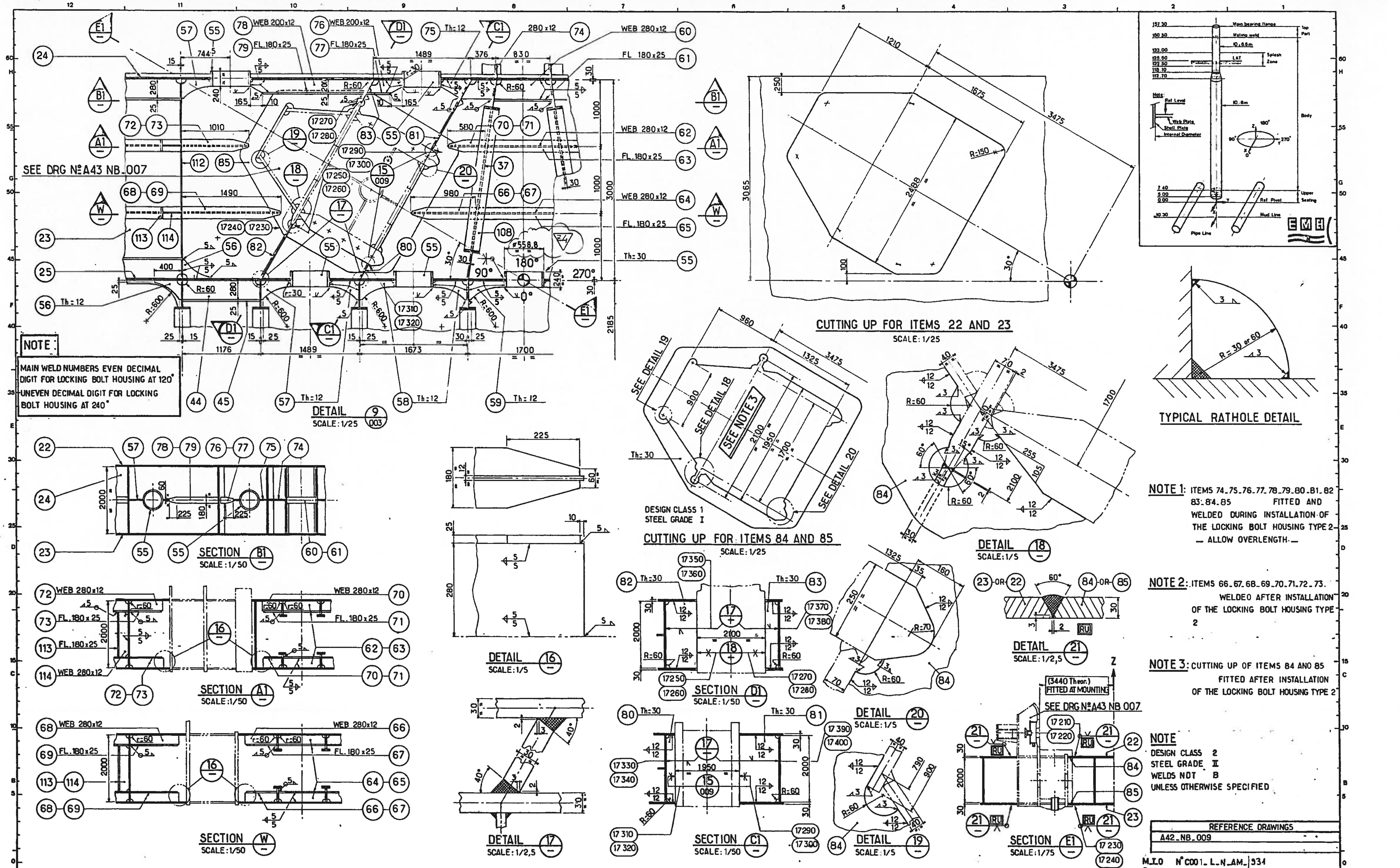
Contractor ACN Articulated Columns Norway A.S

GULLFAKS "A" SPM C-90106

TITLE: BASE STRUCTURE – SECTIONS 2

SCALE 1/75, 1/3

DRAWING NO: C001-L-A42-NB-003 01 Z4



DRG. NO.	REFERENCE DRAWINGS
A43 NB_007	BASE STRUCTURE _ LOCKING BOLT HOUSING TYP. 2
A42 NB_009	BASE STRUCTURE _ DETAILS 2
A42 NB_003	BASE STRUCTURE _ SECTIONS 2

REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
Z4	AS BUILT	15.07.86	AAA			

REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
0	ISSUED FOR CONSTRUCTION	3.09.84	MR			
03A	ISSUED FOR BID	20.04.84	B. ch.			
03 A	ISSUED FOR DETAIL ENG. COMPL.	06.02.84				
02	ISSUED FOR APPR. DETAIL ENG. COMPL.	19.11.83				
01	ISSUED FOR I.D.C	13.10.83	FM			

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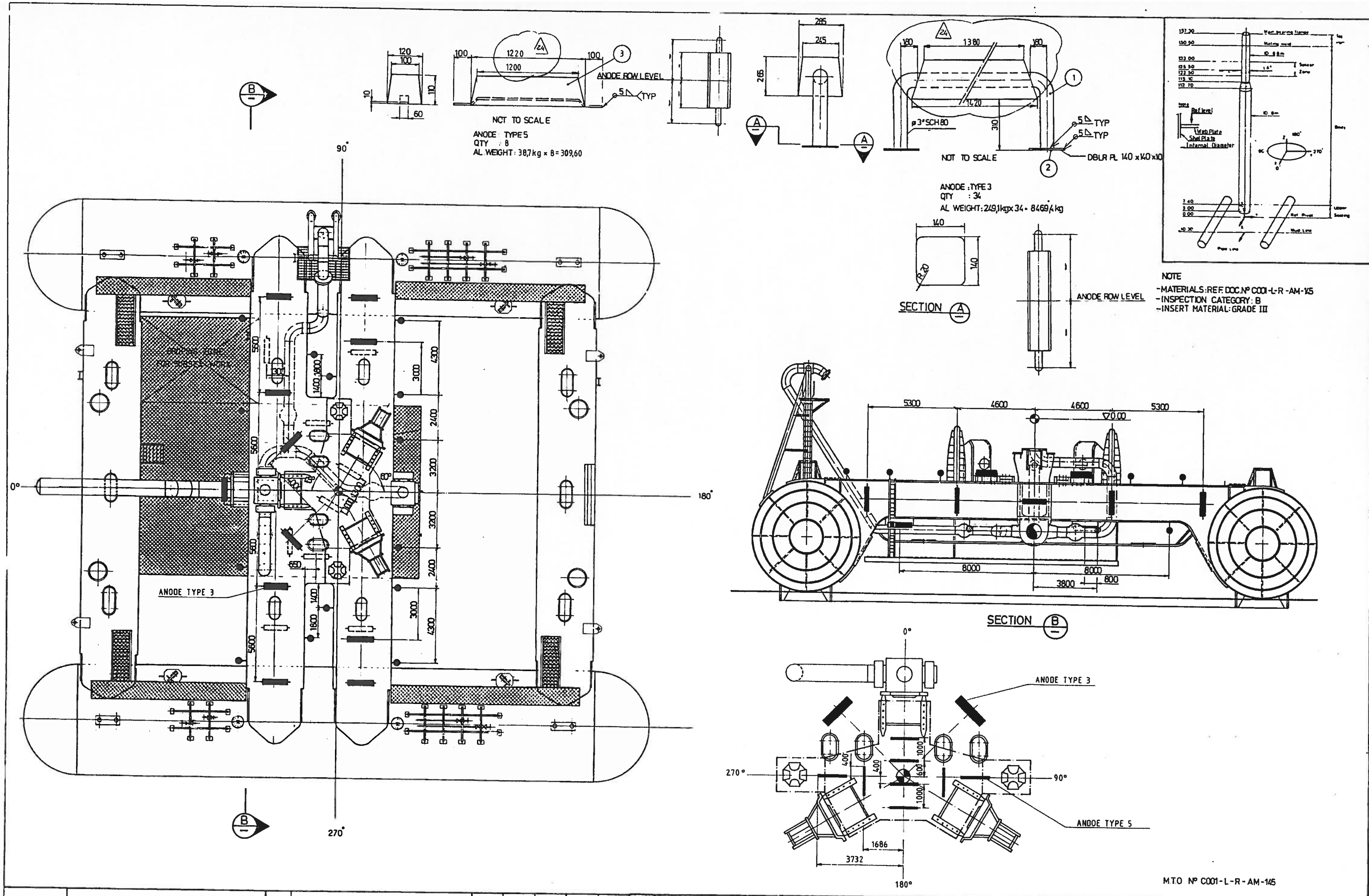
GULLFAKS "A" SPM C-90106

TITLE: BASE STRUCTURE _ DETAILS 3

DRAWING NO.: C001 - L - A42 - NB - 010 | 01 | Z4

88 - 44



NOTE
- MATERIALS: REF. DOC. Nº C001-L-R-AM-145
- INSPECTION CATEGORY: B
- INSERT MATERIAL: GRADE III

M.T.O Nº C001-L-R-AM-145

DRG NO	REFERENCE DRAWINGS	REV	REASON FOR ISSUE	DATE	DRN	CHK	APPR BY	PT
		Z4	AS BUILT	21.07.86				
C001-L-A40-NA-002	BASE GENERAL ARRANGEMENT SECTIONS	A	ISSUED FOR CONSTRUCTION	18.12.85				
C001-L-A40-NA-001	BASE GENERAL ARRANGEMENT HORIZONTAL VIEW	0	ISSUED FOR CONSTRUCTION	25/10.84				

REV.	REASON FOR ISSUE	DATE	DRN	CHK	APPR BY	PT
4A	ISSUED FOR BIDS	30.04.84				
4A	ISSUED FOR DETAIL ENG. COMPL.	03.04.84				
3A	ISSUED FOR DET.ENG.COMPL.	24.02.84				
02	ISSUED FOR APPR. DET. ENG. COMPL.	24.01.84				
01	ISSUED FOR IDC	6.1.84				

W.P. NO. 4 1 1 1
SYS. NO
SCALE 1/100
MTO ☒ YES ☐ NO

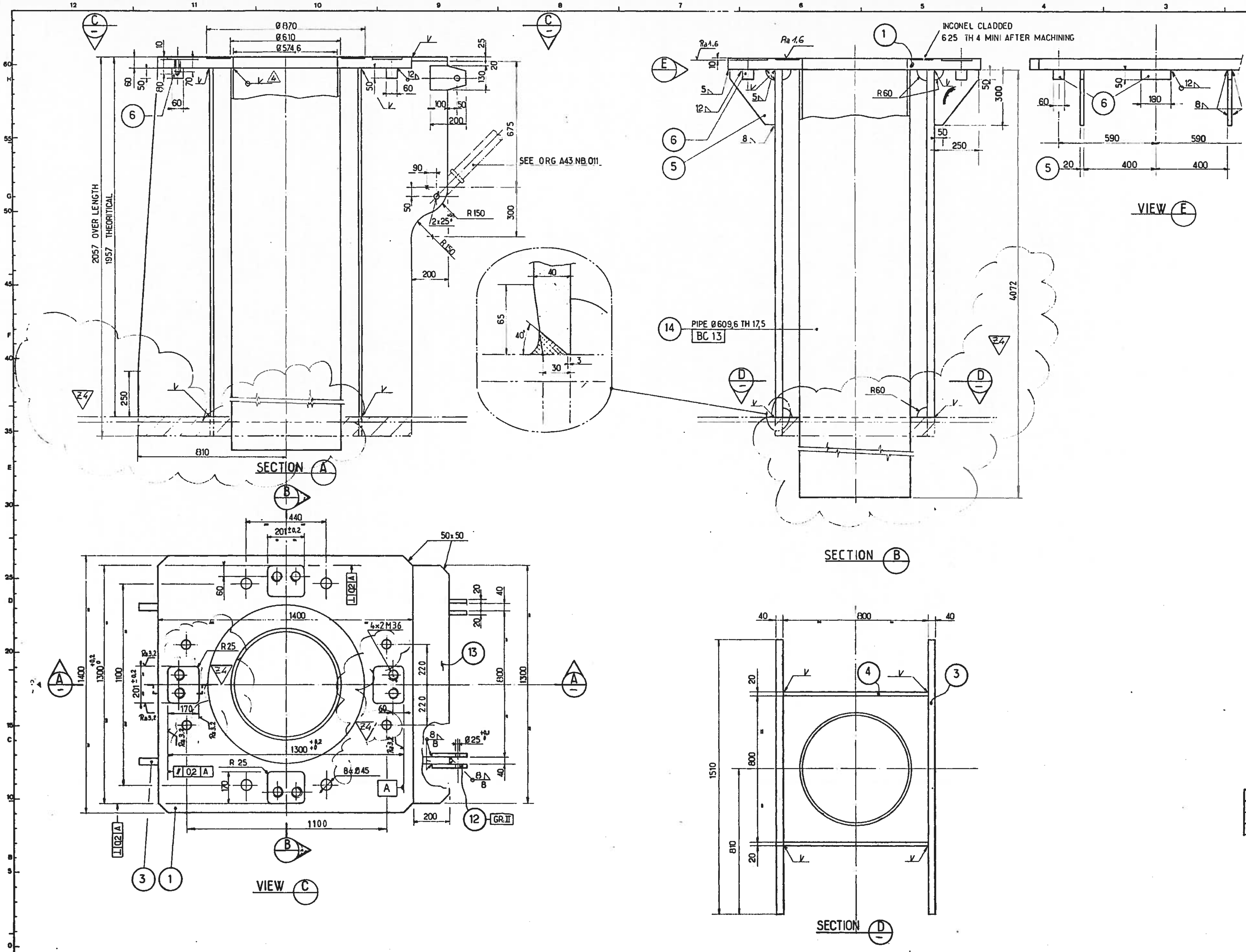
Statoil — Den norske stats oljeselskap a.s
Contractor: ACN — Articulated Columns Norway A.S

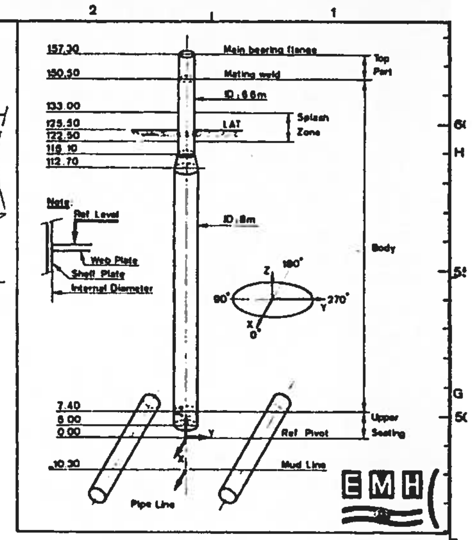
GULLFAKS "A" SPM C-90106

TITLE: BASE-CATHODIC PROTECTION TRANSVERSE MID. FRAME-EXTERNAL

DRAWING NO					SHT NO	REV
PROJECT NO	CONTR	AREA	DISC	NUMBER		
C001	L	A42	RA	002	01	Z4

88 - 58
1006033 L-A42--RA-002-01 Z4





NOTE

DESIGN CLASS 2
STEEL GRADE I
WELDS NDT A
UNLESS OTHERWISE SPECIFIED

- GENERAL TOLERANCE Js12 MACHINING
- REMOVED SHARP EDGES
- CLADDING SPEC L.M.SF 304 p 3.6
- P.W.H.T AFTER CLADDING AND BEFORE FINAL MACHINING SPEC: A N.SP. 304

M.T.O N° C001-L-N-AM-945

REFERENCE DRAWINGS
A 43-NB-011

DRG. NO.	REFERENCE DRAWINGS	REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
A40 NA 001	B.GENERAL ARRANGEMENT HORIZONTAL VIEW	Z4	AS BUILT	15.07.86				
A42 NB 001	BASE STRUCTURE HORIZONTAL VIEW	0	ISSUED FOR CONSTRUCTION	06.09.84	B.ch.			
A30 MA 001	ARTICULATION AND CONNECTION GEN-ARR[T]	04A	ISSUED FOR DETAIL ENG. COMPL.	5.06.84	MR			

REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
03A	ISSUED FOR BID	20.04.84	B.ch.			
03A	ISSUED FOR DETAIL ENG. COMPL.	30.3.84	FCH			
02A	ISSUED FOR DETAIL ENG. COMPL.	16.1.84	RC			
01	ISSUED FOR APPR. DETAIL ENG. COMPL.	29.10.83				
01	ISSUED FOR I.D.C	24.6.83	FCH			

W.P. NO. 4.1.1.1
SYS. NO.
SCALE 1/10
MTO ☒ YES ☐ NO

statoil — Den norske stats oljeselskap a.s

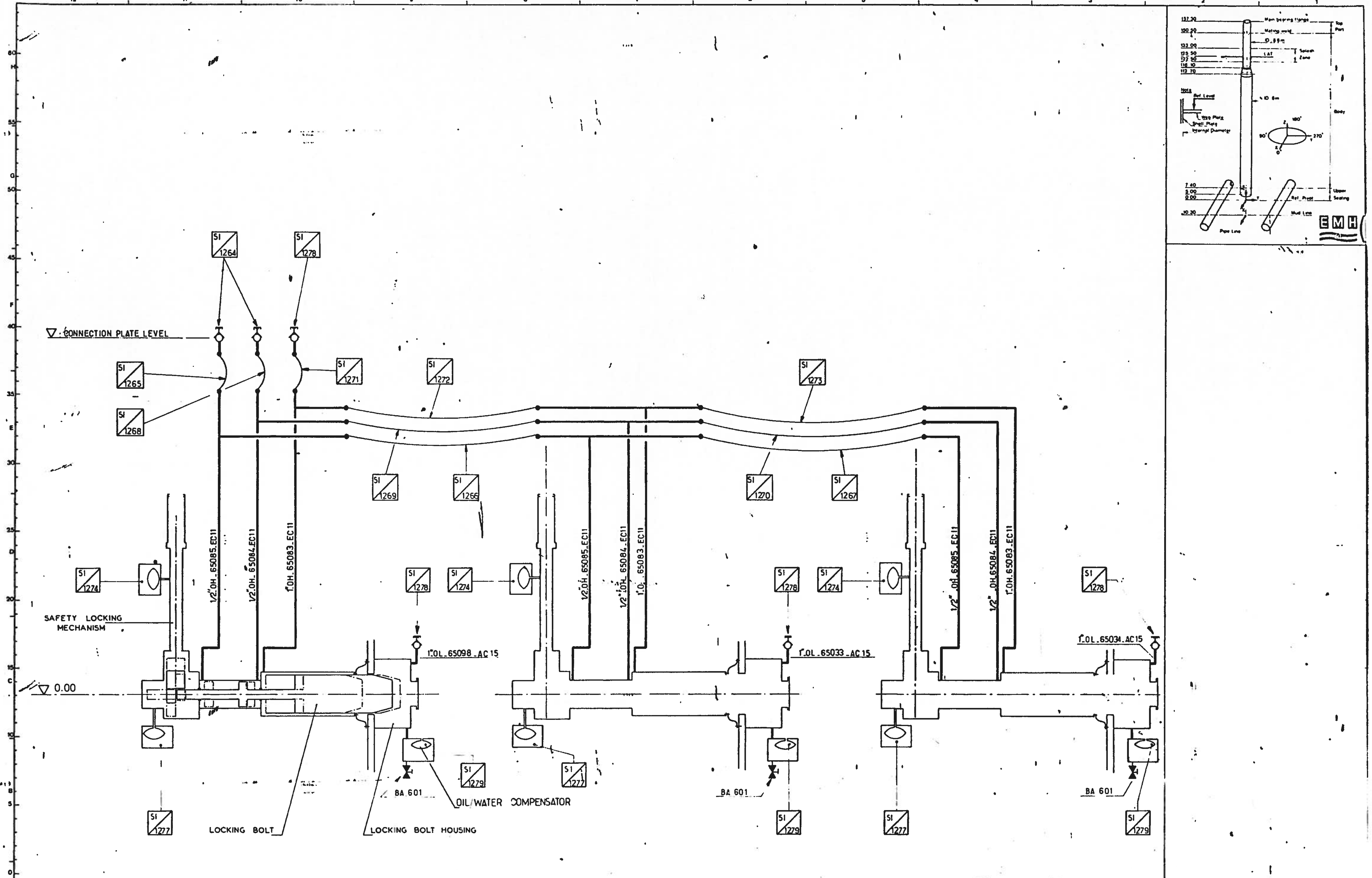
Contractor: ACN — Articulated Columns Norway A.S

GULLFAKS "A" SPM C-90106

TITLE: BASE STRUCTURE CONNECTION JOINT SUPPORT TYPE 2

DRAWING NO.	SHT.NO.	REV.
C001 - L - A43 - NB - 010	01	Z4

88 - 51



		0	ISSUED FOR CONSTRUCTION SPM 2	14.12.84	K.S.		AKF	
			NEW SPM 2 DRAWING					
		~~0~~	~~ISSUED FOR CONSTRUCTION~~	~~06.09.84~~	~~B.ch.~~			
		~~05A~~	~~ISSUED FOR DETAIL ENG COMP.~~	~~21.06.84~~	~~B.ch.~~			
A82.LB.001.	HYDRAULIC SYSTEM CONNECTION PLATE PIPING LAYOUT AND DETAILS	~~04A~~	~~ISSUED FOR DETAIL ENG COMPL.~~	~~27.4.84~~	~~BOURDY~~			
DRG. NO.,	REFERENCE DRAWINGS	REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR BY	PT

~~03A~~	~~ISSUED FOR BIC~~	~~20.04.84~~	~~B.ch.~~			
~~03~~	~~ISSUED FOR APPR. ENG. COMPL.~~	~~29.03.84~~	~~B.ch.~~			
~~02~~	~~ISSUED FOR APPR. DETAIL ENG. COMPL.~~	~~21.12.83~~	~~BOURDY~~			
Z4	AS BUILT	21.09.87	JAP		DA	AKF
REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT

W.P. NO. 4.1.1.9
SYS. NO.
SCALE
MTO ☐ YES ☒ NO

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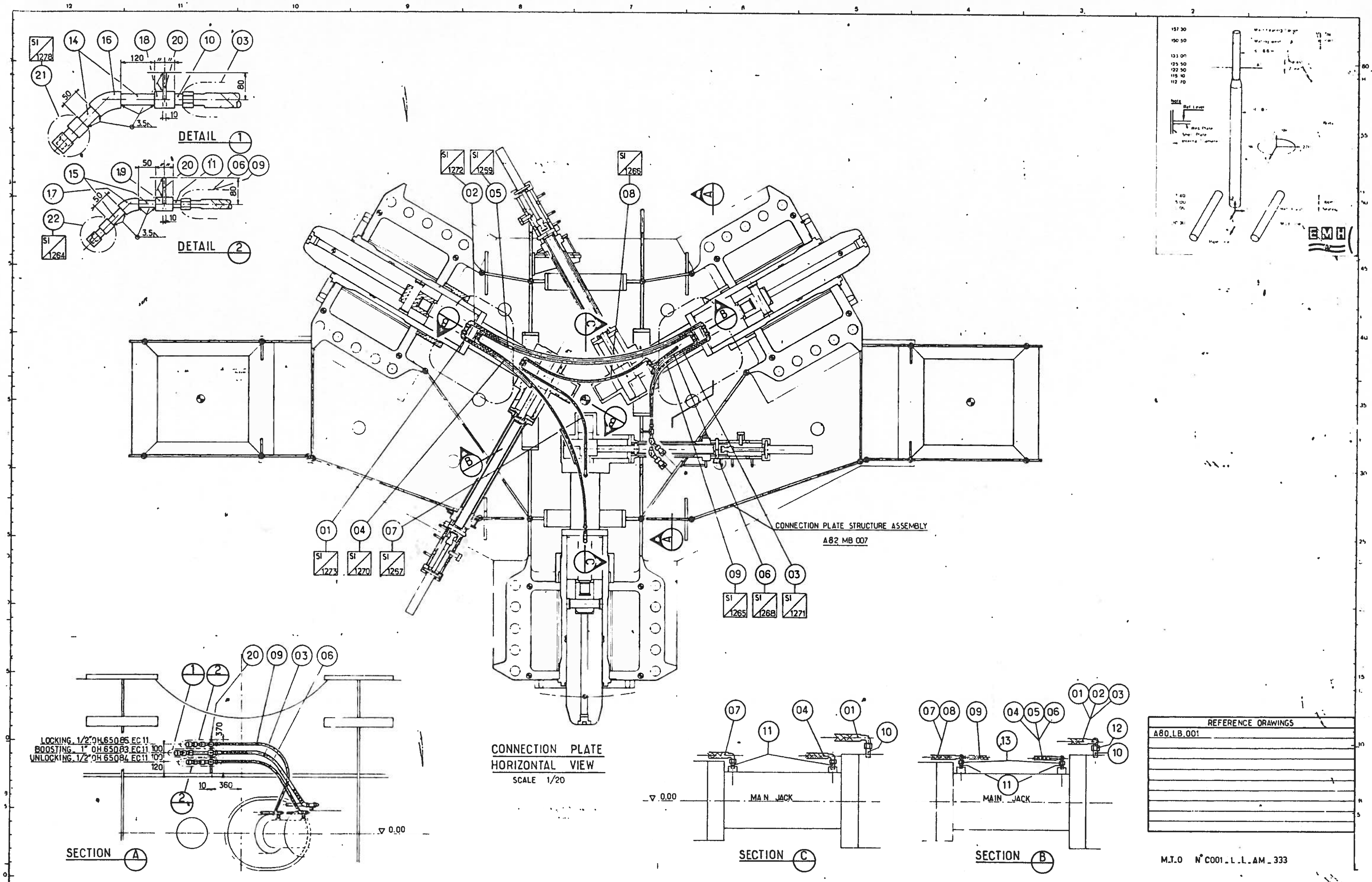
Contractor: ACN Articulated Columns Norway A.S

GULLFAKS "A" SPM2 C - 90106

TITLE: HYDRAULIC SYST. DIAGRAM. CONTROL OF THE CONNECTION SYST.

DRAWING NO.: C001 - L - A80 - LB - 001 | SHT NO 01 | REV Z4

PROJECT NO. | CONTR. | AREA | DISC | NUMBER | SHT NO | REV



REV	REASON FOR ISSUE	
0	~~ISSUED FOR CONSTRUCTION~~	06.09.84
01A	~~ISSUED FOR BID~~	20.04.84
01A	~~ISSUED FOR DETAIL ENG. COMPL.~~	30.03.84
01	~~ISSUED FOR APPR. DETAIL ENG. COMPL.~~	
01	~~ISSUED FOR IDC~~	26.1.84

REV	REASON FOR ISSUE	DATE
Z4	AS BUILT	21-5-87
0	ISSUED FOR CONSTRUCTION SPM 2	14.12.84
	NEW SPM 2 DRAWING	

REFERENCE DRAWINGS

statoil

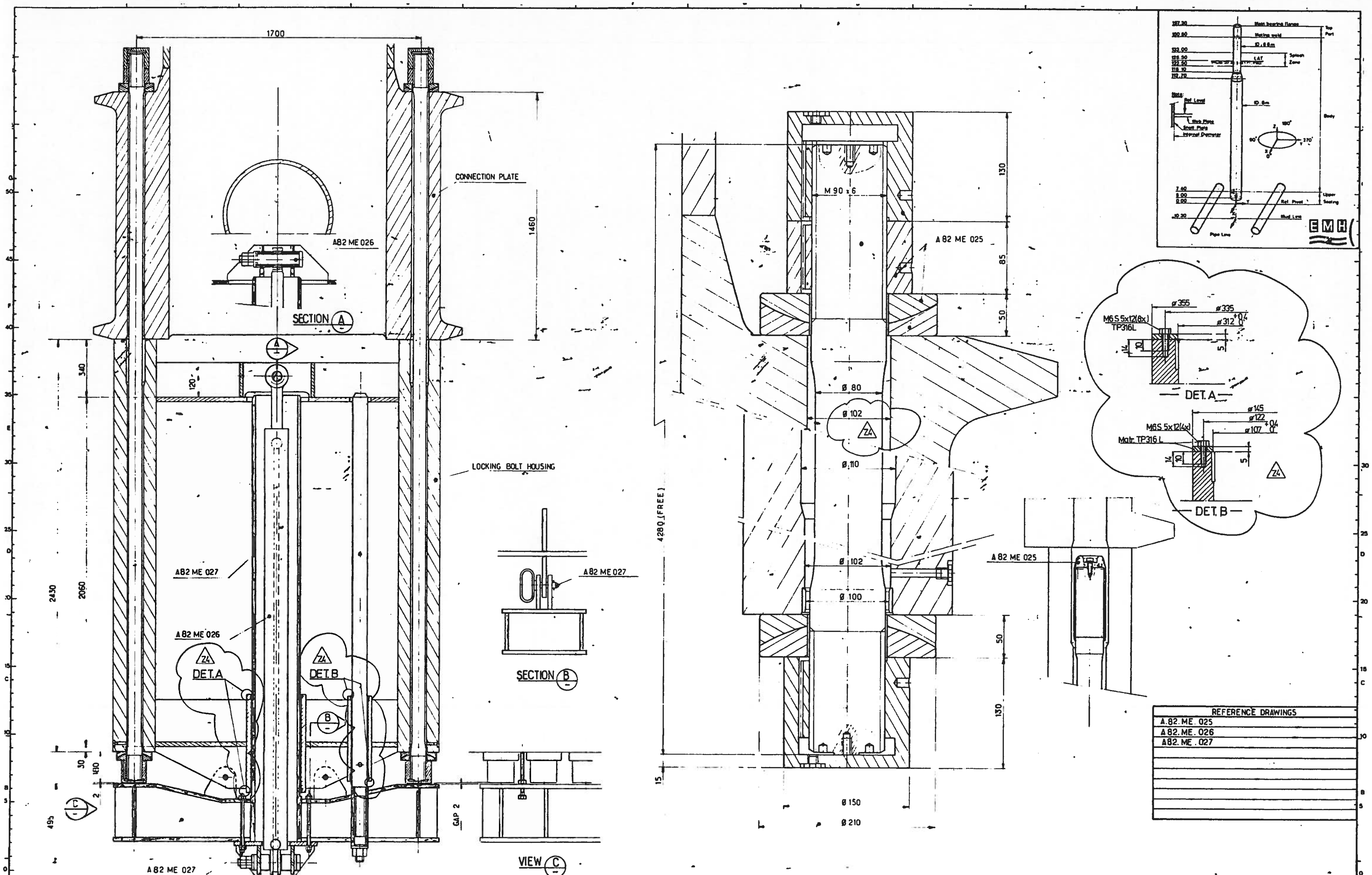
ACN

GULLFAKS "A" SPM2 C 90106

HYDRAULIC SYSTEM
CONNECTION PLATE PIPING
LAYOUT AND DETAILS

C001 L A82 LB 001 01 Z4

313-30



DRG NO	REFERENCE DRAWINGS
A80 MA 001	ARTICULATION AND CONNECTION GENERAL ARRANGEMENT

REV	REASON FOR ISSUE	DATE	DRN	CHK	APPR BY	PT
Z4	AS BUILT	21-5-87				
0	ISSUED FOR CONSTRUCTION SPM 2	14.12.84				
	NEW SPM 2 DRAWING.					

REV.	REASON FOR ISSUE	DATE	DRN	CHK	APPR BY	PT
0	ISSUED FOR CONSTRUCTION	06.09.84	B.ch.			
02A	ISSUED FOR DETAIL ENG. COMPL.	22.05.84	MR			
01	ISSUED FOR APPR. DETAIL ENG. COMPL.	21.03.84				
01A	ISSUED FOR BID	22.01.84	B.ch.			
01	ISSUED FOR I.D.C.	6.09.83	R.F.			

W.P. NO. 4.1.1.6
SYS. NO.
SCALE 1/10 1/2
MTO YES / NO

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Den norske stats oljeselskap a.s

Contractor: ACN Articulated Columns Norway A.S

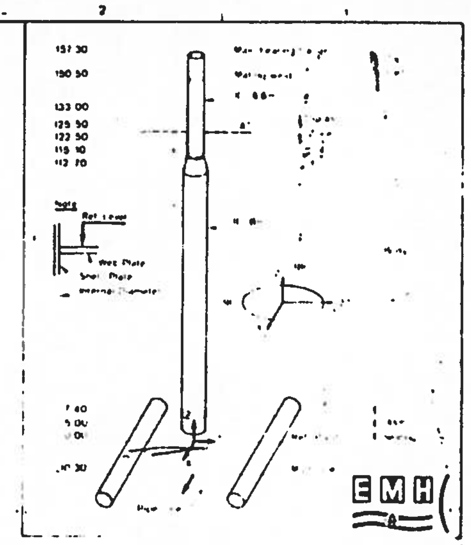
GULLFAKS "A" SPM 2 C - 90106

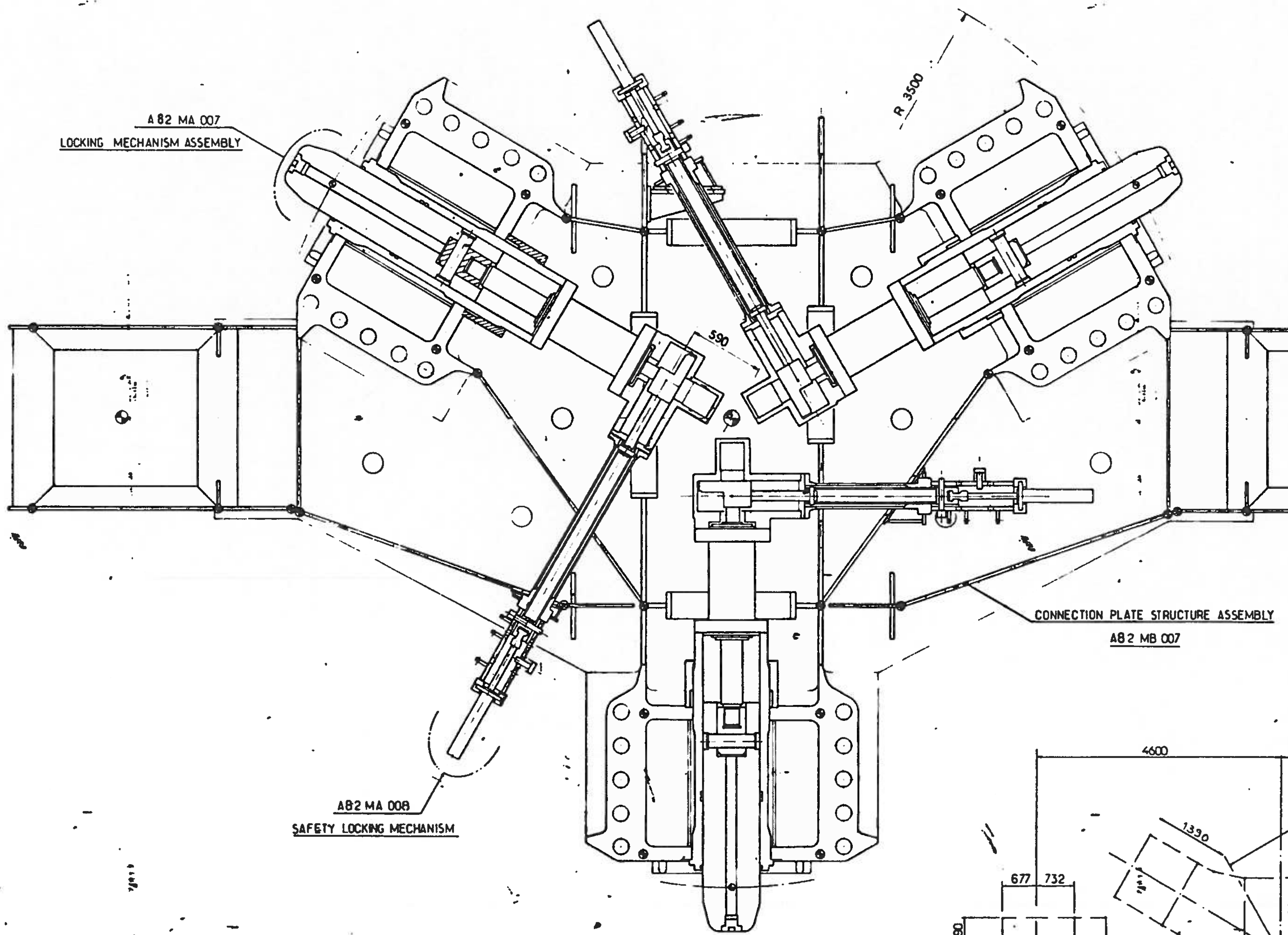
TITLE: CONNECTION PRESTESSED BOLTS ASSEMBLY

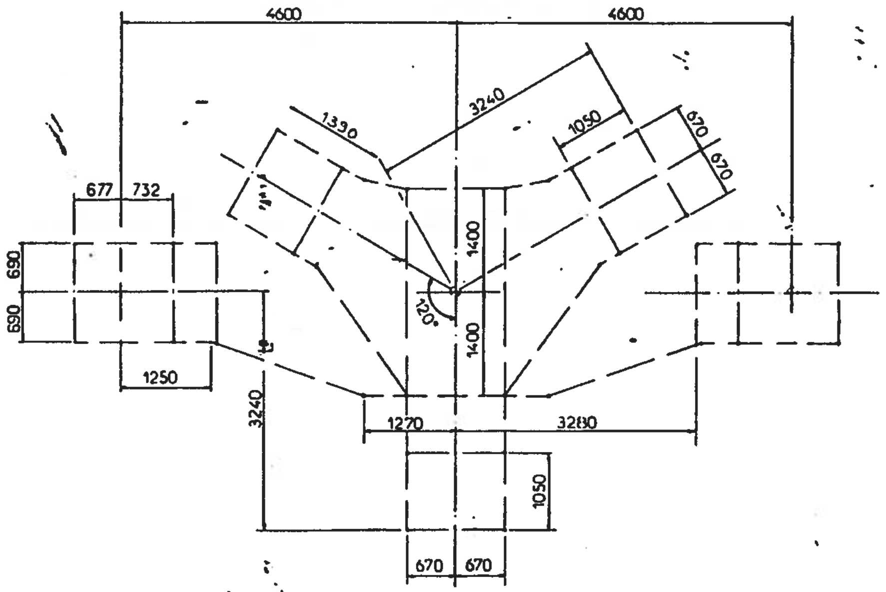
DRAWING NO: C001 - L - A82 - MA - 009 01 Z4

PROJECT NO.	CONTR.	AREA	DISC.	NUMBER	SHT NO	REV
C001	L	A82	MA	009	01	Z4

314-8







REFERENCE DRAWINGS
A82 MA 007 _ 008
A82 MB 007

REV	REASON FOR ISSUE	DATE	DRN	CHK	APPR BY	PT
Z4	AS BUILT	21.09.87	JAP			
0	ISSUED FOR CONSTRUCTION SPM 2 NEW SPM 2 DRAWING	14.12.84			AKF	
~~0~~	~~ISSUED FOR CONSTRUCTION~~	~~06.09.84~~	~~B.ch.~~			
~~03A~~	~~ISSUED FOR BID~~	~~20.04.84~~	~~B.ch.~~			

REV.	REASON FOR ISSUE	DATE	DRN	CHK	APPR BY	PT
~~03A~~	~~ISSUED FOR DETAIL ENG. COMPL.~~	~~10.02.84~~	~~FCH~~			
~~02~~	~~ISSUED FOR APPR. DETAIL ENG. COMPL.~~	~~22.12.83~~				
~~02~~	~~REISSUED FOR I.D.C~~	~~3.11.83~~	~~FCH~~			
~~01~~	~~ISSUED FOR APPROVAL OF 30.MA.001.~~	~~29.9.83~~				
~~01~~	~~ISSUED FOR I.D.C~~	~~18.8.83~~	~~FCH~~			

DRG NO	REFERENCE DRAWINGS

W.P. NO
SYS NO
SCALE 1/20
MTO ☐ YES ☒ NO

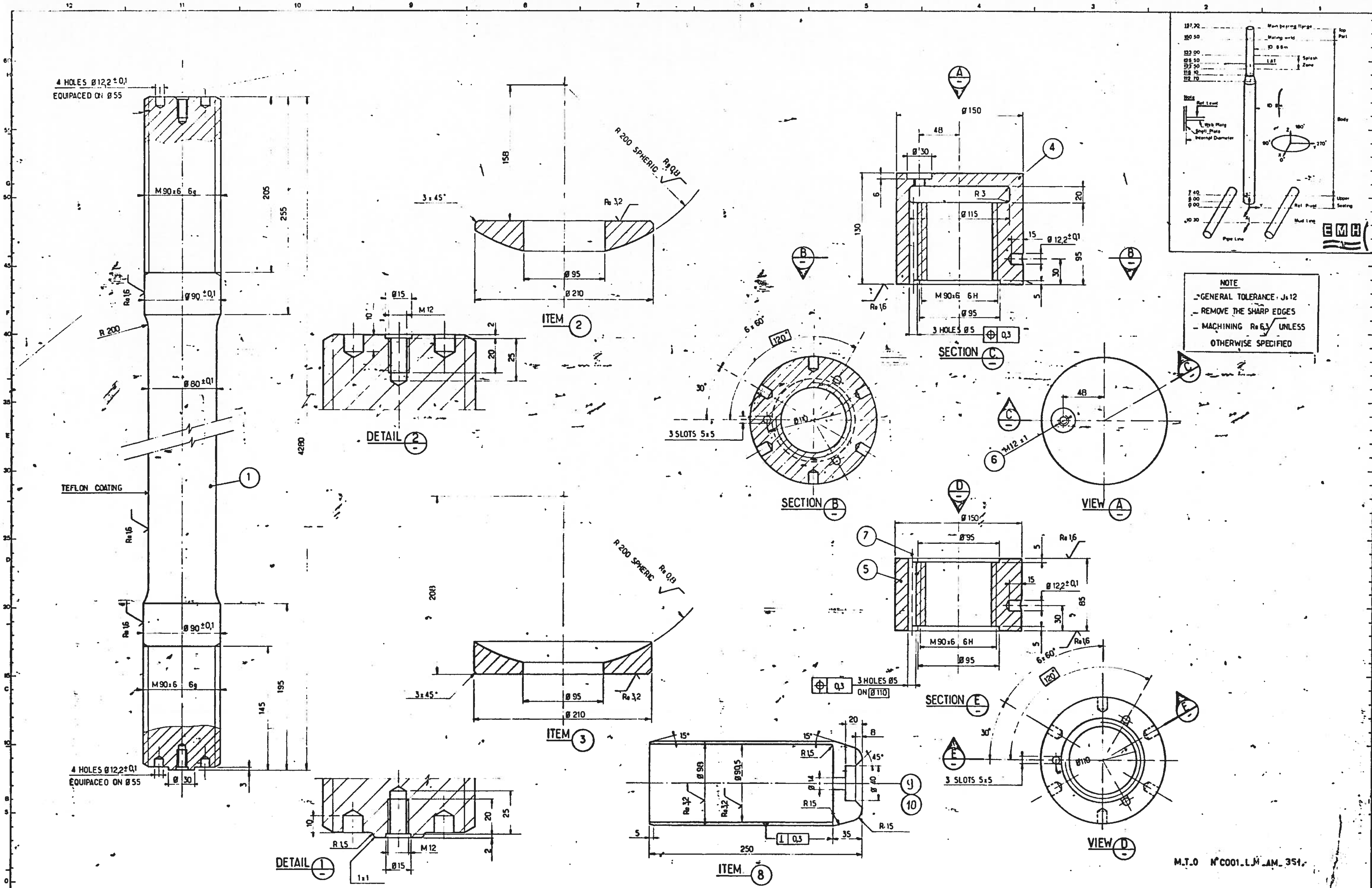
statoil
Den norske stats oljeselskap a.s

Contractor: ACN Articulated Columns Norway A.S

GULLFAKS "A" SPM 2 C - 9010

TITLE
CONNECTION PLATE STRUCTURE AND MECHANISM ASSEMBLY

DRAWING NO					SHT NO	REV
PROJECT NO	CONTR	AREA	DISC	NUMBER	SHT NO	REV
C001	L	A82	ME	001	01	Z4



		Z4	AS BUILT	22-5-87				AHF
		A	Reissued for construction	22.11.85				AHF
		0	ISSUED FOR CONSTRUCTION SPM 2	14.12.84			AHF	
A82 MA 009	CONNECTION PRESTRESSED BOLTS ASSEMBLY		[NEW SPM 2 DRAWING]					
DRG. NO.	REFERENCE DRAWINGS	REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT

REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
~~0~~	~~ISSUED FOR CONSTRUCTION~~	06.09.84	B.ch.			
~~01 A~~	~~ISSUED FOR DETAIL ENG. COMPL.~~	16.05.84	B.ch.			
~~01~~	~~ISSUED FOR APPR. DETAIL ENG. COMPL.~~					
~~01 A~~	~~ISSUED FOR BID~~	20.01.84	B.ch.			
~~01~~	~~ISSUED FOR I.D.&~~	23.09.83	FCH			

W.P. NO. 4.1.1.4
SYS. NO.
SCALE 1/2
MTO ☒ YES ☐ NO

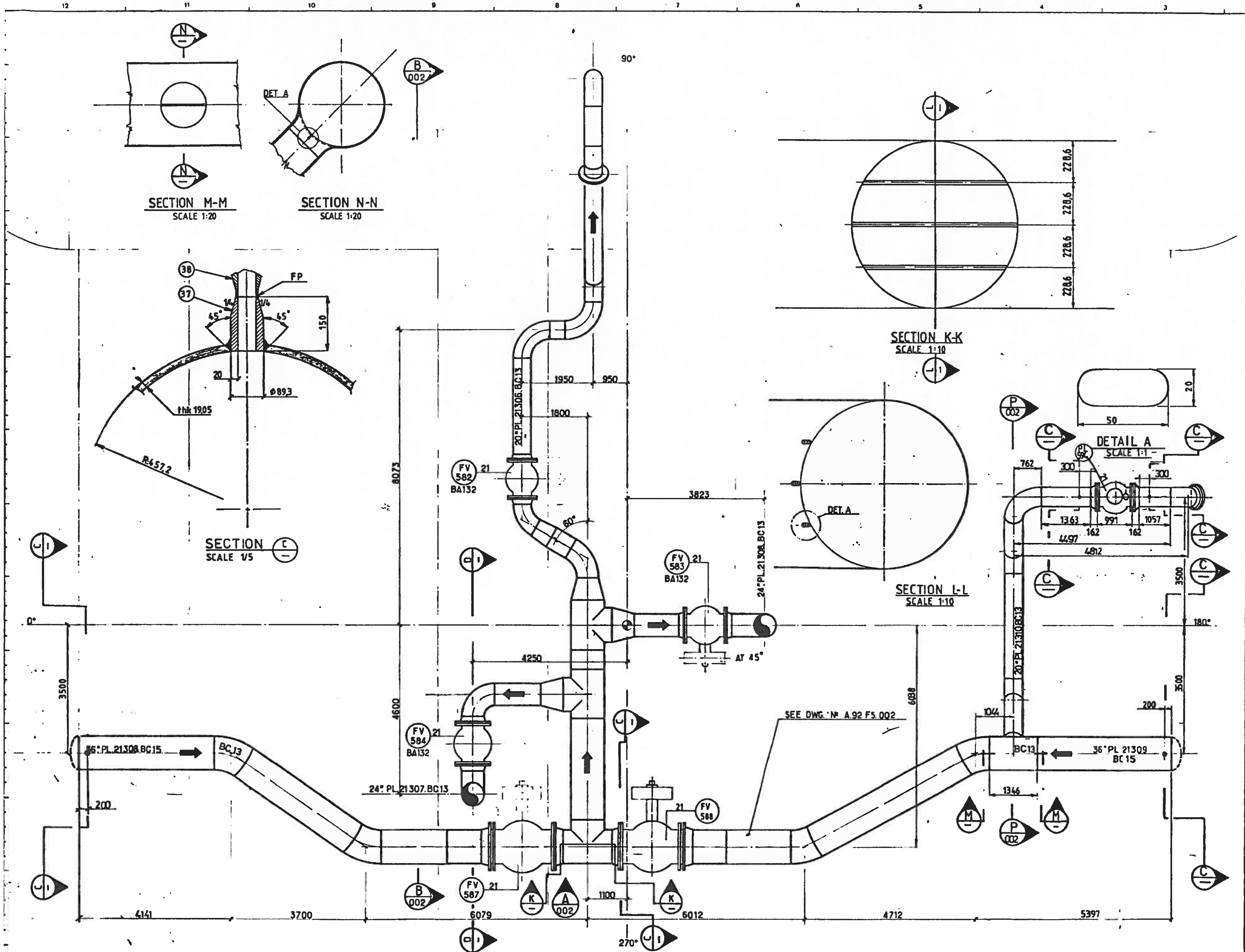
statoil
Den norske stats oljeselskap a.s.

Contractor: ACN Articulated Columns Norway A.S

GULLFAKS "A" SPM 2 C - 90106

TITLE: CONNECTION PRESTRESSED BOLTS DETAILS 1

DRAWING NO.	SHT. NO.	REV.
C001 - L - A82 - ME - 025	01	Z4
PROJECT NO. / CONTR. / AREA / DISC. / NUMBER		



NOTE :
FOR SECTIONS C AND D :
NTD CLASS B C001.A.N.CG.509
WELDING PROCEDURE ACCORDING
TO C001.A.L.SP.501

NOTE :
VALVE (PL 594) TO BE INSTALLED WITH STEM IN VERTICAL POSITION, CAP POINTING UPWARDS. HEADING OF WHEEL IS TO BE 90 DEGREE

M.T.O. Nº C001.L.F.AM.322

REFERENCE DRAWINGS
A 90 FB 002
A 90 FD 001

REV	REASON FOR ISSUE	DATE	DRN	CHK	APPR BY	ET
Z4	AS BUILT	4-6-87				
E	REISSUED FOR CONSTRUCTION SPM 2	130287				
D	REISSUED FOR CONSTRUCTION SPM 2	6.10.86				
C	REISSUED FOR CONSTRUCTION SPM 2	24.09.85				
B	REISSUED FOR CONSTRUCTION SPM 2	15.04.85	J.P.			
A	REISSUED FOR CONSTRUCTION SPM 2	14.02.85	Q.F.			
0	ISSUED FOR CONSTRUCTION SPM 2	14.12.84				
	NEW SPM 2 DRAWING					
~~0~~	~~ISSUED FOR CONSTRUCTION~~	14.02.85	Q.F.			

DRG. NO. | REFERENCE DRAWINGS

SCALE 1/50

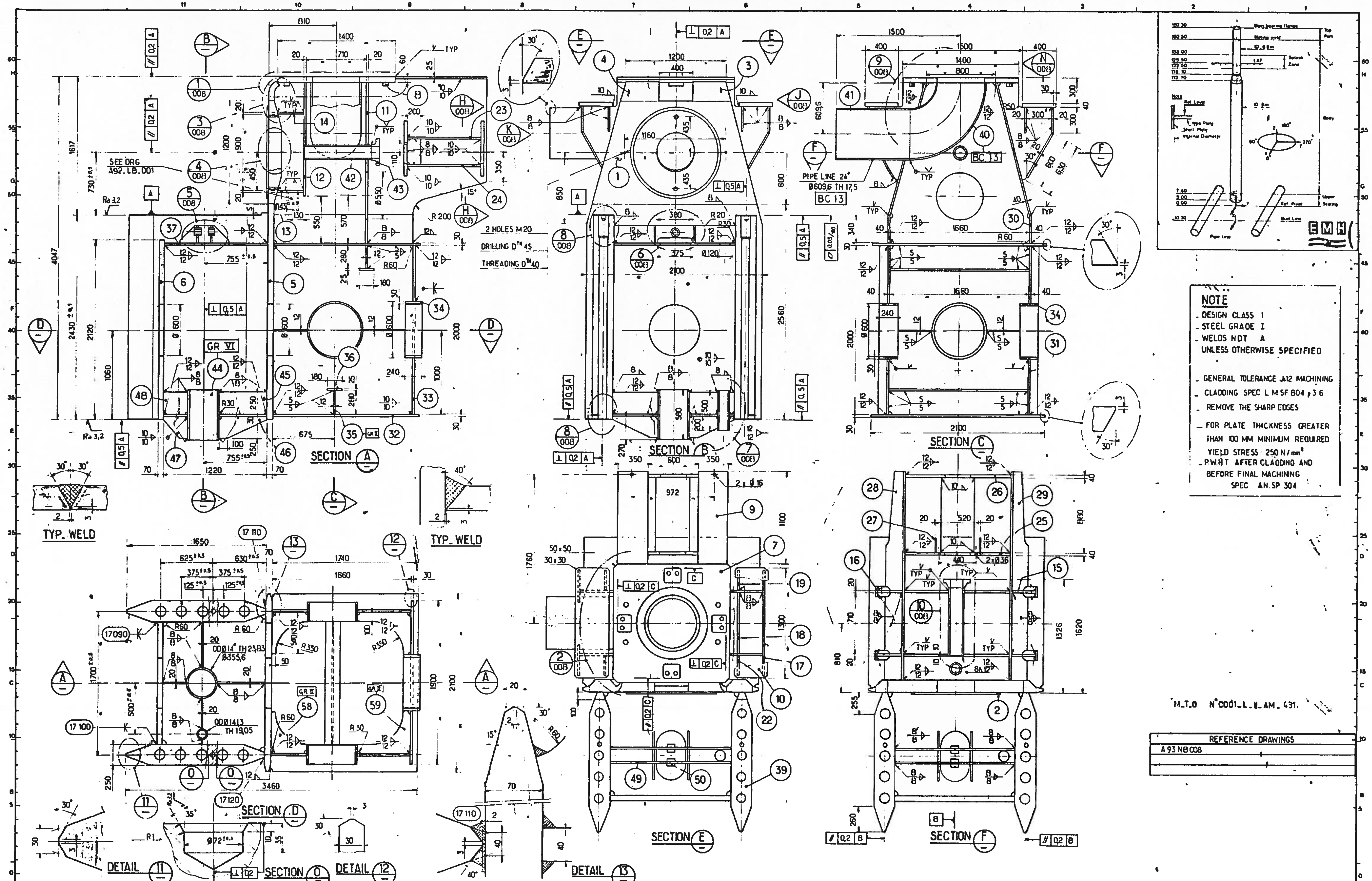
statoil
Den norske stats oljeselskap a.s

Contractor: ACN Articulated Columns Norway A S

GULLFAKS "A" SPM 2 C 90106

TITLE: BASE-CRUDE OIL PIPING ARRANGEMENT

DRAWING NO: C001-L-A90 FB-001 01 Z4



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			NEW SPM 2 DRAWING					
A90 NA 001	BASE GENERAL ARRANGEMENT HORIZONTAL V	0	ISSUED FOR CONSTRUCTION	3.09.84	MR			
A92 NB 001	BASE STRUCTURE HORIZONTAL VIEW	03A	ISSUED FOR DETAIL ENG. COMPL.	04.07.84	MR			
A80 MA 001	ARTICULATION AND CONNECTION GEN. ARR^T	04A	ISSUED FOR DETAIL ENG. COMPL.	06.06.84	B. ch.			

REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
03A	ISSUED FOR BID	20.04.84	B. ch.			
03A	ISSUED FOR DETAIL ENG. COMPL.	30.3.84	FCH			
02A	ISSUED FOR DETAIL ENG. COMPL.	13.1.84	RC			
01	ISSUED FOR APPR. OF DETAIL ENG. COMPL.	29.10.83				
Z4	AS BUILT	22-6-87				

SCALE 1/20

statoil — Den norske stats oljeselskap a.s

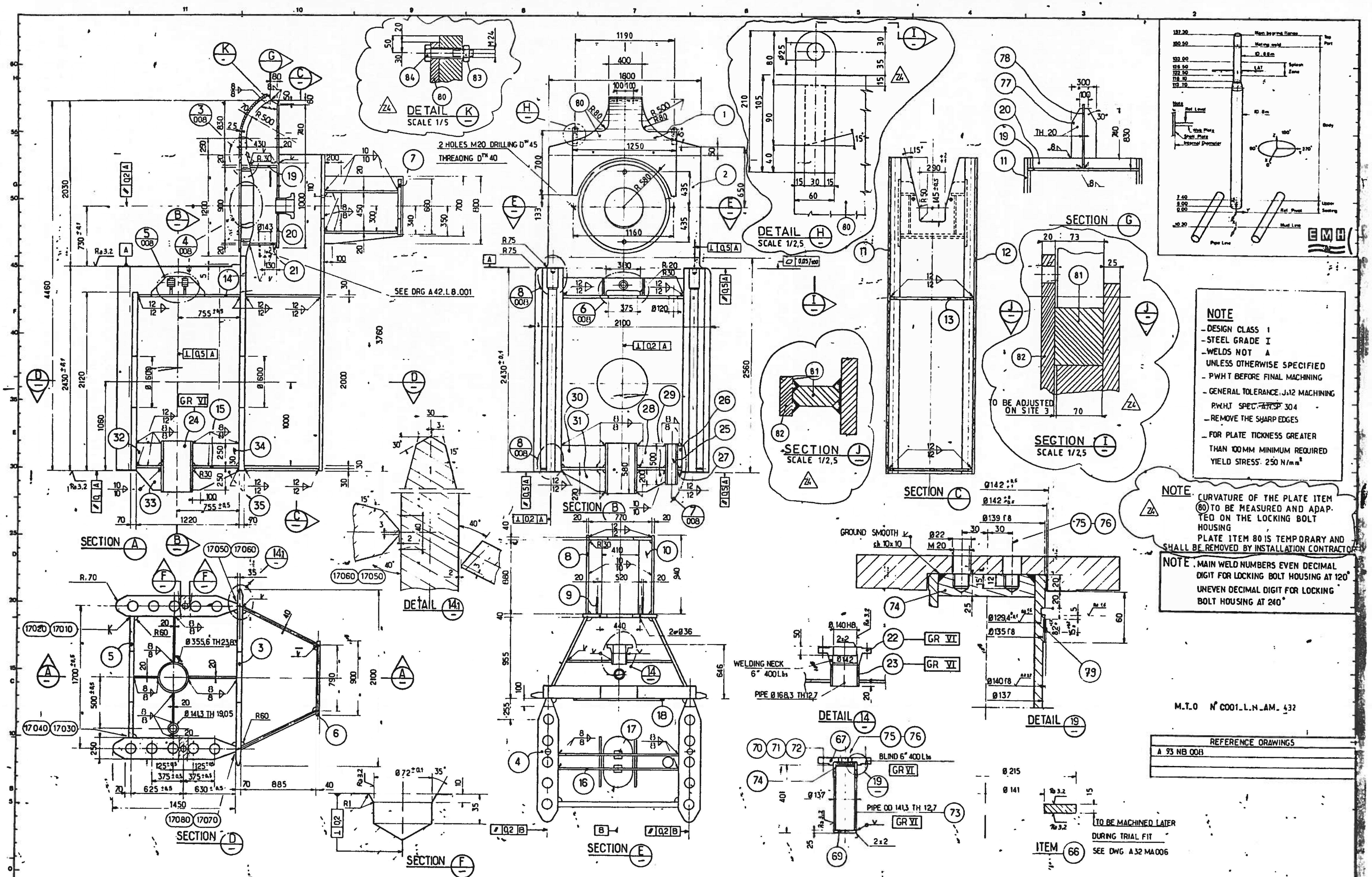
Contractor: ACN — Articulated Columns Norway A.S

GULLFAKS "A" SPM2 C-90106

TITLE: B.S LOCKING BOLT HOUSING AND CONNECTION JOINT TYPE 1

DRAWING NO: C001 - L - A93 - NB - 004 | 01 | Z4

PROJECT NO. | CONTR. | AREA | DISC. | NUMBER | SHT NO. | REV.



DRG. NO.	REFERENCE DRAWINGS
A90 NA 001	B. GENERAL ARRANGEMENT HORIZONTAL VIEW
A92 NB 001	BASE STRUCTURE HORIZONTAL VIEW
A80 MA 001	ARTICULATION AND CONNECTION GEN. ARR.

REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
A	REISSUED FOR CONSTRUCTION SPM 2	8 02.85	FCH			
0	ISSUED FOR CONSTRUCTION SPM 2	14.12.84			ACF	
	NEW SPM 2 DRAWING					
~~0~~	~~ISSUED FOR CONSTRUCTION~~	~~3.09.84~~	~~MR~~			
~~04A~~	~~ISSUED FOR DETAIL ENG. COMPL.~~	~~29.05.84~~	~~MR~~			

REV.	REASON FOR ISSUE	DATE	DRN.	CHK.	APPR. BY	PT
~~03A~~	~~ISSUED FOR DID~~	~~20.04.84~~				
~~03A~~	~~ISSUED FOR DETAIL ENG. COMPL.~~	~~30.3.84~~	~~FCH~~			
~~02A~~	~~ISSUED FOR DETAIL ENG. COMPL.~~	~~13.1.84~~	~~RC~~			
Z4	AS. BUILT	23-6-87			ACF	
B	REISSUED FOR CONSTRUCTION SPM 2	14.05.86			ACF	

W.P. NO. 4.1.1.4
SYS. NO.
SCALE 1/20
MTO YES / NO

statoil
Den norske stats oljeselskap a.s

Contractor
ACN
Articulated Column Norway A.S

GULLFAKS "A" SPM2 C - 90106

TITLE
BASE STRUCTURE LOCKING BOLT HOUSING TYPE 2

PROJECT NO.	CONTR.	AREA	DISC.	NUMBER	SHT. NO.	REV.
C001	L	A93	NB	007	01	Z4

REF.A.	SERIAL NR.:	TYPE	JOINT NUMBER and NIPPLE THK (mm)	
1	09-08 176	ADMIRAL 1401 S EXTRA PU	B 9	C 9
2	08-08 171	ADMIRAL 1402 S PU	C 9	D 9
3	08-08 172	ADMIRAL 1402 S PU	D 9	E 9
4	08-08 173	ADMIRAL 1402 S PU	E 9	F 9
5	09-08 174	ADMIRAL 1402 S PU	H 9	I 9
6	03-09 243	ADMIRAL 1402 S PU	I 12	J 12
7	03-09 244	ADMIRAL 1402 S PU	J 12	K 12
8	03-09 245	ADMIRAL 1402 S PU	K 12	L 12
9	03-09 246	ADMIRAL 1402 S	L 12	M 12
10	03-09 247	ADMIRAL 1402 S	M 12	N 12
11	04-09 248	ADMIRAL 1402 S	N 12	O 12
12	04-09 249	ADMIRAL 1402 S	O 12	P 12
13	04-09 250	ADMIRAL 1402 S	P 12	Q 12
14	05-10-315	ADMIRAL 1401 S EXTRA	Q 12	R 15
15	05-10-316	ADMIRAL 1401 S EXTRA	U 15	V 12
16	04-09 251	ADMIRAL 1402 S	V 12	W 12
17	04-09 252	ADMIRAL 1402 S	W 12	X 12
18	04-09 253	ADMIRAL 1402 S	X 12	Y 12
19	04-09 254	ADMIRAL 1402 S	Y 12	Z 12
20	04-09 255	ADMIRAL 1402 S	Z 12	AA 12
21	05-10-314	ADMIRAL 1401 S SUPER EXTRA	AA 12	AB 22

NOTE:

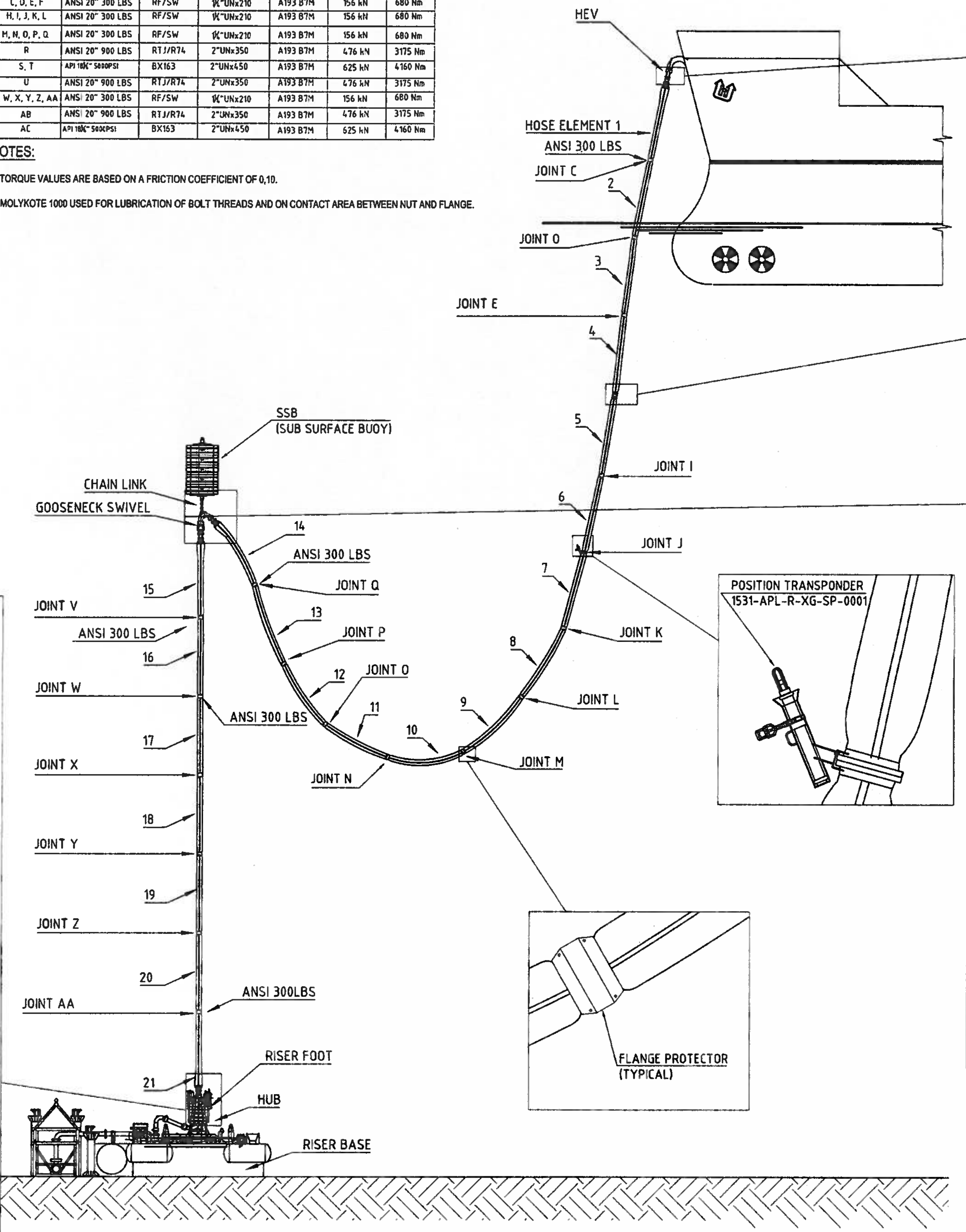
1. HOSE/JOINT NO 14/Q, 15/V, 21/AA HAVE MODIFIED 12mm NIPPLE DESIGN ACCORDING TO DWG NO. 1531-BAO-R-XS-SM-0011
   OTHER 12mm NIPPLES HAVE DESIGN AS PER DWG NO. 1531-BAO-R-XS-SM-0006

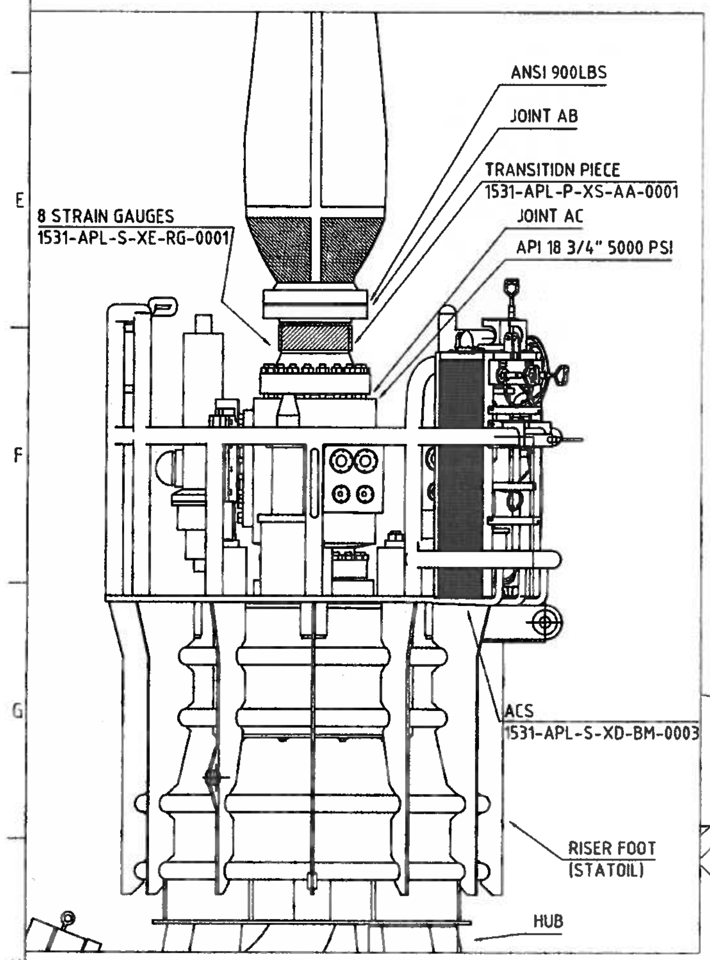
FLANGES	FLANGE TYPE	GASKET	BOLT DIMENSION	BOLT MATERIAL	BOLT LOAD	TORQUE
A	ANSI 20" 300 LBS	RF/SW	M30x200	A193 B7M	156 kN	690 Nm
B	ANSI 20" 900 LBS	RTJ/R74	2"UNx350	A193 B7M	476 kN	3175 Nm
C, D, E, F	ANSI 20" 300 LBS	RF/SW	1¼"UNx210	A193 B7M	156 kN	680 Nm
H, I, J, K, L	ANSI 20" 300 LBS	RF/SW	1¼"UNx210	A193 B7M	156 kN	680 Nm
M, N, O, P, Q	ANSI 20" 300 LBS	RF/SW	1¼"UNx210	A193 B7M	156 kN	680 Nm
R	ANSI 20" 900 LBS	RTJ/R74	2"UNx350	A193 B7M	476 kN	3175 Nm
S, T	API 18¾" 5000PSI	BX163	2"UNx450	A193 B7M	625 kN	4160 Nm
U	ANSI 20" 900 LBS	RTJ/R74	2"UNx350	A193 B7M	476 kN	3175 Nm
V, W, X, Y, Z, AA	ANSI 20" 300 LBS	RF/SW	1¼"UNx210	A193 B7M	156 kN	680 Nm
AB	ANSI 20" 900 LBS	RTJ/R74	2"UNx350	A193 B7M	476 kN	3175 Nm
AC	API 18¾" 5000PSI	BX163	2"UNx450	A193 B7M	625 kN	4160 Nm

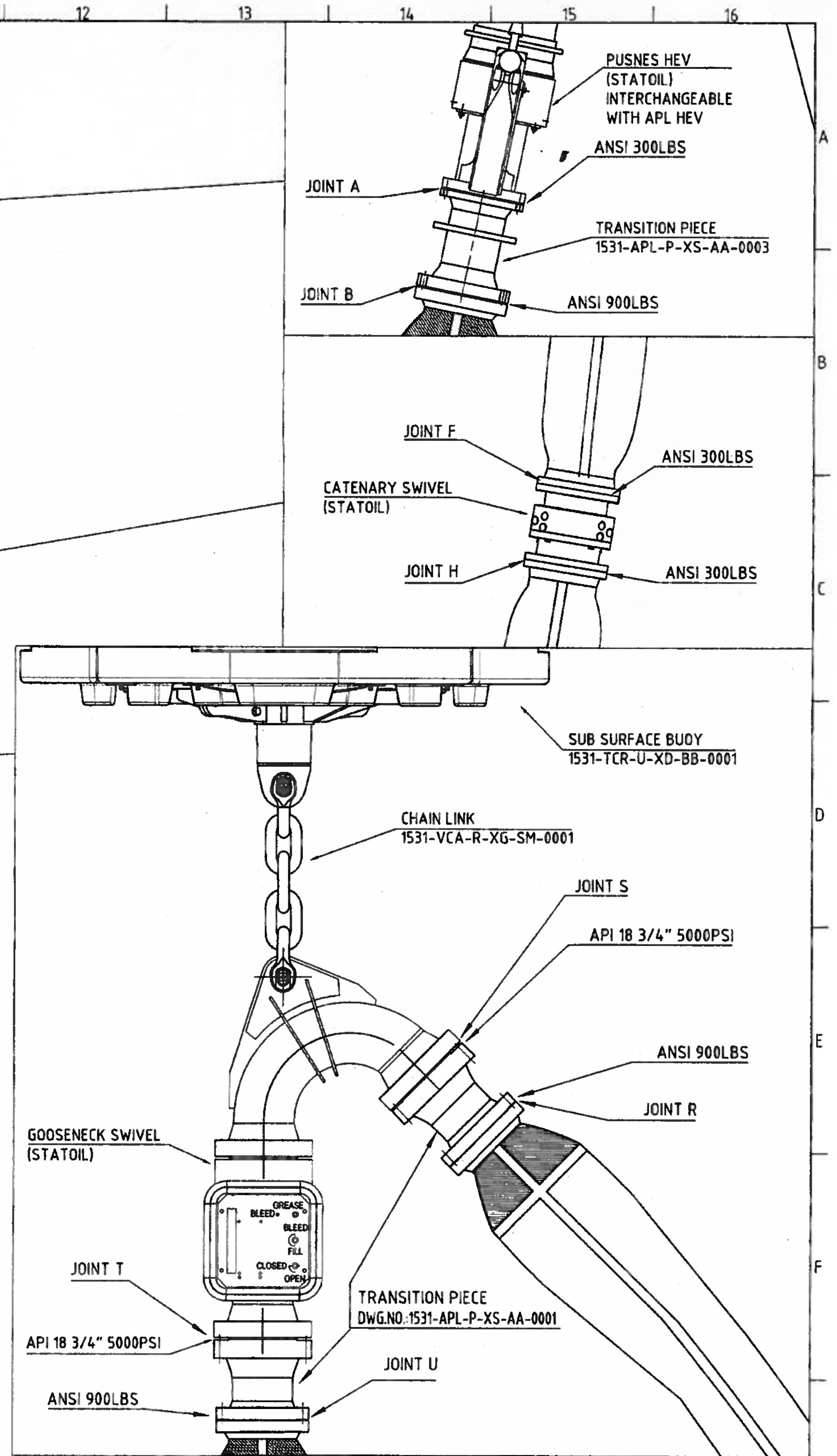
NOTES:

1. TORQUE VALUES ARE BASED ON A FRICTION COEFFICIENT OF 0,10.

2. MOLYKOTE 1000 USED FOR LUBRICATION OF BOLT THREADS AND ON CONTACT AREA BETWEEN NUT AND FLANGE.







Statoil		OLS B REPAIR APL project no.1531	Client Drawing No.: BA-SU-VA-001.001		Rev.: A3
Z2	15.04.11	AS-BUILT	ECH	UC	JKF
Z1	28.02.11	AS-BUILT (REF A POS 14, 15 AND 21)	RSA	JKF	JKF
A	16.09.10	REISSUED FOR CONSTRUCTION	ECH	UC	JKF
3	27.07.09	ISSUED FOR INFORMATION	GUV	ALE	SOM
2	25.05.09	ISSUED FOR INFORMATION	KKV	ALE	SOM
1	07.05.09	ISSUED FOR INFORMATION	KKV	ALE	SOM
Rev.	Date	Reason for issue/Ref. DCN No.	Traced by	Checked	Approved

Date: 10.06.08 | Design: | Reference dwg.: | Format: A1 | Scale: -

APL — Advanced Production and Loading AS

OLS B GENERAL ARRANGEMENT, DETAILS

INFORMATION

DWG No.: 1531-APL-S-XD-BM-0002 | Rev.: Z2

Replacement for: | Replaced by: | Flag: --

Appendix B

Video references

The attached DVD contains the following videos:

- As found survey
- Bolt housing H1 inspection
- Bolt housing H2 inspection
- Bolt housing H3 inspection
- By-pass structure
- Connection bladder H1 inspection
- Connection bladder H2 inspection
- Connection bladder H3 inspection
- Connection joint type 1
- Connection joint type 2
- Lifting frame H1 inspection
- Lifting frame H2 inspection
- Lifting frame H3 inspection
- Locking pin H1
- Locking pin H1
- Locking pin H1

Reference DVD attached below

Appendix C

SPM column buoyancy calculation

SPM column buoyancy calculation

Given weights from DFI SPM 1:

Structure part	Weight
Base structure	Net: 1449 tons, ballasted: 3949 tons
Universal joint	164,7 tons (included in column weight)
Column	Net: 2310 tons, permanent ballast: 1419 tons, water ballast: 1988 tons, top-part: 63,7 tons
Rotating head	340 tons
Column and universal joint buoyancy	-6308 tons

Table 1: Structure weights and buoyancy

The interesting force to calculate is the buoyancy force acting on the base structure. The buoyancy weight without water ballast in the column is as followed:

$$\boldsymbol{Weight}\ (\boldsymbol{no\ ballast}) = 164{,}7 + 2310 + 1419 + 63{,}7 + 340 - 6308 = -\mathbf{2010{,}6}\ \boldsymbol{tons}$$

The buoyancy weight with water ballast in the column is as followed:

$$\boldsymbol{Weight}\ (\boldsymbol{ballast}) = 164{,}7 + 2310 + 1419 + 63{,}7 + 1988 + 340 - 6308 = -\mathbf{22{,}6}\ \boldsymbol{tons}$$

Appendix D

Locking bolt housing oil calculation

Locking bolt housing oil calculation

The area inside the compartment shown on figure 1 must be calculated in order to determine the amount of oil inside the locking bolt housing. The oil can be drained by dismantle a flange which are mounted onto the flange surface.

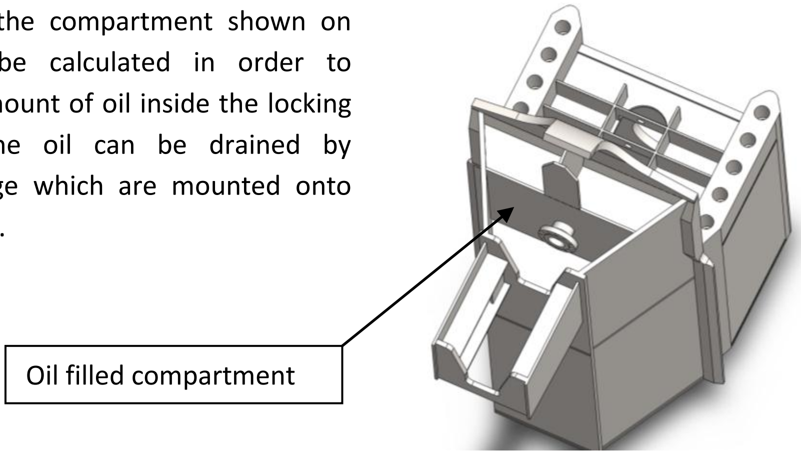


Figure 1: Oil filled compartment

The volume can be determined be calculating the top area of the compartment multiplied by the depth of the compartment. The depth of the compartment is 1 meter and the top area is shown on figure 2. The area is divided into three areas to simplify the calculation.

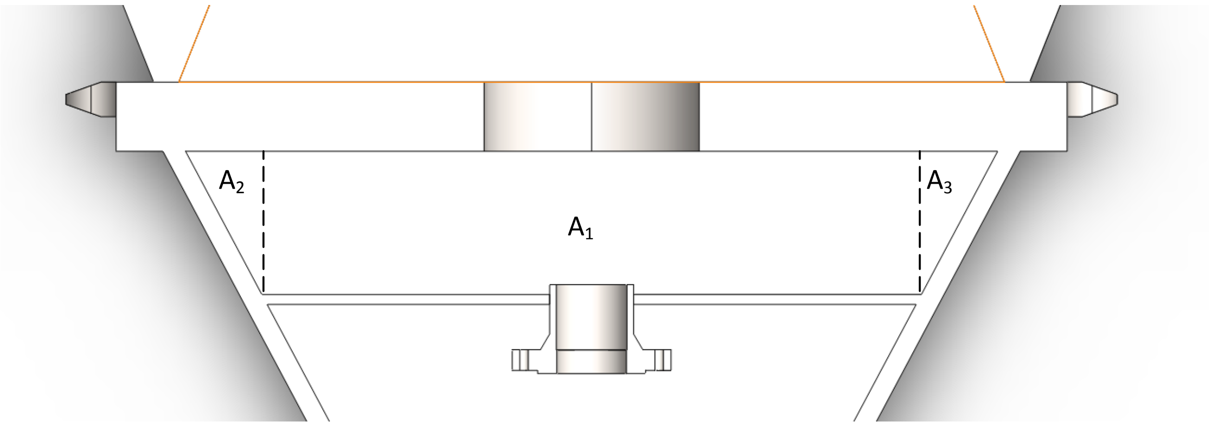


Figure 2: Top area of oil filled compartment (section view through flange)

$$A_1 = 1{,}317 \times 0{,}326 = 0{,}43m^2$$

$$A_2 = A_3 = \frac{0{,}172 \times 0{,}326}{2} = 0{,}028m^2$$

$$\boldsymbol{V} = (A_1 + A_2 + A_3) \times depth = (0{,}43 + 0{,}028 + 0{,}028) \times 1 = \boldsymbol{0{,}49m^3}$$

The total volume in each compartment is approximately 0,5m^3, but there are some oil between the bladder connection and the locking bolt. It is assumed that the total amount of oil in each locking bolt housing will be approximately 0,75m^3. The total amount of oil that needs to be drained is approximately 2,25m^3.

Appendix E

Verification of pre-stressed bolt length after cutting

Pre-stressed bolt length after cutting

The total length of the pre-stressed bolts is 4280mm. The total height of the locking bolt housing and connection plate is 3890mm. The lifting frame cylinder has a stroke length of 2063mm. The pre-stressed bolts will be resting in the lifting frame and partly inside the locking bolt housing when the cutting is completed. The following calculations are valid for alternative 2 described in section 5.3.3 in the master thesis.

The length of the bolt after cutting will be bolt length minus nut and counter nut.

$$Length\ after\ cutting = 4280 - 265 = 4015mm$$

The height of the connection plate, which the bolts go through, is 1460mm. The final bolt location will be 603mm down into the locking bolt housing:

$$Location = Connection\ plate\ height - lifting\ frame\ stocke\ lengt$$

$$Location = 1460 - 2063 = -603mm$$

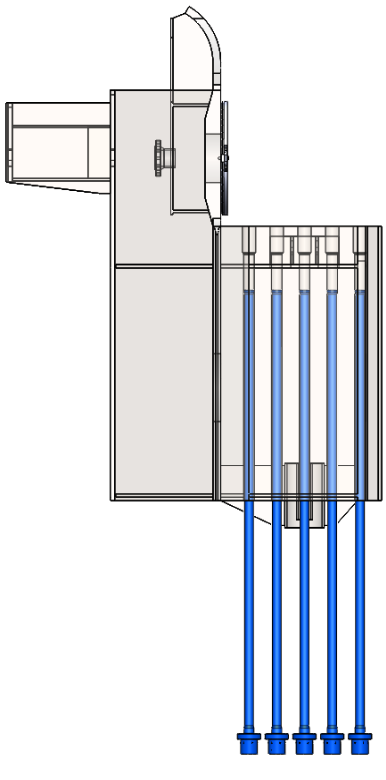


Figure 1: Bolt location after cutting

The bolts will not cause any interface difficulties for the new offloading system with alternative 2 as cutting solution.

Appendix F

Strength Analysis for locking bolt housing

1 Force and angle of force

Two find the angle of attack when the offloading hose is fully stretched (linear), the following parameters must be known:

- Water depth at riser foot
- Total length of offloading hose, including length of riser
- Height from sea surface to tanker

These parameters will determine the angle of attack for the force if the tanker should cause an accidental load too the offloading system. The hose will disconnect at a tension at 120 tons. The force used in the analysis is 1800 kN, resulting in a safety factor of just above 1,5.

The system is not made, so assumption must be taken to determine an angle. The water depth at the area is 136 meters and it is assumed that the riser foot will connect at approximately 128 meters. The distance from sea surface to tanker connection point is assumed to be approximately 10 meters. This results in the geometry shown in figure 1.1. The angle α between the hypotenuse and the horizontal side can be found by the following equation:

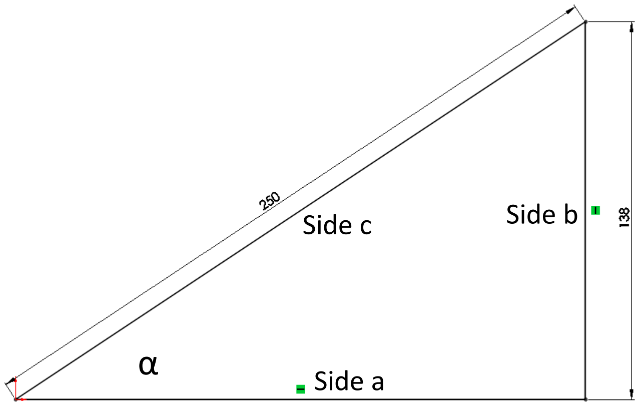


Figure 1.1: Force angle

$$Sin\ \alpha = \frac{side\ b}{side\ c} = \frac{128 + 10}{250} \rightarrow \alpha = Sin^{-1}\left(\frac{138}{250}\right) = 33{,}5°$$

The larges uncertainty regarding this angle is the length of the offloading hose.

The force used throughout this analysis is **1800 kN** with an **33,5°** angle from horizontal line.

2 Finding reaction forces

A virtual riser base was modeled to be able to get the reaction forces acting on the locking bolt housing when accidental load occur. The angle of attack is estimated to be 33,5°. The force F is defined to be -1800 kN. The virtual riser base is shown in figure 2.1.

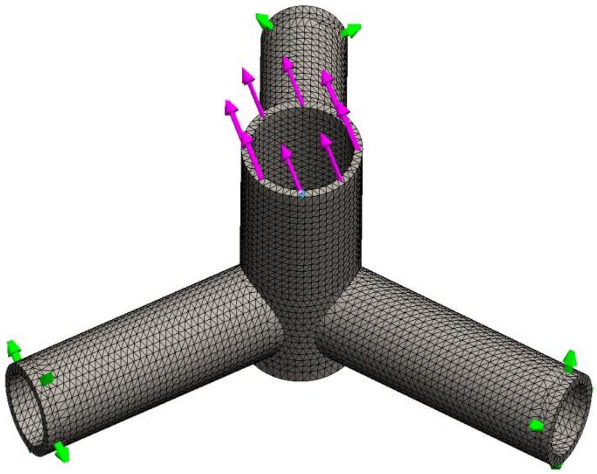


Figure 2.1: Virtual riser base for determining reaction forces

The pink arrows on the top indicate the action force on the geometry. Important parameters to this structure is the length from the center of the geometry and out to the end of the cylinders. The length of the three legs is 3500 mm and the height of the center cylinder is assumed to be two meters. Reaction force from the action force is on a split line on each end of the legs, as shown with the green arrows figure 2.1. The geometry is made cylindrical to reduce the number of nodes for calculation purposes. The reaction forces at the given areas will not be affected.

The geometry is fixed around where the green arrows are located. The geometry is free in the axial direction and locked in radial direction. The result of this is reaction forces in y- and z- direction.

Mesh type:	Solid Mesh
Mesher used:	Standard mesh, fine
Element size:	86,4918 mm
Tolerance:	4,32459 mm
Mesh quality:	High
Number of nodes:	76614

Table 2.1: Virtual riser base mesh details

The angle β of the force acting on the riser base was changed around the geometry from 0° to 180° degrees with 15° degree intervals. See figure 2.2.

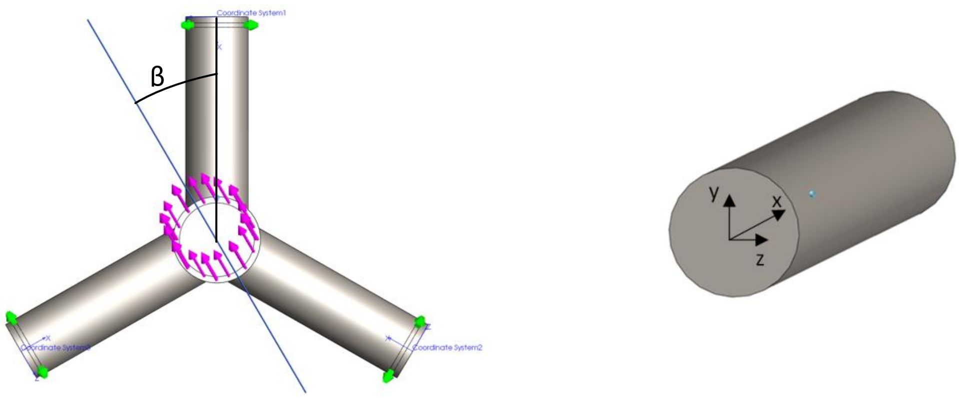


Figure 2.2: Angle of force and local coordinate system

The result from each angle is listed in table 2.2. The forces are listed with reference to respectively local coordinate systems for each support, illustrating the locking bolt housings.

Angle	Support	X [kN]	Y [kN]	Z [kN]	Angle	Support	X [kN]	Y [kN]	Z [kN]
0°	Support 1	0	301	0	105°	Support 1	0	-467	-994
	Support 2	0	-614	-891		Support 2	0	-741	727
	Support 3	0	-614	891		Support 3	0	281	266
15°	Support 1	0	281	-266	120°	Support 1	0	-615	-891
	Support 2	0	-741	-728		Support 2	0	-614	891
	Support 3	0	-467	994		Support 3	0	301	0
30°	Support 1	0	220	-514	135°	Support 1	0	-741	-727
	Support 2	0	-838	-515		Support 2	0	-467	993
	Support 3	0	-309	1029		Support 3	0	281	-267
45°	Support 1	0	122	-727	150°	Support 1	0	-838	-514
	Support 2	0	-899	-267		Support 2	0	-309	1029
	Support 3	0	-151	993		Support 3	0	220	-515
60°	Support 1	0	0	-891	165°	Support 1	0	-899	-266
	Support 2	0	-919	0		Support 2	0	-151	994
	Support 3	0	0	890		Support 3	0	123	-727
75°	Support 1	0	-151	-994	180°	Support 1	0	-919	0
	Support 2	0	-899	266		Support 2	0	0	891
	Support 3	0	123	727		Support 3	0	0	-891
90°	Support 1	0	-309	-1029					
	Support 2	0	-838	514					
	Support 3	0	220	514					

Table 2.2: Reaction forces

Simple check: When the force is applied at β equals 0° it is assumed that the support 1 only can absorb forces in the y-direction. The force is acting upwards, and given the geometry, it is expected that the force is directed this way. For the support 2 and 3 it is expected that these will absorb forces in both y- and z-direction. The force distribution for these two should be symmetric, only with different directions in the z-direction. The forces in the y-direction should be directed downwards.

Out from the result at the 0°angle one can see that all these assumptions occur, which greatly confirm the fixture of the model to be correct.

A further analysis on the locking bolt housing is performed on the following cases:

- 15° force angle on support 3
- 105° force angle on support 2
- 135° force angle on support 1

These are evaluated as the worst cases of the listed alternatives.

3 Finding stress in locking bolt housing

The mesh details which are used in the element division are listed in table 3.1.

Mesh type:	Solid Mesh
Mesher used:	Custom mesh (extra fine)
Element size:	46,4592 mm
Tolerance:	2,32296 mm
Mesh quality:	High
Number of nodes:	400475

Table 3.1: Locking bolt mesh details

The material is defined in DFI as construction class 1, steel grade 1 or 2. This gives yield strength of minimum 310 MPa (depending on thickness) and a tensile strength of minimum 460 MPa. The E-modulus is not given, but it is assumed to be approximately 200 GPa.

The forces are applied in the locking bolt housing hold in such a way that only compression forces can occur. This is what`s realistic compared to three rods intersecting in holes, such the case is. Figure 3.1 and 3.2 shows forces applied in y- and z- direction. Both these forces are added into the analysis. Figure 3.3 is just to illustrate an example of wrongly applied force in these cases. Tension forces can`t occur.

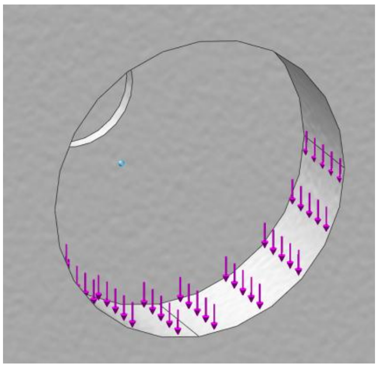


Figure 3.1: Positive y-direction

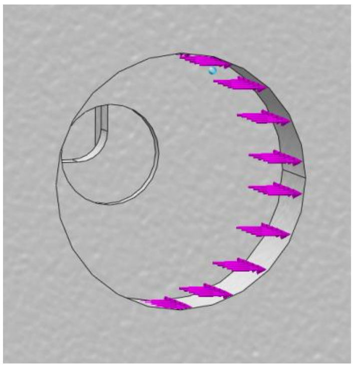


Figure 3.2: Negative z-direction

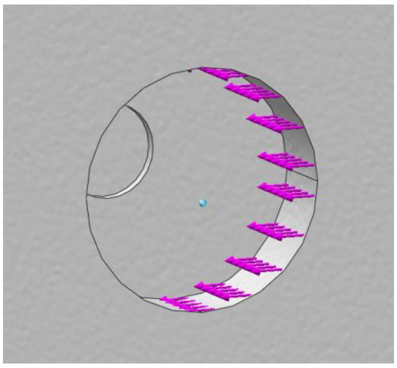


Figure 3.3: Wrongly applied force

The locking bolt housings are welded to the base structure on several places. The welds were strong enough to resist the forces from the SPM column and will therefore be strong enough for the new riser system. The model fixture is defined with the fixed geometry at the places where the locking bolt housing is welded to the base structure. The fixture areas are illustrated in figure 3.4.

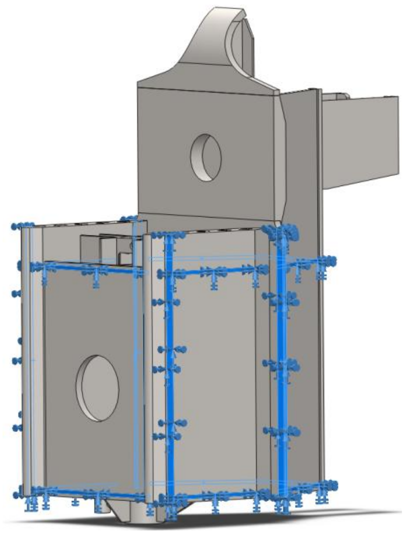


Figure 3.4: Geometry fixture

15° force angle at support 3

Figure 3.5 shows the result of the stress analysis for a 15° force angle at support 3 and the average stress is far below the yield strength. The highest stress is 135,1 MPa, but this is on an edge near the fixed geometry. It is reasonable to believe that this stress will be much lower due to the edge. The edges are more rounded on the actual locking bolt housing, which will result in lower local stresses. The iso-clipping illustrate the areas with larger stresses then given in the figure description. These assumptions will be valid for all the cases in this analysis.

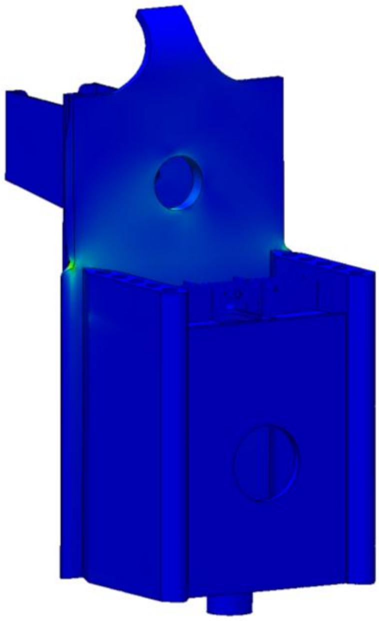


Figure 3.5: Stress distribution

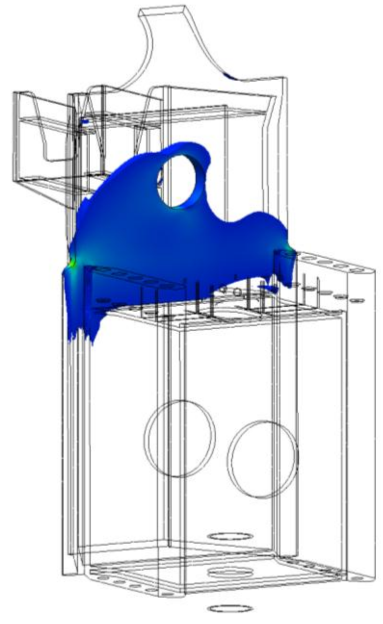
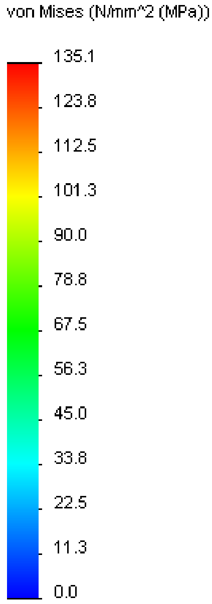


Figure 3.6: 5 MPa iso-clipping



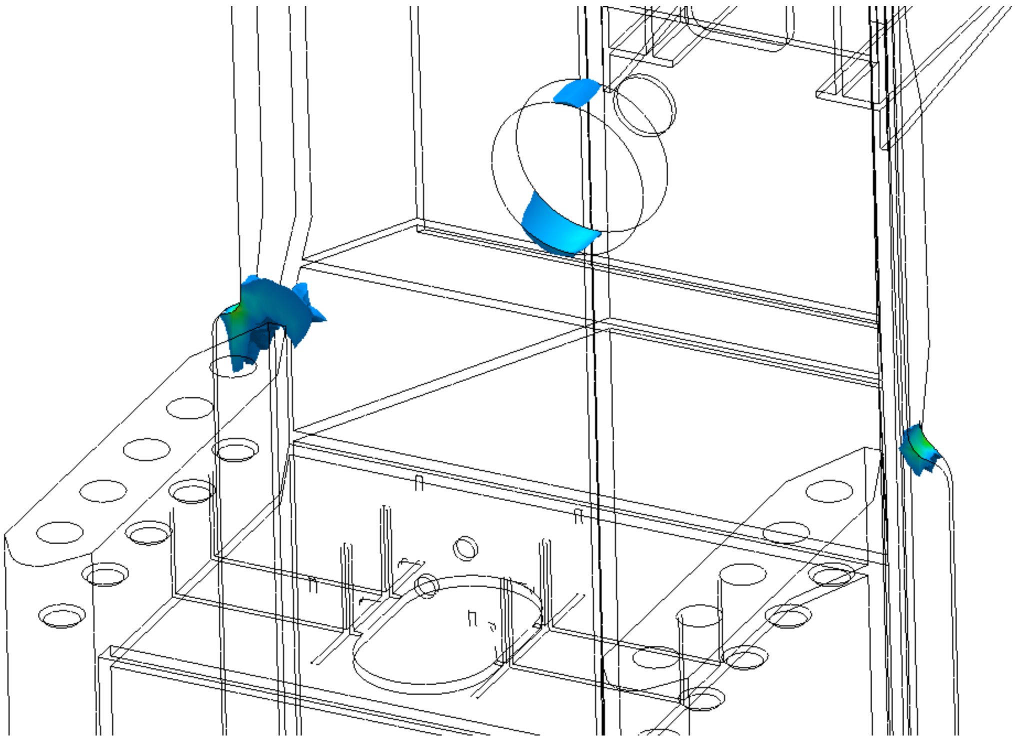


Figure 3.7: 20 MPa iso-clipping

105° force angle at support 2

Figure 3.8 shows the result of the stress analysis for a 105° force angle at support 2 and the average stress is far below the yield strength. The highest stress is 144,6 MPa, but this is on a edge near the fixed geometry and earlier assumption is still valid.

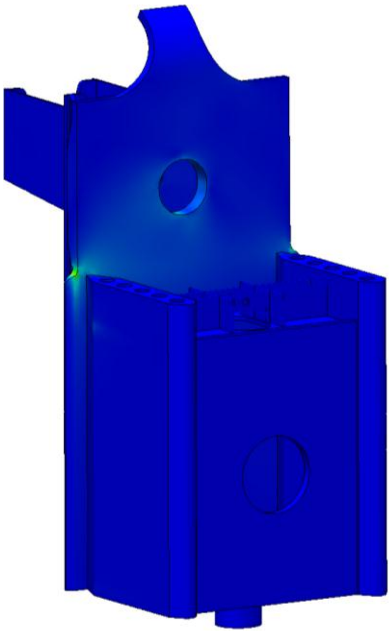


Figure 3.8: Stress distribution

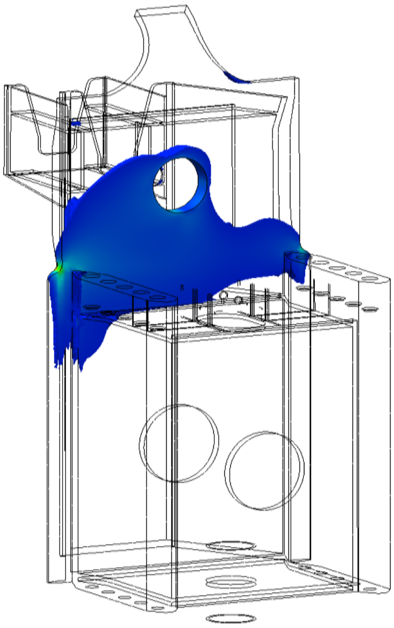


Figure 3.9: 5 MPa iso-clipping

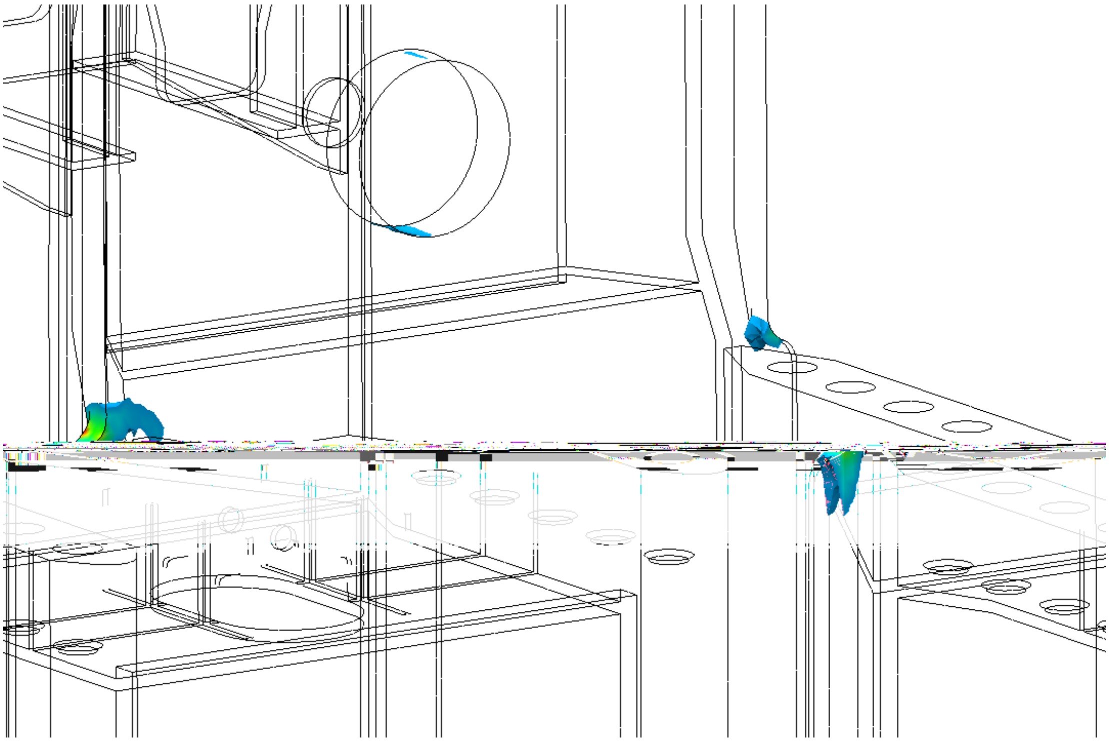


Figure 3.10: 25 MPa iso-clipping

135° force angle at support 1

Figure 3.11 shows the result of the stress analysis for a 135° force angle at support 1 and the average stress is far below the yield strength. The highest stress is 111,0 MPa, but this is on a edge near the fixed geometry and earlier assumption is still valid.

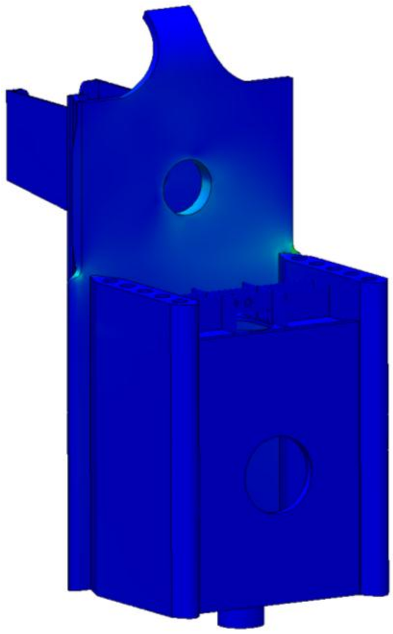


Figure 3.11: Stress distribution

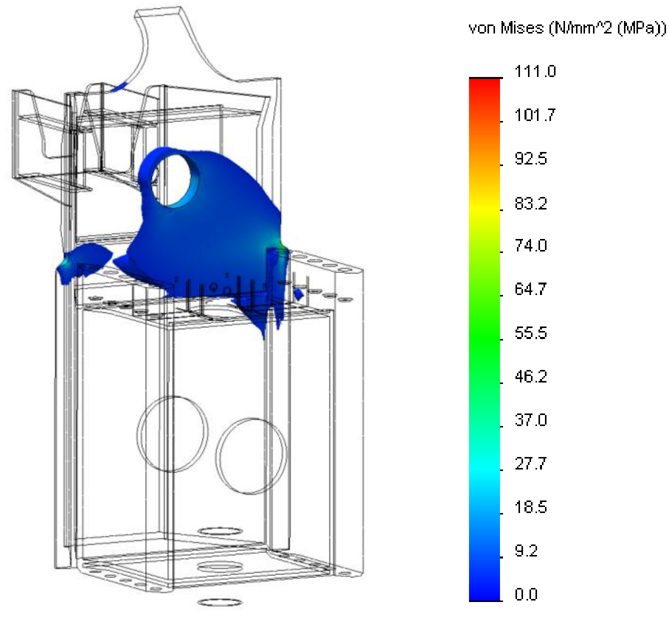


Figure 3.12: 5 MPa iso-clipping

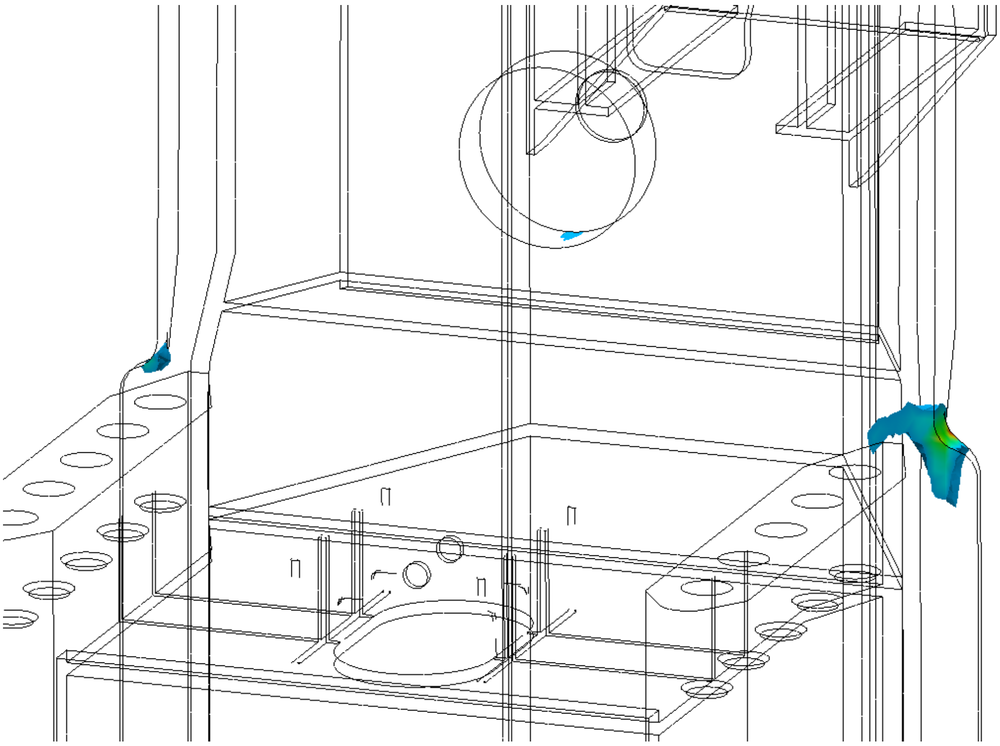


Figure 3.13: 20 MPa iso-clipping