Modelling, analysis and qualification of thin steel membrane in Hot Tap Tee

by

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Supervisors: Jostein Hellesland and Ulf Lønnemo

Preface

This is thesis is written with the Product area department at Nemo Engineering AS, to achieve the degree of Master of Science in Computational science and engineering at the University of Oslo, Mechanics division, Department of mathematics. The content presented herein is property of Nemo Engineering AS, and are at present Patent Pending.

The work is mainly done at Nemo HQ at Lysaker, and experiments were done at Nemo's production site Haatech AS, at Hokksund. Test equipment was produced at Haatech AS and the test specimens were machined at Central Sveis & Mek. AS at Rommen Oslo. Special thank goes to Snorre and Cato for quick production of test membranes, and for doing the nightshift with me. Great thanks go to leader of analysis department at Nemo, Ivar Hordnes for his great ability to explain, as well as huge interest in the subjects and methods used in this thesis.

Further I thank my external supervisor Ulf Lønnemo for good follow-up and encouragement during hard times, and for always have time for any questions. I also thank internal supervisor Professor Jostein Hellesland for the supervision during the work with this thesis, and advisory during my whole education at the University of Oslo.

It has been a demanding task to author this thesis, and part time work in Nemo's design department. I would like to thank everybody at Nemo for their contributions, big or small.

At last a special thanks goes to my wife, Vibecke and the baby inside, for the cheering and encouragement as well as keeping up with me "living at work" for the last months.

Blindern, 1st of March 2009

Abstract

Nemo Engineering AS (Nemo) has built a series of Tees for welding into offshore pipelines for transportation of hydrocarbons. The purpose with the Tees is to allow connection of new pipelines from existing or future oil and gas fields. This is often a cost-effective solution which minimises the need for construction of new pipelines. Some of the Tees are designed with open tee branch which is isolated with a ball valve system. Another solution is to design a Tee where the branch is blinded off by a solid steel barrier plate. This is a so-called Hot Tap Tee (HTT). At the time when a new pipeline is to be connected to the HTT, the steel barrier plate is drilled open by a core drill operation. This operation is performed when the pipeline is at full flow and operational pressure. The core drill operation is complex and requires a large amount of subsea tooling equipment. In addition, the operation is time consuming and involves elements of risk in case of failing equipment.

Nemo Engineering as is currently working on the Ormen Lange project where two HTTs at 850 m water depth will be opened by core drilling in 2009 for connection of pipelines from a new gas field (Ormen Lange Southern Field). During this project, equipment for blinding/sealing of the opened HTT's has been developed. This is an Isolation Plug (IP), which is used to seal off the open HTT. The purpose with the IP is to use it in case of future disassembly of the connected pipeline and isolation ball valve without compromising the integrity and operational service condition for the HTT-pipeline.

Nemo Engineering as has initiated a development project of a new HTT design where the steel barrier plate is changed out with a combination of using the IP and a steel membrane seal in the tee branch. The membrane will function as a substitution for the thick steel barrier plate and function as a metallic seal until the IP is removed. The idea is that the steel membrane will break when the IP is removed, and the core drilling operation is no longer necessary.

This Thesis contains the work related to preliminary design, modelling, analysis and testing of a steel membrane prototype. The main conclusion from the work is that there is good correlation between the results from the finite element analysis and the observed test loads.

Symbols

E - Young's modulus
E_{tt} **- Young's modulus from tensile test**
σ_y **- Yield strength**
σ_u **- Ultimate yield strength**
ϵ_y **- Yield strain**
μ **- Poisson ratio**

S_m **- Material strength (ASME VIII)**
S_y **- Yield strength (ASME VIII)**
S_u **- Ultimate strength (ASME VIII)**

σ_p **- Propotionality limit**
$\sigma_{0.2}$ **- Yield strength (0.2-limit)**
$\sigma_{1.0}$ **- Ultimate yield strength**
E_{s0} **- Young's modulus**
E_s **- Secant modulus**
$e_{0.2}$ **- Secant yield strain**
$e_{1.0}$ **- Secant ultimate yield strain**
$\epsilon_{0.2}$ **- Yield strain**
$\epsilon_{1.0}$ **- Ultimate yield strain**

K - Global stiffness matrix
D - DOF matrix
R - Global load matrix
k - Stiffness matrix
d - Local DOF matrix
r - Local load matrix

S_m**P - Differential pressure**

Abbreviations

HTT - Hot Tap Tee

HTO - Hot Tap Opertion

MHTT - Membrane Hot Tap Tee

HTVM - Hot Tap Valve Module

HTCU - Hot Tap Cutting Unit

Nemo - Nemo Engineering AS

SH - StatiolHydro ASA

CAD - Computer Aided Design

FEA - Finite Element Analysis

FEM - Finite Element Method

LVDT - Linear Variable Differential Transducer

MHTP - Membrane Hot Tap Procedure

ROV - Remotely Operated Vehicle

NA - Not Applicable

TBA - To Be Advised

LF - Load Factor

NDT - Non Destructive Testing

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Chapter 1

Introduction

1.1 General

As the development of oil- and gas fields increases throughout the world, more new oil- and gas fields are developed at deepwater. From the North Sea there are large transportation pipelines to processing plants on-shore and directly to the European market. Long pipelines are very expensive, in which marginal oil- and gas (small to medium large) fields cannot carry the cost. These fields will utilize existing pipeline network infrastructure.

The method of Hot Tapping is used for this purpose. Hot Tapping is to connect a new pipeline to an existing pipeline (which is in operation at full pressure) trough a tee branch called a Hot Tap Tee (HTT). The transported medium inside the pipeline will not be affected by the hot tapping operation and will be delivered to the receiving party without any interruption [11].

The Ormen Lange field is located approximately 120km outside the Norwegian West coast from the city of Nyhamna. To secure future plateau production capacity, the Southern Field Development is planned for a new eight-slot template that will be connected to the existing Ormen Lange subsea infrastructure by 2 off 16" production flowlines. The production flowlines will be connected to the 30" export pipeline by using 2 (out of 6) preinstalled 30"x16" HTTs. The Ormen Lange field is planned to be fully operational in 2009 and the depth ranges from approximately 800-1000 meters. This will demand a fully remotely operated Hot Tap Operation (HTO) as divers cannot perform at such water depths. All subsea tooling to be used for the hot tapping operation is remotely operated by Remotely Operated Vehicles (ROVs) and other heavy equipment.

Figure 1.1 below shows the Ormen Lange Field, a typical deep water field on the Norwegian continental shelf.

Figure 1.1: The Ormen Lange field[6].

Figure 1.2 shows the field layout where the HTT's are identified. This field has two HTT's installed on the 30″ transportation flowline in order to connect 16″ production flowlines in the future.

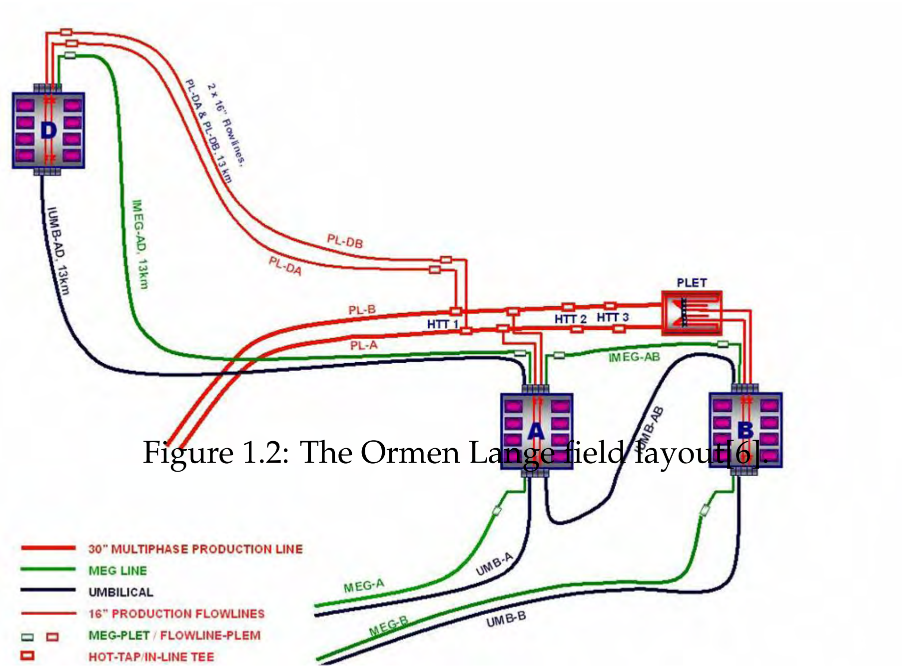

Figure 1.2: The Ormen Lange field layout[6].

1.2 Objective

The objective of this thesis is to simulate the membrane (metallic seal) with numerical methods (Finite Element Method - FEM) and use of commercial FEM software. A secondary target is to produce test equipment and test membranes, and carry out tests in order to compare with the mathematical model. To the extent possible it is a third target to calibrate the mathematical model against test results.

This thesis is written and attempted solved in a practical way. This means that there is less explanations regarding the theory of applied matehematics, derivtions and proof for the equations in finite element analysis (FEA). The methods used herein are understood and used “as is”, which gives the thesis a practical expression. The use of ANSYS as a complete $FEA - tool$ and to express the undertanding of the solutions are more important than to re-write derivations done in books on the methods.

It is assumed that the reader has a insight in mechanics and some knowledge of the finite element method (FEM).

1.3 Scope

The scope is limited to the following items:

1) Design of Membrane and crack initiation
- Calculate principal dimensions
- Choose metallic materials

2) Calculate and produce test membrane
- Discuss tolerances with Nemo
- Evaluate methods for clamping , production and installing of steelmembrane
- Evaluate methods for removal of membrane (fracture surface, energy, point of initiation)

3) Test. Define scope of test, conduct test
4) Report (thesis)

1.4 Comment

The items above are in accordance with the subject text, which could be found in Appendix D.

With respect to the choice of metallic materials in the membrane seal, this will be of a preliminary nature, as the Thesis is a first step in a development of a subsea pipeline component. It is therefore put more emphasis into developing a numerical model and define a preliminary design, and to do physical tests in the workshop.

A general note about the explanations of the finite element method and the building of the models, are that these are taken from the work with the test membrane model. *Obviously, this is the model that is most tuned and thoroughly prepared.*

1.4.1 Nemo Engineering AS (Nemo)

Nemo is an engineering company that specializes in methods, systems and underwater opertions in the oil- and gas industry. Its main area of products lie within subsea riser- and pipeline products, and spans from large and complex steel constuctions to small "tailor made" special tools and solutions. Nemo was founded in 1989 and are at present approx. 80 employees.

1.5 Problems on the way

1.5.1 Tensile test of material - reported datas

The material used in the tests were tensile tested at Bodycote AS in Stavanger. For the tensile test a SERCAL MTS/Rubicon(an english tester with a capacity of 250kN) and the 50 mm gauge length Howden Extensiometer RT50 were utilized. The material tested was S355 and the following datas was logged:

- Load
- Position
- Extension
- Stress
- Strain

- Time

The strain data is a function of the position signal in the tensile machine and is dismounted before the strain hardening starts. Bodycote explains that most tensile tests are done in order to find the yield limit, and for this reason, the data reported were a bit strange and insufficient. For this Thesis it was important to get the full strain hardening in order to fit a Ramberg-Osgood curve for implementation in ANSYS. Figure 1.3 shows the stress-strain curve reported and that it is sufficiently good to report yield strength, ultimate yield strength and Young's modulus. It does not show the curvature of the strain hardening, which is of interest for the Ramberg-Osgood curve fitting. The upper end of the vertical line is the ultimate yield strength.

The data received had to be processed in order to develop a full material curve. Firstly, the stress and strain were calculated from the load and extension data and the geometry of the tensile specimen, which gave a complete stress-strain curve. Further, the signal from the extensiometer between the start of the strain hardening and the fracture had to be removed, and swapped with the calculated stress-strain curve. A figure (1.4) is presented to illustrate the adjustments. Note that the section of the curve is between 0 and 0.05% strain (small strain value). After the adjustment of the material curve the Ramberg-Osgood equation could be fitted to the tensile test curve. A summary of the curve adjustment is shown in figure 1.5 and 1.6. When the discussion around the tensile test data were sorted out, the curve fitting was successful with respect to the calibration of the analysis.

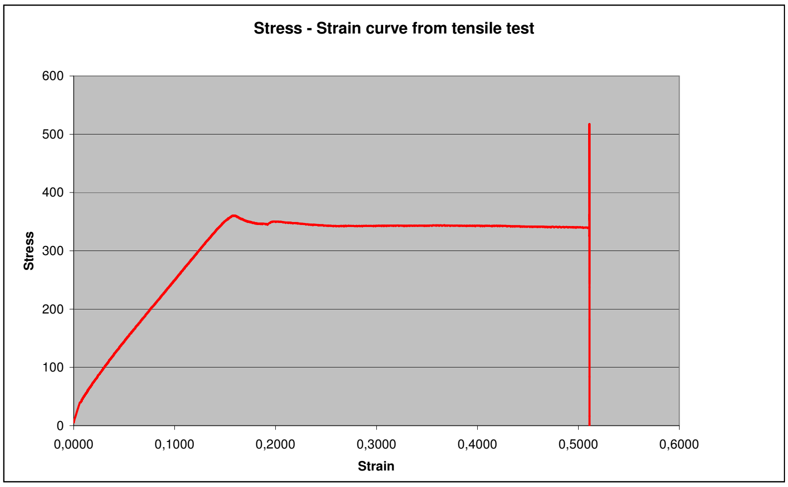

Figure 1.3: Stress-strain curve, tensile test

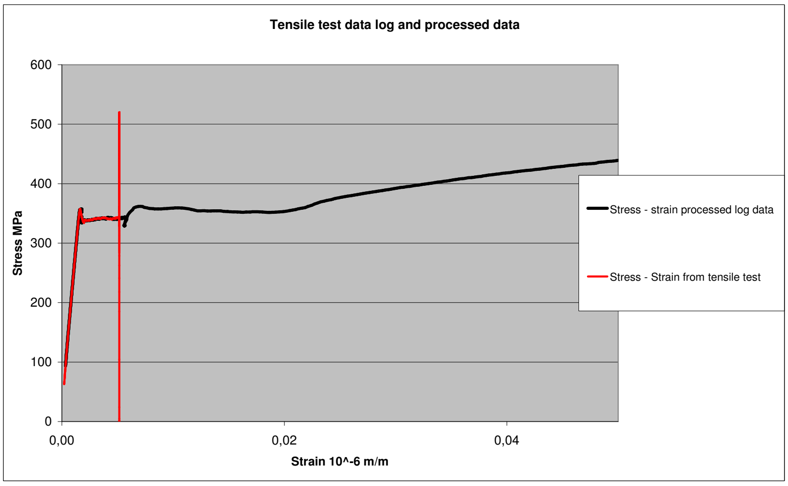

Figure 1.4: Original and constructed stress-strain curve

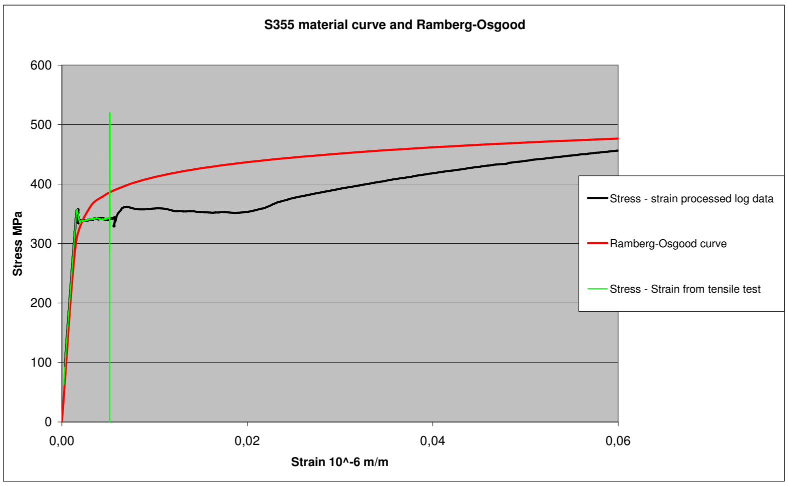

Figure 1.5: Original and constructed stress-strain curve

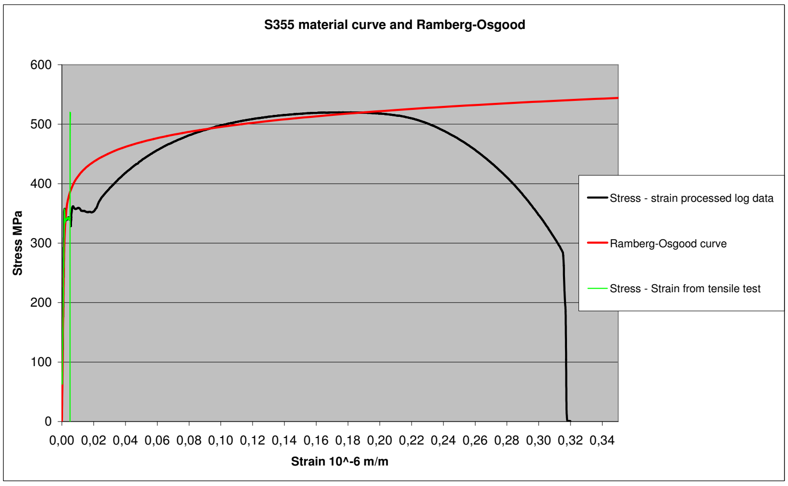

Figure 1.6: Ramberg-Osgood, original and processed curve

Chapter 2

Background

2.1 General

Hot Tapping is a method for engagement of new pipelines to existing export pipelines. The method is widely used at oil- and gas fields at shallow waters with diver assisted Hot Tap Operation (HTO). As new fields are developed at much larger water depths the HTO has to be done remotely, by ROVs and other remotely operated tooling. The HTO has been done remotely a number of times, more or less successful. The method contains core drilling of a thick (often about 50mm) steel barrier plate which is machined inside the upper periphery of the Tee branch where the new pipeline system is to be connected.

The export pipeline is installed with HTTs placed on strategic places along the pipeline. When a new oil or gas field is developed the new pipelines can be connected to the HTT and the existing export pipeline can be utilized to transport the gas or oil to typically onshore refinery plants or processing platforms.

The HTO is the critical step in the HT procedure, and there have been reported incidents where the HTO has been aborted due to malfunction of the core drilling equipment. There are large sums connected to the HTO. This is related to the cost of the construction vessels and the costs associated with the large, heavy and complex equipment and long operational time. The core drilling equipment consists of rotating machinery (drilling equipment) with numerous hydraulic driven and movable parts which increases the risk of malfunction. The latest problems reported is the large amount of filings accumulated inside the HTT and under the cutting equipment during the HTO.

The Membrane Hot Tap Tee (MHHT) concept is similar to the conventional HTT, but the core drilling part in the procedure is left out. The main purpose with the MHHT is to obtain a simpler and safer operation and shorter operational time.

For the reader of this document to understand the different methods, the next chapters in this Thesis are used to explain the pipeline installation and the two Hot Tapping procedures. These are mainly described by use of simplified figures, pictures and text.

It is important to notice that the equipment in the following is existing and has been utilized several times on offshore projects. An exception is the Isolation Plug which has not been used before.

2.2 Installation of pipeline

There are several different methods to install pipelines which to some degree differs with the water depth. At deep waters the two most used methods are the J- and S-lay methods, were the names are adapted from the pipeline curvature during the laying. The S-lay is the more applicable of the two so the explanation is in this theis limited to this method. Figure 2.1 shows the S-lay configuration and the distinct curvature of the pipeline.

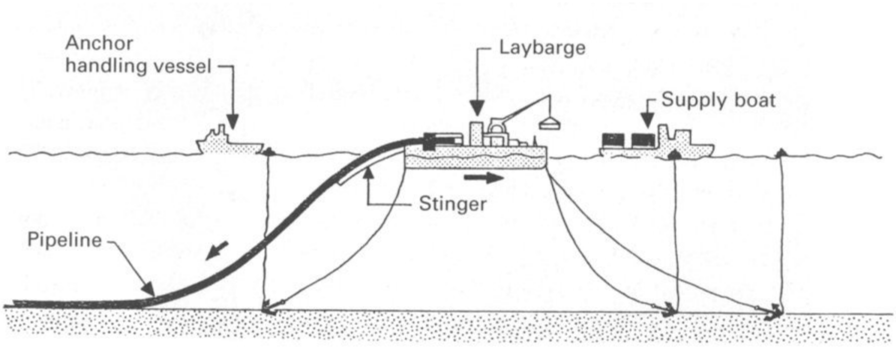

Figure 2.1: S-lay configuration [7]

The installation of a pipeline is done by utilizing a lay barge containg welding stations and a large stack of pipe joints. Transportation vessels are laying along side the lay barge with new stacks of pipe joints as the stacks on the lay barge decreases during production and installation of the pipeline. The new stacks are loaded from the transportation vessel onto the lay barge. On the lay barge the joints are welded together to a continuous pipeline at the weld stations. The welded spot is called the field joint, and the field joints are coated before the completed pipeline is rolled into the sea. When a HTT is planned to be placed at one specific area, a pipe joint conaining a pre-welded HTT comes into the production line and are welded into the pipeline. The HTT is at this point protected with a Glas Fiber Reinforced Protection Cover (GRP cover). Figure 2.2 shows the pipe joints stacked on the lay barge and the HTT stacked outside the production site. Figure 2.3 shows the welding station and the welding of pipe joint number 1865.

Figure 2.2: Pipe joints with and without HTT[7] [6].

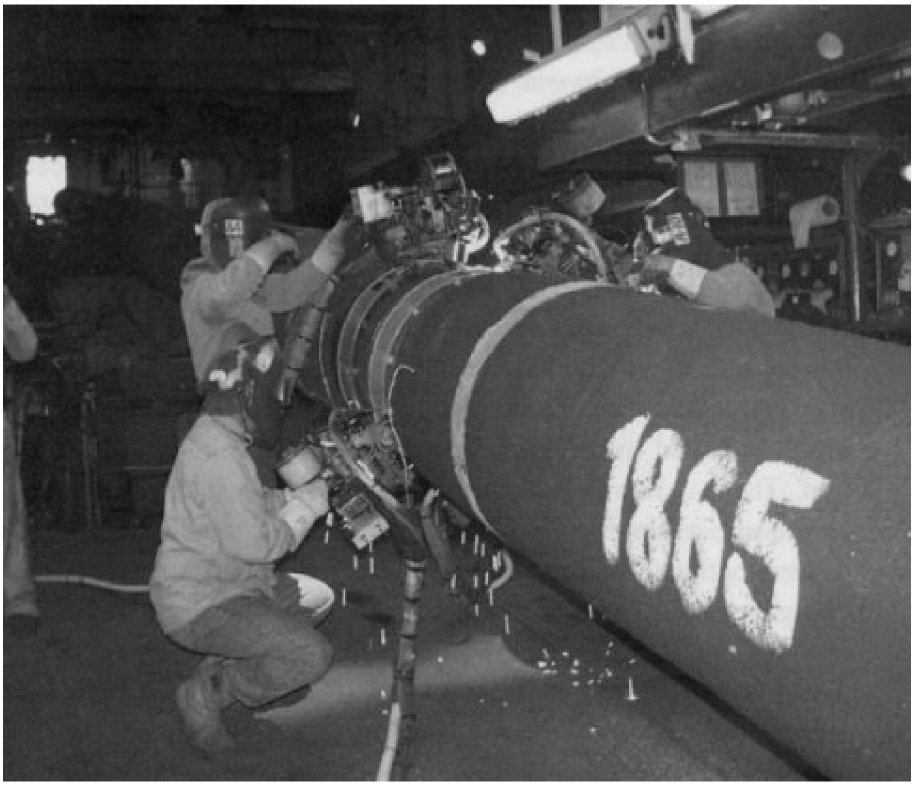

Figure 2.3: Weld station on the lay barge[7]

The field joint is an area with bare steel and the weld. Outside this area the Pipe joints have a coating of asphalt enamel, multilayer polyolefines, elastomers or concrete. To prevent seawater and debris to come i contact with the field joint the area is coated at the coating station. The coating can be done in different ways, with different material[7]. Figure 2.4 shows the application of tape wrap type coating.

Figure 2.4: Application of field joint coating [7]

After application of coating to the field joints, the pipeline is rolled into the sea over a stinger. The stinger is a large structure at the aft of the lay barge which supports and steer the pipeline into the sea and onto the seabed. Figure 2.5 shows the pipeline with a conventional HTT going over the stinger.

Figure 2.5: Pipeline with HTT over stinger[6].

The HTT in Figure 2.5 is of conventional type the MHHT is intended to be installed with the same procedure. The steel plate in the MHHT is more fragile than the massive 50 mm steel plate in the HTT. From this reason the weldneck (tee neck) of the MHHT has to be reinforced in order to install the MHTT. This is outside the objective and scope of this thesis.

2.3 The Hot Tap method

This chapter outlines the main points in the HT procedure.

As shown i Figure 2.5 the HTT is insalled as a piece on the continuos pipeline during installation. This Tee piece (HTT) is prepared for a future connection of a new pipeline, and has a 50mm thick steelplate in the body of the Tee. Figure 2.6 shows the HTT.

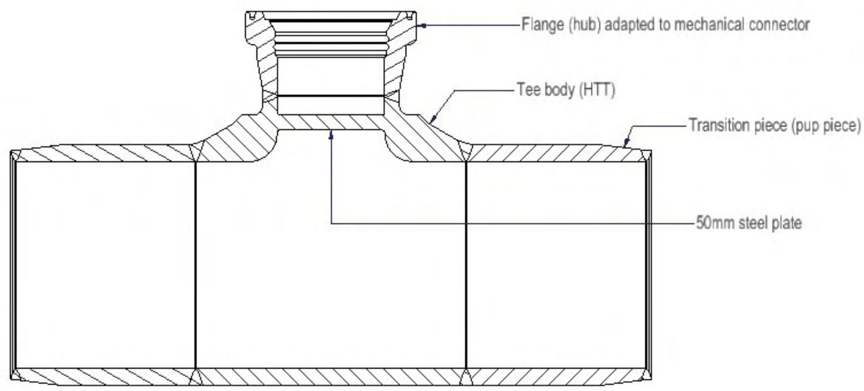

Figure 2.6: Section view of HTT with 50 mm steel plate[6].

The steelplate is a pressure barriere against the external- and internal pressure. The HTT flange is adapted to a mechanical connector, and a debis cap (DC) is installed as a protection of the flange. The DC is there for protection of connecting flange and do not need further explanaition. DC and mechanical connectors are shown in the figures below.

Figure 2.7: HTT with debris cap[6].

Figure 2.8: Mechanical connector [6].

2.3.1 Pipeline Interface Frame - PIF

The Pipeline Interface frame (PIF) is a tool that interface with the pipeline near the HTT. The frame orientates axial to the pipeline, adjusts the height and clamps on to the pipe at a specific distance from the HTT. A this point the GRP cover and the Debis Cap (DC) are removed, and the steel plate in the HTT and the connecting flange (hub) are now fully exposed. The PIF has a frame in which Hot Tap Ball Valve Module (HTVM) and the Hot Tap Cutting Unit (HTCU) can be installed, for the execution of the HTO. The PIF is a very heavy (Approx. 42 tonnes) and complex tool with extensive hydraulic system, and contingency systems in case of malfunction. Figure 2.14 shows the PIF engaged on the pipeline and the HTT and HTVM in front. Figure 2.10 showing launch and recovery of the PIF from the installation vessel.

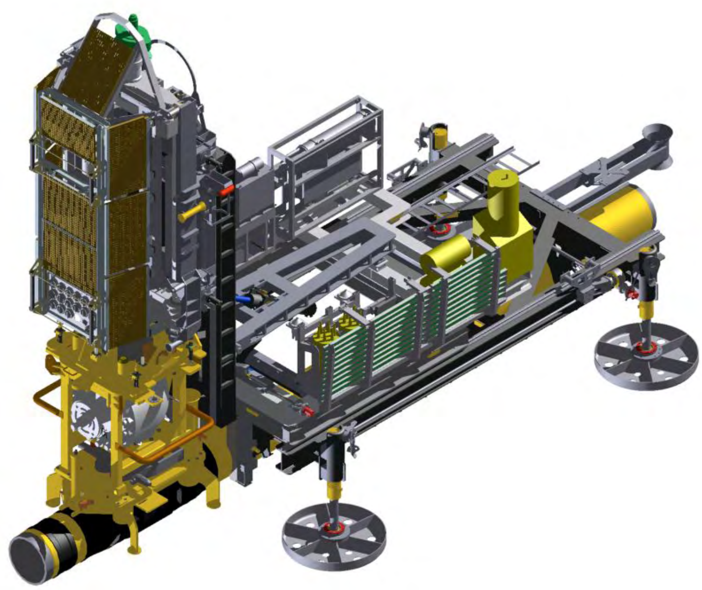

Figure 2.9: CAD figure of the PIF engaged with the HTT and HTVM[6].

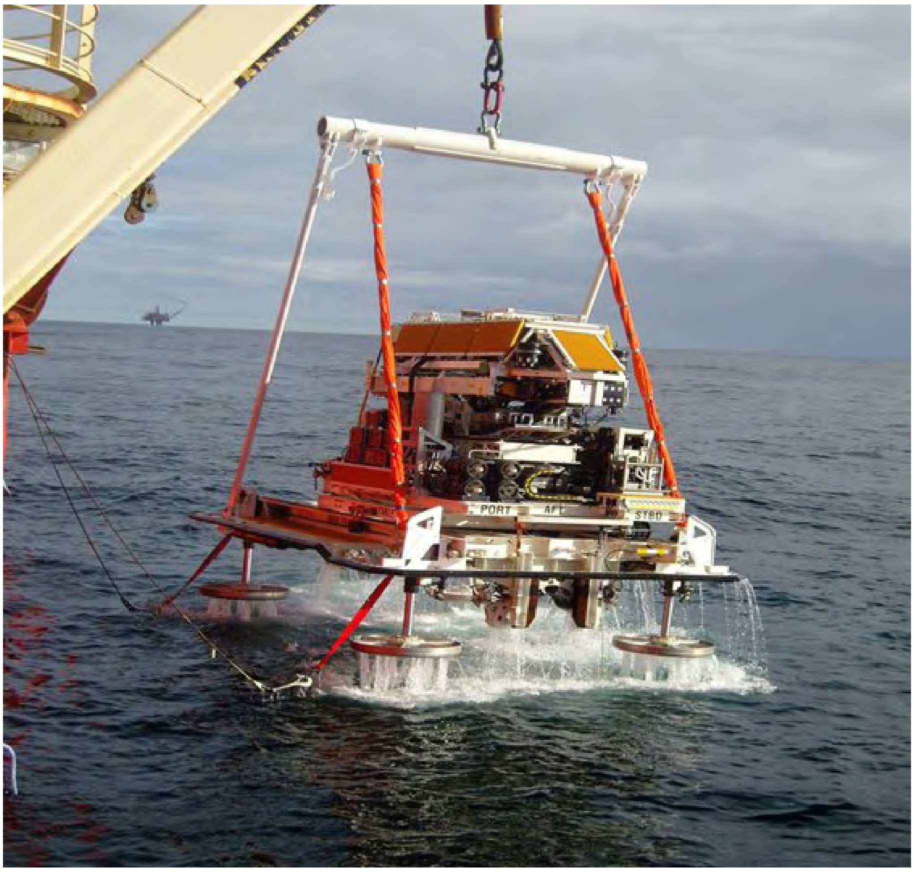

Figure 2.10: Lanuch/recovery of the PIF[6].

2.3.2 Isolation Plug - IP

The HTT assembly includes HTVM and spool connection (SC). The installation procedure is reversible so that the equipment can be removed to change defective parts, or disassebly when the pipeline production duty is over. The Isolation Plug (IP) is an appliance made to seal off a HTT if the HTVM has to be changed or the connection is shut down. At this point the HTVM is closed, the production pipeline is no longer operable and the pressure is controlled to zero. When the HTVM is closed the spool can be removed from the HTVM. A Isolation Plug Running Tool (IPRT) is engaged to the HTVM, the ball valve are opened and the IP is installed. Further the IPRT is retracted, the ballvalve closed and the IPRT is disengaged from the HTVM. At this point the IP seals of the HTT and the HTVM can be dismounted. The IP is then deployed togheter with a Pressure Cap (PC). The IP contains elastomer seals which seals against the HTT neck and the PC is mounted on the HTT flange as a second pressure barrier. The HTT is finally protected with a Glas fiber reinforced cover (GRP cover) and abandoned, keeping the transportation pipline fully intact.

The figure below (2.11) shows the complete stack-up with the HTT in the bottom, the HTVM and the spool on top.

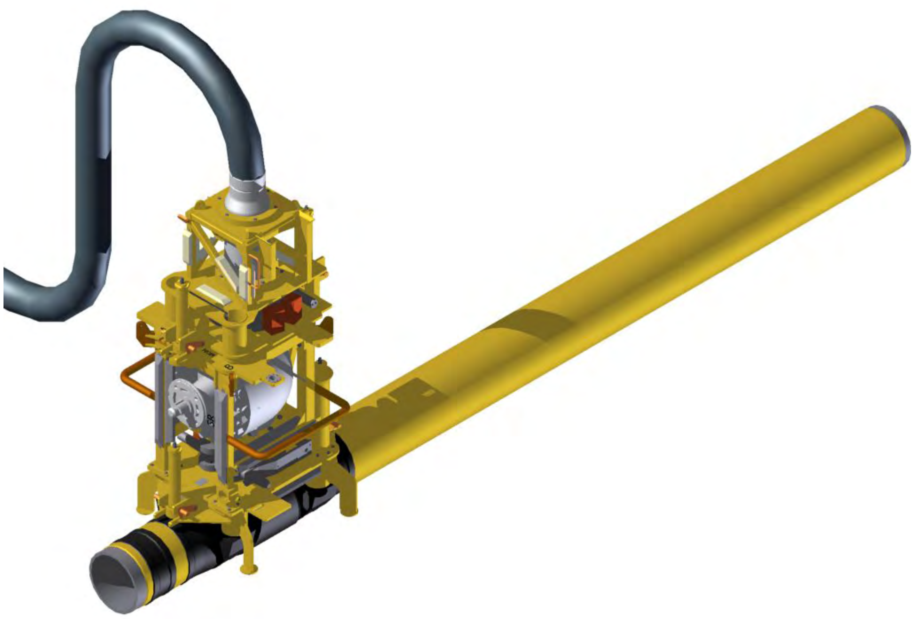

Figure 2.11: Complete HT system[6].

Figure 2.12 shows the IP in the workshop during testing.

Figure 2.12: Isolation Plug during testing[6].

Figure 2.13 shows the cross section HTT with IP in the tee neck. (This is a HTT which is not yet opened but shows how the IP is placed in the tee branch..)

Figure 2.13: Cross section of the IP in the tee neck [6].

2.3.3 Hot Tap Cutting Unit - HTCU

The HTCU is attached on the PIF and contains a saw to cut out the plate from the HTT. The figures are extracted form the HTO cutting sequence, with the engagement of the PIF, and the HTVM in front. In the next figure the cutting unit is close to the steel plate just before cutting takes place. The arrows symbolizes the medium in the transportation pipeline at full pressure.

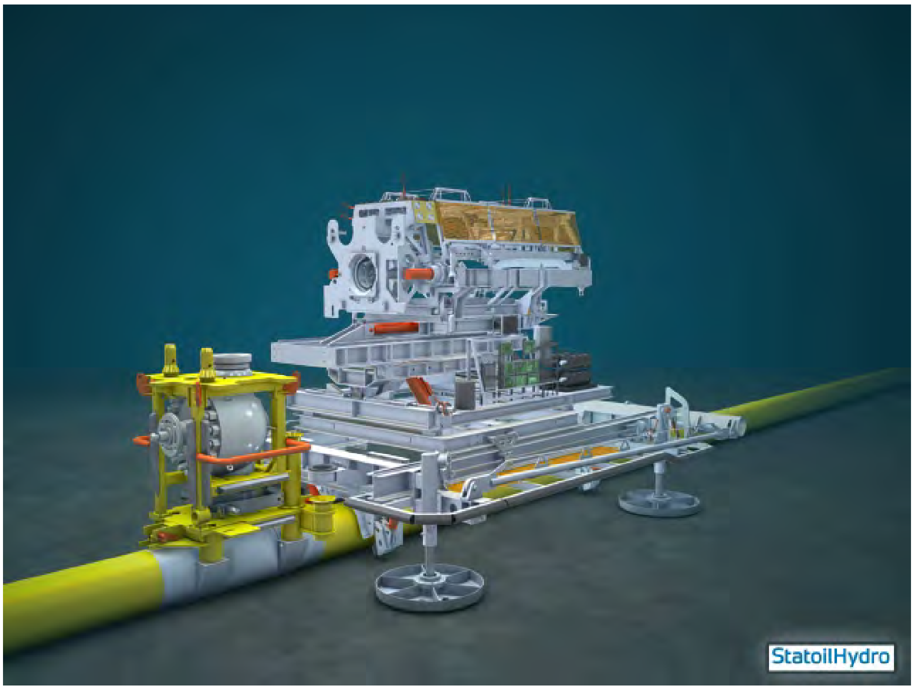

Figure 2.14: PIF during cutting of plate [16].

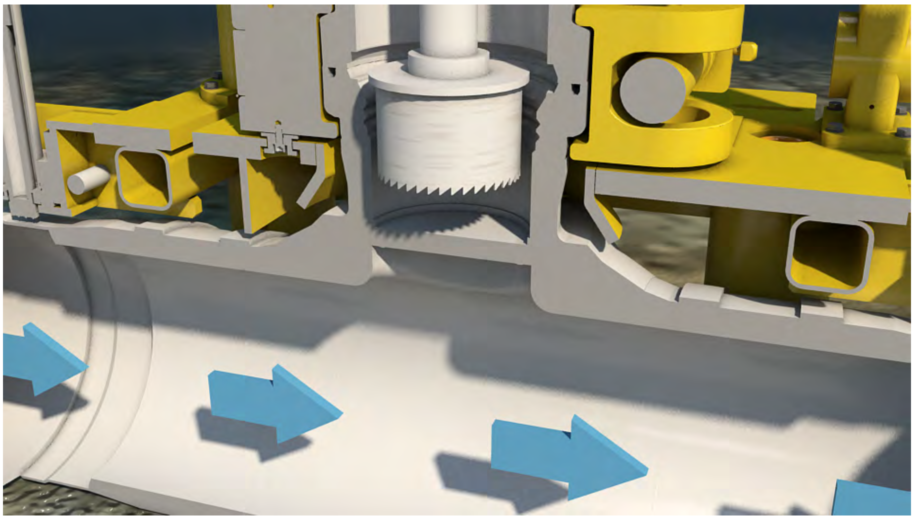

Figure 2.15: Cutting of plate [16].

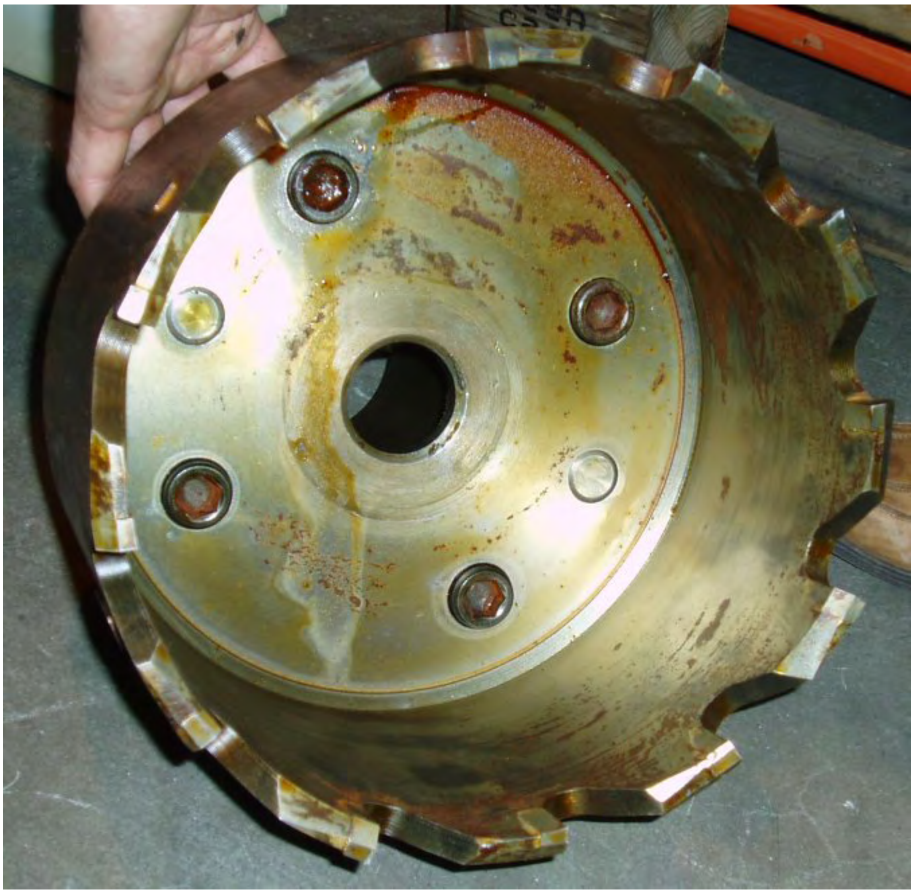

Figure 2.16: The core drill saw [6]

The intension of this chapter is not to teach the reader about Hot Tapping, but to explain the main feature of the HTO. A thorough explanation of the Membrane Hot Tap Tee and its design and system are in the Chapter 5 Design and Construction.

Chapter 3

Design basis

3.1 General

This design basis add up the technical standards and regulations which are gouverning for the developement for the pipeline and pipeline components. This theis is however thought as research work for a possible Nemo product and *could be* the start of the developement of a product in Nemos portfolio. So, in this design basis the codes are identified for the total developement of the product, but there are limitations and assumptions made in order to do the "first-shot"-research work of the Membrane Hot Tap Tee (MHTT). These are found in chapter 3.4.

A few keywords are highlighted in order to express the correct standard to check the application up against.

- Metallic materials: weldability, material props for stress analysis
- Removal of membrane: *pull out*-force
- Crack initiation
- Point of initiation
- Qualify: standard check for the membrane

For a product to be incorporated in the pipeline infrastructure in the North Sea, the Technical Requriements (TR) in StatoilHydro (SH) is the governing standard for the design, construction, production and testing of the equipment. According to TR1831 components, such as a Tee piece on the pipeline, subjected to other loads than internal pressure shall undergo FEA according to ASME VIII, Div.2 App.4. Boiler and pressure vessels code , or equivalent recognised standard[15]. Further the TR1831 refers to offshore standard DNV-OS-F-101 Submarine pipeline systems with respect to welding and different test procedures of pipeline components[17].

Design criteria for pipeline components, such as bends, flanges and connectors, Tees, valves etc., for submarine use, recognized codes shall be used. Pressure containing components shall generally represent at least the same safety level as connecting pipeline. Further the standard lists the use of ASME VIII-Division 2 - Boiler and Pressure Vessel Code [14], for building Tees.

For the membrane loadcases locally, these two codes are gouverning, and the loads are derived from mentioned ASME code.

The following recommended standards will be used for the design and calculations:

Primary

- ASME Boiler& Pressure Vessel Code (ASME VIII) [14]
- DNV OS F-101 Submarine Pipeline System, lates revisison [17]

Secondary

- DNV - Rules for planning and Execution of Marine Operations
- NS 3472 Calculations and dimension of steel structures

3.2 Standards, rules and regulations

3.2.1 ASME VIII

The ASME VIII regulations states that the component shall undergo a non-linear FEA with no work hardening in the material curve [14]. The bi-linear material curve is explained in chapter 4.5. Further the material properties shall be conservative, so that for the operational case the yield stress to be used in the calculations shall be S_y = 1.5*S_m

where:

$$S_m = min \begin{cases} \frac{1}{3}S_u \\ \\ \frac{2}{3}S_y \end{cases} \tag{3.1}$$

and 1.5 is the load factor (LF). The bi-linear curve shall not take strain hardening into considerations [6].

Further the lower of the two is choosed which gives $S_m = 177MPa$, and from here we find the yield stress for the material in the FEA to be $S_y = 265MPa$. The material shown here are for the tee body which is ASTM A694M-03 F65, and the material curve arr shown in chapter 4.5.

Material Properties	F-65	Unit
Young's modulus, E	200	GPa
Poisson's ratio, ν	0.3	-
Min. Yield strength, S_y	450	MPa
Min. Ultimate Strength, S_u	530	MPa

Table 3.1: Material properities for F-65 according to ASME VIII

3.2.2 DNV-OS-F-101 Submarine pipeline systems

For the construction and local analysis of the Membrane it is necessary to divide the loadcases into different categories. In this thesis the code check is limited to check the membrane locally, in order to indentify the operational loads. Operational loads on a local level is:

- Mechanical force to tear out the membrane
- Capacity to withstand external pressure,ΔP negative
- Capacity to withstand internal pressure,ΔP positive

During operation the IP will mechanically withstand the deflections caused by internal pressure. The most delicate loadcase is therefore presented during the pipeline installation sequence as the pipe will be air filled, and the ΔP=150bar.

3.2.3 Overall system criteria

[17]

A standrardized method for analysis of installation of pipeline is found in DNV OS-F-101 [17]. In this document the most unfavourable load scenario is listed as:

- Installation

- As-laid
- Water filled
- System pressure test
- Operation
- Shut-down

I will however as stated only code check for operational pressure, as this thesis is the *preliminary* design of the MHTT.

3.2.4 Weldability

In OS-F-101 Appendix C Item 308 it is stated that the welding of pipeline components the weld metal shall have a ductility and toughness meeting the requirements of the material and the actual yield stress of the deposited weld metal shall at least be 80 MPa above SMYS of the base material. If two materials are joined, the requirements applies to the SMYS of the lower strenght base material [17]. The welds performed must undergo a non destrutive test, such as x-ray.

3.3 Loads

3.3.1 Environmental loads

- Operating pressure (30″ Pipeline) 255 bara at 890m below MSL
- Test pressure 1.5 x 255 bara at 890m below MSL
- Temperature -20 - +85°C
- Wather depth 800m - 1000m

3.3.2 Accidental loads

Relevant accidental loads shall be identified in accordance with the case list below [17] :

- Loads from welding and pipeline installation operation, such as lifting, impacts from equipment during work on deck etc.

- Loads caused by pendulum movement during pipelaying
- Impact from free fall of operational equipment, maximum landing velocity 0,5 m/s

Dynamical analysis is not performed in this thesis.

3.3.3 Functional loads

Functional load cases shall include:

- Loads from pipeline installation
- Loads from lifting, rigging, sea fastening and marine operations
- Loads from pipe clamping equipment such as PIF,HTVM,IPRT etc.
- Other loads that may occur based on the offshore installation operation and the detail design of tools and equipment (impacts during establishment of equipment, guiding etc.)

Loads from lifting, rigging, sea fastening and offshore operations design shall be based on DnV "Standard for insurance, Warranty Surveys in Marine Operations" and " Rules for Design, Construction and Inspection of Offshore Structures, App. H, section H.1 - Lifting".

3.3.4 Strength

Structural steel design shall be performed in accordance with NS3472 "Calculation and dimension of steel structures"

The loads implied to the pipeline during pipe clamping operations shall be calculated. The strength of the pipeline shall be taken according to DnV "Rules for Submarine Pipeline Systems".

3.4 Assumptions and limitations

As stated earlier this thesis is limited to deal with the membrane locally and to find out if this is a product that can be fully developed and produced. In order to do so the calculation of strenght for the membrane is most essential to find out if it will withstand the internal- and external pressure, as well as the possibility to open the MTTH with only a linaer movement and tear the membrane out.

On the background of the primary codes these are the assumptions and limitations:

- The material in the Tee body is ASTM A694M-03 F65 (a common high alloy wideliy used in pipeline components [6]
- Corrosion allowence is zero (normally t=2-5mm)
- The notch will be filled with a material which will prevent contact with the pipeline medium and formation of flux (Cladding of material, GRP, rubber etc.)
- Forces and moments from pipeline intallation and handling of the MHTT is not taken into conciteration
- Dymanic analysis is not taken into conciteration

The items above is assumed to be *Further work*.

Chapter 4

Materials and material properties

4.1 General

For this thesis most material properties for the materials analysed are collected from a large material library on the internet, named MATWEB [1]. Here we can find any materials we want to explore, such as metals and different alloys, plastics, fabrics, fluids, concretes and many more. The information here are general and for specific experiments a sample of the material for the use in the specific application has to be tested, in order to obtain an exact material curve for the FEA.

To discuss material selection for the membrane in the MHTT weldable materials with the desired material characteristics must be used. These characteristics are important to prepare and fit the material curve in the mathematical model to explore the important differences in material selection for the particular problem in this thesis.

The Tee body material is defined by earlier projects such as the Ormen Lange Field development. In this project the high-alloy steel ASTM A694M-03 F65 are used in the Tee body [6].

To test the validity of the mathematical model a common steel grade (S355) plate were used. This material had a tensile test to more accurately fit the material curve in the FEA.

In order to choose material in the membrane the first study is to find a weldable material to join with the forged F-65 material in the tee body. As a general rule the weldability divides with the tensile strength of the materials and the amount of carbon in the chemical compound [2]. The carbon equivalent (CE%) is used to rate the weldability.

[1] http://www.matweb.com

The metals tested in the FE-model are outer extremes of super alloys, and the main reason for running them is to test the applicability of the model.

The items sums up the limits for weldability [2]:

- CE % < 0.14 Excellent weldability
- 0.14 < CE % < 0.45 Martensite forms and modest preheats, low hydrogen electrodes
- CE%> 0.45 Complicated, preheat in the range 100-400°C, low hydrogen electrodes

Figure 4.1 shows the material curves used in the FE-models in this chapter.

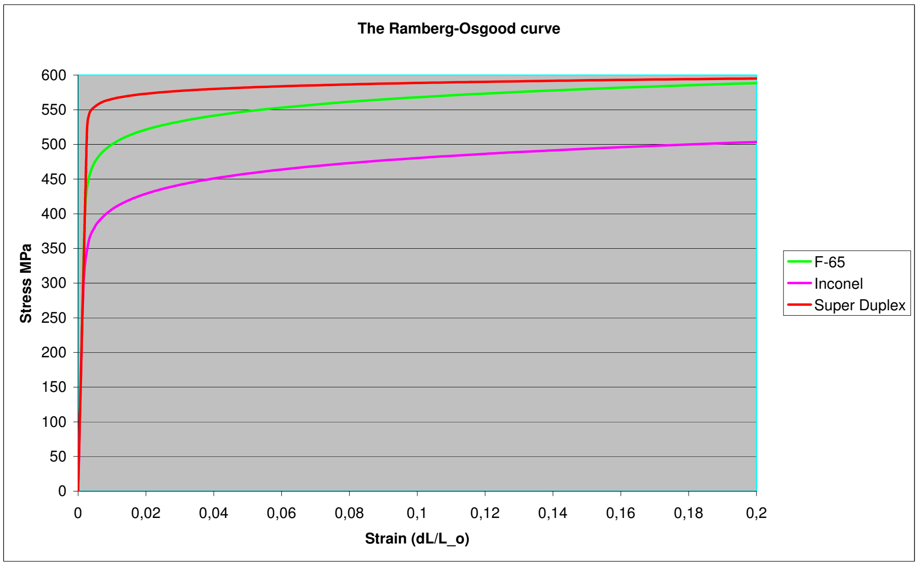

Figure 4.1: Material curves for tested materials

4.2 Materials

4.2.1 ASTM A694M-03 F65 - the mother metal

As stated in 4.1 material used in the HTT body is the stainless steel ASTM A694M-03 Gr.65 (F65). It is a wideliy used material in pipeline components, and it is therefore an obvious choice to test this material in the FEA. By the use of this material it could be welded inside the Tee neck as well as machined from the same piece of material. More on this in 5.3. It is a very tensile resistant steel grade and it is therefor expected to apply very high loads to obtain fracture.

Material Properties	F 65	Unit
Young's modulus, E	209	MPa
Poisson's ratio, ν	0.3	-
Min. Yield strength, S_y	450	MPa
Min. Ultimate Strength, S_u	530	MPa
Elongation at break	21	%
Mass density, ρ	7850	kg/m^3
Carbon Equivalent, CE	0.20	%

Table 4.1: Material Properties F-65.

4.2.2 INCONELL C276 Nickel Superalloy Plate

In order to test a superalloy with good reputation in the ofshore industry a analysis were run with a Ramberg-Osgood curve adapted to thsi metal. The material properties are typical for annealed plate, and found in the table below. The material has a large deviation between yield strength and ultimate yiled strength, and a very large elongation. It is tested in this thesis to observe the models capability to run different metals.

Material Properties	C275	Unit
Young's modulus, E	205	GPa
Poisson's ratio, ν	0.3	-
Min. Yield strength, S_y	347	MPa
Min. Ultimate Strength, S_u	740	MPa
Elongation at break	67	%
Carbon Equivalent, CE	0.010	%
Mass density, ρ	8890	kg/m^3

Table 4.2: Material Properties C276 Inconell

4.2.3 47N+ 25 Super Duplex Stainless Steel

The Duplex metal is another popular metal widely used in offhore industry. It has a very small deviation between yield strength and ultimate yiled strength, and a very short elongation.

Material Properties	F 65	Unit
Young's modulus, E	200	MPa
Poisson's ratio, ν	0.33	-
Min. Yield strength, S_y	550	MPa
Min. Ultimate Strength, S_u	570	MPa
Elongation at break	27	%
Carbon Equivalent, CE	0.030	%
Mass density, ρ	7820	kg/m^3

Table 4.3:

4.3 The Ramberg-Osgood equation

The Ramberg-Osgood equation is a simple formula to describe the stress-strain curve for a metallic material in term of three parameters; Young's modulus and two secant yield strengths [18]. It is a simplification of the progress between stress and strain in tensile- and compressive material tests which gives a good approximation to a particular material, and the curve is put together by the elastic- and the plastic parts in the progress of the material test. Hellesland express the equation generalized as[9]

$$\varepsilon_s = \frac{|\sigma_s|}{E_{so}} + K\left(\frac{|\sigma_s| - \sigma_p}{E_{so}}\right)^r \qquad \text{for} \qquad |\sigma_s| \geq \sigma_p \tag{4.1}$$

where the factors are expressed as

$$K = e_{0.2}\left(\frac{E_{so}}{\sigma_{0.2} - \sigma_p}\right)^r \tag{4.2}$$

and

$$r = \log\left(\frac{e_{1.0}}{e_{0.2}}\right) \tag{4.3}$$

$$\sigma_s = \frac{F}{A} \tag{4.4}$$

- σ_p is the propotionality limit for the steel[4]
- $\sigma_{0.2}$ is the yield strenght (0.2-limit)[4]
- $\sigma_{1.0}$ is the ultimate yield strenght
- E_{s0} is the secant modulus (slope of the elastic curve)
- E_s is secant modulus as the material changes subjected to load
- $e_{0.2}$ is the secant strain at the yield limit
- $e_{1.0}$ is the secant strain at ultimate yield stress
- $\epsilon_{0.2}$ strain at yield stress
- $\epsilon_{1.0}$ strain at ultimate yield stress

So in generalized form the necking occurs at $\epsilon_{1.0}$ [9].

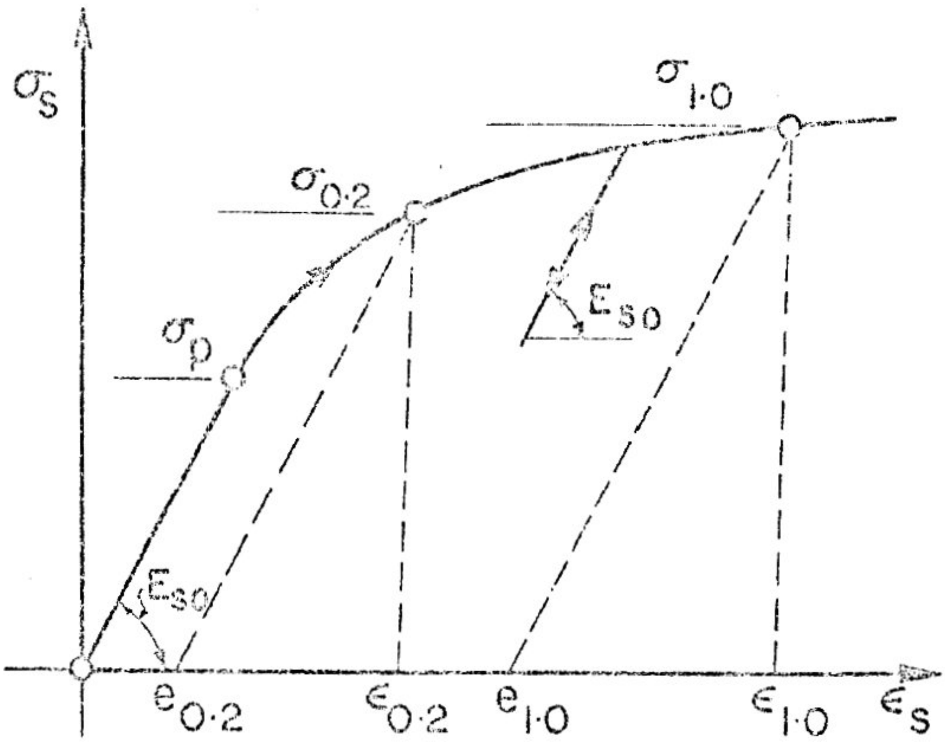

Figure 4.2: Stress-strain curve for steel [9]

In the plot we identify the elastic part of the curve as the line between $(0, 0)$ and (ϵ_p, σ_p). σ_p is also called the proportionality limit of the material and is a tiny bit lower than $\sigma_{0.2}$[4]. We discover the secants which are paralell displaced from

σ_p) to $\sigma_{0.2}$ and $\sigma_{1.0}$.These are lines which indicate the strain hardening, as if we unload the test specimen it will return to $e_{0.2}$ and $e_{1.0}$, repectively. The vertical lines indicates actual strain.

From this we undertand that that the sectant modulus decreases as the plastic strain increases after the 0.2-limit. This is a phenomena called strain hardening, a characteristic widely used in production of steel with different material properties[2].

The secant modulus are expressed generalized as [9]

$$E_s = \frac{\mathrm{d}\sigma}{\mathrm{d}\epsilon_s} = \frac{E_{so}}{1 + rK\left(\frac{|\sigma_s| - \sigma_p}{E_{so}}\right)^{r-1}} \tag{4.5}$$

4.4 Applied Ramberg-Osgood - Multilinear isotropic hardening

As we saw in 4.3 the curve is constructed from the three mentioned parameters. These parameters has to be obtained from a tensile- or compression test of the material in use. The equation is adjusted to several different geometries and applications.

A simplified Ramberg-Osgood equation is used in this thesis[10]

$$\varepsilon = \frac{\sigma}{E}\left[1 + \frac{3}{7}\left(\frac{\sigma}{\sigma_{0.2}}\right)^{n-1}\right] \tag{4.6}$$

were the different parameters are described in 4.3.

The n - and $\sigma_{0.2}$ parameters are obtained by material tests and iterative curve fitting. In this thesis I used Microsoft Exel to obtain the Ramberg-Osgood curves for my material species, a common method of curve fitting in pipeline analysis, among other [10]. The equation was written in Exel and the varity of stresses were constructed. It is imortant to define the σ - steps small scale around the yield strength $\sigma_{0.2}$ to obtain a smooth curve to utilise in ANSYS. The TB-command is used to fit the curve in the script. ANSYS is a bit "fastidious" as it will not do nonlinear calcualtions if the elastic curve is not defined. The TB-command has to have the two first points on the curve defined [1].

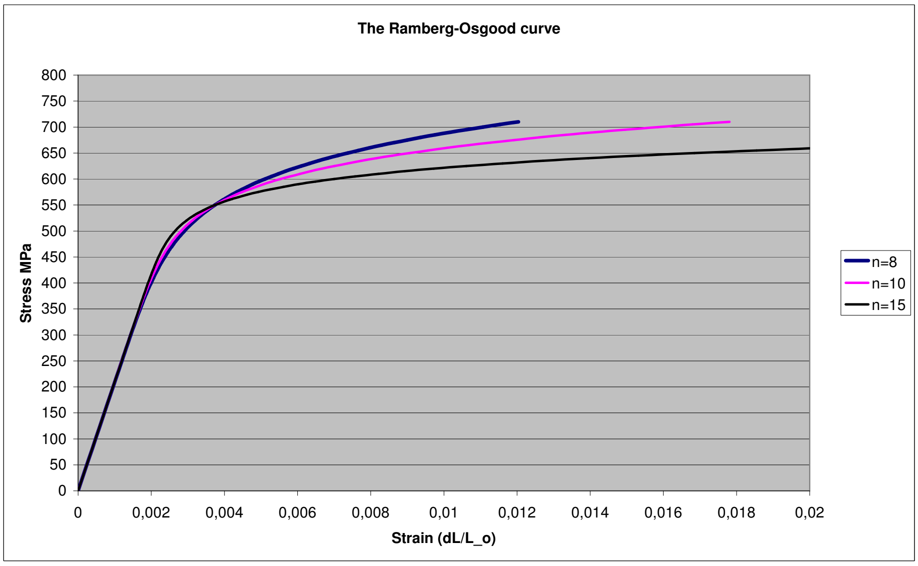

Figure 4.3: Ramberg-Osgood curve with different values for the n-parameter

The curve is fitted in the ANSYS script with the table command TB [1], togheter with the Multilinear isotropic hardening label, MISO [1], for the different materials tested in this thesis.

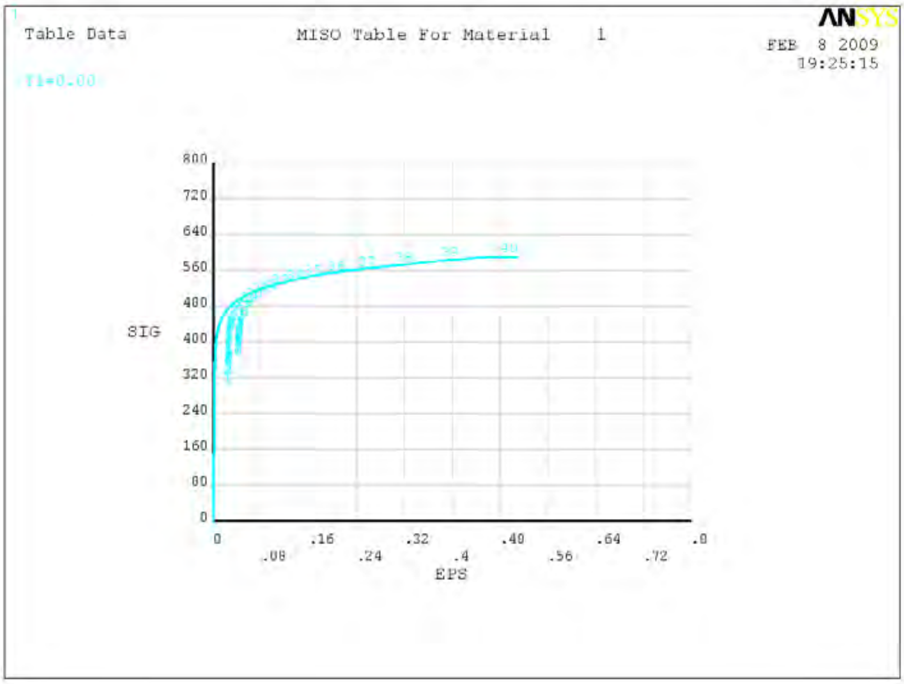

Figure 4.4: Ramberg-Osgood table plot in ANSYS

The purpose of the Ramberg-Osgood curve is to implement it into ANSYS so the software can run the analysis with a simplified, yet accurate material properties curve. The complete material curve is obtained by a tensile test of the matrial and from this information the Ramberg-Osgood curve are created. As explained in chapter 4.3 the curve is described by Young's modulus and two secant yield strengths. In this thesis the yield strength (0.2-limit) and the ultimate yield strength are used, which is a common practice. Figures 7.11 and 7.12 shows the engineering material- and applied Ramberg-Osgood curve. Notice that the curve plot in figure 4.12 are between 0 - 0.05% strain (small values). In this area it is not always possible to obtain a close fit for the Ramberg-Osgood curve, but in this case the curve runs trough the yield stress plateu [10]. In the next figure the the complete relation is shown. Also note that the Ramberg-Osgood curve continues to rise after the ultimate yield point occurs, which indicates a continuing strain hardening. The tensile test, however, does not take the contraction of the test specimen before fracture into the equation, a incorrectness in the common tensile test results. The true stress keeps ascending, and a matter of fact increases more untill fracture occurs, as the area subjected to load are getting smaller after contraction. From this it is understood that the Ramberg-Osgood equation represents the true material curve with a good accuracy.

This is more correct than the tensile test

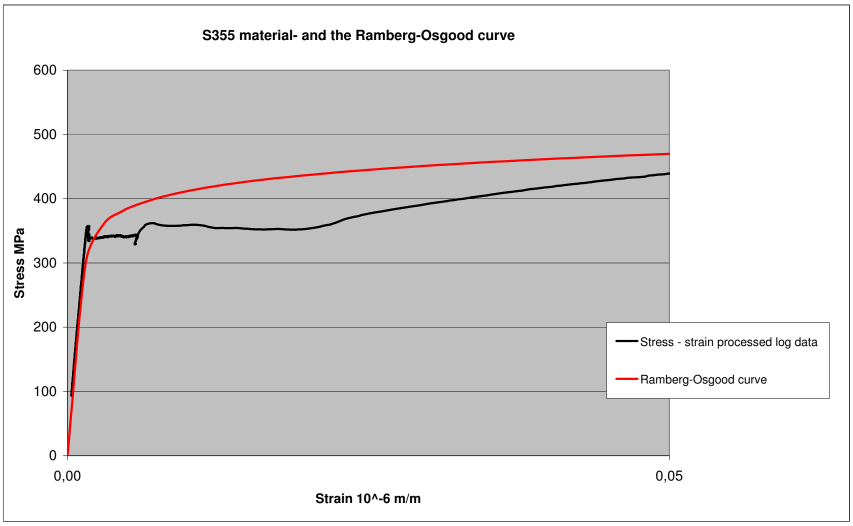

Figure 4.5: Material curves up to 0.5% strain

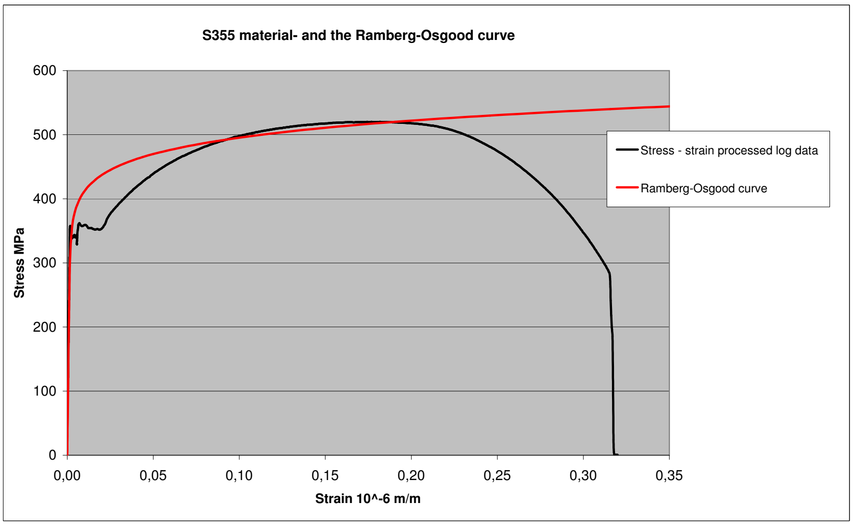

Figure 4.6: S355 material- and complete Ramberg-Osgood curve

4.5 Bilinear Isotroptic hardening

According to ASME VIII the pressurized components shall undergo a non-linear analysis, without any strain hardening. From chapter 3.2.1 we understand that the analysis will be bi-linear and the slope on the second linear curve will be zero.In order to model this loadcase the TB-command and the Bilinear Isotropic hardening label, BISO[1] are used. Since this is for the code check only and the most common use of bi-linearity is *with strain hardening*, figure 4.4 shows the curve in the code check on the left. The right curve is get from the attemptable calibration of the model, which is better explained in chapter 7.5.1.

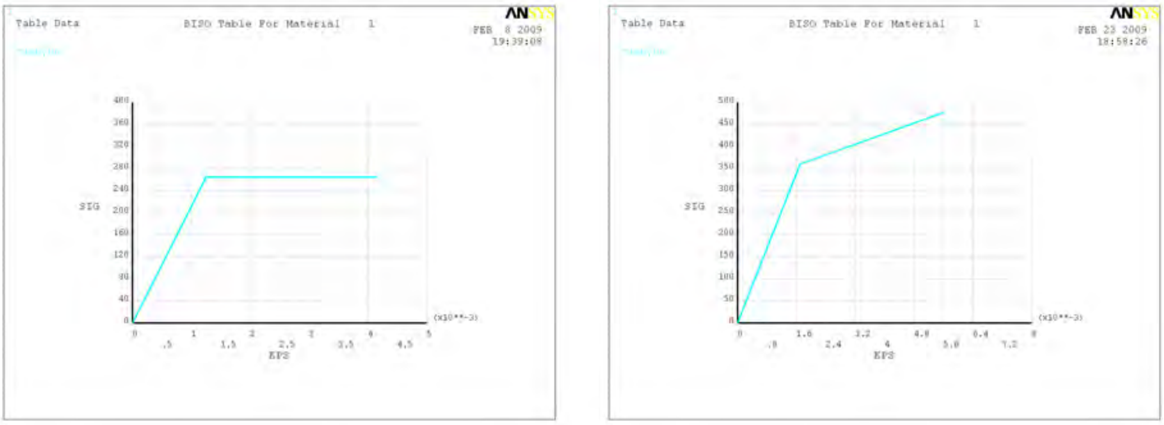

Figure 4.7: Bi-linear material curves i ANSYS

4.6 Material testing

4.6.1 Production of specimen

The material tests were done at Bodycote AS in Stavanger. Material sertificate and test reference is found in Appendix G.

The material is tensile tested in one direction, as the test membrane is circular and the strains are monitored with strain gauges in four directions. The figure shows a drawing of the plate from which the test specimens are machined. It is important to machine the test specimen a minimum of 25mm away from the outside of the material piece in order not get material subjected to heat from machining or cutting torch [2].

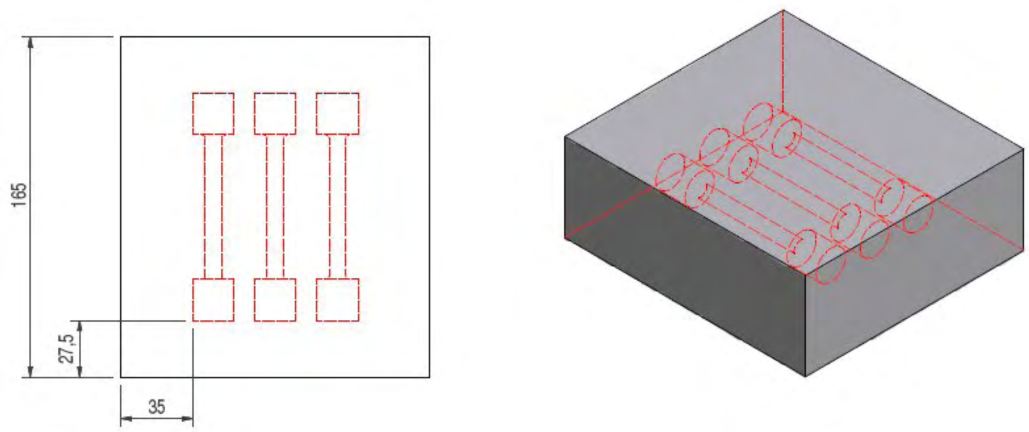

Figure 4.8: CAD drawing of test material

A standard material test is a minimum of tree specimen in order to compare the test and find possible deviations between them. This way a statistical evaluation can be done, which results in a better adaptation of the material curve for the FEM model for the experiment at hand. The blury pictures below (figure 4.9) shows the plate piece, the cutting and the three specimen before machining.

Further the material pieces are machined to become standarized testprobes. Figure 4.10 are showing the material pieces before and after machining in the lathe. Note the markings at the end of the rough machined cylindrical pieces. At this point the specimens have got their number.

At last the material goes trough a refined machining and the machining tolerances are controlled, in figure 4.11. The picture of the caliper is over exposed by the flash, but it reads Ø10.020 mm. The specimens are produced.

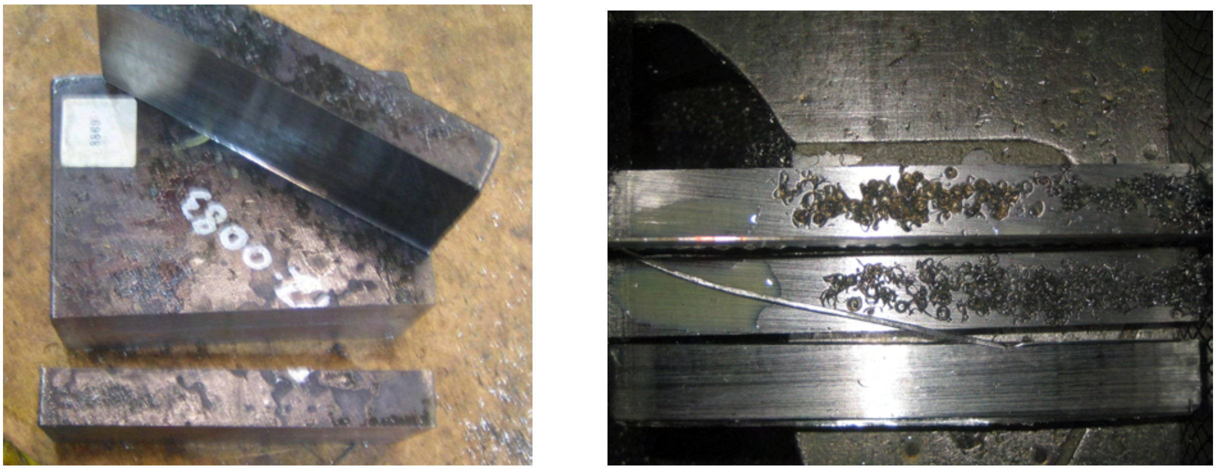

Figure 4.9: Cutting of test specimen

Figure 4.10: Machining of test specimen

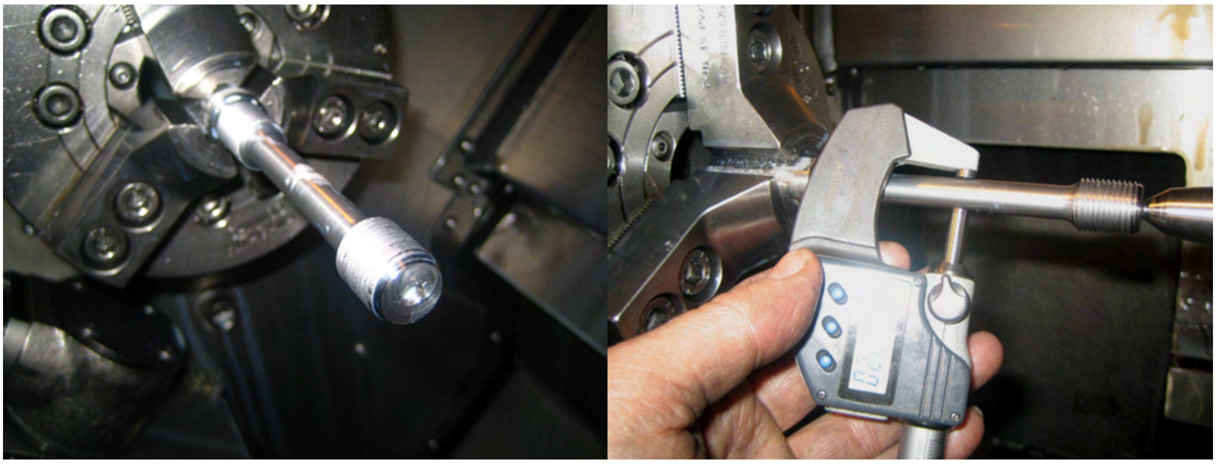

Figure 4.11: Test specimen taken

Figure 4.12: Three finished specimens

4.6.2 The tensile test

For the tensile test a SERCAL MTS/Rubicon, an english tester with a capacity of 250kN, and the 50 mm gauge length Howden Extensiometer RT50 were utilized. The specimen is attached on the threads in the ends and the machine pulls it off, as the datas are collected.

This tensile set-up logs:

- Load
- Position
- Extension
- Stress
- Strain
- Time

Figure 4.13 shows the tensile test set-up with the 250kN SERCAL MTS/Rubicon, the Howden extensiometer and the specimen.

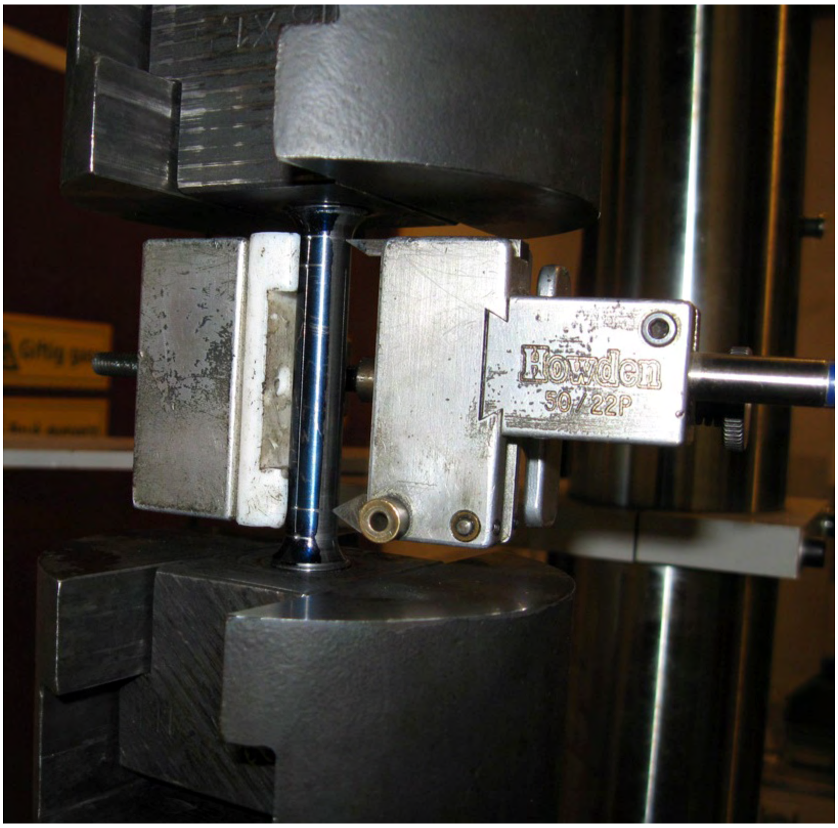

Figure 4.13: Tensile test set-up

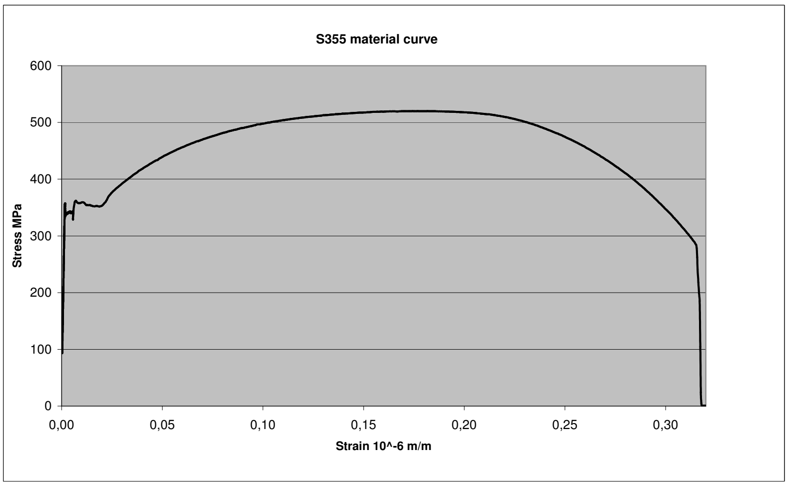

Figure 4.14: Material curve from tenile test

Young's modulus from the tensile was reported as:

- 217.1 GPa
- 213.5 GPa
- 214.5 GPa

which gives an average value 215 GPa. From this it is concluded that Young's modulus will have to be corrected from the 209 MPa in the preliminary analysis to 215 MPa after the tensile test.

Material Properties	S355	Unit
Young's modulus, E	215	GPa
Poisson's ratio, ν	0.3	-
Min. Yield strength, S_y	345	MPa
Min. Ultimate Strength, S_u	518	MPa
Mass density, ρ	7850	kg/m^3

Table 4.4: Tensile test values - S355G+10

A new Ramberg-Osgood curve was fitted for the analysis.

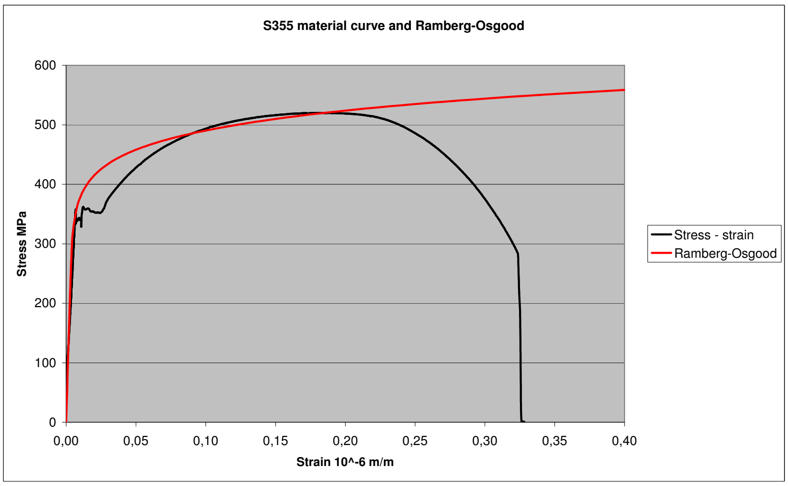

Figure 4.15: Ramberg-Osgood adapted to tensile test curve

Chapter 5

Design and construction

5.1 Construction and assembly

The design and construction in this thesis is done in the 3D-modelling programme Autodesk Inventor 2009 and ANSYS Structural FEM software. The main dimensions are analysis in 2D considertion (axi symmetry) and visualized in 3D.

A 48 mm steel plate called the membrane in which a notch is cut on the lathe (after welding). The fracture zone in the membrane is slim in order to complete the removal from the MHTT.

The MHTT is built in the steel quality F-65, see chapter 4.2.1. In the analysis it is simple to change the material caracteristics in the future if the material is not properly suited for this application.

In the following the complete Tee assembly and operation is explained.

The Tee is made by machined parts welded together. It must be assembled in a specific sequence in order to get the membrane correct set up in to the tee neck with the required welding access. The assembly contains Isolation Plug (IP), tee neck, membrane and tee body. All these parts are machined separately.

The following list outlines the assembly sequence after machining:

- Tee neck is placed in vertical position (standing on the weld seam)
- The Coupon is placed on to the bearing barackets inside the Tee neck
- The IP lower body is placed on the Coupon and Lock nut tighten
- The IP upper arrangement is installed

- IP expansion ring is activated in order to preload the Coupon towards the bearing bracket
- This subassembly is attach to a weld jig and the Membrane is welded to the lower side of the bearing bracket
- The IP is removed
- The welded tee neck and coupon is post baked for stress releiving
- The notch is cut on the lathe in position
- The subassembly is welded on to the Tee body
- The IP is again assembled

The following figures showing the main assembly for the MHTT.

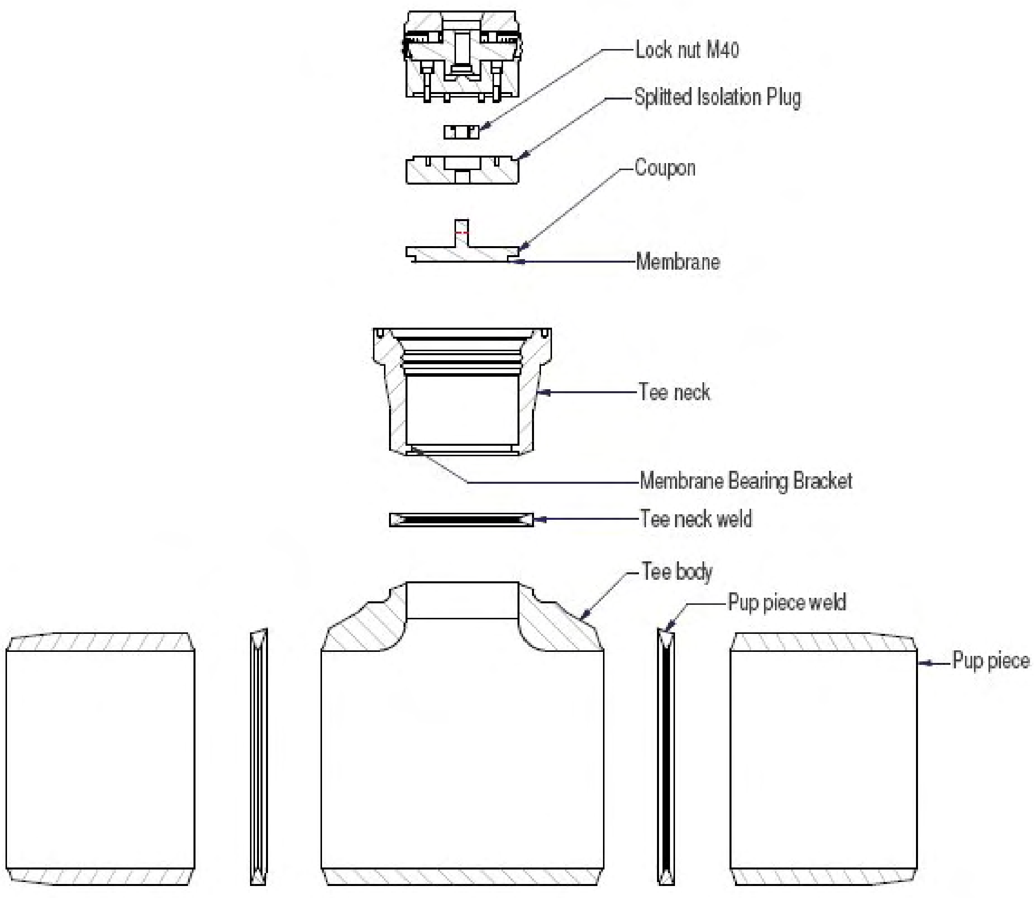

Figure 5.1: MHTT assembly parts

Figure 5.2: Exploded ISO view

In the conventional Hot Tap tees the coupon is machined in the Tee body. The solid Hot Tap plate is 50mm thick and located below the Tee neck weld, and as a result is is closer to the pipeline outer diameter and does see stress from the pipeline during installation and handling. In the MHTT the Coupon is located above the Tee neck weld in order not to pospone the Membrane for stress from the pipeline.

5.2 The membrane

The membrane is a 48 mm thick plate, a Ø40mm bolt that interfaces with the IP and outer diameter of Ø355.6 mm (14"). It is machined with a radial groove of 12mm between the upper- and lower part. The lower part has a thickness of 6mm and contains a notch machined axial at a raduis of R=173mm. The hole plate is called the membrane. See figure 5.3.

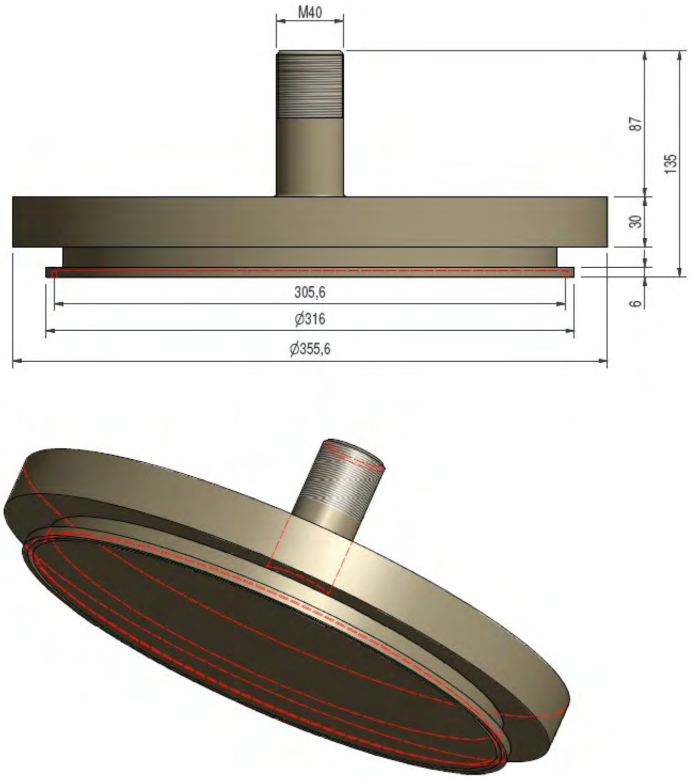

Figure 5.3: Membrane with outer dimensions

The upper part of the plate bear against a bracket inside the tee neck and are prestressed between this bracket and the split ring grooves, trough the IP.

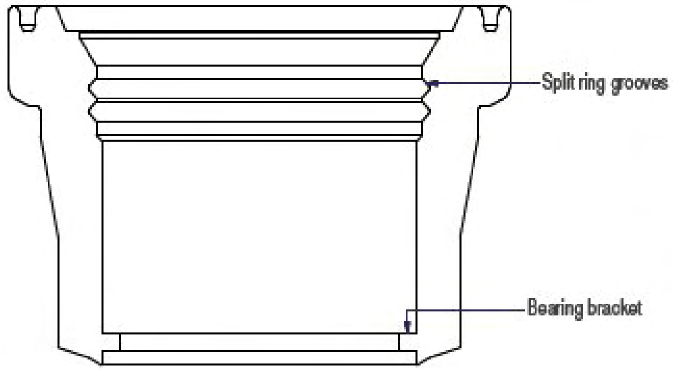

Figure 5.4: Tee neck with split ring grooves and bearing bracket

The figure(5.5) below shows the membrane welded into the tee neck according to the assembly list in chapter 5.1.1.

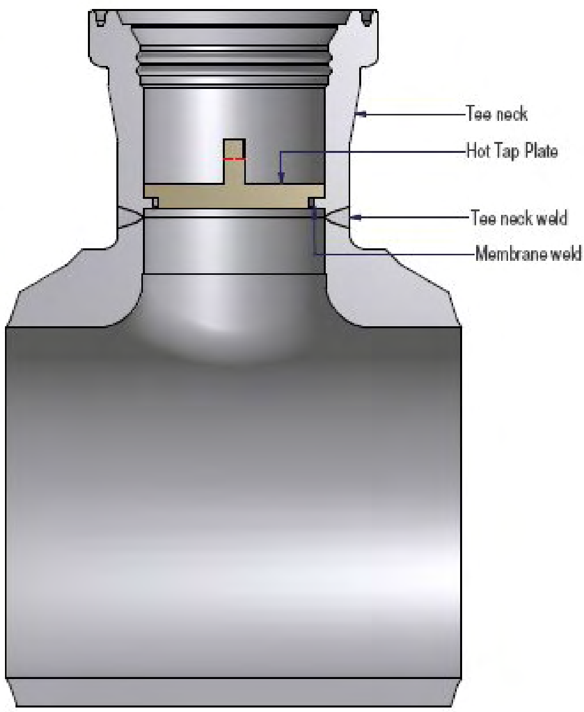

Figure 5.5: Membrane welded into the tee neck

5.2.1 Test membrane

For the test of a simplified membrane was constructed in order to be able to bolt it into the test jig and change it after test runs. The geometry of the fracture area is the exact same as the membrane in the MHTT concept. Drawing nr IP556-NE-MA-011 is found in Appendix C, but a figure(5.6) is shown here. In order to design the notch (fracture initiation groove) several geometries was tested with the ANSYS-model. The model was run with different geometry parameters, such as:

- Radius un the bottom of the notch
- Angle of the notch
- Diametral placement of the notch

A general "rule" in design is that sharp edges will give large stress concentrations, so a first notch design was with a radius of 0.2mm. The mechanic tried this, but had to give up as the radius of the turning-tool in the lathe was worn away. The lowest radius possibe is 1.1mm.

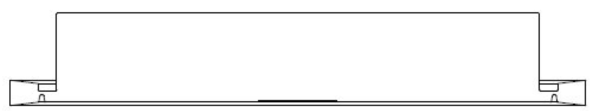

Figure 5.6: Section wiev of test mebrane

5.2.2 Isolation Plug

The IP is constructed different from the original for the use in the MHTT. It lower body is splitted in order to mount it onto the bolt on the membrane with a lock nut, and the two lower body parts are bolted togheter. It is not done any analysis on the IP for the MHTT, as this is not a part of the scope. The IP assembly is shown i figure 5.6.

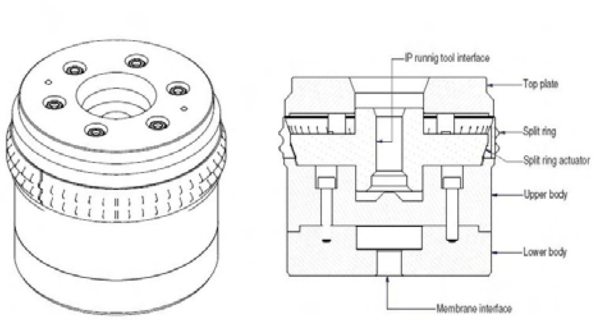

Figure 5.7: Isolation plug

5.2.3 Calculation of split ring grooves

The split ring grooves are dimensioned earlier in an other product developement project. The bearing capacity is 300ton [6]. Figure 5.8 shows a picture from the split ring calculations. The pre-tension on the membrane in the MHTT is not in the scope of this Thesis and by this reason not calulated.

Figure 5.9 shows the test bucket for the split ring grooves.

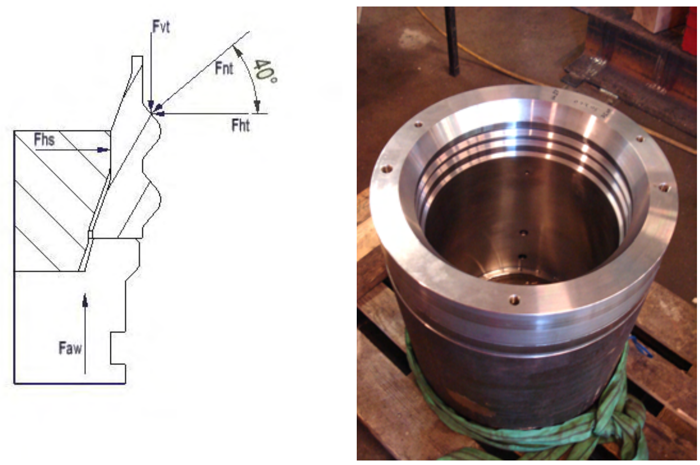

Figure 5.8: Bi-linear material curves i ANSYS

Chapter 6

Analysis

6.1 Finite Element Method

6.1.1 General

The finite element method (FEM) is a numerical method for analysis of constructions and continuum, and are valid for both solid state mechanics (design engineering/structure analysis), continum mechancis (engineering swimsuits etc.) and other fields where solving partial differential equations is essential. The method gives approximate solutions to partial differential equations[13]. For large and complex constructions it is necesary to use computerised power to solve the mathematical problems [5]. The FEM is a mathematical model of one particular construction divided into elements, and these elements are connected in nodes. Each element has a geometrical shape simpler than the constructions original geometry. The dividing is called meshing and makes the analysis simpler to calculate. Element types- and size are important for the degree of accuarcy. Subjected to loads the Nodes will deflect, and this deflection can be calculated. Global formulation of the structure equilibrium equations is[5]:

$$[\mathbf{K}]\{\mathbf{D}\} = \{\mathbf{R}\} \tag{6.1}$$

Here the **K** is the global stiffness matrix, **D** are the DOF's and the **R** are the loads on the structure nodes. For one element in one dimension the formulation is[5]:

$$[\mathbf{k}]\{\mathbf{d}\} = -\{\mathbf{r}\} \tag{6.2}$$

6.1.2 ANSYS

ANSYS is a commercial FEM software to analyse linear and non-linear 2D and 3D problems. The user defines the geometry by creating keypoints, stretch lines between them and generates areas. Further the areas are meshed to the wanted element size and the elements are created. The process og meshing will be described later. (In the past it was important to define boundary conditions and loads before meshing the elements, but nowadays the elements are better, so the meshing can take place on an earlier stage[12]). Next is to apply the boundary conditions and loads to run an analysis.

There are two different options to and carry out an analysis. The Graphical User Interface (GUI) gives the user possibility to model and add different parameters by the use of different menus. The second option is to punch commandos directly into the *ANSYS Command Prompt line* , or with an input file [1]. A script is created by writing ANSYS commands in a word processor and copy-paste it into the input line, or modify the toolbar to read the input file. In this thesis there are scripts written for the different calculations in the different loadcases. ANSYS has a large library of element types with different properties The element types are discussed later.

In this thesis the FEA were modelled axi symmetric for the studies of the main dimensions such as geometry and placement of the notch and code checks. For the non symmetric features of the construction ANSYS Workbench is utilized .

6.1.3 Nonlinearity - Newton-Raphson in ANSYS

The ANSYS software solves the FEA with the Newton-Raphson Procedure[1]. A model is formulated by the physical problems in an application/construction, such as geometric shape, boundary condition and loads or displacements [13]. There are three types of nonlinearity in structural mechanics[5]:

- Material nonlinearity. Material properties are functions of the state of stress or strain.
- Contact nonlinearity. Contact area between parts changes subjected to forces or frictional contact.
- Geometriy nonlinearity. Deformation is so large that the equilibrium equations has to be rewritten for the deformed geometry. Loads changes directions as they increase.

In this thesis I run non-linear material properties as well as non-linear geometries at lagre strains, which gives a nonlinear issue of the structure equilibrium equation, equation (6.1). With a non-linear material curve implemented in ANSYS the stiffness matrix **K** and or the load vector **R** becomes functions of the nodal dof matrix **D**. Caused by lack of information needed to construct **K** and **R**, **D** cannot be solved for the subjected load. ANSYS solves the equation with a iteration process to obtain equilibrium, so that[5]:

$$\mathbf{K}(\mathbf{r})\mathbf{D} = \mathbf{R}(\mathbf{r}) \tag{6.3}$$

The Newton-Raphson procedure is a incremental-iteration method used to generate P vs. u curve, which shows the relations between the load and the displacement in order to achieve convergens. The equation of equilibrium is non-linear and therefore have to linearised, which is done by equilibrium iterations to reduce imbalance to zero. ANSYS use the absolute convergence vs. cumulative iterations curve to eventually obtain equilibrium. In this thesis I applied displacements to chosen nodes on the model of the the membrane, and from here got the reaction forces in these nodes. Figur shows the first two iterations of the linearizing process in ANSYS.

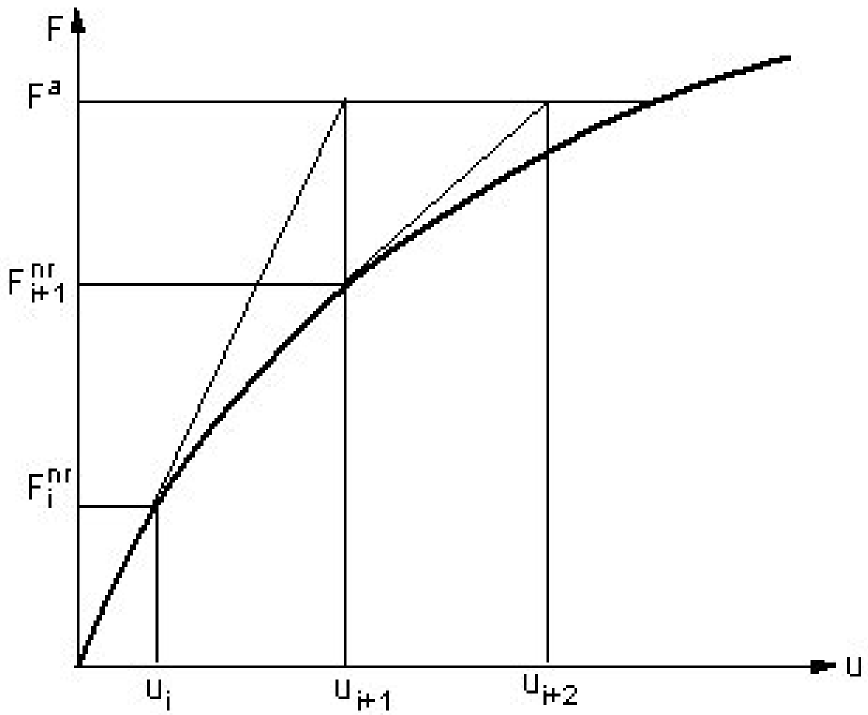

Figure 6.1: The first Newton-Raphson iteration[1]

6.1.4 Element types and mesh

For the 2D axi symetrical model in this theis the two PLANE elements 42 and 82 were tested. PLANE42 is a four node element with two DOF in each node, translation in x- and y-directions, and capabilities of stress stiffening and large strain. PLANE 82 is a eight node element with the same properties as PLANE42, but also have mid-side nodes, which makes it easier to mesh around radiis and circles. Yhe most important element properties in this analysis as it's being observed stress and strain up to yield limit in attempt to obtain fracture. Figure 6.2 showing the PLANE 42 element and its four nodes. This element is well suited for axi symmetric conciderations.

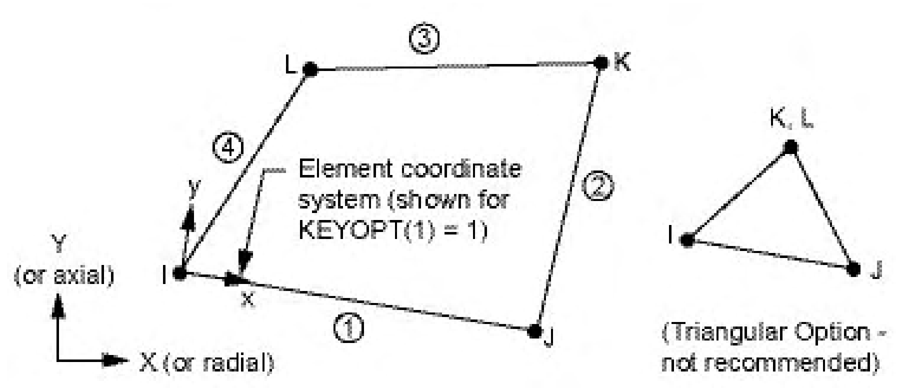

Figure 6.2: PLANE42 element with nodes

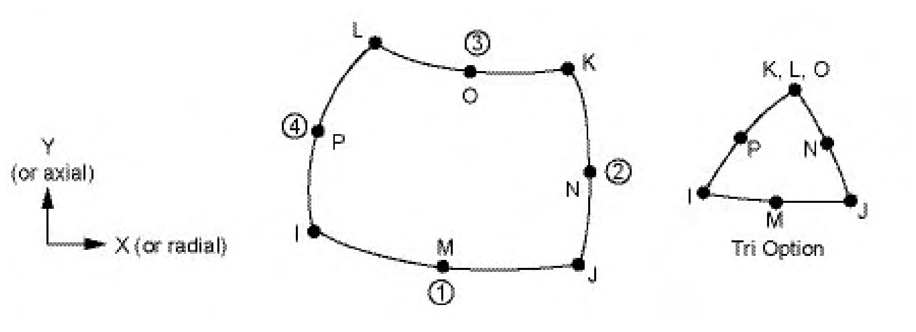

Figure 6.3: PLANE82 element with nodes

Figure showing the PLANE 82 element and its eight nodes. This element is well suited for axi symmetric concierations, but we must be awared that the midside node and corner nodes have different properties, such as read stress and strain as an example[12], the latter observed when picking nodes with the *GET command. By this reason picking of nodes were done manually in order to make sure to read the correct data from a corner node and not a midside node.

Figure 6.4 shows the node numbering used to pick out nodes to read strain, for the placing of strain gauges for the experiments. More on this in chapter 7.

As a general comment of choosing between these two element types, it was observed that it is needed twice as many PLANE42 elements to obtain the same degree of accuracy in the analysis, as with PLANE82. This is explained by the mid-side nodes and the elements isoparametric function, in combination with the fillets (radiis) in the notch areas.

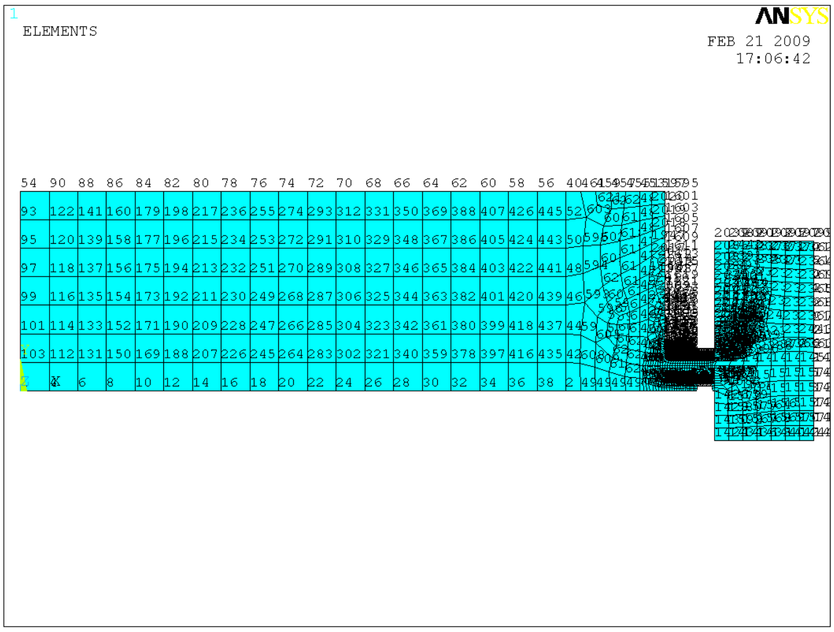

Figure 6.4: Node numbers in ANSYS

6.2 The model - displacement control

In this thesis the analysis mainly are solved by the use of the *displacement control*. The geometry, material curve and boundary conditions are made first, which gives the compatibility (relations between displacements and strains)[12], and then the displacements are subjected to the geometry in chosen nodes. The chosen nodes simulates the interface where the forces are applied in in the test, in order to tear out the membrane (and accomplish a HTO).

The FE model is a simplified model of the membrane in the tee neck. The boundary conditions are modelled as a piece of the wall thickness of the tee neck, fully constrained for translation in x- and y-diretions on the upper- and lower horisontal bound, and in vertical bound. Both the horisontal - and vertical bounds are far away from the areas where the stress and strain propagates when the system is subjected to loads. This way we can conclude that the nodal reactions maintains compatibility as a representative for the whole tee neck material (wall thickness), and that the boundary condtitions are valid. Further the center is locked for translations in x-direction and free to move in y-direction, accoring to axial symmetry. Figure 6.5 shows a nodal plot in ANSYS with the boundary conditions and the *displacements* subjected in the nodes at the horisontal left, that represents the radius of the Ø40mm bolt in the test set-up. The model is a ANSYS-script were the displacements are subjected in steps of 0.1 mm and the stress- and strain level, in and around the notch, are increasing successively. It is assumed that when the hole area around the notchs has reached yield limit, the material will collapse, and that fracture, after an *unknown peroid of time*, will occure.

This model is also used to find the geometry and placement of the notch. The ANSYS-model is run with the different

The material curve (Ramberg-Osgood) in ANSYS is fitted with a continuing hardening after the ultimate yield point is reached.

Figure 6.5 and 6.6 shows the bundary conditions of the test membrane.

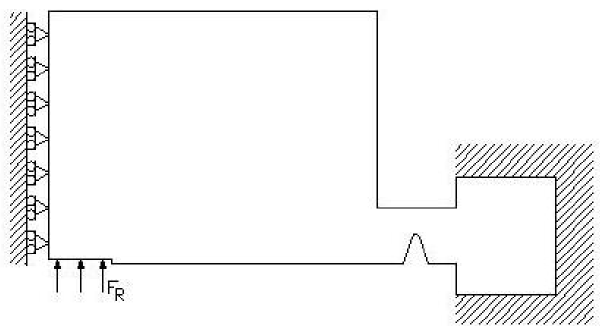

Figure 6.5: Boundary condition and displacements

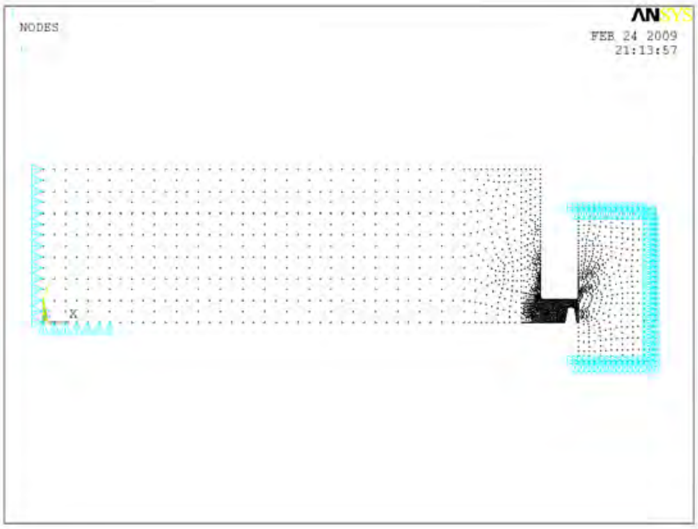

Figure 6.6: Boundary condition and displacements in ANSYS

6.3 Axial symmetry and circular plates

6.3.1 Reference calculations

" If you can keep it simple, keep it simple" [1]

The local analysis of the membrane is done with a half 2D axi symmetrical consideration. When a load symetrical about the plates central axis is appplied to a circular plate, the deflection surface is also symmetrical about the same axis [4]. Benham [et.al] derives the deflection of a circular plate fixed suported based on the figure 6.7:

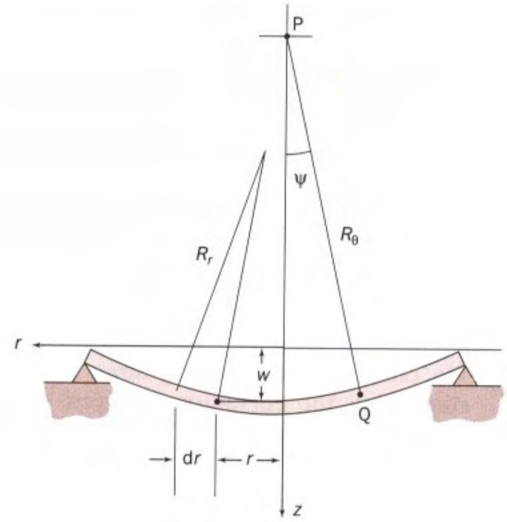

Figure 6.7: Diametral section to prove deflection curve, assosiated slope and deflection at any radius. Source [4]

which results in an equation for maximum deflection

$$w_{max} = \frac{pa^4}{64D} \tag{6.4}$$

where

$$D = \frac{Et^3}{12(1-\nu^2)} \tag{6.5}$$

is the *flexural rigidity* of the plate.

The choice of element type is important to get accurate results. It is a widely used method to compare the results of a reference element and handcalculations to choose the element type and mesh best for your particular problem[5]. I have used the theory of circular plates and done a reference calculation of the deflection, and compared it to FEA.

In this theis it is done analysis with the two PLANE elements to compare the hand calculation from the literature [4] and the actual plate (membrane). There are observeations made with respect to mesh density, elements sizing, effect of large deflections, and linear vs. non-linear FEA. It seems that the smaller displacements the more hand calcs and FEA coincide.

Roark's Formulas for Stress and Strain (Raymond J. Roark (1890-1966)) [19] was used for reference calculations.

6.3.2 Calculation of deflection

As a benchmark I used a circular plate with fixed outer edge and guided inner edge, applied with a uniform load (item 1f from table 24 in [19]).
(The choice of mechanical situation is not very important, as long as the two calculations are equal in geometry, boundary conditions, material properties and load case.)

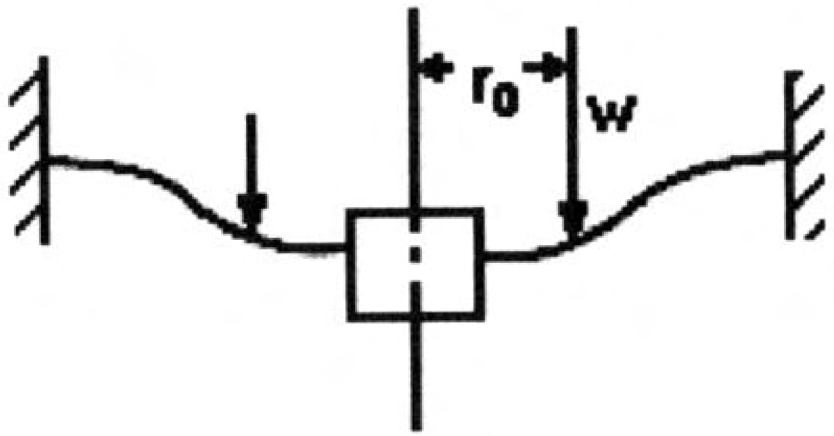

Figure 6.8: Item 1f in table 24, Roark's Formulas for Stress and Strain[19]

These formulas are highly empirical and based on very closely approximate mathematical analysis. It is therefore of high importance that the following assumpions are held true[19]:

- The plate is flat, of uniform thickness, of homogeneous isotropic material
- Thickness is no more than quart of the least transverse dimension, maximun deflection is not more than one-half the thickness
- All loads and reactions are normal to the plane of the plate (axisymetric, no warp)
- The plate is nowhere stressed beyon the elastic limit
- The plate plane is horisontal

Summarized we can express the assumptions as:

$$\frac{1}{4}D_{plate} \leq t_{plate} \tag{6.6}$$

$$y_b \leq \frac{t}{2} \tag{6.7}$$

Roark's plate theory is based on experiments and containing a large set of factors and plate constants depending on the ratio r_a/r_b , and loading constants r_a/r_0 . I used the deflection of the circular plate as a reference calculation to the ANSYS model and choice of Elementtype and mesh.

The physics of the plate observed analytically is:

- r_a - Outer radius 150 mm
- r_b - Inner radius 10 mm
- r_0 - Location of applied lineload radius 15 mm
- w - Applied lineload at circulference lenght 10 kN/mm
- t - Plate thickness 20 mm
- E - Young's modulus 210000N/mm^2
- ν - Poisson's ratio 0.3

Boundary conditions for the plate is:

- $\theta_a = 0$- Radial slope at the outer boundary
- $\theta_b = 0$ - Radial slope at the inner boundary
- $Q_b = 0$ - Unit shear force at the inner boundary
- w - Applied lineload at circulference lenght 10 kN/mm
- t - Plate thickness 20mm
- E - Young's modulus 210000N/mm^2
- ν - Poisson's ratio 0.3

The deflection at the inner radis is calcualted by the equation:

$$y_b = \frac{-wa^3}{D}\left(\frac{C_2 L_6}{C_5} - L_3\right) \tag{6.8}$$

where the empirical factor are defined by:

$D = \frac{Et^3}{12(1-\nu^2)}$

$C_2 = \frac{1}{4}\left[(1-(\frac{r_b}{r_a})^2(1+2\ln(\frac{r_a}{r_b})\right]$

$C_5 = \frac{1}{2}\left[(1-(\frac{r_b}{r_a})^2\right]$

$L_3 = \frac{r_0}{4a}\left[\left((\frac{r_0}{r_a})^2+1\right)\ln(\frac{r_a}{r_0})+(\frac{r_0}{r_a})-1\right]$

$L_6 = \frac{r_0}{4a}\left[(\frac{r_0}{r_a})^2-1+2\ln(\frac{r_a}{r_0})\right]$

The deflection, with different r_0, from the handcalculations and the ANSYS model of the plate is plotted in Exel and shown in fugure 6.8. Note the both the PLANE42(green) and PLANE82 (red) are plottet, but are so similar it is hardly visible.

In figure 6.9 we can se that the deviation between the two element types and the hand calculations vary between 5-13%, and shows that the FEM is ″softer″ than Roark's formula for circular plates. This can be explained by the lack of shear force contribution in the hand calculations. Benham also points out that equation 6.4 are only valid for "thin plates", by means a ratio of 10:1 indicates the thickness of the plate compared to the overall diameter [4]. This ″rule″ is caused by the increase of contribution of shear forces, which the equation is missing[8]. Hals derives this with a simply supported beam subjected to a line load, in which he concludes with the table in the figure 6.7 below.

From this we can expect a deviation in reference calculations and the FEA model. As the length increases in proportion to the height the contribution of moment is increasing. From this we understand that *the thicker plate the more prominent contribution of shear forces*, and as the plate in this thesis is 48mm thick the machanics will be similar to a *punch*.

On this background it's concluded that the elements tested is good for the analysis. A more refined argument for the choice of element is however done during the modelling of the mesh in the notch. The figure (6.12) below shows the 2D axi symmetric plate modelled in ANSYS, equal to reference calculations.

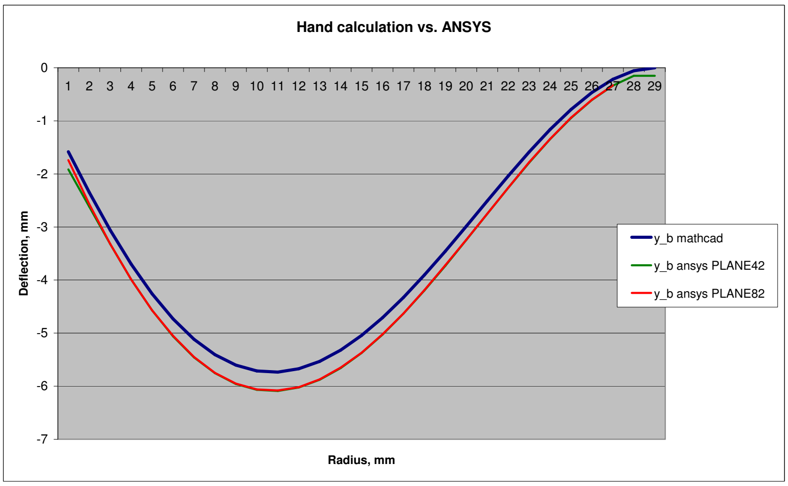

Figure 6.9: Deflection plot from hand calculations and ANSYS

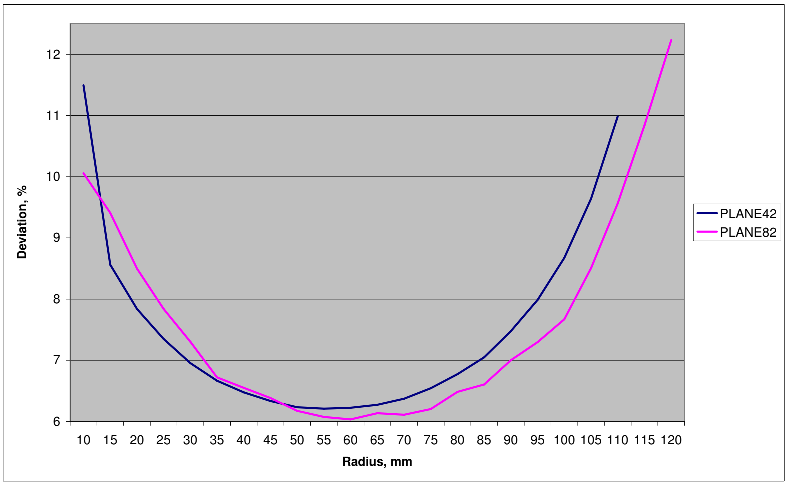

Figure 6.10: Percentual deviation between hand calculations and the PLANE 42 and 82 elements

h/ℓ =	β = (V on rectangular section)	β = (V on I-section)
0	0	0
0,1	0,025	0,083
0,2	0,1	0,333
0,5	0,63	2,083
1,0	2,5	8,333

Figure 6.11: Contribution of shear forces vs. (h/l) [8]

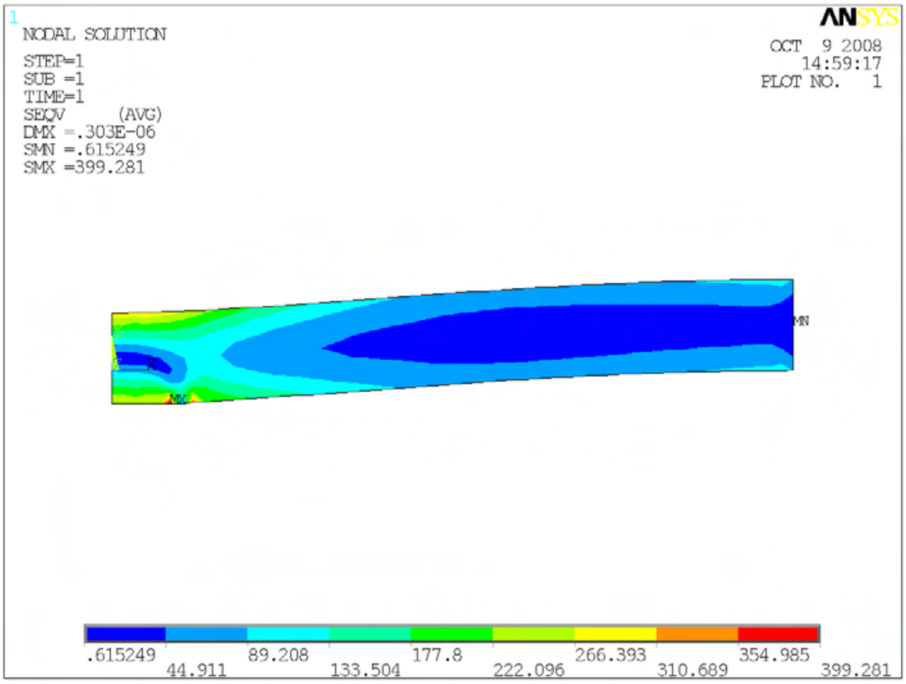

Figure 6.12: ANSYS model of Roark's plate

6.4 Applied elements and mesh size

In chapter 6.2 the two current element types were discussed. The ANSYS-model was buildt up with areas with the AL-command in order to make the mesh process controlled within these areas. Further the mesh were refined, by variation of the mesh along a line with the LESIZE-command. In order to modell a radius of 1.1 mm the mesh in that area, along that line must be smaller than the radius itself. In the ANSYS script the element size were set up like a parameter, in order to easily test the different element sizes.

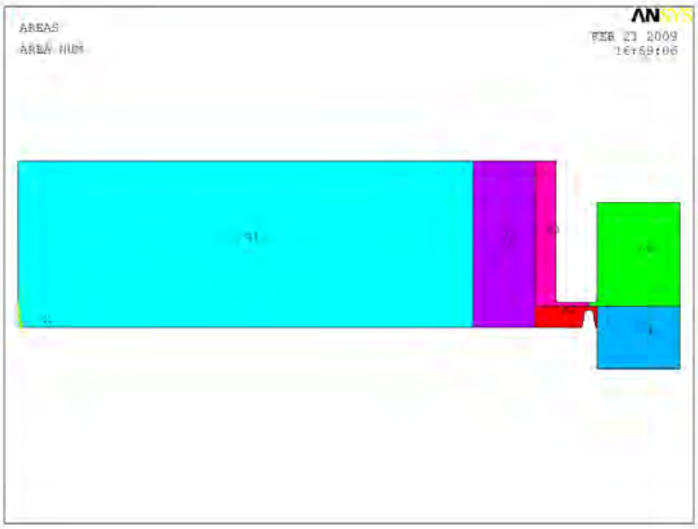

Figure 6.13: ANSYS model. Areas.

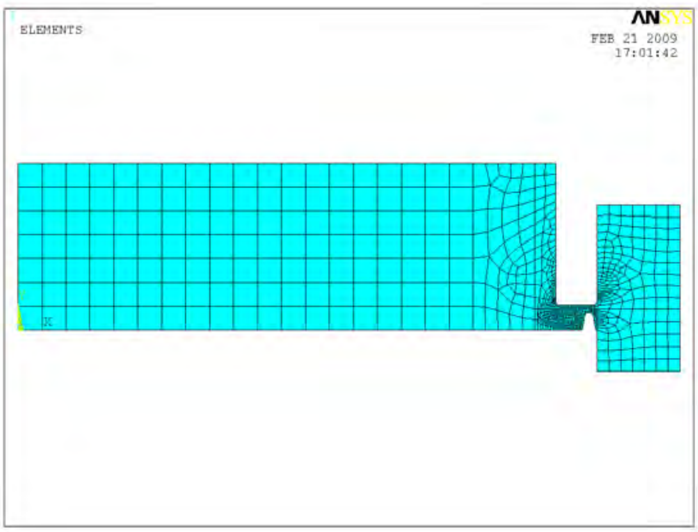

Figure 6.14: ANSYS model. Elements.

An example on the meshing technique used are done with the plate modelled for physical experiments, but are the same for all the other ANSYS run in this thesis. The coming figures shows the that were tried for element choice.

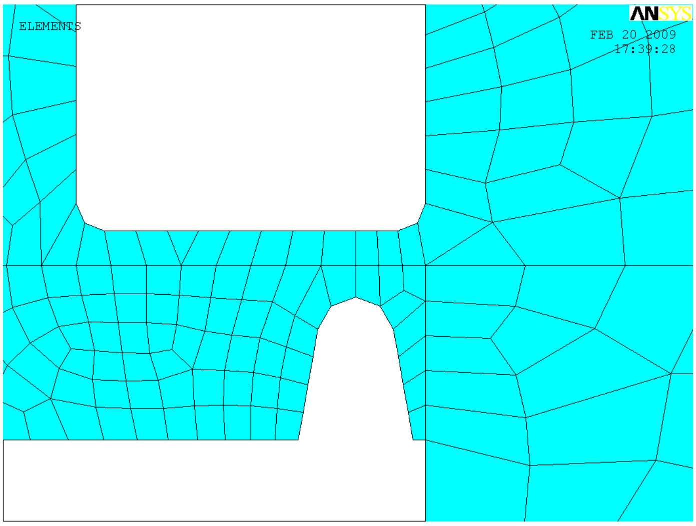

Figure 6.15: Coarse mesh. Element size 1mm

Figure 6.15 shows a coarse mesh that will not be suitable for modelling the notch with the raduis of 1.1mm, as the nodes will obtain stress concentrations.

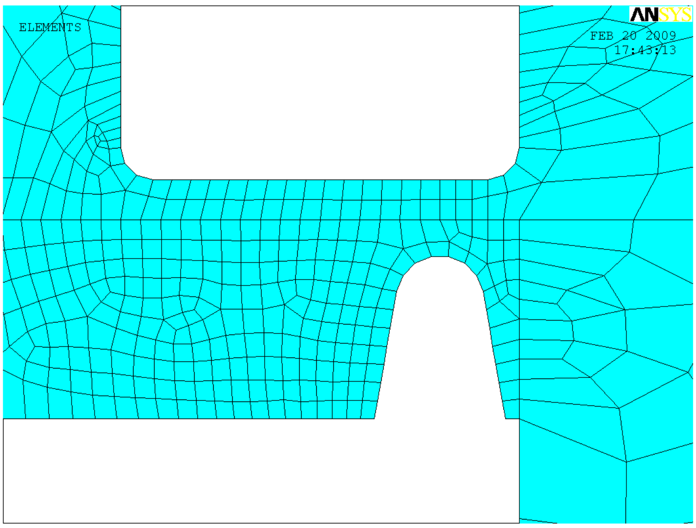

Figure 6.16: Coarse mesh. Element size 0.5mm.

In figure 6.16 the mesh is refined by dividing the element size with two. Still the radius in the notch are not satisfactory. The next figure (6.17) shows yet another dividing. Also note that the vertical lines above the notch gradually gets smaller into the 0.8 mm radius in the groove over the notch, by the use of the LESIZE-command.

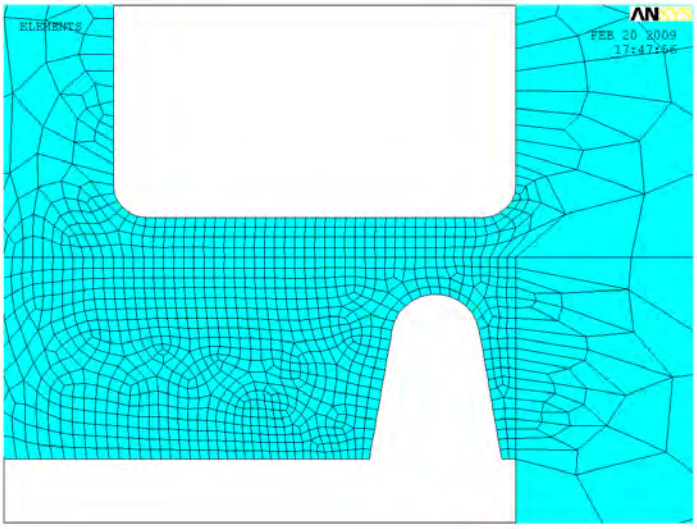

Figure 6.17: Refined mesh. Element size 0.25mm.

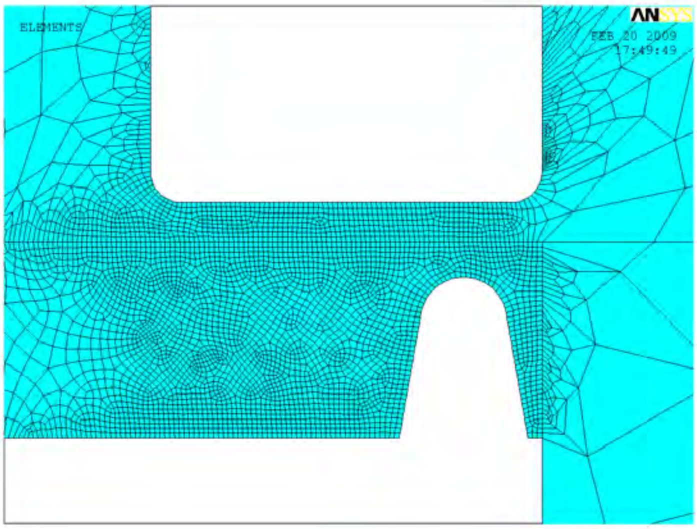

Figure 6.18: Refined mesh. Element size 0.125mm.

At this point the meshing process start to take some time.

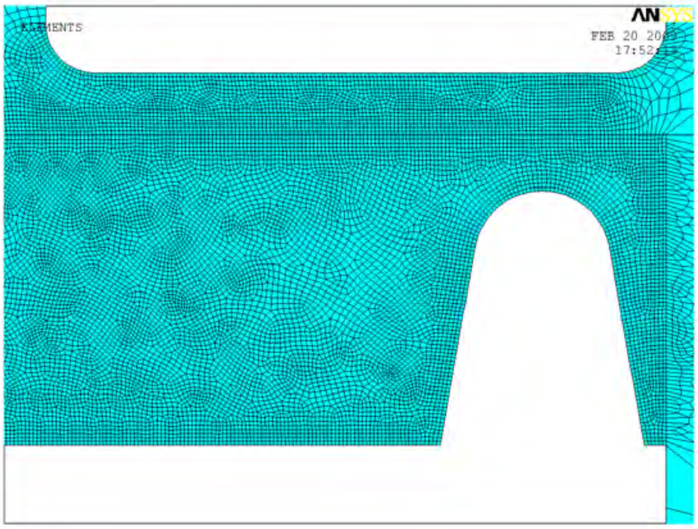

Figure 6.19: Refined mesh. Element size 0.0625mm.

A table is presented to show the importance of the element size in the notch. As we ca see from the figures above in order to achieve the radius and the true situation of the physical problem we must divide the mesh into acceptable small size.

Element size	Reaction forces
ES=1 mm	427kN
ES=0.5 mm	551kN
ES=0.025 mm	556kN
ES=0.125 mm	558kN
ES=0.0625	561kN

Table 6.1: Element size in notch

Table 6.1 shows a convincing convergence with respect to element size in the notch. Here we could easily used the ES=0.5mm, but because of the geometrical shape in the notch in figure 6.10, ES=0.25mm (figure 6.11) is chosen. The choice of element size is calculated but the final choice is on a visual basis. All scenarios are done with ANSYS, and since it's not very time consuming to increase the mesh refinement, this the choice is good.

6.4.1 Material properties in ANSYS

The analysis performed are non-linear, which in ANSYS depends on the material curve and the settings in the software. In this thesis

In chapter 4.3 the Ramberg-Osgood curve fitting is presented. The curve is adjusted on the background of of material properties from MATWEB [1] for the high-alloys in the membrane and the tensile test of the plate material. In order to make it legible for ANSYS the *TB-command* to fit the points on the material curve into ANSYS [1]. ANSYS has to have the linear part of the material curve in order to perform non-linear analysis, i.e the straight line between the points $(0,0)$ and $(\sigma_f, \sigma_f/EMOD)$, were σ_f is the stress from the forces subjected and EMOD is Young's modulus which is a parameter. A substract of a material curve with the TB-command is presented here:

```
TBPT,DEFI,0,0
TBPT,DEFI,240/EMOD,240
TBPT,DEFI,1,17E-03,240
TBPT,DEFI,1,69E-03,325
TBPT,DEFI,1,74E-03,330
TBPT,DEFI,1,79E-03,335
TBPT,DEFI,1,86E-03,340
TBPT,DEFI,1,93E-03,345
TBPT,DEFI,2,01E-03,350
TBPT,DEFI,2,10E-03,355
```

The TBPT,DEFI are points on the Ramberg-Osgood curve from 0,0 to the specified yield strenght of the S355 carbon steel used in the test. More on this in chapter7.

[1] www.mateb.com

6.5 Analysis results

6.5.1 Pull-out force for membrane

As mentioned earlier the main goal in this thesis is to model and simulate the membrane and conduct tests. The test membrane is therefore emphasised thorough this thesis, and the results of the work with the test membrane are presented here. The building of the analysis is presented in chapter 6.2, and the results are presented here with a series of countour plots.

The table shows the results of the analysis, and second the countour plots from the preliminary analysis. Default material is the S355 used in the test with the material properties from the material sertificate. The figures (6.19, 6.20,6.21) showing the notch area have reached yield limit in the hole section. The displacements in the figures are true scale.

Run	Material curve	Load step	Displacement	Force	Comment
1	Mat. sertificate	30	3 mm	56.6 Tonnes	Prior to test
2	Tensile test	50	5 mm	66 Tonnes	After test
3	Tensile test	55	5 mm	77 Tonnes	Calibrated

Table 6.2: Summary of analysis results

Item	Value	Unit
R-O parameter, n	15	NA
Load steps	30	NA
Element size in notch	0.25	mm
Min. Yield strength, S_y	373	MPa
Min. Ultimate strength, S_u	508	MPa
Young's modulus	209	GPa

Table 6.3: Parameters in FE-model according to commercial material sertificate

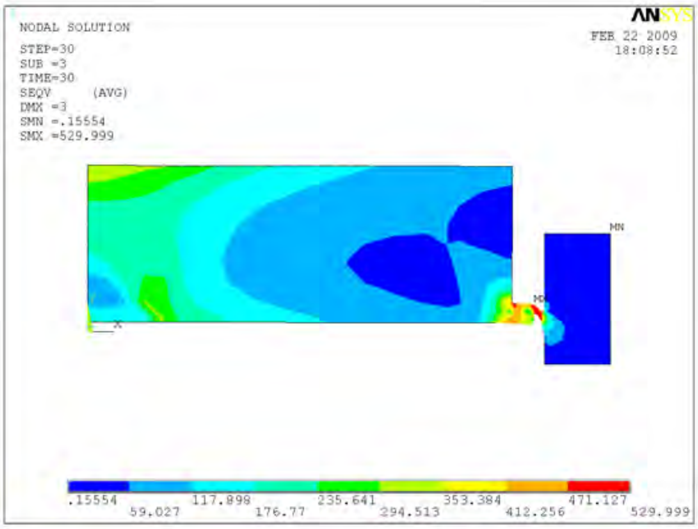

Figure 6.20: Contour plot ANSYS-model prior to test. Full model.

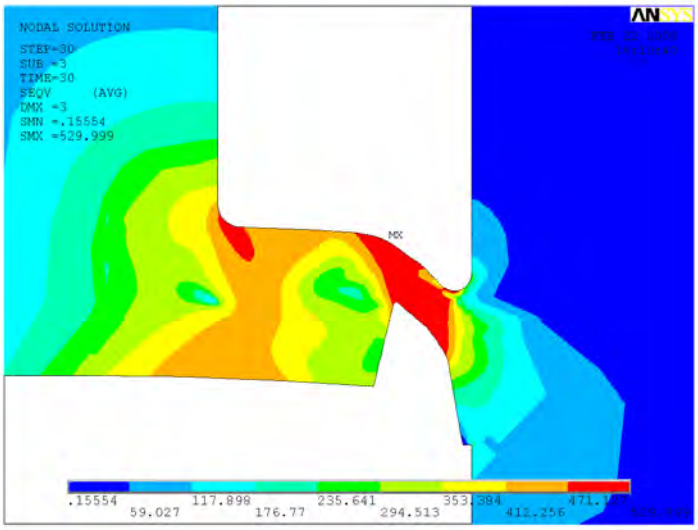

Figure 6.21: Contour plot ANSYS-model prior to test. Zoomed.

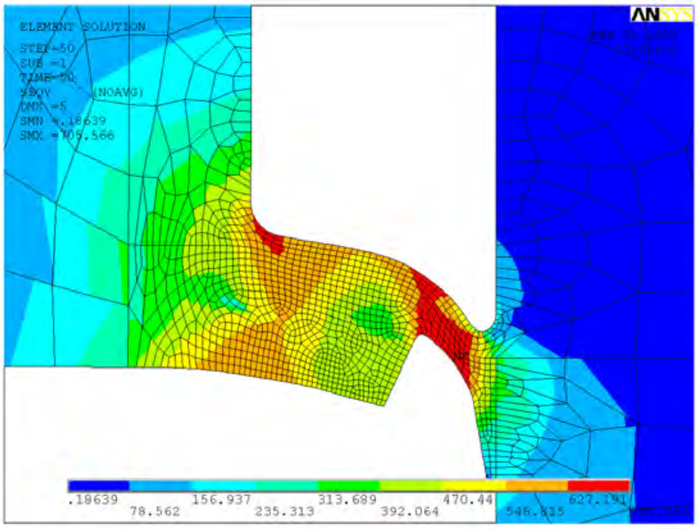

Figure 6.22: Contour plot with elements

After the tensile test was reported a new analysis were run according to the new material properties.

Item	Value	Unit
R-O parameter, n	13	NA
Load steps	55	NA
Element size in notch	0.25	mm
Min. Yield strength, S_y	343	MPa
Min. Ultimate strength, S_u	520	MPa
Young's modulus	215	GPa

Table 6.4: Parameters in FE-model according to tensile test

6.5.2 Standard check - ASME VIII

The ASMEVIII standard is used to check the design on a preliminary basis.

The results will not be discussed further, but the analysis shows that it might be possible to make the design as thin as in this thesis.

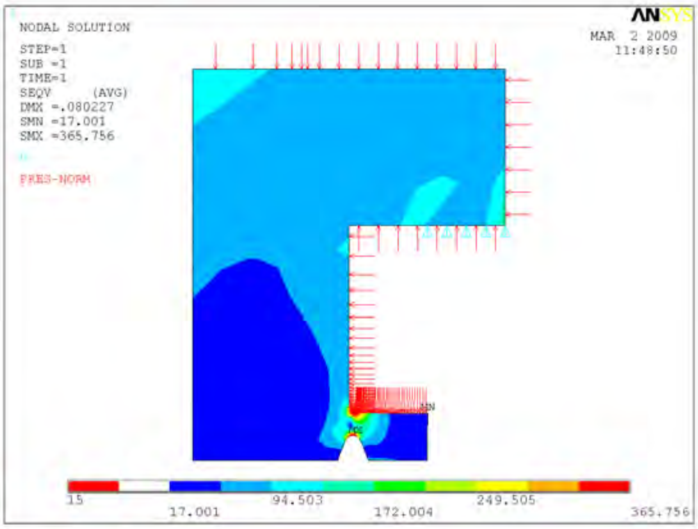

Figure 6.23: Extrenal pressure - ASMEVIII

The ASMEVIII standard is used to check the design on a preliminary basis.

The results will not be discussed further, but the analysis shows that it might be possible to make the design as thin as in this thesis.

The boundary conditions are shown in figure 6.24 and 6.25, and the analysis results are shown in 6.26 - 6.30.

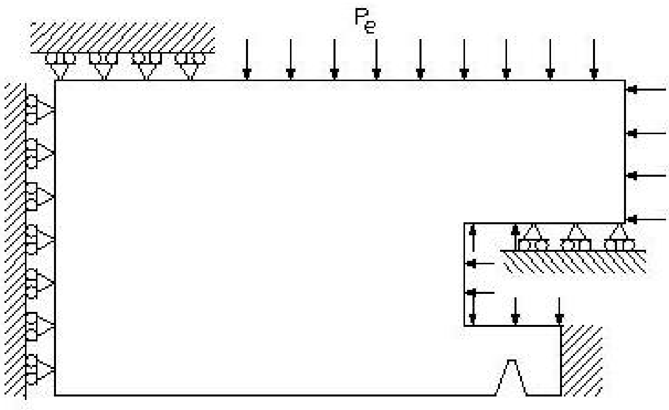

Figure 6.24: Boundary conditions external pressure

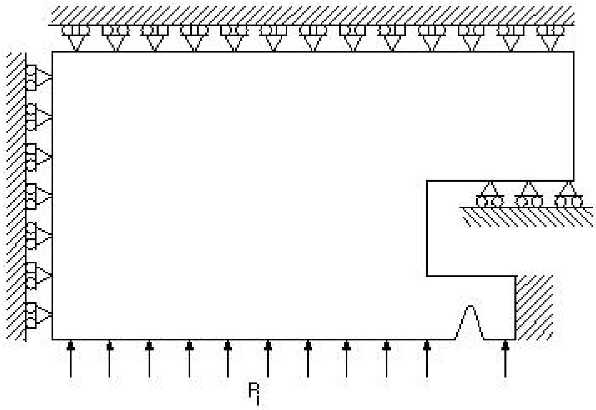

Figure 6.25: Boundary conditions internal pressure

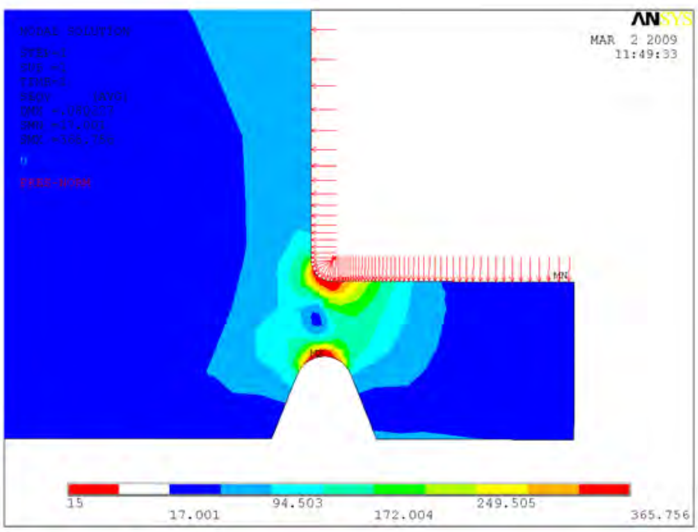

Figure 6.26: Extrenal pressure, zoome- ASMEVIII

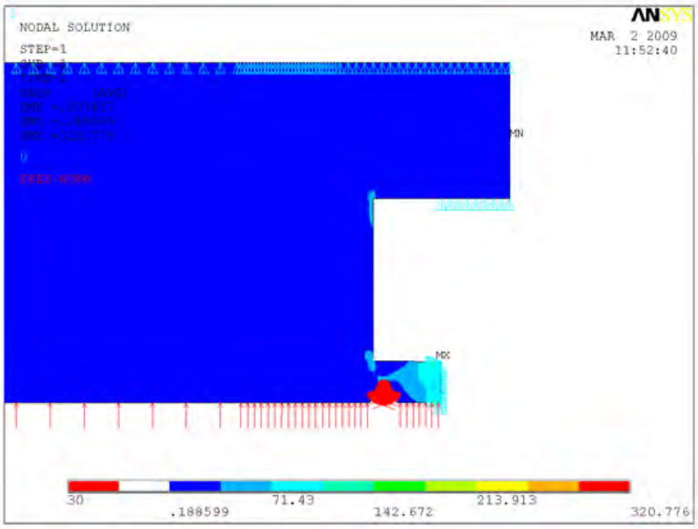

Figure 6.27: Internal pressure - ASMEVIII

The ASMEVIII standard is used to check the design on a preliminary basis.

The results will not be discussed further, but the analysis shows that it is possible to make the design as thin as in this thesis.

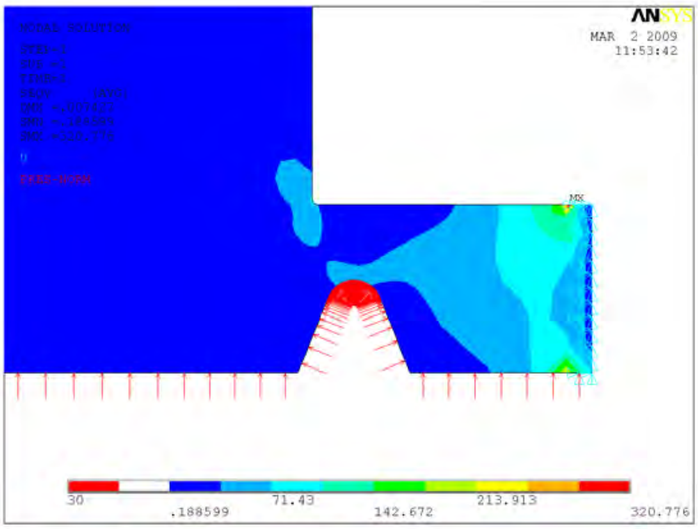

Figure 6.28: Internal pressure, zoome- ASMEVIII

6.5.3 Geometry

The notch geometry was decided with backgruond in analysis run with different geometry. These calculations is not presented herein, however, the geometry CAD-drawings used to decide key points for the analysis.

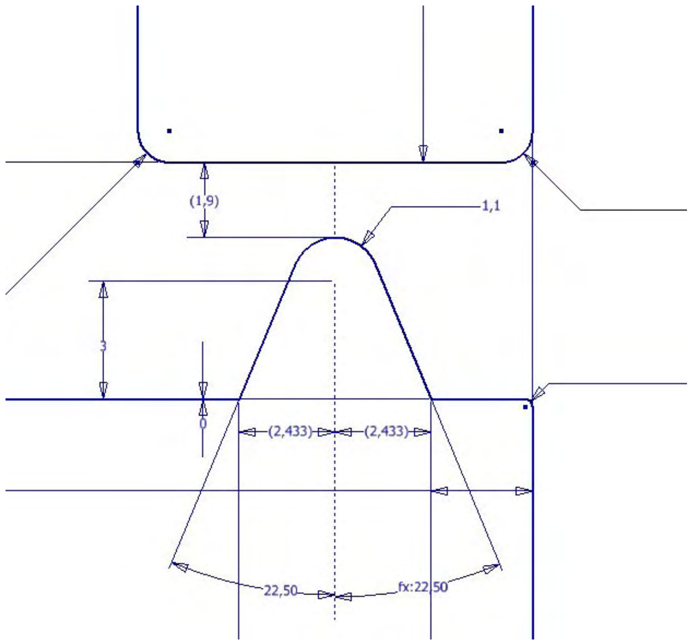

Figure 6.29: Notch geometry 45 degrees r=1.1mm

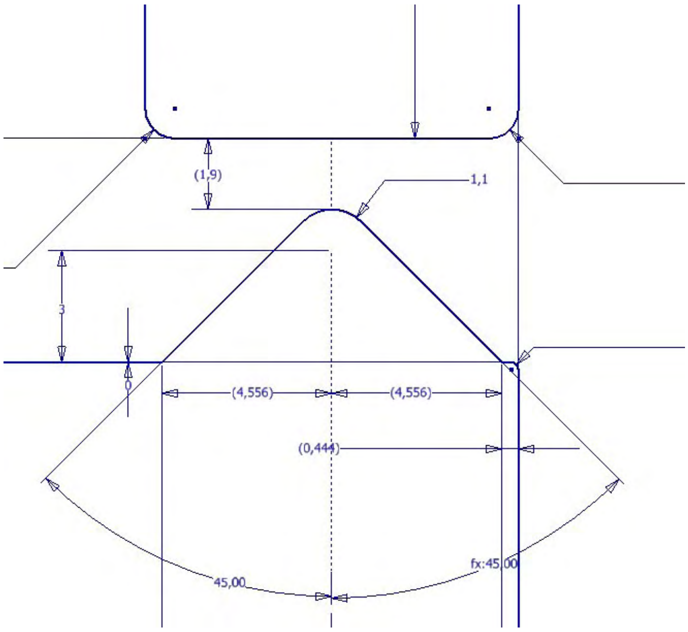

Figure 6.30: Notch geometry 90 degrees r=1.1mm

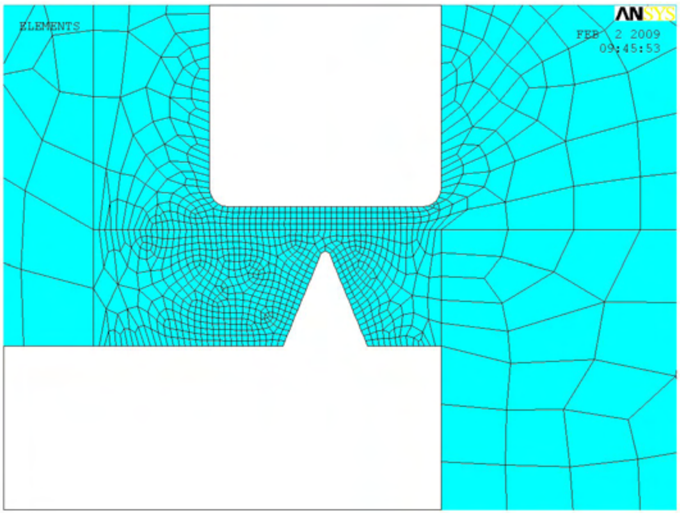

Figure 6.31: Notch geometry 45 degrees mesh

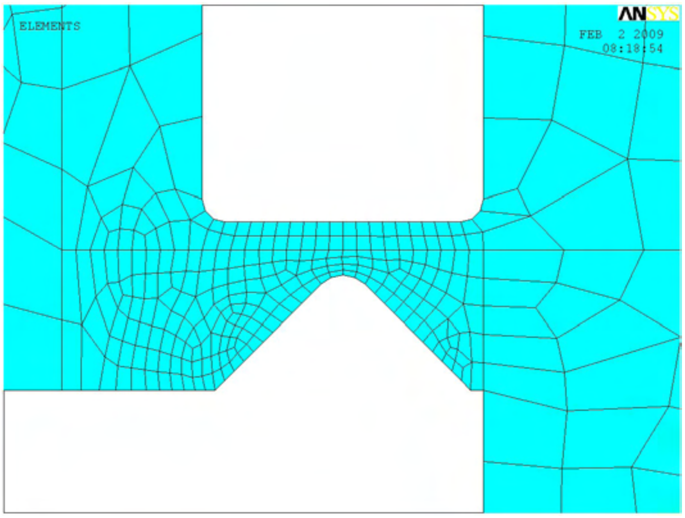

Figure 6.32: Notch geometry 90 degree mesh

Chapter 7

Testing

7.1 Summary

The tests were performed at Nemos production site Haatech AS at Hokksund over a period of two days in February 2009.

The main objective performing this test was to compare and qualify the mathematical model scripted in ANSYS towards the experimental data, and to gather experience about the membrane.

A test jig was constructed and produced for the experiments in this thesis. The test jig assembly contains of welded and bolted parts, test membrane and hydraulic jack. Measuring equipment was strain gauges and Linear variable differential transducers(LVDT) on the top of the test membrane main body and loadcell on the jack. Strain gauges, LVDT-probes and a loadcell were used as measuring equipment, and the HBM software Catman 5.0 was used to log data. The Catman software can log data up to 1000 times per second. In this test we used 10 log steps per second, which was additional information decided on site. Constructional drawings are attached in Appendix F.

All three membranes were destructive tested, however test no. 1 was monitored with three LVDT that was destroyed during the test, and this reason test nr. 2 and 3 was aborted n order to dismount the LVDT. The abortion of the tests took place just before fracture, far into the plastic area. Test no. 2 was not continued in order to have one test membrane for visual inspection in the future. Test no. 3 was activated after disassembly of the LVDT and loaded to fracture, without measuring signal. This is straight forward as the comparison of the ANSYS-model and test results is valid *up to yield, and not to fracture.* In test no. 3 the hydrulic hand pump was changed, which resulted in an inaccuracy in the test results.

Prior to the test run a Safe job analysis (SJA) was performed, in order to identify the hazards and make neccessary precautions. The SJA-form used is from the Norwegian Oil Industry Association (OLF) recomended guidelines, “Common model for SJA”. The SJA-form is attched in Appendix E.

7.2 The test

7.2.1 Methods

In chapter 6.4.1 the ANSYS-model and *displacement control* is explained, which is the method used for solving the equilibrium equations in the FEA.

A data print-out of the analysis results was first made from the ANSYS model, containing lists of displacements (mm), reaction forces (Tonnes) and strain at different locations in the model. Node numbers were picked in the ANSYS script to read strain according to contour plots in ANSYS. See chapter 6.1.4 and figure 6.4 for more info on “node picking”. Further the radius on the test membrane was calculated in order to place the strain gauges at the same location on the test membranes, as in the ANSYS model. The strain gauges were attached (glued) on to the locations so the datas from the analysis and the physical test could become as accurate as possible. The same way the displacement in centre was decided, and the LVDT-probes were placed at locations accoring to the analysis. Reaction forces in the nodes subjected to displacements and the maximum stress and strain in the fracture zone was also printed, in order to establish a connection between the measured values (experimental data) and the non-measurable values, such as shear stress- and strain (analysis data) in the fracture zone. The nodes which obtain the largest stress and strain is listed in the printout to control their locations, it was expected that these would be in the fracture zone. One printout for the analysis run is attached in Appendix C.

The connection between node numbers in the ANSYS-model and radius on the test membranes are shown in table 7.1. Figure 7.1 shows a section from drawing IP556-NE-AS-006 and the strain gauges attached on the test membrane.

Readout	Node nr.	Radius
Displacement	54	0 mm
Strain gauge 1	84	24 mm
Strain gauge 2	78	56 mm
Max stress	10638	NA
Max strain	1101	NA

Table 7.1: Node numbers in ANSYS script

Maximum stress and strain varies between different nodes during the coarse of loading and are gathered with the **GET-command*, in the printout. Nodes with maximum strain in the last load step are also listed in table 7.1. Displacement, strain gauge 1 and 2 are picked manually, maximum stress and strain are picked with *GET. See printout in Appendix C to view the complete analysis result sheet.

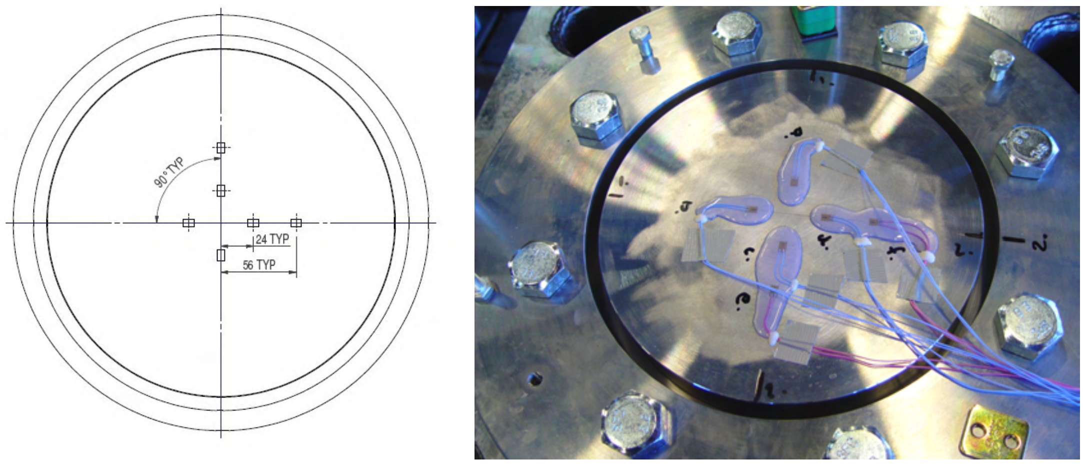

Figure 7.1: Strain gauges applied to test membrane accoring to drawing.

As seen in figure 7.1 the strain gauges were named a,b,c,d,e and f, so in the following discussion the strain gauges will be called SGa, SGb, SGc,SGd,SGe anf SGf. Also see figures 7.10 to 7.15.

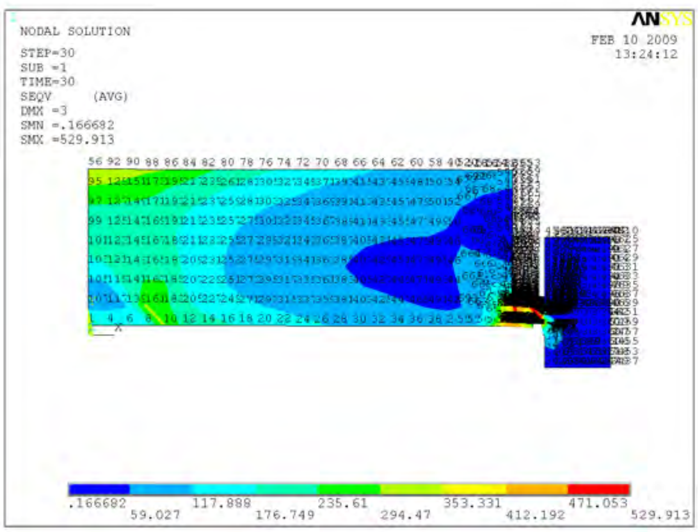

Figure 7.2: Stress plot and node numbers

7.2.2 The test equipment

The test equipment existed of:

- Main test jig
- Test membranes
- Lock ring
- M24 x 160 bolts (8 off), nuts and washers (the latter only under the nut)
- Ø114 mm tube (load transfer)
- 100 Tonne hydralic jack with hand pump
- 100 Tonne load cell
- Strain gauges (6 off per test membrane)
- LVDT (3 off test no. 1, 1 off test no. 2 and 3)
- Ø40 mm adapter plate on load transfer tube
- Protection plate on load cell
- Headless bolts and plate to secure for energy release

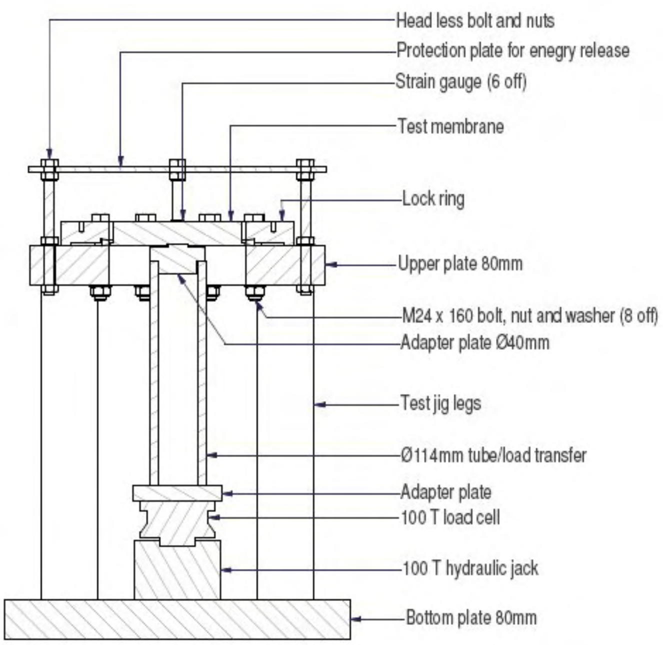

Figure 7.3: Section view of test jig from assembly drawing

All the parts (test jig and membranes) was made in the duration of this thesis. The complete test jig was welded and machined at Haatech AS in Hokksund, and the test membranes was machined at Central Sveis og mekaniske AS at Rommen, Oslo. The 100 Tonne hydraulic jack, load cell and hand pump were rented for this purpose. A reprecentative from HBM Norge AS, Arnt-Henning Andersson, was hired to assist with the strain gauges set-up and measuring equipment during the test, however instructed by the author. In order to complete the test it was prepared a test log that were used as a procedure, in order to make the three tests as identical as possible. Test logs can be found in Appendix D.

As explained in chapter 7.2 the locations for the strain gauges and LVDT probes was planned and chosen by means of the contour plots in the analysis. The following pictures shows the complete set-up at the test site, and the locations of the measuring equipment. Note that the test mambrane and lock ring are oriented in accordance with markings, and that the bolts are numbered for identical repetition. The Thanks to Terje Pedersen for splendid photography work!

Figure 7.4: Complete test arrangement with protection walls

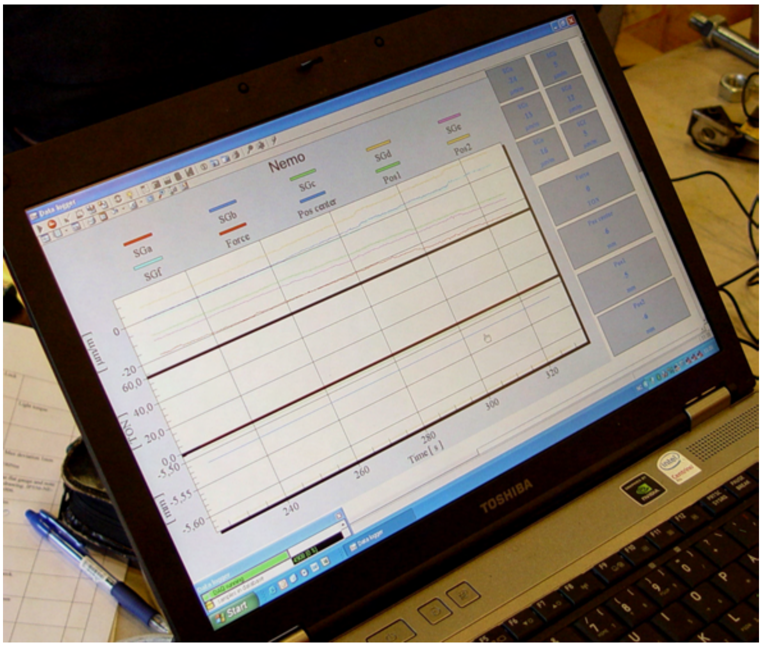

Figure 7.5: Laptop with Catman 5.0

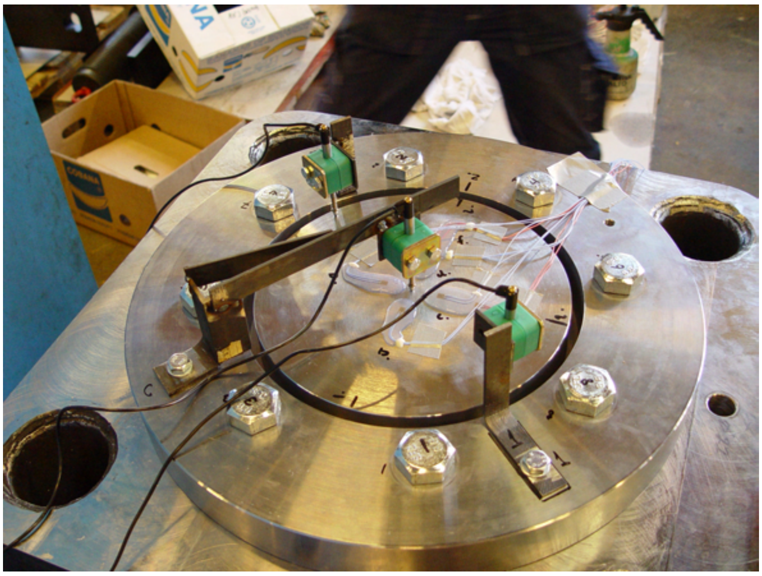

Figure 7.6: LVDT set-up

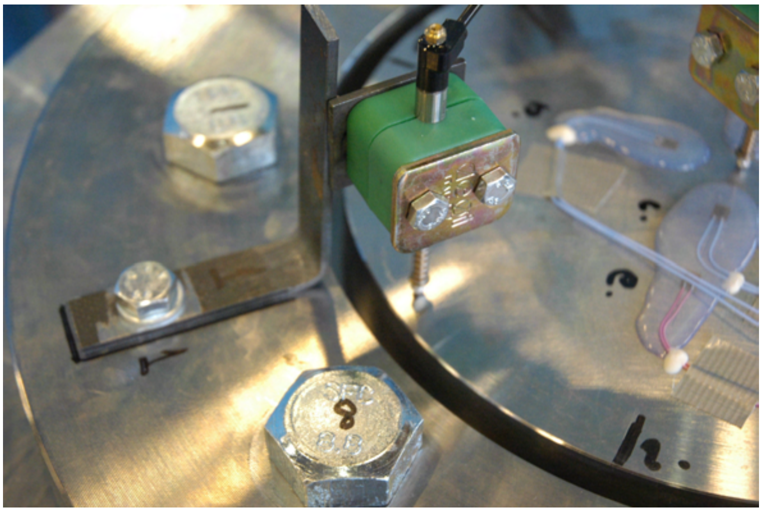

Figure 7.7: LVDT on " home made" brackets

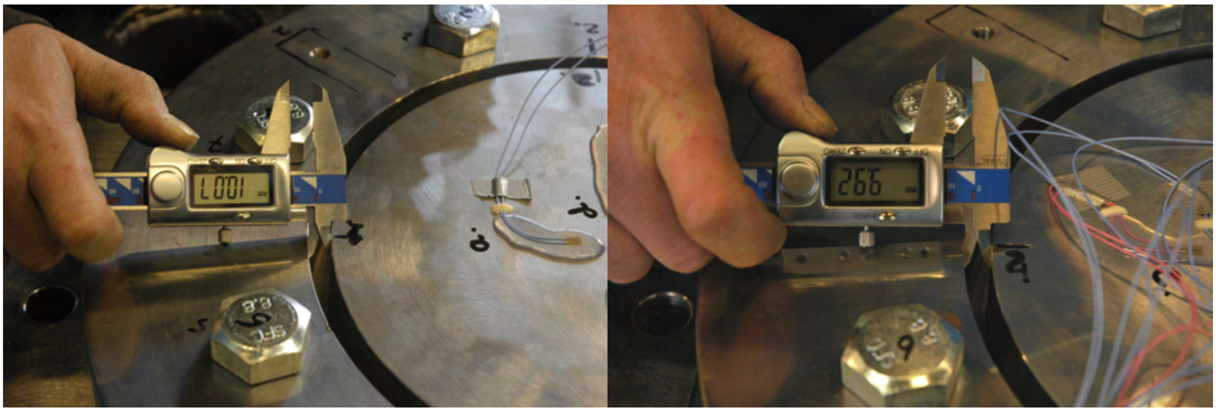

Figure 7.8: Measuring of radial correctness

The eight M24 bolts was torqued up in three steps,$1/3M_{max}$, $2/3M_{max}$ and M_{max}. M_{max} is 80% yield stress, according to Nemo's standard for fasteners, in the last tourqe-step, which gave a pre-tension of 173kN per bolt and a total of 1384kN (138 Tonnes)[3].

Figure 7.9: Torque-up according to test log

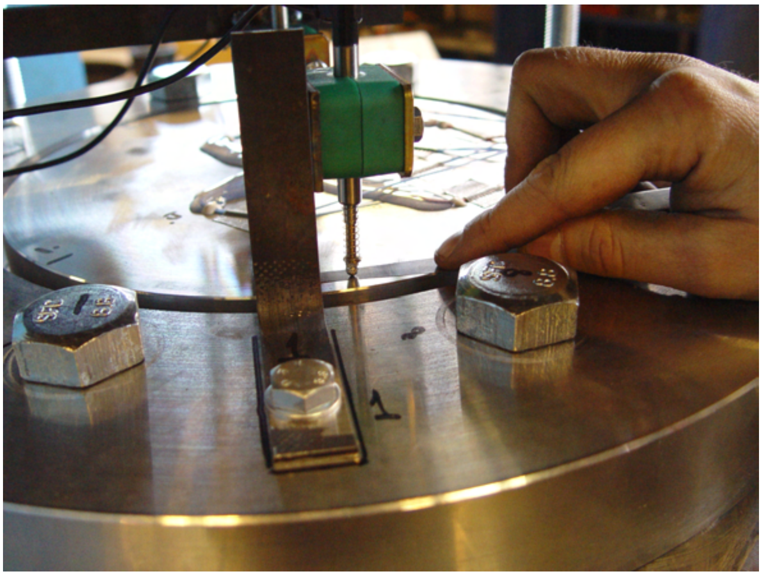

Figure 7.10: Zero-ground of LVDT according to test log

Figure 7.11: Straightness controll of load transfer

7.2.3 Test procedure - test log

In order to carry out an experiment it is common to write and use a test procedure. For simplicity, since there are only one person employed in the work with this theis, it was decided to use the test log as a procedure. The test log has all the items a procedure would have, but it is prepared for signing out each item after completion. Changes made to the test log in the duration of the test was noted in the test log, therefore they are attached to this document, in Appendix D.

The loadsteps in the test was in accordance with the analysis result sheet that were attached to the test log.

7.2.4 Material properties

The material used in the test is a hot rolled carbon steel plate in grade S355G10+N, a common constrution steel in the offshore industry. It is cheap and available and therefore a good choice for this purpose. The material sertificate values for the plate were used to construct a material curve for the preliminary analysis. This is however not good enough as this sertificates are general for a whole batch of plates, so a test piece were tested exclusively for the experiment in this thesis. Table 7.1 shows the tensile test values.

Material Properties	S355	Unit
Young's modulus, E	215	MPa
Poisson's ratio, ν	0.3	-
Min. Yield strength, σ_y	343	MPa
Min. Ultimate Strength, σ_u	520	MPa
Mass density, ρ	7850	kg/m^3

Table 7.2: Material Properties S355

7.3 Measuring results

7.3.1 Data log and curves from measuring

The values from the strain gauges, LVDT-probes and load cell was saved in the data log software from HBM, Catman 5.0. The results are large lists of measuring points converted to Exel files containing test data, i.e they cannot be attached in this document. Table 7.3 shows amount of data points logged in the duration of the test, and loading time. Note that table present time of loading and not rigging time. Test no. 1 was clearly most time consuming as the outcome was unknown. It was not expected to achieve successful results, and sertainly not a clean and quick fracture.

Test nr.	Number of measurements	Time
1	12737	21 min
2	9866	16 min
4	4020	7 min

Table 7.3: Test data log point and time

According to the analysis result print-out the yield stress would be obtained at a subjected load of 56.6 Tonnes and a deflection of 3 mm. See Figure 6.24 in 6.5.1 for contur plot of the situation.

Figures 7.12, 7.13 and 7.14 shows the measuring results, were the curves are up-loading, displacement and strains vs. time. The measurments are very good and it is very clear when the yield point is reached.

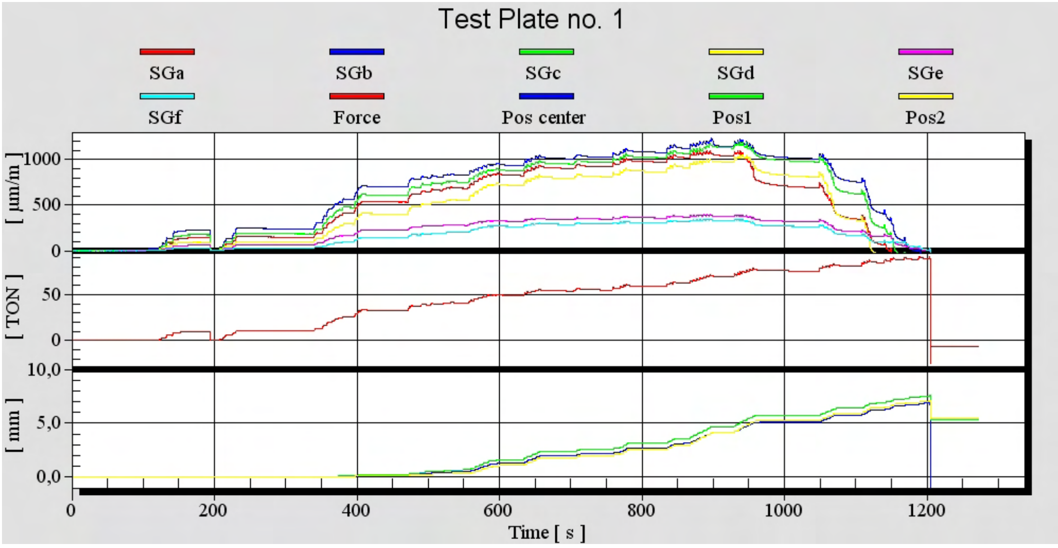

Figure 7.12: Strain, displacements and load results test no.1

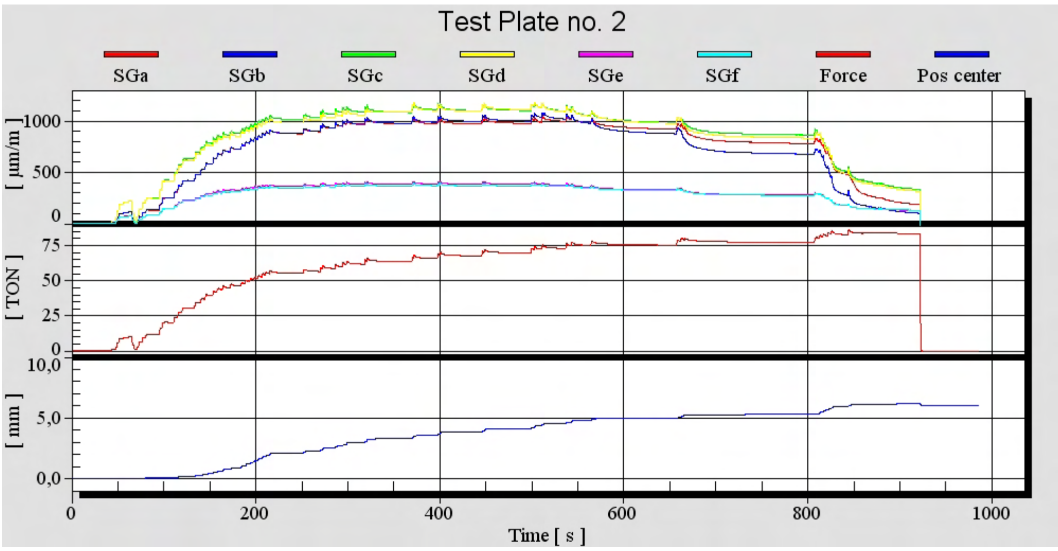

Figure 7.13: Strain, displacements and load results test no.2

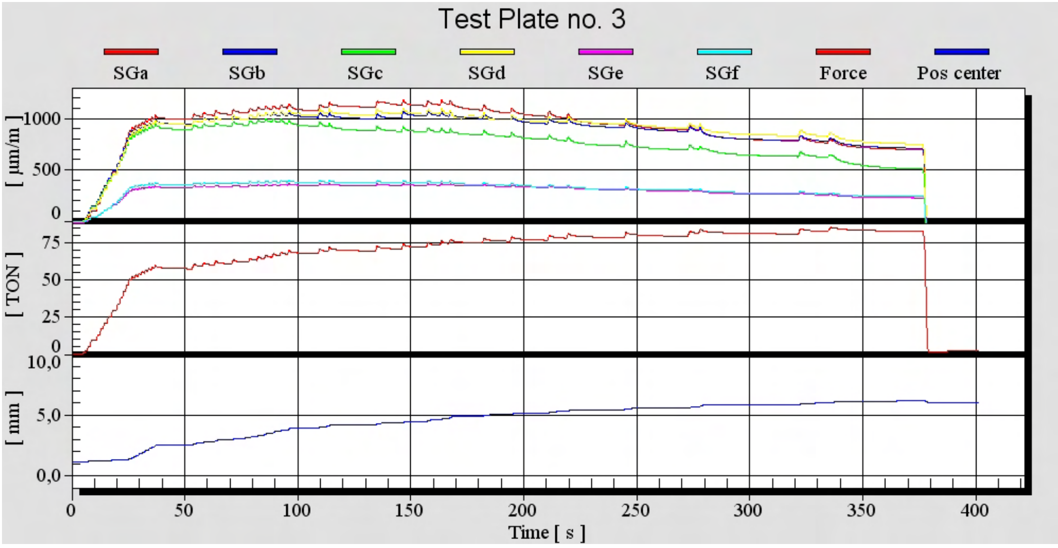

Figure 7.14: Strain, displacements and load results test no. 3

The torque-up of the test jig was also measured, and the curves are presented in the figures 7.15, 7.16 and 7.17. Here it is observed that the torque-up are very exact, but also that there are small deviation in strains around the circle were the strain gauges are placed. A deviation of approx. $46\mu m/m$ at the most is acceptable for this test set-up, though it must be taken into concideration in discussions about the comparison of analysis and measuring results.

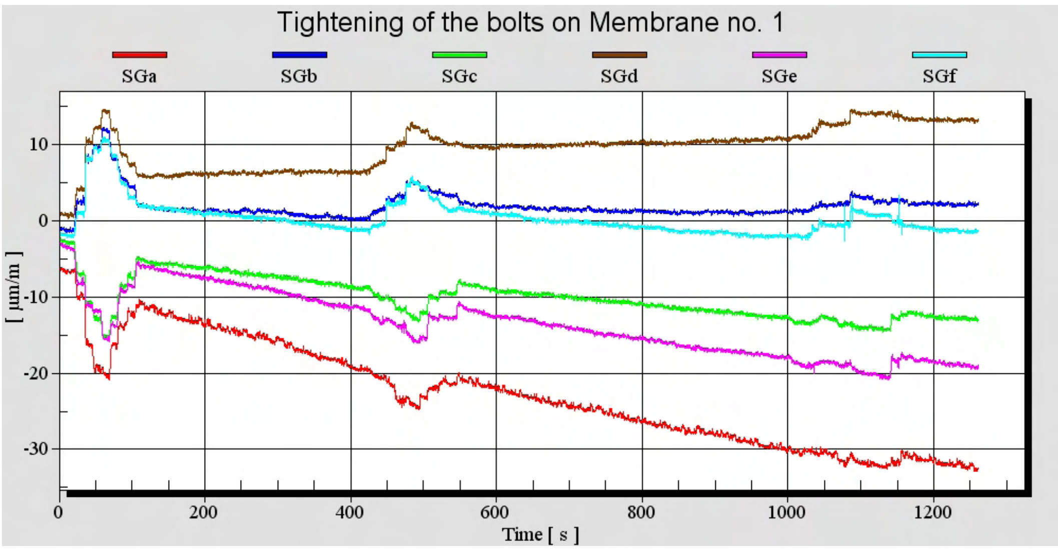

Figure 7.15: Bolt torque-up test no. 1

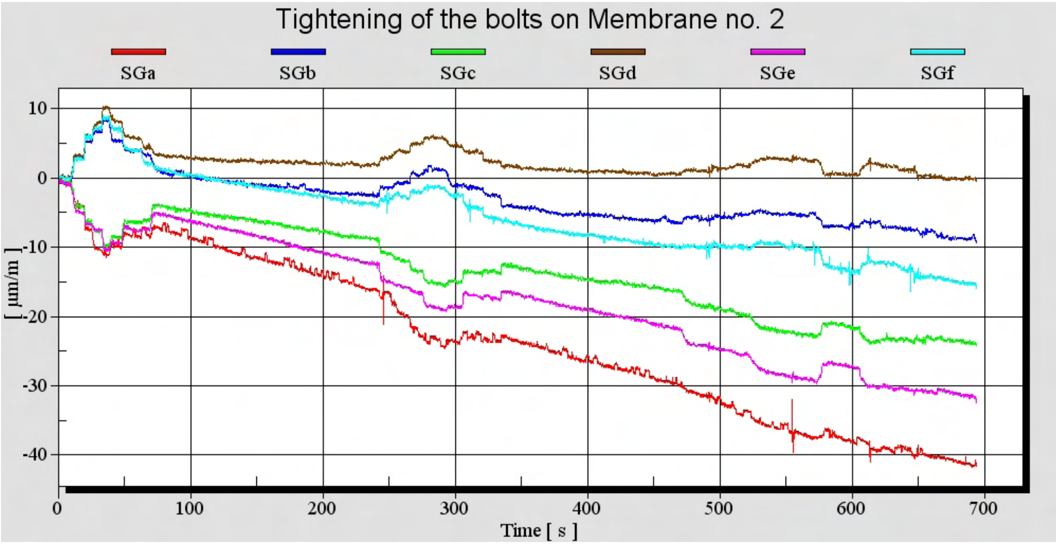

Figure 7.16: Bolt torque-up test no. 2

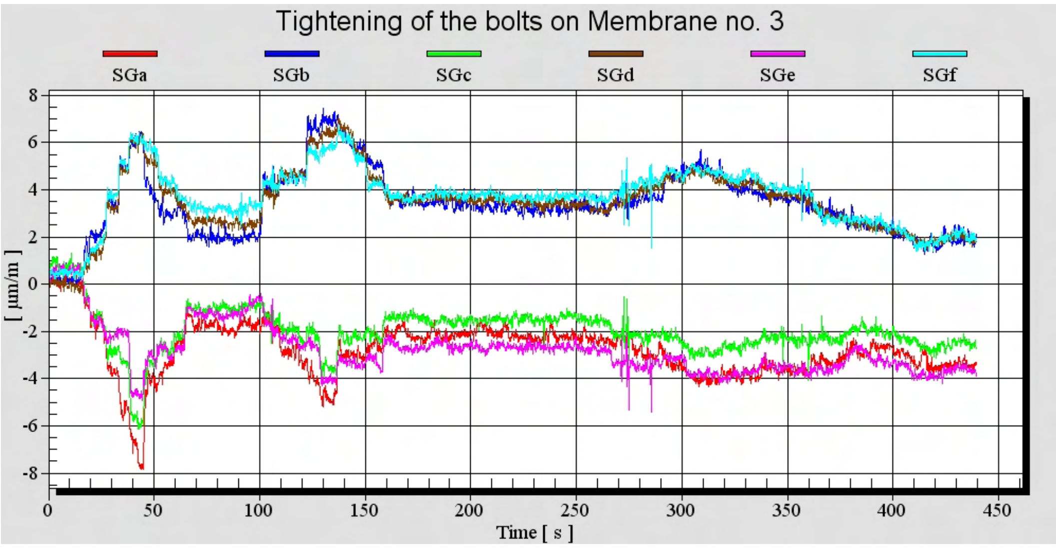

Figure 7.17: Bolt torque-up test no. 3

The measured values are done with respect to time, so in order to compare the data up against the analysis. The results are plotted in Exel in order to produce the proper basis for comparison, and the results are presented here:

Figure 7.18: Load-displacement results from tests

Figure 7.18 shows the complete test results were test no. 1 are loaded directly to fracture and test no. 2 and 3. are aborted in order to save some test equipment. The strange start at test no.3 (green plot) is explained by a change of hydraulic hand pump, caused by to much internal bleeding that resulted in "noise" in the measuring results. This is, however, not a big problem for the use of the results, as they coincide very well in the validity area of the analysis.

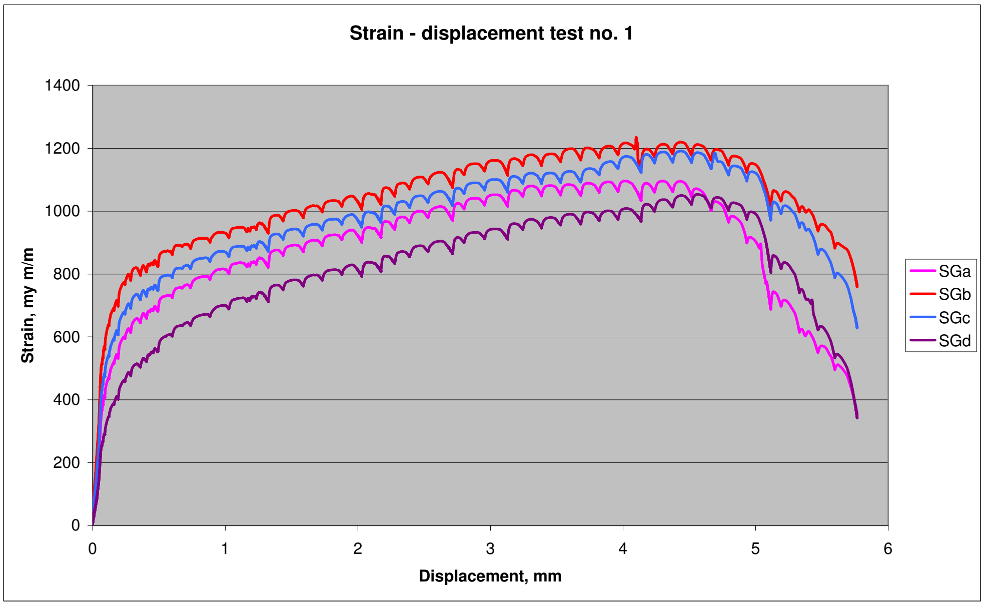

Figure 7.19: Strain-displacement results from tests

The curvses shows how extremely accurate the measuring becomes with the use of strain gauges. Tough there are deviations within the measuring points, the curvature of the graphs are clearly equal up to the yielding starts. After this point there are some small differences in curvature which can express in which orientation the fracture started.

As seen in figure 7.19 the strain around SGa (purple plot) starts to decrease first and that the curvature differs form the others. SGd continious to increase but has a sudden drop and catches up with SGa at fracture. A study of the fracture zone and placing of strain gauges on the test mebranes, confirms this theory. Figure 7.16 shows the fracture zone near SGb and SGa. A zoomed plot of the situation is shown in figure 7.20. Note that SGb has a very early deviations from the other strain gauges, and that such observations can be done further along the graphs untill fracture occurs.

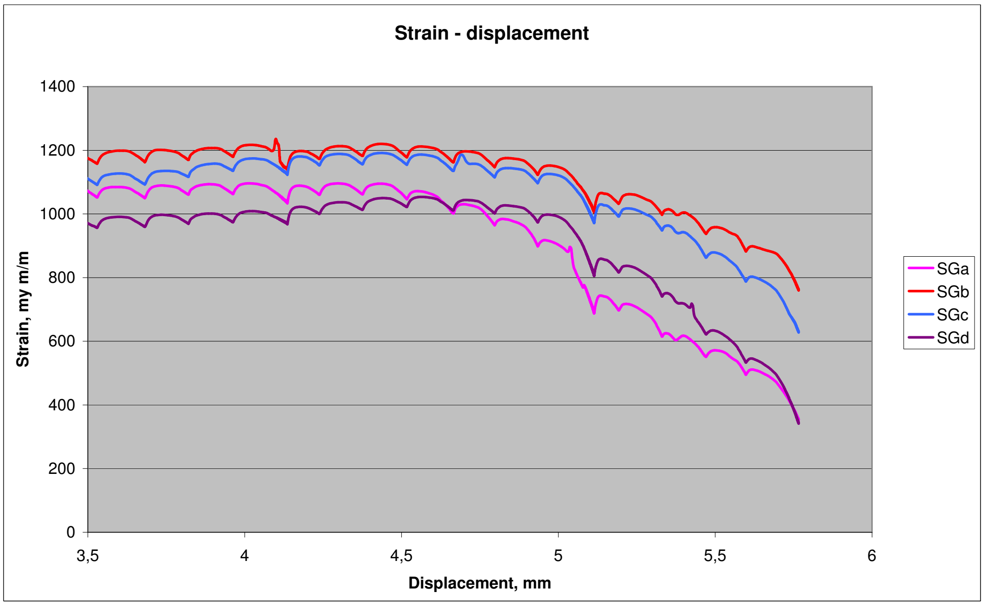

Figure 7.20: Strain-displacement curves - zoomed in on yielding

7.4 Comparison of analysis- and test results

The results from the analysis and the test are compared. In order to discuss the validity of the analysis, the test result curves are plotted to the same displacement as the analysis no. 1 (material curve- sertificate) and 2 (material curve-tensile test). Figure 7.20 and table 7.4 shows the deviations between the analysis no. 1 and the three tests. The strain comparison is shown in figure 7.22 does also have similarities, and does not need further explanation.

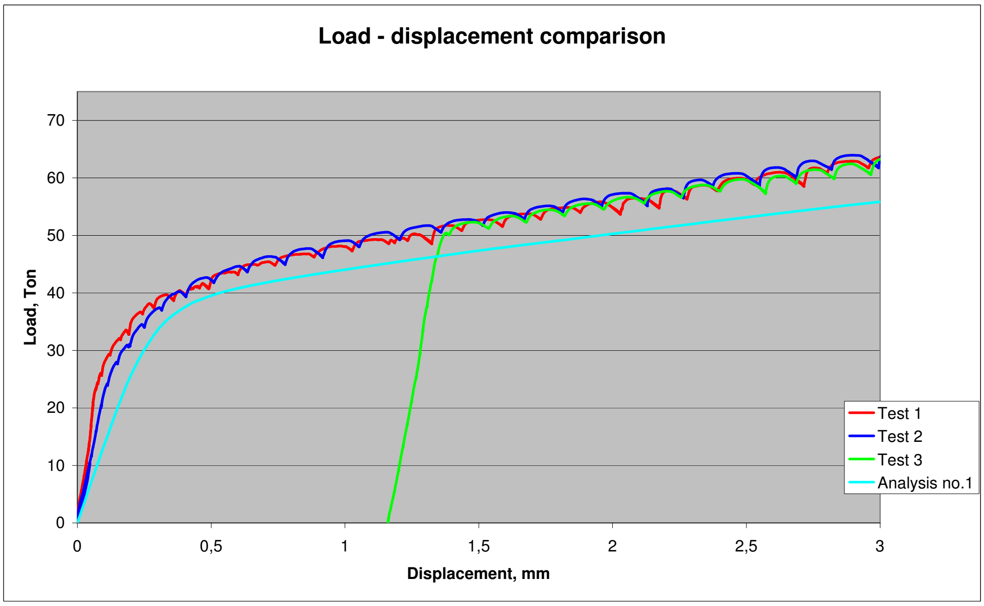

Figure 7.21: Load-displacement curves - comaprison with analysis no. 1

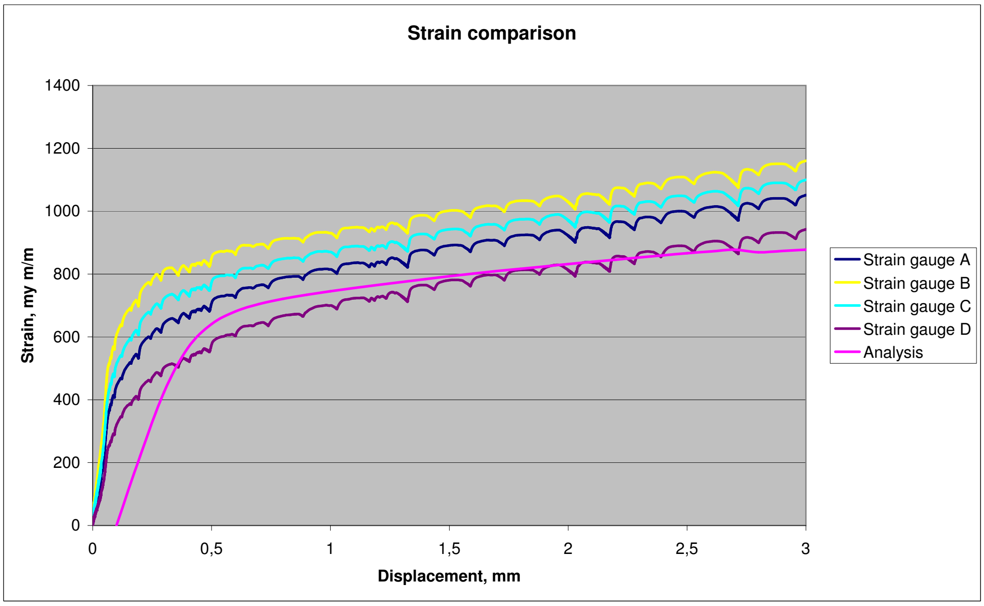

Figure 7.22: Strain-displacement curves - comaprison with analysis no. 1

Item	Displacement	Reaction force	Deviation
Analysis 1	3 mm	56.6 T	NA
Test 1	2.9959 mm	60.5 T	6.45 %
Test 2	2.9989 mm	63.2 T	10.44 %
Test 3	2.9901 mm	63.0 T	10.15 %

Table 7.4: Deviation - analysis no. 1 vs. test

As seen in the plot and in the table, the deviation is between 5-11 % which is approoved for first analiysis run.

The next analysis is with the refines Ramberg-Osgood material curv. Analysis no. 2 is presented in figure 7.21 and table 7.5.

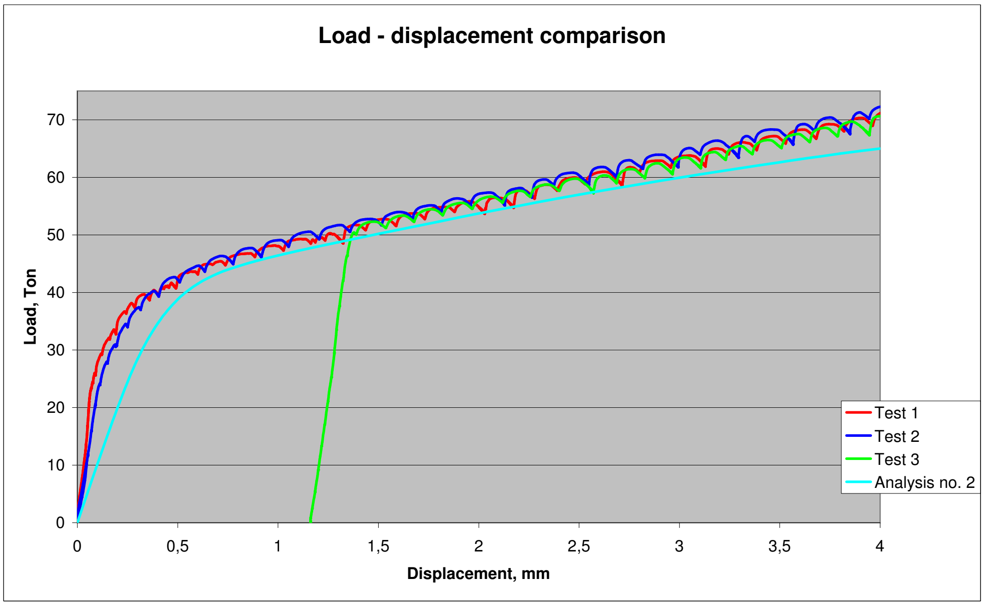

Figure 7.23: Load-displacement curves - comaprison with analysis no. 2

Item	Displacement	Reaction force	Deviation
Analysis 2	3 mm	60.0 T	NA
Test 1	2.9960 mm	63.57 T	5.6 %
Test 2	2.9961 mm	63.62 T	5.69 %
Test 3	2.9901 mm	63.02 T	4.79 %

Table 7.5: Deviation - analysis no. 2 vs. test

From the figure and the table it is noted that a refined material curve fitted in the ANSYS-model gives a deviation between 4-6%, which is as espected. The data from the tensile test increased the ultimate yield limit on the steel with 1.9%.

As the tensile test gave new information about the S355 steel, analysis no. 2 were run further as the Ramberg-Osgood curve became a bit longer. It was run to 4 mm displacement, wich gave the these numbers:

Item	Displacement	Reaction force	Deviation
Analysis 2	4 mm	65.0 T	NA
Test 1	3.9947 mm	60.5 T	8.45 %
Test 2	4.003 mm	63.2 T	9.84 %
Test 3	3.9934 mm	70.6 T	7.93 %

Table 7.6: Deviation - analysis no. 2 vs. test

From these numbers it is observed that the Ramberg-Osgood curve should have been a bit steeper both before and after the 0.2-limit, in order to coinceide better with the measured curves. Some of the deviations are blamed on the settlement in the test jig, as the curves gets a bit closer just after the 0.2-limit.

7.5 Calibration of material curve

As stated in chapter 7.4 the material curve should be adjusted in order to get the analysis model more exact compered to the test results. The Ramberg-Osgood equation is explained in chapter 4.3. The equation consists of two parts, one linear up to the proportional limit (o.1-limit), and one multilinear from the 0.1-limit up to ultimate yield limit. It is from this understood that the gradient of the linear part of the curve must be increased in order to "tilt" the curve up left and closer to the measured results. The gradient in this case is Young's modulus, which is "fixed" after the tensile test, so the only calibration possible at this point is to *try different n-parameters in the Ramberg-Osgood equation.* Figure 7.24 shows the measured results from test no.1 and 2, togheter with analysis no. 2 and an analysis no. 3.

Item	n-parameter	Young's modulus
Analysis 2	12	215 GPa
Analysis 3	10	215 GPa

Table 7.7: Ramberg-Osgood n- parameter

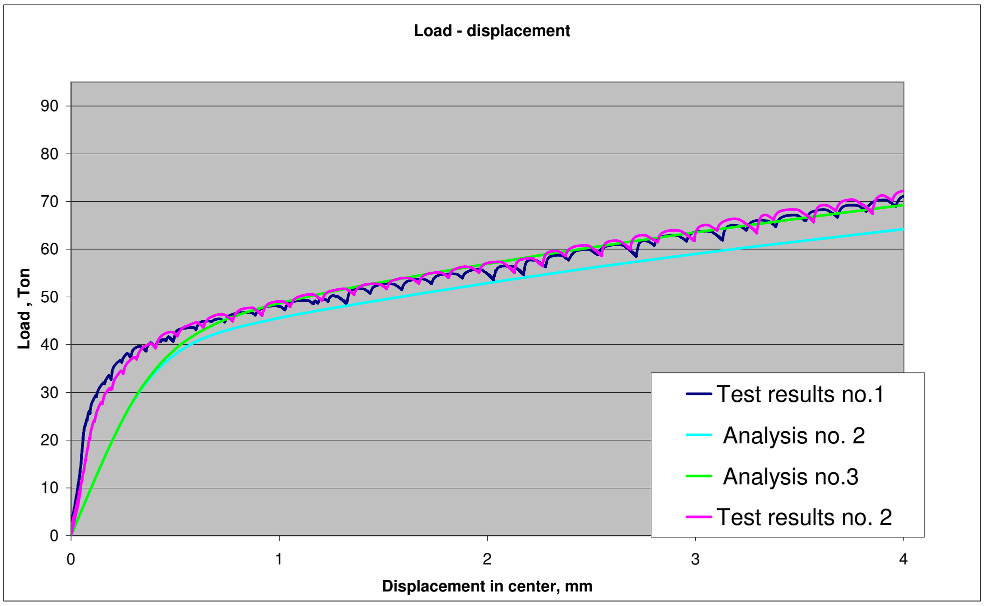

Figure 7.24: Two tests for the n-parameter in the Ramberg-Osgood equation

As the figure (7.24) shows analysis no. 3 with a material curve fitted, Ramberg-Osgood n-parameter $n = 10$ clearly gives a better result. As for the gradient of the test restults, this must be explain by settlement issues, inaccurate set-up of the test jig etc.

7.6 Observations

7.6.1 General

A study of the measuring results shows that there are some matter of necessity to revise the test log for future test runs. Also there is

- Study of shape of fracture zone
- Settlement of equipment
- Deviation in strain around the strain gauge circle
- Evident point of yield

7.6.2 Fracture zone shape study

After the test, test membrane no. 3 was cut in four sections in order to study the shape of the membrane and the fracture zone. A very interesting discovery were done, as the fracture actually occured on the *outside* of the notch, exept from in the fracture starting point. The three next figures shows the section of the test membrane.

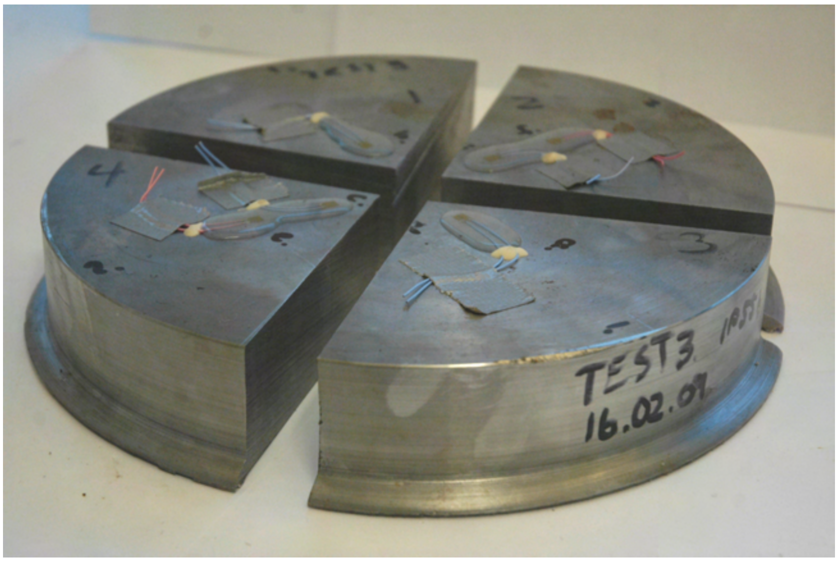

Figure 7.25: Test membrane no.3 cut in four sections

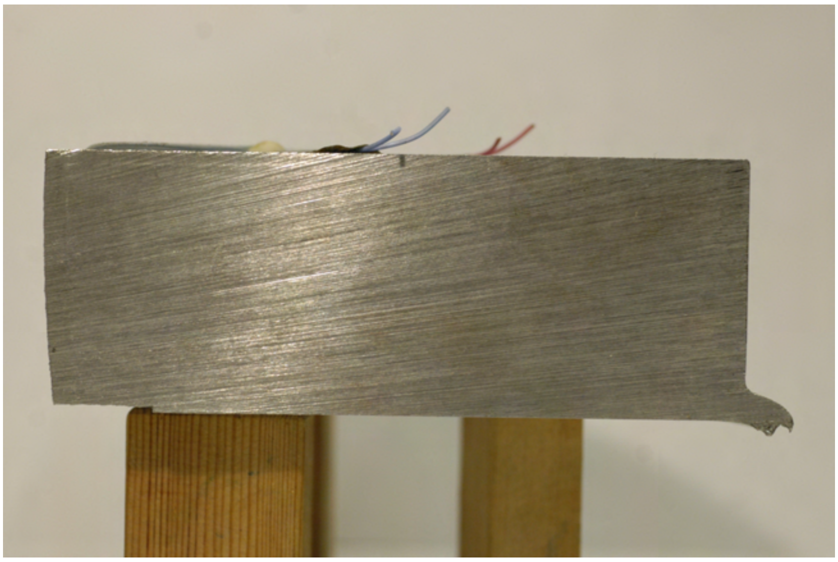

Figure 7.26: Test membrane no.3 cut section

Figure 7.27: Macro photography of notch section

Figure 7.27 shows that the machining of the notch, with a radius in the bottom, will have to be dicussed further. The fracture has started with a vast amount of shear forces, as dicussed earlier, and the contribution of moments from the 6mmmembrane-lip, and in addition got another contribution of moment fro the 2mm “small membrane-lip”. Also note the similarities to the contour plots (figure6.20) of the axis symetric model in chapter 6.5.1.

Fracture initiation, as discussed in chapter 7.3.1 (figures 7.19 and 7.20), has some differens, as the fracture clearly started in the notch. The series of figures shows the fracture initiation.

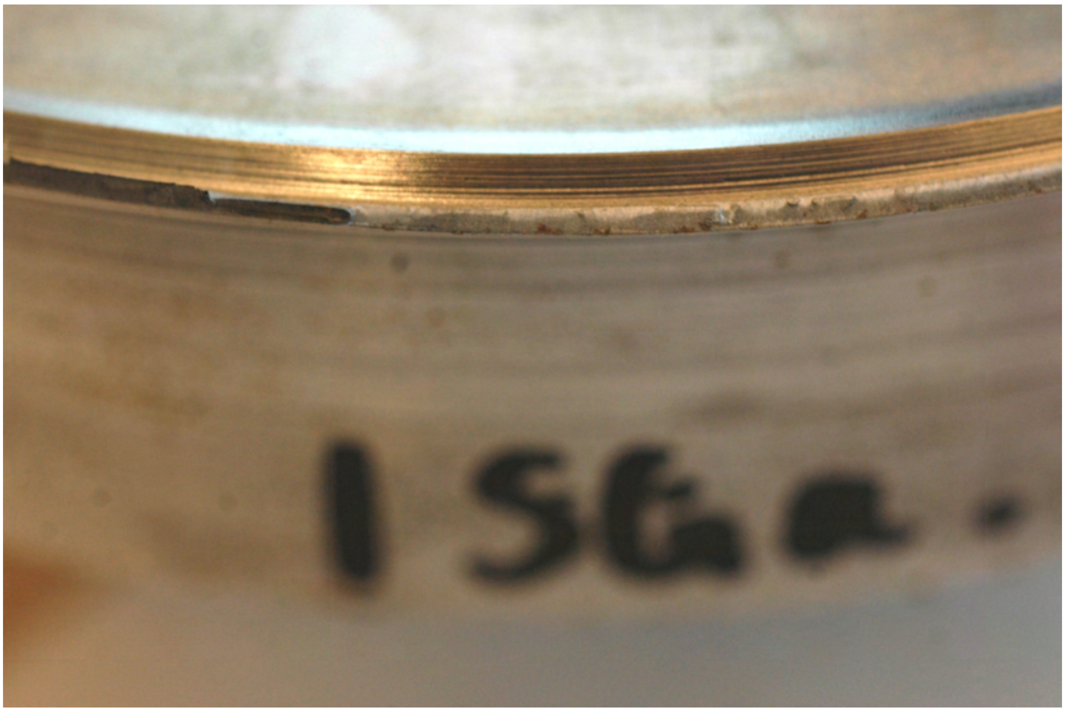

Figure 7.28: Photo of fracture initiation zone, membrane

Figure 7.29: Photo of fracture initiation zone, membrane support ring

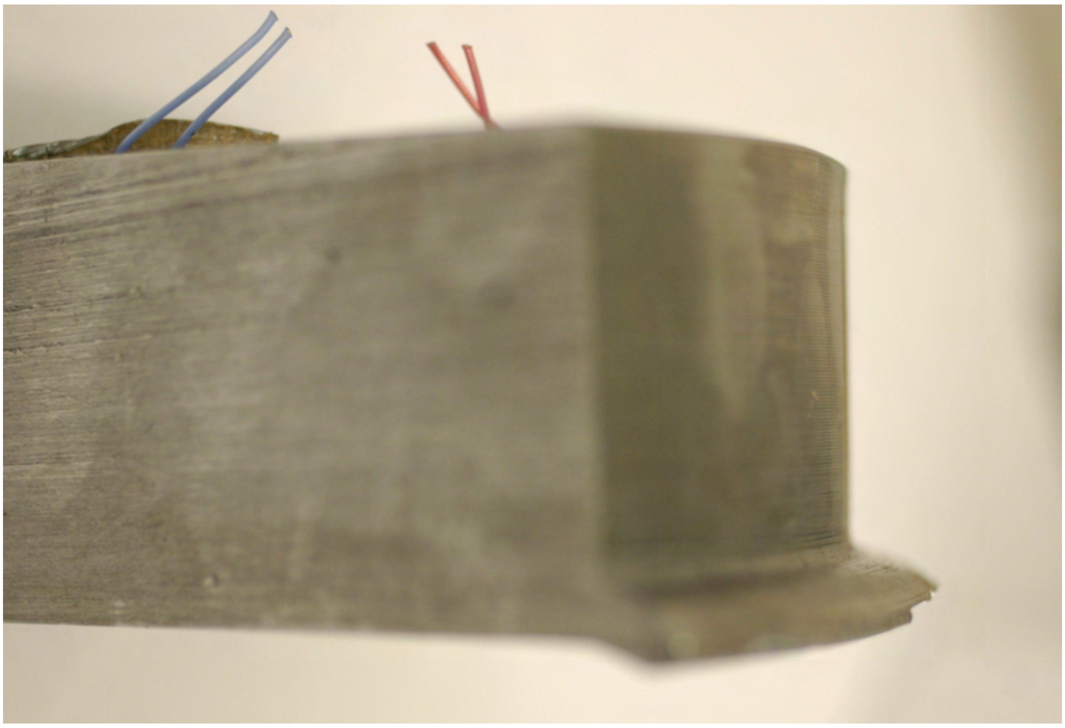

Figure 7.30: Macro photography of fracture init

7.6.3 Settlement of test jig

The settlement was of the test jig was with background in the analysis assumed to done after a double up- and off load sequence of 5-12 Tonnes. This was done in order to register possible deviations from settlement, and bring these observations into the study of the test results. Figure 7.20 shows a zoom-in of the strain-displacement measuring were it appears that the settlement is not fully sat untill approx. $480\mu m/m$. Figure 7.21 shows that a more correct settlement-sequence should rather be 15-20 Tonnes, than the 5-12 tonnes specified in the test log. Figures 7.25, 7.26 and 7.27 in chapter 7.6.4 also shows to analouge meter measures. These was of obvious reasons not observed continually, but had showed that the lock ring did deflect, and must be re-desiged in the future in order not to get measuring faulty.

Figure 7.31: Strain-displacement settlement

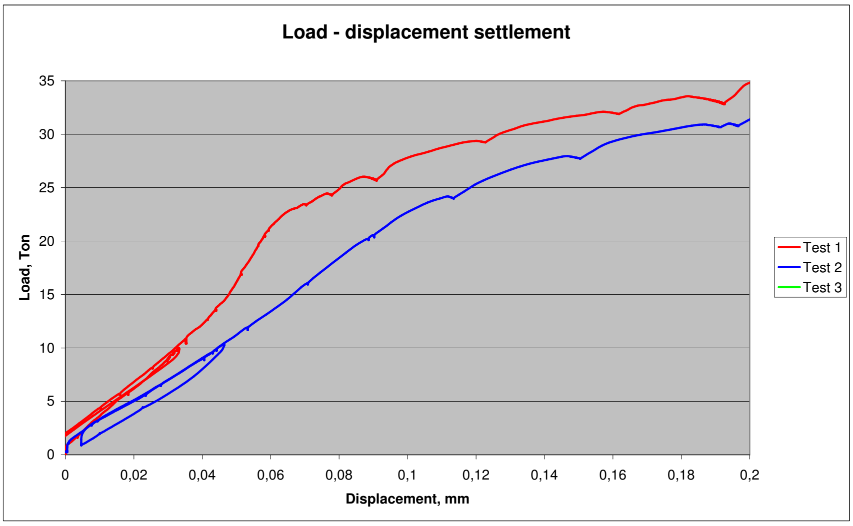

Figure 7.32: Load-displacement settlement

7.6.4 Deviations in measuring plots

As the analysis were concidered axi-symmetric it also assumed that the measurement should be exactly equal. It is obviously not possible to obtain equal measuring in a test such this thesis test. It is obsereved deviations between the measurments from the strain gauges, which can be explained by:

- Some inexact machining tolerances in the test jig
- Small angular straightness deviation of load and load transfer
- Small cylindrical error in load placement
- Some compression of the load transfer
- Small incorrectness from placing of strain gauges
- Inhomogeneity in material or surface (not likely)

All in all there are very small deviations in he measurements, and it has to be seen in connection of the loads subjecte to the test membranes. As it is subject 80-100 Tonnes to a test specimen, a deviation $200\mu m/m$ must be seen as exact enough for this application. As for the further work in the developement of the MHTT, the correctness of the test set-up should be discussed and a more precise analysis be executed.

7.6.5 Evident point of yield

The strain plots in figures 7.13, 7,14 and 7.15 shows an evident point of yield. A close study of the plots shows that there are small local yield points and the strain hardening occures just after a load step. This is the horisontal "plateaus" in between the small "tops". At the top the yield limit has been met, and the curves starts to fall, and the hole noch area is at yield. Still there are some signs of strain hardening, but the material is clearly "giving up".

7.6.6 Pictures of tested membranes

In the following a series of pictures taken from the filming of the test are presented. The camera used was a Canon IXUS with a recording of 25 frames/second, so some of the "snap shots" are a bit blury. Note the test mambrane elevates up trough the lock ring and the movement on the LVDT's.

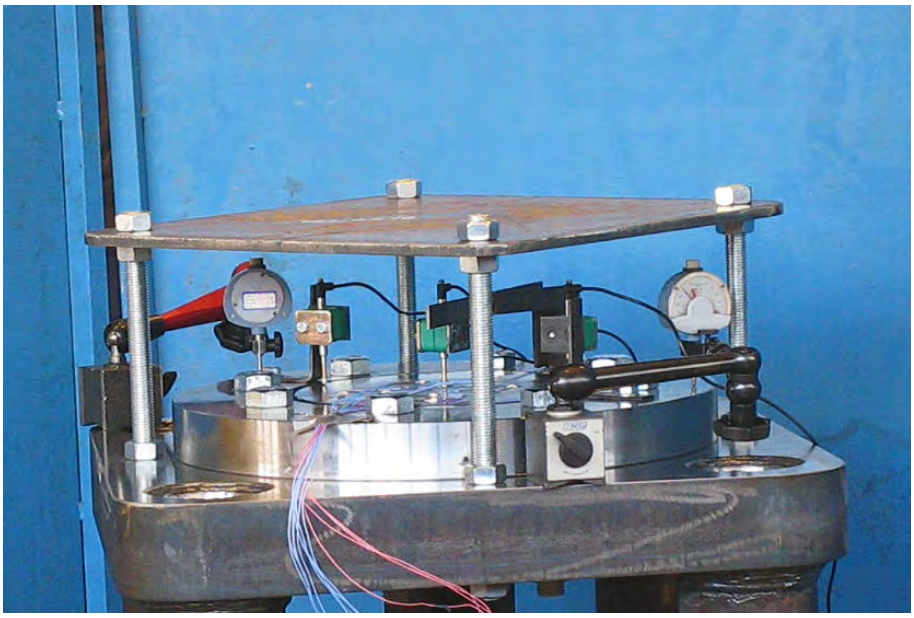

Figure 7.33: Up-loaded to approx. 30 Tonnes. Test no. 1

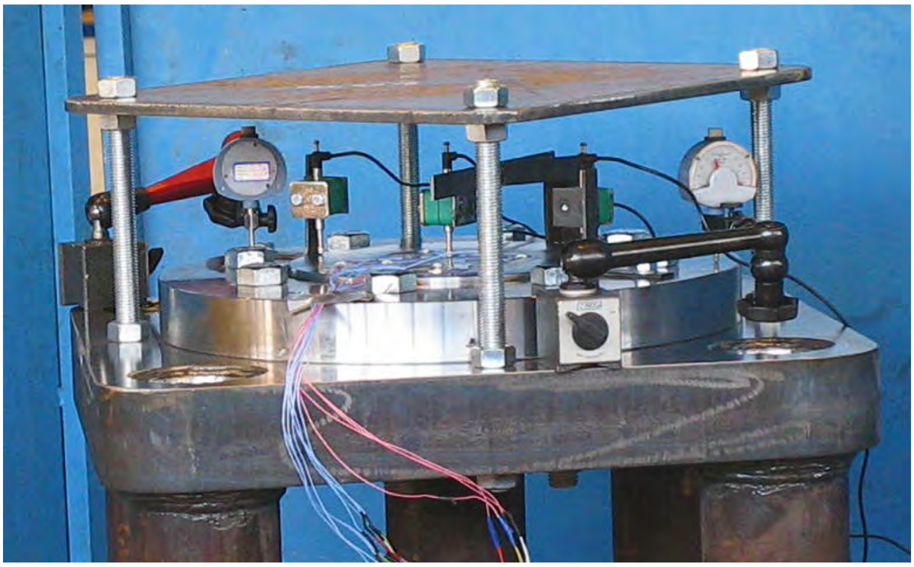

Figure 7.34: Stabilized yield at approx. 70 Tonnes. Test no. 1

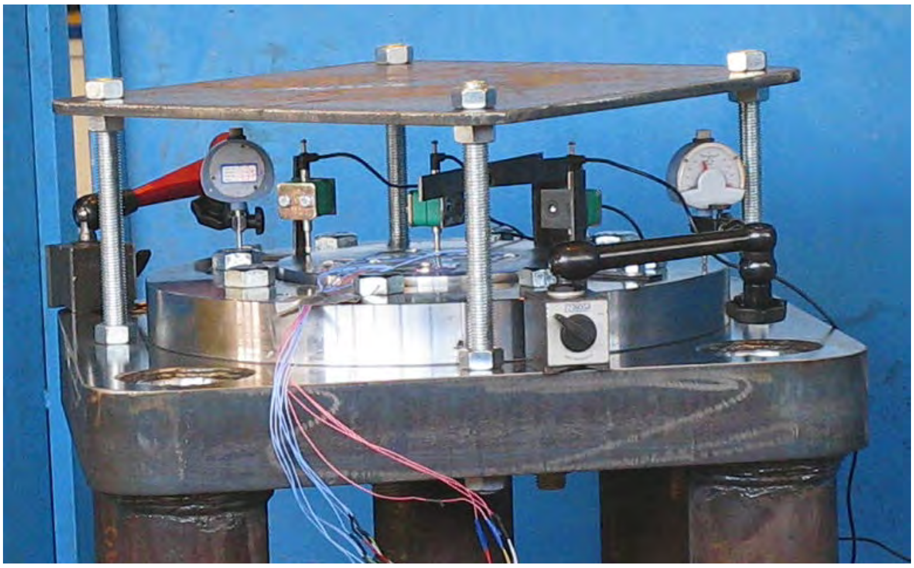

Figure 7.35: Just before fracture at approx. 88 Tonnes. Test no. 1

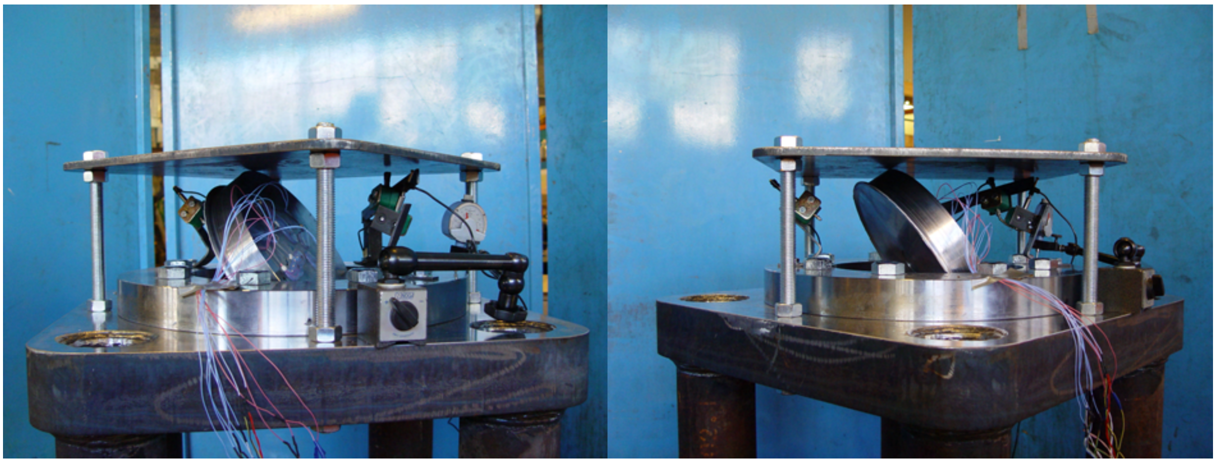

Figure 7.36: Test no. 1. Success, but destroyed LVDT

The next picture is from test no. 3 after dismounting of the logging equipment. The next figure shows the enegry release at fracture. Note the *"jumpin' jack",(but no flash).*

Figure 7.37: Fracture occurs. Energy release.

Chapter 8

Summary and conclusion

8.1 Conclusion and further work

8.1.1 Conclusion

In this Thesis a prototype of the Membrane Hot Tap Tee plate has been designed and modelled in ANSYS. Three test plates and test jig have been fabricated and tested with physical experiments. There is good agreement between the mathematical model and the test results.

There is done some very interesting discoverys, both theoretical and practical during the work with this thesis. That the powerful theory of axis symmetry is valid in the analysis of circular objects, makes a relatively simple mathematial model valid up to the ultimate yield limit. A refined ANSYS-model, with adaptive meshing would have gotten the analysis farther, and to model a fracture by killing elements[1]. However, the comparison of the model and the test data showed a very accurate result for this purpose, as it ranged a bit lower than the test. Only a minor adjustment of the material curve got the model to meet the test data.

The use of the Ramberg-Osgood equation to fit the material curve in the ANSYS-model have shown remarkably good approximation to the real material used in the test membranes. The deviations between the anlysis model and the test results was between 5-11%.

As a “first-shot” in the developement of the Membrane Hot Tap Tee, the thesis gives a good impression of the behaviour of the membrane, and is a good foundation to further work.

8.2 Further work

8.2.1 ANSYS-model

The ANSYS-model developed in this Thesis is adapted to a complete circular plate. During the work with this Thesis there are done observations that prepares to further develope the model. Since the shear force is the main force component, the model should be developed with a “knob”, or discontinuity, on the diameter of the notch groove in order to transfer even more shear forces directly into the notch. The “knob” could be called a *stress intensifier*. This way a fracture may be obtained with a lower load subjected to the system. A preliminary 3D-model is prepared to support this theory. Figure 8.1and 8.2 shows a preliminary 3D-model of the test mebrane. Several issues of the discontinuity on the diameter are analysed, and so far this is the most promising.

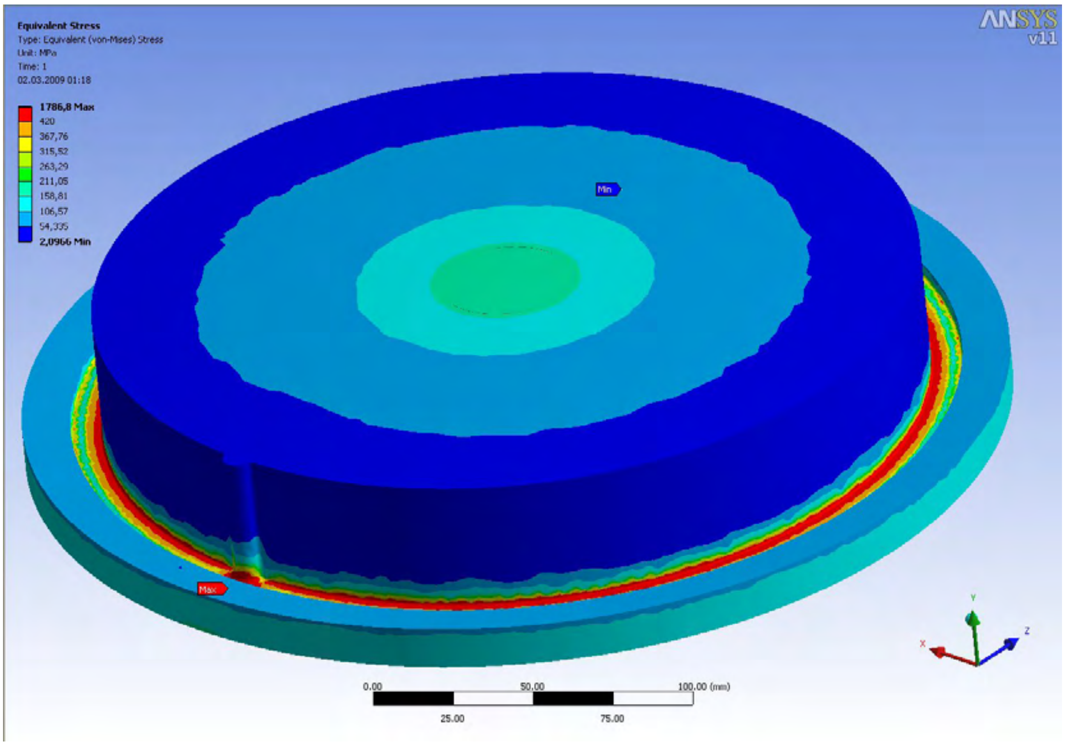

Figure 8.1: Preliminary 3D-model of the test membrane

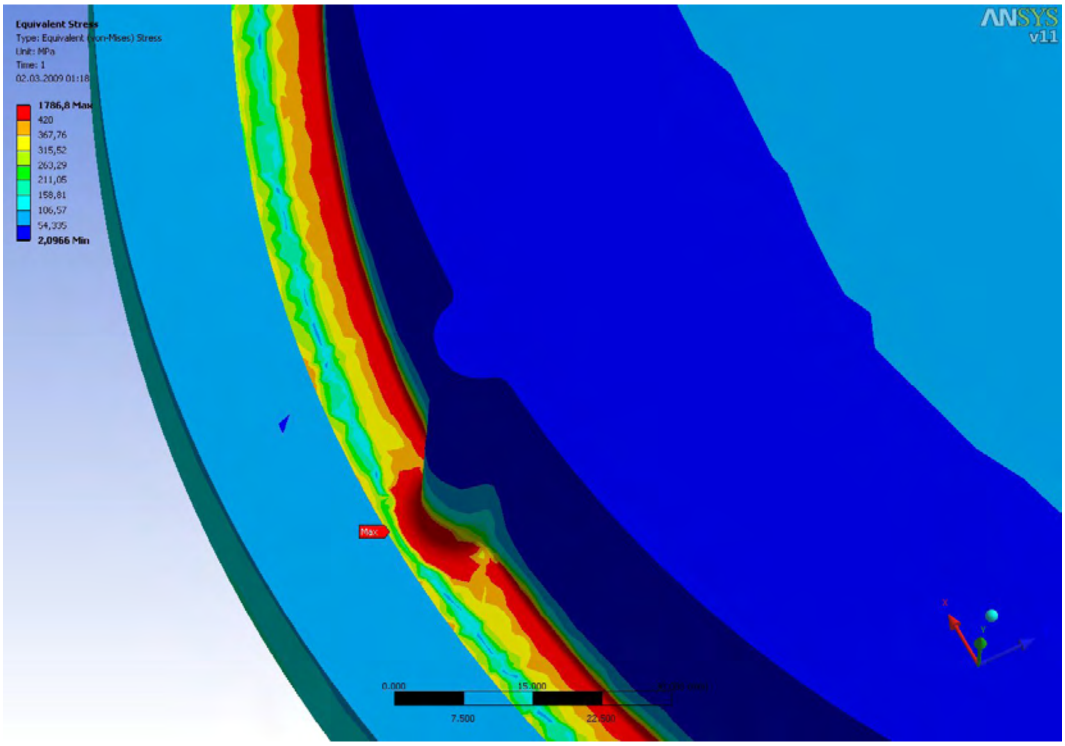

Figure 8.2: Preliminary 3D-model of the test membrane. Zoomed.

8.2.2 Standard check

If a further developement of the Mebrane Hot Tap Tee will take place, it obvious that the standrad check must be more exact. The list sums up the limitations assumed to be out of the scpoe of this thesis.

- Corrosion allowence
- The notch will be filled with a material which will prevent contact with the pipeline medium and formation of flux (Cladding of material,GRP, rubber etc.)
- Forces and moments from pipeline installation and handling of the MHTT
- Temperature variations

Bibliography

[1] ANSYS. Inc., Pittsburgh. *Release 11.0 Documentation for ANSYS*.

[2] Geir Rune Arntsen. *Stålboka*. Tapir Akademisk Forlag, Trondheim, første edition, 2000.

[3] Nemo Engineering AS. *Standard for fasteners*, 2008.

[4] Crawford Benham and Armstrong. *Mechanics of Engineering Materials*. PEARSON Prentice Hall, Essex England, second edition, 1996.

[5] Robert D. Cook, David S. Malkus, Michael E. Plesha, and Robert J. Witt. *Concepts and Applications of Finite Element Analysis*. John Wiley & Sons. inc.,New York, fourth edition, 2002.

[6] Nemo Engineering. Ormen lange southern development. Project file.

[7] Mikael W. Braestrup [et.al]. *Design and installation of Marine Pipelines*. Blackwell Publishing, Oxford, first edition, 2005.

[8] Tor Erik Hals. *Konstruksjonsmekanikk*. Tapir Forlag, Trondheim, second edition, 1999.

[9] Jostein Hellesland. *A study into the sustained and cyclic load behaviour of reinforced concrete colomns*. Department of Civil Engineering,UNIVERSITY OF WATERLOO, Waterloo, Ontario, 1970.

[10] Stelios Kyriakides and Edmundo Corona. *Mechanics of offshore pipelines, Vol. 1: Buckling and Collapse*. ELSEVIER, Oxford, first edition, 2007.

[11] Carl Henrik Ahlen & Per Lillejordet. Developement of a diverless hot tapping system for deep water pipelines. Paper.

[12] NAFEMS. *A Finite Element Primer*. NAFEMS BIRNIEHILL EAST KILBBRIDE GLASGOW, third edition, 1992.

[13] Geir Skeie. Mek4560 elementmetoden i faststoffmekanikk i. Avdeling for mekanikk, Matematisk institutt, Universitetet i Oslo.

[14] American Society Mechanical Engineers Standards. *2007 ASME Boiler & Pressure Vessel Code*, 2007.

[15] Statoil. *Specification for Manufacturing of Forged and Hot Formed Components in Low Alloy Steel*, Valid from 2007-03-26.

[16] StatoilHydro. Ormen lange southern development. Project file.

[17] Det Norske Veritas. *Offshore Standard DNV OS-F-101, Submarine Pipeline Systems*, Jan. 2000.

[18] W.Ramberg & W.R.Osgood. Description of stress-strain curves by three parameters. TECHNICAL NOTE no. 902, NASA.

[19] Warren C. Young. *Roark's Formulas for Stress and Strain, Sixth Edition*. McGraw-Hill Book Company, New York, 1989.

Appendix A

Input files

A.1 Input file

```
FINISH
/CLEAR

!========================
!    Parameters
!========================

*ABBR,INPUT,/INP,IP556-HTT-AKJ-01-RE-2D-10_11_es0125,INP


EMOD=207000
POIS=0.3

ALPHA=11.7e-6
DENS=7850*0.87*e-9



ID=0
R1=150 !Ytre radie
R2=140 !Radie sveis/fastinnspent opplager
R3=135 !KJERVPLASSERING
R4=125 !
R5=134
K=135
```

```
T1=5
T2=T1+1
T3=30 !
T4=48
T5=0 !avstand fra T1

RA=2.999 !Flytter kjerv radielt Fra -5 til 2.95
RB=1.646 !kjervvinkel Fra 1.1(0deg) til 4.556(90deg)
RC=1.1 !Kjerv radie fra 1.1 til 0.2


!Plassering av forskyvning i Y-rtning langs X

D1=0 !start x1
D2=D1+20 !slutt x2

D3=0.0 !Forskyvninger i loadstep


!Meshsizing


ES1=0.125 !ELEMENTSTR

ES2=ES1*2

ANT=30 !ant lastskritt


!=========================
!    MODEL
!=========================

/prep7

! ----------- Material properties ----------------

MP,EX,1,EMOD
MP,PRXY,1,POIS
MP,ALPX,1,ALPHA
MP,DENS,1,DENS


TB,MISO,1,1,40  ! Ramberg-Osgood S355 svart
TBPT,DEFI,0,0
```

```
TBPT,DEFI,300/EMOD,300
TBPT,DEFI,1.94E-03,330
TBPT,DEFI,2.05E-03,335
TBPT,DEFI,2.17E-03,340
TBPT,DEFI,2.32E-03,345
TBPT,DEFI,2.49E-03,350
TBPT,DEFI,2.70E-03,355
TBPT,DEFI,2.94E-03,360
TBPT,DEFI,3.23E-03,365
TBPT,DEFI,3.58E-03,370
TBPT,DEFI,3.98E-03,375
TBPT,DEFI,4.46E-03,380
TBPT,DEFI,5.03E-03,385
TBPT,DEFI,5.71E-03,390
TBPT,DEFI,6.51E-03,395
TBPT,DEFI,7.45E-03,400
TBPT,DEFI,8.56E-03,405
TBPT,DEFI,9.87E-03,410
TBPT,DEFI,1.14E-02,415
TBPT,DEFI,1.32E-02,420
TBPT,DEFI,1.53E-02,425
TBPT,DEFI,1.78E-02,430
TBPT,DEFI,2.41E-02,440
TBPT,DEFI,3.26E-02,450
TBPT,DEFI,4.40E-02,460
TBPT,DEFI,5.94E-02,470
TBPT,DEFI,7.98E-02,480
TBPT,DEFI,1.07E-01,490
TBPT,DEFI,1.42E-01,500
TBPT,DEFI,1.89E-01,510
TBPT,DEFI,2.50E-01,520
TBPT,DEFI,3.29E-01,530



! ----------- Real constants ----------------

R,1,! PLANE42
!R,2,,,!CONTAC12

! ----------- Geometry ----------------

K,1,0,0,0 !
K,2,R4-15,0,0
K,3,R4-15,T4,0
```

```
K,4,0,T4,0

L,1,2
L,2,3
L,3,4
L,4,1

AL,1,2,3,4

K,5,R4,0,0
K,6,R4,T1,0
K,7,R4,T4,0

L,2,5
L,5,6
L,6,7
L,7,3 !linje 8

AL,2,5,6,7,8

!!!!KJERV

K,8,R3+RA-RB,0,0
K,9,R3+RA,9.335,0  !kjervhøyde fra null
K,10,R3+RA+RB,0,0


K,11,R2,0,0 !-0.05
K,12,R2,-10,0 !-0.05
K,13,R1+10,-10,0
K,14,R1+10,T1,0
K,15,R2,T1,0

K,16,R3+RA,T1,0
K,17,R3+RA,T2,0

L,5,8 !LINJE 9
L,8,9
L,9,10
L,10,11
L,11,12 !13
L,12,13
L,13,14
L,14,15
L,15,16
```

```
L,16,17
L,16,6 !19
L,11,15

K,18,R3+RA,T1-0.1,0

LFILLT,10,11,RC,18

AL,6,9,10,21,11,12,20,17,19
AL,13,14,15,16,20

!11/EOF

K,21,R3-5,T4,0
K,22,R3-5,T2,0
K,23,R2,T2,0
K,24,R2,T3,0
K,25,R1+10,T3,0

L,7,21
L,21,22
L,23,24
L,24,25
L,25,14
L,22,17
L,17,23

LFILLT,23,27,0.8,
LFILLT,28,24,0.8,

AL,7,22,23,27,18,19,29
!/EOF
AL,17,18,28,24,25,26,16,30


!/eof
 ----------- Element types ----------------

ET,1,82,,0,1,0,0 !2-D Structural Solid-Axisymmetric
TYPE,1
REAL,1

!AREA 1
ALLSEL
ESIZE,6
```

```
MSHKEY,1
AMESH,1


!AREA 2
ALLSEL
ESIZE,3
MSHKEY,0
AMESH,2

!AREA 3
ALLSEL
ESIZE,1
MSHKEY,0

LESIZE, 9,  ES1 !,       ,     ,0.005    ,    ,   1  ,20     ,0

!LESIZE, NL1, SIZE, ANGSIZ, NDIV, SPACE, KFORC, LAYER1, LAYER2, KYNDIV

LESIZE,10,ES1!11,,,es1,,,0,0 !kjerv venstre
LESIZE,21,ES1,180,,,,ES1,50,0 !MESH I kJERVRADIE
LESIZE,11,ES1,!,,5,,1,0,0 !kjerv høyre
LESIZE,12,ES1

LESIZE,19,ES1!,,,1250,,1

LESIZE,17,ES1!111,,,0.005,,1
LESIZE,20,ES1
AMESH,3

!AREA 4
ALLSEL
ESIZE,3
MSHKEY,0
AMESH,4


!AREA 5
ALLSEL
ESIZE,3
MSHKEY,0

LESIZE,23,ES2,,,0.25,,3, !R=0.2 ON, R=1.1 OFF
LESIZE,27,ES1
LESIZE,29,ES1
```

```
LESIZE,18,ES1
AMESH,5

!AREA 6
ALLSEL
ESIZE,3
MSHKEY,0

LESIZE,28,ES1
LESIZE,24,ES2,,,25,,3,
LESIZE,30,ES1
AMESH,6

allsel

!/eof

!!! mesh slutt

NSEL,S,LOC,X,R1+10
NSEL,R,LOC,Y,-10,T3
CM,RLIN1,NODE

NSEL,S,LOC,X,R2 !Vertikal linje på R1
NSEL,R,LOC,Y,0,T2
CM,RLIN2,NODE

ALLSEL

NSEL,S,LOC,X,R1+10,R2
NSEL,R,LOC,Y,T3
CM,TLIN1,NODE

ALLSEL

NSEL,S,LOC,Y,-10
NSEL,R,LOC,X,R1+10,R2 !understøtte på kjerv
CM,TLIN2,NODE

NSEL,S,LOC,X,0
NSEL,R,LOC,Y,0,T4
CM,CENT,NODE

NSEL,S,LOC,X,0,50
NSEL,R,LOC,Y,T5
```

```
CM,TOPL,NODE

!*GET, NMID, NODE, 0, NUM, MAX
SAVE

NSEL,S,LOC,X,R1

NSEL,R,LOC,Y,T3,T3+10
CM,YLIN,NODE

allsel
FINISH

!/eof

!=======================
!    SOLUTION
!=======================


/SOL

OUTRES,ALL,ALL
NLGEOM,ON
AUTOTS,ON


*DO,J,1,ANT,1

! ------Load step :Apply vertical displacement----------------

ALLSEL

!D,RLIN1,ALL

D,TLIN1,ALL !D-DOF constrains at Node

D,TLIN2,ALL

ALLSEL

D,CENT,UX
!D,YLIN,UX,0

NSEL,S,LOC,X,D1,D2
```

```
NSEL,R,LOC,Y,T5

D,ALL,UY,D3+(1/10)*J

ALLSEL
SOLVE
*ENDDO

FINISH

!=======================
!    POST PROCESSING
!=======================

/POST1

*DO,I,1,ANT,1

*IF,I,EQ,1,THEN

/OUTPUT,REACTIONS,TXT

*VWRITE,
('Project no: IP556 - Membrane HTT')
*VWRITE,
('Analysis:   Pull-out force and deflection')



*VWRITE,
(' ')
*VWRITE,
('      DEF1    REACTION     STRAIN GAUGE1   STRAIN GAUGE2   MAX STRESS   NOD.NR SIG

STRAIN   NOD.NR EPS ')
*VWRITE,
('_______________________________________________________________________________

_____________________')

/OUTPUT, TERM

*ENDIF
```

```
SET,I
NSEL,S,LOC,X,D1,D2
NSEL,R,LOC,Y,T5
FSUM,,
*GET, REACT%I%, FSUM, 0, ITEM, FY,

PK1=NODE(D1,T5,0)
*GET, DEFL%I%, NODE, PK1, U, Y

!PK2=NODE(50,T4,0)
*GET, STRA1%I%, NODE, 86, EPTO, X !STREKKLAPP1

!PK2=NODE(50,T4,0)
*GET, STRA3%I%, NODE, 76, EPTO, X !STREKKLAPP2

ALLSEL
NSORT,S,EQV,0,0,,,
*GET, STRE1%I%, SORT,0,MAX,,,
*GET, NSTRE1%I%, SORT,0,IMAX,,,

!NSORT, Item, Comp, ORDER, KABS, NUMB, SEL
ALLSEL
NSORT ,EPTO , XY  ,     0,    ,     ,0

*GET, STRA2%I%, SORT,0,MAX,,,
*GET, NSTRA2%I%, SORT,0,IMAX,,,


/OUTPUT,REACTIONS,TXT,,APPEND

*VWRITE,DEFL%I%,REACT%I%,STRA1%I%,STRA3%I%,STRE1%I%,NSTRE1%I%,STRA2%I%,NSTRA2%I%,
(F10.3,F11.0,F13.6,F16.6,F14.2,F12.0,F15.6,F10.0)

/OUTPUT, TERM

*ENDDO

/OUTPUT,TERM


PLNSOL,S,EQV

!YB=UY(NMID)
```

```
/EOF
```

Appendix B

Table plots in ANSYS

B.1 Material curves

B.1.1 S355 - Material sertificate

Ramberg-Osgood curve table implemented in ANSYS for analysis run with material sertificate values. Simple adaption.

```
TBPT,DEFI,0,0
TBPT,DEFI,300/EMOD,300
TBPT,DEFI,1.94E-03,330
TBPT,DEFI,2.05E-03,335
TBPT,DEFI,2.17E-03,340
TBPT,DEFI,2.32E-03,345
TBPT,DEFI,2.49E-03,350
TBPT,DEFI,2.70E-03,355
TBPT,DEFI,2.94E-03,360
TBPT,DEFI,3.23E-03,365
TBPT,DEFI,3.58E-03,370
TBPT,DEFI,3.98E-03,375
TBPT,DEFI,4.46E-03,380
TBPT,DEFI,5.03E-03,385
TBPT,DEFI,5.71E-03,390
TBPT,DEFI,6.51E-03,395
TBPT,DEFI,7.45E-03,400
TBPT,DEFI,8.56E-03,405
TBPT,DEFI,9.87E-03,410
TBPT,DEFI,1.14E-02,415
TBPT,DEFI,1.32E-02,420
TBPT,DEFI,1.53E-02,425
```

```
TBPT,DEFI,1.78E-02,430
TBPT,DEFI,2.41E-02,440
TBPT,DEFI,3.26E-02,450
TBPT,DEFI,4.40E-02,460
TBPT,DEFI,5.94E-02,470
TBPT,DEFI,7.98E-02,480
TBPT,DEFI,1.07E-01,490
TBPT,DEFI,1.42E-01,500
TBPT,DEFI,1.89E-01,510
TBPT,DEFI,2.50E-01,520
TBPT,DEFI,3.29E-01,530
```

B.1.2 S355 - Tensile test

Ramberg-Osgood curve table implemented in ANSYS for analysis run with tensile test values.

```
TBPT,DEFI,0,0
TBPT,DEFI,280/emod,280
TBPT,DEFI,1.51E-03,300
TBPT,DEFI,2.99E-03,360
TBPT,DEFI,4.49E-03,380
TBPT,DEFI,5.68E-03,390
TBPT,DEFI,7.31E-03,400
TBPT,DEFI,8.33E-03,405
TBPT,DEFI,9.51E-03,410
TBPT,DEFI,1.09E-02,415
TBPT,DEFI,1.25E-02,420
TBPT,DEFI,1.43E-02,425
TBPT,DEFI,1.65E-02,430
TBPT,DEFI,1.89E-02,435
TBPT,DEFI,2.18E-02,440
TBPT,DEFI,2.50E-02,445
TBPT,DEFI,2.88E-02,450
TBPT,DEFI,3.31E-02,455
TBPT,DEFI,3.81E-02,460
TBPT,DEFI,4.38E-02,465
TBPT,DEFI,5.02E-02,470
TBPT,DEFI,5.76E-02,475
TBPT,DEFI,6.61E-02,480
TBPT,DEFI,7.57E-02,485
```

```
TBPT,DEFI,8.66E-02,490
TBPT,DEFI,1.13E-01,500
TBPT,DEFI,1.47E-01,510
TBPT,DEFI,1.91E-01,520
TBPT,DEFI,2.46E-01,530
TBPT,DEFI,3.16E-01,540
TBPT,DEFI,4.04E-01,550
TBPT,DEFI,5.14E-01,560
TBPT,DEFI,5.79E-01,565
TBPT,DEFI,6.52E-01,570
TBPT,DEFI,7.34E-01,575
TBPT,DEFI,8.24E-01,580
TBPT,DEFI,9.25E-01,585
TBPT,DEFI,1.04E+00,590
TBPT,DEFI,1.16E+00,595
TBPT,DEFI,1.30E+00,600
TBPT,DEFI,1.46E+00,605
TBPT,DEFI,1.63E+00,610
TBPT,DEFI,1.82E+00,615
TBPT,DEFI,2.02E+00,620
TBPT,DEFI,2.26E+00,625
TBPT,DEFI,2.51E+00,630
TBPT,DEFI,2.79E+00,635
TBPT,DEFI,3.11E+00,640
TBPT,DEFI,3.45E+00,645
TBPT,DEFI,3.83E+00,650
TBPT,DEFI,4.25E+00,655
TBPT,DEFI,4.70E+00,660
TBPT,DEFI,5.21E+00,665
TBPT,DEFI,5.76E+00,670
TBPT,DEFI,6.37E+00,675
TBPT,DEFI,7.04E+00,680
TBPT,DEFI,7.77E+00,685
TBPT,DEFI,8.57E+00,690
TBPT,DEFI,9.45E+00,695
TBPT,DEFI,1.04E+01,700
TBPT,DEFI,1.15E+01,705
TBPT,DEFI,1.26E+01,710
```

B.1.3 S355 - Adapted

Ramberg-Osgood curve table implemented in ANSYS for analysis run with values adapted to increase slope.

```
TBPT,DEFI,0,0
TBPT,DEFI,300/EMOD,300
TBPT,DEFI,1.57E-03,300
TBPT,DEFI,2.78E-03,360
TBPT,DEFI,3.67E-03,380
TBPT,DEFI,4.28E-03,390
TBPT,DEFI,5.04E-03,400
TBPT,DEFI,5.49E-03,405
TBPT,DEFI,5.98E-03,410
TBPT,DEFI,6.53E-03,415
TBPT,DEFI,7.13E-03,420
TBPT,DEFI,7.81E-03,425
TBPT,DEFI,8.56E-03,430
TBPT,DEFI,9.38E-03,435
TBPT,DEFI,1.03E-02,440
TBPT,DEFI,1.13E-02,445
TBPT,DEFI,1.24E-02,450
TBPT,DEFI,1.37E-02,455
TBPT,DEFI,1.50E-02,460
TBPT,DEFI,1.65E-02,465
TBPT,DEFI,1.81E-02,470
TBPT,DEFI,1.99E-02,475
TBPT,DEFI,2.19E-02,480
TBPT,DEFI,2.41E-02,485
TBPT,DEFI,2.65E-02,490
TBPT,DEFI,3.19E-02,500
TBPT,DEFI,3.85E-02,510
TBPT,DEFI,4.63E-02,520
TBPT,DEFI,5.55E-02,530
TBPT,DEFI,6.65E-02,540
TBPT,DEFI,7.94E-02,550
TBPT,DEFI,9.46E-02,560
TBPT,DEFI,1.03E-01,565
TBPT,DEFI,1.12E-01,570
TBPT,DEFI,1.23E-01,575
TBPT,DEFI,1.33E-01,580
TBPT,DEFI,1.45E-01,585
TBPT,DEFI,1.58E-01,590
TBPT,DEFI,1.71E-01,595
TBPT,DEFI,1.86E-01,600
TBPT,DEFI,2.02E-01,605
TBPT,DEFI,2.19E-01,610
TBPT,DEFI,2.38E-01,615
TBPT,DEFI,2.57E-01,620
```

```
TBPT,DEFI,2.79E-01,625
TBPT,DEFI,3.02E-01,630
TBPT,DEFI,3.26E-01,635
TBPT,DEFI,3.53E-01,640
TBPT,DEFI,3.81E-01,645
TBPT,DEFI,4.11E-01,650
TBPT,DEFI,4.44E-01,655
TBPT,DEFI,4.79E-01,660
TBPT,DEFI,5.16E-01,665
TBPT,DEFI,5.56E-01,670
TBPT,DEFI,5.99E-01,675
TBPT,DEFI,6.44E-01,680
TBPT,DEFI,6.93E-01,685
TBPT,DEFI,7.45E-01,690
TBPT,DEFI,8.01E-01,695
TBPT,DEFI,8.60E-01,700
TBPT,DEFI,9.23E-01,705
TBPT,DEFI,9.91E-01,710
```

Appendix C

Analysis results

C.1 Printout from analysis

REACTIONS_es_025_ro_n10_E215_til oppgave.txt

Project no: IP556 - Membrane HTT
Analysis: Pull-out force and deflection

DEF1 STRAIN	REACTION	STRAIN GAUGE1	STRAIN GAUGE2	MAX STRESS	NOD.NR STRESS	MAX STRAIN	NOD.NR
0.100	-140423.	0.00022127	0.00008569	371.47	911.	0.00053887	903.
0.200	-264661.	0.00042157	0.00016605	440.03	909.	0.00097649	805.
0.300	-350418.	0.00056762	0.00022917	488.11	909.	0.00115928	805.
0.400	-402033.	0.00066024	0.00027177	522.30	911.	0.00123420	2968.
0.500	-433176.	0.00071748	0.00029881	548.77	911.	0.00183819	4375.
0.600	-454015.	0.00075536	0.00031649	568.96	911.	0.00278960	4374.
0.700	-469561.	0.00078205	0.00032853	584.67	911.	0.00374821	4374.
0.800	-482156.	0.00080104	0.00033702	597.33	911.	0.00465602	4374.
0.900	-493069.	0.00081605	0.00034344	607.59	911.	0.00550315	4374.
1.000	-502925.	0.00082859	0.00034865	616.04	911.	0.00628730	4374.
1.100	-512260.	0.00083801	0.00035296	622.93	911.	0.00706522	4374.
1.200	-521008.	0.00084523	0.00035691	628.70	911.	0.00771177	4374.
1.300	-529431.	0.00083591	0.00036045	633.66	911.	0.00825412	4375.
1.400	-537542.	0.00083956	0.00036375	639.17	909.	0.00882107	4375.
1.500	-545635.	0.00084281	0.00036672	644.14	909.	0.00931629	4375.
1.600	-553257.	0.00084796	0.00036974	648.66	909.	0.01030049	905.
1.700	-560902.	0.00085613	0.00037247	652.85	909.	0.01465945	905.
1.800	-568343.	0.00086400	0.00037511	656.56	909.	0.01893062	905.
1.900	-575555.	0.00084118	0.00037771	659.85	909.	0.02284868	905.
2.000	-582698.	0.00085491	0.00038004	662.76	909.	0.02681183	905.
2.100	-589829.	0.00086861	0.00038227	665.20	909.	0.03058032	905.
2.200	-596742.	0.00088229	0.00038456	667.23	909.	0.03420864	905.
2.300	-603620.	0.00089446	0.00038677	669.02	909.	0.03756866	905.
2.400	-610390.	0.00090625	0.00038887	670.84	909.	0.04061554	905.
2.500	-616988.	0.00091868	0.00039087	672.65	909.	0.04322806	905.
2.600	-623464.	0.00093023	0.00039260	674.35	909.	0.04587990	905.
2.700	-629902.	0.00094069	0.00039425	675.99	909.	0.04863492	905.
2.800	-636320.	0.00095123	0.00039579	677.56	909.	0.05162737	905.
2.900	-642688.	0.00096066	0.00039715	679.05	909.	0.06050211	903.
3.000	-649037.	0.00097012	0.00039822	680.43	909.	0.07164554	903.
3.100	-655286.	0.00098012	0.00039923	681.80	909.	0.08177283	903.
3.200	-661376.	0.00099009	0.00040034	683.14	909.	0.09158487	903.
3.300	-667407.	0.00099971	0.00040135	684.44	909.	0.10133206	903.
3.400	-673417.	0.00100962	0.00040214	685.65	909.	0.11110161	903.
3.500	-679473.	0.00101968	0.00040251	686.72	909.	0.12094750	903.
3.600	-685384.	0.00102978	0.00040296	687.72	909.	0.13050922	903.
3.700	-691259.	0.00103997	0.00040327	688.65	909.	0.13997121	903.
3.800	-697098.	0.00105007	0.00040360	689.50	909.	0.14913038	903.
3.900	-702910.	0.00106019	0.00040383	690.31	909.	0.15822838	903.
4.000	-708799.	0.00106940	0.00040380	691.08	909.	0.16755260	903.
4.100	-714631.	0.00107918	0.00040340	691.93	909.	0.17734711	903.
4.200	-720513.	0.00108898	0.00040279	692.75	909.	0.18751141	903.

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REACTIONS_es_025_ro_n13_E215_til oppgave.txt

4.300	-639427.	0.00091980	0.00037078	586.30	897.	0.25438648	903.
4.400	-644316.	0.00092693	0.00037143	586.61	897.	0.26415899	903.
4.500	-649215.	0.00093411	0.00037199	586.48	897.	0.27429523	903.
4.600	-654121.	0.00094135	0.00037255	586.08	897.	0.28481586	903.
4.700	-658974.	0.00094882	0.00037313	585.71	897.	0.29568211	903.
4.800	-663664.	0.00095619	0.00037374	585.64	897.	0.30727526	903.
4.900	-666729.	0.00096154	0.00037446	588.65	897.	0.32074606	903.
5.000	-660616.	0.00095386	0.00037228	590.23	897.	0.33326815	903.

REACTIONS_es_025_ro_n10_E215_til oppgave.txt

Project no: IP556 - Membrane HTT
Analysis: Pull-out force and deflection

DEF1	REACTION	STRAIN GAUGE1	STRAIN GAUGE2	MAX STRESS	NOD.NR STRESS	MAX STRAIN	NOD.NR STRAIN
0.100	-140423.	0.00022127	0.00008569	371.47	911.	0.00053887	903.
0.200	-264661.	0.00042157	0.00016605	440.03	909.	0.00097649	805.
0.300	-350418.	0.00056762	0.00022917	488.11	909.	0.00115928	805.
0.400	-402033.	0.00066024	0.00027177	522.30	911.	0.00123420	2968.
0.500	-433176.	0.00071748	0.00029881	548.77	911.	0.00183819	4375.
0.600	-454015.	0.00075536	0.00031649	568.96	911.	0.00278960	4374.
0.700	-469561.	0.00078205	0.00032853	584.67	911.	0.00374821	4374.
0.800	-482156.	0.00080104	0.00033702	597.33	911.	0.00465602	4374.
0.900	-493069.	0.00081605	0.00034344	607.59	911.	0.00550315	4374.
1.000	-502925.	0.00082859	0.00034865	616.04	911.	0.00628730	4374.
1.100	-512260.	0.00083801	0.00035296	622.93	911.	0.00706522	4374.
1.200	-521008.	0.00084523	0.00035691	628.70	911.	0.00771177	4374.
1.300	-529431.	0.00083591	0.00036045	633.66	911.	0.00825412	4375.
1.400	-537542.	0.00083956	0.00036375	639.17	909.	0.00882107	4375.
1.500	-545635.	0.00084281	0.00036672	644.14	909.	0.00931629	4375.
1.600	-553257.	0.00084796	0.00036974	648.66	909.	0.01030049	905.
1.700	-560902.	0.00085613	0.00037247	652.85	909.	0.01465945	905.
1.800	-568343.	0.00086400	0.00037511	656.56	909.	0.01893062	905.
1.900	-575555.	0.00084118	0.00037771	659.85	909.	0.02284868	905.
2.000	-582698.	0.00085491	0.00038004	662.76	909.	0.02681183	905.
2.100	-589829.	0.00086861	0.00038227	665.20	909.	0.03058032	905.
2.200	-596742.	0.00088229	0.00038456	667.23	909.	0.03420864	905.
2.300	-603620.	0.00089446	0.00038677	669.02	909.	0.03756866	905.
2.400	-610390.	0.00090625	0.00038887	670.84	909.	0.04061554	905.
2.500	-616988.	0.00091868	0.00039087	672.65	909.	0.04322806	905.
2.600	-623464.	0.00093023	0.00039260	674.35	909.	0.04587990	905.
2.700	-629902.	0.00094069	0.00039425	675.99	909.	0.04863492	905.
2.800	-636320.	0.00095123	0.00039579	677.56	909.	0.05162737	905.
2.900	-642688.	0.00096066	0.00039715	679.05	909.	0.06050211	903.
3.000	-649037.	0.00097012	0.00039822	680.43	909.	0.07164554	903.
3.100	-655286.	0.00098012	0.00039923	681.80	909.	0.08177283	903.
3.200	-661376.	0.00099009	0.00040034	683.14	909.	0.09158487	903.
3.300	-667407.	0.00099971	0.00040135	684.44	909.	0.10133206	903.
3.400	-673417.	0.00100962	0.00040214	685.65	909.	0.11110161	903.
3.500	-679473.	0.00101968	0.00040251	686.72	909.	0.12094750	903.
3.600	-685384.	0.00102978	0.00040296	687.72	909.	0.13050922	903.
3.700	-691259.	0.00103997	0.00040327	688.65	909.	0.13997121	903.
3.800	-697098.	0.00105007	0.00040360	689.50	909.	0.14913038	903.
3.900	-702910.	0.00106019	0.00040383	690.31	909.	0.15822838	903.
4.000	-708799.	0.00106940	0.00040380	691.08	909.	0.16755260	903.
4.100	-714631.	0.00107918	0.00040340	691.93	909.	0.17734711	903.
4.200	-720513.	0.00108898	0.00040279	692.75	909.	0.18751141	903.

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REACTIONS_es_025_ro_n10_E215_til oppgave.txt

4.300	-726439.	0.00109892	0.00040216	693.51	909.	0.19795937	903.
4.400	-732414.	0.00110833	0.00040144	694.25	909.	0.20866341	903.
4.500	-738425.	0.00111644	0.00040056	695.00	909.	0.21954036	903.
4.600	-744454.	0.00112452	0.00039938	695.65	909.	0.23055726	903.
4.700	-750534.	0.00113275	0.00039814	696.17	909.	0.24176807	903.
4.800	-756663.	0.00114083	0.00039683	696.65	909.	0.25359535	903.
4.900	-762852.	0.00114830	0.00039550	697.07	909.	0.26582148	903.
5.000	-769094.	0.00115539	0.00039410	697.42	909.	0.27840327	903.

Appendix D

Test log

D.1 Test log

- Page 137-143: Test log no.1
- Page 144-150: Test log no.2
- Page 151-157: Test log no.3

Test procedure Membrane Hot Tap Tee

TESTLOG: 13.02.09 (TEST 1)

Nr.	Action	Comment	Time	Sign
1	Check for all parts according to Test assembly drawing: IP556-NE-AS-001		09.00	al
2	Clean upper plate on test jig, test Membrane and Lock ring	No debris on contact surfaces.	09.050	
3	Check for damage to parts, including strain gauges	Visual inspection	9.00	
4	Check bolts and nuts for damage	Visual inspection	09.15	
5	Install membrane in grooves at top plate on test jig	Center. Visual	09.20	
6	Mount lifting straps on Lock ring		—	
7	Install Lock ring	Gently. Center	0927	
8	Install all bolt, washers and nuts. Lubricate with Molykote	By hand	09.33	
9	Measure radial distance between Lock ring and Membrane at marked orientation.	Max deviation 1 mm	09.34	

10	Mount analogue micrometer on Lock ring. At marks.		10.39	
11	Tighten bolts with spanner	Light torque	11.22	
12	Start strain gauge logging		11.23	
13	Tighten bolts to 1/3 moment and control radial distance	Max deviation 1mm 190Nm	11 30	
14	Check Lock ring parallel to plate. Observe difference from bolted area and between bolts.	Use flat gauge and note on drawing. IP556-NE-AS-006.	11:38	
15	Tighten bolts to 2/3 moment and control radial distance. Diagonal order, start at 1o'clock	~~360Nm~~ 380	11:~~40~~ 33	
16	Repeat post 14.		/	
17	Tighten max moment.	570Nm	1150	
18	Install safety plate. Use spanner.	No moment speck.	1205	
19	Install hydraulic jack and load cell at lower plate. Use marked ring and measure placement relative to plate dimensions	Deviation max 2mm	1207	
20	Install tube piece, upper- and lower plate in marked ring		12.15	

21	Start jacking and stop when upper plate contacts test membrane.		12:17	
22	Measure straightness of pipe with vater and angle	Use rubber hammer to adjust straightness	1228	
23	Mount LVDT probe at top center of test membrane		/	
24	Mount LVDT probe at periphery marks of test membrane	Malt hauger Sielle merker	/	
25	Check that test area is closed of with shields and inform all workers that test starts	Inform workshop manager	ok 1228	
26	Inspect and secure hydraulics connections		1230	
27	Visual inspection of complete test jig		1230	
28	Calibrate all sensors **and restart logging for test run.**	Repeat posts 1- 27	1234	
29	Load 5 tones and carefully inspect log	Look for "settninger" between parts	1234	
30	Load 10 tones	Look for "settninger" between parts	–|–	
31	Load off and repeat post 29-30		|–|–	

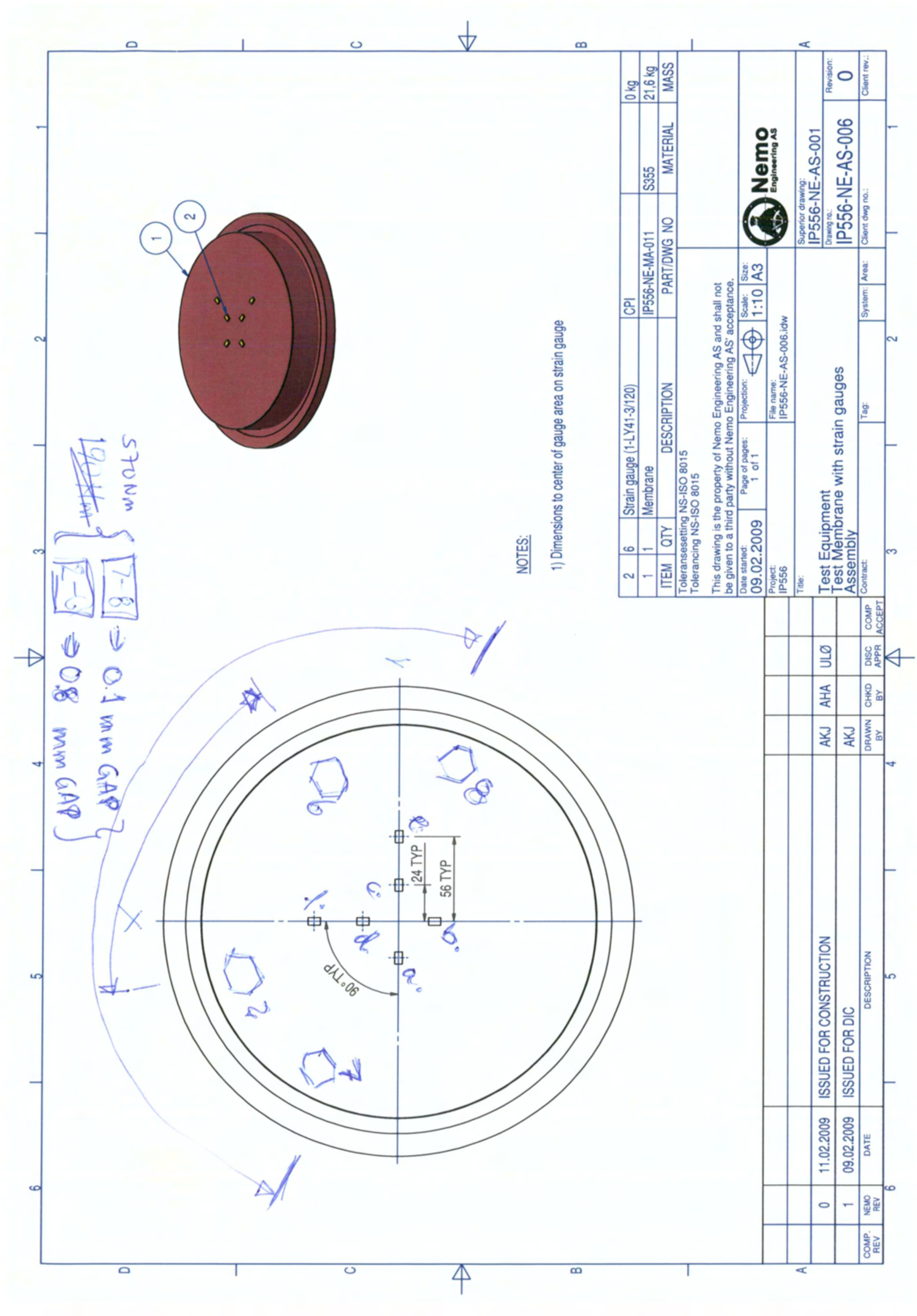
32	Load 12 tones		1236	
33	Load 12 tones		NA	
34	Load 13,5 tones		—	
35	Load 25,6 tones		—	
36	Load 30 tones		—	
37	Load 35 tones		—	
38	Load 37,5 tones		—	
39	Keep loading up steps in print form analysis	Film and pictures	—	
40	Load to facture or 100 tones	FRACTURE OCCURED AT APPROX 88 TONES AND 7.5 mm DISPLAC.	—	
41	Load of		1242	
42	Pictures during disassembly	Contact points, fracture etc	NA	

43	Demount test jig	CANCELLED IN ORDER TO PERFORM TESTS		
44	Pack up fractured/damaged parts in plastic. Seal of.			

TESTRUN 30STEP_ES0,125.txt

Project no: IP556 - Membrane HTT
Analysis: Pull-out force and deflection

DEF1	REACTION	STRAIN GAUGE1	STRAIN GAUGE2	MAX STRESS	NOD.NR STRESS	MAX STRAIN	NOD.NR STRAIN
0.100	-135451.	0.00022159	0.00008575	367.10	1115.	0.00059241	1101.
0.200	-256570.	0.00042404	0.00016676	414.49	1113.	0.00092984	909.
0.300	-335379.	0.00056442	0.00022809	448.86	1113.	0.00100554	7929.
0.400	-374820.	0.00064065	0.00026467	473.29	1113.	0.00116575	13542.
0.500	-395210.	0.00068076	0.00028425	490.56	1113.	0.00193356	13542.
0.600	-407925.	0.00070453	0.00029521	502.81	1113.	0.00278431	13468.
0.700	-417487.	0.00072096	0.00030199	511.96	1113.	0.00360577	13468.
0.800	-425696.	0.00073405	0.00030680	519.25	1113.	0.00425967	13468.
0.900	-433206.	0.00074530	0.00031046	524.97	1113.	0.00467733	13468.
1.000	-440275.	0.00075556	0.00031358	529.40	1113.	0.00515226	14864.
1.100	-447181.	0.00076532	0.00031636	529.60	1095.	0.00611000	14864.
1.200	-453977.	0.00077482	0.00031899	529.68	1095.	0.00712792	14864.
1.300	-460597.	0.00078400	0.00032148	529.99	8678.	0.00836592	14864.
1.400	-467101.	0.00079298	0.00032389	530.00	8678.	0.01095681	1105.
1.500	-473359.	0.00080147	0.00032614	530.00	8678.	0.01847880	1103.
1.600	-479346.	0.00080940	0.00032828	530.00	8588.	0.02632738	1103.
1.700	-485163.	0.00081687	0.00033027	530.00	14935.	0.03520302	1103.
1.800	-490995.	0.00082424	0.00033216	530.00	10644.	0.04422293	1103.
1.900	-496812.	0.00083154	0.00033410	530.00	10644.	0.05351492	1103.
2.000	-502583.	0.00083888	0.00033614	530.00	10644.	0.06708030	1101.
2.100	-508313.	0.00084581	0.00033806	530.00	10642.	0.08329542	1101.
2.200	-514146.	0.00085284	0.00033997	530.00	8139.	0.09887069	1101.
2.300	-519923.	0.00085981	0.00034188	530.00	10642.	0.11226820	1101.
2.400	-525778.	0.00086626	0.00034394	530.00	15051.	0.12650693	1101.
2.500	-531342.	0.00087182	0.00034595	530.00	10640.	0.14166205	1101.
2.600	-537012.	0.00087747	0.00034798	530.00	10640.	0.15643097	1101.
2.700	-542705.	0.00086935	0.00035008	530.00	10638.	0.17007527	1101.
2.800	-548100.	0.00087370	0.00035213	530.00	10638.	0.18254181	1101.
2.900	-553327.	0.00087772	0.00035384	530.00	10638.	0.19395079	1101.
3.000	-558520.	0.00088166	0.00035551	530.00	10638.	0.20396100	1101.



NOTES:
1) Dimensions to center of gauge area on strain gauge
24 TYP
56 TYP
90° TYP
0.8 mm GAP
0.1 mm GAP
2 6 Strain gauge (1-LY41-3/120) CPI 0 kg
1 1 Membrane IP556-NE-MA-011 S355 21,6 kg
ITEM QTY DESCRIPTION PART/DWG NO MATERIAL MASS
Toleransesetting NS-ISO 8015
Tolerancing NS-ISO 8015
This drawing is the property of Nemo Engineering AS and shall not be given to a third party without Nemo Engineering AS' acceptance.
Date started: 09.02.2009
Page of pages: 1 of 1
Projection:
Scale: 1:10
Size: A3
Project: IP556
File name: IP556-NE-AS-006.idw
Nemo Engineering AS
Superior drawing: IP556-NE-AS-001
Drawing no.: IP556-NE-AS-006
Revision: 0
Title: Test Equipment Test Membrane with strain gauges Assembly
0 11.02.2009 ISSUED FOR CONSTRUCTION AKJ AHA ULØ
1 09.02.2009 ISSUED FOR DIC AKJ
COMP. REV NEMO REV DATE DESCRIPTION DRAWN BY CHKD BY DISC APPR COMP ACCEPT

Test procedure Membrane Hot Tap Tee

TESTLOG: 16.02.09 (TEST 2)

Nr.	Action	Comment	Time	Sign
1	Check for all parts according to Test assembly drawing: IP556-NE-AS-001		07.17	ak
2	Clean upper plate on test jig, test Membrane and Lock ring	No debris on contact surfaces.	0.7.17	~
3	Check for damage to parts, including strain gauges	Visual inspection	07.23	~
4	Check bolts and nuts for damage	Visual inspection	07.24	~
5	Install membrane in grooves at top plate on test jig	Center. Visual	07.25	ak
6	Mount lifting straps on Lock ring		07.30	ak
7	Install Lock ring	Gently. Center	07.32	ak
8	Install all bolt, washers and nuts. Lubricate with Molykote	By hand	07.38	ak
9	Measure radial distance between Lock ring and Membrane at marked orientation.	Max deviation 1 mm	07.47	ak

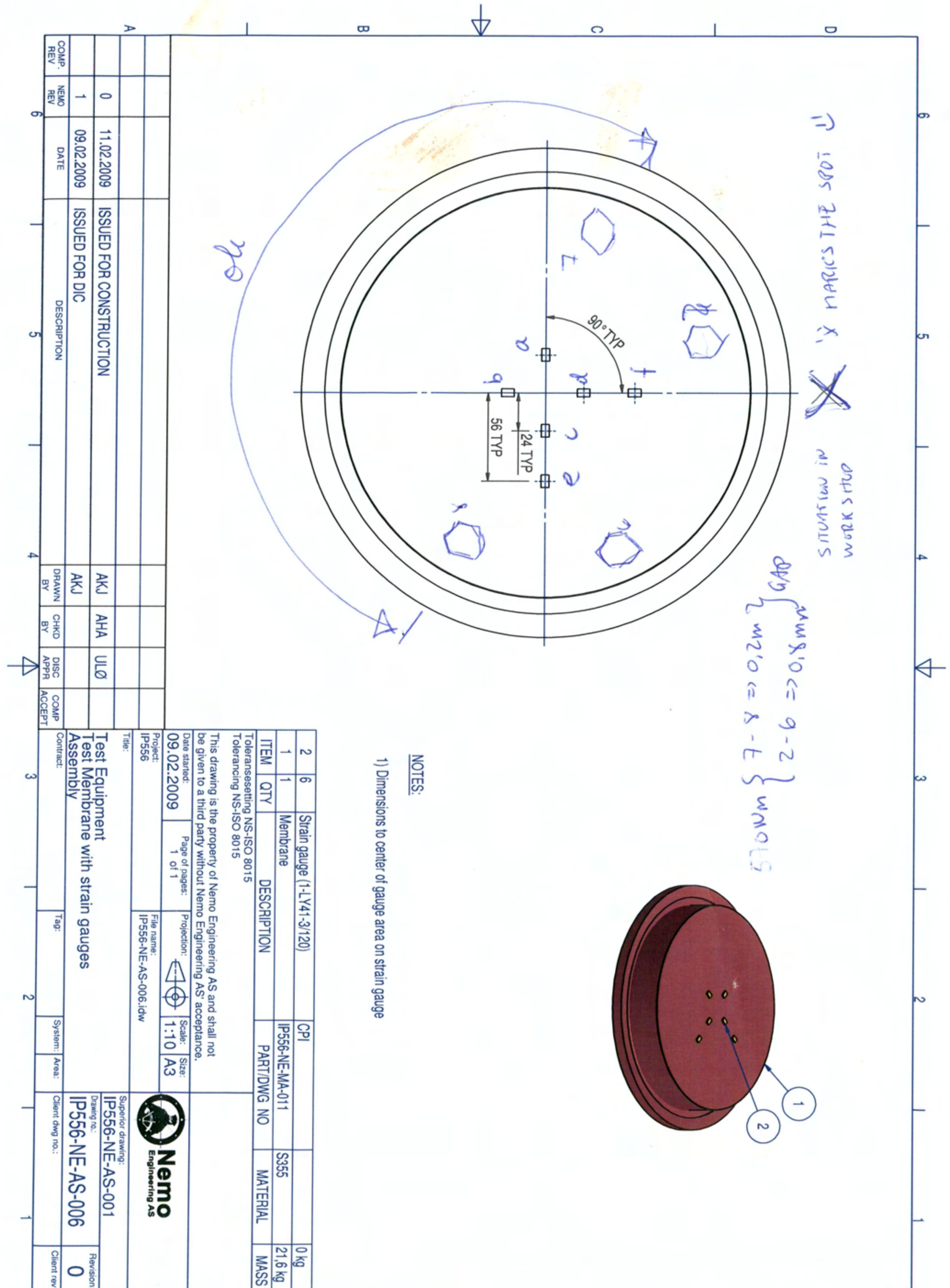
10	Mount analogue micrometer on Lock ring. At marks.		NA	ah
11	Tighten bolts with spanner	Light torque	07.50	ah
12	Start strain gauge logging		07.58	ah
13	Tighten bolts to 1/3 moment and control radial distance	Max deviation 1mm 190Nm	08.10	ah
14	Check Lock ring parallel to plate. Observe difference from bolted area and between bolts.	Use flat gauge and note on drawing. IP556-NE-AS-006.	08.17	ah
15	Tighten bolts to 2/3 moment and control radial distance. Diagonal order, start at 1o'clock	~~360Nm~~ 380Nm	08.32	ah
16	Repeat post 14.		08.45	ah
17	Tighten max moment.	570Nm STRAIN GAUGE LOGGING ABORTED AND SAVED*	09.05	ah
18	Install safety plate. Use spanner.	No moment speck.	09.07	ah
19	Install hydraulic jack and load cell at lower plate. Use marked ring and measure placement relative to plate dimensions	Deviation max 2mm	09.15	ah
20	Install tube piece, upper- and lower plate in marked ring	SUPORTED BY WOODEN-STIFFENERS	09.27	ah

* STRAIN GAUGE LOGGING ENDED FOR BOLT TIGHTENING

21	Start jacking and stop when upper plate contacts test membrane.		09.37	al
22	Measure straightness of pipe with vater and angle	Use rubber hammer to adjust straightness	09.39	h
23	Mount LVDT probe at top center of test membrane		09.40	h
24	Mount LVDT probe at periphery marks of test membrane		09.41	h
25	Check that test area is closed of with shields and inform all workers that test starts	Inform workshop manager	10.00	h
26	Inspect and secure hydraulics connections		10.00	h
27	Visual inspection of complete test jig		10.00	h
28	Calibrate all sensors **and restart logging for test run.**	Repeat posts 1- 27	10.00	h
29	Load 5 tones and carefully inspect ~~log~~ LOGGING DATA FOR EVENTUAL ABNORMALITY	Look for ~~"settninger"~~* between parts SETTLEMENTS	10.05	h
30	Load 10 tones	Look for "settninger" between parts	10.05	h
31	Load off and repeat post 29-30		10.07	h

32	Load 12 tones		NA	ah
33	Load 12 tones		-"-	ah
34	Load 13,5 tones		-"-	ah
35	Load 25,6 tones		-"-	ah
36	Load 30 tones		-"-	ah
37	Load 35 tones		-"-	ah
38	Load 37,5 tones		-"-	ah
39	Keep loading up steps in print form analysis	Film and pictures	10.09	A
40	Load to facture or 100 tones	TEST ABORTED AT A DISPLACEMENT OF APPROX. 6MM	10.16	ah
41	Load of	IN ORDER TO STUDY THE GEOMETRY AND YIELD SETTLEMENT		q
42	Pictures during disassembly	Contact points, fracture etc		q

43	Demount test jig	CANCELLED, FOR TEST 3.	10.30	ol
44	Pack up fractured/damaged parts in plastic. Seal of.	Gh	NA	Col


90° TYP
24 TYP
56 TYP
NOTES:
1) Dimensions to center of gauge area on strain gauge
2 6 Strain gauge (1-LY41-3/120) CPI 0 kg
1 1 Membrane IP556-NE-MA-011 S355 21,6 kg
ITEM QTY DESCRIPTION PART/DWG NO MATERIAL MASS
Toleransesetting NS-ISO 8015
Tolerancing NS-ISO 8015
This drawing is the property of Nemo Engineering AS and shall not be given to a third party without Nemo Engineering AS' acceptance.
Date started: 09.02.2009
Page of pages: 1 of 1
Scale: 1:10
Size: A3
Project: IP556
File name: IP556-NE-AS-006.idw
Title:
Test Equipment
Test Membrane with strain gauges
Assembly
Superior drawing: IP556-NE-AS-001
Drawing no.: IP556-NE-AS-006
Revision: 0
Nemo Engineering AS
0 11.02.2009 ISSUED FOR CONSTRUCTION AKJ AHA ULØ
1 09.02.2009 ISSUED FOR DIC AKJ
COMP. REV
NEMO REV
DATE
DESCRIPTION
DRAWN BY
CHKD BY
DISC APPR
COMP ACCEPT
Contract:
Tag:
System:
Area:
Client dwg no.:
Client rev

TESTRUN 30STEP_ES0,125.txt

Project no: IP556 - Membrane HTT
Analysis: Pull-out force and deflection

DEF1	REACTION	STRAIN GAUGE1	STRAIN GAUGE2	MAX STRESS	NOD.NR STRESS	MAX STRAIN	NOD.NR STRAIN
0.100	-135451.	0.00022159	0.00008575	367.10	1115.	0.00059241	1101.
0.200	-256570.	0.00042404	0.00016676	414.49	1113.	0.00092984	909.
0.300	-335379.	0.00056442	0.00022809	448.86	1113.	0.00100554	7929.
0.400	-374820.	0.00064065	0.00026467	473.29	1113.	0.00116575	13542.
0.500	-395210.	0.00068076	0.00028425	490.56	1113.	0.00193356	13542.
0.600	-407925.	0.00070453	0.00029521	502.81	1113.	0.00278431	13468.
0.700	-417487.	0.00072096	0.00030199	511.96	1113.	0.00360577	13468.
0.800	-425696.	0.00073405	0.00030680	519.25	1113.	0.00425967	13468.
0.900	-433206.	0.00074530	0.00031046	524.97	1113.	0.00467733	13468.
1.000	-440275.	0.00075556	0.00031358	529.40	1113.	0.00515226	14864.
1.100	-447181.	0.00076532	0.00031636	529.60	1095.	0.00611000	14864.
1.200	-453977.	0.00077482	0.00031899	529.68	1095.	0.00712792	14864.
1.300	-460597.	0.00078400	0.00032148	529.99	8678.	0.00836592	14864.
1.400	-467101.	0.00079298	0.00032389	530.00	8678.	0.01095681	1105.
1.500	-473359.	0.00080147	0.00032614	530.00	8678.	0.01847880	1103.
1.600	-479346.	0.00080940	0.00032828	530.00	8588.	0.02632738	1103.
1.700	-485163.	0.00081687	0.00033027	530.00	14935.	0.03520302	1103.
1.800	-490995.	0.00082424	0.00033216	530.00	10644.	0.04422293	1103.
1.900	-496812.	0.00083154	0.00033410	530.00	10644.	0.05351492	1103.
2.000	-502583.	0.00083888	0.00033614	530.00	10644.	0.06708030	1101.
2.100	-508313.	0.00084581	0.00033806	530.00	10642.	0.08329542	1101.
2.200	-514146.	0.00085284	0.00033997	530.00	8139.	0.09887069	1101.
2.300	-519923.	0.00085981	0.00034188	530.00	10642.	0.11226820	1101.
2.400	-525778.	0.00086626	0.00034394	530.00	15051.	0.12650693	1101.
2.500	-531342.	0.00087182	0.00034595	530.00	10640.	0.14166205	1101.
2.600	-537012.	0.00087747	0.00034798	530.00	10640.	0.15643097	1101.
2.700	-542705.	0.00086935	0.00035008	530.00	10638.	0.17007527	1101.
2.800	-548100.	0.00087370	0.00035213	530.00	10638.	0.18254181	1101.
2.900	-553327.	0.00087772	0.00035384	530.00	10638.	0.19395079	1101.
3.000	-558520.	0.00088166	0.00035551	530.00	10638.	0.20396100	1101.

Test procedure Membrane Hot Tap Tee

TESTLOG: 10.02.09 (TEST 3)

Nr.	Action	Comment	Time	Sign
1	Check for all parts according to Test assembly drawing: IP556-NE-AS-001		12.00	ah
2	Clean upper plate on test jig, test Membrane and Lock ring	No debris on contact surfaces.	– " –	h
3	Check for damage to parts, including strain gauges	Visual inspection	– " –	h
4	Check bolts and nuts for damage	Visual inspection	– " –	h
5	Install membrane in grooves at top plate on test jig	Center. Visual	12.02	h
6	Mount lifting straps on Lock ring		12.03	h
7	Install Lock ring	Gently. Center	12.06	h
8	Install all bolt, washers and nuts. Lubricate with Molykote	By hand	12.09	h
9	Measure radial distance between Lock ring and Membrane at marked orientation.	Max deviation 1 mm	12.17	h

10	Mount analogue micrometer on Lock ring. At marks.	CANCELLED	NA	ah
11	Tighten bolts with spanner	Light torque	12.30	ah
12	Start strain gauge logging		12.38	ah
13	Tighten bolts to 1/3 moment and control radial distance	Max deviation 1mm 190Nm	12.42	ah
14	Check Lock ring parallel to plate. Observe difference from bolted area and between bolts.	Use flat gauge and note on drawing. IP556-NE-AS-006.	NA*	ah
15	Tighten bolts to 2/3 moment and control radial distance. Diagonal order, start at 1o'clock	~~360Nm~~ 380Nm	12.47	ah
16	Repeat post 14.		12.47	ah
17	Tighten max moment.	570Nm	13.02	ah
18	Install safety plate. Use spanner.	No moment speck.	13.10	ah
19	Install hydraulic jack and load cell at lower plate. Use marked ring and measure placement relative to plate dimensions	Deviation max 2mm	13.30	ah
20	Install tube piece, upper- and lower plate in marked ring		—"—	ah

* SAME ON TEST 1 AND 2. (DEVIATION ACCORDING TO POOR MACHINING OF TOLERANCES ON DRAWINGS)

21	Start jacking and stop when upper plate contacts test membrane.		12.37	al
22	Measure straightness of pipe with vater and angle	Use rubber hammer to adjust straightness	12.39	h
23	Mount LVDT probe at top center of test membrane		12.41	L
24	Mount LVDT probe at periphery marks of test membrane	CANCELED*	NA	L
25	Check that test area is closed of with shields and inform all workers that test starts	Inform workshop manager	12.50	L
26	Inspect and secure hydraulics connections		—ıı—	L
27	Visual inspection of complete test jig		—ıı—	L
28	Calibrate all sensors **and restart logging for test run.**	Repeat posts 1- 27	12.58	h
29	Load 5 tones and carefully inspect log	Look for "settninger" between parts	1259	a
30	Load 10 tones	Look for "settninger" between parts	1300	L
31	Load off and repeat post 29-30		1301	L

* DUE TO EARLIER TEST RESULTS.

32	Load 12 tones		1302	ak
33	Load 12 tones	NA	NA	✓
34	Load 13,5 tones		13.05	✓
35	Load 25,6 tones		13.06	✓
36	Load 30 tones		13.06	✓
37	Load 35 tones		13.08	✓
38	Load 37,5 tones		1309	✓
39	Keep loading up steps in print form analysis	Film and pictures	1312	✓
40	Load to facture or 100 tones	LOADING ABORTED AT A DISPLACEMENT OF 6mm IN ORDER TO DEMOUNT	1330	✓
41	Load of	LVDT -PROBE'S BEFORE FRACTURE	—I—	✓
42	Pictures during disassembly	Contact points, fracture etc	NA	✓

43	Demount test jig	ok	NA	ok
44	Pack up fractured/damaged parts in plastic. Seal of.	ok	WA	h

TESTRUN 30STEP_ES0,125.txt

Project no: IP556 - Membrane HTT
Analysis: Pull-out force and deflection

DEF1	REACTION	STRAIN GAUGE1	STRAIN GAUGE2	MAX STRESS	NOD.NR STRESS	MAX STRAIN	NOD.NR STRAIN
0.100	-135451.	0.00022159	0.00008575	367.10	1115.	0.00059241	1101.
0.200	-256570.	0.00042404	0.00016676	414.49	1113.	0.00092984	909.
0.300	-335379.	0.00056442	0.00022809	448.86	1113.	0.00100554	7929.
0.400	-374820.	0.00064065	0.00026467	473.29	1113.	0.00116575	13542.
0.500	-395210.	0.00068076	0.00028425	490.56	1113.	0.00193356	13542.
0.600	-407925.	0.00070453	0.00029521	502.81	1113.	0.00278431	13468.
0.700	-417487.	0.00072096	0.00030199	511.96	1113.	0.00360577	13468.
0.800	-425696.	0.00073405	0.00030680	519.25	1113.	0.00425967	13468.
0.900	-433206.	0.00074530	0.00031046	524.97	1113.	0.00467733	13468.
1.000	-440275.	0.00075556	0.00031358	529.40	1113.	0.00515226	14864.
1.100	-447181.	0.00076532	0.00031636	529.60	1095.	0.00611000	14864.
1.200	-453977.	0.00077482	0.00031899	529.68	1095.	0.00712792	14864.
1.300	-460597.	0.00078400	0.00032148	529.99	8678.	0.00836592	14864.
1.400	-467101.	0.00079298	0.00032389	530.00	8678.	0.01095681	1105.
1.500	-473359.	0.00080147	0.00032614	530.00	8678.	0.01847880	1103.
1.600	-479346.	0.00080940	0.00032828	530.00	8588.	0.02632738	1103.
1.700	-485163.	0.00081687	0.00033027	530.00	14935.	0.03520302	1103.
1.800	-490995.	0.00082424	0.00033216	530.00	10644.	0.04422293	1103.
1.900	-496812.	0.00083154	0.00033410	530.00	10644.	0.05351492	1103.
2.000	-502583.	0.00083888	0.00033614	530.00	10644.	0.06708030	1101.
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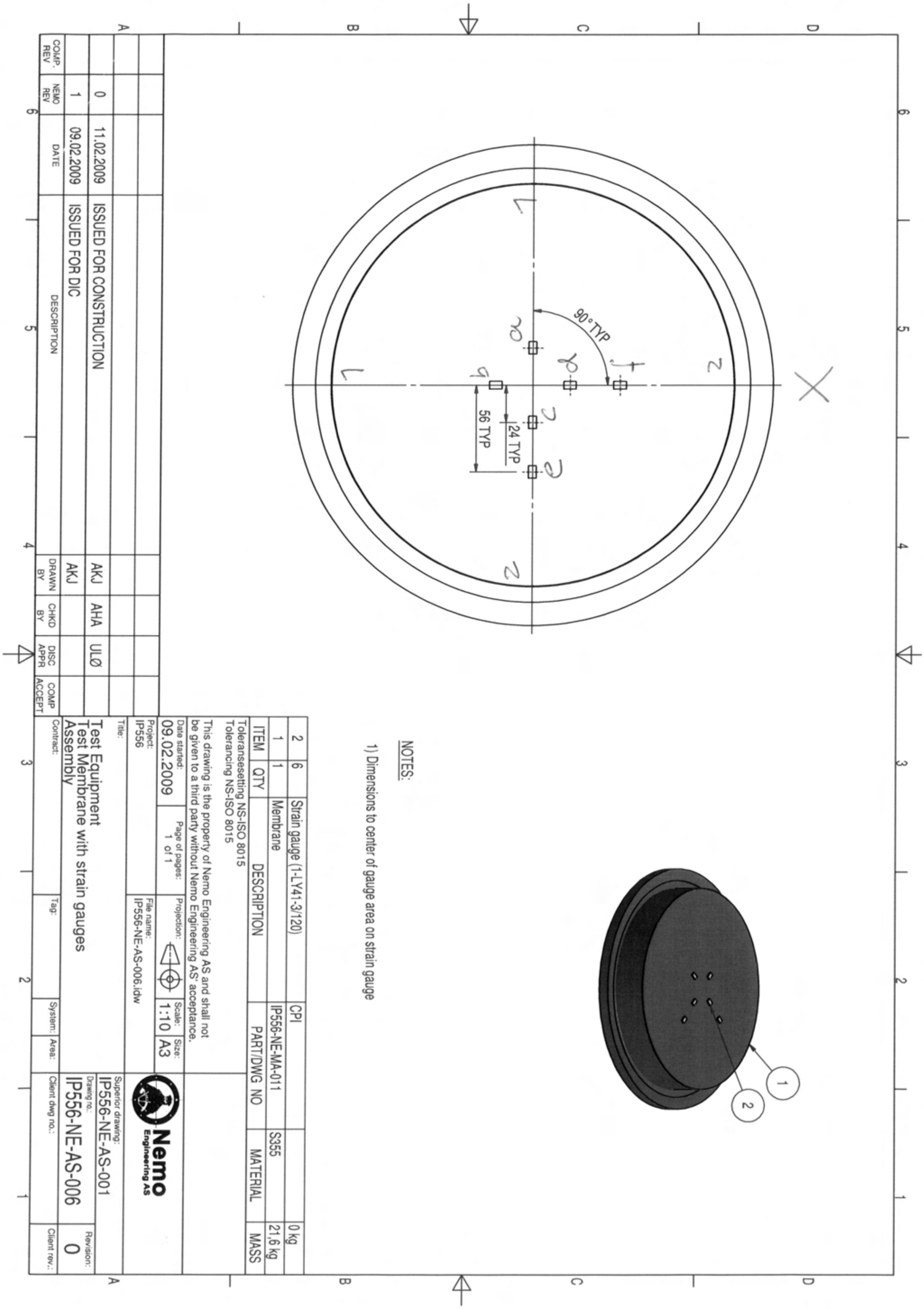
2.400	-525778.	0.00086626	0.00034394	530.00	15051.	0.12650693	1101.
2.500	-531342.	0.00087182	0.00034595	530.00	10640.	0.14166205	1101.
2.600	-537012.	0.00087747	0.00034798	530.00	10640.	0.15643097	1101.
2.700	-542705.	0.00086935	0.00035008	530.00	10638.	0.17007527	1101.
2.800	-548100.	0.00087370	0.00035213	530.00	10638.	0.18254181	1101.
2.900	-553327.	0.00087772	0.00035384	530.00	10638.	0.19395079	1101.
3.000	-558520.	0.00088166	0.00035551	530.00	10638.	0.20396100	1101.


90°TYP
24 TYP
56 TYP
NOTES:
1) Dimensions to center of gauge area on strain gauge
1
2
2 6 Strain gauge (1-LY41-3/120) CPI 0 kg
1 1 Membrane IP556-NE-MA-011 S355 21,6 kg
ITEM QTY DESCRIPTION PART/DWG NO MATERIAL MASS
Toleransesetting NS-ISO 8015
Tolerancing NS-ISO 8015
This drawing is the property of Nemo Engineering AS and shall not be given to a third party without Nemo Engineering AS' acceptance.
Date started: 09.02.2009
Page of pages: 1 of 1
Projection:
Scale: 1:10
Size: A3
Nemo Engineering AS
Project: IP556
File name: IP556-NE-AS-006.idw
Superior drawing: IP556-NE-AS-001
Title: Test Equipment
Test Membrane with strain gauges
Assembly
Drawing no.: IP556-NE-AS-006
Revision: 0
Contract:
Tag:
System:
Area:
Client dwg no.:
Client rev.:
0 11.02.2009 ISSUED FOR CONSTRUCTION AKJ AHA ULØ
1 09.02.2009 ISSUED FOR DIC AKJ
COMP. REV
NEMO REV
DATE
DESCRIPTION
DRAWN BY
CHKD BY
DISC APPR
COMP ACCEPT

Appendix E

SJA check list

E.1 Safe Job Analysis

OLF Recommended Guidelines: Common model for Safe Job Analysis (SJA)

No.: 090 Date effective: 05.11.03 Revision no: 2 Date revised: 01.03.06 Page: 18

No	Checklist for SJA No: SJA Title:	Taken care off?			Comments
		Yes	No	Not Applic.	
A	**Documentation and experience**				
1	Is this a familiar work operation for the crew?	✓			
2	Is there an adequate procedure/instruction/work package?	✓			TEST LOG
3	Is the group aware of experiences/ incidents from similar activities/SJA?	✓			
B	**Competence**				
1	Do we have the necessary personnel and skills for the job?	✓			
2	Are there other parties that should participate in the SJA meeting?		✓		
C	**Communication and coordination**				
1	Is this a job where several units/crews must be coordinated?		✓		
2	Is good communications and suitable means of communication in place?	✓			
3	Are there potential conflicts with simultaneous activities (system/area/ installation)?		✓		
4	Has it been made clear who is in charge for the work?	✓			
5	Has sufficient time been allowed for the planning of the activities?	✓			
6	Has the team considered handling of alarm/emergency situations and informed emergency functions about possible measures/actions?			✓	
D	**Key physical safety systems**				
1	Are barriers, to reduce the likelihood of unwanted release/leakage maintained intact (safety valve, pipe, vessel, control system etc.)?	✓			
2	Are barriers, to reduce the likelihood of the ignition of a HC leakage maintained intact (detection, overpressure protection, isolation of ignition sources etc.)?			✓	
3	Are barriers to isolate leakage sources/lead hydrocarbons to safe location maintained intact (process/emergency shutdown system, blowdown system, x-mas tree, drains etc.)?			✓	
4	Are barriers to extinguish or limit extent/spread of fire/explosion maintained intact (detection/ alarm, fire pump, extinguishing system/equipment etc.)?			✓	
5	Are barriers to provide safe evacuation of personnel maintained intact (emergency power/lightning, alarm/PA, escape-ways, lifeboats etc.)?			✓	
6	Are barriers that provide stability to floating installations maintained intact (bulkheads/doors, open tanks, ballast pumps etc.)?			✓	
E	**Equipment worked on/involved in the job**				
1	Is the necessary isolation from energy provided (rotation, pressure, electrical voltage etc.)?	✓			*
2	May high temperature represent a danger?		✓		
3	Is there sufficient machinery protection/shields?	✓			
F	**Equipment for the execution of the job**				
1	Is lifting equipment, special tools, equipment/material for the job available, familiar to the users, checked and found in order?	✓			
2	Do the involved personnel have proper and adequate protective equipment?	✓			**
3	Is there danger of uncontrolled movement/rotation of equipment/tools?	✓			
G	**The area**				
1	Is it necessary to make a worksite inspection to verify access, knowledge about the working area working conditions etc.?	✓			**
2	Has work at heights/at several levels above each other/falling objects been considered?			✓	
3	Has flammable gas/liquid/material in the area been considered?			✓	
4	Has possible exposure to noise, vibration, poisonous gas/liquid, smoke, dust, vapour, chemicals, solvents or radioactive substances been considered?	✓			***
H	**The workplace**				
1	Is the workplace clean and tidy?	✓			
2	Has the need for tags/signs/barriers been considered?	✓			
3	Has the need for transportation to/from the workplace been considered?	✓			
4	Has the need for additional guards/watches been considered?			✓	
5	Has weather, wind, waves, visibility and light been considered?			✓	
6	Has access/escape been considered?			✓	
7	Have difficult working positions, potential for work related diseases been considered?			✓	
I	**Additional local questions**				

* HYDRAULIC JACK SECURED AND TOP-PLATE MOUNTED

** WERY SMALL AREA ; LIMITED WITH PROTECTION WALLS

*** HYDRAULIC HOSES INSPECTED AND SECURED

OLF Recommended Guidelines: Common model for Safe Job Analysis (SJA)

No.: 090 Date effective: 05.11.03 Revision no: 2 Date revised: 01.03.06 Page: 19

App D Standard SJA participant list

SJA PARTICIPANT LIST ***SJA TITLE:*** ***SJA NO:***

SJA Meeting Date: 13.02.09 (16.02.09) Time: 0900 (07.00) Place: HAATECH

SJA-responsible:

Signature when changing personnel etc.

Name (Block letters)	Dep/Discipline	Date	Signature	Name (Block letters)	Dep/Discipline	Date	Signature
ARNE JOHNSEN	TEST LEAD	13.02					
SVEN-ERIK ANDESEN	MECHANIC	13.02					
ARNT-HE. ANDERSON	PERSONELL	13.02	NA				
				NA			

OLF Recommended Guidelines: Common model for Safe Job Analysis (SJA)

No.: 090 Date effective: 05.11.03 Revision no: 2 Date revised: 01.03.06 Page: 20

App E Standard SJA form

SJA title: MHTT - test	SJA No.: NA	Department/Discipline: EXPERIMENT	Person responsible for SJA:
Description of the work: LOAD UP TO 100 TONNES ACCORDING TO TEST LOG.		Installation: NA	Tag/line no.: NA
		Area/Module/Deck: NA	
Requirements/Preconditions:		WP/WO no.: NA	Number of attachments: NA

No	Basic steps	Hazard/cause	Potential consequence	Measures	Person responsible for measures
1	PROTECTION WALLS	MOVING OBJECTS	PERSONS INJURY		AKJ
			AND		
			DAMAGE TO OTHER		
2	TOP PLATE, TEST JIG	ENERGY RELEASE	EQUIPMENT		AKJ
3	INSPECTED AND SECURED				AKJ.
	HYDRAULIC HOSES				

Is the total risk acceptable: (Yes/No)?	Approval	Date/Signature	Checklist for SJA applied –tick off
Conclusion/comments:	Person responsible for SJA	(Recom.)	Summary of experience after completion of the work:
	Responsible for execution	(Recom.)	
	Area/Operations supervisor	(Appro.)	
	Other position	(Appro.)	

Appendix F

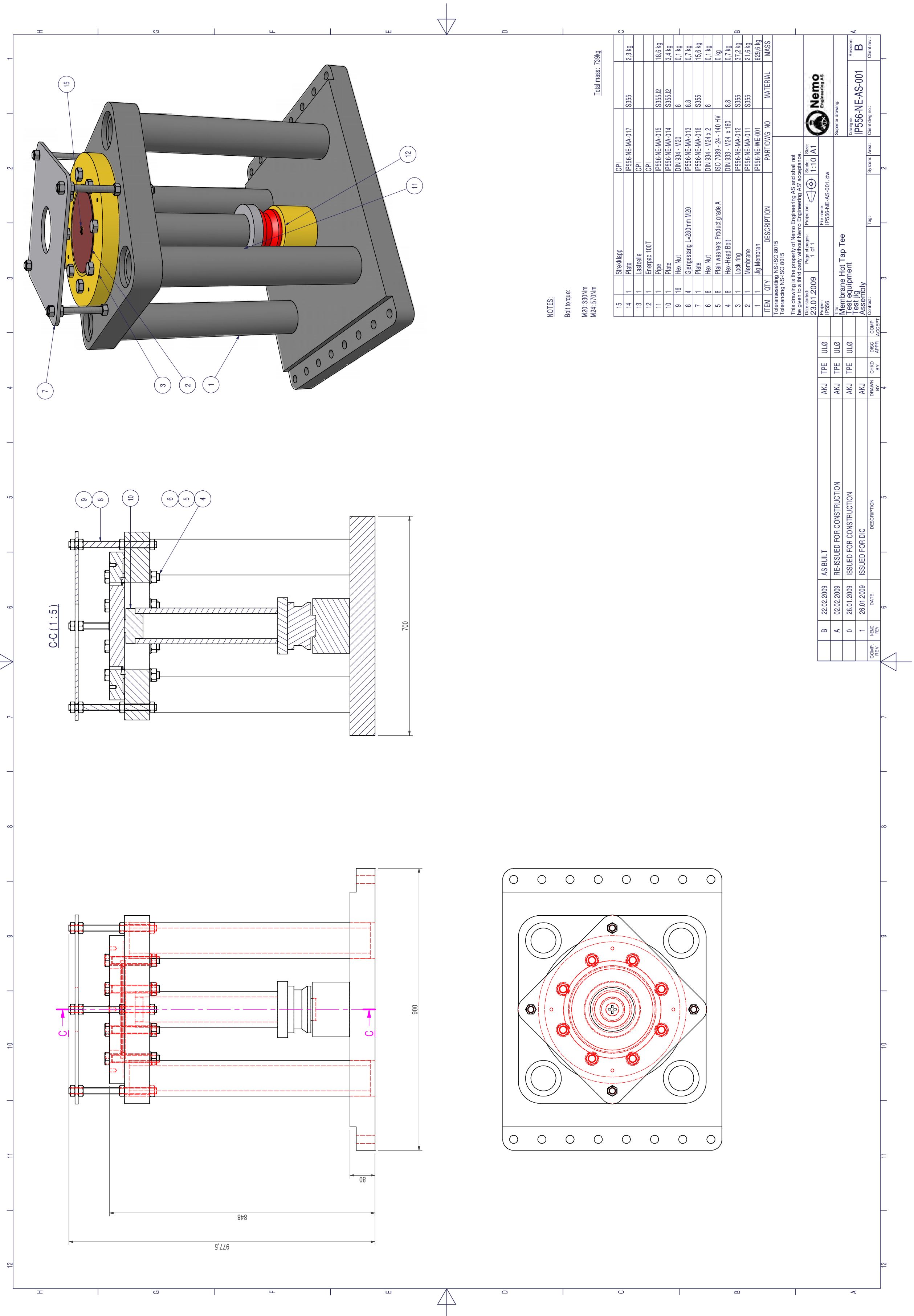
Drawings

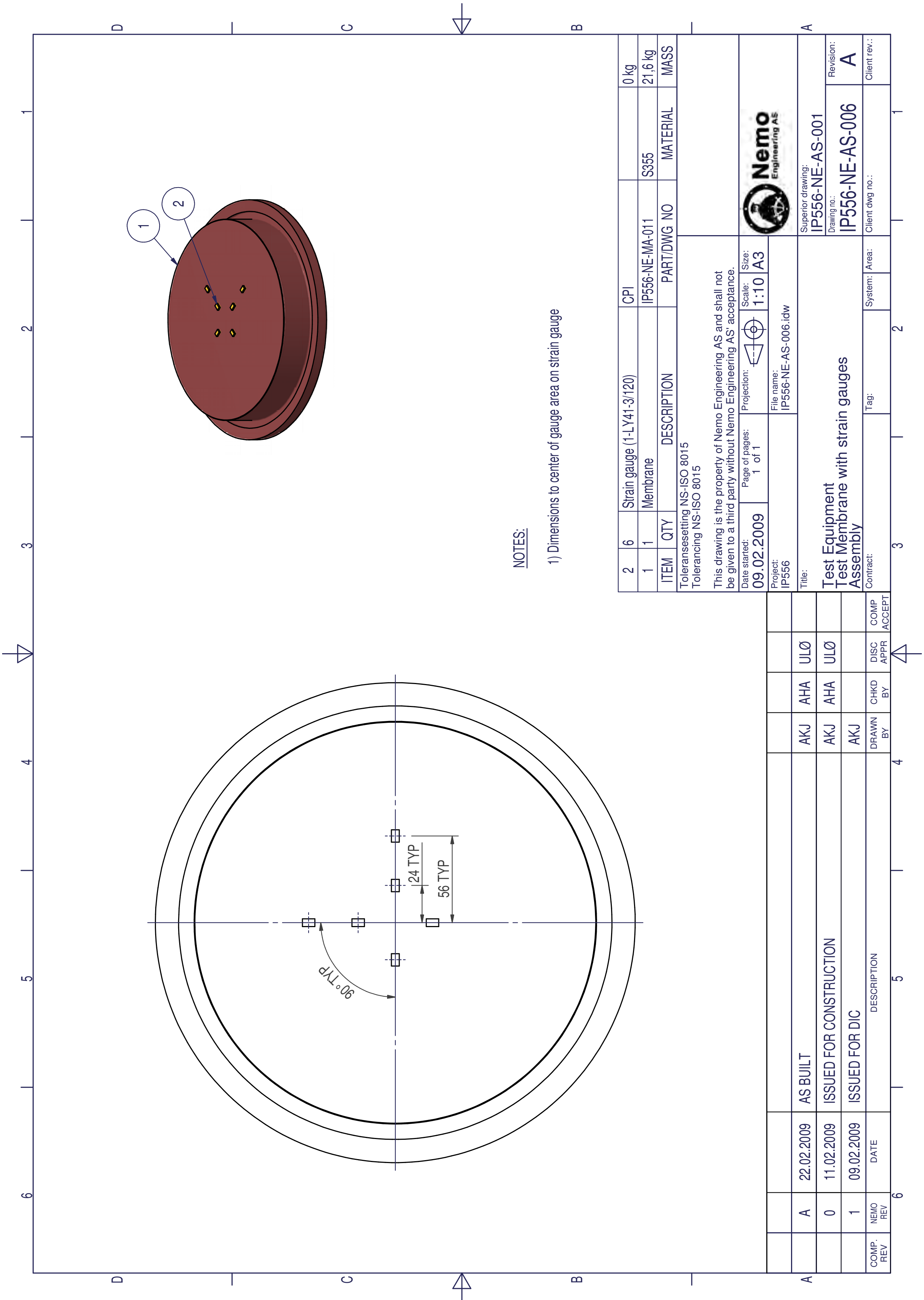
F.1 Drawings - experiment equipment

List of drawings:

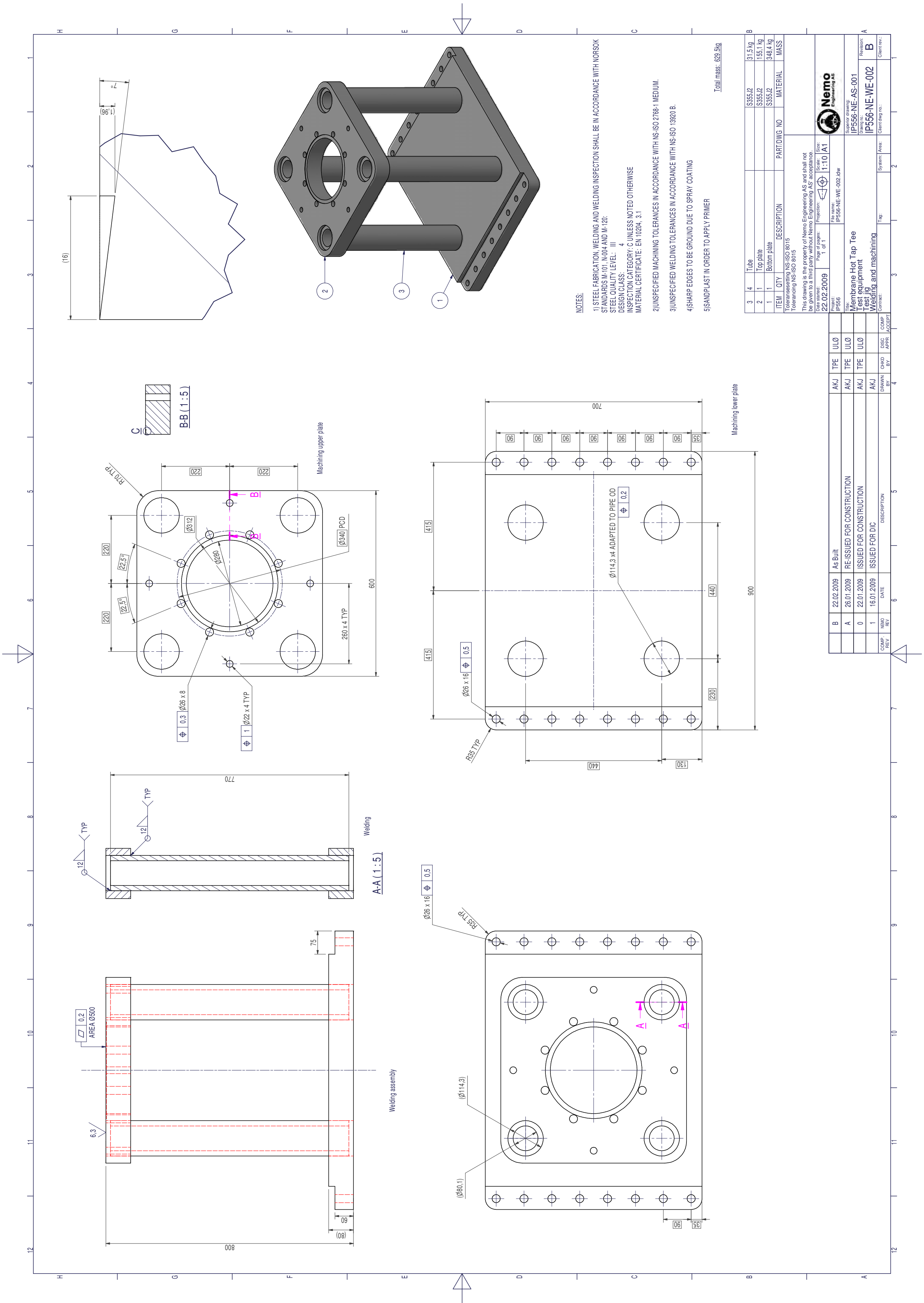
- IP556-NE-AS-001 Testjig, assembly
- IP556-NE-AS-006 Test membrane with strain gauges, assembly
- IP556-NE-WE-002 Testjig welding and machining, assembly
- IP556-NE-MA-011 Test membrane, machining
- IP556-NE-MA-012 Test membran lock ring, machining
- IP556-NE-MA-014 Plate, machining
- IP556-NE-MA-015 Pipe, machining
- IP556-NE-MA-016 Plate, machining
- IP556-NE-MA-017 Plate, machining (VOIDED)
- IP556-NE-MA-018 Plate, machining
- WU 100T CT Hydraulic jack assembly

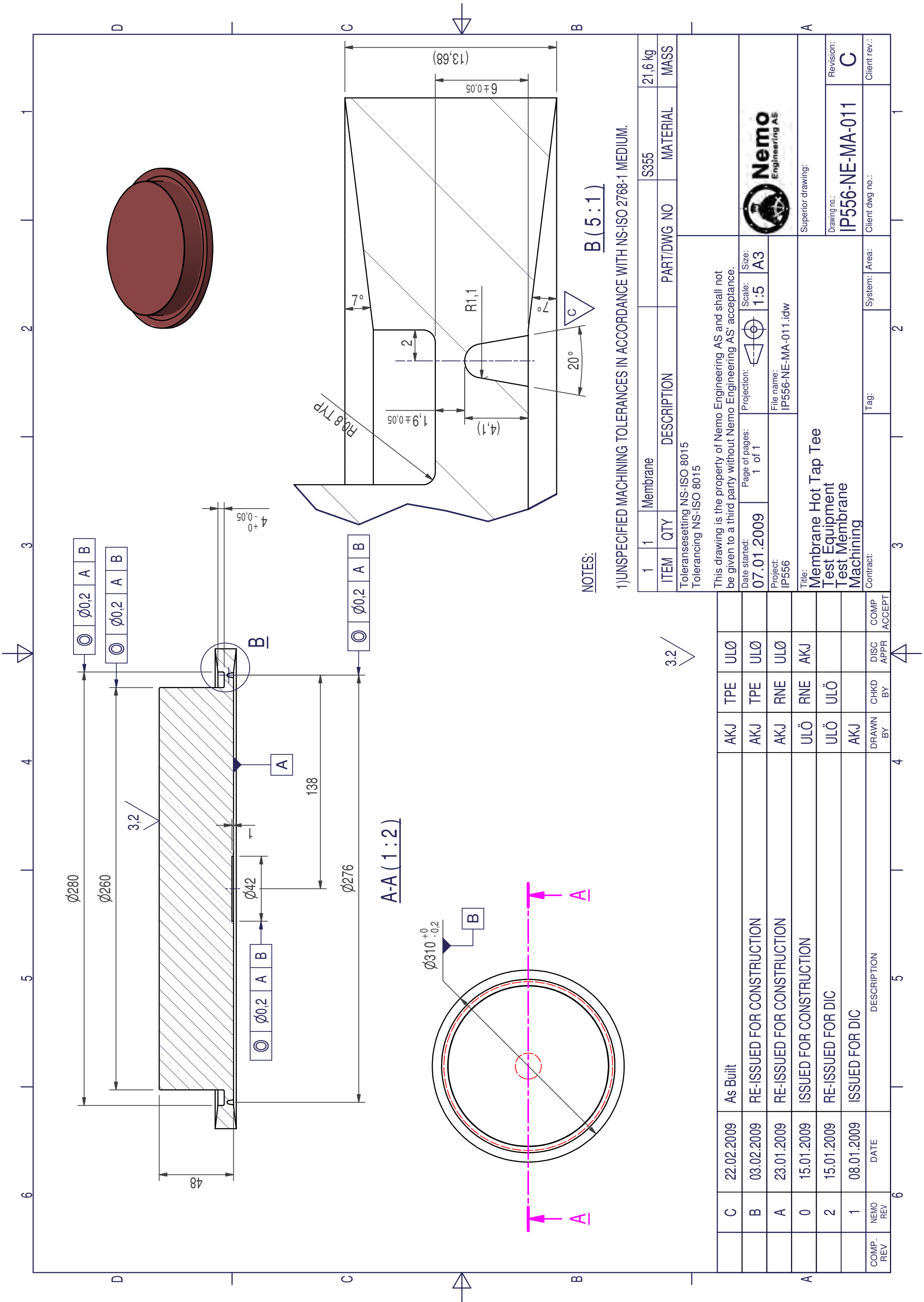
All drawings are revision AS BUILT.

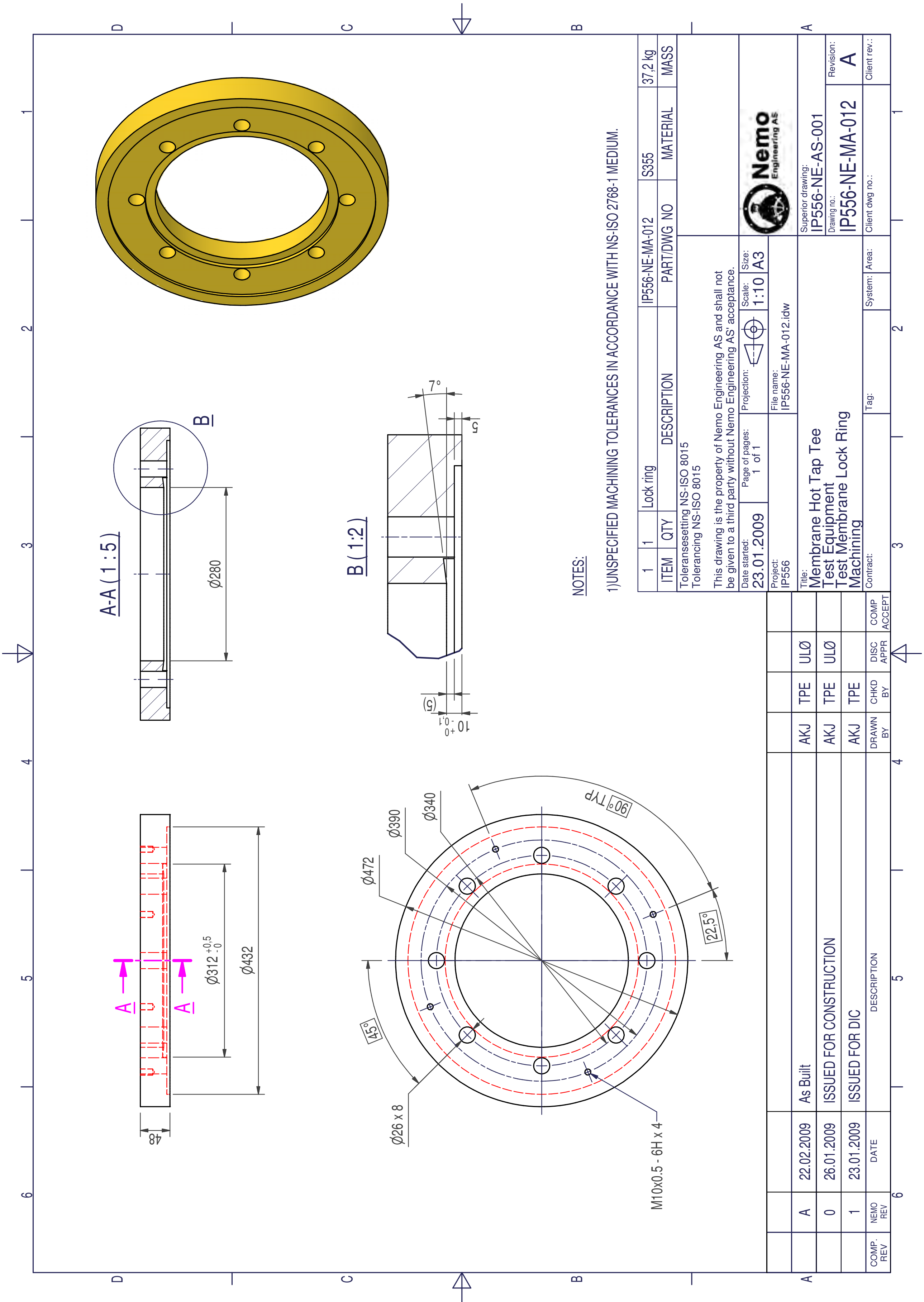

C-C (1 : 5)
977,5
848
80
900
700
NOTES:
Bolt torque:
M20: 330Nm
M24: 570Nm
Total mass: 739kg
15 Strekklapp CPI
14 1 Plate IP556-NE-MA-017 S355 2,3 kg
13 1 Lastcelle CPI
12 1 Enerpac 100T CPI
11 1 Pipe IP556-NE-MA-015 S355J2 18,6 kg
10 1 Plate IP556-NE-MA-014 S355J2 3,4 kg
9 16 Hex Nut DIN 934 - M20 8 0,1 kg
8 4 Gjengestang L=280mm M20 IP556-NE-MA-013 8.8 0,7 kg
7 1 Plate IP556-NE-MA-016 S355 15,6 kg
6 8 Hex Nut DIN 934 - M24 x 2 8 0,1 kg
5 8 Plain washers Product grade A ISO 7089 - 24 - 140 HV 0 kg
4 8 Hex-Head Bolt DIN 933 - M24 x 160 8.8 0,7 kg
3 1 Lock ring IP556-NE-MA-012 S355 37,2 kg
2 1 Membrane IP556-NE-MA-011 S355 21,6 kg
1 1 Jig Membran IP556-NE-WE-001 629,6 kg
ITEM QTY DESCRIPTION PART/DWG NO MATERIAL MASS
Toleransesetting NS-ISO 8015
Tolerancing NS-ISO 8015
This drawing is the property of Nemo Engineering AS and shall not be given to a third party without Nemo Engineering AS' acceptance.
Date started: 23.01.2009
Page of pages: 1 of 1
Scale: 1:10
Size: A1
Nemo Engineering AS
Project: IP556
File name: IP556-NE-AS-001.idw
Title: Membrane Hot Tap Tee Test equipment Test jig Assembly
Drawing no: IP556-NE-AS-001
Revision: B
B 22.02.2009 AS BUILT AKJ TPE ULØ
A 02.02.2009 RE-ISSUED FOR CONSTRUCTION AKJ TPE ULØ
0 26.01.2009 ISSUED FOR CONSTRUCTION AKJ TPE ULØ
1 26.01.2009 ISSUED FOR DIC AKJ

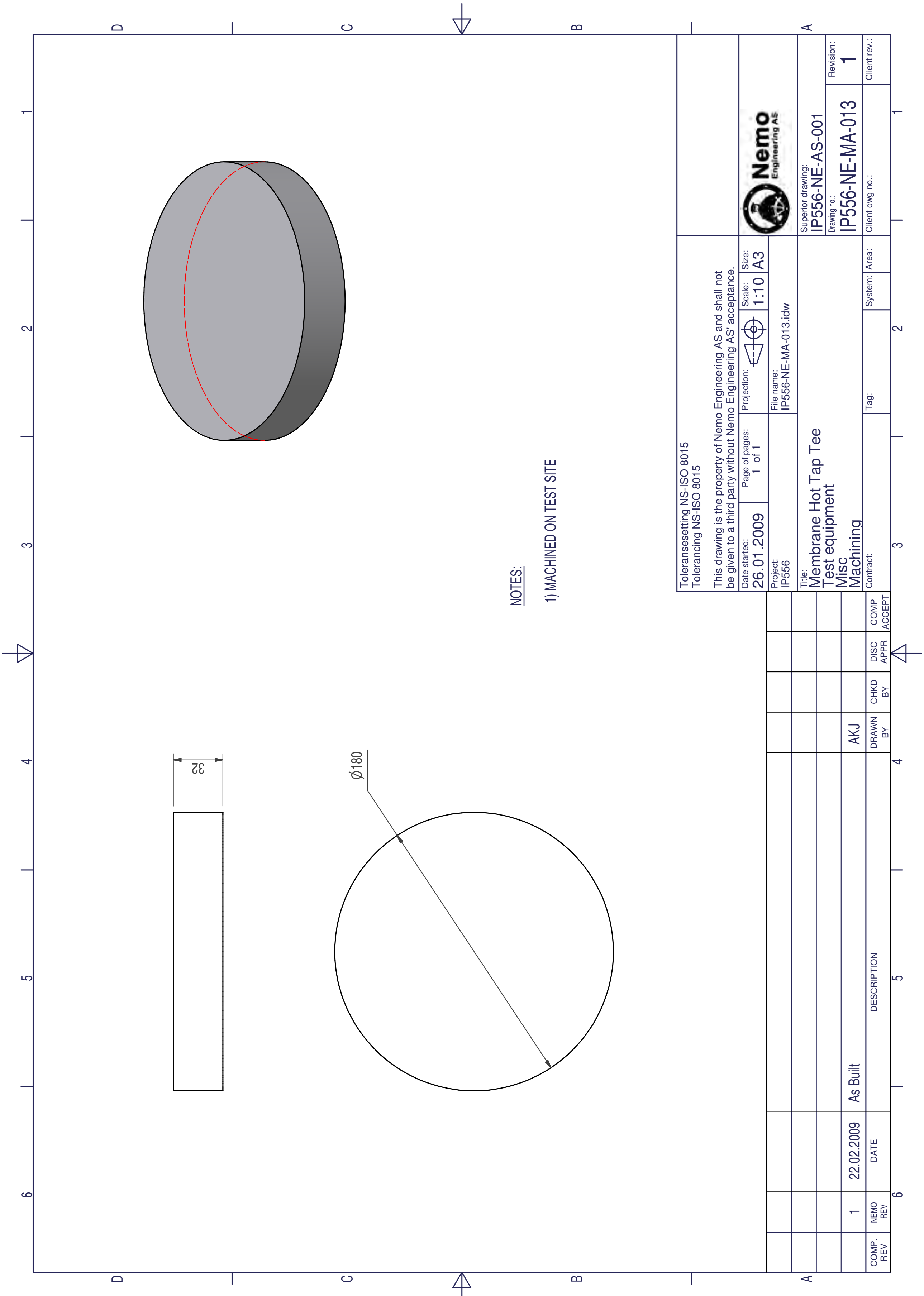


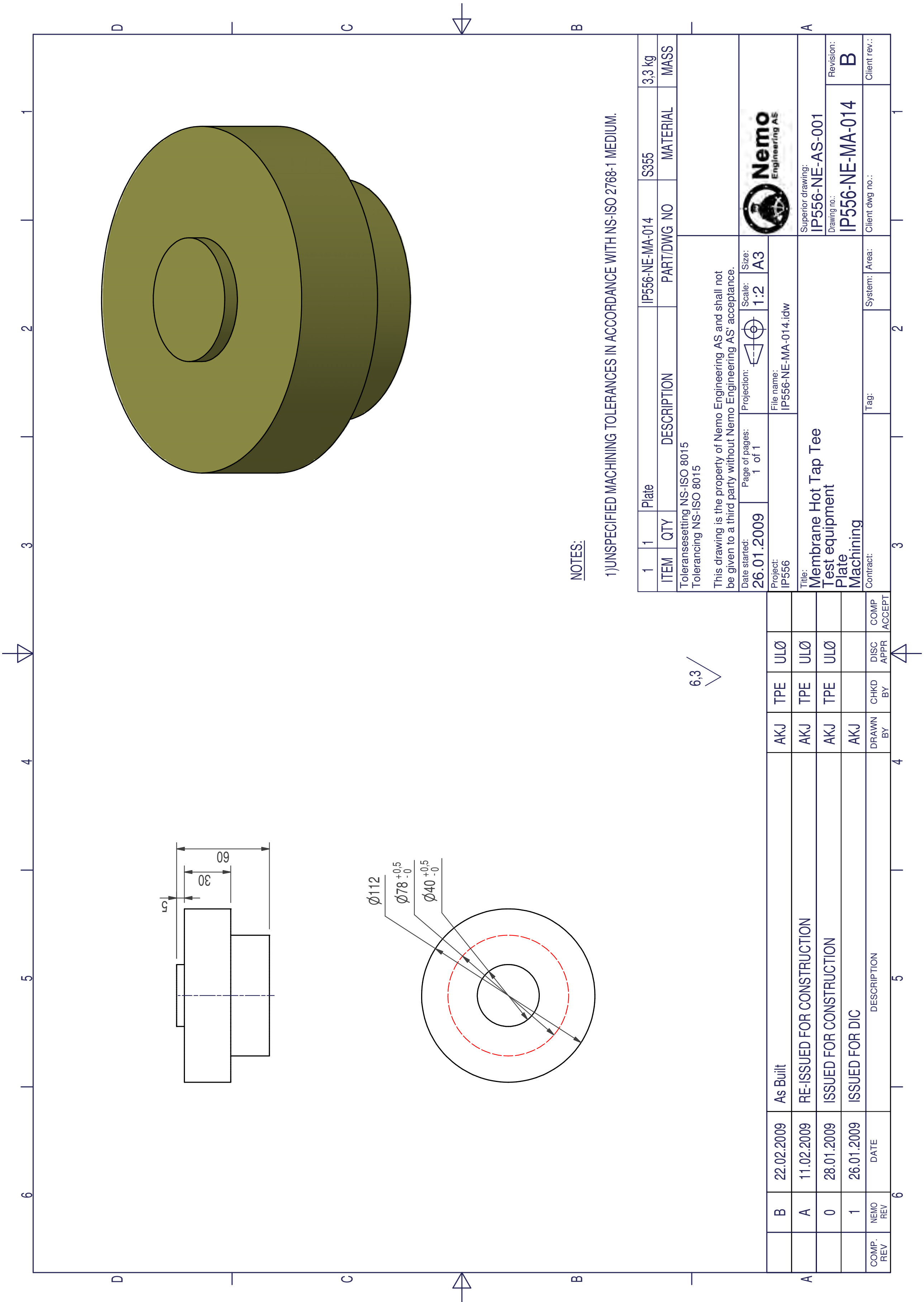
NOTES:
1) Dimensions to center of gauge area on strain gauge
24 TYP
56 TYP
90° TYP
2 6 Strain gauge (1-LY41-3/120) CPI 0 kg
1 1 Membrane IP556-NE-MA-011 S355 21,6 kg
ITEM QTY DESCRIPTION PART/DWG NO MATERIAL MASS
Toleransesetting NS-ISO 8015
Tolerancing NS-ISO 8015
This drawing is the property of Nemo Engineering AS and shall not be given to a third party without Nemo Engineering AS' acceptance.
Date started: 09.02.2009
Page of pages: 1 of 1
Projection:
Scale: 1:10
Size: A3
Nemo Engineering AS
Project: IP556
File name: IP556-NE-AS-006.idw
Superior drawing: IP556-NE-AS-001
Title: Test Equipment Test Membrane with strain gauges Assembly
Drawing no.: IP556-NE-AS-006
Revision: A
Contract:
Tag:
System:
Area:
Client dwg no.:
Client rev.:
A 22.02.2009 AS BUILT AKJ AHA ULØ
0 11.02.2009 ISSUED FOR CONSTRUCTION AKJ AHA ULØ
1 09.02.2009 ISSUED FOR DIC AKJ
COMP. REV NEMO REV DATE DESCRIPTION DRAWN BY CHKD BY DISC APPR COMP ACCEPT


NOTES:
1) STEEL FABRICATION, WELDING AND WELDING INSPECTION SHALL BE IN ACCORDANCE WITH NORSOK STANDARDS M-101, N-004 AND M-120:
STEEL QUALITY LEVEL: III
DESIGN CLASS: 4
INSPECTION CATEGORY: C UNLESS NOTED OTHERWISE
MATERIAL CERTIFICATE: EN 10204, 3.1
2)UNSPECIFIED MACHINING TOLERANCES IN ACCORDANCE WITH NS-ISO 2768-1 MEDIUM.
3)UNSPECIFIED WELDING TOLERANCES IN ACCORDANCE WITH NS-ISO 13920 B.
4)SHARP EDGES TO BE GROUND DUE TO SPRAY COATING
5)SANDPLAST IN ORDER TO APPLY PRIMER
Total mass: 629.5kg
Machining upper plate
Machining lower plate
Welding
Welding assembly
A-A (1 : 5)
B-B (1 : 5)
Ø114,3 x4 ADAPTED TO PIPE OD
Nemo Engineering AS
Membrane Hot Tap Tee
Test equipment
Test jig
Welding and machining
IP556-NE-AS-001
IP556-NE-WE-002
1:10 A1
22.02.2009
As Built
RE-ISSUED FOR CONSTRUCTION
ISSUED FOR CONSTRUCTION
ISSUED FOR IDC
Tube
Top plate
Bottom plate
S355J2
31,5 kg
155,1 kg
348,4 kg

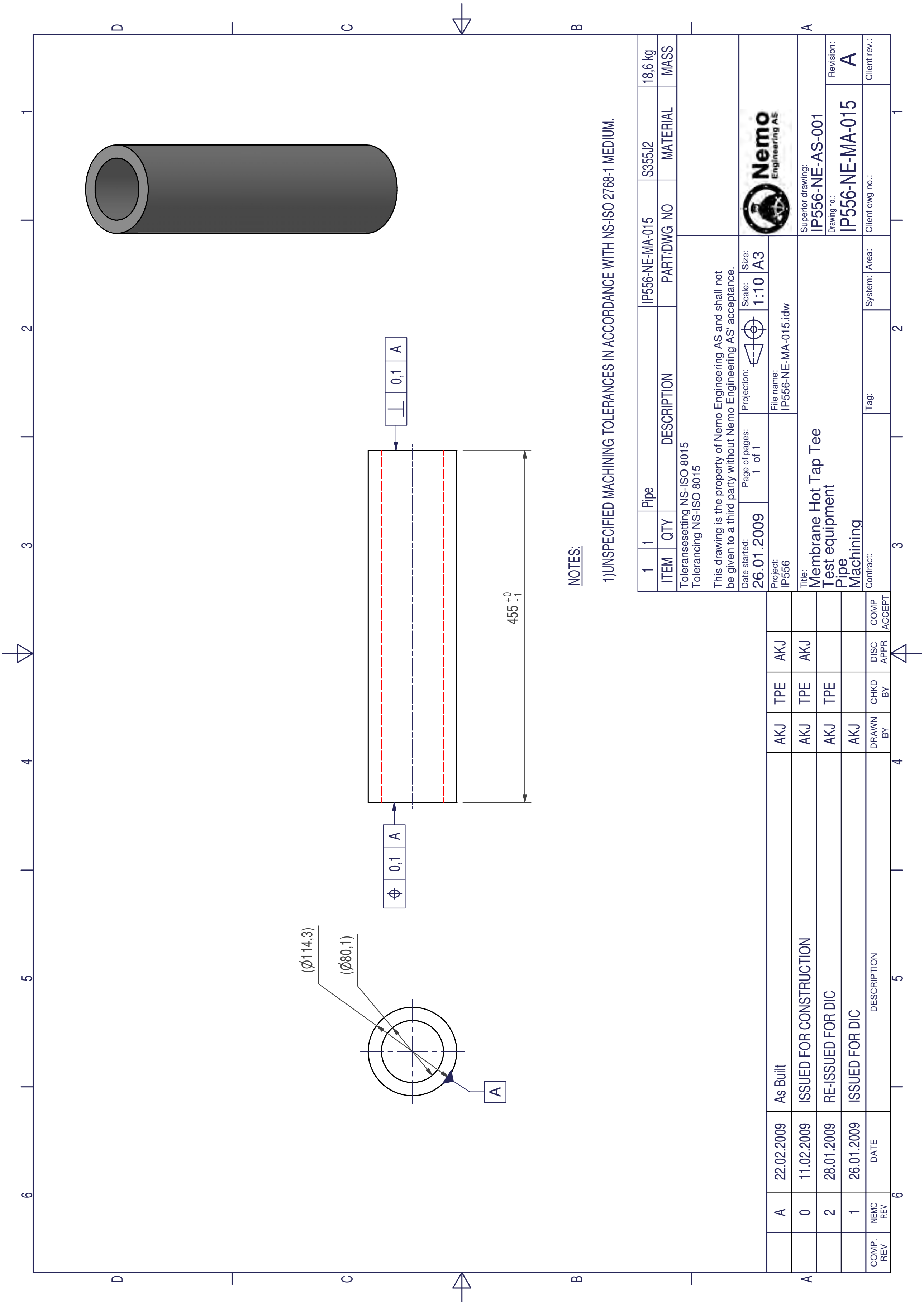

NOTES:
1)UNSPECIFIED MACHINING TOLERANCES IN ACCORDANCE WITH NS-ISO 2768-1 MEDIUM.
A-A (1 : 2)
B (5 : 1)
1 1 Membrane S355 21,6 kg
ITEM QTY DESCRIPTION PART/DWG NO MATERIAL MASS
Tolerancesetting NS-ISO 8015
Tolerancing NS-ISO 8015
This drawing is the property of Nemo Engineering AS and shall not be given to a third party without Nemo Engineering AS' acceptance.
Date started: 07.01.2009
Page of pages: 1 of 1
Projection:
Scale: 1:5
Size: A3
Nemo Engineering AS
Project: IP556
File name: IP556-NE-MA-011.idw
Superior drawing:
Title: Membrane Hot Tap Tee Test Equipment Test Membrane Machining
Drawing no.: IP556-NE-MA-011
Revision: C
Contract:
Tag:
System:
Area:
Client dwg no.:
Client rev.:
C 22.02.2009 As Built
B 03.02.2009 RE-ISSUED FOR CONSTRUCTION AKJ TPE ULØ
A 23.01.2009 RE-ISSUED FOR CONSTRUCTION AKJ RNE ULØ
0 15.01.2009 ISSUED FOR CONSTRUCTION ULÖ RNE AKJ
2 15.01.2009 RE-ISSUED FOR DIC ULÖ ULÖ
1 08.01.2009 ISSUED FOR DIC AKJ
COMP. REV NEMO REV DATE DESCRIPTION DRAWN BY CHKD BY DISC APPR COMP ACCEPT

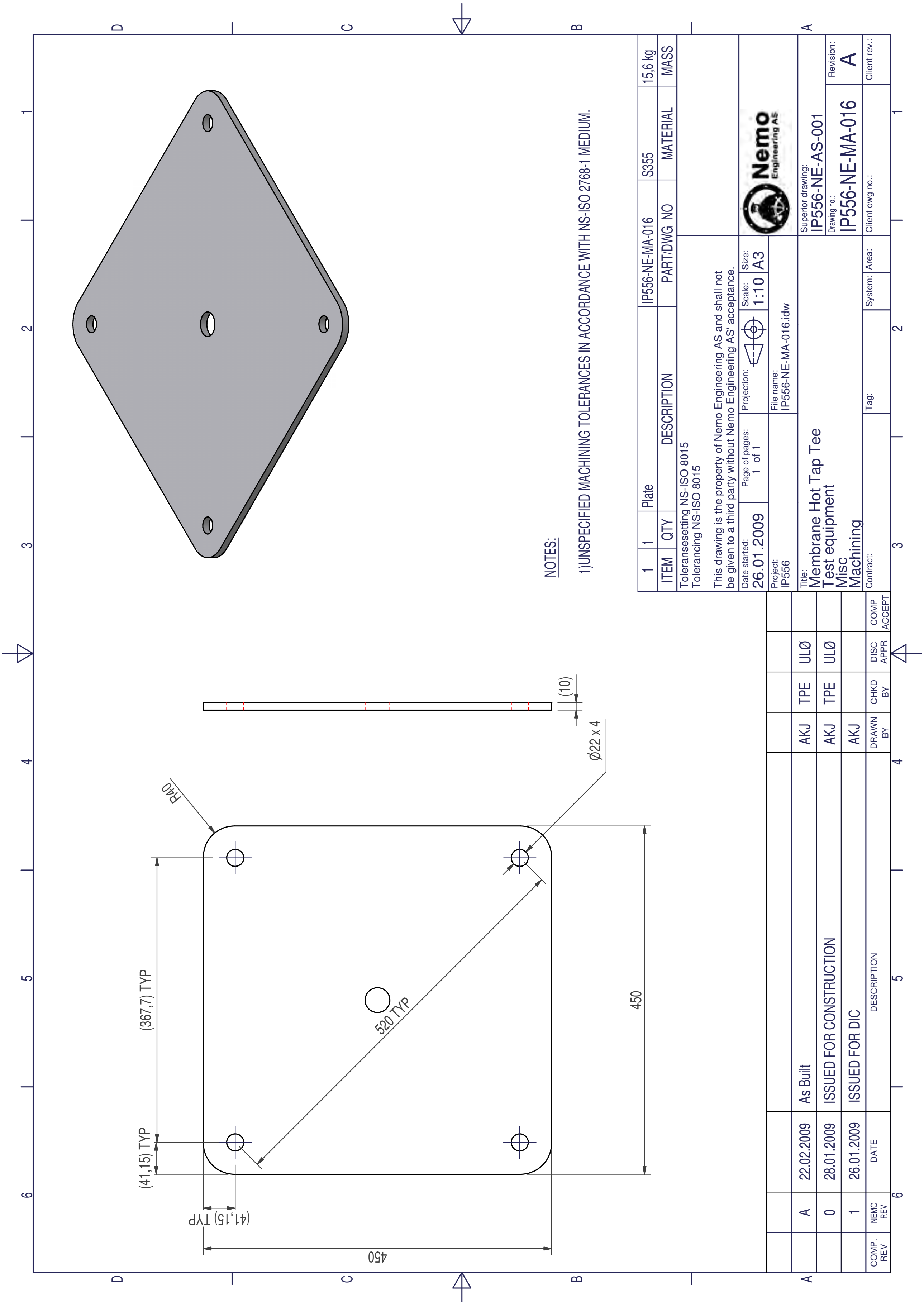

A-A (1 : 5)
B
Ø280
B (1:2)
7°
5
(5)
10 +0 -0,1
A
A
Ø312 +0,5 -0
Ø432
48
Ø472
Ø390
Ø340
90° TYP
22,5°
45°
Ø26 x 8
M10x0.5 - 6H x 4
NOTES:
1)UNSPECIFIED MACHINING TOLERANCES IN ACCORDANCE WITH NS-ISO 2768-1 MEDIUM.
1 | 1 | Lock ring | IP556-NE-MA-012 | S355 | 37,2 kg
ITEM | QTY | DESCRIPTION | PART/DWG NO | MATERIAL | MASS
Tolerancesetting NS-ISO 8015
Tolerancing NS-ISO 8015
This drawing is the property of Nemo Engineering AS and shall not be given to a third party without Nemo Engineering AS' acceptance.
Date started: 23.01.2009
Page of pages: 1 of 1
Projection:
Scale: 1:10
Size: A3
Nemo Engineering AS
Project: IP556
File name: IP556-NE-MA-012.idw
Superior drawing: IP556-NE-AS-001
Title: Membrane Hot Tap Tee Test Equipment Test Membrane Lock Ring Machining
Drawing no.: IP556-NE-MA-012
Revision: A
Contract:
Tag:
System:
Area:
Client dwg no.:
Client rev.:
A | 22.02.2009 | As Built | AKJ | TPE | ULØ
0 | 26.01.2009 | ISSUED FOR CONSTRUCTION | AKJ | TPE | ULØ
1 | 23.01.2009 | ISSUED FOR DIC | AKJ | TPE
COMP. REV | NEMO REV | DATE | DESCRIPTION | DRAWN BY | CHKD BY | DISC APPR | COMP ACCEPT

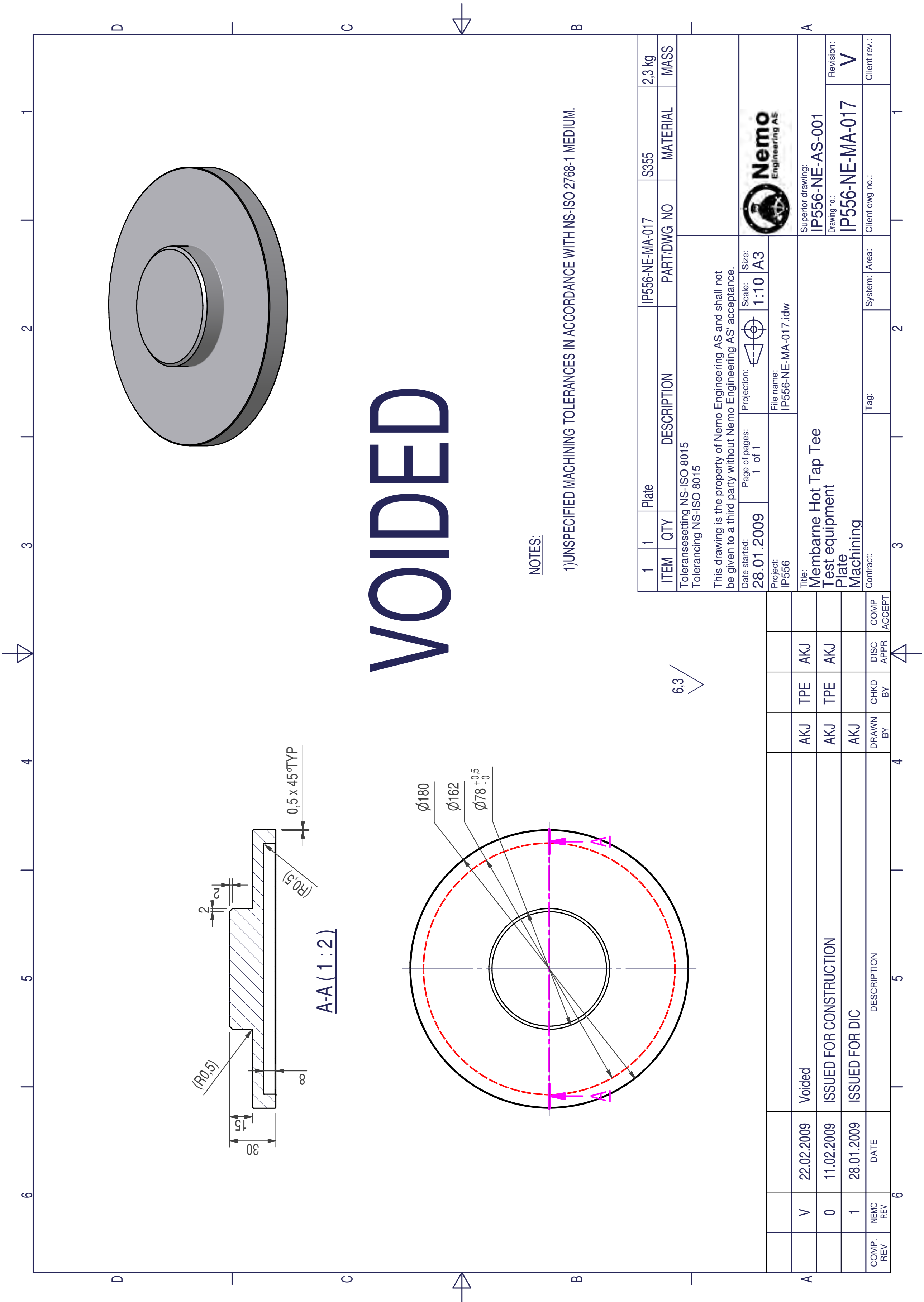

Ø180
32
NOTES:
1) MACHINED ON TEST SITE
Toleransesetting NS-ISO 8015
Tolerancing NS-ISO 8015
This drawing is the property of Nemo Engineering AS and shall not be given to a third party without Nemo Engineering AS' acceptance.
Date started: 26.01.2009
Page of pages: 1 of 1
Projection:
Scale: 1:10
Size: A3
Nemo Engineering AS
Project: IP556
File name: IP556-NE-MA-013.idw
Title: Membrane Hot Tap Tee
Test equipment
Misc
Machining
Superior drawing: IP556-NE-AS-001
Drawing no.: IP556-NE-MA-013
Revision: 1
Contract:
Tag:
System:
Area:
Client dwg no.:
Client rev.:
1
22.02.2009
As Built
AKJ
COMP. REV
NEMO REV
DATE
DESCRIPTION
DRAWN BY
CHKD BY
DISC APPR
COMP ACCEPT

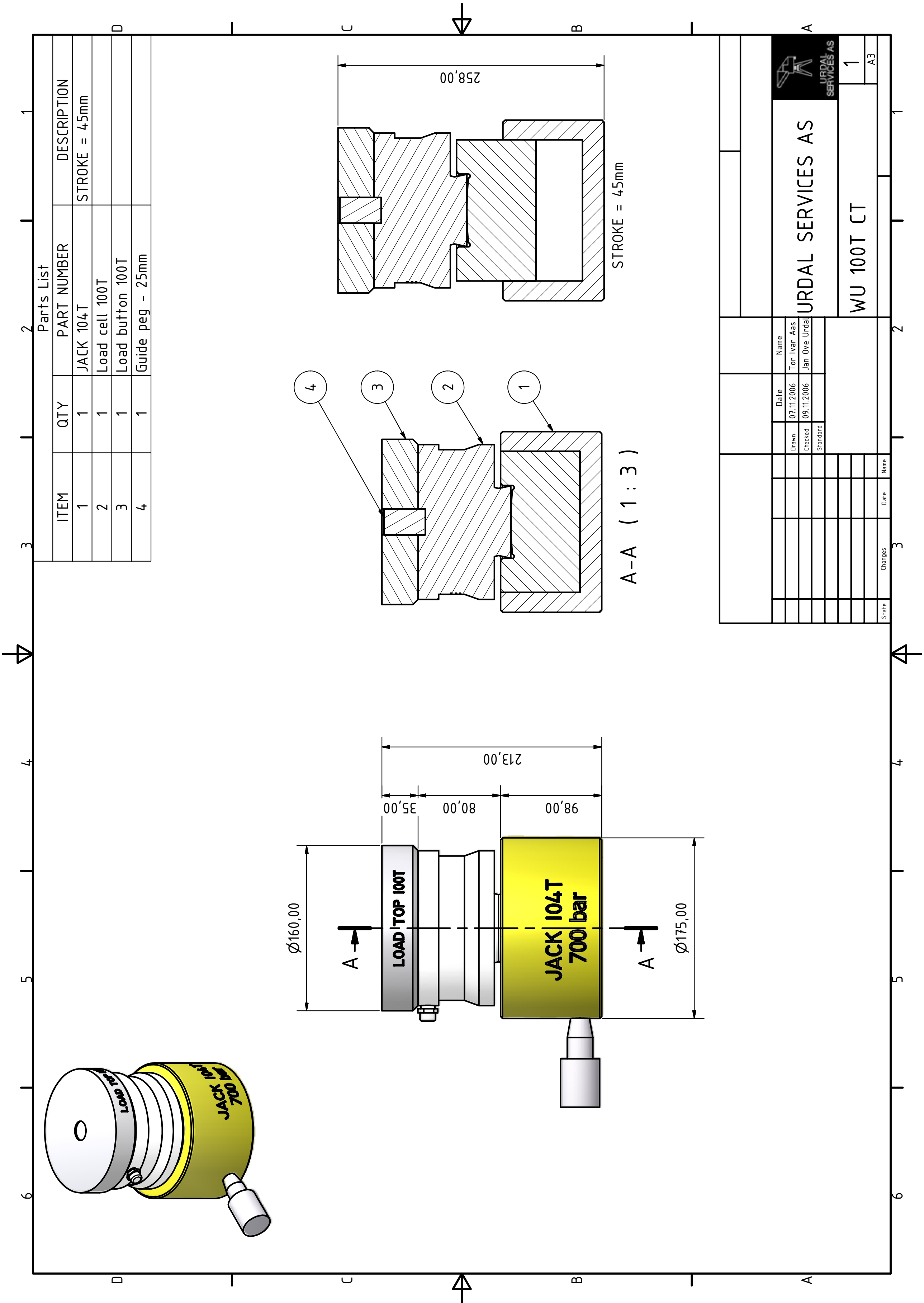


NOTES:
1)UNSPECIFIED MACHINING TOLERANCES IN ACCORDANCE WITH NS-ISO 2768-1 MEDIUM.
60
30
5
Ø112
Ø78 +0,5 -0
Ø40 +0,5 -0
6,3
1
1
Plate
IP556-NE-MA-014
S355
3,3 kg
ITEM
QTY
DESCRIPTION
PART/DWG NO
MATERIAL
MASS
Toleransesetting NS-ISO 8015
Tolerancing NS-ISO 8015
This drawing is the property of Nemo Engineering AS and shall not be given to a third party without Nemo Engineering AS' acceptance.
Date started:
26.01.2009
Page of pages:
1 of 1
Projection:
Scale:
1:2
Size:
A3
Nemo
Engineering AS
Project:
IP556
File name:
IP556-NE-MA-014.idw
Superior drawing:
IP556-NE-AS-001
Title:
Membrane Hot Tap Tee
Test equipment
Plate
Machining
Drawing no.:
IP556-NE-MA-014
Revision:
B
Contract:
Tag:
System:
Area:
Client dwg no.:
Client rev.:
B 22.02.2009 As Built AKJ TPE ULØ
A 11.02.2009 RE-ISSUED FOR CONSTRUCTION AKJ TPE ULØ
0 28.01.2009 ISSUED FOR CONSTRUCTION AKJ TPE ULØ
1 26.01.2009 ISSUED FOR DIC AKJ
COMP. REV
NEMO REV
DATE
DESCRIPTION
DRAWN BY
CHKD BY
DISC APPR
COMP ACCEPT


NOTES:
1)UNSPECIFIED MACHINING TOLERANCES IN ACCORDANCE WITH NS-ISO 2768-1 MEDIUM.
(Ø114,3)
(Ø80,1)
A
0,1 A
455 +0 -1
1 1 Pipe IP556-NE-MA-015 S355J2 18,6 kg
ITEM QTY DESCRIPTION PART/DWG NO MATERIAL MASS
Toleransesetting NS-ISO 8015
Tolerancing NS-ISO 8015
This drawing is the property of Nemo Engineering AS and shall not be given to a third party without Nemo Engineering AS' acceptance.
Date started: 26.01.2009
Page of pages: 1 of 1
Projection:
Scale: 1:10
Size: A3
Nemo Engineering AS
Project: IP556
File name: IP556-NE-MA-015.idw
Title: Membrane Hot Tap Tee Test equipment Pipe Machining
Superior drawing: IP556-NE-AS-001
Drawing no.: IP556-NE-MA-015
Revision: A
Contract:
Tag:
System:
Area:
Client dwg no.:
Client rev.:
A 22.02.2009 As Built AKJ TPE AKJ
0 11.02.2009 ISSUED FOR CONSTRUCTION AKJ TPE AKJ
2 28.01.2009 RE-ISSUED FOR DIC AKJ TPE
1 26.01.2009 ISSUED FOR DIC AKJ
COMP. REV
NEMO REV
DATE
DESCRIPTION
DRAWN BY
CHKD BY
DISC APPR
COMP ACCEPT


NOTES:
1)UNSPECIFIED MACHINING TOLERANCES IN ACCORDANCE WITH NS-ISO 2768-1 MEDIUM.
R40
Ø22 x 4
(10)
(367,7) TYP
(41,15) TYP
520 TYP
450
ITEM QTY DESCRIPTION PART/DWG NO MATERIAL MASS
1 1 Plate IP556-NE-MA-016 S355 15,6 kg
Toleransesetting NS-ISO 8015
Tolerancing NS-ISO 8015
This drawing is the property of Nemo Engineering AS and shall not be given to a third party without Nemo Engineering AS' acceptance.
Date started: 26.01.2009
Page of pages: 1 of 1
Projection:
Scale: 1:10
Size: A3
Nemo Engineering AS
Project: IP556
File name: IP556-NE-MA-016.idw
Superior drawing: IP556-NE-AS-001
Title: Membrane Hot Tap Tee Test equipment Misc Machining
Drawing no.: IP556-NE-MA-016
Revision: A
Contract:
Tag:
System:
Area:
Client dwg no.:
Client rev.:
A 22.02.2009 As Built AKJ TPE ULØ
0 28.01.2009 ISSUED FOR CONSTRUCTION AKJ TPE ULØ
1 26.01.2009 ISSUED FOR DIC AKJ
COMP. REV
NEMO REV
DATE
DESCRIPTION
DRAWN BY
CHKD BY
DISC APPR
COMP ACCEPT


VOIDED
NOTES:
1)UNSPECIFIED MACHINING TOLERANCES IN ACCORDANCE WITH NS-ISO 2768-1 MEDIUM.
A-A (1 : 2)
Ø180
Ø162
Ø78 +0,5 -0
0,5 x 45° TYP
(R0,5)
(R0,5)
30
15
8
2
2
6,3
1 1 Plate IP556-NE-MA-017 S355 2,3 kg
ITEM QTY DESCRIPTION PART/DWG NO MATERIAL MASS
Tolerancesetting NS-ISO 8015
Tolerancing NS-ISO 8015
This drawing is the property of Nemo Engineering AS and shall not be given to a third party without Nemo Engineering AS' acceptance.
Date started: 28.01.2009
Page of pages: 1 of 1
Projection:
Scale: 1:10
Size: A3
Nemo Engineering AS
Project: IP556
File name: IP556-NE-MA-017.idw
Title: Membrane Hot Tap Tee Test equipment Plate Machining
Superior drawing: IP556-NE-AS-001
Drawing no.: IP556-NE-MA-017
Revision: V
Client dwg no.:
Client rev.:
Contract:
Tag:
System:
Area:
V 22.02.2009 Voided AKJ TPE AKJ
0 11.02.2009 ISSUED FOR CONSTRUCTION AKJ TPE AKJ
1 28.01.2009 ISSUED FOR DIC AKJ
COMP. REV NEMO REV DATE DESCRIPTION DRAWN BY CHKD BY DISC APPR COMP ACCEPT


Parts List
ITEM | QTY | PART NUMBER | DESCRIPTION
1 | 1 | JACK 104T | STROKE = 45mm
2 | 1 | Load cell 100T |
3 | 1 | Load button 100T |
4 | 1 | Guide peg - 25mm |
258,00
STROKE = 45mm
A-A (1 : 3)
213,00
35,00
80,00
98,00
Ø160,00
Ø175,00
A
LOAD TOP 100T
JACK 104T 700 bar
URDAL SERVICES AS
WU 100T CT
Drawn 07.11.2006 Tor Ivar Aas
Checked 09.11.2006 Jan Ove Urdal
Standard
A3
1

Appendix G

Material sertificates

G.1 Material sertificates

Bodycote MATERIALS TESTING
METAL TECHNOLOGY

NORSK AKKREDITERING TEST007

Bodycote Materials Testing AS, Luramyrveien 69, Postboks 1084, 4391 Sandnes, Norway
Tel: 51 70 96 60, Fax: 51 70 96 61

Test Certificate

Nemo Engineering AS		REF No	N900475 : Issue 1
Prof. Kohts vei 15		Ord No	tba
1366 LYSAKER			
		Date Tested	13/02/09
		Date Reported	13/02/09

Attn: Arne-Kristian K. Johnsen

Item - 60mm plate
PZ-0083

Specification - Not Applicable

Tensile Test - EN 10002-1:2007

	Dimensions [mm]	Area [mm^2]	GL [mm]	0.20%PS [N/mm^2]	UTS [N/mm^2]	%El	%RA	Comments
001:L/T Parent	10.00	78.54	50.50	350	518	36.0	81	Top
002:L/T Parent	10.00	78.54	51.00	341	520	30.0	78	Middle
003:L/T Parent	10.00	78.54	50.00	343	517	37.0	82	Bottom

* Test equipment verified in accordance with EN 10002-2 & EN 10002-4

Certificate Comments

This is an electronic copy. See original certificate for terms and conditions.

Nicholas Smith

Tested by N. Smith

....
For and on authority of
Bodycote Materials Testing AS

DILLINGER HÜTTE

Erläuterungen siehe Rückseite/Explications voir au verso/See reverse for explanations (www.dillinger.de/certificate)

A02 INSPECTION CERTIFICATE 3.1 AS PER EN 10204:2004
INSPECTION CERTIFICATE 3.1.B AS PER EN 10204:1991+A1:1995 + AS PER ISO 10474:1991
MATERIAL TEST REPORT (MTR)

A10 Advice of dispatch No./Date of dispatch: 261903-22.06.07

A08/A03 Manufacturer's order/Certificate No: 321299-002 — Sheet: 2/...

A05 Established inspecting body: DH

A06 Purchaser: NORSK,NESBRU — A07.1 No. 70210116 PROJECT

Final receiver: NORSK STAAL,STAVANGE — A07.2 No.

B01 Product: HOT ROLLED PLATES

B02/ Steel design.: S355G10+N

B03 Any suppl. requirements: MDS-Y20:REV.4/EN-10225:01

B06 Marking of the product

ITEM NO.: 01-03,05-07
STEEL DESIGNATION S355G10+N
HEAT NO. / TRADEMARK / ROLLED PLATE NO.-TEST NO. / INSPECTOR'S STAMP

C10-C29 Tensile test

B14 Item No.	B07.2 Heat No.	B07.1 Rol.plate/Test No.	B05 Reference (heat) treatment	C01	C02/C01	C03 Temp. GR.C	C10 C11 MPA REH	C12 RM	C13 A % L0=5D	C14-C15 REH/RM	Z %
01	296065	44713		K2	S	RT		503			74,7
				K2	S	RT		503			78,0
				K2	S	RT		500			75,1
				K4	Q	RT	362	495	33,5	0,73	
01	296065	44751 *		K4	Q	RT	389	505	34,5	0,77	
01	296067	48876 *		K4	Q	RT	365	511	34,0	0,71	
02	296067	44707 *		K2	S	RT		511			71,5
		*		K2	S	RT		512			77,1
		*		K2	S	RT		513			76,1
		*		K4	Q	RT	363	510	33,3	0,71	
03	296067	44694		K4	Q	RT	378	512	33,3	0,74	
05	296684	87188		K2	SV	RT		515			78,9
				K2	SV	RT		513			78,5
				K2	SV	RT		516			78,0
				K4	Q	RT	382	512	32,4	0,75	

A04 Manufacturer's mark: DH

Z01/Z02/Z03 We hereby certify, that the above mentioned materials have been delivered in accordance with the terms of order

QM-System: Certification as per ISO 9001

B. MUELLER
Test House Manager

Inspector's stamp: AHB

Haatech ID
PZ-0083

AG der Dillinger Hüttenwerke
Postfach 1580, D-66748 Dillingen/Saar
Inspection department

Date 25.06.07 — KW 1 — A01

01 O.nr: 45775 Ref: LILLEAS Mrk: MRK.KOMMER R.nr: 7184 Ch.nr-P.nr: 296067 447112 Dim: 60,00 X 2000 X 6000 MM

Appendix H

Thesis subject text

Masteroppgave («lang») for Arne-Kristian Johnsen

Foreløpig tittel
Modellering, analyse og kvalifisering av membrantetning i avblindet grenrør.

Problemstilling
Nemo Engineering har prosjektert og bygget en serie av ulike T-stykker for innsveising på hovedrørledninger for transport av gass. Noen av T-stykkene er åpne, mens andre er blindet av ved hjelp av en stålplate. De blinde T-stykkene blir åpnet ved kjerneboring en gang i fremtiden mens rørledningen er i full produksjon, såkalt hot tapping, for å koble opp en ny rørledning til den eksisterende linjen. Nemo er for tiden igang med et prosjekt for StatoilHydro der to allerede installerte T-stykker skal åpnes i 2009 (Ormen Lange Prosjektet). I dette prosjektet inngår også utstyr for å kunne plugge/tette T-stykkene etter en gjennomført boringsoperasjon. Grunnlaget for dette utstyret er lagt i to tidligere diplomoppgaver.

Nemo Engineering ønsker nå å videreutvikle denne teknologien slik at pluggene kan brukes som permanent erstatning for stålplaten som kuttes ut i boringsoperasjonen. Det er da nødvendig med en metallisk tetning i tillegg til eksisterende pluggkonsept. T-stykkene vil bli sveist inn på rørledningen med en forhåndsinnstallert plugg og en metallmembran. Membranen skal kunne fjernes (rives, stanses, e.l.) på en kontrollert måte samtidig med demontering(fjerning) av pluggen. Membranen har funksjon som metallisk tetning frem til uttrekning av pluggen. Tradisjonell kjerneboring er da ikke nødvendig når T-stykket skal tas i bruk.

Mål
Målet med oppgaven er å modellere og simulere tetningsmembranen med numeriske metoder og bruk av kommersielt analyseverktøy. Det er videre et delmål å tilvirke forsøksutstyr og -membraner på bakgrunn av simuleringene, og å gjennomføre forsøk. I den grad det vil la seg gjøre, vil de benyttede numeriske metoder (matematiske modell) bli kalibrert opp mot de målte resultater.

Typiske deloppgaver
- Definere et «design» av membrantetningen og bruddinitieringskjerv
  - Gjennomføre nødvendige beregninger av hoveddimensjoner
  - Velge metalliske materialer

- Beregne og tilvirke forsøksmembran
  - Diskutere toleranser med Nemo
  - Vurdere metoder for innspenning, tilvirkning og montasje av stålmembran
  - Vurdere metoder for å fjerne membranen (bruddflater, energi, initieringspunkt)
- Definere testomfang, bestemme testprosedyre, gjennomføre forsøk
- Rapportering (masteroppgaven). Fremdriftsplan, med milepeler, skal utarbeides tidlig i arbeidet (se pkt. 7 i mastergradssøknaden).

Evt. endringer i oppgavens innhold som det kan være ønskelig å gjøre underveis, avtales med veilederne.