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MASTER'S THESIS

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"The secret of change is to focus all of your energy, not on fighting the old, but building the new"

Socrates.

PREFACE

This thesis is the final product of my master degree in Mechanical and Structural Engineering with a specialization in Offshore Construction, at the University of Stavanger.
It is written in collaboration with Rosenberg Worley Parsons at Buøy, Stavanger.
The thesis is combining a variety of different topics related to structural engineering and the offshore industry into a final product which shows what I have learned during my studies.

I would like to thank Rosenberg Worley Parsons and Rune Røisland for giving me the opportunity to write this thesis, and for giving me an office space and all the necessary software needed.
Thanks to Leif Inge Torgersen and Steinar Kristensen for helping me with the setup and execution of my testing.
Thanks to my supervisor at Rosenberg Andreas Christersson, and to my professor and supervisor at UiS Sudath Siriwardane, for providing me with knowledge and encouragement.

Last but not least thanks to the entire project team at Ekofisk Hook-up and Commissioning for helping me with various subjects and information regarding my thesis.

I am grateful to you all for the support and guidance you have given me over the past few months, while working on this thesis.

Stavanger, May 2014.

Renathe Kvalvåg.

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ABSTRACT

There is a lot going on offshore at the Norwegian Sector these days. Especially on the Ekofisk field, this is one of the oldest and most important fields in the North Sea.
Ekofisk 2/4 Lima (EKOL) is the newest addition to the field and houses the biggest offshore accommodation facility in the world. Ref. Chapter 2.1.

The purpose of the thesis is addressing different issues, and various parts of an offshore hook-up project. The aim is to perform experimental tests using 3.25 tons pad eyes with regard to actual lifting operations. But also highlight other important aspects in projects like this, such as the use of relevant standards, assess risk, the importance of safety and overall project management.

Rosenberg is in the process of updating their procedures for pad eyes to current applicable standards. Here both NORSOK and DNV standards have been used as a basis.

This thesis is divided into two main parts. Part one examines the various factors that are important to consider in a hook-up project, and provides important theoretical basis. Part two takes up execution, analysis and results of the experimental testing.

To conduct the testing, I had to design and produce a variety of test pieces.
I then looked at the significance of welding methods, and how the steel pad eyes behaved when they were subjected to strain both vertically and angularly. More information regarding the experimental testing is provided in chapter 4.

According to the experimental testing the welding methods and welding types, had little or no effect on the strength while testing. Thus, the original test procedures were replaced with new ones, that explores how the pad eyes reacted to strain at different hole sizes. This is to check what would happen if the pad eyes were not designed according to the requirements of the approved standards.
This proved to be useful learning for both the thesis and the company's part.

The test pieces which were prepared according to the standard, tolerated the stresses that were applied, and got minimal deformations. While pad eyes that deviated from the standard got much larger deformation and some failed completely.

This only emphasizes the importance to follow the standards' requirements as this may have fatal consequences if neglected.

NUMENCLATURE

Symbols

In this list the most commonly used symbols are presented.

F_y	Yield strenght
F_u	Ultimate strenght
A	Area
a_w	Weld thickness part pen
DAF	Dynamic amplifier factor
DF	Design factor
d_h	Hole diameter
γ_c	Load faktor
γ_p	Consequence factor
$\gamma_{R.m}$	Material faktor
h	Height, to center of hole
L	Length
R	Radius
SWL	Safe Working Load
t_p	Thickness plate
WLL	Working Load Limit
γ_{M1}	Partial safety factor
E	Youngs modulus
α	Angle
σ	strain
SF	Safety factor
ν	Poissons ratio
g	Gravity acceleration constant
F	Force

Abbreviations

ROS – Rosenberg Worley Parsons
EKOL – New accommodation platform 2/4 L
HU – Hook-Up
NOK – Norske Kroner
SSCV – Semi Submersible Crane Vessel
SAR – Search and Rescue center

PO – Production Order
MTO – Material Take-Off
COW – Carry over Work
CR – Change Request
VO – Variation Order
VOR – Variation Order Request
PEP – Project Execution Plan

ALARP – As Low as Reasonably Possible
DAF – Dynamic Amplification Factor
AFH – After Facility Handover
LSD - Limit State Design

ULS – Ultimate Limit States
SLS – Serviceability Limit States
FLS - Fatigue Limit States.
ALS – Accidental Limit States.
HAZ – Heat Affected Zone

NDT – Non Destruktive Testing
Full Pen - Full penetration
Part Pen – part penetration

TERMS OVERWIEW

Pad eyes
Is an attachment point for lifting, and is often used in combination with a shackle.
Also called lifting lug but in this thesis pad eye is used consistently.

A project scope
Is the work that needs to be done, in order to deliver a result, a product or a service, with pre-determined features and functions.

Hook-up
The actual connection of the accommodation platform

Commissioning
Are completion, activation and testing of all systems.

Ductility
Is a material's ability to be plastically deformed under stress, without fracture.

First sleep
The first time that people spend the night at the accommodation platform.
Basics as electricity, water and systems has to be operative to make it happen.

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EKOFISK

"Named after a fish that has never been proven, in an oilfield nobody thought existed ..."[i]

CHAPTER 1

1 INTRODUCTION

The Norwegian oil age is an adventure without a specific ending. When companies such as Phillips petroleum and Mobil started to show interest in the Norwegian Continental Shelf in 1962, no one knew what awaited them.

The following year they got permission to do seismic tests and position them self in Norway. The Esso owned Ocean Traveler is the first platform to start drilling on the NCS in 1967. Soon after in 1969 Phillips announces the first discoveries on the Ekofisk field, located southwest of Stavanger. This was the breakthrough that led to other major developments in the North Sea, and the start of Norway's oil era.
The production started in 1971, and field is growing fast both in complexity and size. In 1974 the first permanent platform is in place, Ekofisk 2/4 Alpha. Exploration continues and the following year production starts from surrounding platforms on the field, Albuskjell, Tor, Eldfisk A and B, Edda to name a few. In total the Ekofisk field has consisted of 31 installations.

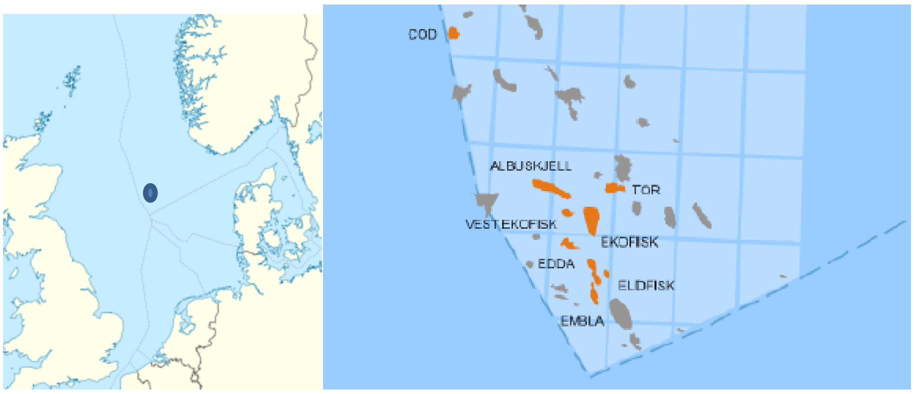

Figure 1.1: Map of the Ekofisk area.

In 2002 Phillips Petroleum merged with Conoco Inc. to form what we today know as ConocoPhillips AS (COPSAS).
Ekofisk is still one of the most important oil fields in the North Sea, and has been producing oil and gas for over 40 years. Due to resent upgrades the field it is set to continue operation up to 2050.

1.1 Thesis background

In 2010 ConocoPhillips was granted permission to install a new accommodation facility, Ekofisk 2/4 L (EKOL). The offshore facilities were finished in 2013, and it is now known as the biggest offshore accommodation facility in the world.

The accommodation facilities are built by SMOE in Singapore, and the hook-up and commissioning work is done by Rosenberg Worley Parsons (ROS) in Stavanger. (Former Bergen Group Rosenberg.)
The jacket which houses the accommodation platform and a bridge support jacket are built by Aker Solutions. The bridge to access the platform is built by Aibel.

When dealing with a Hook-up and Commissioning contract there are a lot of factors to take into consideration. Especially when it is built on a continent, then shipped and installed in another.

Some of the challenges are:

- Managing and planning across national and continental boundaries.
- Cultural and social differences, different work ethic.
- Essential to have a project plan with realistic expectations, and realistic budget, with respects to all parties.
- Most of the communication will be conducted by mail or through the internet.
- There will only be a small project team from the company to oversee the build of the current structure.
- Plan the project using “bottom up” methodology, the installation phase will drive the design.
- Different rules for the use of standards and regulations.
- Various laws and regulations for the use of HSE.
- Different perceptions of risk and risk prevention work.

By adding a lot of effort during the planning phase, the project has a greater chance of success according to both time and costs. Another important success factor is that both the operator and the supplier have the expertise that is necessary for this kind of project.

1.2 Goal and scope of work

The aim of this paper is to summarize a hook-up project in a clear and easily understandable manner. By extracting what it takes to implement a successful project and what should be avoided.

In the thesis, I have focused on using different parts of the curriculum of my study, in addition to project information from Rosenberg's internal documents. Information and knowledge are also obtained from staff at Rosenberg who has been directly involved in the execution of the project.
To restrict the thesis I will look at the planning stage, fabrication phase and installation phase of the project, focusing mainly on the structural discipline.

By performing experimental testing of lifting devices associated with the thesis, I have verified that the Rosenberg’s procedures are in accordance with what is applicable in practice.

CHAPTER 2

2 BACKGROUND

The accommodation at Ekofisk 2/4 L is a multifunction addition to the Ekofisk field. It has 2000 rooms, 552 single cabins, a helideck, hangar for helicopters, antenna signal tower, a permanent crane and 10 free fall lifeboats.

Figure 2.1: Placement of the new 2/4 L platform.

2.1 The EKOL Hook-up Project

The main challenge in the startup phase of the project was to reduce the weight and the size of the platform for offshore lifting purposes. But still attend to all platforms' features.
The magnitude of everything is quite extensive, so we need some key information to start with.
In late April 2012, (former) Bergen Group Rosenberg was assigned a pairing contract for ConocoPhillips' new Ekofisk 2/4 L platform.
The work on this contract started in May 2012, and was finished in spring 2014.

Offshore hook-up work was scheduled to start in the end of July in 2013, after the accommodation unit had been transported by boat for 30 days, from Singapore through the Suez Canal to Norway.
The workload in an extensive project like this cannot always be planned in advance, so to make it worth it for both the builder and the contractor a reimbursable contract was used.

The workload for ROS contained; job setting, installation offshore and commissioning assistance.
To perform the offshore lift they used Saipem 7000, the world's second largest semi-submersible crane vessel (SSCV). It has a lifting capability of 14000 tones.

The accommodation platform weighs in at 12000 tones, and the weight was set to be a problem that may increase the work offshore.

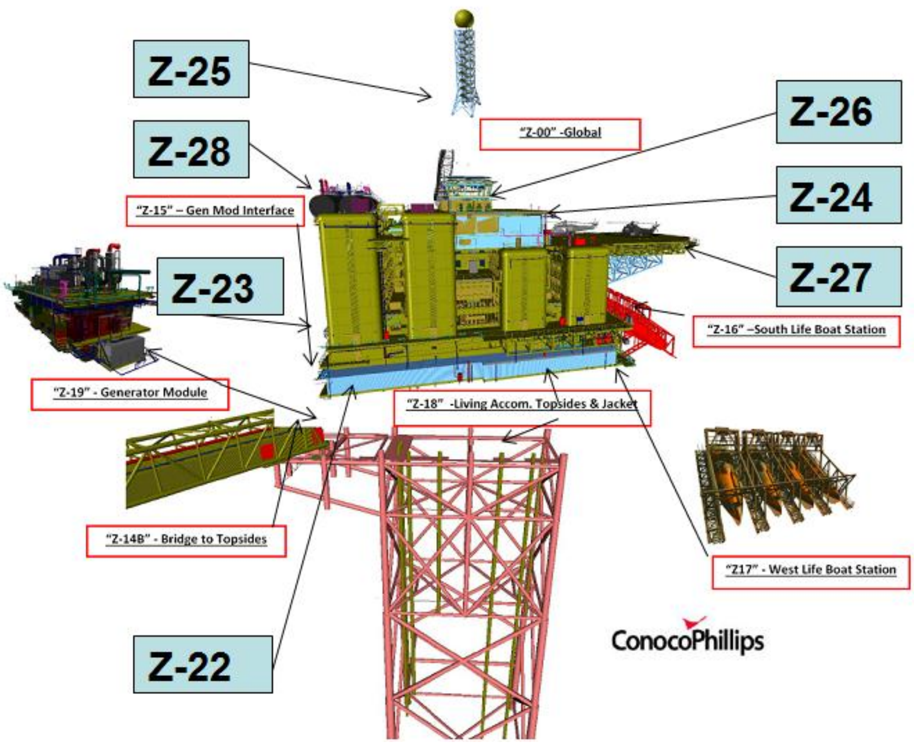

Figure 2.2: Hook-up zones EKOL.

The living quarter (LQ) in area Z18 is the main module, and then we have four other separate units, the generator module in area Z19, the helicopter deck in area Z27, the south lifeboat station in area Z16, and the west lifeboat station in area Z17.

The helicopter deck which is shown in the figure is a separate module in area Z27, this will help to handle and control the air transport to and from the platform.

In addition to this the platform will contain many field center functions and systems. It has a telecommunication center in area Z26 and a helicopter hangar to handle the air traffic.

No hydrocarbons are involved in the building and operating of the accommodation platform, only diesel tanks and helicopter fuel.

2.2 Definition of hook-up zones

An overview and definition of the hook up (HU) zones in ROSs scope. Each hook up zone has its own scope of work for each discipline.

Z00 Hook-up area general, all work with no predefined HU zone, and loose items.
Z14B Hook-up area between bridge and topsides
Z15 Hook-up area between utility module (UM) and power generator module (PGM).
Z16 Hook-up area lifeboat davits, south side
Z17 Hook-up area lifeboat davits, west side
Z18 Hook-up area between PGM and jacket
Z19 Hook-up area between UM and jacket
Z22 Hook-up area between seawater and firewater pumps
Z23 Hook-up area laydown platforms, east side
Z24 Hook-up area helicopter hangar
Z25 Hook-up area antenna tower
Z26 Hook-up area sling laydown platform
Z27 Hook-up area helicopter deck

The highlighted areas are where the structural discipline has performed their work. This consists mainly of: Installation of access bridges, remove temporary steel, bolting or welding of hinged platforms, install loose items, and install handrail and flexi barriers.
They had five Field engineers in rotation offshore to overlook everything related to the HU scope. The field engineers have been an important link between offshore and onshore, and are invaluable in projects like this.

2.3 Planning and fabrication

Before starting the building of the accommodation platform, there is a lot of details and planning to be done.
One of the main focus points from the start of the project in 2012 was safety. And one of the company goals was to keep the number of accidents equal to 0, both onshore and offshore. This referred to both lost-time injuries and medical treatment injuries.

Read more about safety and risk analysis in chapter 3.4.

Project control systems were implemented to suite both the bidder and the contractor. Zones were defined, and a detailed hook-up planning team took place in Singapore in the fourth quarter of 2012.

The scope is then divided into four main phases.

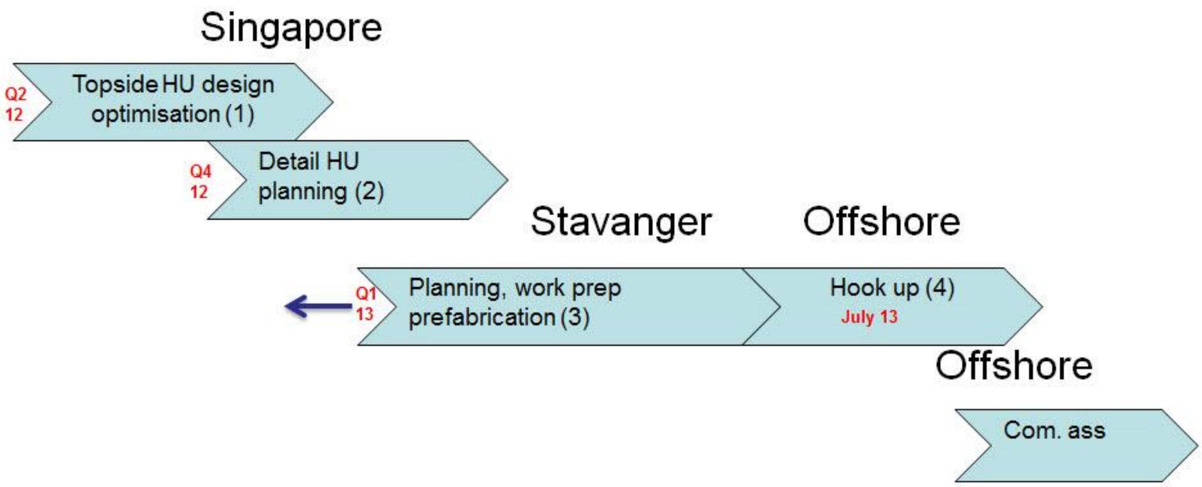

Figure 2.3: Hook-up phases.

- Phase 1: Design optimization for the hook-up topside.
  Verify and develop registers, obtain documentation, plan material provision, and how to tag and mark pieces that had to be fabricated throughout the project.

- Phase 2: Detailed planning.
  Establishing risk and opportunity registers. Establish safety plans and procedures, implement tolerance requirements, and prepare for testing onshore and offshore. Interact with core team in Stavanger, identify carry over work, and assist in preparations of mechanical completion (MC) procedures as required from the company.

- Phase 3: Onshore planning in Stavanger.
  Engineering and work preparation of the hook
  -up scope created in phase 1.
  Finalize plans for procurement, fabrication work and establishment of job packages. A familiarization program is then carried out between workers from Singapore and Stavanger, to increase expertise. Upon sail away of the EKOL topside, workers from Singapore will be mobilized to both onshore and offshore positions at Rosenberg.

- Phase 4: Offshore hook-up.
  After Sail away from Singapore, the living quarter is expected to use about 30 days on the journey up to Norway. Onshore preparation of activities, and perform relevant training. Mobilize personnel offshore, and preparing to relocate facilities to the living quarter. Continue to cooperate with COPSAS platform organisation, and report man-hour progress.

In parallel with Phase 4 there was also given commissioning assistance by ROS. They provided the necessary tools and skilled personnel, while COPSAS provided supervisors and materials as requested by ROS.

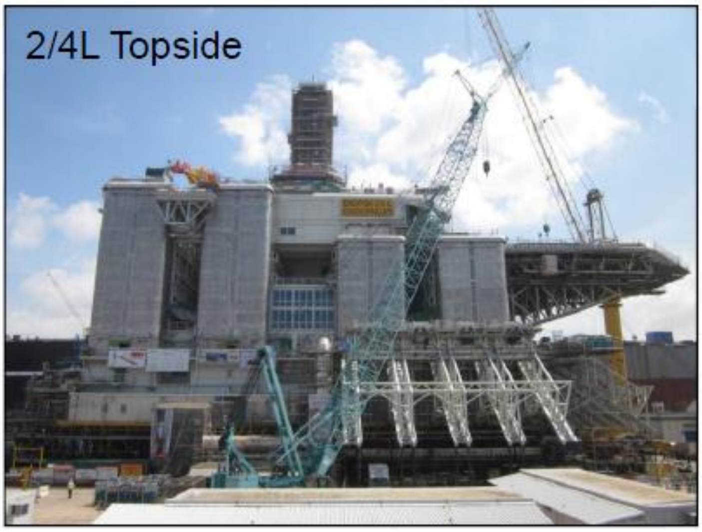

Figure 2.4: Building the 2/4L topside.

Fabrication has mainly been done in Singapore, but some things had to be executed at Rosenberg.

The main reasons that work had to be performed at the yard were:

- Missing items
- Items that had been shipped from Singapore but did not fit.
- Unavailable drawings on location of items, had to make new in place to fit.
- Procedures were not available according to ROS standards. Make new items to fit our requirements. Like welding documentation, pad eyes size, etc.
- Items that had to be assembled before sail away from Singapore, that they did not have time to put on.
- Modification on existing parts to fit in place.
- Replacement of damaged goods from the transportation.

It was more fabrication work than first expected, but with a solid project plan to work with, and good communication between all parties involved, this was not a problem.

More information about project planning can be found in chapter 3.6.

2.4 Offshore lifting of the accommodation platform

The EKOL arrived in Norway, Stavanger in the beginning of August 2013. It was then located in the Åmøy fjord, before being prepared for tow in Mekjarvik. The towing out to the Ekofisk field started on Friday, August 9.
Saipem was responsible for both towing and installation of the living quarter, and it was lifted into place Sunday, August 11, with no major problems.

Figure 2.5: Saipem heavy lift.

Figure 2.6: Installation of living quarter 2/4L on the Ekofisk field.

When the living quarter was in place there were still three major offshore lifts to be done:

- Generator module PGM
- Lifeboat station, west.
- Helicopter deck

They had to remove these modules before the main lift due to stability, weight, and center of gravity.
The modules then got lifted into place by Saipem the following week.
The whole installation sequence of the living quarter was developed together with COPSAS.

The First priority after the modules were installed was to establish a safe access between the main bridge and the platform. Then to perform a general safety check of all areas, and to make sure that all openings was secured by temporary handrails and kickboards.
Furthermore the connection of temporary supply of power, fire water, diesel, instrument air and potable water from the center had to be done. The diesel lines were set to supply diesel to two temporary generators, securing sufficient power until the permanent power systems were in operation.

First sleep was on time, and was executed 30 November – 1 December 2013. After this more personnel were mobilized, and the installation could begin.

The Official opening of the 2/4 L platform at Ekofisk was April 1, 2014.

During the summer/autumn 2013, 3000 people were employed at the Ekofisk field.
And the various upgrades done to the field in the past few years, is going to secure Norway's position in the oil industry for several years to come.

2.5 Ongoing installation and future work

- Rosenberg is now finished with their scope of work, and has no longer field engineers on the platform.
- Remaining work is taken as after facility handover (AFH).
- All major systems are up and running, only small points remaining.
- Other firms and companies are taking over the remaining work, for the different disciplines. Like touch up, modification and maintenance.

The official completion date was April 10, when it was handed over to COPSAS.

Figure 2.7: Overview of the entire Ekofisk complex.

CHAPTER 3

3 THEORY

This chapter provides background theory and relevant information to get on an overall understanding of the thesis.

3.1 Steel materials

Steel is produced by the refining of pig iron, consisting of iron, carbon, alloying and companion elements. It is a material that is well suited for prefabrication and it fits well with other materials.

Iron is the main component of steel, and the materials structure changes depending on how much of the other items it contains. Increases the carbon content gives increased yield, increased hardness, and higher tensile strength. If, however, reduces the carbon content reduces the steel elongation ability and weld ability.

One wants manganese, silicon, hydrogen, nitrogen and oxygen as companion elements, and the phosphorus and sulfur are undesirable.
Alloying elements are added in order to highlight specific features, and to introduce new properties of steel.

Classification of steels can happen in many ways, you can divide them according to function and usage or by composition.
Dividing then by function include structural steel, tool steel, refractory steel, acid-resistant steel. When we divide it by composition we divide it according to the percentage of alloying elements in the steel.

Structural steel is mostly used for welding as it has high yield strength, that are further used to carry and support structures both onshore and offshore.

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3.1.1 Welding

Welding is the best way to create lasting and strong connections, assuming normal working conditions. Welding materials means that steel is rapidly melted and rapidly cooled. The process leads to structural changes in the steel and large residual stresses in the heat affected zone (HAZ).
The HAZ is the area of parent material, which is melted and gets their microstructure and properties altered by welding.

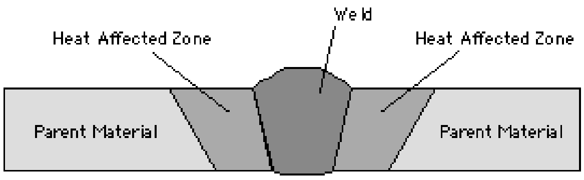


Figure 3.1: The HAZ zone in a weld.

It is not uncommon to experience various weld defects. The most common defects are surface flaws, connective failure, hot cracks, transverse cracks, crater cracking and cold cracking. The worst welding defect is cold cracking in the heat affected zone parallel to the weld. If the steel has low ductility and there are large residual stresses present, it is very likely that cold cracking may occur. Other factors affecting crack formation is the material's thickness, the steels chemical composition and the welding method used.

There are two types of welding that are appropriate for structural steel, butt and fillet welds.

We use fillet welding if the parts that need to be connected are parallel and do not intersect. It is a reliable and economical method of joining materials, and do not require usage of additional components.

Butt Welds have many different joint types. The most common are V, X, and K joints. The different joint types are selected from the welds area of application. We also distinguish between full - and part penetration of the weld.

3.1.2 Pad eyes and shackles

Pad eye is a device intended for the lifting of various components, both onshore and offshore. It is a fairlead that is welded to the components to be lifted, or directly on the deck of small platforms.

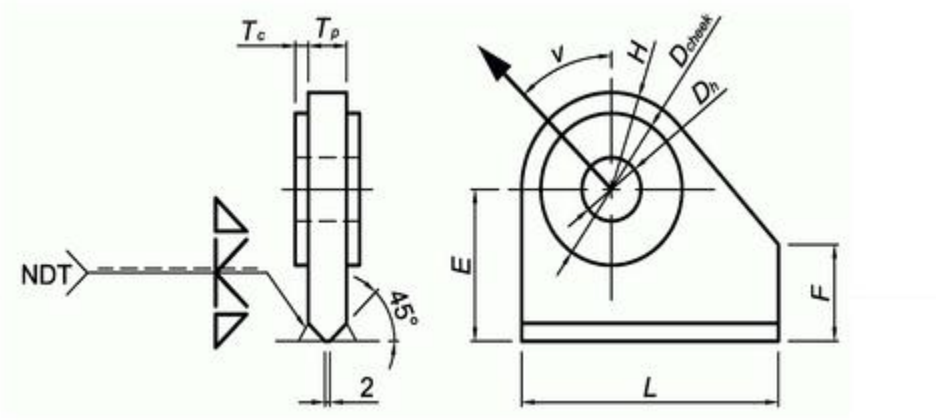


Figure 3.2: General pad eye design.

They are made of steel, plain or stainless. They have a hole at the upper part, with a given radius, and they are welded at the base. The actual lifting operation is done with the help of a shackle, or slings in some cases.

When the pad eyes go up in dimension they may have cheek plates welded around the hole, to secure the centration of the shackle.

When designing pad eyes it is important to check that the stresses are within the allowance, both at the hole and the base.

Table 3.1: Pad eye dimensions, based on shackle size.

Rating[mtons]				Shackle	D_h	H	F	E	L	T_p	T_c	D_{ch}
Sling angle 45°		Sling angle 30°										
from	to	from	to	[mtons]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]
		-	3.1	**3.25**	20	35	25	55	115	15	5	45
-	5.1	3.1	6.5	**4.75**	23	35	30	55	110	15	5	55
5.1	7.8	6.5	10.8	**6.5**	26	45	35	55	130	20	5	60
7.8	12.0	10.8	16.9	**8.5**	29	52	35	68	160	25	5	70
12.0	14.5	16.9	19.8	**9.5**	33	60	40	75	180	25	8	80
14.5	20.5	19.8	25.0	**12**	36	60	40	90	190	35	5	80
20.5	23.5			**13.5**	39	65	50	100	200	35	8	90
23.5	25.0			**17**	43	75	70	120	230	40	8	100

Shackles are made up of a U-shaped body and a pin, often secured with a bolt.
They are used together with different lifting devices, and from table 3.1 we see that the size of the shackle are relative to the hole diameter of the pad eye.

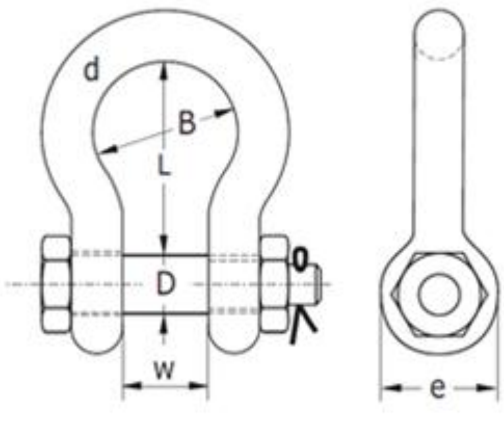


Figure 3.3: General shackle design.

To make sure that the shackles are according to standard, with no excess wear and tear, it is important to do a visual inspection. Check that the pin is seated correctly, with no excessive bending, or elongation. If this is the case it is time to discard it, and replace it with a new one. This is important to keep lifting operations safe for all involved.

Statutory requirements will be different depending on where the equipment is being used, onshore or offshore, and depending on how old the equipment is. But all equipment used shall be designed to be safe when it is in use, it should also be clearly marked and get the maintenance required.

The maintenance and examination of lifting equipment should always be done by a certified and competent person.
It is the company that has overall responsibility for ensuring that they fulfill given requirements and regulations.

3.1.3 None Destructive Testing

NDT is used when measuring or inspecting materials without doing any damage to the material itself. This is done to determine the integrity of a structure, but also to measure and find the characteristics of an object.

The most commonly used NDT techniques are; Visual inspection, magnetic particles, liquid penetrants, ultrasonic and X-ray.
Magnetic particle inspection is used to check for cracks in steel materials, and ultrasonic inspection can be used to check if there is any welding defects or flaws.

Different methods of NDT are also applied in the service industry to check for wear and tear on equipment, not visible for the bare eye. It is indispensable in everything from aircraft and automotive industry to engineer firms that build bridges and ships.

Rosenberg has its own department; quality control (QC) which checks that everything that is built in the hall is up to the standard the customer expects and deserves.

3.1.4 Stress and strain

Different types of deformation can occur in the steel. This depends on the steel type, quality and the size of material.

If we choose high quality steel like S420, this will have higher yield strength than normal quality steel S355, and is therefore able to withstand greater stresses before it goes to failure. See Appendix A, Table 1; Material data sheet for structural steel for more information on steel grades.

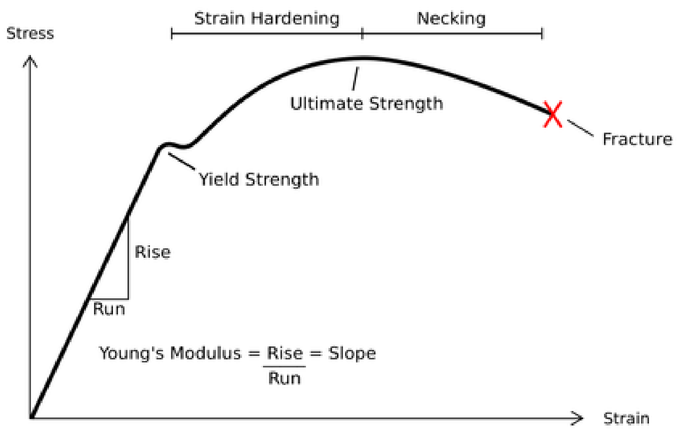


Figure 3.4: stress vs. strain diagram for a typical ductile material such as steel.

We distinguish between elastic and plastic deformation.

Elastic deformation:

- When the forces applied to the steed decreases, the steel goes back to its original shape.
- Linear elastic deformation is given by Hooke's law;

$$\sigma = E \cdot \varepsilon$$

Where; σ is applied stress, ε is the resulting strain, and E is a constant called Young's modulus.

The elastic zone ends when the material reaches its yield strength. Then the plastic deformation begins.

Plastic deformation:

- This type of deformation is irreversible. The steel will not go back to its original shape when the force decreases.
- After reaching the steels yield strength the material will stay in the plastic zone, until there is fracture in the material. As shown in figure 3.2.

3.1.5 Material failure

We have two main types of fracture in steel materials:

Ductile fracture:

- Have their characteristics at both the macroscopic and the microscopic level. The fracture process takes place at different stages.

1.) Constriction begins, and then it forms small micro pores in the material.
2.) The pores continues to expand, they blend into each other, and expand to large cavities inside the material.
3.) The cavity continues to expand in the direction perpendicular to the applied stress.
4.) Eventually only a ring around the outer edge of the material is holding it together. Shear Forces leads to a rapid 45 degrees fracture of this ring.

Brittle fracture:

- The characteristic of brittle fracture is minimal plastic deformation and fracture quick development so that the fracture surface being a flat surface that is perpendicular to the direction of the applied force.
- The crack that occurs in the material propagates by breaking of atom bindings along specific crystallographic plane. And eventually leads to failure.

Fracture toughness of a material is a measure of a material's resistance to brittle fracture when a crack is present.

No matter which material quality that is used, there will always be small microscopic cracks both inside and on the surface of the material.
It is important to have knowledge of fracture mechanics to avoid catastrophic fracture of materials with low to medium ductility.

3.2 NORSOK

The NORSOK standards are developed by the Norwegian petroleum industry. This is done to ensure security and development in the industry, and to create a common standard for all companies. The standards should as long as it is possible, replace the company's internal regulations, and is also used as reference for different regulations.

I have chosen to focus on four different NORSOK standards that address various aspects relating to lifting operations..

3.2.1 R-002 Lifting equipment

The main purpose of the standard is to secure safety for humans, material assets and the environment, but also to give technical requirements for lifting operations.

Annex H - Foundations and suspensions.

Foundations and suspensions are not considered lifting appliances, but are structural elements which are considered to be the interface between a lifting appliance and the general structure.

Table 3.2: Group overview, from R-002.

Group no.	Group	Definitions
H1	Runway beams	Monorails and beams including their fastening to structure for suspension of permanent or temporary lifting equipment.
H2	Lifting lugs	Lugs including their fastening to structure for suspension of permanent or temporary lifting equipment.
H3	Sheave brackets	Sheave brackets including their fastening to structure for suspension of permanent or temporary sheaves.
H4	Foundations	Structural or mechanical parts used as foundation for permanent or temporary mounted lifting equipment to structure.

As seen from Table 3.2, pad eyes are in group H2 and shall be designed in accordance to annex J.

The design shall be based on the loads described from the manufacturer, of the specified lifting equipment to be suspended by the lifting lug.

The following design criteria shall be used:

- DAF is 1.5 for SWL up to, and including 3 tons.

Design load is defined as: Pp. = SWL*DAF*DF

Where DF = $J_P \cdot J_C$

Table 3.3: Design factors (DFs).

ELEMENT CATEGORY	J_p	J_c	DF ($J_p \cdot J_c$)□
Single critical elements of the suspension or foundation	1,34	1,25	1,68
Main elements of the suspension or foundation	1,34	1,10	1,48
Other structural elements of the suspension or foundation	1,34	1,0	1,34

The following documentation shall be available:
- Drawings
- Calculations
- manufacturing records

Annex J – Lifting lugs and mating shackles.

All dimensions in this annex are given as nominal values, in mm.
There are 3 main types of designing a lifting lug:

- Type 1: Made from one single plate
- Type 2: Has check plates, and fillet welds.
- Type 3: Has a boss partly welded to the plate, and full penetration welds.

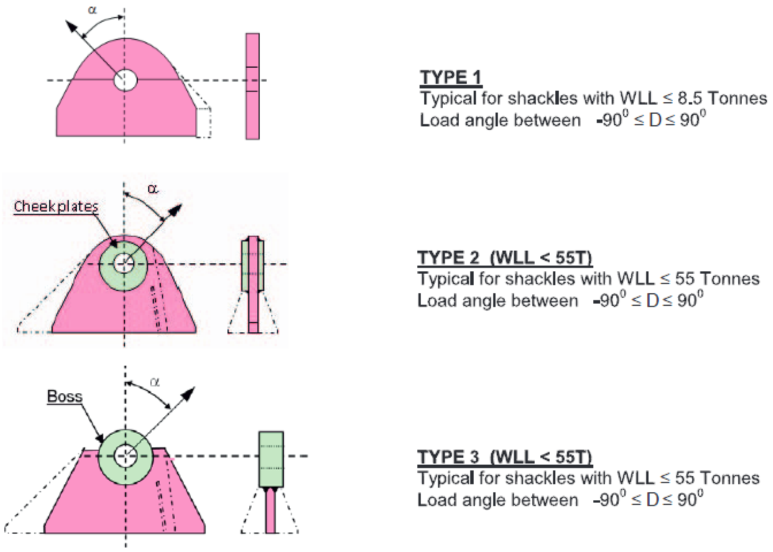


Figure 3.5 Different types of lifting lugs, from R-002.

For the experimental testing it will be used a selection of 3 tons pad eyes, which is type 1. More about pad eyes and shackles strength calculation refer to Chapter 3.6: General calculations for testing.

Pad eyes should also be designed to match the standard shackle dimension. So that the shackle can house both the pad eye and the preferred sling or hook.

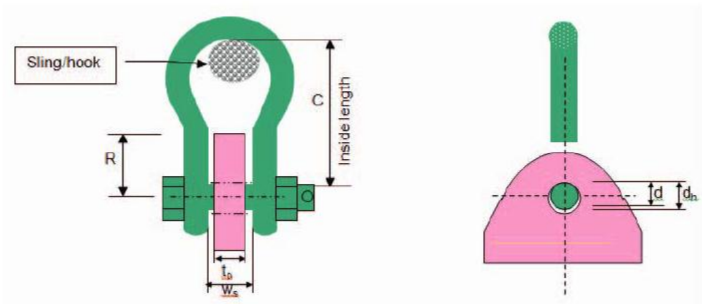


Figure 3.6: Lifting lug and shackle interface, with type 1 pad eye, from R-002.

3.2.2 R-003 Safe use of lifting equipment

The standard's main goal is to provide sufficient information so that lifting operations are carried out safely and in accordance with specified requirements.

Before a fixed attachment point, such as pad eye are applied, the enterprise of competence must confirm that they are ready to use. Any limitations must be specified for the user, either by marking the pad eyes or as information in the material data sheet.

For lifting cargo and people you may only use shackles with double locking, e.g. nut plus split pin. It should not be used any pins that can break loose out during the lift. Only by securing static loads, other types of shackles can be used.
Shackles with a rotating bolt should not be used in permanently installed lifting arrangements. This is because rotary powers may be transferred to the shackle bolt.
There are experts that are responsible for verifying the lifting equipment technical security. Thus they act as an additional safety barrier.

3.2.3 N-001 Integrity of offshore structures

The standard is the main standard for the offshore industry, and also refers to ISO 19900.

Here we must take into account various limit state designs. (LSD) The principles of this design method include these four limit states:

- ULS – Ultimate limit states.
  The material factors for steel structures shall be 1, 15. The safety level shall be adjusted to desired value through the factors. Refer to NORSOK N-004 for all steel structures.

- SLS – Serviceability limit states.
  The material factors in this state shall be 1.0. The limit state is defined by the operator for the specific project. The limitations that should be part of the design premises are regarding deflections, displacements, settlement, and vibrations.

- FLS - Fatigue limit states.
  Structures shall be designed to withstand fatigue actions during the service life of the facility. Design fatigue factors shall be applied when taking damage and consequence into account.

- ALS – Accidental limit states.
  The material factor shall be 1.0 in this state. Checking these limit states will ensure that accidents do not lead to complete loss of integrity and performance of the structure. Minor damage is accepted for the ALS, but only if there is no danger for loss of human life, significant pollution or major financial consequences.

3.2.4 N-004 Design of steel structures

The standard shall fulfill the Norwegian Petroleum Directorates regulations focusing on the design and outfitting of offshore facilities.

Selection of steel quality level for structural components shall be based on the most strict design class of joints involved in the component. The initial stresses should be considered.

Ductile failure will allow structures to redistribute forces consistent with the assumed static model. Brittle failure should be avoided or shall in cases where it may happen have excess resistance, to protect the structure.

For high strength materials such as 420 MPa and above, Safety data sheets assume the same minimum yield strength regardless of material thickness of the plates. The plates can also be tested by NDT methods, to check that no tearing of the material has happened.
The plates can also be tested by NDT methods, to check that there has been no damage to the material.

3.3 DNV

DNV is a different set of standards which is widely used in the offshore industry. The standards are developed by "Det Norske Veritas". They have 150 years of operational experience and are a leading provider of standards to various disciplines. The standards are based on research, and experience.

I have chosen to look at two main DNV standards regarding hook-up, and lifting operations.

3.3.1 2.7-2 Offshore service modules

The objective of the Standard is to set requirements for offshore modules, and to focus on the safety impact when the modules are being installed.

To ensure correct and suitable connections in the interface between the module and offshore installation, the certification shall specify all relevant interfaces.

These interfaces may include hook-up of:

- The power supplies
- Telephones and systems
- Signals and two from the control room
- Utility systems, like air, steam, hydraulics, and water.

The specification of these interfaces shall be sufficiently detailed and precise.

There are different requirements related to different modules and functional groups. It is the manufacturer's responsibility to ensure that all requirements applicable for the type and the functions within the module are addressed. The EKOL is an accommodation module and are in group one.

Table 3.4: Summary of the requirements based on module type.

Section	Title	Accommodation Module	Pressurised Workspace	Non Pressurised Workspace	Laboratory (internal Source of Release)	Workshop for Hot Work	Flammable Material Store	Refrigeration Room	Local Equipment Room	Non Specific Equipment Module (A)
3	Structural	Structural assessments for dynamic loads are required for "Important Service" modules. Requirements for Sea fastenings shall always be applicable on floating offshore installations.								
4.1 - 4.5		Requirements for these sections shall always be considered.								
4.6	Ignition Prevention	1	X	3	X	3	4	1	X	3
4.7	Fire and Gas	X	X	X	X	X	X	5	X	X
4.8	Communications	6	X	7	X	7	7	7	7	7
4.9	Fire fighting	8	9	9	10	9	11	9	9 and 17	9
4.10	Fire Protection	12	12	13	12	13	13	-	13	13
4.11	Escape	X	X	X	X	X	14	15	14	X
4.12	Ventilation	X	7	7	7	7 and 16	7	7	7	7
4.12.4	Over-pressure	18	X	-	X	18	-	-	X	-

After the module is installed, it is necessary to do surveys to confirm assembly and functionality of the module is in accordance with the approved drawings.
In the final phase of a project, all documentation and certifications must be approved.

3.3.2 2.7-3 Portable offshore units

The standard covers requirements for offshore units, focusing on design, production and certification.

Structural steel materials shall meet the requirements of the relevant standard, have good ductility at low temperatures and also be able to withstand dynamic loads.

During lifting operations, all parts shall have robust lifting points, and have sufficient safety against failure. This can be related to material failure, overload, damage, or badly fitted equipment such as shackles.

Regarding the positioning of pad eyes, they should be located so that the sling loads are equal, and sufficient stability is assured throughout the entire lift. Certificates for lifting equipment shall at all times be updated.

3.4 Risk analysis

Risk assessment:

- Accept criteria.
- Identify.
- Evaluate and analyze.
- Risk reduction and verification.

To understand the term risk, it can be put as:

Risk = the probability for an unwanted event times the consequence of that event.

Table 3.5: Risk matrix criteria.

				Increasing Severity of Consequences >				
		People		Minor injury	Loss time accident	Single or few serious injuries	Single or few fatalities	Many fatalities (> 5)
		Assets		Minor damage	Significant damage	Severe damage	Major damage	Catastrophic damage
Min-Max	Median			1	2	3	4	5
> 1	10	Frequent	E	E1	E2	E3	E4	E5
10^{-2} - 1	10^{-1}	Probable	D	D1	D2	D3	D4	D5
10^{-4} - 10^{-2}	10^{-3}	Unlikely	C	C1	C2	C3	C4	C5
10^{-6} - 10^{-4}	10^{-5}	Very unlikely	B	B1	B2	B3	B4	B5
$<10^{-6}$	10^{-7}	Extremely unlikely	A	A1	A2	A3	A4	A5

Increasing Likelihood >

Consequence will be divided into categories, and each category should have specific criteria associated to the HSE policy. In the marine and offshore industry risk is defined as low, medium, or high. Everyone shall strive to keep the risk as low as reasonably possible (ALARP). There are also various types of risks, examples of this is the risk to personnel, environment, property, or reputation.

The EKOL project has developed their own risk management register, as a framework for the management of risk across all parts of the organization, both strategic and operational. It incorporates all the activities required to identify and control the exposure to any type of risk, positive or negative

Risk management follows COPSAS procedure and a risk register is prepared.
The risk register is including, identified risks, risk categorization, qualitative and quantitative analysis.

3.4.1 Weather window for installation

An operation offshore is seen as a temporary condition, because the operation is of a limited duration. The installation phase is a critical part of a job including heavy and large lifting operations. It is dependent on the weather to be completed at the scheduled time.
When handling these kinds of operations it is important to plan the activities properly and take the necessary precautions. Planning the activities that needs to be done will determine the time needed for a controlled and safe finalization of an operation.

The EKOL heavy lift was carefully planned, According To these precautions.
It had to be must be ensured that Saipem was available at this time, and that they could perform the operation within given time frames.
The operation was also planned to be executed in the late summer months when the probability of great weather is at its highest.

It was optimal to have a SSCV for this operation as they are stable and have optimized geometry for lifts in rough sea.
One must often compromise on design in these kinds of projects, to get the final product installed correctly. The installation phase can drive the design, as there is no reason to build something great if it cannot be installed according to the customer's budget and timeframe.

Operators must expect that they might be waiting on weather, and the contractor has to estimate the cost and consequences of the delay. Again, it is important to plan ahead, and have backup plans.

The weather criteria's is selected from two different reliable sources to get a complete view of the reality.

It is used a special distribution to calculate the probability that the waves are too high to operate in. It makes out the probability for not being able to carry out the operation at the given time.

The Weibull distribution:

$$1 - \exp\left[-\left(\frac{\Delta}{d}\right)\right]^{\beta}$$

Δ = length or duration of operation.

d = mean duration when Hs < h'

And β = 1

3.5 HSE

There is always performed a Health Safety and Environment risk evaluation as a standard procedure before the start-up of all projects. This is done to identify risk reducing activities, and minimize all types of damage.

During the construction of the LQ in Singapore, between 15 and 17 million work hours was carried out without any damage.

The main risk management activities are:

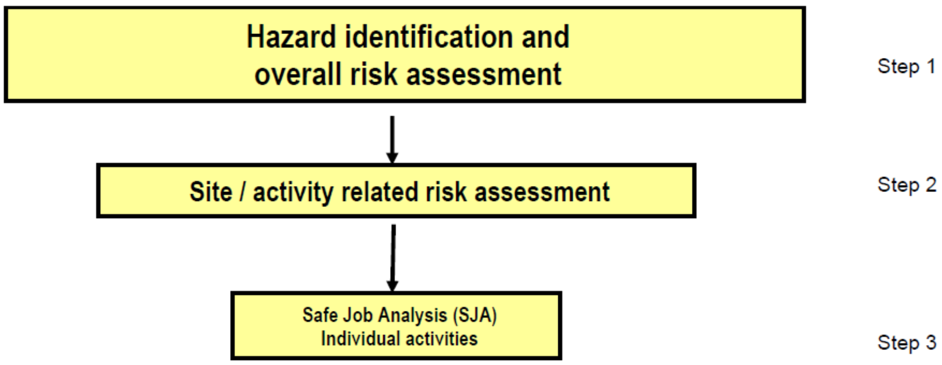


Figure 3.7: Risk assessment, from NORSOK S-012.

All managers should work actively and systematically within their organizations with relevant HSE matters. Their responsibilities are reflected in the job descriptions, and are based on the following principle:

- All HSE activities are to be planned and scheduled.
- All HSE requirements and their given criteria are to be known and understood.
- Everyone should have a proactive approach to HSE.
- Requirements and criteria shall be implemented in both design and practical work.
- There should at all times be obtained an acceptable level of HSE, and there must be qualified personnel to ensure, verify and document that HSE requirements are understood.
- A “zero harm mindset” should be supported and promoted.

3.6 Project management

To get an overall view of the term project management, we have to look at what a project consists of.
A project is a group activity which is temporary, and is created to produce a product, a result or a service in a given time frame. Every project is unique, and has been given a set of operations to perform and a given goal.

Table 3.6: The main activities involved in offshore contracts.

E	Engineering
P	Procurement
C	Construction
I	Installation
C	Commissioning
H	Hook-up
F	Fabrication

NORSOK has been a big part of the process of standardizing requirements and shorten the implementation time of projects. Total Contracts were essential to achieving this.

Project management is on the other hand the actual execution of operations, where the leader uses their knowledge, skills and techniques to execute the project as efficiently as possible.

The main management processes is; initiating, planning, executing, monitoring, and closing. But the main focus of project management is shaped by the schedule, resources and goals of each project.

When planning the accommodation platform at EKOL, the Project Execution Plan (PEP) defined how the project would be executed, but it also showed an overview of the project as a part of COPSAS field development plan.

The PEP covered the main activities to be performed during the execution phase, which was being overseen by the project team.

This was including:

- ROS Singapore
- Job setting.
- Hook-up, Mechanical Completion, commissioning (COPSAS) and final handover to Operations
- All supporting functional and technical activities/processes.

Design was not a part of ROS scope of work.

The project goals for the EKOL hook-up project were; to be able to perform all activities without injury to persons, and without any damage to equipment or on the environment. They also wanted to achieve the project milestones, in accordance with the project team's expectations.

The project execution strategy for Rosenberg Worley parsons was to reduce offshore scope for both installation and commissioning to a minimum.

- Project shall be flexibility, in regards to eventual increases or decreases in the scope of work.
- Implementation of effective work methods and documentation system, with the objective to perform all types of work correctly at first attempt.
- Close cooperation with the Singapore organization to find optimal solutions in all the main hook-up zones.

ROS is using the project execution model (PEM), to get a total picture of the workload. PEM is a computerized work process, with active processing blocks, giving access to more detailed information, such as routines, check list, procedures, forms, and flow charts.

3.6.1 Successful management in a hook-up project

The most important factors in relation to the success of major projects are according to basic management theory; the work that is done in the early phases of the project, the contract strategy, and project follow-up.

These factors are included when we look at the actual success factors in the EKOL project.

To sum up the key factors:

- Early in the project the focus was on the organization. The offshore staff and field engineers were integrated onshore before mobilization, and everyone had had plenty of time for familiarization of the project. This phase was important so that everyone knew what to do, and knew the platform's construction.

- It was mobilized resources with the necessary experience and who was qualified for the positions, and this enabled the establishment of priorities in the right order.

- Clear and precise roles and responsibilities for the mobilized engineers, both in relation to the topside supplier and the company organization. They had a certain degree of influence on decisions and access to all required documents and systems.

- Early definition of the hook-up scope of work, and the detailed planning. Predetermined and clearly defined hook-up register.

- Had all the necessary capacity and expertise through all phases of the project and an efficient management.

- There was a limited time to reach milestones, thus we had a high staffing early in the project.

- Had the company representatives at the project office at the construction site. Effective decision-making and management of technical issues.

- Close collaboration with the customer, COPSAS.

- Planners offshore focused on progress, and getting the right staffing at the right time. Focusing on how to report correct relative to all work packages so that it always showed an accurate picture of the remaining work.

- Safety and reporting has always been a priority. Have had dedicated safety representative from ROS who have had it as their only job, and not as a second job such it tends to be.

- And last, but not least, the importance of good communication between all parties should not be underestimated. A major success factor throughout the entire project.

3.6.2 Cost and Carry over work

The EKOL project team has established a cost management to effectively plan and control the costs involved within the project. This involved various activities such as collecting, analyzing, evaluating and reporting cost for budgeting.
To keep the project within the given budget, and identify future expenses the cost manager steps in as a form of management consultant.
In the first phase in the project, all expected cost throughout the project is carefully planned, and is then monitored during the projects execution period.

When the project comes to an end, the expected costs are compared to actual costs.
This is to help management predict certain costs in future projects.

Carry over work is work that had to be done after the accommodation platform was installed in the North Sea, on various tasks that was not done before sail away from Singapore.
This work went on separate carry over activities, in addition to planned activities. It included change requests, variation orders and variation order requests.

3.6.3 Job setting and redline markup

A multidiscipline job setting group was established at Rosenberg in Stavanger.
All job setting was carried out according to the hook-up register established at the contractor in Singapore.

All new work in addition to the established scope was presented through the hook-up register or the ship loose register. These were dealt with by ROS workers, to insure that all loose items were encountered for.
Work packs were checked up against the model or in the yard according to checklists.
This was done to ensure that the planned installation method, material handling and the acquired tools for the job was correct. A vital part was also to ensure material coverage on the individual work packages, and to check pre-planned work hours.

The structural discipline has completed a total of 174 job packages, including changes and revisions, and has carried out approximately 35,000 man hours on the project.

There was a strong focus on achieving work packages in good time to the planned sequence, and also verification of the material coverage. Full material coverage was enabling the offshore staff to work efficient and according to the planned schedule. Lifting methods was developed and included in the job package. This showed the operations in detail, and was taking into consideration HSE aspects and safe job analysis (SJA).

All additional work that were not described in the job packages, was registered as a red line mark-up (RLM).It was the field engineers responsibility to ensure that all job packages was checked, and red lined.

It was essentially ROS's responsibility to produce red line mark ups to identify changes to drawings and documentation. They then had to make a system to send the mark-ups to the contractor COPSAS, so the master drawings could be updated. Commissioning was also able to produce the mark-ups and submit them to ROS.

3.7 General calculations for testing

All of the calculations in the thesis are performed using Mathcad.

Basis for design:

Material data

Material factors	ULS
General	$\gamma_{M1.ULS} := 1.15$
Bolted and welded connections	$\gamma_{M2.ULS} := 1.3$

Structural steel

Y 30

Yield strength of plate material	$F_{y.420} := 420\,MPa$
Tensile strength	$F_{u.420} := 500\,MPa$
Allowable stress in plates	$\sigma_{420.d} := \frac{F_{y.420}}{\gamma_{M1.ULS}} = 365.2\,MPa$

Welds

S420 $\qquad B_{w.420} := 1.0$

$$\sigma_{420.w} := \frac{F_{u.420}}{\gamma_{M2.ULS} \cdot B_{w.420}} = 384.615\,MPa$$

$$\sigma_{n.420.w} := \frac{0.9 \cdot F_{u.420}}{\gamma_{M2.ULS}} = 346.154\,MPa$$

Bolts

Yield strength of bolt material, 8.8 $F_{yb\_8.8} := 640\,MPa$

Ultimate tensile strength of bolts, 8.8 $F_{ub\_8.8} := 800\,MPa$

M24

Area of bolt $A_{24} := 353\,mm^2$

Tensile capacity per bolt $F_{t.Rd.M24} := \frac{0.9 \cdot F_{ub\_8.8}}{\gamma_{M2.ULS}} \cdot A_{24} = 195.508\ kN$

Shear capacity per bolt $F_{v.Rd.M24} := \frac{0.6 \cdot F_{ub\_8.8}}{\gamma_{M2.ULS}} \cdot A_{24} = 130.338\ kN$

4 bolts in total $F_{t.Rd.M24} \cdot 4 = 782.031\ kN$

$F_{v.Rd.M24} \cdot 4 = 521.354\ kN$

CHAPTER 4

4 EXPERIMENTAL TESTS

The reason for the experimental testing was mainly the poor quality of the calculation basis for the pad eyes used in different parts of EKOL.

After a review of the submitted material, as well as pictures of the appropriate lifting devices conclusion was that the pad eyes could not be approved by ROS in its current form.

The main reasons for this were:

- There was no correlation between the various calculations presented.
- It lacked references to the standards that were the basis for the calculations.
- There were missing links between detailed calculation of pad eyes and drawings of the actual eyes.
- Photos of the ears show large deviations between drawings, and the ears that were actually produced.

With this as a basis, it was performed a review and survey of the pad eyes that were produced and installed. Then, they made the necessary calculations to show that they met the requirements of the current standards. A new ROS procedure for the design of pad eyes was made based on this.

The experimental test was performed to see what the consequences are if the lifting devices are not manufactured in accordance with the current standard.

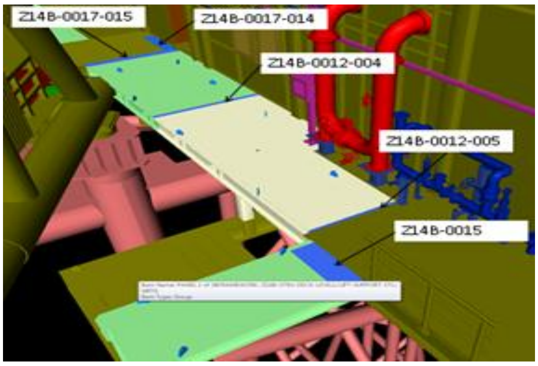


Figure 4.1: The placement of the relevant pad eyes on the actual platform.

ROSENBERG WorleyParsons Group

Universitetet i Stavanger

4.1 Design of test samples

ROS obtained all the necessary equipment to perform the experimental tests. All of the tests were performed at their yard at Buøy, with the help of skilled personnel from the enterprise of competence.

To test the capacity of the different pad eye test samples, we used a tensile cylinder. This could originally simulate a tensile force up to 21 tons.

The plates and the pad eye test samples were designed using MicroStation.

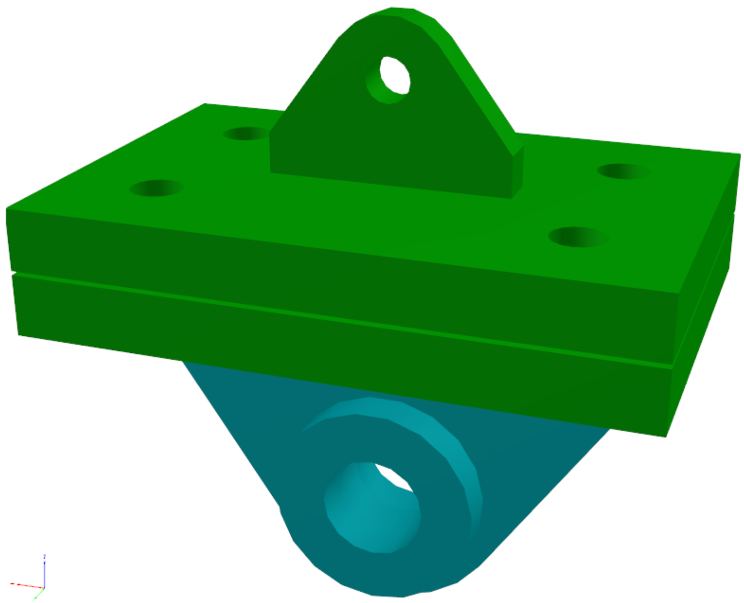


Figure 4.2: Pad eye 3D design, using MicroStation.

The pad eye on top is a standard 3.25 tons lifting devise, the plates are 30 mm thick to keep it from bending, and the bottom eye is a modified 12 ton pad eye.

It was modified to fit the existing equipment in the tensile bench. It was made a bit wider, and higher too keep it from moving during testing.

The four holes in the plates were drilled to suit M24 bolts, and the pad eyes and plates were welded at the ROS fabrication yard.

Figure 4.3: Finished test sample of a 3.25 ton pad eye.

Figure 4.4: Finished test sample of the modified 12 ton pad eye.

The dimensions of the test samples were designed according to ROS standard pad eye design, se Appendix B for additional information.

Table 4.1: Summary of the test samples that were made.

Type:	Material specification:	Number of:
3.25 ton pad eye.	Plate 20 mm, Y30	10
Bottom plates	Plate 30 mm, Y30	11
Modified 12 tons pad eye	Plate 20 mm, Y30	1
Cheek plates	Plate 20 mm, Y30	2

The pad eyes were welded to the plates using full penetration welds, and 8 mm joints. The welds were then tested using magnetic particle inspection and ultrasound, the most commonly used NDT methods.

This was done to verify that the test pieces were marked with the correct welding type. Since most of the markings on the ears had been removed during the welding process.

From the new revision of the ROS standard pad eye report, the welds now only have to be 7 mm. But the test samples were made with 8 mm which was described in the previous audit; anyway it did not affect the results of the testing.

In addition to the pad eye test samples, shackles in the corresponding dimensions were also an important part of the tests. The shackles were used as connection points between the tension cylinder, the dynamometer and the pad eye test samples.

Figure 4.5: Dynamometer used during testing.

4.2 Test setup

The main goal of the tests was to see what happens if pad eyes are not designed according to the given standards.
I planned to do five different tests, with two test samples on each test. Where I would test the weld utilization, and see what happened if the diameter of the hole in the pad eyes increased.

Table 4.2: Test setup, revision 1.

Pad eyes 3.25 tons	
Test 1	Vertical strain, 22 mm diameter, fillet weld 8 mm joint, 3.25 tons shackles.
Test 2 and 3	Vertical strain, 32 mm diameter, part penetration weld, one with 9.25 ton shackle and one with standard 3.25.
Test 4 and 5	Vertical strain, 22 mm diameter, part penetration weld, 3.25 tons shackles.
Test 6 and 7	Angular strain, 22 mm diameter, fillet weld 8 mm joint, 3.25 tons shackles.
Test 8 and 9	Angular strain, 22 mm diameter, part penetration weld, 3.25 tons shackles.
Test 10	Vertical strain, 22 mm diameter, fillet weld 8 mm joint, 3.25 tons shackles.

As table 4.2 shows, the testing was supposed to include any damage to the weld, but after the first test day, it became clear that this was not necessary to take into consideration. This was because there was not enough force in the tensile cylinder. So in the following revision the welding type was neglected.

It was only three tests from test revision 1 that got performed; test 1, 2 and 3. Then I decided to change the testing procedure.

To improve the testing procedure, I decided to get 5 of the remaining 7 test samples drilled to a larger hole diameter.
So instead of testing what would happen to the welds of the test samples, I decided to look at the deformations of the pad eyes with larger hole diameter than accepted.

As some of the pad eyes originally installed on various platforms at EKOL, had hole diameters and dimensions not according to standards.

Three pad eyes were drilled with a 42 mm diameter hole, and two with a 32 mm hole.

Table 4.3: Test setup, revision 2.

Pad eyes 3.25 tons	
Test 4	Vertical strain, 42 mm diameter, 3.25 ton shackle.
Test 5	Angular strain, 22mm diameter, 3.25 ton shackle.
Test 6	Angular strain, 32mm diameter, 3.25 ton shackle.
Test 7	Angular strain, 42mm diameter, 3.25 ton shackle.
Test 8	Vertical strain, 22 mm diameter, 3.25 ton shackle.
Test 9	Vertical strain, 32 mm diameter, 3.25 ton shackle.
Test 10	Vertical strain, 42 mm diameter, 9.25 ton shackle.

Too keep the tensile cylinder straight during test 5, 6 and 7, and to be able to perform the angular strain test we used an additional IPE beam (175x120x1600), chains and fiber slings. Using this setup we got an equally angular load on both sides of the beam, and the pad eye test sample was subjected to an angular strain of approximately 45 degrees.

The end results of the testing are found in chapter 4.4.

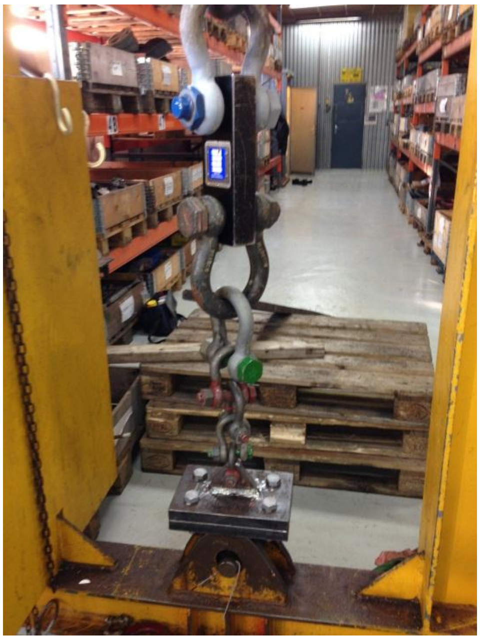


Figure 4.6: Vertical strain test

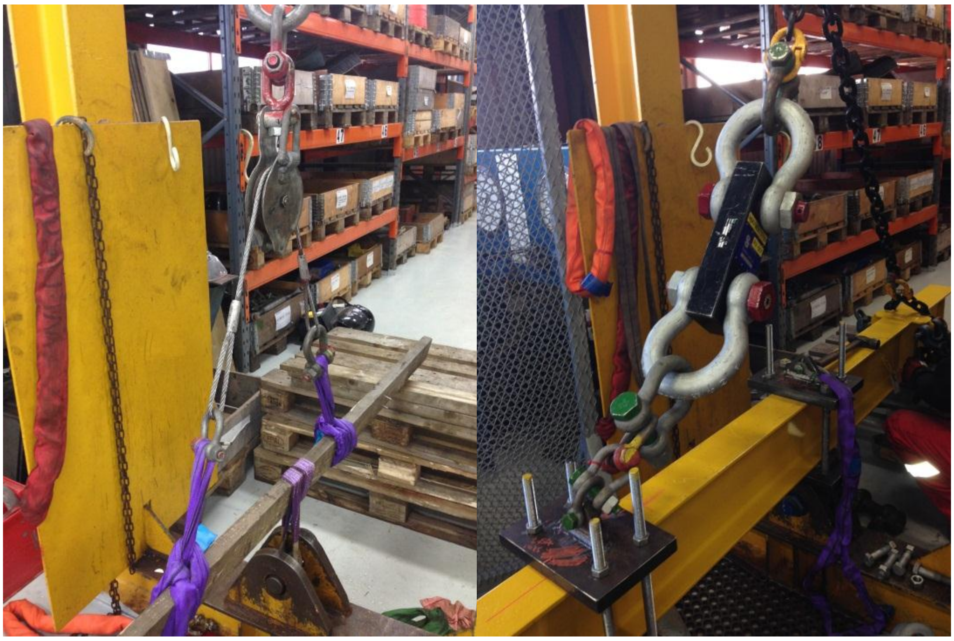


Figure 4.7: The test setup and the actual setup of the angular strain test.

4.2.1 HSE and safety during testing

When dealing with all types of testing there should always be a strong focus on safety, in order to avoid unwanted injuries and incidents. Since the tests were performed on Rosenberg's area, we were required to follow their rules for use of safety.

Everyone involved had to wear appropriate work clothes, which are overalls and safety shoes. If it were to be used machines that are considered as hot work, it was only certified personnel who could use them. Hot work refers to the various machines that generate sparks which could cause fire. The use of open flames, welding or grinding equipment is then considered as hot work. I also used safety glasses and a helmet when necessary.

When I rigged up and down the equipment between each test, I made sure to wear appropriate gloves to avoid crushing injuries.
As a preventive measure we also installed a security mesh wall between test station and the control panel of the cylinder.

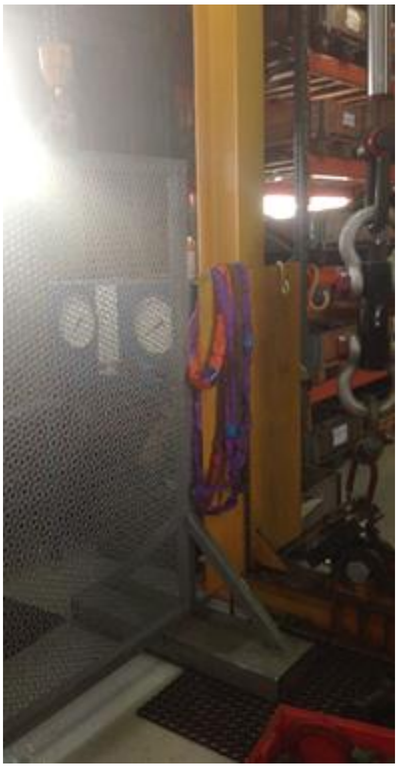


Figure 4.8 Safety wall.

4.3 General notes during testing, and simplified results

Test day 1, 31.01.14.

- Test 1, 2 and 3, vertical strain.
- Used a dynamometer with a capacity up to 25 tons.

- Was only able to get forces up to 21 tons.
- None of the ears went to failure.
- However, the subjected forces created large deformations in the shackles, and up to 3.5 mm deformation of the pad eyes with 32mm holes.
- The weld is not affected by the vertical load.
- Test setup with plates and bolts 4xM24 works as it should, no deformation of any of the materials.

Further work:

- Should find out if it is possible to pull with greater force, for example by increasing the pressure on the tensile cylinder at ROS, or contacting Teo Technique at Nærbø, to do further tests in collaboration with them.
- Find out what happens if the hole diameter is increased by another 10mm to a total of 42mm in diameter, then it is only 9mm steels left on top of the pad eye. And then subject it to forces both vertically and angularly.

Test day 2, 11.02.14.

- Test 4, vertical strain
- Used a dynamometer with a capacity up to 50 tons.

- Increased force up to 26 tons in the tensile cylinder, by increasing the oil pressure in the cylinder.
- Pad eye went to failure

Further work:

- Create a functional test set up for the angular strain test.

Test day 3, 12.02.14.

- Test 5, 6 and 7, angular strain.
- Used a dynamometer with a capacity up to 50 tons.
- Used a IPE beam to get a 45 degree angle on the angular strain

- Evenly distributed powers between the two lifting points on the beam. Up to 30 tons of force in the cylinder, divided on the two parts.
- large deformations of the pad eyes
- Deformation of the IPE beam due to unbalance and torsional forces.

Further work:

- New vertical tests on 22, 32, and 42 diameter hole sizes to see if there was any change in the results with increased force in the cylinder.

Test day 4, 13.02.14.

- Test 8, 9 and 10, vertical strain.
- Used a dynamometer with a capacity up to 50 tons.

- Increased force from the first tests by approximately 5 tons.
- Replacing the 3.25 ton shackle with a 9.25 ton shackle on the pad eye with 42mm diameter holes.
- Failure in a majority of the pad eyes.

Remark:
Shackles were replaced between each test, due to tension in the steel and due to large deformations.

4.4 Results and summary from testing

As mentioned in the previous chapter a lot of the test samples went to failure with increasing hole diameter of the pad eyes. The increased pressure was also helpful to receive the results.

I initially thought that some of the shackles used would go to failure before the pad eyes did, this proved to be wrong due to the high safety factors. It even went beyond the theoretical tolerance.

Table 4.4: End results of the experimental testing.

Pad eyes 3.25 tons						
	Hole diameter pad eye:	**Pull direction:**	**Shackle size:**	**Theoretical fracture force:**	**Actual fracture force:**	**Actual deformations:**
Test 1	22 mm	Vertical	3.25	26.2 tons	No failure, reached force of 21 tons.	0.5 mm def. in hole.
Test 2	32 mm	Vertical	9.25	20.7 tons.	No failure, reached force of 21 tons.	1.5 mm def. in hole.
Test 3	32 mm	Vertical	3.25	20.7 tons	No failure, reached force of 21 tons.	3.5 mm def. in hole.
Test 4	42 mm	Vertical	3.25	15.3 tons	Failure at 14.5 tons.	Large Shackle deformations.
Test 5	22 mm	Angular	3.25	18.5 tons	No failure, reached force of 14 tons.	Large deformations.
Test 6	32 mm	Angular	3.25	14.7 tons	No failure, reached force of 15 tons.	Large deformations.

	Hole diameter pad eye:	Pull direction:	Shackle size:	Theoretical fracture force:	Actual fracture force:	Actual deformations:
Test 7	42 mm	Angular	3.25	10.8 tons	No failure, reached force of 14.5 tons.	Large deformations in both pad eye and IPE beam.
Test 8	22 mm	Vertical	3.25	26.2 tons	No failure, reached force of 25.5 tons.	Large deformations.
Test 9	32 mm	Vertical	3.25	20.7 tons	Failure at 24.2 tons.	Large Shackle deformations.
Test 10	42 mm	Vertical	9.25	15.3 tons	Failure at 18.0 tons.	Large Shackle deformations.

When using a larger shackle than the pad eye is supposed to be paired with, as in test 10. The contact surface between the pad eye and the shackle gets larger, and you need higher strain powers for the pad eye to go to failure.

All of the failure modes is created over time, and gets an angular fracture surface. This can be seen as a ductile fracture.

Pictures of the pad eyes, from test 1 to 10:


Test 1, vertical: Deformation of 0.5 mm in the pad eye hole.


Test 2, vertical: Deformation of 1.5 mm in the pad eye hole.


Test 3, vertical: Deformation of 3.5 mm in the pad eye hole.

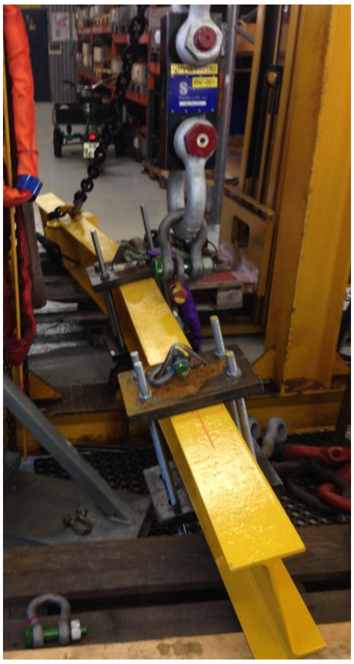
Test 4, vertical: Fractured pad eye.

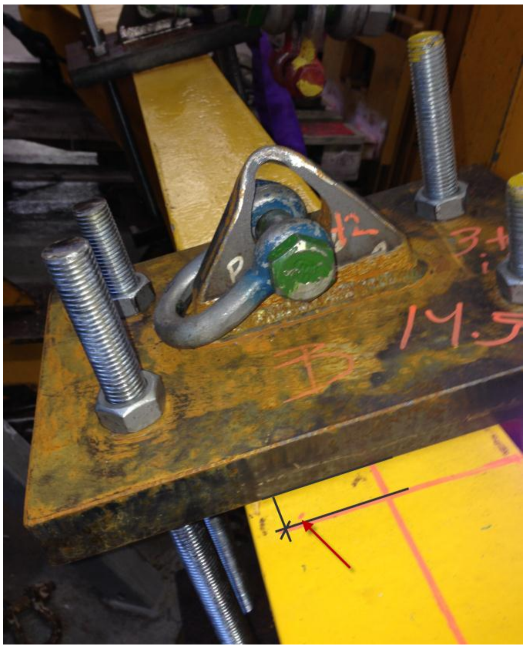
Test 5, angular: Deformation and twisting of the Pad eye.

Test 6, angular: Large deformation and twisting of the ear.

Test 7, angular: Very large deformation and significant twisting of the ear.

Remark:
The beam used in test 5, 6 and 7 also got large torsional damages. When performing test number 7, the plate device with the pad eye attached moved towards the middle of the beam. This resulted in large forces in the chain at the other side of the beam.
This caused the beam to slightly lift from where it was held in the middle, and twist horizontally. The beam were subjected to lateral torsional buckling and got permanent deformations.





The picture shows how much it actually moved, about 15 mm.

The IPE beam after the testing twisted and deformed.

This only shows that even when we are handling small dimension pad eyes, and performing experimental lifts. The forces involved can still do great damage.

Test 8, vertical: Deformation of 1.5 mm in the pad eye hole.

Test 9, vertical: Fractured and cracked pad eye.

Test 10, vertical: Fractured and deformed pad eye.

Pictures of the shackles used during testing:

All of the 3.25 tons shackles used, got severe deformations, and some got minor fractures in the steel.

For more pictures from the experimental testing see Appendix C.

CHAPTER 5

5 ANALYSIS FROM TESTING

This chapter deals with the relevant calculations according to the conducted testing.
I will focus mainly on pad eye calculations, but will include some calculations for shackles and beams as well. I choose to restrict the calculations like this, to focus on the key points and not so much on the general.

5.1 Calculations from testing

Pad eye type 1, strength calculations. From R-002

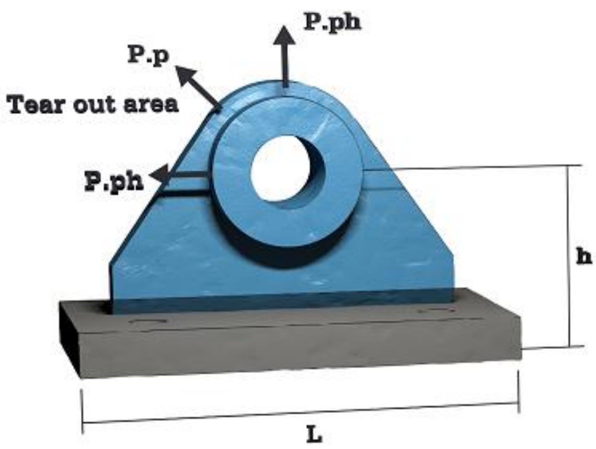
<u>Load components</u>

Pad eye design force is P_p

The vertical and horizontal components is

$P_{p.v} = P_p \cdot \cos\alpha$

$P_{p.h} = P_p \cdot \sin\alpha$



Limit design stress

Material resistance factor $\gamma_{R.m} := 1.15$

$$f_d := \frac{F_{y.420}}{\gamma_{R.m}}$$

But to make the calculations as close to reality as possible

$\gamma_{R.m.1} := 1$ and $DF := 1$ $DAF := 1$

$$f_{d.1} := \frac{F_{y.420}}{\gamma_{R.m.1}} = 420 \cdot MPa$$

Tear- out limit design stress

Tear out stress $\tau_{E.d}$

Limit design shear stress $f_{R.d}$

$$f_{R.d} = \frac{F_{y.420}}{\sqrt{3} \cdot \gamma_{R.m.1}} \geq \tau_{E.c}$$

$$\tau_{E.d} = \frac{P_p}{2 \cdot A_{sh}}$$

$$A_{sh} = \left(R - \frac{d_h}{2}\right) \cdot t_p$$

Pad eye	Hole diameter	Plate thickness	Radius	Height	Length	Weld
SWL	d_h	t_p	R	h	L	a_w
tonn	mm	mm	mm	mm	mm	mm
3.25	22	20	35	50	120	8
3.25	32	20	35	50	120	8
3.25	42	20	35	50	120	8

We have three different hole diameters

$d_{h.1} := 22mm$

$d_{h.2} := 32mm$

$d_{h.3} := 42mm$

The other parameters stay the same

$R := 35mm$ $h := 50mm$

$t_p := 20mm$ $L := 120mm$

$$A_{sh.1} := \left(R - \frac{d_{h.1}}{2}\right) \cdot t_p = 0.48\, m \cdot mm$$

$$A_{sh.2} := \left(R - \frac{d_{h.2}}{2}\right) \cdot t_p = 0.38\, m \cdot mm$$

$$A_{sh.3} := \left(R - \frac{d_{h.3}}{2}\right) \cdot t_p = 0.28\, m \cdot mm$$

If we put Limit design shear stress = Tear out stress

$f_{R.d} = \tau_{E.d}$

$$\tau_{E.d} := \frac{F_{y.420}}{\sqrt{3} \cdot \gamma_{R.m.1}} = 242.487 \cdot MPa$$

And we find how much load each ear can tolerate by defining

$$P_p = \tau_{E.d} \cdot (2 \cdot A_{sh})$$

$$P_{p.1} := \tau_{E.d} \cdot (2 \cdot A_{sh.1}) = 232.79 \cdot kN$$

$$P_{p.2} := \tau_{E.d} \cdot (2 \cdot A_{sh.2}) = 184.29 \cdot kN$$

$$P_{p.3} := \tau_{E.d} \cdot (2 \cdot A_{sh.3}) = 135.793 \cdot kN$$

$$g = 9.80665 \frac{m}{s^2} \qquad \alpha := 45deg$$

$$\frac{\begin{pmatrix} P_{p.1} \\ P_{p.2} \\ P_{p.3} \end{pmatrix}}{g} = \begin{pmatrix} 26.2 \\ 20.7 \\ 15.3 \end{pmatrix} \cdot ton$$

Vertical components

$$P_{pv.1} := P_{p.1} \cdot \cos(\alpha) = 164.606 \cdot kN$$

$$P_{pv.2} := P_{p.2} \cdot \cos(\alpha) = 130.313 \cdot kN$$

$$P_{pv.3} := P_{p.3} \cdot \cos(\alpha) = 96.02 \cdot kN$$

Horizontal components

$$P_{ph.1} := P_{p.1} \cdot \sin(\alpha) = 164.606 \cdot kN$$

$$P_{ph.2} := P_{p.2} \cdot \sin(\alpha) = 130.313 \cdot kN$$

$$P_{ph.3} := P_{p.3} \cdot \sin(\alpha) = 96.02 \cdot kN$$

$$\frac{\begin{pmatrix} P_{pv.1} \\ P_{pv.2} \\ P_{pv.3} \\ P_{ph.1} \\ P_{ph.2} \\ P_{ph.3} \end{pmatrix}}{g} = \begin{pmatrix} 18.502 \\ 14.648 \\ 10.793 \\ 18.502 \\ 14.648 \\ 10.793 \end{pmatrix} \cdot ton$$

Load bearing limit design stress

Pin hole bearing stress σ_b

Design bearing limit stress f_d

$$f_d = 1.5 \cdot \frac{F_{y.420}}{\gamma_{R.m}} \geq \sigma_b$$

$$\sigma_b = \frac{P_p}{t_{eff} \cdot d}$$

$$t_{eff} = t_p$$

If we put Load bearing limit design stress = Pin hole bearing stress

$$\sigma_b = f_d$$

$$\sigma_b := 1.5 \cdot \frac{F_{y.420}}{\gamma_{R.m.1}} = 630 \cdot MPa$$

$$P_p = \sigma_b \cdot (t_p \cdot d)$$

$$P_{p.1.1} := \sigma_b \cdot (t_p \cdot d_{h.1}) = 277.2 \cdot kN$$

$$P_{p.2.1} := \sigma_b \cdot (t_p \cdot d_{h.2}) = 403.2 \cdot kN$$

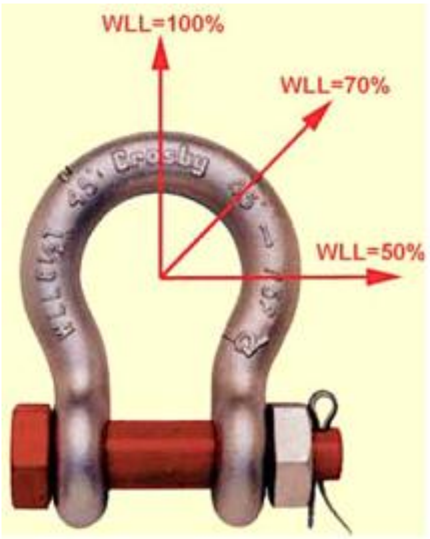
$$P_{p.3.1} := \sigma_b \cdot (t_p \cdot d_{h.3}) = 529.2 \cdot kN$$

$$g = 9.80665 \frac{m}{s^2}$$

$$\frac{\begin{pmatrix} P_{p.1.1} \\ P_{p.2.1} \\ P_{p.3.1} \end{pmatrix}}{g} = \begin{pmatrix} 31.2 \\ 45.3 \\ 59.5 \end{pmatrix} \cdot ton$$

Shackles theoretical load

WLL = Working Load Limit



From the testing

$WLL_1 := 3.25\,ton$

$WLL_2 := 9 \cdot ton$

Safety factor $SF := 6$

$WLL_1 \cdot SF = 19.5\ ton$

$WLL_2 \cdot SF = 54\ ton$

Angular load test

$WLL_1 \cdot SF \cdot 70\% = 13.65\ ton$

$WLL_2 \cdot SF \cdot 70\% = 37.8\ ton$

General calculations on torsional buckling of a beam

$f_{y.S355} := 355\,MPa$

$f_{uS355} := 500\,MPa$

$E := 210000\,MPa$ $\nu := 0.3$

$G := \frac{E}{2\cdot(1+\nu)} = 80769.231\,MPa$

$c := 133$ $t := 10$ $\frac{c}{t} = 13.3$

$\varepsilon := 0.81$

$72\cdot\varepsilon = 58.32$ = Class 1

Buckling

$N_{b.R.d} = \chi\cdot A\cdot\frac{f_{y.S355}}{\gamma_{M1.ULS}}$ For Class 1, 2 and 3 $\frac{c}{t} \le 72\varepsilon$

From this we can find the buckling curve.

CHAPTER 6

6 CONCLUSION

The main purpose of the thesis has been to get an overall understanding of what a hook-up project like EKOL consists of, and what must be taken into account when designing and using pad eyes for actual lifting operations.

The testing got audited after the first day, because the desired results could not be obtained at the time, and with equipment that was available.
But I managed to change the test setup, to prove how important it is to follow the rules and regulations given in the relevant standards.

It took a lot of effort to get started with the testing, but after a few attempts I managed to come up with a setup that worked, and a design that was based on the NORSOK standards.

It is always a challenge to do experimental testing, as you never know exactly what the results will be. It has been a steep learning curve, but in the end it has increased my understanding of how steel materials behave under considerable strain and tension, and also what must be taken into account when doing operations involving lifting.

As shown from results in chapter 4, and from calculations in chapter 5; the pad eyes can, when made according to standards, withstand larger forces than they are dimensioned for. But it does not take an severe increase in hole diameter, before the pad eye gets noticeably weakened.

Hopefully more tests like this will be carried out in the future.

6.1 Future work

The experimental testing proved to be useful not only to me, but to Rosenberg also.
The operations regarding lifting are an area that it pays to be updated on, as it is a big part of onshore and offshore work.

There is always room for improving the test setup, and to get more accurate test results.

Some main points that can be improved:

- Higher applicable force to:
  - Test the welds tolerance.
  - Be able to test bigger dimensions of pad eyes if needed.
- Find other ways to perform testing, like in a test jig, then it is possible to control the angle of the angular tensile tests better.
- Test a higher number of test specimens on each test, to obtain a greater variation in the testing, and more accurate results.
- Use measuring devices to get the measurements digitally, for more accurate results.

CHAPTER 7

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[i] Quote from a speech for the official opening of the Ekofisk 2/4 L platform, by Robert Eriksson.

APPENDIX A - Material data sheet for structural steel

Table 1 - Material data sheets for structural steel

MDS No.	Rev. no.	Standard	Steel grade (see EN 10225)	Product type	Steel quality level
Y01	5	EN 10025-(all parts) EN 10210-(all parts) EN 10219-(all parts)	S235JR S235JRH S235JRH	Plates and sections Hot finished tubulars Cold formed tubulars	IV
Y02	4	EN 10025-(all parts) EN 10210-(all parts) EN 10219-(all parts)	S275JR S275J0H S275J0H	Plates and sections Hot finished tubulars Cold formed tubulars	IV
Y04	2	EN 10025-(all parts) EN 10210-(all parts) EN 10219-(all parts)	S355J0 S355J0H S355J2H	Plates and sections Hot finished tubulars Cold formed tubulars	IV
Y05	3	EN 10025-(all parts)	S355J2 S355K2	Plates	III
		EN 10025-(all parts)	S355J2 S355K2	Plates and sections	III
Y06	3	EN 10225	S355G1+N	Hot finished seamless tubulars	III
Y07	3	EN 10210-(all parts)	S355NH/S355K2H	Hot finished tubulars	III
Y08	3	EN 10219-(all parts)	S355MLH	Cold formed tubulars	III
Y15	3	EN 10025-(all parts)	S420ML	Plates and sections	III
Y16	3	EN 10219-(all parts)	S420MLH	Cold formed tubulars	III
Y20	5	EN 10225	S355G10+N/G10+M	Plates	I
Y21	5	EN 10225	S355G12+N/G12+M	Rolled sections	I
Y22	5	EN 10225	S355G15+Q/G15+N	Seamless tubulars	I
Y25	5	EN 10225	S355G9+N/G9+M	Plates	II
Y26	5	EN 10225	S355G11+N/G11+M	Rolled sections	II
Y27	4	EN 10225	S355G14+Q/G14+N	Seamless tubulars	II
Y28	3	EN 10225	S355G13+N	Welded tubulars	II
Y30	5	EN 10225	S420G2+Q/G2+M	Plates	I
Y31	5	EN 10225	S420G4+M	Rolled sections	I
Y32	5	EN 10225	S420G6+Q	Seamless tubulars	I
Y35	4	EN 10225	S420G1+Q/G1+M	Plates	II
Y36	5	EN 10225	S420G3+M	Rolled sections	II
Y37	5	EN 10225	S420G6+Q	Seamless tubulars	II
Y40	5	EN 10225	S460G2+Q/G2+M	Plates	I
Y41	5	EN 10225	S460G4+M	Rolled sections	I
Y42	5	EN 10225	S460G6+Q	Seamless tubulars	I
Y45	5	EN 10225	S460G1+Q/G1+M	Plates	II
Y46	5	EN 10225	S460G3+M	Rolled sections	II
Y47	5	EN 10225	S460G6+Q	Seamless tubulars	II
Y50	5	EN 10225	S500G2+Q/G2+M [a]	Plates	I

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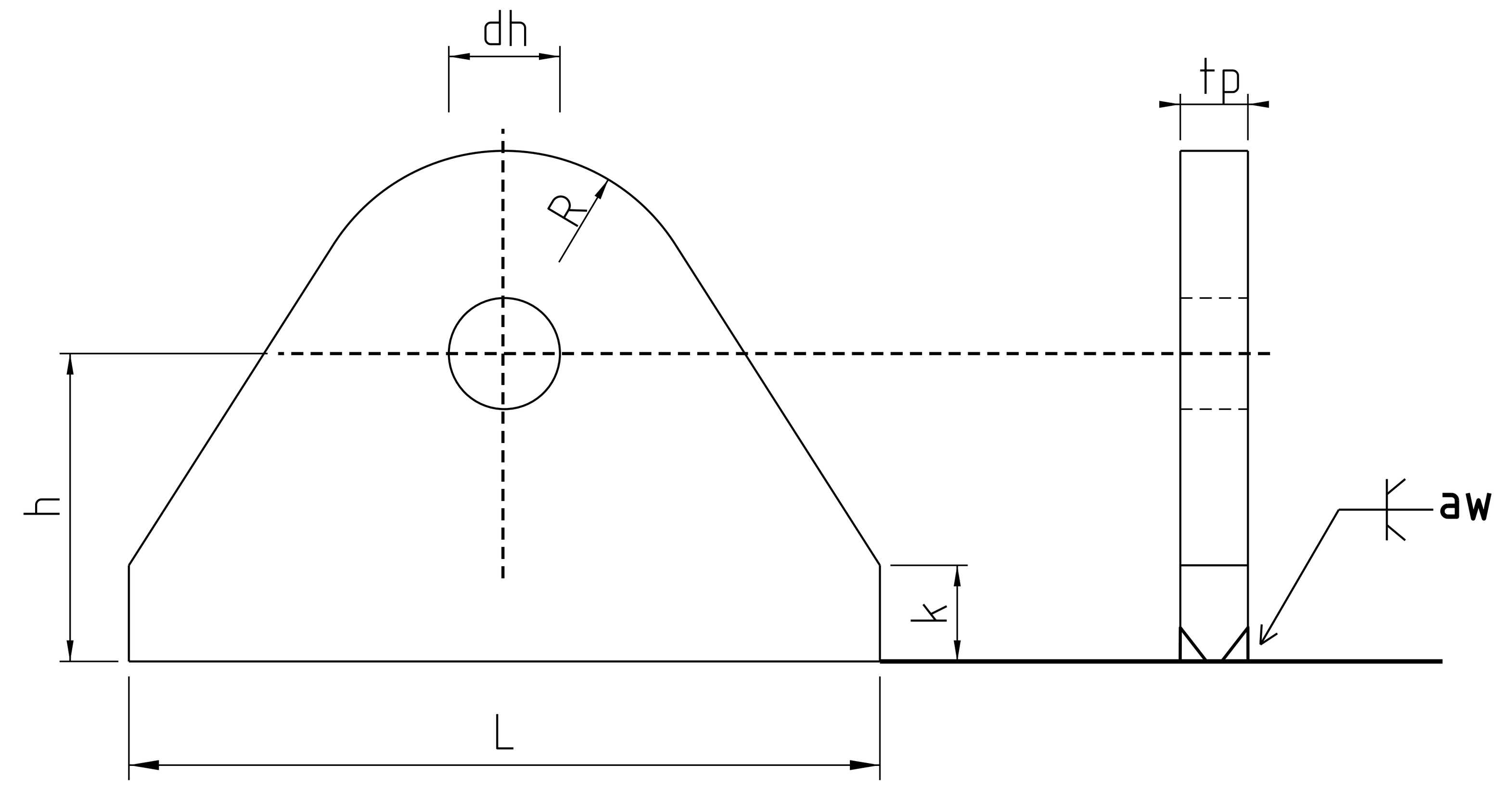
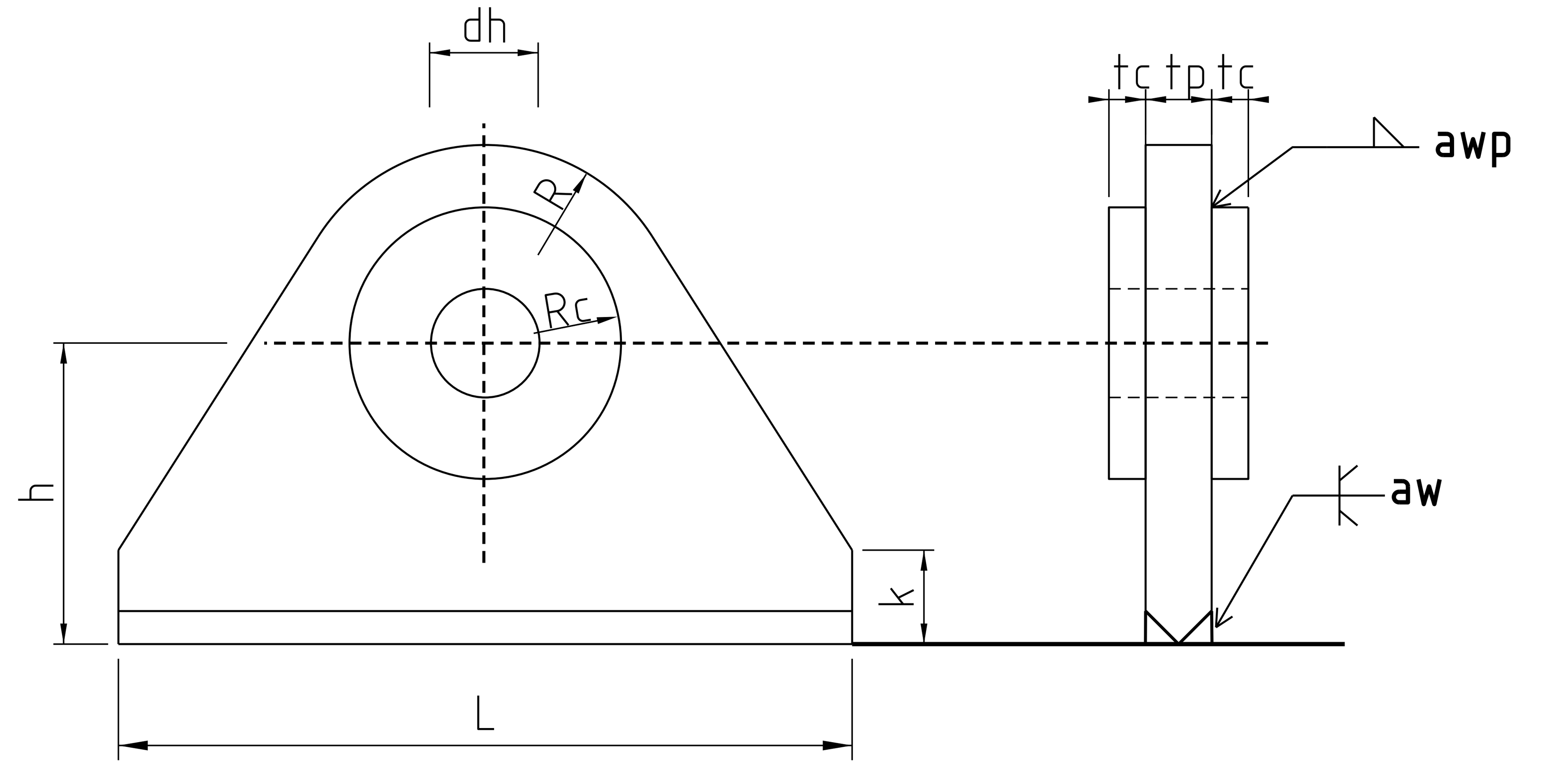
APPENDIX B - Design drawings for testing



Type 1

Type 1 Lifting lug

SWL	dh	tp	R	h	L	k	aw
tonn	mm	mm	mm	mm	mm	mm	mm
2	19	15	30	45	110	15	6
3,25	22	20	35	50	120	20	7
4,75	25	25	35	55	140	25	7
6,5	28	30	40	65	160	30	8
8,5	31	35	50	70	180	35	9
9,5	35	35	50	80	200	35	9



Type 2

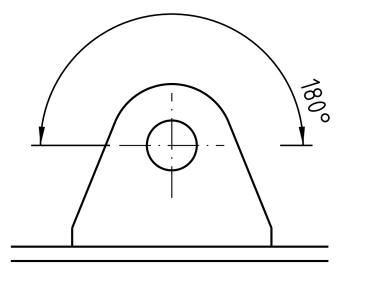
Type 2 Lifting lug

SWL	dh	tp	tc	R	Rc	h	L	k	a_{wp}	a_w
tonn	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
8,5	31	20	8	43	35	70	180	20	3	Full pen
9,5	35	20	8	48	40	80	210	20	3	Full pen
12	39	25	8	53	45	90	240	25	3	9
13,5	42	30	8	58	50	95	250	30	3	9
17	46	35	8	58	50	105	280	35	3	9
25	54	35	12	72	60	120	320	35	4	12

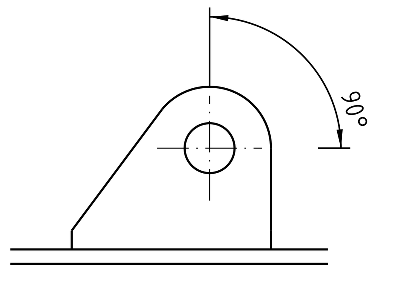
NOTES

1. LIFTING LUGS ARE DESIGNED ACCORDANCE TO NORSOK R-002 EDITION 2, SEP 2012.
2. SHACKLE GEOMETRY AND TOLERANCES ARE BASED ON BOW SHACKLES ACCORDING TO EN13889 AND US FEDERAL SPEC RR-C-271.
3. STEEL QUALITY LEVEL 1 MINIMUM 355-Y20, NORSOK N-004 DESIGN CLASS 1.
4. THE STRUCTURE SUPPORTING LIFTING LUG MUST BE VERIFIED BY CALCULATIONS.
5. WELD INSPECTION CATEGORY B.
6. WELDS OR PARTS OF WELDS WITH NO ACCESS FOR IN-SERVICE INSPECTION AND REPAIR SHOULD BE ASSIGNED WITH WELD CATEGORY A.
7. WELDS WITH HIGH FATIGUE UTILIZATION SHOULD BE ASSIGNED WITH WELD CATEGORY A AND ALSO AN ASSESSMENT IF STRICTER NDT ACCEPTANCE CRITERIA ARE NEEDED.
8. SUPPORTING STRUCTURE MUST HAVE DOCUMENTED STRENGTH THROUGH THICKNESS OF FLANGE EITHER BY MATERIAL SERTIFICATE OR LAMINATION CONTROL ON SURFACE.
9. LIFTING LUGS TYPE 2 INTENDED FOR REPEATEDLY USE NEED TO BE WELDED ON THE INSIDE OF HOLE TO AVOID CORROSION.
10. SPECIFIED WLL ON SHACKLE SHALL NOT BE LESS THAN THE STATIC SLING FORCE IN EACH LEG OF A LIFTING SET RESULTING FROM THE WEIGHT OF THE LIFTED OBJECT.
11. LIFTING LUGS INTENDED FOR LIFTING ACCESSORY SHALL HAVE FULL PENETRATION WELDS.

LOAD ANGLE



ALTERNATIVE DESIGN



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0	01.11.10	ISSUED FOR INFO	HeF	RRØ	RRØ

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Project name: BASIS

Drawing title: RV Standard Lifting lug

Projection:

Sheet: 01 of 01

Scale: NA | Size: A1 | Contr. no | Area | System

Drawing no: RV-N-XX-038-01 (Project-Contract-Area-Discipline-Type-Sequence-Sheet)

Rev.: 02

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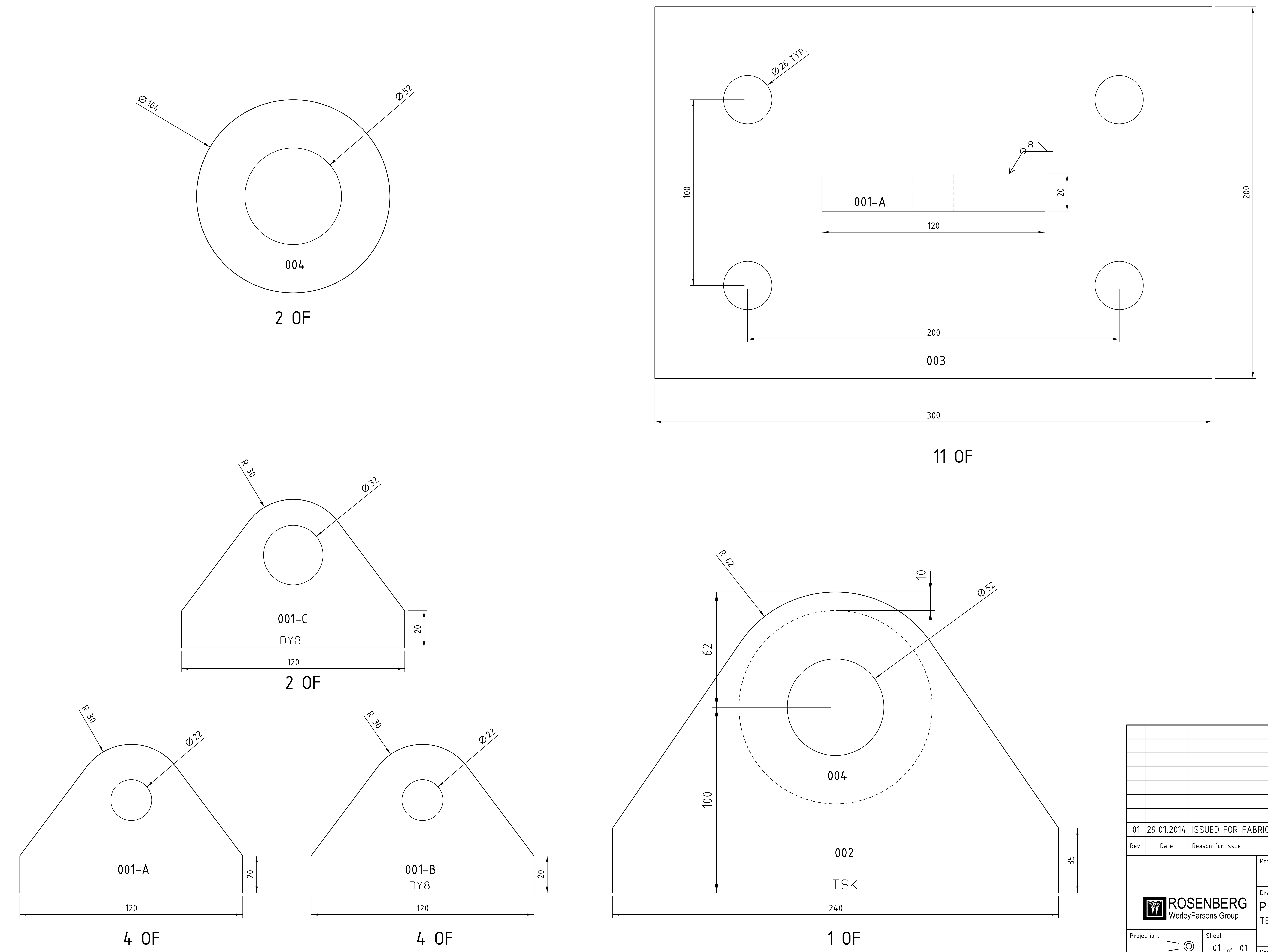


01	29.01.2014	ISSUED FOR FABRICATION	RK	SAS	HeF
Rev.	Date	Reason for issue	Drawn	Checked	Approved

ROSENBERG
WorleyParsons Group

Project name: MASTER THESIS EKOL 2/4L
6066

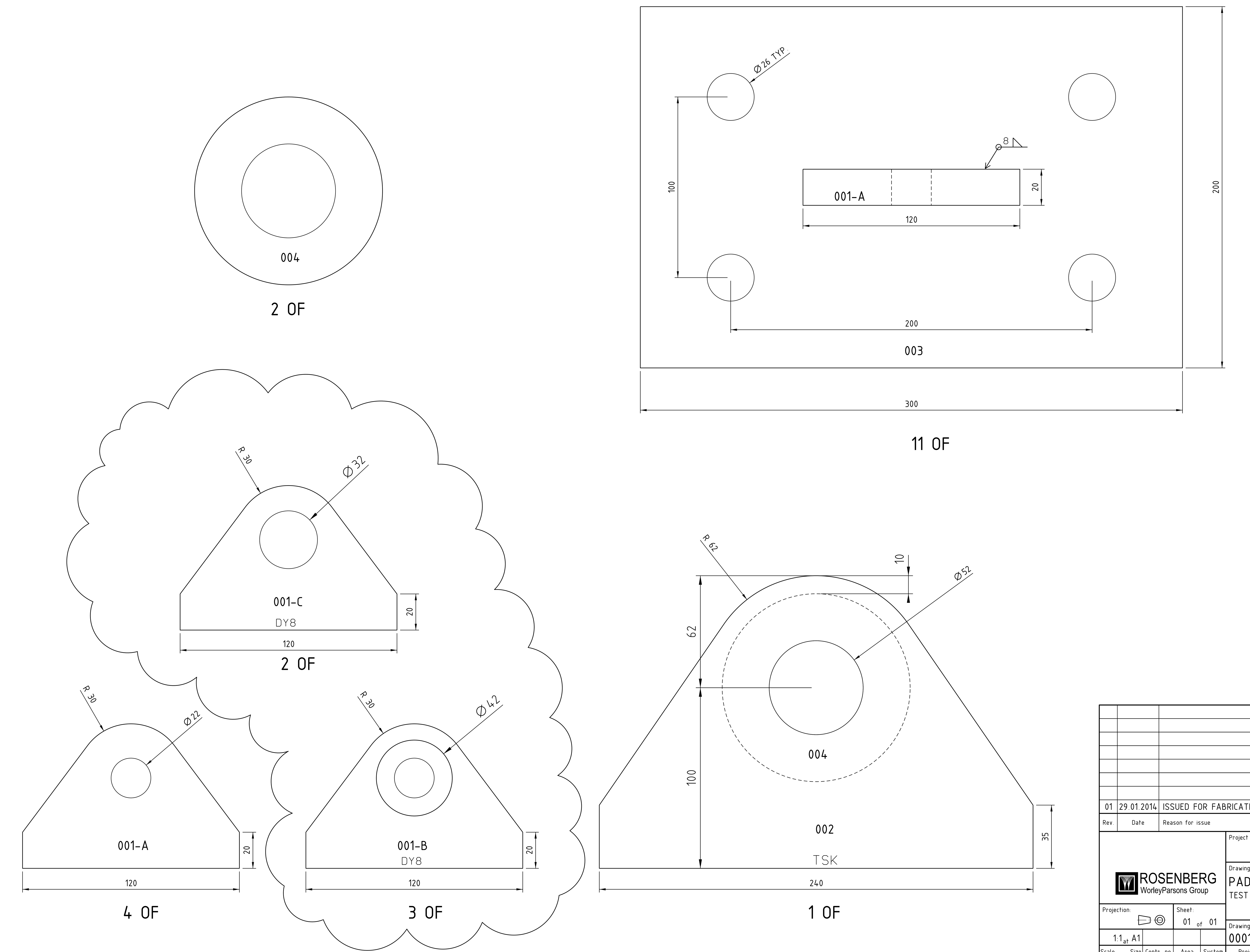
Drawing title:
PAD EYES
TEST

Projection:

Sheet: 01 of 01

1:1	at A1				Drawing no. 0001	01
Scale	Size	Contr. no	Area	System	Project-Contract-Area-Discipline-Type-Sequence-Sheet	Rev.

seed file: stoil a1.dgn



Rev.	Date	Reason for issue	Drawn	Checked	Approved
01	29.01.2014	ISSUED FOR FABRICATION	RK	SAS	HeF

Project name:	MASTER THESIS EKOL 2/4L 6066
ROSENBERG WorleyParsons Group	Drawing title: PAD EYES TEST
Projection:	Sheet: 01 of 01
Scale / Size: 1:1 at A1	Contr. no / Area / System
Drawing no. (Project-Contract-Area-Discipline-Type-Sequence-Sheet)	0001
Rev.	01

seed file: stoil a1.dgn

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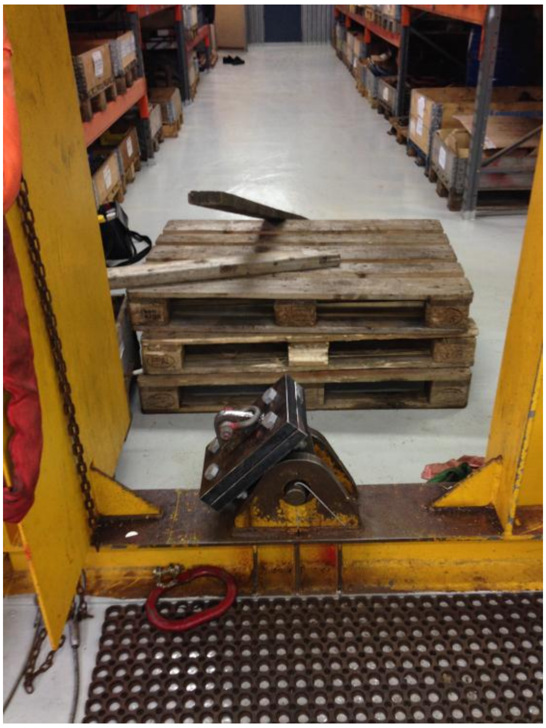
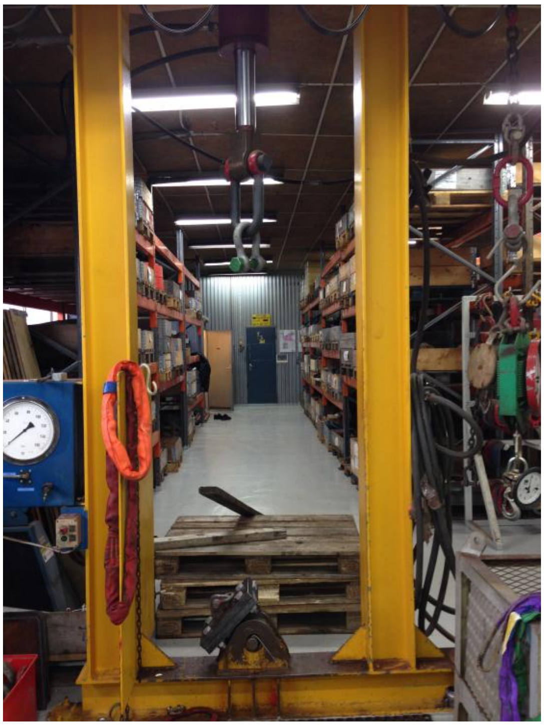
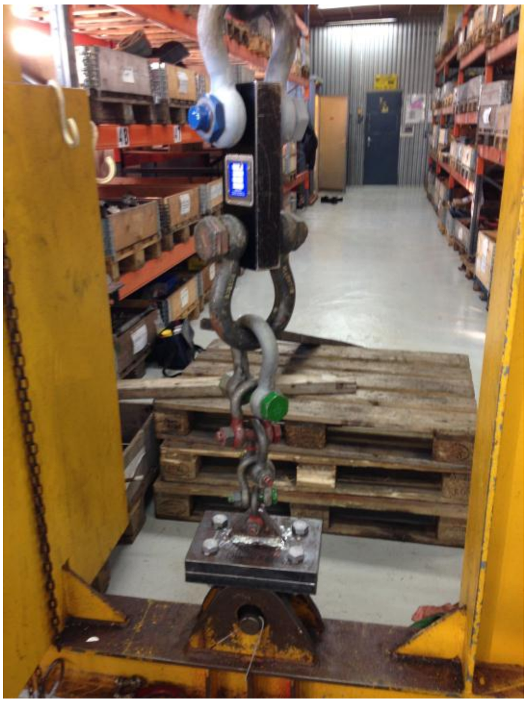
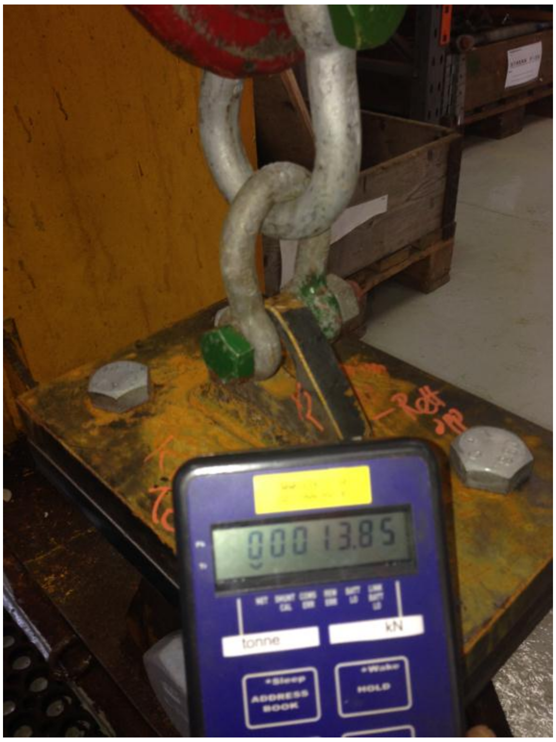
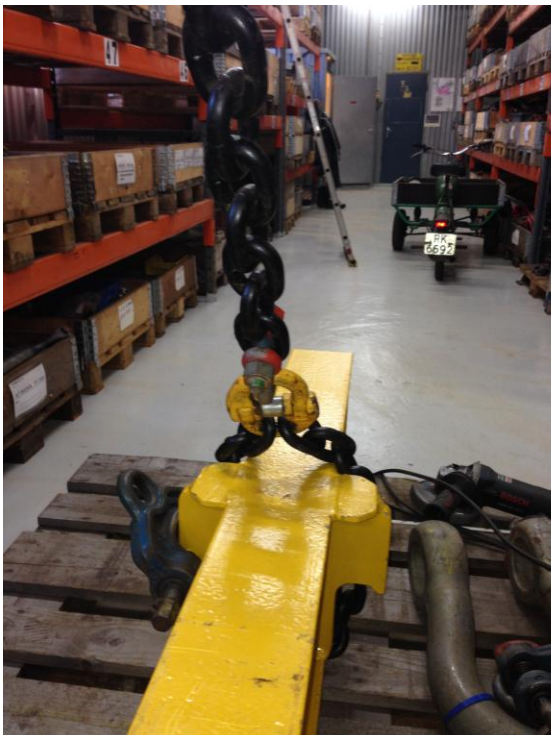
APPENDIX C - Pictures from testing






000 13.85
tonne
kN
*Sleep
ADDRESS BOOK
*Wake
HOLD



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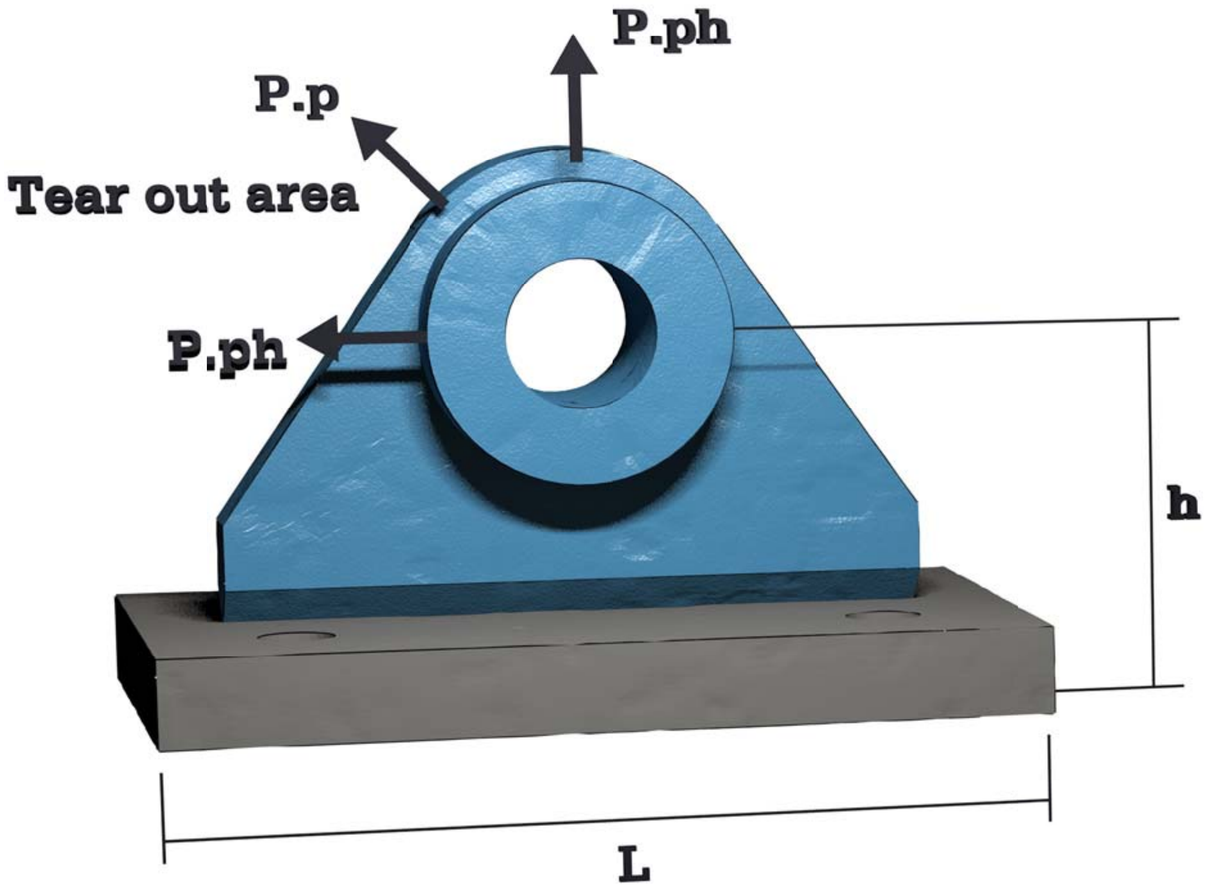
APPENDIX D - Additional info from testing, material ordering

MicroStation Padeye scetch. Created 21.05.2014, By Renathe Kvalvåg.



Art.nr	Beskrivelse	Infotekst	Behov	Enhet	
PLA020Y30	PL20 420I	PLATE 20MM GR 420I, MDS-Y30	0,15	M^2	
PLA025Y30	PL25 420I	PLATE 25MM GR 420I, MDS-Y30	0,1	M^2	
PLA030Y05	PL30 355III	PLATE 30MM GR 355III, MDS-Y05	1	M^2	
HBM24X10093388G	HEX-BOLT M24X100 DIN933 8.8 GALV	HEX-BOLT M24X100 DIN933 8.8 GALV HELGJ 2.2 SERT	50	EA	
NUTM249348G	NUT M24 DIN934 8 GALV	NUT M24 DIN934 8 GALV	50	EA	
WAM241258G	WASHER M24 DIN125 8 GALV	WASHER M24 DIN125 8 GALV	50	EA	

APPENDIX E - Testing equipment certificate

TEO TEKNIKK AS

RV-1

Proof report

Instrument Calibrated		Calibration Normals	
TYPE: Description: Manufacture: Serie No: Range: Accuracy:	RLP Crane Scales Straightpoint 6944 0-50000 Kg 0,30%	ID No.: Description: Manufacture: Last Calibrated: Proof No: Traceability	K 767906 5103-C3 100K 30NT Revere 2012.11.19 MTmPX26067-K03 Sveriges Provnings-ock Forskningsinstitut

Calibrationresults at 20° C

ID: MMVVEKT 0150 RV-001

Real Weight	Read Weight			Average deviation	Variance	Variance	variance of max. load
	test 1	test 2	test 3				
kg	kg	kg	kg	kg	kg	%	%
5000	5000	5010	5010	5007	7	0,14	0,01
10000	10020	10020	10020	10020	20	0,20	0,04
15000	15010	15010	15010	15010	10	0,07	0,02
20000	20000	20000	20000	20000	0	0,00	0,00
25000	24980	24980	24980	24980	-20	-0,08	-0,04
30000	29980	29980	29980	29980	-20	-0,07	-0,04
35000	34990	34990	34990	34990	-10	-0,03	-0,02
40000	40010	40000	40000	40003	3	0,01	0,01
45000	45030	45030	45030	45030	30	0,07	0,06
50000	50070	50070	50070	50070	70	0,14	0,14

Calibrated: 01.03.2013
Arvid Stokkeland
Terje Obrestad
Even Obrestad Hægstad *Even Hægstad*
Åge Obrestad

Postadresse: 4365 NÆRBØ | *Besøksadresse:* Haavegen 196 | *Telefon:* 51 79 84 00 | *Telefax:* 51 79 84 01 | *E-post:* teo@teo.no | *Internett:* www.teo.no | *Foretaksregisteret:* NO 936 940 218 MVA

TEO TEKNIKK AS

RV-1

Proof report

Instrument Calibrated	
TYPE:	RLP
Description:	Crane Scales
Manufacture:	Straightpoint
Serie No:	7591
Range:	0-25000 Kg
Accuracy:	0,30%

Calibration Normals	
ID No.:	K 767906
Description:	5103-C3 100K 30NT
Manufacture:	Revere
Last Calibrated:	2012.11.19
Proof No:	MTmPX26067-K03
Traceability	Sveriges Provnings-ock Forskningsinstitut

Calibrationresults at 20° C
ID: MMVVEKT 0125 RV-001

Real Weight	Read Weight			Average deviation	Variance in	Variance in	Variance of max. load
	1.test	2.test	3.test				
kg	kg	kg	kg	kg	kg	%	%
2500	2510	2510	2510	2510	10	0,40	0,04
5000	5020	5020	5020	5020	20	0,40	0,08
7500	7560	7560	7555	7558	58	0,77	0,23
10000	10090	10090	10090	10090	90	0,90	0,36
12500	12610	12615	12615	12613	113	0,90	0,45
15000	15110	15110	15110	15110	110	0,73	0,44
17500	17585	17590	17590	17588	88	0,50	0,35
20000	20040	20050	20050	20047	47	0,24	0,19
22500	22505	22510	22510	22508	8	0,04	0,03
25000	24960	24970	24970	24967	-33	-0,13	-0,13

Kalibrert 01.03.2013
Arvid Stokkeland
Terje Obrestad
Even Obrestad Hægstad *Even Hægstad*
Åge Obrestad