



Comparative analysis of design codes for portable offshore units

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Master Thesis

presented in partial fulfillment
of the requirements for the double degree:
“Advanced Master in Naval Architecture” conferred by University of Liège
“Master of Sciences in Applied Mechanics, specialization in Hydrodynamics, Energetics and Propulsion” conferred by Ecole Centrale de Nantes

developed at West Pomeranian University of Technology, Szczecin
in the framework of the

**“EMSHIP”
Erasmus Mundus Master Course
in “Integrated Advanced Ship Design”**

Ref. 159652-1-2009-1-BE-ERA MUNDUS-EMMC

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Szczecin, January 2013



Traditio et Innovatio



Zachodniopomorski
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w Szczecinie

*“Pray as if everything depended on God.
Work as if everything depended on you”.*

(St. Augustine)

*“Reza como si todo dependiera de Dios.
Trabaja como si todo dependiera de ti”.*

(San Agustín)

A mis padres, Dulce y José Eduardo

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Declaration of Authorship

I declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

Where I have consulted the published work of others, this is always clearly attributed.

Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.

I have acknowledged all main sources of help.

Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma.

I cede copyright of the thesis in favour of the West Pomeranian University of Technology (Szczecin, Poland).

Szczecin, January 15th 2012

A handwritten signature in blue ink. The name 'Eduardo Pérez' is written in a cursive style, with 'Bidal' written below it. A horizontal line is drawn across the signature.

ABSTRACT (ENGLISH VERSION)



In the last years, offshore industry has become into one of the most innovative and profitable industries all over the world. Due to its high complexity requirements and the huge number of technologies involved, this industry is now a vast ocean where young engineers can dive in search of new knowledge and opportunities to contribute to the development of the engineering.

Some of those technologies involved in offshore industry are special portable devices designed to transport special equipment from the shore to offshore facilities. In addition, different international organizations have been developing design codes for steel structures in the last years. However, how similar are these codes? Are there significant differences between them?

A comparative analysis between five offshore design codes (API, DNV, Eurocode, ISO and Norsok) has been carried out for a portable offshore unit in this master thesis. DNV software and different codes and standards have been available to accomplish this task and try to get to a conclusion. To do this, several analysis in different scenarios were done to have a wide enough range of results and be able to do an accurate study of the situation.

Clear and solid conclusions have been got for these codes and a “pattern of behavior” has been determined for all of them. Results show that one of the codes is very conservative in its results, with differences from 40% up to 190% of its values. Furthermore, some ideas for future research in this topic have been proposed.

ABSTRACT (SPANISH VERSION)



En los últimos años, la industria offshore se ha convertido en una de las industrias más innovadoras y rentables del mundo. Debido a sus requerimientos de gran complejidad y al alto número de tecnologías relacionadas, esta industria es, en la actualidad, un vasto océano donde jóvenes ingenieros pueden adentrarse en busca de nuevos conocimientos y oportunidades para contribuir al desarrollo de la ingeniería.

Algunas de estas tecnologías relacionadas con la industria offshore son estructuras portátiles diseñadas para transportar equipos especiales de tierra adentro a instalaciones offshore. Además, distintos organismos internacionales han desarrollado códigos de diseño para estructuras de acero durante los últimos años. Pero, ¿cómo de similares son estos códigos? ¿Hay diferencias significativas entre ellos?

Un análisis comparativo entre cinco códigos de diseño ha sido realizado para una unidad offshore portátil en esta tesis. Software desarrollado por DNV y diversos códigos y estándares han sido utilizados para completar los objetivos propuestos y tratar de llegar a unas conclusiones. Para hacer esto, diversos análisis en escenarios variados fueron llevados a cabo para disponer de un rango de resultados lo suficientemente amplio como para poder estudiar la situación de forma apropiada.

Conclusiones sólidas y claras han sido obtenidas para estos códigos y un “patrón de comportamiento” ha sido determinado para ellos. Los resultados muestran que uno de los códigos es especialmente conservador en sus resultados, con diferencias que van desde el 40% hasta el 190% del resultado de los otros tres códigos. Además, se han propuesto ideas para posibles investigaciones futuras.

ABSTRACT (POLISH VERSION)



W przeciągu ostatnich lat, przemysł offshore stał się jednym z najbardziej innowacyjnych i profitujących przemysłów na całym świecie. W wyniku wysokich i kompleksowych wymagań oraz dużej liczby wdrożonych technologii, przemysł ten jest obecnie jak niezmierny ocean, w którym młodzi inżynierowie mogą zanurkować w celu poszukiwania nowej wiedzy, a tym samym wnieść swój wkład w rozwój inżynierii.

Niektóre z technologii zaangażowane w przemysł offshore są specjalnymi urządzeniami przenośnymi zaprojektowanymi do transportowania specjalistycznego sprzętu z nabrzeży do instalacji morskich. Co więcej, w ostatnich latach różne międzynarodowe organizacje pracują nad rozwojem kodów projektowania dla konstrukcji stalowych. Pytanie jednak, jak podobne są do siebie te kody? Czy są jakieś znaczące różnice pomiędzy nimi?

Analiza porównawcza w tej pracy magisterskiej pomiędzy pięcioma kodami projektowania offshore (API, DNV, Eurocode, ISO i Norsok) przeprowadzona została dla przenośnej jednostki offshore. Oprogramowanie DNV oraz różne kody i standardy są konieczne do zakończenia tego zadania i wyciągnięcia odpowiedniego wniosku. W tym celu zostało podanych kilka analiz różnych scenariuszy, których wnioski mają umożliwić studium tego przypadku.

Praca ta pozwoliła na uzyskanie jasnych i solidnych wniosków dla kodów offshore oraz ustalenie dla nich „zasad zachowania”. Wnioski wskazują, iż jeden z tych kodów jest bardzo konserwatywny. Jest to wynikiem różnic w wartościach wahających się od 40% do 190%. Ponadto zostały zaproponowane nowe pomysły do kolejnych badań w przyszłości w tej dziedzinie.

ABBREVIATIONS

API	American Petroleum Institute
CE	Conformité Européenne (European Conformity)
COG	Centre/s of gravity
DNV	Det Norske Veritas
ECS	European Committee for Standardization
EIA	Energy Information Administration
EN	Eurocode
IEA	International Energy Agency
ISO	International Organization for Standardization
MBpd	Million barrels per day
NS	Norwegian Standards
OPEC	Organization of the Petroleum Exporting Countries
OS	Offshore Standard
POU	Portable Offshore Unit
RP	Recommended practice
UF, UfTot	Usage factor
ULS	Ultimate Limit Strength
US	United States

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION TO OFFSHORE INDUSTRY

Offshore industry has become more and more important during the last decades. Due to the growth of the necessity of oil and gas all around the world, there has been an impressive amount of new fields. In Figure 1, the amount of oil production all around the world is shown. It is very remarkable the growth of offshore production, almost doubled, from 15 more than 25 million barrels per day.

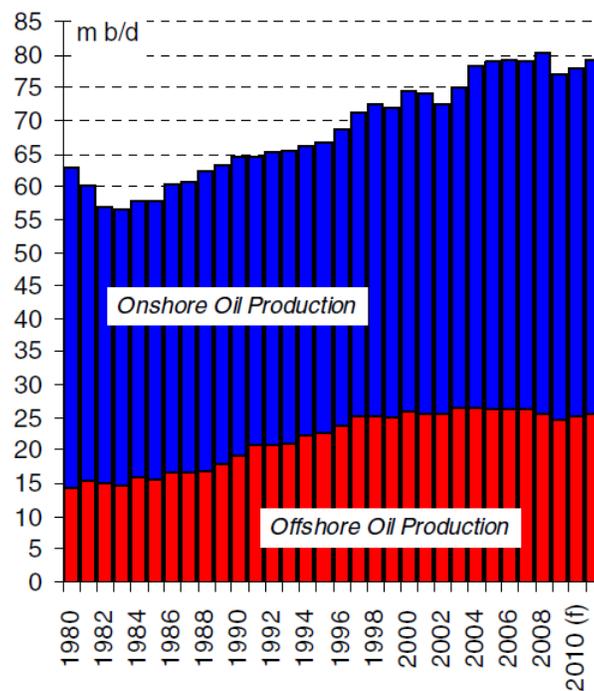


Figure 1. Onshore & offshore oil production in MBpd between 1980 and 2010

In this moment, different offshore areas can be divided into the different activities developed there¹:

- a) Offshore areas of exploration activity: Gulf of Mexico, West Africa, Mediterranean and Black Sea
- b) Offshore areas of development activity: Gulf of Mexico, South & Central America
- c) Offshore areas in production: Middle East/Indian Sub-Continent, Asia-Pacific
- d) Offshore areas in decline: North Sea, Gulf of Mexico (Shallow Water)

Offshore oil and gas production is more challenging than land-based installations due to the remote and harsher environment. The main reasons of the need of high technology and a constant search of better ideas are those:

- a) Natural differences between onshore and offshore facilities. Obviously, the complexity related to design, manufacturing and exploitation of those facilities requires a very high technology.
- b) Increase of the average depth of the offshore fields

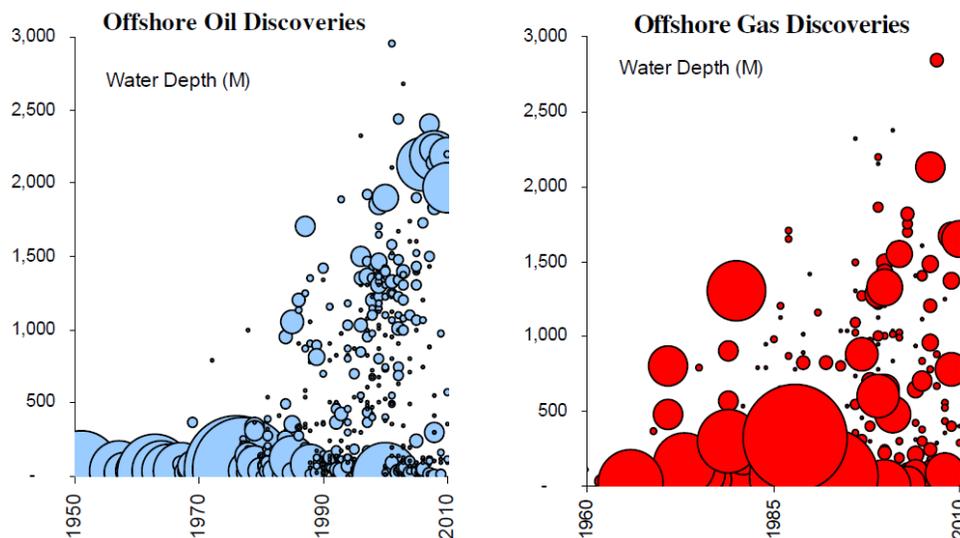


Figure 2. Onshore & offshore oil production in MBpd between 1980 and 2010

¹ Offshore review & Outlook. A half-yearly report for the offshore forecast club (Spring 2011). Clarkson Research Services Limited. The previous and the two following figures are taken also from this report.

c) Increase of the average distance to the shore of the offshore fields ²

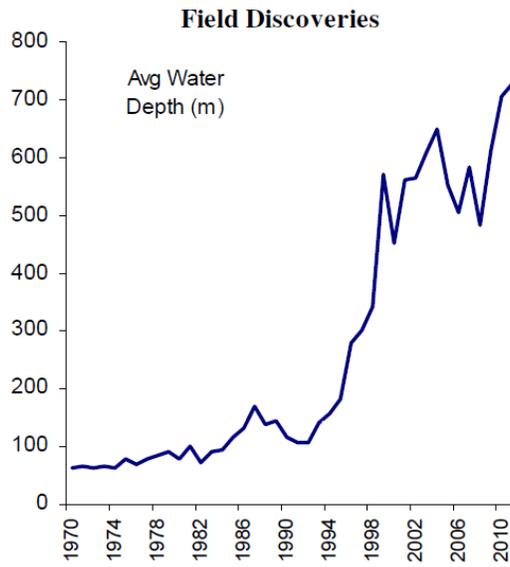


Figure 3. Offshore field discoveries by water depth

d) Amount of the needs of oil in the world ³

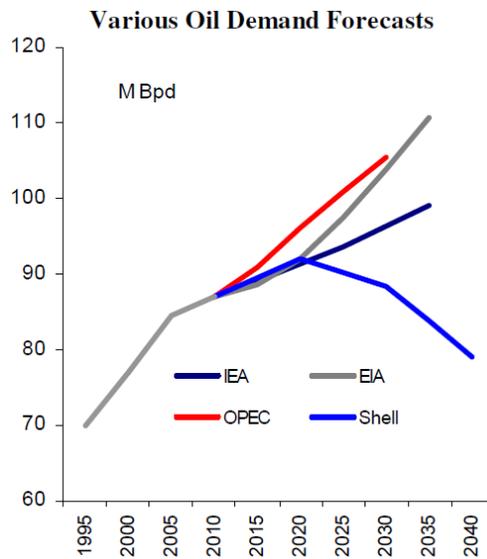


Figure 4. Oil demand forecasts

² Offshore review & Outlook. A half-yearly report for the offshore forecast club (Spring 2011).

³ Offshore review & Outlook. A half-yearly report for the offshore forecast club (Spring 2011).

1.2 OBJECTIVES OF THE MASTER THESIS

The main objective of this master thesis is to analyze and compare the differences between design codes for portable offshore units. This is almost a copy of the title of the thesis but some questions can be answered to have a better idea about what has been done in this thesis and how.

What is going to be analyzed?

Portable offshore units (chapter 3) are analyzed in this master thesis; as well as the methodology related to load calculation (chapter 4), codes comparison (chapters 5 and 8), welding calculation (chapter 6) and lifting equipment calculation (chapter 7).

What is going to be compared?

As was written in the first paragraph, different design codes have been compared. However, there are many ways to compare these codes.

First of all, the formulation to calculate the loads acting on a structure is different between codes. Also, each code has its own factors to combine the different load cases that might happen in a structure, and the same with security factors. Finally, and the most important difference between them, is the own formulation to calculate the usage factors and the results that this will generate. This is better explained in Chapter 5.

How is it going to be compared?

To compare the codes and try to reach to some conclusions, some loads have been applied on the structure. With these applied loads in different scenarios and after running the different codes, the result is a usage factor for each beam, scenario and code.

As there is more than one input, many crosses analysis had to be done to ensure that the range of results is wide enough to be sure about the conclusions.

What kind of results are expected?

In the beginning of this thesis and even without having done any analysis, it was expected to have results that would let us compare the codes from a conservative/non-conservative point of view.

1.3 METHODOLOGY

To accomplish the objectives of this master thesis, three main elements have been used:

- Design codes & standards
- A portable offshore unit
- FEM software

PO Unit description is done in Chapter 3.

The codes used in this master thesis are quite used in maritime & offshore industry. Those are distributed by the American Petroleum Institute (API), European Union (Eurocodes), International Organization for Standardization (ISO codes), Standards Norway (Norsok) and Det Norske Veritas (DNV). A further explanation has been done in Chapter 2.

The second essential element is the software. In this case, DNV Sesam software was the software chosen. This software has many different pieces but just two have been used: GeniE and Xtract.

GeniE is a tool for designing and analyzing offshore and maritime structures made of beams and shells. GeniE can be used for design analyses of offshore and maritime structures composed of beams and shells. Typical examples are tankers, bulk ships, container ships, FPSOs, jackets, jack ups, topsides, modules, flare towers bridges, helidecks, underwater installations, cranes and crane pedestals. For sea-bed supported structures (jackets and jack-ups) the hydrodynamic and soil properties are an integral part of the analysis models. It has an integrated code check and reporting of beams using the most recent versions of API/WSD, API/LRFD, Norsok, ISO 19902, AISC and Eurocode 3.

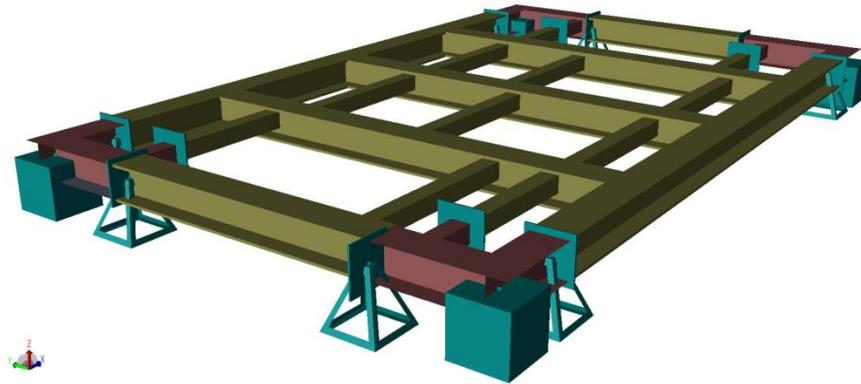


Figure 5. Structure built with beam and shell elements in GeniE

Xtract is a high-performance general purpose model and results visualization program.

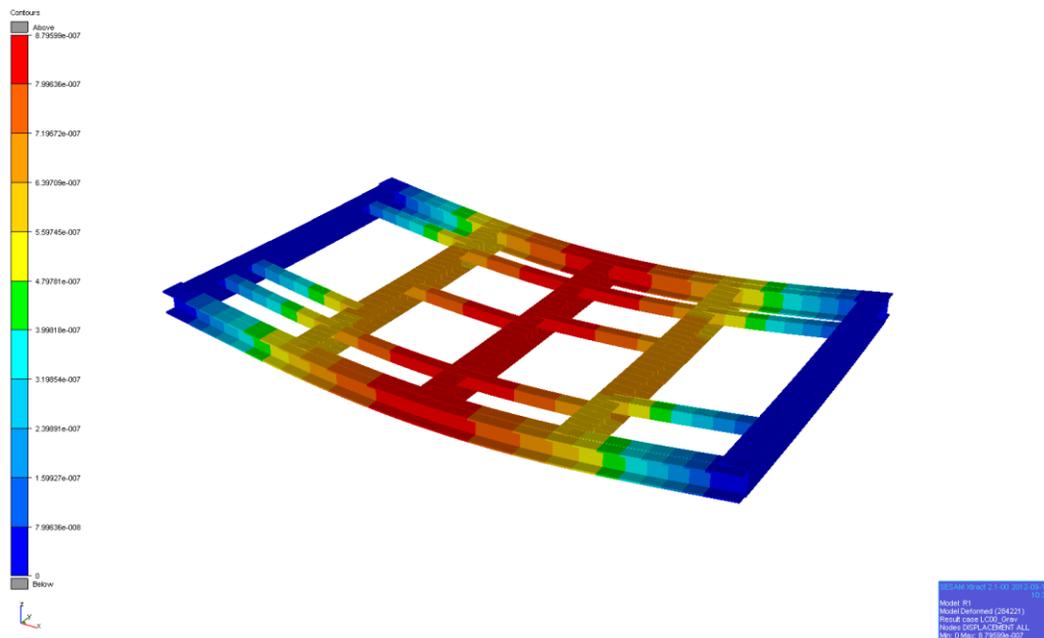


Figure 6. 3D view of the structure in Xtract

CHAPTER 2

DESIGN CODES

2.1 AMERICAN PETROLEUM INSTITUTE

API codes are written by the American Petroleum Institute. API is the largest US trade association for the oil and natural gas industry. It claims to represent about 400 corporations involved in production, refinement, distribution, and many other aspects of the petroleum industry.

Some of the key aspects of the oil and gas industry that are addressed in API standards include exploration and production; refining; fire protection and safety; petroleum measurement and marine transportation. API standards also reference offshore production, drilling, structural pipe, pipeline, health and environmental issues, valves and storage tanks to name a few.

API standards include manuals, standards, specifications, recommended practices, bulletins, guidelines and technical reports.

API standards cover:

- Environmental and safety
- Exploration and production
- Inspection measurement
- Petroleum measurement
- Refining

- Transportation, marketing & safety

In this master thesis, these API codes have been used:

- API Recommended Practice 2A-WSD (RP 2A-WSD), 21st EDITION (2000). Planning, Designing and Constructing Fixed Offshore Platforms - Working Stress Design.
- API Recommended Practice 2FPS, 2nd EDITION (2011). Planning, Designing, and Constructing Floating Production Systems.
- API Recommended Practice 2N (1995). Recommended Practice for Planning, Designing, and Constructing Structures and Pipelines for Arctic Conditions.

2.2 EUROCODES

Eurocodes are a set of harmonized technical rules developed by the European Committee for Standardisation (ECN) for the structural design of construction works in the European Union. Eurocodes are intended to be used as reference documents to:

- prove the compliance of building and civil engineering works or parts thereof with Essential Requirements of the Construction Products Directive, and express them in technical terms;
- determine the performance of structural components and kits (information relevant to CE marking);
- define the technical specifications in public contracts according to the Public Procurement Directive, The Eurocodes are relevant to the single market, competitiveness and other policies.

The Eurocodes are published as a separate European Standards, each having a number of parts. By 2002, ten sections have been developed and published:

Table 1. Eurocodes

EN 1990	Basis of structural design
EN 1991 (Eurocode 1)	Actions on structures
EN 1992 (Eurocode 2)	Design of concrete structures
EN 1993 (Eurocode 3)	Design of steel structures
EN 1994 (Eurocode 4)	Design of composite steel and concrete structures
EN 1995 (Eurocode 5)	Design of timber structures
EN 1996 (Eurocode 6)	Design of masonry structures
EN 1997 (Eurocode 7)	Geotechnical design
EN 1998 (Eurocode 8)	Design on structures for earthquake resistance
EN 1999 (Eurocode 9)	Design of aluminum structures

In this master thesis these Eurocode parts have been used:

- EN 1677-4 Master links and sub-assembly
- EN 1990 Basis of structural design
- EN 1991 Actions on structures
 - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings
 - Part 1-3: General actions - Snow loads
 - Part 1-4: General actions - Wind actions
- EN 1993 Design of steel structures
 - Part 1-1: General rules and general rules for buildings
 - Part 1-1: General rules and general rules for buildings

2.3 INTERNATIONAL STANDARDS

The International Organization for Standardization is the world's largest developer of voluntary International Standards. International Standards give state of the art specifications for products,

services and good practice, helping to make industry more efficient and effective. Developed through global consensus, they help to break down barriers to international trade.

In this moment, more than 16,000 ISO norms are available. ISO codes used in this master thesis are the following:

- ISO 12494 Atmospheric icing of structures
- ISO 13535 Hoisting equipment
- ISO 19902 Petroleum and natural gas industries – Fixed steel offshore structures
- ISO 19903 Fixed concrete offshore structures
- ISO 19906 Petroleum and natural gas industries – Arctic offshore structures

2.4 NORWEGIAN STANDARDS

The Norsok standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations. Furthermore, Norsok standards are as far as possible intended to replace oil company specifications and serve as references in the authorities' regulations.

Norsok standards are normally based on recognized international standards, adding the provisions deemed necessary to fill the broad needs of the Norwegian petroleum industry. Where relevant, Norsok standards will be used to provide the Norwegian industry input to the international standardization process. Subject to development and publication of international standards, the relevant Norsok standard will be withdrawn.

Norsok standards are developed according to the consensus principle generally applicable standards work and according to established procedures defined in Norsok A-001.

Norsok standards are prepared and published with support by The Norwegian Oil Industry Association (OLF) and Federation of Norwegian Manufacturing Industries (TBL).

Norsok standards are administered and published by Standards Norway. NORSOK codes used in this master thesis are the following:

- N-001 Integrity of offshore structures
- N-003 Actions and action effects
- N-004 Design of steel structures
- NS-EN 12385-4 Weights and breaking loads for steel wire rope
- NS-ISO 2553 Welded, brazed and soldered joints. Symbolic representation on drawings
- NORSOK R-002 Lifting equipment

2.5 DET NORSKE VERITAS

DNV rules and standards are developed by Det Norske Veritas, a classification society organized as a foundation, with the objective of safeguarding life, property, and the environment.

DNV has many types of publications; such as Rules, Standards, Recommended Practices, Guidelines, etc. Det Norske Veritas publications used in this master thesis are the following:

- DNV Classification Notes No. 30.1 (2004). Buckling strength analysis of bars and frames and spherical shells.
- DNV-OS-C101 (2011). Design of offshore steel structures, general (LRFD method).
- DNV-OS-C105 (2011). Structural design of TLPS (LRFD method).
- DNV-OS-C201 (2012). Structural design of offshore units (WSD method).
- DNV-RP- C102 (2002). Structural design of offshore ships.
- DNV-RP-C205 (2010). Environmental conditions and environmental loads.
- DNV Standard for Certification No. 2.7-1 (2006). Offshore containers.
- DNV Standard for Certification No. 2.7-3 (2011). Portable offshore units.

CHAPTER 3

DESCRIPTION OF THE STRUCTURE

3.1 INTRODUCTION TO PORTABLE OFFSHORE UNITS

According to DNV Standard 2.7-3, a Portable Offshore Unit “is a package or unit intended for repeated or single offshore transportation and installation/lifting”.

Normally, those units are designed to carry equipment over its main frame and to be lifted from deck to deck. The main difference between PO Units and containers is that they are not intended to carry general cargo and usually, the maximum mass of PO Units is between 25 and 100 tons, while containers do not exceed 25 tons.

As their characteristics and purposes are not the same, different rules are used. For containers, DNV Standard 2.7-1 is used, while 2.7-3 is the one for PO Units.

“Their structure can be divided into primary and secondary. Primary structures are divided into two sub-groups:

- Essential primary structure includes the following main structural components:
 - All members that participate in the global structural strength (calculations) of the PO Unit for sea transport and lifting (and fork lifting if applicable)
 - Padeyes

- Other elements, if present, which normally should also be considered as primary structure are:
 - Lashing points
 - Fork lift pockets
 - Load distributing floor/deck beams/panels
 - supporting structures for tanks
 - supports for heavy equipment

Parts which are not essentially load carrying. Secondary structure includes the following structural components:

- panel stiffeners and corrugations of non-structural nature
- doors, wall and roof panels
- structural components used for protection only”.

PO Units can be divided into five groups:

“**Type A** PO Units with a primary structure frame (including skids arranged with crash frames). Type A units typically share many characteristics with offshore containers, but deviate from the definition given in DNV 2.7- 1, e.g. with $R > 25$ tonnes or because they are intended for a single transport event. PO Units which for other reasons are not able to comply with the requirements for containers in DNV 2.7-1 may also be accepted as PO Units of Type A. Type A units will typically be service packages such as pumps, generation units, coiled tubing units, skid mounted manifolds, pressure vessels or process arrangements of portable nature.

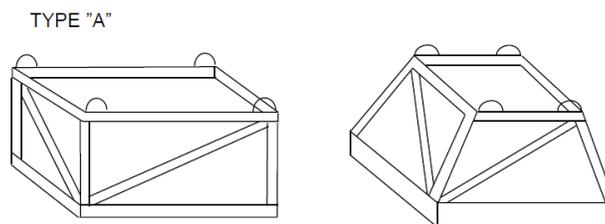


Figure 7. Portable offshore unit type “A”⁴

⁴ Taken from from DNV Standard 2.7-3, Figure 1-1, page 9

Type B is PO Units with skid based installations but without a primary structure frame (skids arranged without crash frames). Type B units could have installations with the same type of main functions as mentioned for type A units. The reason for omitting the crash frame may be related to the size or shape of the PO Unit or other considerations.

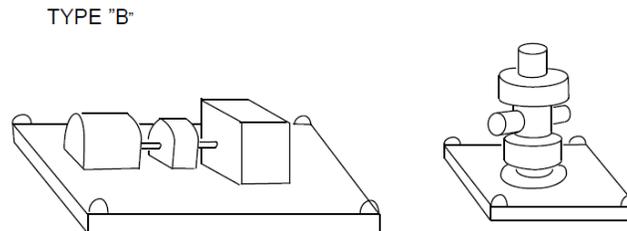


Figure 8. Portable offshore unit type "B" ⁵

Type C is PO Units that lack a dedicated skid or frame. Type C units may be arranged with self-supporting feet, skirts or support points integrated in the units' own structure. Example of this type could be; x-mas trees, reels, manifolds, pressure vessels with stools, etc.

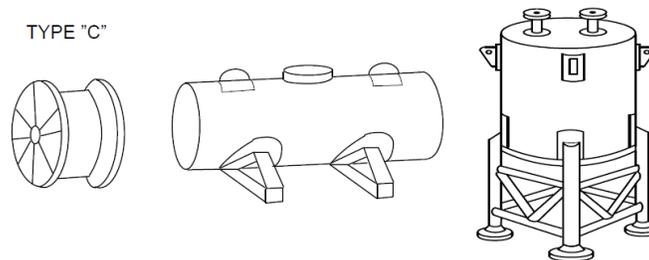


Figure 9. Portable offshore unit type "C" ⁶

Type D is mainly boxes or units of stress skin design, where the suitability for transportation is arranged in the shell through attachments and reinforcements to achieve adequate structural integrity. These types of structures do normally depend on the shell or skin to resist transportation generated loads. Examples of the type D PO Units would be control cabins or smaller modules for different services.

⁵ Taken from from DNV Standard 2.7-3, Figure 1-1, page 9

⁶ Taken from from DNV Standard 2.7-3, Figure 1-1, page 9

TYPE "D"
"STRESS SKIN"

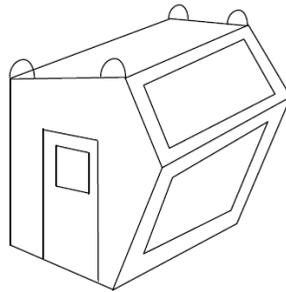


Figure 10. Portable offshore unit type "D" ⁷

Type E is a PO Unit that does neither fall into any of the PO Unit types A through D nor is a DNV 2.7-1 container. It shall be agreed with DNV in each case if it is applicable to certify a type E unit as a PO Unit".

A PO Unit type "B" has been used in this master thesis due to the easiness of modeling and because as a comparison of codes is the purpose of the thesis, the shape of the unit is not relevant for achieving conclusions.



Figure 11. PO Unit type "B" Dual 50 HP Instrument Air / Starting Air Skid. ⁸

⁷ Taken from from DNV Standard 2.7-3, Figure 1-1, page 9

⁸ Taken from http://www.sullairhouston.com/custom_engineered_industrial_air_compressor_packages.htm

3.2 DESIGN REQUIREMENTS

3.2.1 Environmental data

Table 2. Air temperature and density ⁹

Design maximum air temperature	+23°C
Design minimum air temperature	-10°C
Maximum relative humidity	100%

Table 3. Sea water temperature and density ¹⁰

Sea temperature at sea level	max. +20°C, min +3 °C
Sea temperature at seabed level	max. +11°C, min +4 °C
Density of seawater	1025 kg/m ³

3.2.2 Snow and ice

Snow will only accumulate on horizontal surfaces. Snow will be assumed to have a maximum depth of 250 mm and density 100 kg/m³. Ice and snow shall not be assumed to act simultaneously.

Ice loads are specified in Table 4:

Table 4. Ice loads ¹¹

Height above LAT (m)	Thickness (mm)	Density (kg/m ³)
3-15	40	850
15-100	Linear reduction from 40-20	Linear reduction from 850-500

⁹ Taken from DNV internal documents

¹⁰ “ “

¹¹ “ “

3.2.3 Wind loads

Table 5 shows predicted extremes for the 1-hour average wind velocity at 10 m above sea level. The characteristic wind velocity at height z above sea level, and corresponding averaging time period less than or equal to 3600s may be calculated as shown in NORSOK N-003 (Section 6.3.2). The wind spectrum for the longitudinal wind speed fluctuations are given in of NORSOK N-003 (Section 6.3.2).

Table 5. Directional and omni-directional extremes for wind speed.¹²

WiDir	Weibull parameters			Wind speed (m/s)				
	Scale	Shape	Location	1	10	100	1000	10000
N	9.125	2.074	0.545	22.6	26.3	29.4	32.2	34.7
NE	7.472	1.707	0.775	21.4	26.0	30.0	33.7	37.1
E	10.757	2.182	0.000	24.6	28.5	31.9	34.8	37.6
SE	11.437	2.606	0.000	23.3	26.2	28.7	30.9	32.8
S	10.337	2.220	0.682	24.8	28.3	31.3	34.0	36.5
SW	12.042	2.536	0.000	25.8	28.9	31.5	33.9	36.0
W	11.935	2.310	0.000	27.5	31.2	34.4	37.2	39.7
NW	8.907	1.878	1.440	25.3	29.6	33.3	36.7	39.9
Omni	10.364	2.100	0.000	28.8	32.2	35.3	38.2	40.8

3.3 ELEMENTS

3.3.1 Profiles

The skid structure was modeled entirely with beam elements. There are two types of profiles used in the structure, as shown in Tables 6 and 7. Profile shown in Table 8 will be further explained in Chapter 5.

¹² Weibull parameters for winter season October-April. Duration of extreme event is 1 hour. Taken from DNV internal documents.

Table 6. Dimensions of HEB profile

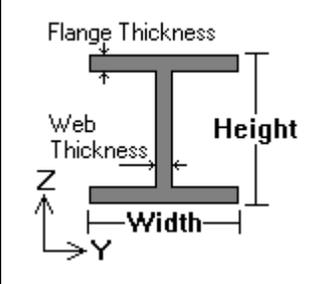
	Height	200	mm
	Width	200	mm
	Web thickness	9	mm
	Flange thickness	15	mm

Table 7. Dimensions of SHS profile

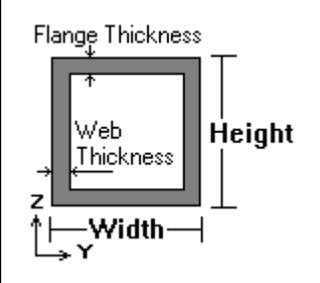
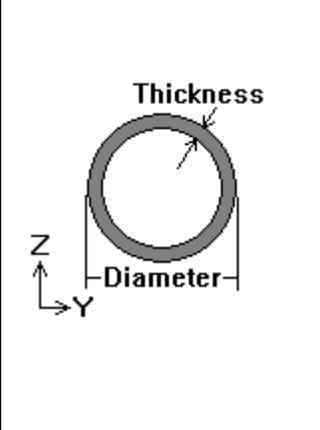
	Height	100	mm
	Width	100	mm
	Web thickness	6	mm
	Flange thickness	6	mm

Table 8. Dimensions of pipe profile

	Pipe section 1		
	Diameter	200	mm
	Thickness	10	mm
	Pipe section 2		
	Diameter	100	mm
	Thickness	7.5	mm

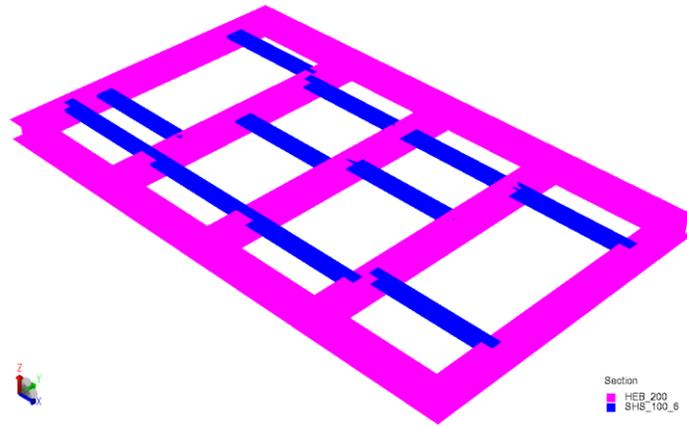


Figure 12. Beams of the skid coloured

3.3.2 Material

The same material is applied to the whole structure.

Table 9. Properties of S355

Yield point	355	MPa
Density	7.85	t/m ³
Young´s modulus	2.1E08	MPa
Poisson ratio	0.3	-
Thermal	1.2E-5	kNs/m
Damping	0.03	-

3.3.3 Supports

Four supports are placed in the skid; each one in each corner in the union between transversal and longitudinal beams. The support is applied in a single node.

Table 10. Boundary conditions for the supports of the skid

Symbol	dx	dy	dz	ϕ_x	ϕ_y	ϕ_z
	Fixed	Fixed	Fixed	Free	Free	Free

These boundary conditions were taken because it is the most condition closest to the in-place situation of the structure during the analysis.

3.4 MODELING

Modeling of skid structure has been performed using GeniE software. The procedure has been divided in the following steps:

- Introduce the preliminary parameters: profiles, material and (3.3.1 and 3.3.2)
- Place the beam elements (Appendix A)
- Place the supports in the four corners of the skid (3.3.3)
- Finally, after modeling, the skid structure is ready to introduce the different load cases, apply the loads calculated by the codes and analyze the model (Chapters 4 and 5)

The primary structure of the frame includes these beams:

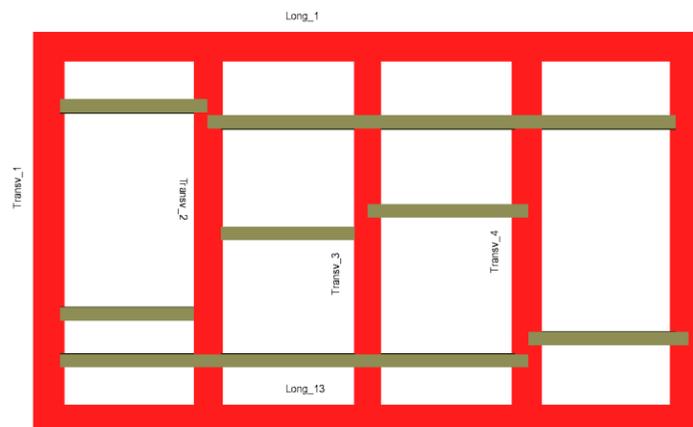


Figure 13. Primary structure of the skid

- Longitudinal beams: Long_1 and Long_13
- Transversal beams: Transv_1 to Transv_5

The secondary structure of the frame includes the following beams:

- Transversal beams: Long_2 to Long_12

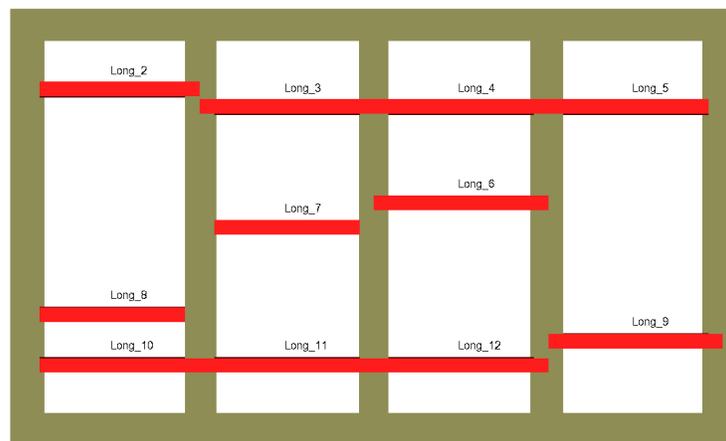


Figure 14. Secondary structure of the skid

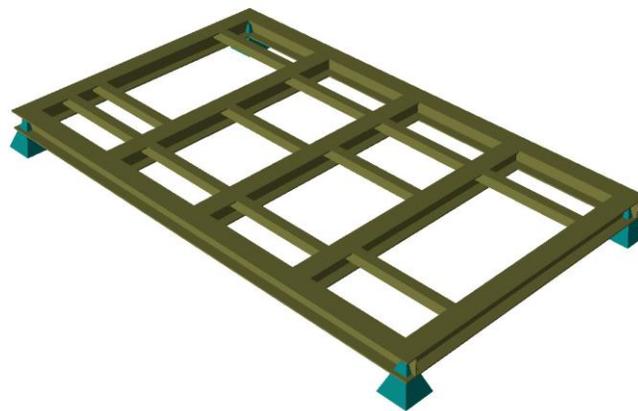


Figure 15. Isometric view of the skid

3.5 LIST OF WEIGHTS

Table 11. List of weights of the skid

Discipline:		Structural			
Name	Weight (kg)	X _G (mm)	Y _G (mm)	Z _G (mm)	
Base frame	1652.4	2476.9	1492.0	7.1	
Pipe supports	563.0	2487.0	1492.0	894.0	
Gratings, railings	80.0	730.0	1920.0	2615.0	
Total	2295.4	2418.5	1506.9	315.5	
Discipline:		Mechanical			
Ejector A	105.0	1897.0	315.0	1714.0	
Ejector B	51.0	2196.0	557.0	1362.0	
Ejector C	187.0	2264.0	2543.0	1533.0	
Ejector D	110.0	2808.0	2080.0	1503.0	
Silencer	550.0	2409.0	2600.0	846.0	
Total	1003.0	2361.3	2189.3	1163.2	
Discipline:		Piping			
Piping (dry)	3804.0	2540.0	1718.0	1283.0	
Piping insulation	320.0	2400.0	1600.0	1200.0	
Pipe clamps	228.0	2447.0	1763.0	977.0	
Total	4352.0	2524.8	1711.7	1260.9	
Discipline:		Instrumentation			
Instrument lockers	40.0	850.0	1030.0	1650.0	
Tubing	50.0	1200.0	1450.0	800.0	
Total	90.0	1044.4	1263.3	1177.8	
Discipline:		Electrical			
Junction boxes	32.0	900.0	2865.0	1025.0	
Cables & trays	30.0	1100.0	1450.0	1350.0	
Total	62.0	996.8	2180.3	1182.3	
Total summary	7802.4	2443.3	1711.4	968.6	

CHAPTER 4

LOAD CALCULATION

4.1 LOADS IN CODES

4.1.1 Introduction

In general, the codes used for this master thesis agree about the classification of loads applied on a structure. These loads are separated in three types of actions: permanent, variable and environmental actions.

Permanent actions are actions that will not vary in magnitude, position or direction during the time period considered. Examples are:

- a) weight of the structure
- b) weight of permanent ballast and equipment, including mooring and risers
- c) external hydrostatic pressure up to the mean water level

Variable actions are those which are originated from normal operation of the structure and vary in position, magnitude and direction during the period considered. They include those from:

- a) people
- b) helicopters
- c) lifeboats

- d) cranes
- e) tank pressures
- f) variable ballast
- g) both impact, fendering and mooring
- h) etc

Environmental actions are those which are originated by the environment and are determined by theoretical predictions. When those predictions are subjected to significant uncertainties, theoretical calculations shall be supported by model tests or observations of existing structures or by a combination of such tests and observations. The different actions that might interact with a structure are:

- a) hydrodynamic actions
- b) wind
- c) snow
- d) ice
- e) earthquakes

4.1.2 Permanent actions

Weights and COG of the different concepts of the weight list are shown in the Table 12.

Table 12. Weight and centers of gravity ¹³

Name	Weight (kg)	X _G (mm)	Y _G (mm)	Z _G (mm)
Structure	2295.4	2418.5	1506.9	315.5
Mechanics	1003.0	2361.3	2189.3	1163.2
Piping	4352.0	2524.8	1711.7	1260.9
Instrumentation	90.0	1044.4	1263.3	1177.8
Electrical	62.0	996.8	2180.3	1182.3

¹³ Taken from DNV internal documents

4.1.3 Variable actions

There are two loads in the skid that can be interpreted as variable actions.

1. Based on DNV internal documents referring to this skid, variable load of 410 kg has been calculated. The weight used in the calculation comes from fulfilment of piping by water as conservative approach.
2. The second one is the load on the deck areas.

Table 13. Variable actions in deck areas¹⁴

Area	Local design	
	Distribution action, p kN/m ²	Point action, P kN
Storage areas	q	1.5q
Laydown areas	q	1.5q
Lifeboat platforms	9.0	9.0
Area between equipment	5.0	5.0
Walkways, staircases and platforms	4.0	4.0
Walkways and staircases for inspection and repair only	3.0	3.0
Roofs, accessible for inspection and repair only	1.0	2.0

As the dimensions of the main frame are:

$$L = 5 \text{ m}, \quad B = 3 \text{ m:}$$

L = Length of the skid,

B = beam of the skid,

¹⁴ N-003 Actions and actions effects, Table 1, page 8.

$$P = \frac{F}{A} \quad (1)$$

P = Pressure applied over the surface,
 F = force acting over the surface,
 A = area of the surface.

$$\begin{aligned}
 F &= p \cdot A = \\
 F &= 5 \cdot (5 \cdot 3); \\
 F &= 75 \text{ kN} = 7645 \text{ kg}
 \end{aligned} \quad (2)$$

4.1.4 Environmental actions: wind load

4.1.4.1 API

The wind drag force on an object should be calculated as:

$$F = \frac{1}{2} \cdot \rho \cdot C_s \cdot A \cdot U_m^2 \cdot \alpha \quad (3)$$

F = wind force,
 ρ = mass density of air, (1.224 kg/m³ for standard temperature and pressure),
 C_s = shape coefficient,
 A = area normal to the direction of the force,
 U_m = wind speed,
 α = angle between the direction of the wind and the axis of the exposed surface.

The total exposed area of the skid with all the equipment placed on it is:

$$A = L \cdot B \cdot 0.8 \quad (4)$$

Plane XZ (North-South):

$$A = L \cdot B \cdot 0.8 = 5 \cdot 0.2 \cdot 0.8 = 8 \text{ m}^2 \quad (5)$$

Plane YZ (West-East):

$$A = L \cdot B \cdot 0.8 = 3 \cdot 0.2 \cdot 0.8 = 4.8 \text{ m}^2 \quad (6)$$

A coefficient of 0.8 was assumed to take into account the free spaces in the section. Wind force is shown in Table 4.3. Wind force was taken from Table 3.4.

Table 14. Wind force vs. wind direction

Wind direction	U_m (m/s)	Force (N)
N	29.4	4200
NE	30.0	5000
E	31.9	3000
SE	28.7	4600
S	31.3	4800
SW	31.5	5500
W	34.4	3500
NW	33.3	6100

4.1.4.2 Eurocode

Wind forces for the whole structure or a structural component should be determined by calculating forces using force coefficients.

$$F = c_s c_d \cdot c_f \cdot q_p(z_e) \cdot A_{ref} \quad (7)$$

- $c_s c_d$ = structural factor (1),
- c_f = force coefficient of the structure or structural element (2),
- $q_p(z_e)$ = peak velocity pressure at reference height z_e (3),
- A_{ref} = reference area of the structure or structural element (4),

(1) For buildings with a height less than 15 m, the value of $c_s c_d$ can be taken as 1. We can assume that the skid with the equipment over it can be treated as a building.

(2) Force coefficient c_f

$$c_f = c_{f,0} \cdot \psi_r \cdot \psi_\lambda \quad (8)$$

$c_{f,0}$ = force coefficient of rectangular sections with sharp corners and without free-end flow as given in Figure 17,

ψ_r = reduction factor for square sections with rounded corners (2.2),

ψ_λ = end-effect factor for elements with free-end flow (2.3),

(2.1) Force coefficient $c_{f,0}$

$$c_{f,0} = f\left(\frac{d}{b}\right) \quad (9)$$

d = length of the side parallel to wind direction,

b = length of the side perpendicular to wind direction.

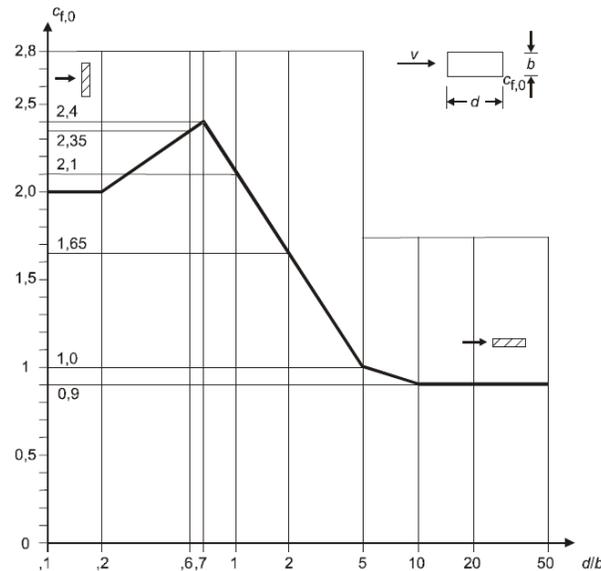


Figure 16. Force coefficients $c_{f,0}$ of rectangular sections with sharp corners ¹⁵

¹⁵ Taken from EN 1991-1-4, figure 7.23

For N-S winds:

$$\frac{d}{b} = \frac{3}{5}; c_{f,0} = 2.35$$

For W-E winds:

$$\frac{d}{b} = \frac{5}{3}; c_{f,0} = 1.8$$

For NE, SE, SW and NW winds

$$c_{f,0} = \frac{c_{f,0,N-S} + c_{f,0,W-E}}{2} = 2.075$$

(2.2) Reduction factor ψ_r

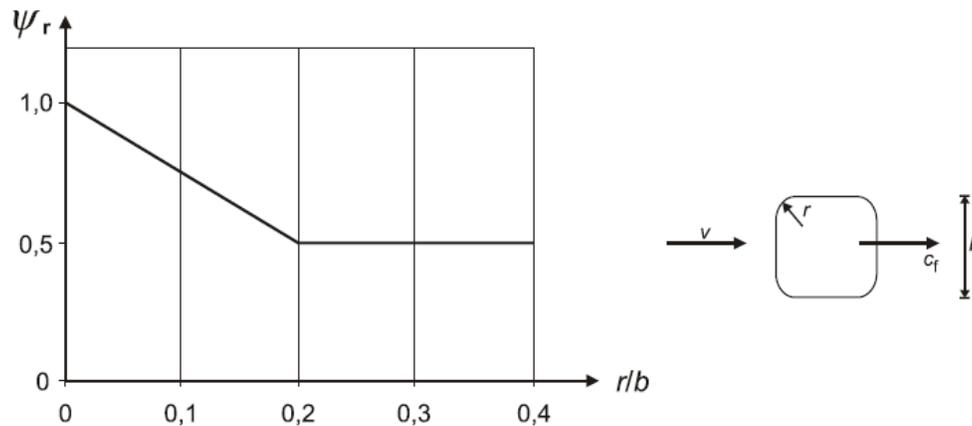


Figure 17. Reduction factor ψ_r for a square cross-section with rounded corners ¹⁶

r = radius of the corner,

b = length of the side perpendicular to wind direction.

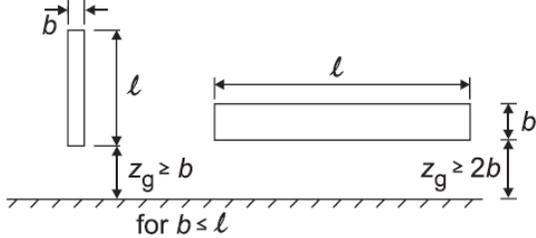
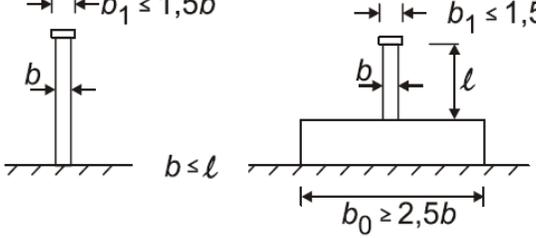
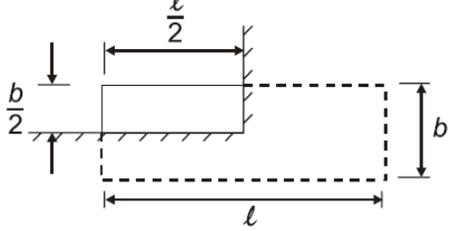
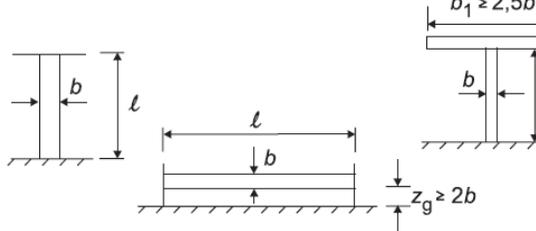
As the skid with equipment is being considered as a rectangular prism, $r=0$

$$\psi_r = 1$$

(2.3) End-effect factor ψ_λ

¹⁶ Taken from EN 1991-1-4, figure 7.24

Table 15. Recommended values of for cylinders, polygonal sections, rectangular sections, sharp edged structural sections and lattice structures¹⁷

No.	Position of the structure, wind normal to the plane of the page	Effective slenderness λ
1		<p>For polygonal, rectangular and sharp edged sections and lattice structures: for $l \geq 50$ m, $\lambda = 1.4, l/b$ or $\lambda = 70$, whichever is smaller for $l < 15$ m, $\lambda = 2, l/b$ or $\lambda = 70$, whichever is smaller</p>
2		<p>for circular cylinders: for $l \geq 50$ m, $\lambda = 0.7, l/b$ or $\lambda = 70$, whichever is smaller for $l < 15$ m, $\lambda = l/b$ or $\lambda = 70$, whichever is smaller</p>
3		<p>For intermediate values of l, linear interpolation should be used</p>
4		<p>for $l \geq 50$ m, $\lambda = 0.7 l/b$ or $\lambda = 70$, whichever is larger for $l < 15$ m, $\lambda = l/b$ or $\lambda = 70$, whichever is larger</p>

For N-S winds:

$$\lambda = 2 \frac{l}{b} = 2 \frac{5}{2}; \lambda = 5 \tag{10}$$

¹⁷ Taken from NS-EN 1991-1-4, table 7.16, pag. 80.

For W-E winds:

$$\lambda = 2 \frac{l}{b} = 2 \frac{3}{2}; \quad \lambda = 3 \quad (11)$$

For NE, SE, SW and NW winds

$$\lambda = \frac{\lambda_{N-S} + \lambda_{W-E}}{2} = 4 \quad (12)$$

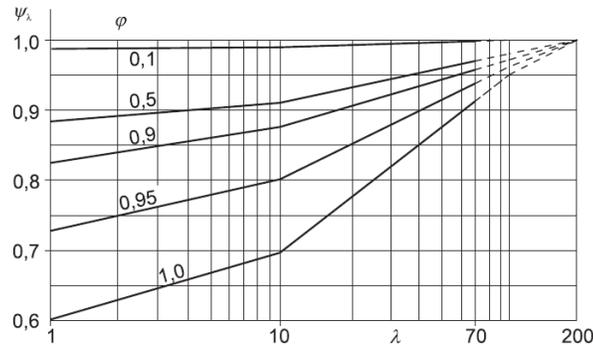


Figure 18. Indicative values of the end-effect factor $\psi\lambda$ as a function of solidity ratio φ vs slenderness¹⁸

Solidity ratio φ still has to be calculated:

$$\varphi = \frac{A}{A_c} \quad (13)$$

A = sum of the projected areas of the members

A_c = overall envelope area

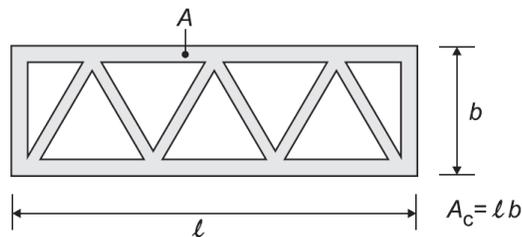


Figure 19. Definition of solidity ratio φ ¹⁹ (from EN 1991-1-4, figure 7.37)

¹⁸ Taken from EN 1991-1-4, figure 7.36

¹⁹ Taken from EN 1991-1-4, figure 7.37

$$\varphi = 1; \quad (14)$$

With φ and λ we can calculate the end-effect factor:

For N-S winds: $\psi_\lambda = 0.675$

For W-E winds: $\psi_\lambda = 0.675$

For NE, SE, SW and NW winds $\psi_\lambda = 0.67$

Finally, we can calculate (2)

$$c_f = c_{f,0} \cdot \psi_r \cdot \psi_\lambda \quad (15)$$

For N-S winds:

$$c_f = 2.35 \cdot 1 \cdot 0.675; c_f = 1.586 \quad (16)$$

For W-E winds:

$$c_f = 1.8 \cdot 1 \cdot 0.66; c_f = 1.188 \quad (17)$$

For NE, SE, SW and NW winds

$$c_f = 2.075 \cdot 1 \cdot 0.67; c_f = 1.39 \quad (18)$$

(3) Peak velocity pressure $q_p(z_e)$

$$q_p(z_e) = \frac{1}{2} [1 + l_v(z)] \cdot \rho \cdot v_m^2(z) \quad (19)$$

$l_v(z)$ = turbulence intensity at height z (3.1),

ρ = mass density of air, (1.224 kg/m³ for standard temperature and pressure),

v_m = mean wind velocity.

Turbulence intensity $l_v(z)$

$$l_v(z) = \frac{k_1}{c_0(z) \cdot \ln(z/z_0)} \quad (20)$$

- $l_v(z)$ = turbulence factor, recommended value is 1.0,
 $c_0(z)$ = orography factor, can be taken as 1.0,
 z = height of the structure,
 z_0 = 0.003 m for sea and coastal areas.

$$l_v(z) = \frac{1}{1 \cdot \ln(z/0.003)}; l_v(z) = 0.154 \quad (21)$$

$$q_p(z_e) = \frac{1}{2} [1 + 0.154] \cdot 1.224 \cdot v_m^2(z) \quad (22)$$

And with (1), (2) and (3) we can calculate:

$$F = c_s c_d \cdot c_f \cdot q_p(z_e) \cdot A_{ref} \quad (23)$$

Table 16. Wind forces from Eurocode

Wind direction	U_m (m/s)	c_f	$q_p(z_e)$	A_{ref} (m ²)	F (N)
N	29.4	1.6	610.5	8.0	7747
NE	30.0	1.4	635.6	9.3	8245
E	31.9	1.2	718.7	4.8	4098
SE	28.7	1.4	581.7	9.3	7546
S	31.3	1.6	691.9	8.0	8780
SW	31.5	1.4	700.8	9.3	9090
W	34.4	1.2	835.7	4.8	4766
NW	33.3	1.4	783.2	9.3	10158

4.1.4.3 *ISO*

The calculation procedure is the same as the one shown in API.

4.1.4.4 *Norsok*

The calculation procedure is the same as the one shown in API.

4.1.5 Environmental loads: Snow load

4.1.5.1 *API*

No formulation for snow loading.

4.1.5.2 *Eurocode*

According to EN 1993-1-3, calculation for snow load on roofs is:

$$S = \mu_i \cdot C_e \cdot C_t \cdot s_k \quad (24)$$

- μ_i = snow load coefficient ($\mu_i = 0.8$),
- C_e = exposure coefficient ($C_e = 1.0$),
- C_t = thermal coefficient ($C_t = 1.0$),
- s_k = characteristic value of snow load on the ground.

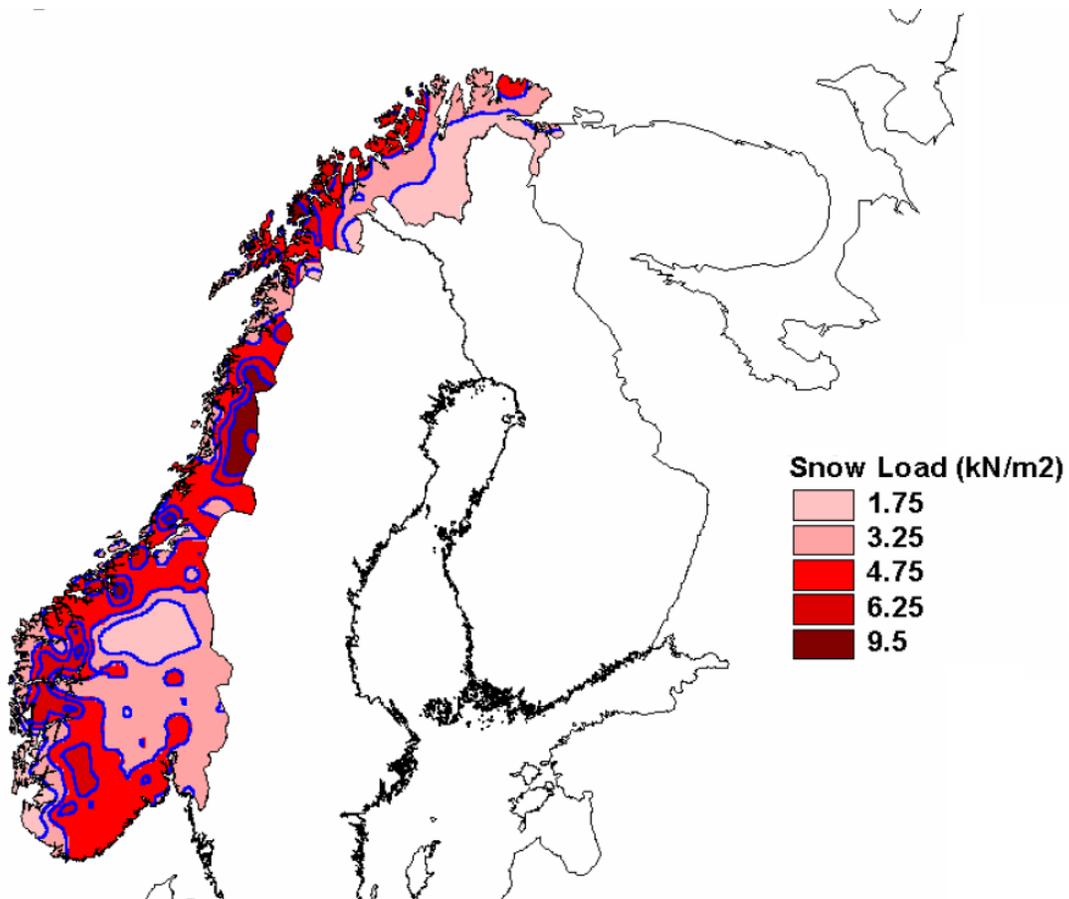


Figure 20. Snow load in the ground in Norway ²⁰

To calculate the snow load, the maximum value of s_k is taken.

$$s_k = 9.5 \text{ kN}$$

$$S = 0.8 \cdot 1 \cdot 1 \cdot 9.5; S = 7.6 \text{ kN} \quad (25)$$

4.1.5.3 ISO

According to ISO 4355, formulation for snow load is the same as the one used in Eurocode.

²⁰ Taken from EN 1991-1-3, figure C.10

4.1.5.4 *Norsok*

According to N-003, formulation for snow load is the same as the one used in Eurocode and ISO.

However, it is interesting to show the snow load for areas where accurate meteorological observations have not been performed. For those areas, characteristic snow action may be set equal to 0.5 kPa for the entire Norwegian continental shelf.

The shape factors given in NS 3491-3 may be used.

$$F = p \cdot A = 0.5 \cdot 5 \cdot 3; F = 7.5 \text{ kN} \quad (26)$$

4.1.6 Ice load

4.1.6.1 *API*

No ice load calculation available for API.

4.1.6.2 *Eurocode*

According to EN 1991-1-3: "... This Part does not give guidance on specialist aspects of snow loading, for example: ice loading". Therefore, no ice load calculation has been done for EUROCODE.

4.1.6.3 *ISO*

According to ISO 12494, there is no formulation for ice load in roofs.

4.1.6.4 *Norsok*

According to N-003, formulation for ice load is:

Table 17. Ice actions with annual probability of exceedance 10^{-2} ²¹

Height above sea level mm	ACTION CASE 1			ACTION CASE 2	
	Ice caused by sea-spray			Ice caused by rain/snow	
	56°N to 68°N mm	North of 68°N mm	Density kg/m ³	Thickness mm	Density kg/m ³
5 to 10	80			10	900
10 to 25	Linear reduction from 80 to 0	Linear reduction from 150 to 0	Linear reduction from 850 to 500	10	900
Above 25	0	0	-	10	900

As the height is more than 25 mm, the load due to ice caused by sea-spray will be zero.

For action case 2, ice load will be calculated as an horizontal load. However, the requirements say that the thickness is 40 mm.

$$P = V \cdot \rho = L \cdot B \cdot t \cdot \pi \cdot \rho = 5 \cdot 3 \cdot 0.8 \cdot 0.04 \cdot \pi \cdot 900;$$

$$P = 1357.3 \text{ kg} \quad (27)$$

4.2 LOAD CASES

4.2.1 Permanent & variable loads

For permanent and variable actions, loads have been applied as a prismatic equipment with the same length and width as the skid with specified centers of gravity mentioned in Table 11. Although there are five different weight groups, six load cases have been created. The first load case, LC00_Grav, just takes into account the weight of the modeled structure and the second one, LC01_Struct applies the weight of pipe supports, grating and railings.

²¹ N-003 Actions and actions effects, Table 2, page 26.

Table 18. Permanent & variable load cases (from Table 11)

Name	Load case	Weight (kg)
Modeled structure	LC00_Grav	1652
Non-modeled structure	LC01_Struc	643
Mechanical equipment	LC02_Equip	1003
Piping	LC03_Pip	4352
Instrumentation	LC04_Inst	90
Electrical equipment	LC05_Elec	62
Variable load	LC06_Var	410
Live load	LC07_Live	7645

4.2.2 Wind load

Eight different load cases have been created depending on the wind direction: north, north-east, east, south-east, south, south-west, west and north-west.

To calculate the load cases due to wind the skid with his equipment has been considered as a prism with plane walls in each side with a height of 2 meters. For diagonal winds (NE, SE, SW, NW), the incoming wind forces have been discomposed in their two projections (x and y axis). To apply the loads it is necessary to divide the load per the length of the beam because the software requires for a linear load. The result is the following:

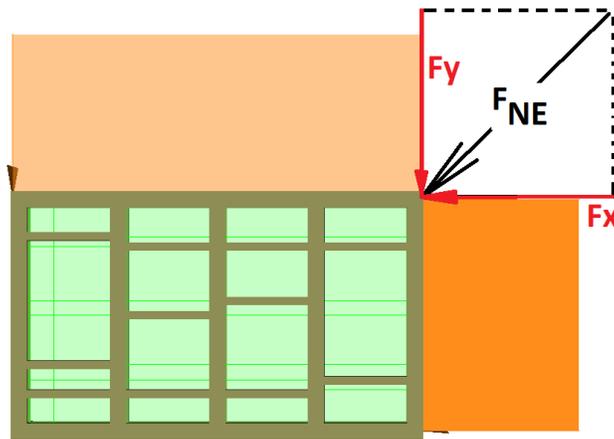


Figure 21. Decomposition of a diagonal wind

$$F_X(kN) = F \cdot \cos(45^\circ) \quad (28)$$

$$F_Y(kN) = F \cdot \cos(45^\circ) \quad (29)$$

$$F'_X(kN/m) = F_X/B \quad (30)$$

$$F'_Y(kN/m) = F_Y/L \quad (31)$$

Table 19. Wind force decomposition from API, ISO and Norsok

Load case	F (kN)	F_X, F_Y (kN)	F'_X (kN/m)	F'_Y (kN/m)
LC08_Wind_N	4.20	-	-	0.84
LC09_Wind_NE	5.00	3.54	1.26	0.71
LC10_Wind_E	3.00	-	1.07	-
LC11_Wind_SE	4.60	3.25	1.16	0.65
LC12_Wind_S	4.80	-	-	0.96
LC13_Wind_SW	5.50	3.89	1.39	0.78
LC14_Wind_W	3.50	-	1.25	-
LC15_Wind_NW	6.10	4.31	1.54	0.86

Table 20. Wind force decomposition from Eurocode

Load case	F (kN)	F_X, F_Y (kN)	F'_X (kN/m)	F'_Y (kN/m)
LC08_Wind_N	7.75	-	-	1.55
LC09_Wind_NE	8.25	5.83	2.08	1.17
LC10_Wind_E	4.10	-	1.46	-
LC11_Wind_SE	7.55	5.34	1.91	1.07
LC12_Wind_S	8.78	-	-	1.76
LC13_Wind_SW	9.09	6.43	2.30	1.29
LC14_Wind_W	4.77	-	1.70	-
LC15_Wind_NW	10.16	7.18	2.56	1.44

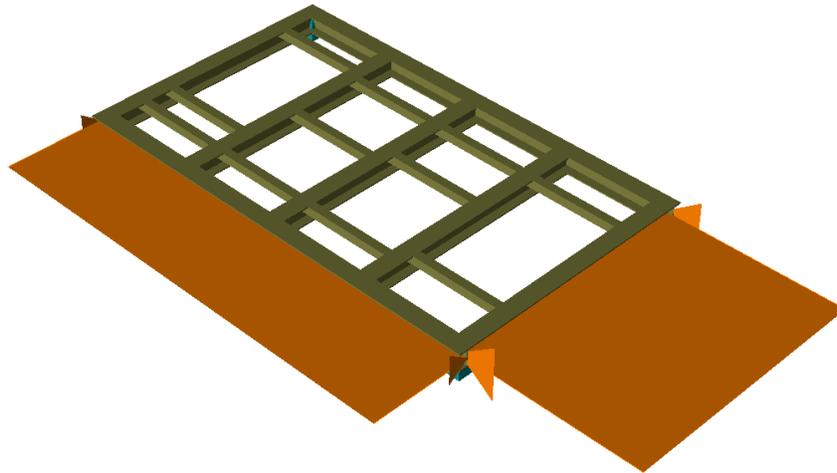


Figure 22. Load case LC11_Wind_SE

4.2.3 Ice load

Although ice and snow loads have been calculated, ice load has a greater value than snow load, so ice load has been considered as more crucial and snow loadcase has been neglected.

A prismatic equipment of 1357 kg has been applied on the structure through the load case LC16_Ice.

4.3 COMBINED LOAD CASES

4.3.1 Introduction to combined load cases

There are sixteen different load cases applied to the model. However, as some of them happen at the same time, some combined load cases have been established to simulate real conditions effecting on skid construction.

Those combined load cases are:

Table 21. Combined load cases

	Combined load cases								
Load cases	00	01_N	02_NE	03_E	04_SE	05_S	06_SW	07_W	08_NW
LC00_Grav	X	ULS00							
LC01_Struc	X								
LC02_Equip	X								
LC03_Pip	X								
LC04_Inst	X								
LC05_Elec	X								
LC06_Var	X								
LC07_Live	X								
LC08_Wind_N		X							
LC09_Wind_NE			X						
LC10_Wind_E				X					
LC11_Wind_SE					X				
LC12_Wind_S						X			
LC13_Wind_SW							X		
LC14_Wind_W								X	
LC15_Wind_NW									X
LC16_Ice	X								

Load case LC00_Grav is multiplied per 1.1, due to uncertain welding weight.

4.3.2 API

Table 22. Load combinations and load factors

	Operating wave	Operating ice	Extreme wave wind current	Desing ice frequent events	Design ice infrequent events
Gravity dead	1.3	1.3	1.1 0.9	1.1 0.9	1.1 0.9
Gravity live	1.5	1.5	1.1 0.8	1.1 0.8	1.1 0.8
Inertial load	1.5	1.5	1.7	1.7	1.7
Extreme wind	-	-	1.35	-	-
Design ice	-	-	-	1.35	-

Table 23. Load combinations and load factors for API

Load case name	ULS							
	N	NE	E	SE	S	SW	W	NW
LC00_Grav *	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
LC01_Struc	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
LC02_Equip	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
LC03_Pip	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
LC04_Inst	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
LC05_Elec	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
LC06_Var	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
LC07_Live	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
LC08_Wind_N	1.35	-	-	-	-	-	-	-
LC09_Wind_NE	-	1.35	-	-	-	-	-	-
LC10_Wind_E	-	-	1.35	-	-	-	-	-
LC11_Wind_SE	-	-	-	1.35	-	-	-	-
LC12_Wind_S	-	-	-	-	1.35	-	-	-
LC13_Wind_SW	-	-	-	-	-	1.35	-	-
LC14_Wind_W	-	-	-	-	-	-	1.35	-
LC15_Wind_NW	-	-	-	-	-	-	-	1.35
LC16_Ice	1.35	1.35	1.35	1.35	1.35	1.35	1.35	1.35

4.3.3 Eurocode

Table 24. Recommended values of Ψ_0 factor for buildings ²²

Action	Ψ_0
Imposed loads in buildings (see EN 1991-1-1)	
Category A: domestic, residential areas	0.7
Category B: office areas	0.7
Category C: congregation areas	0.7
Category D: shopping areas	0.7
Category E: storage areas	1.0
Category F: traffic area, vehicle weight ≤ 30 kN	0.7
Category G: traffic area, 30 kN \leq vehicle weight ≤ 160 kN	0.7
Category H: roofs	0
Snow loads on buildings (see EN 1991-1-3)	
Finland, Iceland, Norway, Sweden	0.7
Wind load on buildings (see EN 1991-1-4)	0.6

Table 25. Load combinations and load factors for Eurocode

Load case name	ULS							
	N	NE	E	SE	S	SW	W	NW
LC00_Grav *	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
LC01_Struc	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
LC02_Equip	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
LC03_Pip	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
LC04_Inst	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
LC05_Elec	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
LC06_Var	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
LC07_Live	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
LC08_Wind_N	0.6	-	-	-	-	-	-	-
LC09_Wind_NE	-	0.6	-	-	-	-	-	-
LC10_Wind_E	-	-	0.6	-	-	-	-	-
LC11_Wind_SE	-	-	-	0.6	-	-	-	-
LC12_Wind_S	-	-	-	-	0.6	-	-	-
LC13_Wind_SW	-	-	-	-	-	0.6	-	-
LC14_Wind_W	-	-	-	-	-	-	0.6	-
LC15_Wind_NW	-	-	-	-	-	-	-	0.6
LC16_Ice	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7

²² Taken from EN 1990, page 49, Table A1.1

4.3.4 ISO

Table 26. Partial action factors for in-place situations ²³

Design situation	Partial action factors					
	$\gamma_{f,G1}$	$\gamma_{f,G2}$	$\gamma_{f,Q1}$	$\gamma_{f,Q1}$	$\gamma_{f,Eo}$	$\gamma_{f,Ee}$
Permanent and variable actions only	1.3	1.3	1.5	1.5	0.0	0.0
Operating situation with corresponding wind, wave and/or current conditions	1.3	1.3	1.5	1.5	0.9 $\gamma_{f,E}$	0.0
Extreme conditions when the action effects due to permanent and variable actions are additive	1.1	1.1	1.1	0.0	0.0	$\gamma_{f,E}$
Extreme conditions when the action effects due to permanent and variable actions oppose	0.9	0.9	0.8	0.0	0.0	$\gamma_{f,E}$

Table 27. Partial action factors for in-place situations for ISO

Load case name	ULS							
	N	NE	E	SE	S	SW	W	NW
LC00_Grav *	1.43	1.43	1.43	1.43	1.43	1.43	1.43	1.43
LC01_Struc	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
LC02_Equip	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
LC03_Pip	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
LC04_Inst	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
LC05_Elec	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
LC06_Var	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
LC07_Live	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
LC08_Wind_N	0.9	-	-	-	-	-	-	-
LC09_Wind_NE	-	0.9	-	-	-	-	-	-
LC10_Wind_E	-	-	0.9	-	-	-	-	-
LC11_Wind_SE	-	-	-	0.9	-	-	-	-
LC12_Wind_S	-	-	-	-	0.9	-	-	-
LC13_Wind_SW	-	-	-	-	-	0.9	-	-
LC14_Wind_W	-	-	-	-	-	-	0.9	-
LC15_Wind_NW	-	-	-	-	-	-	-	0.9
LC16_Ice	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9

²³ Taken from ISO 19902, page 52, Table 8.10-1

4.3.5 Norsok

Table 28. Partial action factors for in-place situations ²⁴

Limit state	Action combinations	Permanent actions (G)	Variable actions (Q)	Environmental Actions (E)	Deformation actions (D)
ULS	a	1.3	1.3	0.7	1.0
ULS	b	1.0	1.0	1.3	1.0

a For permanent actions and/or variable actions, and action factor of 1.0 shall be used where this gives the most unfavourable action effect
b Actions with annual probability of exceedance = 10^{-4}

Table 29. Partial action factors for in-place situations for NORSOK

Load case name	ULS							
	N	NE	E	SE	S	SW	W	NW
LC00_Grav *	1.43/1.1	1.43/1.1	1.43/1.1	1.43/1.1	1.43/1.1	1.43/1.1	1.43/1.1	1.43/1.1
LC01_Struc	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0
LC02_Equip	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0
LC03_Pip	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0
LC04_Inst	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0
LC05_Elec	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0
LC06_Var	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0
LC07_Live	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0	1.3/1.0
LC08_Wind_N	0.7/1.3	-	-	-	-	-	-	-
LC09_Wind_NE	-	0.7/1.3	-	-	-	-	-	-
LC10_Wind_E	-	-	0.7/1.3	-	-	-	-	-
LC11_Wind_SE	-	-	-	0.7/1.3	-	-	-	-
LC12_Wind_S	-	-	-	-	0.7/1.3	-	-	-
LC13_Wind_SW	-	-	-	-	-	0.7/1.3	-	-
LC14_Wind_W	-	-	-	-	-	-	0.7/1.3	-
LC15_Wind_NW	-	-	-	-	-	-	-	0.7/1.3
LC16_Ice	0.7/1.3	0.7/1.3	0.7/1.3	0.7/1.3	0.7/1.3	0.7/1.3	0.7/1.3	0.7/1.3

²⁴ Taken from N-001, page 15, Table 1

CHAPTER 5

CAPACITY MODELS

5.1 INTRODUCTION

Capacity models are used to check the allowable stress levels on beams on onshore and offshore structures. The code checks available in GeniE are:

- Member check
- Hydrostatic collapse
- Punching shear
- Conical transition

Only member check has been taken into account in this master thesis. A member check of a frame structural member is performed to assess whether the member is subjected to acceptable stress levels. This check is performed through the use of the equations presented in the various code checking standards. These equations deliver results – the usage factor – according to capacity of the cross-sections and capacity taking into account the potential failure due to buckling phenomena. If this usage factor is less than 1.0 then the member is regarded to be “safe”. If the usage factor is greater than 1.0 then the member is “overloaded” and this is highlighted by the program. A member check is by default performed at five positions; at the two ends of the member, the midpoint and at the quart positions. In addition, additional code checking positions are determined based on variations in section profiles or materials (like in a segmented

member) or where the maximum moments (in-plane and out-of- plane) occur. This means that the code checking positions may vary from load case to load case.

Section types that may be code checked are:

- Tubular sections (PIPE)
- Symmetrical/un-symmetrical I or H sections (I)
- Channel sections
- Box sections (BOX)
- Massive bar sections
- Angle sections
- General sections

Table 30 shows the type of check that may be performed for each code of practice and the section type that may be processed.

Table 30. Code of practice for each member section

Code of practice	Member section		
	PIPE	I	BOX
API-WSD 2005	API	AISC	AISC
EUROCODE 3	EUR	EUR	EUR
ISO 19902-1997	ISO	EUR	EUR
NORSOK 2004	NOR	EUR	EUR

According to the structure of the skid, just two codes (AISC and EUR) would be checked with GeniE capacity models. As can be seen in Table 30, it would be much more interesting to have tubular (PIPE) sections in the skid. In addition, AISC codes were not available for DNV subscription.

A “new” skid have been modeled, just changing I and BOX beams into tubular ones (Table 8). This skid has been explained with detail in Chapter 3.

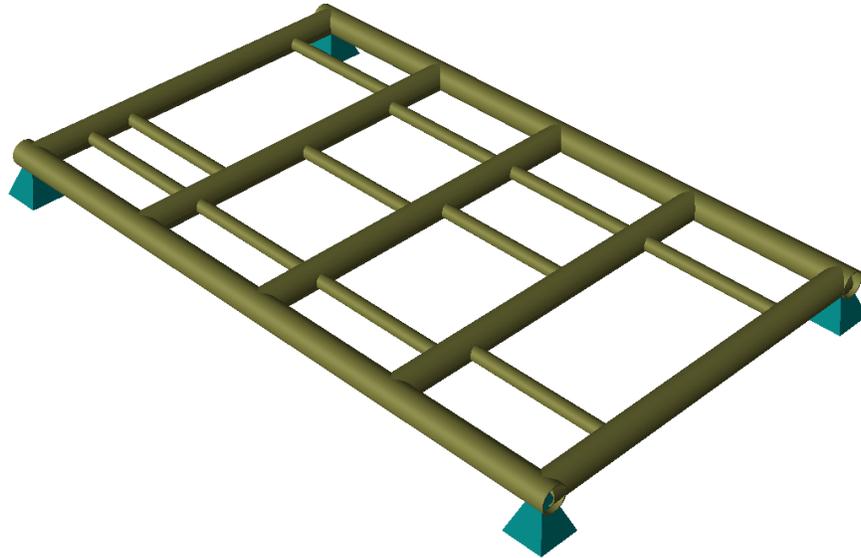


Figure 23. New skid for capacity models comparison, with tubular section beams

5.2 CODE CHECKING STANDARDS

The codes for offshore structures used in this master thesis for capacity models comparison are the following:

Table 31. Code checking standards

API-WSD 2005	American Petroleum Institute RP 2A-WSD (21 st edition December 2000, Errata and Supplement 2, October 2005)
Eurocode 3	Eurocode 3, EN 1993 Part 1-1: General rules and rules for buildings.
ISO 19902 2007	International Standard ISO 19902, Petroleum and natural gas industries — Fixed steel offshore structures (First edition 1 December 2007)
Norsok 2004	Norsok Standard N-004, Rev. 2, October 2004, Design of steel structures.

5.3 CODE CHECKING PROCEDURE

The procedure followed in this master thesis for members code check is explained below:

- a) Modeling of material, sections, structure, loads and boundary conditions (from 3.3.1 to 3.3.3).
- b) Define relevant load combinations (4.4.1).
- c) Run the finite element analysis.
- d) Create the appropriate capacity managers.
- e) Define the members and joints. When defining the members the global default buckling length of each member is assigned. For members, it has to be defined how to split continuous concept members into code checking members. In this case, split at beam ends option has been chosen. This option ensures that the capacity members are identical to the structural beam model.
- f) Create a code check run. The purpose of this task is to decide which code of practice to use, which load cases to include and to specify other global factors, for example buckling lengths or safety factors.
- g) Compute the code checking forces. These are computed at pre-defined positions (at ends, in middle and at quarter positions), at positions where material or section properties change (like in segmented beams) or where maximum in-plane and out-of-plane moments occur.
- h) Create a report. The results of the capacity managers created have been shown in tables. First of all, the different members have been separated in primary and secondary structure. Then, for each beam, the maximum usage factor is shown, specifying also in which position of it length and in which load case happen. Formulas used by GeniE to get the worst case (highest usage factor) are described in Appendix B.

5.4 CAPACITY MODELS COMPARISON

In order to compare the results for the codes with enough accuracy, the maximum number of possibilities have been taken into account.

There are four main aspects related to the codes that determine the results of the usages factor for each beam and for each code. Varying some of them, more results will be available and the conclusions will be more accurate.

These aspects are:

- 1) Loading calculation procedure: each code has their own formulas to calculate the different loads acting on the structure. For this aspect, two different options can be performed to compare the codes:
 - A) Apply the own loads for each code
 - B) Apply the same loads for the four codes, for example the maximum one

- 2) Combined load cases factors (CLC factors): each code has their own factors for combined load cases, as shown in 4.4. For this aspect, two different options can be done too to compare the codes:
 - A) Use the own CLC factors for each code
 - B) Use the same CLC factors for all of them, for example, one

- 3) Security factors: each code has their own security factors, for example for axial tensile and compressive strength, torsion, etc. For all the codes, the security factor has been taken as one.

- 4) Formulation for usage factors: each code has their own formulas to calculate the usage factor in each beam for each load case. There is no possible change in this point. Considering this, four hypothesis have been considered and for each hypothesis, four different analysis have been carried out (API, Eurocode, ISO and Norsok), sixteen in total.

Table 32. Analysis for comparison of capacity models

No. of hypothesis	No. of analysis	Load calculation (1)	CLC factors (2)	Code check
1	1	A	A	API
	2	A	A	Eurocode
	3	A	A	ISO
	4	A	A	NORSOK
2	5	A	B	API
	6	A	B	Eurocode
	7	A	B	ISO
	8	A	B	NORSOK
3	9	B	A	API
	10	B	A	Eurocode
	11	B	A	ISO
	12	B	A	NORSOK
4	13	B	B	API
	14	B	B	Eurocode
	15	B	B	ISO
	16	B	B	NORSOK

5.5 RESULTS

The results calculated with the combinations explained in the previous section are shown in tables in the following pages. The structure is divided into primary and secondary one, as was explained properly in chapter 3. For both structures it is possible to see five columns:

- Member: name of the beam
- Load case: loadcase where the usage factor is maximum
- Position: place where the usage factor is maximum, according to local longitudinal axis of each beam.

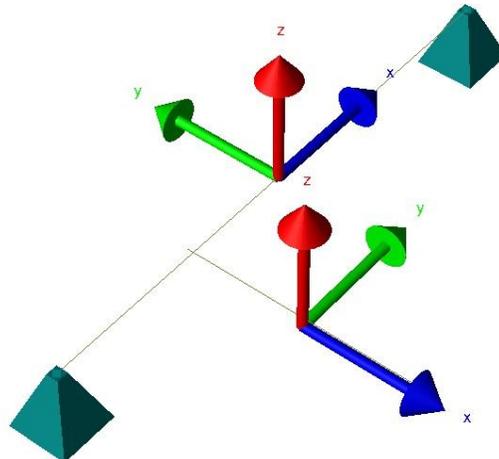


Figure 24. Local axis for beams

- Uf_{Tot} : usage factor, must be less than one.
- Formula: formula used for each code which gets the maximum usage factor. These formulas are shown in Appendix C.

HYPHOTESIS 1

Analysis 1: API

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS02_NE	0.50	0.62	uf3313
	Long_13	ULS06_SW	0.50	0.59	uf3313
	Transv_1	ULS06_SW	0.63	0.50	uf3313
	Transv_2	ULS01_N	0.50	0.14	uf3313
	Transv_3	ULS05_S	0.50	0.12	uf3313
	Transv_4	ULS05_S	0.44	0.14	uf3313
	Transv_5	ULS02_NE	0.48	0.13	uf3313
Secondary structure	Long_2	ULS06_SW	0.00	0.23	uf3313
	Long_3	ULS06_SW	0.83	0.30	uf3313
	Long_4	ULS04_SE	0.25	0.29	uf3313
	Long_5	ULS06_SW	0.00	0.23	uf3313
	Long_6	ULS08_NW	0.17	0.28	uf3313
	Long_7	ULS08_NW	0.81	0.28	uf3313
	Long_8	ULS08_NW	0.00	0.18	uf3313
	Long_9	ULS02_NE	0.00	0.22	uf3313
	Long_10	ULS08_NW	1.00	0.20	uf3313
	Long_11	ULS08_NW	0.67	0.29	uf3313
	Long_12	ULS02_NE	0.17	0.29	uf3313

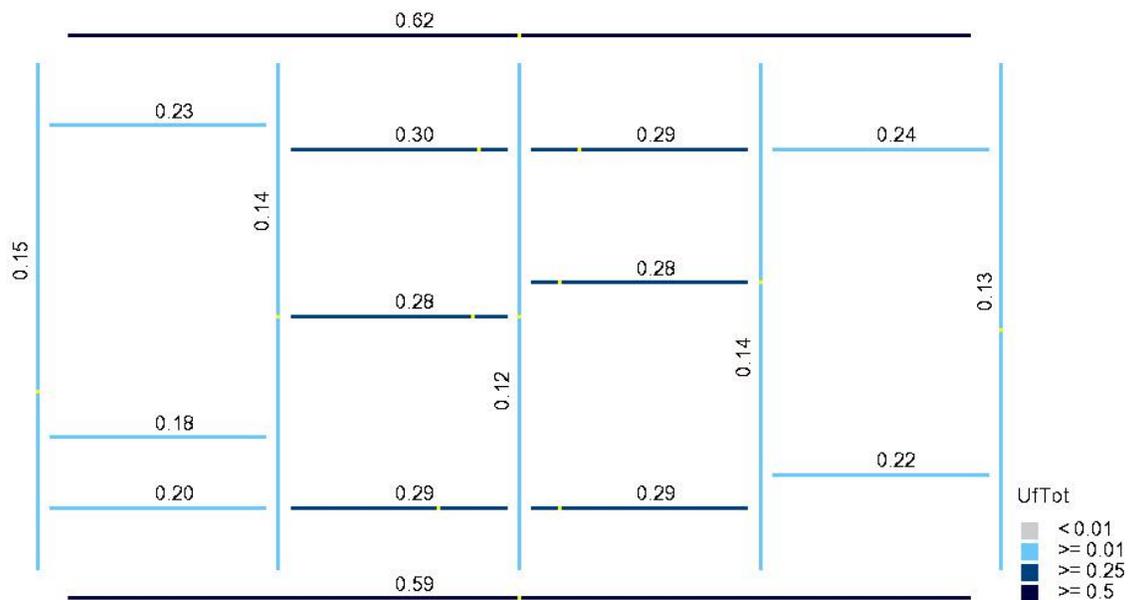


Figure 25. Usage factors for analysis 1

Analysis 2: Eurocode

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS08_NW	0.50	0.33	uf661
	Long_13	ULS05_S	0.26	0.32	uf661
	Transv_1	ULS08_NW	0.84	0.08	uf661
	Transv_2	ULS08_NW	0.00	0.08	uf661
	Transv_3	ULS08_NW	0.80	0.07	uf661
	Transv_4	ULS08_NW	0.00	0.08	uf661
	Transv_5	ULS05_S	0.80	0.07	uf661
Secondary structure	Long_2	ULS08_NW	0.00	0.08	uf62
	Long_3	ULS05_S	0.83	0.11	uf62
	Long_4	ULS06_SW	0.00	0.10	uf661
	Long_5	ULS05_S	0.00	0.09	uf62
	Long_6	ULS05_S	0.17	0.10	uf62
	Long_7	ULS08_NW	0.00	0.10	uf661
	Long_8	ULS06_SW	0.00	0.07	uf62
	Long_9	ULS05_S	0.00	0.08	uf62
	Long_10	ULS05_S	1.00	0.07	uf62
	Long_11	ULS08_NW	0.67	0.10	uf62
	Long_12	ULS08_NW	0.17	0.10	uf62

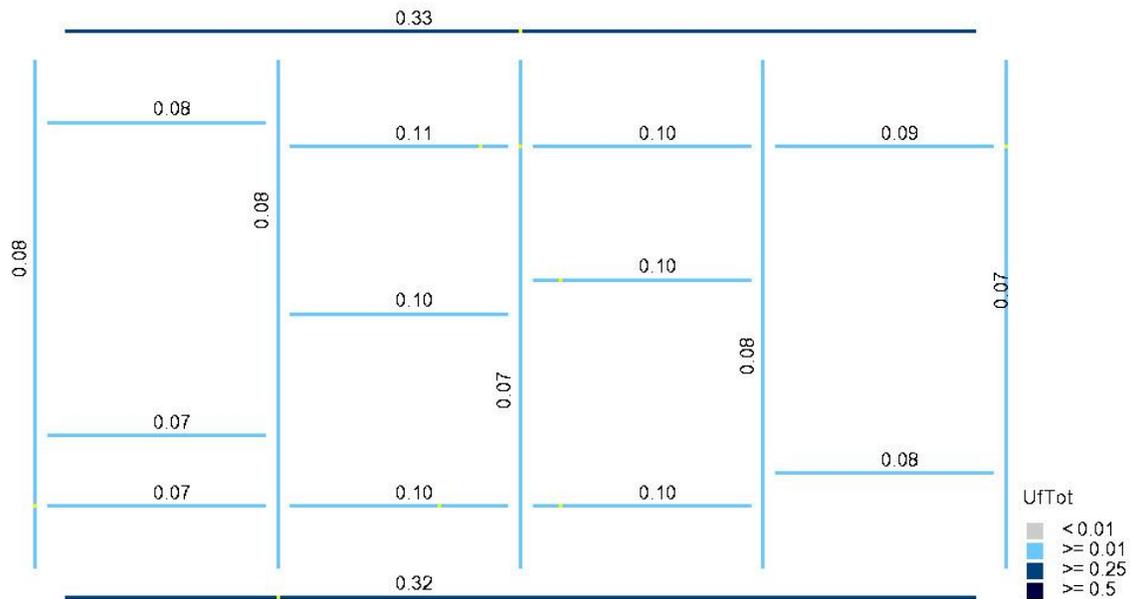


Figure 26. Usage factors for analysis 2

Analysis 3: ISO

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS06_SW	0.74	0.42	(13.3-7)
	Long_13	ULS08_NW	0.74	0.40	(13.3-7)
	Transv_1	ULS01_N	0.84	0.10	(13.3-7)
	Transv_2	ULS05_S	0.84	0.10	(13.3-7)
	Transv_3	ULS05_S	0.00	0,08	(13.3-7)
	Transv_4	ULS05_S	0.78	0.10	(13.3-7)
	Transv_5	ULS05_S	0.80	0.09	(13.3-7)
Secondary structure	Long_2	ULS06_SW	0.00	0.10	(13.3-7)
	Long_3	ULS06_SW	0.00	0.13	(13.3-7)
	Long_4	ULS04_SE	0.00	0.13	(13.3-7)
	Long_5	ULS04_SE	0.00	0.11	(13.3-7)
	Long_6	ULS08_NW	0.00	0.13	(13.3-7)
	Long_7	ULS08_NW	0.00	0.13	(13.3-7)
	Long_8	ULS08_NW	0.00	0.08	(13.3-7)
	Long_9	ULS02_NE	0.00	0.10	(13.3-7)
	Long_10	ULS08_NW	0.00	0.09	(13.3-7)
	Long_11	ULS08_NW	0.00	0.13	(13.3-7)
	Long_12	ULS02_NE	0.00	0.13	(13.3-7)

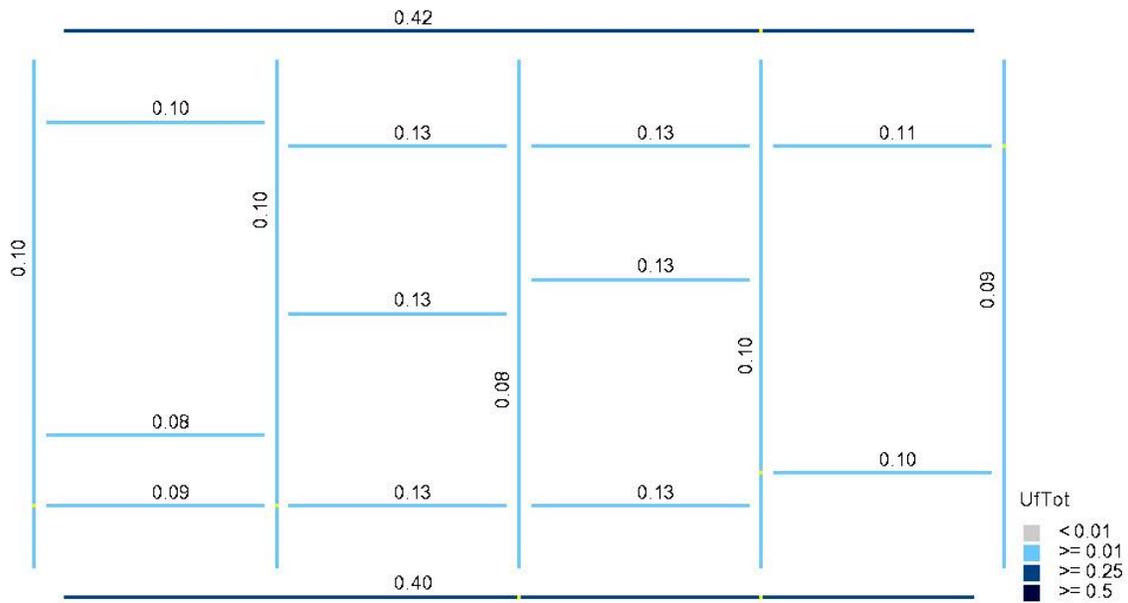


Figure 27. Usage factors for analysis 3

Analysis 4: Norsok

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS06_SW	0.74	0.39	uf6_27
	Long_13	ULS08_NW	0.74	0.37	uf6_27
	Transv_1	ULS01_N	0.84	0.09	uf6_27
	Transv_2	ULS05_S	0.84	0.09	uf6_27
	Transv_3	ULS05_S	0.00	0.08	uf6_27
	Transv_4	ULS05_S	0.78	0.09	uf6_27
	Transv_5	ULS05_S	0.80	0.08	uf6_27
Secondary structure	Long_2	ULS06_SW	0.00	0.09	uf6_27
	Long_3	ULS06_SW	0.00	0.12	uf6_27
	Long_4	ULS04_SE	0.00	0.12	uf6_27
	Long_5	ULS04_SE	0.00	0.10	uf6_27
	Long_6	ULS08_NW	0.00	0.12	uf6_27
	Long_7	ULS08_NW	0.00	0.12	uf6_27
	Long_8	ULS08_NW	0.00	0.07	uf6_27
	Long_9	ULS02_NE	0.00	0.09	uf6_27
	Long_10	ULS08_NW	0.00	0.08	uf6_27
	Long_11	ULS08_NW	0.00	0.12	uf6_27
	Long_12	ULS02_NE	0.00	0.12	uf6_27

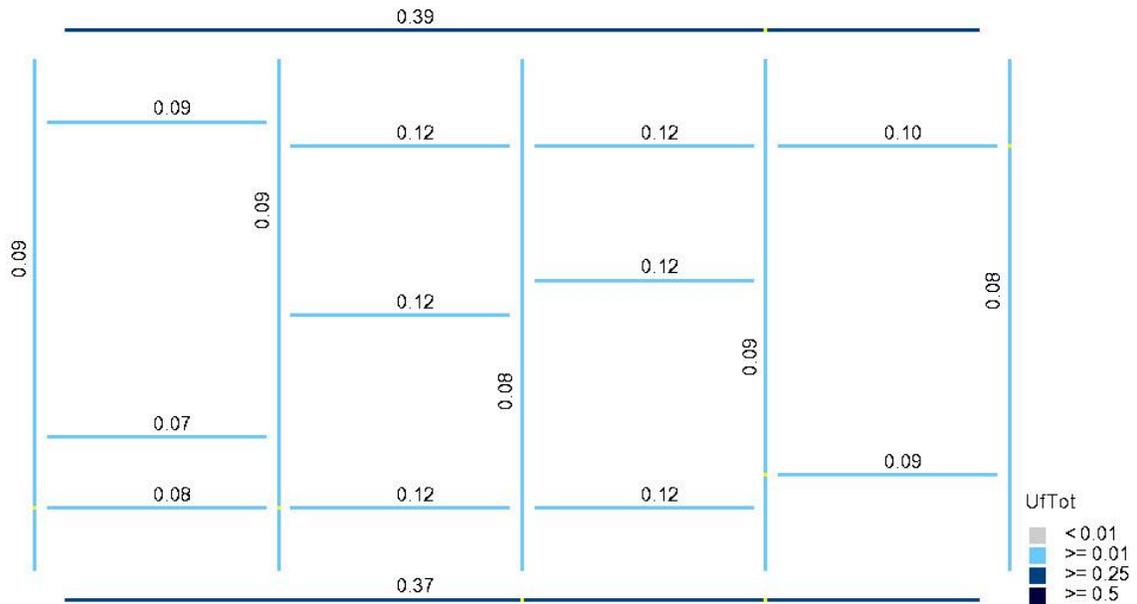


Figure 28. Usage factors for analysis 4

HYPHOTESIS 2

Analysis 5: API

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS02_NE	0.50	0,55	uf3313
	Long_13	ULS06_SW	0.50	0,52	uf3313
	Transv_1	ULS06_SW	0.63	0,13	uf3313
	Transv_2	ULS01_N	0.50	0,13	uf3313
	Transv_3	ULS05_S	0.50	0,11	uf3313
	Transv_4	ULS05_S	0.44	0,13	uf3313
	Transv_5	ULS02_NE	0.48	0,12	uf3313
Secondary structure	Long_2	ULS06_SW	0.00	0,2	uf3313
	Long_3	ULS06_SW	0.83	0,27	uf3313
	Long_4	ULS04_SE	0.25	0,26	uf3313
	Long_5	ULS04_SE	0.00	0,22	uf3313
	Long_6	ULS08_NW	0.17	0,25	uf3313
	Long_7	ULS08_NW	0.81	0,25	uf3313
	Long_8	ULS08_NW	0.00	0,16	uf3313
	Long_9	ULS02_NE	0.00	0,19	uf3313
	Long_10	ULS08_NW	1.00	0,17	uf3313
	Long_11	ULS08_NW	0.67	0,25	uf3313
	Long_12	ULS02_NE	0.17	0,26	uf3313

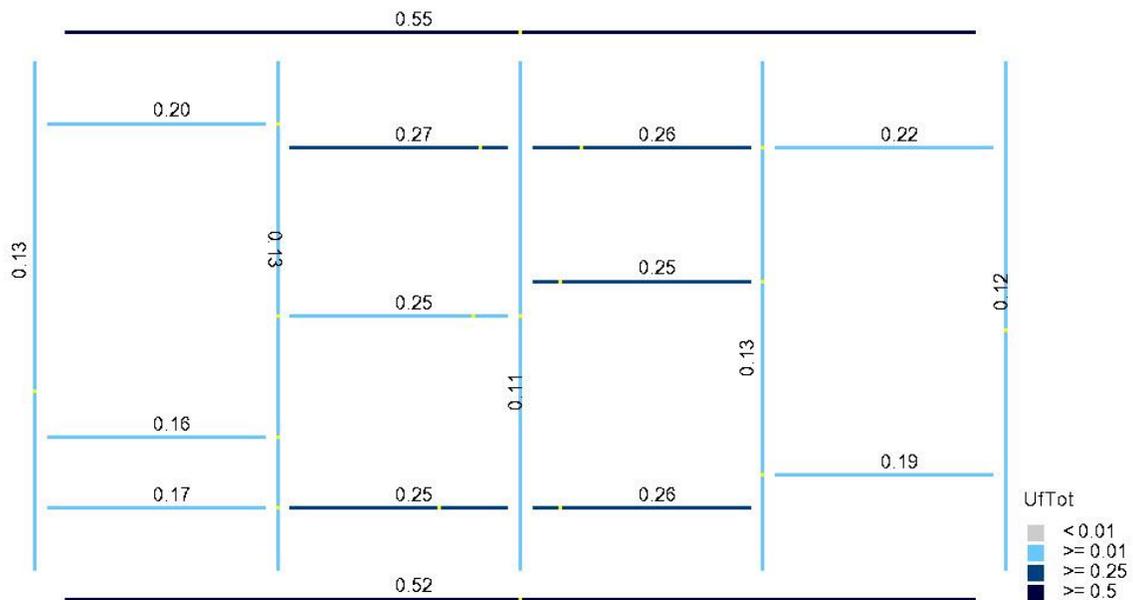


Figure 29. Usage factors for analysis 5

Analysis 6: Eurocode

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS08_NW	0.50	0.31	uf661
	Long_13	ULS05_S	0.26	0.30	uf661
	Transv_1	ULS08_NW	0.84	0.08	uf661
	Transv_2	ULS08_NW	0.00	0.08	uf661
	Transv_3	ULS08_NW	0.50	0.06	uf62
	Transv_4	ULS08_NW	0.00	0.08	uf661
	Transv_5	ULS05_S	0.80	0.07	uf661
Secondary structure	Long_2	ULS08_NW	0.00	0.08	uf62
	Long_3	ULS05_S	0.83	0.10	uf62
	Long_4	ULS06_SW	0.00	0.10	uf661
	Long_5	ULS05_S	0.00	0.08	uf62
	Long_6	ULS05_S	0.17	0.09	uf62
	Long_7	ULS08_NW	0.00	0.09	uf661
	Long_8	ULS06_SW	0.00	0.06	uf62
	Long_9	ULS05_S	0.00	0.07	uf62
	Long_10	ULS05_S	1.00	0.07	uf62
	Long_11	ULS08_NW	0.67	0.09	uf62
	Long_12	ULS08_NW	0.17	0.10	uf62

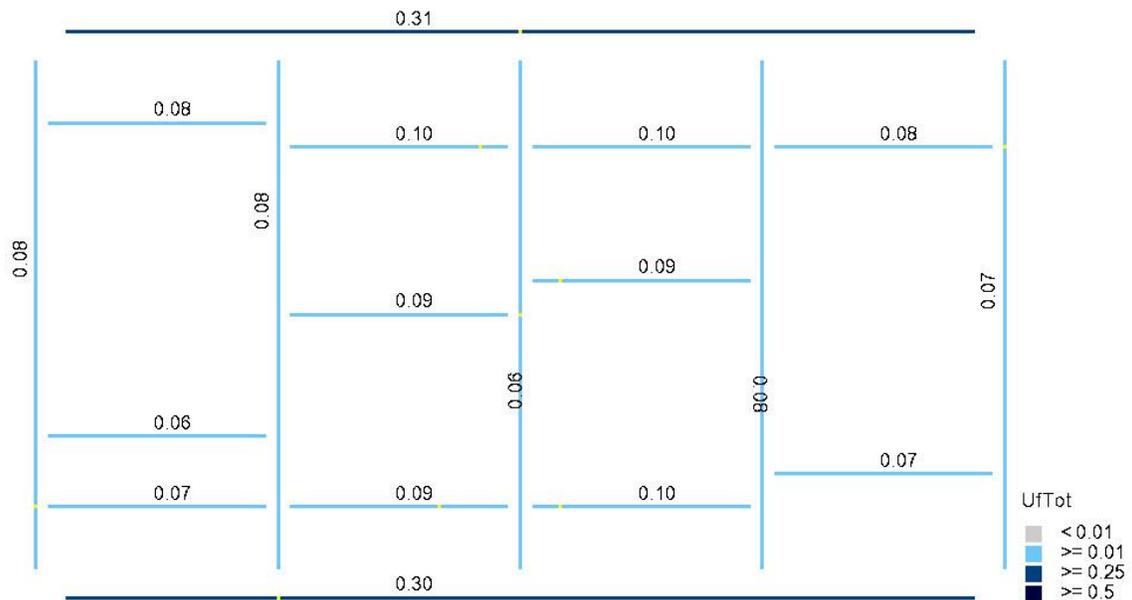


Figure 30. Usage factors for analysis 6

Analysis 7: ISO

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS06_SW	0,74	0,31	(13.3-7)
	Long_13	ULS08_NW	0,74	0,29	(13.3-7)
	Transv_1	ULS08_NW	0,84	0,07	(13.3-7)
	Transv_2	ULS05_S	0,84	0,07	(13.3-7)
	Transv_3	ULS05_S	0,00	0,06	(13.3-7)
	Transv_4	ULS05_S	0,78	0,07	(13.3-7)
	Transv_5	ULS05_S	0,8	0,07	(13.3-7)
Secondary structure	Long_2	ULS06_SW	0,00	0,07	(13.3-7)
	Long_3	ULS06_SW	0,00	0,1	(13.3-7)
	Long_4	ULS04_SE	0,00	0,1	(13.3-7)
	Long_5	ULS04_SE	0,00	0,08	(13.3-7)
	Long_6	ULS08_NW	0	0,09	(13.3-7)
	Long_7	ULS08_NW	0	0,09	(13.3-7)
	Long_8	ULS08_NW	0	0,06	(13.3-7)
	Long_9	ULS02_NE	0	0,07	(13.3-7)
	Long_10	ULS08_NW	0	0,06	(13.3-7)
	Long_11	ULS08_NW	0	0,09	(13.3-7)
	Long_12	ULS08_NW	0	0,09	(13.3-7)

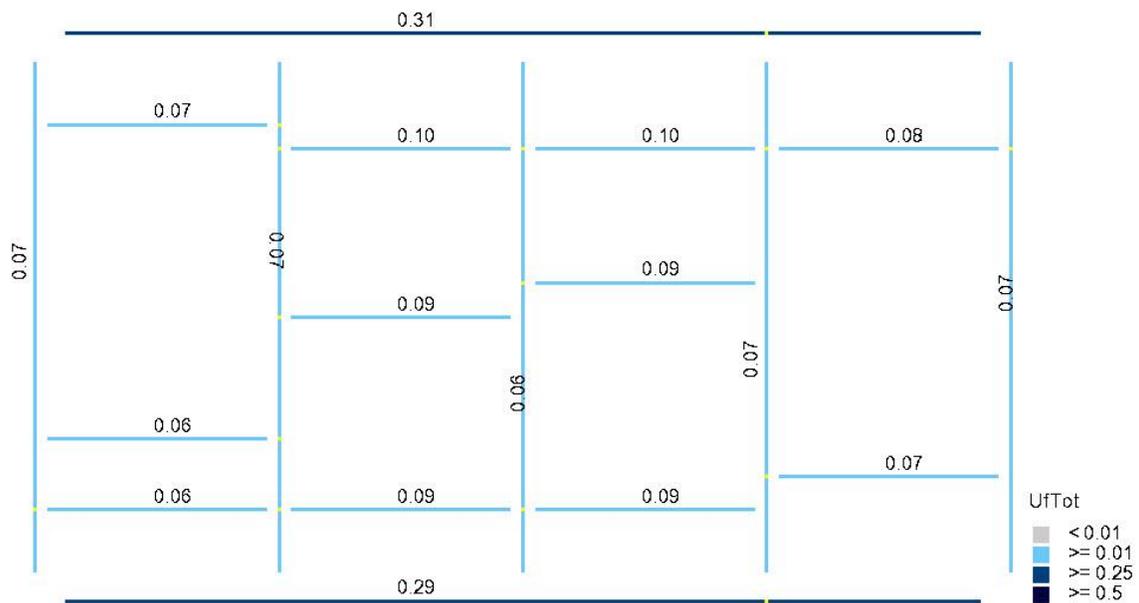


Figure 31. Usage factors for analysis 7

Analysis 8: Norsok

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS06_SW	0,74	0,31	uf6_27
	Long_13	ULS08_NW	0,74	0,29	uf6_27
	Transv_1	ULS08_NW	0,84	0,07	uf6_27
	Transv_2	ULS05_S	0,84	0,07	uf6_27
	Transv_3	ULS05_S	0	0,06	uf6_27
	Transv_4	ULS05_S	0,78	0,07	uf6_27
	Transv_5	ULS05_S	0,8	0,07	uf6_27
Secondary structure	Long_2	ULS06_SW	0	0,07	uf6_27
	Long_3	ULS06_SW	0	0,1	uf6_27
	Long_4	ULS04_SE	0	0,1	uf6_27
	Long_5	ULS04_SE	0	0,08	uf6_27
	Long_6	ULS08_NW	0	0,09	uf6_27
	Long_7	ULS08_NW	0	0,09	uf6_27
	Long_8	ULS08_NW	0	0,06	uf6_27
	Long_9	ULS02_NE	0	0,07	uf6_27
	Long_10	ULS08_NW	0	0,06	uf6_27
	Long_11	ULS08_NW	0	0,09	uf6_27
	Long_12	ULS08_NW	0	0,09	uf6_27

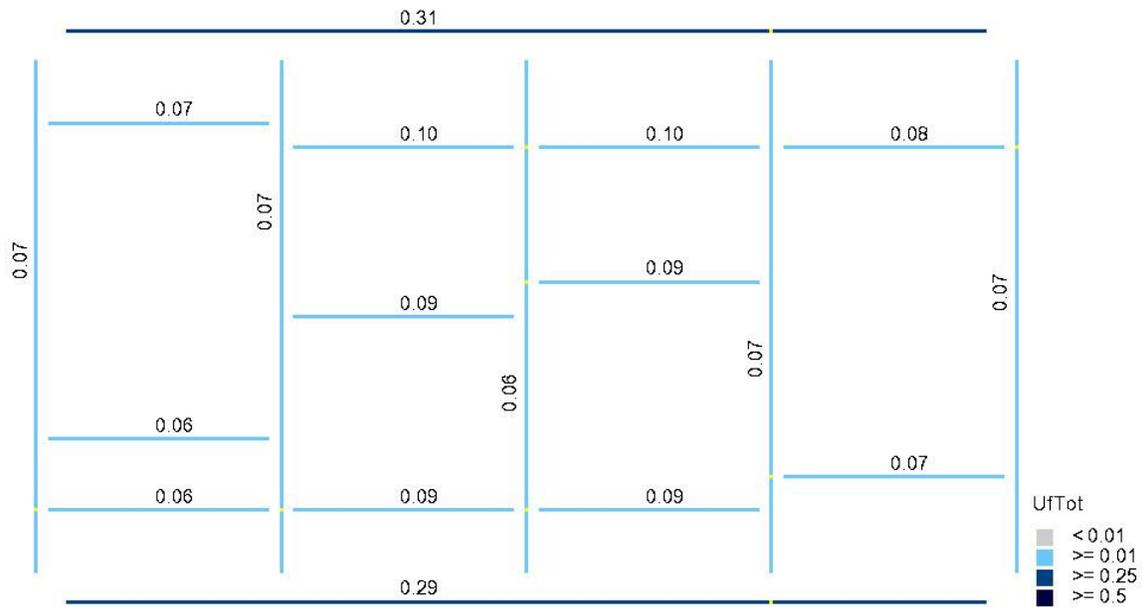


Figure 32. Usage factors for analysis 8

HYPHOTESIS 3**Analysis 9: API**

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS02_NE	0.50	0.62	uf3313
	Long_13	ULS06_SW	0.50	0.59	uf3313
	Transv_1	ULS06_SW	0.63	0.15	uf3313
	Transv_2	ULS01_N	0.50	0.14	uf3313
	Transv_3	ULS05_S	0.50	0.12	uf3313
	Transv_4	ULS05_S	0.44	0.14	uf3313
	Transv_5	ULS02_NE	0.48	0.13	uf3313
Secondary structure	Long_2	ULS06_SW	0.00	0.23	uf3313
	Long_3	ULS06_SW	0.83	0.30	uf3313
	Long_4	ULS04_SE	0.25	0.29	uf3313
	Long_5	ULS04_SE	0.00	0.25	uf3313
	Long_6	ULS08_NW	0.17	0.28	uf3313
	Long_7	ULS08_NW	0.81	0.28	uf3313
	Long_8	ULS08_NW	0.00	0.18	uf3313
	Long_9	ULS02_NE	0.00	0.22	uf3313
	Long_10	ULS08_NW	1.00	0.20	uf3313
	Long_11	ULS08_NW	0.67	0.29	uf3313
	Long_12	ULS08_NW	0.17	0.29	uf3313

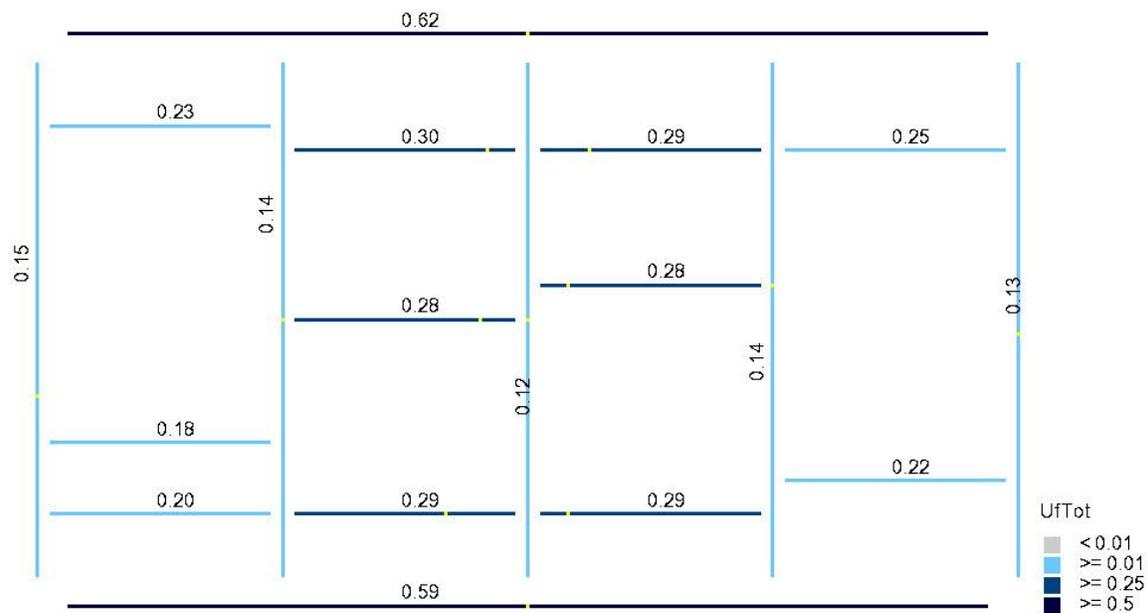


Figure 33. Usage factors for analysis 9

Analysis 10: Eurocode

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS08_NW	0.50	0.33	uf661
	Long_13	ULS05_S	0.26	0.32	uf661
	Transv_1	ULS08_NW	0.84	0.08	uf661
	Transv_2	ULS08_NW	0.00	0.08	uf661
	Transv_3	ULS08_NW	0.80	0.07	uf661
	Transv_4	ULS08_NW	0.00	0.08	uf661
Secondary structure	Long_2	ULS08_NW	0.00	0.08	uf62
	Long_3	ULS05_S	0.83	0.11	uf62
	Long_4	ULS06_SW	0.00	0.10	uf661
	Long_5	ULS05_S	0.00	0.09	uf62
	Long_6	ULS05_S	0.17	0.10	uf62
	Long_7	ULS08_NW	0.00	0.10	uf661
	Long_8	ULS06_SW	0.00	0.07	uf62
	Long_9	ULS05_S	0.00	0.08	uf62
	Long_10	ULS05_S	1.00	0.07	uf62
	Long_11	ULS08_NW	0.67	0.10	uf62
	Long_12	ULS08_NW	0.17	0.10	uf62

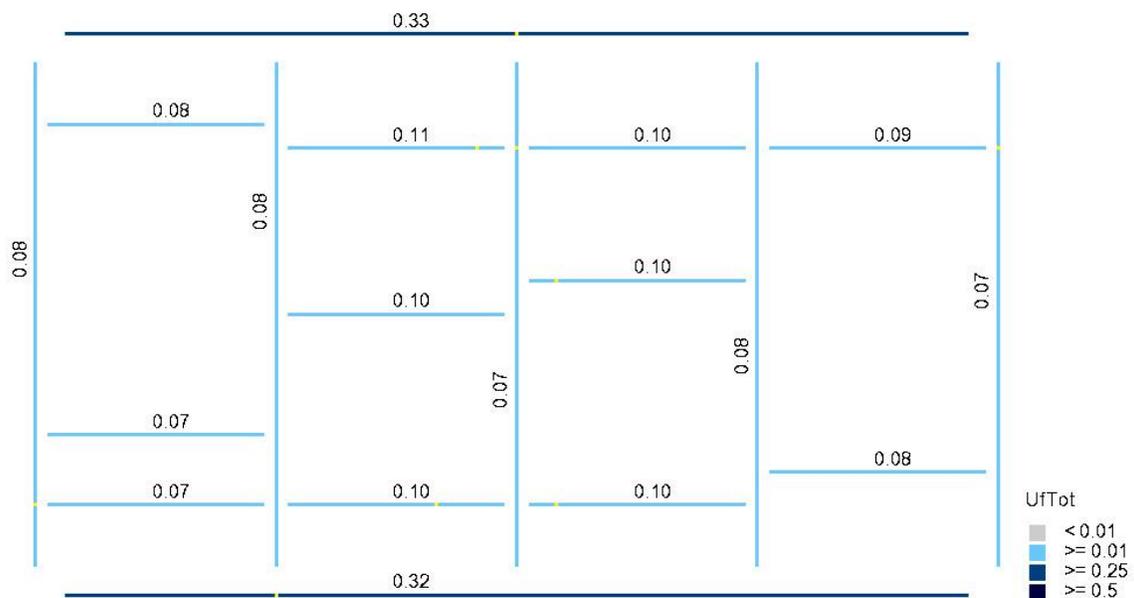


Figure 34. Usage factors for analysis 10

Analysis 11: ISO

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS06_SW	0.74	0.42	(13.3-7)
	Long_13	ULS08_NW	0.74	0.40	(13.3-7)
	Transv_1	ULS05_S	0.00	0.10	(13.3-7)
	Transv_2	ULS05_S	0.84	0.10	(13.3-7)
	Transv_3	ULS05_S	0.00	0.08	(13.3-7)
	Transv_4	ULS05_S	0.78	0.10	(13.3-7)
	Transv_5	ULS05_S	0.80	0.09	(13.3-7)
Secondary structure	Long_2	ULS06_SW	0.00	0.10	(13.3-7)
	Long_3	ULS06_SW	0.00	0.14	(13.3-7)
	Long_4	ULS04_SE	0.00	0.13	(13.3-7)
	Long_5	ULS04_SE	0.00	0.11	(13.3-7)
	Long_6	ULS08_NW	0.00	0.13	(13.3-7)
	Long_7	ULS08_NW	0.00	0.13	(13.3-7)
	Long_8	ULS08_NW	0.00	0.08	(13.3-7)
	Long_9	ULS02_NE	0.00	0.10	(13.3-7)
	Long_10	ULS08_NW	0.00	0.09	(13.3-7)
	Long_11	ULS08_NW	0.00	0.13	(13.3-7)
	Long_12	ULS08_NW	0.00	0.13	(13.3-7)

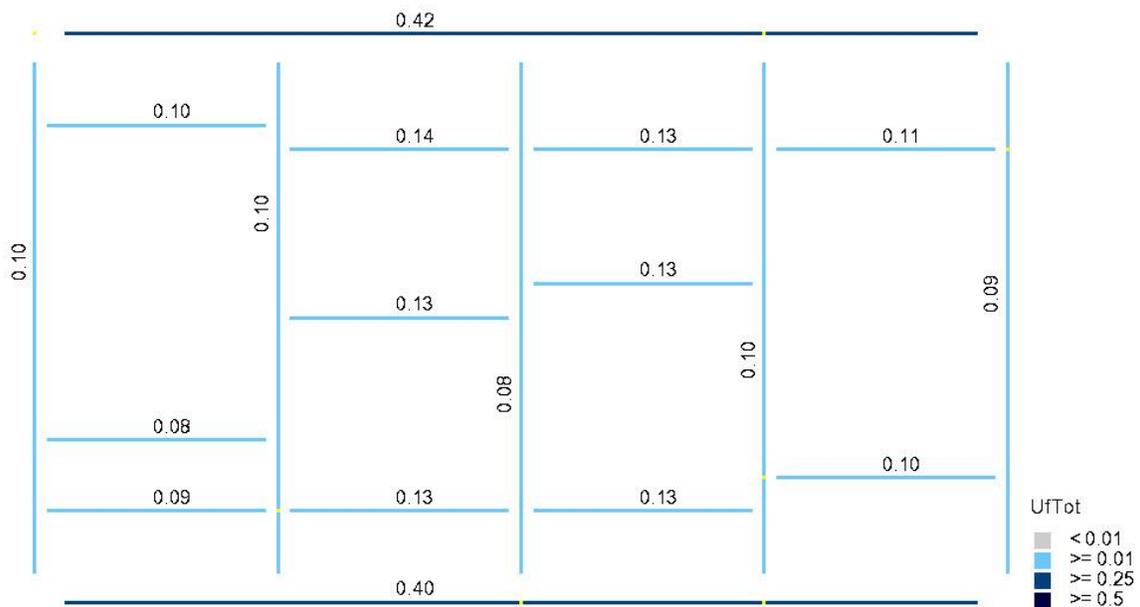


Figure 35. Usage factors for analysis 11

Analysis 12: Norsok

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS06_SW	0.74	0.39	uf6_27
	Long_13	ULS08_NW	0.74	0.37	uf6_27
	Transv_1	ULS01_N	0.84	0.09	uf6_27
	Transv_2	ULS05_S	0.84	0.09	uf6_27
	Transv_3	ULS05_S	0.00	0.08	uf6_27
	Transv_4	ULS05_S	0.78	0.09	uf6_27
Secondary structure	Long_2	ULS06_SW	0.00	0.09	uf6_27
	Long_3	ULS06_SW	0.00	0.12	uf6_27
	Long_4	ULS04_SE	0.00	0.12	uf6_27
	Long_5	ULS04_SE	0.00	0.10	uf6_27
	Long_6	ULS08_NW	0.00	0.12	uf6_27
	Long_7	ULS08_NW	0.00	0.12	uf6_27
	Long_8	ULS08_NW	0.00	0.07	uf6_27
	Long_9	ULS02_NE	0.00	0.09	uf6_27
	Long_10	ULS08_NW	0.00	0.08	uf6_27
	Long_11	ULS08_NW	0.00	0.12	uf6_27
	Long_12	ULS08_NW	0.00	0.12	uf6_27

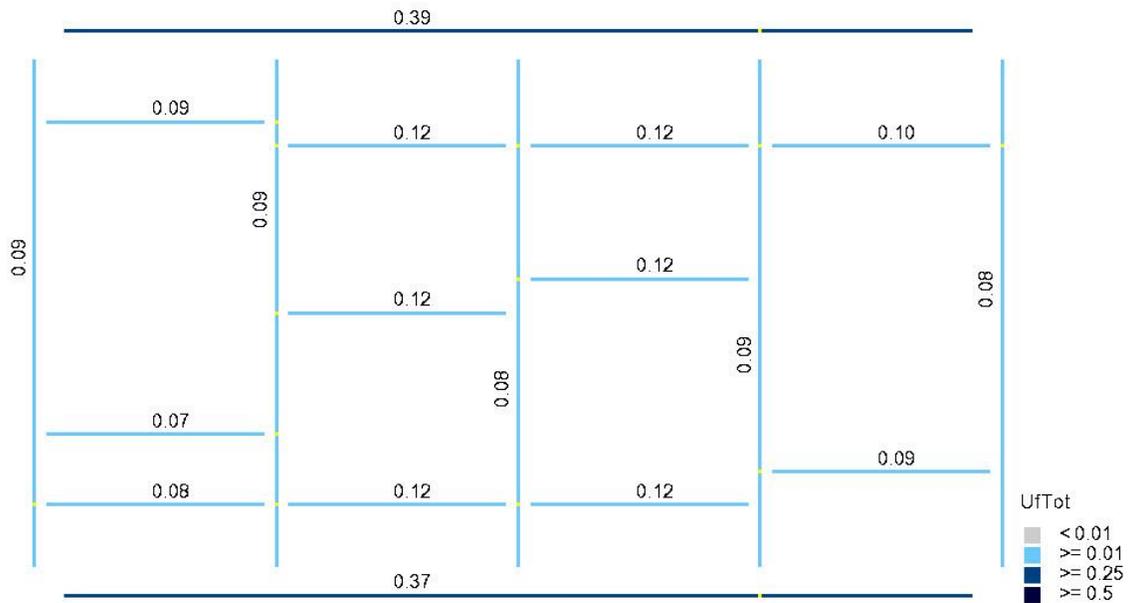


Figure 36. Usage factors for analysis 12

HYPHOTESIS 4

Analysis 13: API

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS02_NE	0.50	0.55	uf3313
	Long_13	ULS06_SW	0.50	0.52	uf3313
	Transv_1	ULS06_SW	0.63	0.13	uf3313
	Transv_2	ULS01_N	0.50	0.13	uf3313
	Transv_3	ULS05_S	0.50	0.11	uf3313
	Transv_4	ULS05_S	0.44	0.13	uf3313
Secondary structure	Transv_5	ULS02_NE	0.48	0.12	uf3313
	Long_2	ULS06_SW	0.00	0.20	uf3313
	Long_3	ULS06_SW	0.83	0.27	uf3313
	Long_4	ULS04_SE	0.25	0.26	uf3313
	Long_5	ULS04_SE	0.00	0.22	uf3313
	Long_6	ULS08_NW	0.17	0.25	uf3313
	Long_7	ULS08_NW	0.81	0.25	uf3313
	Long_8	ULS08_NW	0.00	0.16	uf3313
	Long_9	ULS02_NE	0.00	0.19	uf3313
	Long_10	ULS08_NW	1.00	0.17	uf3313
	Long_11	ULS08_NW	0.67	0.25	uf3313
	Long_12	ULS08_NW	0.17	0.26	uf3313

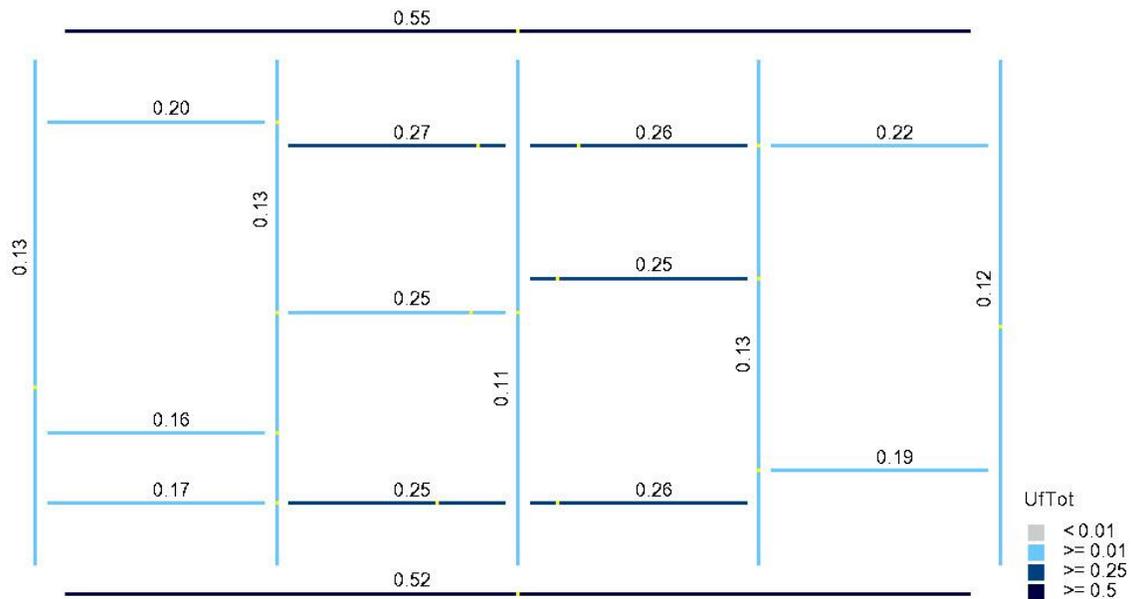


Figure 37. Usage factors for analysis 13

Analysis 14: Eurocode

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS08_NW	0.50	0.31	uf661
	Long_13	ULS05_S	0.26	0.30	uf661
	Transv_1	ULS08_NW	0.84	0.08	uf661
	Transv_2	ULS08_NW	0.00	0.08	uf661
	Transv_3	ULS08_NW	0.50	0.06	uf62
	Transv_4	ULS08_NW	0.00	0.08	uf661
	Transv_5	ULS05_S	0.80	0.07	uf661
Secondary structure	Long_2	ULS08_NW	0.00	0.08	uf62
	Long_3	ULS05_S	0.83	0.10	uf62
	Long_4	ULS06_SW	0.00	0.10	uf661
	Long_5	ULS05_S	0.00	0.08	uf62
	Long_6	ULS05_S	0.17	0.09	uf62
	Long_7	ULS08_NW	0.00	0.09	uf661
	Long_8	ULS06_SW	0.00	0.06	uf62
	Long_9	ULS05_S	0.00	0.07	uf62
	Long_10	ULS05_S	1.00	0.07	uf62
	Long_11	ULS08_NW	0.67	0.09	uf62
	Long_12	ULS08_NW	0.17	0.10	uf62

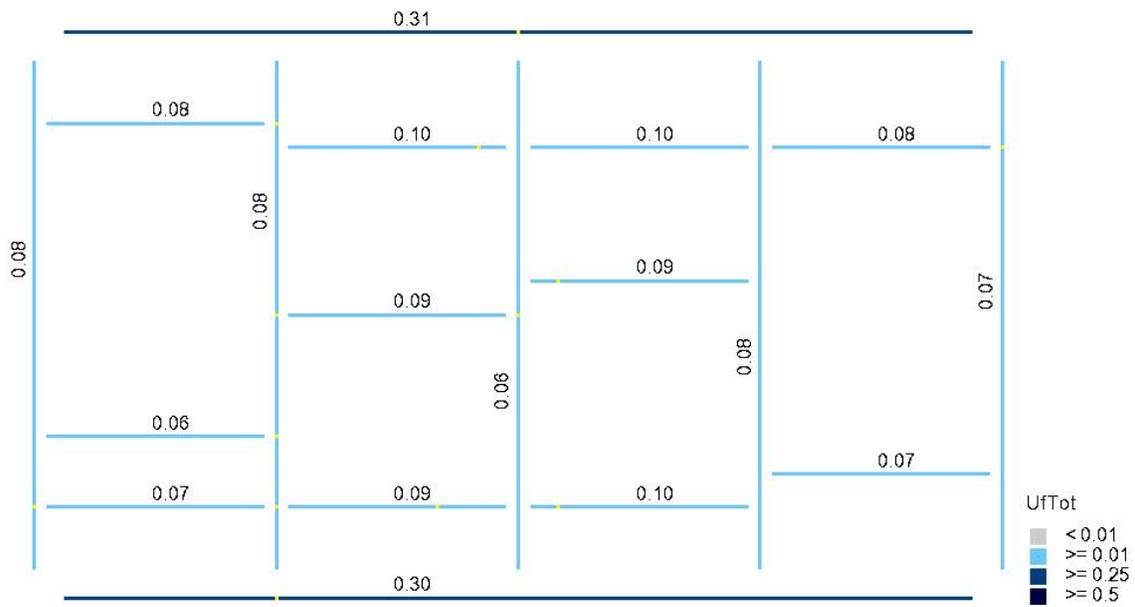


Figure 38. Usage factors for analysis 14

Analysis 15: ISO

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS06_SW	0.74	0.31	(13.3-7)
	Long_13	ULS08_NW	0.74	0.29	(13.3-7)
	Transv_1	ULS08_NW	0.84	0.07	(13.3-7)
	Transv_2	ULS05_S	0.84	0.07	(13.3-7)
	Transv_3	ULS05_S	0.00	0.06	(13.3-7)
	Transv_4	ULS05_S	0.78	0.07	(13.3-7)
	Transv_5	ULS05_S	0.80	0.07	(13.3-7)
Secondary structure	Long_2	ULS06_SW	0.00	0.07	(13.3-7)
	Long_3	ULS06_SW	0.00	0.10	(13.3-7)
	Long_4	ULS04_SE	0.00	0.10	(13.3-7)
	Long_5	ULS04_SE	0.00	0.08	(13.3-7)
	Long_6	ULS08_NW	0.00	0.09	(13.3-7)
	Long_7	ULS08_NW	0.00	0.09	(13.3-7)
	Long_8	ULS08_NW	0.00	0.06	(13.3-7)
	Long_9	ULS02_NE	0.00	0.07	(13.3-7)
	Long_10	ULS08_NW	0.00	0.06	(13.3-7)
	Long_11	ULS08_NW	0.00	0.09	(13.3-7)
	Long_12	ULS08_NW	0.00	0.10	(13.3-7)

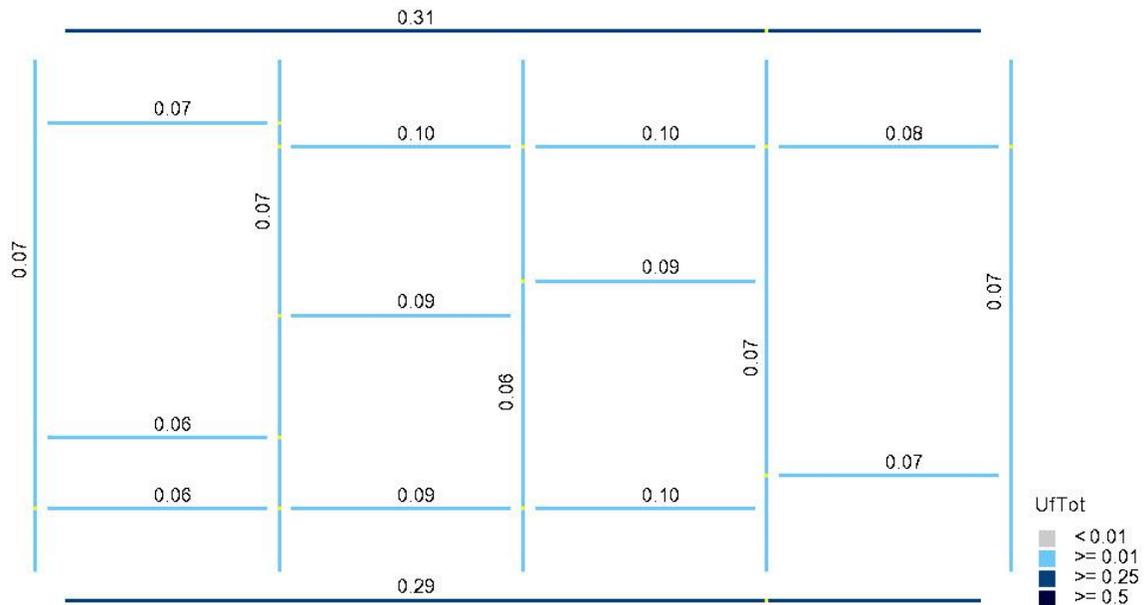


Figure 39. Usage factors for analysis 15

Analysis 16: Norsok

	Member	LoadCase	Position	UfTot	Formula
Primary structure	Long_1	ULS06_SW	0.74	0.31	uf6_27
	Long_13	ULS08_NW	0.74	0.29	uf6_27
	Transv_1	ULS08_NW	0.84	0.07	uf6_27
	Transv_2	ULS05_S	0.84	0.07	uf6_27
	Transv_3	ULS05_S	0.00	0.06	uf6_27
	Transv_4	ULS05_S	0.78	0.07	uf6_27
	Transv_5	ULS05_S	0.80	0.07	uf6_27
Secondary structure	Long_2	ULS06_SW	0.00	0.07	uf6_27
	Long_3	ULS06_SW	0.00	0.10	uf6_27
	Long_4	ULS04_SE	0.00	0.10	uf6_27
	Long_5	ULS04_SE	0.00	0.08	uf6_27
	Long_6	ULS08_NW	0.00	0.09	uf6_27
	Long_7	ULS08_NW	0.00	0.09	uf6_27
	Long_8	ULS08_NW	0.00	0.06	uf6_27
	Long_9	ULS02_NE	0.00	0.07	uf6_27
	Long_10	ULS08_NW	0.00	0.06	uf6_27
	Long_11	ULS08_NW	0.00	0.09	uf6_27
	Long_12	ULS08_NW	0.00	0.10	uf6_27

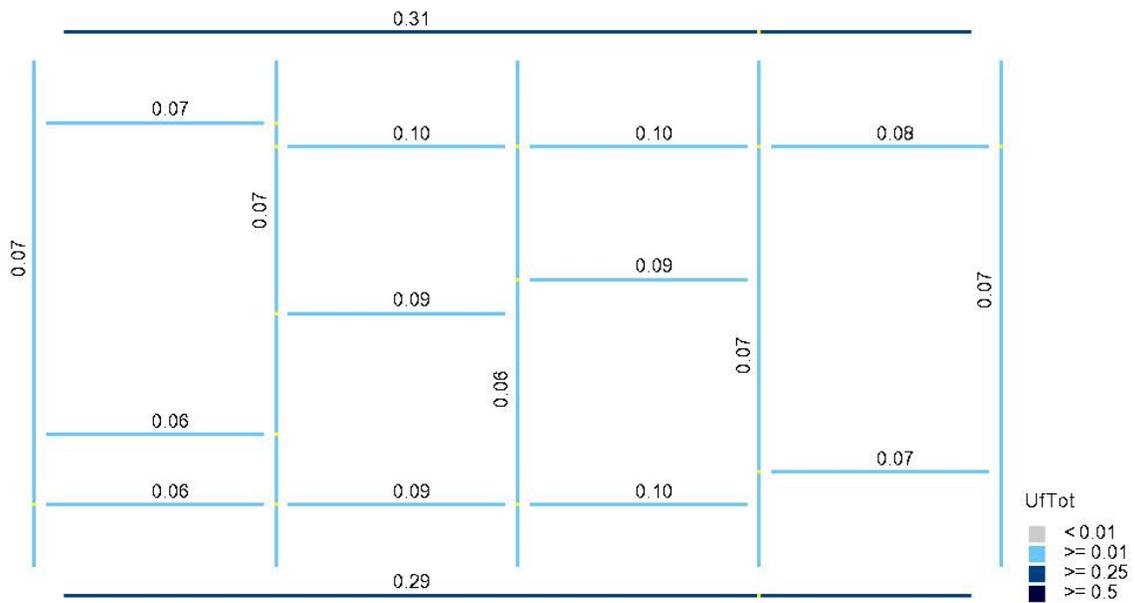


Figure 40. Usage factors for analysis 16

CHAPTER 6

WELDED JOINTS

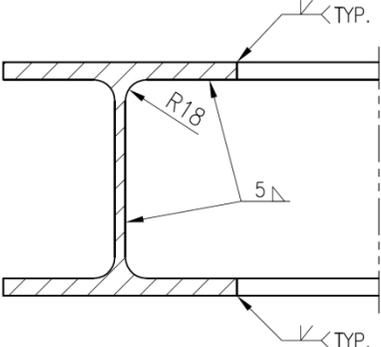
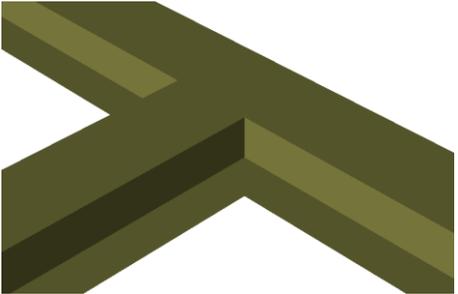
6.1 INTRODUCTION

In this chapter the welded joints calculation has been done. It is interesting to remark that for DNV Standards, Norsok and Eurocode, welded joints are calculated with the same formulation. Weld strength calculations have been carried out according to DNV Offshore Standard C101.

According to the structure, there are two different joint sections in the skid:

- Section 1: HEB 200 – HEB 200
- Section 2: HEB 200 – SHS 100

Table 33. Welded sections in the skid

Section No	Section view from the drawing	Isometric view of the section
1		

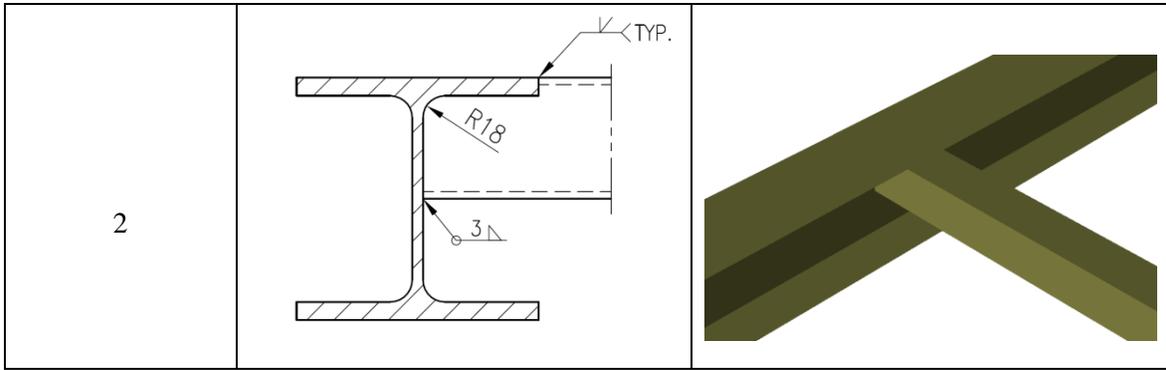


Figure 41. Welded sections in the skid

According to the symbols shown in each section view in the drawings, there are two types of welded joints for both sections. From NS-ISO 2553:

Table 34. Symbols and illustrations for welded joints in the skid

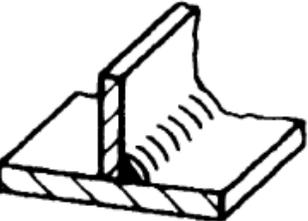
Symbol	Illustration	Designation
		Fillet weld
		Single-level butt weld

Figure 42. Symbols and illustrations for welded joints in the skid²⁵

²⁵ Taken from NS-ISO 2553

6.2 LOCATION OF WELDED JOINTS

The location of the welded joints is this one:

- a) Section 1, between HEB 200 beams, ten joints in total:
 - a.1) Long_1 with Trans_1, Trans_2, Trans_3, Trans_4 and Trans_5
 - a.2) Long_2 with Trans_1, Trans_2, Trans_3, Trans_4 and Trans_5

- b) Section 2, between profiles HEB 200 and SHS 100, twenty-two joints in total:
 - b.1) Long_2, Long_8 and Long_10 with Transv_1 and Transv_1
 - b.2) Long_3, Long_7 and Long_11 with Transv_2 and Transv_3
 - b.3) Long_4, Long_6 and Long_12 with Transv_3 and Transv_4
 - b.4) Long_5 and Long_9 with Transv_4 and Transv_5

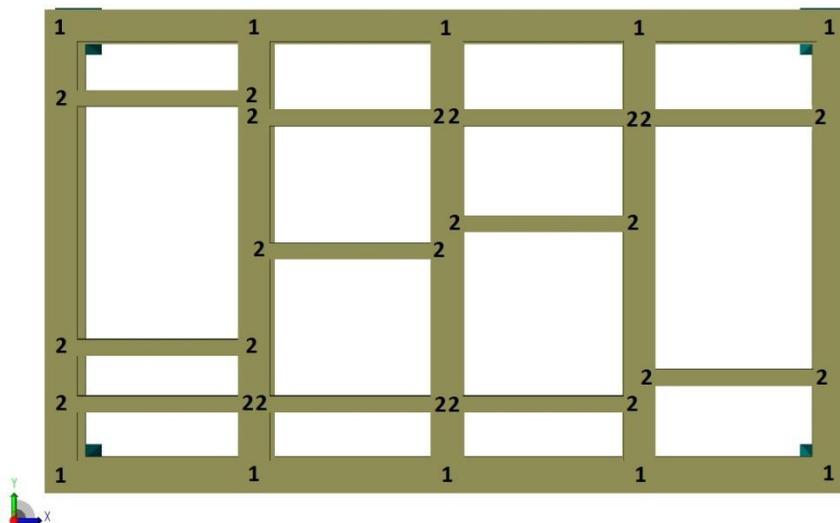


Figure 43. Symbols and illustrations for welded joints in the skid

6.3 FORMULATION

The design resistance of the weld will be sufficient if both the following conditions are satisfied:

$$\sqrt{\sigma_{\perp d}^2 + 3(\tau_{\parallel d}^2 + \tau_{\perp d}^2)} \leq \frac{f_u}{\beta_w \cdot \gamma_{Mw}}; \quad (32)$$

and

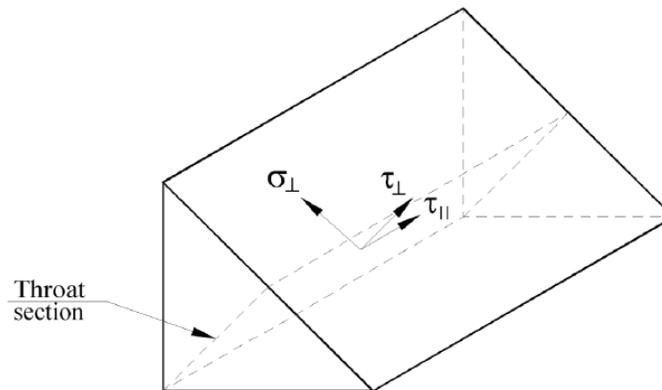
$$\sigma_{\perp d} \leq \frac{f_u}{\gamma_{Mw}}; \quad (33)$$

- $\sigma_{\perp d}$ = normal design stress perpendicular to the throat (including load factors),
- $\tau_{\perp d}$ = shear design stress (in plane of the throat) perpendicular to the axis of the weld,
- $\tau_{\parallel d}$ = shear design stress (in plane of the throat) parallel to the axis of the weld, see Fig 6.2.
- f_u = nominal lowest ultimate tensile strength of the weaker part joined,
- β_w = appropriate correlation factor, see Table 34
- γ_{Mw} = material factor for welding, table 35

So,

$$UF_1 = \frac{\sqrt{\sigma_{\perp d}^2 + 3(\tau_{\parallel d}^2 + \tau_{\perp d}^2)}}{f_u} \beta_w \cdot \gamma_{Mw} \leq 1 \quad (34)$$

$$UF_2 = \frac{\sigma_{\perp d} \cdot \gamma_{Mw}}{f_u} \leq 1 \quad (35)$$

Figure 44. Weld coordination system ²⁶Table 35. Correlation factor β_w ²⁷

Steel grade	Lowest ultimate tensile strength f_u	Correlation factor β_w
NV NS	400	0.83
NV 27	400	0.83
NV 32	440	0.86
NV 36	490	0.89
NV 40	510	0.90
NV 420	530	1.00
NV 460	570	1.00

Table 36. Material factors for γ_{Mw} welded connections ²⁸

Limit states	Material factor
ULS	1.3
ALS	1.0

²⁶ Taken from DNV-OS-C111, page 55, fig. 6

²⁷ Taken from DNV-OS-C111, page 55, table C4

²⁸ Taken from DNV-OS-C111, page 51, table C1

6.4 STRENGTH OF WELDED JOINTS

6.4.1 Weld connection for section 1

6.4.1.1 Von Mises Stresses

Von Mises stresses have been obtained in the connections of section 1 to check the welded joint within the one where Von Mises stress is maximum.

Table 37. Von Mises stresses at the joints between HEB 200 beams

Beam 1	Beam 2	Von Mises (kPa)	Load case
Transv_1	Long_1	18454	ULS01_N
Transv_2	Long_1	20262	ULS01_N
Transv_3	Long_1	12109	ULS01_N
Transv_4	Long_1	23269	ULS08_NW
Transv_5	Long_1	19189	ULS05_S
Transv_1	Long_13	17304	ULS05_S
Transv_2	Long_13	20296	ULS05_S
Transv_3	Long_13	11339	ULS05_S
Transv_4	Long_13	20368	ULS05_S
Transv_5	Long_13	16824	ULS08_NW

The point where the Von Mises stress is maximum is the joint between the transversal beam no 4 and the longitudinal beam no 1 for the load case ULS01_N.

6.4.1.2 Loads in the welding

The forces and moments in that point are shown in Table 37.

Table 38. Loads acting in the connection between Transv_4 and Long_1

	F (N)	M (Nmm)
x	-3388	1.05E+05
y	16992	-2.09E+04
z	-14141	-4.48E+06

a) Loads acting on the weld parallel to x-global axis

$$A = 2ts + 2t(s - g) \quad (36)$$

- t = thickness of the welding,
 s = width of the profile,
 g = web thickness.

$$A = 3910 \text{ mm}^2$$

	F	F (N)
x'	$\frac{F_x}{2} + \frac{M_y}{h}$	-3583
y'	0	0
z'	0	0

b) Loads acting on the weld parallel to y-global axis

$$A = 4t \left(\frac{s - g}{2} \right) \quad (37)$$

- t = thickness of the welding,
 s = width of the profile,
 g = web thickness.

$$A = 1910 \text{ mm}^2$$

	F	F (N)
x'	F_y	16992
y'	0	0
z'	0	-105

c) Loads acting on the weld parallel to z-global axis

$$A = 2th \quad (38)$$

t = thickness of the welding,

h = Height of the profile.

$$A = 2000 \text{ mm}^2$$

	F	F (N)
x'	F_z	-14141
y'	0	0
z'	0	0

6.4.1.3 Usage factors

$$UF_1 = \frac{\sqrt{\sigma_{\perp d}^2 + 3(\tau_{\parallel d}^2 + \tau_{\perp d}^2)}}{f_u} \beta_w \cdot \gamma_{Mw} \leq 1 \quad (39)$$

$$UF_2 = \frac{\sigma_{\perp d} \cdot \gamma_{Mw}}{f_u} \leq 1 \quad (40)$$

f_u	=	490 MPa
β_w	=	0.89
γ_{Mw}	=	1.3

To find relevant stress components in the welded joint this matrix has to be solved:

$$A \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos(\alpha) & -\sin(\alpha) \\ 0 & \sin(\alpha) & \cos(\alpha) \end{bmatrix} \begin{bmatrix} \tau_{\parallel d} \\ \sigma_{\perp d} \\ \tau_{\perp d} \end{bmatrix} = \begin{bmatrix} F'_x \\ F'_y \\ F'_z \end{bmatrix} \quad (41)$$

Weld direction	$\tau_{\parallel d}$ (MPa)	$\sigma_{\perp d}$ (MPa)	$\tau_{\perp d}$ (MPa)	UF_1	UF_2
x	-0.916	0.000	0.000	0.004	0.000
y	8.896	0.000	0.000	0.036	0.000
z	-7.070	0.000	0.000	0.029	0.000

$$UF_1, UF_2 \leq 1$$

The capacity of the respective fillet welds is sufficient.

6.4.2 Weld connection for Section 2

6.4.2.1 Von Mises Stresses

Von Mises stresses have been obtained in the connections of section 1 to check the welded joint within the one where Von Mises stress is maximum.

Table 39. Von Mises stresses for Section 2.

Beam 1	Beam 2	Von Mises (kPa)	Load case
Long_2	Transv_1	24845	ULS05_S
Long_2	Transv_2	26078	ULS05_S
Long_8	Transv_1	12019	ULS01_N
Long_8	Transv_2	9356	ULS01_N
Long_10	Transv_1	30091	ULS01_N
Long_10	Transv_2	45149	ULS01_N
Long_3	Transv_2	23223	ULS05_S
Long_3	Transv_3	54498	ULS05_S
Long_7	Transv_2	13110	ULS01_N
Long_7	Transv_3	19437	ULS01_N
Long_11	Transv_2	40210	ULS02_NE
Long_11	Transv_3	49933	ULS02_NE
Long_4	Transv_3	52211	ULS06_SW
Long_4	Transv_4	36507	ULS06_SW
Long_6	Transv_3	20038	ULS05_S
Long_6	Transv_4	13490	ULS05_S
Long_12	Transv_3	52362	ULS08_NW
Long_12	Transv_4	23969	ULS08_NW
Long_5	Transv_4	45548	ULS05_S
Long_5	Transv_5	27380	ULS05_S
Long_9	Transv_4	17246	ULS08_NW
Long_9	Transv_5	19026	ULS08_NW

The point where the Von Mises stress is maximum is the joint between the transversal beam no 3 and the longitudinal beam no 3 for the load case ULS05_S.

6.4.2.2 Loads in the welding

The forces and moments in that point are shown in Table 40.

Table 40. Loads acting in the connection between Transv_3 and Long_1

	F (N)	M (Nmm)
x	-24619	-7.43E+04
y	-596	2.81E+06
z	108	-2.78E+05

a) Loads acting on the weld parallel to x-global axis

The effective weld area is:

$$A = 600 \text{ mm}^2$$

	F	F (N)
x'	$\frac{F_x}{2} + \frac{M_y}{h}$	-10545
y'	0	0
z'	0	0

b) Loads acting on the weld parallel to y-global axis

The effective weld area is:

$$A = 573 \text{ mm}^2$$

	F	F (N)
x'	F_y	-596
y'	0	0
z'	0	33115

c) Loads acting on the weld parallel to z-global axis

The effective weld area is:

$$A = 600 \text{ mm}^2$$

	F	F (N)
x'	F_z	108
y'	0	0
z'	0	0

$$UF_1 = \frac{\sqrt{\sigma_{\perp d}^2 + 3(\tau_{\parallel d}^2 + \tau_{\perp d}^2)}}{f_u} \beta_w \cdot \gamma_{Mw} \leq 1 \quad (39)$$

$$UF_2 = \frac{\sigma_{\perp d} \cdot \gamma_{Mw}}{f_u} \leq 1 \quad (40)$$

Table 41. Results of welding strength

Weld direction	$\tau_{\parallel d}$ (MPa)	$\sigma_{\perp d}$ (MPa)	$\tau_{\perp d}$ (MPa)	UF_1	UF_2
x	-17.575	0.000	0.000	0.072	0.000
y	-1.041	40.865	40.865	0.193	0.108
z	-0.180	0.000	0.000	0.001	0.000

$$UF_1, UF_2 \leq 1$$

The capacity of the respective fillet welds is sufficient.

CHAPTER 7

LIFTING EQUIPMENT

7.1 LIFTING EQUIPMENT DESCRIPTION

The lifting equipment proposed for this portable offshore unit has the following elements:

- Spreader bar
- Lifting lungs
 - Four lifting lungs attached to the skid; one on each corner.
 - Four lifting lungs attached to the spreader bar; two in the lower part and two in the upper part.
- Shackles: in each lung there is a shackle too.
- Slings:
 - Four slings between the skid and the lower part of the spreader bar.
 - Two slings between the upper part of the spreader bar and the top link.
- Top link

In the figure 45 it is possible to see a perspective view of the skid with the lifting equipment.

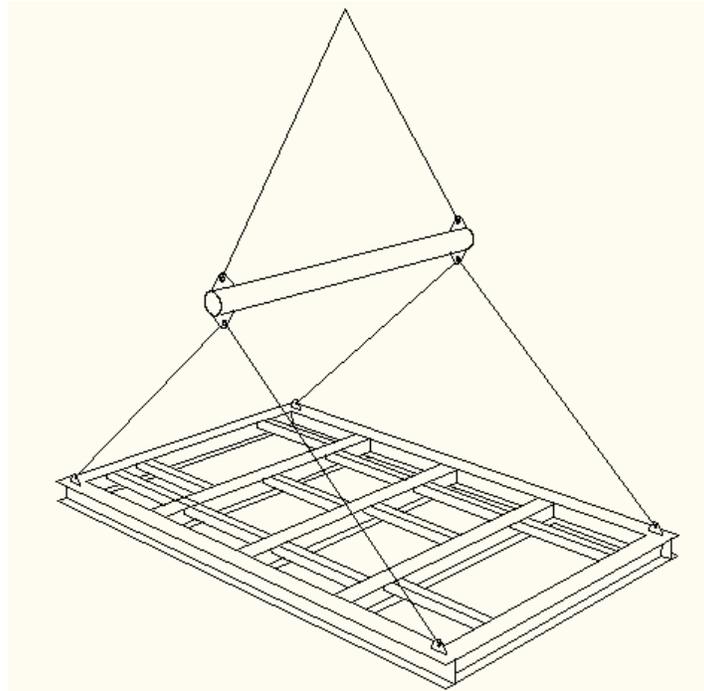


Figure 45. Perspective view of the skid and his lifting equipment

7.2 LIFTING EQUIPMENT CALCULATION

7.2.1 Slings

7.2.1.1 Lower slings

According to NORSOK R-002, the sling legs shall be selected on the basis of minimum breaking load in the following expression:

$$MBL_{LOW\ SLINGS} = \frac{P_{LP} \cdot \gamma_{Rm} \cdot DF}{\cos \alpha_B \cdot \gamma_e} \quad (41)$$

MBL_{SLING} = Minimum breaking load of the slings,
 P_{LP} = Maximum vertical reaction for design (1),

γ_{Rm}	=	Material resistance factor,
DF	=	Design factor,
α_B	=	Angle between the vertical of the COG and the sling,
γ_e	=	End termination factor

(1) Maximum vertical reaction for a four-part sling arrangement

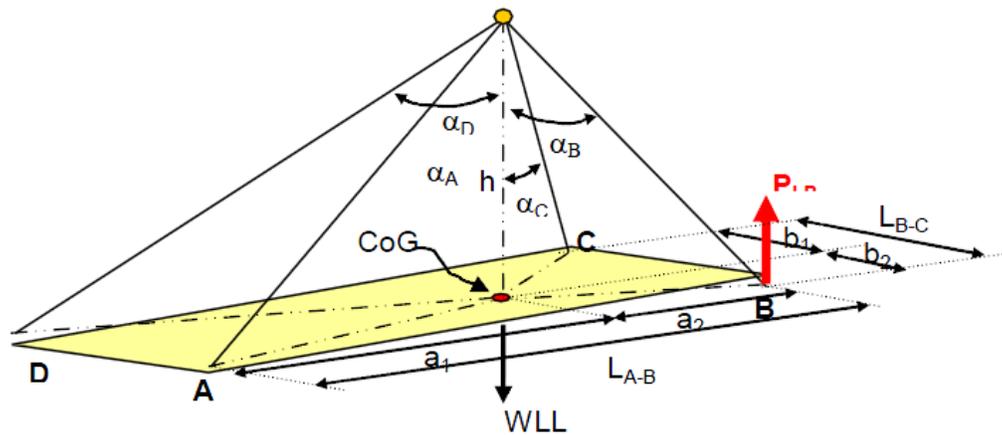


Figure 46. Maximum vertical reaction for a four-part sling arrangement ²⁹

$$P_{LP} = \frac{WLL \cdot b_1 \cdot a_1 \cdot W_{COG} \cdot SKL \cdot DAF}{L_{A-B} \cdot L_{B-C}} \quad (42)$$

P_{LP}	=	Maximum vertical reaction for design (1.1),
WLL	=	Working load limit
b_1	=	Half length of the skid
a_1	=	Half width of the skid
W_{COG}	=	Centre of gravity envelope factor
SKL	=	Skew load factor
DAF	=	Dynamic amplifying factor (1.2)
L_{A-B}	=	Length of the skid
L_{B-C}	=	Width of the skid

²⁹ Taken from Norsok R.002, page 135, figure F.4

Maximum vertical reaction for design (1.1) is:

$$WLL = W \cdot W_{CF} \quad (43)$$

WLL	=	Working load limit
W	=	Estimated weight of the lifted object
W_{CF}	=	Weight contingency factor

In this case, it has been considered that the weight was determined by a detailed calculation, based on updated drawings and information.

$$WLL = 7.8 \cdot 1.2;$$

$$WLL = 9.4 \text{ tonnes}$$

Dynamic amplifying factor (2) for $WLL \leq 50$ tonnes.

$$DAF = 1.09 + 0.41 \sqrt{\frac{50}{WLL}} \quad (44)$$

$$DAF = 1.09 + 0.41 \sqrt{\frac{50}{9.4}};$$

$$DAF = 2.0$$

Maximum vertical reaction is:

$$P_{LP} = \frac{WLL \cdot b_1 \cdot a_1 \cdot W_{COG} \cdot SKL \cdot DAF}{L_{A-B} \cdot L_{B-C}};$$

$$P_{LP} = \frac{9.4 \cdot 1.4 \cdot 2.33 \cdot 1.1 \cdot 1.25 \cdot 2.0}{4.65 \cdot 2.8};$$

$$P_{LP} = 5.8 \text{ tonnes}$$

$$MBL_{LOW SLINGS} = \frac{P_{LP} \cdot \gamma_{Rm} \cdot DF}{\cos \alpha_B \cdot \gamma_e}$$

$$MBL_{LOW SLINGS} = \frac{5.8 \cdot 1.8 \cdot 1.68}{\cos 49.3 \cdot 1.0};$$

$$MBL_{LOW SLINGS} = 26.7 \text{ tons} = 261.6 \text{ kN}$$

The minimum breaking load of the lower slings is 261.6 kN. According to NS-EN 12385-4, steel core slings with a diameter of 22 mm and MBL= 305 kN.

7.2.1.2 Upper slings

(1) Maximum vertical reaction for a two-part sling arrangement

$$P'_{LP} = \frac{WLL \cdot W_{COG} \cdot DAF \cdot L_2}{L_1 + L_2} \quad (45)$$

$$P'_{LP} = \frac{9.4 \cdot 1.1 \cdot 2.0 \cdot 1.4}{1.4 + 1.4};$$

$$P'_{LP} = 11.5 \text{ tonnes}$$

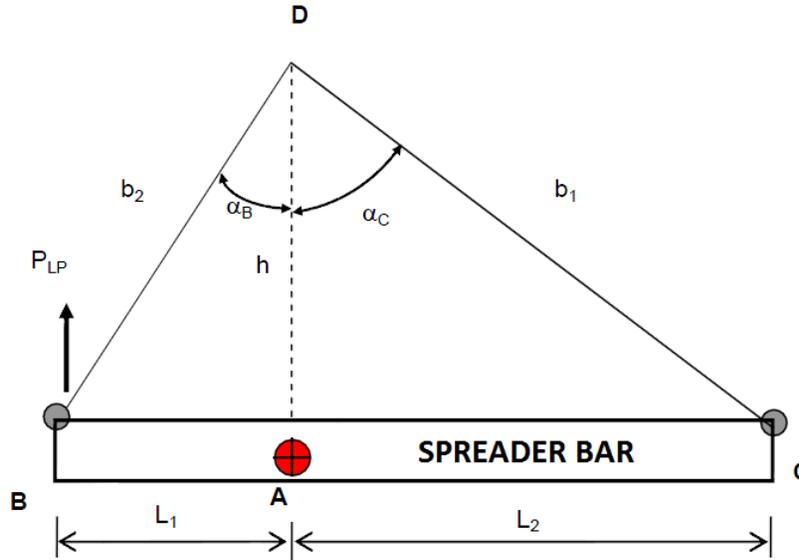


Figure 47. Maximum vertical reaction for a two-part sling arrangement ³⁰

$$MBL_{UPP\ SLINGS} = \frac{P'_{LP} \cdot \gamma_{Rm} \cdot DF}{\cos \alpha_B \cdot \gamma_e}$$

$$MBL_{UPP\ SLINGS} = \frac{11.5 \cdot 1.8 \cdot 1.68}{\cos 35 \cdot 1.0};$$

$$MBL_{UPP\ SLINGS} = 42.5 \text{ tonnes} = 416.7 \text{ kN}$$

The minimum breaking load of the upper slings is 416.7 kN. According to NS-EN 12385-4, steel core slings with a diameter of 26 mm and MBL= 426 kN.

7.2.2 Shackles

Shackles are used in lifting and static systems as removable links to connect (steel) wire rope, chain and other fittings. Screw pin shackles are used mainly for non-permanent applications. Safety bolt shackles are used for long-term or permanent applications or where the load may slide on the pin causing rotation of the pin.

³⁰ Taken from Norsok R.002, page 137, figure F.6

Chain or dee shackles are mainly used on one-leg systems whereas anchor or bow shackles are mainly used on multi-leg systems.

Determination of required shackle size is done with the following expression:

$$MBL_{SHACKLE} \geq \frac{P_{LP} \cdot \gamma_{Rm} \cdot DF}{\cos \alpha_B} \quad (46)$$

The rated WLL for the shackle will be:

$$WLL_{SHACKLE} \geq \frac{MBL_{SHACKLE}}{SF_m} \quad (47)$$

where SF_m is the safety factor as specified by the shackle manufacturer. Van Beest shackles have been selected in this master thesis, in particular Green Pin Standard Shackles (bow shackles with screw collar pin).

Table 42. Shackle selected for this skid

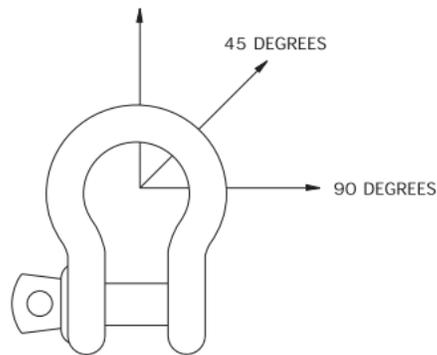
Material	Bow and pin high tensile steel, Grade 6, quenched and tempered
Safety factor	MBL equals 6 x WLL
Standard	EN 13889

The WLL of shackles shall not be less than the static sling force in each leg of a lifting set resulting from the weight of the lifted object.

Side loads should be avoided as well, as the products are not designed for this purpose. If side loads cannot be avoided, the following reduction factors must be taken into account:

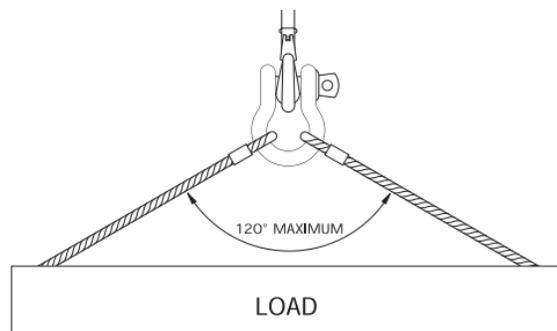
Table 43. Reduction for side loading in function of the load angle

Load angle	Reduction for side loading New working load limit
0°	100% of original Working Load Limit
45°	70% of original Working Load Limit
90°	50% of original Working Load Limit

Figure 48. Reduction for side loading on shackles³¹

In-line loading is considered to be a load perpendicular to the pin and in the plane of the bow. Load angles in the table are the deviating angles from the in line loads.

When using shackles in connection with multi-leg slings, due consideration should be given to the effect of the angle between the legs of the sling. As the angle increases, so does the load in the sling leg and consequently in any shackle attached to that leg.

Figure 49. Maximum allowed angle between slings³²

³¹ Taken from <http://www.vlierodam.nl/files/Shackles.pdf>

³² Taken from <http://www.vlierodam.nl/files/Shackles.pdf>

7.2.2.1 Shackles attached to the skid

$$MBL_{SHACKLE} = \frac{5.8 \cdot 1.8 \cdot 1.6}{\cos 49.3} = 26.7 \text{ tonnes} \quad (48)$$

$$MBL_{SHACKLE} = SFm \cdot WLL_{SHACKLE} \quad (49)$$

$$WLL_{SHACKLE} = 4.4 \text{ tonnes} \quad (50)$$

According to EN 13889 the following shackle is selected:

Working load limit	4.75	tons
Diameter bow	19	mm
Diameter pin	22	mm
Diameter eye	47	mm
Width eye	19	mm
Width inside	31	mm
Length inside	76	mm
Width bow	51	mm
Length	136	mm
Length bolt	107	mm
Width	94	mm
Weigth each	1.01	kg

7.2.2.2 Shackles attached to the lower part of the spreader bar

$$MBL_{SHACKLE} = \frac{11.5 \cdot 1.8 \cdot 1.6}{\cos \left(\frac{49.3}{2} \right)} = 38.3 \text{ tonnes} \quad (51)$$

$$WLL_{SHACKLE} = 6.4 \text{ tonnes} \quad (52)$$

As this case is the same as shown in figure 48, the new working load limit for shackles is 70%. According to EN 13889 the following shackle is selected:

Table 44. Shackle attached to the lower part of the spreader bar

Working load limit	9.5	tons
Diameter bow	28	mm
Diameter pin	32	mm
Diameter eye	67	mm
Width eye	28	mm
Width inside	47	mm
Length inside	108	mm
Width bow	75	mm
Length	197	mm
Length bolt	158	mm
Width	137	mm
Weigth each	3.16	kg

7.2.2.3 Shackles attached to the upper part of the spreader bar

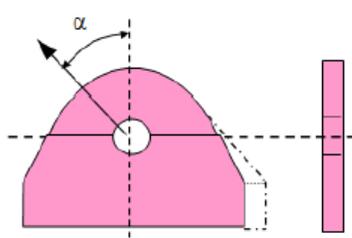
$$MBL_{SHACKLE} = \frac{11.5 \cdot 1.8 \cdot 1.6}{\cos\left(\frac{35}{2}\right)} = 36.5$$

$$WLL_{SHACKLE} = 6.1 \text{ tonnes}$$

For the upper part of the spreader bar the same shackles will be used.

7.2.3 Lifting lugs

Norsok R-002 considers three types of lifting lugs. Type 1 has been selected because of the WLL calculated for shackles and is the basic type manufactured from one single plate.



TYPE 1

- Typical for shackles with WLL ≤ 8.5 tonnes
- Load angle between $-90^\circ \leq \alpha \leq 90^\circ$

To calculate lifting lug geometry we have some formulas:

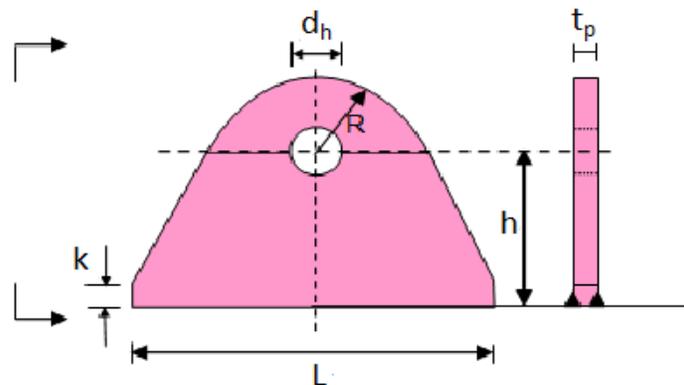


Figure 50. Lifting lug geometry formulation³³

$$d_h = (1.03 \cdot d) + 2$$

$$1.03 \cdot d_h < R < 1.08 \cdot d_h$$

$$0.75 \cdot w_s \leq t_p \leq 0.9 \cdot (w_s - 3)$$

$$2.2 \cdot d_h \leq t_p \leq 2.4 \cdot d_h$$

$$2.4 \cdot h \leq L \leq 2.7 \cdot h$$

d = Shackle bolt diameter

d_h = Minimum hole diameter

³³ Taken from Norsok R.002, page 169, figure J.1

w_s = Inside width of shackle at bolt section
 L = Length of the lung

7.2.3.1 Lifting lungs attached to the skid

Table 45. Lifting lungs attached to the skid

d	22	mm
d_h	26	mm
R	40	mm
h	58	mm
L	146	mm
k	20	mm
w_s	31	mm
t_p	24	mm

7.2.3.2 Lifting lungs attached to the spreader bar

Table 46. Lifting lungs attached to the spreader bar

d	32	mm
d_h	36	mm
R	46	mm
h	80	mm
L	210	mm
k	20	mm
w_s	47	mm
t_p	38	mm

7.2.4 Top link

$$MBL_{TL} \geq WLL \cdot DAF \cdot DF \cdot \gamma_{Rm}$$

$$MBL_{TL} \geq 9.4 \cdot 2.0 \cdot 1.68 \cdot 1.8;$$

$$MBL_{TL} \geq 57.5 \text{ tonnes}$$

Applying the same security factor as we did with shackles:

$$WLL_{TL} \geq 9.6 \text{ tonnes}$$

Table 47. Top link

Working load limit	11.2	tons
Diameter (D_1)	32	mm
Length (L_1)	200	mm
Width (W_1)	110	mm
Mass	3.9	kg

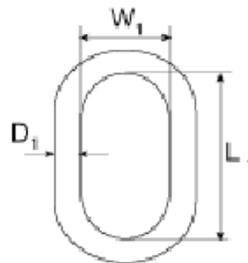


Figure 51. Geometry of the top link ³⁴

³⁴ Taken from <http://www.vlieroordam.nl/files/Shackles.pdf>

CHAPTER 8

CAPACITY MODELS CONCLUSIONS

8.1 INTRODUCTION

As was written in chapter 5, there are four main aspects in the codes which determine the results of usage factors.

- Loading calculation procedure
- Combined load cases factors (CLC factors)
- Security factors
- Formulation for usage factors

Just the first two have been manipulated in order to make some combinations and try to reach to accurate conclusions. Security factors have been taken as one for all the codes and there is no way and it does not make sense to change anything in the own formulation of the codes.

8.2 LOADING CALCULATION PROCEDURE

Two combinations have been carried out; applying the own loads for each code run and applying the same loads for all of them.

Results for hypothesis 1 and 3 are almost equal and the same for 2 and 4.

Table 48. Differences between hypotheses

No. of hypothesis	Load calculation (1)	CLC factors (2)
1	Own loads	Own CLC
2	Own loads	Equal CLC
3	Equal load	Own CLC
4	Equal load	Equal CLC

The results show that the calculation of loads does not have almost any influence in the final results. This was obvious even before running the analysis; the differences between own loads was reduced to wind loads.

Table 49. Own loads calculated with each code formulation

	API (kN)	Eurocode (kN)	ISO (kN)	Norsok (kN)
LC08_Wind_N	4.20	7.75	4.20	4.20
LC09_Wind_NE	5.00	8.25	5.00	5.00
LC10_Wind_E	3.00	4.10	3.00	3.00
LC11_Wind_SE	4.60	7.55	4.60	4.60
LC12_Wind_S	4.80	8.78	4.80	4.80
LC13_Wind_SW	5.50	9.09	5.50	5.50
LC14_Wind_W	3.50	4.77	3.50	3.50
LC15_Wind_NW	6.10	10.16	6.10	6.10

The main conclusion according to the results is that Eurocode is the most conservative code due to acting loads formulation.

8.3 COMBINED LOAD CASES FACTORS

As it has been shown previously, acting loads calculation does not have almost any influence in the usage factor. So, the differences between them have to be due to CLC factors and/or own formulation for usage factors.

Focusing on hypothesis 3 and 4, the difference between both is that in the first one, each code uses his CLC factors, while in the second one all the codes have been run with the same CLC factor.

To check the influence on the final results of CLC factors, the difference between results due to using one as CLC factor or using their own factors has been done and shown in Table 32. The percentage growth of usage factors between hypothesis 3 and 4 is calculated with formula 53:

$$\Delta UF = \frac{UF_{HYP 3}}{UF_{HYP 4}} \cdot 100 \quad (53)$$

ΔUF = Percentage growth of usage factor between hypothesis 3 and 4,
 $UF_{HYP 3,4}$ = usage factor for hypothesis 3 and 4.

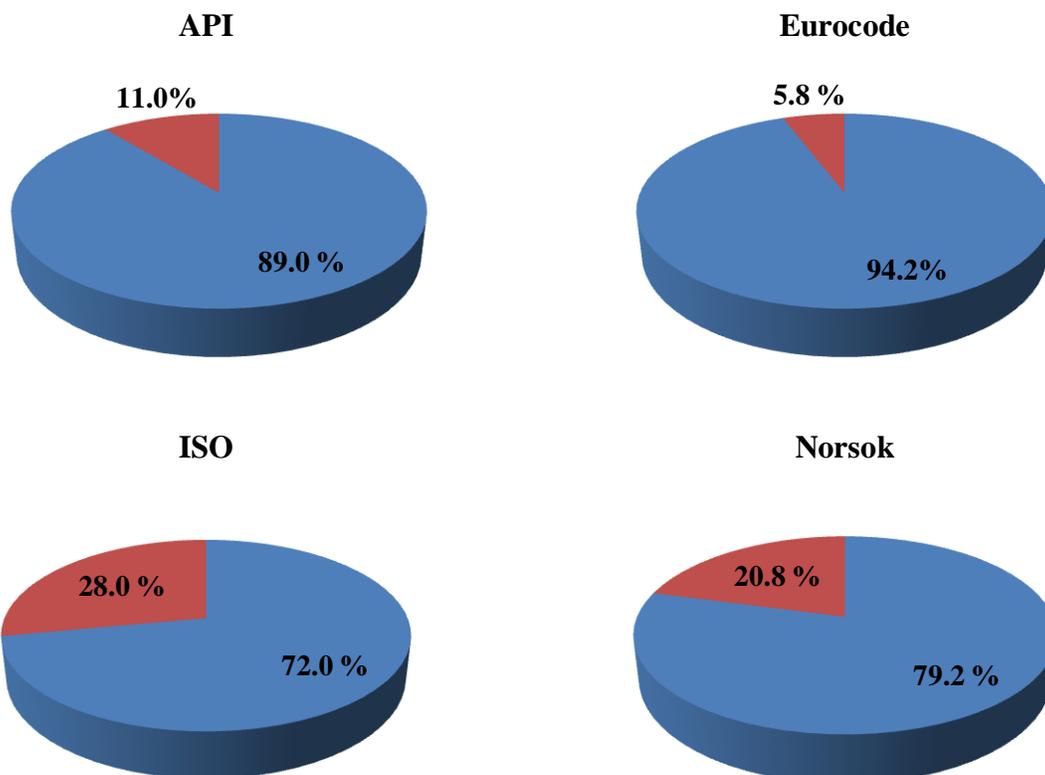
The unique difference between these two hypothesis is CLC factors. So, the differences between results are because of these factors.

Table 50. Percentage growth of usage factor between hypothesis 3 and 4 for the four codes

		API	Eurocode	ISO	Norsok
Primary structure	Long_1	11.3 %	6.1 %	26.2 %	20.5 %
	Long_13	11.9 %	6.3 %	27.5 %	21.6 %
	Transv_1	13.3 %	0.0 %	30.0 %	22.0 %
	Transv_2	7.1 %	0.0 %	30.0 %	22.0 %
	Transv_3	8.3 %	14.3 %	25.0 %	25.0 %
	Transv_4	7.1 %	0.0 %	30.0 %	22.2 %
	Transv_5	7.7 %	0.0 %	22.2 %	12.5 %

		API	Eurocode	ISO	Norsok
Secondary structure	Long_2	13.0 %	0.0 %	30.0 %	22.2 %
	Long_3	10.0 %	9.1 %	28.6 %	16.7 %
	Long_4	10.3 %	0.0 %	23.1 %	16.7 %
	Long_5	12.0 %	11.1 %	27.3 %	20.0 %
	Long_6	10.7 %	10.0 %	30.8 %	25.0 %
	Long_7	10.7 %	10.0 %	30.8 %	25.0 %
	Long_8	11.1 %	14.3 %	25.0 %	14.3 %
	Long_9	13.6 %	12.5 %	30.0 %	22.2 %
	Long_10	15.0 %	0.0 %	33.3 %	25.0 %
	Long_11	13.8 %	10.0 %	30.8 %	25.0 %
	Long_12	10.3 %	0.0 %	23.1 %	16.7 %

The main conclusion according to the results is that CLC factors for ISO are the most conservative, followed in this order by Norsok, API and Eurocode.



8.4 FORMULATION FOR USAGE FACTORS

To being able to reach a conclusion about the influence of the formulation for usage factors calculation, the fourth hypothesis is the best to do it because applied loads and CLC factors are the same for the four code runs.

Table 51. Results of the hyphotesis 4

		API	Eurocode	ISO	Norsok
Primary structure	Long_1	0.55	0.31	0.31	0.31
	Long_13	0.52	0.30	0.29	0.29
	Transv_1	0.13	0.08	0.07	0.07
	Transv_2	0.13	0.08	0.07	0.07
	Transv_3	0.11	0.06	0.06	0.06
	Transv_4	0.13	0.08	0.07	0.07
	Transv_5	0.12	0.07	0.07	0.07
Secondary structure	Long_2	0.20	0.08	0.07	0.07
	Long_3	0.27	0.10	0.10	0.10
	Long_4	0.26	0.10	0.10	0.10
	Long_5	0.22	0.08	0.08	0.08
	Long_6	0.25	0.09	0.09	0.09
	Long_7	0.25	0.09	0.09	0.09
	Long_8	0.16	0.06	0.06	0.06
	Long_9	0.19	0.07	0.07	0.07
	Long_10	0.17	0.07	0.06	0.06
	Long_11	0.25	0.09	0.09	0.09
	Long_12	0.26	0.10	0.10	0.10

The main conclusion according to the results is that formulation for usage factors of API is largely the most conservative, followed by Eurocode in the second place and ISO and NORSOK sharing the third place because their results are exactly the same.

8.5 CONCLUSIONS

After checking all this variables, some final conclusions can be said:

- API is largely the most conservative analyzed code. Its usage factors are always greater than those calculated with Eurocode, ISO or Norsok, with percentage differences between 40 and 190%. Even neglecting the influence of their own CLC factors, API usage factors are still greater than the others.
- ISO is the second most conservative analyzed code, but still far away from API. Its minimal difference compared with API is the 40%.
- Norsok is the second less conservative analyzed code. Its results are pretty similar to those from ISO: differences between them are around 10%.
- Eurocode is the less conservative code. Its results are largely the lowest. It is also interesting that is the one which CLC factors influence is also the lowest, just around 6% of its total value.

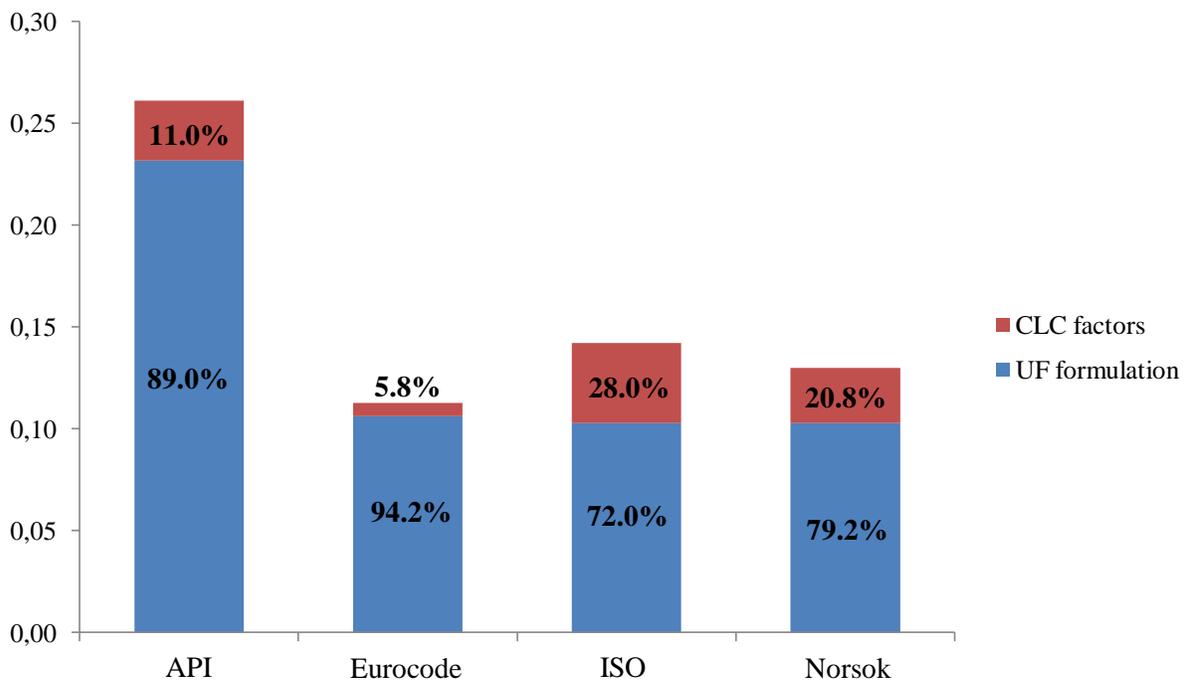


Figure 52. Average value of usage factors and percentage distributions for Hypothesis 3

8.6 IDEAS FOR FUTURE RESEARCH

Considering the approach done in this subject and the knowledge acquired during these months, there are some points where I think that future research could be done in order to compare different design codes for portable offshore units.

First of all, it would be interesting to dive into the formulation of codes; why those differences, how those differences are important in the results, etc. This idea would be deeply laborious but quite interesting for the researcher.

Another idea would be to go on with the lifting equipment calculation. Not just calculating the lifting equipment with one code, but do it with many codes and compare the differences with the elements involved: slings, lifting lugs, shackles, etc.

The last idea is not directly related to PO Units but it is with design codes for steel structures. It would be great to work not just with PO Units but with offshore units where hydrodynamic loads are considerable.

APPENDIX A

Plan of the structure attached as a pdf file.

APPENDIX B

a.1) Usage factors for Hypothesis 1

		USAGE FACTORS			
		API (1)	EUR (2)	ISO (3)	NS (4)
Primary structure	Long_1	0.62	0.33	0.42	0.39
	Long_13	0.59	0.32	0.40	0.37
	Transv_1	0.50	0.08	0.10	0.09
	Transv_2	0.14	0.08	0.10	0.09
	Transv_3	0.12	0.07	0.08	0.08
	Transv_4	0.14	0.08	0.10	0.09
	Transv_5	0.13	0.07	0.09	0.08
Secondary structure	Long_2	0.23	0.08	0.10	0.09
	Long_3	0.30	0.11	0.13	0.12
	Long_4	0.29	0.10	0.13	0.12
	Long_5	0.23	0.09	0.11	0.10
	Long_6	0.28	0.10	0.13	0.12
	Long_7	0.28	0.10	0.13	0.12
	Long_8	0.18	0.07	0.08	0.07
	Long_9	0.22	0.08	0.10	0.09
	Long_10	0.20	0.07	0.09	0.08
	Long_11	0.29	0.10	0.13	0.12
	Long_12	0.29	0.10	0.13	0.12

a.2) Usage factors for Hypotesis 2

		USAGE FACTORS			
		API (5)	EUR (6)	ISO (7)	NS (8)
Primary structure	Long_1	0,55	0,31	0,31	0,31
	Long_13	0,52	0,3	0,29	0,29
	Transv_1	0,13	0,08	0,07	0,07
	Transv_2	0,13	0,08	0,07	0,07
	Transv_3	0,11	0,06	0,06	0,06
	Transv_4	0,13	0,08	0,07	0,07
	Transv_5	0,12	0,07	0,07	0,07
Secondary structure	Long_2	0,2	0,08	0,07	0,07
	Long_3	0,27	0,1	0,1	0,1
	Long_4	0,26	0,1	0,1	0,1
	Long_5	0,22	0,08	0,08	0,08
	Long_6	0,25	0,09	0,09	0,09
	Long_7	0,25	0,09	0,09	0,09
	Long_8	0,16	0,06	0,06	0,06
	Long_9	0,19	0,07	0,07	0,07
	Long_10	0,17	0,07	0,06	0,06
	Long_11	0,25	0,09	0,09	0,09
	Long_12	0,55	0,1	0,09	0,09

a.3) Usage factors for Hypothesis 3

		USAGE FACTORS			
		API (9)	EUR (10)	ISO (11)	NS (12)
Primary structure	Long_1	0,62	0.33	0.42	0.39
	Long_13	0,59	0.32	0.40	0.37
	Transv_1	0,15	0.08	0.10	0.09
	Transv_2	0,14	0.08	0.10	0.09
	Transv_3	0,12	0.07	0.08	0.08
	Transv_4	0,14	0.08	0.10	0.09
	Transv_5	0,13	0.07	0.09	0.08
Secondary structure	Long_2	0,23	0.08	0.10	0.09
	Long_3	0,3	0.11	0.14	0.12
	Long_4	0,29	0.10	0.13	0.12
	Long_5	0,25	0.09	0.11	0.10
	Long_6	0,28	0.10	0.13	0.12
	Long_7	0,28	0.10	0.13	0.12
	Long_8	0,18	0.07	0.08	0.07
	Long_9	0,22	0.08	0.10	0.09
	Long_10	0,2	0.07	0.09	0.08
	Long_11	0,29	0.10	0.13	0.12
	Long_12	0,29	0.10	0.13	0.12

a.4) Usage factors for Hypothesis 4

		USAGE FACTORS			
		API (13)	EUR (14)	ISO(15)	NS (16)
Primary structure	Long_1	0.55	0.31	0.31	0.31
	Long_13	0.52	0.30	0.29	0.29
	Transv_1	0.13	0.08	0.07	0.07
	Transv_2	0.13	0.08	0.07	0.07
	Transv_3	0.11	0.06	0.06	0.06
	Transv_4	0.13	0.08	0.07	0.07
	Transv_5	0.12	0.07	0.07	0.07
Secondary structure	Long_2	0.20	0.08	0.07	0.07
	Long_3	0.27	0.10	0.10	0.10
	Long_4	0.26	0.10	0.10	0.10
	Long_5	0.22	0.08	0.08	0.08
	Long_6	0.25	0.09	0.09	0.09
	Long_7	0.25	0.09	0.09	0.09
	Long_8	0.16	0.06	0.06	0.06
	Long_9	0.19	0.07	0.07	0.07
	Long_10	0.17	0.07	0.06	0.06
	Long_11	0.25	0.09	0.09	0.09
	Long_12	0.26	0.10	0.10	0.10

b.1) Usage factors for API analysis

		Hyp 1	Hyp 2	Hyp 3	Hyp 4
		Analysis 1	Analysis 5	Analysis 9	Analysis 13
Primary structure	Long_1	0.62	0.55	0.62	0.55
	Long_13	0.59	0.52	0.59	0.52
	Transv_1	0.15	0.13	0.15	0.13
	Transv_2	0.14	0.13	0.14	0.13
	Transv_3	0.12	0.11	0.12	0.11
	Transv_4	0.14	0.13	0.14	0.13
	Transv_5	0.13	0.12	0.13	0.12
Secondary structure	Long_2	0.23	0.20	0.23	0.20
	Long_3	0.30	0.27	0.30	0.27
	Long_4	0.29	0.26	0.29	0.26
	Long_5	0.24	0.22	0.25	0.22
	Long_6	0.28	0.25	0.28	0.25
	Long_7	0.28	0.25	0.28	0.25
	Long_8	0.18	0.16	0.18	0.16
	Long_9	0.22	0.19	0.22	0.19
	Long_10	0.20	0.17	0.20	0.17
	Long_11	0.29	0.25	0.29	0.25
	Long_12	0.29	0.26	0.29	0.26

b.2) Usage factors for EUROCODE analysis

		Hyp 1	Hyp 2	Hyp 3	Hyp 4
		Analysis 2	Analysis 6	Analysis 10	Analysis 14
Primary structure	Long_1	0.33	0.31	0.33	0.31
	Long_13	0.32	0.30	0.32	0.30
	Transv_1	0.08	0.08	0.08	0.08
	Transv_2	0.08	0.08	0.08	0.08
	Transv_3	0.07	0.06	0.07	0.06
	Transv_4	0.08	0.08	0.08	0.08
	Transv_5	0.07	0.07	0.07	0.07
Secondary structure	Long_2	0.08	0.08	0.08	0.08
	Long_3	0.11	0.10	0.11	0.10
	Long_4	0.10	0.10	0.10	0.10
	Long_5	0.09	0.08	0.09	0.08
	Long_6	0.10	0.09	0.10	0.09
	Long_7	0.10	0.09	0.10	0.09
	Long_8	0.07	0.06	0.07	0.06
	Long_9	0.08	0.07	0.08	0.07
	Long_10	0.07	0.07	0.07	0.07
	Long_11	0.10	0.09	0.10	0.09
	Long_12	0.10	0.10	0.10	0.10

b.3) Usage factors for ISO analysis

		Hyp 1	Hyp 2	Hyp 3	Hyp 4
		Analysis 3	Analysis 7	Analysis 11	Analysis 15
Primary structure	Long_1	0.42	0.31	0.42	0.31
	Long_13	0.40	0.29	0.40	0.29
	Transv_1	0.10	0.07	0.10	0.07
	Transv_2	0.10	0.07	0.10	0.07
	Transv_3	0.08	0.06	0.08	0.06
	Transv_4	0.10	0.07	0.10	0.07
	Transv_5	0.09	0.07	0.09	0.07
Secondary structure	Long_2	0.10	0.07	0.10	0.07
	Long_3	0.13	0.10	0.14	0.10
	Long_4	0.13	0.10	0.13	0.10
	Long_5	0.11	0.08	0.11	0.08
	Long_6	0.13	0.09	0.13	0.09
	Long_7	0.13	0.09	0.13	0.09
	Long_8	0.08	0.06	0.08	0.06
	Long_9	0.10	0.07	0.10	0.07
	Long_10	0.09	0.06	0.09	0.06
	Long_11	0.13	0.09	0.13	0.09
	Long_12	0.13	0.09	0.13	0.10

b.4) Usage factors for NORSOK analysis

		Hyp 1	Hyp 2	Hyp 3	Hyp 4
		Analysis 4	Analysis 8	Analysis 12	Analysis 16
Primary structure	Long_1	0.39	0.31	0.39	0.31
	Long_13	0.37	0.29	0.37	0.29
	Transv_1	0.09	0.07	0.09	0.07
	Transv_2	0.09	0.07	0.09	0.07
	Transv_3	0.08	0.06	0.08	0.06
	Transv_4	0.09	0.07	0.09	0.07
	Transv_5	0.08	0.07	0.08	0.07
Secondary structure	Long_2	0.09	0.07	0.09	0.07
	Long_3	0.12	0.10	0.12	0.10
	Long_4	0.12	0.10	0.12	0.10
	Long_5	0.10	0.08	0.10	0.08
	Long_6	0.12	0.09	0.12	0.09
	Long_7	0.12	0.09	0.12	0.09
	Long_8	0.07	0.06	0.07	0.06
	Long_9	0.09	0.07	0.09	0.07
	Long_10	0.08	0.06	0.08	0.06
	Long_11	0.12	0.09	0.12	0.09
	Long_12	0.12	0.09	0.12	0.10

APPENDIX C

API Recommended practice 2A-WSD (RP 2A-WSD)

Planning, designing and constructing fixed offshore platforms

3.3.3 Axial tension and hydrostatic pressure, equation 3.3.3-1

$$A^2 + B^2 + 2\nu|A|B \leq 1.0 \quad (\text{uf3313})$$

where

- A = maximum tensile stress combination,
- B = $\frac{f_h}{F_{hc}}(SF_h)$,
- ν = Poisson' s ratio,
- F_y = yield strength,
- f_a = absolute value of acting axial stress,
- f_b = absolute value of acting resultant bending stress,
- f_h = absolute value of hoop compression stress,
- F_{hc} = critical hoop stress,
- SF_x = safety factor for axial tension,
- SF_h = safety factor for hoop compression.

Eurocode 3: Design of steel structures

Part 1-1: General rules and rules for buildings

6.2 Resistance of cross-sections, equation 6.2

$$\frac{N_{ed}}{N_{Rd}} + \frac{M_{y,ed}}{M_{y,Rd}} + \frac{M_{z,ed}}{M_{z,Rd}} \leq 1 \quad (\text{uf62})$$

where

- N_{Ed} = design values of the compression force
- N_{Rd} = maximum moments about the y-y and z-z axis along the member, respectively
- $M_{y,Ed}, M_{z,Ed}$ = reduction factors due to flexural buckling
- $M_{y,Rd}, M_{z,Rd}$ = characteristic value of resistance to compression

6.2.7 Torsion, equation 6.23

$$\frac{T_{Ed}}{T_{Rd}} \leq 1 \quad (\text{ufTorsion})$$

where

- T_{Ed} = torsional moment
- T_{Rd} = design torsional resistance of the cross section

6.3.3 Uniform members in bending and axial compression, equation 6.61

$$\frac{N_{ed}}{\frac{\chi_y N_{Rk}}{\gamma_{M1}}} + k_{yy} \frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT} \frac{M_{y,Rk}}{\gamma_{M1}}} + k_{yz} \frac{M_{z,Ed} + \Delta M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \leq 1 \quad (\text{uf661})$$

where

- N_{ed} = design values of the compression force
- $M_{y,Ed}, M_{z,Ed}$ = maximum moments about the y-y and z-z axis along the member, respectively
- χ_y = reduction factors due to flexural buckling
- N_{Rk} = characteristic value of resistance to compression
- γ_{M1} = partial factor for resistance of members to instability assessed by member checks
- k_{yy}, k_{yz} = interaction factors
- $\Delta M_{y,Ed}, \Delta M_{z,Ed}$ = are the moments due to the shift of the centroidal axis
- χ_{LT} = reduction factor due to lateral torsional buckling
- $M_{y,Rk}, M_{z,Rk}$ = characteristic value of resistance to bending moments about y-y and z-z axis, respectively

ISO 19902: Petroleum and natural gas industries - Fixed steel offshore structures

13.3.3 Axial compression and bending

$$U_m = \frac{\gamma_{R,c}\sigma_c}{f_c} + \frac{\gamma_{R,b}}{f_b} + \left[\left(\frac{C_{m,y}\sigma_{b,y}}{1 - \sigma_c/f_{e,y}} \right)^2 + \left(\frac{C_{m,z}\sigma_{b,z}}{1 - \sigma_c/f_{e,z}} \right)^2 \right]^{0.5} \quad (13.3-7)$$

where

- $\gamma_{R,c}$ = partial resistance factor for axial compressive strength
- $\gamma_{R,b}$ = partial resistance factor for bending strength
- σ_c = axial compressive stress due to forces from factored actions
- f_c = representative axial compressive strength
- f_b = representative bending strength
- $C_{m,y}, C_{m,z}$ = moment reduction factors corresponding to the member y- and z-axes, respectively
- $\sigma_{b,y}$ = bending stress about the member y-axis (in-plane) due to forces from factored actions
- $\sigma_{b,z}$ = bending stress about the member z-axis (out-of-plane) due to forces from factored actions
- $f_{e,y}, f_{e,z}$ = smaller of the Euler buckling strengths in the y- and z-directions

NORSOK N-004: Design of steel structures

6.3.8.1 Axial tension and bending

$$\frac{N_{Sd}}{N_{c,Rd}} + \frac{1}{M_{Rd}} \left[\left(\frac{C_{my} M_{y,Sd}}{1 - \frac{N_{Sd}}{N_{Ey}}} \right)^2 + \left(\frac{C_{mz} M_{z,Sd}}{1 - \frac{N_{Sd}}{N_{Ez}}} \right)^2 \right]^{0.5} \leq 1 \quad (\text{uf6_27})$$

where

- N_{Sd} = design axial compression force,
- $N_{c,Rd}$ = design axial local buckling resistance,
- M_{Rd} = design bending moment resistance,
- C_{my}, C_{mz} = reduction factors corresponding to the member y and z axes,
- $M_{y,Sd}$ = in-plane design bending moment,
- $M_{z,Sd}$ = design out-of-plane bending moment resistance,
- N_{Ey}, N_{Ez} = Euler buckling strengths corresponding to the member y and z axes.

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ACKNOWLEDGEMENTS

In this paragraphs I would like to acknowledge to everybody who helped me during these eighteen months.

First of all I would like to thank to Dr.-Ing. Philippe Rigo from Université de Liège (ULg) as coordinator of EMship program and Dr.-Ing. Pierre Ferrant from Ecole Centrale de Nantes (ECN) and Dr Inż. Maciej Taczała from Zachodniopomorski Uniwersytet Technologiczni w Szczecinie (ZUT), as local coordinators of EMship program in France and Poland. Thank you for your permanent help and comprehension.

I would like also to appreciate the help and useful comments from Dr Inż. Tomasz Urbański from ZUT as my master thesis supervisor. His advices were very helpful to improve this master thesis.

As this master thesis was mainly developed in Det Norske Veritas office in Gdynia (Poland), I can not finish it without giving my most sincere thanks to everybody there. During the four months I stayed there, they did not treat me as an intern, but as a employee and buddy. Special mention to Joanna Reichel, Magdalena Kubiak-Krupa, Adrianna Seredyka, Tomasz Msciwujewski, Łukasz Kurzynski, Leszek Czaplinski and my dear friend Przemysław Feiner.

Finally I would like to give thanks to all the people who made these eighteen months the best experience in my life, both family and friends. The people who met in Liège, Nantes, Gdynia and Szczecin will be always be my friends and also the indelible remember of this part of my life. Special thanks to my dearest friend Magdalena Scherl, who translated the abstract into Polish and made my stay in Gdynia unforgettable.

This thesis was developed in the frame of the European Master Course in “Integrated Advanced Ship Design” named “EMSHIP” for “European Education in Advanced Ship Design”, Ref.: 159652-1-2009-1-BE-ERA MUNDUS-EMMC.

