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Abstract

The objective of this thesis is to analyze and compare the capacity limits, hence the inherent safety level for the actual structure, using various standards and regulations such as Eurocode, NORSOK and ISO. The main tool for the analyses is DNV's software SESAM: Genie, which is used for modeling and code check of the structures.

All the three codes adopt the same design approach, namely the Load and Resistance Factor Design (LRFD). The analysis of the formulas for the three design standards shows that the standards are similar in the way that they provide formulae for load effects acting alone and in combination. The analysis of the formulas in the parameter studies shows significant differences in the capacity between Eurocode and NORSOK/ISO and in the partial factors for the design. The design formulas for NORSOK and ISO are identical and the differences in design results are entirely due to the differences in the partial factors.

In addition to the parameter studies, two case studies are performed for a redesigned topside module consisting of tubular cross sections. The first case study was performed using the resistance and action factors according to the design standards, whereas the second case was carried out based on the resistance factors and action factors according to NORSOK. The results of the analysis identified significant differences between the design codes, with Eurocode to be the most conservative approach for most of the cases.

Preface

This master thesis represents the final part of the master degree in Construction and Material technology with specialization in Offshore Constructions at the University of Stavanger. The master degree has been an expansion on my bachelor degree in Civil Engineering at the University in Stavanger. The combination of construction and offshore subjects on my master degree has been varying and demanding, and this thesis represents a natural closure on my degree.

Structural Resistance Safety Level in Eurocode versus NORSOK and ISO is a relevant topic to the offshore industry, and after finalizing my master degree I will start working in this industry. When working on this thesis it has been a goal for me to achieve as much knowledge as possible on the subject. It has also been a motivation factor for me to learn and use the computer tool SESAM: Genie and to study the different design standards. The learning outcome has been great, and I hope that other people will appreciate the outcome from my master thesis.

I wish to direct a big thank to Erlend Opheim, my external supervisor at Aker Solutions, for taking his time and given me good follow up and instructive conversations. My supervisors at the University of Stavanger, Rolf A. Jackobsen and S.A. Sudath C. Siriwardane have contributed with good advice and guidance in connection with my thesis. I will also thank Aker Solutions in Stavanger for giving me the opportunity to write my thesis in their premises and provide the topic of the thesis, it has been inspiring to work in such a good professional environment. Last, but most of all, I want to thank my cohabitant, Erlend Revheim and my father, Kjell Arvid Tuen who has been the best support while writing this thesis.

Stavanger, juni 2012

Elisabeth Skarås Tuen

LIST OF TABLES

LIST OF FIGURES

APPENDIX

1 INTRODUCTION

1.1 Background

In the past, the emphasis for the criteria and the procedures of structural design were based on the Allowable Stress Design, ASD and simplified buckling checks for structural elements. The ASD is a common method based on successful similar past experience, where the method assumes that the structural material behaves as a linear elastic manner, and that the adequate safety can be ensured by suitably restricting the stresses in the material induced by the expected “working loads” on the structure.

However, it is difficult to determine the real safety margin of any structure using linear elastic method alone, and it is well recognized that the limit state approach is a better basis for design (Paik and Thayamballi, 2003). The concept for limit state design and probabilistic safety were presented in 1926 by Max Mayer. It was not until the middle of 1940s that the method was introduced into a design code. This was the first codified attempt to link all aspects of structural analysis, including the specification of loads and analysis of safety into one code. The first probability based limit state code for offshore structures were introduced in the mid 1970s by the Norwegian Petroleum Directorate (NPD). The last 30 years the utilization of the limit state design has steadily increased in structural design codes and the method is used for all the Norwegian design standards (Bomel Limited, 2001).

The limit state design is based on the explicit consideration of the various conditions under which the structure may cease to fulfill its intended function. For these conditions, the strength or applicable capacity is estimated and used in design as a limit for such behavior. In limit state design there are four limit states considered (Paik and Thayamballi, 2003).

- Ultimate Limit State (ULS)
- Serviceability Limit State (SLS)
- Fatigue Limit State (FLS)
- Accidental Limit State (ALS)

The limit state method is also known as the load and resistance factors design (LRFD), where the resistance factors are applied to both resistance and load. This separately takes the uncertainty of the different parameters that are appropriate in the design into account. The resistance factors are derived based on statistical data on resistance and load effect using the reliability theory based on a target reliability level (Larsen, 2010a).

The framework for addressing safety and serviceability issues in structural design are provided from design codes and standards, the natural and the man-made forces are identified and considered. The magnitudes of these forces and the method for determining the structural resistances are given from the structural codes and standards. The engineer needs to address the question “How safe is safe enough?” which will vary from code to code (Ellingwood and Galambos, 1983).

With the continued growth of the standards, there is still evidence of differences in the design formulations, calculations and procedures when comparing different design codes. From time to time different standard regimes such as Eurocode (EN 1993-1-1, 2005), NORSOK (NORSOK N-004, 2004) and ISO 19902 (ISO 19902, 2007) are applied when designing and checking the capacity of steel structures for the petroleum industry. These standards are based on partly different design philosophies, and a consequence of this is that the various regulations may give different capacity limits for the structure at hand. Knowledge of these differences is important where regulations need to be evaluated against each other.

1.2 Objective

The objectives of this thesis are to analyze and compare the capacity limits hence the inherent safety level for the actual structure using various standards and regulations such as Eurocode 1993-1-1, NORSOK N-004 and ISO 19902.

1.3 Scope of work

The master thesis will investigate and examine differences as well as introduce the design standards for ISO 19902, NORSOK N-004 and Eurocode EN-1993-1-1. The task is addressed by analyzing selected design models with different standards and different methods for capacity check. The capacity limits are then compared and the trends in the results are evaluated.

The main scope of work entails the following three main parts:

- Literature and regulations study of the three design standards;
- Parameter study of single span simply supported members;
- Analysis of a topside module.

The purpose of the literature study is to find existing and similar reviews. Relevant findings are presented and discussed, such as the design methods and formulas in the design standards. The relevant parts of the standard regimes in Eurocode, NORSOK and ISO are studied and compared and the highlights are presented and discussed.

After identifying the design methods and formulas used in the design standards, the main task of the thesis is carried out, namely the parameter study of single span simply supported members. The parameter study is carried out to look at the effect of the capacity limit, hence the inherent safety level when the member is subjected to different variations of loading using various design standards. It is of significant importance to find a representative number of variations and still keep the number of analyses at an acceptable level. Typical parameters that are varied are:

- Load level;
- Force components mix;
- Slenderness;
- Cross-section class limited to class 2 and 3.

The last part of the thesis is an analysis of a topside module structure, largely built by tubular sections. Two case studies will be performed and checked according to relevant regulations. The consequences of applying different standards and the difference in the capacity limits of the structure in the two case studies are evaluated and discussed.

The main tool for the analyses is the computer program SESAM: GeniE which is used for modeling and code checking of structures.

1.4 Limitations

The thesis will only investigate tubular member, and in the parameter study the following limitations are prevailing:

- Tubular cross section;
- Cross section class limited to class 2 and 3;
- Single member check;
- Regulations: Eurocode EN 1993-1-1, NORSOK N-004 and ISO 19902;
- Material S355.

Local buckling, hydrostatic pressure and the combination of axial tension force and bending are not discussed in Eurocode, and will not be taken into account in this thesis.

1.5 Organization of the work

The content of this master thesis is composed in twelve chapters and a reference chapter, of which this is the introductory chapter. Chapter 2 presents an introduction to the hierarchy of rules and regulations in Norway and a description of the different categories of standards.

Chapter 3 contains a general presentation of the standard regimes for Eurocode, NORSOK and ISO and goes into details in the relevant design standards used in this thesis such as Eurocode 3 1993-1-1, NORSOK N-004 and ISO 19902.

Chapter 4 presents the design philosophy and a description of the Limit State Method. The derivation of the reliability of a structure is given in the part chapter for safety in structures, which leads to the Load and Resistance factor design method (LRFD) that is used in all the three structural codes.

Chapter 5 looks at the steel design formulae to calculate the tubular member stress and utilization ratio. A comparison of the formulas in the structural design standards are carried out in this section and the relevant formulae and findings are presented and discussed.

Chapter 6 describes the parametric studies of a single span simply supported member analyzed according to Eurocode, NORSOK and ISO. The results of the analysis are presented and discussed in this chapter. All the resistance factors are set to 1.0 since the similarities and differences in the formulas are considered.

Chapter 7 contains a presentation and structural information of the re-designed topside module which will be used for the case studies comparing impact of different design codes.

Chapter 8 contains the design basis for case study 1. The case study 1 sets basis in comparing Eurocode, NORSOK and ISO when subjected to the original material factors and action factors given in the individual standards.

Chapter 9 contains the numerical results for the three applicable standards for case study 1, and the ten most utilized members are further investigated and discussed.

Chapter 10 is dedicated to the design basis for case study 2, where the action and material factors in NORSOK are used except for the material factor in the ISO code check.

Chapter 11 contains the numerical results for the three applicable standards for case study 2, and the ten most utilized members are further investigated and discussed.

Chapter 12 includes conclusion and recommendations.

Chapter 13 contains the reference list.

1.6 Nomenclature and Abbreviations

Abbrevations

Accidental limit state	ALS
Allowable stress design	ASD
Det Norske Veritas	DNV
European Committee for Electrotechnical Standardization	CENELEC
European Committee for Standardization	CEN
European Standardizations Organizations	ESO
European structural standard	EN
European Telecommunications Standards Institute	ETSI
Finite Element Method	FEM
International Electrotechnical Commission	IEC
International federation of standardization association	ISA
International Organization for Standardization	ISO
International Telecommunication Union	ITU
Limit state design	LSD
Load and resistance factor design	LRFD
Nationally determined parameter	NDP
National Standard	NS
Norwegian Petroleum Directorate	NPD
Offshore Technology Conference	OTC
Serviceability limit state	SLS
Ultimate Limit State	ULS
United Nations Standard Coordinating Committee	UNCSS
Utilization Ratio	UC
Working stress design	WSD

Nomenclature

A	Cross sectional area
A_{eff}	Effective area
C_m	Reduction factor

C_{my}, C_{mz}	Reduction factors corresponding to the member y and z axis
C_x	Critical buckling coefficient
D	Diameter
E	Young’s modulus of elasticity
f_R	Probability density
f_s	Load-effect density
F_s	Cumulative distribution
I	Moment of inertia
k_{yy},k_{yz},k_{zy},k_{zz}	Interaction factor
L	Length
L_{cr}	Derived property to determine the buckling reduction factor
m_E	Mean value load
m_R	Mean value section
M_{Ed}	Design value of bending moment
M_F	Yield moment
M_P	Plasticity moment
$M_{c,Rd}$	Design resistance for bending
$M_{pl,Rd}$	Design plastic bending moment resistance
M_{Rd}	Design bending moment resistance
M_{Sd}	Design bending moment
$M_{y,Ed}$	Design bending moment, y-y axis
$M_{y,Rd}$	Design in-plane bending moment resistance
$M_{y,Rk}$	Characteristic value of resistance to bending moments about y-y axis
$M_{z,Rk}$	Characteristic value of resistance to bending moments about z-z axis
$M_{y,Sd}$	In-plane design bending moment
$M_{z,Ed}$	Design bending moment, z-z axis
$M_{z,Rd}$	Design out-of plane bending moment resistance
$M_{z,Sd}$	Out-of-plane design bending moment
$N_{b,Rd}$	Design buckling resistance of the compression member
N_{cr}	Design axial compressive resistance
N_{cl}	Characteristic local buckling resistance
$N_{c,Rd}$	Design resistance to normal forces of the cross-section uniform compression
$N_{cl,Rd}$	Design local buckling resistance
N_{Ed}	Design normal force
N_{Ey}, N_{Ez}	Euler buckling strengths corresponding to the member y and z axes respectively
N_{Sd}	Design axial force
$N_{t,Rd}$	Design axial tension resistance
N_{Rd}	Design values of the resistance to normal forces
R_d	Design resistance
R_k	Characteristic resistance
S_d	Design action effect
S_k	Characteristic action effect

t	Wall thickness
W	Elastic section modulus
W_{pl}	Plastic section modulus
$W_{el,min}$	Elastic section modulus
Z	Plastic section modulus
f_c	Characteristic axial compression strength
f_{cl}	Characteristic local buckling strength
$f_{cl,Rd}$	Design local buckling strength
f_{cle}	Characteristic elastic local buckling strength
f_{cr}	Critical buckling strength
f_d	Design yield strength
f_m	Characteristic bending strength
f_y	Characteristic yield strength
f_{yc}	Characteristic local buckling strength
f_u	Characteristic tensile strength
f_{xe}	Characteristic elastic local buckling stress
i	Radius of gyration
r	radius
β	factor
γ	factor
γ_m	Material factor to take into account model uncertainties in material properties
γ_f	Partial factor for actions
ε	Factor
λ	Column slenderness parameter
$\bar{\lambda}$	Non-dimensional slenderness
$\bar{\lambda}_s$	Reduced slenderness
χ	Reduction factor for the relevant buckling mode
χ_y , χ_z	Reduction factors due to flexural buckling,
α	Imperfection factor
σ_R	Standard deviation section
σ_E	Standard deviation load
$\sigma_{c,Sd}$	Combined design compressive stress

2 RULES AND REGULATIONS

2.1 Government principal and regulations

All the petroleum activity on the Norwegian continental shelf needs to fulfill the requirements in Norwegian laws and regulations. The hierarchy of legislation in Norway is illustrated in Figure 2-1.

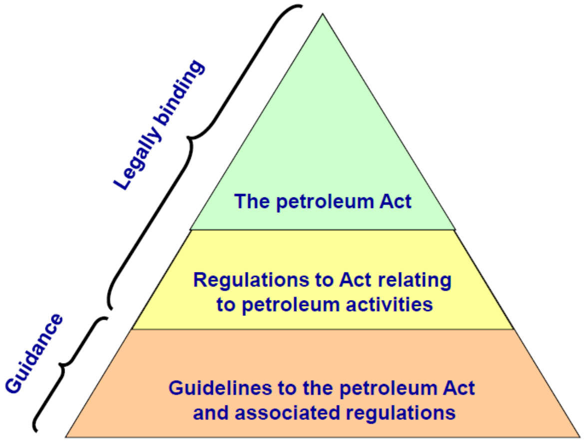


Figure 2-1 Hierarchy structure legal system (Odland, 2011).

The national organization of the petroleum sector in Norway is illustrated in Figure 2-2. Stortinget is the Norwegian parliament and establish the framework for the Norwegian petroleum activities, this include passing of legislation and adopting propositions, as well as discussing and responding to activities concerning the petroleum activities. The government holds the executive power and is responsible over the petroleum policy vis-à-vis with the Norwegian parliament. The responsibility for executing the various roles over the petroleum policy is shared as follows between the different Ministries (Odland, 2011):

- The Ministry of Petroleum Energy
    - Overall responsibility for management of petroleum resources on the Norwegian continental shelf. Includes ensuring that the petroleum activities are carried out in accordance with the mandates given by the parliament and the government. In addition, the ministry monitors the state-owned companies such as Petoro AS, Gassco AS and Gassnova, and the partly state-owned Statoil ASA.
- The Ministry of Labour and Social Inclusion
    - Responsible for the work environment and for health, safety and contingency measures in relation to the petroleum sector.
- The Ministry of Finance
    - Responsible for ensuring that the state collects taxes, fees and other revenues from the petroleum sector.
- The Ministry of Fisheries and Coastal Affairs
    - Responsible for maintaining adequate contingency measures against acute pollution in Norwegian waters.
- The Ministry of the Environment
    - Responsible for management of the Norwegian external environment.

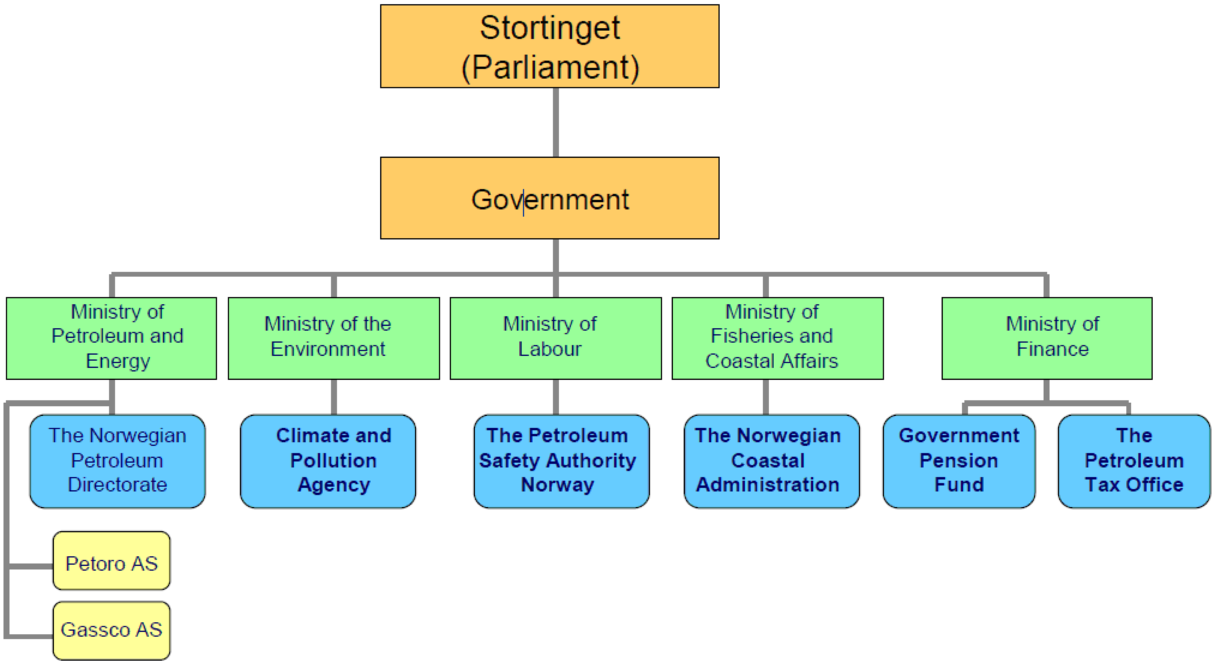


Figure 2-2 National organization of the petroleum sector in Norway (Odland, 2011).

2.2 Levels of Standards

The definition of a standard is provided in EN 45020 and states that "*a standard is a document which is established by consensus and approved by a recognized body, that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context"* (EN 45020, 2007). The standards should be based on the consolidated results of science, technology and experience, and aimed at the promotion of optimum community benefits (ISO/IEC Directives, 2011).

The standards within the petroleum industry can be grouped into 4 main levels:

1. International Standards
2. Regional (European) Standards
3. National Standards
4. Industry and association standards

2.2.1 International Standards

The international standards are adopted by recognized international standardization/standards organization and made available to the public. The international standards are prepared by the committee secretariats of the International Organization for Standardization (ISO), the international telecommunication union (ITU) and the International Electrotechnical Commission (IEC). ISO and IEC produce international standards for the oil and gas industry (ISO/IEC Directives, 2011).

2.2.2 Regional (European) Standards

The three European Standardizations Organizations (ESOs) that are competent in technical standardization is the European Committee for Standardization (CEN), European Committee for Electrotechnical Standardization (CENELEC) and European Telecommunications Standards Institute (ETSI). The standardization organization CEN produces the European structural standards (EN) (CEN, 2012).

2.2.3 National Standards

In Europe there has been a drive for harmonization of standardization through CEN. Norway is a member of CEN which produces European Standards (EN), and when CEN issues a new standard, these standards automatically, as a part of the joint European membership rules in CEN becomes a national standard. Each country provides a National Annex for the structural Eurocodes in addition to the national standards, with nationally determined parameter (NDP).

2.2.4 Industry and association standards

Industry and association standards are standards that provide the industry with technical input. The NORSOK standards are industry standards and are developed by the Norwegian petroleum industry. The Norwegian petroleum industries have bought standardization services from Standard Norway, so Standard Norway develops the NORSOK standards. These standards ensure adequate safety, cost effectiveness and value adding for the petroleum industry developments and operations. The NORSOK standards refer to the recognized regional, national and international standards. Furthermore, NORSOK standards are, as far as possible, intended to replace oil company specifications and serve as reference in the authorities' regulations (NORSOK N-004, 2004).

3 DESIGN STANDARD

This section includes a general presentation of the standard regimes for Eurocode, NORSOK and ISO. A short presentation is given for the relevant design standards: Eurocode 1993-1-1, NORSOK N-004 and ISO 19902, these are the design standards evaluated in the thesis, and are referred in the text as Eurocode, NORSOK and ISO, respectively.

3.1 EUROCODE

3.1.1 Introduction

“Structural Eurocodes” are a set of European structural design codes for construction and civil engineering works, and is governed and developed by the European Committee for Standardization (CEN). The Structural Eurocodes are given the status of national standards, and are divided into packages of the main material. The main standards for construction are listed below:

EN 1990 Eurocode:	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 of structures for earthquake resistance
EN 1999 Eurocode 9:	Design of aluminium structures

It all started in 1975 when the Commission of the European Community decided to start working on a common set of design rules for structures, which in the first stage were supposed to be a supplement to national standards. 1.April.2010 the Eurocodes was induced as the only valid standard in Norway, and all the conflicting standards were withdrawn (EN 1993-1-1, 2005).

The European standards provide common structural design rules for everyday use for the design of whole structures or parts of a structure. The main Eurocode standards applicable for offshore steel structures are:

- EN 1990 Eurocode: Basis of Structural Design, which establishes the principles and requirements for safety, serviceability and durability of structures (EN 1990, 2008).
- EN 1991 Eurocode 1: Actions on structures, which includes the characteristic values for various types of loads and densities for all materials that are likely to be used in construction (EN 1991-1-1, 2008).
- EN 1993 Eurocode 3- Design of Steel Structures, which gives basic design rules for steel structures (EN 1993-1-1, 2005).

The standards may be followed by a National annex which contains information on the parameters left open in the Eurocodes for national choice, known as Nationally Determined Parameters, to be used for the design of buildings and civil engineering works to be constructed in the relevant country (EN 1990, 2008).

3.1.2 EN 1993 Eurocode 3

EN 1993 Eurocode 3 applies to design of buildings and civil engineering works in steel. The primary objectives of the standard are to improve structural safety and to enhance the competitiveness of the European Construction industry. EN 1993 complies with the principles and requirements for the safety and serviceability of structures and concerns the requirements for resistance, serviceability, durability and fire resistance of steel structures, the basis of their design is found in EN 1990 – Basis of structural design (EN 1993-1-1, 2005).

The standard is applicable for steel structures with material thickness $t \leq 40$ mm with specified minimum yield strength less or equal to 460 MPa, and for material thickness $40 \text{ mm} < t \leq 80$ mm with specifies minimum yield strength less or equal to 440 MPa.

EN 1993 Eurocode are based on the limit state method which adopts the load and partial resistance factor design (LRFD) see section 4.3.2. The partial factor for actions, γ_f are found in EN-1991 Eurocode 1 (EN 1991-1-1, 2008), and takes account of the possibility of unfavorable deviations of the actions values from the representative values. The partial factor for the material, γ_m takes account of the possibility of unfavorable deviation of the material or product property from its characteristic value and is specified in section 5.3.1.

3.2 NORSOK

3.2.1 Introduction

NORSOK standard stands for "**NOR**sk **SO**kkel **K**onkurranseposisjon" and specifies general principles and guidelines for the design and assessment of offshore facilities and verification of load bearing structures subjected to foreseeable actions and related maritime systems and are developed by the Norwegian Petroleum industry. The NORSOK standards are given the status of a industry standard, and are divided into packages of the main material, where the notation N is the structural standards (NORSOK N-001, 2004). The NORSOK standardization started in 1993, to provide new industry standards to replace the internal company specifications and provide input to the Norwegian petroleum industry which were not already covered by the international standards (SNL, 2012).

The NORSOK standards applicable for offshore steel constructions are:

• NORSOK N-001:	Integrity of offshore structures
• NORSOK N-003:	Actions and actions effect
• NORSOK N-004:	Design of steel structures

The NORSOK standards refer to recognized standards such as DNV, Eurocode and ISO. The relevant NORSOK standard will be withdrawn when the international standards covers the content of the NORSOK standard (NORSOK N-001, 2004).

3.2.2 NORSOK N-004

NORSOK N–004 Design of Steel structures, gives specific guidelines and requirements for design and documentation of offshore steel structures. The primary objectives of the standard are to fulfill NPD regulations relating to design and outfitting of facilities etc. in the petroleum activities. The design principles follows the requirements in ISO 19900, and recognized standards such as DNV, EN 1993-1-1, ISO 19900 includes provision and guidelines which, through reference in the standard, constitute provisions and guidelines to NORSOK N-004.

The standard is applicable for all type of offshore structures made of steel with minimum yield strength less or equal to 500 MPa and tubular member having a thickness $t \geq 6$mm and $D/t < 120$. The requirements in N-004 assume that the tubular member is constructed in accordance with the fabrication tolerance given in NORSOK M-101 (NORSOK N-004, 2004).

NORSOK N-004 is based on the limit state method which adopts the load and partial resistance factor design (LRFD) ref. section 4.3.2. The partial factor for actions, γ_f, are found in NORSOK N- 003 and takes account of the possibility of unfavorable deviations of the actions values from the representative values (NORSOK N-003, 2007). The partial factor for the material, γ_m, takes account of the possibility of unfavorable deviation of the material or product property from its characteristic value and is specified in section 5.3.2.

3.3 ISO

3.3.1 Introduction

ISO stands for the International Organization for Standardization which is a worldwide federation of national standards bodies. The ISO standards are developed by the technical committee and international organization.

The ISO standards are given the status of international standards and are divided into series of international standards applicable for offshore structures, ISO 19900 to ISO 19906. These standards constitute a common basis covering the design requirements and assessments of all offshore structures used by the petroleum and natural gas worldwide (ISO 19902, 2007).

ISO was born from the union of two organizations in USA, the ISA (International federation of the National Standardization Association) and the UNSCC (United Nations Standard Coordinating Committee). In October 1946, delegates from 25 countries decided to create a new international organization. The objectives of the new organization would be “to facilitate the international coordination and unification of industry standards”. ISO was born and the operations started 23 February 1947.

Today, ISO is the world’s largest standard organization and has published over 19 000 international standards (ISO, 2012).

3.3.2 ISO 19902

ISO 19902 is an international standard that specified and provides recommendations applicable to specific types of fixed steel offshore structures for the petroleum and natural gas industries.
ISO 19902 should satisfy the requirements laid down in ISO 19900.

The standard is applicable for all type of offshore structures made of steel. For cylindrical tubular members the material should meet the requirements specified in clause 19 in ISO 19902, and having a thickness $t \geq 6$mm and a diameter to thickness ratio of $D/t < 120$. The yield strength should be less than 500 Mpa and the ratio of yield strength as used to ultimate tensile strength shall not exceed 0.90 (ISO 19902, 2007). Annex A provides guidance and background information to ISO 19902.

ISO 19902 are based on the limit state method which adopts the load and partial resistance factor design (LRFD) ref. section 4.3.2. The partial factor for actions, γ_f, takes account of the possibility of unfavorable deviations of the characteristic actions values. The partial factor for the material, γ_m, which are constant in value for the type of resistance under consideration, takes account of the possibility of unfavorable deviation of the material or product property from its characteristic value and is specified in section 5.3.3.

4 DESIGN PHILOSOPHY

4.1 General

The design philosophy, requirements and terminology are considered differently from country to country and from standard to standard, e.g (Kurobane and tubulaire, 2004):

- Limit states vs. allowable stress design;
- Requirements or not requirements for structural integrity;
- Material yield strength, tensile strength or a combination of both;
- The methodology and specific value of partial safety factors, or resistance factors for both load and capacity;
- Design details;
- The symbols used in the standards will vary not only for country to country, but also within the country.

4.2 Limit State Design Philosophy

4.2.1 Limit State Design

During the last two decades, the emphasis in structural design has been moving from Working Stress Design, WSD to the limit state design, LSD.

Working Stress Design, also called Allowable Stress Design, ASD is a common design method, but has in high degree been replaced by the limit state design. The principal for WSD is a method based on successful similar past experience were the method assumes that the structural material behaves in a linear elastic manner, and that adequate safety can be ensured by suitably restricting the stresses in the material induced by the expected “working loads” on the structure.

In contrast to this, limit state design is based on the explicit consideration of the various conditions under which the structure may cease to fulfill its intended function. For these conditions, the strength or applicable capacity is estimated and used in design as a limit for such behavior.

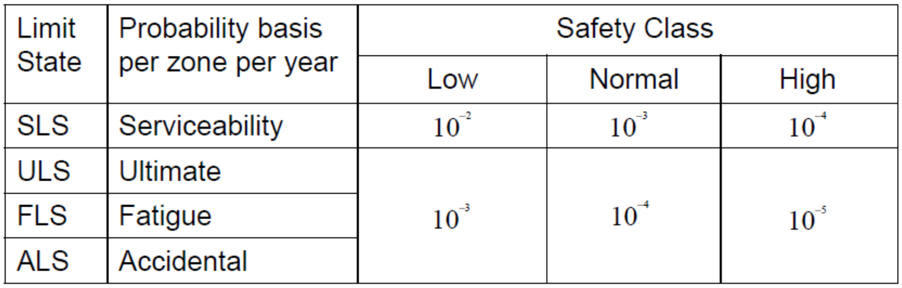
In limit state design there are four different limit states, each limit state is defined by the description of a condition for which a particular structural member or an entire structure fails to perform the function that is expected of it. The four limit states that are considered for steel structures are:

- Ultimate Limit State (ULS)
- Serviceability Limit State (SLS)
- Fatigue Limit State (FLS)
- Accidental Limit State (ALS)

It is important to emphasize that in limit state design, the different limit states may have different safety levels. The guidelines for determining the partial safety factors for the different limit states are found in the different design standards (Paik and Thayamballi, 2003).

Table 4-1 illustrates the safety class for the different limit states. Limit state design is design on the basis of achieving target reliability (i.e. a defined probability of failure). The required reliability depends on consequence of failure: Risk = Probability x Consequence.

Table 4-1 Limit State Design (Karunakaran, 2011).



Limit State	Probability basis per zone per year	Safety Class		
		Low	Normal	High
SLS	Serviceability	10^{-2}	10^{-3}	10^{-4}
ULS	Ultimate	10^{-3}	10^{-4}	10^{-5}
FLS	Fatigue			
ALS	Accidental			

4.2.2 Ultimate Limit State

Ultimate limit state (ULS) is the state that corresponds to the ultimate resistance for carrying loads and represents the collapse of the structure caused by loss of structural stiffness and strength. Such loss of capacity may be related to:

- Loss of structural resistance (yield or buckling);
- Failure due to brittle fractures;
- Loss of static equilibrium in the entire structure or parts of it, it is often considered as a rigid body, e.g. overturning or capsizing;
- Attainment of the maximum resistance of structural regions, members or connections by gross yielding, rupture or fracture;
- Failure of critical components caused by exceeding the ultimate resistance;
- Instability in part or of the entire structure resulting from buckling or plastic collapse.

The structural criteria to prevent ULS are based on plastic collapse or ultimate strength (Paik and Thayamballi, 2003).

4.2.3 Serviceability Limit State

Serviceability limit state (SLS) is the state where the construction is exposed to common use, it represents the failure states for normal operations due to deterioration of routine functionality. The consideration of SLS design may address:

- Local damage which reduces the durability or affects the efficiency of structure;
- Deformations which change the distribution of loads between the support rigid object and the supporting structure and can affect the efficient use of structural elements;
- Excessive vibration or noise producing discomfort to people or affect the proper functioning of equipment;
- Deformations and deflections which may spoil the aesthetic appearance of the structure.

The structural criteria used for SLS design are normally based on the limits of deflection or vibration for normal use (Paik and Thayamballi, 2003).

4.2.4 Fatigue Limit State

Fatigue limit state (FLS) involves the fatigue crack occurrence of structural details due to stress concentration and damage accumulation. The consideration of FLS design may address:

- Cumulative damage due to cyclic dynamic loads.

The structural criteria used for FLS are carried out to ensure that the structure has an adequate fatigue life (Paik and Thayamballi, 2003).

4.2.5 Accidental Limit State

Accidental limit state (ALS) represents excessive structural damage as a consequence of accidents, e.g. collisions, grounding, explosion and fire, which can affect the safety of the structure, environment and personnel. The consideration of ALS design may address:

- Structural damage caused by accidental loads
- Resistance and structural integrity of damaged structures

In ALS design, it is necessary to achieve a design such that the main safety functions of the structure must not be impaired during and after an accident event (Paik and Thayamballi, 2003).

4.3 Design Philosophy in the structural codes

4.3.1 Safety in structures

In general the criteria for dimensioning are given in the following term:

$$R > S \qquad F\ 4\text{-}1$$

Where R is the capacity while S is the load-action, and they are not given constants. Variations in the production will equivalently give statistical variations in the cross section dimensions of a given steel profile, if a test is performed with steel of a specified quality we can see that the yield stress σ_y has a certain statistical spread around a mean value.

For a steel beam, the resistance R is a function of the yield stress and the moment of resistance. The statistical spread of the yield stress, moment of inertia I and the moment of resistance W is shown in Figure 4-1. From these figures one can calculate the spread or the distribution of the yield moment M_F and the plasticity moment M_P.

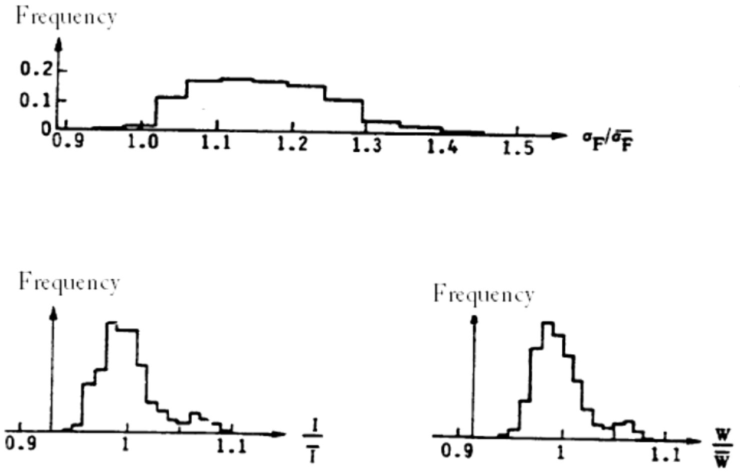


Figure 4-1 Variation in yield stress and dimensions for steel profiles (Gudmestad, 2011)

The load is not a deterministic size. The variation of the load action S is due to the uncertainties in estimation in e.g. deck, wind and wave loads. These loads are stochastically determine processes and are described by means of statistical parameters.

In Figure 4-2, it is assumed that the capacity R, due to the spread of σ_y and W_P has a probability density f_R around a mean-value r. Likewise for the load-effect S, the density f_S around a mean-value s.

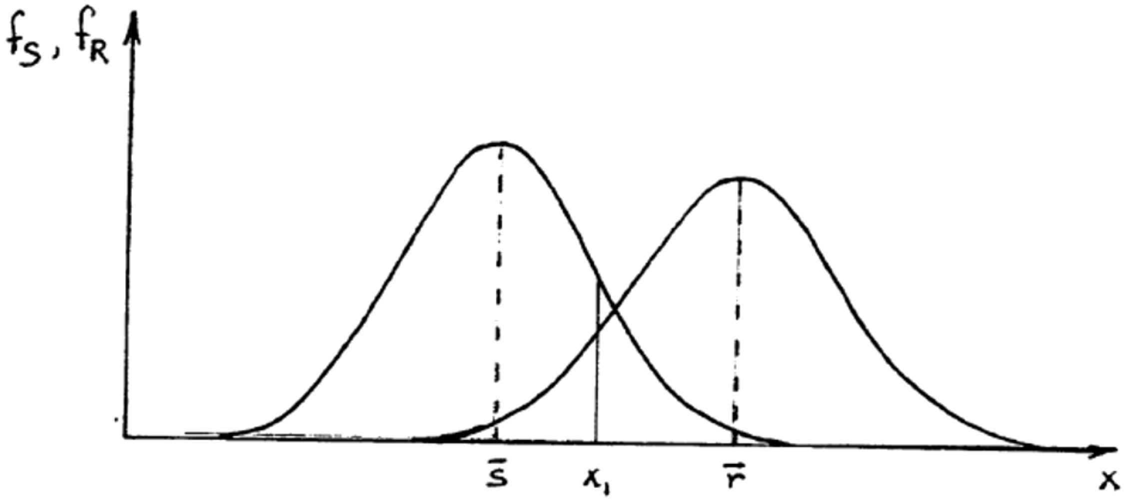


Figure 4-2 Density-functions for load-effects and capacity (Gudmestad, 2011).

The criteria for dimensioning are as before:

$$R - S \leq 0 \qquad \text{F 4-2}$$

From formula F 4-2 it is seen that even if the mean-value of resistance is greater than the mean value of load-effect:

$$\bar{r} - \bar{s} > 0 \qquad \text{F 4-3}$$

There can be a significant probability of fracture, and with basis from the Figure 4-2 this probability can be calculated. The probability that the load-effect is larger than a chosen value x_1 is given by:

$$P\,(S > s \mid s = x_1) = \int_{x_1}^{\infty} f_s\,(x)\,dx = 1 - F_s(x_1) \qquad \text{F 4-4}$$

Where F_s is the cumulative distribution of the load-effect S. The probability that the capacity is found in the region between x_1 and x_1 + dx is:

$$P\,(x_1 < R < x_1 + dx) = f_R\,(x_1)dx \qquad \text{F 4-5}$$

The probability for fracture when R = x_1 is:

$$dP_f = (1 - F_s\,(x_1))\,f_R\,(x_1)\,dx \qquad \text{F 4-6}$$

The total probability of fracture by integrating all possible x_1:

$$P_f = P(S > R) = \int_0^\infty (1 - F_s(x))\, f_R(x)dx = 1 - \int_0^\infty 1 - F_s(x)\, f_R(x)dx \tag{F 4-7}$$

The expression given in formula F 4-7 can be rewritten by partial integration:

$$P_f = \int_0^\infty F_R\,(x)\, f_S(x)dx \tag{F 4-8}$$

A constructions reliability is defined as the probability for e.g. that a construction can satisfy its functional requirement for a given time period under given conditions. If the probability of a fracture is p_f then the reliability r is given by:

$$r = 1 - p_f \tag{F 4-9}$$

The defined reliability is given as:

$$P_s = 1 - P_f = \int_0^\infty F_s\,(x) f_R(x)dx \tag{F 4-10}$$

In principal it is possible to determine P_f and P_s when the distribution functions for load-actions and resistance are given. The calculations of P_f and P_s are complex, and one can make use of simplified methods most of the time, such as the method of load and resistance factor design (LRFD) (Gudmestad, 2011).

4.3.2 Load and resistance factor design

The load and resistance factor design (LRFD) method springs out from a characteristic value for load and capacity, both defined by a probability-level (Annual probability of excess). All the codes adopt a load and resistance factor design (LRFD) also known as a limit state method. The design rules are based on use of the partial coefficient method for design, which are a design method that uses safety factors (partial coefficient) which separately takes the uncertainty of the different parameters that are appropriate in the structural design into account.

The basis for the LRFD philosophy is that the design load effect S_d does not exceed the design resistance R_d:

$$S_d \leq R_d \tag{F 4-11}$$

In each limit state the characteristic values of R_k and E_k of characteristic section capacity and characteristic load respectively is defined as:

$$R_k = m_R - k_R \cdot \sigma_R \tag{F 4-12}$$

$$S_k = m_E - k_E \cdot \sigma_E \tag{F 4-13}$$

Where m_R and m_E are the mean values, σ_R and σ_E are the standard deviation and k_R and k_E are the coefficients which defines the fractile for exceedance and under exceedance in the probability distribution of R_k and S_k respectively.

In order to achieve the intended reliability the dimensioning values for S_d and R_d is defined as:

$$S_d = \gamma_f R_k \qquad \textit{F 4-14}$$

$$R_d = \frac{\mathrm{R_k}}{\mathrm{\gamma_M}} \qquad \textit{F 4-15}$$

The partial coefficients γ_f and γ_m are introduced to compensate for that the chosen fractile levels for R_k and E_k are achieved. The partial coefficient γ_f maintains the possibility of unfavorable load deviations, the possibility of inaccurate load models and uncertainties in the calculation of the load effect. The partial coefficient γ_m takes care of the unfavorable deviation from the characteristic material values, the geometric deviations and also the uncertainties in the calculation model for capacity.

In Eurocode, NORSOK and ISO the fractiles level for exceedance and under exceedance of S_k and R_k are defined as 5% respectively.

The capacity control is done by checking that in all the limit states the following criteria is valid (Larsen, 2010a):

$$S_d = \gamma_f R_k \leq R_d = \frac{\mathrm{R_k}}{\mathrm{\gamma_M}} \qquad \textit{F 4-16}$$

Guidelines in determining the partial safety factors related to limit state design of steel structures is found in the design standards. The method of LRFD can be called a semi-probabilistic method, because it is stochastically defined, and has one given safety level. The process of dimensioning can be summed up as shown in Figure 4-3, where S and R are assumed to be independent quantities, the load action and the resistance calculations are assumed to be performed independently (Gudmestad, 2011).

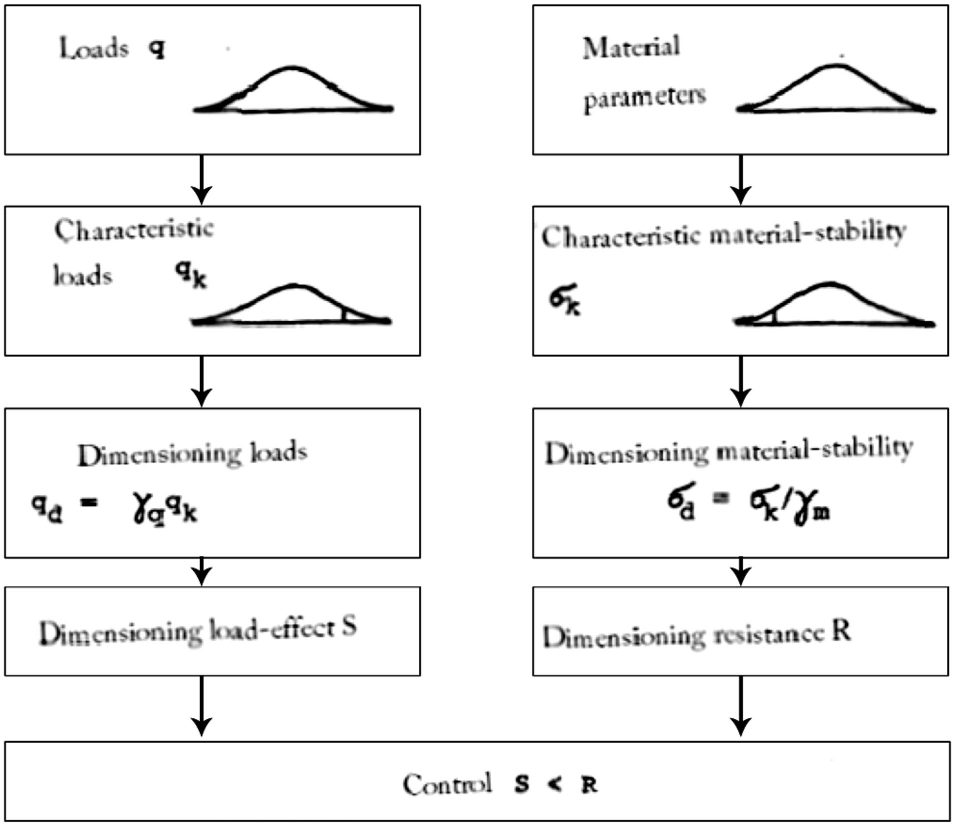


Figure 4-3 Dimensioning (Gudmestad, 2011).

5 COMPARISON OF TUBULAR MEMBER STRENGTH IN CODES AND STANDARDS

5.1 General

This section provides a comparison of tubular member strength in the structural design standards Eurocode 3 EN 1993-1-1, NORSOK N-004 and ISO 19902, and is referred in the text as Eurocode, NORSOK and ISO, respectively.

The comparison is also made through parametric studies, see chapter 6 and two case studies of a topside module see chapter 7 to 11.

- The formulas for Eurocode are provided in Eurocode 3 EN 1993-1-1 ref. (EN 1993-1-1, 2005).
- The formulas for NORSOK are provided in NORSOK N-004 ref. (NORSOK N-004, 2004).
- The formulas for NORSOK are provided in NORSOK N-004 ref. (ISO 19902, 2007).

5.2 Cross Section Classification

Eurocode defines four classes of cross-sections, the particular class the cross section falls within depends upon the slenderness of each element and the compressive stress distribution. The role of cross section classification is to identify the extent to which the resistance and rotation capacity of cross sections is limited by its local buckling resistance.

The four classes of cross sections are defined in EN-1993-1-1 is as follows:

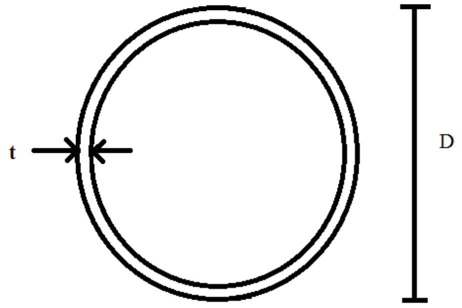
- Class 1 cross-sections are those which can form a plastic hinge with the rotation capacity required from plastic analysis without reduction of the resistance.
- Class 2 cross-sections are those which can develop their plastic moment resistance, but have limited rotation capacity because of local buckling.
- Class 3 cross-sections are those in which the stress in the extreme compression fibre of the steel member assuming an elastic distribution of stresses can reach the yield strength, but local buckling is liable prevent development of the plastic moment resistance.
- Class 4 cross-sections are those in which local buckling will occur before the attainment of yield stress in one or more parts of the cross-section.

The classification process can be summarized in four basic steps for tubular members:

1. Evaluate the slenderness ratio D/t
2. Evaluate the parameter $\varepsilon = \sqrt{\frac{235}{f_y}}$
3. Determine the class of that element based on limiting value of thickness ratio, according to the table below.
4. Classify the cross-section according to the least favorable classification

Extract from the table for cross sectional classification from EN 1993-1-1 is shown in Table 5-1, for determining the cross section class for tubular members (EN 1993-1-1, 2005)

Table 5-1 Cross section classification for tubular sections (EN 1993-1-1, 2005)

<table>
<tr><td colspan="7">Tubular Sections
 </td></tr>
<tr><th colspan="2">Class</th><th colspan="5">Section in bending and/or compression</th></tr>
<tr><td colspan="2">1</td><td colspan="5">$D / t \leq 50\ \varepsilon^2$</td></tr>
<tr><td colspan="2">2</td><td colspan="5">$D / t \leq 70\ \varepsilon^2$</td></tr>
<tr><td colspan="2">3</td><td colspan="5">$D / t \leq 90\ \varepsilon^2$</td></tr>
<tr><td rowspan="3">$\varepsilon = \sqrt{\frac{235}{f_y}}$</td><td>$f_y$</td><td>235</td><td>275</td><td>355</td><td>420</td><td>460</td></tr>
<tr><td>ε</td><td>1,00</td><td>0,92</td><td>0,81</td><td>0,75</td><td>0,71</td></tr>
<tr><td>ε^2</td><td>1,00</td><td>0,85</td><td>0,66</td><td>0,56</td><td>0,51</td></tr>
</table>

5.3 Material factor according to the codes

5.3.1 Material factor according to Eurocode

The general requirements for the material factor, γ_m is according to Eurocode 3 1993-1-1 is:

$$\gamma_{m0} = 1.0$$
$$\gamma_{m1} = 1.0$$
$$\gamma_{m2} = 1.25$$

Standard Norway decided not to deviate from the recommendations for nationally determined parameters unless additional information that justified other values (EN 1993-1-1, 2005). The requirement for the material factor, γ_{m} is according to Eurocode 3 1993-1-1 and the Norwegian National Annex for NS-EN 1993-1-1:

$$\begin{aligned}\gamma_{m0} &= 1.05\\ \gamma_{m1} &= 1.05\\ \gamma_{m2} &= 1.25\end{aligned}$$

5.3.2 Material factor according to NORSOK

The requirements for the material factor in general, γ_{m} is according to NORSOK N-004:

$$\gamma_m = 1.15$$

γ_{m} is according to NORSOK N-004 a variable safety factor dependent on the slenderness of the member considered used ($1.15 \leq \gamma_{\mathrm{m}} \leq 1.45$), the formulas for determining the material factor is given as:

$$\begin{aligned}\gamma_m &= 1.15 && \text{for } \bar{\lambda}_s < 0.5\\ \gamma_m &= 0.85 + 0.60\,\bar{\lambda}_{\mathrm{s}} && \text{for } 0.5 \leq \bar{\lambda}_s \leq 1.0\\ \gamma_m &= 1.45 && \text{for } \bar{\lambda}_s > 1.0\end{aligned}$$

Assume no hydrostatic pressure, and the reduced slenderness $\bar{\lambda}_{\mathrm{s}}$ becomes:

$$\bar{\lambda}_s = \frac{|\sigma_{c,Sd}|}{f_{cl}}\lambda_c \qquad \text{F 5-1}$$

Where $\lambda_c = \sqrt{\frac{f_y}{f_{cl}}}$ and f_{cl} is the characteristic local buckling strength derived in section 5.7.3 and the maximum combined design compressive stress $\sigma_{\mathrm{c,Sd}}$ is (NORSOK N-004, 2004):

$$\sigma_{c,Sd} = \frac{N_{Sd}}{A} + \frac{\sqrt{M_{y,Sd}^2 + M_{z,Sd}^2}}{W} \qquad \text{F 5-2}$$

5.3.3 Material factor according to ISO

The material factor is called the resistance factor in ISO 19902. The resistance factors in ISO varies for the force acting (ISO 19902, 2007):

$$\begin{aligned}\gamma_m &= 1.05 && \text{For tension}\\ \gamma_m &= 1.18 && \text{For compression}\\ \gamma_m &= 1.05 && \text{For bending}\\ \gamma_m &= 1.05 && \text{For shear}\end{aligned}$$

5.4 Material Validity

Eurocode 1993-1-1:2005 consider steel with yield strength of up to 460 Mpa whereas in NORSOK N-004 and ISO 19902 this limit is set to 500 Mpa. NORSOK and ISO have limits of applicability on the geometric slenderness, the standard is valid when the thickness $t \geq 6$ mm, and the diameter to thickness ratio is $D/t \leq 120$.

5.5 Axial Tension

The formulations for axial tension in Eurocode, NORSOK and ISO are identical. The design criteria for tubular members subjected to axial tension loads is:

$$\frac{N_{Ed}}{N_{t,Rd}} \leq 1{,}0 \qquad \textit{F 5-3}$$

Where the design tension resistance $N_{t,Rd}$ is:

$$N_{t,Rd} = \frac{A f_y}{\gamma_m} \qquad \textit{F 5-4}$$

The partial material factor γ_m is different in the three codes:

For Eurocode 1993-1-1	$\gamma_m = 1.05$
For NORSOK N-004	$\gamma_m = 1.15$
For ISO 19902	$\gamma_m = \gamma_{Rt} = 1.05$

Hence, in comparing the design resistance with respect to partial safety factor alone, NORSOK is 1.15/1.05 = 9.5 % more conservative than Eurocode and ISO in the capacity evaluations. The differences in the design tension resistance are entirely due to the differences in resistance factors.

5.6 Axial Compression

The formulas for axial compression are different in the three codes. Eurocode 1993-1-1:2005 states that the design values of the compression force N_{Ed} should be less than the design cross-sectional resistance of the sections to the uniform compression force $N_{c,Rd}$.

$$\frac{N_{Ed}}{N_{c,Rd}} \leq 1{,}0 \qquad \textit{F 5-5}$$

For cross sections in class 1, 2 or 3:

$$N_{c,Rd} = \frac{A f_y}{\gamma_{m0}} \qquad \textit{F 5-6}$$

For cross sections in class 4:

$$N_{c,Rd} = \frac{A_{eff}\, f_y}{\gamma_{m0}} \tag{F 5-7}$$

Eurocode 1993-1-1:2005 states that the general material factor is γ_{m0} = 1.0, according to the Norwegian National Annex the material factor is defined as γ_{m0} = 1.05. When slender cross section parts subjected to axial compression force can buckle locally it is important to distinguish between cross sections in 1, 2 and 3 where local buckling will not occur, and for cross sections in class 4 which can buckle locally (Larsen, 2010a). Only cross sectional class 1, 2 and 3 are considered in this report. For members subjected to overall buckling the design according to Eurocode should be based on the formulas in section 5.7.2.

The same level of axial compression capacity is provided in NORSOK and ISO, the only difference being that NORSOK operates with forces, while ISO operates with stress. The requirement for axial compression given in NORSOK states (NORSOK N-004, 2004):

$$N_{Sd} \leq N_{Rd} = \frac{A\, f_c}{\gamma_m} \tag{F 5-8}$$

The characteristic axial compression strength f_c is found in section 5.7.3. The partial resistance factor for axial compressive strength in ISO is set to $\gamma_{Rc} = \gamma_m$ = 1.18, while the range of material factors in NORSOK is 1.15 – 1.45, which is dependent on elastic local buckling strength.

The local buckling check in NORSOK and ISO is dependent on geometry and the elastic modulus of the members. A short tubular member that is subjected to axial compression will fail either by material yielding or by local buckling depending on the diameter to thickness (D/t) ratio, the upper limit for the D/t ratio is 120. Tubular members with low D/t ratio are not subjected to local buckling under axial compression and are designed with respect to material failure, where the local buckling stress is taken equal to the yield stress. For high D/t ratios the elastic local buckling strength will decrease, and the tubular member should be checked for local buckling.

The characteristic elastic local buckling stress, f_{xe} subjected to axial compression is:

$$f_{xe} = 2\, C_x\, E\, \frac{t}{D} \tag{F 5-9}$$

In which E is Young’s modulus of elasticity, t is the wall thickness of the member and D is the diameter of the member. In NORSOK the value for the elastic critical buckling coefficient, C_x is set to 0,3 while according to ISO the theoretical value is 0,6 but due to the tolerance limits for fabrication since the shells are very sensitive to imperfections a reduced value of C_x = 0,3 is used.

The characteristic local buckling strength, f_{yc} should be determined from:

for $\frac{f_y}{f_{xe}} \leq 0.170$ $$f_{yc} = f_y \tag{F 5-10}$$

for 0.170 $> \frac{f_y}{f_{xe}}$ $$f_{yc} = (1.047 - 0{,}274 \frac{f_y}{f_{xe}})\, f_y \qquad \textit{F 5-11}$$

A comparison between test data and the characteristic local buckling strength equation is plotted in Figure 5-1. Based on the test data, it is considered to be conservative for tubular members with t ≥ 6 mm and D/t ≤ 120, for thinner tubular and tubular with higher D/t ratios, larger imperfection reduction factors can be required. The development equations have a bias of 1,065, a standard deviation of 0,073, with a coefficient variation of 0,068.

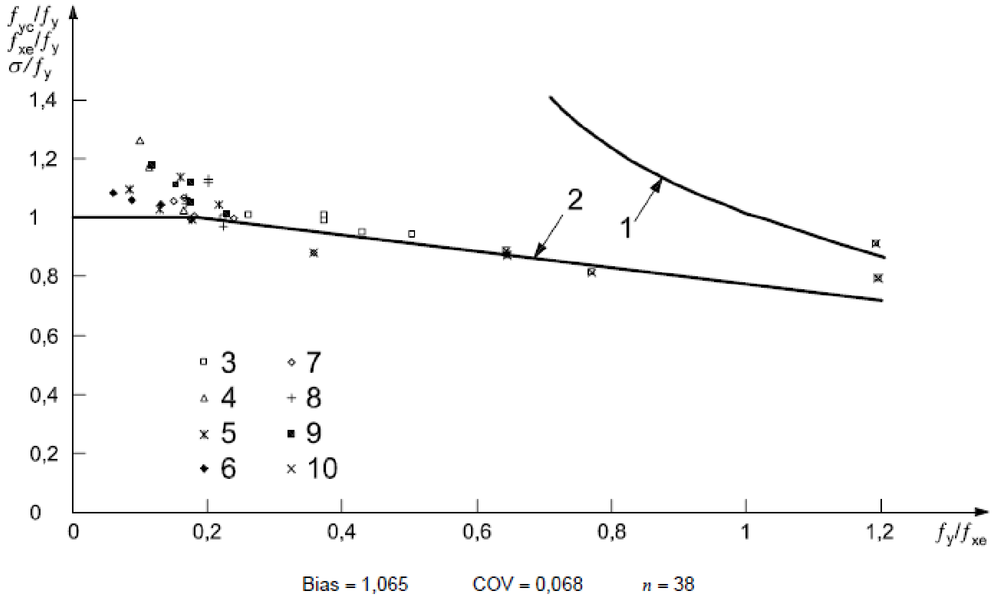


Figure 5-1 Comparison of test data and the local buckling strength equations subjected to axial compression (ISO 19902, 2007)

When the tubular member is subjected to buckling, there is a sudden drop in the load-carrying capacity of the member so the post-buckling reserve strength of tubular members is small. In contrast, the post-buckling behavior of flat plates in compression will usually continue to carry substantial load after local buckling. For this reason, there is a need for more conservatism in the definition of the buckling strength for tubular elements than for other structural elements, to achieve a robust design, the member geometry should be selected such that local buckling due to axial forces are avoided (ISO 19902, 2007).

The most significant difference in the three codes with respect to axial compression is particularly with respect to local buckling. Eurocode does not include local buckling in the formula, but takes care of the effect of local buckling through cross section classification, while NORSOK and ISO includes global and local buckling when determining the characteristic axial compressive strength f_c. When comparing the material factors, the design resistance in NORSOK varies between 1.15/1.18 = 97 % and 1.45/1.18 = 123 % of ISO. Eurocode adopts a lower capacity than NORSOK an ISO, meaning that Eurocode is more conservative.

5.7 Overall Column Buckling

5.7.1 General

Buckling is a form of collapse due to the stability of the cross section fails even though the stresses are below the yield strength. Buckling will always occur around the weakest axis, the weakest axis is the axis with the highest slenderness. The formulas in Eurocode are different than for NORSOK and ISO, and the description of the formulas are therefore divided into two sections.

5.7.2 Buckling resistance in Eurocode:

A compression member should be verified against buckling as follows:

$$\frac{N_{Ed}}{N_{b,Rd}} \leq 1.0 \qquad \textit{F 5-12}$$

Where:

N_{Ed} = Design value of the compression force
$N_{b,Rd}$ = Design buckling resistance of the compression member

The design buckling resistance, $N_{b,Rd}$ of a compression member is determined from:

For cross-section class 1, 2 and 3:

$$N_{b,Rd} = \frac{\chi f_y A}{\gamma_{M1}} \qquad \textit{F 5-13}$$

For cross-section class 4:

$$N_{b,Rd} = \frac{\chi f_y A_{eff}}{\gamma_{M1}} \qquad \textit{F 5-14}$$

Where χ is the reduction factor for the relevant buckling mode. Members with tapered sections or for non-uniform distribution of the compression force, a second order analysis can be carried out. The cross sectional classes are defined in section 5.2.

For axial compression in members, the reduction factor, χ:

$$\chi = \frac{f_k}{f_y} = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} \leq 1.0 \qquad \textit{F 5-15}$$

Where α is an imperfection factor and $\phi = 0.5\left[1 + \alpha(\bar{\lambda} - 0{,}2) + \bar{\lambda}^2\right]$.

The non-dimensional slenderness $\bar{\lambda}$ is determined from the different cross section classes.

For cross-section class 1, 2 and 3:

$$\bar{\lambda} = \sqrt{\frac{Af_y}{N_{cr}}} = \frac{L_{cr}}{i}\frac{1}{\lambda_1}$$

F 5-16

For cross-section class 4:

$$\bar{\lambda} = \sqrt{\frac{A_{eff}f_y}{N_{cr}}} = \frac{L_{cr}}{i}\frac{\sqrt{\frac{A_{eff}}{A}}}{\lambda_1}$$

F 5-17

In the formulas for the non-dimensional slenderness, i is the radius of gyration of the relevant axis, while $\lambda_1 = \pi\sqrt{f_y/E}$. N_{cr} is the elastic critical force for the relevant buckling mode based on the gross sectional properties. EN 1993-1-1 does not give any general information of calculation of the buckling length, L_{cr}which is a derived property used only for determination of the buckling reduction factor, χ.

The imperfection factor, α correcponding to the appropriate buckling curve should be obtained from Table 5-2. The buckling curve is determined from Table 5-3.

Table 5-2 Imperfection factors for buckling curves (Eurocode EN 1993-1-1)

Buckling Curve	a_o	a	b	c	d
Imperfection Factor α	0.13	0.21	0.34	0.49	0.76

The values for the reduction factor χ for the appropriate non-dimensional slenderness $\bar{\lambda}$ may be obtained from Figure 5-2.

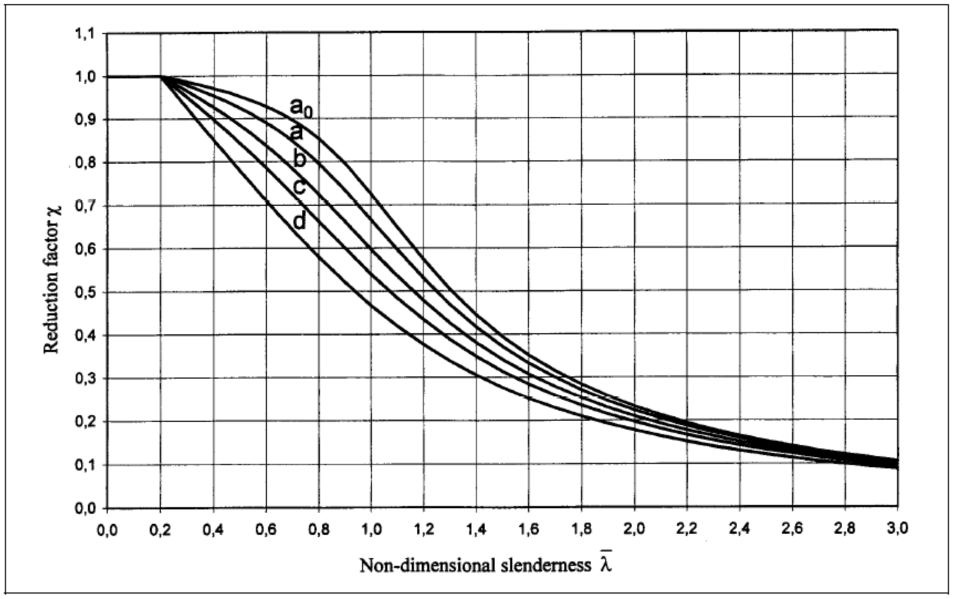
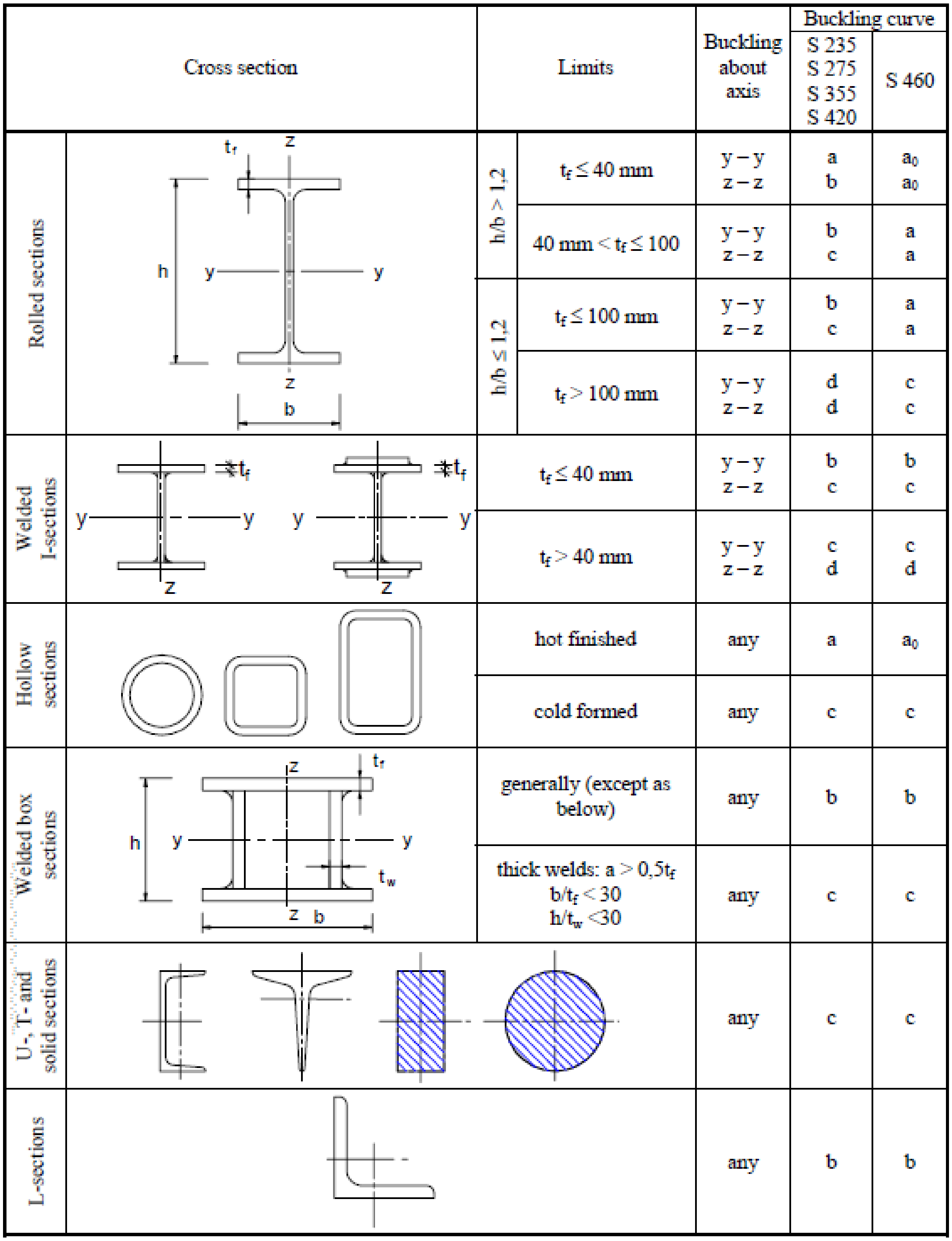


Figure 5-2 Buckling Curves (Eurocode EN 1993-1-1)

For slenderness $\bar{\lambda} \leq 0.2$ or for $\frac{N_{Ed}}{N_{cr}} \leq 0.04$ the buckling effect may be ignored and only cross sectional checks apply (Larsen, 2010a).

Table 5-3 Selection of buckling curves for the cross section (EN 1993-1-1, 2005)



Cross section		Limits		Buckling about axis	Buckling curve	
					S 235 S 275 S 355 S 420	S 460
Rolled sections		h/b > 1,2	$t_f \le 40$ mm	y – y z – z	a b	a_0 a_0
			40 mm < $t_f \le 100$	y – y z – z	b c	a a
		h/b ≤ 1,2	$t_f \le 100$ mm	y – y z – z	b c	a a
			$t_f > 100$ mm	y – y z – z	d d	c c
Welded I-sections		$t_f \le 40$ mm		y – y z – z	b c	b c
		$t_f > 40$ mm		y – y z – z	c d	c d
Hollow sections		hot finished		any	a	a_0
		cold formed		any	c	c
Welded box sections		generally (except as below)		any	b	b
		thick welds: $a > 0{,}5t_f$ $b/t_f < 30$ $h/t_w < 30$		any	c	c
U-, T- and solid sections				any	c	c
L-sections				any	b	b

5.7.3 Column Buckling NORSOK and ISO

NORSOK N-004 and ISO have the same approach for column buckling. The equation for the representative column buckling strength is a function of λ, which is a normalized form of column slenderness parameter given by $(f_{yc}/f_e)^{0.5}$ where f_{yc} is the local bucking strength of the cross section and f_e is the Euler buckling strength for a perfect column.

In the absence of hydrostatic pressure, the representative axial compressive strength, f_c for tubular members shall be the smaller of the in-plane and the out-of-plane buckling strengths (ISO 19902, 2007):

$$for\ \lambda \leq 1.34 \qquad f_c = (1.0 - 0.278\lambda^2) f_{yc} \qquad \textit{F 5-18}$$

$$for\ \lambda > 1.34 \qquad f_c = \frac{0.9}{\lambda^2} f_{yc} \qquad \textit{F 5-19}$$

Where the column slenderness parameter, λ is derived from:

$$\lambda = \sqrt{\frac{f_{yc}}{f_e}} = \frac{k}{\pi}\frac{L}{r}\sqrt{\frac{f_{yc}}{E}} \qquad \textit{F 5-20}$$

Where k is the effective buckling factor, r is the ratio of gyration, L is the unbraced length and f_{yc} is the local buckling strength of the cross section and f_e is the Euler buckling strength for a perfect column (NORSOK N-004, 2004). The representative axial compressive strength, f_c is set into the requirement for axial compression, formula F 5-8 in section 5.6 for NORSOK and ISO:

$$N_{Sd} \leq N_{Rd} = \frac{A\, f_c}{\gamma_m}$$

A comparison between the test tubular and the predictions by the equations are shown in Figure 5-3, together with the statistics of the fit. The bias is 1,057 and a COV of 0,041, no relevant data exist for $\lambda > 1.0$. The representative column strength equation can be seen to approximate a lower bound of the tested strength.

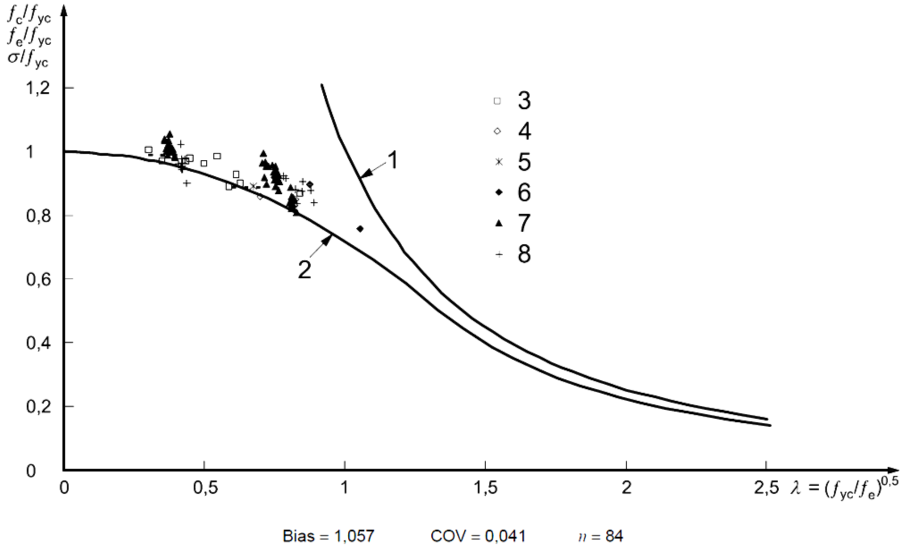


Figure 5-3 Comparison of test data with representative column buckling strength equations for fabricated cylinders subjected to axial compression (ISO 19902)

The range of the material factors in NORSOK is 1.15 -1.45 and depends on the local buckling strength ref. section 5.3.1, while the factor in ISO is set to 1.18 ref. section 5.3.3.

5.8 Bending Moment

The formulas for bending moment according to NORSOK and ISO are identical.

Eurocode states that the design value of the bending moment, M_{Ed} at each cross-section shall satisfy:

$$\frac{M_{Ed}}{M_{c,Rd}} \leq 1,0 \qquad \text{F 5-21}$$

The design resistance for bending, $M_{c,Rd}$ about one principal axis of a cross-section is:

For class 1 or 2 cross sections:

$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl} f_y}{\gamma_{M0}} \qquad \text{F 5-22}$$

For class 3 cross sections:

$$M_{c,Rd} = M_{el,Rd} = \frac{W_{el,min} f_y}{\gamma_{M0}} \qquad \text{F 5-23}$$

For class 4 cross sections:

$$M_{c,Rd} = \frac{W_{el,min} f_y}{\gamma_{M0}} \qquad F\ 5\text{-}24$$

Where W_{pl} is the plastic modulus when then cross section are in class 1 or 2, and $W_{el,min}$ is the elastic section modulus when the cross section is in class 3. Eurocode states that the general material factor is γ_{m0} = 1.0, according to the Norwegian National Annex the material factor is defined as γ_{m0} = 1.05.

The same level of bending capacity is provided in NORSOK and ISO, the difference is that NORSOK operates with forces, while ISO operates with stress. Tubular members subjected to bending loads should be designed to satisfy the following requirement (NORSOK N-004, 2004):

$$M_{Sd} \leq M_{Rd} = \frac{f_m W}{\gamma_M} \qquad F\ 5\text{-}25$$

Where f_m is the characteristic bending strength and W is the elastic section modulus. The partial resistance factor for axial compressive strength in ISO is set to $\gamma_{Rb} = \gamma_m$ = 1.05, while the range of material factors in NORSOK is 1.15 – 1.45, which is dependent on elastic local buckling strength. NORSOK is more conservative in the capacity evaluations, since the range of material factors is considerably higher.

The characteristic bending strength, f_m for tubular members shall be determined from:

$$for\ \frac{f_y D}{E\,t} \leq 0{,}0517 \qquad f_m = \frac{Z}{W} f_y \qquad F\ 5\text{-}26$$

$$for\ 0{,}0517 < \frac{f_y D}{E\,t} \leq 0{,}103 \qquad f_m = \left(1.13 - 2.58\left(\frac{f_y D}{E\,t}\right)\right)\left(\frac{Z}{W}\right) f_y \qquad F\ 5\text{-}27$$

$$for\ 0{,}1034 < \frac{f_y D}{E\,t} \leq 120\frac{f_y}{E} \qquad f_m = \left(0.94 - 0.76\left(\frac{f_y D}{E\,t}\right)\right)\left(\frac{Z}{W}\right) f_y \qquad F\ 5\text{-}28$$

Where:

W = Elastic section modulus = $\frac{\pi}{32}\frac{(D^4 - (D-2t)^4)}{D}$

Z = Plastic section modulus = $\frac{1}{6}(D^3 - (D-2t)^3)$

The bending strength equations in NORSOK and ISO contain elastic section modulus, plastic section modulus and yield strength. The approach in NORSOK and ISO allows full plasticity in the section and therefore allow the section to go beyond first yield for $\frac{f_y D}{E\,t} \leq 0.0517$, whereas the Eurocode allows for full plasticity for cross sections in class 1 and 2 only.

5.9 Biaxial bending

Biaxial bending is bending of a member about two perpendicular axes at the same time. Eurocode provides the following criteria for biaxial bending for cross sectional class 1 and 2:

$$\left[\frac{M_{y,Ed}}{M_{N,y,Rd}}\right]^{\alpha} + \left[\frac{M_{z,Ed}}{M_{N,z,Rd}}\right]^{\beta} \leq 1.0 \tag{F 5-29}$$

In which α and β are constants, for circular hollow sections α = 2 and β = 2.

For cross section class 3 a conservative approximation of linear summation of the utilization ratios for each stress resultant may be used when the member is subjected to biaxial bending:

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} + \frac{M_{z,Ed}}{M_{z,Rd}} \leq 1.0 \tag{F 5-30}$$

where:

N_{Ed}	Design normal force.
N_{Rd}	Design values of the resistance to normal forces.
$M_{y,Ed}$, $M_{z,Ed}$	Design bending moment, y-y axis and z-z axis, respectively.
$M_{y,Rd}$, $M_{z,Rd}$	Design values of the resistance to bending moment, y-y and z-z axis, respectively.

NORSOK and ISO do not provide general design guidance on tubular members subjected to biaxial bending. However, the formulas for combined axial compressive force and bending assuming no axial force can be used:

$$\frac{N_{sd}}{N_{c,Rd}} + \frac{1}{M_{Rd}}\left\{\left[\frac{C_{my}\, M_{y,Sd}}{1-\frac{N_{sd}}{N_{ey}}}\right]^{2} + \left[\frac{C_{mz}\, M_{z,Sd}}{1-\frac{N_{sd}}{N_{ez}}}\right]^{2}\right\}^{0.5} \leq 1{,}0 \tag{F 5-31}$$

and

$$\frac{N_{sd}}{N_{cl,Rd}} + \frac{\sqrt{{M_{y,Sd}}^{2} + {M_{z,Sd}}^{2}}}{M_{Rd}} \leq 1{,}0 \tag{F 5-32}$$

where:

$M_{y,Sd}$, $M_{z,Sd}$	Design bending moment to the member y and z axes, respectively.
N_{sd}	Design axial compression force
$N_{cl,Rd}$	Design axial local buckling resistance
N_{ey}, N_{ez}	Euler buckling strengths corresponding to the member y and z axes, respectively
C_{my}, C_{mz}	Moment reduction factors corresponding to the member y and z axis, respectively

5.10 Uniform Members in Bending and Axial compression

The formulae for uniform members subjected to bending and axial compression in Eurocode is different to the formulas provided in NORSOK and ISO. Therefore the formulas in the codes are presented in two sections.

5.10.1 Uniform Members in Bending and Axial compression in Eurocode

A real member with initial deformation, residual stresses and variation of yield strength is replaced by a homogeneous model member with the same geometry but with an equivalent deformation with amplitude e^*. The amplitude e^* of the equivalent deformation accounts for the distribution and magnitude of residual stresses, variation in initial deformations, residual stresses and the variation of the yield strength etc, and the information is contained in the column buckling curves, ref section 5.7.2.

The capacity of the homogeneous model member is determined by the cross sectional capacity at the critical section (Larsen, 2010b):

$$\frac{N_{Ed}}{N_{pl,Rd}} + \frac{1}{1-\frac{N_{Ed}}{N_{Cr}}} \frac{N_{Ed}\, e^*}{M_{pl,Rd}} \leq 1{,}0 \qquad F\ 5\text{-}33$$

At incipient buckling:

$$N_{ed} = N_{b,Rd} = \chi\, N_{pl,Rd} \qquad F\ 5\text{-}34$$

Introducing the definition of the reduced slenderness:

$$\bar{\lambda}^2 = \frac{N_{pl,Rd}}{N_{cr}} \qquad F\ 5\text{-}35$$

The amplitude can be expressed by:

$$e^* = \frac{1-\chi}{\chi}\left(1-\chi\,\bar{\lambda}^2\right)\frac{M_{pl,Rd}}{N_{pl,Rd}} = \frac{1-\chi}{\chi}\left(1-\chi\,\bar{\lambda}^2\right)\frac{W_{pl}}{A} \qquad F\ 5\text{-}36$$

Interaction equations are based on the elastic cross sectional capacity, of the model member subjected to axial force N and first order moment.

Elastic capacity after first order theory:

$$\sigma_{\max} = \frac{N_{Ed}}{A} + \frac{M_{Ed} + N_{Ed}\, e^*}{W_{el}} \leq f_y \qquad F\ 5\text{-}37$$

Elastic capacity after second order theory:

$$\frac{N_{Ed}}{A\,f_y} + \frac{1}{1-\frac{N_{Ed}}{N_{Cr}}}\,\frac{(M_{Ed} + N_{Ed}\,e^{*})}{f_y W_{el}} \leq 1.0 \tag{F 5-38}$$

Replacing $M_{el} = f_y W_{el}$ by $M_{pl} = f_y W_{pl}$ a linear interaction between $N_{pl,Rd}$ and $M_{pl,Rd}$ is obtained:

$$\frac{N_{Ed}}{N_{pl,Rd}} + \frac{1}{1-\frac{N_{Ed}}{N_{Cr}}}\,\frac{(M_{Ed} + N_{Ed}\,e^{*})}{M_{pl,Rd}} \leq 1.0 \tag{F 5-39}$$

The maximum first and second order moments do not necessarily occur at the same section, and M_{Ed} is replaced by $C_m M_{Ed}$, which gives us the interaction expression:

$$\frac{N_{Ed}}{N_{pl,Rd}} + \frac{1}{1-\frac{N_{Ed}}{N_{Cr}}}\,\frac{C_m M_{Ed} + N_{Ed}\,e^{*}}{M_{pl,Rd}} \leq 1.0 \tag{F 5-40}$$

Introducing the expression found for the amplitude e^{*} for the interaction equation the formula for member which are subjected to combined bending and axial compression force should satisfy:

$$\frac{N_{Ed}}{\frac{\chi_y N_{Rk}}{\gamma_{M1}}} + kyy\,\frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}} + kyz\,\frac{M_{z,Ed} + \Delta M_{z,Ed}}{\chi_{LT}\frac{M_{z,Rk}}{\gamma_{M1}}} \leq 1{,}0 \tag{F 5-41}$$

$$\frac{N_{Ed}}{\frac{\chi_z N_{Rk}}{\gamma_{M1}}} + kzy\,\frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}} + kzz\,\frac{M_{z,Ed} + \Delta M_{z,Ed}}{\chi_{LT}\frac{M_{z,Rk}}{\gamma_{M1}}} \leq 1{,}0 \tag{F 5-42}$$

Where:

N_{Ed}	The design values of the compression force
$M_{y,Ed}, M_{z,Ed}$	The maximum moments about the y-y and z-z axis along the member
$\Delta M_{y,Ed}, \Delta M_{z,Ed}$	The moments due to the shift and the centroidal axis for class 4 sections.
χ_y, χ_z	Reduction factors due to flexural buckling,
χ_{LT}	χ_{LT} =1,0 for members not susceptible to torsional deformation
k_{yy}, k_{yz}, k_{zy}, k_{zz}	Interaction factors

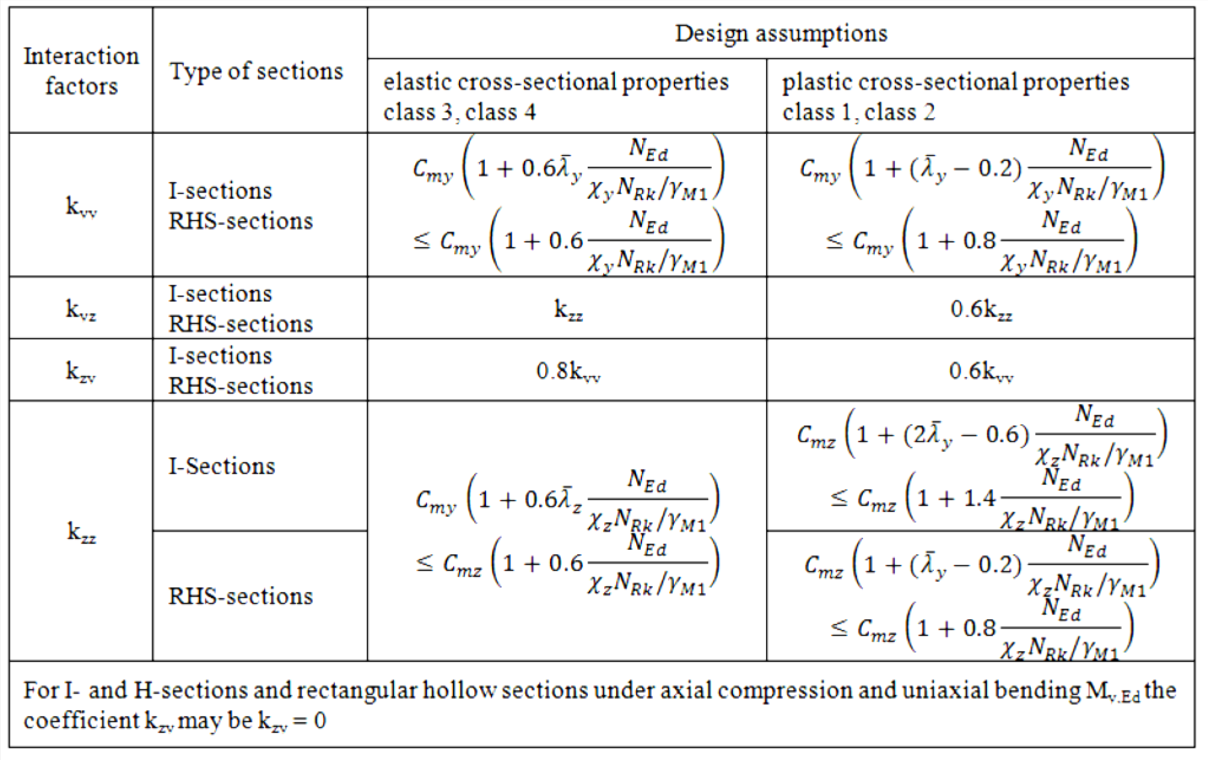
The interaction factors k_{yy}, k_{yz}, k_{zy}, k_{zz} account for geometric amplification and moment modification factor C_m (Larsen, 2010b). NS EN 1993-1-1 gives two sets of expression for k_{ij}, method 1 (Annex A) and method 2 (Annex B). The two methods can be used equally, since it is a national choice and NS-En 1993-1-1 gives no recommendation (EN 1993-1-1, 2005).
The interactions formula for Method 2 (Annex B) for members not subjected to torsion is used in this thesis and is found in Table 5-4 to Table 5-6.

For more detailed information on the derivation of the combined bending and axial compression formulas, reference is given to "Dimensjonering av stålkonstruksjoner av Per Kr. Larsen" (Larsen, 2010a).

A conservative approximation of linear summation of the utilization ratios for each stress resultant may be used when the member is subjected to the combination of bending and axial compression (EN 1993-1-1, 2005):

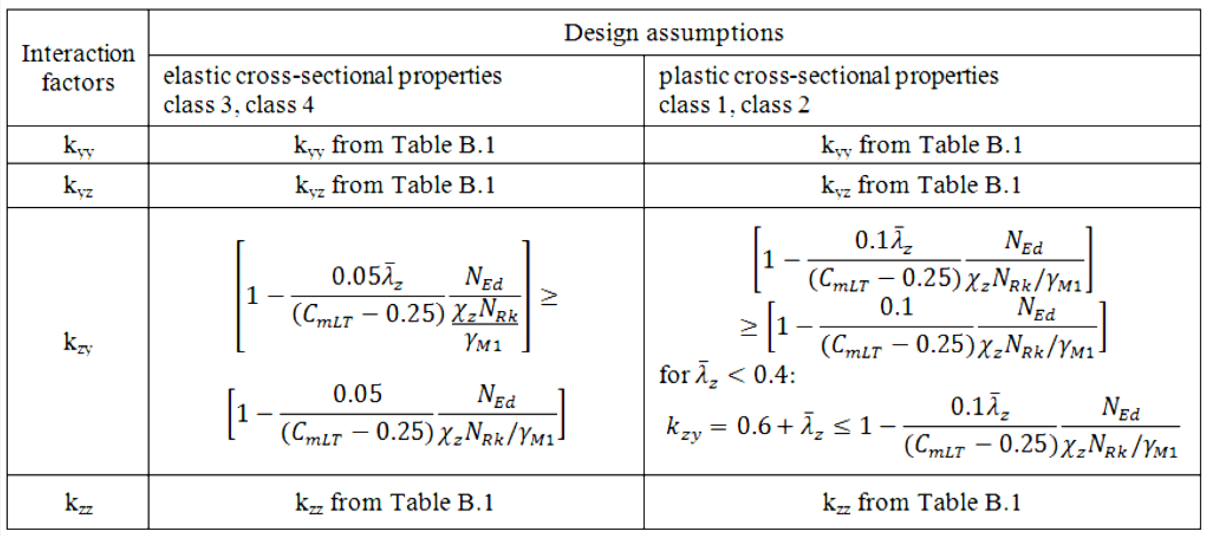
$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} + \frac{M_{z,Ed}}{M_{z,Rd}} \leq 1.0 \qquad \text{F 5-43}$$

Table 5-4 Annex B: Interaction factors kij for members not susceptible to torsional deformations (EN 1993-1-1, 2005)



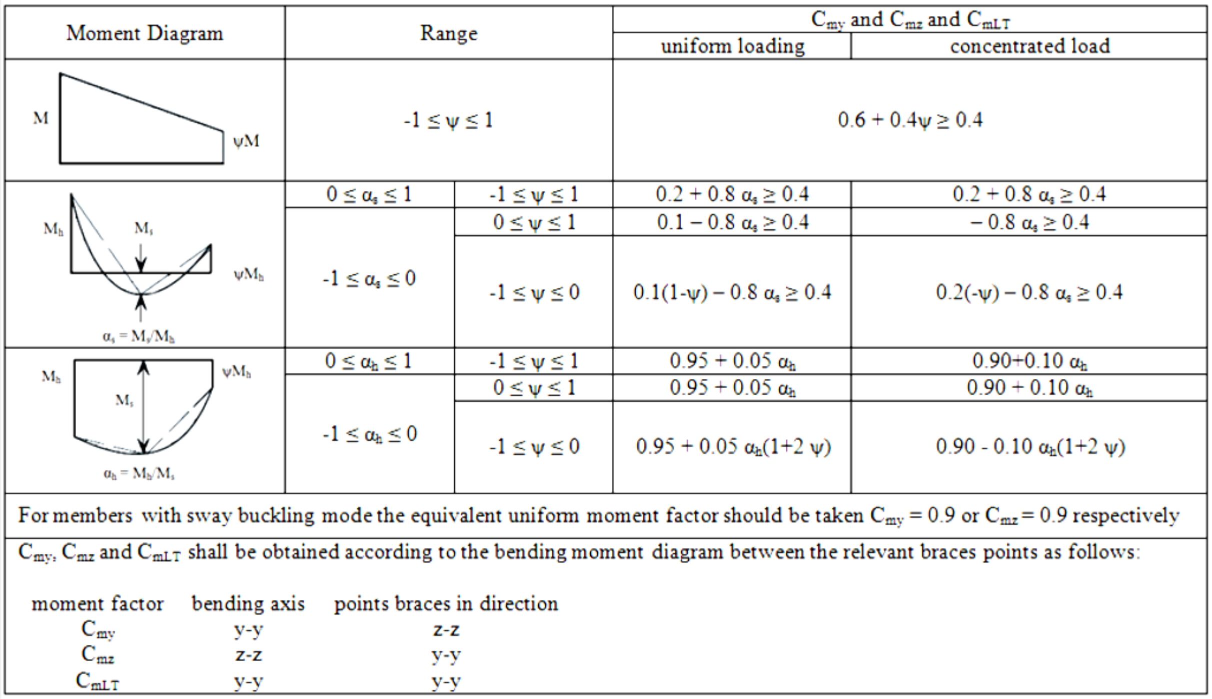
Interaction factors	Type of sections	Design assumptions	
		elastic cross-sectional properties class 3, class 4	plastic cross-sectional properties class 1, class 2
k_{yy}	I-sections RHS-sections	$C_{my}\left(1+0.6\bar{\lambda}_y\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}}\right)$ $\leq C_{my}\left(1+0.6\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}}\right)$	$C_{my}\left(1+(\bar{\lambda}_y-0.2)\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}}\right)$ $\leq C_{my}\left(1+0.8\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}}\right)$
k_{yz}	I-sections RHS-sections	k_{zz}	$0.6k_{zz}$
k_{zy}	I-sections RHS-sections	$0.8k_{yy}$	$0.6k_{yy}$
k_{zz}	I-Sections	$C_{my}\left(1+0.6\bar{\lambda}_z\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$ $\leq C_{mz}\left(1+0.6\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$	$C_{mz}\left(1+(2\bar{\lambda}_y-0.6)\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$ $\leq C_{mz}\left(1+1.4\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$
	RHS-sections		$C_{mz}\left(1+(\bar{\lambda}_y-0.2)\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$ $\leq C_{mz}\left(1+0.8\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right)$
For I- and H-sections and rectangular hollow sections under axial compression and uniaxial bending $M_{y,Ed}$ the coefficient k_{zy} may be $k_{zy} = 0$			

Table 5-5 Annex B: Interaction factors kij for members susceptible to torsional deformations (EN 1993-1-1, 2005)



Interaction factors	Design assumptions	
	elastic cross-sectional properties class 3, class 4	plastic cross-sectional properties class 1, class 2
k_{yy}	k_{yy} from Table B.1	k_{yy} from Table B.1
k_{yz}	k_{yz} from Table B.1	k_{yz} from Table B.1
k_{zy}	$\left[1-\frac{0.05\bar{\lambda}_z}{(C_{mLT}-0.25)}\frac{N_{Ed}}{\frac{\chi_z N_{Rk}}{\gamma_{M1}}}\right] \geq$ $\left[1-\frac{0.05}{(C_{mLT}-0.25)}\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right]$	$\left[1-\frac{0.1\bar{\lambda}_z}{(C_{mLT}-0.25)}\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right]$ $\geq \left[1-\frac{0.1}{(C_{mLT}-0.25)}\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}\right]$ for $\bar{\lambda}_z < 0.4$: $k_{zy} = 0.6+\bar{\lambda}_z \leq 1-\frac{0.1\bar{\lambda}_z}{(C_{mLT}-0.25)}\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}}$
k_{zz}	k_{zz} from Table B.1	k_{zz} from Table B.1

Table 5-6 Annex B: Equivalent uniform factors Cm for National Annex B (EN 1993-1-1, 2005)



Moment Diagram	Range		C_{my} and C_{mz} and C_{mLT}	
			uniform loading	concentrated load
M ψM	$-1 \leq \psi \leq 1$		$0.6 + 0.4\psi \geq 0.4$	
M_h M_s ψM_h $\alpha_s = M_s/M_h$	$0 \leq \alpha_s \leq 1$	$-1 \leq \psi \leq 1$	$0.2 + 0.8\,\alpha_s \geq 0.4$	$0.2 + 0.8\,\alpha_s \geq 0.4$
	$-1 \leq \alpha_s \leq 0$	$0 \leq \psi \leq 1$	$0.1 - 0.8\,\alpha_s \geq 0.4$	$-0.8\,\alpha_s \geq 0.4$
		$-1 \leq \psi \leq 0$	$0.1(1-\psi) - 0.8\,\alpha_s \geq 0.4$	$0.2(-\psi) - 0.8\,\alpha_s \geq 0.4$
M_h ψM_h M_s $\alpha_h = M_h/M_s$	$0 \leq \alpha_h \leq 1$	$-1 \leq \psi \leq 1$	$0.95 + 0.05\,\alpha_h$	$0.90+0.10\,\alpha_h$
	$-1 \leq \alpha_h \leq 0$	$0 \leq \psi \leq 1$	$0.95 + 0.05\,\alpha_h$	$0.90 + 0.10\,\alpha_h$
		$-1 \leq \psi \leq 0$	$0.95 + 0.05\,\alpha_h(1+2\,\psi)$	$0.90 - 0.10\,\alpha_h(1+2\,\psi)$
For members with sway buckling mode the equivalent uniform moment factor should be taken $C_{my} = 0.9$ or $C_{mz} = 0.9$ respectively				
C_{my}, C_{mz} and C_{mLT} shall be obtained according to the bending moment diagram between the relevant braces points as follows:				

moment factor	bending axis	points braces in direction
C_{my}	y-y	z-z
C_{mz}	z-z	y-y
C_{mLT}	y-y	y-y

5.10.2 Uniform Members in Bending and Axial compression in NORSOK and ISO

The same level of combined axial compression and bending capacity is provided in NORSOK and ISO, the only difference is that NORSOK operates with strength, while ISO operates with stress. The requirement for combined axial compression and bending given in NORSOK states that tubular members subjected to combined axial compression and bending should be designed to satisfy the following conditions at all cross sections along their length:

$$\frac{Nsd}{Nc,Rd} + \frac{1}{M_{Rd}} \left\{ \left[\frac{C_{my}\ M_{y,Sd}}{1 - \frac{Nsd}{Ney}} \right]^2 + \left[\frac{C_{mz}\ M_{z,Sd}}{1 - \frac{Nsd}{Nez}} \right]^2 \right\}^{0.5} \leq 1{,}0 \qquad \textit{F 5-44}$$

And

$$\frac{Nsd}{Ncl,Rd} + \frac{\sqrt{{M_{y,Sd}}^2 + {M_{z,Sd}}^2}}{M_{Rd}} \leq 1{,}0 \qquad \textit{F 5-45}$$

where:

M_{Sd}	Design bending moment
N_{Sd}	Design axial compression force
$N_{cl,Rd}$	Design axial local buckling resistance
N_{Ey}, N_{Ez}	Euler buckling strengths corresponding to the member y and z axes
C_{my}, C_{mz}	Moment reduction factors corresponding to the member y and z axis

The equation for the design axial local buckling resistance, $N_{cl,Rd}$ is presented as:

$$N_{cl,Rd} = \frac{A \cdot f_{cl}}{\gamma_m} \qquad \textit{F 5-46}$$

Euler buckling strengths corresponding to the member y and z axes:

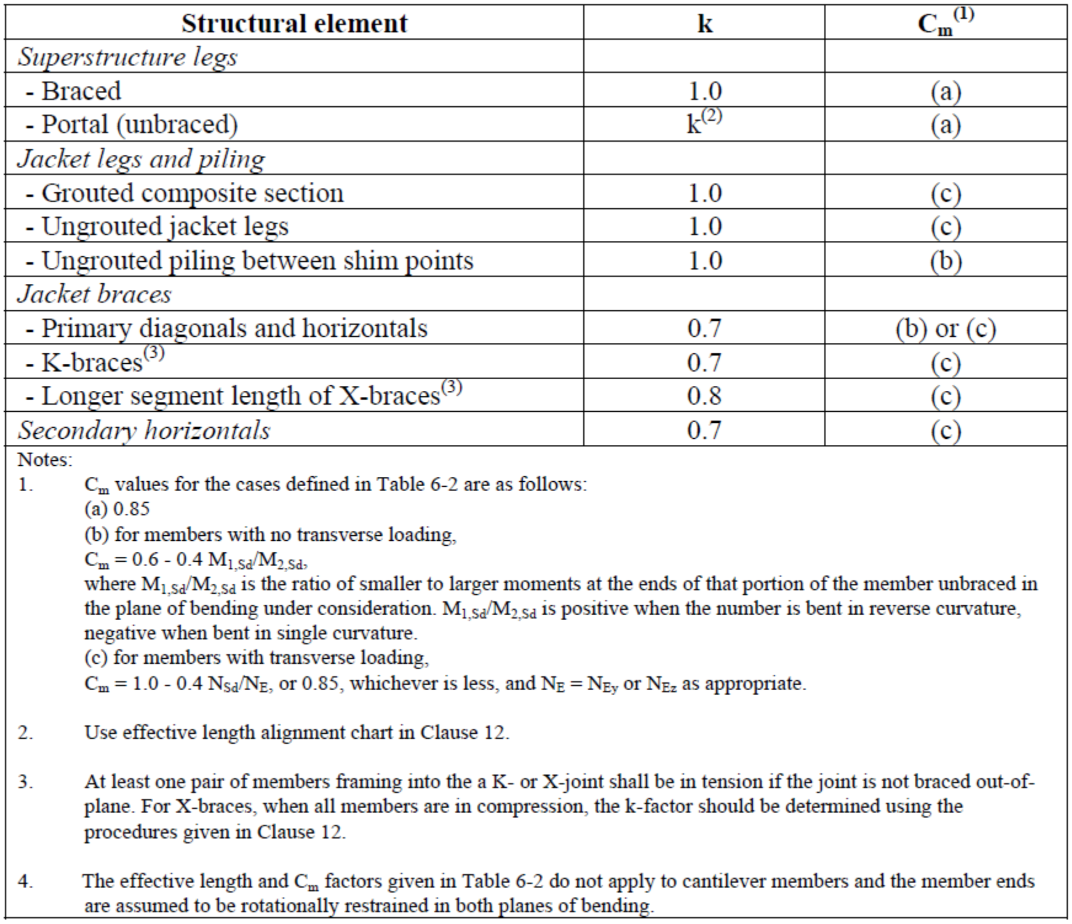
$$N_{Ey} = \frac{\pi^2\ EA}{\left[\frac{kl}{i}\right]_y^2}$$

$$N_{Ez} = \frac{\pi^2\ EA}{\left[\frac{kl}{i}\right]_z^2}$$

K in the formulas for N_{Ey}, N_{Ez} are related to buckling in the y and z direction, respectively. These factors can be determined using a rational analysis that includes joint flexibility and side sway.

In lieu of such a rational analysis, values of effective length factors, k, and moment reduction factors C_m, may be taken from Table 5-7, all lengths are measured centerline to centerline (NORSOK N-004, 2004).

Table 5-7 Effective length and moment reduction factors for member strength checking (NORSOK N-004, 2004)



Structural element	**k**	**C_m**$^{(1)}$
Superstructure legs		
- Braced	1.0	(a)
- Portal (unbraced)	$k^{(2)}$	(a)
Jacket legs and piling		
- Grouted composite section	1.0	(c)
- Ungrouted jacket legs	1.0	(c)
- Ungrouted piling between shim points	1.0	(b)
Jacket braces		
- Primary diagonals and horizontals	0.7	(b) or (c)
- K-braces$^{(3)}$	0.7	(c)
- Longer segment length of X-braces$^{(3)}$	0.8	(c)
Secondary horizontals	0.7	(c)

Notes:

1. C_m values for the cases defined in Table 6-2 are as follows:
   (a) 0.85
   (b) for members with no transverse loading,
   $C_m = 0.6 - 0.4\ M_{1,Sd}/M_{2,Sd}$,
   where $M_{1,Sd}/M_{2,Sd}$ is the ratio of smaller to larger moments at the ends of that portion of the member unbraced in the plane of bending under consideration. $M_{1,Sd}/M_{2,Sd}$ is positive when the number is bent in reverse curvature, negative when bent in single curvature.
   (c) for members with transverse loading,
   $C_m = 1.0 - 0.4\ N_{Sd}/N_E$, or 0.85, whichever is less, and $N_E = N_{Ey}$ or N_{Ez} as appropriate.

2. Use effective length alignment chart in Clause 12.

3. At least one pair of members framing into the a K- or X-joint shall be in tension if the joint is not braced out-of-plane. For X-braces, when all members are in compression, the k-factor should be determined using the procedures given in Clause 12.

4. The effective length and C_m factors given in Table 6-2 do not apply to cantilever members and the member ends are assumed to be rotationally restrained in both planes of bending.

5.11 Discussion of the formulas in the design standards

All the design standards provide formulas for load effects acting alone and in combination. The comparison is also made through a parameter study in chapter 6 and two case studies of a topside module in chapters 7 to 11. The results for the comparison of the formulas in the three design standards are summed up and discussed in this section.

Eurocode, NORSOK and ISO provide identical formulas for axial tension, the differences in the design tension resistance are entirely due to the differences in the material factors. Hence, one may conclude that NORSOK is 1.15/1.05 = 9.5 % more conservative than Eurocode and ISO in the capacity evaluations.

The most significant difference in the three codes with respect to axial compression is particularly with respect to local buckling. Eurocode does not include local buckling in the formula, but takes care of the effect of local buckling through cross section classification. NORSOK and ISO includes global and local buckling when determining the characteristic axial compressive strength f_c. When comparing the material factors, the design resistance in NORSOK varies between 1.15/ 1.18 = 97 % and 1.45/1.18 = 123 % of ISO. Eurocode adopts a lower capacity than NORSOK an ISO, meaning that Eurocode is more conservative.

Eurocode provides formulas for biaxial bending for cross sectional class 1 and 2, whereas for cross sectional 3, a conservative approximation of linear summation of the utilization ratios for each stress resultant is provided. NORSOK and ISO do not provide general design guidance on tubular members subjected to biaxial bending. However, the formulas for combined bending and axial compression force assuming no axial force can be used.

The formulas for uniform members subjected to a combination of bending and axial compression in Eurocode is different to the formulas provided in NORSOK and ISO.

6 PARAMETERSTUDY OF SINGLE SPAN SIMPLY SUPPORTED TUBULAR MEMBERS

6.1 General

The parameter study is based on two single span simply supported tubular members. The aim of the parametric study is to determine the similarities and differences in the formulas provided in Eurocode (EN 1993-1-1, 2005), NORSOK (NORSOK N-004, 2004) and ISO (ISO 19902, 2007). All the analysis conducted in the parameter study can be found in Appendix A-1, an extract of the input file for member 1 subjected to bi-axial bending in Sesam:Genie are found in Appendix A-4.

Two tubular members with same thickness and different diameters are considered. The tubular members have lengths of 10 and 15 m to account for the difference in slenderness.

Eurocode is used as a basis for the parameter study and the code check results are compared with NORSOK and ISO. Eurocode operates with different cross section classes, and the effects of the different cross section classes are considered. In cross section class 1 and 2, the calculations are based on plastic theory, while in cross section class 3 and 4 the calculations are based on elastic theory. Eurocode and NORSOK operate with forces, while ISO uses stress in the formulas.

The code checking of the single span simply supported members are done in SESAM: Genie, were Sesam Genie provides adequate code checks according to requirements given in Eurocode, NORSOK and ISO. All the partial resistance factors and the load factors are set to 1.0, so that there is no hidden safety and only the similarities and differences in the formulas are considered.

The utilization ratio, UC, is a measure of the capacity of the member when subjected to forces, a member is fully utilized when the UC is 1.0. All design according to Eurocode, NORSOK and ISO is based on the principal that UC < 1.0.

6.2 Input Data

6.2.1 Tubular member data

The input design data for the tubular members are given in Table 6-1:

Table 6-1 Input design data for tubular members

Section	Diameter [m]	Thickness [m]	Length [m]
Tubular member 1	0,457	0,0127	10
Tubular member 1	0,457	0,0127	15
Tubular member 2	0,610	0,0127	10
Tubular member 2	0,610	0,0127	15

6.2.2 Material Data

In the parameter study the steel quality S355 is used for the single span simply supported tubular members. According to section 3.2 and table 3.1 in EN-1993-1-1 the nominal values for the steel grade S355 is (EN 1993-1-1, 2005):

Yield strength	f_y =	355 N/mm^2
Ultimate tensile strength	f_u =	510 N/mm^2

Pursuant to EN-1993-1-1, the following design values should be adopted for calculations in structural steel (EN 1993-1-1, 2005).

Modulus of Elasticity	E =	2.1 x 10^5 N/mm^2
Shear Modulus	G =	81 000 N/mm^2
Poisson's Ratio	ν =	0.3
Density	ρ =	7850 kg/m^3

6.3 Limitations for the parameter study of single member

The following limitations are prevailed for the parameter study of the single span simply supported members:

- Tubular cross section
- Single member check
- Regulations: Eurocode EN-1993-1-1/ NORSOK N-004 / ISO 19902
- Material S355

6.4 Axial Tension

The formulas for axial tension in Eurcode, NORSOK and ISO are identical, and since the partial factors and load factors are set equal to 1.0, it can be concluded that there is no difference in the three codes for axial tension, ref section 5.5.

Unlike compression members, tension members do not fail by buckling and is thus a stress problem. The capacity for tubular member 1 and 2 are 6250 kN and 8500 kN, respectively.

6.5 Axial Compression

The parameter study will study the effect of increasing axial compression on single span simply supported tubular members, with a length of 10 m and a length of 15 m. The parameter study on axial compression is to determine the effect, similarities and differences in the formulas used in Eurocode, NORSOK and ISO, ref section 5.6.

6.5.1 Axial Compression, Tubular member 1, cross sectional class 2, L = 10m

Figure 6-1 illustrates the tubular member 1 when subjected to increasing axial compression force in the range of 0 to 6000 kN. The length of the tubular member is 10 m and according to Eurocode tubular member 1 is in cross sectional class 2.

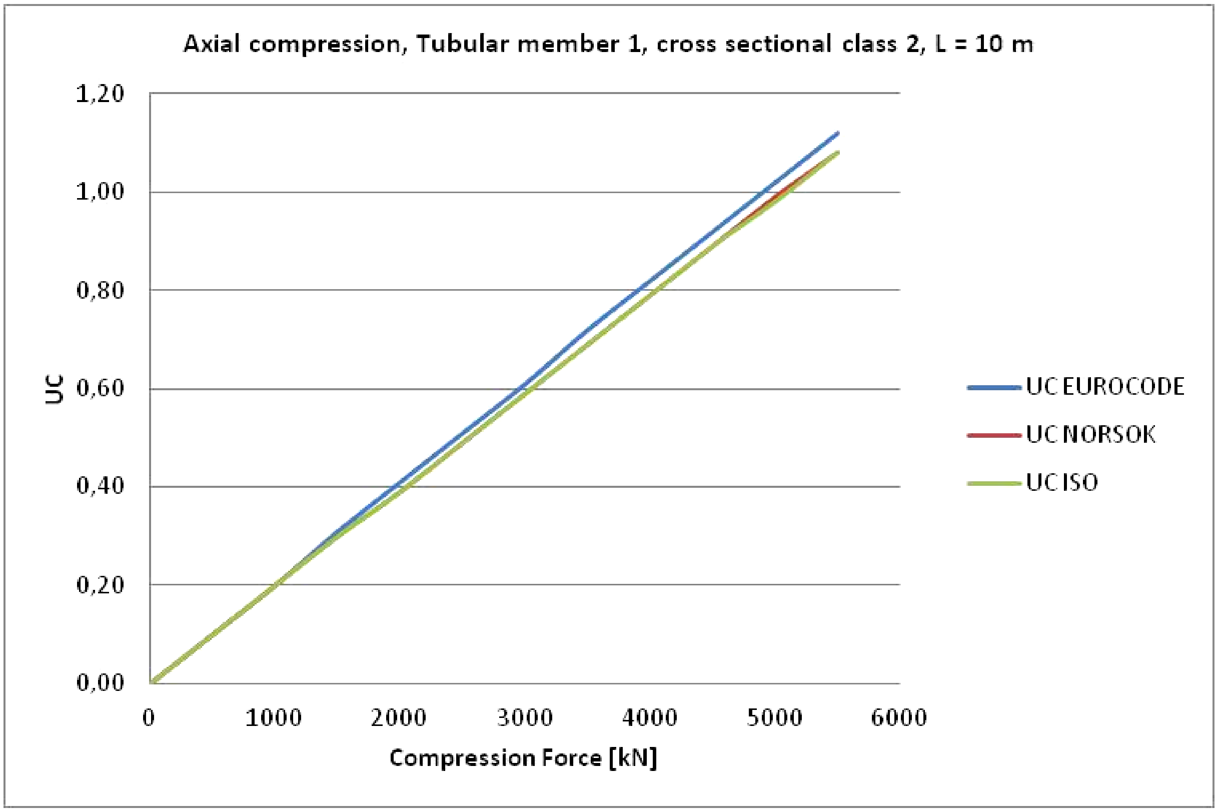


Figure 6-1 Axial Compression - Member 1 - Cross sectional class 2, L=10m

The graph increases linearly, the slope for Eurocode is steeper which means that Eurocode is slightly more conservative than NORSOK and ISO. The capacity for axial compression of the tubular member (UC = 1.0) is 4900 kN for Eurocode and 5200 kN for NORSOK and ISO, the difference in the capacity between the codes are 6.12 %.

6.5.2 Axial Compression, Tubular member 1, cross sectional class 2, L = 15m

Figure 6-2 illustrates the tubular member 1 when subjected to increasing axial compression force in the range of 0 – 4000 kN. The length of the tubular member is 15 m, and according to Eurocode the tubular member is in cross section class 2.

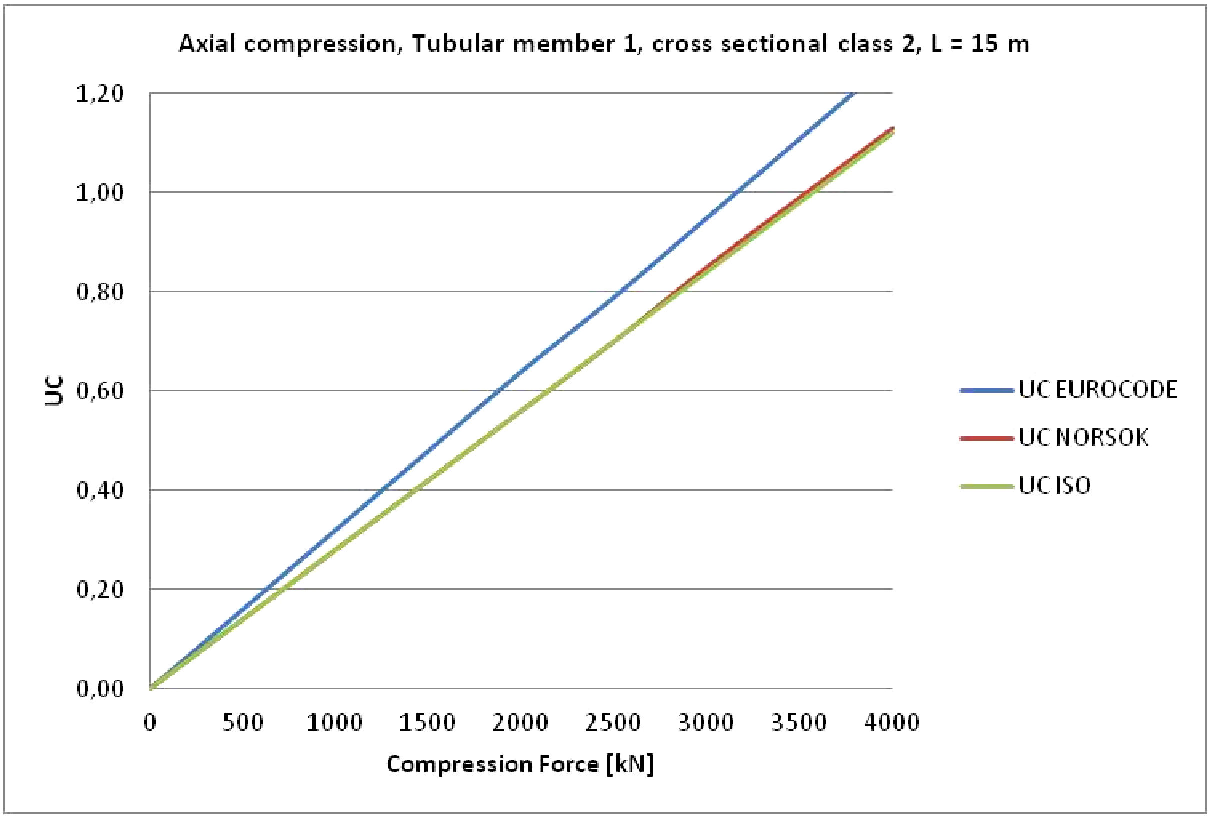


Figure 6-2 Axial Compression - Member 1 - Cross sectional class 2, L=15m

The graph shows that Eurocode is more conservative than NORSOK and ISO, the difference in the capacity is 11.7 %. As shown the graph is increasing linearly with the compression force.

6.5.3 Axial Compression, Tubular member 2, cross sectional class 3, L = 10m

Figure 6-3 illustrates the tubular member 2, when subjected to increasing axial compression force in the range of 0 – 8000 kN. The length of the tubular member is 10 m, and according to Eurocode the tubular member is in cross section class 3.

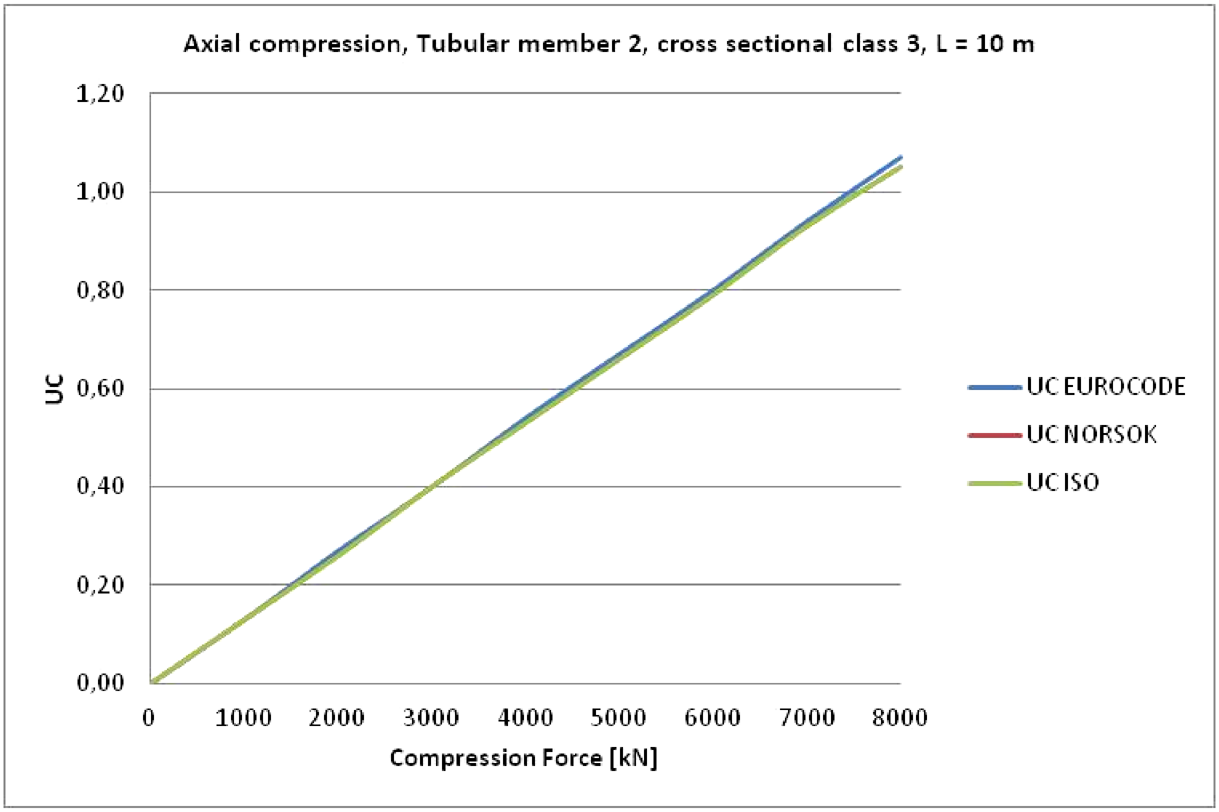


Figure 6-3 Axial Compression – Member 2 - Cross sectional class 3, L=10m

The graph increases linearly with the compression force. The capacity for axial compression is 7500 kN for Eurocode and 7600 kN for NORSOK and ISO, the difference in the capacity between the codes are 1.3 %.

6.5.4 Axial Compression, Tubular member 2, cross sectional class 3, L = 15m

Figure 6-4 illustrates the tubular member 2, when subjected to increasing axial compression force in the range of 0 – 7000 kN. The length of the tubular member is 15 m, and according to Eurocode the tubular member is in cross section class 3.

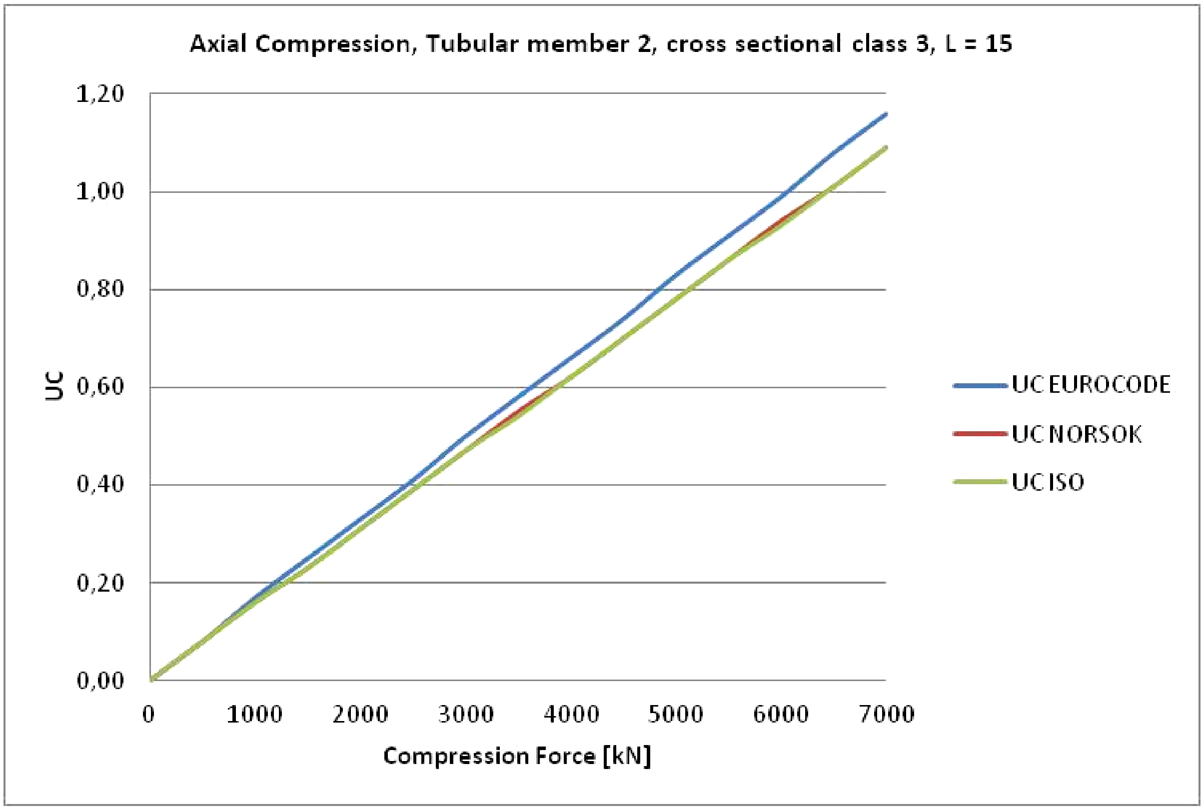


Figure 6-4 Axial Compression - Member 2 - Cross sectional class 3, L=15m

The graph increases linearly when the member is subjected to axial compression force. The slope of Eurocode is steeper, which means that Eurocode is more conservative than NORSOK and ISO. The capacity of the member is reached according to Eurocode at 6050 kN and 6400 kN for NORSOK and ISO, the difference in the capacity of the members are 5.8 %.

6.5.5 Discussion of the formulas for Axial Compression

From the parameter study the results for axial compression is as expected. The graphs are linearly increasing with the axial compression force subjected to the member. As a trend the parameter study shows that Eurocode is more conservative than NORSOK and ISO, the difference in the capacity seems to be larger with increasing slenderness.

The main difference between the codes is that Eurocode has no reduction in the capacity in the axial compression strength, f_c with increasing slenderness of the member compared to NORSOK and ISO.

The capacity for axial compression is less than for axial tension, ref. section 6.4, and meaning that the members subjected to axial compression force will fail due to buckling (stability).

6.6 Bending Moment

The parameter study will study the effect of increasing bending moment of single span simply supported tubular members, with length of 10 m and 15 m. The parametric study on bending moment is to determine the similarities and differences in the formulas used in Eurocode, NORSOK and ISO, ref section 5.8.

6.6.1 Bending moment, Tubular member 1, cross sectional class 2, L = 10m

Figure 6-5 illustrates the tubular member 1, when subjected to increasing bending moment in the range of 0 – 900 kNm. The length of the tubular member is 10 m, and according to Eurocode the tubular member is in cross section class 2.

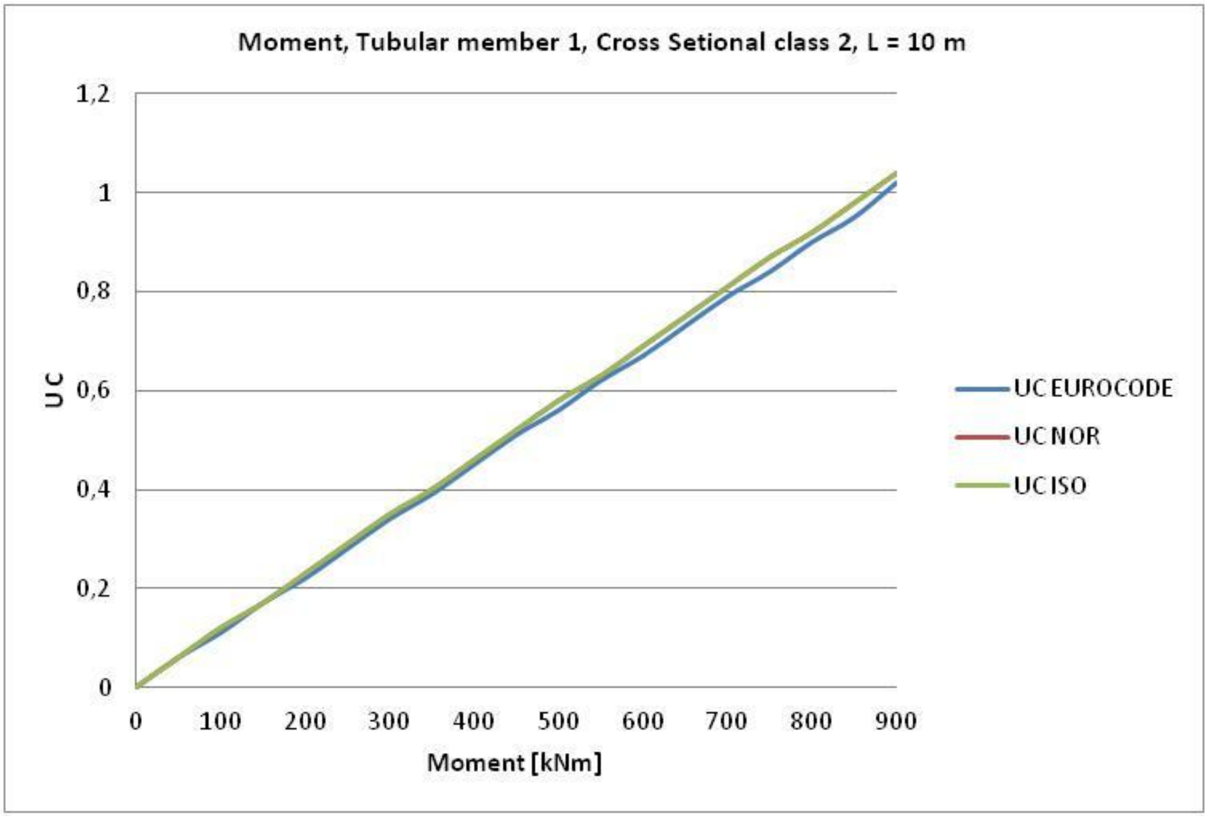


Figure 6-5 Moment - Member 1- Cross sectional class 2, L=10 m

The UC increases linearly with bending moment. The slope for NORSOK and ISO is marginal steeper than Eurocode, which means that NORSOK and ISO is slightly more conservative than Eurocode. The capacity for bending moment of the tubular member (UC = 1,0) is 860 kNm for NORSOK and ISO and 890 for Eurocode, the difference in the capacity between the codes are 3,5 %.

6.6.2 Bending moment, Tubular member 2, cross sectional class 3, L = 10m

Figure 6-6 illustrates the tubular member 2, when subjected to increasing bending moment in the range of 0 – 1500 kNm. The length of the tubular member is 10 m, and according to Eurocode the tubular member is in cross section class 3.

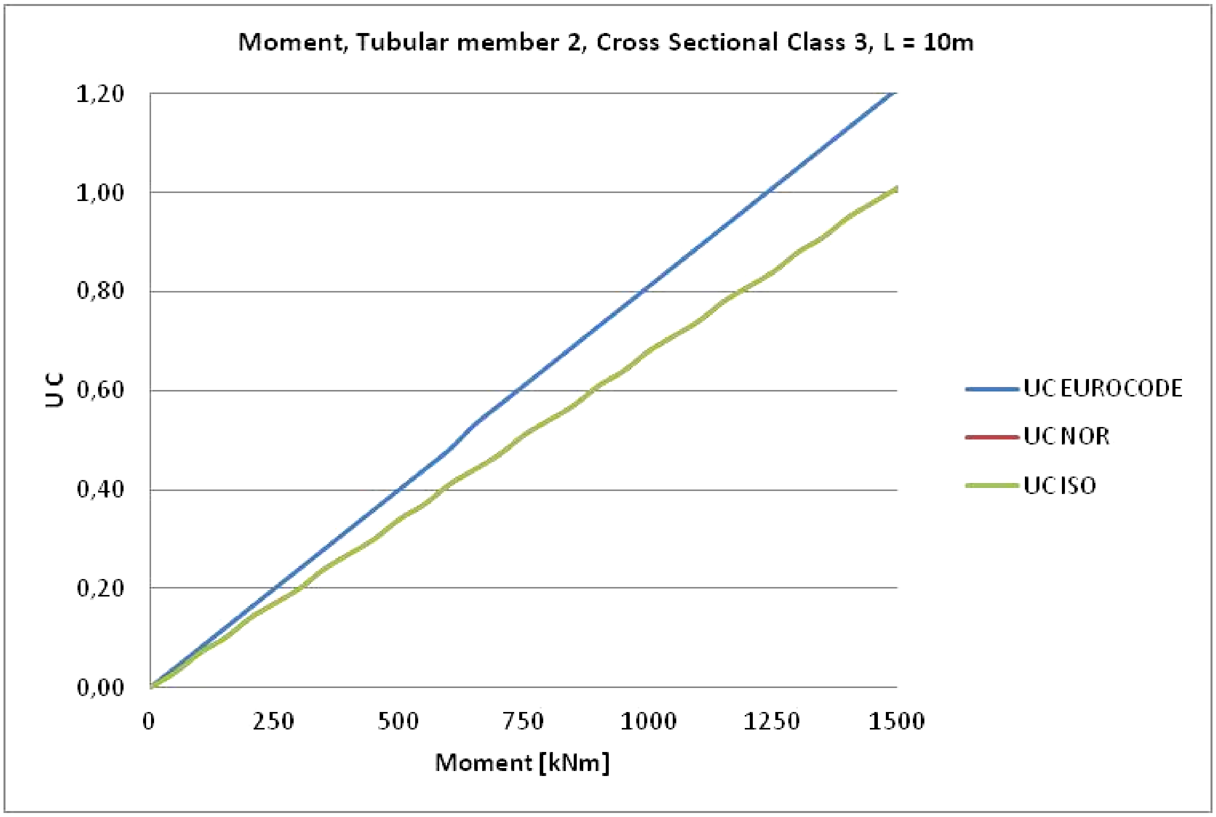


Figure 6-6 Moment - Member 2 - Cross sectional class 3, L = 10m

The graph shows that the UC increase linearly with increasing bending moment, as expected. The slope of Eurocode is steeper, which means that Eurocode is more conservative than NORSOK and ISO. The capacity of the member is reached according to Eurocode at 1230 kNm and 1470 kNm for NORSOK and ISO respectively, the difference in the capacity between the codes are 19.5 %. Full plastic moment capacity $M_p = W_{pl} \times f_y = 1608$ kNm, shows that NORSOK and ISO for this section property gives a capacity of approximately 91 % of M_p.

6.6.3 Discussion of the formulas for Bending moment

From the parameter study the results for bending moment is as expected. The UC are linearly increasing with increasing bending moment. For cross sectional class 2, NORSOK and ISO are marginal more conservative than Eurocode, 3.5 %. However, for cross sectional class 3 Eurocode is 19.5 % more conservative than NORSOK and ISO, the reason for this is that NORSOK and ISO allows the section to go beyond first yield. Similar for all the three codes is that the slenderness does not influence the capacity of the member.

6.7 Biaxial moment

The parameter study will study the effect of increasing biaxial moment on the single spans simply supported members, with a length of 10 m and a length of 15 m. The parametric study on biaxial moment is to determine the effect, the similarities and the differences in the formulas used in Eurocode, NORSOK and ISO.

For cross section class 1 and 2 Eurocode has separate formula for biaxial moment and for cross section class 3 Eurocode uses a conservative approximation, see section 5.9. NORSOK and ISO use the formula for combined axial compression and bending when the member is subjected to biaxial moment ref. section 5.9.

6.7.1 Biaxial moment for Tubular member 1

Figure 6-7 illustrates tubular member 1 when subjected to biaxial moment. The length of the member is 10 m and according to Eurocode the tubular member is in cross sectional class 2. In the graph below, the moment about the y-axis is set to M_y = 445 kNm, corresponding to 50 % of the moment capacity about the y-axis. The moment about the z-axis will vary from 0 to 800 kNm.

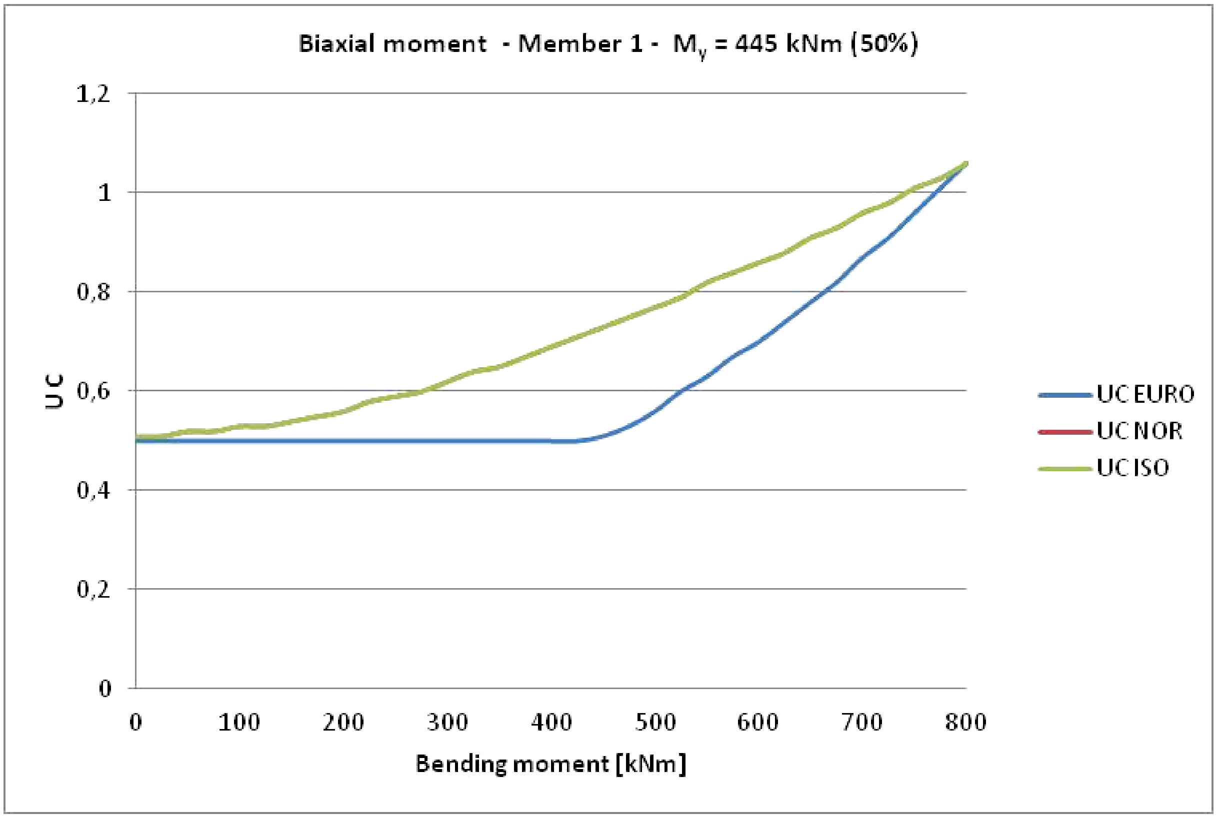


Figure 6-7 Biaxial moment - Member 1 - My = 445 kNm (50%)

According to Eurocode, member 1 is in cross sectional class 2, which means that the formula for biaxial bending is used. NORSOK and ISO are marginal conservative than Eurocode and the capacity for biaxial bending of the tubular member 1 (UC=1,0) is 740 kNm for NORSOK and ISO and 765 kNm for Eurocode given a difference in the capacity between the codes of 3,3 %.

For cross sections in class 1 and 2 according to Eurocode, there are two formulas where biaxial bending is considered, ref section 5.9. In the plot in Figure 6-8, the two formulas are generated to identify the difference in the formulas.

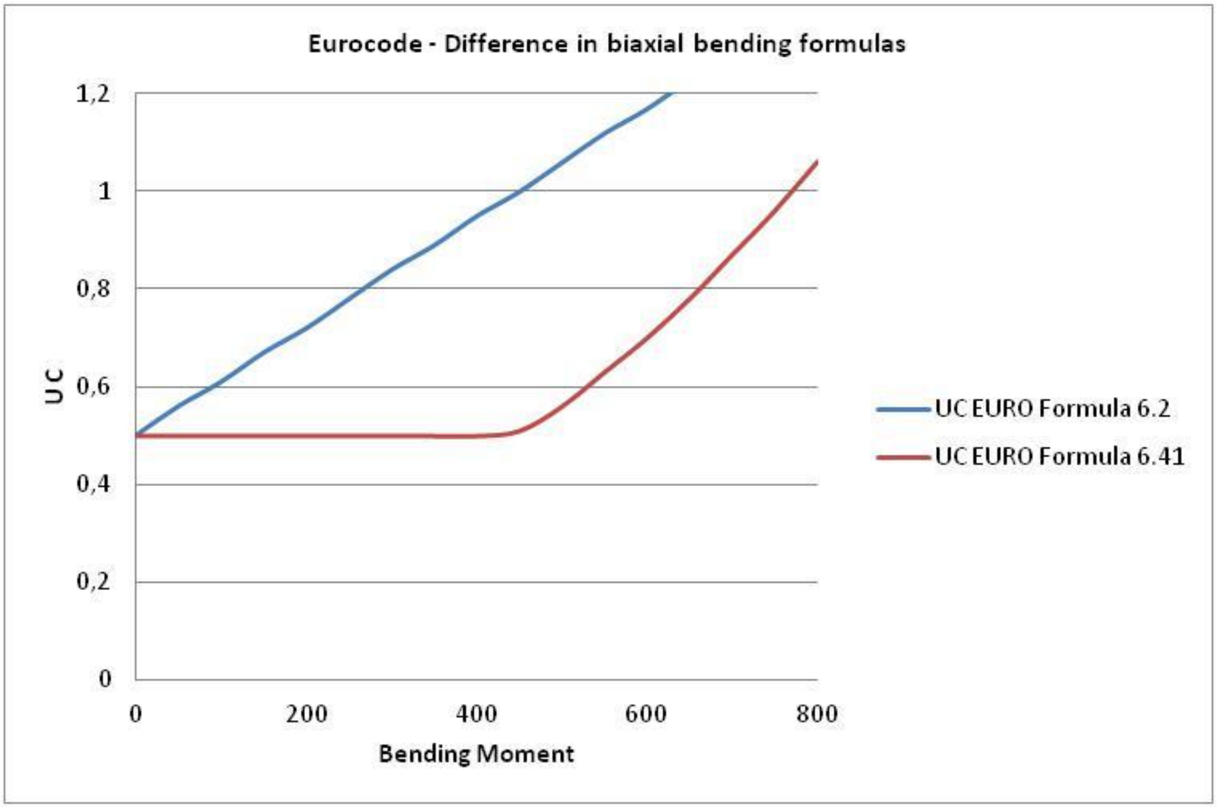


Figure 6-8 Eurocode - Difference in biaxial bending formulas

The difference in the capacity of the two formulas is major, from the graph we can see that the conservative formula gives 450 kNm whereas the formula for biaxial bending for cross sections class 1 and 2 is 780 kNm, giving a difference of 73 %.

In Figure 6-9 the moment about the y-axis is set to M_y = 620 kNm, corresponding to 70 % of the moment capacity about the y-axis. The moment about the z-axis will vary from 0 to 700 kNm.

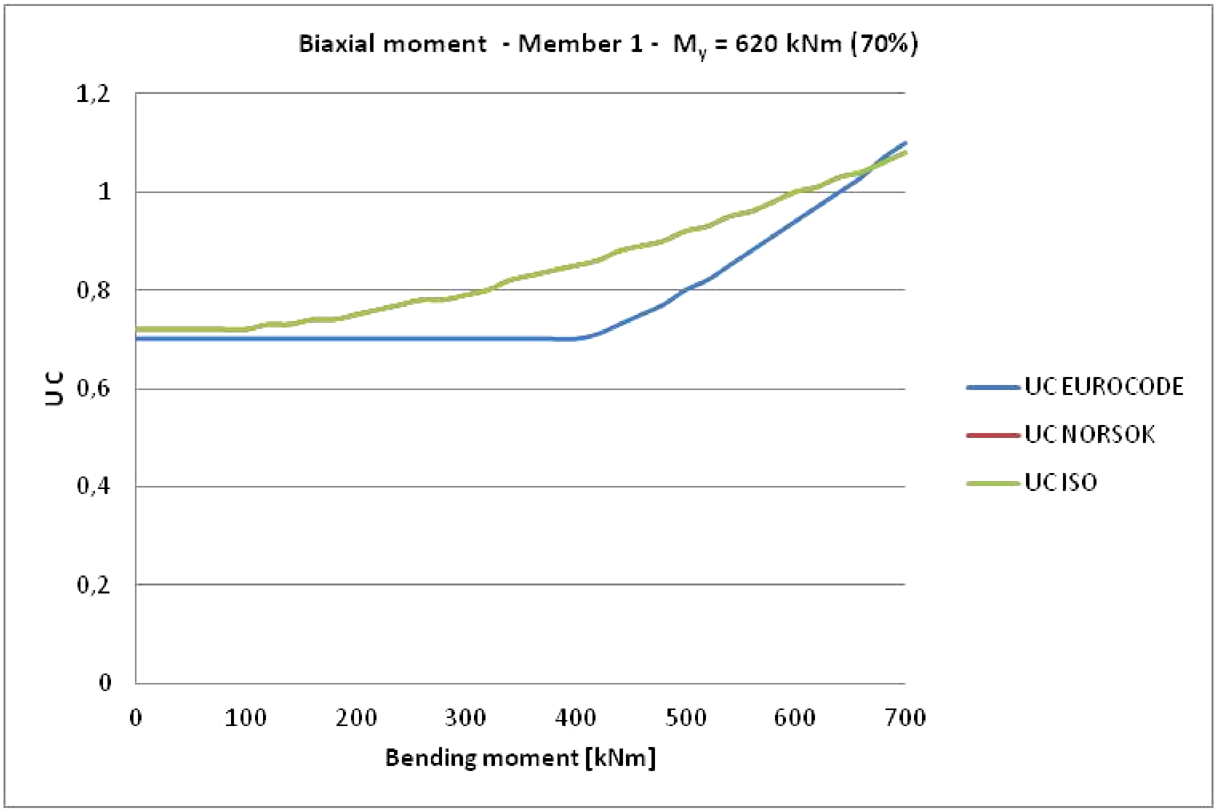


Figure 6-9 Biaxial moment - Member 1 - My = 620 kNm (70%)

As can be seen of the graph the difference has now increased to 6.3 % giving a capacity of 600 kNm for NORSOK and ISO, and 640 for Eurocode.

In Figure 6-10 the moment about the y-axis is set to M_y = 800 kNm, corresponding to 90 % of the moment capacity about the y-axis. The moment about the z-axis will vary from 0 to 400 kNm.

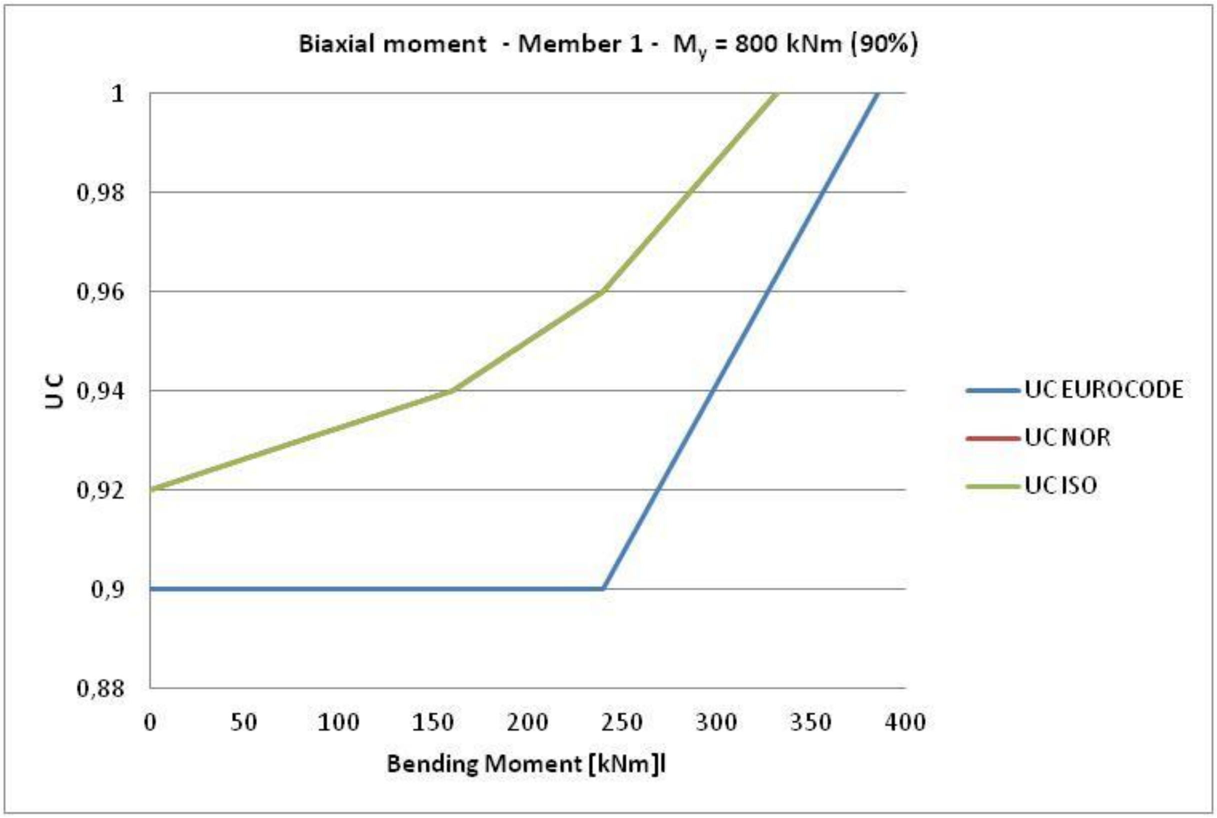


Figure 6-10 Biaxial moment - Member 1 - My = 800 kNm (90%)

As can be seen on the graph the difference in the capacity is increased to 12.8 % giving a capacity of 340 kNm and 390 for NORSOK/ISO and Eurocode respectively.

6.7.2 Biaxial moment for Tubular member 2

Figure 6-11 illustrates tubular member 2 when subjected to biaxial moment. The length of the member is 10 m and according to Eurocode the tubular member is in cross sectional class 3. In the graph below, the moment about the y-axis is set to M_y = 620 kNm, corresponding to 50 % of the moment capacity about the y-axis. The moment about the z-axis will vary from 0 to 1400 kNm.

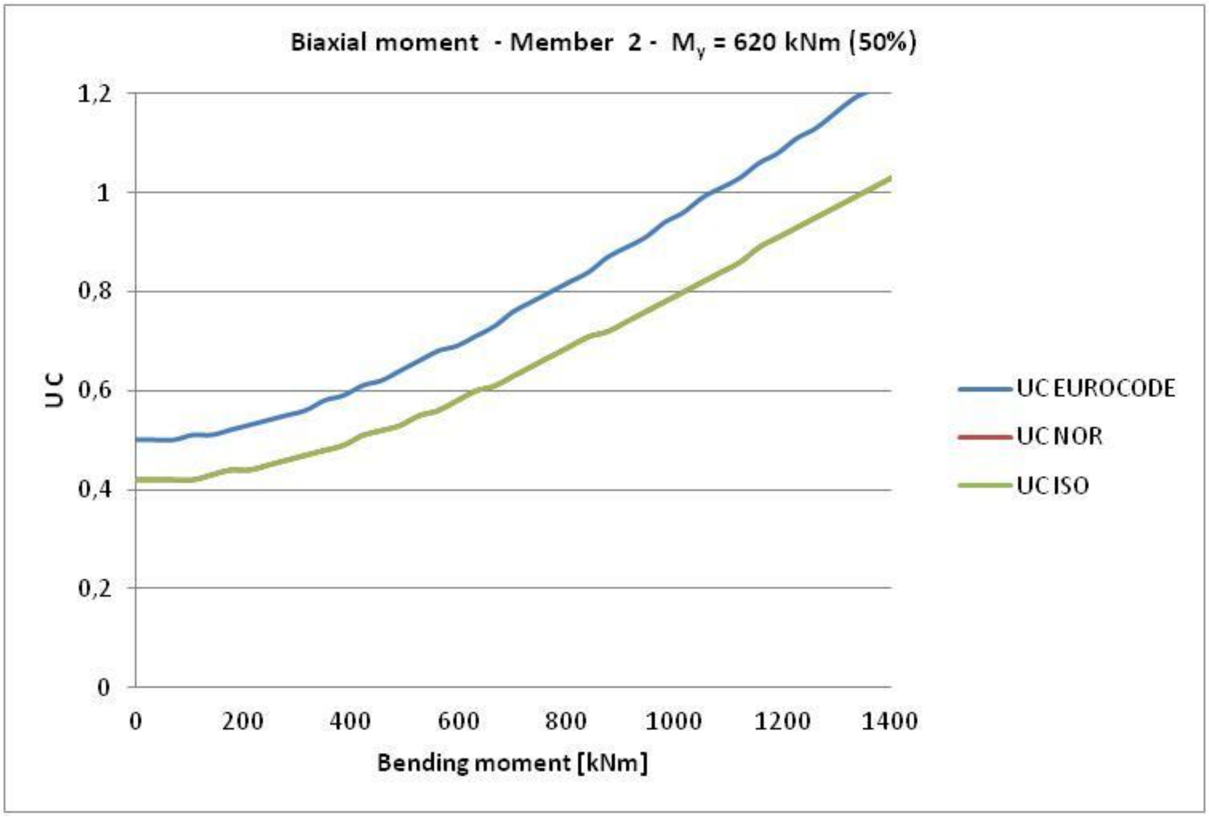


Figure 6-11 Biaxial moment - Member 2 - My = 620 kNm (50%)

The difference in the capacity of the codes are 26,4 % due to the Eurocode conservative approach, the capacity is 1075 kN for Eurocode and 1335 kN for NORSOK and ISO.

In Figure 6-12 the moment about the y-axis is set to M_y = 870 kNm, corresponding to 70 % of the moment capacity about the y-axis. The moment about the z-axis will vary from 0 to 1190 kNm.

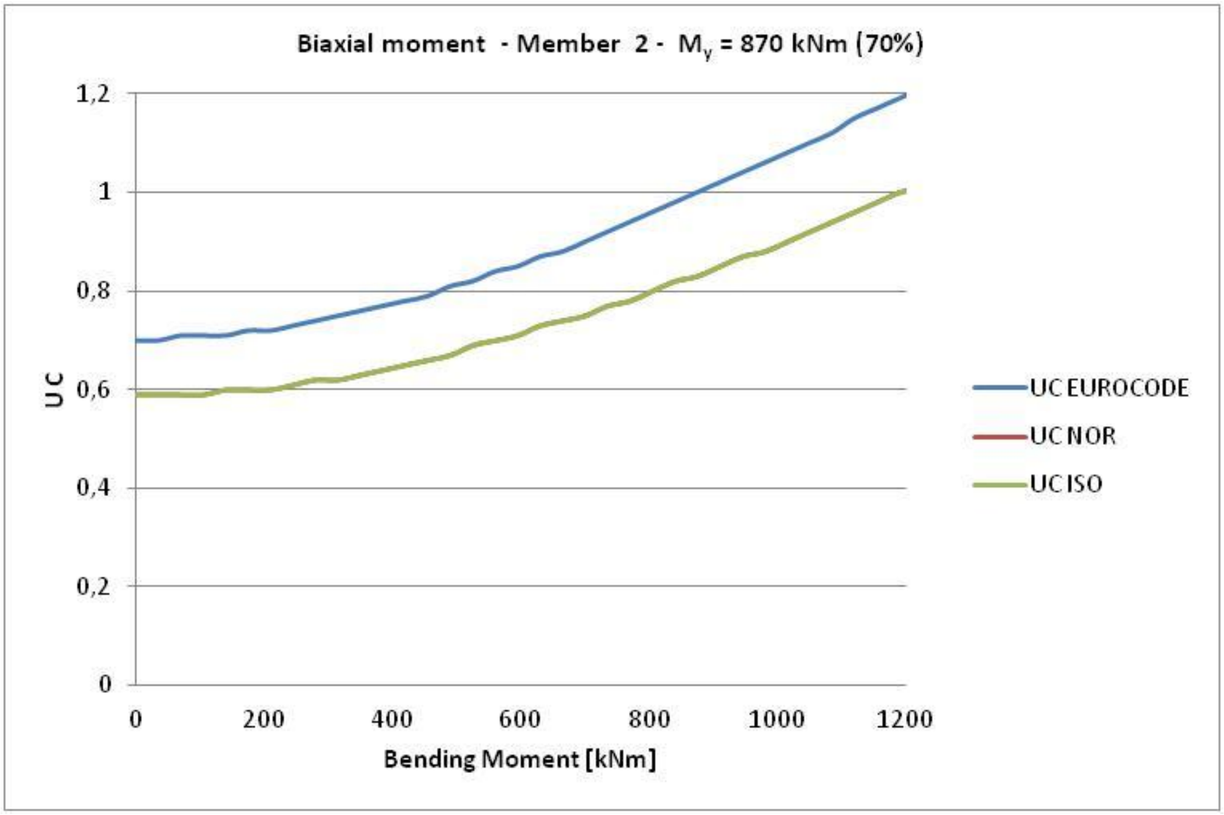


Figure 6-12 Biaxial moment - Member 2 - My = 870 kNm (70%)

As can be seen of the graph the difference has now increased to 36 % giving a capacity of 875 kNm for Eurocode, and 1140 kNm for NORSOK and ISO.

In Figure 6-13 the moment about the y-axis is set to M_y = 1140 kNm, corresponding to 90 % of the moment capacity about the y-axis. The moment about the z-axis will vary from 0 to 1000 kNm.

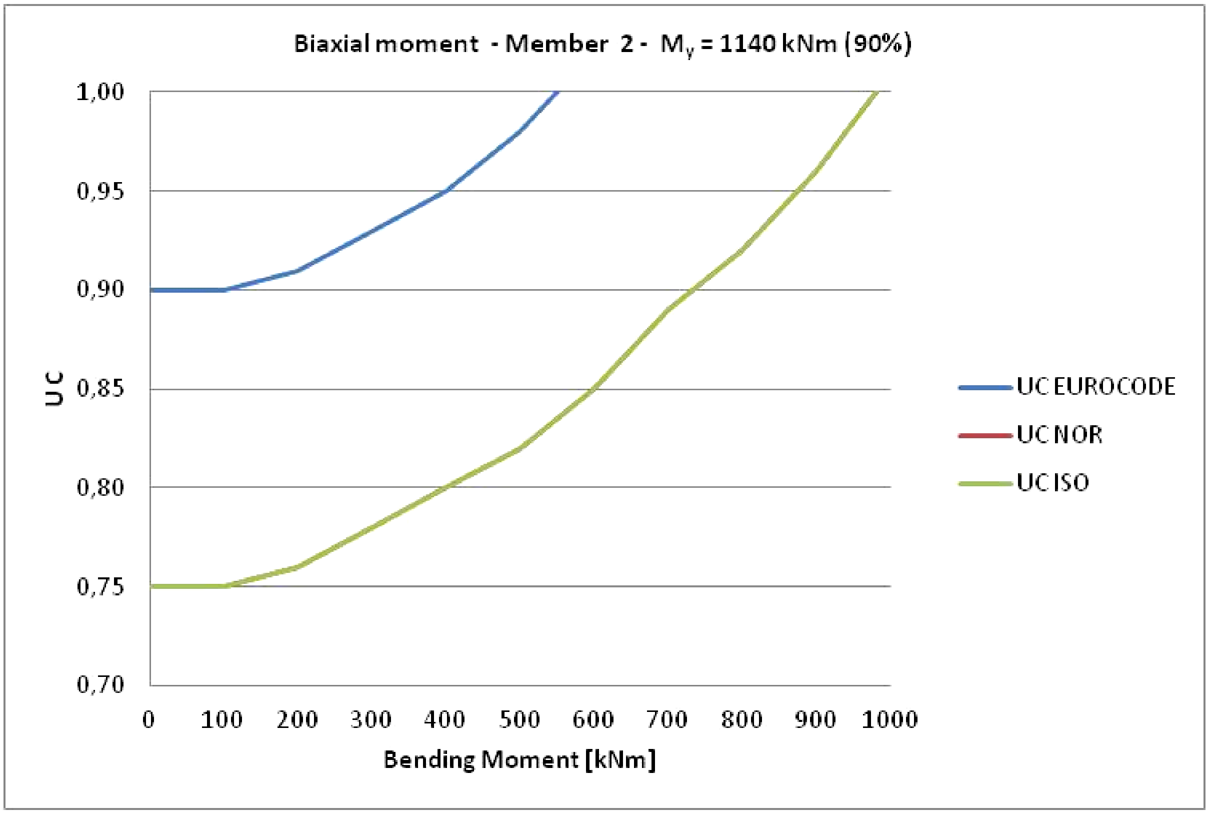


Figure 6-13 Biaxial moment - Member 2 - My = 1140 kNm (90%)

As can be seen on the graph the difference in the capacity is 81 % since the capacity is 540 kNm for Eurocode and 975 kNm for NORSOK and ISO.

6.7.3 Discussion on the formulas for Biaxial moment

Based on the parameter study it can be concluded that NORSOK/ISO are more conservative than Eurocode when the member is in cross sectional class 2, the variation is between 3.3 % to 12.8 % and the differences in the capacity is increasing with increased constant value for M_y.

For cross sectional class 3, the results of the parameter study shows the opposite trend. For this case Eurocode is the most conservative approach with a variation between 26,4 % to 81 %. The same trend appears here that the differences in the capacity is increasing with increased constant value for M_y.

The slenderness of the members will not have an effect on the capacity of the member.

6.8 Axial compression and bending moment

The parameter study will study the effect of increasing combined axial compression and bending moment on the single span simply supported members, with a length of 10 m and a length of 15 m. The parametric study of combined axial compression and bending is to determine the effect, the similarities and the differences in the formulas used in Eurocode, NORSOK and ISO, ref section 5.10. Eurocode uses interaction formulas in the formula for combined axial compression and bending, these interaction formulas can be derived from two alternative approaches found in the National Annex A or B. In this parametric study the method in Annex B is used.

6.8.1 Tubular member 1 with L = 10 m subjected to axial compression and bending

The parameter study is performed on tubular member 1 with a length of 10 m in cross sectional class 2 according to Eurocode. The bending moment increases while the design axial compression force, N_{ed} is set to a constant value corresponding to 50 %,70 % , 90 % of the axial compression capacity, ref. section 6.5.1.

- 50 % utilized when N_{ed} = 2450 kN
- 70% utilized when N_{ed} = 3400 kN
- 90 % utilized when N_{ed} = 4400 kN

In Figure 6-14, the axial force is set to N_{ed} = 2450 kN, corresponding to 50 % of the axial compression capacity. The moment about the z-axis will vary from 0 to 400 kNm.

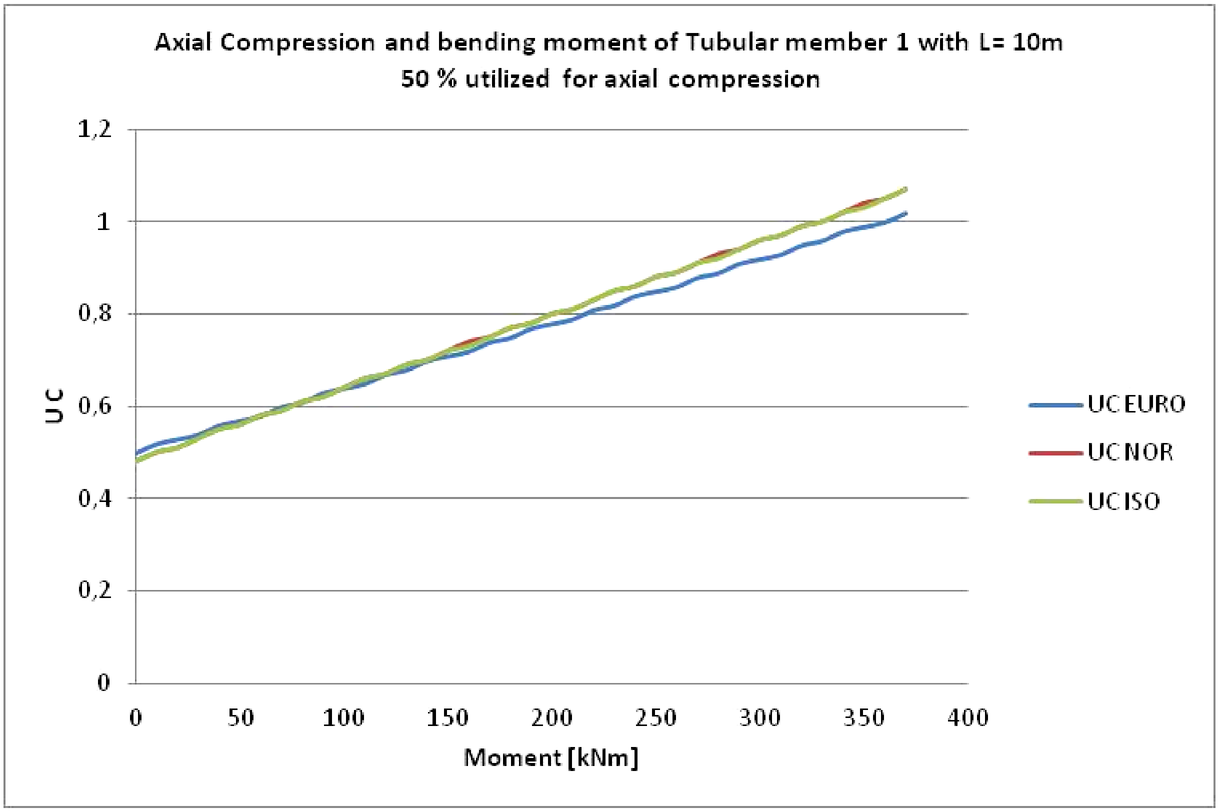


Figure 6-14 Axial compression and bending moment - Member 1 with L=10m (50%)

From the graph it can be seen that Eurocode is the conservative approach for a moment up to approximately 75 kNm, while NORSOK and ISO gives more conservative results above this level. The capacity for axial compression and bending of the tubular member (UC = 1.0) is 330 kNm for NORSOK and ISO and 360 kNm for Eurocode, the difference in the capacity between the codes are 8.3 %.

In Figure 6-15 the axial compression about the y-axis is set to N_{ed} = 3400 kN, corresponding to 70 % of the axial compression capacity. The moment about the z-axis will vary from 0 to 200 kNm.

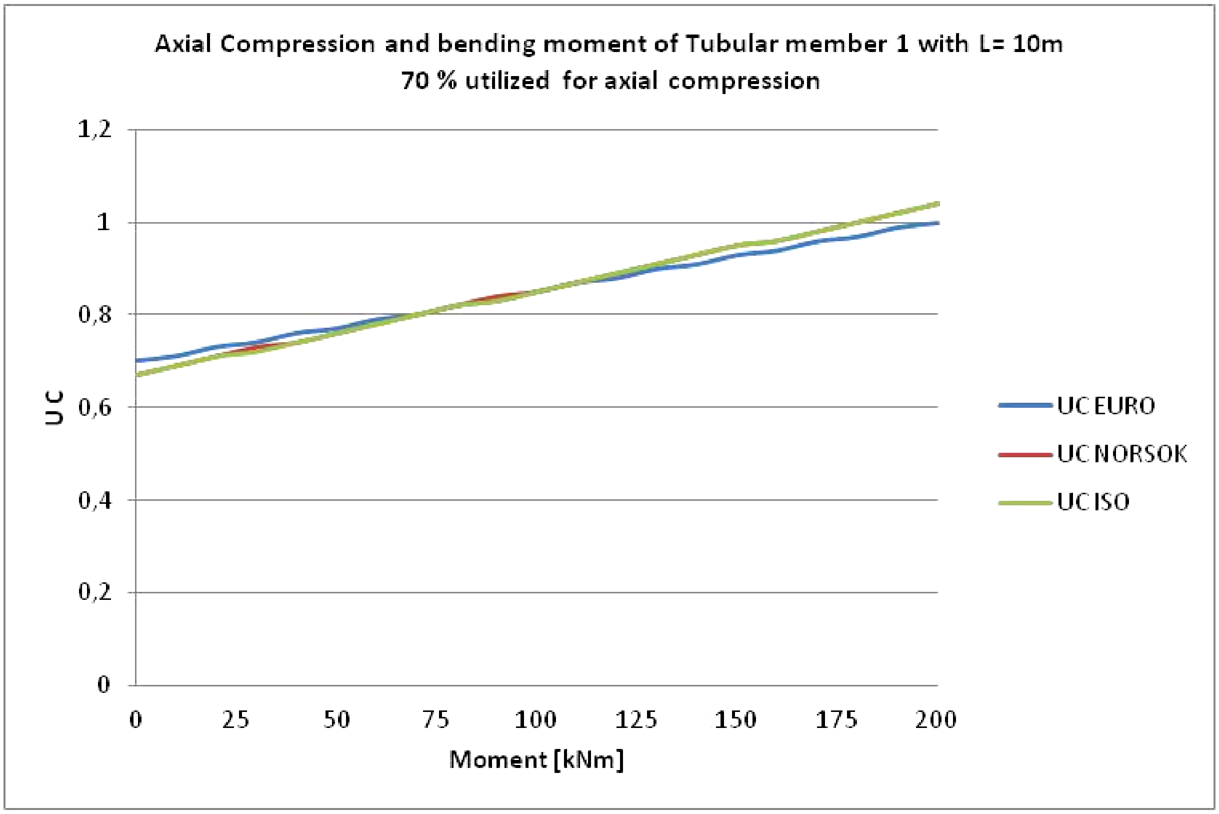


Figure 6-15 Axial compression and bending moment - Member 1 with L=10m (70%)

The same trend appears here as the above graph, Eurocode is slightly more conservative for small values for the moment up to approximately 65 kNm, while NORSOK and ISO are marginal more conservative above this level. The capacity for axial compression and bending of the tubular member 1 is 180 kNm for NORSOK and ISO and 200 kNm for Eurocode, the difference in the capacity between the codes are 10 %.

In Figure 6-16 the moment about the y-axis is set to N_{ed} = 4400 kN, corresponding to 90 % of the axial compression capacity. The moment about the z-axis will vary from 0 to 70 kNm.

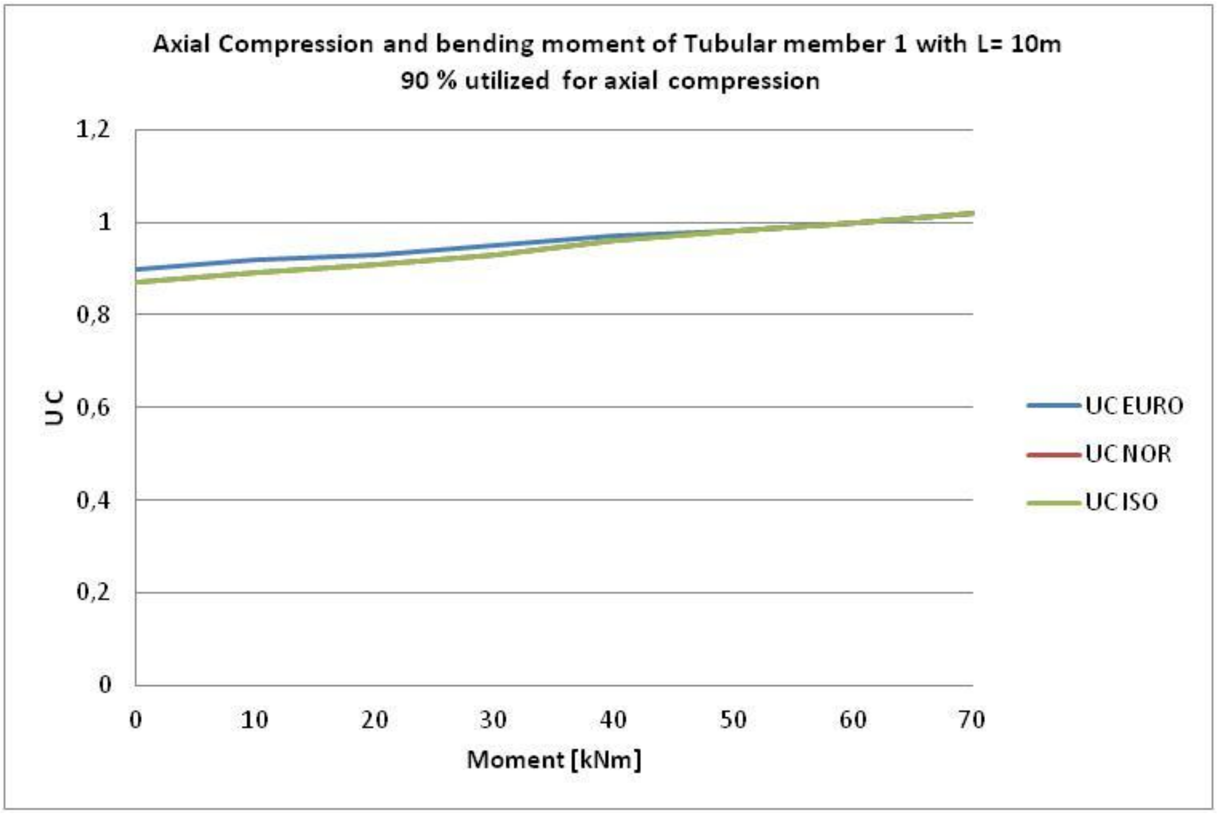


Figure 6-16 Axial compression and bending moment - Member 1 with L=10m (90%)

The graph shows the same trend as the previous results, the capacity is 55 kNm for Eurocode and 60 kNm for NORSOK and ISO, giving a difference in the capacity of 9 %.

6.8.2 Tubular member 1 with L = 15 m subjected to axial compression and bending

The parameter study is performed on tubular member 1 with a length of 15 m in cross sectional class 2 according to Eurocode. The bending moment increases while the design axial compression force, N_{ed} is set to a constant value corresponding to 50 %,70 % , 90 % of the axial compression capacity, ref. 0.

- 50 % utilized when N_{ed} = 1575 kN
- 70% utilized when N_{ed} = 2200 kN
- 90 % utilized when N_{ed} = 2825 kN

In Figure 6-17, the axial force is set to N_{ed} = 1575 kN, corresponding to 50 % of the axial compression capacity. The moment about the z-axis will vary from 0 to 350 kNm.

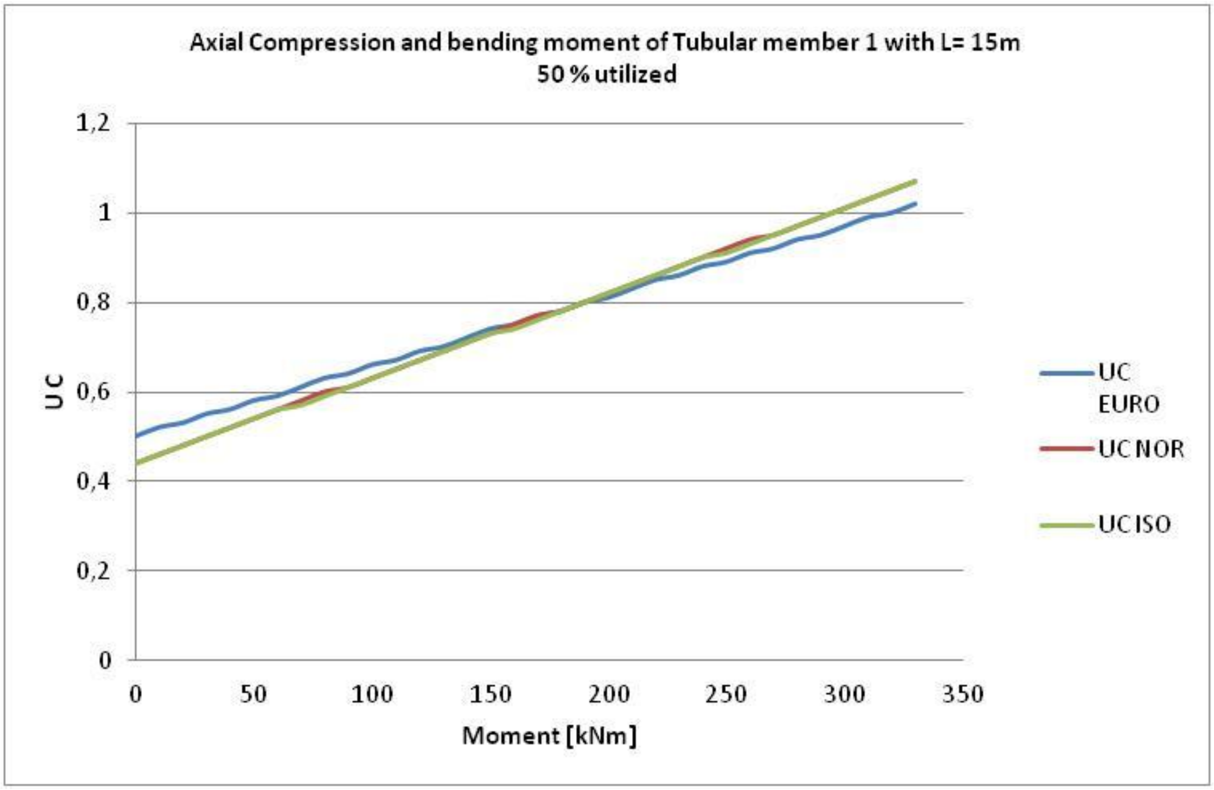


Figure 6-17 Axial compression and bending moment - Member 1 with L=15m (50%)

From the graph it can be seen that Eurocode is the conservative approach for a moment up to approximately 175 kNm, while NORSOK and ISO gives more conservative results above this level. The capacity for axial compression and bending of the tubular member is 295 kNm for NORSOK and ISO and 320 kNm for Eurocode, the difference in the capacity between the codes are 7.8 %.

In Figure 6-18 the moment about the y-axis is set to N_{ed} = 2200 kN, corresponding to 70 % of the axial compression capacity. The moment about the z-axis will vary from 0 to 180 kNm.

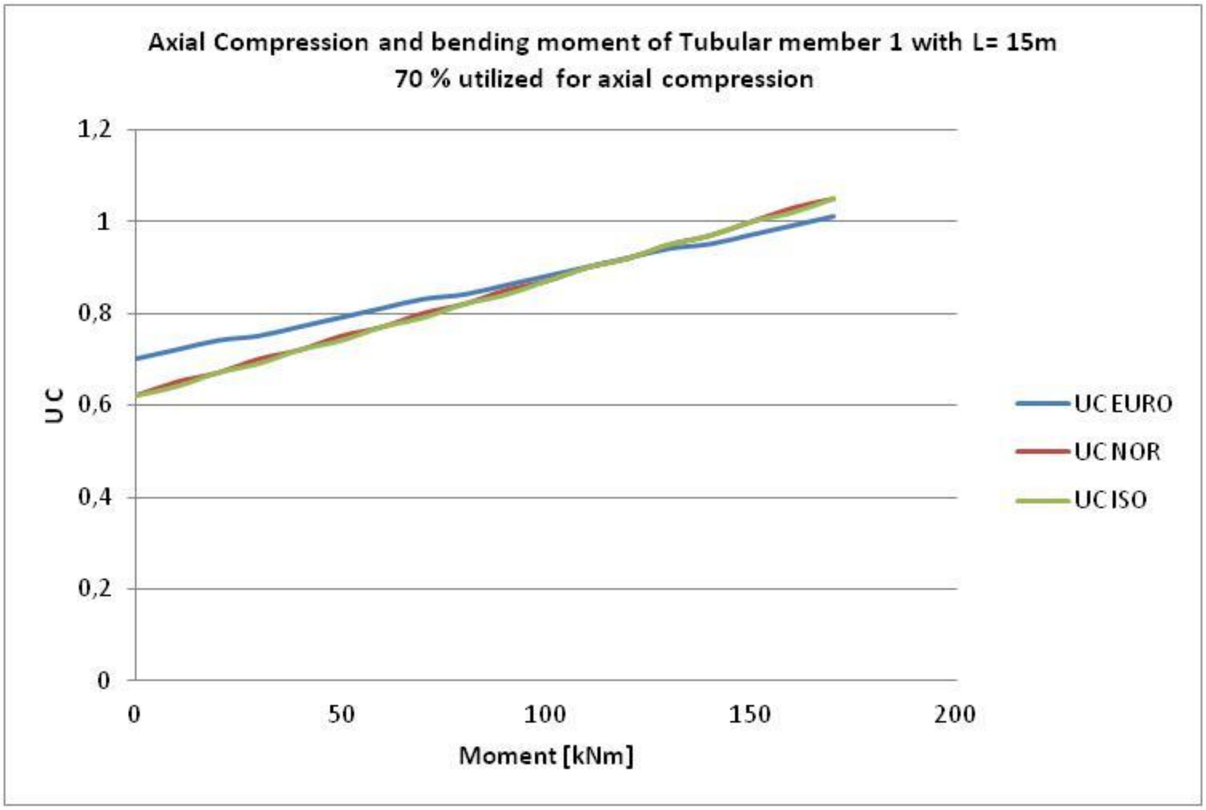


Figure 6-18 Axial compression and bending moment - Member 1 with L=15m (70%)

The same trend appears here as the above graph, Eurocode is slightly more conservative for small values for the moment up to approximately 125 kNm, while NORSOK and ISO are marginal more conservative above this level. The capacity for axial compression and bending of the tubular member 1 is 150 kNm for NORSOK and ISO and 165 kNm for Eurocode, the difference in the capacity between the codes are 10 %.

In Figure 6-19 the moment about the y-axis is set to N_{ed} = 2825 kN, corresponding to 90 % of the axial compression capacity. The moment about the z-axis will vary from 0 to 60 kNm.

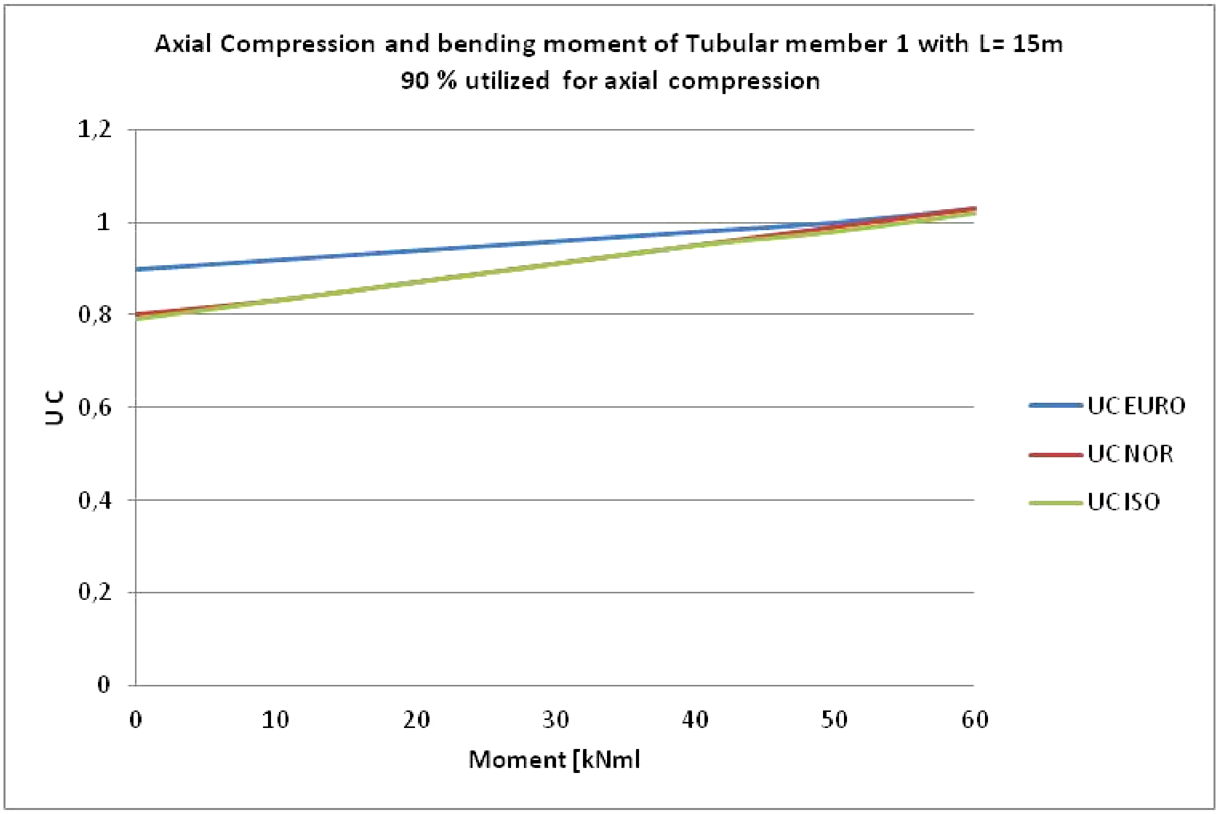


Figure 6-19 Axial compression and bending moment - Member 1 with L=15m (90%)

The graph shows the same trend as the previous results, the capacity is 50 kNm for Eurocode and 55 kNm for NORSOK and ISO, giving a difference in the capacity of 10 %.

6.8.3 Tubular member 2 with L = 10 m subjected to axial compression and bending

The parameter study is performed on tubular member 2 with a length of 10 m in cross sectional class 3 according to Eurocode. The bending moment increases while the design axial compression force, N_{ed} is set to a constant value corresponding to 50 %,70 % , 90 % of the axial compression capacity, ref. 0.

- 50 % utilized when N_{ed} = 3700 kN
- 70% utilized when N_{ed} = 5250 kN
- 90 % utilized when N_{ed} = 6700 kN

In Figure 6-20, the axial force is set to N_{ed} = 3700 kN, corresponding to 50 % of the axial compression capacity. The moment about the z-axis will vary from 0 to 650 kNm.

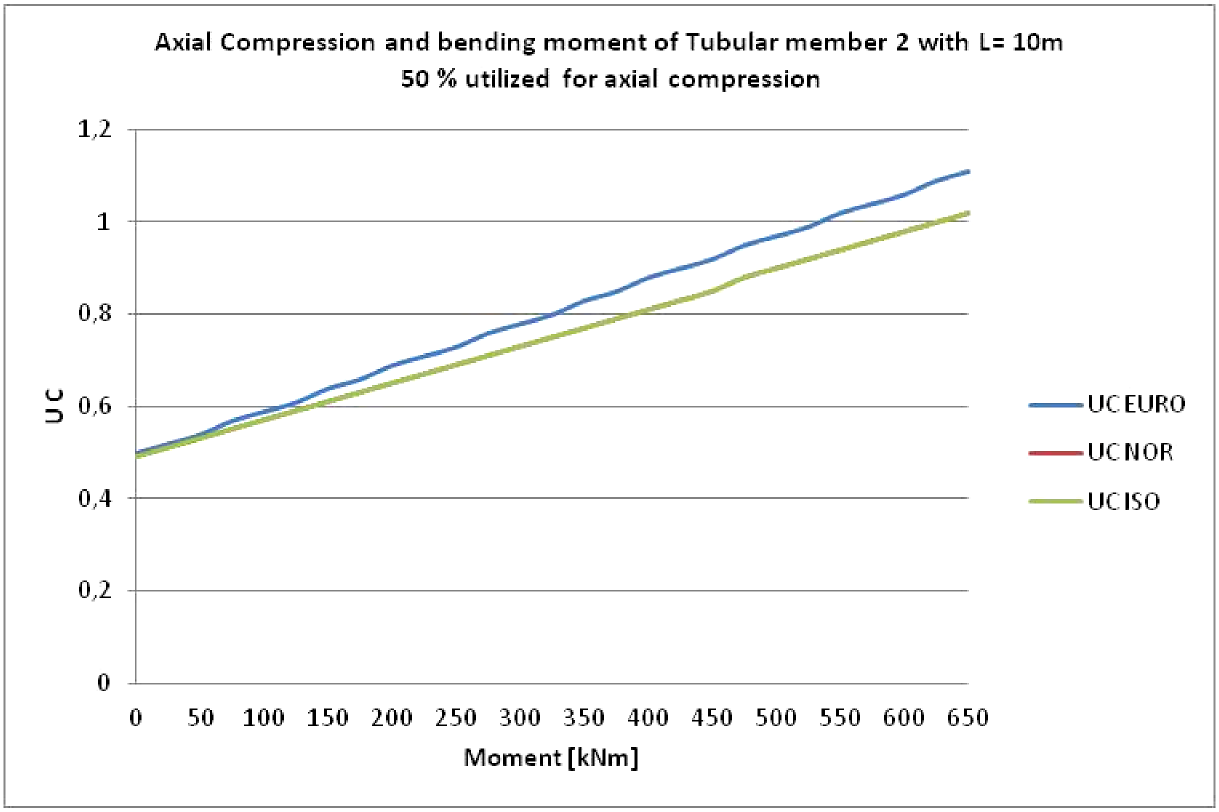


Figure 6-20 Axial compression and bending moment - Member 2 with L=10m (50%)

The graph increases linearly, the slope for Eurocode is steeper which means that Eurocode is more conservative than NORSOK and ISO. The capacity is 535 kNm and 625 kNm for Eurocode and NORSOK/ISO respectively, giving a difference in the capacity of 16.8 %.

In Figure 6-21 the moment about the y-axis is set to N_{ed} = 5250 kN, corresponding to 70 % of the axial compression capacity. The moment about the z-axis will vary from 0 to 350 kNm.

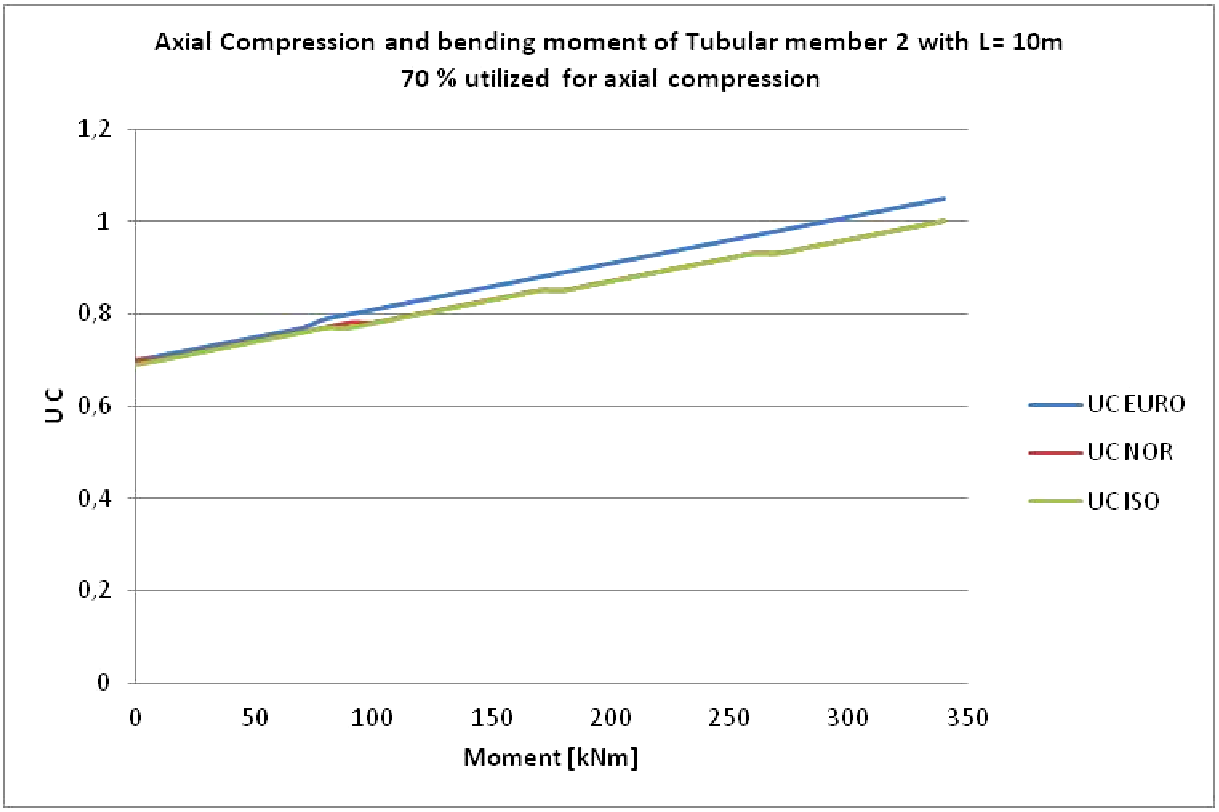


Figure 6-21 Axial compression and bending moment - Member 2 with L=10m (70%)

Eurocode is more conservative than NORSOK and ISO, the capacity for axial compression and is 290 kNm for Eurocode and 340 kNm for NORSOK and ISO, the difference in the capacity between the codes are 17.2 %.

In Figure 6-22 the moment about the y-axis is set to N_{ed} = 6700 kN, corresponding to 90 % of the axial compression capacity. The moment about the z-axis will vary from 0 to 120 kNm.

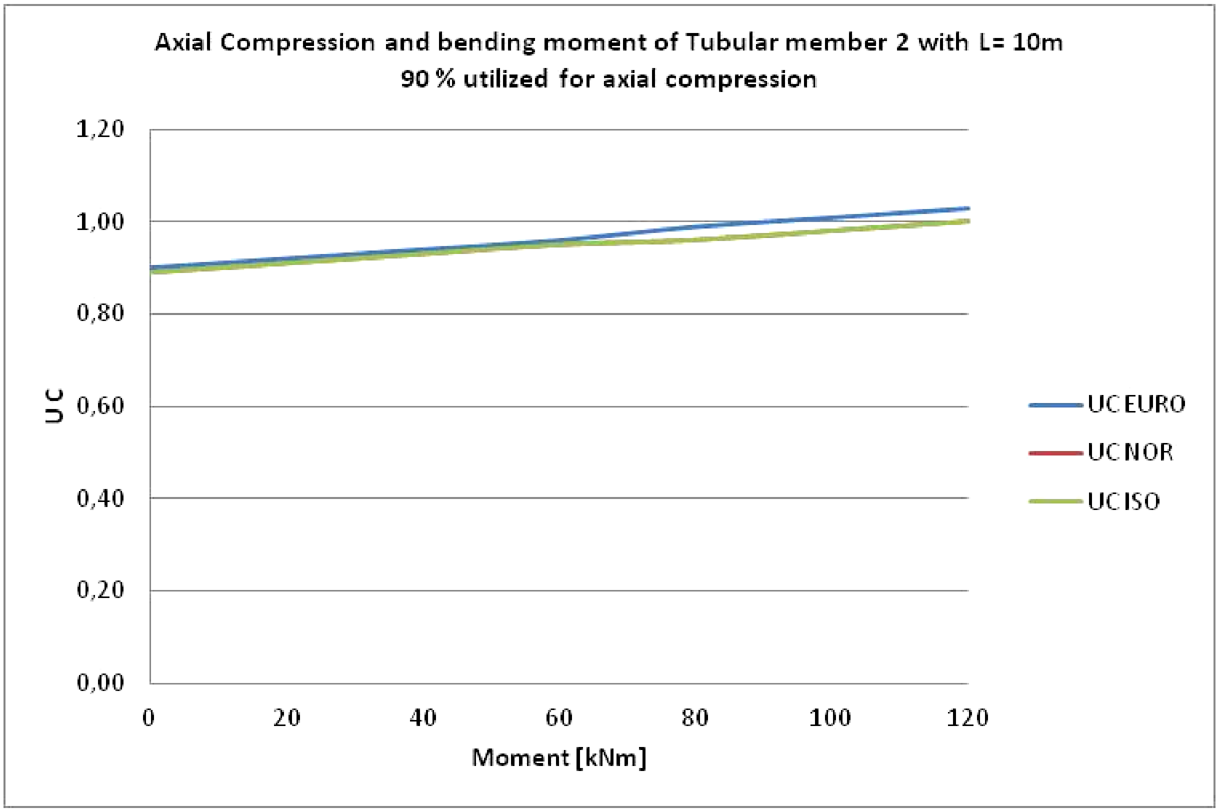


Figure 6-22 Axial compression and bending moment - Member 2 with L=10m (90%)

The graph shows the same trend as the previous results, the capacity is 90 kNm for Eurocode and 110 kNm for NORSOK and ISO, giving a difference in the capacity of 9 %.

6.8.4 Tubular member 2 with L = 15 m subjected to axial compression and bending

The parameter study is performed on tubular member 2 with a length of 15 m in cross sectional class 3 according to Eurocode. The bending moment increases while the design axial compression force, N_{ed} is set to a constant value corresponding to 50 %,70 % , 90 % of the axial compression capacity, ref. 0.

- 50 % utilized when N_{ed} = 3000 kN
- 70% utilized when N_{ed} = 4250 kN
- 90 % utilized when N_{ed} = 5450 kN

In Figure 6-23, the axial force is set to N_{ed} = 3000 kN, corresponding to 50 % of the axial compression capacity. The moment about the z-axis will vary from 0 to 550 kNm.

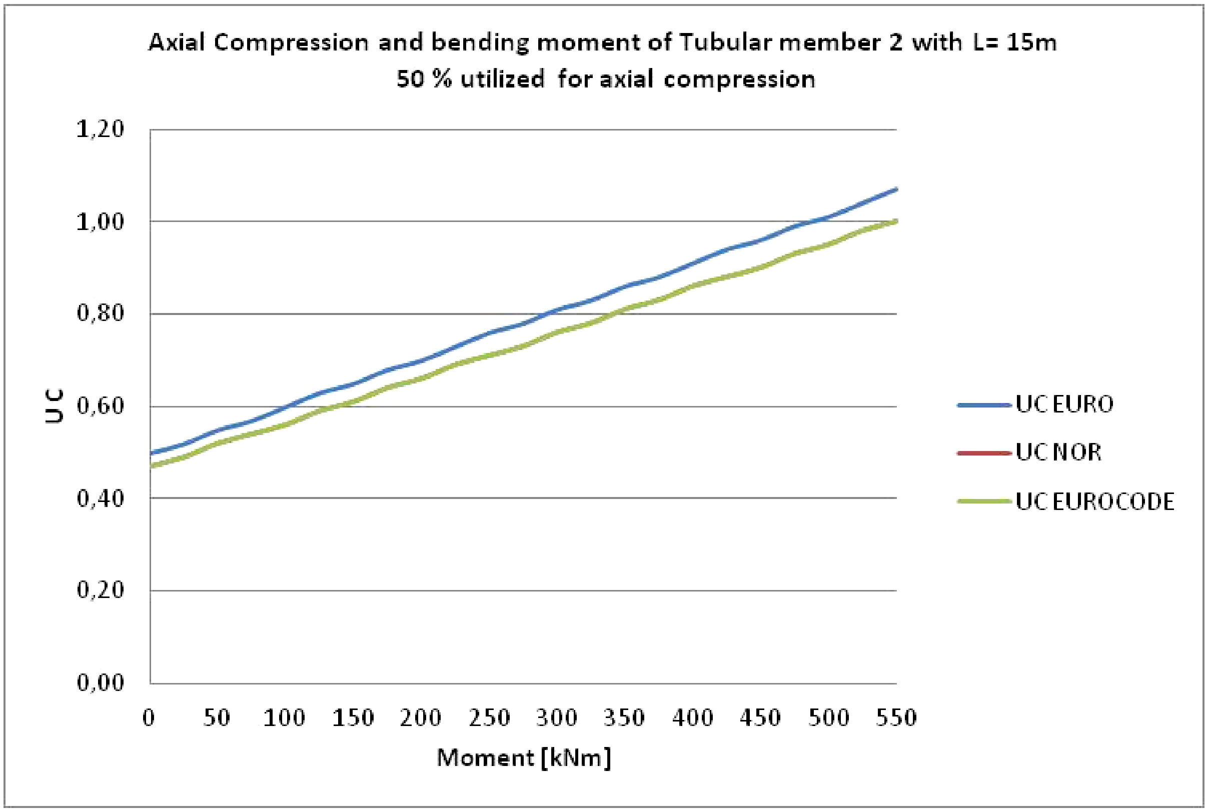


Figure 6-23 Axial compression and bending moment - Member 2 with L=15m (50%)

The graph increases linearly, the slope for Eurocode is slightly steeper which means that Eurocode are more conservative than NORSOK and ISO. The capacity for axial compression and bending of the tubular member is 470 kNm for Eurocode and 550 kNm for NORSOK and ISO, the difference in the capacity between the codes are 17 %.

In Figure 6-24 the moment about the y-axis is set to N_{ed} = 4250 kN, corresponding to 70 % of the axial compression capacity. The moment about the z-axis will vary from 0 to 300 kNm.

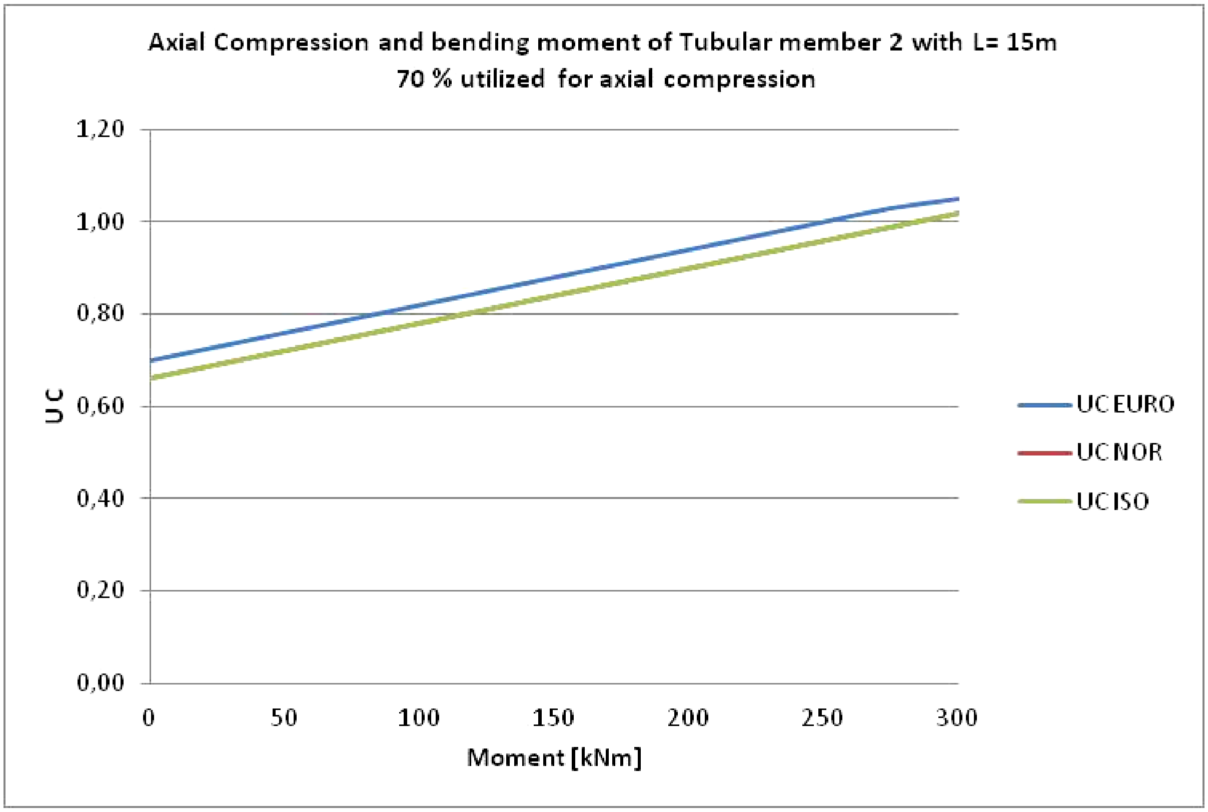


Figure 6-24 Axial compression and bending moment - Member 2 with L=15m (70%)

As can be seen on the graph the difference in the capacity is increased to 16 % giving a capacity of 250 kNm and 290 Eurocode and NORSOK/ISO respectively.

In Figure 6-25 the moment about the y-axis is set to N_{ed} = 5250 kN, corresponding to 90 % of the axial compression capacity. The moment about the z-axis will vary from 0 to 100 kNm.

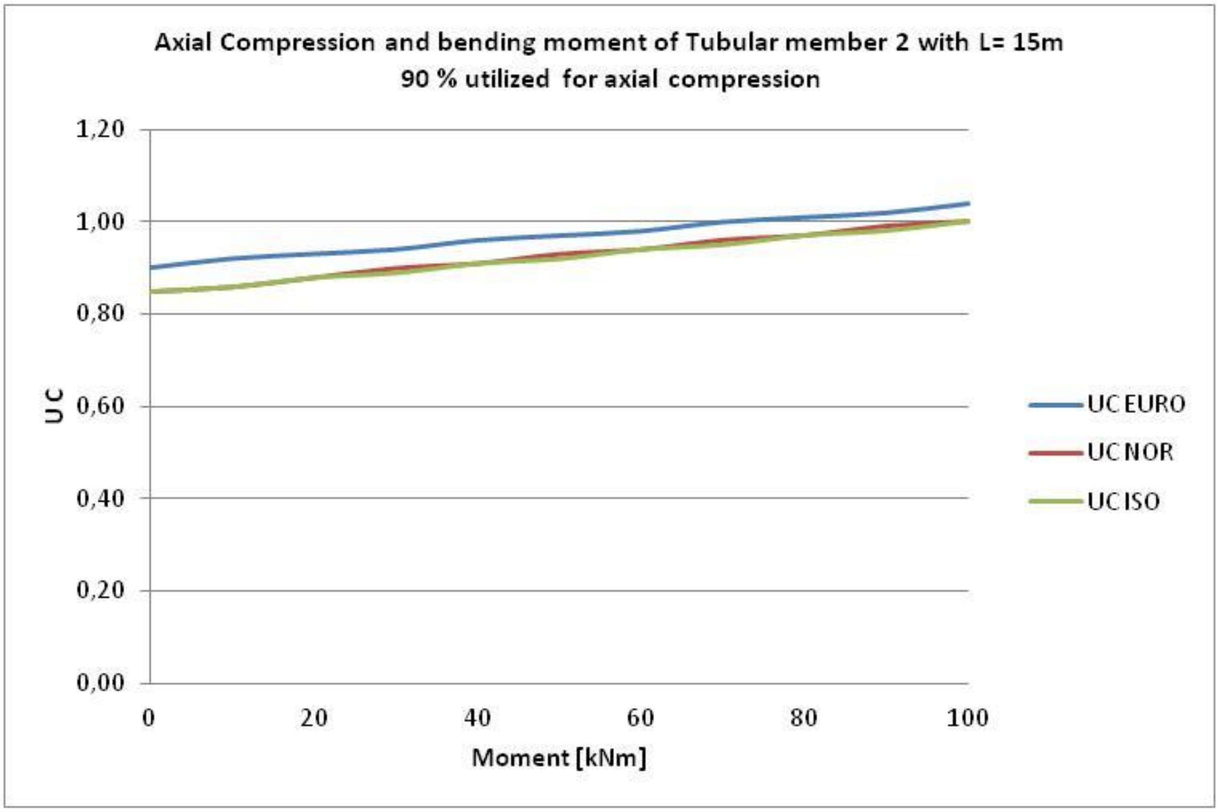


Figure 6-25 Axial compression and bending moment - Member 2 with L=15m (90%)

The graph shows the same trend as the previous results, the capacity is 73 kNm for Eurocode and 95 kNm for NORSOK and ISO, giving a difference in the capacity of 23 %.

6.8.5 Discussion on the formulas for combined axial compression and bending

Based on the parameter study it can be concluded that NORSOK/ISO are more conservative than Eurocode, when the member is in cross sectional class 2. The variation between the codes is an average of 9 %, and the differences in the capacity are more or less constant with increased constant value for N_{ed}. The slenderness of the members seems to have no effect on the results between the different codes.

For cross sectional class 3, the results of the parameter study shows the opposite trend. Eurocode is the most conservative approach with an average of 19 % compared with NORSOK and ISO. The same trend appears here that the differences in the capacity are more or less constant with increased constant value of N_{ed}. Also for this case the effect of the slenderness seems to be marginal.

6.9 Axial compression and biaxial bending moment

The parameter study will study the effect of increasing combined axial compression and biaxial bending moment on the single span simply supported members, with a length of 10 m. The parametric study of combined axial compression and biaxial bending is to determine the effect, the similarities and the differences in the formulas used in Eurocode, NORSOK and ISO, ref section 5.9.

Eurocode uses interaction formulas in the formula for combined axial compression and biaxial bending, these interaction formulas can be derived from two alternative approaches found in the National Annex A or B (EN 1993-1-1, 2005). In this parametric study the method in Annex B is used.

6.9.1 Tubular member 1 with L = 10 m subjected to axial compression and biaxial moment

The parameter study is performed on tubular member 1 with a length of 10 m in cross sectional class 2 according to Eurocode. The biaxial bending moment increases proportional, while the design axial compression force, N_{ed} is set to a constant value corresponding to 50 %,70 % , 90 % of the axial compression capacity, ref. 6.5.1.

- 50 % utilized when N_{ed} = 2450 kN
- 70% utilized when N_{ed} = 3400 kN
- 90 % utilized when N_{ed} = 4400 kN

In Figure 6-26 Axial Compression and biaxial bending, tubular member 1 (50%), the axial force is set to N_{ed} = 2450 kN, corresponding to 50 % of the axial compression capacity. The biaxial moment about the y-axis and z-axis will vary proportional with each other from 0 to 250 kNm.

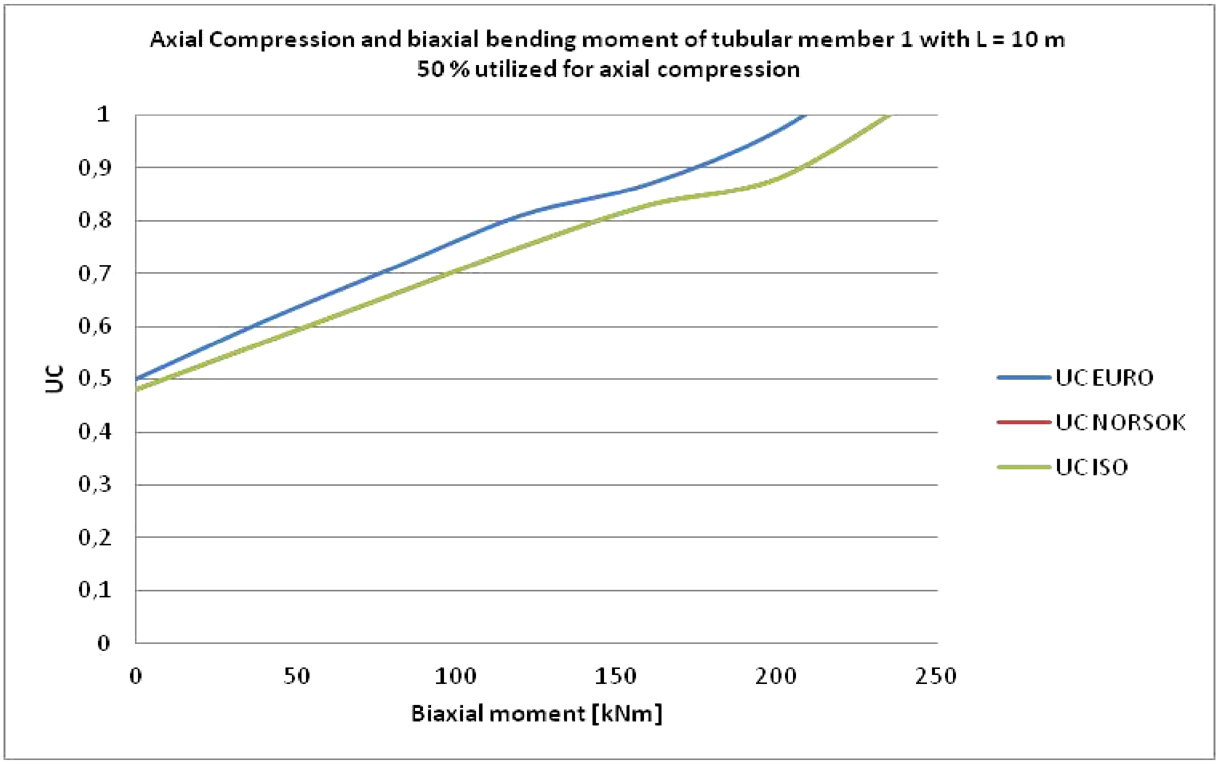


Figure 6-26 Axial Compression and biaxial bending, tubular member 1 (50%)

From the graph it can be seen that Eurocode is the conservative approach. The capacity for axial compression and biaxial bending of the tubular member (UC = 1.0) is 210 kNm for Eurocode and 240 kNm for Eurocode, the difference in the capacity between the codes are 12 %.

In Figure 6-27 the axial compression about the y-axis is set to N_{ed} = 3400 kN, corresponding to 70 % of the axial compression capacity. The biaxial moment about the y-axis and the z-axis will vary from 0 to 140 kNm.

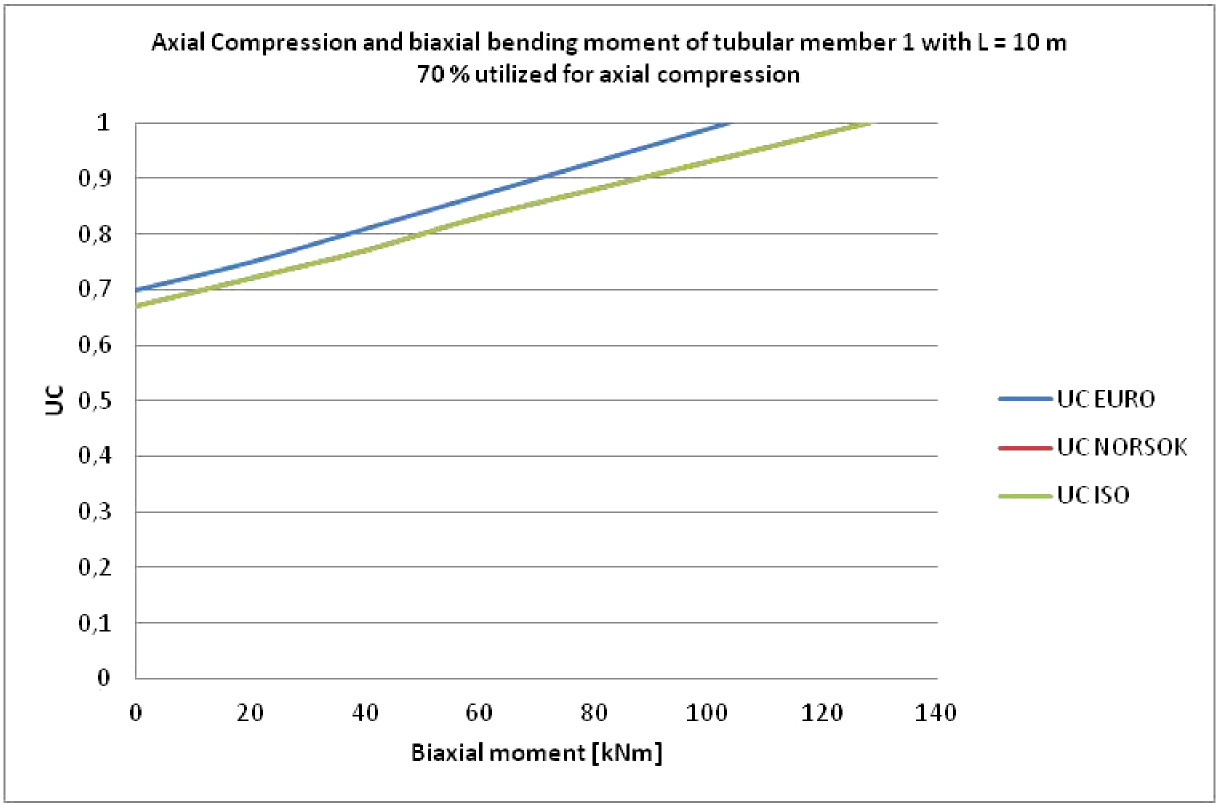


Figure 6-27 Axial Compression and biaxial bending, tubular member 1 (70%)

From the graph it can be seen that Eurocode is the conservative approach. The capacity for axial compression and biaxial bending moment of the tubular member is 104 kNm for Eurocode and 127 kNm for Eurocode, the difference in the capacity between the codes are 22,1 %.

In Figure 6-28 the moment about the y-axis is set to N_{ed} = 4400 kN, corresponding to 90 % of the axial compression capacity. The biaxial moment about the y and z-axis will vary proportional from 0 to 70 kNm.

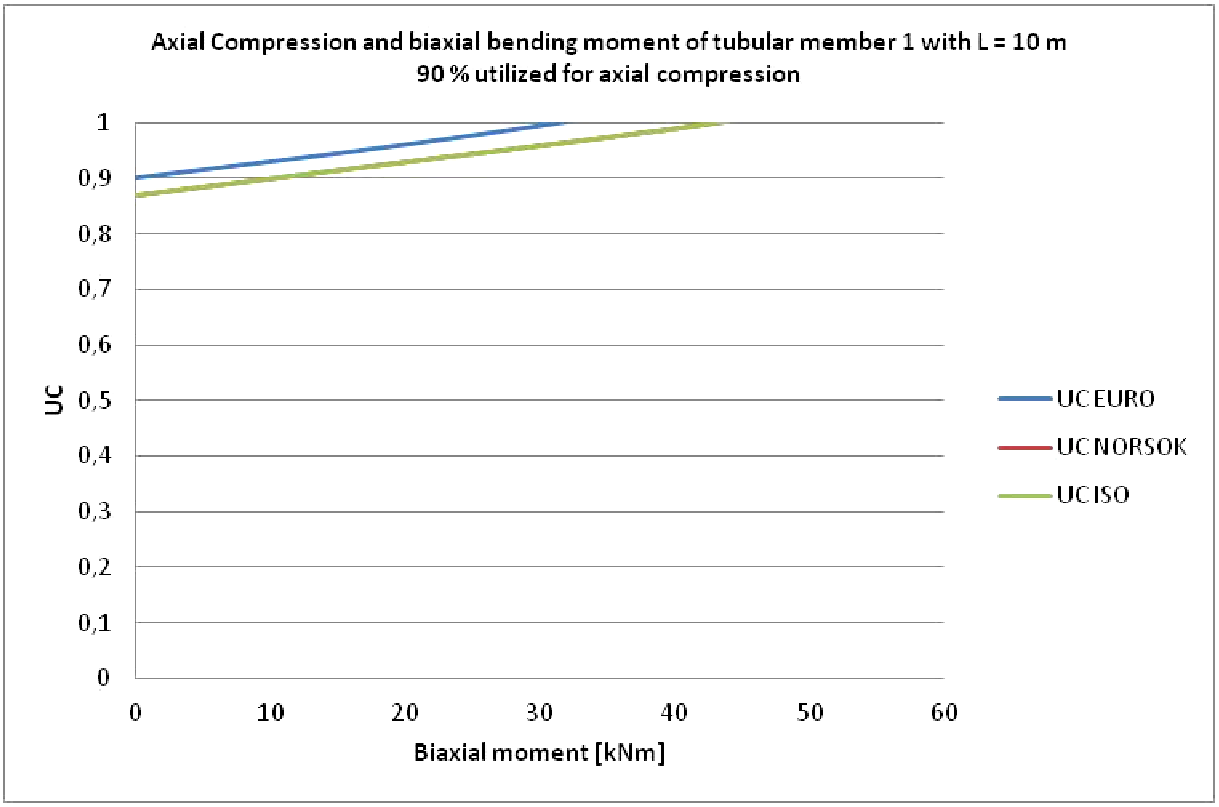


Figure 6-28 Axial Compression and biaxial bending, tubular member 1 (90%)

The graph shows the same trend as the previous results, the capacity is 30 kNm for Eurocode and 44 kNm for NORSOK and ISO, giving a difference in the capacity of 46 %.

6.9.2 Tubular member 2 with L = 10 m subjected to axial compression and biaxial moment

The parameter study is performed on tubular member 2 with a length of 10 m in cross sectional class 3 according to Eurocode. The biaxial bending moment increases proportional, while the design axial compression force, N_{ed} is set to a constant value corresponding to 50 %,70 % , 90 % of the axial compression capacity, ref. section 0.

- 50 % utilized when N_{ed} = 3700 kN
- 70% utilized when N_{ed} = 5250 kN
- 90 % utilized when N_{ed} = 6700 kN

In Figure 6-29, the axial force is set to N_{ed} = 3700 kN, corresponding to 50 % of the axial compression capacity. The biaxial moment about the y-axis and z-axis will vary proportional with each other from 0 to 500 kNm.

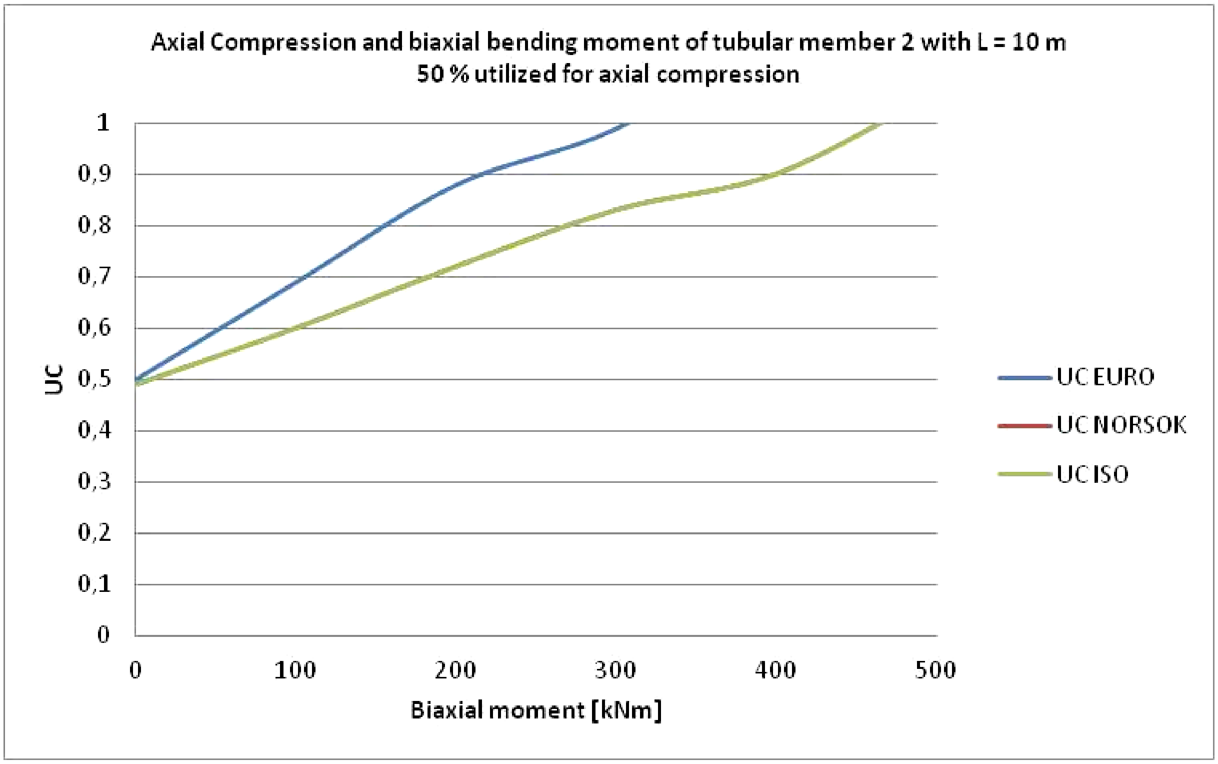


Figure 6-29 Axial Compression and biaxial bending, tubular member 2 (50%)

The slope for Eurocode is steeper which means that Eurocode is more conservative than NORSOK and ISO. The capacity is 310 kNm and 470 kNm for Eurocode and NORSOK/ISO respectively, giving a difference in the capacity of 51.6 %.

In Figure 6-30 the moment about the y-axis is set to N_{ed} = 5250 kN, corresponding to 70 % of the axial compression capacity. The biaxial moment about the y-axis and the z-axis will vary from 0 to 240 kNm.

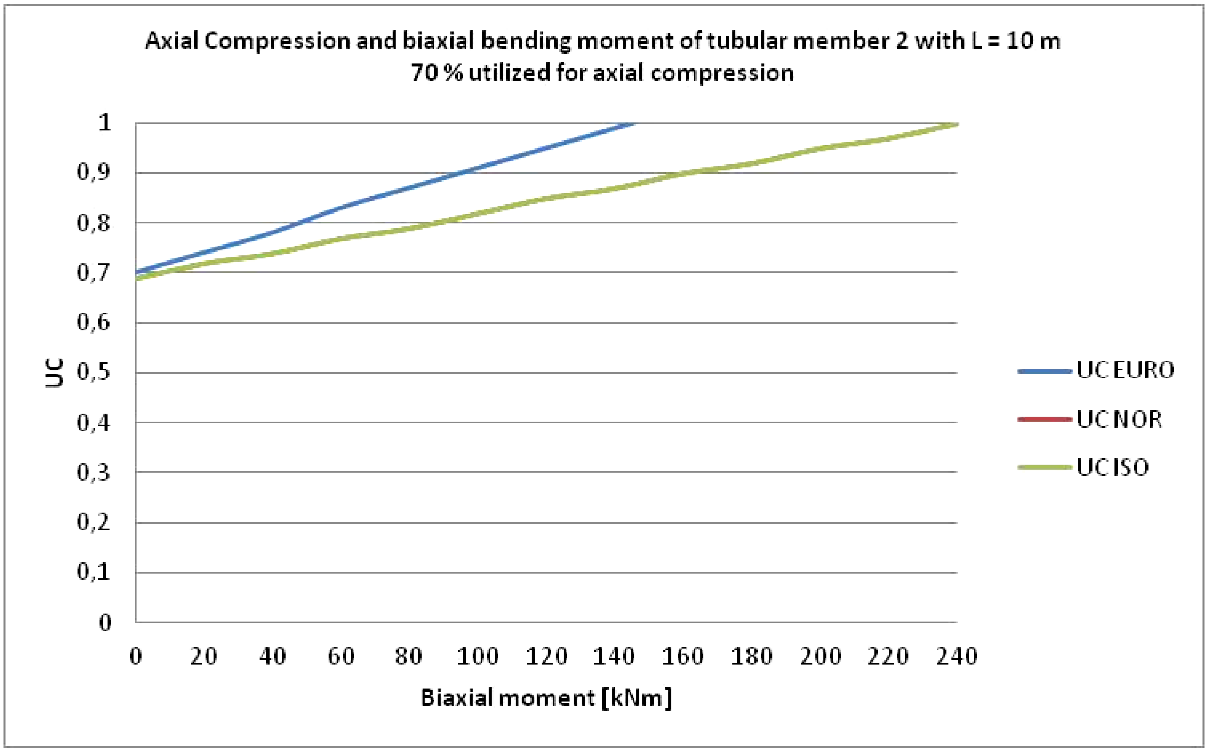


Figure 6-30 Axial Compression and biaxial bending, tubular member 2 (70%)

Eurocode is more conservative than NORSOK and ISO, the capacity for axial compression and is 145 kNm for Eurocode and 240 kNm for NORSOK and ISO, the difference in the capacity between the codes are 65.5 %.

In Figure 6-31 the moment about the y-axis is set to N_{ed} = 6700 kN, corresponding to 90 % of the axial compression capacity. The biaxial moment about the y-axis and the z-axis will vary from 0 to 80 kNm.

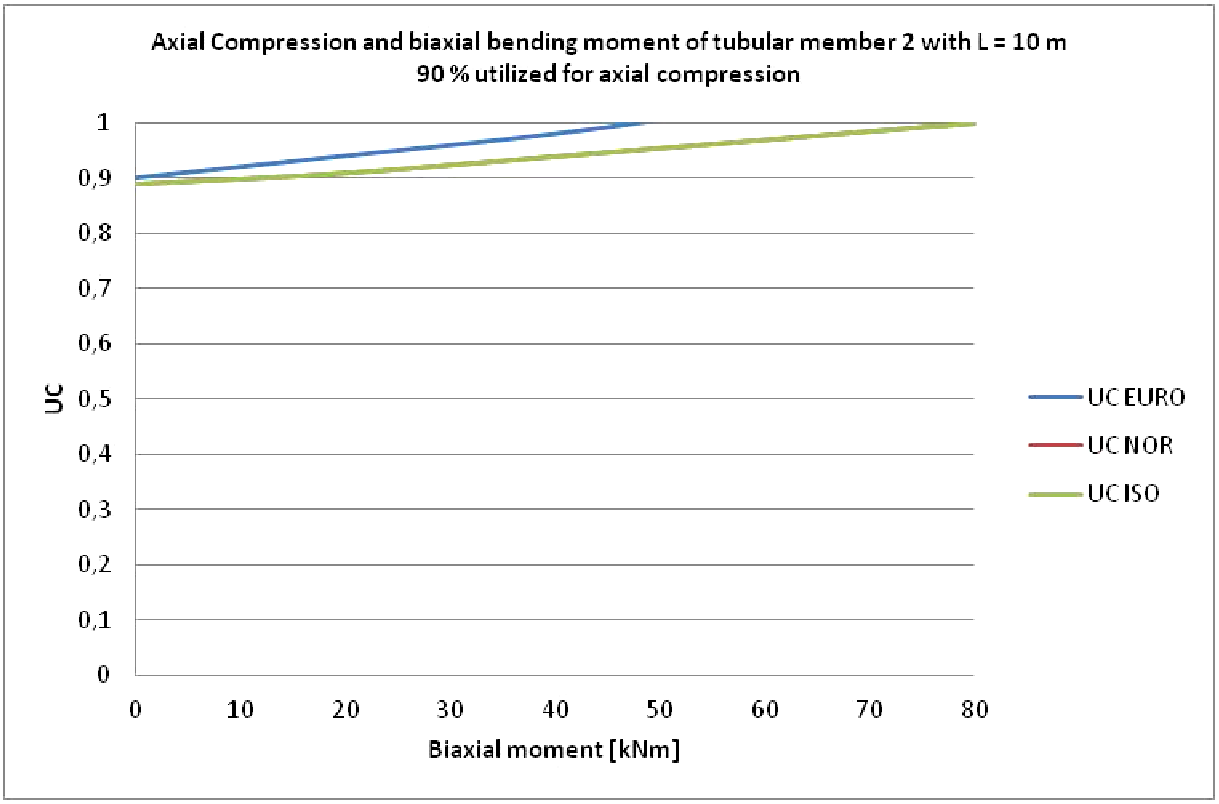


Figure 6-31 Axial Compression and biaxial bending, tubular member 2 (90%)

The graph indicates the same trend as the previous results, the capacity is 50 kNm for Eurocode and 80 kNm for NORSOK and ISO, giving a difference in the capacity of 60 %.

6.9.3 Discussion on the formulas for combined axial compression and biaxial bending

Based on the parameter study it can be concluded that Eurocode is more conservative than NORSOK and ISO when the members are subjected to axial compression and biaxial bending for all the cross sectional classes.

For tubular member 1, which is in cross sectional class 2 it can be concluded that the moment capacity is decreasing with increasing axial compression. The difference in the moment capacity between the codes increases significant, from 12% to 46%, a factor of 3.8 when the axial compression force increse with a factor of 1.8.

However, a different trend is observed for tublar member 2 in cross sectional class 3 according to Eurocode. NORSOK/ISO gives a moment capacity which is more than 50% higher than Eurocode. The difference between the code with increasing axial compression force is insignificant.

6.10 Slenderness

The parameter study will study the effect of slenderness of single span simply supported tubular members, with a length of 10 m and a length of 15 m. The slenderness of the member is determined by the length and the cross section of the member, ref section 5.7. The aim of the parametric study is to determine the effect of slenderness when the members are subjected to axial compression and axial compression and bending moment in Eurocode, NORSOK and ISO.

6.10.1 The effect of slenderness on tubular member 1 subjected to axial compression

Figure 6-32 illustrates tubular member 1, when subjected to increasing axial compression force in the range of 0 – 5000 kN according to Eurocode. The length of the tubular member is 10 m and 15 m and according to Eurocode the tubular member is in cross section class 2.

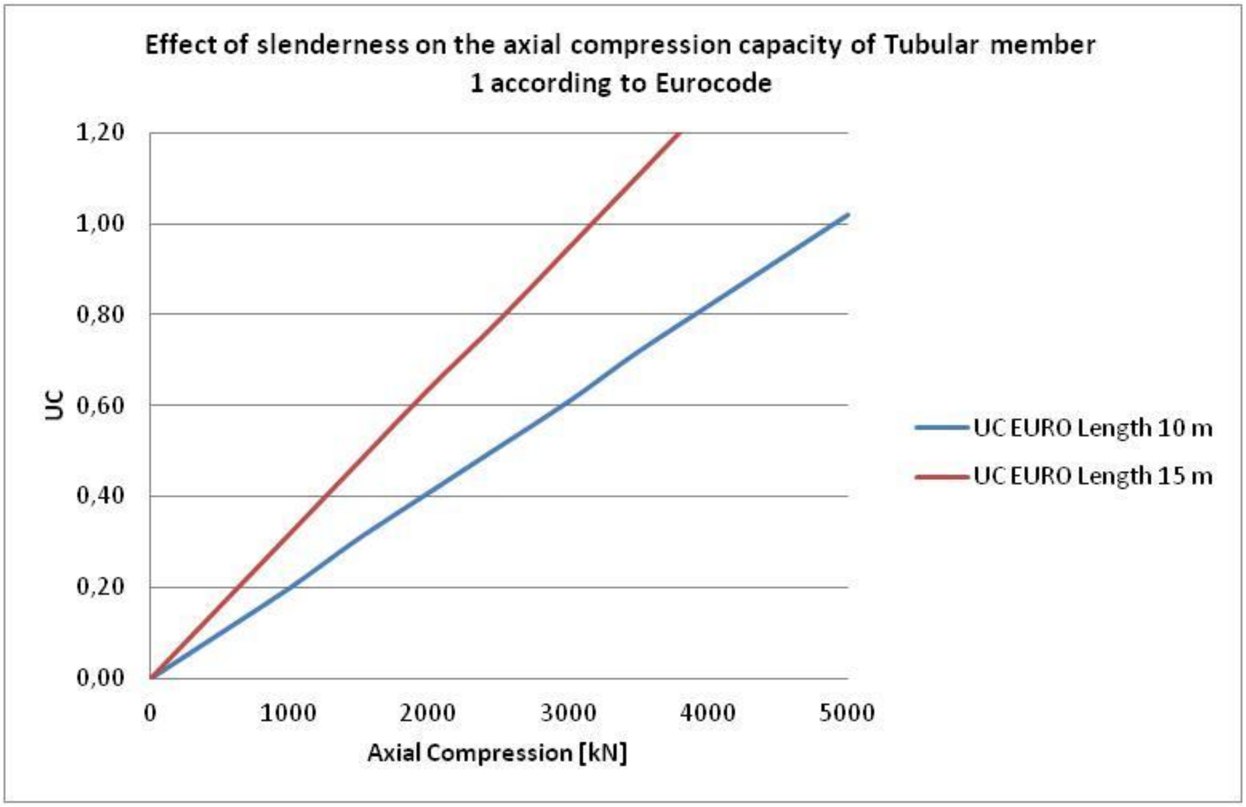


Figure 6-32 Slenderness – Axial compression - Member 1- Eurocode

The graphs are showing that the axial compression capacity is decreased with 36 %, from 4900 kN to 3200kN when the slenderness of the member increases with 50%.

Figure 6-33 illustrates the effect of slenderness on the tubular member 1according to NORSOK and ISO.

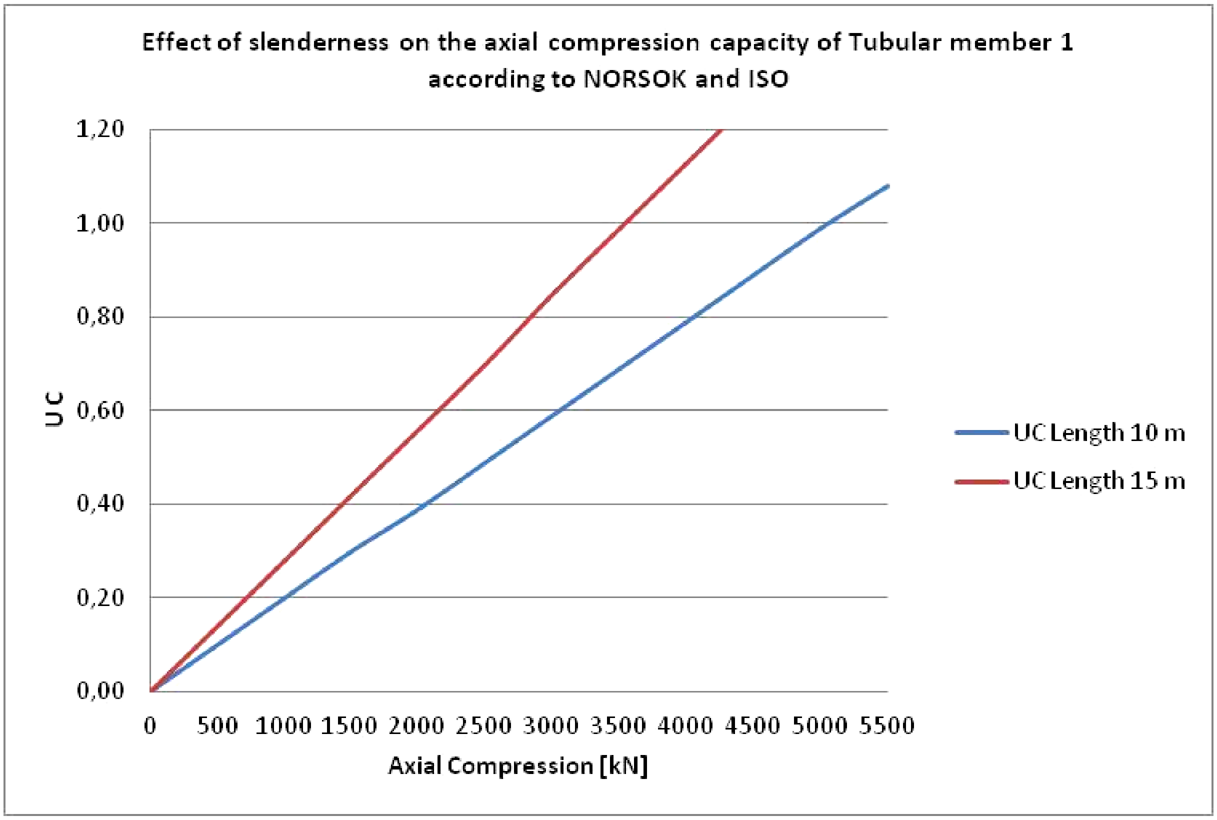


Figure 6-33 Slenderness – Axial compression - Member 1- NORSOK and ISO

As seen on the graph for NORSOK and ISO the axial compression capacity is decreased with 30% from 5050 kN to 3550 kN slightly less than for Eurocode, when the slenderness is increased with 50%.

6.10.2 The effect of slenderness on tubular member 2 subjected to axial compression

Figure 6-34 illustrates the tubular member 2, when subjected to increasing axial compression force in the range of 0 – 8000 kN according to Eurocode. The length of the tubular member is 10 m and 15 m and according to Eurocode the tubular member is in cross section class 3.

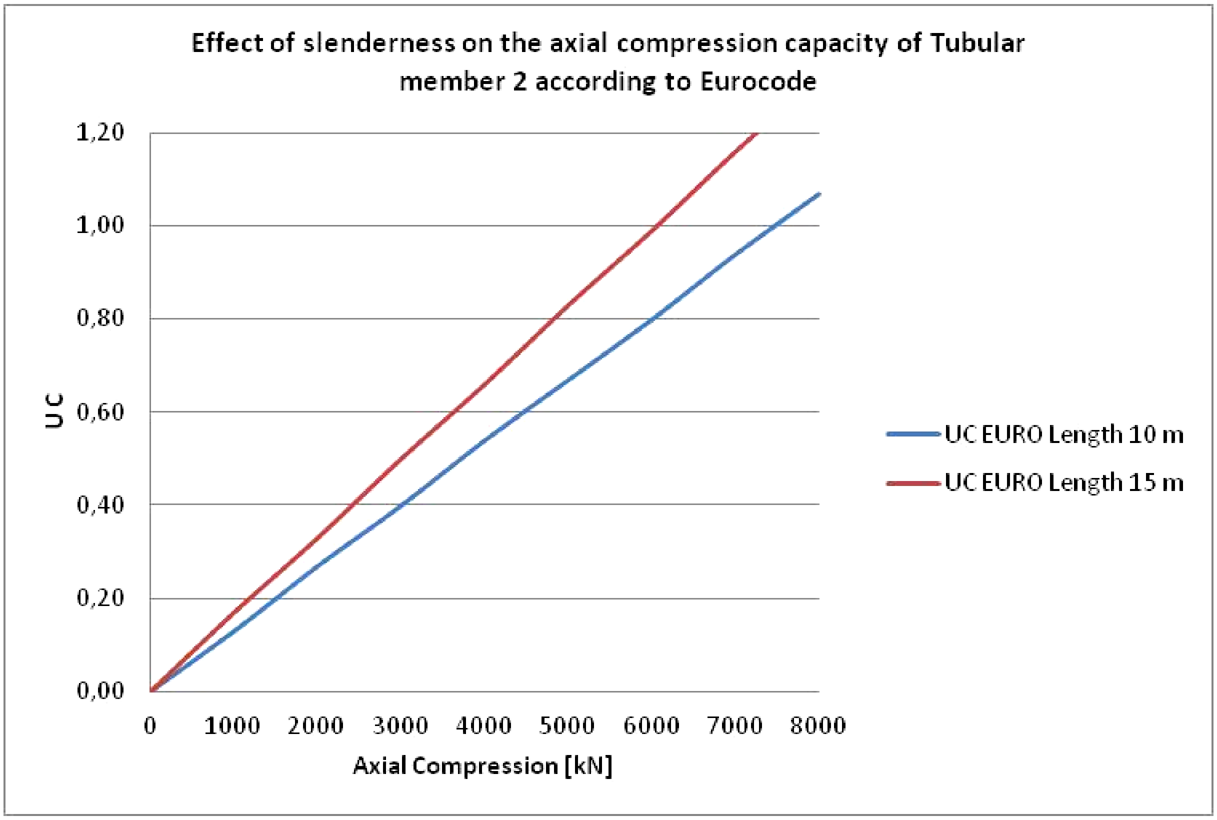


Figure 6-34 Slenderness – Axial compression - Member 2- Eurocode

The graph is showing a reduction in axial compression capacity from 7500 kN to 6050 kN, close to 20 %, when the slenderness is increased with 50 %.

Figure 6-35 illustrates the effect of slenderness on tubular member 2 for NORSOK and ISO.

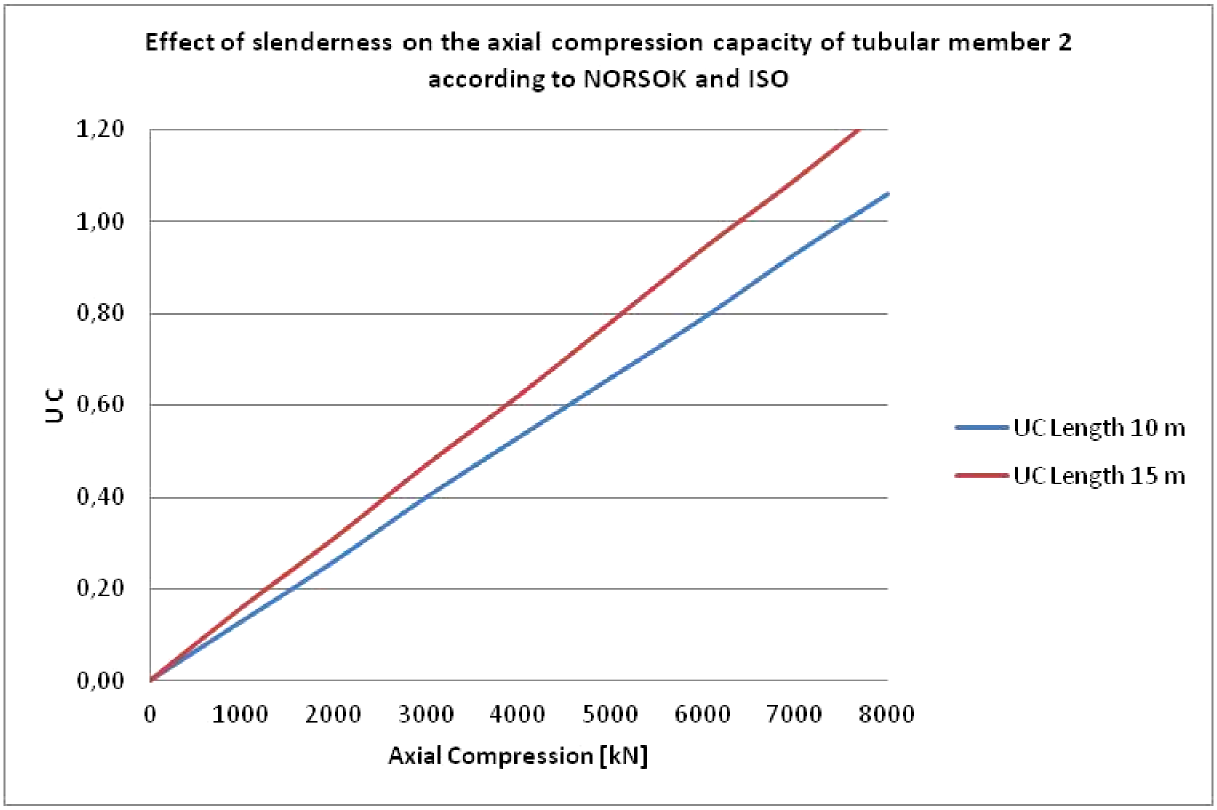


Figure 6-35 Slenderness – Axial compression - Member 2- NORSOK and ISO

The graph is showing a reduction in axial compression capacity from 7500 kN to 6400 kN, 15 %, when the slenderness is increased with 50 %.

6.10.3 The effect of slenderness on moment capacity of member 1 subjected to axial compression

In Figure 6-36, the axial force is set to N_{ed} = 2450 kN, corresponding to 50 % of the axial compression capacity when the length is 10 m.

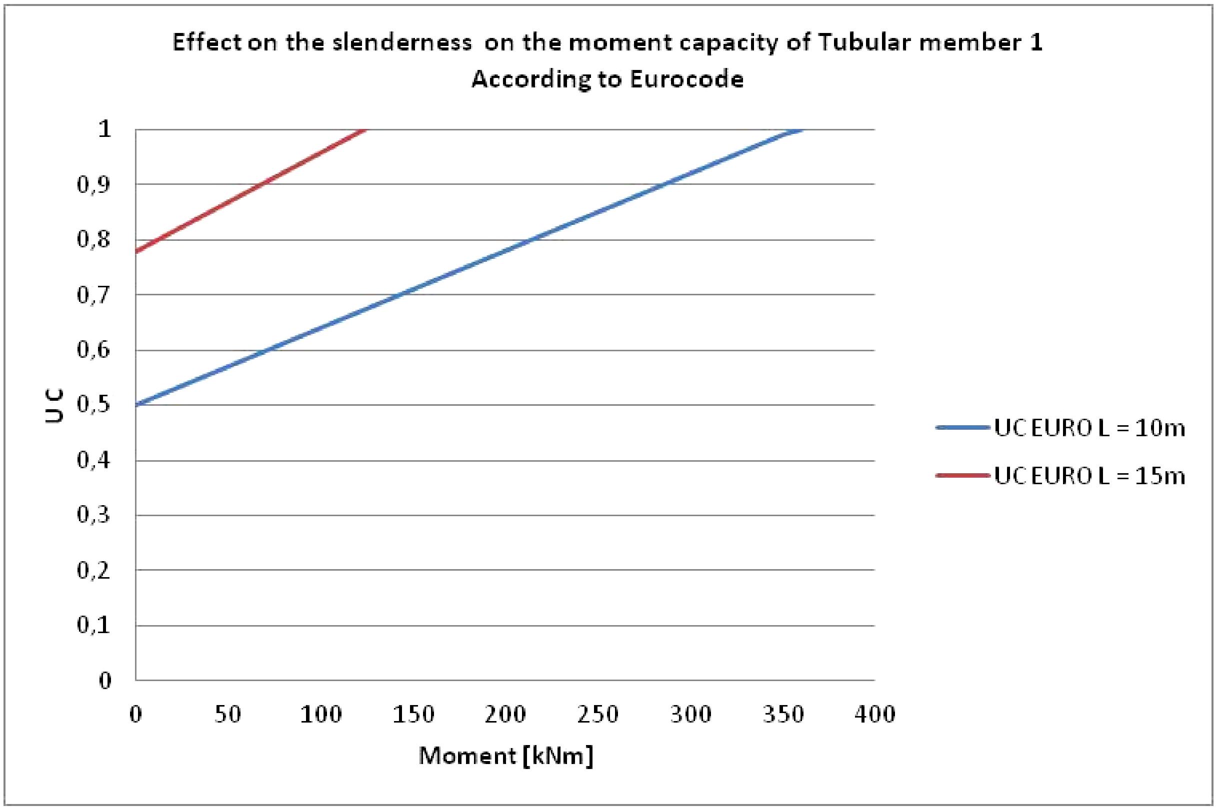


Figure 6-36 Slenderness –Moment and axial compression - Member 1- Eurocode

The graph is showing a reduction in moment capacity from 360 kNm to 120 kNm, 67%, when the slenderness is increased with 50%

The axial force is set to N_{ed} = 2450 kN in Figure 6-37:

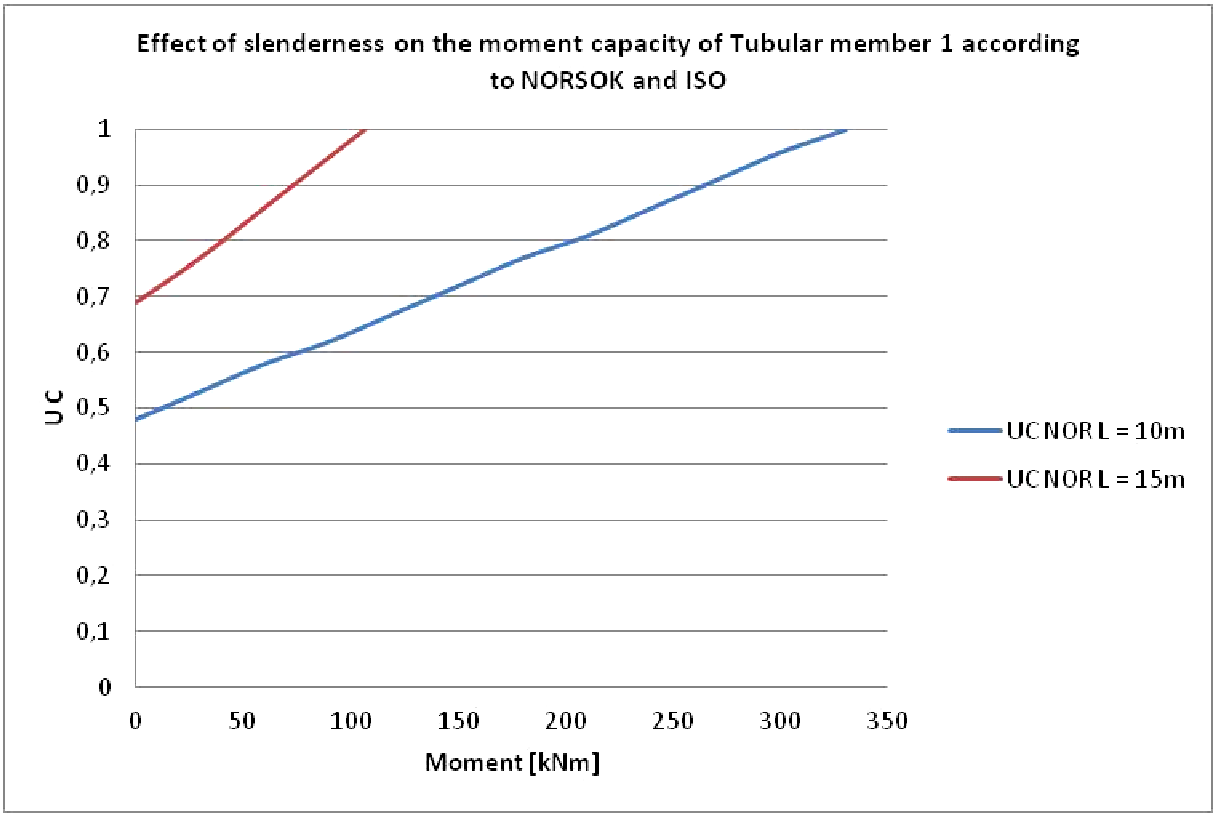


Figure 6-37 Slenderness –Moment and axial compression - Member 1- NORSOK and ISO

The graph is showing a reduction in moment capacity from 330 kNm to 107 kNm, 67%, when the slenderness is increased with 50%.

6.10.4 The effect of slenderness on moment capacity of member 2 subjected to axial compression

In Figure 6-38, the axial force is set to N_{ed} = 3700 kN, corresponding to 50 % of the axial compression capacity when L = 10 m. The aim is to investigate the effect of slenderness on the moment capacity of member 2 subject to axial compression.

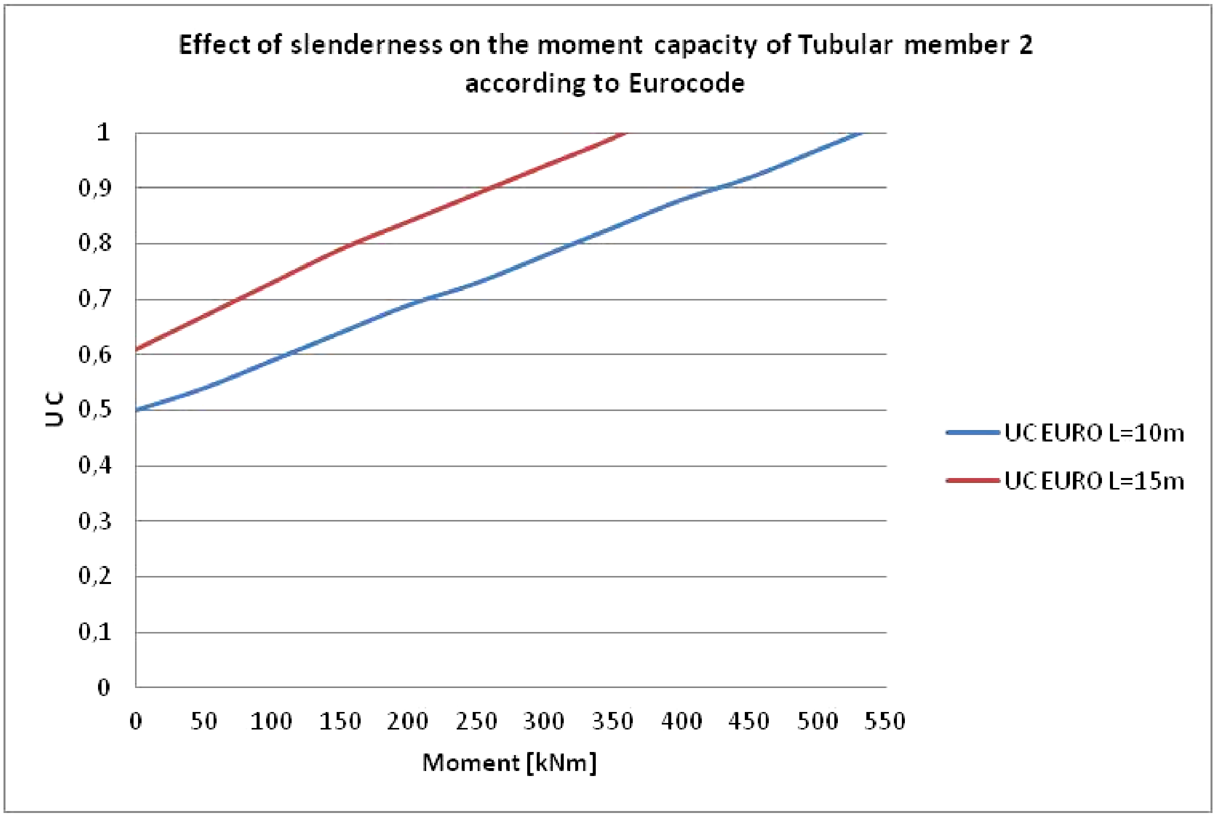


Figure 6-38 Slenderness –Moment and axial compression - Member 2- Eurocode

The graph is showing a reduction in moment capacity from 540 kNm to 360 kNm corresponding to 33%, when the slenderness is increased with 50%

In the Figure 6-39 the moment capacity according to NORSOK and ISO is shown.

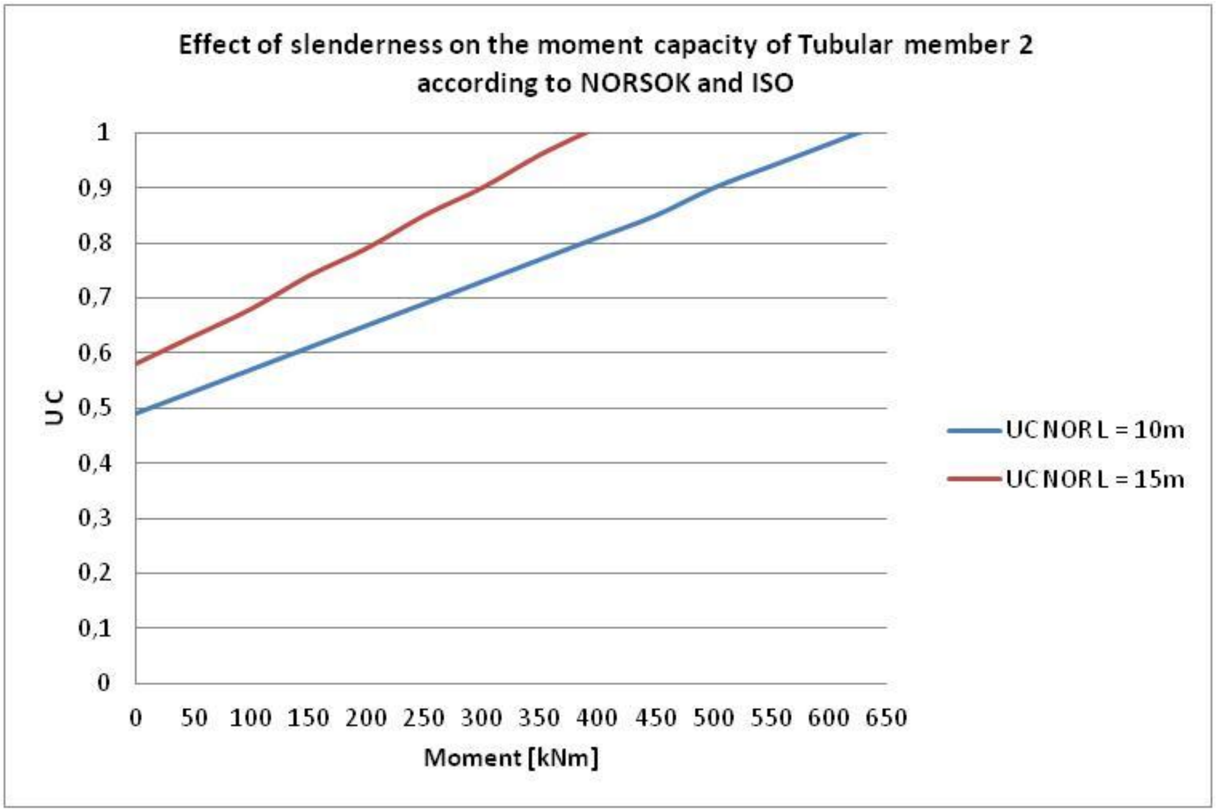


Figure 6-39 Slenderness –Moment and axial compression - Member 2- NORSOK and ISO

From the graph it can be seen a reduction in moment capacity from 620 kNm to 390 kNm corresponding to 37 % when the slenderness is increased with 50 %.

6.10.5 Discussion of the effect of slenderness

Based on the parameter studied it can be concluded that the slenderness will have an effect on the capacity when axial compression force is applied. There is not observed a significant difference between Eurocode and NORSOK/ISO either for axial compression nor combined axial compression and moment.

It can be observed that the reduction in capacity for an increasing slenderness is more significant for member 2 (cross sectional class 3) than for member 1.

6.11 Cross Section Class

The parameter study will study the effect of cross sections of two single span simply supported tubular members. The aim of the parameter study is to determine the effect of different cross section when subjected to axial compression and combined axial compression and bending in Eurocode, NORSOK and ISO. In Eurocode the cross sections are classified into cross sectional classes, to determine if the capacity of the section should be determined on elastic or plastic dimensioning, see section 5.2. NORSOK and ISO do not operate with cross section classes, the elastic and plastic dimensioning is implied in their formulas.

6.11.1 Cross Section Data

The parameter study will look at the effect of single span simply supported tubular members with the same diameter and different thickness, the table below shows the data and the cross sectional class according to Eurocode.

Tubular Member	D [mm]	t [mm]	Cross Section Class According to Eurocode
Tubular member 1	457	12,7	2
Tubular member 2	610	12,7	3

6.11.2 Effect of the cross sectional class when subjected to axial compression

Figure 6-40 shows the utilization ratio for member 1 and member 2 when subjected to increasing axial compression in the range of 0 to 8000 kN.

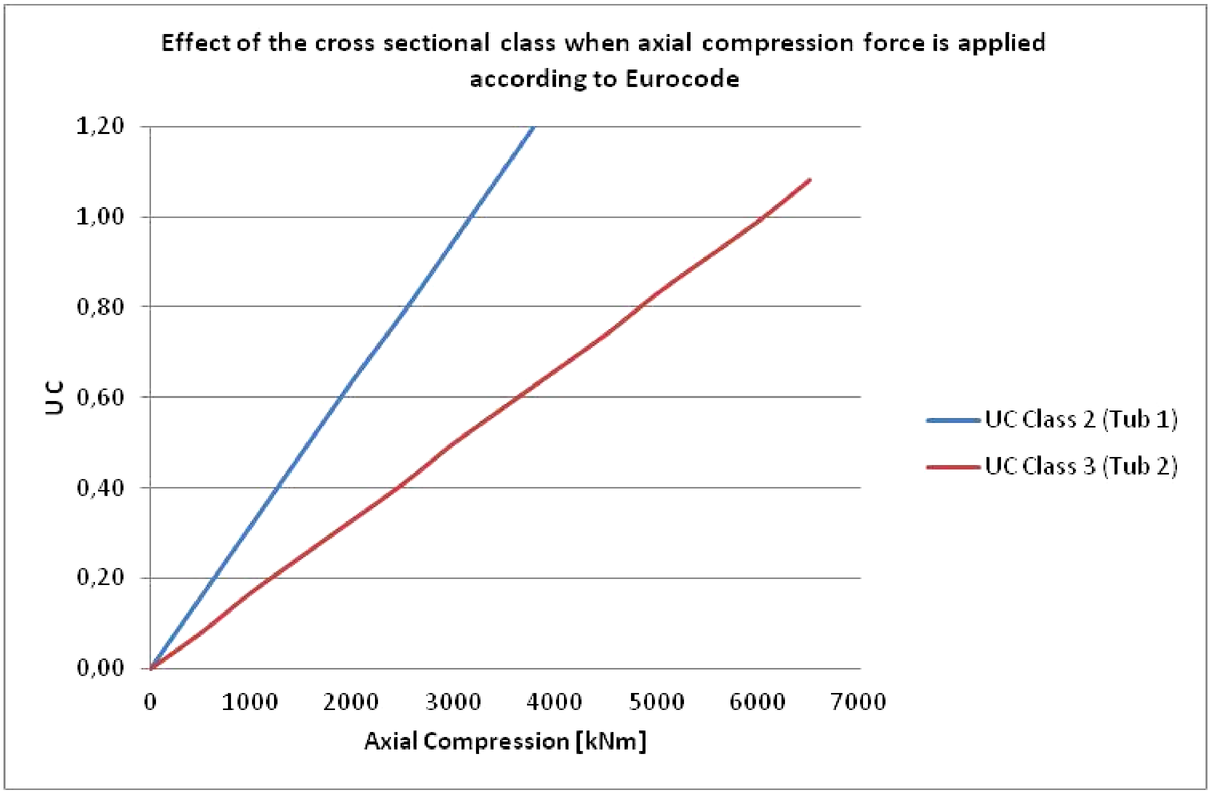


Figure 6-40 Cross sectional class –Axial compression – Eurocode

The capacity for axial compression of the tubular member (UC = 1.0) is 4900 kN for tubular member 1 and 7500 kN for tubular member 2, corresponding to 78% and 89% of the yield capacity of the section respectively.

Figure 6-41 shows the utilization ratio for member 1 and member 2 according to NORSOK and ISO when subjected to increasing axial compression in the range of 0 to 8000 kN.

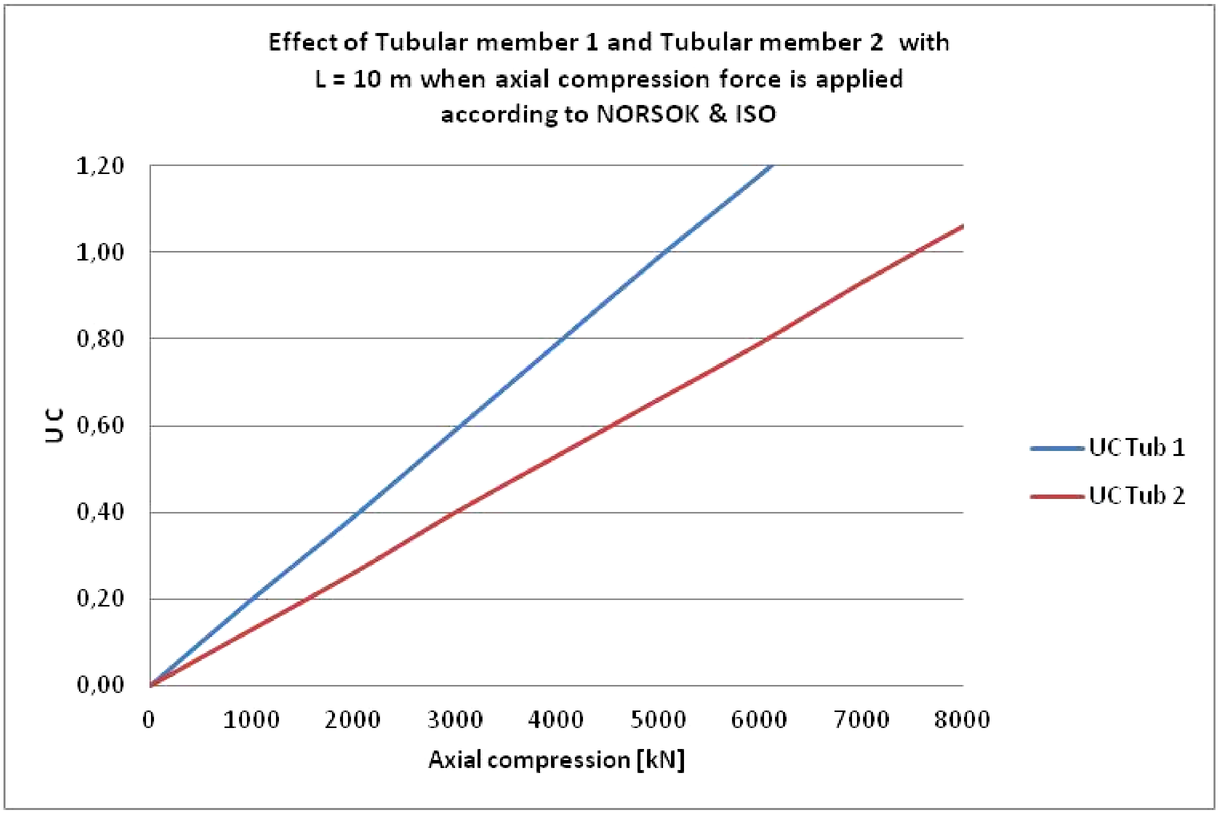


Figure 6-41 Cross sectional class –Axial compression - NORSOK and ISO

The capacity for axial compression of the tubular member is 5200 kN for tubular member 1 and 7600 kN for tubular member 2, corresponding to 80% and 90% of the yield capacity of the section respectively

6.11.3 Effect of the cross sectional class with combined axial compression force and bending

In Figure 6-42, the axial force is set to N_{ed} = 2450 kN, corresponding to 50 % of the axial compression capacity.

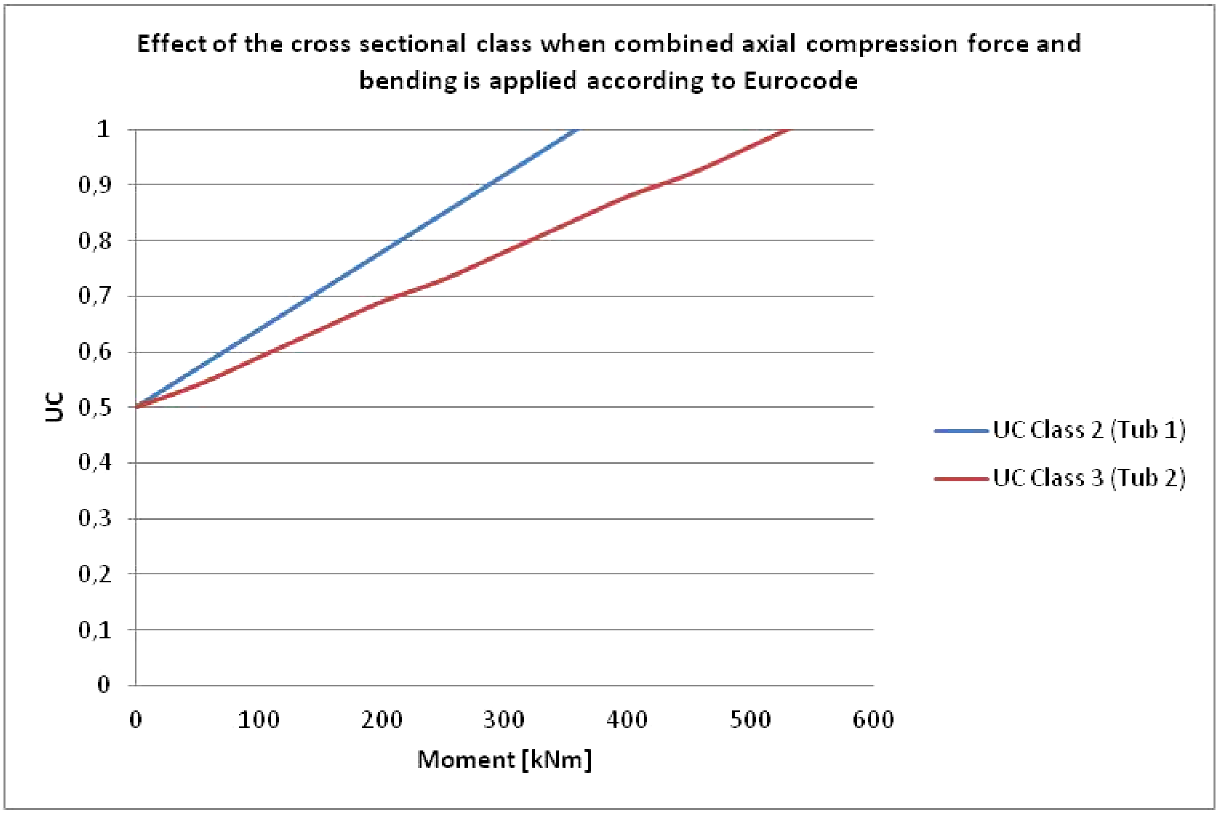


Figure 6-42 Cross sectional class –Moment and Axial compression - Eurocode

From the graph above it can be seen that the moment capacity according to Eurocode for the tubular member subjected to a axial compression force of 2450 kN is 360kNm and 540kNm for tubular member 1 and tubular member 2 respectively, corresponding to 53% and 44% of the yield moment capacity of the section.

In Figure 6-43 the utilization factor according to Norsok and ISO is shown for the same axial compression force as above.

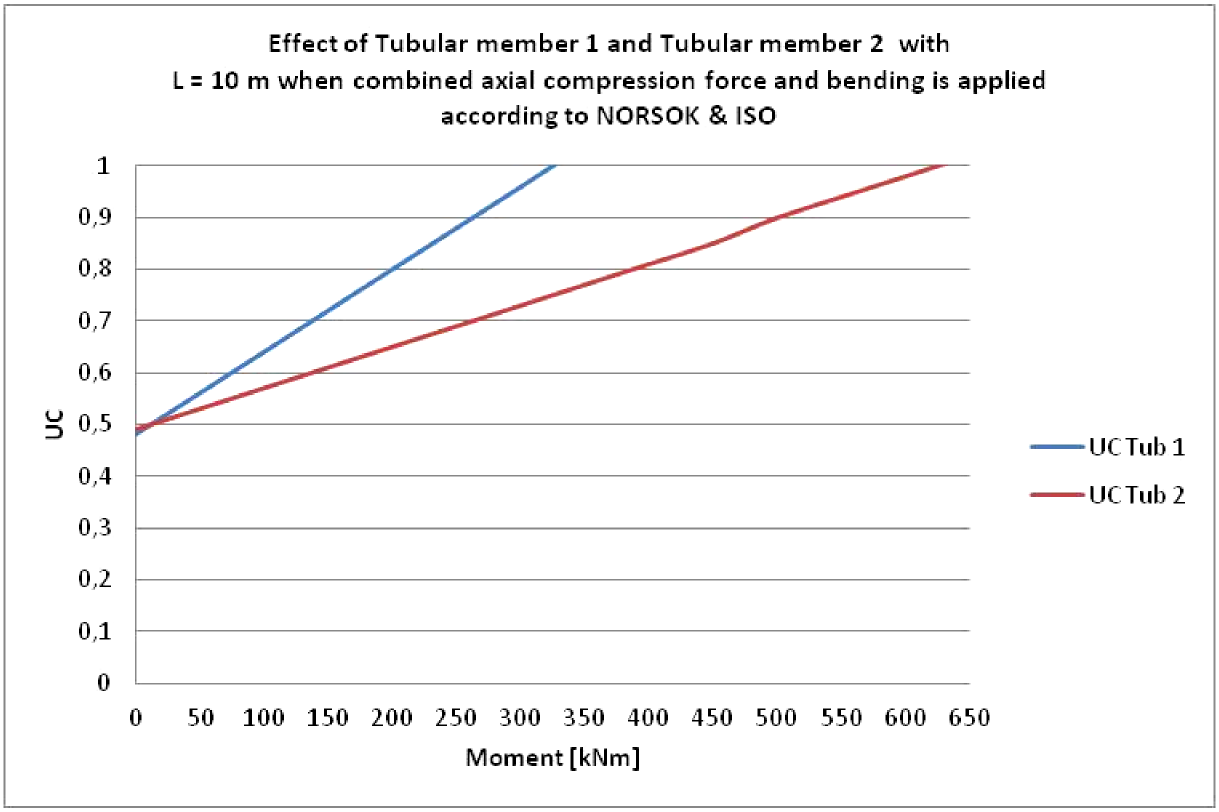


Figure 6-43 Cross sectional class –Moment and Axial compression - NORSOK and ISO

The moment capacity according to NORSOK and ISO for of the tubular member subjected to a axial compression force of 2450 kN is 330kNm and 625kNm for tubular member 1 and tubular member 2 respectively, corresponding to 49% and 51% of the yield moment capacity of the section.

6.11.4 Discussion of the effect of cross section class

The results for the cross sections subjected to axial compression are as expected. There is not identified any significant differences between the codes that are related to cross section classes.

7 FINITE ELEMENT MODEL OF THE TOPSIDE MODULE IN SESAM:GENIE

7.1 General

The aim of this comparison is to determine the similarities and the differences in the resistance formulas provided in the codes of Eurocode, NORSOK and ISO by analysis of a topside module that consist of tubular members. Figure 7-1 illustrates the re-designed topside module.

The computer software SESAM:GeniE is an advanced engineering software tool for designing and analysing offshore and maritime structures. In the two case studies, SESAM:GeniE were used to re-build and modify a typically offshore module provided by Aker Solutions, that originally consisted of I-sections and box-sections. The sections in the module are changed to tubular members by use of COLBEAM. The analyses are based on two different case studies and the modelling, load application, analysis and code checking were performed in GeniE. The finite element analysis is performed in Sestra, which is a solver for linear structural FE analysis provided by DNV, the results from Sestra are imported into GeniE for further post-processing.

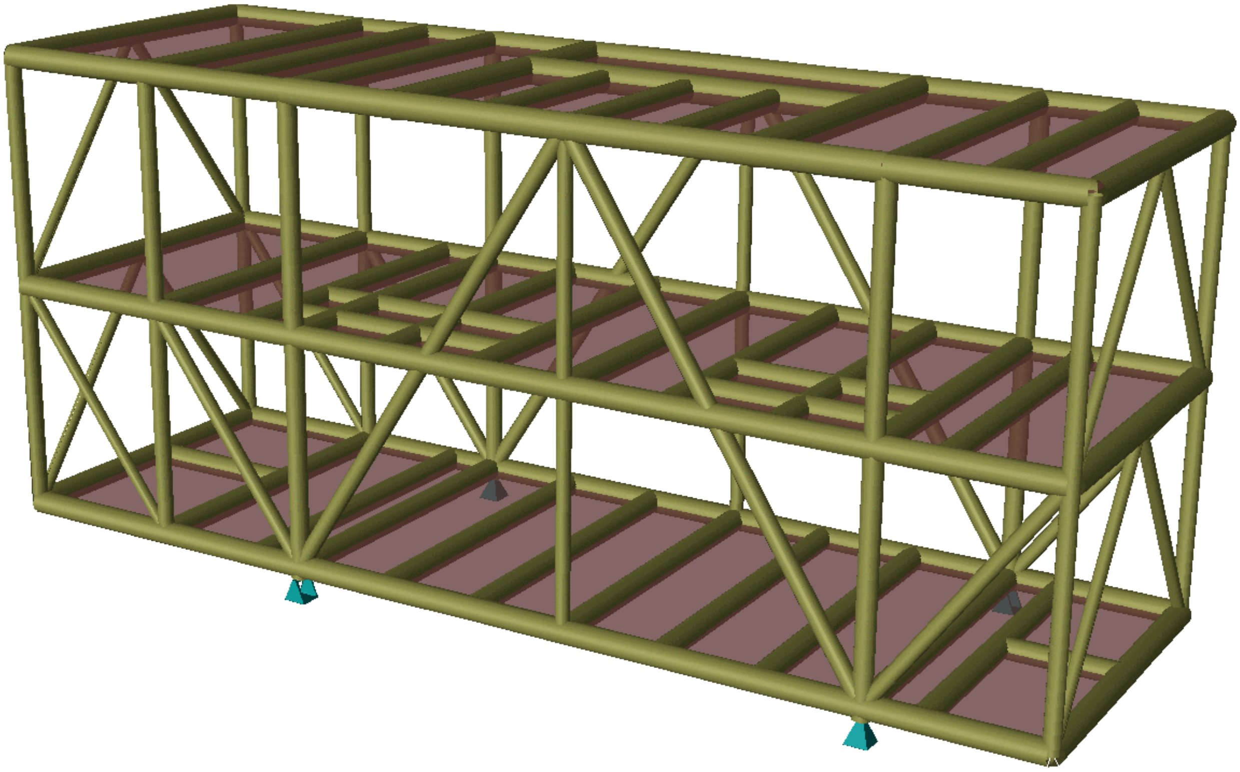


Figure 7-1 Perspective of the topside module

The comparison of the utilization ratio from the analysis is to investigate the effect of the three standards Eurocode, NORSOK and ISO. The analysis is divided into two methods to look at the effect in the capacity of the ten highest utilized members according to Eurocode and compare these with the results from NORSOK and ISO.

The first method, case study 1 sets basis in comparing Eurocode, NORSOK and ISO when subjected to the original resistance and action factors given in the individual standards.

The second method, case study 2 is performed due to the fact that the facilities regulations under Norwegian law states that for load-bearing structures, the standards NORSOK N-001, NORSOK N-003 and NORSOK N-004 should be used for steel structures (PSA, 2007). To assure that the results are comparable the action factors and loads for permanent, variable and environmental were set identical.

The input file for Case study 2 in Sesam:Genie can be found in Appendix A-5.

7.2 Limitations

The analysis will look at tubular members only and the cross sectional classes are limited to class 1, 2 and 3 according to Eurocode.

7.3 Regulations

The regulations used in the comparison by regulations by analysis of a topside module are:

- Eurocode 3 1993-1-1 (EN 1993-1-1, 2005)
- NORSOK N-004 (NORSOK N-004, 2004)
- ISO 19902 (ISO 19902, 2007)

7.4 Structural Information

7.4.1 Geometry

The topside module consists of three decks: main deck, mezzanine deck and weather deck. The dimensions of the module are LxWxH = 48.1x14.8x20.3 m, and are illustrated in Figure 7-2. The module consists of tubular sections and plates.

The model is established by the computer tool Sesam Genie by graphical-modeling and use of commando codes in the commando line box. The colours in the model are defined in Genie as standard colours.

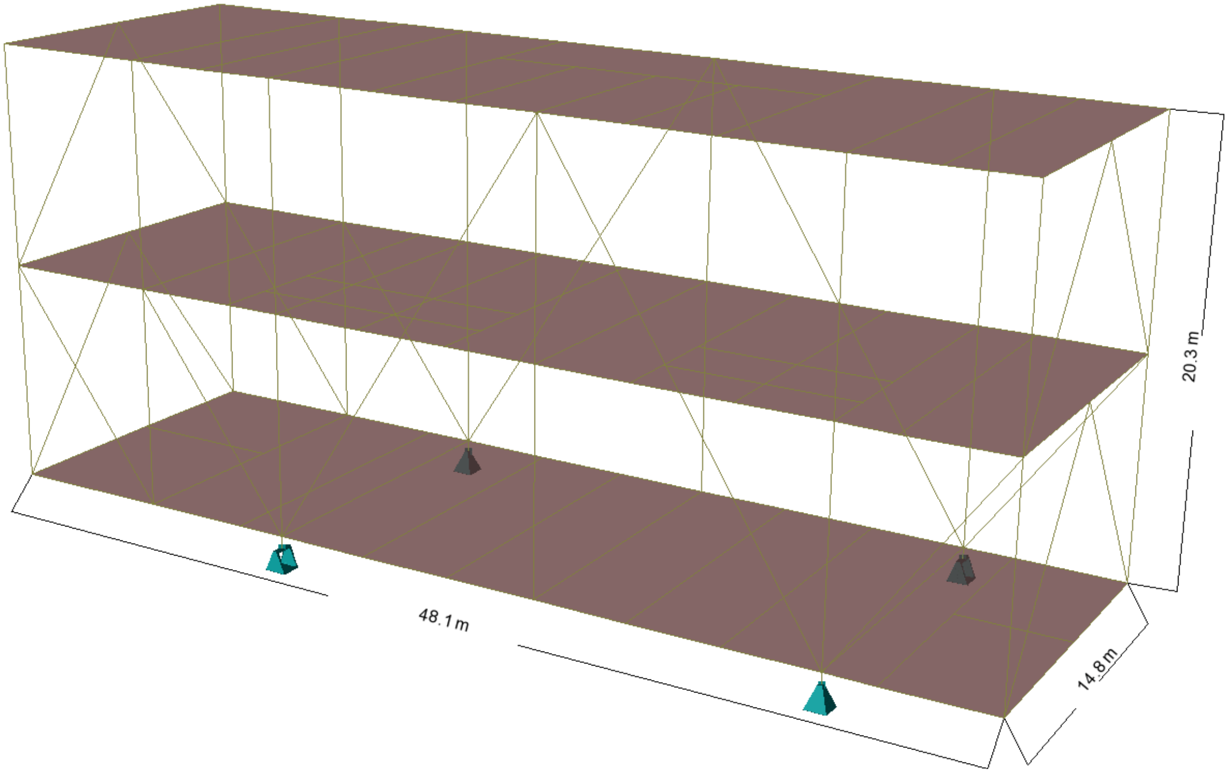


Figure 7-2 Parallel projection, dimensions of topside module

7.4.2 Material

For the topside module the steel quality S355 is used for the whole structure. According to section 3.2 and table 3.1 in EN-1993-1-1 the nominal values for the steel grade S355 is:

Yield strength	f_y =	355 N/mm^2
Ultimate tensile strength	f_u =	510 N/mm^2

Pursuant to EN-1993-1-1, the following design values should be adopted for calculations in structural steel.

Modulus of Elasticity E = 2.1×10^5 N/mm^2

Shear Modulus G = 81 000 N/mm^2
Poisson's Ratio ν = 0.3
Density ρ = 7850 kg/m^3

7.4.3 Supports

The module is supported on four locations, the support boundary conditions are given in Table 7-1.

Table 7-1 Boundary conditions of topside module

Name	X [m]	Y [m]	Z [m]	X- Tra	Y-Tra	Z-Tra	X-Rot	Y- ROT	Z - ROT
Sp1	14.75	0	-0.5	Free	Fixed	Fixed	Fixed	Free	Free
Sp2	40.75	0	-0.5	Fixed	Fixed	Fixed	Free	Free	Free
Sp3	40.75	14.8	-0.5	Free	Fixed	Fixed	Fixed	Free	Free
Sp4	14.75	14.8	-0.5	Fixed	Fixed	Fixed	Free	Free	Free

Figure 7-3 illustrates the locations of the support points of the topside module.

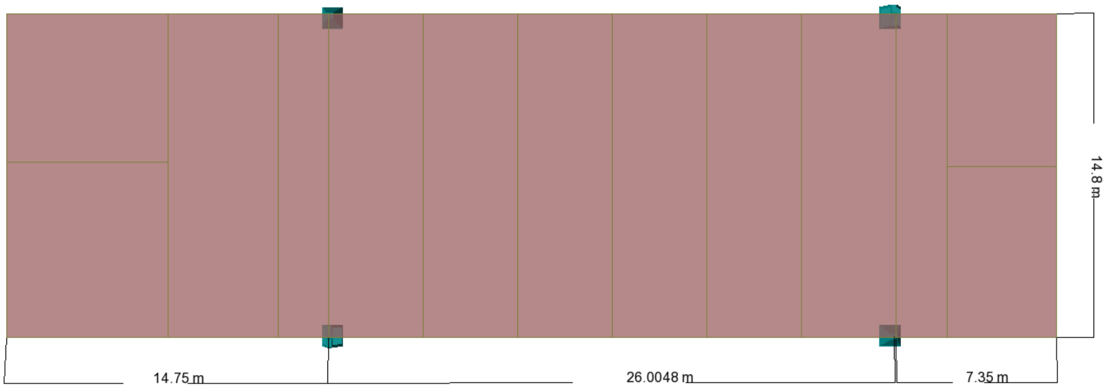


Figure 7-3 Plan, Support points of topside module

7.4.4 Tubular member sections

The sections of the module is modeled as tubular members, to maintain the COG and the weight of the original module, the tubular members was designed in COLBEAM where it was emphasized that the bending moment resistance should be equal to the original members. The topside module consists of 156 tubular members and 381 nodes.

According to Eurocode the tubular members are classified into cross section classes. Cross sectional class 1 and 2 provides equal formulas for plastic dimensioning while for cross sectional class 3 the formulas are based on elastic design. In the report it has been emphasized that the tubular members should be in cross sectional class 1, 2 or 3.

Table 7-2 shows the dimensions of the tubular members and the cross sectional class of the member according to Eurocode, ref. section 5.2 which is used to design the topside module in Sesam Genie.

Table 7-2 Cross section data

Name	Diameter [m]	Thickness [m]	Area [m^2]	Elements used	Cross Section Class
Tub1000x16_9	1.0	0.017	5.2196E-002	35	3
Tub1000x18_9	1.0	0.019	5.8254E-002	18	3
Tub1000x20_2	1.0	0.020	6.2178E-002	36	3
Tub1050x20_1	1.05	0.020	6.5034E-002	2	3
Tub1100x20_3	1.1	0.020	6.8857E-002	12	3
Tub1100x22_4	1.1	0.022	7.5833E-002	1	3
Tub1200x20_7	1.2	0.021	7.6691E-002	3	3
Tub500x37_4	0.5	0.037	5.4353E-002	10	1
Tub600x33	0.6	0.033	5.8782E-002	4	1
Tub600x57_3	0.6	0.057	9.7693E-002	4	1
Tub700x29_1	0.7	0.029	6.1334E-002	2	1
Tub700x54_2	0.7	0.054	1.0996E-001	10	1
Tub800x50_2	0.8	0.050	1.1825E-001	13	1
Tub800x70	0.8	0.070	1.6054E-001	2	1
Tub900x18	0.9	0.018	4.9876E-002	4	3

Figure 7-4 illustrates the color coding of the sections used in the topside module, the dimensions of the sections are found in Table 7-2.

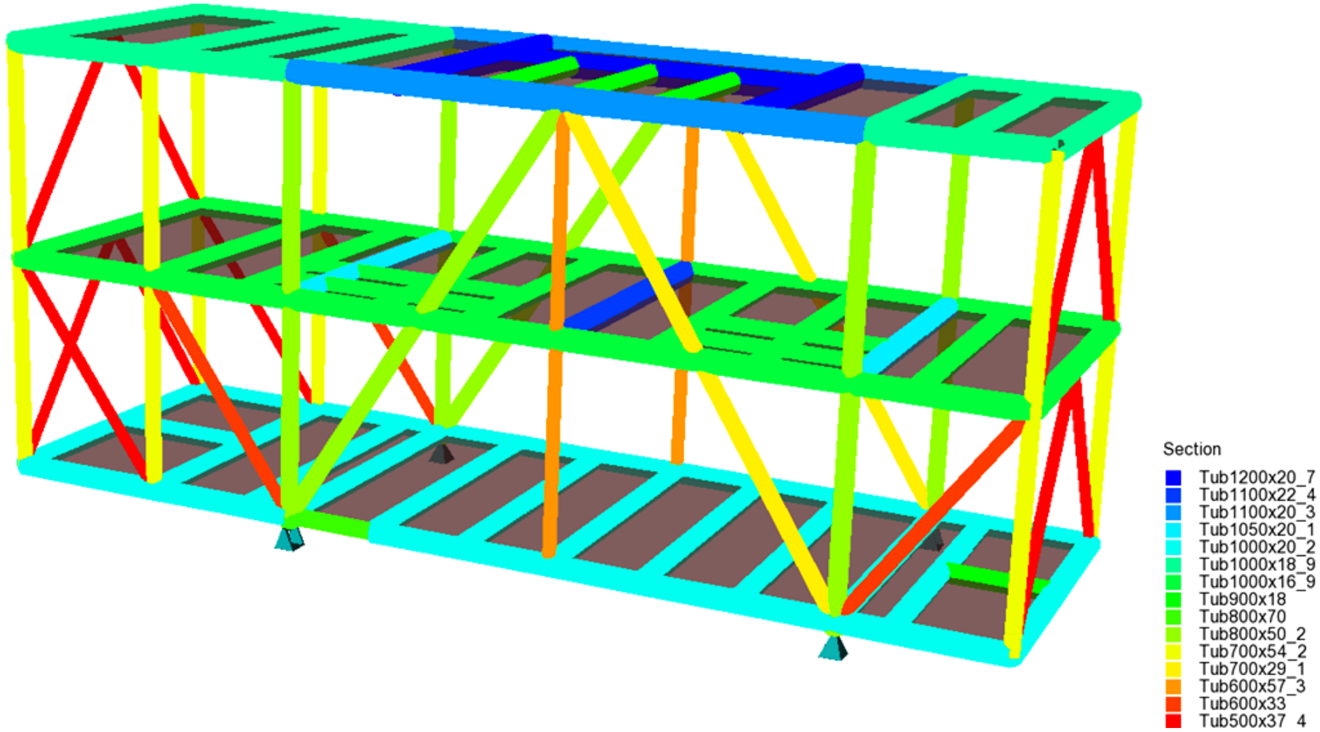


Figure 7-4 Perspective, Color coding of the cross section in SESAM:Genie

7.4.5 Plates

The plate thickness is 10 mm, and to achieve the correct weight and center of gravity in the module the plates were modeled on the three decks. The module consists of 45 plates, which do not contribute to stiffness of the module. Table 7-3 shows the number of plates modeled on each deck:

Table 7-3 Modeled plates on deck

Deck	**Plate thickness [mm]**	**Number of plates [mm]**
Main Deck	10	13
Mezzanine Deck	10	20
Weather Deck	10	12

Figure 7-5 illustrates the plates modeled on the main deck.

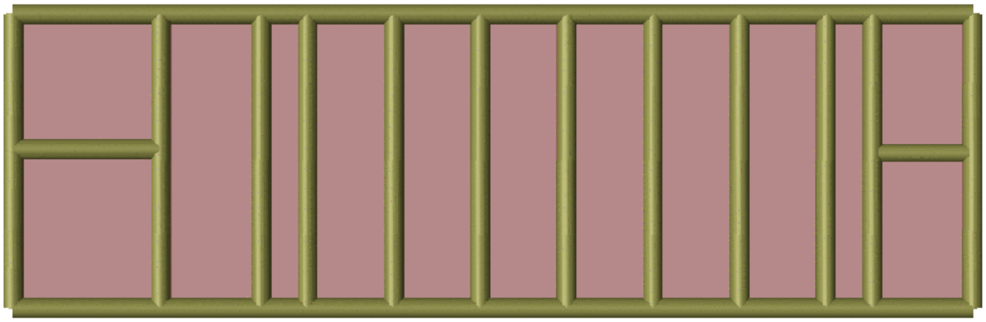


Figure 7-5 Plan, Plates modeled on main deck

Figure 7-6 illustrates the plates modeled on the mezzanine deck.

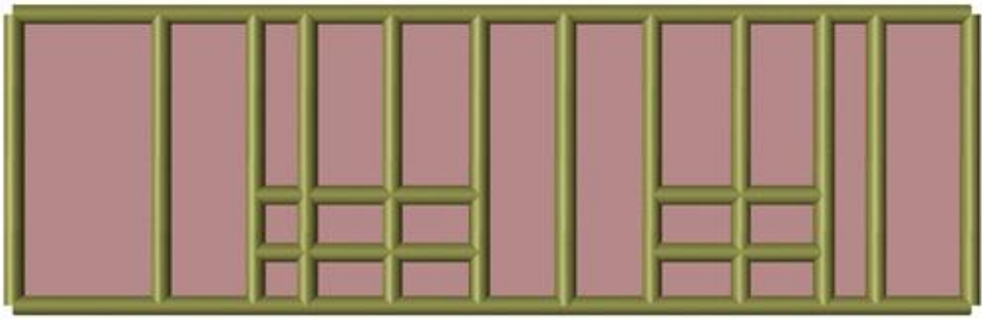


Figure 7-6 Plan, Plates modeled on mezzanine deck

Figure 7-7 illustrates the plates modeled on the weather deck.

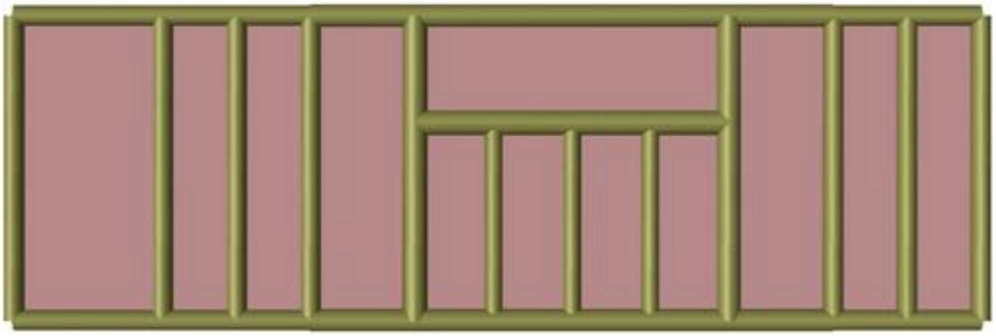


Figure 7-7 Plan, Plates modeled on weather deck

7.5 Loads

7.5.1 General

The analyses are based on the loads for the operational phase of the topside module, which in this context is: Dead load, live load and wind load.

7.5.2 Dead load

The topside module dead load is 3400 t, and includes the self weight of the steel, pipes and equipment. SESAM: Genie represents the dead load applying a constant acceleration field in vertical direction, e.g. -9,81m/s^2. The total self weight is 3400 t, where 912 t is the weight of the structural steel, while the remaining 2488 t is permanent equipment. The permanent equipment is distributed over the whole deck, because the exact position of the equipment does not affect the comparison.

7.5.3 Live load

The live load is a varying load, and can vary in size, direction or position within the timeperiode. The module is designed for a total live load of 700 t, where 450 t is distributed on the main deck, 200 t is distributed on the mezzanine deck and 50 t is distributed on the weather deck. The line load is assumed to be evenly distributed over the area in each deck. The live load is placed on as a line load on each main beam, for calculations see Appendix A-3.

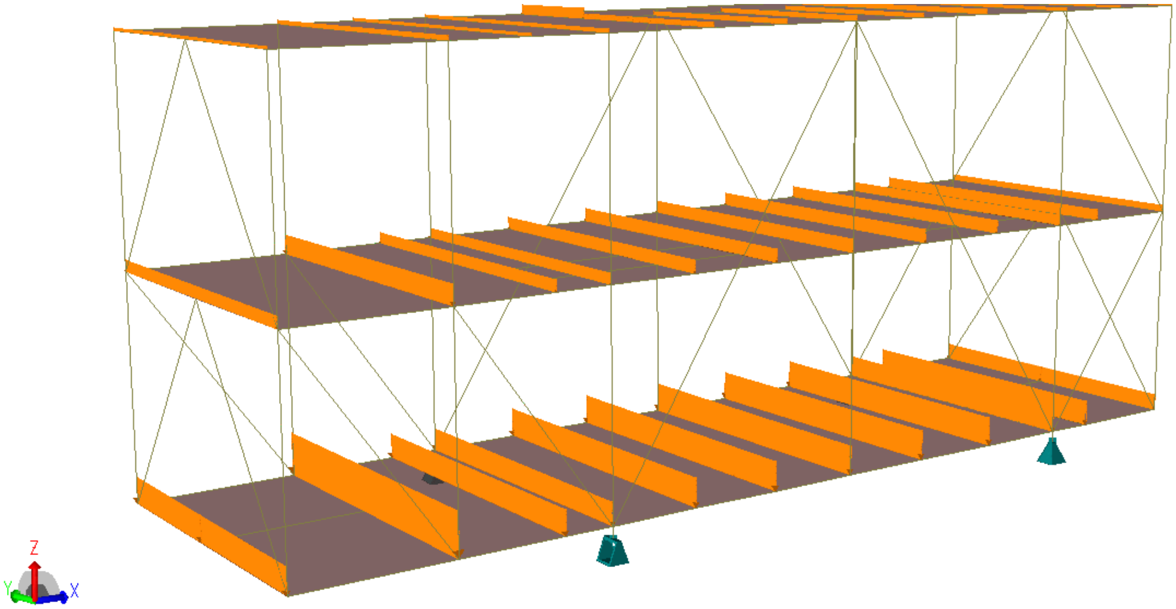


Figure 7-8 Parallel projection, Live loads on topside module

7.5.4 Wind loads

The total wind force in all direction is 225.2 t, Table 7-4 illustrates the total wind force acting on the topside module:

Table 7-4 Total wind force

Basic Loadcase	Load Name	Total [t]
LC_WIND_N	North-wind (-y)	35.3
LC_WIND_S	South-wind (+y)	35.3
LC WIND_W	West_wind (+x)	77.3
LC WIND_E	East_Wind (-x)	77.3

The wind force on the directions are given in ton, and calculated into an evenly distributed load given in [kN/m]. The wind load is applied as a line load on the horizontal beams on the walls in the module. See Appendix A-2 for calculations.

Figure 7-9 illustrates the contribution of the wind load from south on the topside module.

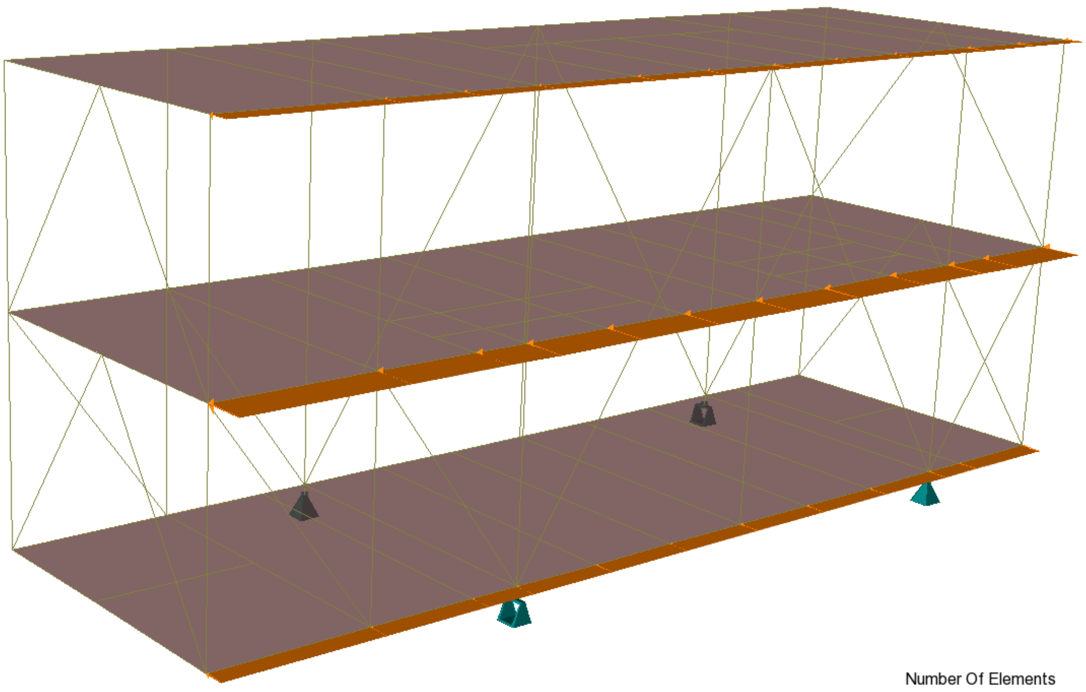


Figure 7-9 Parallel projection, Wind load from south on topside module

8 COMPARISON OF REGULATIONS BY ANALYSIS OF TOPSIDE MODULE CASE STUDY 1

8.1 Introduction

This chapter describes the case study 1 performed within the framework of the comparison study, the aim is to demonstrate how the differences in the design standards would affect the strength utilization of the topside module.

The case study 1 sets basis in comparing Eurocode, NORSOK and ISO when subjected to the material factors and action factors given in the individual standards. The analysis is carried out for 4 load combinations according to Eurocode, NORSOK and ISO in ULS A and ULS B.

It should be noted that optimization of the design is not a part of the thesis, the objectives is to analyze the topside module and compare the design standards.

8.2 Resistance and Action Factors According to Eurocode

8.2.1 Material factor according to Eurocode

The general requirements for the material factor, γ_m is according to Eurocode 3 1993-1-1 is:

ULS: $\gamma_m = 1.0$

The analysis in Case 1 is based on the Norwegian National Annex to Eurocode 3 1993-1-1(EN 1993-1-1, 2005):

ULS: $\gamma_m = 1.05$

8.2.2 Action factors according to Eurocode

The Action factors for ULS A and ULS B are given in equation 6.10.a and 6.10.b according to Eurocode EN 1991-1-1, an extract of the table is given in Table 8-1 (EN 1991-1-1, 2008).

Table 8-1 Action factors according to Eurocode

Limit State	Action Combinations	Permanent actions (G)	Variable actions (Q1)	Environmental actions (Q2)	Equation in Eurocode
ULS	A	1,35	1,5 x Ψ_{01}	1,5 x Ψ_{02}	6.10.a
ULS	B	1,35 x ξ	1,5 x Ψ_{01}	1,3 x Ψ_{02}	6.10.b

The values for $\Psi_{01,}$ Ψ_{02}, and ξ are found in the Norwegian National Annex and the values are as following:

ξ = 0,89
Ψ_{01} = 1,0 for variable actions and
Ψ_{02} = 0,6 for wind loads

8.3 Resistance and Action Factors according to NORSOK

8.3.1 Material factor according to NORSOK

The general requirements for the material factor, γ_m is according to NORSOK N-004 (NORSOK N-004, 2004):

ULS: $\gamma_m = 1.15$

For compression members γ_m is a variable safety factor dependent on the slenderness of the member considered used ($1.15 \leq \gamma_m \leq 1.45$), ref section 5.3.2.

8.3.2 Action factors according to NORSOK

According to NORSOK N-001 the combinations of actions should be determined on the basis of relevant national or international requirements, with regard to reliability. When checking the ULS A and ULS B the action factors shall be used according to Table 8-2 (NORSOK N-001, 2004).

Table 8-2 Action factors according to NORSOK

Limit State	Action Combinations	Permanent actions (G)	Variable actions (Q)	Environmental actions (E)	Deformation actions (D)
ULS	A[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, an action factor of 1,0 shall be used where this gives the most unfavorable action effect.					

ULS A and ULS B will be considered in the analysis for the topside module.

8.4 Resistance and Action Factors according to ISO

8.4.1 Material factor according to ISO 19902

The requirements for the resistance factor, γ_m is according to ISO 19902 for the ultimate limit state (ISO 19902, 2007):

ULS:		
	γ_m = Resistance Factor, Tension	1.05
	γ_m = Resistance Factor, Compression	1.18
	γ_m = Resistance Factor, Bending	1.05
	γ_m = Resistance Factor, Shear	1.05

8.4.2 Action factors according to ISO 19902

The partial action factors according for the load combinations according to ULS A and ULS B for ISO 19902 are given in Table 8-3 (ISO 19902, 2007).

Table 8-3 Action factors according to ISO

Limit State	Action Combinations	Permanent actions (G)	Variable actions (Q)	Environmental actions (E)
ULS [a]	A	1,3	1,5	0,9 x $\gamma_{f,E}$
ULS [b]	B	1,1	1,1	$\gamma_{f,E}$

a) Operating situation with corresponding wind, wave, and/or current conditions
b) Extreme conditions when the action effects due to permanent and variable actions are additive.

$\gamma_{f,E}$, is the partial action factors for the environmental actions, and for this analysis the partial action factor is found from Table A.9.9-2 in ISO 19902 (ISO 19902, 2007) and set to $\gamma_{f,E}$ = 1,09.

8.5 Load combination for analysis of Case Study 1

Each analysis are performed with a total of 8 load combinations, four load combinations for ULS A and four load combinations for ULS B. Table 8-4 shows the action factors that are combined with the different load combinations for the load combinations for ULS A and ULS B for the code check according to Eurocode, NORSOK and ISO, see section 8.2 to 8.4.

Table 8-4 Load combinations for analysis of case study 1

CODE OF PRACTICE	ULS	Load Combination	Direct of Wind	Load case 1: Self weight	Load case 2: Self weight of permanent equipment	Load case 3: Live load	Load case 4: Wind from north	Load case 5: Wind from south	Load case 6: Wind from east	Load case 7: Wind from west
Eurocode	ULS A	E1A	North	1.35	1.35	1.5	0.9			
		E2A	South	1.35	1.35	1.5		0.9		
		E3A	East	1.35	1.35	1.5			0.9	
		E4A	West	1.35	1.35	1.5				0.9
	ULS B	E1B	North	1.2	1.2	1.5	0.78			
		E2B	South	1.2	1.2	1.5		0.78		
		E3B	East	1.2	1.2	1.5			0.78	
		E4B	West	1.2	1.2	1.5				0.78
NORSOK	ULS A	N1A	North	1.3	1.3	1.3	0.7			
		N2A	South	1.3	1.3	1.3		0.7		
		N3A	East	1.3	1.3	1.3			0.7	
		N4A	West	1.3	1.3	1.3				0.7
	ULS B	N1B	North	1.0	1.0	1.0	1.3			
		N2B	South	1.0	1.0	1.0		1.3		
		N3B	East	1.0	1.0	1.0			1.3	
		N4B	West	1.0	1.0	1.0				1.3
ISO	ULS A	I1A	North	1.3	1.3	1.5	0.98			
		I2A	South	1.3	1.3	1.5		0.98		
		I3A	East	1.3	1.3	1.5			0.98	
		I4A	West	1.3	1.3	1.5				0.98
	ULS B	I1B	North	1.1	1.1	1.1	1.09			
		I2B	South	1.1	1.1	1.1		1.09		
		I3B	East	1.1	1.1	1.1			1.09	
		I4B	West	1.1	1.1	1.1				1.09

9 RESULTS AND DISCUSSION OF CASE STUDY 1

9.1 General

It is performed analysis in ultimate limit state for both combinations ULS A and ULS B with combined load factors according to the individual design standard requirements ref. Chapter **Feil! Fant ikke referansekilden.**. The load combinations are defined in Table 8-4. The ten most utilized members according to Eurocode are selected and further investigated. Figure 9-1 illustrates the selected members that have the highest utilization ratio.

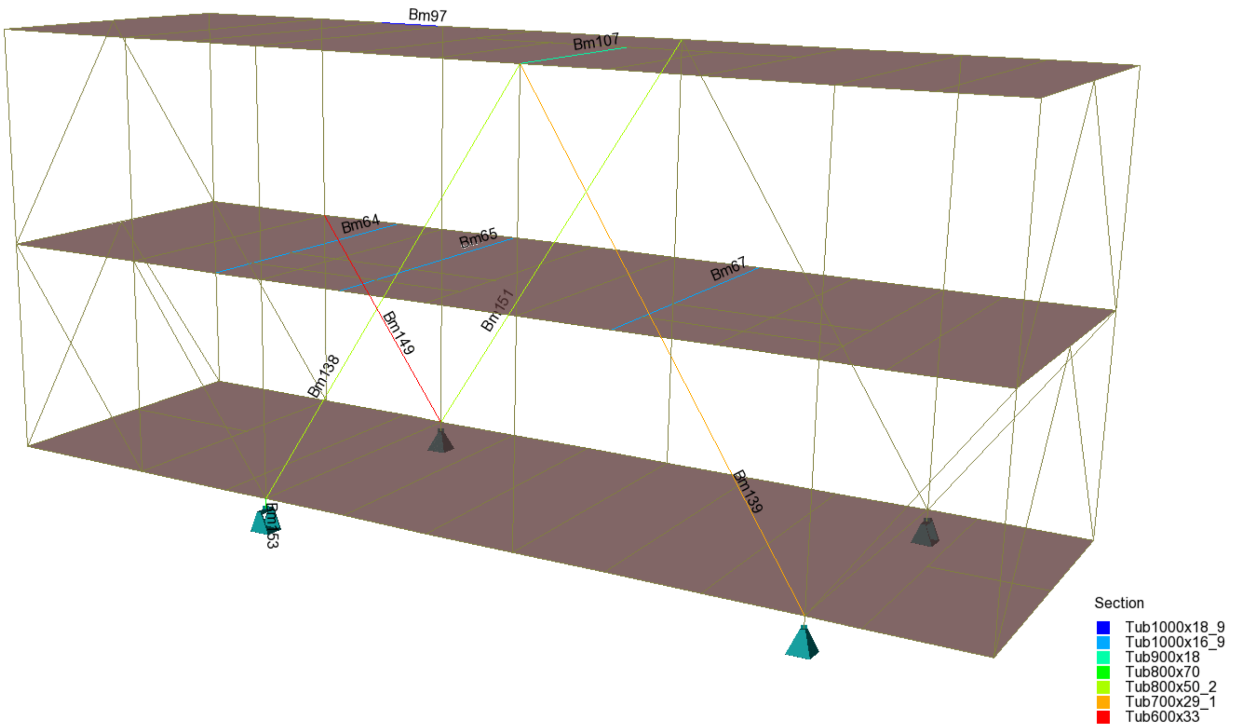


Figure 9-1 Parallel projection. The ten members with highest utilization ratio

9.2 Results of selected members

The factors of resistance and the load combinations factors used in case 1 is according to the requirements given in Eurocode, NORSOK and ISO, the factors used in the analysis is described in section 8 to 8.4. The load combinations referred to in this chapter is found in 8.5.

This chapter presents the results for the Eurocode, with the corresponding results for the same members according to the code check runs for NORSOK and ISO. The Utilization Ratios (UC) of the ten (10) highest utilized members from the Eurocode Code Check are presented side-by-side with the UCs calculated for the corresponding members, for the same load cases, from the NORSOK and ISO code check runs. The critical load combinations are found for ULS A. The ten elements with the highest utilization ratio are element number: 138, 65, 107, 67, 64, 139, 151, 149, 153 and 97, these elements are further investigated.

9.2.1 Element 138

Element number 138 is a diagonal tubular member in the south wall, and according to Eurocode the member is in cross sectional class 1. The results are illustrated in Figure 9-2. The utilization ratio for Eurocode, NORSOK and ISO are found for the load combinations E1A, N1A and I1A respectively.

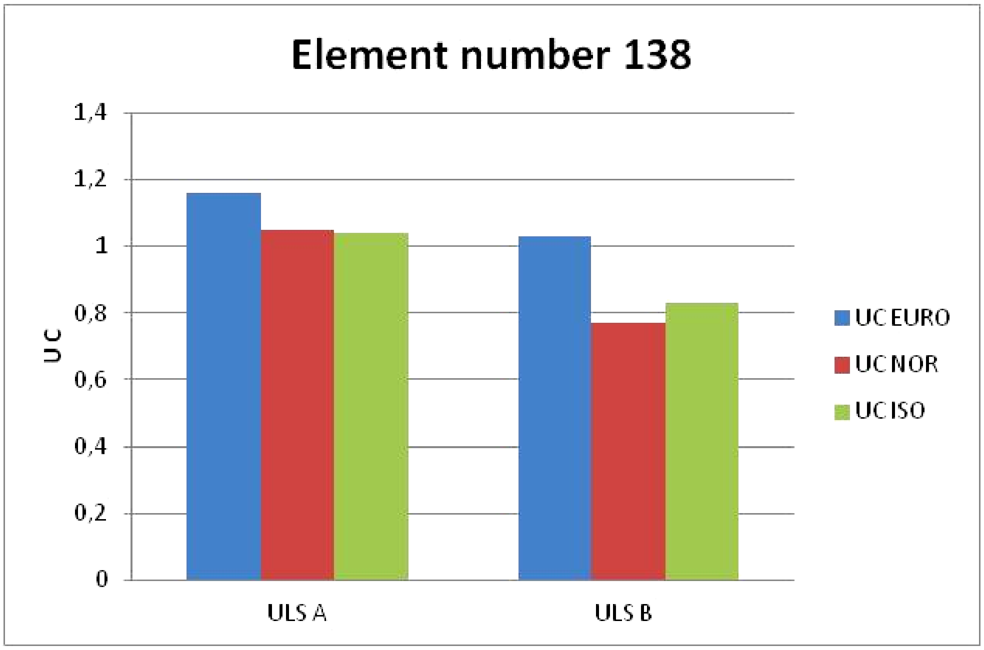


Figure 9-2 Element 138

9.2.2 Element 65

Element number 65 is a horizontal tubular member in the mezzanine deck, and according to Eurocode the member is in cross sectional class 1. The utilization ratio for Eurocode, NORSOK and ISO are found for the load combinations E1A, N1A and I1A, respectively. The results for element 65 are shown in Figure 9-3.

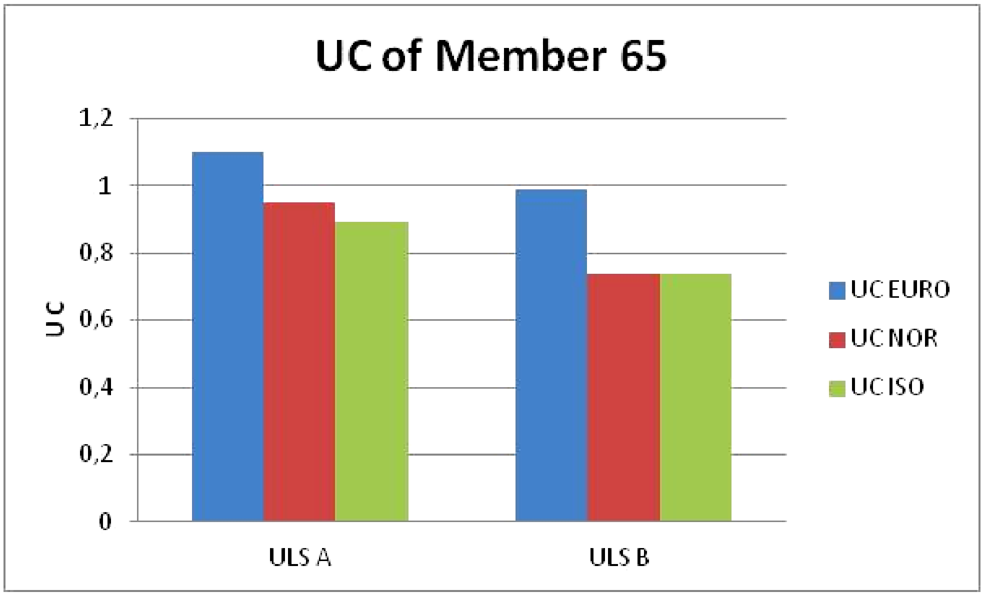


Figure 9-3 Element 65

9.2.3 Element 107

Figure 9-4 illustrates the results for element number 107 which is a horizontal tubular member in the weather deck, and according to Eurocode the member is in cross sectional class 3. The utilization ratio for Eurocode, NORSOK and ISO are found for the load combinations E3A, N3A and I3A, respectively for ULS A and E1B, N1B and I1B, respectively for ULS B.

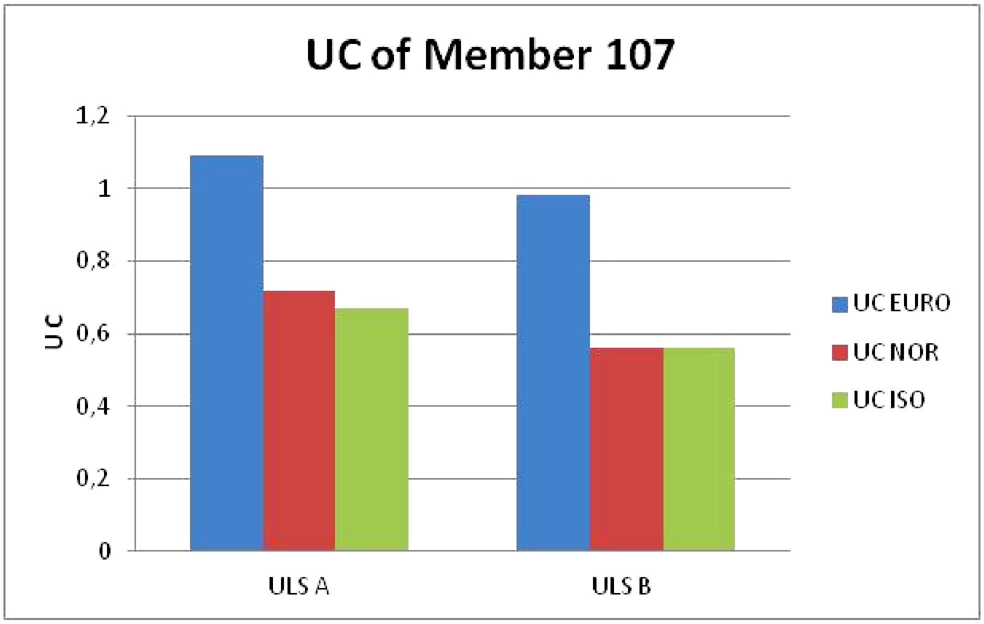


Figure 9-4 Element 107

9.2.4 Element 67

Element number 67 is a horizontal tubular member in the mezzanine deck, and according to Eurocode the member is in cross sectional class 3. The utilization ratio for Eurocode, NORSOK and ISO are found for the load combinations E2A, N2A and I2A. Figure 9-5 illustrates the results for member 67.

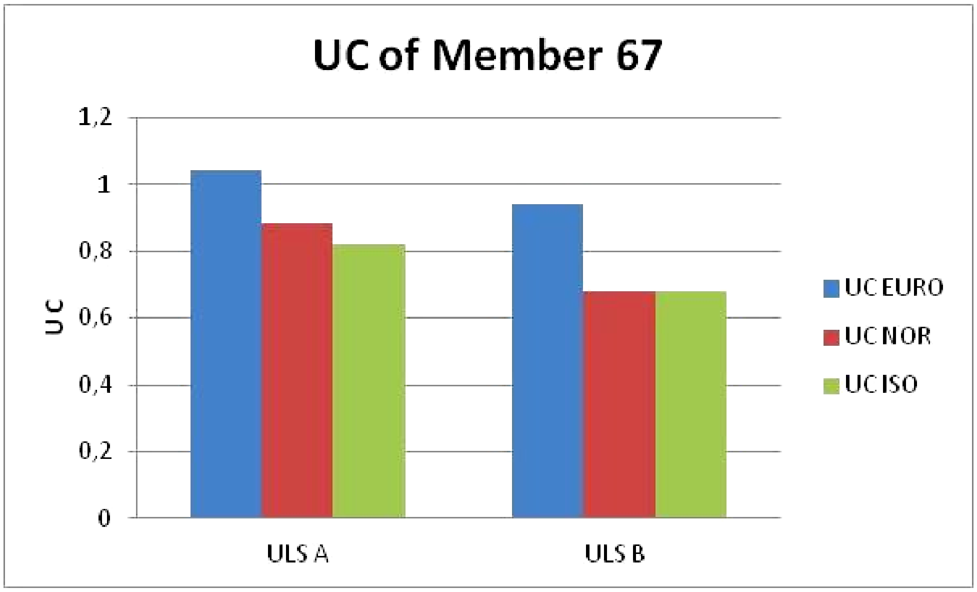


Figure 9-5 Element 67

9.2.5 Element 64

Element number 64 is a horizontal tubular member in the mezzanine deck, and the results are shown in Figure 9-6. According to Eurocode the member is in cross sectional class 3. The utilization ratio for Eurocode, NORSOK and ISO are found for the load combinations E2A, N2A and I2A, respectively.

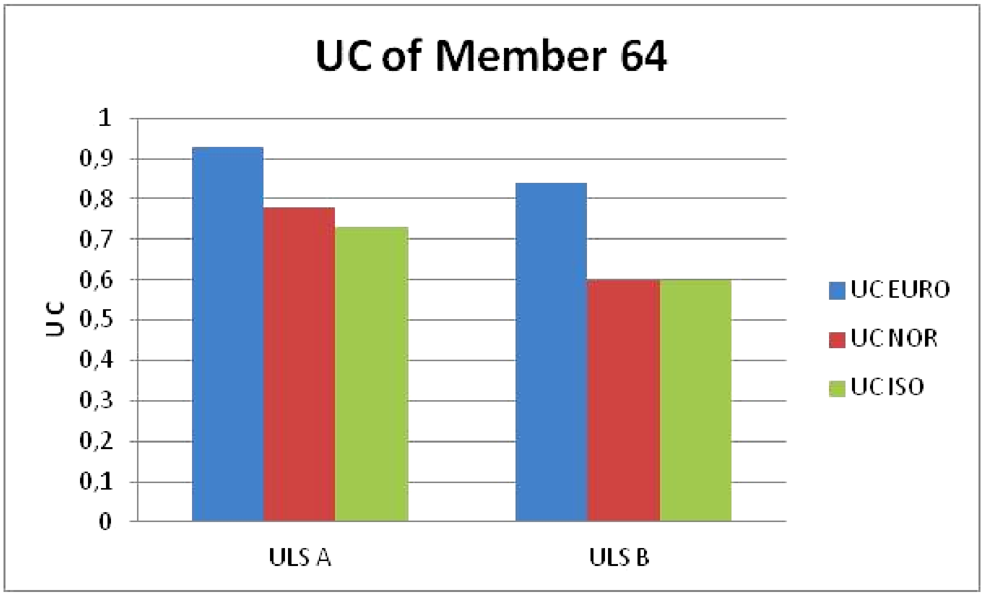


Figure 9-6 Element 64

9.2.6 Element 139

Figure 9-7 illustrates the results for element number 139 which is a diagonal tubular member in the south wall. According to Eurocode the member is in cross sectional class 1. The utilization ratio for Eurocode, NORSOK and ISO are found for the load combinations E4A, N4A and I4A, respectively.

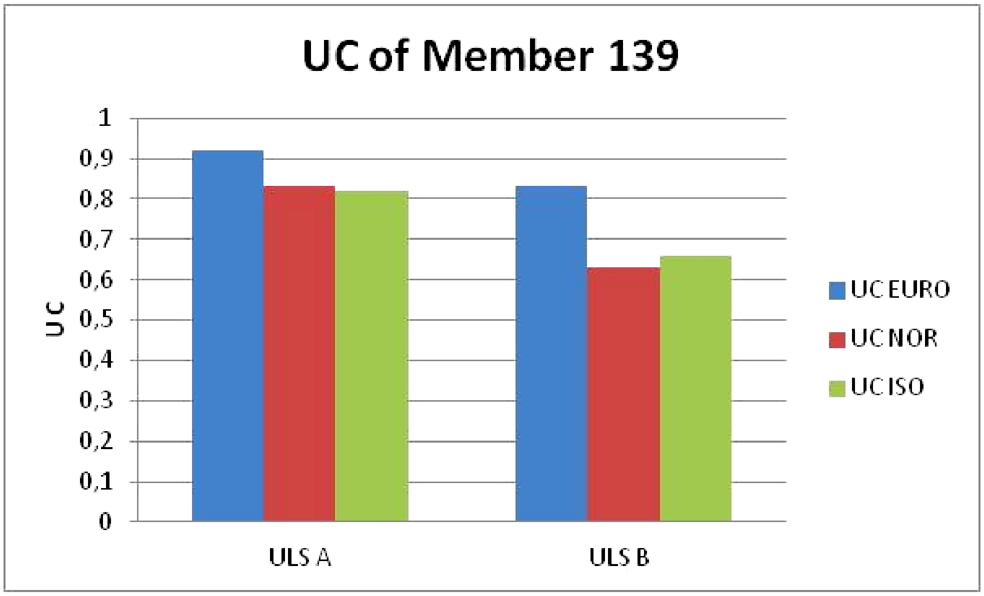


Figure 9-7 Element 139

9.2.7 Element 151

Element number 151 shown in Figure 9-8 is a diagonal tubular member in the north wall, and according to Eurocode the member is in cross sectional class 1. The utilization ratio for Eurocode, NORSOK and ISO are found for the load combinations E2A, N2A and I2A, respectively.

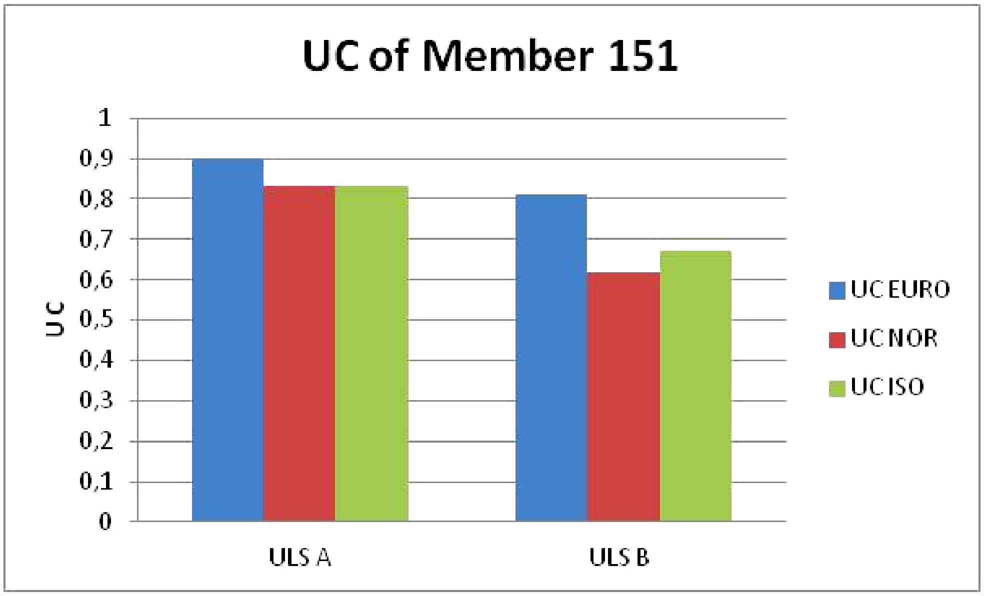


Figure 9-8 Element 151

9.2.8 Element 149

Element number 149 is a diagonal tubular member in the north wall, and according to Eurocode the member is in cross sectional class 1. The results for element 139 are illustrates in Figure 9-9. The utilization ratio for Eurocode, NORSOK and ISO are found for the load combinations E2A, N2A and I2A, respectively.

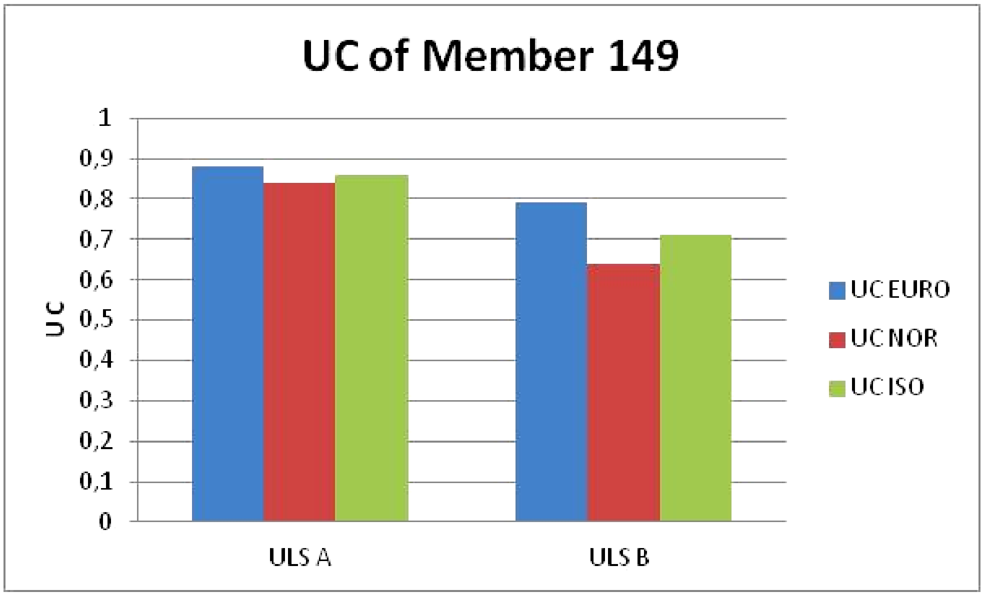


Figure 9-9 Element 149

9.2.9 Element 153

Element number 153 is a vertical tubular member connecting the supports and the main deck. Figure 9-10 illustrates the results for member 153, which is in cross sectional class 1 according to Eurocode. The utilization ratio for Eurocode, NORSOK and ISO are found for the load combinations E2A, N2A and I2A, respectively.

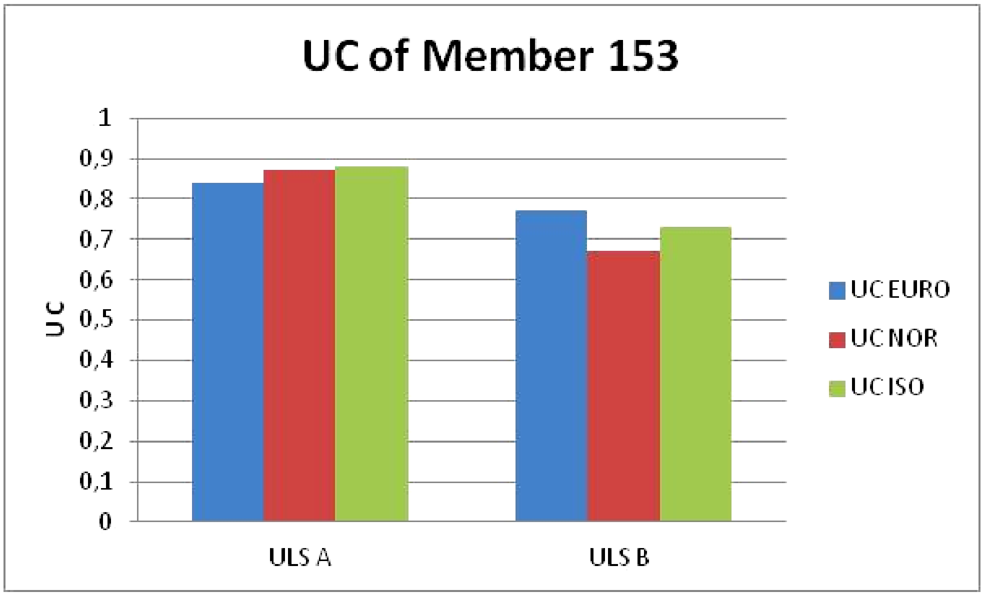


Figure 9-10 Element 153

9.2.10 Element 97

Element number 149 is a horizontal tubular member in the weather deck, and according to Eurocode the member is in cross sectional class 3. The results for member 97, are illustrates in Figure 9-11. The utilization ratio for Eurocode, NORSOK and ISO are found for the load combinations E2A, N2A and I2A, respectively.

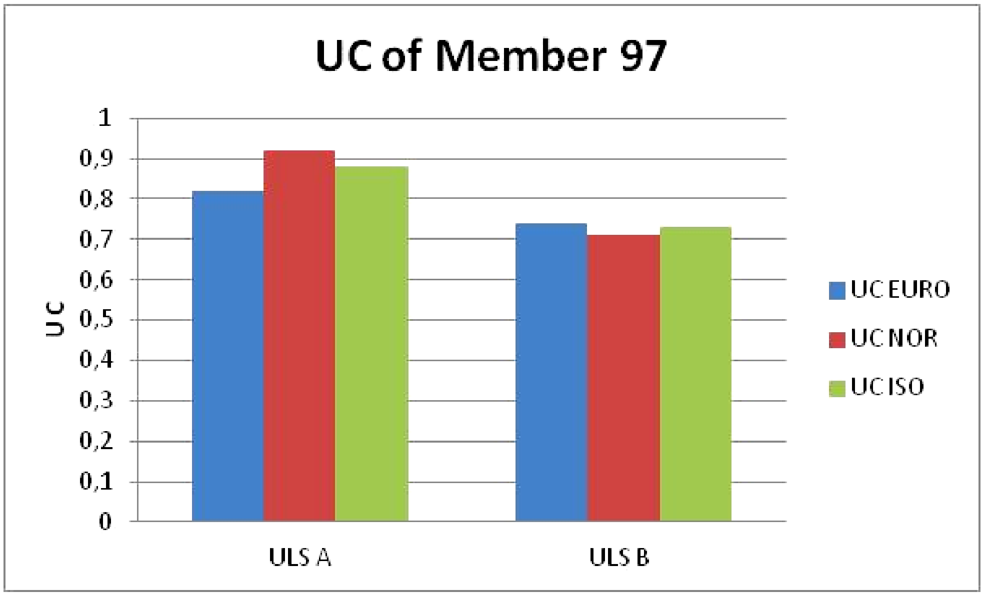


Figure 9-11 Element 97

9.3 Discussion of case study 1

The main purpose of case study 1 has been to analyze and compare the member utilization according to the design standards, when subjected to the original resistance and action factors given in the individual standards. The results from the diagrams in section 9.2 indicate that Eurocode is the conservative approach for the comparison of regulations when analyzing the global topside module. It can be seen from the diagrams that four of the members will fail due to the code check in Eurocode, while one member will fail due to the code check in NORSOK and ISO. The trend in the diagrams illustrates that the results for NORSOK and ISO are similar to each other, and the maximum difference in the utilization ratio for these two codes are 7 % for both ULS A and ULS B. The code check formulas for the NORSOK and ISO codes are identical see chapter 0, and the difference in utilization is caused by the application of the different resistance factors and the action factors applied to the load combinations, see Table 8-4 in section 8.5.

Four of the members (member 138, 139,151 and 149) investigated are in cross sectional class 1 and 2, and were checked based on the formulae for combined bending and axial compression force. Eurocode was observed to be the conservative approach. The average difference between the code checks for Eurocode and NORSOK/ISO were roughly 10.5 %. From the parameter study for axial compression and bending ref. section 6.8.1 and section 6.8.2, the graphs indicates that Eurocode is more conservative up to a certain level of force, above this level (UC=0.85) the graphs are crossing each other. This means that NORSOK and ISO are more conservative for utilization above 85%. Due to this, it is expected that NORSOK and ISO would be the conservative approach when the load level is close to the capacity of the member.

Three of the members (member 65, 67 and 64) investigated are in cross sectional class 3, and the capacity was checked based on the formulae for combined bending and axial compression. The average difference between the code checks according to Eurocode was 18 % and 26 % for NORSOK and ISO, respectively with Eurocode as the conservative approach. From the parameter study the similar results were found, the average difference between Eurocode and NORSOK/ISO were 19 %. The small deviations between these results are due to the application of the original resistance and load factors in the code checks.

Element number 107 (cross sectional class 3) deviates from the other graphs in order that the difference in the capacity between the three codes are relative large. The utilization ratio is 1.09 according to Eurocode, and the member where checked according to the combination of axial compression and biaxial bending. For NORSOK and ISO the code check gave a utilization ratio of 0.72 and 0.67 respectively. The main difference in the capacities is due to the contribution of the moment around the z-axis, found in the formulas F 5-41 to F 5-42 for Eurocode and formulas for F 5-44 to F 5-45 for NORSOK and ISO, in section 5.10. In Eurocode the moment around the z-axis contributes to 0.4 of the total utilization ratio, while in NORSOK/ISO the contribution is approximately 0.01 of the total utilization ratio, ref. Appendix A-6. The differences in the code checks according to Eurocode were 51 % and 62 % for NORSOK and ISO. The results corresponds satisfactory with the results obtained from the parameter study for combined axial compression and biaxial moment for members in cross sectional class 3, ref section 6.9.2. The average differences between Eurocode and NORSOK/ISO were 59%.

Element number 97 was checked with the conservative formulae in Eurocode, namely formula F 5-43 in section 5.10.1, while NORSOK and ISO were checked based on the formula for combined axial tension and bending. NORSOK and ISO are for this member more conservative than Eurocode, the difference in the utilization ratio between NORSOK/ISO and Eurocode are 10 % and 6 % respectively. There was not carried out a parameter study in combined bending and axial tension, since Eurocode does not have a derived specified formula on combined axial tension and bending.

When the utilization ratio for the code check in Eurocode, falls below 0.9, it is observed from the results that the difference between the codes decreases and the differences in the utilization ratios between the code checks are marginal. For tubular member 153, the difference in the utilization ratio is 3.5 % between the code checks for Eurocode and NORSOK, and between Eurocode and ISO 4.5 %. For tubular member 149, the difference in the utilization ratio is 4.5 % between the code checks for Eurocode and NORSOK, and between Eurocode and ISO 2.3 %. The same results are obtained from the parameter study when the members utilization ratio are below 0.9, the average differences calculated from the parameter study between Eurocode and NORSOK/ISO were 3 %.

As seen on the diagrams, the load combinations for ULS A give higher utilization ratios for the elements than the load combinations for ULS B.

10 COMPARISON OF REGULATIONS BY ANALYSIS OF TOPSIDE MODULE CASE STUDY 2

10.1 Introduction

This chapter describes the case study 2 performed within the framework of the comparison study, the aim is to demonstrate how the differences in the design standards would affect the strength utilization of the topside module, when the load and action factors are kept identical.

The purpose of case study 2 was to analyze a topside module utilizing the design formulas described in the different design standards. The facilities regulations under Norwegian law states that for load-bearing structures, the standards NORSOK N-001, NORSOK N-003 and NORSOK N-004 should be used for steel structures (PSA, 2007). Therefore, to assure that the results obtained from the analysis are comparable the action factors and the loads for permanent, variable and environmental were kept identical, and the action factors according to NORSOK N-001 were set as a basis for all the analysis. The resistance factor for NORSOK (NORSOK N-004, 2004) γ_m = 1.15 is adopted in the code check for Eurocode according to the facilities regulations stipulated by the Petroleum Safety Authority in Norway (PSA, 2007), whereas the original resistance factors are used for the code check for ISO (ISO 19902, 2007).

It should be noted that optimization of the design is not a part of the thesis, the objectives is to analyze the topside module and compare the design standards.

10.2 Resistance factors

The requirements for the material factor, γ_m for ULS A and ULS B is according to NORSOK N-004 (NORSOK N-004, 2004):

ULS: $\gamma_m = 1.15$

NORSOK N-004 overrules Eurocode in the oil industry (PSA, 2007), the material factor for Eurocode is set to the material factor used in NORSOK γ_m = 1.15.

The original requirements for the material factor are used in the analysis, and according to ISO 19902 (ISO 19902, 2007):

ULS:	γ_m = Resistance Factor, Tension	1.05
	γ_m = Resistance Factor, Compression	1.18
	γ_m = Resistance Factor, Bending	1.05
	γ_m = Resistance Factor, Shear	1.05

10.3 Action Factors for Analysis

The action factors for ultimate limit state A and B according to NORSOK N-001, is set as a basis for Eurocode, NORSOK and ISO when analyzing the topside module. The action factors for the load combinations according to Table 1 in NORSOK N-001 are shown in the Table 10-1 (NORSOK N-001, 2004):

Table 10-1 Action factors according to NORSOK

Action Combinations	Permanent actions (G)	Variable actions (Q)	Environmental actions (E)
ULS A	1,3	1,3	0,7
ULS B	1,0	1,0	1,3

10.4 Load combination for Analysis of Case Study 2

The analysis are performed with a total of 8 load combinations, four load combinations for ULS A and four load combinations for ULS B. The Table 10-2 shows the action factors that are combined with the different load combinations for the load combinations for ULS A and ULS B.

Table 10-2 Load combinations for analysis of case study 2

NORSOK	Load Combination	Direct Of Wind	Load case1: Self weight	Load case 2: Self weight of permanent equipment	Load case 3: Live load	Load case 4: Wind from north	Load case 5: Wind from south	Load case 6: Wind from east	Load case 7: Wind from west
ULS A	N1A	North	1.3	1.3	1.3	0.7			
	N2A	South	1.3	1.3	1.3		0.7		
	N3A	East	1.3	1.3	1.3			0.7	
	N4A	West	1.3	1.3	1.3				0.7
ULS B	N1B	North	1.0	1.0	1.0	1.3			
	N2B	South	1.0	1.0	1.0		1.3		
	N3B	East	1.0	1.0	1.0			1.3	
	N4B	West	1.0	1.0	1.0				1.3

11 RESULTS AND DISCUSSION OF CASE STUDY 2

11.1 General

It is performed analysis in ultimate limit state, ULS A and ULS B, for the combinations defined in Table 10-2 .The ten most utilized members according to Eurocode are selected for further investigation. The Figure 11-1 illustrates the selected members that have the highest utilization ratio.

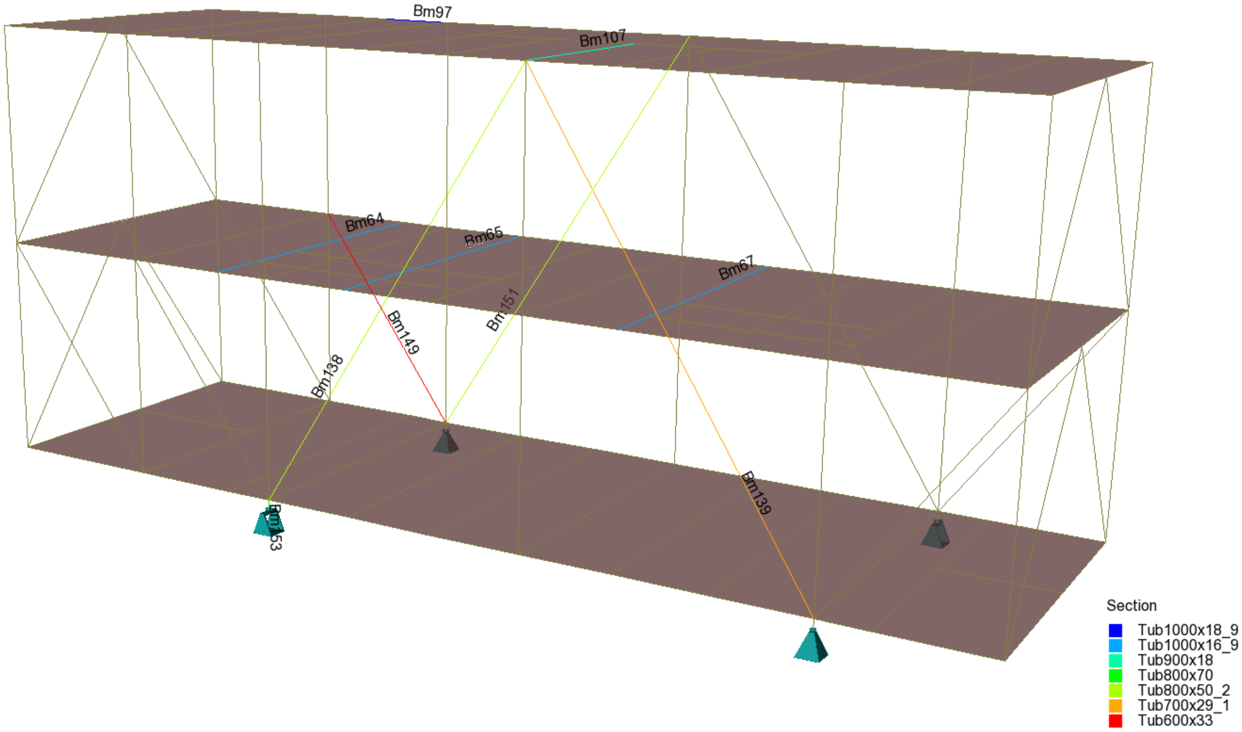


Figure 11-1 Parallel projection, the ten members with highest utilization ratio.

11.2 Results of selected members

The factors of resistance used in case 2 are according to the requirements given in section 10.1 to 10.3. The load combinations for NORSOK are set as a basis and used for all the load combinations in the analysis, reference are made to section 10.4.

This chapter presents the results for the Eurocode, with the corresponding results for the same members according to the code check runs for NORSOK and ISO. The Utilization Ratios (UC) of the ten (10) highest utilized members from the Eurocode Code Check are presented side-by-side with the UCs calculated for the corresponding members, for the same load cases, from the NORSOK and ISO code check runs. The critical load combinations are found for ULS A.

The ten elements with the highest utilization ratio are element number: 138, 107, 65, 67, 139, 64, 151, 149, 153 and 97. These elements are illustrated in Figure 11-1 and further investigated in this section.

11.2.1 Element 138

Element number 138 is a diagonal tubular member in the south wall, and according to Eurocode the member is in cross sectional class 1. The results for the element are shown in Figure 11-2 and the utilization ratio for the element is found for the load combination N3A.

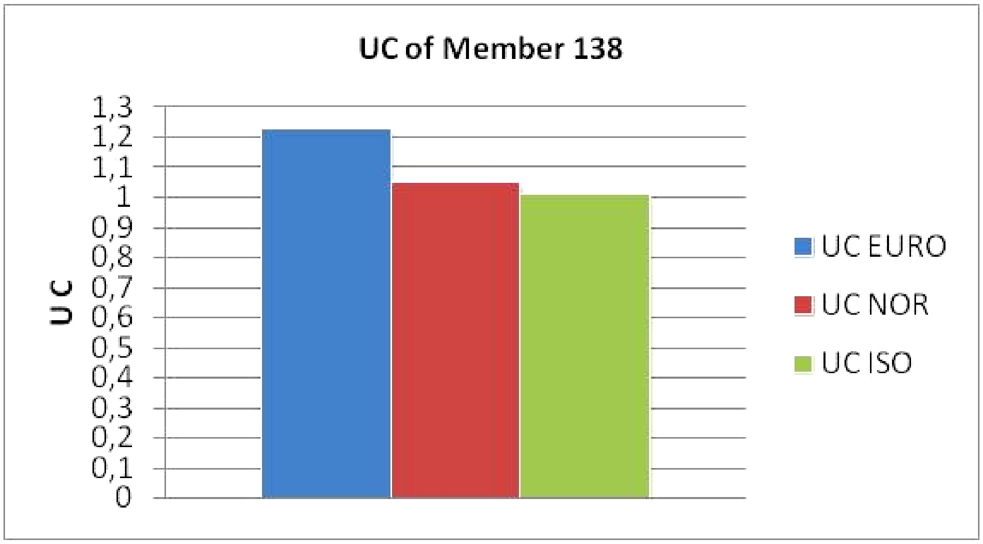


Figure 11-2 Element 138

11.2.2 Element 107

The tubular member number 107 is a horizontal tubular member in the weather deck, and according to Eurocode the member is in cross sectional class 3. The utilization ratio for the element is found for the load combination N3A. Figure 11-3 illustrates the results for the utilization ratio of member 107.

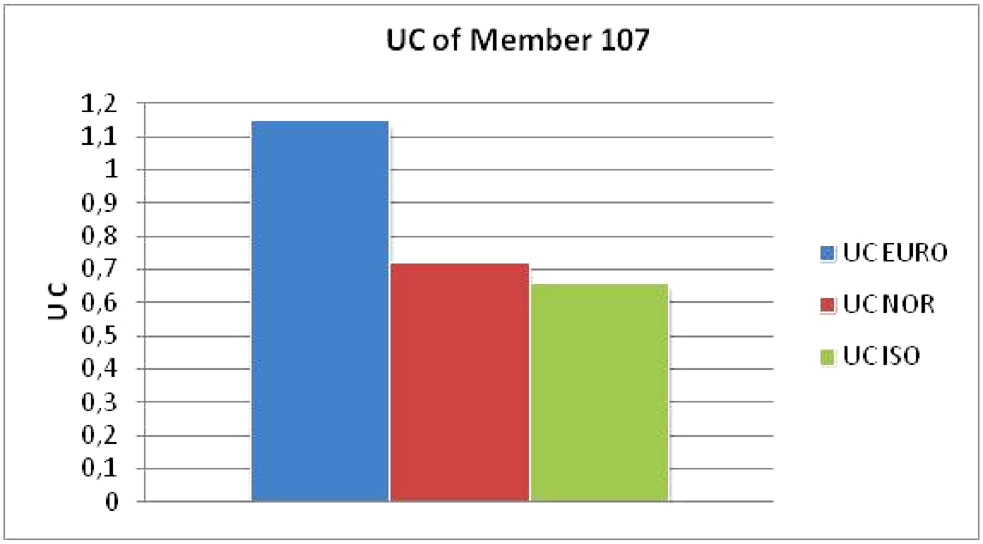


Figure 11-3 Element 107

11.2.3 Element 65

Element number 65 is a horizontal tubular member in the mezzanine deck, and according to Eurocode the member is in cross sectional class 3. The results for the member are shown in Figure 11-4 and the utilization ratio for the element is found for the load combination N2A.

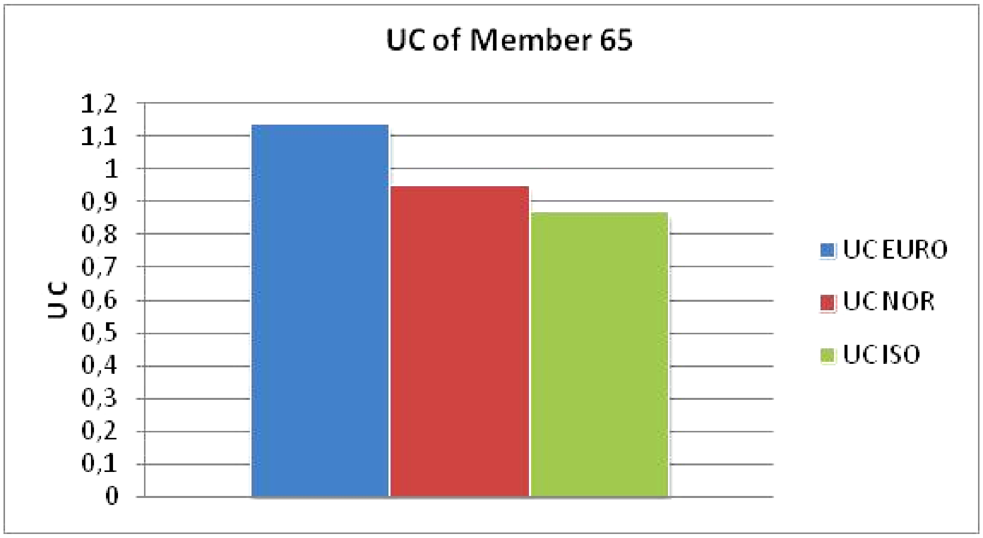


Figure 11-4 Element 65

11.2.4 Element 67

Figure 11-5 illustrates the results for element number 67 which is a horizontal tubular member in the mezzanine deck, and according to Eurocode the member is in cross sectional class 3. The utilization ratio for the element is found for the load combination N2A.

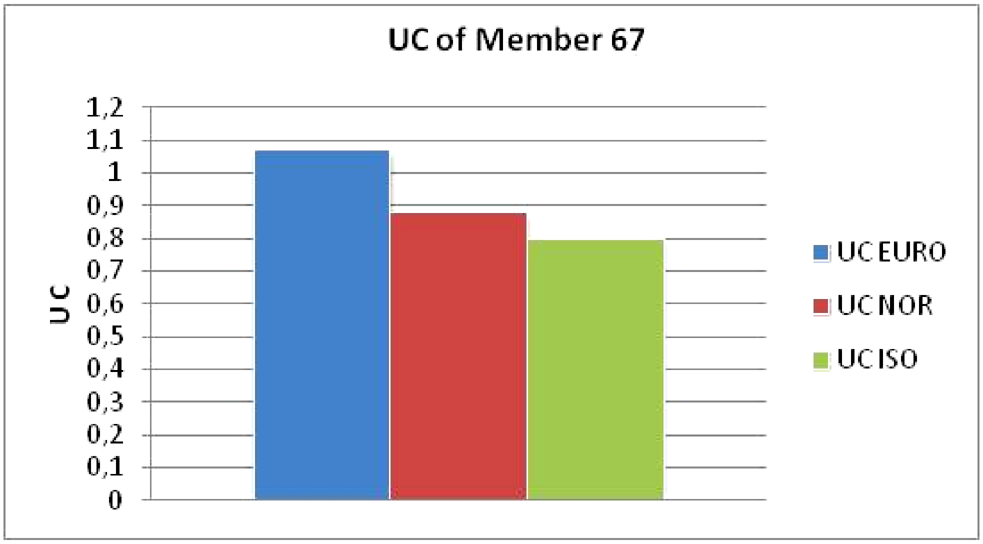


Figure 11-5 Element 67

11.2.5 Element 139

The results for element 139 are illustrated in Figure 11-6. Element 139 is a diagonal tubular member in the south wall, and according to Eurocode the member is in cross sectional class 1. The utilization ratio for the element is found for the load combination N4A.

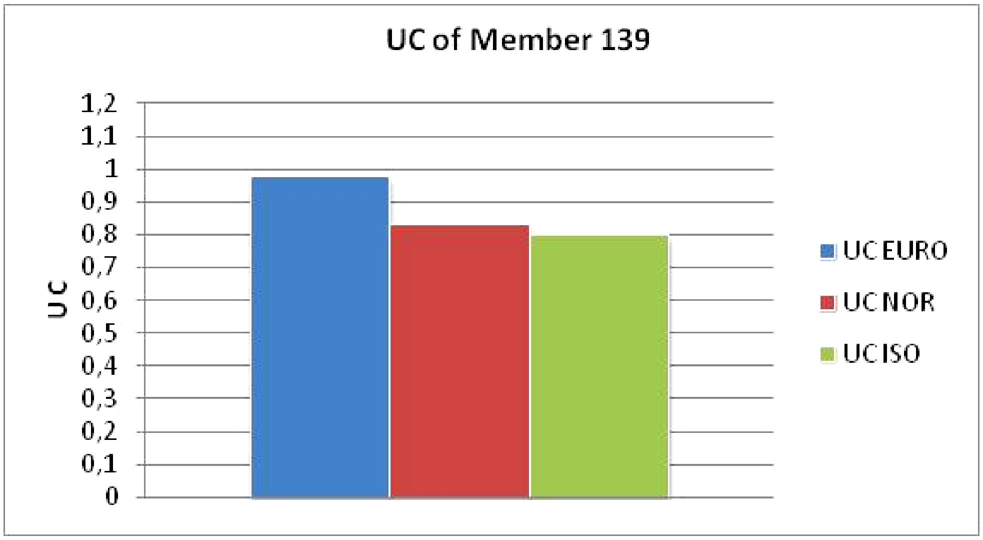


Figure 11-6 Element 139

11.2.6 Element 64

Element number 64 is a horizontal tubular member in the mezzanine deck, and according to Eurocode the member is in cross sectional class 3.The results are illustrated in Figure 11-7. The utilization ratio for the element is found for the load combination N2A.

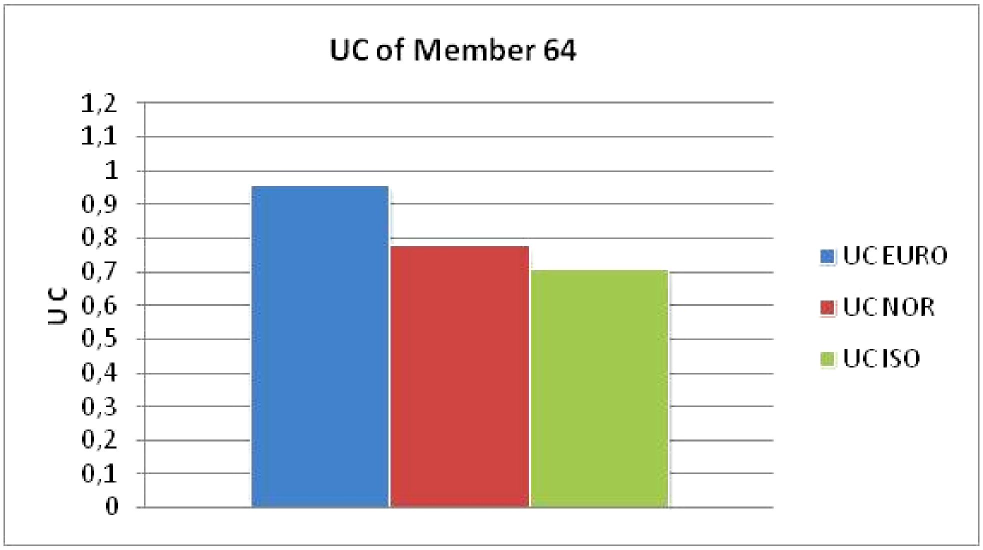


Figure 11-7 Element 64

11.2.7 Element 151

The results for element 151 are shown in Figure 11-8. The element is a diagonal tubular member in the north wall, and according to Eurocode the member is in cross sectional class 1. The utilization ratio for the element is found for the load combination N3A.

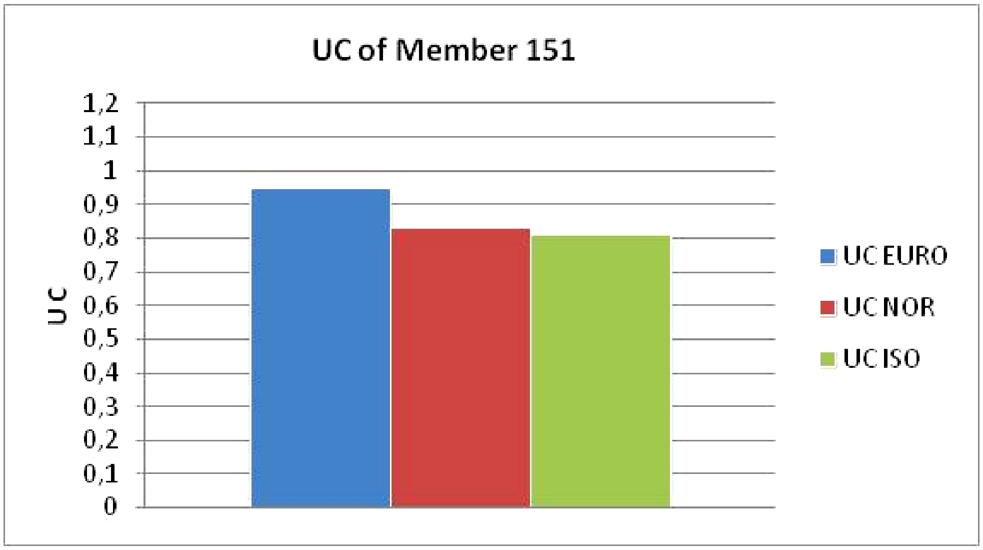


Figure 11-8 Element 151

11.2.8 Element 149

Element number 149 is a diagonal tubular member in the north wall, and according to Eurocode the member is in cross sectional class 1. The results of the member are illustrated in Figure 11-9. The utilization ratio for the element is found for the load combination N2A.

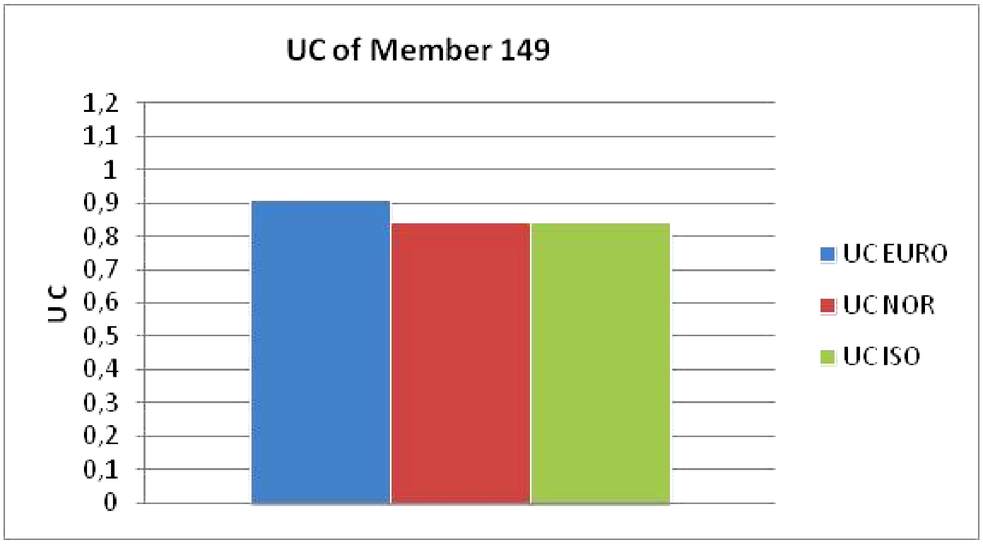


Figure 11-9 Element 149

11.2.9 Element 153

The results of the code checks for element 153 are shown in Figure 11-10. The element is a vertical tubular member connecting the supports and the main deck, and according to Eurocode the member is in cross sectional class 1. The utilization ratio for the element is found for the load combination N2A.

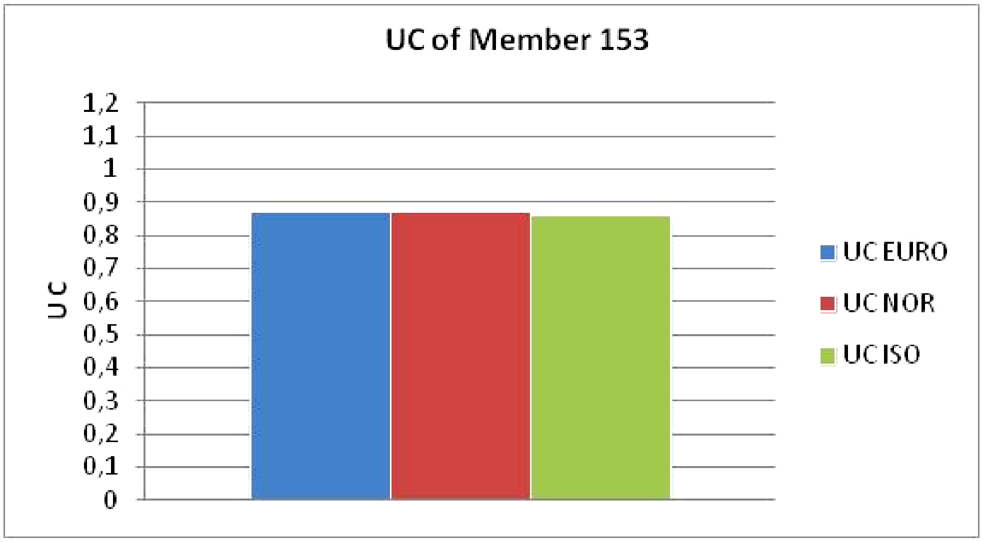


Figure 11-10 Element 153

11.2.10 Element 97

The tubular member number 97 is a horizontal tubular member in the weather deck, and according to Eurocode the member is in cross sectional class 3. Figure 11-11 illustrates the results for the member, the utilization ratio is found for the load combination N3A.

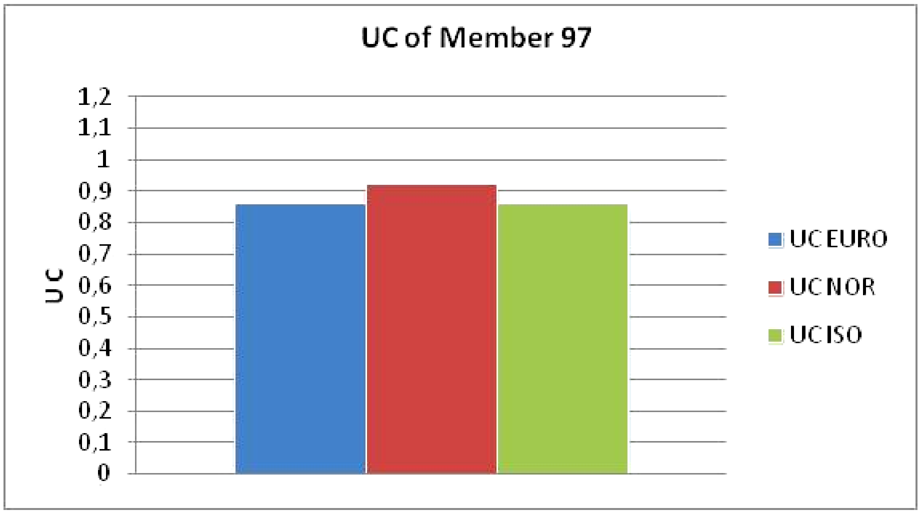


Figure 11-11 Element 97

11.3 Discussion of case study 2

The main purpose of case study 2 has been to analyze and compare the member utilization according to the different design standards when the load and action factors are identical. The action factors in NORSOK N-001 was set as a basis, and used for all the three codes. The original resistance factors are used in ISO, while the material factor given in NORSOK, γ_m = 1.15 is also used for Eurocode, since NORSOK overrules Eurocode in the oil industry.

The results from the diagrams in section 11.2 indicate that Eurocode is the conservative approach for the comparison of regulations when analyzing the global topside module. The lowest utilization ratios were calculated for the ISO code check. It can be seen from the diagrams that four of the members will fail due to the code check in Eurocode, while one member will fail due to the code check in NORSOK and ISO. The trend in the diagrams illustrates that the results for NORSOK and ISO are similar to each other, and the maximum difference in the utilization ratio for these two codes are 8 %. The code check formulas for the NORSOK and ISO codes are identical, ref. chapter 0, and the difference in the utilization is caused by the application of the different resistance factors, see chapter 10.2.

Four of the members (member 138, 139,151 and 149) investigated are in cross sectional class 1 and 2, and were checked based on the formulae for combined bending and axial compression force. Eurocode was observed to be the conservative approach. The average difference between the code checks for Eurocode and NORSOK/ISO were roughly 11.5 %.From the parameter study for axial compression and bending ref. section 6.8.1 and section 6.8.2, the graphs indicates that Eurocode is more conservative up to a certain level of force, above this level (approximately UC=0.85) the graphs are crossing each other, meaning that NORSOK and ISO are more conservative. Due to this, it is expected that NORSOK and ISO would be the conservative approach, when the load level is close to the capacity of the member.

Three of the members investigated (member 65, 67 and 64) are in cross sectional class 3, and the capacity was checked based on the formulae for combined bending and axial compression force. The average difference between the code checks according to Eurocode was 21 % and 33 % for NORSOK and ISO, respectively with Eurocode as the conservative approach. From the parameter study the similar results were found, the average difference between the members in Eurocode and NORSOK were 19 %. The deviation between the results for Eurocode and ISO are due to the differences in the material factors.

Element number 107 (cross sectional class 3) deviates from the other graphs in order that the difference in the capacity between the three codes are relative large. The utilization ratio is 1.15 according to Eurocode, and the member where checked according to the combination of axial compression and biaxial bending. For NORSOK and ISO the code check gave a utilization ratio of 0.72 and 0.66, respectively. The main difference in the capacities is due to the contribution of the moment around the z-axis, found in the formulas F 5-41 to F 5-42 for Eurocode and formulas for F 5-44 to F 5-45 for NORSOK and ISO, in section 5.10. In Eurocode the moment around the z-axis contributes to 0.4 of the total utilization ratio, while in NORSOK/ISO the contribution is approximately 0.1 of the total utilization ratio, ref Appendix A7. The differences in the code checks according to Eurocode were 59 % and 72 % for NORSOK and ISO. The results corresponds satisfactory with the results obtained from the parameter study for combined axial compression and biaxial moment for members in cross sectional class 3, ref section 6.9.2 where the maximum differences between Eurocode and NORSOK/ISO were 66%.

Element number 97 was checked with the conservative formulae in Eurocode, namely formula F 5-43 in section 5.10.1, while NORSOK and ISO were checked based on the formula for combined axial tension and bending. NORSOK and ISO are for this member more conservative than Eurocode, the difference in the utilization ratio between Eurocode and NORSOK are 7 %, while there is no difference in the utilization ratio between Eurocode and ISO. There was not carried out a parameter study in combined bending and axial tension, since Eurocode does not have a derived specified formula on combined axial tension and bending.

When the utilization ratio for the code check in Eurocode, falls below 0.9, it is observed from the results that the difference between the codes decreases and the differences in the utilization ratios between the code checks are marginal, around 1.5 %. The same results are obtained from the parameter study when the members utilization ratio are below 0.9, the average differences calculated from the parameter study between Eurocode and NORSOK/ISO were 3 %.

12 CONCLUCION AND FURTHER RECOMMENDATIONS

This study covers an extensive scope in comparison of the structural standards Eurocode EN 1993-1-1, NORSOK N-004 and ISO 19902. All the design standards provide formulae for load effects acting alone and in combination. Eurocode has specific formulas for all cross sections, while NORSOK and ISO provide specific formulas for tubular members. On background of the results presented and discussed, the following conclusion may be drawn according to the scope of work for the thesis.

- All the codes adopt the same design approach, namely the Load and Resistance factor design (LRFD): $S_d = \gamma_f R_k \leq R_d = \frac{\mathrm{R_k}}{\mathrm{\gamma_M}}$ where the partial coefficient γ_f takes care of the uncertainties in the calculation of the load effect and the partial coefficient γ_m takes care of the uncertainties in the calculation model for the capacity. The differences in the material factors are shown in Table 12-1.

Material factor	Eurocode	NORSOK	ISO
γ_m	1.05	$1.15 \leq \gamma_\mathrm{m} \leq 1.45$	1.05 for tension and bending 1.18 for compression

Table 12-1 Material factors in the design standards

The differences in the action factors for ULS A between the codes are illustrated in the Table 12-2.

Design Standard	Permanent actions (G)	Variable actions (Q1)	Environmental actions (Q2)
Eurocode	1,35	1,5 x Ψ_{01}	1,5 x Ψ_{02}
NORSOK	1,3	1,3	0,7
ISO	1,3	1,5	0,9 x $\gamma_{\mathrm{f,E}}$

Table 12-2 Action factors in the design standards

- With respect to axial tension, the three design codes provide identical formulas, and the differences in the codes are entirely due to the partial factors alone.

- Except for the formulas for axial tension, there are significant differences in the design formulas and the partial factors in the codes. NORSOK and ISO provide identical formulas, and design differences between these codes are due to the differences in the partial factors. Each country provides different partial factors to allow for the differences in the acceptance level.

- Eurocode is evaluated to be the most conservative design standard, based on the parameter study (partial factors = 1.0). The exception from this is members in cross sectional class 1 or 2 subjected to bending, biaxial bending moment or the combination of axial compression force and bending, where NORSOK and ISO are found to be the most conservative approach, with an observed difference of 13 %.

- The formulas for members in cross sectional class 1 and 2 are based on a semi empirical approach, which means that formulas are based on theory and experimental work. The parameter study indicates that Eurocode gives the most conservative design, for members subjected to combined axial compression and bending up to a certain level of force (approximately UC = 0.85). Above this level of force the graph are crossing each other, meaning that NORSOK and ISO are the conservative approach, when the capacity of the member is reached. From the parameter studies it is found that the difference in capacity between Eurocode and NORSOK/ISO is 10 %.
    - For case study 1, subjected to original resistance and action factors, the differences in utilization ratio between the differences in utilization ratio between Eurocode, NORSOK and ISO are 11 % and 17%, respectively.
    - For case study 2, where the material and environmental criteria in NORSOK is set as a basis, the differences in utilization ratio between Eurocode, NORSOK and ISO are 14 % and 33%, respectively.
- The most significant difference between the codes is found for members in cross sectional class 3, subject to a combination of axial compression and biaxial bending. The maximum capacity difference identified in the parameter study was 59% between Eurocode and NORSOK/ISO.
    - For case study 1, subjected to original resistance and action factors, the differences in utilization ratio between Eurocode, NORSOK and ISO are found to be 51 % and 62%, respectively.
    - For case study 2, where the material and environmental criteria in NORSOK is set as a basis, 1 the differences in utilization ratio between Eurocode, NORSOK and ISO are 59 % and 72%, respectively.

Future recommendations

- Detail study and comparison of the principals and methodology for the actions/load factors in the LRFD design standards.
- Detail study of the acceptable level of acceptance in the design standards.
- Further analysis of the parameter study and the case studies, to gain a better understanding of the design standards.

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APPENDIX

APPENDIX A-1 Analysis done in the Parameter Study

Analysis	Name of Analysis	Code	Tubular Member	Length [m]	Force [kN]	Moment My [kNm]	Moment Mz [kNm]
Axial Tension	AxialTensionPipe1_1	Eurocode	1	10	0 - 6500		
Axial Tension	AxialTensionPipe2_1	Eurocode	2	10	0 - 9000		
Axial Tension	AxialTensionPipe1_2	Eurocode	1	15	0 - 7000		
Axial Tension	AxialTensionPipe2_2	Eurocode	2	15	0 - 9000		
Axial Tension	AxialTensionPipe1_1	NORSOK	1	10	0 - 6500		
Axial Tension	AxialTensionPipe2_1	NORSOK	2	10	0 - 9000		
Axial Tension	AxialTensionPipe1_2	NORSOK	1	15	0 - 7000		
Axial Tension	AxialTensionPipe2_2	NORSOK	2	15	0 - 9000		
Axial Tension	AxialTensionPipe1_1	ISO	1	10	0 - 6500		
Axial Tension	AxialTensionPipe2_1	ISO	2	10	0 - 9000		
Axial Tension	AxialTensionPipe1_2	ISO	1	15	0 - 7000		
Axial Tension	AxialTensionPipe2_2	ISO	2	15	0 - 9000		
Axial Compression	AxialCompressionPipe1_1	Eurocode	1	10	0 - 6000		
Axial Compression	AxialCompressionPipe2_1	Eurocode	2	10	0 - 8000		
Axial Compression	AxialCompressionPipe1_2	Eurocode	1	15	0 - 4000		
Axial Compression	AxialCompressionPipe2_2	Eurocode	2	15	0 - 7000		
Axial Compression	AxialCompressionPipe1_1	NORSOK	1	10	0 - 6000		
Axial Compression	AxialCompressionPipe2_1	NORSOK	2	10	0 - 8000		
Axial Compression	AxialCompressionPipe1_2	NORSOK	1	15	0 - 4000		
Axial Compression	AxialCompressionPipe2_2	NORSOK	2	15	0 - 7000		
Axial Compression	AxialCompressionPipe1_1	ISO	1	10	0 - 6000		
Axial Compression	AxialCompressionPipe2_1	ISO	2	10	0 - 8000		
Axial Compression	AxialCompressionPipe1_2	ISO	1	15	0 - 4000		
Axial Compression	AxialCompressionPipe2_2	ISO	2	15	0 - 7000		
Bending Moment	MomentPipe1_1	Eurocode	1	10			0 - 1300
Bending Moment	MomentPipe2_1	Eurocode	2	10			0 - 2000
Bending Moment	MomentPipe1_2	Eurocode	1	15			0 - 1300
Bending Moment	MomentPipe2_2	Eurocode	2	15			0 - 2000
Bending Moment	MomentPipe1_1	NORSOK	1	10			0 - 1300
Bending Moment	MomentPipe2_1	NORSOK	2	10			0 - 2000

Analysis	Name of Analysis	Code	Tubular Member	Length [m]	Force [kN]	Moment My [kNm]	Moment Mz [kNm]
Bending Moment	MomentPipe1_2	NORSOK	1	15			0 - 1300
Bending Moment	MomentPipe2_2	NORSOK	2	15			0 - 2000
Bending Moment	MomentPipe1_1	ISO	1	10			0 - 1300
Bending Moment	MomentPipe2_1	ISO	2	10			0 - 2000
Bending Moment	MomentPipe1_2	ISO	1	15			0 - 1300
Bending Moment	MomentPipe2_2	ISO	2	15			0 - 2000
Bi-axial Moment	Moment50MomentPipe1_1	Eurocode	1	10		445	0 - 1000
Bi-axial Moment	Moment50MomentPipe2_1	Eurocode	2	10		620	0 - 1400
Bi-axial Moment	Moment50MomentPipe1_2	Eurocode	1	15		445	0 - 1000
Bi-axial Moment	Moment50MomentPipe2_2	Eurocode	2	15		620	0 - 1400
Bi-axial Moment	Moment50MomentPipe1_1	NORSOK	1	10		445	0 - 1000
Bi-axial Moment	Moment50MomentPipe2_1	NORSOK	2	10		620	0 - 1400
Bi-axial Moment	Moment50MomentPipe1_2	NORSOK	1	15		445	0 - 1000
Bi-axial Moment	Moment50MomentPipe2_2	NORSOK	2	15		620	0 - 1400
Bi-axial Moment	Moment50MomentPipe1_1	ISO	1	10		445	0 - 1000
Bi-axial Moment	Moment50MomentPipe2_1	ISO	2	10		620	0 - 1400
Bi-axial Moment	Moment50MomentPipe1_2	ISO	1	15		445	0 - 1000
Bi-axial Moment	Moment50MomentPipe2_2	ISO	2	15		620	0 - 1400
Bi-axial Moment	Moment70MomentPipe1_1	Eurocode	1	10		620	0 - 700
Bi-axial Moment	Moment70MomentPipe2_1	Eurocode	2	10		870	0 - 1200
Bi-axial Moment	Moment70MomentPipe1_2	Eurocode	1	15		620	0 - 700
Bi-axial Moment	Moment70MomentPipe2_2	Eurocode	2	15		870	0 - 1200
Bi-axial Moment	Moment70MomentPipe1_1	NORSOK	1	10		620	0 - 700
Bi-axial Moment	Moment70MomentPipe2_1	NORSOK	2	10		870	0 - 1200
Bi-axial Moment	Moment70MomentPipe1_2	NORSOK	1	15		620	0 - 700
Bi-axial Moment	Moment70MomentPipe2_2	NORSOK	2	15		870	0 - 1200
Bi-axial Moment	Moment70MomentPipe1_1	ISO	1	10		620	0 - 700
Bi-axial Moment	Moment70MomentPipe2_1	ISO	2	10		870	0 - 1200
Bi-axial Moment	Moment70MomentPipe1_2	ISO	1	15		620	0 - 700
Bi-axial Moment	Moment70MomentPipe2_2	ISO	2	15		870	0 - 1200

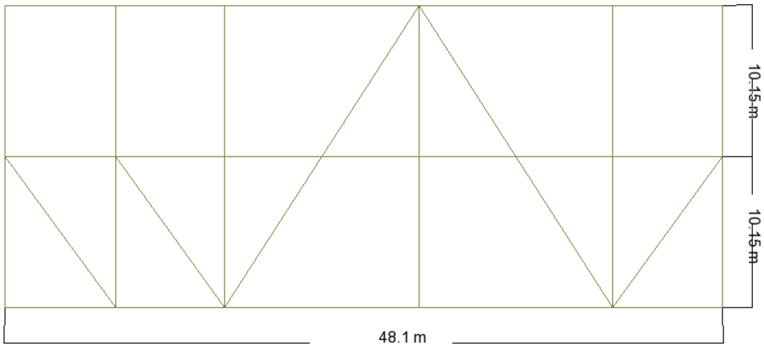
Analysis	Name of Analysis	Code	Tubular Member	Length [m]	Force [kN]	Moment My [kNm]	Moment Mz [kNm]
Bi-axial Moment	Moment90MomentPipe1_1	Eurocode	1	10		800	0 - 400
Bi-axial Moment	Moment90MomentPipe2_1	Eurocode	2	10		1100	0 - 1000
Bi-axial Moment	Moment90MomentPipe1_2	Eurocode	1	15		800	0 - 400
Bi-axial Moment	Moment90MomentPipe2_2	Eurocode	2	15		1100	0 - 1000
Bi-axial Moment	Moment90MomentPipe1_1	NORSOK	1	10		800	0 - 400
Bi-axial Moment	Moment90MomentPipe2_1	NORSOK	2	10		1100	0 - 1000
Bi-axial Moment	Moment90MomentPipe1_2	NORSOK	1	15		800	0 - 400
Bi-axial Moment	Moment90MomentPipe2_2	NORSOK	2	15		1100	0 - 1000
Bi-axial Moment	Moment90MomentPipe1_1	ISO	1	10		800	0 - 400
Bi-axial Moment	Moment90MomentPipe2_1	ISO	2	10		1100	0 - 1000
Bi-axial Moment	Moment90MomentPipe1_2	ISO	1	15		800	0 - 400
Bi-axial Moment	Moment90MomentPipe2_2	ISO	2	15		1100	0 - 1000
Comb. Compression and Bending	Axial50MomentPipe1_1	Eurocode	1	10	2450		0 - 400
Comb. Compression and Bending	Axial50MomentPipe2_1	Eurocode	2	10	1575		0 - 1000
Comb. Compression and Bending	Axial50MomentPipe1_2	Eurocode	1	15	3700		0 - 400
Comb. Compression and Bending	Axial50MomentPipe2_2	Eurocode	2	15	3000		0 - 1000
Comb. Compression and Bending	Axial50MomentPipe1_1	NORSOK	1	10	2450		0 - 400
Comb. Compression and Bending	Axial50MomentPipe2_1	NORSOK	2	10	1575		0 - 1000
Comb. Compression and Bending	Axial50MomentPipe1_2	NORSOK	1	15	3700		0 - 400
Comb. Compression and Bending	Axial50MomentPipe2_2	NORSOK	2	15	3000		0 - 1000
Comb. Compression and Bending	Axial50MomentPipe1_1	ISO	1	10	2450		0 - 400
Comb. Compression and Bending	Axial50MomentPipe2_1	ISO	2	10	1575		0 - 1000
Comb. Compression and Bending	Axial50MomentPipe1_2	ISO	1	15	3700		0 - 400
Comb. Compression and Bending	Axial50MomentPipe2_2	ISO	2	15	3000		0 - 1000
Comb. Compression and Bending	Axial70MomentPipe1_1	Eurocode	1	10	3400		0 - 200
Comb. Compression and Bending	Axial70MomentPipe2_1	Eurocode	2	10	5250		0 - 350
Comb. Compression and Bending	Axial70MomentPipe1_2	Eurocode	1	15	2200		0 - 200
Comb. Compression and Bending	Axial70MomentPipe2_2	Eurocode	2	15	4250		0 - 300
Comb. Compression and Bending	Axial70MomentPipe1_1	NORSOK	1	10	3400		0 - 200
Comb. Compression and Bending	Axial70MomentPipe2_1	NORSOK	2	10	5250		0 - 350
Comb. Compression and Bending	Axial70MomentPipe1_2	NORSOK	1	15	2200		0 - 200
Comb. Compression and Bending	Axial70MomentPipe2_2	NORSOK	2	15	4250		0 - 300

Analysis	Name of Analysis	Code	Tubular Member	Length [m]	Force [kN]	Moment My [kNm]	Moment Mz [kNm]
Comb. Compression and Bending	Axial70MomentPipe1_1	ISO	1	10	3400		0 - 200
Comb. Compression and Bending	Axial70MomentPipe2_1	ISO	2	10	5250		0 - 350
Comb. Compression and Bending	Axial70MomentPipe1_2	ISO	1	15	2200		0 - 200
Comb. Compression and Bending	Axial70MomentPipe2_2	ISO	2	15	4250		0 - 300
Comb. Compression and Bending	Axial90MomentPipe1_1	Eurocode	1	10	4400		0 - 70
Comb. Compression and Bending	Axial90MomentPipe2_1	Eurocode	2	10	2825		0 - 60
Comb. Compression and Bending	Axial90MomentPipe1_2	Eurocode	1	15	6700		0 - 120
Comb. Compression and Bending	Axial90MomentPipe2_2	Eurocode	2	15	5450		0 - 100
Comb. Compression and Bending	Axial90MomentPipe1_1	NORSOK	1	10	4400		0 - 70
Comb. Compression and Bending	Axial90MomentPipe2_1	NORSOK	2	10	2825		0 - 60
Comb. Compression and Bending	Axial90MomentPipe1_2	NORSOK	1	15	6700		0 - 120
Comb. Compression and Bending	Axial90MomentPipe2_2	NORSOK	2	15	5450		0 - 100
Comb. Compression and Bending	Axial90MomentPipe1_1	ISO	1	10	4400		0 - 70
Comb. Compression and Bending	Axial90MomentPipe2_1	ISO	2	10	2825		0 - 60
Comb. Compression and Bending	Axial90MomentPipe1_2	ISO	1	15	6700		0 - 120
Comb. Compression and Bending	Axial90MomentPipe2_2	ISO	2	15	5450		0 - 100
Comb. Compression and biaxial	Axial50Bi-axialPipe 1_1	Eurocode	1	10	3700	0-400	0-400
Comb. Compression and biaxial	Axial50Bi-axialPipe 2_1	Eurocode	2	10	3400	0-560	0-560
Comb. Compression and biaxial	Axial50Bi-axialPipe 1_2	Eurocode	1	15	1575	0-320	0-320
Comb. Compression and biaxial	Axial50Bi-axialPipe 2_2	Eurocode	2	15	3000	0-460	0-460
Comb. Compression and biaxial	Axial50Bi-axialPipe 1_1	NORSOK	1	10	3700	0-400	0-400
Comb. Compression and biaxial	Axial50Bi-axialPipe 2_1	NORSOK	2	10	3400	0-560	0-560
Comb. Compression and biaxial	Axial50Bi-axialPipe 1_2	NORSOK	1	15	1575	0-320	0-320
Comb. Compression and biaxial	Axial50Bi-axialPipe 2_2	NORSOK	2	15	3000	0-460	0-460
Comb. Compression and biaxial	Axial50Bi-axialPipe 1_1	ISO	1	10	3700	0-400	0-400
Comb. Compression and biaxial	Axial50Bi-axialPipe 2_1	ISO	2	10	3400	0-560	0-560
Comb. Compression and biaxial	Axial50Bi-axialPipe 1_2	ISO	1	15	1575	0-320	0-320
Comb. Compression and biaxial	Axial50Bi-axialPipe 2_2	ISO	2	15	3000	0-460	0-460
Comb. Compression and biaxial	Axial70Bi-axialPipe 1_1	Eurocode	1	10	3400	0-200	0-200
Comb. Compression and biaxial	Axial70Bi-axialPipe 2_1	Eurocode	2	10	5250	0-260	0-260
Comb. Compression and biaxial	Axial70Bi-axialPipe 1_2	Eurocode	1	15	2200	0-200	0-200

Analysis	Name of Analysis	Code	Tubular Member	Length [m]	Force [kN]	Moment My [kNm]	Moment Mz [kNm]
Comb. Compression and biaxial	Axial70Bi-axialPipe 2_2	Eurocode	2	15	4250	0-260	0-260
Comb. Compression and biaxial	Axial70Bi-axialPipe 1_1	NORSOK	1	10	3400	0-200	0-200
Comb. Compression and biaxial	Axial70Bi-axialPipe 2_1	NORSOK	2	10	5250	0-260	0-260
Comb. Compression and biaxial	Axial70Bi-axialPipe 1_2	NORSOK	1	15	2200	0-200	0-200
Comb. Compression and biaxial	Axial70Bi-axialPipe 2_2	NORSOK	2	15	4250	0-260	0-260
Comb. Compression and biaxial	Axial70Bi-axialPipe 1_1	ISO	1	10	3400	0-200	0-200
Comb. Compression and biaxial	Axial70Bi-axialPipe 2_1	ISO	2	10	5250	0-260	0-260
Comb. Compression and biaxial	Axial70Bi-axialPipe 1_2	ISO	1	15	2200	0-200	0-200
Comb. Compression and biaxial	Axial70Bi-axialPipe 2_2	ISO	2	15	4250	0-260	0-260
Comb. Compression and biaxial	Axial90Bi-axialPipe 1_1	Eurocode	1	10	4400	0-100	0-100
Comb. Compression and biaxial	Axial90Bi-axialPipe 2_1	Eurocode	2	10	6700	0-160	0-160
Comb. Compression and biaxial	Axial90Bi-axialPipe 1_2	Eurocode	1	15	2825	0-100	0-100
Comb. Compression and biaxial	Axial90Bi-axialPipe 2_2	Eurocode	2	15	5450	0-120	0-120
Comb. Compression and biaxial	Axial90Bi-axialPipe 1_1	NORSOK	1	10	4400	0-100	0-100
Comb. Compression and biaxial	Axial90Bi-axialPipe 2_1	NORSOK	2	10	6700	0-160	0-160
Comb. Compression and biaxial	Axial90Bi-axialPipe 1_2	NORSOK	1	15	2825	0-100	0-100
Comb. Compression and biaxial	Axial90Bi-axialPipe 2_2	NORSOK	2	15	5450	0-120	0-120
Comb. Compression and biaxial	Axial90Bi-axialPipe 1_1	ISO	1	10	4400	0-100	0-100
Comb. Compression and biaxial	Axial90Bi-axialPipe 2_1	ISO	2	10	6700	0-160	0-160
Comb. Compression and biaxial	Axial90Bi-axialPipe 1_2	ISO	1	15	2825	0-100	0-100
Comb. Compression and biaxial	Axial90Bi-axialPipe 2_2	ISO	2	15	5450	0-120	0-120

APPENDIX A-2 Wind Calculations on Topside Module

Wind force in North and South



Total wind force direction north/south: 35.3 t = 346.3 kN

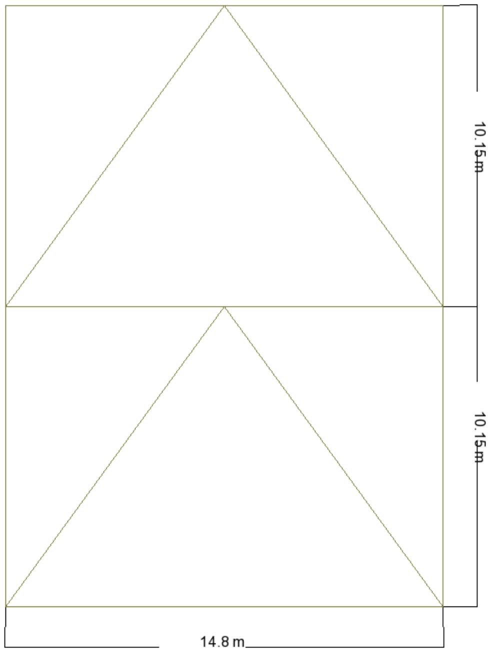
$$P_1 = \frac{346.174\ kN}{48.1\ m}\ x\ \frac{\left(\frac{10.15}{2}\right) m}{20.3\ m} = 1.8\ \frac{kN}{m}\ \text{on beam 1}$$

$$P_2 = \frac{346.174\ kN}{48.1\ m}\ x\ \frac{\left(\frac{10.15}{2}\right)+\left(\frac{10.15}{2}\right) m}{20.3\ m} = 3.6\ \frac{kN}{m}\ \text{on beam 2}$$

$$P_3 = \frac{346.174\ kN}{48.1\ m}\ x\ \frac{\left(\frac{10.15}{2}\right) m}{20.3\ m} = 1.8\ \frac{kN}{m}\ \text{on beam 3}$$

Check:
$(1.8 + 3.6 + 1.8)\ \frac{kN}{m}$ x 48.1 = 346.2 kN, Check OK

Wind force west and east



Total wind force direction west/east: 77.3 t = 758.3 kN

$$P_1 = \frac{758.3\ kN}{14.8\ m}\ x\ \frac{\left(\frac{10.5}{2}\right) m}{20.3\ m} = 12.8\ \frac{kN}{m} \text{ on beam 1}$$

$$P_2 = \frac{758.3\ kN}{14.8\ m}\ x\ \frac{\left(\frac{10.5}{2}\right)+\left(\frac{10.5}{2}\right) m}{20.3\ m} = 25.6\ \frac{kN}{m} \text{ on beam 2}$$

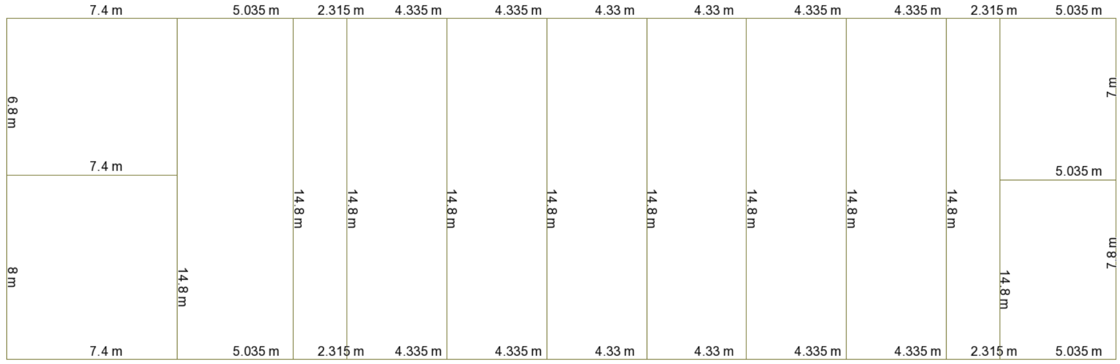
$$P_3 = \frac{758.3\ kN}{14.8\ m}\ x\ \frac{\left(\frac{10.5}{2}\right) m}{20.3\ m} = 12.8\ \frac{kN}{m} \text{ on beam 3}$$

Check:
(12.8 + 25.6 + 12.8) $\frac{kN}{m}$ x 14.8m = 758 kN, Check OK

APPENDIX A-3 Live Load Calculations on Topside Module

Live loads on Plain main deck

Total live loads on plain main deck: 450 t = 4415 kN



$$P_1 = \frac{4415\ kN}{14.8\ m}\ x\ \frac{\left(\frac{7.4}{2}\right) m}{48.1\ m} = 22.9\ \frac{kN}{m}$$

$$P_2 = \frac{4415\ kN}{14.8\ m}\ x\ \frac{\left(\frac{7.4}{2}\right)+\left(\frac{5.035}{2}\right) m}{48.1\ m} = 38.56\ \frac{kN}{m}$$

$$P_3 = \frac{4415\ kN}{14.8\ m}\ x\ \frac{\left(\frac{5.035}{2}\right)+\left(\frac{2.315}{2}\right) m}{48.1\ m} = 22.79\ \frac{kN}{m}$$

$$P_4 = \frac{4415\ kN}{14.8\ m}\ x\ \frac{\left(\frac{2.315}{2}\right)+\left(\frac{4.335}{2}\right) m}{48.1\ m} = 20.6\ \frac{kN}{m}$$

$$P_5 = \frac{4415\ kN}{14.8\ m}\ x\ \frac{\left(\frac{4.335}{2}\right)+\left(\frac{4.335}{2}\right) m}{48.1\ m} = 26.9\ \frac{kN}{m}$$

$$P_6 = \frac{4415\ kN}{14.8\ m}\ x\ \frac{\left(\frac{4.335}{2}\right)+\left(\frac{4.330}{2}\right) m}{48.1\ m} = 26.9\ \frac{kN}{m}$$

$$P_7 = \frac{4415\ kN}{14.8\ m}\ x\ \frac{\left(\frac{4.330}{2}\right)+\left(\frac{4.330}{2}\right) m}{48.1\ m} = 26.9\ \frac{kN}{m}$$

$$P_8 = \frac{4415\ kN}{14.8\ m}\ x\ \frac{\left(\frac{4.330}{2}\right)+\left(\frac{4.335}{2}\right) m}{48.1\ m} = 26.9\ \frac{kN}{m}$$

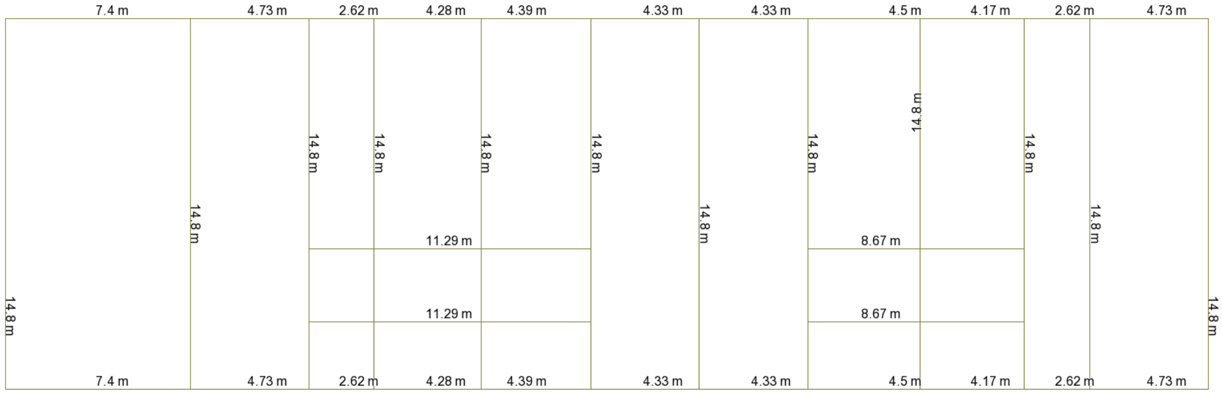
$$P_9 = \frac{4415\ kN}{14.8\ m}\ x\ \frac{\left(\frac{4.335}{2}\right)+\left(\frac{4.335}{2}\right) m}{48.1\ m} = 26.9\ \frac{kN}{m}$$

$$P_{10} = \frac{4415\ kN}{14.8\ m}\ x\ \frac{\left(\frac{4.335}{2}\right)+\left(\frac{2.315}{2}\right) m}{48.1\ m} = 20.9\ \frac{kN}{m}$$

$$P_{11} = \frac{4415\ kN}{14.8\ m}\ x\ \frac{\left(\frac{2.315}{2}\right)+\left(\frac{5.035}{2}\right) m}{48.1\ m} = 22.8\ \frac{kN}{m}$$

$$P_{12} = \frac{4415\ kN}{14.8\ m}\ x\ \frac{\left(\frac{5.035}{2}\right) m}{48.1\ m} = 15.61\ \frac{kN}{m}$$

Live loads on Lower Mezzanine Deck



Total live loads on plain main deck: 200 t = 1962 kN

$$P_{13} = \frac{1962\ kN}{14.8\ m}\ x\ \frac{\left(\frac{7.4}{2}\right) m}{48.1\ m} = 10.2\ \frac{kN}{m}$$

$$P_{14} = \frac{1962\ kN}{14.8\ m}\ x\ \frac{\left(\frac{7.4}{2}\right)+\left(\frac{4.73}{2}\right) m}{48.1\ m} = 16.7\ \frac{kN}{m}$$

$$P_{15} = \frac{1962\ kN}{14.8\ m}\ x\ \frac{\left(\frac{4.73}{2}\right)+\left(\frac{2.62}{2}\right) m}{48.1\ m} = 10.1\ \frac{kN}{m}$$

$$P_{16} = \frac{1962\ kN}{14.8\ m}\ x\ \frac{\left(\frac{2.62}{2}\right)+\left(\frac{4.28}{2}\right) m}{48.1\ m} = 9.5\ \frac{kN}{m}$$

$$P_{17} = \frac{1962\ kN}{14.8\ m}\ x\ \frac{\left(\frac{4.28}{2}\right)+\left(\frac{4.39}{2}\right) m}{48.1\ m} = 11.9\ \frac{kN}{m}$$

$$P_{18} = \frac{1962\ kN}{14.8\ m}\ x\ \frac{\left(\frac{4.39}{2}\right)+\left(\frac{4.33}{2}\right) m}{48.1\ m} = 11.9\ \frac{kN}{m}$$

$$P_{19} = \frac{1962\ kN}{14.8\ m}\ x\ \frac{\left(\frac{4.330}{2}\right)+\left(\frac{4.33}{2}\right) m}{48.1\ m} = 11.9\ \frac{kN}{m}$$

$$P_{20} = \frac{1962\ kN}{14.8\ m}\ x\ \frac{\left(\frac{4.33}{2}\right)+\left(\frac{4.5}{2}\right) m}{48.1\ m} = 12.1\ \frac{kN}{m}$$

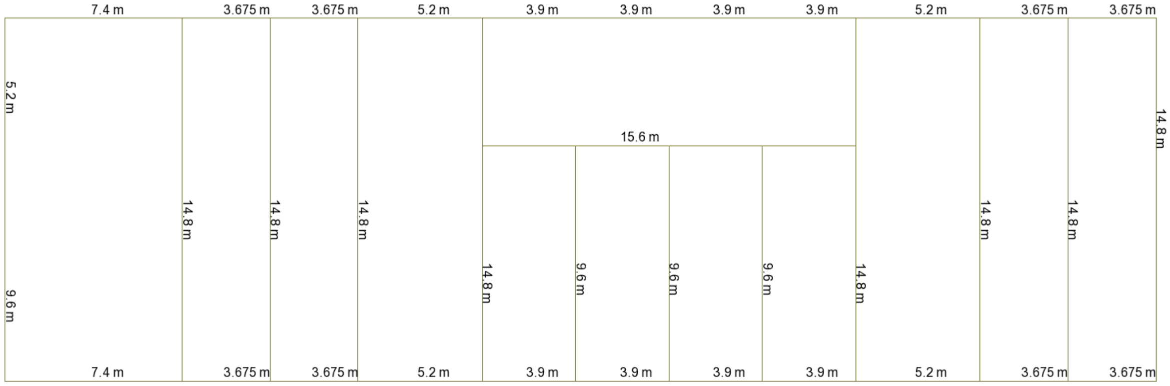
$$P_{21} = \frac{1962\ kN}{14.8\ m}\ x\ \frac{\left(\frac{4.5}{2}\right)+\left(\frac{4.17}{2}\right) m}{48.1\ m} = 11.9\ \frac{kN}{m}$$

$$P_{22} = \frac{1962\ kN}{14.8\ m}\ x\ \frac{\left(\frac{4.17}{2}\right)+\left(\frac{2.62}{2}\right) m}{48.1\ m} = 9.4\ \frac{kN}{m}$$

$$P_{23} = \frac{1962\ kN}{14.8\ m}\ x\ \frac{\left(\frac{2.62}{2}\right)+\left(\frac{4.73}{2}\right) m}{48.1\ m} = 10.1\ \frac{kN}{m}$$

$$P_{24} = \frac{1962\ kN}{14.8\ m}\ x\ \frac{\left(\frac{4.73}{2}\right) m}{48.1\ m} = 6.5\ \frac{kN}{m}$$

Live loads on weather deck



Total live loads on weather deck: 50 t = 491 kN

$$P_{25} = \frac{491\ kN}{14.8\ m}\ x\ \frac{\left(\frac{7.4}{2}\right) m}{48.1\ m} = 2.55\ \frac{kN}{m}$$

$$P_{26} = \frac{491\ kN}{14.8\ m}\ x\ \frac{\left(\frac{7.4}{2}\right) + \left(\frac{3.675}{2}\right) m}{48.1\ m} = 3.8\ \frac{kN}{m}$$

$$P_{27} = \frac{491\ kN}{14.8\ m}\ x\ \frac{\left(\frac{3.675}{2}\right) + \left(\frac{3.675}{2}\right) m}{48.1\ m} = 2.5\ \frac{kN}{m}$$

$$P_{28} = \frac{491\ kN}{14.8\ m}\ x\ \frac{\left(\frac{3.675}{2}\right) + \left(\frac{5.2}{2}\right) m}{48.1\ m} = 3.0\ \frac{kN}{m}$$

$$P_{29} = \frac{491\ kN}{9.6\ m}\ x\ \frac{\left(\frac{5.2}{2}\right) + \left(\frac{3.9}{2}\right) m}{48.1\ m} = 4.8\ \frac{kN}{m}$$

$$P_{30} = \frac{491\ kN}{9.6\ m}\ x\ \frac{\left(\frac{3.9}{2}\right) + \left(\frac{3.9}{2}\right) m}{48.1\ m} = 4.1\ \frac{kN}{m}$$

$$P_{31} = \frac{491\ kN}{9.6\ m}\ x\ \frac{\left(\frac{3.9}{2}\right) + \left(\frac{3.9}{2}\right) m}{48.1\ m} = 4.1\ \frac{kN}{m}$$

$$P_{32} = \frac{491\ kN}{9.6\ m}\ x\ \frac{\left(\frac{3.9}{2}\right) + \left(\frac{3.9}{2}\right) m}{48.1\ m} = 4.1\ \frac{kN}{m}$$

$$P_{33} = \frac{491\ kN}{9.6\ m}\ x\ \frac{\left(\frac{3.9}{2}\right) + \left(\frac{5.2}{2}\right) m}{48.1\ m} = 4.8\ \frac{kN}{m}$$

$$P_{34} = \frac{491\ kN}{14.8\ m}\ x\ \frac{\left(\frac{5.2}{2}\right) + \left(\frac{3.675}{2}\right) m}{48.1\ m} = 3.0\ \frac{kN}{m}$$

$$P_{35} = \frac{491\ kN}{14.8\ m}\ x\ \frac{\left(\frac{3.675}{2}\right) + \left(\frac{3.675}{2}\right) m}{48.1\ m} = 2.5\ \frac{kN}{m}$$

$$P_{36} = \frac{491\ kN}{14.8\ m}\ x\ \frac{\left(\frac{3.675}{2}\right) m}{48.1\ m} = 1.27\ \frac{kN}{m}$$

$$P_{37} = \frac{491\ kN}{5.2\ m}\ x\ \frac{\left(\frac{3.9}{2}\right) + \left(\frac{5.2}{2}\right) m}{48.1\ m} = 8.9\ \frac{kN}{m}$$

$$P_{38} = \frac{491\ kN}{5.2\ m}\ x\ \frac{\left(\frac{3.9}{2}\right) + \left(\frac{5.2}{2}\right) m}{48.1\ m} = 8.9\ \frac{kN}{m}$$

APPENDIX A-4 Extract from the input file in SESAM:Genie on the parameter study for tubular member 2 when subjected to bi-axial moment

```
GenieRules.Tolerances.useTolerantModelling = true;
GenieRules.Compatibility.version = "V5.3-10";
GenieRules.Meshing.autoSimplifyTopology = true;
// ** Myy Moment 50 % and Bending Moment Mzz**

// ** UNIT **
GenieRules.Units.resetToDatabaseUnits();
Genierules.Units.SetInputUnit(Angle, "deg");
Genierules.Units.SetInputUnit(Force, "N");
Genierules.Units.SetInputUnit(Length, "m");
Genierules.Units.SetInputUnit(Tempdiff, "delC");


// **** PROPERTIES ****
// ** Section **
Pipe1 = PipeSection(457.2 mm, 12.7 mm);
Pipe2 = PipeSection(0.610 m, 0.0127 m);

// ** Material **//
S355 = MaterialLinear(355000000, 7850, 210000000000, 0.3, 0, 0);

// **** RULES ****
// ** Meshing Rules **
Genierules.Meshing.activate(mpMinEdge, false);
Genierules.Meshing.setLimit(mpMinEdge, 0.1);
Genierules.Meshing.activate(mpMaxChord, false);
Genierules.Meshing.activate(mpMaxAngle, 0.2);
Genierules.Meshing.activate(mpMaxAngle, mpFail, true);
Genierules.Meshing.setLimit(mpMaxAngle, mpFail, 179 deg);
Genierules.Meshing.activate(mpMaxAngle, mpSplit, false);
Genierules.Meshing.setLimit(mpMaxAngle, mpSplit, 165 deg);
Genierules.Meshing.activate(mpMinAngle, mpFail, false);
Genierules.Meshing.setLimit(mpMinAngle, mpFAil, 1 deg);
Genierules.Meshing.activate(mpMinAngle, mpSplit, false);
Genierules.Meshing.setLimit(mpMinAngle, mpSplit, 15 deg);
Genierules.Meshing.activate(mpMaxRelativeJacobi, mpFAil, false);
Genierules.Meshing.setLimit(mpMaxRelativeJacobi, mpFAil, 10);
Genierules.Meshing.activate(mpMaxRelativeJacobi, mpSplit, false);
Genierules.Meshing.setLimit(mpMaxRelativeJacobi, mpSplit, 5);
Genierules.Meshing.activate(mpMinNormalizedJacobi, mpFAil, false);
Genierules.Meshing.setLimit(mpMinNormalizedJacobi, mpFAil, 0);
Genierules.Meshing.activate(mpMinNormalizedJacobi, mpSplit, false);
Genierules.Meshing.setLimit(mpMinNormalizedJacobi, mpSplit, 0.2);
Genierules.Meshing.activate(mpMaxTwistAngle, mpFail, false);
Genierules.Meshing.setLimit(mpMaxTwistAngle, mpFail, 30 deg);
Genierules.Meshing.activate(mpMaxTwistAngle, mpSplit, false);
Genierules.Meshing.setLimit(mpMaxTwistAngle, mpSplit, 10 deg);
```

```
Genierules.Meshing.elementType = mp1stOrder;
Genierules.Meshing.autoSimplifyTopology = false;
Genierules.Meshing.superElementType = 1;
Genierules.Meshing.basicLCfactor = 1;
Genierules.Meshing.analysisFolders = true;
Genierules.Meshing.preference(mpPreferRectangularMesh, false);
Genierules.Meshing.preference(mpAllowTriangularElements, true);
Genierules.Meshing.preference(mpIncludeUnusedProperties, false);
Genierules.Meshing.preference(mpPreferPointMassAsNodeMass, true);
Genierules.Meshing.preference(mpMeshDensityRounded, false);
Genierules.Meshing.preference(mpUseDrillingElements, false);
Genierules.Meshing.preference(mpUseLongLoadcaseNames, false);
Genierules.Meshing.preference(mpUseLongSetNames, false);
Genierules.Meshing.preference(mpAdjustNumberofElements, false);

// ** Tolerances Rules
GenieRules.Tolerances.angleTolerance = 0 deg;
GenieRules.Tolerances.pointTolerance = 0.01 m;
GenieRules.Tolerances.useTolerantModelling = true;

// ** Set Rules **
Genierules.Sets.scriptCompact = true;

// ** STRUCTURE **
// ** Guiding Geometry **
GuidePlane1 = GuidePlane(Point(0 m,0 m,0 m),Point(10 m,0 m,0 m),Point(10 m,10 m,0 m),Point(0 m,10 m,0 m),4,4,1,1,1,1,1,1,1,1);
GuidePlane1.snapmode = true;

// ** BEAM **
S355.setDefault();
Pipe2.setDefault();
Bm1 = Beam(Point(0 m,0 m,0 m), Point(10 m,0 m,0 m));

// ** Supports **
Sp1 = SupportPoint(Point(0 m,0 m,0 m));
Sp2 = SupportPoint(Point(10 m,0 m,0 m));

// ** Boundary Conditions **
Sp1.boundary = BoundaryCondition(Fixed, Fixed, Fixed, Free, Free, Free);
Sp2.boundary = BoundaryCondition(Free, Fixed, Fixed, Fixed, Free, Free);

// ****LOAD MODELLING AND ANALYSIS ****
// ** Load Combination **
LC0 = LoadCase();
LC1 = LoadCase();
LC2 = LoadCase();
LC3 = LoadCase();
LC4 = LoadCase();
LC5 = LoadCase();
```

```
LC6 = LoadCase();
LC7 = LoadCase();
LC8 = LoadCase();
LC9 = LoadCase();
LC10 = LoadCase();
LC11 = LoadCase();
LC12 = LoadCase();
LC13 = LoadCase();
LC14 = LoadCase();
LC15 = LoadCase();
LC16 = LoadCase();
LC17 = LoadCase();
LC18 = LoadCase();
LC19 = LoadCase();
LC20 = LoadCase();
LC21 = LoadCase();
LC22 = LoadCase();
LC23 = LoadCase();
LC24 = LoadCase();
LC25 = LoadCase();
LC26 = LoadCase();
LC27 = LoadCase();
LC28 = LoadCase();
LC29 = LoadCase();
LC30 = LoadCase();
LC31 = LoadCase();
LC32 = LoadCase();
LC33 = LoadCase();
LC34 = LoadCase();
LC35 = LoadCase();
LC36 = LoadCase();
LC37 = LoadCase();
LC38 = LoadCase();
LC39 = LoadCase();
LC40 = LoadCase();

// ** Moment Myy 50 %  and varying Moment Mzz**

LC0.setCurrent();
PLoad0 = PointLoad(LC0, Point(10 m,0 m,0 m), 0 N, 0 N, 0 N, 0 N*m, 0 kN*m, 620 kN*m);
LC1.setCurrent();
PLoad1 = PointLoad(LC1, Point(10 m,0 m,0 m), 0 N, 0 N, 0 N, 0 N*m, 35 kN*m, 620 kN*m);
LC2.setCurrent();
PLoad2 = PointLoad(LC2, Point(10 m,0 m,0 m), 0 N, 0 N, 0 N, 0 N*m, 70 kN*m, 620 kN*m);
LC3.setCurrent();
PLoad3 = PointLoad(LC3, Point(10 m,0 m,0 m), 0 N, 0 N, 0 N, 0 N*m, 105 kN*m, 620 kN*m);
LC4.setCurrent();
PLoad4 = PointLoad(LC4, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 140 kN*m, 620 kN*m);
LC5.setCurrent();
PLoad5 = PointLoad(LC5, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 175 kN*m, 620 kN*m);
```

```
LC6.setCurrent();
PLoad6 = PointLoad(LC6, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 210 kN*m, 620 kN*m);
LC7.setCurrent();
PLoad7 = PointLoad(LC7, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 245 kN*m, 620 kN*m);
LC8.setCurrent();
PLoad8 = PointLoad(LC8, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 280 kN*m, 620 kN*m);
LC9.setCurrent();
PLoad9 = PointLoad(LC9, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 315 kN*m, 620 kN*m);
LC10.setCurrent();
PLoad10 = PointLoad(LC10, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 350 kN*m, 620 kN*m);
LC11.setCurrent();
PLoad11 = PointLoad(LC11, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 385 kN*m, 620 kN*m);
LC12.setCurrent();
PLoad12 = PointLoad(LC12, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 420 kN*m, 620 kN*m);
LC13.setCurrent();
PLoad13 = PointLoad(LC13, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 455 kN*m, 620 kN*m);
LC14.setCurrent();
PLoad14 = PointLoad(LC14, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 490 kN*m, 620 kN*m);
LC15.setCurrent();
PLoad15 = PointLoad(LC15, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 525 kN*m, 620 kN*m);
LC16.setCurrent();
PLoad16 = PointLoad(LC16, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 560 kN*m, 620 kN*m);
LC17.setCurrent();
PLoad17 = PointLoad(LC17, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 595 kN*m, 620 kN*m);
LC18.setCurrent();
PLoad18 = PointLoad(LC18, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 630 kN*m, 620 kN*m);
LC19.setCurrent();
PLoad19 = PointLoad(LC19, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 665 kN*m, 620 kN*m);
LC20.setCurrent();
PLoad20 = PointLoad(LC20, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 700 kN*m, 620 kN*m);
LC21.setCurrent();
PLoad21 = PointLoad(LC21, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 735 kN*m, 620 kN*m);
LC22.setCurrent();
PLoad22 = PointLoad(LC22, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 770 kN*m, 620 kN*m);
LC23.setCurrent();
PLoad23 = PointLoad(LC23, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 805 kN*m, 620 kN*m);
LC24.setCurrent();
PLoad24 = PointLoad(LC24, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 840 kN*m, 620 kN*m);
LC25.setCurrent();
PLoad25 = PointLoad(LC25, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 875 kN*m, 620 kN*m);
LC26.setCurrent();
PLoad26 = PointLoad(LC26, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 910 kN*m, 620 kN*m);
LC27.setCurrent();
PLoad27 = PointLoad(LC27, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 945 kN*m, 620 kN*m);
LC28.setCurrent();
PLoad28 = PointLoad(LC28, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 980 kN*m, 620 kN*m);
LC29.setCurrent();
PLoad29 = PointLoad(LC29, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 1015 kN*m, 620 kN*m);
LC30.setCurrent();
PLoad30 = PointLoad(LC30, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 1050 kN*m, 620 kN*m);
```

```
LC31.setCurrent();
PLoad31 = PointLoad(LC31, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 1085 kN*m, 620 kN*m);
LC32.setCurrent();
PLoad32 = PointLoad(LC32, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 1120 kN*m, 620 kN*m);
LC33.setCurrent();
PLoad33 = PointLoad(LC33, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 1155 kN*m, 620 kN*m);
LC34.setCurrent();
PLoad34 = PointLoad(LC34, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 1190 kN*m, 620 kN*m);
LC35.setCurrent();
PLoad35 = PointLoad(LC35, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 1225 kN*m, 620 kN*m);
LC36.setCurrent();
PLoad36 = PointLoad(LC36, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 1260 kN*m, 620 kN*m);
LC37.setCurrent();
PLoad37 = PointLoad(LC37, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 1295 kN*m, 620 kN*m);
LC38.setCurrent();
PLoad38 = PointLoad(LC38, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 1330 kN*m, 620 kN*m);
LC39.setCurrent();
PLoad39 = PointLoad(LC39, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 1365 kN*m, 620 kN*m);
LC40.setCurrent();
PLoad40 = PointLoad(LC40, Point(10 m,0 m,0 m), 0 kN, 0 N, 0 N, 0 N*m, 1400 kN*m, 620 kN*m);

// ** Load Combinations **

LC41 = LoadCombination();
LC41.addCase(LC0, 1);
LC42 = LoadCombination();
LC42.addCase(LC1, 1);
LC43 = LoadCombination();
LC43.addCase(LC2, 1);
LC44 = LoadCombination();
LC44.addCase(LC3, 1);
LC45 = LoadCombination();
LC45.addCase(LC4, 1);
LC46 = LoadCombination();
LC46.addCase(LC5, 1);
LC47 = LoadCombination();
LC47.addCase(LC6, 1);
LC48 = LoadCombination();
LC48.addCase(LC7, 1);
LC49 = LoadCombination();
LC49.addCase(LC8, 1);
LC50 = LoadCombination();
LC50.addCase(LC9, 1);
LC51 = LoadCombination();
LC51.addCase(LC10, 1);
LC52 = LoadCombination();
LC52.addCase(LC11, 1);
LC53 = LoadCombination();
LC53.addCase(LC12, 1);
LC54 = LoadCombination();
```

```
LC54.addcase(LC13, 1);

LC55 = LoadCombination();
LC55.addCase(LC14, 1);
LC56 = LoadCombination();
LC56.addCase(LC15, 1);
LC57 = LoadCombination();
LC57.addCase(LC16, 1);
LC58 = LoadCombination();
LC58.addCase(LC17, 1);
LC59 = LoadCombination();
LC59.addCase(LC18, 1);
LC60 = LoadCombination();
LC60.addCase(LC19, 1);
LC61 = LoadCombination();
LC61.addCase(LC20, 1);
LC62 = LoadCombination();
LC62.addCase(LC21, 1);
LC63 = LoadCombination();
LC63.addCase(LC22, 1);
LC64 = LoadCombination();
LC64.addCase(LC23, 1);
LC65 = LoadCombination();
LC65.addCase(LC24, 1);
LC66 = LoadCombination();
LC66.addCase(LC25, 1);
LC67 = LoadCombination();
LC67.addCase(LC26, 1);
LC68 = LoadCombination();
LC68.addCase(LC27, 1);
LC69 = LoadCombination();
LC69.addCase(LC28, 1);
LC70 = LoadCombination();
LC70.addCase(LC29, 1);
LC71 = LoadCombination();
LC71.addCase(LC30, 1);
LC72 = LoadCombination();
LC72.addCase(LC31, 1);
LC73 = LoadCombination();
LC73.addCase(LC32, 1);
LC74 = LoadCombination();
LC74.addCase(LC33, 1);
LC75 = LoadCombination();
LC75.addCase(LC34, 1);
LC76 = LoadCombination();
LC76.addCase(LC35, 1);
LC77 = LoadCombination();
LC77.addCase(LC36, 1);
LC78 = LoadCombination();
LC78.addCase(LC37, 1);
```

```
LC79 = LoadCombination();
LC79.addCase(LC38, 1);
LC80 = LoadCombination();
LC80.addCase(LC39, 1);
LC81 = LoadCombination();
LC81.addCase(LC40, 1);

//** Run FEM analysis **
Analysis1 = Analysis(true);
// Please check Messages area for 1 information message.
Analysis1.add(MeshActivity());
Analysis1.add(LinearAnalysis());
Analysis1.add(LoadResultsActivity());
//Analysis1.execute();
// Please check Messages area for 1 information message.

// ** CAPACITY MANAGER **
EURO_1 = CapacityManager(Analysis1);
MemberCreationOpts = MemberCreationOption();
MemberCreationOpts.splitAtJoint = false;
MemberCreationOpts.splitAtIncomingBeam = false;
MemberCreationOpts.splitAtBeamEnd = true;
EURO_1.createMembers(MemberCreationOpts);
EURO_1.description = "Code_check_LC1";

// ** CODE CHECK **
EURO_1.setActive();
EURO_1.AddRun(EN199311Run());
EURO_1.run(1).addLoadCase(LC41);
EURO_1.run(1).addLoadCase(LC42);
EURO_1.run(1).addLoadCase(LC43);
EURO_1.run(1).addLoadCase(LC44);
EURO_1.run(1).addLoadCase(LC45);
EURO_1.run(1).addLoadCase(LC46);
EURO_1.run(1).addLoadCase(LC47);
EURO_1.run(1).addLoadCase(LC48);
EURO_1.run(1).addLoadCase(LC49);
EURO_1.run(1).addLoadCase(LC50);
EURO_1.run(1).addLoadCase(LC51);
EURO_1.run(1).addLoadCase(LC52);
EURO_1.run(1).addLoadCase(LC53);
EURO_1.run(1).addLoadCase(LC54);
EURO_1.run(1).addLoadCase(LC55);
EURO_1.run(1).addLoadCase(LC56);
EURO_1.run(1).addLoadCase(LC57);
EURO_1.run(1).addLoadCase(LC58);
EURO_1.run(1).addLoadCase(LC59);
EURO_1.run(1).addLoadCase(LC60);
EURO_1.run(1).addLoadCase(LC61);
EURO_1.run(1).addLoadCase(LC62);
```

```
EURO_1.run(1).addLoadCase(LC63);
EURO_1.run(1).addLoadCase(LC64);
EURO_1.run(1).addLoadCase(LC65);
EURO_1.run(1).addLoadCase(LC66);
EURO_1.run(1).addLoadCase(LC67);
EURO_1.run(1).addLoadCase(LC68);
EURO_1.run(1).addLoadCase(LC69);
EURO_1.run(1).addLoadCase(LC70);
EURO_1.run(1).addLoadCase(LC71);
EURO_1.run(1).addLoadCase(LC72);
EURO_1.run(1).addLoadCase(LC73);
EURO_1.run(1).addLoadCase(LC74);
EURO_1.run(1).addLoadCase(LC75);
EURO_1.run(1).addLoadCase(LC76);
EURO_1.run(1).addLoadCase(LC77);
EURO_1.run(1).addLoadCase(LC78);
EURO_1.run(1).addLoadCase(LC79);
EURO_1.run(1).addLoadCase(LC80);
EURO_1.run(1).addLoadCase(LC81);
EURO_1.run(1).memberOptions.sectionClassification = scClass3;
EURO_1.run(1).generateCodeCheckLoads();
EURO_1.run(1).executeCodeCheck();
```

APPENDIX A-5 Input file in SESAM: Genie for Case study 2

```
// GeniE V5.3-10 started 09-May-2012 12:58:24
GenieRules.Tolerances.useTolerantModelling = true;
GenieRules.Compatibility.version = "V5.3-10";
GenieRules.Meshing.autoSimplifyTopology = true;

// **** TOPSIDE Module ****
// ** UNIT **
GenieRules.Units.resetToDatabaseUnits();
Genierules.Units.SetInputUnit(Angle, "deg");
Genierules.Units.SetInputUnit(Force, "N");
Genierules.Units.SetInputUnit(Length, "m");
Genierules.Units.SetInputUnit(Tempdiff, "delC");

// **** PROPERTIES ****
// ** Section **
Tub1200x20_7 = PipeSection(1200 mm, 20.7 mm);
Tub1100x22_4 = PipeSection(1100 mm, 22.4 mm);
Tub1100x20_3 = PipeSection(1100 mm, 20.3 mm);
Tub1050x20_1 = PipeSection(1050 mm, 20.1 mm);
Tub1000x20_2 = PipeSection(1000 mm, 20.2 mm);
Tub1000x18_9 = PipeSection(1000 mm, 18.9 mm);
Tub1000x16_9 = PipeSection(1000 mm, 16.9 mm);
Tub900x18 = PipeSection(900 mm, 18 mm);
Tub800x70 = PipeSection(800 mm, 70 mm);
Tub800x50_2 = PipeSection(800 mm, 50.2 mm);
Tub800x31_4 = PipeSection(800 mm, 31.4 mm);
Tub700x54_2 = PipeSection(700 mm, 54.2 mm);
Tub700x29_1 = PipeSection(700 mm, 29.1 mm);
Tub600x57_3 = PipeSection(600 mm, 57.3 mm);
Tub600x33 = PipeSection(600 mm, 33 mm);
Tub600x19 = PipeSection(600 mm, 19 mm);
Tub500x37_4 = PipeSection(500 mm, 37.4 mm);
Tub390x18_6 = PipeSection(390 mm, 18.6 mm);

// ** Material **//
S355 = MaterialLinear(355000000, 7850, 210000000000, 0.3, 0, 0);

// **** RULES ****
// ** Meshing Rules **
Genierules.Meshing.activate(mpMinEdge, false);
Genierules.Meshing.setLimit(mpMinEdge, 0.1);
Genierules.Meshing.activate(mpMaxChord, false);
Genierules.Meshing.activate(mpMaxAngle, 0.2);
Genierules.Meshing.activate(mpMaxAngle, mpFail, true);
Genierules.Meshing.setLimit(mpMaxAngle, mpFail, 179 deg);
Genierules.Meshing.activate(mpMaxAngle, mpSplit, false);
Genierules.Meshing.setLimit(mpMaxAngle, mpSplit, 165 deg);
Genierules.Meshing.activate(mpMinAngle, mpFail, false);
Genierules.Meshing.setLimit(mpMinAngle, mpFAil, 1 deg);
```

```
Genierules.Meshing.activate(mpMinAngle, mpSplit, false);
Genierules.Meshing.setLimit(mpMinAngle, mpSplit, 15 deg);
Genierules.Meshing.activate(mpMaxRelativeJacobi, mpFAil, false);
Genierules.Meshing.setLimit(mpMaxRelativeJacobi, mpFAil, 10);
Genierules.Meshing.activate(mpMaxRelativeJacobi, mpSplit, false);
Genierules.Meshing.setLimit(mpMaxRelativeJacobi, mpSplit, 5);
Genierules.Meshing.activate(mpMinNormalizedJacobi, mpFAil, false);
Genierules.Meshing.setLimit(mpMinNormalizedJacobi, mpFAil, 0);
Genierules.Meshing.activate(mpMinNormalizedJacobi, mpSplit, false);
Genierules.Meshing.setLimit(mpMinNormalizedJacobi, mpSplit, 0.2);
Genierules.Meshing.activate(mpMaxTwistAngle, mpFail, false);
Genierules.Meshing.setLimit(mpMaxTwistAngle, mpFail, 30 deg);
Genierules.Meshing.activate(mpMaxTwistAngle, mpSplit, false);
Genierules.Meshing.setLimit(mpMaxTwistAngle, mpSplit, 10 deg);
Genierules.Meshing.elementType = mp1stOrder;
Genierules.Meshing.autoSimplifyTopology = false;
Genierules.Meshing.superElementType = 1;
Genierules.Meshing.basicLCfactor = 1;
Genierules.Meshing.analysisFolders = true;
Genierules.Meshing.preference(mpPreferRectangularMesh, false);
Genierules.Meshing.preference(mpAllowTriangularElements, true);
Genierules.Meshing.preference(mpIncludeUnusedProperties, false);
Genierules.Meshing.preference(mpPreferPointMassAsNodeMass, true);
Genierules.Meshing.preference(mpMeshDensityRounded, false);
Genierules.Meshing.preference(mpUseDrillingElements, false);
Genierules.Meshing.preference(mpUseLongLoadcaseNames, false);
Genierules.Meshing.preference(mpUseLongSetNames, false);
Genierules.Meshing.preference(mpAdjustNumberofElements, false);
Genierules.Sets.scriptCompact = true;
GenieRules.Meshing.autoSimplifyTopology = true;
GenieRules.Meshing.elementType = mp2ndOrder;
GenieRules.Meshing.preference(mpMeshDensityRounded, true);
GenieRules.Meshing.preference(mpAdjustNumberOfElements, true);

// ** Tolerances Rules
GenieRules.Tolerances.angleTolerance = 0 deg;
GenieRules.Tolerances.pointTolerance = 0.01 m;
GenieRules.Tolerances.useTolerantModelling = true;

// ** Guiding Geometry for Plain Main Deck 1 **
GuidePlane1 = GuidePlane(Point(0 m,0 m,0 m),Point(48.1 m,0 m,0 m),Point(48.1 m,14.8 m,0 m),Point(0
m,14.8 m,0
m),11,3,0.1538461538,0.1046777547,0.04812889813,0.09012474012,0.09012474012,0.09002079002,0.
09002079002,0.09012474012,0.09012474012,0.04812889813,0.1046777547,0.527027027,0.0135135135
1,0.4594594595);
GuidePlane1.snapmode = true;
GuidePlane2 = GuidePlane(Point(0 m,0 m,0 m),Point(48.1 m,0 m,0 m),Point(48.1 m,14.8 m,0 m),Point(0
m,14.8 m,0
m),11,3,0.1538461538,0.1046777547,0.04812889813,0.09012474012,0.09012474012,0.09002079002,0.
```

```
09002079002,0.09012474012,0.09012474012,0.04812889813,0.1046777547,0.527027027,0.0135135135
1,0.4594594595);
GuidePlane2.snapmode = true;
// ** Set Material **
S355.setDefault();

// ** Sections for Plain Main Deck  **
Tub1000x20_2.setDefault();
Bm1 = Beam(Point(0 m,0 m,0 m), Point(7.4 m,0 m,0 m));
Bm2 = Beam(Point(7.399999998 m,0 m,0 m), Point(12.435 m,0 m,0 m));
Bm3 = Beam(Point(12.435 m,0 m,0 m), Point(14.75 m,0 m,0 m));
Bm5 = Beam(Point(19.085 m,0 m,0 m), Point(23.42 m,0 m,0 m));
Bm6 = Beam(Point(23.42 m,0 m,0 m), Point(27.75 m,0 m,0 m));
Bm7 = Beam(Point(27.75 m,0 m,0 m), Point(32.08 m,0 m,0 m));
Bm8 = Beam(Point(32.08 m,0 m,0 m), Point(36.415 m,0 m,0 m));
Bm9 = Beam(Point(36.415 m,0 m,0 m), Point(40.75 m,0 m,0 m));
Bm10 = Beam(Point(40.75 m,0 m,0 m), Point(43.065 m,0 m,0 m));
Bm11 = Beam(Point(43.065 m,0 m,0 m), Point(48.1 m,0 m,0 m));
Bm12 = Beam(Point(48.1 m,0 m,0 m), Point(48.1 m,7.8 m,0 m));
Bm13 = Beam(Point(48.1 m,7.8 m,0 m), Point(48.1 m,14.8 m,0 m));
Bm14 = Beam(Point(48.1 m,14.8 m,0 m), Point(43.065 m,14.8 m,0 m));
Bm15 = Beam(Point(43.065 m,14.8 m,0 m), Point(40.75 m,14.8 m,0 m));
Bm16 = Beam(Point(40.75 m,14.8 m,0 m), Point(36.415 m,14.8 m,0 m));
Bm17 = Beam(Point(36.415 m,14.8 m,0 m), Point(32.08 m,14.8 m,0 m));
Bm18 = Beam(Point(32.08 m,14.8 m,0 m), Point(27.75 m,14.8 m,0 m));
Bm19 = Beam(Point(27.75 m,14.8 m,0 m), Point(23.42 m,14.8 m,0 m));
Bm20 = Beam(Point(23.42 m,14.8 m,0 m), Point(19.085 m,14.8 m,0 m));
Bm21 = Beam(Point(19.085 m,14.8 m,0 m), Point(14.75 m,14.8 m,0 m));
Bm22 = Beam(Point(14.75 m,14.8 m,0 m), Point(12.435 m,14.8 m,0 m));
Bm23 = Beam(Point(12.435 m,14.8 m,0 m), Point(7.399999998 m,14.8 m,0 m));
Bm24 = Beam(Point(7.399999998 m,14.8 m,0 m), Point(0 m,14.8 m,0 m));
Bm25 = Beam(Point(0 m,14.8 m,0 m), Point(0 m,7.999999999 m,0 m));
Bm26 = Beam(Point(0 m,7.999999999 m,0 m), Point(0 m,0 m,0 m));
Bm27 = Beam(Point(7.399999998 m,0 m,0 m), Point(7.399999998 m,14.8 m,0 m));
Bm28 = Beam(Point(12.435 m,0 m,0 m), Point(12.435 m,14.8 m,0 m));
Bm29 = Beam(Point(14.75 m,0 m,0 m), Point(14.75 m,14.8 m,0 m));
Bm30 = Beam(Point(19.085 m,0 m,0 m), Point(19.085 m,14.8 m,0 m));
Bm31 = Beam(Point(23.42 m,0 m,0 m), Point(23.42 m,14.8 m,0 m));
Bm32 = Beam(Point(27.75 m,0 m,0 m), Point(27.75 m,14.8 m,0 m));
Bm33 = Beam(Point(32.08 m,0 m,0 m), Point(32.08 m,14.8 m,0 m));
Bm34 = Beam(Point(36.415 m,0 m,0 m), Point(36.415 m,14.8 m,0 m));
Bm35 = Beam(Point(40.75 m,0 m,0 m), Point(40.75 m,14.8 m,0 m));
Bm36 = Beam(Point(43.065 m,0 m,0 m), Point(43.065 m,14.8 m,0 m));
Bm37 = Beam(Point(0 m,7.999999999 m,0 m), Point(7.399999998 m,7.999999999 m,0 m));

Tub800x70.setDefault();
Bm4 = Beam(Point(14.75 m,0 m,0 m), Point(19.085 m,0 m,0 m));
Tub900x18.setDefault();
Bm38 = Beam(Point(43.065 m,7.8 m,0 m), Point(48.1 m,7.8 m,0 m));
```

```
// ** Named Set Plain Main Deck **
Plain_Main_Deck = Set();
Plain_Main_Deck.add(GuidePlane1);
Plain_Main_Deck.add(Bm2);
Plain_Main_Deck.add(Bm1);
Plain_Main_Deck.add(GuidePlane2);
Plain_Main_Deck.add(Bm3);
Plain_Main_Deck.add(Bm4);
Plain_Main_Deck.add(Bm5);
Plain_Main_Deck.add(Bm6);
Plain_Main_Deck.add(Bm7);
Plain_Main_Deck.add(Bm8);
Plain_Main_Deck.add(Bm9);
Plain_Main_Deck.add(Bm11);
Plain_Main_Deck.add(Bm10);
Plain_Main_Deck.add(Bm12);
Plain_Main_Deck.add(Bm13);
Plain_Main_Deck.add(Bm14);
Plain_Main_Deck.add(Bm15);
Plain_Main_Deck.add(Bm16);
Plain_Main_Deck.add(Bm18);
Plain_Main_Deck.add(Bm17);
Plain_Main_Deck.add(Bm19);
Plain_Main_Deck.add(Bm20);
Plain_Main_Deck.add(Bm21);
Plain_Main_Deck.add(Bm22);
Plain_Main_Deck.add(Bm23);
Plain_Main_Deck.add(Bm25);
Plain_Main_Deck.add(Bm24);
Plain_Main_Deck.add(Bm26);
Plain_Main_Deck.add(Bm27);
Plain_Main_Deck.add(Bm28);
Plain_Main_Deck.add(Bm29);
Plain_Main_Deck.add(Bm30);
Plain_Main_Deck.add(Bm32);
Plain_Main_Deck.add(Bm31);
Plain_Main_Deck.add(Bm33);
Plain_Main_Deck.add(Bm34);
Plain_Main_Deck.add(Bm35);
Plain_Main_Deck.add(Bm36);
Plain_Main_Deck.add(Bm37);
Plain_Main_Deck.add(Bm38);

// ** Plate **
Plate_1 = Thickness(10 mm);
Plate_1.setDefault();

// ** Plate on Plain Main Deck
Pl1 = Plate(Point(0 m,0 m,0 m),Point(0 m,7.999999999 m,0 m),Point(7.399999998 m,7.999999999 m,0 m),Point(7.399999998 m,0 m,0 m));
```

```
Pl2 = Plate(Point(0 m,14.8 m,0 m),Point(7.399999998 m,14.8 m,0 m),Point(7.399999998 m,7.999999999
m,0 m),Point(0 m,7.999999999 m,0 m));
Pl3 = Plate(Point(7.399999998 m,0 m,0 m),Point(7.399999998 m,14.8 m,0 m),Point(12.435 m,14.8 m,0
m),Point(12.435 m,0 m,0 m));
Pl4 = Plate(Point(12.435 m,0 m,0 m),Point(12.435 m,14.8 m,0 m),Point(14.75 m,14.8 m,0 m),Point(14.75
m,0 m,0 m));
Pl5 = Plate(Point(14.75 m,0 m,0 m),Point(14.75 m,14.8 m,0 m),Point(19.085 m,14.8 m,0 m),Point(19.085
m,0 m,0 m));
Pl6 = Plate(Point(19.085 m,0 m,0 m),Point(19.085 m,14.8 m,0 m),Point(23.42 m,14.8 m,0 m),Point(23.42
m,0 m,0 m));
Pl7 = Plate(Point(23.42 m,0 m,0 m),Point(23.42 m,14.8 m,0 m),Point(27.75 m,14.8 m,0 m),Point(27.75
m,0 m,0 m));
Pl8 = Plate(Point(27.75 m,0 m,0 m),Point(27.75 m,14.8 m,0 m),Point(32.08 m,14.8 m,0 m),Point(32.08
m,0 m,0 m));
Pl9 = Plate(Point(32.08 m,0 m,0 m),Point(32.08 m,14.8 m,0 m),Point(36.415 m,14.8 m,0 m),Point(36.415
m,0 m,0 m));
Pl10 = Plate(Point(36.415 m,0 m,0 m),Point(36.415 m,14.8 m,0 m),Point(40.75 m,14.8 m,0
m),Point(40.75 m,0 m,0 m));
Pl11 = Plate(Point(40.75 m,0 m,0 m),Point(40.75 m,14.8 m,0 m),Point(43.065 m,14.8 m,0
m),Point(43.065 m,0 m,0 m));
Pl12 = Plate(Point(43.065 m,0 m,0 m),Point(43.065 m,14.8 m,0 m),Point(48.1 m,14.8 m,0 m),Point(48.1
m,0 m,0 m));

// ** Named Set Plain Main Deck 1, with plates
Plain_Main_Deck_1_with_plates = Set();
Plain_Main_Deck_1_with_plates.add(GuidePlane1);
Plain_Main_Deck_1_with_plates.add(Bm2);
Plain_Main_Deck_1_with_plates.add(Bm1);
Plain_Main_Deck_1_with_plates.add(GuidePlane2);
Plain_Main_Deck_1_with_plates.add(Bm3);
Plain_Main_Deck_1_with_plates.add(Bm4);
Plain_Main_Deck_1_with_plates.add(Bm5);
Plain_Main_Deck_1_with_plates.add(Bm6);
Plain_Main_Deck_1_with_plates.add(Bm7);
Plain_Main_Deck_1_with_plates.add(Bm8);
Plain_Main_Deck_1_with_plates.add(Bm9);
Plain_Main_Deck_1_with_plates.add(Bm11);
Plain_Main_Deck_1_with_plates.add(Bm10);
Plain_Main_Deck_1_with_plates.add(Bm12);
Plain_Main_Deck_1_with_plates.add(Bm13);
Plain_Main_Deck_1_with_plates.add(Bm14);
Plain_Main_Deck_1_with_plates.add(Bm15);
Plain_Main_Deck_1_with_plates.add(Bm16);
Plain_Main_Deck_1_with_plates.add(Bm18);
Plain_Main_Deck_1_with_plates.add(Bm17);
Plain_Main_Deck_1_with_plates.add(Bm19);
Plain_Main_Deck_1_with_plates.add(Bm20);
Plain_Main_Deck_1_with_plates.add(Bm21);
Plain_Main_Deck_1_with_plates.add(Bm22);
Plain_Main_Deck_1_with_plates.add(Bm23);
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Plain_Main_Deck_1_with_plates.add(Bm25);
Plain_Main_Deck_1_with_plates.add(Bm24);
Plain_Main_Deck_1_with_plates.add(Bm26);
Plain_Main_Deck_1_with_plates.add(Bm27);
Plain_Main_Deck_1_with_plates.add(Bm28);
Plain_Main_Deck_1_with_plates.add(Bm29);
Plain_Main_Deck_1_with_plates.add(Bm30);
Plain_Main_Deck_1_with_plates.add(Bm32);
Plain_Main_Deck_1_with_plates.add(Bm31);
Plain_Main_Deck_1_with_plates.add(Bm33);
Plain_Main_Deck_1_with_plates.add(Bm34);
Plain_Main_Deck_1_with_plates.add(Bm35);
Plain_Main_Deck_1_with_plates.add(Bm36);
Plain_Main_Deck_1_with_plates.add(Bm37);
Plain_Main_Deck_1_with_plates.add(Bm38);
Plain_Main_Deck_1_with_plates.add(Pl1);
Plain_Main_Deck_1_with_plates.add(Pl2);
Plain_Main_Deck_1_with_plates.add(Pl3);
Plain_Main_Deck_1_with_plates.add(Pl6);
Plain_Main_Deck_1_with_plates.add(Pl4);
Plain_Main_Deck_1_with_plates.add(Pl5);
Plain_Main_Deck_1_with_plates.add(Pl10);
Plain_Main_Deck_1_with_plates.add(Pl7);
Plain_Main_Deck_1_with_plates.add(Pl8);
Plain_Main_Deck_1_with_plates.add(Pl9);
Plain_Main_Deck_1_with_plates.add(Pl11);
Plain_Main_Deck_1_with_plates.add(Pl12);

// ** Guide Geometry for Plan Lower Mezz Deck **
GuidePlane2 = GuidePlane(Point(0 m,0 m,10.15 m),Point(48.1 m,0 m,10.15 m),Point(48.1 m,14.8 m,10.15 m),Point(0 m,14.8 m,10.15 m),11,3,0.1538461538,0.09833679834,0.05446985447,0.08898128898,0.09126819127,0.09002079002,0.09002079002,0.09355509356,0.08669438669,0.05446985447,0.09833679834,0.1824324324,0.1959459459,0.6216216216);
GuidePlane2.snapmode = true;

// ** Sections for Plan Lower Mezz Deck **
Tub1000x16_9.setDefault();
Bm39 = Beam(Point(0 m,0 m,10.15 m), Point(7.399999998 m,0 m,10.15 m));
Bm40 = Beam(Point(7.399999998 m,0 m,10.15 m), Point(12.13 m,0 m,10.15 m));
Bm41 = Beam(Point(12.13 m,0 m,10.15 m), Point(14.75 m,0 m,10.15 m));
Bm42 = Beam(Point(14.75 m,0 m,10.15 m), Point(19.03 m,0 m,10.15 m));
Bm43 = Beam(Point(19.03 m,0 m,10.15 m), Point(23.42 m,0 m,10.15 m));
Bm44 = Beam(Point(23.42 m,0 m,10.15 m), Point(27.75 m,0 m,10.15 m));
Bm45 = Beam(Point(27.75 m,0 m,10.15 m), Point(32.08 m,0 m,10.15 m));
Bm46 = Beam(Point(32.08 m,0 m,10.15 m), Point(36.58 m,0 m,10.15 m));
Bm47 = Beam(Point(36.58 m,0 m,10.15 m), Point(40.75 m,0 m,10.15 m));
Bm48 = Beam(Point(40.75 m,0 m,10.15 m), Point(43.37 m,0 m,10.15 m));
Bm49 = Beam(Point(43.37 m,0 m,10.15 m), Point(48.1 m,0 m,10.15 m));
Bm50 = Beam(Point(48.1 m,14.8 m,10.15 m), Point(48.1 m,0 m,10.15 m));
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Bm51 = Beam(Point(48.1 m,14.8 m,10.15 m), Point(43.37 m,14.8 m,10.15 m));
Bm52 = Beam(Point(43.37 m,14.8 m,10.15 m), Point(40.75 m,14.8 m,10.15 m));
Bm53 = Beam(Point(40.75 m,14.8 m,10.15 m), Point(36.58 m,14.8 m,10.15 m));
Bm54 = Beam(Point(36.58 m,14.8 m,10.15 m), Point(32.08 m,14.8 m,10.15 m));
Bm55 = Beam(Point(32.08 m,14.8 m,10.15 m), Point(27.75 m,14.8 m,10.15 m));
Bm56 = Beam(Point(27.75 m,14.8 m,10.15 m), Point(23.42 m,14.8 m,10.15 m));
Bm57 = Beam(Point(23.42 m,14.8 m,10.15 m), Point(19.03 m,14.8 m,10.15 m));
Bm58 = Beam(Point(19.03 m,14.8 m,10.15 m), Point(14.75 m,14.8 m,10.15 m));
Bm59 = Beam(Point(14.75 m,14.8 m,10.15 m), Point(12.13 m,14.8 m,10.15 m));
Bm60 = Beam(Point(12.13 m,14.8 m,10.15 m), Point(7.399999998 m,14.8 m,10.15 m));
Bm61 = Beam(Point(7.399999998 m,14.8 m,10.15 m), Point(0 m,14.8 m,10.15 m));
Bm62 = Beam(Point(0 m,14.8 m,10.15 m), Point(0 m,0 m,10.15 m));
Bm63 = Beam(Point(7.399999998 m,0 m,10.15 m), Point(7.399999998 m,14.8 m,10.15 m));
Bm64 = Beam(Point(12.13 m,0 m,10.15 m), Point(12.13 m,14.8 m,10.15 m));
Bm65 = Beam(Point(19.03 m,0 m,10.15 m), Point(19.03 m,14.8 m,10.15 m));
Bm66 = Beam(Point(23.42 m,0 m,10.15 m), Point(23.42 m,14.8 m,10.15 m));
Bm67 = Beam(Point(32.08 m,0 m,10.15 m), Point(32.08 m,14.8 m,10.15 m));
Bm68 = Beam(Point(36.58 m,0 m,10.15 m), Point(36.58 m,14.8 m,10.15 m));
Bm69 = Beam(Point(43.37 m,0 m,10.15 m), Point(43.37 m,14.8 m,10.15 m));
Tub1050x20_1.setDefault();
Bm70 = Beam(Point(14.75 m,0 m,10.15 m), Point(14.75 m,14.8 m,10.15 m));
Tub1100x22_4.setDefault();
Bm71 = Beam(Point(27.75 m,0 m,10.15 m), Point(27.75 m,14.8 m,10.15 m));
Tub1050x20_1.setDefault();
Bm72 = Beam(Point(40.75 m,0 m,10.15 m), Point(40.75 m,14.8 m,10.15 m));
Tub1000x16_9.setDefault();
Bm73 = Beam(Point(12.13 m,2.7 m,10.15 m), Point(23.42 m,2.7 m,10.15 m));
Bm74 = Beam(Point(12.13 m,5.599999999 m,10.15 m), Point(23.42 m,5.599999999 m,10.15 m));
Bm75 = Beam(Point(32.08 m,2.7 m,10.15 m), Point(40.75 m,2.7 m,10.15 m));
Bm76 = Beam(Point(32.08 m,5.599999999 m,10.15 m), Point(40.75 m,5.599999999 m,10.15 m));

// ** Named Set Plan Lower Mezz Deck 2 **
Plan_Lower_Mezz_Deck_2 = Set();
Plan_Lower_Mezz_Deck_2.add(Bm39);
Plan_Lower_Mezz_Deck_2.add(GuidePlane2);
Plan_Lower_Mezz_Deck_2.add(Bm40);
Plan_Lower_Mezz_Deck_2.add(Bm41);
Plan_Lower_Mezz_Deck_2.add(Bm42);
Plan_Lower_Mezz_Deck_2.add(Bm44);
Plan_Lower_Mezz_Deck_2.add(Bm43);
Plan_Lower_Mezz_Deck_2.add(Bm45);
Plan_Lower_Mezz_Deck_2.add(Bm46);
Plan_Lower_Mezz_Deck_2.add(Bm47);
Plan_Lower_Mezz_Deck_2.add(Bm48);
Plan_Lower_Mezz_Deck_2.add(Bm49);
Plan_Lower_Mezz_Deck_2.add(Bm50);
Plan_Lower_Mezz_Deck_2.add(Bm51);
Plan_Lower_Mezz_Deck_2.add(Bm53);
Plan_Lower_Mezz_Deck_2.add(Bm52);
Plan_Lower_Mezz_Deck_2.add(Bm54);
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Plan_Lower_Mezz_Deck_2.add(Bm55);
Plan_Lower_Mezz_Deck_2.add(Bm56);
Plan_Lower_Mezz_Deck_2.add(Bm57);
Plan_Lower_Mezz_Deck_2.add(Bm58);
Plan_Lower_Mezz_Deck_2.add(Bm60);
Plan_Lower_Mezz_Deck_2.add(Bm59);
Plan_Lower_Mezz_Deck_2.add(Bm61);
Plan_Lower_Mezz_Deck_2.add(Bm62);
Plan_Lower_Mezz_Deck_2.add(Bm63);
Plan_Lower_Mezz_Deck_2.add(Bm64);
Plan_Lower_Mezz_Deck_2.add(Bm65);
Plan_Lower_Mezz_Deck_2.add(Bm67);
Plan_Lower_Mezz_Deck_2.add(Bm66);
Plan_Lower_Mezz_Deck_2.add(Bm68);
Plan_Lower_Mezz_Deck_2.add(Bm69);
Plan_Lower_Mezz_Deck_2.add(Bm70);
Plan_Lower_Mezz_Deck_2.add(Bm71);
Plan_Lower_Mezz_Deck_2.add(Bm72);
Plan_Lower_Mezz_Deck_2.add(Bm76);
Plan_Lower_Mezz_Deck_2.add(Bm74);
Plan_Lower_Mezz_Deck_2.add(Bm73);
Plan_Lower_Mezz_Deck_2.add(Bm75);

//** Plates for Lower Mezz Deck 2 **
Pl13 = Plate(Point(0 m,0 m,10.15 m),Point(0 m,14.8 m,10.15 m),Point(7.399999998 m,14.8 m,10.15
m),Point(7.399999998 m,0 m,10.15 m));
Pl14 = Plate(Point(7.399999998 m,0 m,10.15 m),Point(7.399999998 m,14.8 m,10.15 m),Point(12.13
m,14.8 m,10.15 m),Point(12.13 m,0 m,10.15 m));
Pl15 = Plate(Point(12.13 m,0 m,10.15 m),Point(12.13 m,2.7 m,10.15 m),Point(14.75 m,2.7 m,10.15
m),Point(14.75 m,0 m,10.15 m));
Pl16 = Plate(Point(12.13 m,2.7 m,10.15 m),Point(12.13 m,5.599999999 m,10.15 m),Point(14.75
m,5.599999999 m,10.15 m),Point(14.75 m,2.7 m,10.15 m));
Pl17 = Plate(Point(12.13 m,5.599999999 m,10.15 m),Point(12.13 m,14.8 m,10.15 m),Point(14.75 m,14.8
m,10.15 m),Point(14.75 m,5.599999999 m,10.15 m));
Pl18 = Plate(Point(14.75 m,0 m,10.15 m),Point(14.75 m,2.7 m,10.15 m),Point(19.03 m,2.7 m,10.15
m),Point(19.03 m,0 m,10.15 m));
Pl19 = Plate(Point(14.75 m,2.7 m,10.15 m),Point(14.75 m,5.599999999 m,10.15 m),Point(19.03
m,5.599999999 m,10.15 m),Point(19.03 m,2.7 m,10.15 m));
Pl20 = Plate(Point(14.75 m,5.599999999 m,10.15 m),Point(14.75 m,14.8 m,10.15 m),Point(19.03 m,14.8
m,10.15 m),Point(19.03 m,5.599999999 m,10.15 m));
Pl21 = Plate(Point(19.03 m,0 m,10.15 m),Point(19.03 m,2.7 m,10.15 m),Point(23.42 m,2.7 m,10.15
m),Point(23.42 m,0 m,10.15 m));
Pl22 = Plate(Point(19.03 m,2.7 m,10.15 m),Point(19.03 m,5.599999999 m,10.15 m),Point(23.42
m,5.599999999 m,10.15 m),Point(23.42 m,2.7 m,10.15 m));
Pl23 = Plate(Point(19.03 m,5.599999999 m,10.15 m),Point(19.03 m,14.8 m,10.15 m),Point(23.42 m,14.8
m,10.15 m),Point(23.42 m,5.599999999 m,10.15 m));
Pl24 = Plate(Point(23.42 m,0 m,10.15 m),Point(23.42 m,14.8 m,10.15 m),Point(27.75 m,14.8 m,10.15
m),Point(27.75 m,0 m,10.15 m));
Pl25 = Plate(Point(27.75 m,0 m,10.15 m),Point(27.75 m,14.8 m,10.15 m),Point(32.08 m,14.8 m,10.15
m),Point(32.08 m,0 m,10.15 m));
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Pl26 = Plate(Point(32.08 m,0 m,10.15 m),Point(32.08 m,2.7 m,10.15 m),Point(36.58 m,2.7 m,10.15 m),Point(36.58 m,0 m,10.15 m));
Pl27 = Plate(Point(32.08 m,2.7 m,10.15 m),Point(32.08 m,5.599999999 m,10.15 m),Point(36.58 m,5.599999999 m,10.15 m),Point(36.58 m,2.7 m,10.15 m));
Pl28 = Plate(Point(32.08 m,5.599999999 m,10.15 m),Point(32.08 m,14.8 m,10.15 m),Point(36.58 m,14.8 m,10.15 m),Point(36.58 m,5.599999999 m,10.15 m));
Pl29 = Plate(Point(36.58 m,0 m,10.15 m),Point(36.58 m,2.7 m,10.15 m),Point(40.75 m,2.7 m,10.15 m),Point(40.75 m,0 m,10.15 m));
Pl30 = Plate(Point(36.58 m,2.7 m,10.15 m),Point(36.58 m,5.599999999 m,10.15 m),Point(40.75 m,5.599999999 m,10.15 m),Point(40.75 m,2.7 m,10.15 m));
Pl31 = Plate(Point(36.58 m,5.599999999 m,10.15 m),Point(36.58 m,14.8 m,10.15 m),Point(40.75 m,14.8 m,10.15 m),Point(40.75 m,5.599999999 m,10.15 m));
Pl32 = Plate(Point(40.75 m,0 m,10.15 m),Point(40.75 m,14.8 m,10.15 m),Point(43.37 m,14.8 m,10.15 m),Point(43.37 m,0 m,10.15 m));
Pl33 = Plate(Point(43.37 m,0 m,10.15 m),Point(43.37 m,14.8 m,10.15 m),Point(48.1 m,14.8 m,10.15 m),Point(48.1 m,0 m,10.15 m));

//** Named Set Plan Lower Mezz Deck with plates **
Plan_Lower_Mezz_Deck2_with_Plates = Set();
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm39);
Plan_Lower_Mezz_Deck2_with_Plates.add(GuidePlane2);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm40);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm41);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm42);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm43);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm45);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm44);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm46);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm47);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm48);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm49);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm50);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm52);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm51);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm53);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm54);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm55);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm56);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm57);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm59);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm58);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm60);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm61);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm62);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm63);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm64);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm66);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm65);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm67);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm68);
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Plan_Lower_Mezz_Deck2_with_Plates.add(Bm69);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm71);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm70);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm72);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm73);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm74);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm75);
Plan_Lower_Mezz_Deck2_with_Plates.add(Bm76);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl13);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl14);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl15);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl26);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl19);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl16);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl17);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl18);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl22);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl20);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl21);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl23);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl24);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl25);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl33);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl29);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl27);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl28);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl30);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl31);
Plan_Lower_Mezz_Deck2_with_Plates.add(Pl32);

// ** Guiding Geometry for Plan Weather Deck **
GP_Plan_Weather_deck = GuidePlane(Point(0 m,0 m,20.3 m),Point(10 m,0 m,20.3 m),Point(10 m,10
m,20.3 m),Point(0 m,10 m,20.3
m),11,4,0.09090909091,0.09090909091,0.09090909091,0.09090909091,0.09090909091,0.09090909091,
0.09090909091,0.09090909091,0.09090909091,0.09090909091,0.09090909091,0.25,0.25,0.25,0.25);
GP_Plan_Weather_deck.snapmode = true;
GP_Plan_Weather_deck.corners(Point(0 m,0 m,20.3 m),Point(48.1 m,0 m,20.3 m),Point(48.1 m,14.8
m,20.3 m),Point(0 m,14.8 m,20.3 m));
GP_Plan_Weather_deck.spacings(11,2,0.1538461538,0.0764033264,0.0764033264,0.1081081081,0.081
08108108,0.08108108108,0.08108108108,0.08108108108,0.1081081081,0.0764033264,0.0764033264,0.
6486486486,0.3513513514);

// ** Sections for  Plan Weather Deck **
Tub1000x18_9.setDefault();
Bm77 = Beam(Point(0 m,0 m,20.3 m), Point(7.399999998 m,0 m,20.3 m));
Bm78 = Beam(Point(7.399999998 m,0 m,20.3 m), Point(11.075 m,0 m,20.3 m));
Bm79 = Beam(Point(11.075 m,0 m,20.3 m), Point(14.75 m,0 m,20.3 m));

Tub1100x20_3.setDefault();
Bm80 = Beam(Point(14.75 m,0 m,20.3 m), Point(19.95 m,0 m,20.3 m));
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Bm81 = Beam(Point(19.95 m,0 m,20.3 m), Point(23.85 m,0 m,20.3 m));
Bm82 = Beam(Point(23.85 m,0 m,20.3 m), Point(27.75 m,0 m,20.3 m));
Bm83 = Beam(Point(27.75 m,0 m,20.3 m), Point(31.65 m,0 m,20.3 m));
Bm84 = Beam(Point(31.65 m,0 m,20.3 m), Point(35.55 m,0 m,20.3 m));
Bm85 = Beam(Point(35.55 m,0 m,20.3 m), Point(40.75 m,0 m,20.3 m));

Tub1000x18_9.setDefault();
Bm86 = Beam(Point(44.425 m,0 m,20.3 m), Point(40.75 m,0 m,20.3 m));
Bm87 = Beam(Point(44.425 m,0 m,20.3 m), Point(48.1 m,0 m,20.3 m));
Bm88 = Beam(Point(48.1 m,0 m,20.3 m), Point(48.1 m,14.8 m,20.3 m));
Bm89 = Beam(Point(48.1 m,14.8 m,20.3 m), Point(44.425 m,14.8 m,20.3 m));
Bm90 = Beam(Point(44.425 m,14.8 m,20.3 m), Point(40.75 m,14.8 m,20.3 m));

Tub1100x20_3.setDefault();
Bm91 = Beam(Point(40.75 m,14.8 m,20.3 m), Point(35.55 m,14.8 m,20.3 m));
Bm92 = Beam(Point(35.55 m,14.8 m,20.3 m), Point(31.65 m,14.8 m,20.3 m));
Bm93 = Beam(Point(31.65 m,14.8 m,20.3 m), Point(27.75 m,14.8 m,20.3 m));
Bm94 = Beam(Point(27.75 m,14.8 m,20.3 m), Point(23.85 m,14.8 m,20.3 m));
Bm95 = Beam(Point(23.85 m,14.8 m,20.3 m), Point(19.95 m,14.8 m,20.3 m));
Bm96 = Beam(Point(19.95 m,14.8 m,20.3 m), Point(14.75 m,14.8 m,20.3 m));

Tub1000x18_9.setDefault();
Bm97 = Beam(Point(14.75 m,14.8 m,20.3 m), Point(11.075 m,14.8 m,20.3 m));
Bm98 = Beam(Point(11.075 m,14.8 m,20.3 m), Point(7.399999998 m,14.8 m,20.3 m));
Bm99 = Beam(Point(7.399999998 m,14.8 m,20.3 m), Point(0 m,14.8 m,20.3 m));
Bm100 = Beam(Point(0 m,9.599999999 m,20.3 m), Point(0 m,14.8 m,20.3 m));
Bm101 = Beam(Point(0 m,9.599999999 m,20.3 m), Point(0 m,0 m,20.3 m));
Bm102 = Beam(Point(7.399999998 m,0 m,20.3 m), Point(7.399999998 m,14.8 m,20.3 m));
Bm103 = Beam(Point(11.075 m,0 m,20.3 m), Point(11.075 m,14.8 m,20.3 m));
Bm104 = Beam(Point(14.75 m,0 m,20.3 m), Point(14.75 m,14.8 m,20.3 m));

Tub1200x20_7.setDefault();
Bm105 = Beam(Point(19.95 m,0 m,20.3 m), Point(19.95 m,14.8 m,20.3 m));

Tub900x18.setDefault();
Bm106 = Beam(Point(23.85 m,0 m,20.3 m), Point(23.85 m,9.599999999 m,20.3 m));
Bm107 = Beam(Point(27.75 m,0 m,20.3 m), Point(27.75 m,9.599999999 m,20.3 m));
Bm108 = Beam(Point(31.65 m,0 m,20.3 m), Point(31.65 m,9.599999999 m,20.3 m));

Tub1200x20_7.setDefault();
Bm109 = Beam(Point(35.55 m,0 m,20.3 m), Point(35.55 m,14.8 m,20.3 m));
Tub1000x18_9.setDefault();
Bm110 = Beam(Point(40.75 m,0 m,20.3 m), Point(40.75 m,14.8 m,20.3 m));
Bm111 = Beam(Point(44.425 m,14.8 m,20.3 m), Point(44.425 m,0 m,20.3 m));
Tub1200x20_7.setDefault();
Bm112 = Beam(Point(19.95 m,9.599999999 m,20.3 m), Point(35.55 m,9.599999999 m,20.3 m));

// ** Named Set Plan Weather Deck 3**
Plan_weather_deck = Set();
Plan_weather_deck.add(GP_Plan_Weather_deck);
```

```
Plan_weather_deck.add(Bm77);
Plan_weather_deck.add(Bm78);
Plan_weather_deck.add(Bm79);
Plan_weather_deck.add(Bm80);
Plan_weather_deck.add(Bm81);
Plan_weather_deck.add(Bm84);
Plan_weather_deck.add(Bm82);
Plan_weather_deck.add(Bm83);
Plan_weather_deck.add(Bm85);
Plan_weather_deck.add(Bm86);
Plan_weather_deck.add(Bm87);
Plan_weather_deck.add(Bm88);
Plan_weather_deck.add(Bm89);
Plan_weather_deck.add(Bm90);
Plan_weather_deck.add(Bm91);
Plan_weather_deck.add(Bm92);
Plan_weather_deck.add(Bm93);
Plan_weather_deck.add(Bm95);
Plan_weather_deck.add(Bm94);
Plan_weather_deck.add(Bm96);
Plan_weather_deck.add(Bm97);
Plan_weather_deck.add(Bm98);
Plan_weather_deck.add(Bm99);
Plan_weather_deck.add(Bm100);
Plan_weather_deck.add(Bm102);
Plan_weather_deck.add(Bm101);
Plan_weather_deck.add(Bm103);
Plan_weather_deck.add(Bm104);
Plan_weather_deck.add(Bm105);
Plan_weather_deck.add(Bm106);
Plan_weather_deck.add(Bm109);
Plan_weather_deck.add(Bm107);
Plan_weather_deck.add(Bm108);
Plan_weather_deck.add(Bm110);
Plan_weather_deck.add(Bm111);
Plan_weather_deck.add(Bm112);

//** Plates for Plan Weather Deck **
// ** Plate Weather Deck **
Pl34 = Plate(Point(0 m,0 m,20.3 m),Point(0 m,14.8 m,20.3 m),Point(7.399999998 m,14.8 m,20.3 m),Point(7.399999998 m,0 m,20.3 m));
Pl35 = Plate(Point(7.399999998 m,0 m,20.3 m),Point(7.399999998 m,14.8 m,20.3 m),Point(11.075 m,14.8 m,20.3 m),Point(11.075 m,0 m,20.3 m));
Pl36 = Plate(Point(11.075 m,0 m,20.3 m),Point(11.075 m,14.8 m,20.3 m),Point(14.75 m,14.8 m,20.3 m),Point(14.75 m,0 m,20.3 m));
Pl37 = Plate(Point(14.75 m,0 m,20.3 m),Point(14.75 m,14.8 m,20.3 m),Point(19.95 m,14.8 m,20.3 m),Point(19.95 m,0 m,20.3 m));
Pl38 = Plate(Point(19.95 m,9.599999999 m,20.3 m),Point(19.95 m,14.8 m,20.3 m),Point(35.55 m,14.8 m,20.3 m),Point(35.55 m,9.599999999 m,20.3 m));
```

```
Pl39 = Plate(Point(19.95 m,9.599999999 m,20.3 m),Point(23.85 m,9.599999999 m,20.3 m),Point(23.85
m,0 m,20.3 m),Point(19.95 m,0 m,20.3 m));
Pl40 = Plate(Point(23.85 m,9.599999999 m,20.3 m),Point(27.75 m,9.599999999 m,20.3 m),Point(27.75
m,0 m,20.3 m),Point(23.85 m,0 m,20.3 m));
Pl41 = Plate(Point(27.75 m,9.599999999 m,20.3 m),Point(31.65 m,9.599999999 m,20.3 m),Point(31.65
m,0 m,20.3 m),Point(27.75 m,0 m,20.3 m));
Pl42 = Plate(Point(31.65 m,9.599999999 m,20.3 m),Point(35.55 m,9.599999999 m,20.3 m),Point(35.55
m,0 m,20.3 m),Point(31.65 m,0 m,20.3 m));
Pl43 = Plate(Point(35.55 m,14.8 m,20.3 m),Point(40.75 m,14.8 m,20.3 m),Point(40.75 m,0 m,20.3
m),Point(35.55 m,0 m,20.3 m));
Pl44 = Plate(Point(40.75 m,14.8 m,20.3 m),Point(44.425 m,14.8 m,20.3 m),Point(44.425 m,0 m,20.3
m),Point(40.75 m,0 m,20.3 m));
Pl45 = Plate(Point(44.425 m,14.8 m,20.3 m),Point(48.1 m,14.8 m,20.3 m),Point(48.1 m,0 m,20.3
m),Point(44.425 m,0 m,20.3 m));

// ** Named Set Plan Weather Deck 3 with plates
Plan_weather_deck3_with_plates = Set();
Plan_weather_deck3_with_plates.add(GP_Plan_Weather_deck);
Plan_weather_deck3_with_plates.add(Bm77);
Plan_weather_deck3_with_plates.add(Bm78);
Plan_weather_deck3_with_plates.add(Bm79);
Plan_weather_deck3_with_plates.add(Bm80);
Plan_weather_deck3_with_plates.add(Bm81);
Plan_weather_deck3_with_plates.add(Bm84);
Plan_weather_deck3_with_plates.add(Bm82);
Plan_weather_deck3_with_plates.add(Bm83);
Plan_weather_deck3_with_plates.add(Bm85);
Plan_weather_deck3_with_plates.add(Bm86);
Plan_weather_deck3_with_plates.add(Bm87);
Plan_weather_deck3_with_plates.add(Bm88);
Plan_weather_deck3_with_plates.add(Bm89);
Plan_weather_deck3_with_plates.add(Bm90);
Plan_weather_deck3_with_plates.add(Bm91);
Plan_weather_deck3_with_plates.add(Bm92);
Plan_weather_deck3_with_plates.add(Bm93);
Plan_weather_deck3_with_plates.add(Bm95);
Plan_weather_deck3_with_plates.add(Bm94);
Plan_weather_deck3_with_plates.add(Bm96);
Plan_weather_deck3_with_plates.add(Bm97);
Plan_weather_deck3_with_plates.add(Bm98);
Plan_weather_deck3_with_plates.add(Bm99);
Plan_weather_deck3_with_plates.add(Bm100);
Plan_weather_deck3_with_plates.add(Bm102);
Plan_weather_deck3_with_plates.add(Bm101);
Plan_weather_deck3_with_plates.add(Bm103);
Plan_weather_deck3_with_plates.add(Bm104);
Plan_weather_deck3_with_plates.add(Bm105);
Plan_weather_deck3_with_plates.add(Bm106);
Plan_weather_deck3_with_plates.add(Bm109);
Plan_weather_deck3_with_plates.add(Bm107);
```

```
Plan_weather_deck3_with_plates.add(Bm108);
Plan_weather_deck3_with_plates.add(Bm110);
Plan_weather_deck3_with_plates.add(Bm111);
Plan_weather_deck3_with_plates.add(Bm112);
Plan_weather_deck3_with_plates.add(Pl34);
Plan_weather_deck3_with_plates.add(Pl37);
Plan_weather_deck3_with_plates.add(Pl35);
Plan_weather_deck3_with_plates.add(Pl36);
Plan_weather_deck3_with_plates.add(Pl40);
Plan_weather_deck3_with_plates.add(Pl38);
Plan_weather_deck3_with_plates.add(Pl39);
Plan_weather_deck3_with_plates.add(Pl44);
Plan_weather_deck3_with_plates.add(Pl41);
Plan_weather_deck3_with_plates.add(Pl42);
Plan_weather_deck3_with_plates.add(Pl43);
Plan_weather_deck3_with_plates.add(Pl45);

// Guiding Geometry for East Elevation (looking west)
GuidePlane5 = GuidePlane(Point(0 m,0 m,0 m),Point(0 m,14.8 m,0 m),Point(0 m,14.8 m,20.3 m),Point(0
m,0 m,20.3 m),2,2,0.5,0.5,0.5,0.5);
GuidePlane5.snapmode = true;
GuidePlane6 = GuidePlane(Point(0 m,0 m,0 m),Point(0 m,14.8 m,0 m),Point(0 m,14.8 m,20.3 m),Point(0
m,0 m,20.3 m),2,2,0.5,0.5,0.5,0.5);
GuidePlane6.snapmode = true;
// ** Sections for East Elevation (Looking west)

Tub700x54_2.setDefault();
Bm113 = Beam(Point(0 m,0 m,0 m), Point(0 m,0 m,10.15 m));
Bm114 = Beam(Point(0 m,0 m,10.15 m), Point(0 m,0 m,20.3 m));
Bm115 = Beam(Point(0 m,14.8 m,0 m), Point(0 m,14.8 m,10.15 m));
Bm116 = Beam(Point(0 m,14.8 m,10.15 m), Point(0 m,14.8 m,20.3 m));
Tub500x37_4.setDefault();
Bm117 = Beam(Point(0 m,14.8 m,0 m), Point(0 m,7.4 m,10.15 m));
Bm118 = Beam(Point(0 m,0 m,0 m), Point(0 m,7.4 m,10.15 m));
Bm119 = Beam(Point(0 m,14.8 m,10.15 m), Point(0 m,7.4 m,20.3 m));
Bm120 = Beam(Point(0 m,0 m,10.15 m), Point(0 m,7.4 m,20.3 m));

//** Named Set East Elevation **
East_Elevation = Set();
East_Elevation.add(Bm25);
East_Elevation.add(Bm26);
East_Elevation.add(Bm62);
East_Elevation.add(Bm100);
East_Elevation.add(Bm101);
East_Elevation.add(Bm113);
East_Elevation.add(Bm114);
East_Elevation.add(Bm115);
East_Elevation.add(Bm116);
East_Elevation.add(Bm117);
East_Elevation.add(Bm119);
```

```
East_Elevation.add(Bm118);
East_Elevation.add(Bm120);

// ** Guiding Plane for West Elevation ( Looking East)
GuidePlane10 = GuidePlane(Point(48.1 m,0 m,0 m),Point(48.1 m,14.8 m,0 m),Point(48.1 m,14.8 m,20.3
m),Point(48.1 m,0 m,20.3 m),2,2,0.5,0.5,0.5,0.5);
GuidePlane10.snapmode = true;
GuidePlane8 = GuidePlane(Point(48.1 m,0 m,0 m),Point(48.1 m,14.8 m,0 m),Point(48.1 m,14.8 m,20.3
m),Point(48.1 m,0 m,20.3 m),2,2,0.5,0.5,0.5,0.5);
GuidePlane8.snapmode = true;

// ** Sections for West Elevation ( Looking East)
Tub700x54_2.setDefault();
Bm121 = Beam(Point(48.1 m,0 m,0 m), Point(48.1 m,0 m,20.3 m));
Bm122 = Beam(Point(48.1 m,14.8 m,0 m), Point(48.1 m,14.8 m,20.3 m));

Tub500x37_4.setDefault();
Bm123 = Beam(Point(48.1 m,0 m,10.15 m), Point(48.1 m,7.4 m,20.3 m));
Bm124 = Beam(Point(48.1 m,14.8 m,10.15 m), Point(48.1 m,7.4 m,20.3 m));
Bm125 = Beam(Point(48.1 m,0 m,0 m), Point(48.1 m,7.4 m,10.15 m));
Bm126 = Beam(Point(48.1 m,14.8 m,0 m), Point(48.1 m,7.4 m,10.15 m));

//** Named Set West Elevation **
West_Elevation = Set();
West_Elevation.add(Bm12);
West_Elevation.add(Bm13);
West_Elevation.add(Bm50);
West_Elevation.add(Bm88);
West_Elevation.add(Bm121);
West_Elevation.add(Bm122);
West_Elevation.add(Bm125);
West_Elevation.add(Bm123);
West_Elevation.add(Bm124);
West_Elevation.add(Bm126);

//** Guiding Geometry for South Elevation **
GP_South_Elevation = GuidePlane(Point(0 m,0 m,0 m),Point(48.1 m,0 m,0 m),Point(48.1 m,0 m,20.3
m),Point(0 m,0 m,20.3
m),5,2,0.1538461538,0.1528066528,0.2702702703,0.2702702703,0.1528066528,0.5,0.5);
GP_South_Elevation.snapmode = true;

//** Sections for South Elevation **
Tub700x54_2.setDefault();
Bm127 = Beam(Point(7.399999998 m,0 m,20.3 m), Point(7.399999998 m,0 m,10.15 m));
Bm128 = Beam(Point(7.399999998 m,0 m,10.15 m), Point(7.4 m,0 m,0 m));
Tub800x50_2.setDefault();
Bm129 = Beam(Point(14.75 m,0 m,20.3 m), Point(14.75 m,0 m,10.15 m));
Bm130 = Beam(Point(14.75 m,0 m,10.15 m), Point(14.75 m,0 m,0 m));
Tub600x57_3.setDefault();
Bm131 = Beam(Point(27.75 m,0 m,20.3 m), Point(27.75 m,0 m,10.15 m));
```

```
Bm132 = Beam(Point(27.75 m,0 m,10.15 m), Point(27.75 m,0 m,0 m));
Tub800x50_2.setDefault();
Bm133 = Beam(Point(40.75 m,0 m,20.3 m), Point(40.75 m,0 m,10.15 m));
Bm134 = Beam(Point(40.75 m,0 m,10.15 m), Point(40.75 m,0 m,0 m));
Bm138 = Beam(Point(14.75 m,0 m,0 m), Point(27.75 m,0 m,20.3 m));
Tub500x37_4.setDefault();
Bm135 = Beam(Point(0 m,0 m,10.15 m), Point(7.4 m,0 m,0 m));
Tub600x33.setDefault();
Bm136 = Beam(Point(7.399999998 m,0 m,10.15 m), Point(14.75 m,0 m,0 m));
Bm137 = Beam(Point(40.75 m,0 m,0 m), Point(48.1 m,0 m,10.15 m));
Tub700x29_1.setDefault();
Bm139 = Beam(Point(27.75 m,0 m,20.3 m), Point(40.75 m,0 m,0 m));

South_Elevation = Set();
South_Elevation.add(Bm2);
South_Elevation.add(Bm1);
South_Elevation.add(Bm3);
South_Elevation.add(Bm4);
South_Elevation.add(Bm5);
South_Elevation.add(Bm6);
South_Elevation.add(Bm7);
South_Elevation.add(Bm8);
South_Elevation.add(Bm9);
South_Elevation.add(Bm11);
South_Elevation.add(Bm10);
South_Elevation.add(Bm39);
South_Elevation.add(Bm40);
South_Elevation.add(Bm41);
South_Elevation.add(Bm42);
South_Elevation.add(Bm43);
South_Elevation.add(Bm45);
South_Elevation.add(Bm44);
South_Elevation.add(Bm46);
South_Elevation.add(Bm47);
South_Elevation.add(Bm48);
South_Elevation.add(Bm49);
South_Elevation.add(Bm77);
South_Elevation.add(Bm78);
South_Elevation.add(Bm79);
South_Elevation.add(Bm80);
South_Elevation.add(Bm81);
South_Elevation.add(Bm84);
South_Elevation.add(Bm82);
South_Elevation.add(Bm83);
South_Elevation.add(Bm85);
South_Elevation.add(Bm86);
South_Elevation.add(Bm87);
South_Elevation.add(Bm113);
South_Elevation.add(Bm114);
South_Elevation.add(Bm121);
```

```
South_Elevation.add(Bm127);
South_Elevation.add(Bm128);
South_Elevation.add(Bm131);
South_Elevation.add(Bm129);
South_Elevation.add(Bm130);
South_Elevation.add(Bm132);
South_Elevation.add(Bm133);
South_Elevation.add(Bm134);
South_Elevation.add(Bm135);
South_Elevation.add(Bm138);
South_Elevation.add(Bm136);
South_Elevation.add(Bm137);
South_Elevation.add(Bm139);

//** Guiding Geometry for North Elevation **
GuidePlane13 = GuidePlane(Point(0 m,14.8 m,0 m),Point(48.1 m,14.8 m,0 m),Point(48.1 m,14.8 m,20.3 m),Point(0 m,14.8 m,20.3 m),5,2,0.1528066528,0.2702702703,0.2702702703,0.1528066528,0.1538461538,0.5,0.5);
GuidePlane13.snapmode = true;
GuidePlane13.corners(Point(0 m,14.8 m,0 m),Point(48.1 m,14.8 m,0 m),Point(48.1 m,14.8 m,20.3 m),Point(0 m,14.8 m,20.3 m));
GuidePlane13.spacings(5,2,0.1538461538,0.1528066528,0.2702702703,0.2702702703,0.1528066528,0.5,0.5);

//** Sections for North Elevation **
Tub800x50_2.setDefault();
Bm140 = Beam(Point(40.75 m,14.8 m,0 m), Point(40.75 m,14.8 m,10.15 m));
Bm141 = Beam(Point(40.75 m,14.8 m,10.15 m), Point(40.75 m,14.8 m,20.3 m));
Tub600x57_3.setDefault();
Bm142 = Beam(Point(27.75 m,14.8 m,0 m), Point(27.75 m,14.8 m,10.15 m));
Bm143 = Beam(Point(27.75 m,14.8 m,10.15 m), Point(27.75 m,14.8 m,20.3 m));
Tub800x50_2.setDefault();
Bm144 = Beam(Point(14.75 m,14.8 m,0 m), Point(14.75 m,14.8 m,10.15 m));
Bm145 = Beam(Point(14.75 m,14.8 m,10.15 m), Point(14.75 m,14.8 m,20.3 m));
Bm151 = Beam(Point(27.75 m,14.8 m,20.3 m), Point(14.75 m,14.8 m,0 m));
Tub700x54_2.setDefault();
Bm146 = Beam(Point(7.399999998 m,14.8 m,0 m), Point(7.399999998 m,14.8 m,10.15 m));
Bm147 = Beam(Point(7.399999998 m,14.8 m,10.15 m), Point(7.399999998 m,14.8 m,20.3 m));
Tub600x33.setDefault();
Bm148 = Beam(Point(48.1 m,14.8 m,10.15 m), Point(40.75 m,14.8 m,0 m));
Bm149 = Beam(Point(7.399999998 m,14.8 m,10.15 m), Point(14.75 m,14.8 m,0 m));
Tub700x29_1.setDefault();
Bm150 = Beam(Point(40.75 m,14.8 m,0 m), Point(27.75 m,14.8 m,20.3 m));
Tub500x37_4.setDefault();
Bm152 = Beam(Point(7.399999998 m,14.8 m,0 m), Point(0 m,14.8 m,10.15 m));

//** Named Set North Elevation **
North_Elevation = Set();
North_Elevation.add(Bm14);
North_Elevation.add(Bm15);
```

```
North_Elevation.add(Bm16);
North_Elevation.add(Bm18);
North_Elevation.add(Bm17);
North_Elevation.add(Bm19);
North_Elevation.add(Bm20);
North_Elevation.add(Bm21);
North_Elevation.add(Bm22);
North_Elevation.add(Bm23);
North_Elevation.add(Bm24);
North_Elevation.add(Bm52);
North_Elevation.add(Bm51);
North_Elevation.add(Bm53);
North_Elevation.add(Bm54);
North_Elevation.add(Bm55);
North_Elevation.add(Bm56);
North_Elevation.add(Bm57);
North_Elevation.add(Bm59);
North_Elevation.add(Bm58);
North_Elevation.add(Bm60);
North_Elevation.add(Bm61);
North_Elevation.add(Bm89);
North_Elevation.add(Bm90);
North_Elevation.add(Bm91);
North_Elevation.add(Bm92);
North_Elevation.add(Bm93);
North_Elevation.add(Bm95);
North_Elevation.add(Bm94);
North_Elevation.add(Bm96);
North_Elevation.add(Bm97);
North_Elevation.add(Bm98);
North_Elevation.add(Bm99);
North_Elevation.add(Bm115);
North_Elevation.add(Bm116);
North_Elevation.add(Bm122);
North_Elevation.add(Bm140);
North_Elevation.add(Bm141);
North_Elevation.add(Bm142);
North_Elevation.add(Bm143);
North_Elevation.add(Bm144);
North_Elevation.add(Bm145);
North_Elevation.add(Bm147);
North_Elevation.add(Bm146);
North_Elevation.add(Bm148);
North_Elevation.add(Bm149);
North_Elevation.add(Bm150);
North_Elevation.add(Bm151);
North_Elevation.add(Bm152);

// ** SUPPORTS **
// ** Guiding Geometry for supports **
```

```
GuidePlane14 = GuidePlane(Point(0 m,0 m,-0.5 m),Point(48.1 m,0 m,-0.5 m),Point(48.1 m,14.8 m,-0.5
m),Point(0 m,14.8 m,-0.5
m),11,3,0.1538461538,0.1046777547,0.04812889813,0.09012474012,0.09012474012,0.09002079002,0.
09002079002,0.09012474012,0.09012474012,0.04812889813,0.1046777547,0.527027027,0.0135135135
1,0.4594594595);
GuidePlane14.snapmode = true;
GuidePlane15 = GuidePlane(Point(0 m,0 m,-0.5 m),Point(48.1 m,0 m,-0.5 m),Point(48.1 m,14.8 m,-0.5
m),Point(0 m,14.8 m,-0.5
m),11,3,0.1538461538,0.1046777547,0.04812889813,0.09012474012,0.09012474012,0.09002079002,0.
09002079002,0.09012474012,0.09012474012,0.04812889813,0.1046777547,0.527027027,0.0135135135
1,0.4594594595);
GuidePlane15.snapmode = true;
Tub800x70.setDefault();
Bm153 = Beam(Point(14.75 m,0 m,-0.5 m), Point(14.75 m,0 m,0 m));
Tub800x50_2.setDefault();
Bm154 = Beam(Point(40.75 m,0 m,-0.5 m), Point(40.75 m,0 m,0 m));
Bm155 = Beam(Point(40.75 m,14.8 m,0 m), Point(40.75 m,14.8 m,-0.5 m));
Bm156 = Beam(Point(14.75 m,14.8 m,0 m), Point(14.75 m,14.8 m,-0.5 m));

// ** SUPPORTS **
Sp1 = SupportPoint(Point(14.75 m,0 m,-0.5 m));
Sp2 = SupportPoint(Point(40.75 m,0 m,-0.5 m));
Sp3 = SupportPoint(Point(40.75 m,14.8 m,-0.5 m));
Sp4 = SupportPoint(Point(14.75 m,14.8 m,-0.5 m));
// ** Boundary conditions - Pinned **
Sp1.boundary = BoundaryCondition(Free, Fixed, Fixed, Fixed, Free, Free);
Sp2.boundary = BoundaryCondition(Fixed, Fixed, Fixed, Free, Free, Free);
Sp3.boundary = BoundaryCondition(Free, Fixed, Fixed, Fixed, Free, Free);
Sp4.boundary = BoundaryCondition(Fixed, Fixed, Fixed, Free, Free, Free);

// ****LOAD MODELLING AND ANALYSIS ****
// ** Load Combination **
LC1 = LoadCase();
LC1.setAcceleration(Vector3d(0 m/s^2,0 m/s^2,-9.80665 m/s^2));
LC1.includeSelfWeight();
LC1.includeStructureMassWithRotationField();
Rename(LC1,"LC_mass");

// ** RUN ANALYSIS **
SimplifyTopology();
SimplifyTopology();
Analysis1 = Analysis(true);
Analysis1.add(MeshActivity());
Analysis1.add(LinearAnalysis());
Analysis1.add(LoadResultsActivity());
SimplifyTopology();
//Analysis1.execute();

// ** Analysis **
SimplifyTopology();
```

```
// Please check Messages area for 1 information message.
SimplifyTopology();
//Analysis1.execute();
// Please check Messages area for 1 information message.

// ** Equipment **
// ** Main Deck **
Equipment_Maindeck = PrismEquipment(48.1,14.8,5.075,1492800);
Equipment_Maindeck.clearFootprint();
Equipment_Maindeck.addToFootprint(-24.05 m,24.05 m,-7.4 m,7.4 m);
// ** Mezz. Deck **
Equipment_Mezzdeck = PrismEquipment(48.1,14.8,5.075,1741600);
Equipment_Mezzdeck.clearFootprint();
Equipment_Mezzdeck.addToFootprint(-24.05 m,24.05 m,-7.4 m,7.4 m);
// ** Weather Deck **
Equipment_Weatherdeck = PrismEquipment(48.1,14.8,5.075,1741600);
Equipment_Weatherdeck.clearFootprint();
Equipment_Weatherdeck.addToFootprint(-24.05 m,24.05 m,-7.4 m,7.4 m);

//** LOADCASE for equipmentbox**
LC_EMainDeck = LoadCase(Analysis1);
LC_EMezzDeck = LoadCase(Analysis1);
LC_EWeatdeck = LoadCase(Analysis1);

LC_EMainDeck.setCurrent();
LC_EMainDeck.placeAtPoint(Equipment_Maindeck,Point(0 m,0 m,0 m),LocalSystem(Vector3d(1 m,0 m,0 m), Vector3d(0 m,0 m,1 m)));
autoMSet = Set();
autoMSet.clear();
autoMSet.add(Equipment_Maindeck);
autoMSet.moveTranslate(Vector3d(24.05 m,7.4m,0 m),geUNCONNECTED);
Delete(autoMSet);
LC_EMezzDeck.setCurrent();
LC_EMezzDeck.placeAtPoint(Equipment_Mezzdeck,Point(0 m,0 m,10.15 m),LocalSystem(Vector3d(1 m,0 m,0 m), Vector3d(0 m,0 m,1 m)));
autoMSet = Set();
autoMSet.clear();
autoMSet.add(Equipment_Mezzdeck);
autoMSet.moveTranslate(Vector3d(24.05 m,7.4m,0 m),geUNCONNECTED);
Delete(autoMSet);
LC_EWeatdeck.setCurrent();
LC_EWeatdeck.placeAtPoint(Equipment_Weatherdeck,Point(0 m,0 m,20.3 m),LocalSystem(Vector3d(1 m,0 m,0 m), Vector3d(0 m,0 m,1 m)));
autoMSet = Set();
autoMSet.clear();
autoMSet.add(Equipment_Weatherdeck);
autoMSet.moveTranslate(Vector3d(24.05 m,7.4m,0 m),geUNCONNECTED);
Delete(autoMSet);

// ** Generate Apllied load **
```

```
LC_EMainDeck.generateAppliedLoads();
LC_EMezzDeck.generateAppliedLoads();
LC_EWeatdeck.generateAppliedLoads();
LC_Liveload_Maindeck = LoadCase(Analysis1);
LC_Liveload_Maindeck.setCurrent();
LineLoad1 = LineLoad(LC_Liveload_Maindeck, FootprintLine(Point(0 m,14.8 m,0 m), Point(0 m,0 m,0 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -22.9 kN/m), Vector3d(0 N/m, 0 N/m, -22.9 kN/m)));
LineLoad2 = LineLoad(LC_Liveload_Maindeck, FootprintLine(Point(7.399999998 m,14.8 m,0 m), Point(7.4 m,0 m,0 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -38.56 kN/m), Vector3d(0 N/m, 0 N/m, -38.56 kN/m)));
LineLoad3 = LineLoad(LC_Liveload_Maindeck, FootprintLine(Point(12.435 m,14.8 m,0 m), Point(12.435 m,0 m,0 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -22.79 kN/m), Vector3d(0 N/m, 0 N/m, -22.79 kN/m)));
LineLoad4 = LineLoad(LC_Liveload_Maindeck, FootprintLine(Point(14.75 m,14.8 m,0 m), Point(14.75 m,0 m,0 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -20.6 kN/m), Vector3d(0 N/m, 0 N/m, -20.6 kN/m)));
LineLoad5 = LineLoad(LC_Liveload_Maindeck, FootprintLine(Point(19.085 m,14.8 m,0 m), Point(19.085 m,0 m,0 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -26.9 kN/m), Vector3d(0 N/m, 0 N/m, -26.9 kN/m)));
LineLoad6 = LineLoad(LC_Liveload_Maindeck, FootprintLine(Point(23.42 m,14.8 m,0 m), Point(23.42 m,0 m,0 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -26.9 kN/m), Vector3d(0 N/m, 0 N/m, -26.9 kN/m)));
LineLoad7 = LineLoad(LC_Liveload_Maindeck, FootprintLine(Point(27.75 m,14.8 m,0 m), Point(27.75 m,0 m,0 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -26.9 kN/m), Vector3d(0 N/m, 0 N/m, -26.9 kN/m)));
LineLoad8 = LineLoad(LC_Liveload_Maindeck, FootprintLine(Point(32.08 m,14.8 m,0 m), Point(32.08 m,0 m,0 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -26.9 kN/m), Vector3d(0 N/m, 0 N/m, -26.9 kN/m)));
LineLoad9 = LineLoad(LC_Liveload_Maindeck, FootprintLine(Point(36.415 m,14.8 m,0 m), Point(36.415 m,0 m,0 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -26.9 kN/m), Vector3d(0 N/m, 0 N/m, -26.9 kN/m)));
LineLoad10 = LineLoad(LC_Liveload_Maindeck, FootprintLine(Point(40.75 m,14.8 m,0 m), Point(40.75 m,0 m,0 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -20.6 kN/m), Vector3d(0 N/m, 0 N/m, -20.6 kN/m)));
LineLoad11 = LineLoad(LC_Liveload_Maindeck, FootprintLine(Point(43.065 m,14.8 m,0 m), Point(43.065 m,0 m,0 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -22.8 kN/m), Vector3d(0 N/m, 0 N/m, -22.8 kN/m)));
LLoad12 = LineLoad(LC_Liveload_Maindeck, FootprintLine(Point(48.1 m,14.8 m,0 m), Point(48.1 m,0 m,0 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -15.6 kN/m), Vector3d(0 N/m, 0 N/m, -15.6 kN/m)));

// ** LIVE LOAD ON LOWER MEZZ DECK **
Rename(LC_Liveload_Maindeck,"LC_Liveload_on_all_decks");
LineLoad13 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(0 m,14.8 m,10.15 m), Point(0 m,0 m,10.15 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -10.2 kN/m), Vector3d(0 N/m, 0 N/m, -10.2 kN/m)));
LineLoad14 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(7.399999998 m,14.8 m,10.15 m), Point(7.399999998 m,0 m,10.15 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -16.7 kN/m), Vector3d(0 N/m, 0 N/m, -16.7 kN/m)));
```

LineLoad15 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(12.13 m,14.8 m,10.15 m), Point(12.13 m,0 m,10.15 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -10.1 kN/m), Vector3d(0 N/m, 0 N/m, -10.1 kN/m)));

LineLoad16 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(14.75 m,14.8 m,10.15 m), Point(14.75 m,0 m,10.15 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -9.5 kN/m), Vector3d(0 N/m, 0 N/m, -9.5 kN/m)));

LineLoad17 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(19.03 m,14.8 m,10.15 m), Point(19.03 m,0 m,10.15 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -11.9 kN/m), Vector3d(0 N/m, 0 N/m, -11.9 kN/m)));

LineLoad18 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(23.42 m,14.8 m,10.15 m), Point(23.42 m,0 m,10.15 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -11.9 kN/m), Vector3d(0 N/m, 0 N/m, -11.9 kN/m)));

LineLoad19 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(27.75 m,14.8 m,10.15 m), Point(27.75 m,0 m,10.15 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -11.9 kN/m), Vector3d(0 N/m, 0 N/m, -11.9 kN/m)));

LineLoad20 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(32.08 m,14.8 m,10.15 m), Point(32.08 m,0 m,10.15 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -12.1 kN/m), Vector3d(0 N/m, 0 N/m, -12.1 kN/m)));

LineLoad21 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(36.58 m,14.8 m,10.15 m), Point(36.58 m,0 m,10.15 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -11.9 kN/m), Vector3d(0 N/m, 0 N/m, -11.9 kN/m)));

LineLoad22 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(40.75 m,14.8 m,10.15 m), Point(40.75 m,0 m,10.15 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -9.4 kN/m), Vector3d(0 N/m, 0 N/m, -9.4 kN/m)));

LineLoad23 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(43.37 m,14.8 m,10.15 m), Point(43.37 m,0 m,10.15 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -10.1 kN/m), Vector3d(0 N/m, 0 N/m, -10.1 kN/m)));

LineLoad24 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(48.1 m,14.8 m,10.15 m), Point(48.1 m,0 m,10.15 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -6.5 kN/m), Vector3d(0 N/m, 0 N/m, -6.5 kN/m)));

// ** Live load on weather deck **

LineLoad25 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(0 m,14.8 m,20.3 m), Point(0 m,0 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -2.55 kN/m), Vector3d(0 N/m, 0 N/m, -2.55 kN/m)));

LineLoad26 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(7.399999998 m,14.8 m,20.3 m), Point(7.399999998 m,0 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -3.8 kN/m), Vector3d(0 N/m, 0 N/m, -3.8 kN/m)));

LineLoad27 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(11.075 m,14.8 m,20.3 m), Point(11.075 m,0 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -2.5 kN/m), Vector3d(0 N/m, 0 N/m, -2.5 kN/m)));

LineLoad28 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(14.75 m,14.8 m,20.3 m), Point(14.75 m,0 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -3.0 kN/m), Vector3d(0 N/m, 0 N/m, -3.0 kN/m)));

LLoad29 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(19.95 m,0 m,20.3 m), Point(19.95 m,9.599999999 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -4.8 kN/m), Vector3d(0 N/m, 0 N/m, -4.8 kN/m)));

LineLoad30 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(23.85 m,9.599999999 m,20.3 m), Point(23.85 m,0 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -4.1 kN/m), Vector3d(0 N/m, 0 N/m, -4.1 kN/m)));

```
LineLoad31 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(27.75 m,9.599999999 m,20.3 m), Point(27.75 m,0 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -4.1 kN/m), Vector3d(0 N/m, 0 N/m, -4.1 kN/m)));
LineLoad32 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(31.65 m,9.599999999 m,20.3 m), Point(31.65 m,0 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -4.1 kN/m), Vector3d(0 N/m, 0 N/m, -4.1 kN/m)));
LineLoad33 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(35.55 m,9.599999999 m,20.3 m), Point(35.55 m,0 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -4.8 kN/m), Vector3d(0 N/m, 0 N/m, -4.8 kN/m)));
LineLoad34 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(40.75 m,14.8 m,20.3 m), Point(40.75 m,0 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -3.0 kN/m), Vector3d(0 N/m, 0 N/m, -3.0 kN/m)));
LineLoad35 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(44.425 m,14.8 m,20.3 m), Point(44.425 m,0 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -2.5 kN/m), Vector3d(0 N/m, 0 N/m, -2.5 kN/m)));
LineLoad36 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(48.1 m,14.8 m,20.3 m), Point(48.1 m,0 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -1.27 kN/m), Vector3d(0 N/m, 0 N/m, -1.27 kN/m)));
LineLoad37 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(35.55 m,14.8 m,20.3 m), Point(35.55 m,9.599999999 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -8.9 kN/m), Vector3d(0 N/m, 0 N/m, -8.9 kN/m)));
LineLoad38 = LineLoad(LC_Liveload_on_all_decks, FootprintLine(Point(19.95 m,14.8 m,20.3 m), Point(19.95 m,9.599999999 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 0 N/m, -8.9 kN/m), Vector3d(0 N/m, 0 N/m, -8.9 kN/m)));
SetNoLoadcase();

//** WIND FROM WEST **
LC_WIND_West = LoadCase(Analysis1);
LC_WIND_West.setCurrent();
Wind_west_Line1 = LineLoad(LC_WIND_West, FootprintLine(Point(0 m,14.8 m,0 m), Point(0 m,0 m,0 m)), Component1dLinear(Vector3d(12.8 kN/m, 0 N/m, 0 N/m), Vector3d(12.8 kN/m, 0 N/m, 0 N/m)));
Wind_west_Line2 = LineLoad(LC_WIND_West, FootprintLine(Point(0 m,14.8 m,10.15 m), Point(0 m,0 m,10.15 m)), Component1dLinear(Vector3d(25.6 kN/m, 0 N/m, 0 N/m), Vector3d(25.6 kN/m, 0 N/m, 0 N/m)));
Wind_west_Line3 = LineLoad(LC_WIND_West, FootprintLine(Point(0 m,14.8 m,20.3 m), Point(0 m,0 m,20.3 m)), Component1dLinear(Vector3d(12.8 kN/m, 0 N/m, 0 N/m), Vector3d(12.8 kN/m, 0 N/m, 0 N/m)));
LC_WIND_East = LoadCase(Analysis1);
LC_WIND_East.setCurrent();
Wind_east_Line1 = LineLoad(LC_WIND_East, FootprintLine(Point(48.1 m,0 m,0 m), Point(48.1 m,14.8 m,0 m)), Component1dLinear(Vector3d(- 12.8 kN/m, 0 N/m, 0 N/m), Vector3d(- 12.8 kN/m, 0 N/m, 0 N/m)));
Wind_east_Line2 = LineLoad(LC_WIND_East, FootprintLine(Point(48.1 m,0 m,10.15 m), Point(48.1 m,14.8 m,10.15 m)), Component1dLinear(Vector3d(- 25.6 kN/m, 0 N/m, 0 N/m), Vector3d(- 25.6 kN/m, 0 N/m, 0 N/m)));
Wind_east_Line3 = LineLoad(LC_WIND_East, FootprintLine(Point(48.1 m,14.8 m,20.3 m), Point(48.1 m,0 m,20.3 m)), Component1dLinear(Vector3d(- 12.8 kN/m, 0 N/m, 0 N/m), Vector3d(- 12.8 kN/m, 0 N/m, 0 N/m)));

// ** Wind north
```

```
LC_WIND_North = LoadCase(Analysis1);
LC_WIND_North.setCurrent();
Wind_north_Line1 = LineLoad(LC_WIND_North, FootprintLine(Point(48.1 m,14.8 m,0 m), Point(0 m,14.8 m,0 m)), Component1dLinear(Vector3d(0 N/m, - 1.8 kN/m, 0 N/m), Vector3d(0 N/m, - 1.8 kN/m, 0 N/m)));
Wind_north_Line2 = LineLoad(LC_WIND_North, FootprintLine(Point(48.1 m,14.8 m,10.15 m), Point(0 m,14.8 m,10.15 m)), Component1dLinear(Vector3d(0 N/m, - 3.6 kN/m, 0 N/m), Vector3d(0 N/m, - 3.6 kN/m, 0 N/m)));
Wind_north_Line3 = LineLoad(LC_WIND_North, FootprintLine(Point(48.1 m,14.8 m,20.3 m), Point(0 m,14.8 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, - 1.8 kN/m, 0 N/m), Vector3d(0 N/m, - 1.8 kN/m, 0 N/m)));
LC_WIND_South = LoadCase(Analysis1);
LC_WIND_South.setCurrent();
Wind_south_Line1 = LineLoad(LC_WIND_South, FootprintLine(Point(0 m,0 m,0 m), Point(48.1 m,0 m,0 m)), Component1dLinear(Vector3d(0 N/m, 1.8 kN/m, 0 N/m), Vector3d(0 N/m, 1.8 kN/m, 0 N/m)));
Wind_south_Line2 = LineLoad(LC_WIND_South, FootprintLine(Point(0 m,0 m,10.15 m), Point(48.1 m,0 m,10.15 m)), Component1dLinear(Vector3d(0 N/m, 3.6 kN/m, 0 N/m), Vector3d(0 N/m, 3.6 kN/m, 0 N/m)));
Wind_south_Line3 = LineLoad(LC_WIND_South, FootprintLine(Point(0 m,0 m,20.3 m), Point(48.1 m,0 m,20.3 m)), Component1dLinear(Vector3d(0 N/m, 1.8 kN/m, 0 N/m), Vector3d(0 N/m, 1.8 kN/m, 0 N/m)));

// ** ANALYSIS **
SimplifyTopology();
SimplifyTopology();
//Analysis1.execute();

// ** LOAD COMBINATIONS **
LC_A_NORTH = LoadCombination(Analysis1);
LC_A_NORTH.addCase(LC_mass, 1.3);
LC_A_NORTH.addCase(LC_EMainDeck, 1.3);
LC_A_NORTH.addCase(LC_EMezzDeck, 1.3);
LC_A_NORTH.addCase(LC_EWeatdeck, 1.3);
LC_A_NORTH.addCase(LC_Liveload_on_all_decks, 1.3);
LC_A_NORTH.addCase(LC_WIND_North, 0.7);
LC_A_SOUTH = LoadCombination(Analysis1);
LC_A_SOUTH.addCase(LC_mass, 1.3);
LC_A_SOUTH.addCase(LC_EMainDeck, 1.3);
LC_A_SOUTH.addCase(LC_EMezzDeck, 1.3);
LC_A_SOUTH.addCase(LC_EWeatdeck, 1.3);
LC_A_SOUTH.addCase(LC_Liveload_on_all_decks, 1.3);
LC_A_SOUTH.addCase(LC_WIND_South, 0.7);
LC_A_EAST = LoadCombination(Analysis1);
LC_A_EAST.addCase(LC_mass, 1.3);
LC_A_EAST.addCase(LC_EMainDeck, 1.3);
LC_A_EAST.addCase(LC_EMezzDeck, 1.3);
LC_A_EAST.addCase(LC_EWeatdeck, 1.3);
LC_A_EAST.addCase(LC_Liveload_on_all_decks, 1.3);
LC_A_EAST.addCase(LC_WIND_East, 0.7);
LC_A_WEST = LoadCombination(Analysis1);
```

```
LC_A_WEST.addCase(LC_mass, 1.3);
LC_A_WEST.addCase(LC_EMainDeck, 1.3);
LC_A_WEST.addCase(LC_EMezzDeck, 1.3);
LC_A_WEST.addCase(LC_EWeatdeck, 1.3);
LC_A_WEST.addCase(LC_Liveload_on_all_decks, 1.3);
LC_A_WEST.addCase(LC_WIND_West, 0.7);
LC_B_NORTH = LoadCombination(Analysis1);
LC_B_NORTH.addCase(LC_mass, 1);
LC_B_NORTH.addCase(LC_EMainDeck, 1);
LC_B_NORTH.addCase(LC_EMezzDeck, 1);
LC_B_NORTH.addCase(LC_EWeatdeck, 1);
LC_B_NORTH.addCase(LC_Liveload_on_all_decks, 1);
LC_B_NORTH.addCase(LC_WIND_East, 1.3);
LC_B_SOUTH = LoadCombination(Analysis1);
LC_B_SOUTH.addCase(LC_mass, 1);
LC_B_SOUTH.addCase(LC_EMainDeck, 1);
LC_B_SOUTH.addCase(LC_EMezzDeck, 1);
LC_B_SOUTH.addCase(LC_EWeatdeck, 1);
LC_B_SOUTH.addCase(LC_Liveload_on_all_decks, 1);
LC_B_SOUTH.addCase(LC_WIND_South, 1.3);
LC_B_EAST = LoadCombination(Analysis1);
LC_B_EAST.addCase(LC_mass, 1);
LC_B_EAST.addCase(LC_EMainDeck, 1);
LC_B_EAST.addCase(LC_EMezzDeck, 1);
LC_B_EAST.addCase(LC_EWeatdeck, 1);
LC_B_EAST.addCase(LC_Liveload_on_all_decks, 1);
LC_B_EAST.addCase(LC_WIND_East, 1.3);
LC_B_WEST = LoadCombination(Analysis1);
LC_B_WEST.addCase(LC_mass, 1);
LC_B_WEST.addCase(LC_EMainDeck, 1);
LC_B_WEST.addCase(LC_EMezzDeck, 1);
LC_B_WEST.addCase(LC_EWeatdeck, 1);
LC_B_WEST.addCase(LC_Liveload_on_all_decks, 1);
LC_B_WEST.addCase(LC_WIND_West, 1.3);

// ** CAPACITY MANAGER **
EuroChk = CapacityManager(Analysis1);
MemberCreationOpts = MemberCreationOption();
MemberCreationOpts.splitAtJoint = false;
MemberCreationOpts.splitAtIncomingBeam = false;
MemberCreationOpts.splitAtBeamEnd = true;
EuroChk.createMembers(MemberCreationOpts);
EuroChk.setActive();
EuroChk.AddRun(EN199311Run());
EuroChk.run(1).addLoadCase(LC_A_NORTH);
EuroChk.run(1).addLoadCase(LC_A_SOUTH);
EuroChk.run(1).addLoadCase(LC_A_EAST);
EuroChk.run(1).addLoadCase(LC_A_WEST);
EuroChk.run(1).addLoadCase(LC_B_NORTH);
EuroChk.run(1).addLoadCase(LC_B_SOUTH);
```

```
EuroChk.run(1).addLoadCase(LC_B_EAST);
EuroChk.run(1).addLoadCase(LC_B_WEST);
EuroChk.run(1).generalOptions.partialFactorM0 = 1.15;
EuroChk.run(1).generalOptions.partialFactorM1 = 1.15;
EuroChk.run(1).generalOptions.method1 = false;
EuroChk.run(1).generalOptions.computeLoadsAsNeeded = true;
EuroChk.run(1).generalOptions.purgePositionResults = true;
EuroChk.run(1).description = "Member Check by Eurocode3 EN 1993-1-1 2005";
EuroChk.run(1).generateCodeCheckLoads();
EuroChk.run(1).executeCodeCheck();
setWorstCodeCheckCase();
NORSOKChk = CapacityManager(Analysis1);
MemberCreationOpts = MemberCreationOption();
MemberCreationOpts.splitAtJoint = false;
MemberCreationOpts.splitAtIncomingBeam = false;
MemberCreationOpts.splitAtBeamEnd = true;
NORSOKChk.createMembers(MemberCreationOpts);
NORSOKChk.AddRun(NorsokRun());
NORSOKChk.run(1).includeJoints = false;
NORSOKChk.run(1).addLoadCase(LC_A_NORTH);
NORSOKChk.run(1).addLoadCase(LC_A_SOUTH);
NORSOKChk.run(1).addLoadCase(LC_A_EAST);
NORSOKChk.run(1).addLoadCase(LC_B_NORTH);
NORSOKChk.run(1).addLoadCase(LC_A_WEST);
NORSOKChk.run(1).addLoadCase(LC_B_SOUTH);
NORSOKChk.run(1).addLoadCase(LC_B_EAST);
NORSOKChk.run(1).addLoadCase(LC_B_WEST);
NORSOKChk.run(1).generalOptions.EN1993_1_1.partialFactorM0 = 1.15;
NORSOKChk.run(1).generalOptions.EN1993_1_1.partialFactorM1 = 1.15;
NORSOKChk.run(1).generalOptions.EN1993_1_1.nationalAnnex = naNorwegian;
NORSOKChk.run(1).generalOptions.EN1993_1_1.method1 = false;
NORSOKChk.run(1).generalOptions.computeLoadsAsNeeded = true;
NORSOKChk.run(1).generalOptions.purgePositionResults = true;
NORSOKChk.run(1).generateCodeCheckLoads();
NORSOKChk.run(1).executeCodeCheck();
setWorstCodeCheckCase();
setWorstCodeCheckCase();
ISOChk = CapacityManager(Analysis1);
MemberCreationOpts = MemberCreationOption();
MemberCreationOpts.splitAtJoint = false;
MemberCreationOpts.splitAtIncomingBeam = false;
MemberCreationOpts.splitAtBeamEnd = true;
ISOChk.createMembers(MemberCreationOpts);
ISOChk.setActive();
ISOChk.AddRun(ISO19902Run());
ISOChk.run(1).includeJoints = false;
ISOChk.run(1).addLoadCase(LC_A_NORTH);
ISOChk.run(1).addLoadCase(LC_A_SOUTH);
ISOChk.run(1).addLoadCase(LC_A_EAST);
ISOChk.run(1).addLoadCase(LC_B_NORTH);
```

```
ISOChk.run(1).addLoadCase(LC_A_WEST);
ISOChk.run(1).addLoadCase(LC_B_SOUTH);
ISOChk.run(1).addLoadCase(LC_B_EAST);
ISOChk.run(1).addLoadCase(LC_B_WEST);
ISOChk.run(1).generalOptions.EN1993_1_1.partialFactorM0 = 1.15;
ISOChk.run(1).generalOptions.EN1993_1_1.partialFactorM1 = 1.15;
ISOChk.run(1).generalOptions.EN1993_1_1.nationalAnnex = naNorwegian;
ISOChk.run(1).generalOptions.EN1993_1_1.method1 = false;
ISOChk.run(1).generalOptions.computeLoadsAsNeeded = true;
ISOChk.run(1).generalOptions.purgePositionResults = true;
ISOChk.generateCodeCheckLoads();
ISOChk.executeCodeChecks();
// GeniE V5.3-10 ended 21-May-2012 13:44:27
// GeniE V5.3-10 started 21-May-2012 13:44:28
// GeniE V5.3-10 ended 21-May-2012 13:45:08
```

APPENDIX A-6 Code check details for Bm107 for Case Study 1

Eurocode	**NORSOK**	**ISO**
Code check details for Bm107	Code check details for Bm107	Code check details for Bm107
ufEuler 0.00313608	uf6_1 0	(13.2-2) 0
ufAxial 0.0202933	uf6_13 0.17444	(13.2-4) 0.0232627
ufTorsion 0.0205406	uf6_14 0.0220869	Euler 0.00305461
ufShearz 0.131074	uf6_15 0	(13.2-12) 0.573774
ufSheary 0.0184562	uf6_41 0	(13.2-17) 0.160537
ufXSection 0.7203	uf6_26 0	(13.2-19) 0.0205866
uf646 0.0213155	uf6_26ax 0	(13.3-2) 0
uf655 0	uf6_26mo 0	(13.3-2ax) 0
uf661 1.08894	**uf6_27 0.723441**	(13.3-2mo) 0
uf661ax 0.0213155	**uf6_27ax 0.0225008**	**(13.3-7) 0.66955**
uf661mo 1.06762	**uf6_27mo 0.700941**	**(13.3-7ax) 0.0232627**
uf661my 0.694317	uf6_28 0.645875	**(13.3-7mo) 0.646287**
uf661mz 0.373305	uf6_28ax 0.0214785	(13.3-8) 0.595987
uf662 0.950074	uf6_28mo 0.624397	(13.3-8ax) 0.0222133
uf662ax 0.0213155	uf6_31 0	(13.3-8mo) 0.573774
uf662mo 0.928759	uf6_33 0.624532	(13.2-31) 0
uf662my 0.555454	uf6_34 0	(13.4-12) 0
uf662mz 0.373305	uf6_34ax 0	(13.4-12ax) 0
uf62 0.711052	uf6_34mo 0	(13.4-12mo) 0
uf62ax 0.0202933	uf6_39 0	(13.4-19) 0
uf62mo 0.690759	uf6_39ax 0	(13.4-19ax) 0
uf62my 0.690759	uf6_39mo 0	(13.4-19mo) 0
uf62mz 0	uf6_42 0	(13.4-20) 0
sldComp 30.7792	uf6_42ax 0	(13.4-20ax) 0
relpos 1e-005	uf6_42mo 0	(13.4-20mo) 0
fy 3.55e+008	uf6_43 0	(13.4-21) 0
E 2.1e+011	uf6_43ax 0	D/t 50
gammaM0 1.05	uf6_43mo 0	thk(m) 0.018
gammaM1 1.05	uf6_44 0	relpos 1e-005
NEd -342202	uf6_44ax 0	D 0.9
MyEd -2.51809e+006	uf6_44mo 0	t 0.018
MzEd 413432	uf6_50 0	fy 3.55e+008
TEd -88190.3	uf6_50ax 0	E 2.1e+011
VyEd -112041	uf6_50mo 0	Nx -333312
VzEd -795708	uf6_51 0	My -2.44407e+006
KLy 9.6	uf6_51ax 0	Mz 405496
KLz 9.6	uf6_51mo 0	V 781474
L 9.6	D/t 50	Mv,t 86656
Ncry 1.09118e+008	thk(m) 0.018	oa -6.68282e+006
Ncrz 1.09118e+008	relpos 1e-005	ot 0
NtRd 1.68628e+007	D 0.9	ft 3.55e+008

classF 3 classW 3 NcRd 1.68628e+007 MycRd 3.6454e+006 MzcRd 3.6454e+006 alphay 0.21 alphaz 0.21 chiy 0.952042 chiz 0.952042 NbRd 1.60541e+007 C1 1 Mcr 2.92592e+008 chiLT 1 MbRd 3.6454e+006 Cmy 1 Cmz 1 CmLT 0 kyy 1.00515 kyz 1.00515 kzy 0.804121 kzz 1.00515	thk 0.018 fy 3.55e+008 E 2.1e+011 NSd -330693 NtRd 1.53965e+007 NEy 1.09118e+008 NEz 1.09118e+008 NcRd 1.4697e+007 NclRd 1.53965e+007 MySd -2.42941e+006 MzSd 396942 MySdMax -2.42941e+006 MzSdMax -1.29926e+006 MRd 3.94241e+006 oaSd -6.63031e+006 oacSd 0 fthRd 3.08696e+008 fEy 2.18778e+009 fEz 2.18778e+009 fclRd 3.08696e+008 fchRd 2.9467e+008 omySd -2.25317e+008 omzSd 3.68146e+007 omySdMax -2.25317e+008 omzSdMax -1.20501e+008 fmhRd 3.65641e+008 yM 1.15 kly 9.6 klz 9.6 Cmy 1 Cmz 1 stfspace 9.6 slendery 30.7792 slenderz 30.7792 fcle 2.52e+009 fcl 3.55e+008 fc 3.38871e+008 fm 4.20487e+008 fhe 7.392e+007 fh 7.392e+007 VSd 775315 VRd 4.44458e+006 MTSd 84886.9 MTRd 3.84332e+006	oc 6.68282e+006 fc 3.38986e+008 fyc 3.55e+008 fxe 2.52e+009 ob,y -2.26677e+008 ob,z 3.7608e+007 ob,yS -2.26677e+008 ob,zS -1.23264e+008 fb 4.20487e+008 taub 3.13367e+007 taut 4.01848e+006 p 0 oh 0 fh 7.392e+007 fhe 7.392e+007 KLy 9.6 KLz 9.6 Cm,y 1 Cm,z 1 Lr 9.6 fe,y 2.18778e+009 fe,z 2.18778e+009 ot,c 0 oc,c 0 ox 0 ft,h 3.55e+008 fb,h 4.20487e+008 fc,h 3.38986e+008

APPENDIX A-7 Code check details for Bm107 for Case Study 2

Eurocode	**NORSOK**	**ISO**
Code check details for Bm107	Code check details for Bm107	Code check details for Bm107
ufEuler 0.0030306	uf6_1 0	(13.2-2) 0
ufAxial 0.0214785	uf6_13 0.17444	(13.2-4) 0.0230799
ufTorsion 0.0216542	uf6_14 0.0220869	Euler 0.0030306
ufShearz 0.138684	uf6_15 0	(13.2-12) 0.570101
ufSheary 0.0194243	uf6_41 0	(13.2-17) 0.159272
ufXSection 0.761058	uf6_26 0	(13.2-19) 0.0201663
uf646 0.0225604	uf6_26ax 0	(13.3-2) 0
uf655 0	uf6_26mo 0	(13.3-2ax) 0
uf661 1.04893	uf6_27 0.723441 (bold)	(13.3-2mo) 0
uf661ax 0.0225604	**uf6_27ax 0.0225008**	**(13.3-7) 0.663069**
uf661mo 1.12636	**uf6_27mo 0.700941**	**(13.3-7ax) 0.0230799**
uf661my 0.733881	uf6_28 0.645875	**(13.3-7mo) 0.639989**
uf661mz 0.392484	uf6_28ax 0.0214785	(13.3-8) 0.59214
uf662 1.00215	uf6_28mo 0.624397	(13.3-8ax) 0.0220388
uf662ax 0.0225604	uf6_31 0	(13.3-8mo) 0.570101
uf662mo 0.979589	uf6_33 0.624532	(13.2-31) 0
uf662my 0.587104	uf6_34 0	(13.4-12) 0
uf662mz 0.392484	uf6_34ax 0	(13.4-12ax) 0
uf62 0.751379	uf6_34mo 0	(13.4-12mo) 0
uf62ax 0.0214785	uf6_39 0	(13.4-19) 0
uf62mo 0.729901	uf6_39ax 0	(13.4-19ax) 0
uf62my 0.729901	uf6_39mo 0	(13.4-19mo) 0
uf62mz 0	uf6_42 0	(13.4-20) 0
sldComp 30.7792	uf6_42ax 0	(13.4-20ax) 0
relpos 1e-005	uf6_42mo 0	(13.4-20mo) 0
fy 3.55e+008	uf6_43 0	(13.4-21) 0
E 2.1e+011	uf6_43ax 0	D/t 50
gammaM0 1.15	uf6_43mo 0	thk(m) 0.018
gammaM1 1.15	uf6_44 0	relpos 1e-005
NEd -330693	uf6_44ax 0	D 0.9
MyEd -2.42941e+006	uf6_44mo 0	t 0.018
MzEd 396942	uf6_50 0	fy 3.55e+008
TEd -84886	uf6_50ax 0	E 2.1e+011
VyEd -107542	uf6_50mo 0	Nx -330693
VzEd -767820	uf6_51 0	My -2.42941e+006
KLy 9.6	uf6_51ax 0	Mz 396942
KLz 9.6	uf6_51mo 0	V 775315
L 9.6	D/t 50	Mv,t 84886.9
Ncry 1.09118e+008	thk(m) 0.018	oa -6.63031e+006
Ncrz 1.09118e+008	relpos 1e-005	ot 0
NtRd 1.53965e+007	D 0.9	ft 3.55e+008

```
classF  3
classW  3
NcRd    1.53965e+007
MycRd   3.32841e+006
MzcRd   3.32841+006
alphay  0.21
alphaz  0.21
chiy    0.952042
chiz    0.952042
NbRd    1.46851e+007
C1      1
Mcr     2.92592e+008
chiLT   1
MbRd    3.32841e+006
Cmy     1
Cmz     1
CmLT    0
kyy     1.00545
kyz     1.00545
kzy     0.804362
kzz     1.00545
```

```
thk     0.018
fy      3.55e+008
E       2.1e+011
NSd     -330693
NtRd    1.53965e+007
NEy     1.09118e+008
NEz     1.09118e+008
NcRd    1.4697e+007
NclRd   1.53965e+007
MySd    -2.42941e+006
MzSd    396942
MySdMax -2.42941e+006
MzSdMax -1.29926e+006
MRd     3.94241e+006
oaSd    -6.63031e+006
oacSd   0
fthRd   3.08696e+008
fEy     2.18778e+009
fEz     2.18778e+009
fclRd   3.08696e+008
fchRd   2.9467e+008
omySd   -2.25317e+008
omzSd   3.68146e+007
omySdMax        -
2.25317e+008
omzSdMax        -
1.20501e+008
fmhRd   3.65641e+008
yM      1.15
kly     9.6
klz     9.6
Cmy     1
Cmz     1
stfspace        9.6
slendery        30.7792
slenderz        30.7792
fcle    2.52e+009
fcl     3.55e+008
fc      3.38871e+008
fm      4.20487e+008
fhe     7.392e+007
fh      7.392e+007
VSd     775315
VRd     4.44458e+006
MTSd    84886.9
MTRd    3.84332e+006
```

```
oc      6.63031e+006
fc      3.38986e+008
fyc     3.55e+008
fxe     2.52e+009
ob,y    -2.25317e+008
ob,z    3.68146e+007
ob,yS   -2.25317e+008
ob,zS   -1.20501e+008
fb      4.20487e+008
taub    3.10897e+007
taut    3.93645e+006
p       0
oh      0
fh      7.392e+007
fhe     7.392e+007
KLy     9.6
KLz     9.6
Cm,y    1
Cm,z    1
Lr      9.6
fe,y    2.18778e+009
fe,z    2.18778e+009
ot,c    0
oc,c    0
ox      0
ft,h    3.55e+008
fb,h    4.20487e+008
fc,h    3.38986e+008
```

APPENDIX A-8 Information about the attached CD

- **Results_Paramterstudy1.xls**
  - Contains code check results from the parameter study in Chapter 6.
- **Results_Paramterstudy2.xls**
  - Cont. contains code check results from the parameter study in Chapter 6.
- **Result_Case_studies.xls**
  - Contains the results for the two case studies in Chapter 8 to Chapter 11.