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MASTER'S THESIS

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SUMMARY

The primary function of a jacket structure is to support the weight of the topside structure by transferring the weight to the foundation. The jacket structure must also be designed to resist environmental loads (from wind and waves) and also accidental loads, such as boat impact, extreme environmental conditions and earthquake.

This thesis presents the results from a strength assessment based on the conceptual design of an eight-legged jacket with V plus X braces pattern and an alternative six-legged jacket with fully X braces pattern. Subsequently, a study was carried out to compare the responses of the two jacket structures when they are subjected to an accidental collision from a floating living quarter (a flotel).

To date, extensive research has been carried out on vessel-to-jacket collisions. However, little work has been performed for flotel-to-jacket collisions. This thesis implements the basic design principles of ship collision and several reasonable assumptions. It is expected that the results could provide an overview of how the different potential impact locations and directions will influence the resistance capacity of the jackets. It is also anticipated that this procedure and the assumptions could be a reference for related research in the future.

PREFACE

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science at the University of Stavanger (UiS), Norway. The work is supported by Det Norske Veritas (DNV), Stavanger.

Part of the work of this thesis depends on some limitations and relevant assumptions, such that the results are on the conservative side. During the studies of this work, I have obtained knowledge and experience about the design principles and general behaviour of a jacket structure both in the ultimate limit state and in the accidental limit state. I also learned how to use the GeniE and USFOS software by performing linear and nonlinear analysis. This experience will be relevant and very useful for my future work.

I am indebted to my supervisors, Professor Ove Tobias Gudmestad and Ole Gabrielsen for the excellent guidance during this work, for a good number of valuable discussions, for reading and correcting diverse reports, articles and the drafts of this thesis.

I am very grateful to DNV for offering me the opportunity to study the topic. I have obtained a good deal of help and support from future colleagues. They always give me useful comments and suggestions, especially to Mr Yohannes Ayele, Mr Robert Ganski, Mr Andreas Sigvardsson, Dr Sung-Jin Choi and Dr Maneesh Singh.

I would also like to thank Nadina Memic and all the nice people contributing to such a positive working environment and such enjoyable lunch breaks. Thanks also to my dear sister, Qian. Her encouragement has always inspired me to overcome the difficulties in my thesis work.

Stavanger, June 2013

Lu Chai

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NOMENCLATURE

Abbreviations

ALS	Accidental Limit State
ASD	Allowable Stress Design
BS	Base Shear
COG	Centre of Gravity
DNV	Det Norske Veritas
DP	Dynamic Positioning
EN	European Standards
FEM	Finite Element Method
FLS	Fatigue Limit States
HAT	Highest Astronomical Tide
IMO	International Maritime Organization
ISO	International Organization of Standards
LAT	Lowest Astronomical Tide
LRFD	Load Resistance Factored Design
MWL	Mean Water Level
NORSOK	Norsk sokkels konkuranseposisjon
OTM	Overturning Moment
PSA	Petroleum Safety Authority
SLS	Serviceability Limit States
SMYS	Specified Minimum Yield Strength
ULS	Ultimate Limit State
VBA	Visual Basic for Applications

Units

Gg	Giga gram
MJ	Mega Joule
MN	Mega Newton
MPa	Mega Pascal

Symbols

ε	Green stain
γ_L	load factor
γ_M	material factor
ϕ	resistance factor
m	flotel mass
m_{added}	flotel added mass
v	impact speed
ρ	density
E	Young's modulus
ν	Poisson's ratio
α	thermal expansion coefficient
C_D	drag coefficient
C_M	inertia coefficient
H_s	significant wave height
T_p	spectral peak period
$U(z)$	one-hour mean wind speed
F_D	drag force
F_I	inertial force
$\mathrm{I_u(z)}$	turbulence intensity factor
θ_0	main wave direction
α_i	potential impact direction

CHAPTER 1

INTRODUCTION

1.1 Background

Fixed steel platforms are widely used in offshore developments. Several thousand jackets have been brought into operation worldwide as the concept is proven to be cost-effective at shallow to medium water depths (typically 5 to 150 m). A considerable number of new jackets are now either being planned or installed. Some of these new jackets are designated for mature fields where additional oil or gas may be recovered. Several other new jackets are planned for discoveries which have been made on the Norwegian Continental Shelf at water depths suitable for the jacket concept.

The primary function of a jacket structure is to support the weight of the topside structure by transferring the weight to the foundation. The jacket structure must be designed to resist design environmental loads (from wind and waves) and also accidental loads, such as boat impact, extreme environmental conditions and earthquake.

A jacket structure typically consists of tubular members of various diameters and wall thicknesses. The air gap between the sea surface and the bottom of the topside structure is made high enough to prevent waves from hitting the topside structure. At the bottom, the jacket is normally outfitted with a temporary foundation which supports the jacket until the permanent foundation is installed. Piles are typically used as the permanent foundation, and are connected to the jacket by pile sleeves and grouted connections.

In the case of a flotel impacting on a platform, the impact energy will be so large that it may have immeasurable consequences such as loss of human lifes and large economic, social or environmental ramifications. Thus reliable risk mitigation measures must be utilized to reduce the likelihood of the collision.

At present, it is not usual to perform rigorous analysis of jackets exposed to flotel collisions. This thesis implements the basic design principles of ship collision and several reasonable assumptions. A ductile design of a jacket structure is implemented. The fixed platform undergoes large plastic deformations and dissipates the major part of the collision energy. The collision effect is evaluated in accordance with the laws of conservation of momentum and conservation of energy. [11]

1.2 Aim of the Project

The first aim of this project is to design a conceptual jacket that has the capacity to resist selected functional and environmental actions, and to perform a first-pass structural optimization for an in-place Ultimate Limit State (ULS) analysis. The second objective is to study the jacket structure’s response when subjected to an accidental collision from a floating living quarter (flotel).

1.3 The Scope of Work

The thesis consists of the following activities:

1. Perform a literature study on jacket design and accidental collision on jacket structures.
2. Establish a Finite Element (FE) model of a conceptual jacket using a software package called GeniE.
3. Perform a global linear FE analysis of the conceptual jacket (ULS).
4. Perform a global nonlinear FE analysis simulating and predicting the behaviour of the jacket structure when impacted by a flotel (ALS).

1.4 Limitations

The primary focus in this thesis is conceptual jacket design in the ultimate limit state and how the flotel impact will affect the jacket structure. Therefore the following parameters are not taken into account:

- Temporary phases (fabrication, transportation, installation, removal)
- Fatigue Limit State (FLS)
- Service Limit State (SLS)
- Topside design
- Snow and ice loads
- Foundation design
- Typical extreme environmental and accidental actions such as 10^{-4} wave or wind loading, impact from ship collisions, impact from dropped objects, earth quake, fire and explosion

This thesis focuses on a single case study, in which a flotel providing additional accommodation is connected at the corner of a fixed platform (Figure 20). A DP (Dynamic Positioning) system is selected for the flotel's station keeping.

In this thesis a mechanics model is set up based upon the mechanics model of a vessel-to-jacket collision with the following assumptions [25]:

- The collision effect is evaluated in accordance with the laws of conservation of momentum and conservation of energy.
- The vessel is assumed to be a rigid body with certain speed and mass for the calculation of the collision effect on the platform structure, while the deformation of the vessel is neglected.
- The additional mass due to the hydrodynamic interaction between sea water and the ship is assumed as 40% of the vessel's mass.

Furthermore, the local deformation and damage of the deck is not considered in this study.

1.5 Organisation of the Thesis

This thesis consists of eight chapters.

CHAPTER 2 introduces the scope of the literature collection and related theories behind the procedure of modelling and analyses.

CHAPTER 3 briefly describes the principles behind GeniE and USFOS software.

In CHAPTER 4, the process of overall geometry modelling is described.

CHAPTER 5 presents the simulation of the external loads acting on the jacket structure in the ULS analysis such as permanent load, variable load, wind load, and wave and current load. In addition, the soil condition and the effect of marine growth are considered.

CHAPTER 6 discusses the results of code checking for an eight-legged jacket and an alternative six-legged jacket. The strengthening of the jackets is performed by changing the thicknesses of pipes several times and redesigning joints.

CHAPTER 7 illuminates the responses of the jackets when an impact from a flotel is involved.

The major conclusions of the work and the suggestions for future work are summarized in CHAPTER 8.

CHAPTER 2

LITERATURE SURVEY

2.1 Scope of Literature Collection

In Norway, the design of facilities in the petroleum industry is governed by the PSA (Petroleum Safety Authority of Norway) [16]. The regulatory role of the PSA covers activities from planning and design through construction and operation to possible ultimate removal, relating to technical and operational safety [29].

Figure 1 illustrates the hierarchical levels of design guidance. Most of the petroleum activities are based on International Standards (ISO) and European Standards (EN). However, the Norwegian safety framework and climate conditions may require their own standards or additions and supplements to ISO and EN standards. The NORSOK standards are developed to fulfil these needs [30].

The relevant ISO standards, NORSOK standards and DNV OS-standards are compared to understand the different design requirements. In addition, several books, papers and technical reports of marine structural design are collected to be able to reinforce the principles of design.

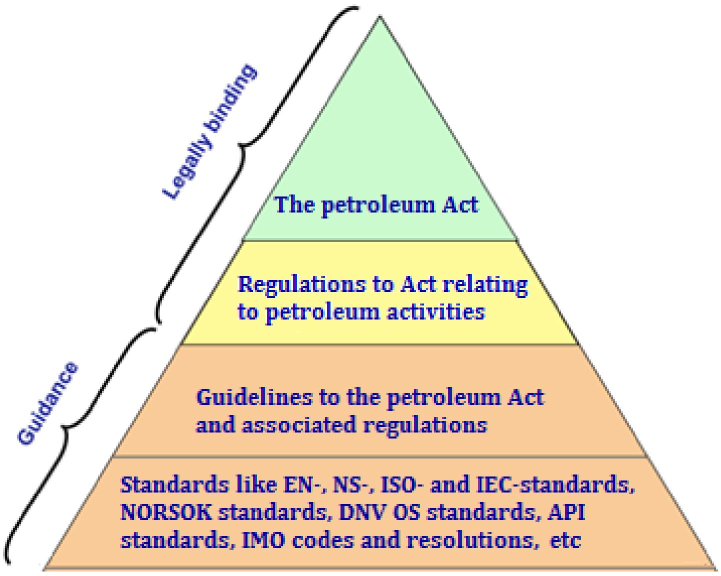


Figure 1 The hierarchical level of the acts, regulations, guidelines and standards [29]

2.2 Conceptual Design Considerations

Jacket design is generally a very complex task. A jacket should be designed depending on the purpose and ocean environment for supporting massive facilities. The subsections below contain the main considerations for first-pass design.

2.2.1 Maximum Topside Weight

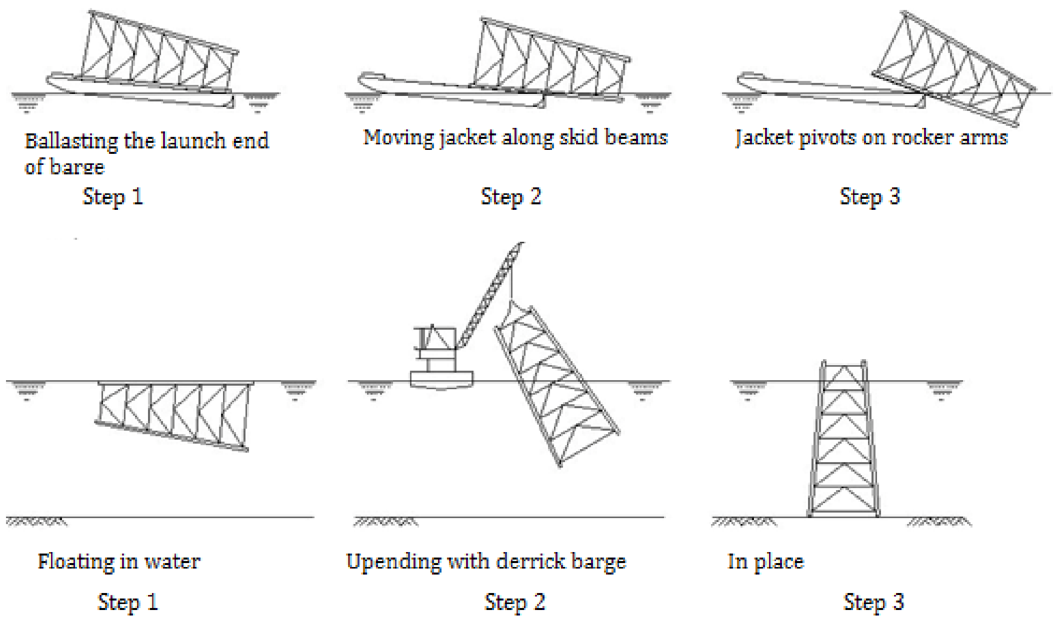
Due to their different main functions, platforms may have one or all of the separate modules or function areas such as living quarters, utility area, wellhead area, process area and drilling area. The maximum topside weight refers to the sum of the fixed and variable payloads under maximum operational loads [18]. The topside weight will establish the weight capacity required for the substructure. If the topside weight is underestimated as a result of poor estimation techniques or changes in the design basis, redesign of the substructure can cause large cost and schedule implications.

2.2.2 Environmental Conditions

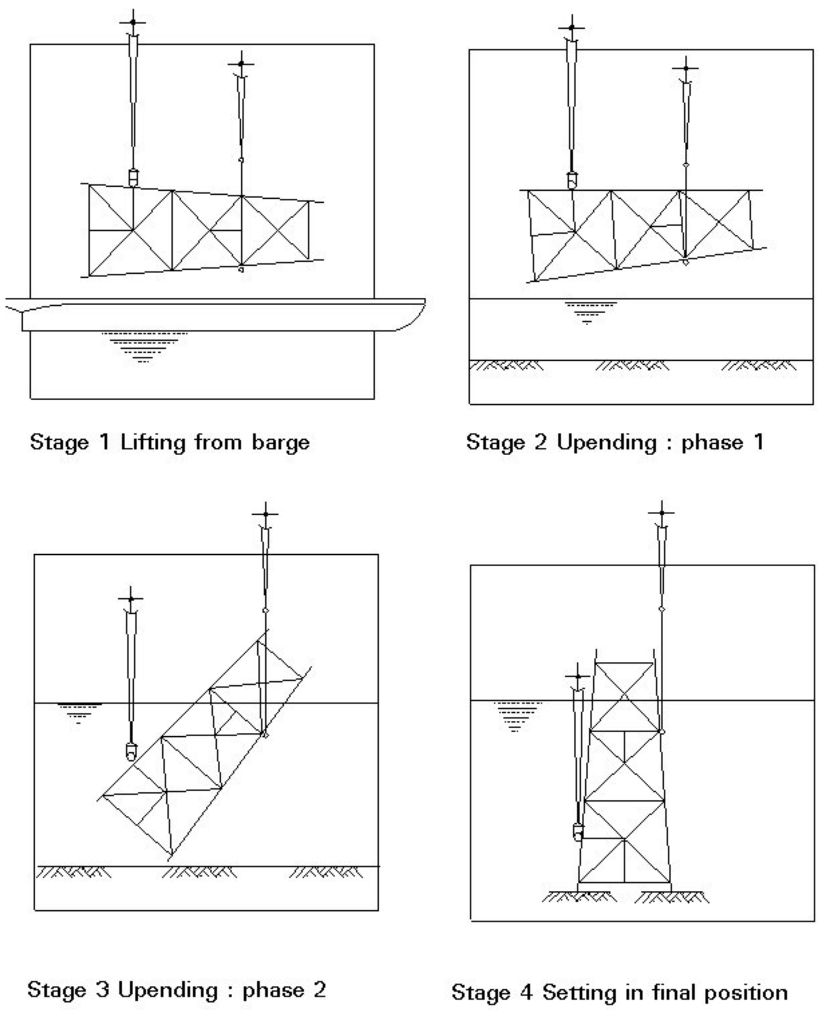
An assessment of the environmental criteria includes a detailed review and evaluation of relevant reports and data on the various environmental parameters that will affect the design of the structure. The most essential environmental parameters include water depth, wave conditions, wind conditions, current, soil conditions, snow and ice accumulation, marine growth, air and water temperature extremes, and earthquake loads [14].

2.2.3 Temporary Phases

According to the mode of installation, the jackets are classified as self-floating jackets, barge-launched jackets or lift-installed jackets. In the early days, the self- floating jacket was most commonly used, as it requires a minimum of offshore installation equipment. With modern heavy lift vessels, now being up to 14000 tonnes, many jackets with weights less than this magnitude have been lift-installed into position [13]. Figure 2a shows the most simple use of a crane to up-end and set-down a jacket that is launched. A second method is to up-end directly, as shown in Figure 2b. This requires special padeyes so that the necessary rotation between slings and jacket can occur [31].



a) Installation of jacket by launching [31]



b) Installation of jacket by lifting [31]

Figure 2 Alternative jacket installation methods

2.3 Limit States

A Limit State is a condition beyond which a structure or part of a structure will no longer meet the requirements laid down for its performance or operation [1]. NORSOK N-001 and ISO19900 divide the limit states into the following four categories:

- the ultimate limit states (ULS) that generally correspond to the resistance to maximum applied actions
- the serviceability limit states (SLS) that correspond to the criteria governing normal functional use
- the fatigue limit states (FLS) that correspond to the accumulated effect of repetitive actions
- the accidental limit states (ALS) that correspond to situations of accidental or abnormal events

In consideration of technical and operational safety, the design of structures should be checked for all groups of limit states. Since this thesis merely focuses on strength for ULS and partially ALS, the FLS and SLS will not be further discussed herein.

2.4 Design Load and Design Resistance

Design codes compensate for the uncertainty which exists in the structural design by ensuring that the safety margin between the maximum likely loads and the resistance of the structure is large enough. Uncertainties are handled in Allowable Stress Design (ASD) codes through a factor of safety, in which only a single variable is used to handle all uncertainty in both load and capacity [8]. The Load Resistance Factored Design (LRFD) comprises of partial safety factors and resistance factor reflecting the uncertainties [9]. The general form for the LRFD method is [9, 22]:

$$\phi R_n \geq \gamma_d Q_d + \gamma_{t1} Q_{t1} + \gamma_{t2} Q_{t2} + \cdots + \gamma_{ti} Q_{ti} \qquad \mathbf{1}$$

where

R_n= nominal resistance

Q_d= nominal dead load effect

Q_{t1} ... Q_{ti}= nominal transient load effects

γ_{ti}= load factor associated with the i^{th} load effect

ϕ= resistance factor

Partial action factors are given in Table 6. NORSOK N-001 requires that the partial action factors comply with two conditions: **a)** ULS-a governs for extreme permanent loads with regular environmental conditions, and **b)** ULS-b governs for large permanent loads with extreme environmental conditions [1].

2.5 Finite Element Method

The global analysis of a steel jacket structure starts from defining the geometrical and material properties of the structural members, the foundation properties and functional, environmental and accidental loads. Over the decades the finite element method has been widely used in the design of complex marine structures. Figure 3 illustrates the process of a structural design based on finite element analysis [20].

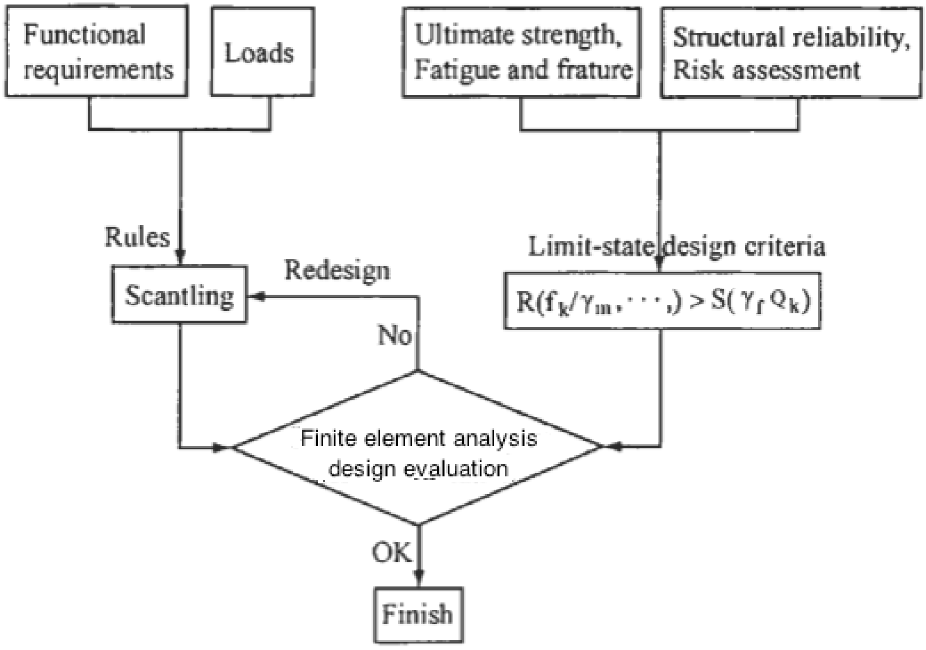


Figure 3 Modern theory for marine structural design [20]

Different types of elements are applied to various types of structures and critical areas where loads or stresses are concentrated. For a simplified linear analysis of the jacket structure, the 3D-beam element is preferred. This two-node beam element has six global degrees of freedom for each node.

Nonlinear finite element methods are being used in collision response analysis to an ever-increasing extent. This requires rigorously detailed shell finite element modelling of both the flotel and the platform. However, for design purposes, a simplified nonlinear space frame analysis has become an accepted tool for jacket structure analysis [24].

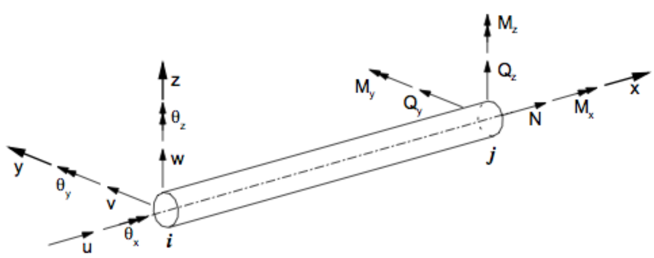


Figure 4 Three-dimensional beam element [17]

2.6 Linear versus Nonlinear Structural Analysis

In this thesis, two types of structural analysis will be performed:

- a linear elastic analysis to check the ultimate strength following industry codes (NORSOK standards)
- a nonlinear finite element analysis of the structural response to flotel collision

The aim of jacket design is to have a characteristic capacity higher than the characteristic environmental loads with a return period of typically 100 years multiplied by some partial safety factors for loads and resistance. The curve in Figure 5 illuminates the relationship between the displacement and the impact load acting on the structure. The figure shows an increasing impact load and the increasing displacement increases until the first member is buckled. The buckling of that member reduces the resistant capacity, but the integrity is not lost. Many components are redundant and may be capable of redistributing stresses and loads.

In a linear structural analysis with respect to ultimate limit state design (ULS), the characteristic capacity is normally taken as first yield or first component buckling. This means that many structures possess significant strength reserves. Thus linear analysis leads to excessively conservative solutions, which will be used in conventional first-pass design procedure for ULS design [24].

Various circumstances may cause the design basis to be changed, e.g. following a reassessment of the strength when the jacket suffers a collision from a flotel. Determining the structural capacity over first yield requires that several nonlinear effects be accounted for. Three types of nonlinearities may arise, in the form of material nonlinearity, geometrical nonlinearity and contact nonlinearity. If we consider a load increment from state n to n+1, assuming that the external forces and the internal forces are balanced at load level n, iterations at state n+1 are carried out until equilibrium is fulfilled for the new external load level n+1. Such procedures are denoted as incremental-iterative. In a static analysis, the nonlinear response is usually simulated in an incremental-iterative way [24].

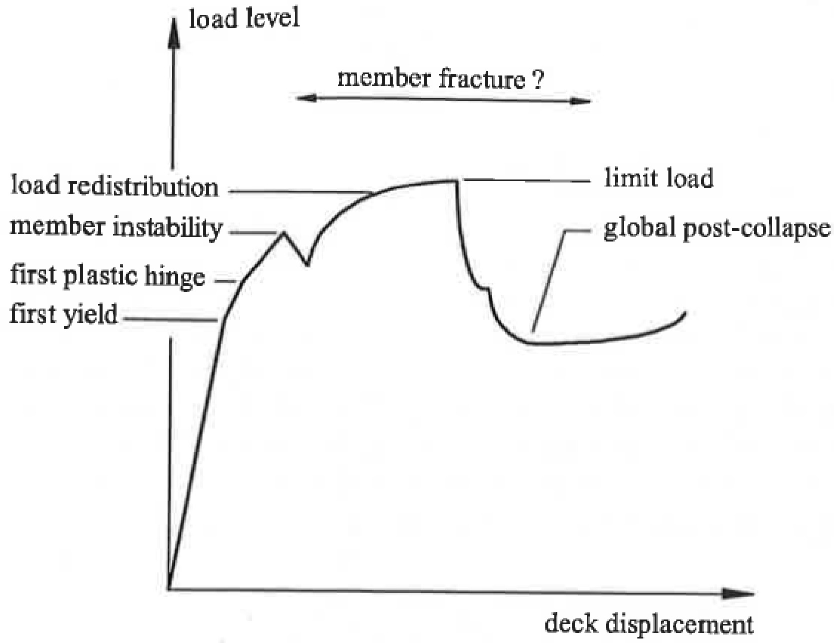


Figure 5 Global load-displacement relationship diagram [24]

2.7 In-Place ULS Analysis

In a linear ULS analysis, if tubular members of a jacket do not satisfy the ultimate strength requirements, resulting in yielding or buckling, it is assumed that the tubular member is not fit for the purpose. Ultimate strength criteria advocated in various codes specify structural strength and stability requirements for jacket tubular members to avoid yielding or buckling. The buckling of a member could be either lateral deformation in the length direction of a column or hoop buckling. Tubular members subjected to combined axial compression and bending may give rise to lateral buckling. The effect of hydrostatic pressure loading on a column may lead to hoop buckling [1, 20, 21].

As discussed above, the aim of in-place ULS design with respect to code checking is to avoid buckling of members. It is important to determine the maximum base shear force of the environmental loads for dimensioning of jacket bracings. Meanwhile, the maximum overturning moment should be established for dimensioning of jacket legs. Thus a proper simulation of the environmental loads is needed.

Usually the simulation is based upon the description of environmental conditions according to the metocean design basis of the specified oil field. The wave observations may be sorted for different sectors with respect to the main wave directions (**Figure 6**). Each main wave direction, θ_0, denotes the middle direction for each of the defined sectors. The angle θ_i is an angle between each main wave direction i and a given reference direction [13]. The specified main wind directions follow the same method. The sector numbering and specified wind and main wave directions are shown in **Figure 6** and **Figure 7**.

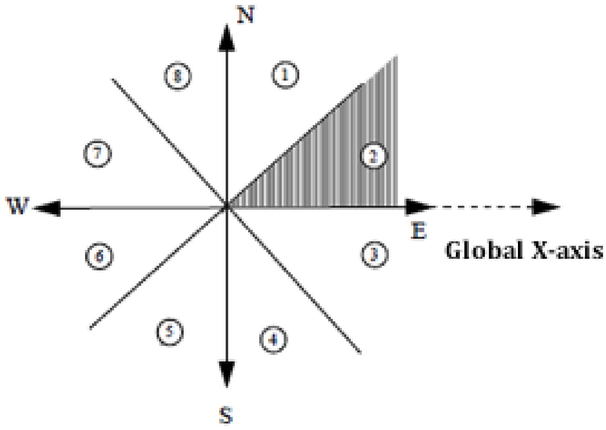


Figure 6 Wave approach direction for ULS analysis [13]

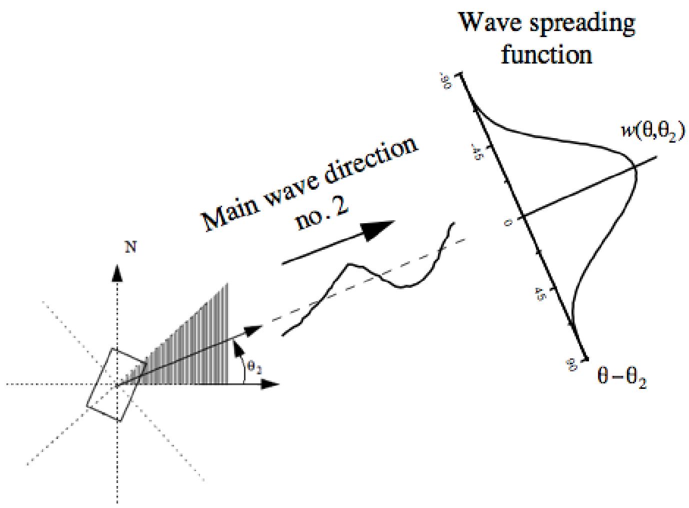


Figure 7 Main wave direction in the structure co-ordinate system [13]

2.8 Offshore Fixed Steel Structures Exposed to Flotel Collision

2.8.1 Design Principles

Extensive research has been carried out on ship-to-jacket collision. The concerns for ship collision are reflected in various design codes [1, 8, 11]. It is unusual to perform rigorous analysis of the jacket exposed to flotel collision.

The analysis of a ship collision with a fixed platform is a very complex problem due to inelastic material and nonlinear geometric behaviour, dynamic effects (inertia, stain rate) and finite material ductility [10]. It is virtually impossible to perform rigorous analysis. In this thesis the mechanics model is set up based upon the mechanics model of a vessel-to-jacket collision with the following assumptions, which are considered to be conservative with respect to the effects on the jacket [25]:

- The collision effect is evaluated in accordance with the laws of conservation of momentum and conservation of energy.

- The vessel is assumed to be a rigid body with certain speed and mass for the calculation of the collision effect on the platform structure, and the deformation of the vessel is neglected.
- The additional mass due to the hydrodynamic interaction between sea water and the ship is assumed as 40% of the vessel's mass.

A significant part of the collision energy is dissipated as strain energy. The design concept with respect to the distribution of strain energy dissipation may distinguish between strength design, ductility design and shared-energy design (Figure 8) [1]. The ductile design is applied in this work. The jacket is assumed as a "soft" body that dissipates the major part of the collision energy and the flotel is simply considered as a "rigid" body.

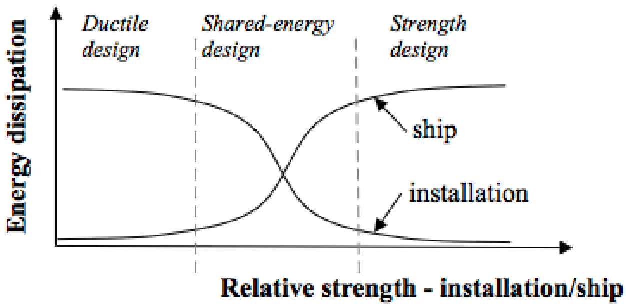


Figure 8 Energy dissipation for different designs [1]

The collision energy from a flotel could be taken as [1]:

$$E = \frac{1}{2}(m + m_{added})v^2 \qquad \mathbf{2}$$

where

m = flotel mass

m_{added} = flotel added mass

v = impact speed

2.8.2 Static Analysis versus Dynamic Analysis

Analysis of collision mechanics is generally to be based upon the solution of the differential equations of the dynamic equilibrium such as conservation of momentum and conservation of energy [11]. Several study results such as ref. [24] and [27] show that the selection of static analysis or dynamic analysis depends on the ratio between collision duration and natural period of the governing motion. If the former is smaller than the latter, the dynamic analysis is more appropriate. For collision durations, which are quite long relative to the natural period for the governing motion, a static solution applies. Normally, static analysis is considered appropriate when evaluating the possible dynamic magnification [27].

CHAPTER 3

BRIEF DESCRIPTION OF SOFTWARE

3.1 General

GeniE is related to the rest of the SESAM system through the SESAM Interface File. It may be used either as a stand-alone tool or in a super element analysis. It will do all modelling, analysis, and results presentation within the same user interface [12].

USFOS, developed by SINTEF Civil and Environmental Engineering, is a finite element program for nonlinear static and dynamic analysis of frame structures. USFOS can deal with geometric nonlinearities due to large lateral displacements and nonlinear material properties [15].

3.2 Finite Element Model

Prior to performing a linear static analysis, GeniE will automatically create a finite element mesh with two-node beam elements, then perform the wave load analysis using a file named WAJAC, and produce a result file that can be accessed by GeniE.

This thesis does not cover any strength assessment of piles. In the analyses, piles that interact nonlinearly with the soil are modelled merely for providing foundation supports. GeniE provides specific pile concepts for this purpose. A pile also relates directly to soil layers and sub-layers in such a way that the division of the pile into nodes and elements is a direct function of the soil layer description. The piles modelled by beams are meshed as two-node beam elements in the finite element model; thereby the piles belong to the first level super-element. In addition, nodes along the piles are automatically defined as super-nodes. GeniE automatically creates a second level super-element and "lifts" all load cases and load combinations to the second level super-element in order to carry out the nonlinear analysis [12].

The connection between GeniE and USFOS goes through the SESAM FEM file. The original structural model in GeniE becomes "read only" and an "intelligent filter" transfers the "linear" model into a model accepted by the USFOS software (Figure 9). USFOS interprets and directly uses the structural information stored in this file. All relevant element information is taken from the FEM file, such as cross-sectional properties and orientation, element end offsets and material properties [15].

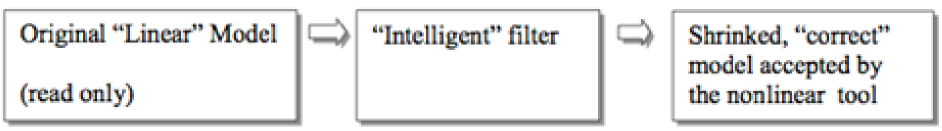


Figure 9 Model repair solution [15]

3.3 GeniE

In this thesis, the computer program GeniE is utilized for implementing the following functions:

- Model jacket structure, environmental and other loads
- Calculate hydrodynamic loads and run static structural analyses
- Visualise and post-process results
- Perform code checking based on NORSOK N-004

3.4 USFOS

In this thesis, the non-linear static analysis of flotel collision is essentially similar to a pushover analysis. The major difference is that the general loading situation (e.g. impact energy, position and direction) and not the actual impact loads should be specified.

The formulation behind USFOS is valid for large displacements, but is restricted to moderate strains. Instead of using a traditional engineering strain, the USFOS formulation is based on *Green strain E*. Green stain will be denoted ε herein. Thus the axial strain can be expressed as follows [15]:

$$\varepsilon_x = u_{,x} + \frac{1}{2}u_{,x}^2 + \frac{1}{2}v_{,x}^2 + \frac{1}{2}w_{,x}^2 \qquad \mathbf{3}$$

where u, v and w are displacements respectively in the x, y and z axes. Subscript x denotes differentiation with respect to x. For moderate element deflection, the von Karman approximation applies, and ε_x simplifies into [15]:

$$\varepsilon_x = u_{,x} + \frac{1}{2}v_{,x}^2 + \frac{1}{2}w_{,x}^2 \qquad \mathbf{4}$$

The stiffness formulation of USFOS is derived from potential energy consideration or the virtual work principle. For an elastic beam element the internal strain energy reads [24, 15]:

$$\begin{aligned} \mathrm{U} &= \frac{1}{2}\int_V \sigma_x \varepsilon_x dV \\ &= \frac{1}{2}\int_0^l EA(u_{,x} + \frac{1}{2}v_{,x}^2 + \frac{1}{2}w_{,x}^2)^2\, dx + \frac{1}{2}\int_0^l (EI_z v_{,xx}^2 + EI_y w_{,xx}^2)\, dx \end{aligned} \qquad \mathbf{5}$$

where EA and EI are axial and bending stiffness, respectively.

CHAPTER 4

DESIGN AND MODELLING OF JACKET

4.1 Introduction

This chapter presents the modelling process of a traditional eight-legged jacket for the purpose of supporting 25000 tonnes maximum operation weight located in Block 15/3 on the Norwegian Continental Shelf, at a water depth of 115 m. An alternative six-legged jacket is modelled in order to compare the effects of X- and K-braced patterns.

The jacket design is governed by the following [13]:

- Functional requirements, i.e., support of the topside
- Water depth
- Foundation soil conditions
- Environmental conditions, i.e., wave, current, wind, marine growth

However, this is merely a coarse design considering the material properties of the structural, members and tubular joint design. The processes of code checking and redesign of structures are described in CHAPTER 6**.**

4.2 Water Depth

This conceptual jacket is assumed to be designed for an oil field located in Block 15/3 in a water depth of 115 m in the Norwegian sector of the North Sea. The maximum wave height in a 100-year return period is **27.7m** based on environmental parameters in a metocean report of this block.

According to NORSOK N-003, an appropriately conservative significant wave height could be selected from **Figure 10**. The solid lines indicate the ISO-curves for wave height while wave period lines are dotted. With respect to the location of this block, $\mathbf{H_s}$ is estimated as 15m. According to NORSOK N-003, the maximum wave height in a 100-year return period for the area of interest for this study can be calculated conservatively as **28.5m** by using 1.9 times $\mathbf{H_s}$.

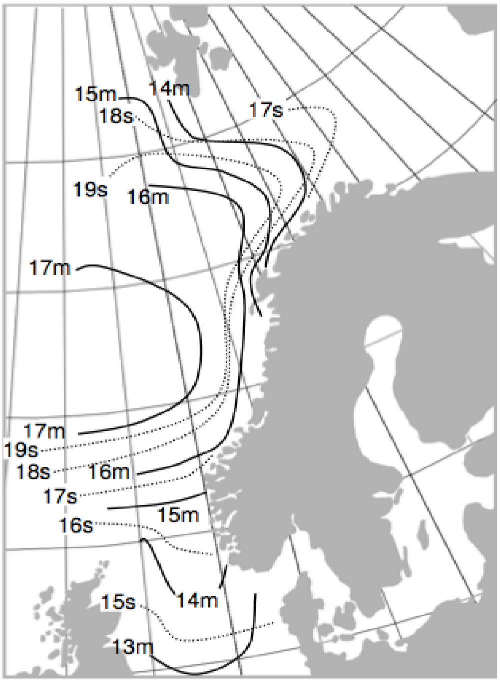


Figure 10 Significant wave height $\mathbf{H_s}$ and related maximum peak period $\mathbf{T_p}$ with annual probability of exceedance of $\mathbf{10^{-2}}$ [3]

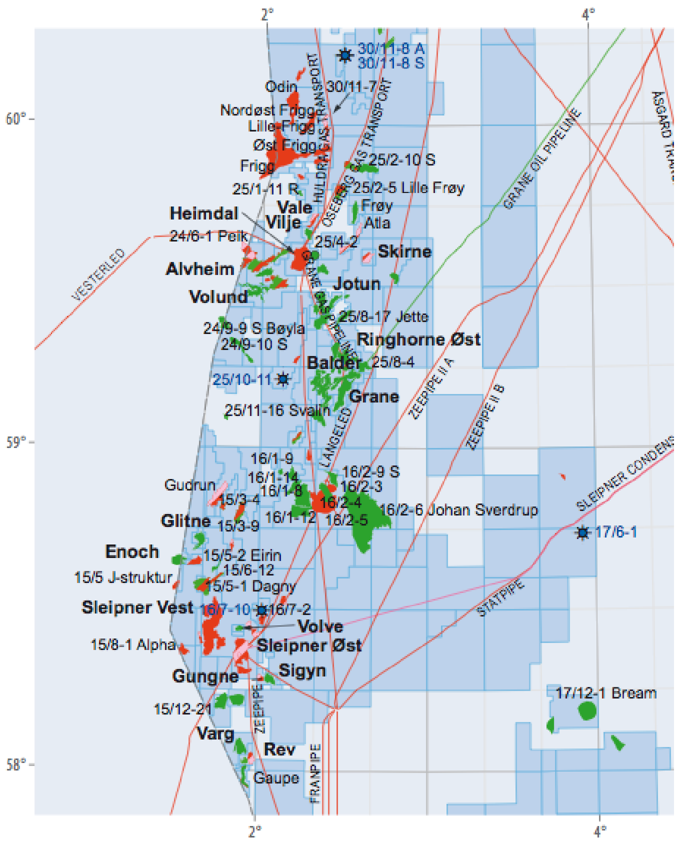


Figure 11 Oilfield blocks in middle of North Sea

4.3 Design of Jacket Overall Geometry

4.3.1 Leg Batter

As shown in Figure 12, the batter of a jacket leg is defined as the slope ratio between the vertical axis and the leg. The selection of batter patterns has a significant effect on the stability of the jacket. According to the study of reference [21], if there are no restrictions on the required stability during installation, the recommended batter is 1:8 or 1:7. Considering the difficulty in welding, we avoid selecting a pattern which has an angle between a brace and the leg smaller than 30° [1, 6].

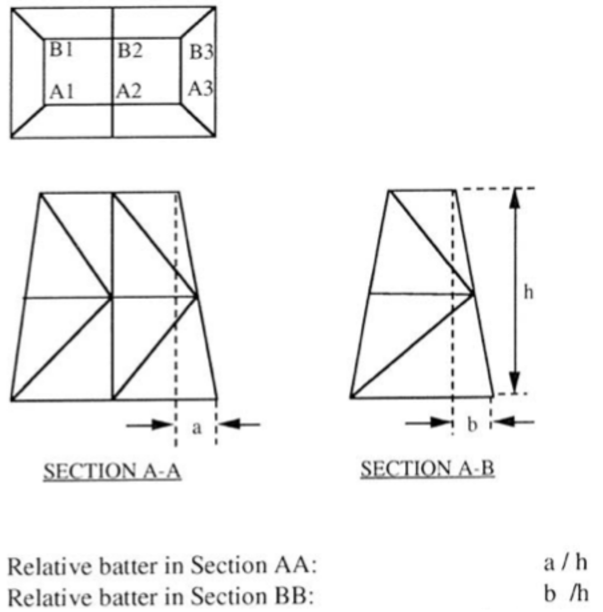


Figure 12 Leg batters of jacket

4.3.2 Brace Pattern Design

There is a wide variation in platform bracing patterns which could be selected such as single diagonals, cross-braces, K-braces and combinations of these patterns. Several of these patterns are shown in Figure 13.

In this work, an eight-legged jacket with **V- plus X-braced pattern** (type 4 brace pattern) is selected, since this pattern is providing adequate symmetry, redundancy and ductility in common use for most offshore locations. The disadvantage of this pattern is the higher number of brace connections at the joints and the V braces at the transverse directions framing into horizontal braces [19].

A **fully X-braced pattern** is selected for design of the six-legged jacket. This pattern type provides high horizontal stiffness, ductility and redundancy. However, the joints in this pattern are crowded and require a high volume of welding. Thus this bracing pattern is in popular use for jackets located in deep waters, where stiffness is needed to reduce sway periods, and in seismically active regions, where ductile behaviour is important [19].

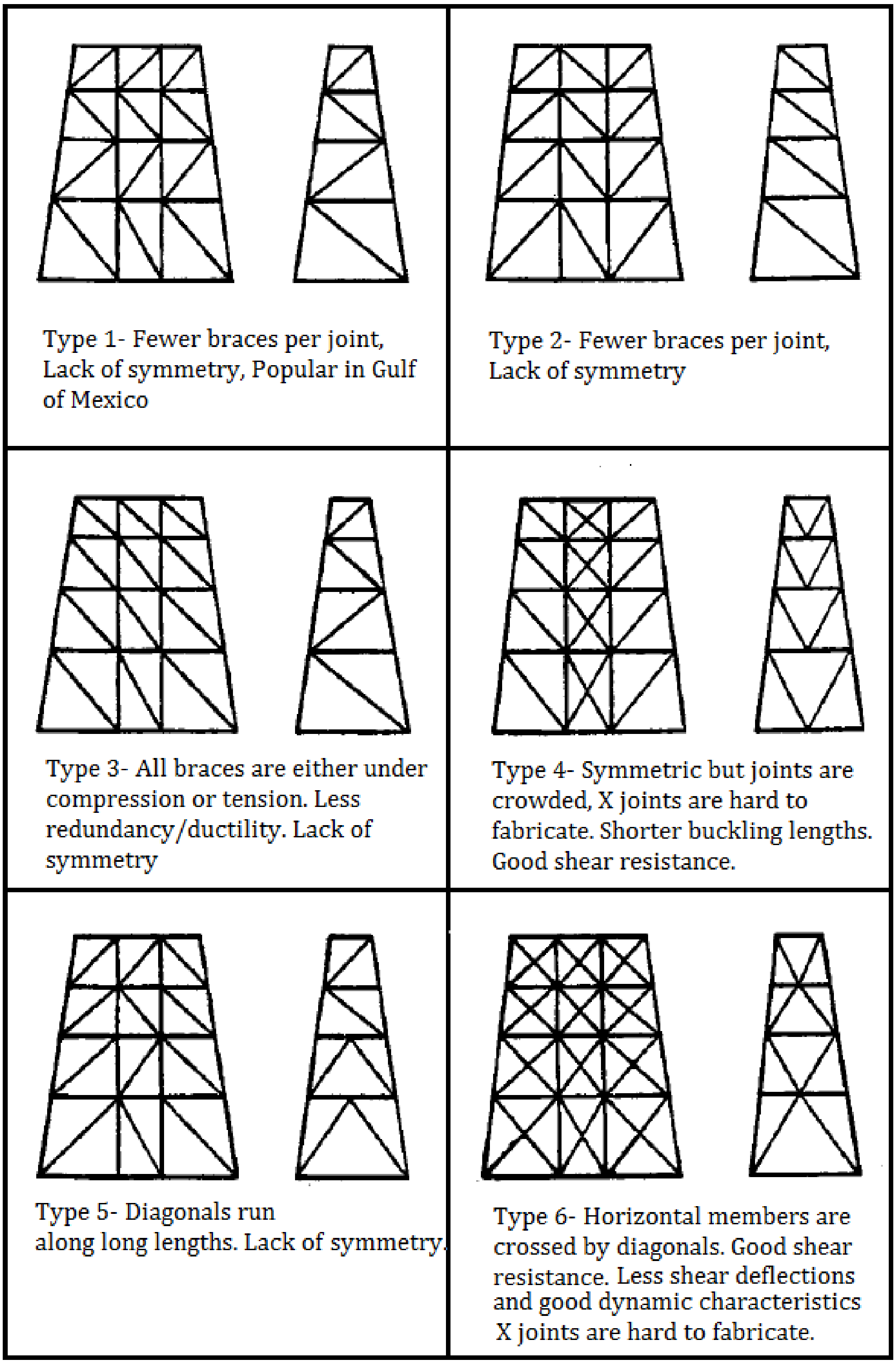


Figure 13 Various bracing patterns [19]

4.3.3 Minimum Height of Jacket

The water depth can be considered to be a more or less stationary design parameter. Thus the minimum height of a jacket should be chosen such that it has available space from the wave crest to the underside of the deck. The minimum height of a jacket could be calculated considering the parameters shown in Figure 14. A conservative maximum wave height of **28.5m** in a 100-year return period (from Section 4.2) is used in this calculation. NORSOK N-003 states the wave height, H_{10000} with annual exceedance probability 10^{-4} can be taken to be 1.25 times H_{100}. Thus the magnitude of H_{10000} is $\mathbf{35.7}\boldsymbol{m}$.

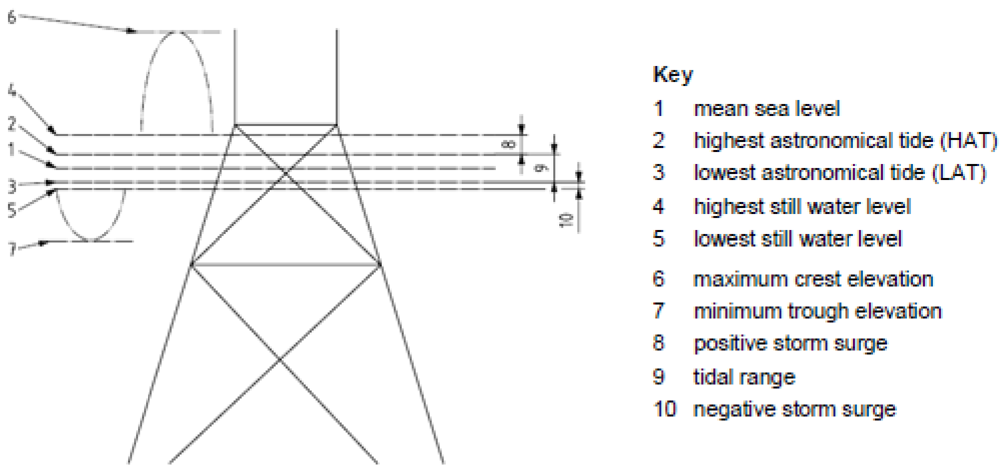


Figure 14 Water depth, tides and storm surges [5]

The requirements and guidance for air gap are given in NORSOK N-003. Due to the complexity and uncertainty associated with determining actions associated with waves hitting the platform's decks, an air gap margin of **1.5 m** on the 10^{-2} wave event is recommended to fulfil the ULS criteria [3].

Several assumptions, such as astronomical tide, storm surge and settlement, are made for dealing with the uncertainties in the design. Consequently, the minimum design height of the jacket is calculated by using the following parameters:

• mean sea level	115	m
• maximum crest elevation (60% of H_{10000})*	21.4	m
• astronomical tide	1.5	m
• storm surge	0.8	m
• settlement	2.5	m
• air gap	1.5	m
Total	**142.7**	**m**

**Note: 5th order stokes wave theory*

4.4 Material Properties

Table 1 and Table 2 list the specified material properties that apply for the structural design. The properties of steel grades S355 and S420 are specified in NS-EN 10025-3. The material factor γ_M is 1.15 in ULS, which is indicated in NORSOK N-004.

Table 1- Material properties

Density	$\rho = 7850\ \mathrm{kg/m^3}$
Young's modulus	$E = 2.1 \cdot 10^{11}\ \mathrm{Pa}$
Poisson's ratio	$\nu = 0.3$
Thermal expansion coefficient	$\alpha = 1.2 \cdot 10^{-5}\ /°\mathrm{C}$

Table 2- The material selection for the structural steel materials

Structural element	**Specified min. yield strength (MPa)**
Legs	420
Primary members	420
Secondary members	355
Piles	420

4.5 Modelling Processes

The design stages of jacket overall geometry introduced in Section 4.3 are programmed in "GeniE wizard" which is an Excel-based tool using VBA macros to create a journal file. This file includes the nodes and elements of the jacket that can be imported to GeniE.

- Identify the structure as an eight-legged/six-legged jacket in the wizard.
- Identify the minimum design height of the jacket.
- Due to the design height of the jacket, calculate and select numbers of bays and each bay's height.
- Select batter ratio and the brace pattern
- Determine the pipe dimensions and material properties separately for legs, piles and horizontal and vertical braces.
- Import model from the wizard into GeniE.
- Include pile modelling and then mesh and complete the jacket model.
- Build a simplified topside model with I-beams and plates

CHAPTER 5

MODELLING OF ENVIRONMENTAL CONDITIONS

5.1 Introduction

An important task in the design of jacket structures is the identification and modelling of all significant loads and load combinations which the structure is exposed to during the service life. This section mainly clarifies the principles of load combinations performed in GeniE (Figure 15).

In this thesis, the wave condition is divided into eight sea states. The origin of the coordinate system is located at Mean Water Level (MWL) in the geometric centre of the jacket. The reference direction is defined as the global x-axis which is pointing towards east. The Z-coordinate points upwards. Both the models and the load combinations from eight different directions follow the same coordinate system.

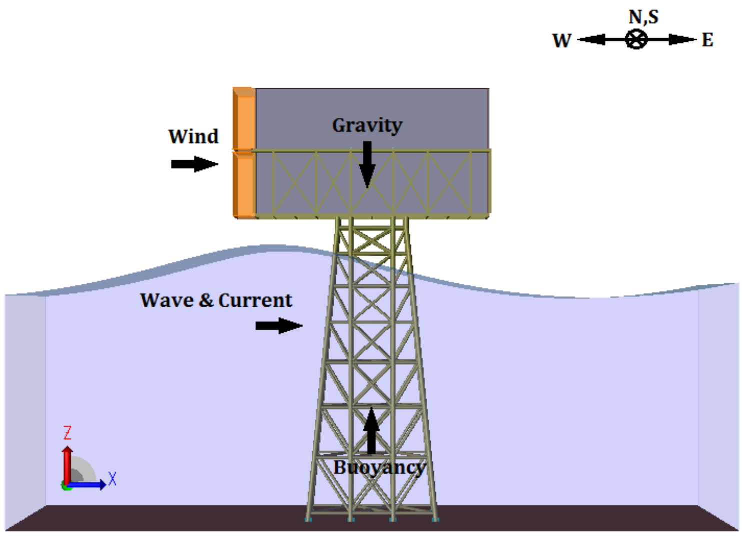


Figure 15 An example of load combinations in GeniE

5.2 Permanent Load and Variable Load

The permanent load model is simulated on the basis of the following:

- mass of jacket (including piles above mud line)
- mass of permanently installed topside and appurtenances supported by the jacket and/or topside
- buoyancy and hydrostatic pressure from sea water
- mass of marine growth

The “not to exceed weight” is assumed as 25000 tonnes. All the contingencies such as mass of accommodation, production equipment and appurtenances are included in the proposed value. In addition, a specified envelope of centre of gravity is utilized to account for variable actions on deck areas (Table 3).

In GeniE, the self-weight of the topside is not included in the calculation. Instead, an equipment box of 25000 tonnes is placed at the location of the topside. The length and width of the equipment are the same as for the topside. The equipment mass is converted to a line load distributed on the frame of the topside. The model of the envelope of the Centre of the Gravity (COG) is build up by changing the COG of the equipment box in eight load cases.

Table 3- COG of topside in GeniE using MWL as reference

	X (East)	Y (North)	Z (Vertical)
Nominal COG for Maximum Operation Weight	0	0	48
The COG envelope	+/-2.0 m	+/-1.0 m	+/-1.0 m

5.3 Environmental Data

According to NORSOK N-003, the environmental parameters shall be based on observations from or in the actual location and on general knowledge about the environmental conditions in the area [3]. The environmental data is based on a metocean design report of an oil field located in Block 15/3. The following environmental parameters are included and shown in Appendix A:

- 1-hour mean wind speed, $U(z)$
- specified wind and main wave directions
- current speed
- significant wave height, H_s
- the spectral peak period, T_p

5.4 Wave and Current Forces

A region of validity of various wave theories has been calculated and developed for the purpose of satisfying designers in choosing the appropriate wave theory for the individual design case. They are applicable to different environments dependent upon the specific environmental parameters, e.g., water depth (d), wave height (H) and wave period (T) [17, 18].

Figure 16 indicates the ranges of valid wave theories. In this thesis, the Stokes 5^{th} order wave is employed in calculations for waves and current loads by using *Morison’s equation*, where the calculations are automatically performed by WAJAC.

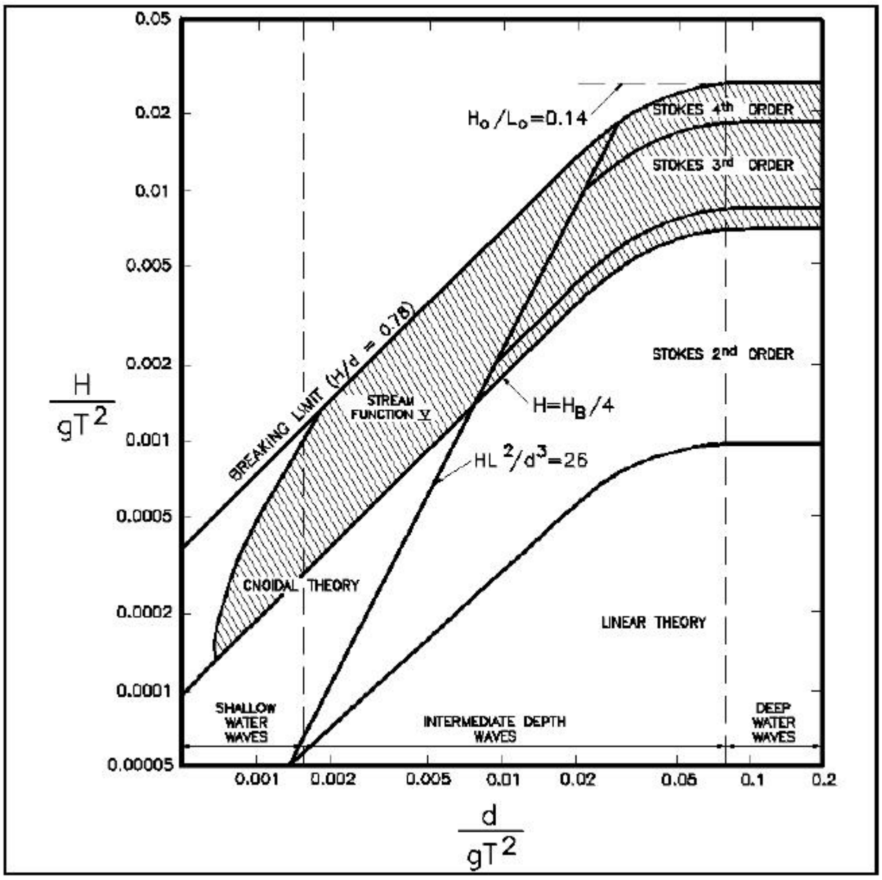


Figure 16 Ranges of suitability of various wave theories [18]

Morison's equation, widely employed in engineering calculations, may be expressed as [17]:

$$f = \frac{1}{2}\rho C_D D|u|u + \rho C_M \frac{\pi D^2}{4} \mathrm{a_x} \qquad \textbf{6}$$

where ρ denotes water density and D denotes the diameter of the cylinder. In this thesis, the coefficients $C_D = 0.65$ and $C_M = 1.6$ are known respectively as the drag and inertia coefficients.

The total horizontal force F exerted on a length of the cylinder ranging from $y = 0$ to $y = y$ is easily seen to be given by the relation:

$$F = \int_0^y f(y)\, dy \qquad \textbf{7}$$

Similarly, the total moment M about $y = 0$ of the force exerted on that part of the cylinder ranging from $y = 0$ to $y = y$ is given by:

$$M = \int_0^y y f(y)\, dy \qquad \textbf{8}$$

When finite-amplitude Stokes waves are considered, the calculation of wave forces from Equation (6) may be expressed as [17]:

$$f = \frac{\rho C_D D^2}{2k^2} \sum_{m=1}^{4} \sum_{n=1}^{5-m} U_m U_n |cos\ \omega t|\ cos\ \omega t - \frac{\rho C_I \pi D \omega}{8k} \sum_{n=1}^{5} R_n \sin n\omega t \qquad \mathbf{9}$$

where the U_n and U_m are velocity coefficients and R_n are acceleration coefficients. Substituting this result into Equation (7), we then find the total force $F(y)$ acting on a cylinder segment of height y above the seafloor expressible in terms of drag and inertia forces, F_D and F_I, as [17]:

$$F(y) = F_D(y) + F_I(y) \qquad \mathbf{10}$$

5.5 Wind Force

The wind force is applied as uniformly distributed on the surface of the topside which is simulated with several plates. The calculation of wind force is attached in Appendix A. The characteristic wind velocity $u(z, t)$ at a height $z(m)$ above sea level and with a corresponding averaging time period t less than or equal to $t_0 = 3600\ s$ may be calculated as [3]:

$$u(z, t) = U(z)(1 - 0.41 I_u(z) \ln(t/t_0)) \qquad \mathbf{11}$$

where the one-hour mean wind speed U(z) is given by:

$$U(z) = U_0 \left[1 + C\ ln(\frac{Z}{10})\right]$$

$$C = 5.37 * 10^{-2}(1 + 0.15\ U_0)^{0.5} \qquad \mathbf{12}$$

and where the turbulence intensity factor $I_u(z)$ is given by:

$$I_u(z) = 0.6[1 + 0.043\ U_0](\frac{Z}{10})^{-0.22} \qquad \mathbf{13}$$

where U_0 is the one-hour mean wind speed at 10 m above the still water level.

The mean wind force, F, acting normally on the surface of the topside model, is calculated by [3]:

$$F = \frac{1}{2} \rho C_s A {U_m}^2 \sin \alpha \qquad \mathbf{14}$$

where

- ρ =the mass density of air
- C_s =the shape coefficient
- A =the area of the member or surface area normal to the direction of the force
- U_m =the wind speed
- α =the angle between the direction of the wind and the axis of the exposed member or surface

5.6 Marine Growth

Marine growth may give rise to increased weight, increased hydrodynamic added mass and increased hydrodynamic actions, and may influence hydrodynamic instability. For typical design situations, global hydrodynamic action on a structure can be calculated using Morison's equation, with the values of the hydrodynamic coefficients for unshielded circular cylinders [6]. In practice, jacket members located more than 2 m above sea level are smooth, and members below 2 m above sea level are rough. Table 4 shows the applied values for thickness of marine growth in the calculation of structural actions, as indicated in NORSOK N-003 and ISO 19902 [6, 23].

Table 4- Thickness of marine growth

Water depth (m)	**Thickness** (mm)	**Drag Coefficient**	**Mass coefficient**
Above +2	0	0.65	1.6
+2 to -40	100	1.05	1.2
Under -40	50	1.05	1.2

5.7 Soil Condition

The analyses include the effect of the non-linear soil stiffness through the soil-structure interaction software named SPLICE. The soil model is subdivided into five layers. In the absence of more detailed documentation, the soil properties are estimated from a design basis report indicated in Table 5.

Table 5- Soil layers

Depth below seabed (m)		**Type of soil**	**Density** (kg/m^3)	**Soil-pile friction angle**
From	To			
0	-3.5	Sand I	1990	40
-3.5	-5.5	Sand II	1990	36
-5.5	-70	Clay I	1940	-
-70	-80	Sand III	2040	37
-80	-115	Clay III	1940	-

5.8 Design Loads and Partial Load Factors

The design load model is based on permanent loads, variable loads, wave and current loads and wind loads. The ULS load combinations are split into eight ULS_A combinations and eight ULS_B combinations for a 100-year wind condition and a 100-year return period wave condition. The relevant factors of safety, according to NORSOK N-003, are presented in Table 6.

Table 6- Partial action factors for calculating design loads

a). ULS_A partial load factors for 100-year wind and 100-year wave

Load	ULS_A_1	ULS_A_2	ULS_A_3	ULS_A_4	ULS_A_5	ULS_A_6	ULS_A_7	ULS_A_8
Permanent load	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Variable load	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Wind from North	0.7	-	-	-	-	-	-	-
Wind from North East	-	0.7	-	-	-	-	-	-
Wind from East	-	-	0.7	-	-	-	-	-
Wind from South East	-	-	-	0.7	-	-	-	-
Wind from South	-	-	-	-	0.7	-	-	-
Wind from South West	-	-	-	-	-	0.7	-	-
Wind from West	-	-	-	-	-	-	0.7	-
Wind from North West	-	-	-	-	-	-	-	0.7
Wave and current from North	0.7	-	-	-	-	-	-	-
Wave and current from North East	-	0.7	-	-	-	-	-	-
Wave and current from East	-	-	0.7	-	-	-	-	-
Wave and current from South East	-	-	-	0.7	-	-	-	-
Wave and current from South	-	-	-	-	0.7	-	-	-
Wave and current from South West	-	-	-	-	-	0.7	-	-
Wave and current from West	-	-	-	-	-	-	0.7	-
Wave and current from North West	-	-	-	-	-	-	-	0.7

b). ULS_B partial load factors for 100-year wind and 100-year wave

Load	ULS_A_1	ULS_A_2	ULS_A_3	ULS_A_4	ULS_A_5	ULS_A_6	ULS_A_7	ULS_A_8
Permanent load	1	1	1	1	1	1	1	1
Variable load	1	1	1	1	1	1	1	1
Wind from North	1.3	-	-	-	-	-	-	-
Wind from North East	-	1.3	-	-	-	-	-	-
Wind from East	-	-	1.3	-	-	-	-	-
Wind from South East	-	-	-	1.3	-	-	-	-
Wind from South	-	-	-	-	1.3	-	-	-
Wind from South West	-	-	-	-	-	1.3	-	-
Wind from West	-	-	-	-	-	-	1.3	-
Wind from North West	-	-	-	-	-	-	-	1.3
Wave and current from North	1.3	-	-	-	-	-	-	-
Wave and current from North East	-	1.3	-	-	-	-	-	-
Wave and current from East	-	-	1.3	-	-	-	-	-
Wave and current from South East	-	-	-	1.3	-	-	-	-
Wave and current from South	-	-	-	-	1.3	-	-	-
Wave and current from South West	-	-	-	-	-	1.3	-	-
Wave and current from West	-	-	-	-	-	-	1.3	-
Wave and current from North West	-	-	-	-	-	-	-	1.3

CHAPTER 6

CODE CHECK AND STRUCTURAL REDESIGN

6.1 Introduction

The jacket components such as legs, primary and secondary braces and joints are designed to satisfy the strength and stability requirements specified in NORSOK N-004. The check is performed through the use of the equations presented in this standard that can deliver the usage factor. If the usage factor is greater than 1.0 then the member is overloaded and does not meet the criteria for fitness for service. In GeniE, a member check is performed by five default positions: at the two ends of the member, at the midpoint and at the quarter positions. Meanwhile, additional code checking positions are determined at variations in section profiles or material or where the maximum moments occur.

6.2 Member Check

A member check of a frame's structural member is performed to assess whether the member is subjected to acceptable stress levels. The terms related to buckling of tubular members are [1]:

- effective buckling lengths
- buckling curves
- effect of external pressure

In general, a buckling length is applied depending on typical member configurations such as X-braces, K-frames, single braces, jacket legs and piles. The effective buckling length may be defined manually from analytical considerations. NORSOK N-004 states that the values of effective length factors with respect to the different structural elements. A conservative default value, 1.0, is used here for reducing the workload.

6.3 Joint Check

The capacity model has tubular joints with cans, stubs, cones and gaps. The code checking utilizes the classification based on the load paths in GeniE. In this case, the selection of joint classification is based on the actual geometry and then force distribution. In order to ensure realism of the calculation, several joints are defined manually.

A punching shear check is carried out on the brace member at a joint to assess the shear through the chord. As for the other checks, these assessments are made through the use of a punching shear interaction equation that delivers a usage factor.

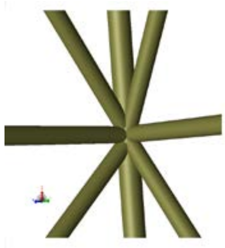
6.4 Modify Structural Data and Re-run Analysis

The re-design feature in GeniE can be used to change design parameters with the aim of bring the utilization check below 1.0. This is an iterative process which typically involves the following steps:

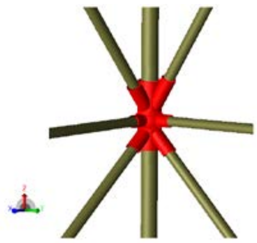
- Modify section (diameter of members, cans, stubs, etc.) or material properties
- Add/ remove additional structural members
- Modify code-checking parameters like safety factors, buckling parameters and moment amplification.
- Update members and joints
- Compute new code checking forces
- Run the code check

Figure 17 shows the modification of a joint by the following steps:

- Increase the thickness of the can and the stubs at the joint
- Add conical transitions between members with different thicknesses
- Add gaps between the can and the stubs which represent fabrication-friendly geometries

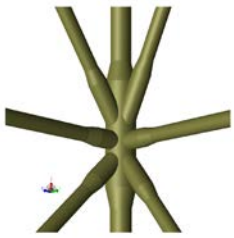


a). Original joint



b). Step1: Increase the thickness

c). Step2: Add the conical transition



d). Step3: Add gaps

Figure 17 Modification process of a joint

6.5 Comparison of Different Design Solutions

6.5.1 General Description

The general characteristics of jackets are summarized in Table 7. Figure 18 and Figure 19 respectively show the dimensions of legs and braces. Since the six-legged jacket has fewer legs, the diameters of the main legs are larger than for the eight-legged jacket. The weight of the jackets does not contain the weight of temporary foundation, pile sleeves, riser clamps and J-tubes. Although the lift capacity of modern heavy lift vessels is up to 14000 tonnes, nevertheless it is expected that the maximum weight of the jackets is to be within that range.

Table 7- General descriptions of eight-legged jacket and six-legged jacket

	Eight-legged jacket	**Six-legged jacket**
Weight of jacket without temporary foundation, pile sleeves, riser damps and J-tubes (tonnes)	9300	8800
Total height of jacket (m)	142.7	142.7
Jacket footprint at the sea floor (m)	40m × 60m	40m × 60m
Topside footing (m)	26.2m × 32.4m	26.2m × 32.4m
Braces pattern	V plus X-braces	X braces
Location of COG	(0,0, -48.8m)	(0,0, -49.8m)

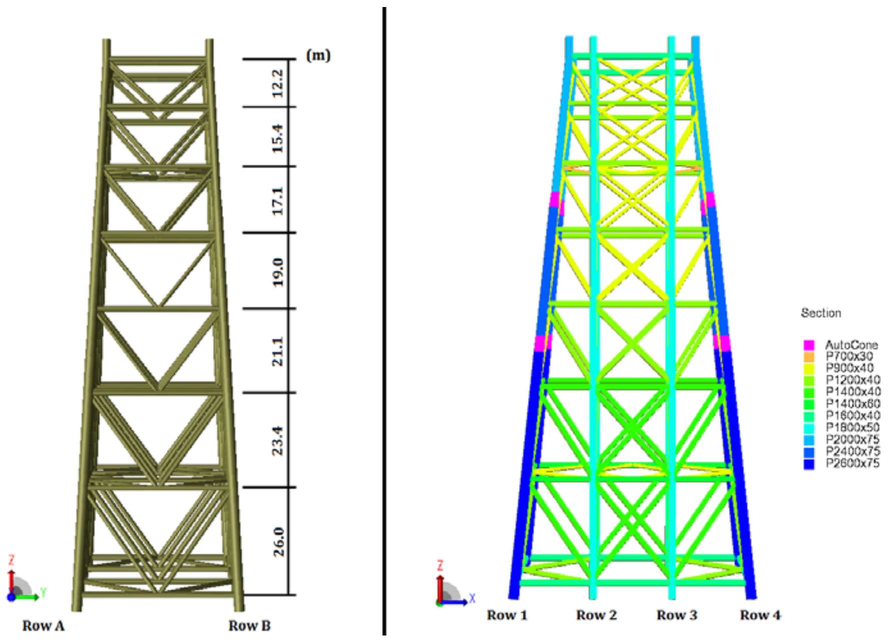


Figure 18 Overview of eight-legged jacket

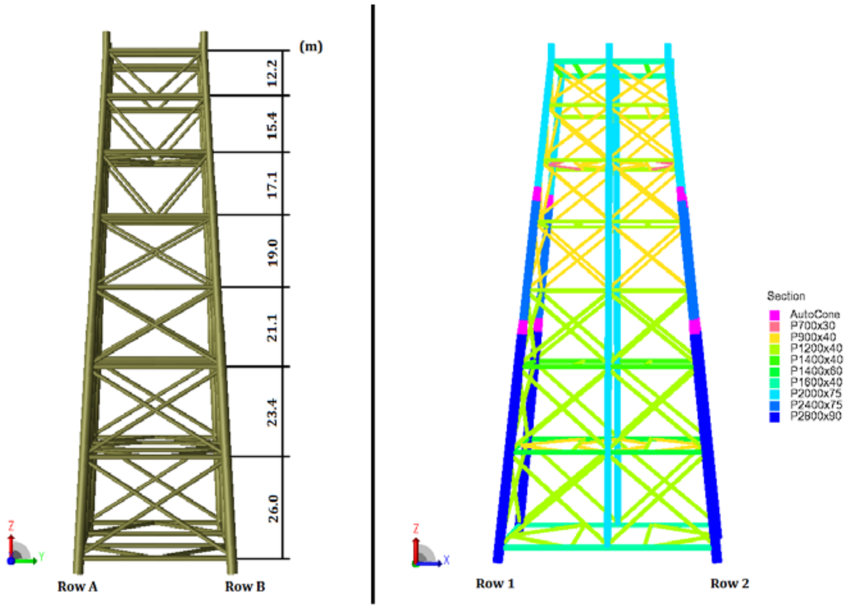


Figure 19 Overview of six-legged jacket

6.5.2 Discussion of Usage Factor Check

The results of the maximum base shear and overturning moment calculations from GeniE are attached in Appendix B. Wave and current loads acting on the eight-legged jacket have higher contribution than when acting on the six-legged jacket due to the brace patterns and dimensions of tubular members.

The COG of the topside is applied eccentrically in order to obtain the worst condition. This assumption is mentioned in Section 5.2. In-place ULS analysis indicates that the environmental load is dominating (ULS_b). The worst-case occurs when the COG of the topside is eccentric while the environmental loads facing towards north act on the structure. The COG shift one meter along the z-axis has a negligible influence on the usage factor check.

The result of the usage factor check is presented in Table 8. In addition, the plots of the usage factor check for the ULS design are attached in Appendix C. The eight-legged jacket has eight usage factors over 0.8 and the maximum is 0.99. This result is higher than for the six-legged jacket. When the permanent load is dominating (in ULS_a condition), the usage factors of the six-legged jacket are much less.

According to the result of the usage factor check, both the eight-legged jacket and the six-legged jacket satisfy the requirements of first-pass design in ULS analysis. The six-legged jacket is recommended, if we consider that the eight-legged jacket has a higher self-weight and may need reinforcement on more joints with respect to high usage factor checks. This in-place strength assessment is merely based on a coarse first-pass ULS design. In a real project, the final solution among several alternatives should be determined from more reliable detailed strength assessments, economic evaluations, project schedules, installation methods, actual topside weight, soil conditions, etc.

Table 8- Usage factor check

COG Envelope (m)	Run	Governing LoadCase	Position	UfTot > 1.00	UfTot > 0.80	UfTot > 0.50	UfTot > 0.01	Status	Uf_Max
8-legged Jacket									
(-2, 1, ±1)	ULS_a	SouthMaxMom	Bm931	0	2	52	402	OK	0.81
	ULS_b	NorthMaxMom	Bm161, 1	0	9	81	366	OK	0.96
(-2, -1, ±1)	ULS_a	NorthMaxMom	Bm161, 1	0	2	51	403	OK	0.83
	ULS_b	NorthMaxMom	Bm161, 1	0	7	81	368	OK	0.99
(2, 1, ±1)	ULS_a	SouthMaxMom	Bm645, 1	0	2	52	402	OK	0.81
	ULS_b	NorthMaxMom	Bm751, 1	0	9	79	368	OK	0.96
(2, -1, ±1)	ULS_a	NorthMaxMom	Bm751, 1	0	2	52	402	OK	0.83
	ULS_b	NorthMaxMom	Bm751, 1	0	9	78	369	OK	0.99
6-legged Jacket									
(-2, 1, ±1)	ULS_a	SouthMaxShear	Bm1392	0	0	20	418	OK	0.63
	ULS_b	NorthMaxMom	Bm1344	0	3	46	389	OK	0.97
(-2, -1, ±1)	ULS_a	SouthMaxShear	Bm1392	0	0	21	417	OK	0.66
	ULS_b	SouthMaxShear	Bm1392	0	4	44	390	OK	0.96
(2, 1, ±1)	ULS_a	SouthMaxShear	Bm1394	0	0	20	418	OK	0.63
	ULS_b	NorthMaxMom	Bm1344	0	3	45	390	OK	0.98
(2, -1, ±1)	ULS_a	SouthMaxShear	Bm1394	0	0	20	418	OK	0.66
	ULS_b	SouthMaxShear	Bm1394	0	4	44	390	OK	0.96

Note:
UfTot>1.00 means the number of members exceeding Uf=1.00
UfTot>0.80 means the number of members exceeding Uf=0.80
UfTot>0.50 means the number of members exceeding Uf=0.50
UfTot>0.01 means the number of members exceeding Uf=0.01
Uf_max= the maximum value of usage factor check

CHAPTER 7

BEHAVIOUR OF THE JACKET STRUCTURE WHEN IMPACTED BY A FLOTEL

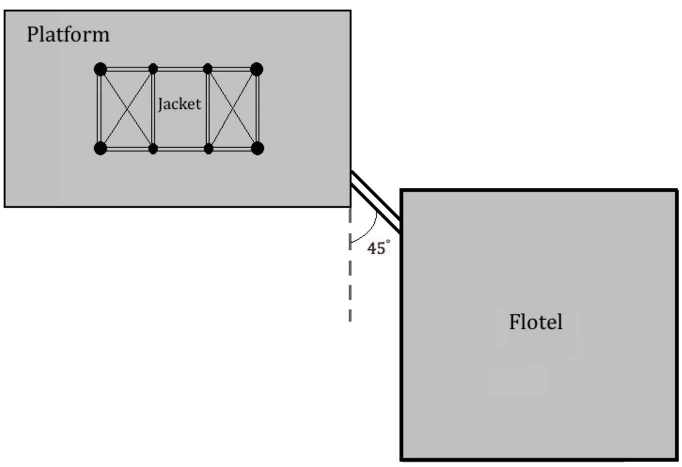
7.1 Introduction

There are several concepts for offshore accommodation such as DP semi, jack-ups, monohull vessels and accommodation barges. Such accommodation units are commonly used to increase the capacity when performing commissioning maintenance and modification works. The semi-submerged flotels offer a large advantage over barges and ships, making it easier to transfer personnel and goods [32].

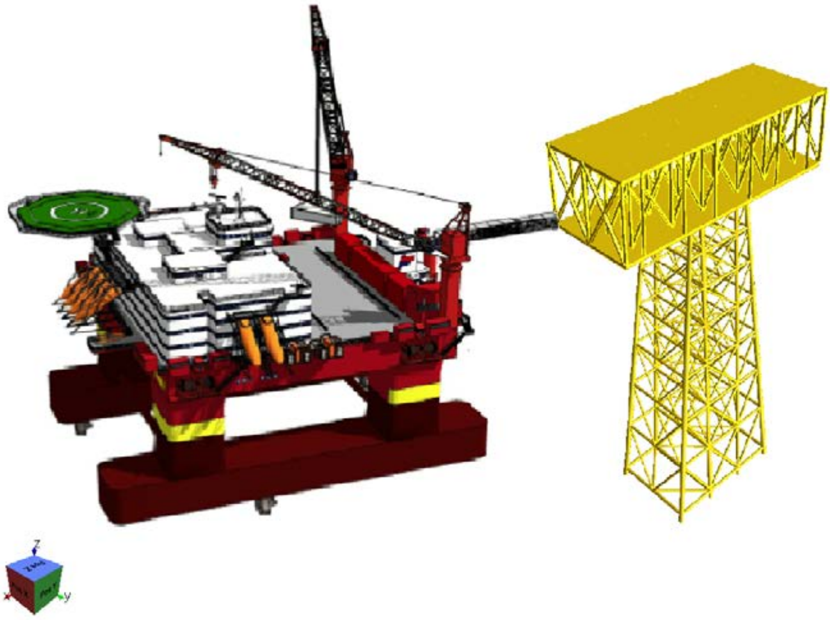
In rough weather, the bridge between the flotel and the platform is lifted off and the flotel is then positioned at a safe distance away from the platform. Although the latest generation of DP systems have high reliability, there is still a small risk that the DP system may fail. Similar events may also occur for anchored (semi-submersible) flotels.

This chapter shows the response behaviour of the jacket when floating living quarter (flotel) impacts on a fixed platform. In this thesis a specified impact energy of 84 MJ is applied at the three potential impact locations introduced in the following section.

Figure 20 shows a typical location of a flotel at the corner of the fixed platform. The topside's model is made of I-beams ($h \times w = 1500\ mm \times 800\ mm$) and plates (10mm) separately on the top and bottom. This model has adequate stiffness to transfer the impact load to the substructure before a serious local damage occurs. The piles are not included in the USFOS model. The jackets are fixed on the seabed with fixed boundary conditions.



a) Location of the flotel from topview



b) Location of the flotel from 3D view

Figure 20 Overview of the flotel and platform in concept design

7.2 Estimation of Impact Energy from Flotel

The gross masses of 14 flotels are summarized in Table 9 (see also Appendix D). This data collection shows that these values usually vary from 10000 metric tonnes to 30000 metric tonnes.

Table 9- Gross tonnages of flotels

Flotel	Gross Tonnage (metric tonne)
Floatel Superior	29000
Floatel Reliance	18038
Floatel Victory	26800
Safe Concordia	16700
Regalia	17624
Safe Caledonia	19045
Safe Britannia	23684
Safe Lancia	13002
Safe Regency	18219
Safe Scandinavia	24103
Safe Astoria	10485
Safe Bristolia	13876
Safe Hibernia	15719
Jasminia	10870

Risk analysis of planned jacket installations has shown that collision with passing vessels, with a kinetic energy in the range of 40-50 MJ, is a potential hazard [26]. According to NORSOK N-004, to avoid possible penetration of a cargo tank, the side structure of the unit shall be capable of absorbing the energy of a vessel collision with an annual probability of 10^{-4} or at least a vessel of 5000 tonnes with an impacting speed of 2 m/s [1].

The value of the impact energy is calculated using the formulas introduced in Section 2.8. The magnitude of impact energy depends on the velocity and mass of the flotel shown in Table 10. In this thesis specified impact energy of 84 MJ is applied at the three potential impact locations introduced in the following section. This implies a flotel of 30000 tonnes displacement travelling with a speed of 2 m/s.

Table 10- Specified values of impact energy

Velocity [m/s]	**Impact Energy [MJ] vs. Flotel Mass [Gg]**				
	10+m_{added}	**15+m_{added}**	**20+m_{added}**	**25+m_{added}**	**30+m_{added}**
0.5	1.75	2.63	3.50	4.38	5.25
1.0	7.00	10.50	14.00	17.50	21.00
1.5	15.75	23.63	31.50	39.38	47.25
2.0	28.00	42.00	56.00	70.00	84.00
	Note: m_{added} = 40%m_{flotel}				

7.3 Potential Impact Nodes

Accounting for the waves, wind and location of the flotel, three potential impact nodes are assumed, as shown in Table 11. α_i is the angle between the y-axis and the impact direction. For the purpose of studying the effects of the impact from various directions, the potential impact directions are specified separately as 30°, 45° and 60° at each contact node. Due to the overhang of the topside structure, the most likely impacts will be directly between the deck of the flotel and the topside structure. Hence, no direct impacts are expected on the jacket members.

Table 11- Specified collision situations

α_i	**Node 1**	**Node 2**	**Node 3**
30°	×	×	×
45°	×	×	×
60°	×	×	×

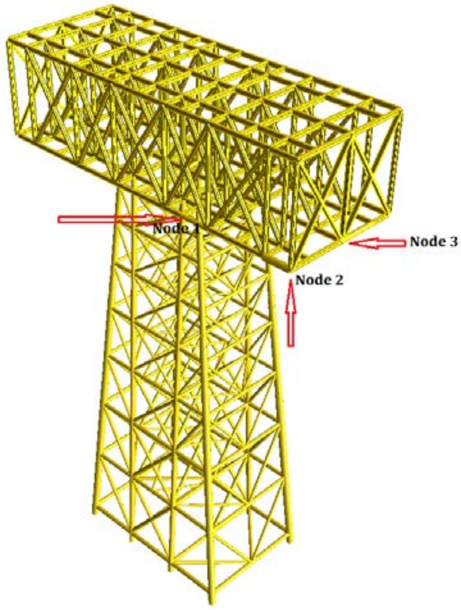
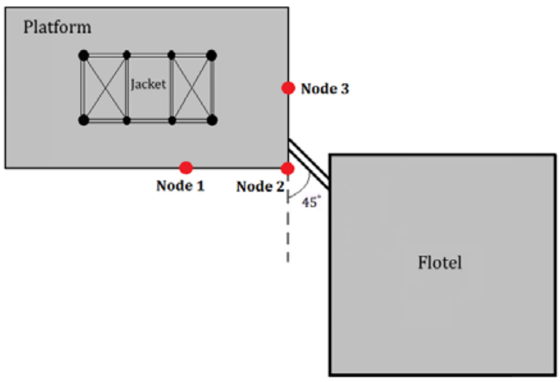
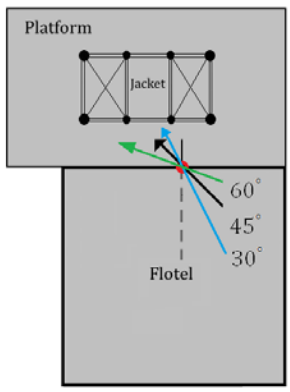


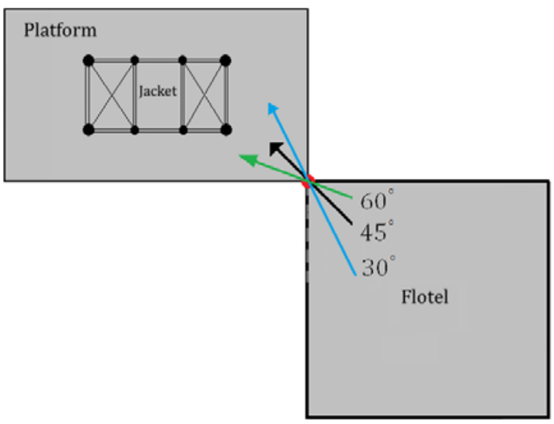
Figure 21 Potential impact nodes in 3D view



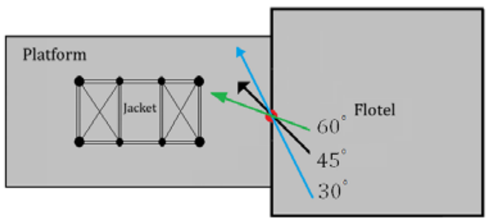
a). Three potential impact nodes



b). Impact on Node 1



c). Impact on Node 2



d). Impact on Node 3

Figure 22 Impact situations from topview

7.4 Limitation of Modelling in USFOS

An input command named "BIMPACT" is used in the USFOS software for static analysis of collision. This command is used to define ship impact load. When the total impact energy has been dissipated, the impact load will be unloaded into a separate program-defined load case. The impact will be terminated if fracture occurs.

However, this command is used merely for beam with pipe-shaped cross-sections. Thus the cross-section of the specified impact element is changed to a pipe-shaped cross-section instead of I-shaped. The former has a stiffness equivalent to that of the latter, so this change will not influence on the reliability of the result.

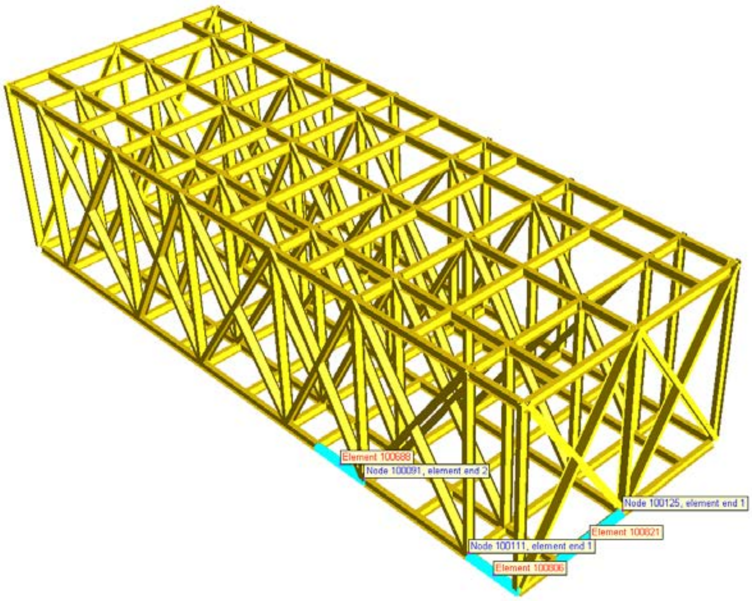
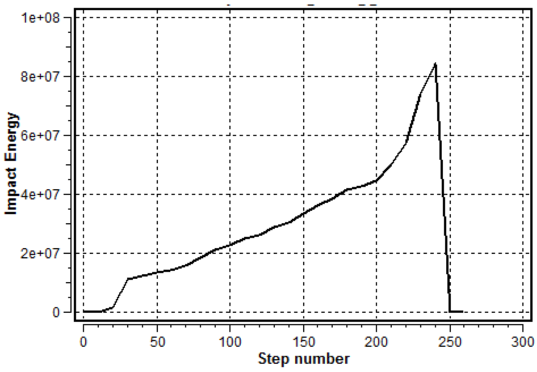


Figure 23 Elements have pipe-shaped cross-section

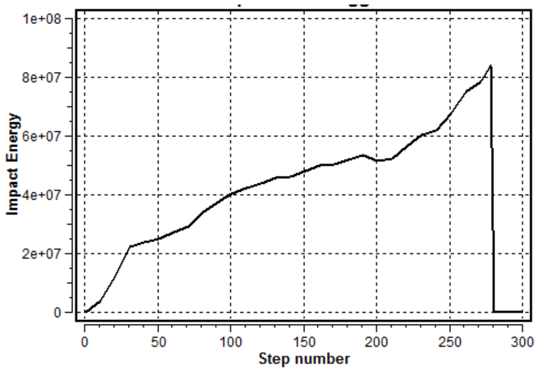
7.5 Application of Specified Impact Energy

The results show how different impact locations and impact directions affect the response behaviour of the eight-legged and six-legged jackets. The maximum impact energy is specified as 84 MJ, as taken from Table 10. For a static analysis in USFOS, the load is applied in steps, and the system stiffness equations are solved at every step. The configuration of the jacket is updated after each step.

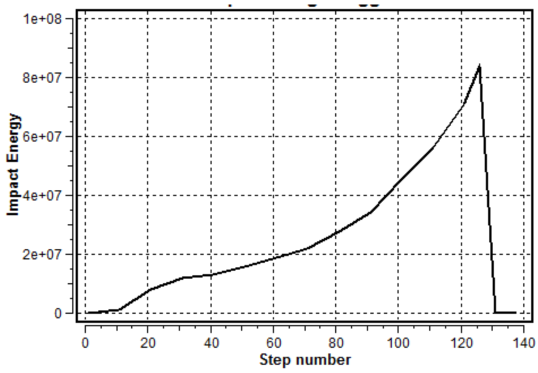
Figure 24, **Figure 25** and **Figure 26** show how the impact energy is absorbed by jackets at each step. The principle behind incremental-iterative is represented in Section 2.6. When the total impact energy of 84 MJ has been absorbed, USFOS unloads the impact load into a separate load case. For this reason, the curve of impact energy in each plot has a dramatic decrease after this specified impact energy is dissipated.



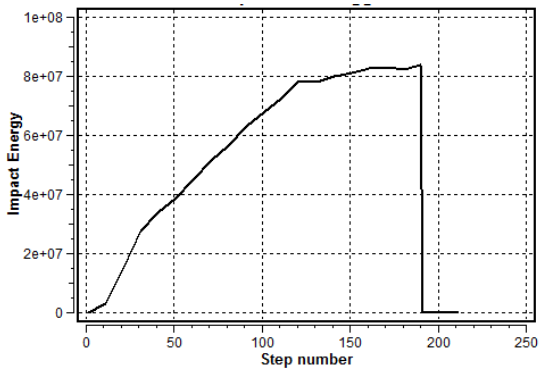
Impact from 30° on eight-legged jacket



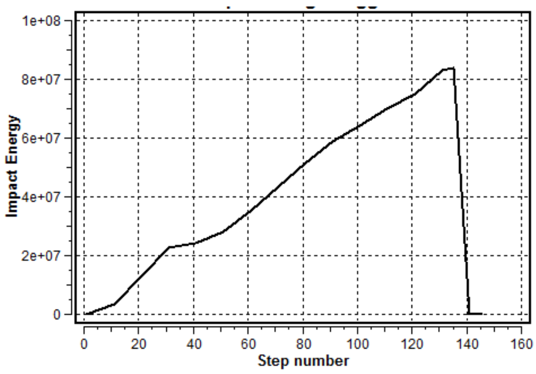
Impact from 30° on six-legged jacket



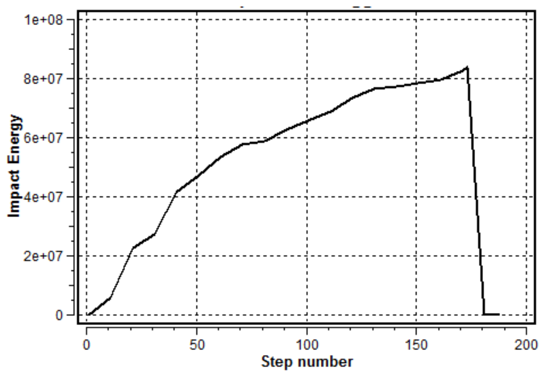
Impact from 45° on eight-legged jacket



Impact from 45° on six-legged jacket

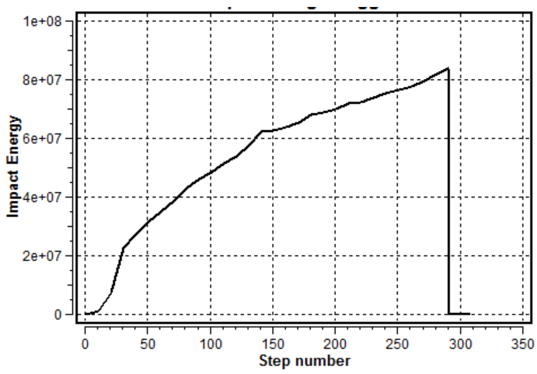


Impact from 60° on eight-legged jacket

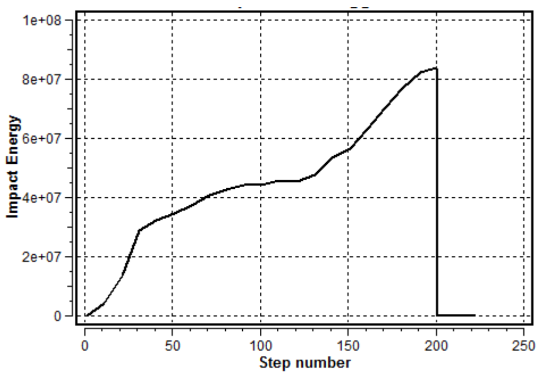


Impact from 60° on six-legged jacket

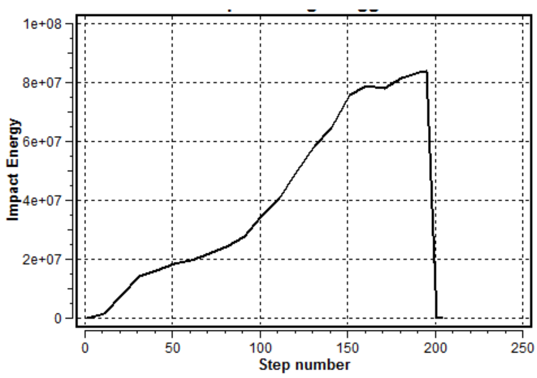
Figure 24 Step number vs. impact energy at Node 1



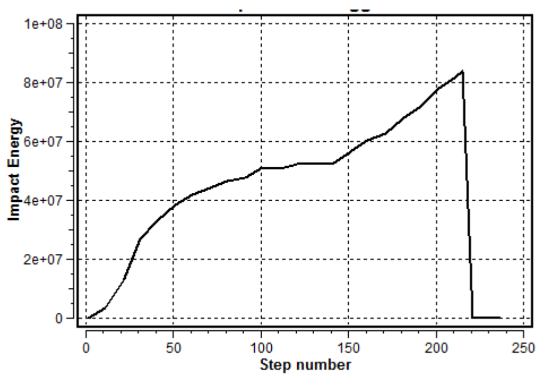
Impact from 30° on eight-legged jacket



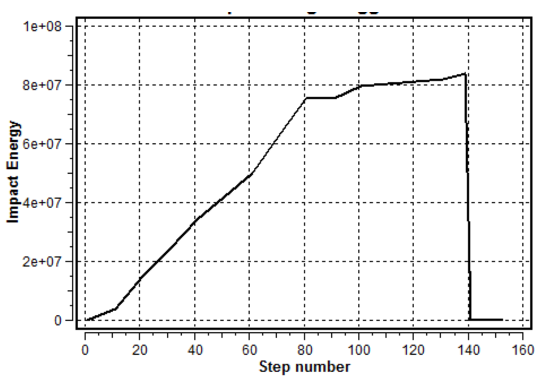
Impact from 30° on six-legged jacket



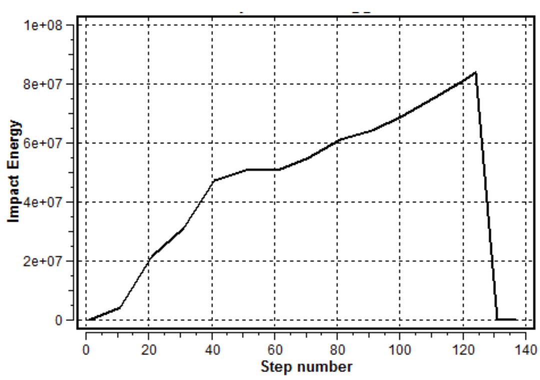
Impact from 45° on eight-legged jacket



Impact from 45° on six-legged jacket

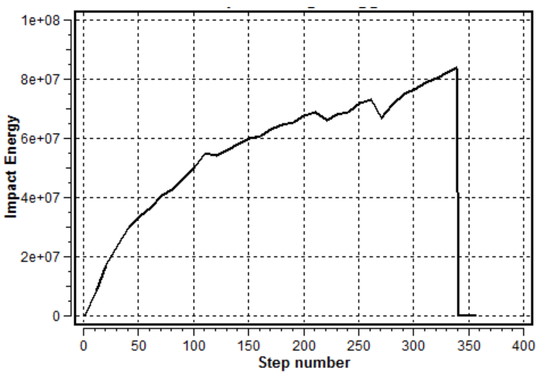


Impact from 60° on eight-legged jacket

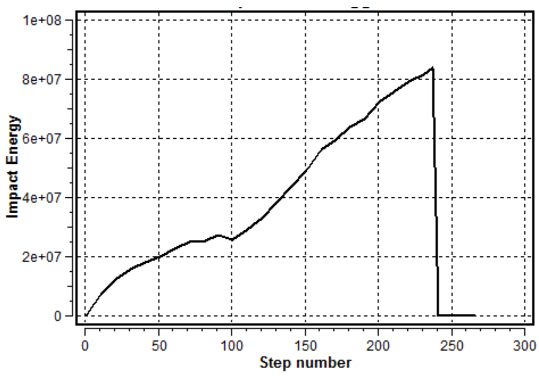


Impact from 60° on six-legged jacket

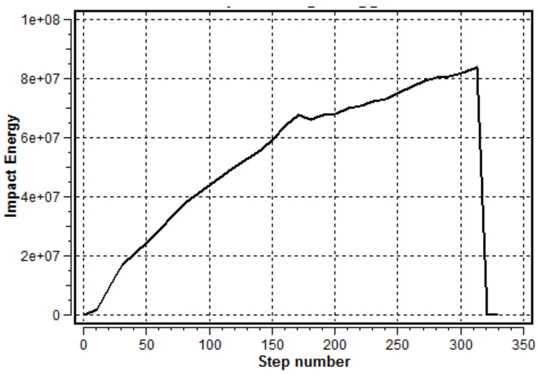
Figure 25 Step number vs. impact energy at Node 2



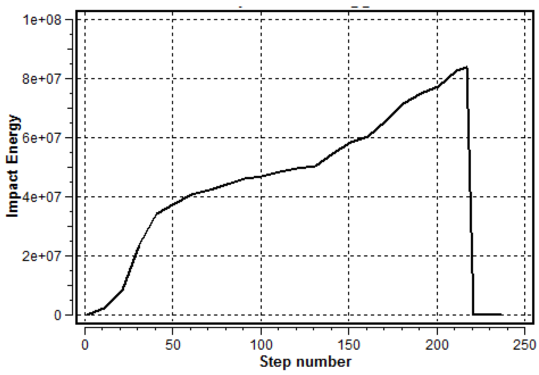
Impact from 30° on eight-legged jacket



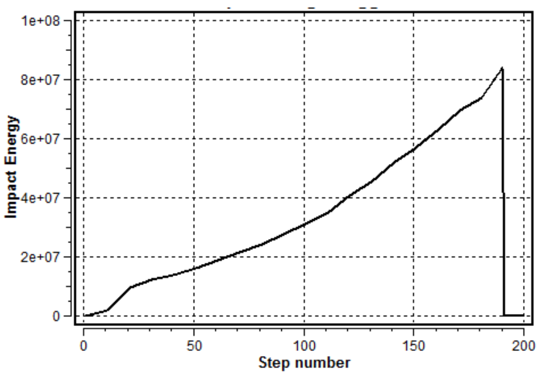
Impact from 30° on six-legged jacket



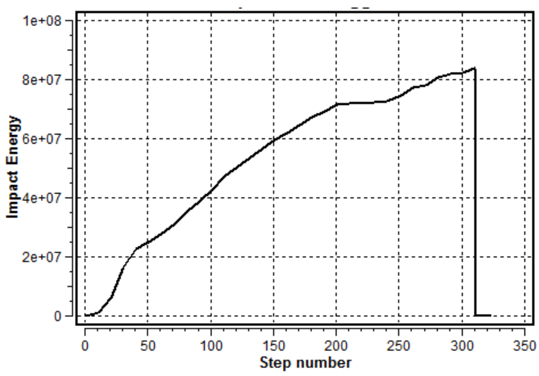
Impact from 45° on eight-legged jacket



Impact from 45° on six-legged jacket



Impact from 60° on eight-legged jacket



Impact from 60° on six-legged jacket

Figure 26 Step number vs. impact energy at Node 3

7.6 Response Behaviour of Jackets Subjected to 84 MJ Impact Energy

Both jacket designs in this thesis are capable of withstanding the applied impact energy of 84 MJ. The response of the eight-legged jacket and the six-legged jacket withstanding 84 MJ of impact energy are in shown in Figure 27 to Figure 29. The visible displacement scale is manually increased five times such that the buckling of the member is visible.

7.6.1 Response of Jackets Subjected to Impact at Node1

The plots in Figure 27 show that the lower end of the leg in the eight-legged jacket suffers very large loads. If the collision occurs at Node 1, the moment load is dominating, resulting obviously in compressible buckling at the lower end of the legs.

Compared with the eight-legged jacket, the six-legged jacket is more flexible. The global twisting load acting on the six-legged jacket causes larger deformations in several primary members and legs.

The worst case for both jackets is a collision from 30 degrees. In this case, two legs of the eight-legged jacket are buckled. Several primary members of the six-legged jacket in the second and third bays fail.

7.6.2 Response of Jackets Subjected to Impact at Node2

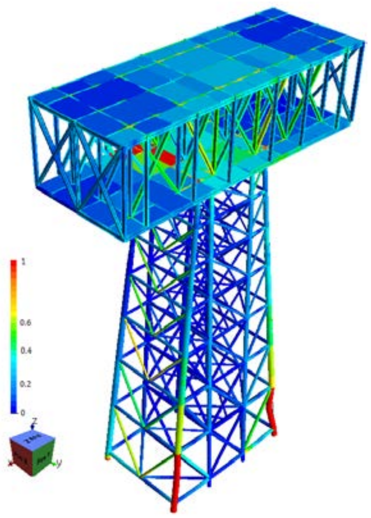
For the eight-legged jackets, an impact at Node2 contributes to a large torsion load that leads to a significant rotation of the topside. If the impact takes place at directions of 30 and 45 degrees, several vertical X-braces in the fourth and fifth bays fail. The strain energy of theses braces absorbs a significant part of the impact energy. Thus the deformation of the legs is less, compared with the impact at Node1. With an increasing impact angle, the global moment load increases. The moment load is dominating when the impact is from 60 degrees. Then buckling is obvious.

As mentioned in Section 7.6.1, the six-legged jacket is more flexible. Since the impact at Node 2 contributes to a larger displacement of topside, the larger global twisting load leads to more serious deformation of members in the second and third bays, especially for the impact from 30 and 45 degrees.

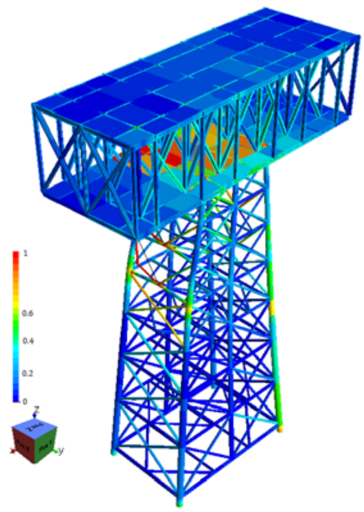
7.6.3 Response of Jackets Subjected to Impact at Node3

The response of the eight-legged jacket suffering impact at Node3 differs little from the response when the collision occurs at Node2. When the impact has a 30-degree angle, a plastic hinge also develops in the legs between the fourth and fifth bay.

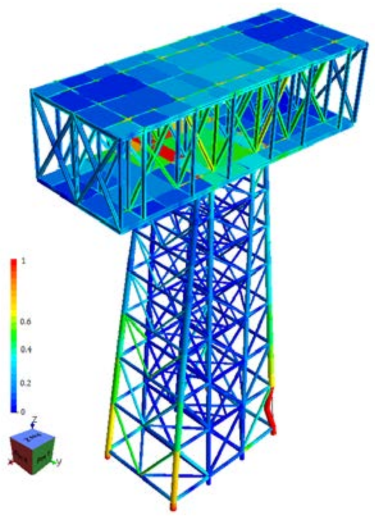
Figure 29 displays that more primary members fail above the third bay. When the impact is from 60 degrees, several vertical X-braces in the first bay fail. In this case, the strain energy of the platform's topside dissipates large a part of the impact energy. Therefore the jacket undertakes less impact energy and merely several secondary members buckle.



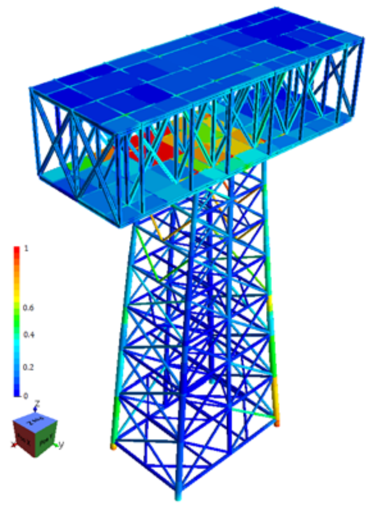
Impact from 30° on eight-legged jacket



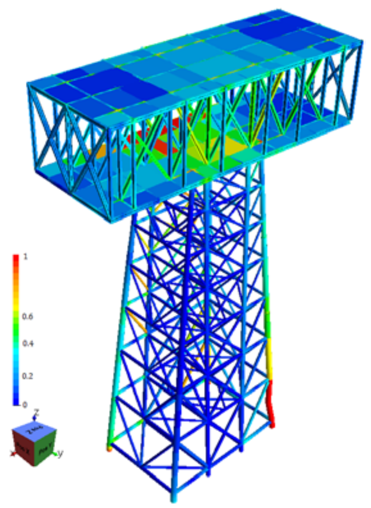
Impact from 30° on six-legged jacket



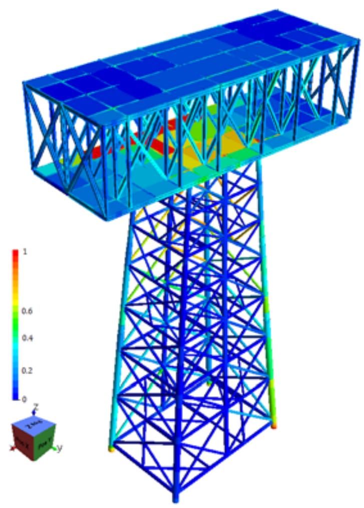
Impact from 45° on eight-legged jacket



Impact from 45° on six-legged jacket

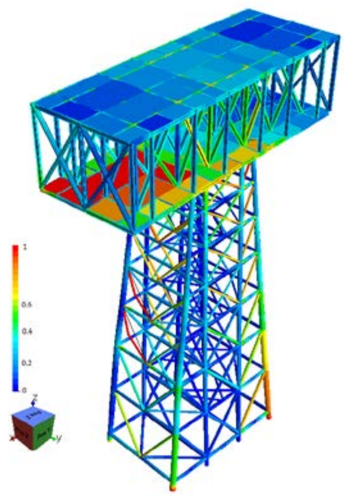


Impact from 60° on eight-legged jacket

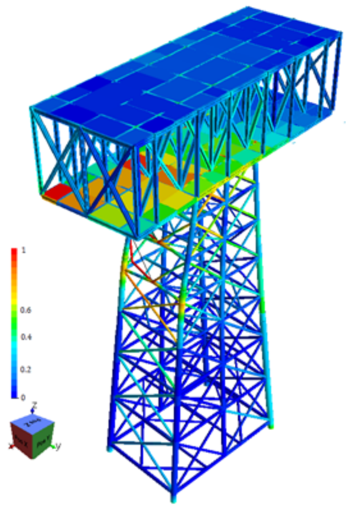


Impact from 60° on six-legged jacket

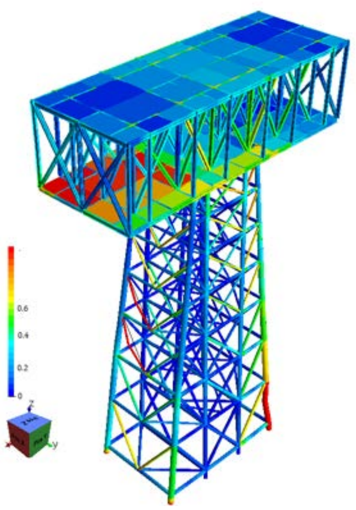
Figure 27 Plastic utilization for impact at Node 1



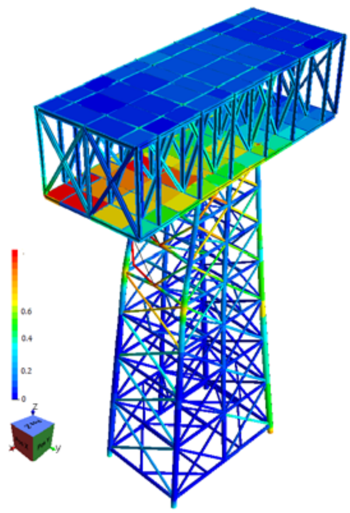
Impact from 30° on eight-legged jacket



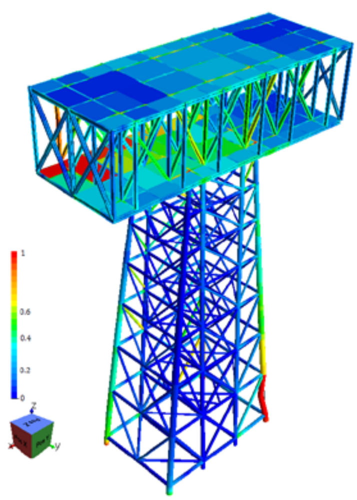
Impact from 30° on six-legged jacket



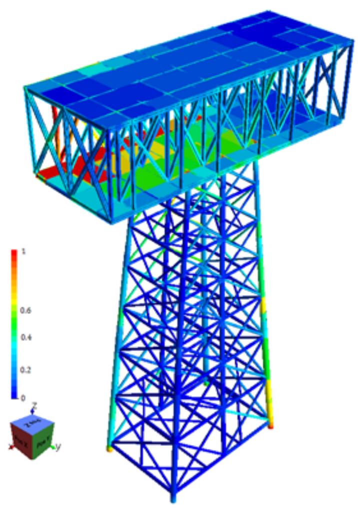
Impact from 45° on eight-legged jacket



Impact from 45° on six-legged jacket

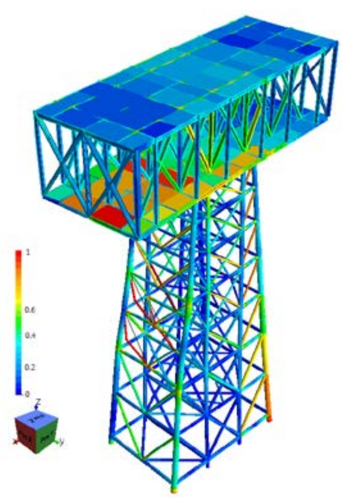


Impact from 60° on eight-legged jacket

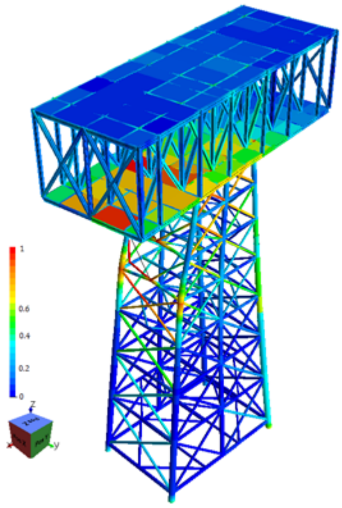


Impact from 60° on six-legged jacket

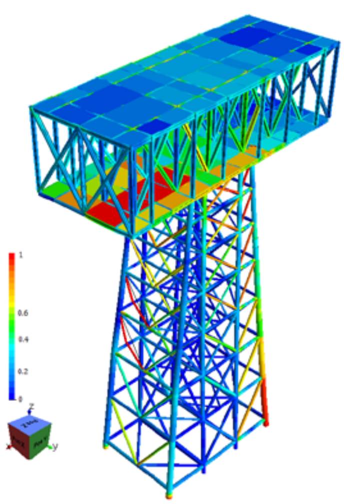
Figure 28 Plastic utilization for impact at Node 2



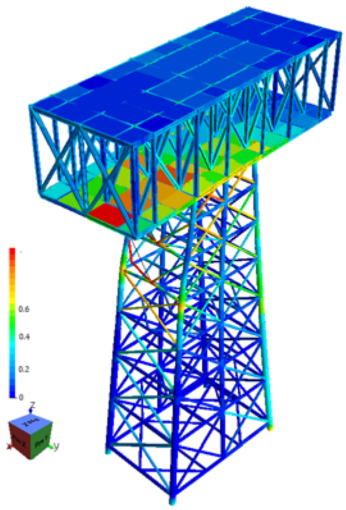
Impact from 30° on eight-legged jacket



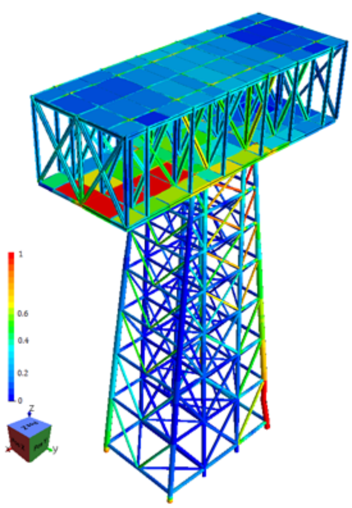
Impact from 30° on six-legged jacket



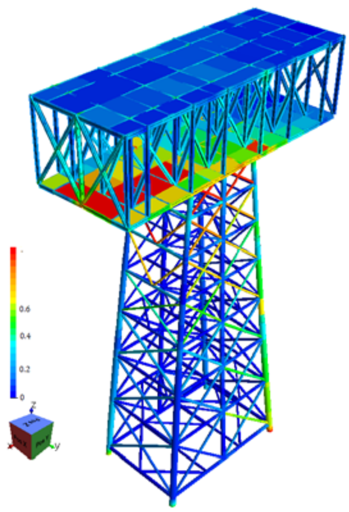
Impact from 45° on eight-legged jacket



Impact from 45° on six-legged jacket



Impact from 60° on eight-legged jacket



Impact from 60° on six-legged jacket

Figure 29 Plastic utilization for impact at Node 3

7.6.4 Maximum Impact Energy the Jackets could resist without Collapse

The principles behind the calculations of capacity against impact energy are discussed in Section 2.6. The global ultimate strength is at the top point where the limit load is applied. After that point, the structure will collapse as a result of excessive yielding or buckling of the most components. An impact energy limit is estimated instead of restricting a limiting impact load in this thesis.

Table 12 and **Table 13** show respectively the resistance capacity of the eight-legged jacket and the six-legged jacket before they fail. The eight-legged jacket can resist 447MJ of impact energy at Node3 from 45 degrees, but only 226 MJ of impact energy at Node2 from 60 degrees. The six-legged jacket can be capable of withstanding the applied impact energy of 326 MJ at Node1 from 60 degrees, but only 131 MJ of impact energy at Node 3 from 60 degrees.

The eight-legged jacket has a higher overall capacity to resist impact, except for the impacts from 60 degrees at Node 1 and from 60 degrees at Node 2. Serious local damage takes place at these two impact locations, while less impact energy transfers to the substructure.

Table 12- Maximum impact energy the eight-legged jacket could resist

Impact node	Impact direction	Maximum impact energy the jacket could resist before collapse
Node 1	30°	227 MJ
	45°	252 MJ
	60°	270 MJ
Node 2	30°	436 MJ
	45°	287 MJ
	60°	226 MJ
Node 3	30°	391 MJ
	45°	447 MJ
	60°	275 MJ

Table 13- Maximum impact energy the six-legged jacket could resist

Impact node	Impact direction	Maximum impact energy the jacket could resist before collapse
Node 1	30°	152 MJ
	45°	188 MJ
	60°	326 MJ
Node 2	30°	163 MJ
	45°	185 MJ
	60°	242 MJ
Node 3	30°	142 MJ
	45°	215 MJ
	60°	131 MJ

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Summary and Conclusions

The aim of this study is to design a conceptual jacket that has the capacity to resist selected functional and environmental actions, and to perform a first-pass structural optimization for an in-place ULS analysis. Subsequently, the jacket structure´s response is studied when subjected to an accidental collision from a floating living quarter (flotel).

The results from in-place ULS analysis show that the X-braced batter performs best in terms of both reserve strength and residual behaviour. This batter design can maintain a much larger load level compared to K-braced structures.

This in-place strength assessment is merely based on a coarse first-pass ULS design. In this case, the six-legged jacket is recommended, if we consider the eight-legged jacket has a higher self-weight and may need reinforcement on more joints with respect to a high usage factor check.

Both jacket designs in this thesis are capable of withstanding the applied impact energy of 84 MJ. Although the eight-legged jacket buckles in one/two legs, where the six-legged jacket does not, the eight-legged jacket has a higher overall capacity to resist impact, with the exception of the impacts from 60 degrees at Node 1 and 60 degrees at Node 2.

The six-legged jacket is more flexible than the eight-legged jacket such that the global load causes larger rotation at the top of the six-legged jacket. Thus, the critical buckling members and buckling locations are different in these two structures. It is interesting to notice that in the eight-legged jacket design, the critical failure occurs when the lower ends of the legs fail. For the six-legged jacket, the global collapse load for the platform is governed by the primary members in the middle and upper parts of the jacket.

Serious local damage occurs to the topside structure before the substructure loses its global strength capacity. Thus, in a realistic project, it is recommend to perform a local analysis of the damaged area at the topside and to find how much impact energy will be absorbed there.

8.2 Suggestions for Future Work

Due to the absence of reliable data support and to the time limitation, this work covers merely a “coarse” static analysis of impact from a flotel. For future work, one could optimize the model in the following ways:

- Since the jackets are modelled by using finite element mesh with two-node beam elements, alternatively one could perform an analysis of the models using shell elements, especially in the contact zone and the potential buckling part. A coarser mesh in the rest of the model could be selected in order to save time and computational space.

- Fixed boundary conditions are used in the accidental analysis. Rigorously, detailed modelling of piles and foundation condition is strongly recommended.
- Perform such analyses for existing jackets which are much more optimized than the two conceptual jacket designs included in this thesis.

A study of shared energy design could be carried out by modelling the flotel with an appropriate finite shell element. In this case both the flotel and the platform would contribute considerably to the energy dissipation.

The influence of dynamic effects has not been taken into account in this thesis. According to Refs. [27] and [28], the dynamic displacement calculated with dynamic analysis may differ significantly from the static mode for a jacket at medium water depth. Such a dynamic analysis should be included in further work.

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APPENDIX A

Environmental Condition for ULS Design

A.1. Speed of current with 100-year return period

Depth (m)	Current speed from different directions (m/s)							
	0 (deg)	45 (deg)	90 (deg)	135 (deg)	180 (deg)	225 (deg)	270 (deg)	315 (deg)
0	0.92	0.92	0.76	0.48	0.48	0.64	0.62	0.92
-10	0.92	0.92	0.76	0.48	0.48	0.64	0.62	0.92
-20	0.79	0.91	0.90	0.65	0.53	0.54	0.58	0.76
-30	0.58	0.72	0.83	0.63	0.49	0.52	0.61	0.59
-40	0.62	0.73	0.66	0.52	0.52	0.57	0.56	0.71
-60	0.62	0.71	0.60	0.56	0.42	0.49	0.51	0.65
-80	0.63	0.64	0.60	0.55	0.38	0.48	0.48	0.63
-112	0.59	0.53	0.48	0.46	0.37	0.41	0.40	0.60

A.2. H_s and T_p of wave with 100-year return period

Direction (deg)	Range (deg)	Wave	
		H_s (m)	T_p (s)
0	337.5-22.5	12.5	13.3
45	22.5-67.5	12.9	13.5
90	67.5-112.5	14.7	14.2
135	112.5-157.5	14.4	14.2
180	157.5-202.5	11.7	12.9
225	202.5-247.5	14.6	14.3
270	247.5-292.5	14.6	14.3
315	292.5-337.5	12.3	13.3

A.3. Wind with 100-year return period

Wind													
Direction (deg)	z (m)	t (s)	t_0 (s)	U_0 (m/s)	C	I_u	U_z (m/s)	u_z (m/s)	C_s	A (m^2)	alpha (deg)	rou (kg/m^3)	F_w (kN)
0.00	44.00	15.00	3600.00	33.00	0.14	0.10	39.83	49.21	0.75	2400.00	1.57	1.23	2672.17
45.00	44.00	15.00	3600.00	33.00	0.14	0.10	39.83	49.21	0.75	2400.00	0.79	1.23	1889.51
									1.23	6600.00	0.79	1.23	8487.05
90.00	44.00	15.00	3600.00	31.00	0.14	0.10	37.26	45.71	1.23	6600.00	1.57	1.23	10357.37
135.00	44.00	15.00	3600.00	32.00	0.14	0.10	38.54	47.45	0.75	2400.00	0.79	1.23	1757.04
									1.23	6600.00	0.79	1.23	7892.04
180.00	44.00	15.00	3600.00	30.00	0.13	0.10	35.97	43.99	0.75	2400.00	1.57	1.23	2135.22
225.00	44.00	15.00	3600.00	31.00	0.14	0.10	37.26	45.71	0.75	2400.00	0.79	1.23	1630.52
									1.23	6600.00	0.79	1.23	7323.77
270.00	44.00	15.00	3600.00	35.00	0.14	0.11	42.43	52.77	1.23	6600.00	1.57	1.23	13802.17
315.00	44.00	15.00	3600.00	33.00	0.14	0.10	39.83	49.21	0.75	2400.00	0.79	1.23	1889.51
									1.23	6600.00	0.79	1.23	8487.05

U_0= 1 h mean wind speed at 10 m height (100-year return period)
I_u= Turbulence intensity factor
U_z= 1 h mean wind speed at height z(m) above sea level
u_z= Characteristic wind velocity at height z(m) above sea level with corresponding averaging time period t
C_s= Shape coefficient
A= Surface area
alpha= Angle between the direction of the wind and the axis of the exposed member or surface
rou= Mass density of air
F_w= Wind force acting on the surface

APPENDIX B

Maximum Base Shear and Overturning Moment in ULS Design

Maximum base shear and maximum overturning moment for 8-legged Jacket in ULS_A analysis									
Load	Reference point	FX [MN]	FY [MN]	FZ [MN]	MX [MN*m]	MY [MN*m]	MZ [MN*m]	BS [MN]	OTM [MN]
Wind from North	(0,0,0)	0.00	9.05	0.00	-531.82	0.00	0.00	9.05	531.82
Wind from North East	(0,0,0)	1.11	4.93	0.00	-285.95	64.49	0.00	5.06	293.13
Wind from East	(0,0,0)	1.46	0.00	0.00	0.00	84.53	0.00	1.46	84.53
Wind from South East	(0,0,0)	1.29	-5.18	0.00	304.19	74.74	0.00	5.34	313.24
Wind from South	(0,0,0)	0.00	-6.79	0.00	399.06	0.00	0.00	6.79	399.06
Wind from South West	(0,0,0)	-1.29	-5.57	0.00	327.08	-74.74	0.00	5.71	335.51
Wind from West	(0,0,0)	-1.82	0.00	0.00	0.00	-105.70	0.00	1.82	105.70
Wind from North West	(0,0,0)	-1.29	5.57	0.00	-327.08	-74.74	0.00	5.71	335.51
Wave and current from North	(0,0,-115)	-0.02	-23.45	-0.69	2169.65	-1.04	0.80	23.45	2169.65
Wave and current from North East	(0,0,-115)	-18.05	-16.15	-1.71	1502.34	-1669.29	4.11	24.23	2245.79
Wave and current from East	(0,0,-115)	-16.48	-0.02	-0.97	2.84	-1531.74	-2.18	16.48	1531.74
Wave and current from South East	(0,0,-115)	-17.27	15.45	-1.74	-1422.12	-1580.81	-8.47	23.17	2126.35
Wave and current from South	(0,0,-115)	0.02	24.14	-0.57	-2223.97	2.97	-0.83	24.14	2223.97
Wave and current from South West	(0,0,-115)	15.59	14.00	-0.97	-1299.55	1449.77	7.04	20.96	1946.96
Wave and current from West	(0,0,-115)	21.39	0.02	-2.09	-0.36	2005.57	2.56	21.39	2005.57
Wave and current from North West	(0,0,-115)	14.45	-13.00	-1.17	1204.14	1339.24	-3.05	19.43	1800.98

Maximum base shear and maximum overturning moment for 8-legged Jacket in ULS_B analysis									
Load	Reference point	FX [MN]	FY [MN]	FZ [MN]	MX [MN*m]	MY [MN*m]	MZ [MN*m]	BS [MN]	OTM [MN]
Wind from North	(0,0,0)	0.00	16.81	0.00	-987.67	0.00	0.00	16.8	987.7
Wind from North East	(0,0,0)	2.07	9.16	0.00	-531.05	119.76	0.00	9.4	544.4
Wind from East	(0,0,0)	2.71	0.00	0.00	0.00	156.98	0.00	2.7	157.0
Wind from South East	(0,0,0)	2.39	-9.62	0.00	564.92	138.81	0.00	9.9	581.7
Wind from South	(0,0,0)	0.00	-12.61	0.00	741.10	0.00	0.00	12.6	741.1
Wind from South West	(0,0,0)	-2.39	-10.34	0.00	607.43	-138.81	0.00	10.6	623.1
Wind from West	(0,0,0)	-3.39	0.00	0.00	0.00	-196.31	0.00	3.4	196.3
Wind from North West	(0,0,0)	-2.39	10.34	0.00	-607.43	-138.81	0.00	10.6	623.1
Wave and current from North	(0,0,-115)	-0.04	-43.56	-1.28	4029.35	-1.94	1.48	43.6	4029.4
Wave and current from North East	(0,0,-115)	-33.53	-30.00	-3.17	2790.06	-3100.11	7.64	45.0	4170.7
Wave and current from East	(0,0,-115)	-30.61	-0.03	-1.81	5.28	-2844.66	-4.05	30.6	2844.7
Wave and current from South East	(0,0,-115)	-32.07	28.70	-3.23	-2641.08	-2935.79	-15.74	43.0	3948.9
Wave and current from South	(0,0,-115)	0.03	44.82	-1.05	-4130.23	5.52	-1.53	44.8	4130.2
Wave and current from South West	(0,0,-115)	28.96	26.01	-1.80	-2413.45	2692.43	13.07	38.9	3615.8
Wave and current from West	(0,0,-115)	39.73	0.03	-3.88	-0.67	3724.63	4.76	39.7	3724.6
Wave and current from North West	(0,0,-115)	26.83	-24.14	-2.17	2236.26	2487.16	-5.66	36.1	3344.7

Maximum base shear and maximum overturning moment for 6-legged Jacket in ULS_A analysis									
Load	**Reference point**	**FX [MN]**	**FY [MN]**	**FZ [MN]**	**MX [MN*m]**	**MY [MN*m]**	**MZ [MN*m]**	**BS [MN]**	**OTM [MN]**
Wind from North	(0,0,0)	0.00	9.05	0.00	-531.82	0.00	0.00	9.05	531.82
Wind from North East	(0,0,0)	1.11	4.93	0.00	-285.95	64.49	0.00	5.06	293.13
Wind from East	(0,0,0)	1.46	0.00	0.00	0.00	84.53	0.00	1.46	84.53
Wind from South East	(0,0,0)	1.29	-5.18	0.00	304.19	74.74	0.00	5.34	313.24
Wind from South	(0,0,0)	0.00	-6.79	0.00	399.06	0.00	0.00	6.79	399.06
Wind from South West	(0,0,0)	-1.29	-5.57	0.00	327.08	-74.74	0.00	5.71	335.51
Wind from West	(0,0,0)	-1.82	0.00	0.00	0.00	-105.70	0.00	1.82	105.70
Wind from North West	(0,0,0)	-1.29	5.57	0.00	-327.08	-74.74	0.00	5.71	335.51
Wave and current from North	(0,0,-115)	-0.01	-19.17	-1.84	1769.11	-0.15	-0.10	19.17	1769.11
Wave and current from North East	(0,0,-115)	-12.62	-12.57	-1.56	1161.37	-1136.31	6.71	17.81	1624.80
Wave and current from East	(0,0,-115)	-11.84	0.00	-0.89	-0.11	-1051.89	0.21	11.84	1051.89
Wave and current from South East	(0,0,-115)	-12.15	12.09	-1.64	-1104.32	-1082.34	-6.49	17.14	1546.28
Wave and current from South	(0,0,-115)	0.00	19.72	-1.80	-1816.50	-0.20	-0.03	19.72	1816.50
Wave and current from South West	(0,0,-115)	10.95	10.93	-1.79	-1006.88	988.33	6.09	15.48	1410.89
Wave and current from West	(0,0,-115)	14.75	0.00	-1.21	-0.43	1346.03	-0.10	14.75	1346.03
Wave and current from North West	(0,0,-115)	10.18	-10.17	-1.88	933.03	915.18	-6.25	14.39	1306.94

Maximum base shear and maximum overturning moment for 6-legged Jacket in ULS_B analysis									
Load	**Reference point**	**FX [MN]**	**FY [MN]**	**FZ [MN]**	**MX [MN*m]**	**MY [MN*m]**	**MZ [MN*m]**	**BS [MN]**	**OTM [MN]**
Wind from North	(0,0,0)	0.00	16.81	0.00	-987.67	0.00	0.00	16.8	987.7
Wind from North East	(0,0,0)	2.07	9.16	0.00	-531.05	119.76	0.00	9.4	544.4
Wind from East	(0,0,0)	2.71	0.00	0.00	0.00	156.98	0.00	2.7	157.0
Wind from South East	(0,0,0)	2.39	-9.62	0.00	564.92	138.81	0.00	9.9	581.7
Wind from South	(0,0,0)	0.00	-12.61	0.00	741.10	0.00	0.00	12.6	741.1
Wind from South West	(0,0,0)	-2.39	-10.34	0.00	607.43	-138.81	0.00	10.6	623.1
Wind from West	(0,0,0)	-3.39	0.00	0.00	0.00	-196.31	0.00	3.4	196.3
Wind from North West	(0,0,0)	-2.39	10.34	0.00	-607.43	-138.81	0.00	10.6	623.1
Wave and current from North	(0,0,-115)	-0.01	-35.60	-3.42	3285.49	-0.27	-0.18	35.6	3285.5
Wave and current from North East	(0,0,-115)	-23.43	-23.35	-2.90	2156.83	-2110.29	12.45	33.1	3017.5
Wave and current from East	(0,0,-115)	-21.98	0.00	-1.65	-0.20	-1953.51	0.39	22.0	1953.5
Wave and current from South East	(0,0,-115)	-22.56	22.45	-3.05	-2050.88	-2010.06	-12.04	31.8	2871.7
Wave and current from South	(0,0,-115)	-0.01	36.62	-3.35	-3373.50	-0.37	-0.06	36.6	3373.5
Wave and current from South West	(0,0,-115)	20.34	20.31	-3.33	-1869.92	1835.47	11.31	28.7	2620.2
Wave and current from West	(0,0,-115)	27.39	0.00	-2.25	-0.79	2499.77	-0.18	27.4	2499.8
Wave and current from North West	(0,0,-115)	18.90	-18.89	-3.49	1732.77	1699.62	-11.60	26.7	2427.2

FX= Shear force from x-axis

FY= Shear force from y-axis

FZ= Shear force from z-axis

MX= Moment from x-axis

MY= Moment from y-axis

MZ= Moment from z-axis

BS= Base shear

OTM= Overturning moment

APPENDIX C

Member Usage Plots in ULS_B Design

C.1. In-Place ULS_B Member Check for Eight-legged Jacket

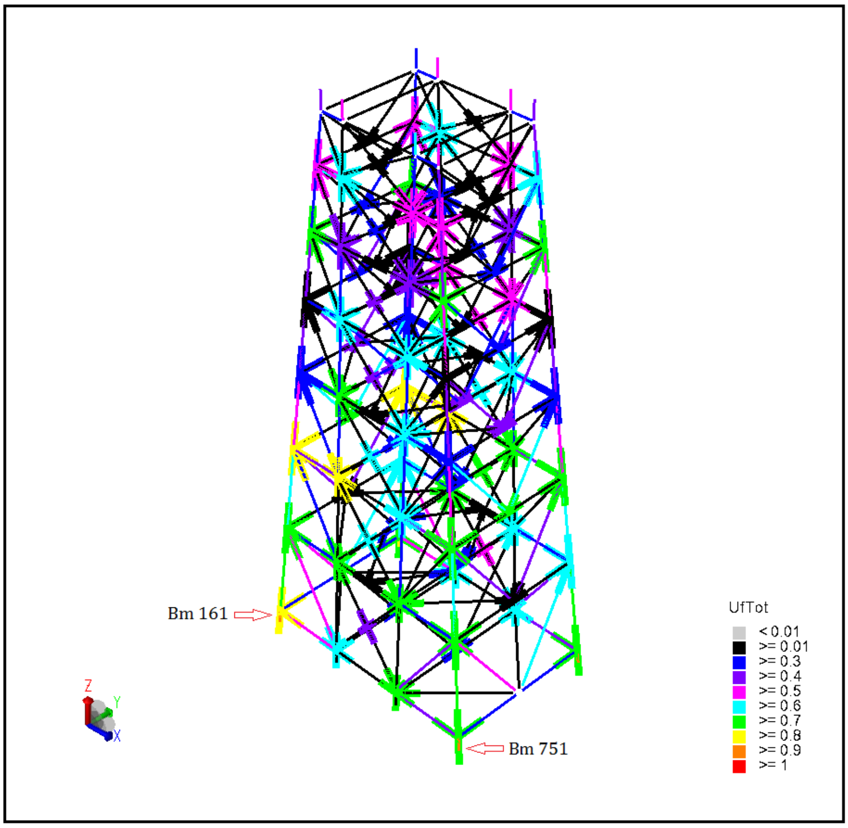

Figure 30 Eight-legged jacket's member check results, overview

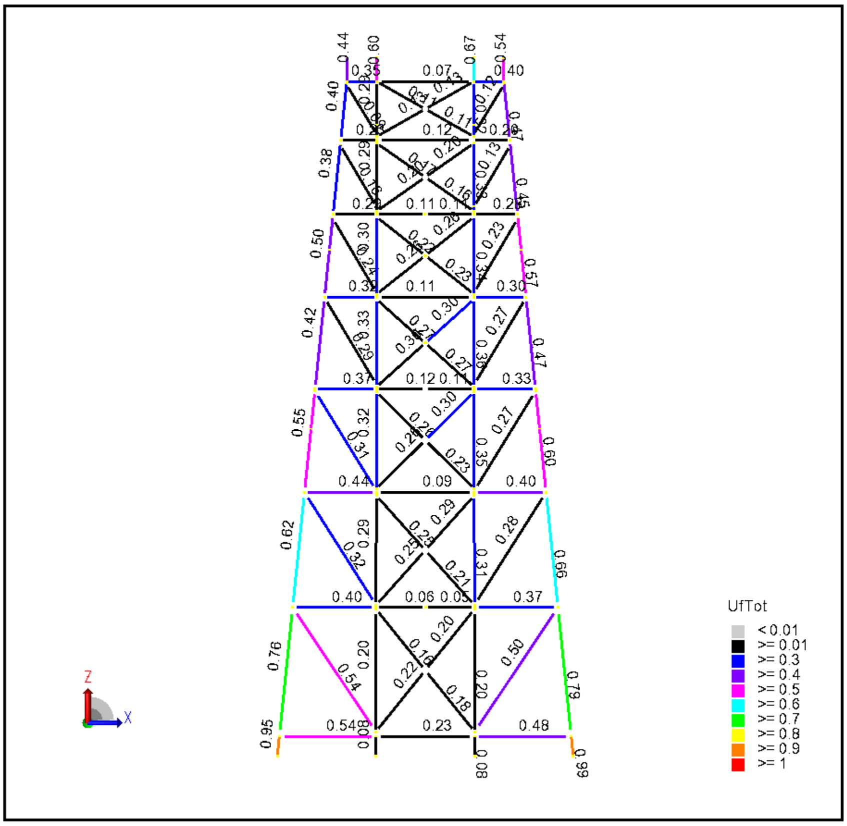

Figure 31 Eight-legged jacket's member check results, Row A

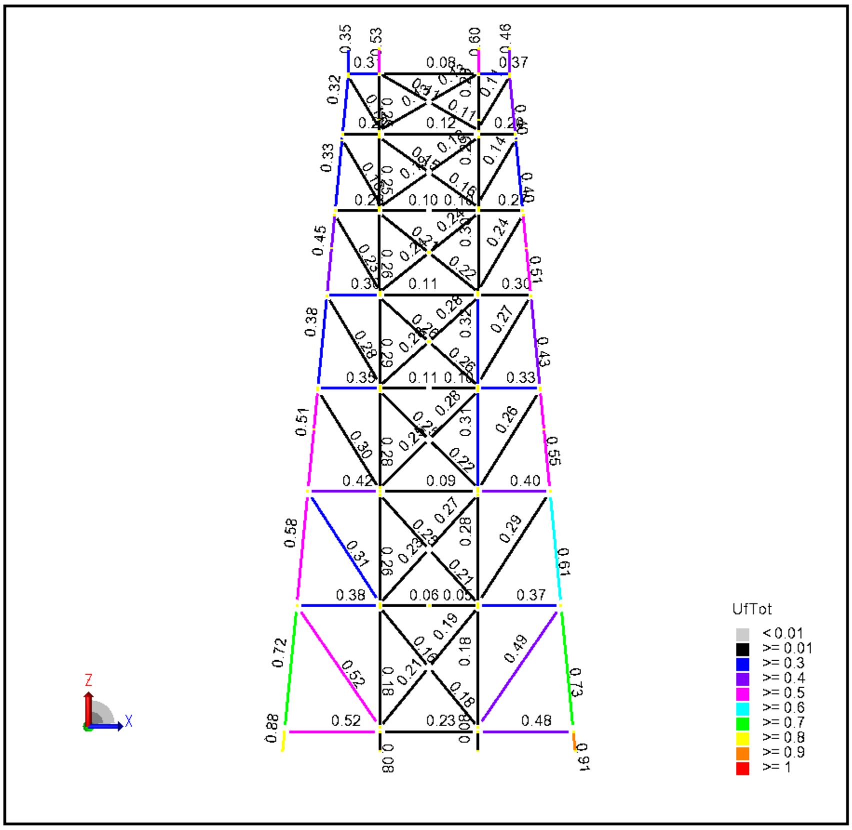

Figure 32 Eight-legged jacket's member check results, Row B

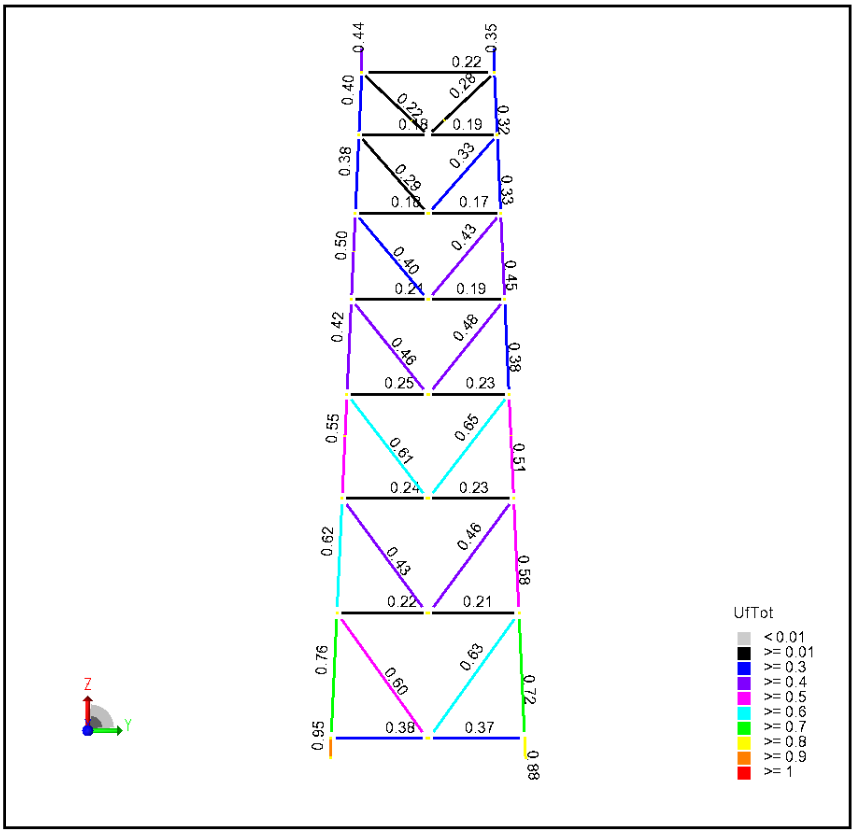

Figure 33 Eight-legged jacket's member check results, Row 1

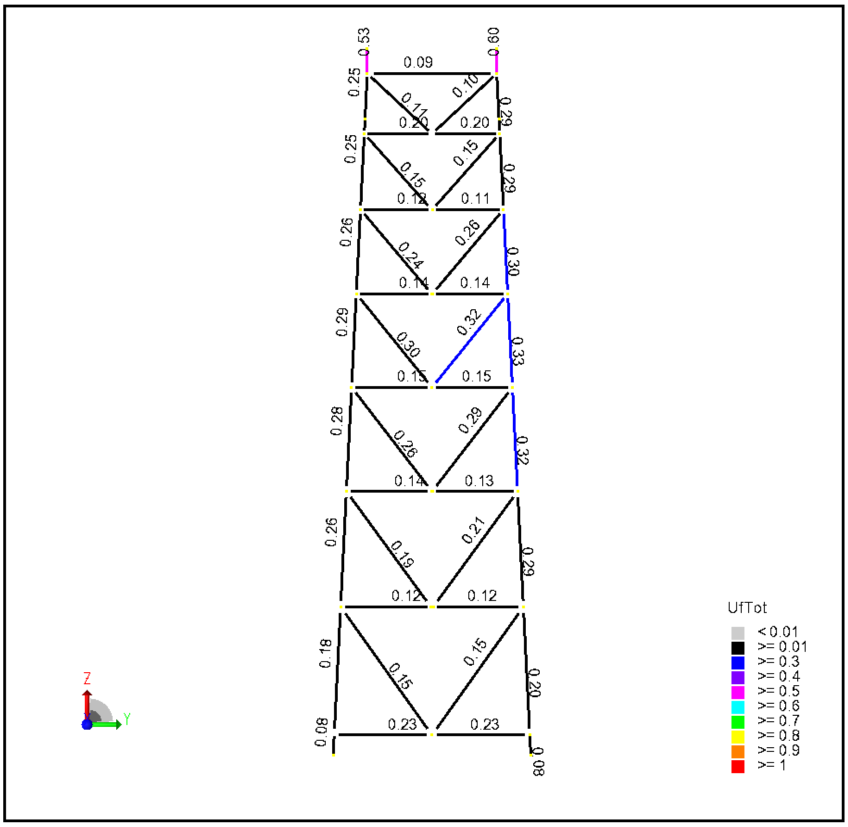

Figure 34 Eight-legged jacket's member check results, Row 2

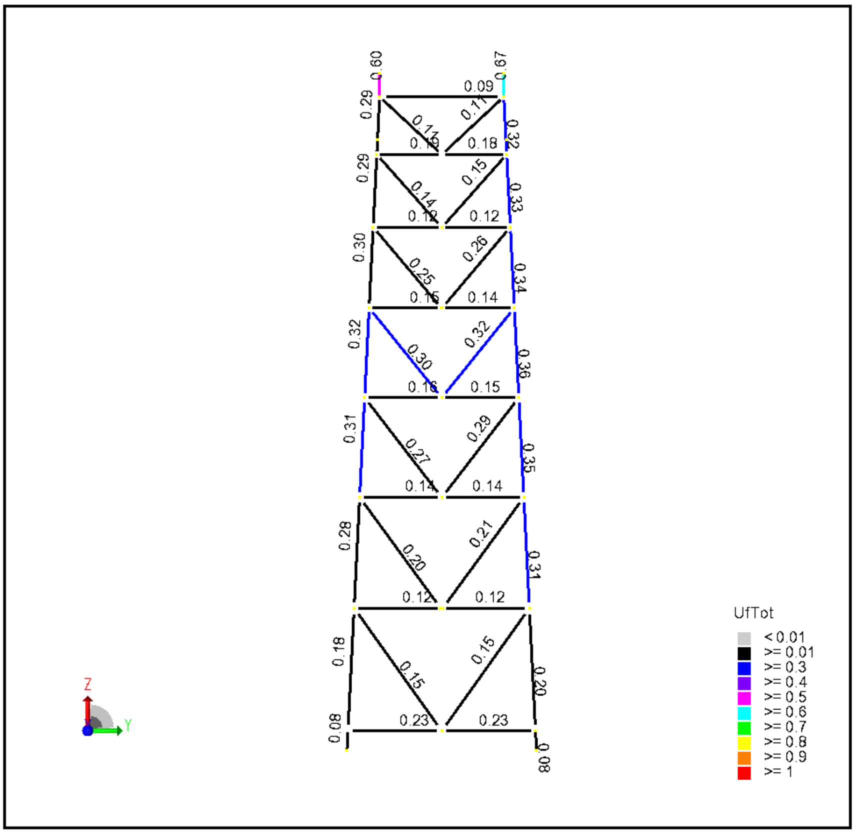

Figure 35 Eight-legged jacket's member check results, Row 3

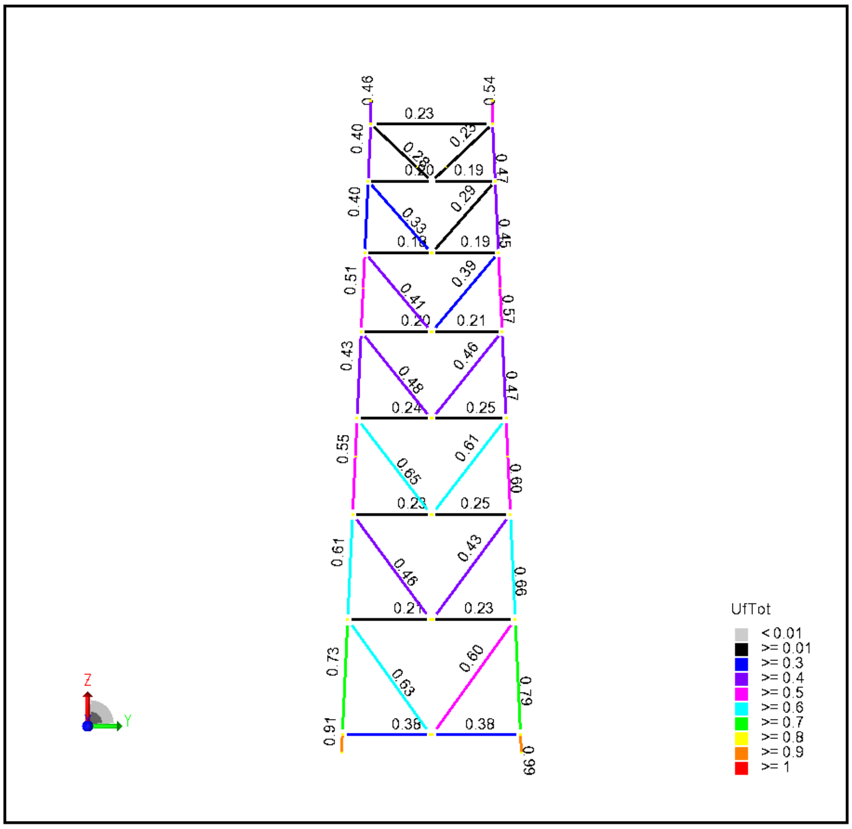

Figure 36 Eight-legged jacket's member check results, Row 4

C.2. In-Place ULS_B Member Check for Six-legged Jacket

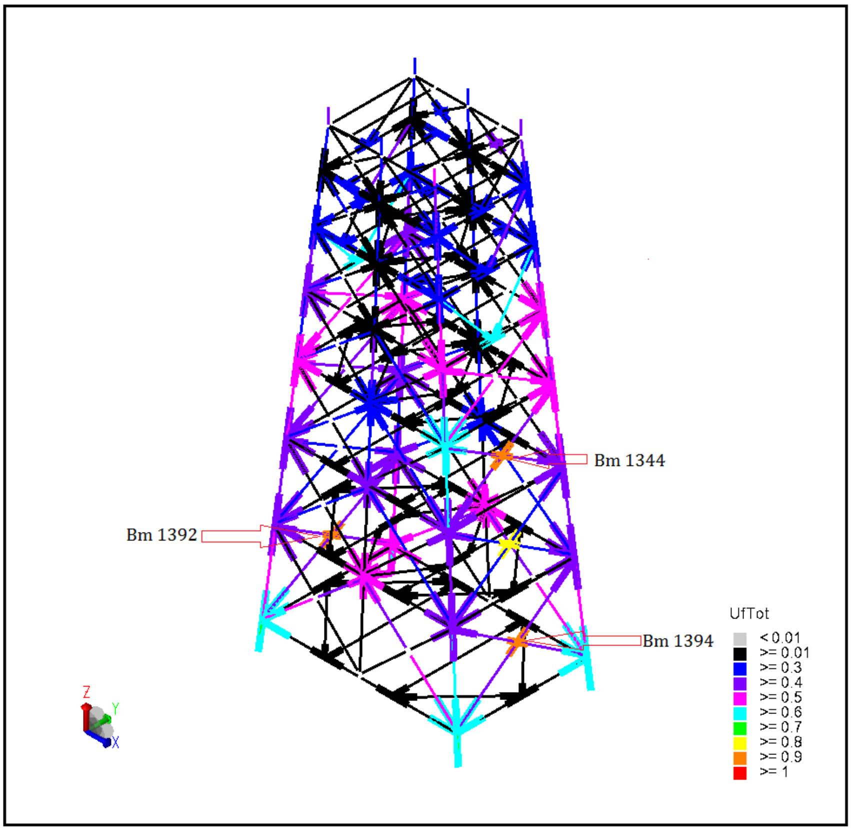

Figure 37 six-legged jacket's member check results, overview

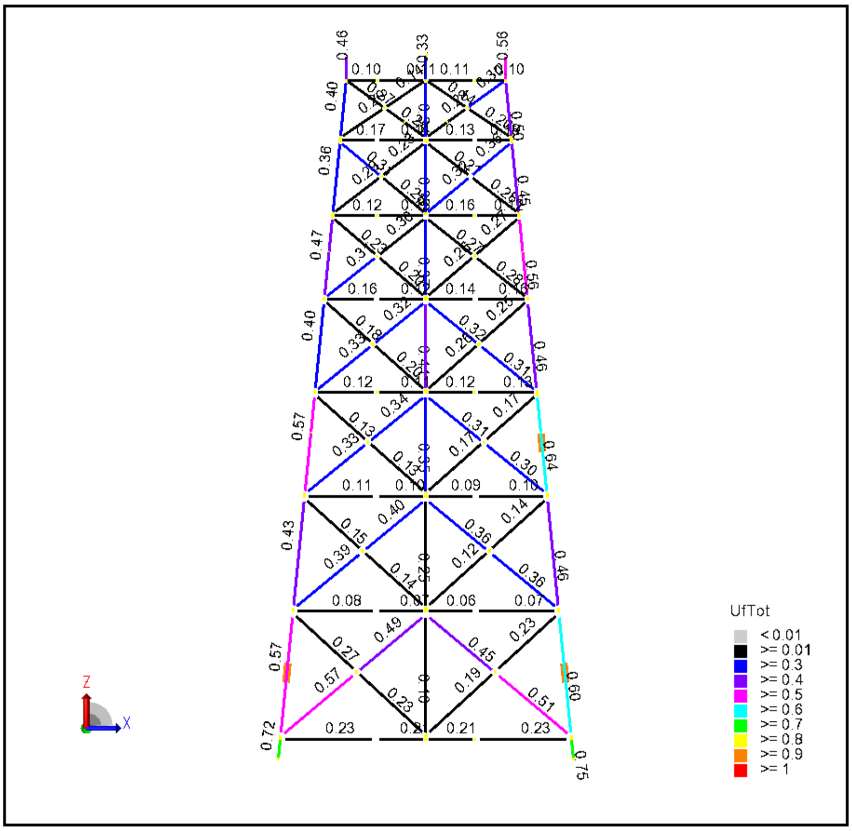

Figure 38 Six-legged jacket's member check results, Row A

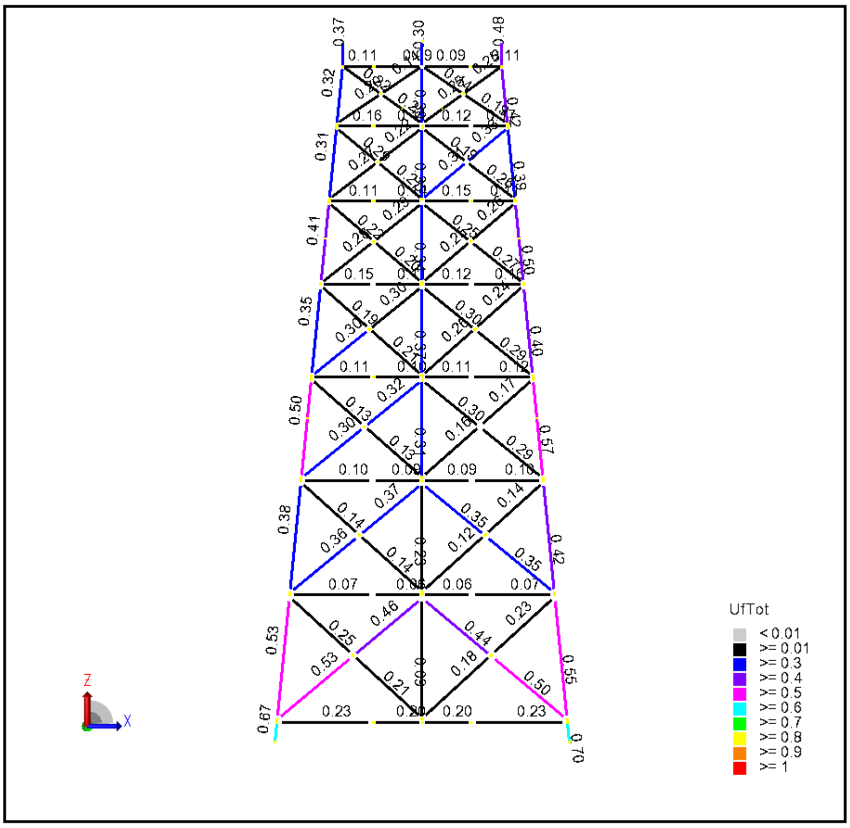

Figure 39 Six-legged jacket's member check results, Row B

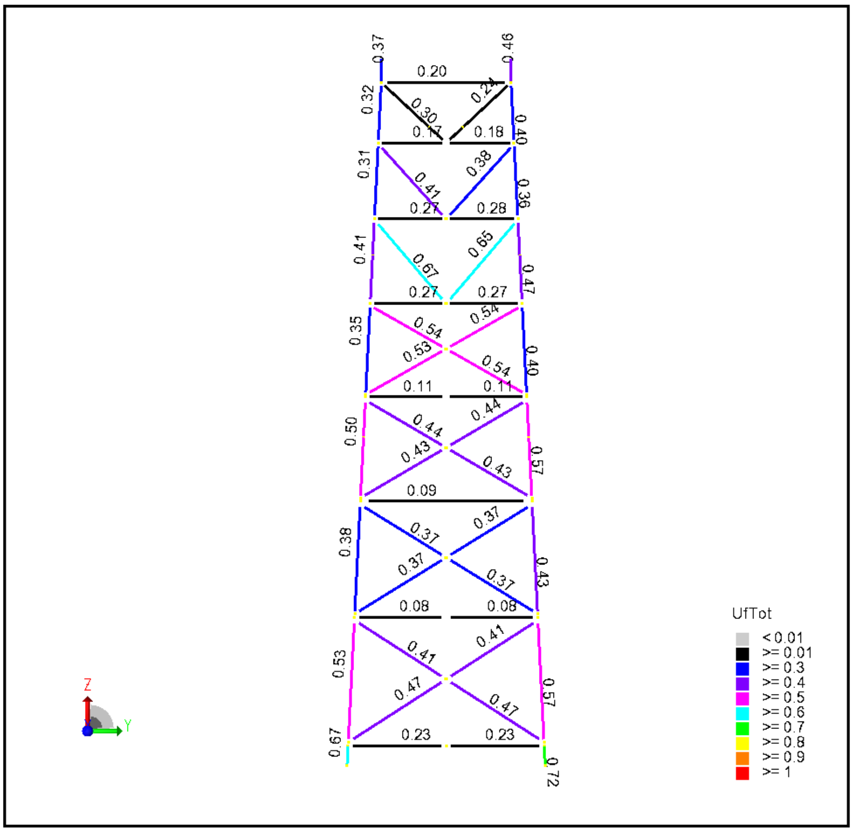

Figure 40 Six-legged jacket's member check results, Row 1

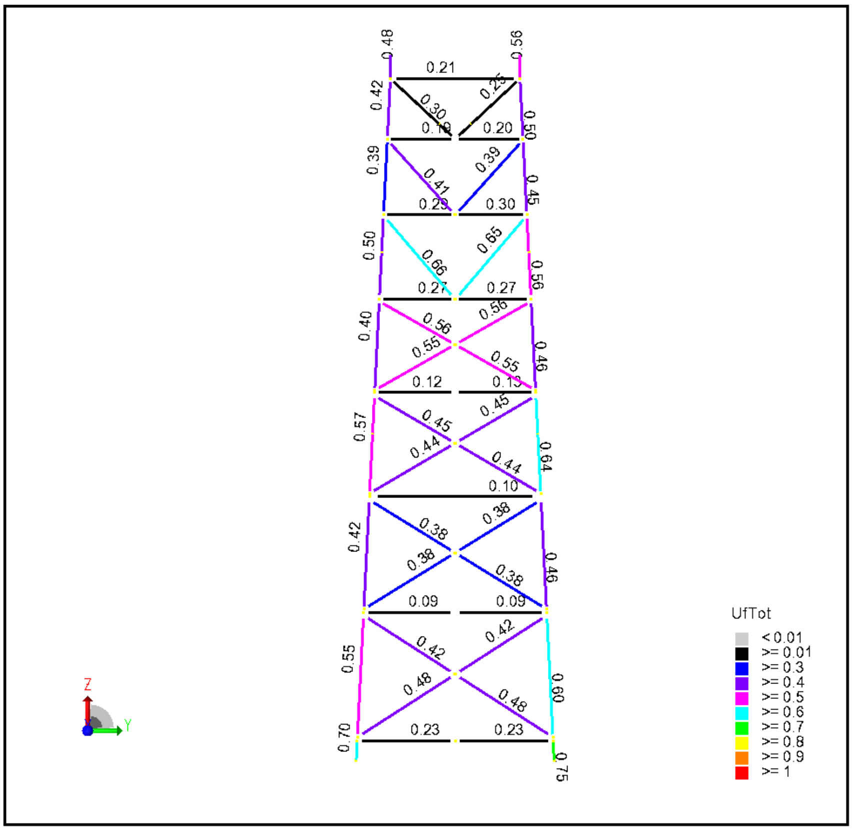

Figure 41 Six-legged jacket's member check results, Row 2

APPENDIX D

Information Collection of Flotels

Flotel		Gross Tonnage (metric tonne)	Keeping station	Accommodate
Floatel Superior		29000	DP3, positioning system 8 point mooring: 3",2000m,breaking strength 490Mt 6 azimuth thrusters,each 3200kw	440 cabins/512 berths 40-50 office work stations
Floatel Reliance		18038	DP2, positioning system 4 azimuth thrusters,each 2500kw 2 point wire mooring for inshore mooring	500 berths 40-50 office work stations
Floatel Victory		26800	DP3, positioning system 10 point 70mm chain mooring,breaking strength 510Mt 6 azimuth thrusters,each 3200kw	500 berths 40 office work stations
Safe Concordia		16700	DP2. 4 x 2,500kW azimuth thrusters (3,350 bhp).	440 persons
Regalia		17624	NMD3. 6 x 2,640kW azimuth thrusters (3,540 bhp)	306 persons
Safe Caledonia		19045	DP2. 4 x 2,400kW azimuth thrusters (3,260 bhp).	454 persons
Safe Britannia		23684	DP2. 4 x 2,400kW azimuth thrusters (3,260 bhp). 2 x 1,500kW fixed thrusters (2,040 bhp).	812 Persons
Safe Lancia		13002	DP2. 4 x 2,400kW azimuth thrusters (3,220 bhp).	605 Persons

Flotel		Gross Tonnage (metric tonne)	Keeping station	Accommodate
Safe Regency		18219	DP2. 4 x 2,400kW azimuth thrusters (3,220 bhp).	780 persons
Safe Scandinavia		24103	Moored 12-point wire anchoring system. 12 x Norwinch 2A-76-1 electro-hydraulic single drum winches.	Maximum number of beds: 583
Safe Astoria		10485	Safe Astoria deploys an 8- point wire anchoring system.	349 persons
Safe Bristolia		13876	8-point wire anchoring system.	587 Persons total capacity.
Safe Hibernia		15719	12-point wire anchoring system. 12 x double hydraulic winches.	635 Persons
Jasminia		10870	8-point wire anchoring system.	612 Persons