University of
Stavanger

Faculty of Science and Technology

MASTER’S THESIS

Study program/Specialization: OFFSHORE STRUCTURAL ENGINEERING	Spring semester, Open
Writer: Ivan Azad Ali	Ivan Azad Ali
Faculty supervisor: Ove Tobias Gudmestad External supervisor(s):	
Title of thesis: Structural modelling of offshore module for loadout, transportation and installation	
Credits (ECTS): 30	
Key words: modelling, offshore module, design, load factors, action and action effects, loadout, transportation, lifting, installation	Pages: 70 enclosures: 9 Stavanger, 14th June 2016

(Intentionally left blank)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

REFERENCING

The Harvard referencing style has been followed throughout this document within the text as well as reference table. Web links are cited in text with the initial address. The complete web link addresses can be seen in the reference table placed at the end of this document.

ABSTRACT

The demand for oil and gas, as well as the proceeding into new harsh areas in the north for exploring and producing oil and gas keep pushing the boundaries of offshore engineering into ever-deeper waters and harsher environments. The exploration and production activities require correct modelling of the offshore platforms to tolerate these challenges. This requires accurate modelling of offshore modules throughout all phases.

This thesis will focus on modelling of an offshore module. A previous Master's thesis in UiS, (Desta, 2012) has already considered loads for designing of an offshore module placed on a platform but neglected transportation, lifting and installation loads. The effects of these loads are significant on the Norwegian Shelf and they will be discussed in the present study. Available literature is reviewed and the modelling is performed by applying the software SAP2000. The modelling will be limited to modelling of a module on a fixed steel platform.

The main focus of the thesis is to stress the many important considerations and conditions during the loadout, transportation, lifting and installation phases. During transportation, the motions of the transport barge is of key concern. During the lifting/ installation phase, the moments of the module caused by the lift arrangement, dynamics as well as possible impact forces must be considered. Moreover, the relative motion between the barge and the crane is of primary importance. These load conditions are evaluated and optimum dimensions are computed. These dimensions are compared to the results given in the Master thesis prepared by Desta (2012) to validate weather the dimensions evaluated by Desta (2012) are within acceptable limits for loadout, transportation, lifting and installation procedures.

This thesis work is performed at the University of Stavanger. In the thesis work, we have in initially selected material properties and cross section geometries for the module from Desta, (2012). The report presents an introduction to the selection of design factors in the different operational phases and presents a comparison of these factors as given in NORSOK, ISO and DNV-GL standards. Structural analysis are carried out for the transportation, lifting and installation phases to check the load capacity of the module and to see if the structure can withstand the different effects during these phases. The design principles and methods will be discussed extensively.

Subjective risk analysis of load-out, transportation and lifting/installation has also been performed and suitable risk reducing measures are proposed.

At the end, the discussions and the main findings, challenges and recommendations based on the modelling results and experiences during the thesis work are highlighted. Recommendations on how to obtain an efficient design process backed by risk assessment are also presented.

It should be noted that the words ‘action’ and ‘load’ are used interchangeably in this report.

ACKNOWLEDGEMENTS

I would like to acknowledge various people who have journeyed with me as I have completed this thesis. Firstly, I owe enormous gratitude and debt to my supervisor, Prof. Ove Tobias Gudmestad for his consistent support throughout the different phases of this thesis. He has been very supportive and helpful throughout my studies.

Secondly, I would be grateful to Dr Yousif Rahim, working in Statoil; Astri Kvassnes, Senior Engineer in UiS ; Samdar Kakay, helped me in SAP2000 and Muhammad Ahmad Tauqeer, my class fellow for assisting me in paraphrasing English sentences in this report.

Lastly, I would like to express my deepest affection for my parents who has been there for me in all thick and thins in my life.

Thank you all for your contribution.

Ivan Azad Ali

ABBREVIATED TERMS

ALS	Accidental Limit State
CND	Operational, Storm or earthquake condition
CoG	Centre of Gravity
CoGE	Centre of Gravity Envelope
DAF	Dynamic Amplification Factor
DC	Design Class
DNV	Det Norske Veritas
DNV-GL	Det Norske Veritas (Norway) and Germanischer Lloyd (Germany)
FLS	Fatigue Limit State
HSE	Health Safety and Environmental
IDC	Inter Discipline Check
IR	Interaction Ratio
ISO	International Standard Organization
L_{buck}	Length between lateral support of compression flange
LC	Load Case
MEL	Master Equipment List
MSF	Module Support Frame
MTO	Material take-off
NS	Norsk Standard
NORSOK	Norsok Standard
PSA	Petroleum Safety Authority Norway
RAO’s	Response Amplitude Operators
SDOF	Single Degree of Freedom
SI	System International
SKL	Skew Load Factor
SLS	Serviceability limit state
SMYS	Specified Minimum Yield Strength
SOP	Swinging Object Protection
SWL	Still Water Level
UF	Utility Factor
UFL	Unsupported Flange Length
ULS	Ultimate Limit State
V Mises	Equivalent stress used in von Mises stress check
WCF	Weight Contingency Factor
WLL	Working Limit Load

1 INTRODUCTION

1.1 General

Oil is undoubtedly, one of the most important necessities of life. We consume more than 85 million barrels of the petroleum products everyday (web link: slipr.com). To meet this big demand for fossil fuels, petroleum companies constantly search the planet for unexplored reserves. The oceans, in this regard, serve as a major source of interest as they cover almost three-quarters of Earth's surface. Therefore, these companies came up with the idea of offshore construction to explore these precious treasures.

Offshore construction may be defined as the installation of structures and instruments in marine conditions without any access to land, usually for the production and transportation of electricity, oil, gas and other resources. Generally, a wellbore is drilled below the seabed and equipment are installed in the deep water to extract petroleum lying in the seabed rocks and transporting it above the sea level.

1.2 History of offshore petroleum (BP Oil Spill Commission, 2010)

In 1896, the California's creative Summerland oilfield was pursued to the beach by an enterprising businessman. Analyzing the scope of offshore construction, the industrialist Henry L. Williams and his associates built a 300 feet deep pier and attached a cable-tool rig on it. Within a year, it was producing oil and 22 companies joined hands with Henry. 14 new piers and over 400 wells were constructed within the next five years and the world saw a completely unfamiliar mean of nourishing a country's economy.

In 1911, The Gulf refining company drilled Ferry Lake No 1 on Caddo Lake, Louisiana. The well became extremely fruitful, extracting 450 barrels of oil per day. An offshore drilling rig of this era is shown in Figure 1-1.

Figure 1-1 An Offshore Oil Rig of 1910's. Taken from web link: aoghs.org

In 1938, Pure Oil and Superior Oil Company built a freestanding drilling platform in the Gulf of Mexico. With the help of a Houston engineering and construction company, a 320x180 wooden deck was installed in 14-feet of water about a mile offshore. By the end of 1949, 44 exploratory wells were functional in the Gulf of Mexico, according to the National Ocean Industries Association.

1.3 Innovations in offshore platforms

The prominent success of this industry has caused the constructors and industrialists to invest extensive money and mind in presenting advanced and better techniques and mechanisms. Progress in offshore technology includes advances in production platforms, which provide a base for operations, drilling and then production. The progressive advancements in the platforms have resulted in increased water depth in which they can operate, the time they take to extract the petroleum and overall processing time. This has resulted in development of several different types of offshore platforms, which are designed to suit different combinations of environmental conditions. Common configurations of offshore platforms are shown in Figure 1-2.

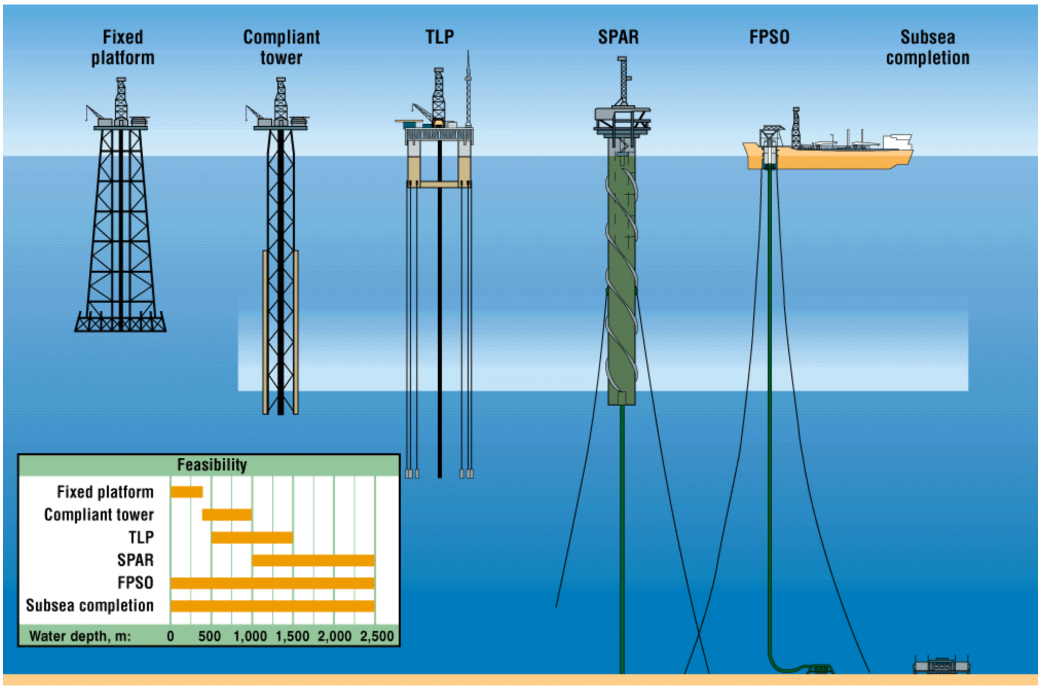


Figure 1-2 Innovations in Offshore Platforms. Taken from web link: offshore-mag.com

The purpose of an offshore platform is not only oil exploration and production but it also serves a mean for navigations, ship loading and unloading, carry a living quarter etc. On average, an offshore platform has a life of 25 years. Throughout its life span, it has to survive very harsh marine environment, intense loads induced by hurricanes winds and waves, fatigue load generated by the waves and also the strong force subjected by constant current which can also cause vortex induced vibrations in mooring systems by creating cyclic loads. Moreover, the structure should operate safely throughout its lifetime with very low probability of error. Oil and gas production makes the situation more critical for design engineers.

Offshore platforms today can be categorized into two main domains. Floating platforms and fixed platforms.

1.4 Floating Platforms (Oil and Gas Offshore Production)

Floating platforms float on the sea and can be shifted from one place to another. The main advantage of the floating platforms in the cost. As for deeper water, the use of fixed platforms will not only be too much expensive also very difficult (for some environmental conditions impossible) and time consuming to construct. Further once installed, a fixed platform cannot be reused. Hence using fixed platform in deeper waters is neither economical nor viable in the sense of design and construction. This forced the engineers to go for floating platform solutions that will totally eliminate the concept of bottom supported platforms in deep water. The floating platforms might be more expensive than the fixed platforms installed in shallow waters, as they require mooring or dynamic positioning in addition, but they can be reused, hence considered economical for medium and deeper waters. Floating platforms include semi-submersibles, Spars, Drill ships and FPSO (Floating, Production, Storage and Offloading) platforms. These structures are moving in six degrees of freedom (heave, surge, sway, pitch, roll and yaw).

1.5 Fixed platforms

Fixed platforms are built on solid foundations, which are fixed directly onto the seabed; hence, they are immobile (Chakrabarti, 1994). They support a deck with space for drilling rigs, production and storage facilities and quarters for workers. The foundation provides the rig a tough base and holds everything out of the water. Fixed platforms may have more than 50 well conductors. Most units are complete, self-contained that include their own power plant, accommodations, drilling equipment, life-saving equipment, and auxiliary services and even their own crane system. Three types of fixed platforms are commonly used. They differ only in the way the bottom support is constructed.

1.5.1 Steel jacket platform (Chakrabarti, 2005)

A steel jacket platform is supported by a tubular frame structure supported at the bottom of the sea by piled foundations. A piled foundation is a circular ring of pipes welded to the legs at the top and driven deep into the soil, through the seabed, on the other. Piles are steel structures hammered into the soil and act as mean of attaching the deck firmly onto the seabed. All the connections between the platform and the reservoir are located in-between the tubular frame structure hence it also acts as a protecting cover to these conduits. Jacket platforms are used in moderate water depth, up to 400m. North Rankin A and B Steel Jacket Platforms are among the platforms using piles as illustrated in Figure 1-3.

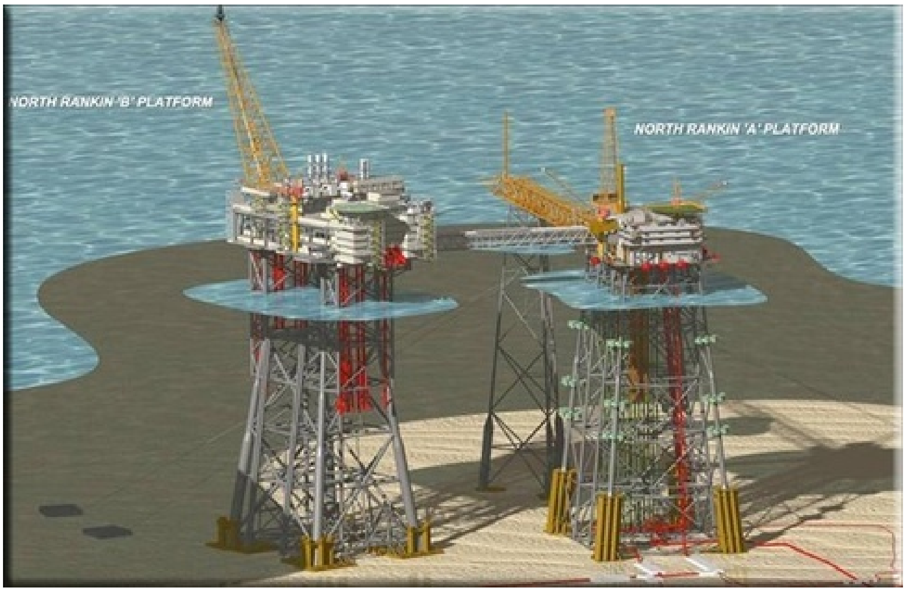


Figure 1-3 North Rankin A and B Steel Jacket Platforms. Taken from web link: quora.com

1.5.2 Complaint platform (Will, Compliant Towers)

A complaint platform (also called a complaint tower (CT)) is a narrow flexible tower with piled structure on the bottom. The platform on this support base cannot be heavy hence; it does not have oil storage capacity. Used in moderate water depths, up to 600m. A typical complaint tower is shown in Figure 1-4.

Figure 1-4 A Typical Compliant Platform (tower). Taken from web link: america.pink

1.5.3 Concrete gravity structures (Holand, et al. 2000)

These are heavy structures made up of concrete, which stay on their place because of their weight hence no need of piles. A structure is partially constructed onshore and then towed offshore for further construction. The deck is placed on the top of the concrete structure. They are used for moderate water depth, up to 300m. A typical concrete gravity structure and platform is shown in Figure 1-5.

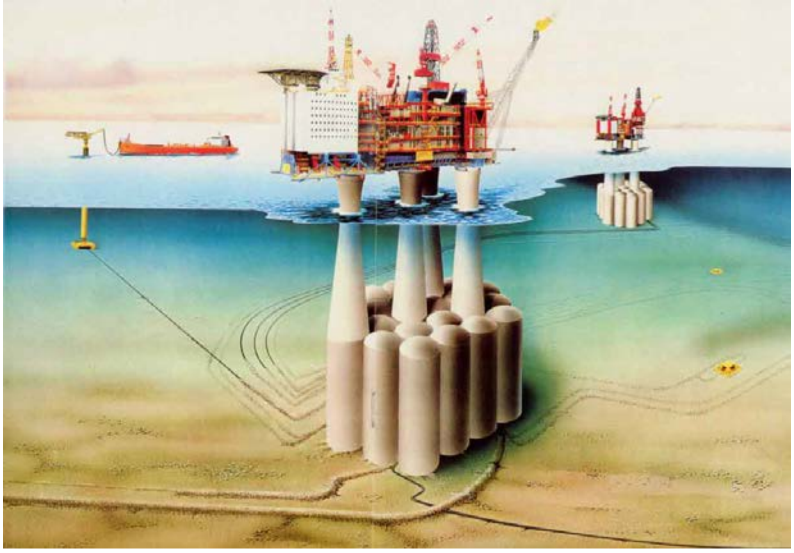


Figure 1-5 A Concrete Gravity Structure and Platform. Taken from web link: www-it.jwes.or.jp

1.6 Basic components of fixed platforms (Sadeghi, 2007)

Fixed platforms are not constructed in one piece. There are many sub components, which are either manufactured onshore, offshore or partially onshore and partially offshore. A fixed offshore platform is basically composed of:

- Base support: this is the supporting foundation, that attaches the platforms with the seabed. It provides the strength against harsh environmental conditions and keeps the platform components lifted up out of the seawater.
- Deck structure: this is the structure above the sea level. It is the support for many important operations. It is the basic structure of the platform facilities, on which all other components reside. A deck is manufactured onshore and after the installation of base foundation, transported to offshore on a barge and then placed on the base foundation. Alternatively, the deck is transferred to the foundation while the foundation is floating in the fjord. Special mechanisms are designed both on the base foundation and on the deck to firmly fix these with each other. After fixing them together, they are welded as well, to ensure secure connections. After the installation of the deck, all other components that are directly involved in petroleum extraction (for example the modules) are installed on the deck
- Living quarter: is the module place on the deck to accommodate the crew working on the platform.

- Riser system: includes the connections between the platform and subsea. All communications between the platform and subsea in done through the riser system.
- Topside: the topside is the main operational area of the platform. All the petroleum related activities take place on the topside. It basically includes three modules
  - Drilling module
  - Operation / utility module
  - Processing module

Only the operational module will be discussed thoroughly in this report. The arrangement of different modules on an offshore platform is shown in Figure 1-6.

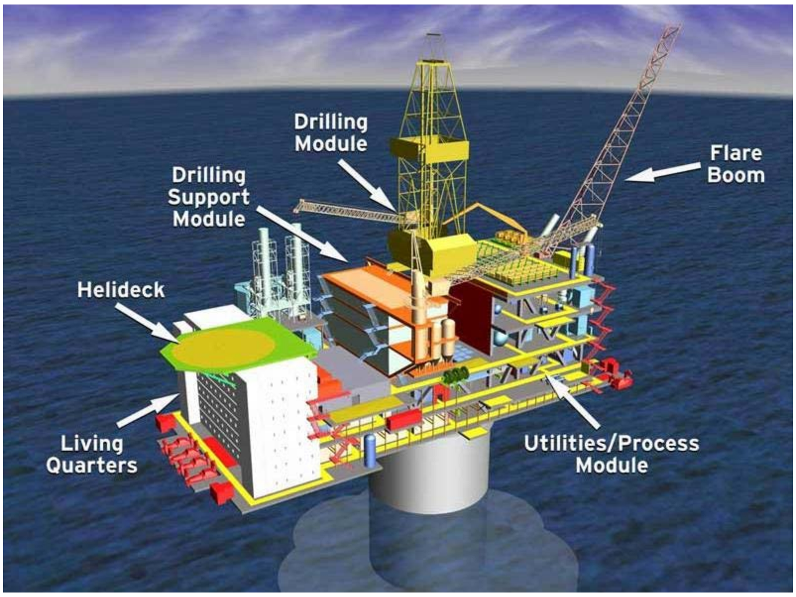


Figure 1-6 Basic Components of Fixed Offshore Platform. Taken form web link: https://mb50.wordpress.com

1.7 Design of fixed platform components:

Fixed offshore platform component structures are completely different from floating platforms in both appearance and selection of construction members. The differences in design of these different types of platforms appear mainly due to (Chakrabarti 2005):

- Their construction methods
- Transporting and installation
- The kind of excitation force they experience
- Their response to those excitation forces
- Decommissioning and recycling methods

The objective of this report is to carry out the modelling of an offshore topside operation module, which is located on a fixed offshore platform. Since the applied load influences fixed offshore structures, it is very necessary that these loads be defined correctly. As the lateral loads such as wind and waves are changeable, the met-ocean environmental data is required in order to estimate the loads on the platform.

The structure design is based on the loads that it will experience during its life span and the strength of material from which it will be constructed. The major loads that act on the platform and that influence the design or the material selection of various components are (El-Reedy 2014):

- Gravity loads
- Wind loads
- Current loads
- Earthquake loads
- Impact loads
- Other loads

An offshore platform, during its lifetime, passes through many phases. During each phase, it experiences the above-mentioned loads in different ways. Few of these loads are critical in one phase while other loads are not so influential. Moreover, all the components of the platform are not designed, manufactured or installed in one go. They are designed separately, manufactured separately and installed separately after which they operate together during the operation phase. If any of the components malfunctions and needs to be replaced, then only that component is replaced instead of the whole platform. Hence, the life span of an offshore platform can also be described as the life span of individual components all together. The phases of the life of an offshore platform are

- Manufacturing phase
- Loadout phase
- Transportation phase
- Installation phase
- Operation phase
    - Drilling phase
    - Production phase
    - Maintenance phase
- Abandonment phase

The design procedure of an offshore platform component has to consider all of these life phases and the critical loads of each one of them as after construction; the platform has to pass through all of these phases and ideally without any maintenance or improvement. Typically, an offshore platform is designed for manufacturing, loadout, transportation, installation and operation phases. Further, the risks related to these phases also have to be taken into account during design procedure. Design regulations and standards also force one to design for accidental situation by including check in the Accidental Limit State (ALS). After all, the design should be economical and within desired profitable economic range otherwise, it will deviate the interest of investors and stakeholders.

1.8 Objectives of the report

The basic purpose of this report is to discuss, for a topside operation module of a fixed offshore platform, different design loads experienced by it during loadout, transportation and installation and different design criteria according to various available standards i.e. ISO, NORSOK and DVN GL. This report does not offer a complete design of an offshore topside operation module; instead, for dimensions and weight, the information is taken from a previous report prepared by Desta, (2012), the effects of different factors on design lifting, transportation and installation phases are discussed. Only the loadout, transportation and installation phases are discussed as Desta, (2012) has designed the module for the operational loads only and these three are also among the module's critical life phases along with the operation phase. Special attention is given to the design criteria defined in standards, the load factors used in those criteria and effect of these factors and criteria on the final design and its performance. The main objectives are defined as:

- Identify load combinations for safe design of the module in loadout, transportation and installation phases
- Comparison of ISO, NORSOK and DNV GL standards for topside operation module design.
- Pros and Cons of design based on each standard for loadout, transportation and installation and transportation phases of the module.
- Selection of appropriate design factors for each phase.
- Analyze the structure of the topside module for loadout phase.
- Analyze the structure of the topside module for transportation phase.
- Analyze the structure of the topside module installation phase.
- Structural design of the module for lifting phase.
- Structural design of the module for transportation phase.
- Structural design of the module for installation phase.
- Discuss various requirements of the construction relating to weight, load-out, sea transport and offshore lifting operations.

2 LOAD-OUT

Loadout is defined as the mean through which manufactured modules are transferred from onshore on to the barge for transportation. This activity is called load-out. There are several techniques for load-out some of the most common ones are discussed here.

2.1 Skidding

Skidding is a technique of load-out on a built-up skid track. A connection is made between the track and the structure to be loaded using a skid shoe. The skid track is lubricated and a special mechanism then pulls the load over the tracks. Another important consideration is the friction. The points of contact should be checked for any signs of friction and material with a low friction coefficient should be used in this process

After analyzing the loads, the barges are provided with suitable skid arrangements. Figure 2-1 shows two different skidding systems used in load-out. In the past, ships were launched from a wooden launch ramp tilting some few degrees by using grease on the launch ramp and taking away the supports that were installed to hold he ships from sliding.

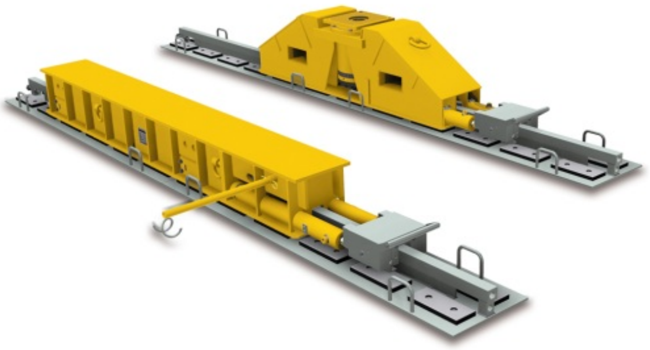


Figure 2-1 Enerpac skidding systems. Taken from web link: www.offshore-technology.com

2.2 Lifting

Load out by direct lift is a common practice. Heavy cranes and lifters are used to carry the cargo from one place to another. As the lifting arrangements are different from that of the lifting operations during installation offshore, the lifting forces are not usually considered. This lifting is quite simple as compared to the lifting during the installation, as the disturbing forces are very less. There is no lateral or vertical motion of the crane involved, only the barge is moving. The contractor needs to analyze the wind speeds and tidal fluctuations before making any move.

2.3 SPMTs

An SPMT (A Self Propelled Modular Transporter) is a vehicle with a large and flat platform having a large number of tires and up to 1500 axles. These transporters are used to transport extremely heavy objects like larges barges, bridges and oil refining accessories etc. Their width ranges from 2.4m to 3m. More than one unit can be coupled with each other to carry a bulky structure. The recent advancements in electronics have made these transporters more efficient and able to carry larger weights. The hydraulic drive systems in the recent SPMT's allow them to retain stability when they cross a ramp or a jump. They are very slow moving vehicles with average speed of 5km/hr. Following (Figure 2-2) is the visual demonstration of an SPMT vehicle:

Figure 2-2 Mammoet SPMT's of Belgium. Taken from web link: www.heavyliftspecialist.com

2.4 Floating-on

In this method, a floating cargo is floated into the cargo space of the ship using superposed tiers. The stowage space for each tier must be greater than the submergence of the floating ship by an amount equal to the difference between the upper and lower previously defined safety margin. This is an expensive method because it requires additional ship depth and dead cargo space that is why only heavy cargos are lifted by this process. The labor requirement in this process is minimum.

3 *TRANSPORTATION*

Transportation is the movement of different offshore structures to and from the site. It is done through barges mostly. The process of transportation involves many complications and it is a very time consuming process. It involves several steps and each step requires proper attention to ensure the integrity of whole process. The major steps involved in the process of transportation are

3.1 Routing

Routing is the analysis to work out the best possible routing for the purpose of transportation. Routing is performed by considering that it should be safest, shortest and cost effective.

3.2 Metocean

Metocean information includes the information of the wind and climate statistics of the parts of ocean, the offshore sites are situated at. This information covers all metocean parameters including significant wave height, swell height, period and direction of waves and velocity and direction of surface current. This information can later be reviewed to decide the best transportation packages and techniques. Effective metocean knowledge helps to plan barge transports and heavy cargo transports. Advanced forecasting services, which use high-quality satellites, have minimized the time lost to calculate weather suitability to perform the transportation processes. Floating offshore buoys are used to collect metocean information and one of buoy capable of operating in strong currents is shown in Figure 3-1.

Figure 3-1 AXYS Watckeeper buoy can be deployed in strong currents to collect metocean data. Taken from web link: www.axystechnologies.com

3.3 Sea-fastening

When the routing is done and weather window is decided, the third step at the time of start of transportation process is sea-fastening. When a cargo is moved on a ship, it must be secured in a way that no movement occurs which could result in the instability of the cargo and in fact, the ship. This may damage the ship and cause harm to the ship crew as well. The practice of securing the transporting cargo and to restrict the movements is called sea-fastening. The securing method depends upon the size, shape and weight of the cargo. Mostly used methods are,

1. Blocking with wooden slabs.
2. Blocking with chains.
3. Welding with steel pipes.
4. Securing with steel straps.
5. Covering with anti-corrosive material.
6. Securing with Steel clamps.

DNV compliant sea fastening clamps are shown in Figure 3-2

Figure 3-2 DNV sea fastening clamps. Taken from web link: http://www.oceanfabricators.com

3.4 Cargo support strength

When preparing the plans for cargo support strength, it should be kept in mind that the ship/ barge might be loaded up towards the maximum of its deadweight. Complications occur in this process. One needs to keep in mind the weight exerted on each compartment of the ship/ barge due to the cargo. This process is important to ensure safety of both transport barge and cargo. The limits of the strength of the deck are calculated by the classification societies. These are given in tones per square meter and written into in the ship's technical manuals. To ensure the limits are not exceeded, it is to be made sure that the weight of the cargo is evenly distributed over the available area. When heavy cargos are mounted on the ship/ barge, plenty of strong steel plates is laid on the surface to make sure the weight is distributed uniformly.

3.5 Ballasting

Ballasting is the filling of dedicated tanks to maintain the stability of the structure. Seawater is a common filler but solid filler is also used which consists of concrete placed over slabs. The ballast helps to lower the center of gravity of a structure, which ensures its safety. If the amount of cargo is large, then the requirement of the ballast is minimal because the weight of the cargo itself helps in lowering the C.O.G. The wind load is a crucial consideration. In case, the filler is the seawater, fluid load comes into play as well. The water placed in tanks and pipes for the ballasting purpose should be calculated to make sure that stable equilibrium is established. Ballast tanks filled with water should be filled completely to ensure that skew loading is not causing water to destabilize the structure when the structure rolls to one side.

3.6 Motion analysis

Motion analysis is done to study the effect of the waves on the motion characteristics of the transportation barge/ship. This is done by computer-aided software, which provides graphical representations and concrete interpretations. After that, several analysis are run, e.g. stress analysis and fatigue analysis. Different equations are used to study the effect of waves hitting the barge/ ship and its effect on its stability. Several parameters are included in the equations to work out a stable design for the ship. Some of the parameters are:

1. Wave period.
2. Wave height.
3. Roll angle of the vessel in the waves.

After the calculations are done, different materials are proposed for the construction of a stable sea fastening on the barge. Then their characteristic values (like strength, shear stress etc.) are put in to equations and the results are used to select the design which is most suitable as per the motion analysis. The relationship between the roll motion of the barge and the forces acting on a module is illustrated as following (Figure 3.3):

$$K_{total} = Mg\sin\varphi + M\theta(t)h$$

$$K_{total} = M\{g\sin\varphi + \theta(t)h\}$$

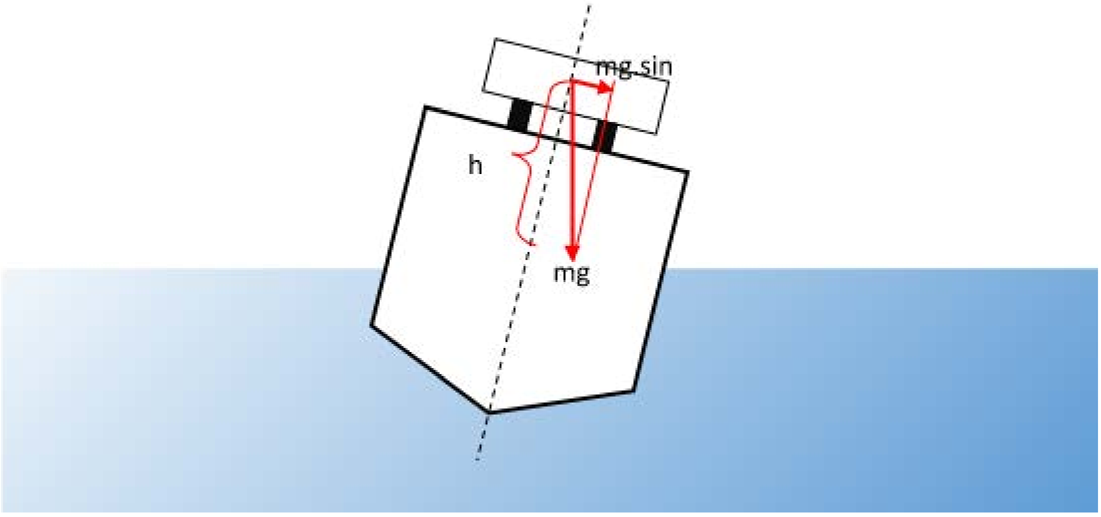


Figure 3-3 Roll motion of barge (Gudmestad, 2015)

4 LIFTING

Lifting is defined as rising the offshore module from the transportation barge to be placed on the fixed platform. Proper care needs to be taken or otherwise the results may be drastic. A typical offshore lifting operation is shown in Figure 4-1. Lifting involves the following steps:

Figure 4-1 Typical offshore lifting. Taken from web link: http://www.chain-connection.com

4.1 Rigging analysis

Rigging analysis is done to make sure the best rigging is selected which is not effected by severe weather conditions, is easy to build and cost-effective. Furthermore, the following points are kept under consideration as well:

1. Weight of lift.
2. Sling angles.
3. Crane and load foundation readings.
4. Work zone safety.
5. Load analysis: This includes live loads like weight of any water for hydrostatic testing, weight of any vessel contents like mud, oil etc., dead loads including all immobile weights of the elements of the handling systems and hook load, which comprises of the rigging weight of the handling devices like beams and slings.

Computations and detailed analysis are employed during the analysis where different parameters are considered after which the final decision is made. In the recent times, due to increase in the assembly size, the rigging analysis is becoming very complicated, therefore balanced assumptions are taken when analysis is being performed. Some of the considerations reviewed in the analysis are as under:

1. Determining the Centre of Gravity of the object.
2. Drawing of a free body diagram to work out the loads on the crane.
3. Classical analysis involving the calculations of movements resulting from the lifted loads.
4. Finite Element Analysis, which provides insight into the behavior of structures.
5. Determining the points and amount of pins and slings to be used.

4.2 Lift points

The lift points should be designed in a way that they are able to withstand maximum sling load and any variable sling angle. Their design should be in accordance with the standard rules of construction which takes in to account the load and the climatic conditions like wind speed and reliability. The load bearing capacity of the lift points can be calculated by available programs. The suitable design considerations are:

1. Proper clearances for connection and removal of lift rigging.
2. Proper load distribution of shackles.
3. Proper functionality of rigging.

There are many types of lift pints like screwed type and weld-on type. The nominal working load for every type of lift point is mentioned in the relevant datasheet and should be used for the mentioned loads only. The loads involved are live loads (e.g. stairways) and dead load (discussed above). A typical screw type lifting point arrangement is shown in Figure 4-2.

Figure 4-2 Screw-type lifting point. Taken from web link: http://www.chain-connection.com/

4.3 Motion analysis

A motion analysis is an important part of the design of offshore construction activities. This analysis gives a comprehensive insight in the selection of suitable lifting sites and techniques. Various analysis are performed some of which are as under:

1. Free vibration analysis.
2. Buckling analysis.
3. Torsion and combined loading analysis.
4. Fatigue analysis.

Computerized simulations provide efficient solutions for the hydrodynamic, hydrostatic and mooring design during the installation activities. Pictorial representations allow the designer to view the points of concern and find their solution. Several load considerations are to be kept in mind during the analysis like the gravity loads (like the weight of storage tanks, weight of snow etc.), fatigue loads (loads that cause structural damage due to cyclic loading) and peak environmental loads created by hurricanes or fast moving winds.

4.4 Lifting using slings

Lifting slings are one of the methods used for lifting. They can safely and efficiently be used to lift heavy offshore equipment with the help of a crane. Lifting slings are usually made up of wire rope, nylon, chain, and polyester. The conventional steel wire lifting slings used for offshore lifting are highly reliable and strong. However, at the same time they are heavy, undergo large elongations, are hard to handle, apply concentrated loads on lifting locations and are always potentially dangerous because of slack possibility. For in-land based rigging operations, these challenges do not have significant importance but in rough seas, they are significant. An offshore sling lifting operation is shown in Figure 4-3.

Figure 4-3 Lifting by slings. Taken from web link: www.piping-engineering.com

4.5 Lifting using spreader bars

A spreader bar is an additional equipment used below the lifting hook in order to distribute load over the equipment being lifted. It helps minimizing the bending moment on the equipment being lifted. It assist rigging operations in lifting up large and heavy loads. The concept used in the spreader bar is to distribute the lift load across on more than one point. This increases overall stability of the operation and decreases hoisting load at the padeyes. The major application of spreader bar lifting is when the object being lifted is too large and does not have the potential to withstand adverse loading caused from angled slings during lift. A spreader bar lifting operation is shown in Figure 4-4.

Figure 4-4 Lifting using spreader bars. Taken from web link: www.hollandiaoffshore.nl

5 INSTALLATION

Installation is defined as the action of installing offshore module on the platform. Installation and lifting have overlapping features and are thus confused with each other in principle. Lifting is the rising of the equipment from the transportation vessel while installation is the lowering of equipment on the installation location. According to the physics of these operations they look like identical however while installation an impact is imparted on the installation equipment while touching the installation location. This impact depends on the lowering speed of the crane and heave motion of the barge. For large offshore modules this impact is of significant importance and must be taken into account while designing the installation operation. An offshore installation operation is shown in the Figure 5-1

Figure 5-1 Installation operation. Taken from web link: www02.abb.com

The stress applied on an offshore module while impacting on the installation location can be modelled as a nonlinear problem. The nonlinear analysis can be conducted by specifying the crane tip motion speed. An alternate way of modelling this impact loading is using the static analysis with a dynamic amplification factor (DAF). Nonlinear analysis is complex and computational demanding while the linear static analysis is time efficient but ignores nonlinearities. Dynamic amplification factors for offshore installation can be taken from DNV-OS-H205 (2014) as shown in the Table 5-1.

Table 5-1 Dynamic amplification factor DNV-OS-H205 (2014)

SHL (Static Hook Load)	*DAF Onshore*	*DAF Inshore*	*DAF Offshore*
3[2] – 100 t	1.10	$1.07 + 0.05\sqrt{100/SHL}$	$1 + 0.25\sqrt{100/SHL}$
100 - 300 t	1.05	1.12	1.25
300 - 1000 t	1.05	1.10	1.20
1000 - 2500 t	1.03	1.08	1.15
> 2500 t	1.03	1.05	1.10

6 *LOAD COMBINATIONS*

A structure (the module) is exposed to many different loads from the manufacturing site until in-place on the platform. During the analysis of the structure, these loads have to be combined in the worst case conditions, however such that the combinations be realistic.

A structural analysis and design should be based on the rules and standards of the respective country. In Norway, it will be based on:

1. NORSOK Standard
2. DNV Standard
3. ISO Standard

In this section NORSOK, DNV and ISO standards will be studied for transportation, lifting and installation with respect to combinations of load effects for the design of the offshore module.

6.1 NORSOK standard load combinations

The NORSOK standards stand for “NORsk SOkkel Konkurranse-posisjon”. The NORSOK standards give general guidelines and recommendations for the designing and analysis of offshore modules and structures. They are developed by the Norwegian Petroleum industry. The N-003 standard represents the summation of actions, action effects for facilities and load bearing structures subjected to probable actions and offshore environmental conditions. The NORSOK standards possess the status of reliable industry standards, and have numerous sub packages, where the notation N is the structural standards (NORSOK N-001, 2004). The first NORSOK standard was issued in year 1993, to replace the internal specifications of each company.

The structural design should satisfy different limit states based on the structural design standard NORSOK, N-001. According to this standard, the design should be capable of withstanding four limit The states (shown in Table 6-1).

Fatigue limit state (FLS) is normally not considered during transportation, lifting and installation phases since fatigue induced damage is normally of negligible importance. Neglecting FLS in these phases is a reasonable assumption since the fatigue loading is much less as compared to the load in the in place phase. Thus a module designed for in place fatigue loading should be safe in transportation, lifting, and installation phases. Secondly, the lifting and installation operations are one-time operations in the lifetime of an offshore module. The transportation of an offshore module on a barge in waves is a cyclic process and appears to be a fatigue inducing process but the offshore modules are to be transported in well-calculated weather windows with limited wave conditions.

NORSOK N-001, (2004) has specified two different ultimate limit states (ULS-a and ULS-b). ULS-a gives a higher partial factor to permanent and variable loads (1.3) and a less partial load factor (0.7) to environmental loads. A higher partial load factor for permanent and variable functional loads describes the uncertainty in these loads by NORSOK N-001, (2004) and a low partial load factor (less than one) defines that the environmental loads will remain under 70% of the worst environmental loads being used for calculation when combined with high permanent and variable loads. Contrarily ULS-b assumes permanent loads and variable functional load to be exactly equal to the calculated characteristic values by taking the partial load factors equal to 1.0 and ULS-b expresses the uncertainty in the environmental loads by increasing these to 130% (partial load factor 1.3). NORSOK N-001, (2004) has given guideline to use the severest of the ULS-a and ULS-b cases for design. This shows that the NORSOK Standard defines ULS as taking either the permanent and variable loads having high partial load factor or taking the environmental loads as having high partial load factor but both cannot be high simultaneously.

Partial load factors for the serviceability limit state (SLS) and accidental limit state (ALS) are 1.0. However, in SLS the deformation is most important while accidental loads are neglected and in the accidental limit state (ALS), deformation loads are neglected.

The load combinations should be used for each limit state with the partial load factors mentioned in Table 6-1, which is referred from (NORSOK N-001, 2004).

Table 6-1 Partial Load factors

Load combination	Permanent loads (P)	Variable functional loads (V)	Environmental loads (E)	Accidental loads (A)
ULS-a	1.3	1.3	0.7	-
ULS-b	1.0	1.0	1.3	-
SLS	1.0	1.0	1.0	-
ALS	1.0	1.0	-	1.0

While Table 6-2 lists symbols used in the design process, Table 6-3 emphasis the permanent load action combinations in vertical direction and Table 6-4 details the variable action combinations in different directions.

Table 6-2 Action and action effects

Action and action effects	Load	Symbol
Permanent action	Dead weight	P_1
	Live load	P_2
	Secondary steel	P_3
	Outfitting steel	P_4
Variable action	Ballast	V_1
	Barge acceleration	V_2
	Installation equipment	V_3
Environmental action	Wind	E_1
	Wave	E_2
	Snow, ice	E_3
Accidental action	Earthquake	A_1
	Ship collision	A_2

Table 6-3 Permanent action combinations

Limit state	Dead weight	Live load	Secondary steel	Outfitting steel
Direction	-Z	-Z	-Z	-Z
ULS-a	Actual weight	Actual weight	Actual weight	Actual weight
ULS-b	Actual weight	Actual weight	Actual weight	Actual weight
SLS	Actual weight	Actual weight	Actual weight	Actual weight
ALS	-	-	-	-

Table 6-4 Variable action combinations

Limit state	Ballast	Barge acceleration	Installation equipment
Direction	-Z	(+X, -X, +Y, -Y, +Z, -Z)	-Z
ULS-a	Actual weight	Acceleration	Actual weight
ULS-b	Actual weight	Acceleration	Actual weight
SLS	Actual weight	Acceleration	Actual weight
ALS	Actual weight	Acceleration	Actual weight

The environmental combinations applied in the analysis are presented in Table 6-5, which is referred from (NORSOK N-003, 2007). Current is not design driving for this module since during transportation, lifting and installation, the role of current is negligible. However, waves will affect these operations. Ice and snow loads are assumed to have minimal effect on the structure. Hence, those loads are ignored for the design. Following (Tables 6-5 and 6-6) is the summary of design governing loads:

Table 6-5 Environmental action combinations

Limit state	Wind	Wave	Snow, ice
Direction	(+X, -X, +Y, -Y)*	(+X, -X, +Y, -Y)*	
ULS-a	10 year return	10 year return	NA
ULS-b	10 year return	10 year return	NA
SLS	10 year return	10 year return	NA
ALS	-	-	-

(* Lifting and installation load combinations are independent of wind direction but transportation load combination is direction dependent)

Table 6-6 Accidental action combinations

Limit state	Earthquake	Ship collision
ULS-a	-	-
ULS-b	-	-
SLS	-	-
ALS	100 year return	Ship impact

Table 6-7 describes the load cases for the wind load with direction. The wind from the west is considered as from the positive X direction, east as negative X direction, south as positive Y direction and north is negative Y direction.

Table 6-7 Wind action

Description	Direction
Wind load from West	+X
Wind load from South	+Y
Wind load from East	-X
Wind load from North	-Y

Table 6-8 describes the load cases for Barge acceleration loads with the directions.

Table 6-8 Barge acceleration action

Description	Direction
Barge acceleration	-Z
Barge acceleration	+X
Barge acceleration	+Y
Barge acceleration	-X
Barge acceleration	-Y

In the transportation load combination, barge acceleration (+X) and barge heave motion (+Z) are considered in combination with head wind (+X), wind from behind (-X) and transverse wind directions. The other directions are excluded because they result in the similar conditions for a symmetrical module, Figures 6-1 to 6-5.

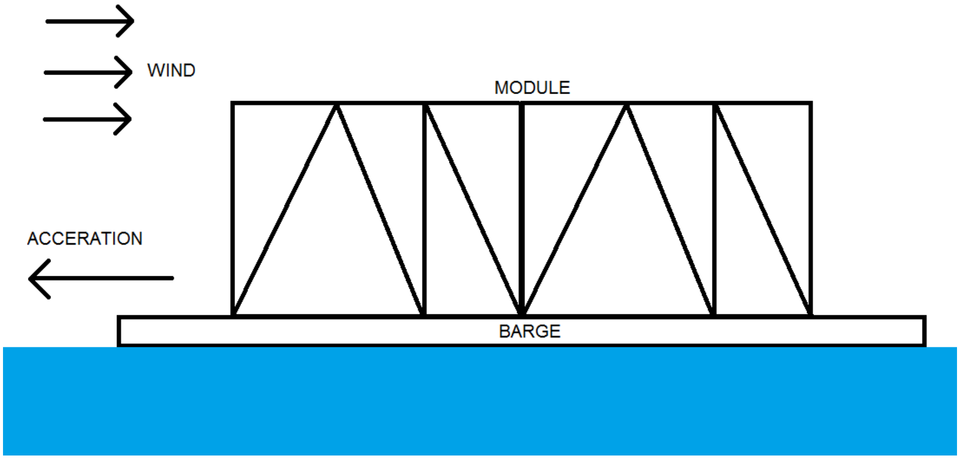


Figure 6-1 Combination of wind direction and barge acceleration

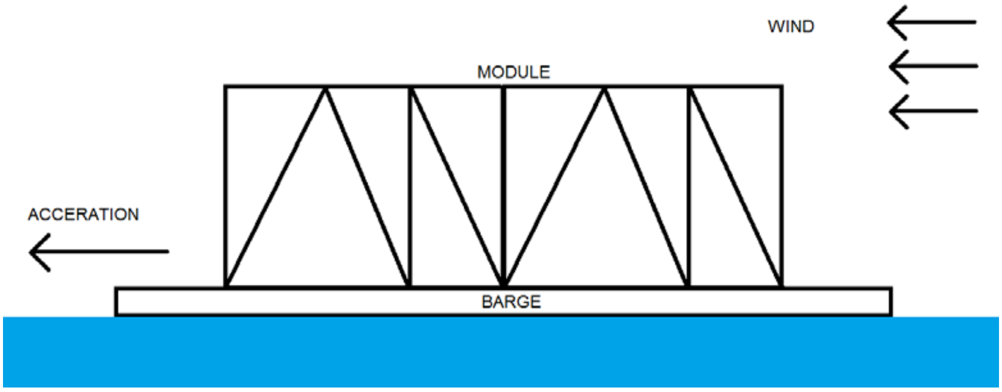


Figure 6-2 Combination of wind direction and barge acceleration

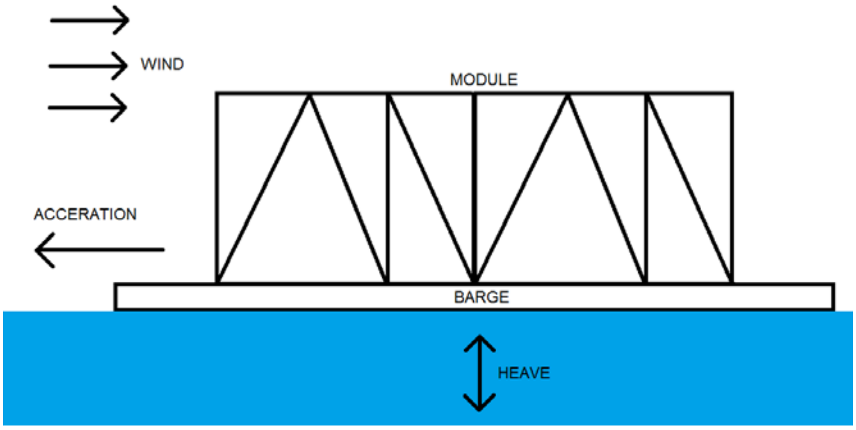


Figure 6-3 Combination of wind, heave and barge acceleration

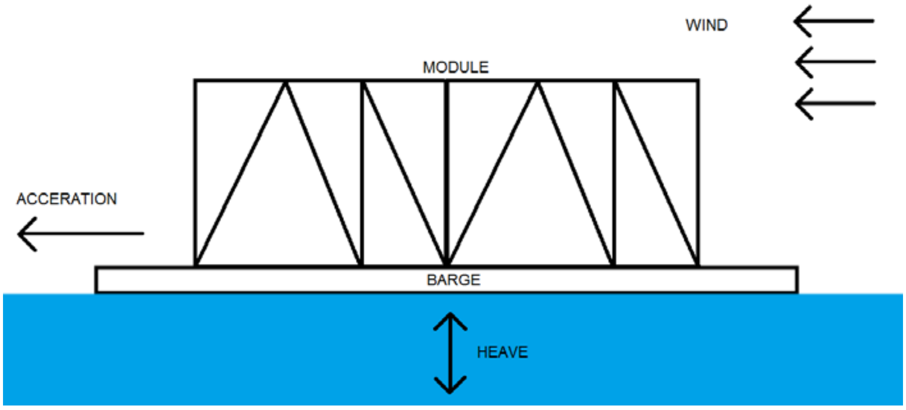


Figure 6-4 Combination of wind, heave and barge acceleration

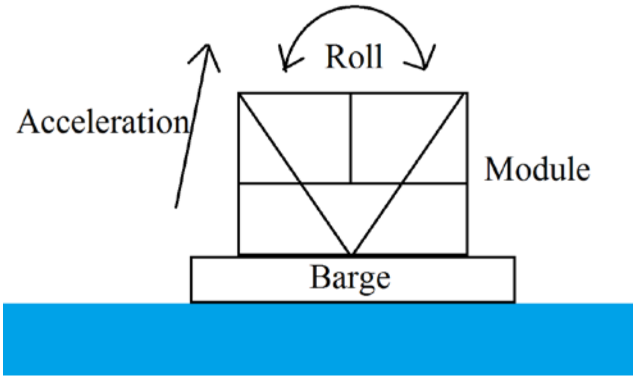


Figure 6-5 Combination of wind, heave, roll barge acceleration. Side view of the figures above

6.1.1 Load combination transportation

The load combinations for transport analysis are summarized in Tables 6-9 and 6-10 for ULS-a and ULS-b, respectively.

Table 6-9 Load combination transportation, ULS-a

No.	P_1	P_2	P_3	P_4	V_1	$V_{2,x}$	$V_{2,-x}$	$V_{2,y}$	$V_{2,-y}$	$V_{2,z}$	V_3	$E_{1,x}$	$E_{1,-x}$	$E_{1,y}$	$E_{1,-y}$	E_2	E_3
T-001	1.3	1.3	1.3	1.3	1.3	0.7	-	-	-	0.7	-	0.7	-	-	-	0.7	-
T-002	1.3	1.3	1.3	1.3	1.3	-	0.7	-	-	0.7	-	-	0.7	-	-	0.7	-
T-003	1.3	1.3	1.3	1.3	1.3	-	-	0.7	-	0.7	-	-	-	0.7	-	0.7	-
T-004	1.3	1.3	1.3	1.3	1.3	-	-	-	0.7	0.7	-	-	-		0.7	0.7	-
T-005	1.3	1.3	1.3	1.3	1.3	-	-	-	-	0.7	-	0.5	-	0.5	-	0.7	-
T-006	1.3	1.3	1.3	1.3	1.3	0.5	-	0.5	-	0.7	-	-	0.5	0.5	-	0.7	-
T-007	1.3	1.3	1.3	1.3	1.3	-	-	-	-	0.7	-	-	0.5	-	0.5	0.7	-
T-008	1.3	1.3	1.3	1.3	1.3	-	0.5	-	0.5	0.7	-	0.5	-	-	0.5	0.7	-

Table 6-10 Load combination transportation, ULS-b

No.	P_1	P_2	P_3	P_4	V_1	$V_{2,x}$	$V_{2,-x}$	$V_{2,y}$	$V_{2,-y}$	$V_{2,z}$	V_3	$E_{1,x}$	$E_{1,-x}$	$E_{1,y}$	$E_{1,-y}$	E_2	E_3
T-001	1.0	1.0	1.0	1.0	1.0	1.3	-	-	-	1.3	-	1.3	-	-	1.3	1.3	-
T-002	1.0	1.0	1.0	1.0	1.0	-	1.3	-	-	1.3	-	-	1.3	-	-	1.3	-
T-003	1.0	1.0	1.0	1.0	1.0	-	-	1.3	-	1.3	-	-	-	1.3	-	1.3	-
T-004	1.0	1.0	1.0	1.0	1.0	-	-	-	1.3	1.3	-	-	-		1.3	1.3	-
T-005	1.0	1.0	1.0	1.0	1.0	-	-	-	-	1.3	-	0.9	-	0.9	-	1.3	-
T-006	1.0	1.0	1.0	1.0	1.0	0.9	-	0.9	-	1.3	-	-	0.9	0.9	-	1.3	-
T-007	1.0	1.0	1.0	1.0	1.0	-	-	-	-	1.3	-	-	0.9	-	0.9	1.3	-
T-008	1.0	1.0	1.0	1.0	1.0	-	0.9	-	0.9	1.3	-	0.9	-	-	0.9	1.3	-

Usually the transportation of an offshore module is a short duration process and has negligible probability of ALS but in some cases the transportation can be from one part of the world to the other and thus it can be subject to ALS, Table 6.11.

Table 6-11 Load combinations for transportation, ALS

No.	**P_1**	**P_2**	**P_3**	**P_4**	**V_1**	**V_2**	**V_3**	**A_1**	**A_2**
T-013	1.0	1.0	1.0	1.0	1.0	1.0	-	-	-
T-014	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	-
T-015	1.0	1.0	1.0	1.0	1.0	1.0	-	1.0	-
T-016	1.0	1.0	1.0	1.0	1.0	1.0	1.0	-	-
T-017	1.0	1.0	1.0	1.0	1.0	1.0	-	-	1.0
T-018	1.0	1.0	1.0	1.0	1.0	1.0	1.0	-	1.0

6.1.2 Load combinations lifting

The load combinations for lifting are summarized in Tables 6-12 and 6-13 for ULS-a and ULS-b, respectively

Table 6-12 Load combinations lifting, ULS-a

No.	**P_1**	**P_2**	**P_3**	**P_4**	**V_1**	**V_2**	**V_3**	**E_1**	**E_2**	**E_3**
L-001	1.3	-	1.3	1.3	-	-	1.3		-	-
L-002	1.3	-	1.3	1.3	-	-	1.3	0.7	-	-
L-003	1.3	-	1.3	1.3	-	-	1.3		0.7	-
L-004	1.3	-	1.3	1.3	-	-	1.3	0.7	0.7	-
L-005	1.3	-	1.3	1.3	-	-	1.3		-	0.7
L-006	1.3	-	1.3	1.3	-	-	1.3	0.7	-	0.7
L-007	1.3	-	1.3	1.3	-	-	1.3		0.7	0.7
L-008	1.3	-	1.3	1.3	-	-	1.3	0.7	0.7	0.7

Table 6-13 Load combinations lifting, ULS-b

No.	**P_1**	**P_2**	**P_3**	**P_4**	**V_1**	**V_2**	**V_3**	**E_1**	**E_2**	**E_3**
L-009	1.0	-	1.0	1.0	-	-	1.0		-	-
L-010	1.0	-	1.0	1.0	-	-	1.0	1.3	-	-
L-011	1.0	-	1.0	1.0	-	-	1.0		1.3	-
L-012	1.0	-	1.0	1.0	-	-	1.0	1.3	1.3	-
L-013	1.0	-	1.0	1.0	-	-	1.0		-	1.3
L-014	1.0	-	1.0	1.0	-	-	1.0	1.3	-	1.3
L-015	1.0	-	1.0	1.0	-	-	1.0		1.3	1.3
L-016	1.0	-	1.0	1.0	-	-	1.0	1.3	1.3	1.3

SLS and ALS limit states are not considered in lifting operations since these limit states are for in/place conditions. All standards incorporate the effect of dynamic amplification factors.

A dynamic amplification factor for 1.10 is used for lifting operation. A small DAF is used since the lifting operation is conducted in carefully calculated weather windows in which the wave loads are not so significant. The loadout speed of offshore module is also very slow so that the dynamic effect is limited.

6.1.3 Load combination installation

The load combinations for installation analysis are summarized in Tables 6-14 and 6-15 for ULS-a and ULS-b, respectively

Table 6-14 Load combinations installation, ULS-a

No.	P_1	P_2	P_3	P_4	V_1	V_2	V_3	E_1	E_2	E_3
L-001	1.3	-	1.3	1.3	-	-	1.3		-	-
L-002	1.3	-	1.3	1.3	-	-	1.3	0.7	-	-
L-003	1.3	-	1.3	1.3	-	-	1.3		0.7	-
L-004	1.3	-	1.3	1.3	-	-	1.3	0.7	0.7	-
L-005	1.3	-	1.3	1.3	-	-	1.3		-	0.7
L-006	1.3	-	1.3	1.3	-	-	1.3	0.7	-	0.7
L-007	1.3	-	1.3	1.3	-	-	1.3		0.7	0.7
L-008	1.3	-	1.3	1.3	-	-	1.3	0.7	0.7	0.7

Table 6-15 Load combinations installation, ULS-b

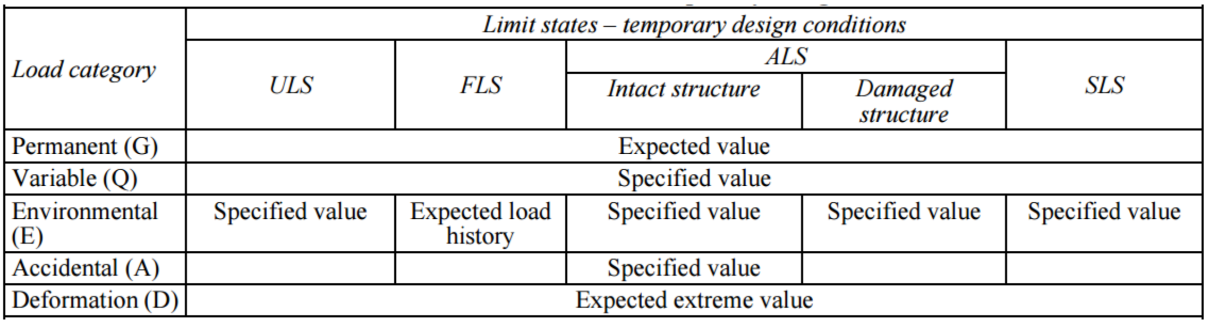
No.	P_1	P_2	P_3	P_4	V_1	V_2	V_3	E_1	E_2	E_3
L-009	1.0	-	1.0	1.0	-	-	1.0		-	-
L-010	1.0	-	1.0	1.0	-	-	1.0	1.3	-	-
L-011	1.0	-	1.0	1.0	-	-	1.0		1.3	-
L-012	1.0	-	1.0	1.0	-	-	1.0	1.3	1.3	-
L-013	1.0	-	1.0	1.0	-	-	1.0		-	1.3
L-014	1.0	-	1.0	1.0	-	-	1.0	1.3	-	1.3
L-015	1.0	-	1.0	1.0	-	-	1.0		1.3	1.3
L-016	1.0	-	1.0	1.0	-	-	1.0	1.3	1.3	1.3

6.2 DNV standard load combinations

DNV-GL's was founded in 1864, when Det Norske Veritas was established in Norway to regulate Norwegian merchant vessels. Counter wise, Germanischer Lloyd was founded in Hamburg around the same period in 1867 by a group of 600 ship owners, ship builders and insurers (DNV-GL annual report 2015).

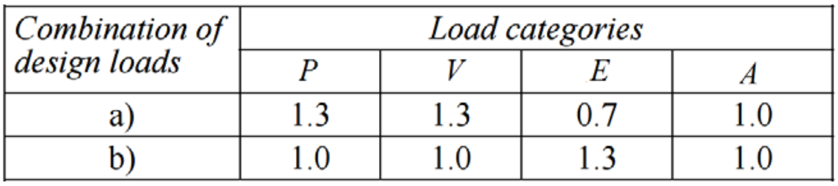
The standard load combinations and load factors for ULS a and b used by DNV are summarized in Tables 6-16 and 6-17, respectively

Table 6-16 DNV Standard Load Combinations



Load category	*Limit states – temporary design conditions*				
	ULS	*FLS*	*ALS*		*SLS*
			Intact structure	*Damaged structure*	
Permanent (G)	Expected value				
Variable (Q)	Specified value				
Environmental (E)	Specified value	Expected load history	Specified value	Specified value	Specified value
Accidental (A)			Specified value		
Deformation (D)	Expected extreme value				

Table 6-17 Load factors for ULS a, b



Combination of design loads	*Load categories*			
	P	*V*	*E*	*A*
a)	1.3	1.3	0.7	1.0
b)	1.0	1.0	1.3	1.0

Load factors for FLS and ALS are 1.0 for all categories. The resistance factor (φ) relate to the material factor γ_M as: $\varphi = 1/\gamma_M$

Table 6-18 Material factors

Type of structure	$\lambda \leq 0.5$	$0.5 < \lambda < 1.0$	$\lambda \geq 1.0$
Girder, beams stiffeners on shells	1.15	1.15	1.15
Shells of single curvature (cylindrical shells, conical shells)	1.15	$0.85 + 0.60\,\lambda$	1.45

Note that the slenderness is based on the buckling mode under consideration.

λ = reduced slenderness parameter

$$= \sqrt{\frac{f_y}{f_E}}$$

f_y = specified minimum yield stress

f_E = elastic buckling stress for the buckling mode under consideration.

The load factors of the DNV standard are the same as in the NORSOK standard. The DNV standard uses the LRFD technique so a material resistance factor is used. Generally, a material factor of 1.15 is used for steel, Table 6.18. This is similar to the NORSOK standard.

SAP2000 is used for the modelling in this thesis and it follows the design method of the NORSOK standard. Thus, the NORSOK load combinations are modelled in SAP2000.

6.3 ISO standard load combinations

ISO stands for the International Standardization Organization. ISO is an international organisation of national standards bodies. The ISO standards have the prominence of international standards. Applicable ISO standards are subdivided into a chain of international standards. ISO standards are widely accepted for offshore structures, ISO 19900 to ISO 19906. All these standards establish a mutual basis covering the design requirements and calculations of all offshore structures used by the oil and gas sector worldwide (ISO 19902, 2007).

The ISO standard gives more general guidelines for design purpose. NORSOK and DNV standards are built on the ISO standard but have different presentations. In the ISO standard no particular requirements to load combinations is mentioned. Various action and action effects are described along with their calculation and partial factors but no specific guidelines on load combinations is given.

7 GEOMETRY AND PROPERTIES

7.1 General

The module is modeled and analyzed by use of the SAP2000 suite of programs.

The SAP name has been synonymous with state-of-the-art analytical methods since its introduction over 30 years ago.

The SAP interface allows the user to create structural models rapidly without long learning curve delays. Complex Models can be generated and meshed with built in templates. Integrated design code features can automatically generate wind, wave, current, and seismic loads with automatic steel and concrete design code checks per US, Canadian and international design standards.

Advanced analytical techniques allow for step-by-step large deformation analysis, Eigen and Ritz analyses based on stiffness of nonlinear cases, catenary cable analysis, material nonlinear analysis with fiber hinges, multi-layered nonlinear shell elements, buckling analysis, progressive collapse analysis, energy methods for drift control, velocity-dependent dampers, base isolators, support plasticity and nonlinear segmental construction analysis. Nonlinear analyses can be static and/or time history, with options for FNA nonlinear time history dynamic analysis and direct integration.

From a simple small 2D static frame analysis to a large complex 3D nonlinear dynamic analysis, SAP2000 is an easy solution for the structural analysis and design needs. (Computers & Structures, INC, 2015)

7.2 Units

The fundamental units (database unites) shown in Table 7-1 that are used in the analyses are the following SI unites or multiples of these:

Table 7-1: SI unites

Length	Meter (m)
Mass	Ton (t) (1000 kg)
Time	Second (s)
Force	kilo Newton (kN)

7.3 Weight reports

The weight accuracy is important in the whole platform. The top side module weight will be taken from the latest topside model that exists during the detail engineering stage. This weight may vary during the final stage of engineering. Therefore, there should be some contingency for the weight to take in to account of the potential increasing weight later. This weight controls the centre of gravity of the whole structure. The weight report gives the weight of each element in the module. The individual weights are assumed for the analysis as per Table 7-2:

Table 7-2: Weight reports

S.I No	Description	Ton
1	Dead Weight	470
2	Secondary Steel	47
3	Outfitting Steel	47

7.4 Coordinate system

Coordinate systems are used to locate different parts of the structural model and to define the directions of loads, displacements, internal forces, and stresses. All coordinate systems in the model are defined with respect to a single, global XY-Z coordinate system. SAP2000 always assumes that Z is the vertical axis, with +Z being upward and Y is pointing North, X is pointing east, Figure 7-1.

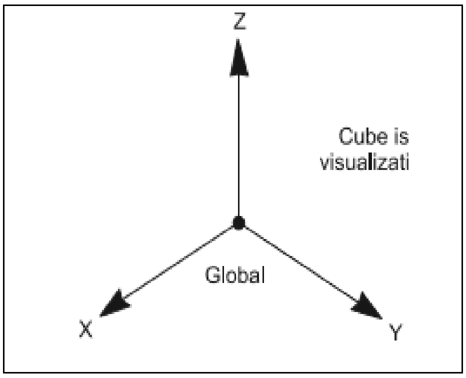


Figure 7-1 Coordinate system

7.5 Material data

The material properties used for structural steel members are shown in Table 7-3. The strength of the structural member is based on the thicknesses as per (Norsk Standard Eurocode 3: Design of steel structures, 2005). S420 denotes the structural steel material used for the topside module. In respect of steel structures, the material coefficient shall be 1.15 as per section 7.2.3 of NORSOK N-001 (2005)

Table 7-3: Material property

Young's modulus	$\mathrm{E} = 210000\ N/mm^2$
Shear modulus	$G = 81000\ N/mm^2$
Density	$\rho = 7850\ kg/m^3$
Poisson's ratio	$\upsilon = 0.3$
Material	$S\ 420$
Yield Strength	$f_y = 420\ MPa$
Material factor	$\Upsilon_m = 1{,}15$

7.6 Cross sections

The selection of the section profile and types of structural members may usually be influenced by the loading orientation. While square hollow sections with hot rolled, HEB and cold welded profiles will also be taken into account for topside structural modules.

Hollow section members (box type or pipes) are employed in jackets, towers, legs and diagonals in topside structures, cranes, microwave towers, flare supports, bridges, helicopter decks support structure and further in various others structures like staircases, ladders, etc.

Rectangular hollow sections by employing rectangular tubes designs are widely used for column members due to their axial compression and torsion efficiency.

For floor beams and columns, HEB type members are mostly used because of their great transverse loading efficiency.

In order to have sufficient structural strength of the members of the structure during in-place, lifting, and transport, the members shown in Table 7-4 are chosen.

Table 7-4 Structural Members of the topside structure

Member	Type	Height [mm]	Width [mm]	t-flange [mm]	t-web [mm]
HE800B	HEB	800	300	33	17.5
BOX400X400X40	Box	400	400	40	40
BOX500X500X50	Box	500	500	50	50

The assigned members for this module are graphically shown in Figure 7-2.

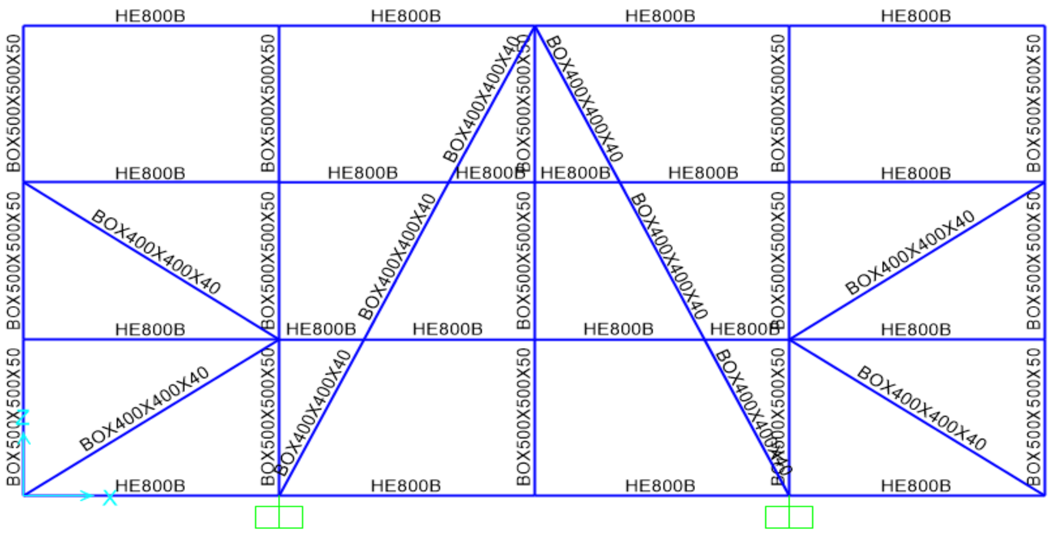
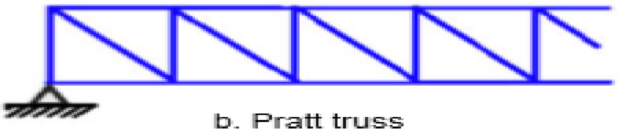


Figure 7-2 Member Sections in the module

7.7 Truss configurations

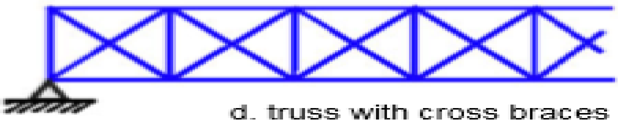
There can many different kinds of trusses that are used in the various offshore modules. In this thesis the module is designed, using the warren type truss with K joints because it has good resistance to the horizontal forces, also it has lower number of joints. This lower number of joints will reduce the fabrication time compared to other types of trusses, which are shown in Figure 7-3. Trusses are characterized by their length L, depth h, geometry and the distance between the joints.

a. Warren truss



b. Pratt truss

c. Vierendeel truss



d. truss with cross braces

Figure 7-3 Types of trusses

7.8 Joint configurations

Every member in the structure should be connected to each other. Those connections are called Joints. The term "joint" represents the zone where two or more members are interconnected: whereas "connection" is used to show the location at which two or more elements meet. Depending on the type of arrangement of the structural members, there are many different types of joints. Different types of joints are shown in Figure 7-4.

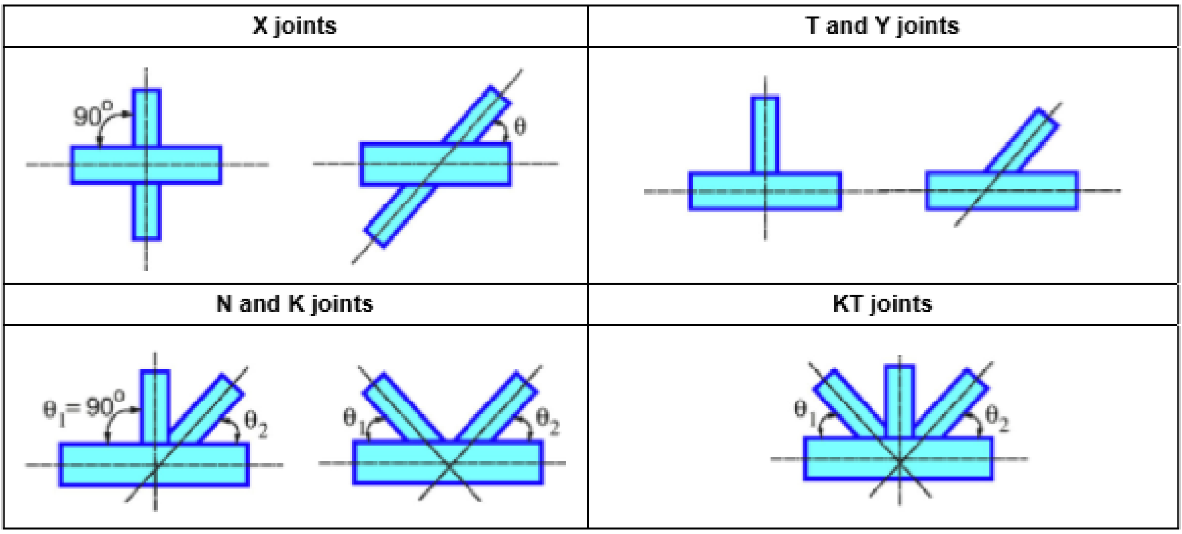


Figure 7-4 Basic Types of Joints taken from Waedenier et al. (2010)

When the force component normal to the chord in a brace member is equilibrated by beam shear (and bending) in the chord member, the joint is classified as a T joint when the brace is perpendicular to the chord, otherwise it is classified as a Y joint.

When the force component normal to the chord in a brace member is essentially equilibrated (within 20%) by loads in other brace member(s) on the same side of the joint, the joint is classified as a K joint. The relevant gap is, in principle, between the primary brace members whose loads equilibrate. An N joint is to be considered as a type of K joint with one brace at 90°.

When the force component normal to the chord is transmitted through the chord member and is equilibrated by brace member(s) on the opposite side, the joint is classified as an X joint.

7.9 Geometry

The geometry of the offshore module used in the current analysis is shown in the following picture, Figure 7-5. The image is taken at standard isometric projection. For a discussion of the selection of geometry, see Desta (2012).

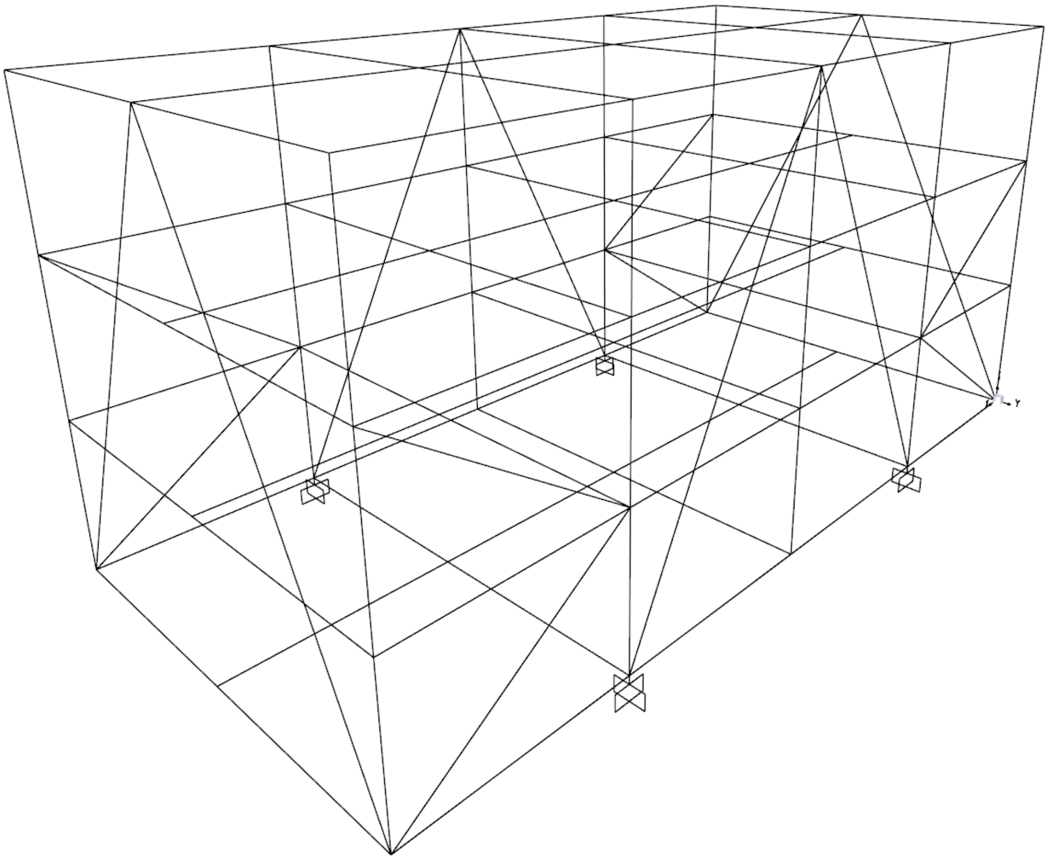


Figure 7-5 Offshore module geometry

8 GLOBAL STRUCTURAL ANALYSIS

Offshore structures are built onshore and transported to the offshore installation. The process of moving a structure to the installation site involves distinct operations referred to as loadout, transportation, lift and installation operations. The design of this topside module should be checked globally and locally against loads in the loadout, transportation, lifting and installation phases. The global analysis is performed to design the primary structural members. Local analysis is more about the detailed design of a particular member.

8.1 Limit state

A limit state is conventionally described as the state when a particular structural member or a whole structure fails to satisfy specific requirements.

The structural design criteria used for the SLS design of steel-plated structures are normally based on the limits of deflections or vibration for normal use. In reality, excessive deformations of a structure may also be indicative of excessive vibration or noise.

The SLS criteria are normally defined by the established practices. The acceptable limits necessarily depend on the type, mission and arrangement of structures. As an example, the limiting values of vertical deflections for beams in steel structures are indicated in Table 8-1.

Table 8-1 Limiting values for vertical deflections

Condition	Limit for $\boldsymbol{\delta_{max}}$	Limit $\boldsymbol{\delta_2}$
Deck beams	L/200	L/300
Deck beams supporting plaster or other brittle finish or non-flexible partitions	L/250	l/350

Based on a definition given by structural engineering the ultimate limit states (ULS) considered for steel constructions are given as below:

- Ultimate Limit States (ULS) –a
- Ultimate Limit States (ULS) –b

8.1.1 Wind

The wind load applied is considered from East/West North and South directions. The module in place is analysed for wind with average recurrence period of 100 years.

Omni directional wind speed with 100 years environmental criterion is taken as 35.3 m/s for the wind load calculation. The wind load duration is considered as 1 hour as the module is exposed to platform accelerations due to the wave and current actions. The mean elevation of wind force from the sea level is assumed to be 10 m.

Wind action and barge acceleration actions for transport analysis are normally considered from eight different directions, i.e. for each 45 degrees. Criteria used are normally the 10-year seasonal wind condition.

During lifting, the criteria used is normally based on weather forecasting and a not to exceed wind condition. Also during loadout, care is taken to avoid load out during heavy wind situations.

Snow and Ice

Snow and Ice loads are not considered for transport and lifting, as the in-place analysis is the predominant case where snow and ice are considered.

8.1.2 Wave

The wave loads are not important in the case of loadout and lifting because these operations are performed in carefully selected weather windows in which the wave action is not very significant. However, during transportation, wave loads are significant. Some offshore modules have even been transported from Singapore to the North Sea. Such a long operation cannot be performed within limited weather windows. Furthermore, transportation of an offshore module can be subject to load effects from the waves. The calculation of load effects is highly subject to the Response Amplitude Operators (RAO's) of the barge. The heave and the roll of the barge are responsible for these load effects. The load effect is dependent on the barge's dynamics and the sea state. In the present study, the maximum load effect has been taken from the table in Appendix A.

It must be noted that the selection of wave conditions for the transportation phase is important. For long transport distances, the maximum seasonal value for the wave conditions should be selected, however, for short tows, the wave conditions could be restricted and care will be taken to transport the module only when the wave forecast is within the criteria set. An assumption of the availability of a safe haven to which the barge and the module could be towed back should the weather deteriorate, is normally implemented when specifying limited wave condition for the transportation.

From the table in Appendix A we have chosen the Heave accelerations $a_{heave} = 0.2g$

8.1.3 Snow/Ice

Characteristic snow load may be estimated and set equal to 0.5 kN/m^2, this applies for the entire Norwegian Continental Shelf. This effect can be ignored in these analyses (NORSOK N-003, 2007)

8.2 Transport analysis

The structure shall be designed to resist permanent actions, variable actions, environmental actions, repetitive actions and accidental actions occurring during its service life, as well as rational combinations thereof, to obtain the most onerous conditions for all structural components. (ISO 19902:2007). The actual structure is verified for a voyage from the assembly yard to the offshore field in the Eldfisk area. Conservative transport accelerations have been taken for the analysis as listed below, Table 8-2.

Table 8-2 Transport criteria

	Heave	Pitch	Roll
Single amplitude		$20°$	$12.5°$
Accelerations	$0.2g$		

The transport accelerations are combined as the worst-case scenario as below.

Heave ± Pitch ± Roll

Heave ± Pitch

Heave ± Roll

These combinations have been implemented in SAP2000 to get the worst-case scenario results.

The results of lifting analysis in the form of maximum utilization are shown in Figure 8-3. The areas of maximum utilization are:

a. Bottom members on the extremes (shown as ‘a’ in Figure 8-3)
b. Bottom members in between the supports (shown as ‘b’ in Figure 8-3)
c. Members above the supports till the top of module (shown as ‘c’ in Figure 8-3)
d. Angular members connecting the supports with the top of module (shown as ‘d’ in Figure 8-3)

The ‘a’ members are those bottom members, which are outside the supports. Hence, they are free from one end and attached to the support from the other. They have very high utilization number as they are under high stress due to the weight of the other members above.

The ‘b’ members are the most critical of all members of the module during the transportation operation for the support arrangement shown in Figure 8-3. They have highest utilization (0.961) of all members. The reason is that they are in extreme stress condition with one end fixed on the support and the weight of all above members on the other end.

The ‘c’ members are also in the same situation as ‘b’ members but as the number of members above are less, hence, there is less weight above them and hence they have less utilization factor.

The ‘d’ members as are the angular members, hence they experience stress from both horizontal and vertical members, hence have somewhat high utilization. Their function is to transfer the forces from top to the support. However, as they are transferring all the forces to the support, the utilization number is not critically high.

The deformed module shown in Figure 8-4 will give better understanding of these ideas.

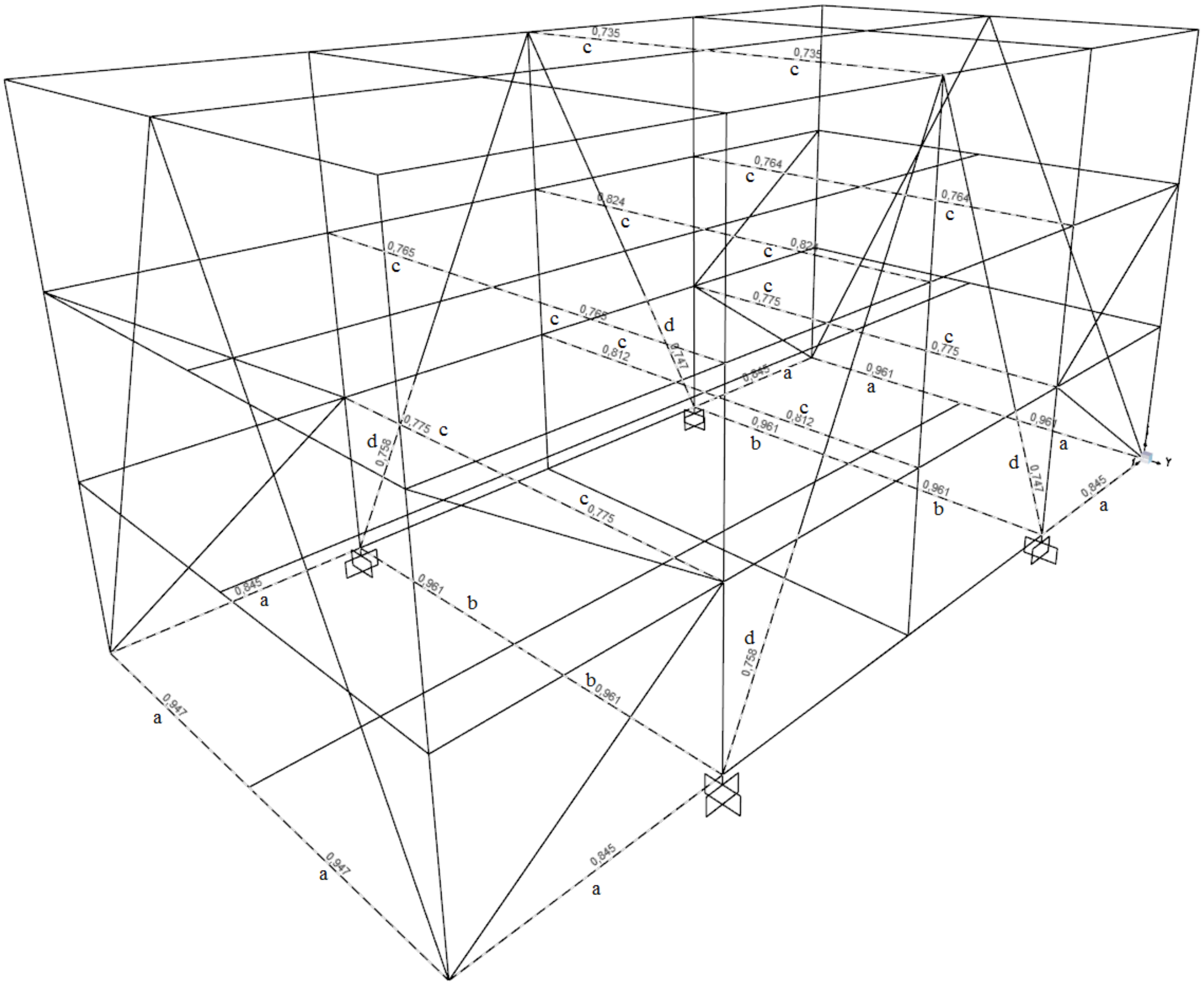


Figure 8-1 Maximum utilization during transportation

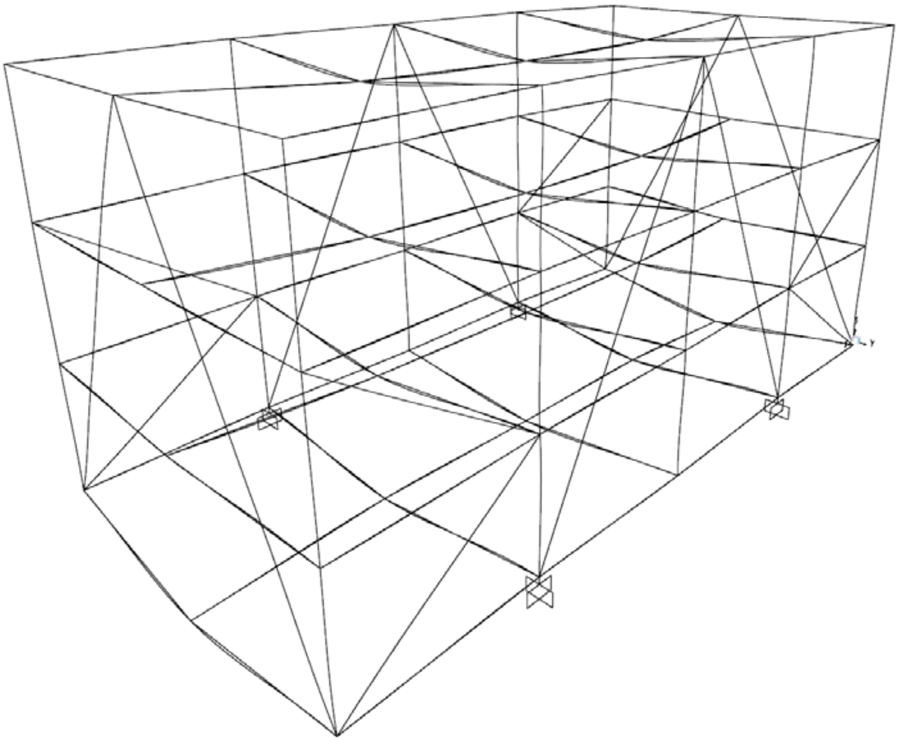


Figure 8-2 Deformed Module during transportation operation

8.3 Lifting analysis

Lifting analysis has been performed using slings. A spreader bar arrangement will have less maximum utilization, thus in order to check the worst-case scenario, a sling arrangement has been selected. This implies that only pad eyes, shackles and starter slings need to be installed on the module prior to the lifting. The lift conditions USL-a and b are the governing load combination. According to the operational requirements, criteria such as, wind speed, wave conditions, relative motions, etc., should be established prior to starting the lifting operation (DNV-OS-H205, 2014).

A load case shifting the COG towards each of the four extreme corners of the envelope as well as in between the extreme corners will be included in order to maximise leg loads/frame loads. A COG shift of 0.25 m between north and south, 0.25 m east to west will be incorporated to account for tolerances. Since the lifting arrangements are rigid and has very small tolerances, 0.25 m is a conservative choice. A DAF of 1.10 is used for lifting analysis.

As mentioned earlier, SAP200 can calculate the material utilization based on the NORSOK standards, thus the calculated loads are compared to the requirements of this standard only. SAP2000 works on the principle that all the loads and load combinations are defined as input to the software and it presents the material utilization of the worst-case scenario.

8.3.1 Maximum utilization:

The results of the lifting analysis in the form of maximum utilization are shown in Figure 8-1. It must be noted that only members with a utilization over a value of 0.75 are shown in the Figure 8-1. The areas of the module, which are exposed to high utilization are mostly:

a. The bottom truss frame (indicated as ‘a’ in Figure 8-1)
b. The vertical members between the lift points (indicated as ‘b’ in Figure 8-1)
c. And lower members on the less wide side of the module (indicated as ‘c’ in Figure 8-1)

The ‘a’ members are the farthest members from the lifting points. It means in the case of any moments around the lifting points, that these members will experience maximum stress and will undergo maximum deformation. This fact makes these members exposed to the maximum utilization.

The ‘b’ members lie in between the lifting points. The members connected at lifting points are in a stable condition during lifting operation as when the module is in the air, the downward acting weight of these members is countered by the tension in the slings. However, ‘b’ members are not attached to the lifting slings. The both ends of these members are free. This makes them more vulnerable to high utilization as downward acting weight is already creating instability in these members and any further imbalance will result in higher utilization.

With the lifting point’s arrangement used and shown in Figure 8-1, the ‘c’ members are exposed to two types of forces i.e. both because of deformation along x-axis and along z-axis. With stresses along two vertical axis, one region of member comes into extreme compression and exactly at 180 degrees of the compression region, there is an extreme tension region. That is why; the ‘c’ members are the ones with maximum utilization.

The deformed module shown in Figure 8-2 gives a better understating of these ideas.

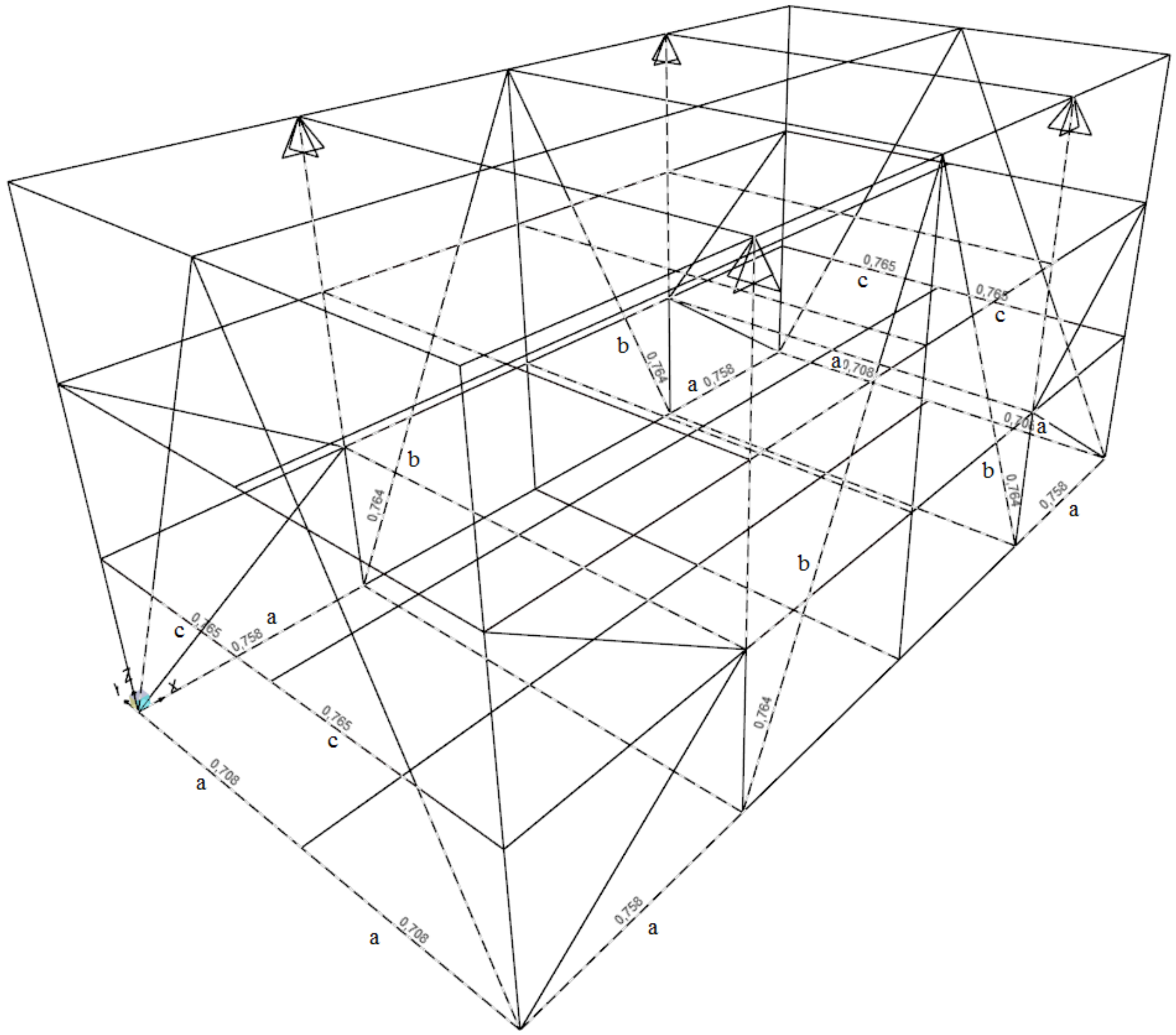


Figure 8-3 Maximum utilization during the lifting operation

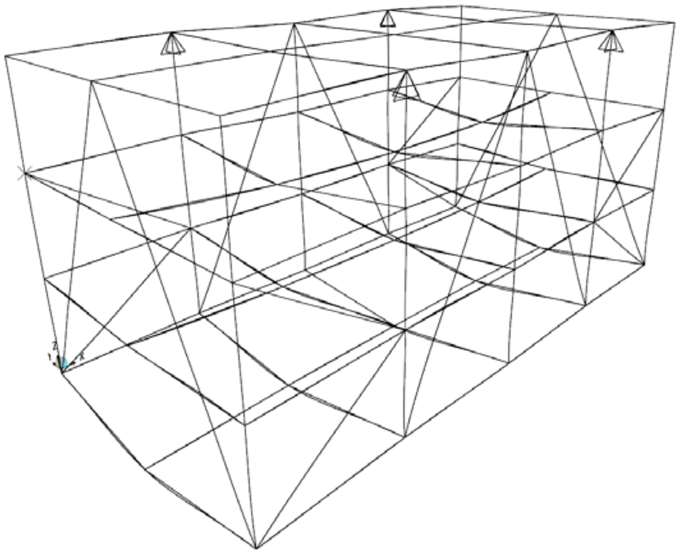


Figure 8-4 Deformed Module during lifting operation

Figure 8-5 Deformed module during transportation (deformation scale 30x)

8.4 Installation analysis

Installation modelling comprises of two phases. Phase one is the lowering of the equipment close to the installation location and phase two is the impact of the equipment onto the installation location. Phase one is identical to the lifting and undergoes the same loading as lifting loads. Phase one of the installation analysis is not conducted since it is the same as the lifting. While phase two is the impact modelling. In the present study, impact is modelled as a linear static model with a dynamic amplification factor of 1.20 taken from Table 5-1.

A COG shift of 0.25 m between north and south, 0.25 m east to west will be incorporated to account for tolerances. The installation is modelled by applying normal reaction supports at four installation locations. These supports act as the impact locations. All the loads scaled up by factor 1.20 are applied in the downward direction (-Z) axis.

The results of the lifting analysis in the form of maximum utilization are shown in Figure 8-5. It must be noted that only the utilization factors over a value of 0.50 are shown in the Figure 8-5. The areas of the module, which are exposed to high utilization, are mostly:

a. The bottom truss frames
b. The vertical members between above the normal reaction support
c. The cross members above the normal reaction support

A common trend observed is that all the members undergoing utilization more than 0.5 are close to the normal reaction support see Figure 8-5. This means that the impact action is localized to the members close to the impact location. The ‘a’ members are the horizontal members that have I cross sections. These members undergo bending moment only. These members have intermediate utilization.

The ‘b’ members are the vertical members above the normal reactions. These members are in pure compression load and the section type used for these members is a square tube with cross section 500x500. They also undergo intermediate utilization.

The cross bracers members ‘c’ are exposed to bending as well as compression. The two forces introduces deformations along x-axis and along z-axis. The section used is square tube with cross section 400 x 400. This section undergoes maximum utilization (0.975) and is close to yielding. With stresses along 2 vertical axis, one region of member comes into extreme compression and exactly at 180 degrees to the compression region, there is an extreme tension region. That is why; the ‘c’ members are the ones with maximum utilization.

The deformed module is shown in Figure 8-6.

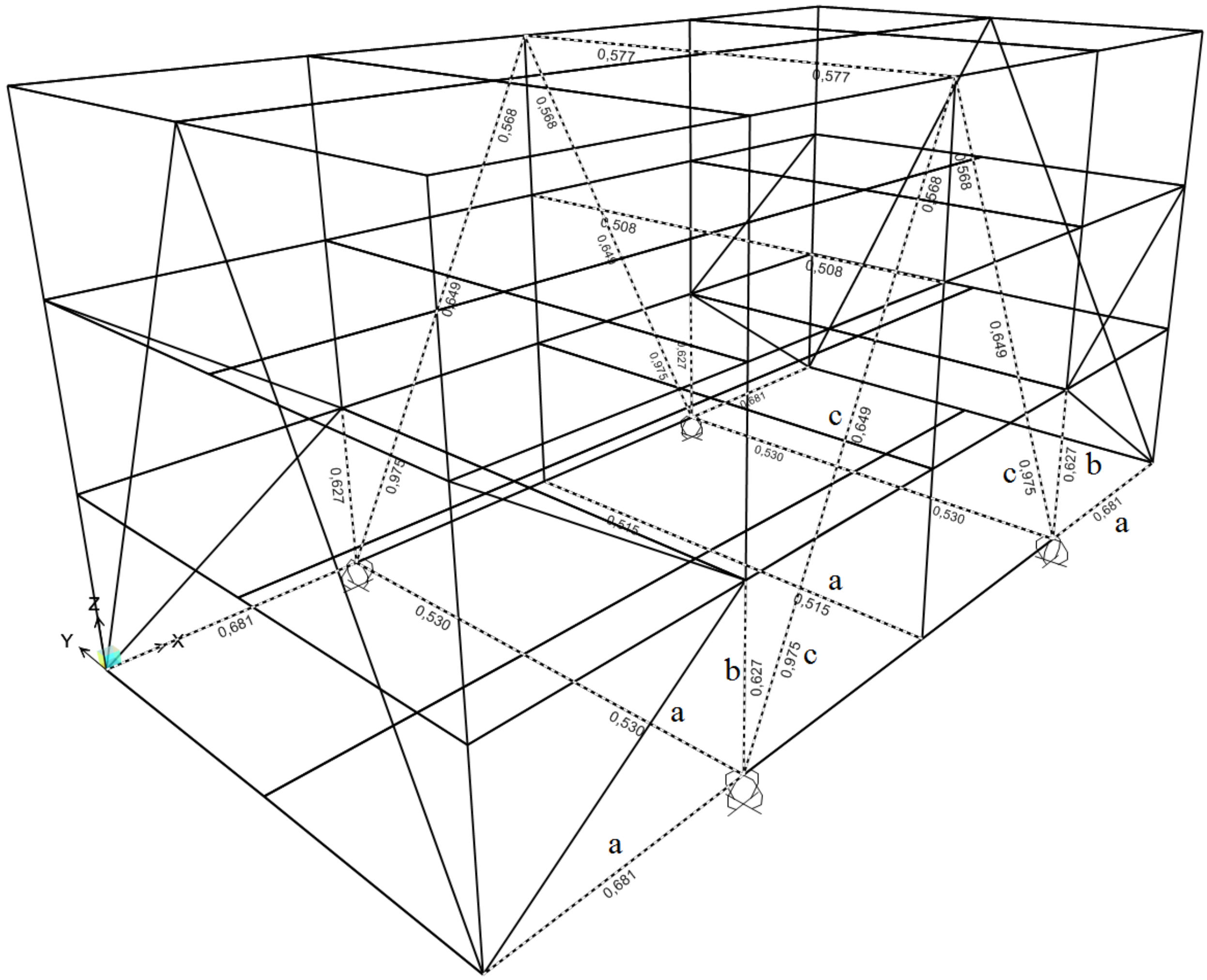


Figure 8-6 Maximum utilization installation

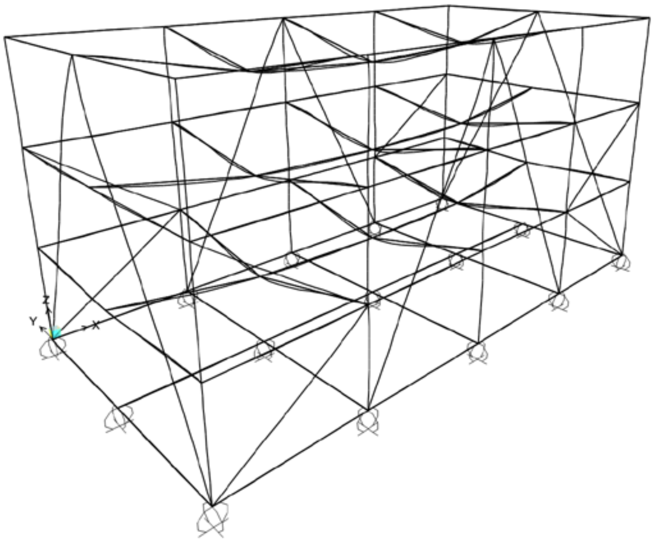


Figure 8-7 Deformed module during installation (deformation scale 30x)

8.5 In place analysis (Desta, 2012)

It can be seen in Figure 8-7 that the horizontal members undergo highest utilization. The maximum utilization is 0.971, which is close to the maximum utilization during transportation and installation. However, the in transportation and installation vertical members undergo highest utilization but of in-place loading, the horizontal members undergo highest utilization. This difference is because of the additional equipment load applied on the horizontal sections. In the in-place condition, there are very few vertical forces. That is why the vertical sections have very less utilization in the in place condition. The vertical sections have to be equally strong as the horizontal sections in order to withstand transportation, lifting and installation loads.

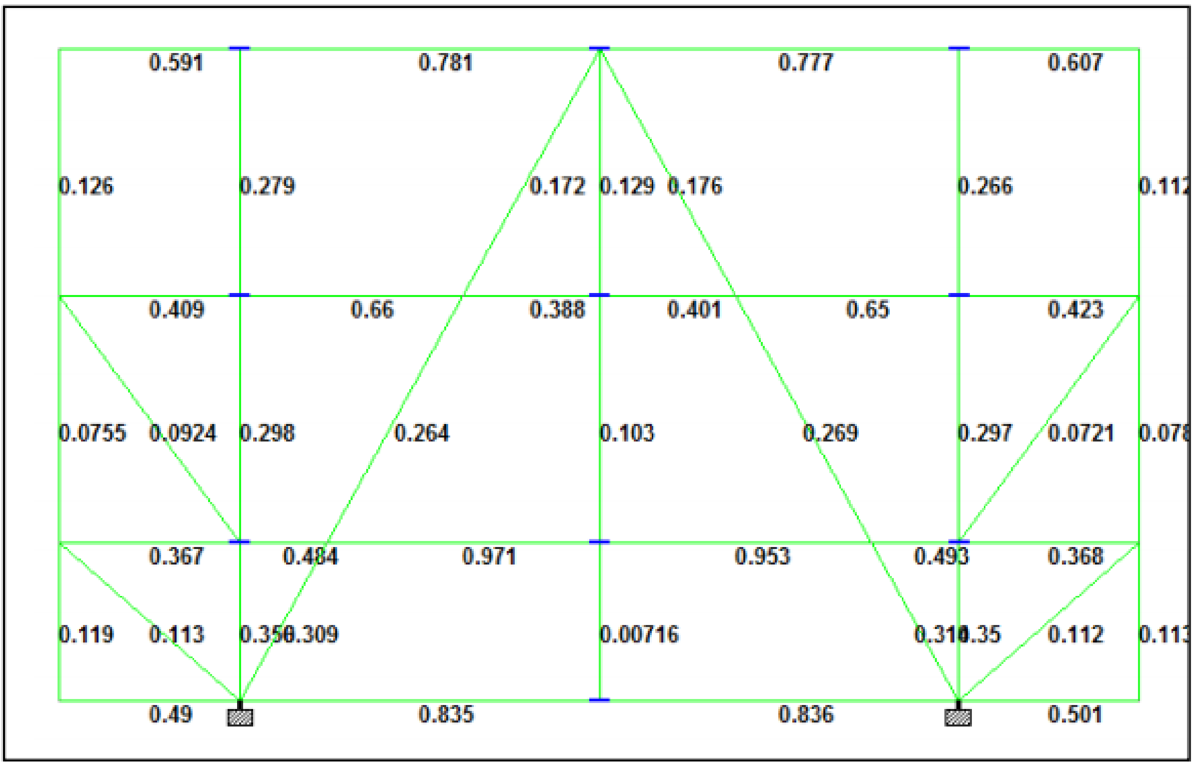


Figure 8-8 Maximum utilization in-place (Desta, 2012)

9 RISK ANALYSIS

During the load-out, transportation, lifting and installation operations, some detrimental events may occur. All such events have certain probability and consequences. Generally, risk is defined as the product of probability and the associated consequence and is evaluated by defining risk acceptance criteria. The risk acceptance criteria is the assigner’s acceptance of the risk. Risk acceptance criteria are subjectively selected, rating the risk as low, medium or high (Cornwell and Meyer, 1997). In this section, a risk analysis of the load-out, transportation and lifting/installation is conducted. The risk analysis includes hazards identification, causes, consequences and risk mitigation possibilities. We have considered a situation in which an offshore module is loaded out, transported by a barge, lifted by a carne and installed on the platform.

9.1 Risk analysis and risk acceptance criteria (RAC)

Risk analysis are used to identify risk involved and place the risk into a certain category. In the present study, a general risk analysis has been adopted for all the cases. The risk analysis answers the following questions:

- What can go wrong?
- How often can it go wrong? (probability)
- What are the consequences of a wrong outcome?
- Is the risk (probability multiplied with consequences) acceptable?
- How can we solve what is unsafe? (Risk mitigation)

The risk analysis could be quantitative or qualitative, depending on the category. A qualitative approach has been used in this study. In this case, the analysis is divided in to three categories:

- Impact on the environment.
- Loss of capital.
- Safety for people.

Each of the categories will be further categorized by the consequences. This is shown in table 9 -1 below.

Table 9-1 Consequences of an unwanted incidence

1) Impact on the environment	2) Loss of capital	3) Safety for people
A. No harm	A. Insignificant	A. Minor injury
B. Minor harm	B. Minor	B. Major Injury
C. Considerable harm	C. Considerable	C. Less than 5 fatalities
D. Serious harm	D. Serious	D. Greater than 5 fatalities

Depending on the frequency of the hazard occurring (the unwanted incidence), the category of probability is added:

- Rarely occurred
- Has happened several times at a location (port, sea etc.)
- Has happened several times during a year

The combination of the probability of an incident and the consequences of the incident represents the risk matrix. The risk acceptance criteria (RAC) are given through the assessment of probabilities and consequences and divide the risk into an acceptable and an unacceptable risk and an intermediate zone where the risk should be reduced to as low as reasonable possible (ALARP).

Impact on the environment may be defined as the amount of and the damaging potential of pollutant released to the environment.

Loss of material – the amount of commodities destroyed or wasted and their value.

Safety for people depends on the number of people injured or killed in a particular hazard.

9.2 HAZID

Hazard Identification Analysis is a methodical assessment to recognize hazards in the fields of operation of a particular process to avoid any adverse impact.

The objectives of HAZID are:

- To identify main hazards linked with a process.
- To generate a worksheet including all the hazards, the estimation of each risk, associated events with that risk and the negative consequences it gives rise to.
- Recommended additional safety measures.

9.3 Risk analysis for load-out

Load-out of an offshore module is one of the integral phases in the life cycle of a module. It is a high precision operation and requires high degree of planning. There are possibilities that undesired events can take place since loadout is one highly complex operation in the life cycle of an offshore module. HAZID analysis has been carried out for the load-out by subjectively identifying possible hazards. Following (Table 9-2) is the HAZID table for the load-out of an offshore module:

Table 9-2 A HAZID Analysis of load-out of an offshore module

	Activity: Load-out of an offshore module		
Hazard identification	Cause	Probability of an incident	Possible consequences of an incident
1. Load-out carrier failure.	1. The carrier wheel can burst. 2. Mechanical failure of bearing, joints etc. 3. Corrosion.		1. Load-out halt for few days. 2. Minor damage to the module. 3. Project delay.
2. Offshore module slip out from the load-out carrier.	1. Unequal distribution of load on the carrier. 2. Failure of one side of the carrier. 3. Poor planning of the job. 4. Tidal water effects during load out onto the barge		1. Small damage to the module. 2. Large damage to the module. 3. Injuries and fatalities. 4. Project delay.
3. Engine failure of the load-out carrier.	1. Poor maintenance. 2. Engine overloaded. 3. Cooling system failure		1. Load-out halted for a few hours 2. Load-out halted for a few days 3. Project delay.
4. Loss of the module.	1. Poor fastening mechanism 2. High wind speed 3. Poor planning 4. Load-out carrier failure 5. Earth quake		1. Minor damage to the cargo. 2. Total loss of cargo. 3. Injuries and fatalities
5. Transportation barge lost while load-out	1. Barge unable to withstand large moment force 2. Weak structural rigidity of the barge 3. Barge over loaded		1. Operation halt 2. Injuries and fatalities 3. Environmental effects (barge fuel can spill into the sea)

9.3.1 Probabilities and consequences

For each hazard identified, we construct our own probability and consequence matrix. Inside the matrix, the serial number of the hazard from the HAZID Analysis is placed. The results are highly influenced by the knowledge and opinion of the assigners. In addition, a crucial consideration is the definition of probabilities and consequences for a specific occurrence. Qualitatively, we should define which event has the worst results among others when ranking them into groups. For this purpose, the pair wise comparison method (PCM) could be employed. The methodology of the PCM is given below:

- Build a table, where first row and column are labeled with the hazards.
- Pair wise comparison of the hazards is made. This is done by considering the next event X+1. If X is more probable than X+1, one point is given to X and vice versa. 0.5 to each X and X+1 if their probability is equal.
- Sum of points is calculated.
- PCM table for the load-out is shown in Table 9-3.

Table 9-3 PCM table for the load-out

Hazards	**1**	**2**	**3**	**4**	**5**
1	0	1	0.5	0.25	0.25
2	1	0	0.25	0.25	0.5
3	0.5	0.25	0	0.5	0.25
4	0.25	0.25	0.5	0	0.5
5	0.25	0.5	0.25	0.5	0
Sum total	2	2	1.5	1.5	1

The hazardous events can, for example, be divided in to probability groups of 3.

Group 1: Rarely occurred (0-1)

Group 2: Has happened several times at a location (port, sea etc.) (1-2)

Group 3: Has happened several times during a year (2-3)

In accordance with the assessment, the consequences will be the following:

Group 1: Event A

Group 2: Event B

Group 3: Event C

Group 4: Event D

For efficient determination of results, we can use the terms described in this section. With the aid of this, we can now construct the probability and consequence matrix for the selected hazards. This is shown in table 9-4 below:

Table 9-4 Risk matrix, load-out

Consequence				
D	🟨	🟥	🟥	
C	🟨 1	🟨 2	🟥	
B	🟩 4, 3	🟨	🟨	
A	🟩 5	🟩	🟩	
	1	**2**	**3**	**Probability**

Events 3, 4 and 5 are located in the ‘green zone’, which can be regarded as acceptable risks. Events 1 and 2 are in the ‘yellow’ zone, thus these events should be discussed further. No event lies in the ‘red zone’.

9.3.2 Uncertainties in the process of load-out

In the load-out operation, various conditions add uncertainty to our analysis. Some of them are:

- Difference in opinions of experts
- Variable weather conditions involving sea state, wave height and wind speed. To increase the effectiveness of the risk analysis, reliable weather forecast data is required.
- Software used for analyzing are not always accurate.

9.3.3 Bow-tie diagrams

The following bow-tie diagram discusses barriers stopping these events to take place:

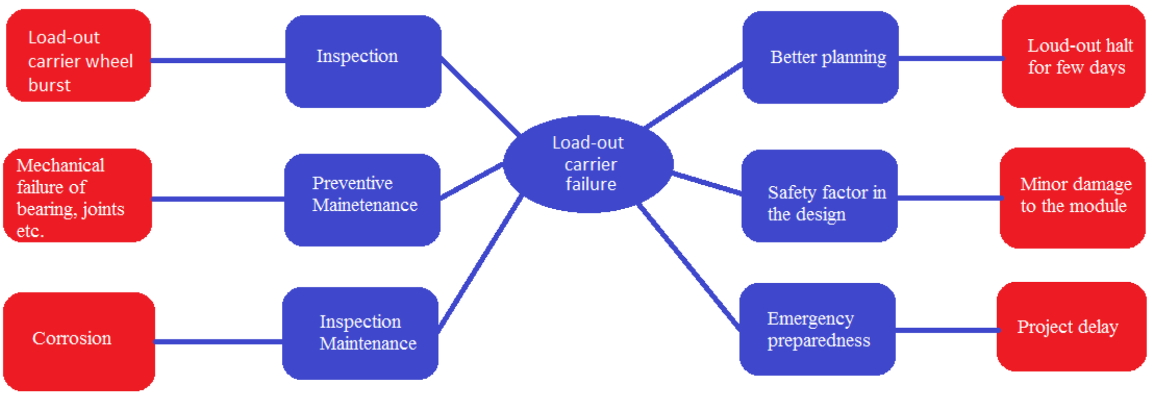


Figure 9-1 Bow-tie diagram, load-out Event 1

9.3.4 Risk reducing factors

We can see from the above diagram, that each probability and consequence has its own barrier, which helps to reduce the risk.

Probability part:

- Visual inspection is necessary: Visual inspection of key components can tremendously reduce the risk of failure.
- Preventive maintenance of the mechanical components: Scheduled maintenance of the key components will minimize the risk associated with failure of the components.
- Inspection: Corrosion can be detected by visual inspection.

Consequence part:

Better planning and emergency preparedness can reduce the overall risk level.

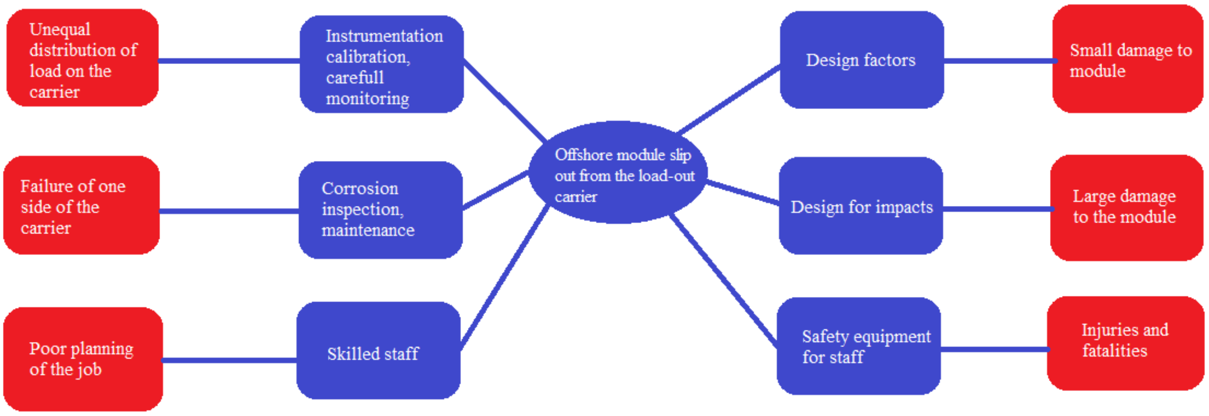


Figure 9-2 Bow-tie diagram, load-out Event 2

9.3.5 Risk reducing factors

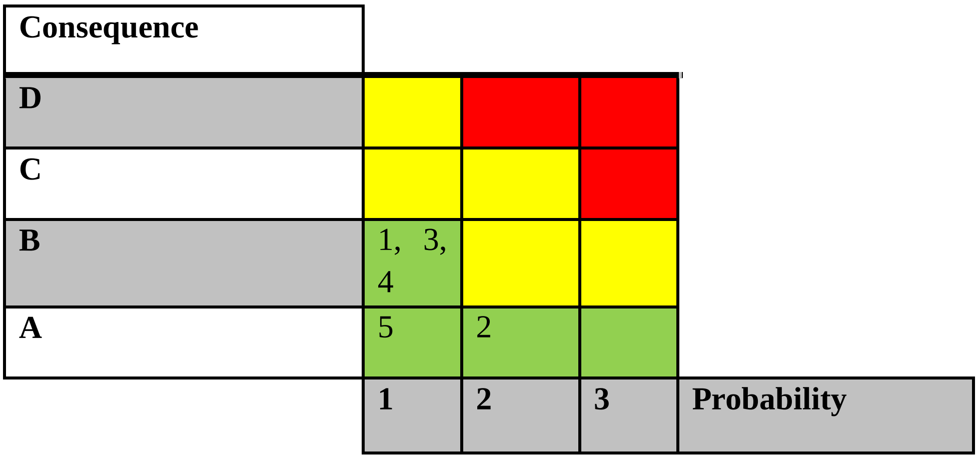
Probability part:

Calibration of all the instruments is necessary so that false data cannot be observed that leads to a wrong decision. The control of instruments is an important barrier to prevent unequal distribution of load. Corrosion can lead to the failure of load-out carrier which can eventually result in slippage of the offshore module from the carrier. Inspection and maintenance are the key elements to detect and prevent corrosion failures.

Consequence part:

Offshore modules are designed with safety factors (design factors) that are to compensate engineering uncertainties as well as unforeseen events such as slipping down of the offshore module from the load-out carrier. Design factors in the design minimize the consequence of the risk.

Table 9-5 Risk matrix, load-out after implementing risk-reducing measures



Consequence				
D	🟨	🟥	🟥	
C	🟨	🟨	🟥	
B	🟩 1, 3, 4	🟨	🟨	
A	🟩 5	🟩 2	🟩	
	1	**2**	**3**	**Probability**

9.4 Risk analysis for transportation

Transportation is a heavy-duty process during which some unwanted events may occur. Every event has its own probability and consequence. Well-defined risk acceptance criterion should be defined after properly analyzing the associated risks.

Statistical data show that 60 % of the risk during transportation is related with the overall process of offshore construction (Thevik et al., 2001). In this section, we will put focus on the transportation of different offshore structures to discuss associated hazards. In the end, several safety measures will be discussed to improve the transport safety. Following (Table 9-3) is the HAZID table for the transportation of an offshore module:

Table 9-6 A HAZID Analysis of transportation of an offshore module

	Activity: Transportation of an offshore module		
Hazard identification	Cause	Probability of an incident	Possible consequences of an incident
1. Collision of ships carrying cargo.	1. Poor visibility. 2. Lack of external and internal vigilance.		1. Loss of lives. 2. Heavy damage to the cargo being carried. 3. Harm to the water life.
2. Powered grounding i.e. taking evasive actions near the obstacle and consequently, collide or be out of course due to lack of propulsion.	1. Rudder struck. 2. Blackout of the main engine due to contaminated fuel or failure of electrical system. 3. Unavailability of proper checkup of the ship before takeoff.		1. Leakage of expensive liquids. 2. Loss of cargo. 3. Injuries and fatalities. 4. Delay in reaching the destination.
3. Fire and explosion	1. Leaks in the cargo containing flammable liquids. 2. Malfunctioned ventilation systems. 3. Use of high-pressure fuels and gases in the boiler rooms.		1. Severe injuries to the onboard staff. 2. Loss of property. 3. The fumes pose a hazard to the environment.
4. Cargo loosening.	1. Poor fastening mechanisms. (Low quality bolts, welding, stapes etc.) 2. High wind speed and wave speed. 3. Carelessness on part of the designing engineer who did not mention the factor of safety.		1. Loss of precious cargo. 2. Instability of ship leads to its sinking. 3. Loss of lives. 4. Damage to the sea life in case chemicals are exposed to the seawater.

9.4.1 Probabilities and consequences

For each hazard identified, we construct our own probability and consequence matrix. Inside the matrix, the serial number of the hazard from the HAZID Analysis is placed. The results are highly influenced by the knowledge and opinion of the assigners. In addition, a crucial consideration is the definition of probabilities and consequences for a specific occurrence. Qualitatively, we should define which event has the worst results among others when ranking them into groups. For this purpose, the pair wise comparison method (PCM) could be employed. The methodology of the PCM is given below:

- Build a table, where first row and column are labeled with the hazards.
- Pair wise comparison of the hazards is made. This is done by considering the next event X+1. If X is more probable than X+1, one point is given to X and vice versa. 0.5 to each X and X+1 if their probability is equal.
- Sum of points is calculated, see for example Table 9-3.

Table 9-7 PCM table, transportation

Hazards	**1**	**2**	**3**	**4**
1	0	0.5	0.5	0.5
2	0	0	1	1
3	0.5	1	0	1
4	0.5	1	0	0
Sum total	1	2.5	1.5	2

The hazardous events can, for example, be divided in to probability groups of 3.

Group 1: Rarely occurred (0-1)

Group 2: Has happened several times at a location (port, sea etc.)(1-2)

Group 3: Has happened several times during a year (2-3)

In accordance with the assessment, the consequences will be the following:

Group 1: Event A

Group 2: Event B

Group 3: Event C

Group 4: Event D

For efficient determination of results, we can use the terms described in this section. With the aid of this, we can now construct the probability and consequence matrix for the selected hazards. This is shown in table 9-4 below:

Table 9-8 Risk matrix, transportation

Consequence				
D	🟨	🟥 2	🟥	
C	🟨	🟨	🟥	
B	🟩 3, 4	🟨	🟨	
A	🟩	🟩	🟩 1	
	1	**2**	**3**	**Probability**

Events 1, 3 and 4 are located in the ‘green zone’, which can be regarded as acceptable risks. Event 2 (power grounding) is in the ‘red’ zone thus mitigating measures for this event must be identified.

9.4.2 Uncertainties in the process of transportation

In the operation of transportation, there are various conditions and factors that add uncertainty to our analysis. Some of which are:

- Difference in opinions of experts
- Variable weather conditions involving sea state, wave height and wind speed. To increase the effectiveness of the risk analysis, reliable weather forecast data is required.
- Software used for analyzing are not always accurate.

9.4.3 Bow-tie diagram

As discussed in this section, event 2 is in red zone therefore it needs to be discussed in detail. Some technical and mechanical upgrades to the system will improve the level of safety and reliability of the process of transportation. The results can be depicted by the bow-tie diagram. Figure 9.1 represents an illustration.

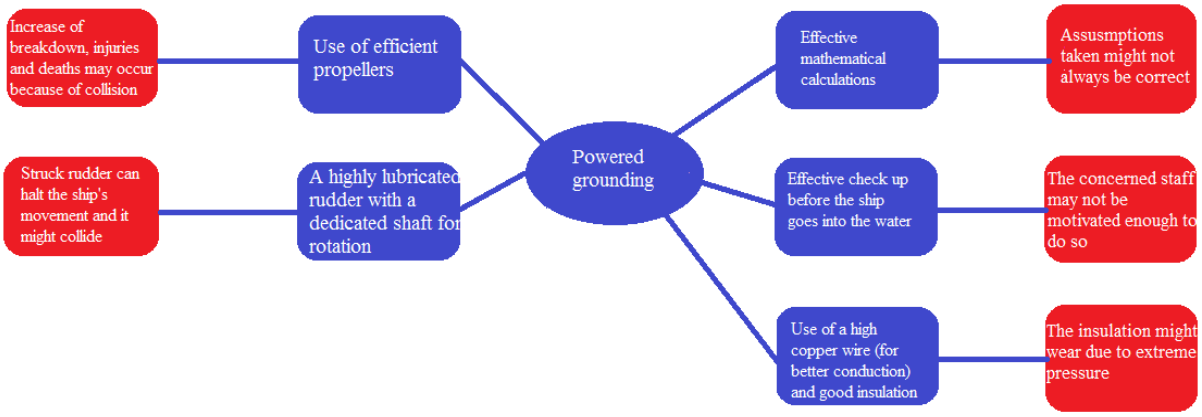


Figure 9-3 Bow-tie diagram, transportation

9.4.4 Risk reducing factors

We can see from the above diagram, each probability and consequence has its own barrier, which helps to reduce the risk.

Probability part:

- Assumptions taken might not always be correct: To solve the complicated math equations linked with powered grounding, a system of assumptions should be taken from different sources to reduce the error. In addition, the design team should be competent.
- The insulation on electric cables in the engine room might wear due to extreme pressure: Manufacture of materials comes into play. The material selected for insulation should be able to withstand high pressure yet remain as an insulator. Special consideration should be given to it.

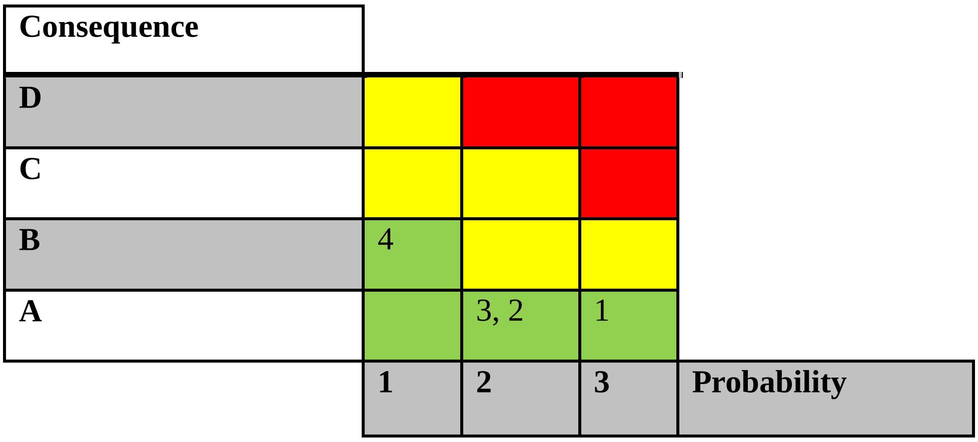
Consequence part:

A struck rudder can halt the ship's movement and the ship might collide: A highly lubricated rudder will ensure the smooth towing of the transportation barge. To fill the gaps of the rudder, a filler material may be added which will disallow any material to enter the gaps and cause the rudder to strike.

To reduce the effect of the second event, efficient propellers needs to be designed. In this regard, several considerations are to be looked after; like pitch, RPM (Rotations per minute), propeller diameter etc. An efficient propeller has a large surface area, a small slip, large diameter of the wings and high RPM.

The resulting risk matrix, after implementing all measures is shown in the table below:

Table 9-9 Risk matrix after implementation of risk reducing measures



Consequence				
D	🟨	🟥	🟥	
C	🟨	🟨	🟥	
B	🟩 4	🟨	🟨	
A	🟩	🟩 3, 2	🟩 1	
	1	**2**	**3**	**Probability**

9.5 Risk analysis for lifting/installation

A lifting/installation operation is an operation of lifting and lowering of a load. The load in the present study is an offshore module. Lifting/installation is a complex process due to which some undesirable events can take place. Following are undesirable events summarized:

Table 9-10 A HAZID Analysis of lifting/installation of an offshore module

	Activity: Lifting/installation of an offshore module		
Hazard identification	Cause	Probability of an incident	Possible consequences of an incident
1. Breakage of lifting sling.	1. Slack in the slings. 2. Large heave motion. 3. High lifting speed.		1. Broken sling can hit a person and cause injury or fatality. 2. Loss of the module. 3. Harm to the water life.
2. Crane failure.	1. Crane hydraulic system can fail 2. Large deflection in the crane boom. 3. Crane subjected to impact loading		1. Can damage module, barge or platform. 2. Loss of module. 3. Injuries and fatalities.

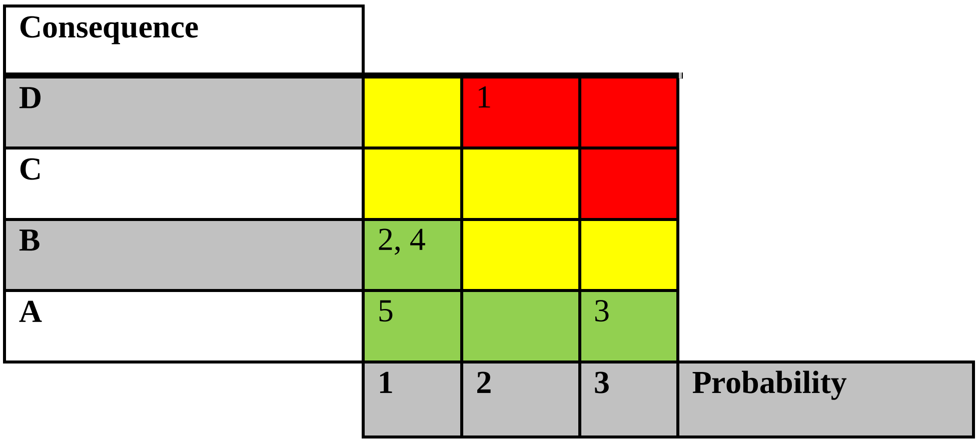
3. Crane boom failure.	1. Leaks in the cargo containing flammable liquids. 2. Malfunctioned ventilation systems. 3. Use of high-pressure fuels and gases in the boiler rooms.		1. Severe injuries to the onboard staff. 2. Loss of property. 3. The fumes pose a hazard to the environment.
4. Offshore module fall into the sea.	1. Lifting system failure 2. High wind speed and wave speed. 3. Carelessness on part of the designing engineer		1. Loss of the module 2. Damage subsea equipment. 3. Damage to the sea life in case chemicals are exposed from the subsea equipment.
5. Offshore module hits the platform.	1. High wind speed and wave speed. 2. Large heave or roll motion. 3. Unstable motion characteristics of the lifting barge		1. Damage to the module 2. Damage To the platform 3. Injuries and fatalities

9.5.1 Probabilities and consequences

Table 9-11 PCM table for lifting/installation

Hazards	**1**	**2**	**3**	**4**	**5**
1	0	0.5	0.5	0.25	0.5
2	0.5	0	0	1	0.25
3	1	0	0	0	0.25
4	0.25	1	0	0	0
5	0.5	0.25	0.25	0	0
Sum total	2.25	1.75	1.25	1.25	1

Table 9-12 Risk matrix, lifting/installation



Consequence				
D	🟨	🟥 1	🟥	
C	🟨	🟨	🟥	
B	🟩 2, 4	🟨	🟨	
A	🟩 5	🟩	🟩 3	
	1	**2**	**3**	**Probability**

Events 2, 3, 4 and 5 are located in the ‘green zone’, which can be regarded as acceptable risks. Event 1 is in the ‘red’ zone thus mitigating measures for this event must be identified.

9.5.2 Bow-tie diagram

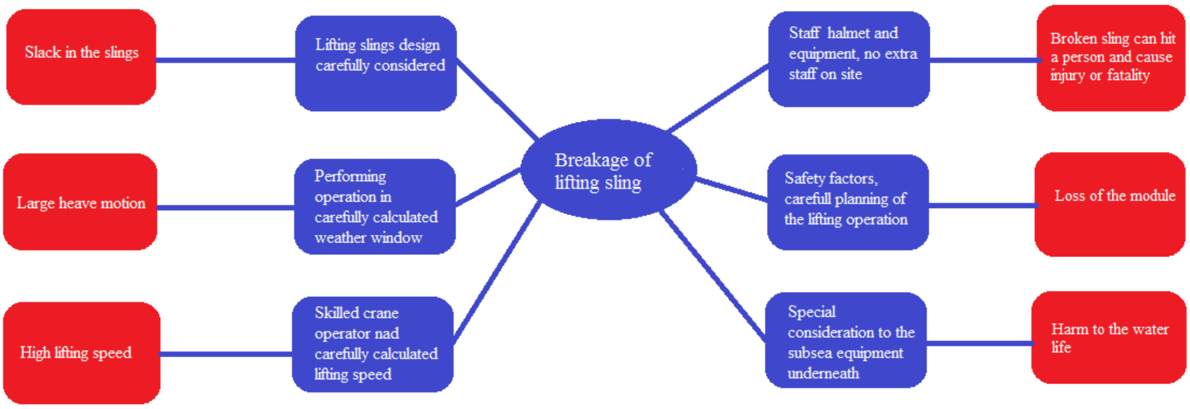


Figure 9-4 Bow-tie diagram, lifting/installation

9.5.3 Risk reducing factors

We can see from the above diagram, each probability and consequence has its own barrier, which helps to reduce the risk.

Probability part:

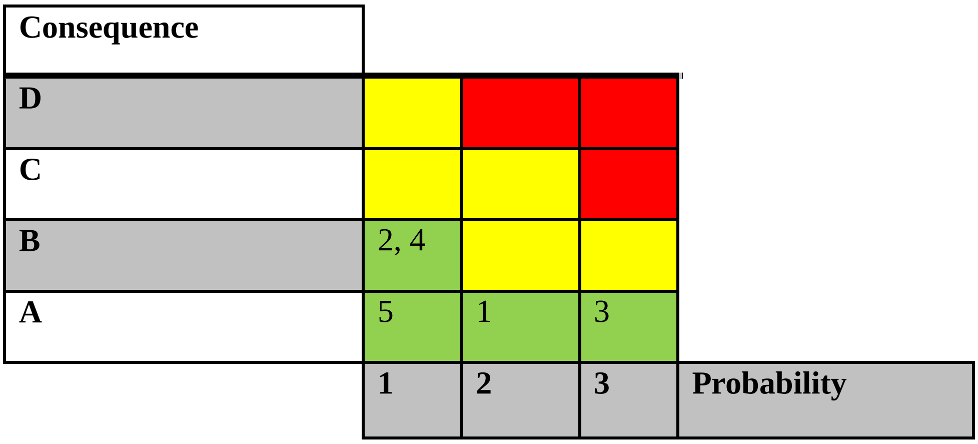
- Slack can be mitigated by carefully designing the lifting arrangement. Sling angles and location of the attachment of the slings determine the robustness of the lifting arrangement. Lifting arrangement should be given special attention in order to minimize the risk associated with lifting.
- Large heave motions can be avoided by carefully calculating a weather window in which operation needs to take place. Also one should formulate an emergency halting plan in case of unfavorable weather conditions.
- Highly skilled crane operator can minimize the risk related to the lowering speed control of the crane.

Consequence part:

- A broken sling will move with very high velocity and can cause severe injury or death of a staff member on site. Personnel safety equipment and less number of staff members on field will reduce this risk.
- Reasonably calculated safety factors used in the design of the offshore module will minimize the risk of total collapse of the module in emergency.

The new risk matrix after implementing the risk reducing measures is as following:

Table 9-13 Risk matrix, lifting/installation after implementing risk reducing measures



Consequence				
D	🟨	🟥	🟥	
C	🟨	🟨	🟥	
B	🟩 2, 4	🟨	🟨	
A	🟩 5	🟩 1	🟩 3	
	1	**2**	**3**	**Probability**

10 CONCLUSION

The present study concerns the forces and problems an offshore operation module encounters during its load-out, transportation, lifting and installation phases. Though these phases contribute very little throughout the life span of an offshore module, they are very critical phases of its life. These phases should be given much attention during the design process and design factors must be selected according to the loading condition that a module experiences during different phases. The explanation and calculation of the loads involved during these life phases in this report gives an idea about the criticalities involved during these phases. These four life phases are critical in the sense that the module is exposed to a large variety of loads, the module is not fixed during these phases as it is during the operational phases, hence is more vulnerable towards accidental situations due to its dynamic behaviour and all these activities have high financial risks involved.

Load combinations analysed in the current study reveal that the combinations resulting in the maximum loads should be taken into consideration. There are possibilities for the loads to act together in real scenarios and the maximum load can rise to a very high value hence these combinations are very important input factors for design. However, the load combinations should be realistic. The results of the analysis are also compared with the results of the offshore operational module design performed by Desta (2012). The maximum utilization calculated by Desta (2012) for the in-place condition is almost equal to the maximum utilization of transportation and installation loads in this study. For in-place loading, horizontal sections are critical while for transportation, lifting and installation vertical section are critical. This key difference is because of the orientation of the loads.

For some of the members, which are pinpointed as critical members, the utilization is very high, up to 0.975. This number indicates that the design of Desta, 2012 is safe for the loads of the discussed life phases in this report, but this utilization is higher than the in-place loads. All the possible loads during the initial life phases and their possible combinations are attempted to be included in the present study and design factors are chosen as specified in the standards, but if further, there may be engineering uncertainties that are not yet been fully published or there are accidental situations. The utilization number can thus shoot the value towards an unsafe value i.e. above 1.0. The utilization must be such that there is a reasonable safe margin for these uncertainties. Hence, the design of Desta, 2012 is good enough for the load combinations studied in this report but doesn’t accommodate for the uncertainties involved in the discussed life phases.

Three standards, namely, NORSOK, ISO and DNV-GL are discussed in context of design factors involved during the life phases discussed. The pros and cons of each standard and their aid towards a safe design is argued upon. The study reveals that DNV-GL standard based on the LRFD method gives the more detailed design approach as compared to the others for transportation, lifting and installation. Hence, for these design conditions and for the cases where the level of uncertainties is high, the DNV-GL standard is recommended.

Risk analysis of load-out, transportation and lifting/installation is also conducted in order to get the insight of the potential risks associated with these offshore operations. The Risk analysis of load-out of offshore module signifies that load-out carrier failure and module slip from the load-out carrier possess high risk. Carful inspection, skilled and motivated staff and careful planning of this operation can minimize the risk. In the transportation operation, power loss of the barge is a high risk event. Preventive maintenance, careful planning and emergency preparedness can minimize the risk level. In the lifting/installation, breakage of the lifting sling is identified as a high risk event. Precisely calculated weather window based upon reliable data, robust lifting arrangement design and skilled crane operator can minimize this risk.

11 FUTURE WORK RECOMMENDATIONS

In this thesis, load-out, transportation, lifting and installation load conditions for an offshore steal module have been studied under the light of NORSOK, DNV-GL and ISO standards. At the end of this thesis, it is feasible to recommend some possible areas of future research. They are listed as following:

1. For the load conditions discussed in this thesis, use of aluminium module can be checked and compared in terms of weight, cost and load bearing capacity, in particular for floating units where weight is a critical factor.

2. Horizontal steel plate is used in the present study for flooring of the module. Fibre reinforced plastic (FRP) plates have high strength to weight ratio. FRP plates can be analysed and compared for pros and cons against steel plates.

3. The joints of the cross sections are critical locations. Cost benefit analysis of welded, casted and mechanical fastened joints can be considered in order to come up with the optimum option.

4. Quantitative risk assessment of transportation and lifting/installation can be conducted by collecting data from different service companies.

12 REFERENCES

BP Deep Horizon Oil Spill Commission (2010), *A Brief History of Offshore Oil Drilling*, National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling, Staff Working Paper No. 1, Page no. 1-2.

Chakrabarti, S. K. (2005). *Handbook of offshore engineering: Vol. 1.* Amsterdam: Elsevier.

Chakrabarti, S. K. (1994). *Offshore Structures modeling.* Singapore: World Scientific.

Computers & Structures, INC. (2015, 07 20).
Web link: http://www.csiamerica.com/products/sap2000

Cornwell, J. B. and Meyer, M. M. (1997), *Risk Acceptance Criteria or "How Safe is Safe enough?"* Risk Control Seminar Petróleos de Venezuela Puerto La Cruz, Venezuela.

Web link: http://www.questconsult.com/papers/risk-acceptance-criteria/

Desta, T. B. (2012). *Structural design principles of offshore topside*, Master thesis, University of Stavanger

"DNV GL Annual Report 2014". DNV GL. Retrieved 14 August 2015.

DNV-OS-H205. (2014). *Lifting operations*. DET NORSKE VERITAS AS, Høvik, Norway.

El-Reedy, M. A. (2015). *Marine structural design calculations*. Oxford, UK: Butterworth-Heinemann.

FOCUS, F. (n.d.). Luchtfotografie.
Web link: www.flyingfocus.nl

GL Noble Denton. (2010). *Guidelines for marine transportations*, London, UK

Gudmestad O.T. (2015). *Marine Technology and Operations*. University of Stavanger, Norway, published by WIT Press, Southampton, UK

Holand, I., Gudmestad, O. T., Jersin, E. (2000). *Design of Concrete Offshore Structures*, SPON Press, UK

Paik, J. K. and Thayamballi, A.K. (2003). *Ultimate limit state design of steel-plated structures*. Chichester: Wiley.

Krabbendam, R. L. (2014). Heavy lift specialist. Taken from HAEVYLIFT SPECIALIST.

Web link: http://www.heavyliftspecialist.com/wp-content/uploads/2012/04/DSCN1189.jpg

MacSween, J. (2004). *Technical and marine aspects while planning and executing the transportation of heavy lift cargoes*. Malin Marine Consultants Ltd.

Norsk Standard Eurocode (2005): *Design of steel structures*. Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings. Lysaker: Standard Norge.

NS-EN ISO 19902:2007. (2007). *Petroleums- og naturgassindustri Faste offshorekonstruksjoner av stål (ISO 19902:2007)*. Lysaker: Standard Norge.

NORSOK N-001. (2004). *Structural design*. Standard Norge.

NORSOK N-003. (2007). *Actions and action effects*. Standard Norge.

Sadeghi, K. (2007). *An overview of design, analysis, construction and installation of offshore petroleum platforms suitable for Cyprus oil/gas fields*, Girne American University, Department of Industrial Engineering, Mersin 10, Turkey.

Seaway Heavy Lifting. (n.d.). Albert Einsteinlaan 50, 2719 ER Zoetermeer. Netherlands.

Shell, US, Alaska: Oil and Gas Offshore Production: Chapter 3, Shell Alaska, USA.

Web link: http://www.safetyinengineering.com/FileUploads/O&G%20offshore%20production_1414488606_2.pdf

Thevik, H.J., Sorgård, E. and Fowler, T. (2001), *A method for assessing the risk of sea transportation*: Numerical examples for the Oslofjord, Norway. In: Proceedings of ESREL, 2001

Waedenier, J., Packer, J., Zhao, X.-L., & van der Vegte, G. (2010). *Hollow sections in structural applications*. Switzerland: CIDECT.

Will, S. Compliant Towers: The Next Generation, Mustang Engineering Inc.

Web links

Web link: http://slipr.com/2009/10/02/how-much-oil-does-the-world-use-in-a-day/

Web link: http://aoghs.org/offshore-history/offshore-oil-history/

Web link: http://www.offshore-mag.com/articles/print/volume-58/issue-10/news/general-interest/race-on-for-deepwater-acreage-3500-meter-depth-capability.html

Web link: https://www.quora.com/How-do-offshore-drilling-platforms-move-from-place-to-place

Web link: http://america.pink/compliant-tower_1058974.html

Web link: http://www-it.jwes.or.jp/weld_example_w_e.html

Web link: https://mb50.wordpress.com/tag/gbs/

Web link: http://www.offshore-technology.com

Web link: http://www.heavyliftspecialist.com/tag/odebrecht/

Web link: http://www.axystechnologies.com

Web link: http://www.oceanfabricators.com

Web link: http://www.chain-connection.com

Web link: www.piping-engineering.com

Web link: www.hollandiaoffshore.nl

Web link: www02.abb.com

13 APPENDIX

13.1 Default Motion criteria

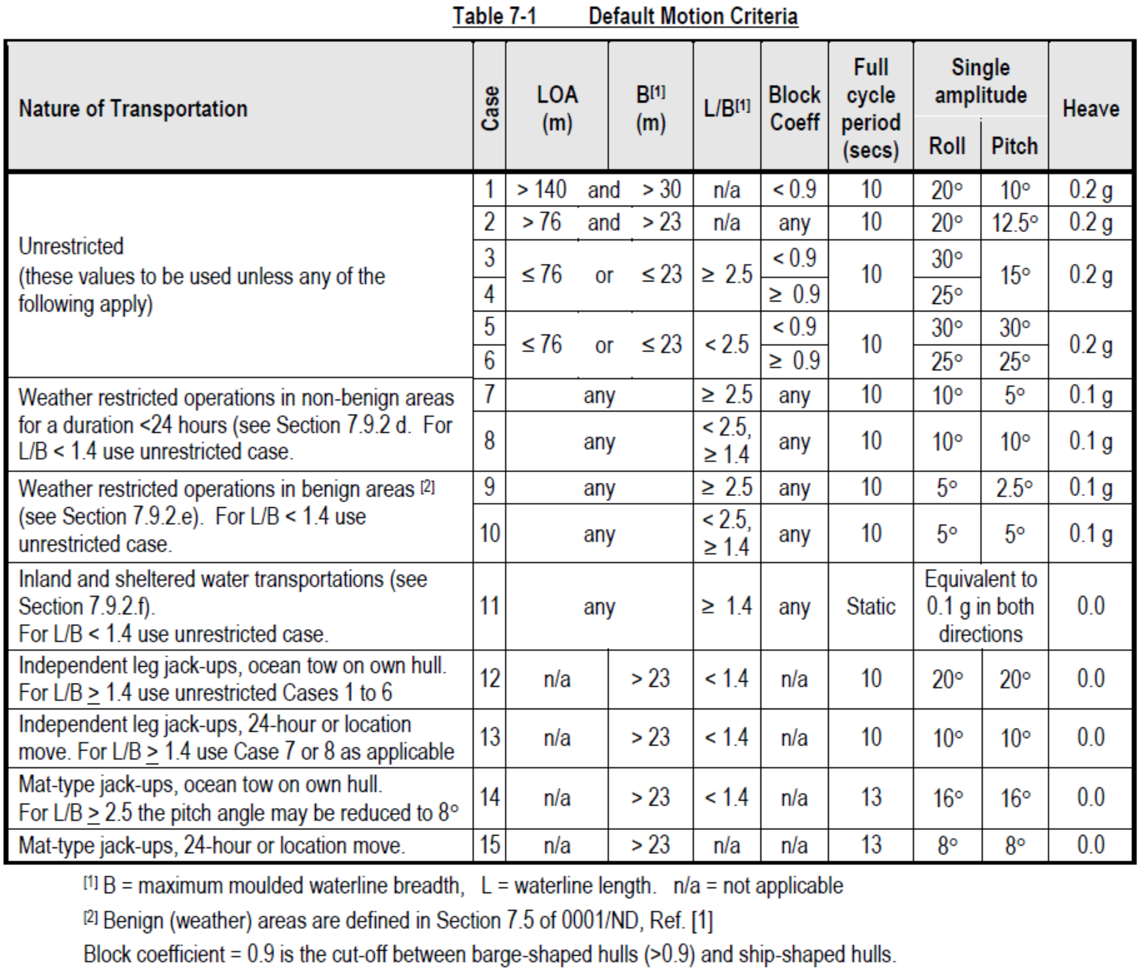


Table 7-1 Default Motion Criteria

Nature of Transportation	Case	LOA (m)	B[1] (m)	L/B[1]	Block Coeff	Full cycle period (secs)	Single amplitude		Heave
							Roll	Pitch	
Unrestricted (these values to be used unless any of the following apply)	1	> 140 and	> 30	n/a	< 0.9	10	20°	10°	0.2 g
	2	> 76 and	> 23	n/a	any	10	20°	12.5°	0.2 g
	3	≤ 76 or	≤ 23	≥ 2.5	< 0.9	10	30°	15°	0.2 g
	4				≥ 0.9		25°		
	5	≤ 76 or	≤ 23	< 2.5	< 0.9	10	30°	30°	0.2 g
	6				≥ 0.9		25°	25°	
Weather restricted operations in non-benign areas for a duration <24 hours (see Section 7.9.2 d. For L/B < 1.4 use unrestricted case.	7	any		≥ 2.5	any	10	10°	5°	0.1 g
	8	any		< 2.5, ≥ 1.4	any	10	10°	10°	0.1 g
Weather restricted operations in benign areas [2] (see Section 7.9.2.e). For L/B < 1.4 use unrestricted case.	9	any		≥ 2.5	any	10	5°	2.5°	0.1 g
	10	any		< 2.5, ≥ 1.4	any	10	5°	5°	0.1 g
Inland and sheltered water transportations (see Section 7.9.2.f). For L/B < 1.4 use unrestricted case.	11	any		≥ 1.4	any	Static	Equivalent to 0.1 g in both directions		0.0
Independent leg jack-ups, ocean tow on own hull. For L/B ≥ 1.4 use unrestricted Cases 1 to 6	12	n/a	> 23	< 1.4	n/a	10	20°	20°	0.0
Independent leg jack-ups, 24-hour or location move. For L/B ≥ 1.4 use Case 7 or 8 as applicable	13	n/a	> 23	< 1.4	n/a	10	10°	10°	0.0
Mat-type jack-ups, ocean tow on own hull. For L/B ≥ 2.5 the pitch angle may be reduced to 8°	14	n/a	> 23	< 1.4	n/a	13	16°	16°	0.0
Mat-type jack-ups, 24-hour or location move.	15	n/a	> 23	n/a	n/a	13	8°	8°	0.0

[1] B = maximum moulded waterline breadth, L = waterline length. n/a = not applicable

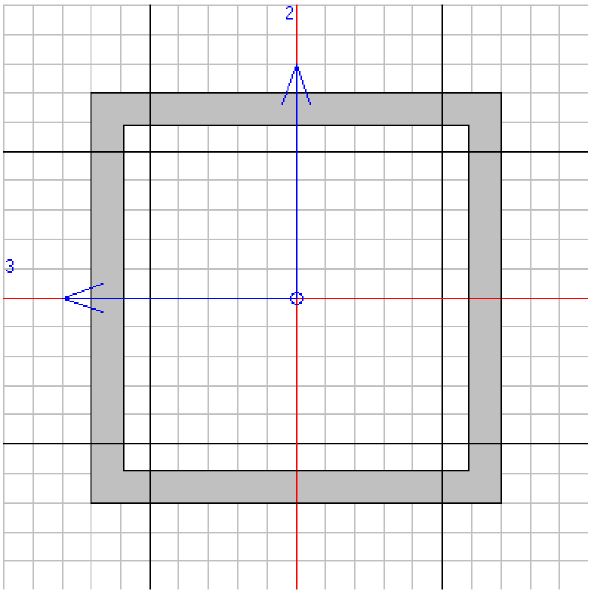
[2] Benign (weather) areas are defined in Section 7.5 of 0001/ND, Ref. [1]

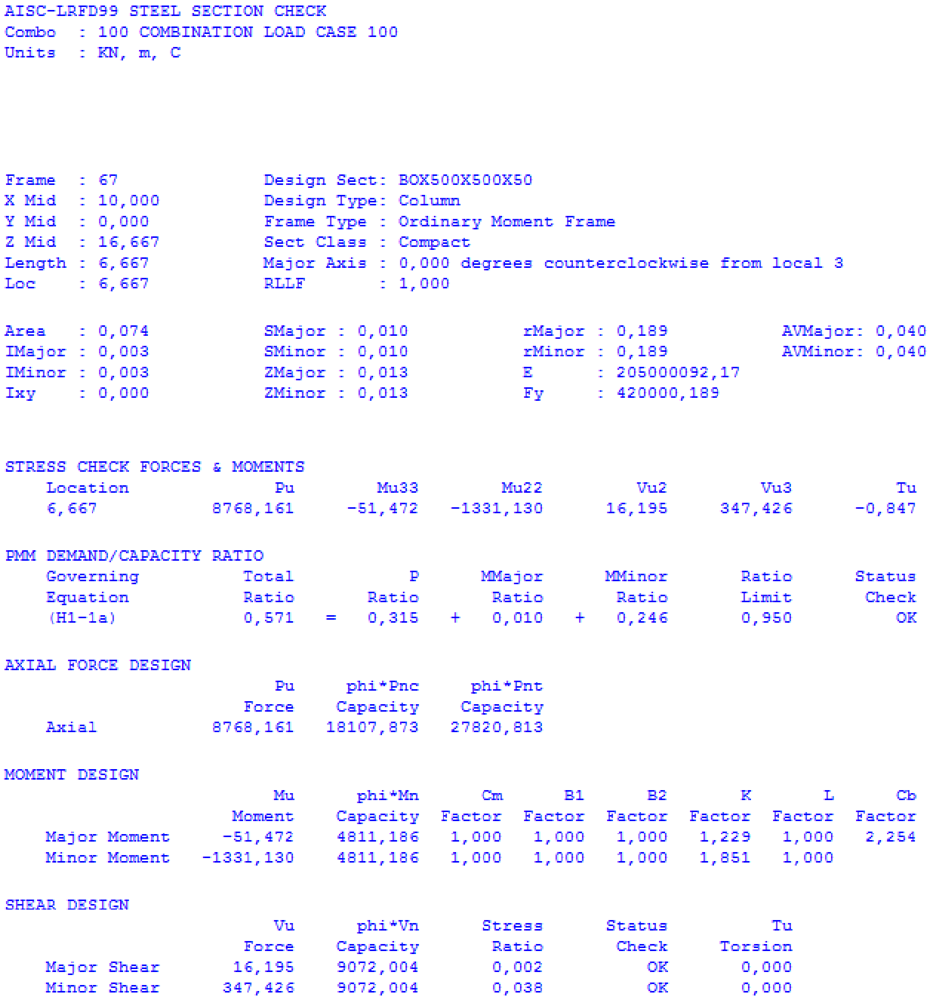
Block coefficient = 0.9 is the cut-off between barge-shaped hulls (>0.9) and ship-shaped hulls.

Reference: NOBLE Denton “GUIDELINES FOR MARINE TRANSPORTATIONS “Motion criteria

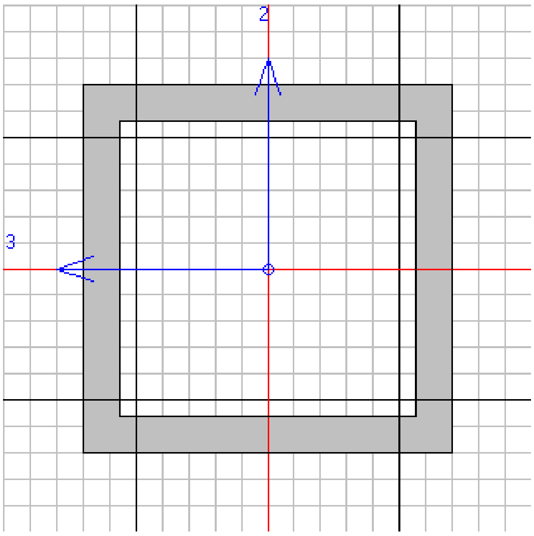
From this table, we have chosen the Heave accelerations $a_{heave} = 0.2g$

13.2 Lifting section details

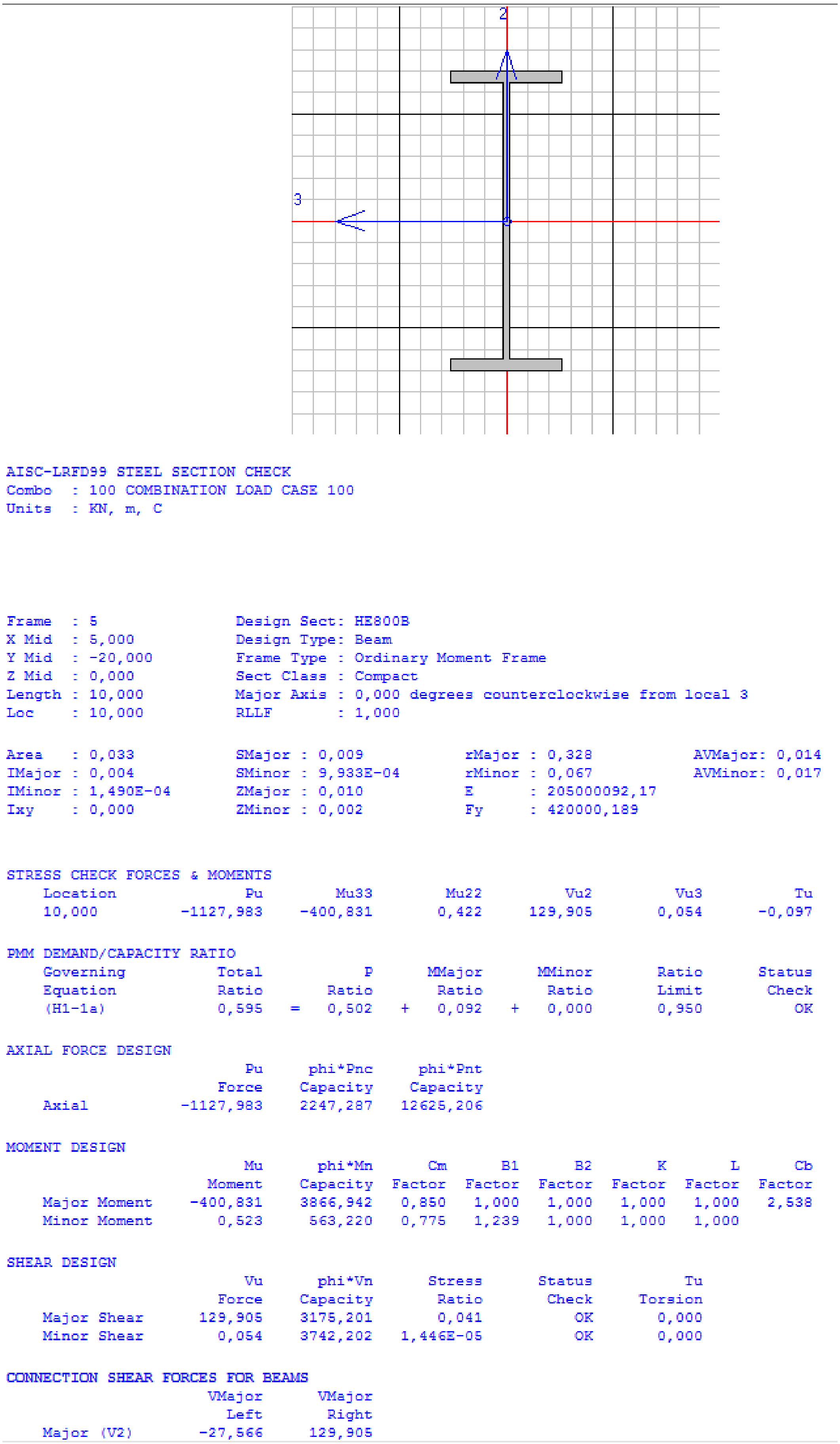




```
AISC-LRFD99 STEEL SECTION CHECK
Combo  : 100 COMBINATION LOAD CASE 100
Units  : KN, m, C



Frame  : 67                Design Sect: BOX500X500X50
X Mid  : 10,000            Design Type: Column
Y Mid  : 0,000             Frame Type : Ordinary Moment Frame
Z Mid  : 16,667            Sect Class : Compact
Length : 6,667             Major Axis : 0,000 degrees counterclockwise from local 3
Loc    : 6,667             RLLF       : 1,000

Area   : 0,074             SMajor : 0,010           rMajor : 0,189          AVMajor: 0,040
IMajor : 0,003             SMinor : 0,010           rMinor : 0,189          AVMinor: 0,040
IMinor : 0,003             ZMajor : 0,013           E      : 205000092,17
Ixy    : 0,000             ZMinor : 0,013           Fy     : 420000,189


STRESS CHECK FORCES & MOMENTS
    Location                  Pu         Mu33         Mu22         Vu2          Vu3           Tu
    6,667               8768,161      -51,472    -1331,130      16,195      347,426       -0,847

PMM DEMAND/CAPACITY RATIO
    Governing              Total            P       MMajor      MMinor        Ratio       Status
    Equation               Ratio        Ratio        Ratio       Ratio        Limit        Check
    (H1-1a)                0,571   =    0,315   +    0,010   +   0,246        0,950           OK

AXIAL FORCE DESIGN
                              Pu      phi*Pnc      phi*Pnt
                           Force     Capacity     Capacity
    Axial               8768,161    18107,873    27820,813

MOMENT DESIGN
                              Mu      phi*Mn       Cm       B1       B2        K        L       Cb
                          Moment    Capacity   Factor   Factor   Factor   Factor   Factor   Factor
    Major Moment         -51,472    4811,186    1,000    1,000    1,000    1,229    1,000    2,254
    Minor Moment       -1331,130    4811,186    1,000    1,000    1,000    1,851    1,000

SHEAR DESIGN
                              Vu      phi*Vn       Stress      Status           Tu
                           Force    Capacity        Ratio       Check      Torsion
    Major Shear           16,195    9072,004        0,002          OK        0,000
    Minor Shear          347,426    9072,004        0,038          OK        0,000
```

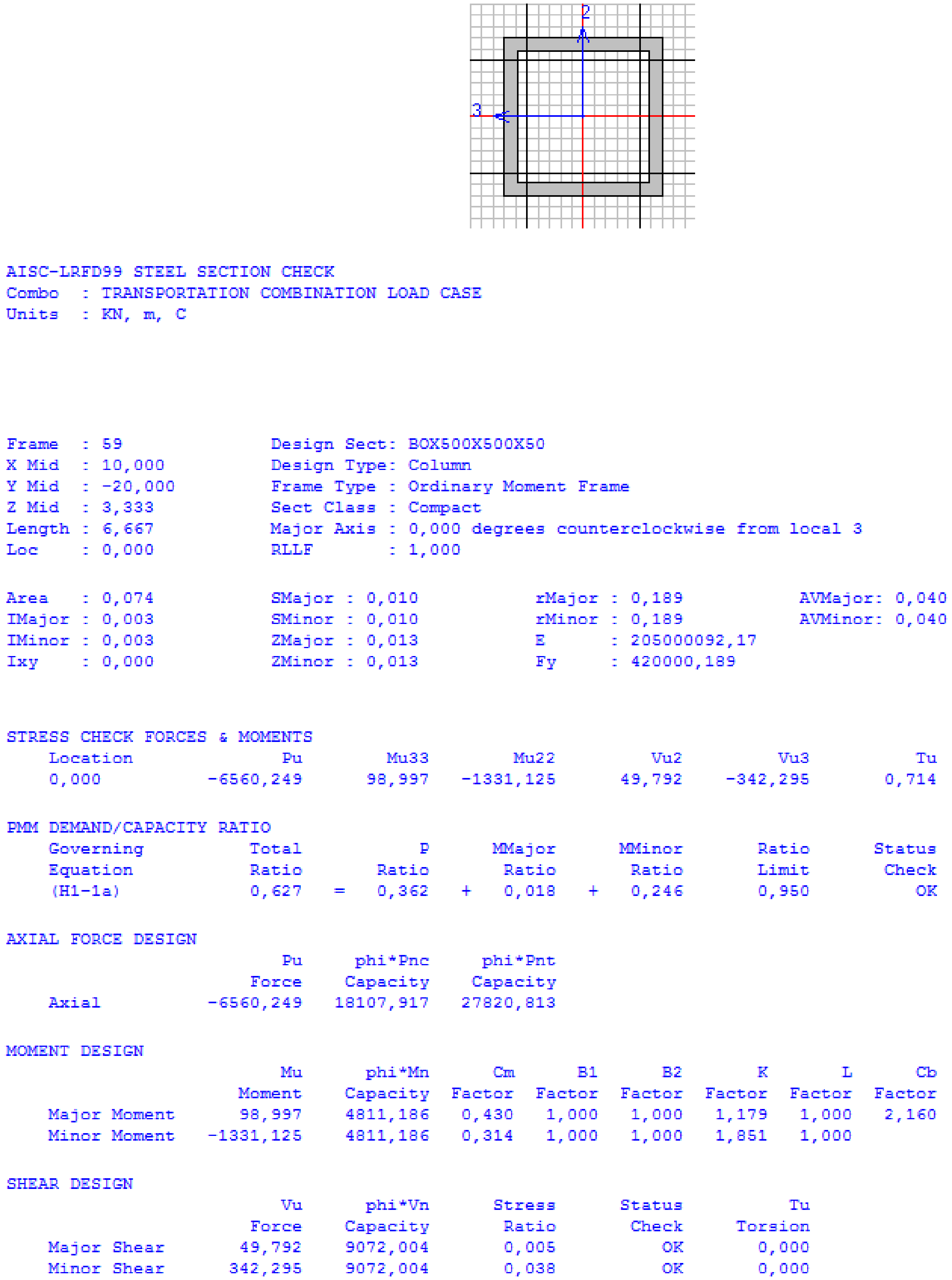


```
AISC-LRFD99 STEEL SECTION CHECK
Combo  : 100 COMBINATION LOAD CASE 100
Units  : KN, m, C



Frame  : 91                Design Sect: BOX400X400X40
X Mid  : 11,667            Design Type: Brace
Y Mid  : -20,000           Frame Type : Ordinary Moment Frame
Z Mid  : 3,333             Sect Class : Compact
Length : 7,454             Major Axis : 0,000 degrees counterclockwise from local 3
Loc    : 0,000             RLLF       : 1,000

Area   : 0,058             SMajor : 0,006           rMajor : 0,148           AVMajor: 0,032
IMajor : 0,001             SMinor : 0,006           rMinor : 0,148           AVMinor: 0,032
IMinor : 0,001             ZMajor : 0,008           E      : 205000092,17
Ixy    : 0,000             ZMinor : 0,008           Fy     : 420000,189


STRESS CHECK FORCES & MOMENTS
    Location                  Pu        Mu33        Mu22         Vu2         Vu3          Tu
    0,000              -2201,683      -5,136     281,490     -24,070      39,310      37,448

PMM DEMAND/CAPACITY RATIO
    Governing           Total           P      MMajor      MMinor       Ratio      Status
    Equation            Ratio       Ratio       Ratio       Ratio       Limit       Check
    (H1-1a)             0,730  =    0,579  +    0,002  +    0,149       0,950          OK

AXIAL FORCE DESIGN
                           Pu     phi*Pnc     phi*Pnt
                        Force    Capacity    Capacity
    Axial           -2201,683    3799,333   21772,810

MOMENT DESIGN
                           Mu      phi*Mn        Cm        B1        B2         K         L        Cb
                       Moment    Capacity    Factor    Factor    Factor    Factor    Factor    Factor
    Major Moment       -5,136    2926,323     0,850     1,000     1,000     1,000     1,000     1,000
    Minor Moment      495,565    2951,425     1,000     1,761     1,000     1,000     3,000

SHEAR DESIGN
                           Vu      phi*Vn      Stress      Status          Tu
                        Force    Capacity       Ratio       Check     Torsion
    Major Shear        24,070    7257,603       0,003          OK       0,000
    Minor Shear        39,310    7257,603       0,005          OK       0,000

BRACE MAXIMUM AXIAL LOADS
                            P           P
                         Comp        Tens
    Axial           -2201,683         N/C
```

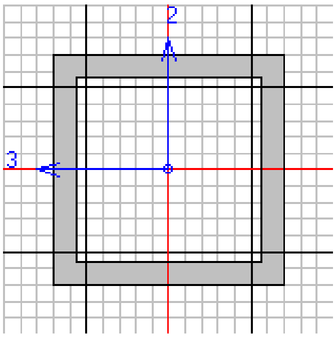


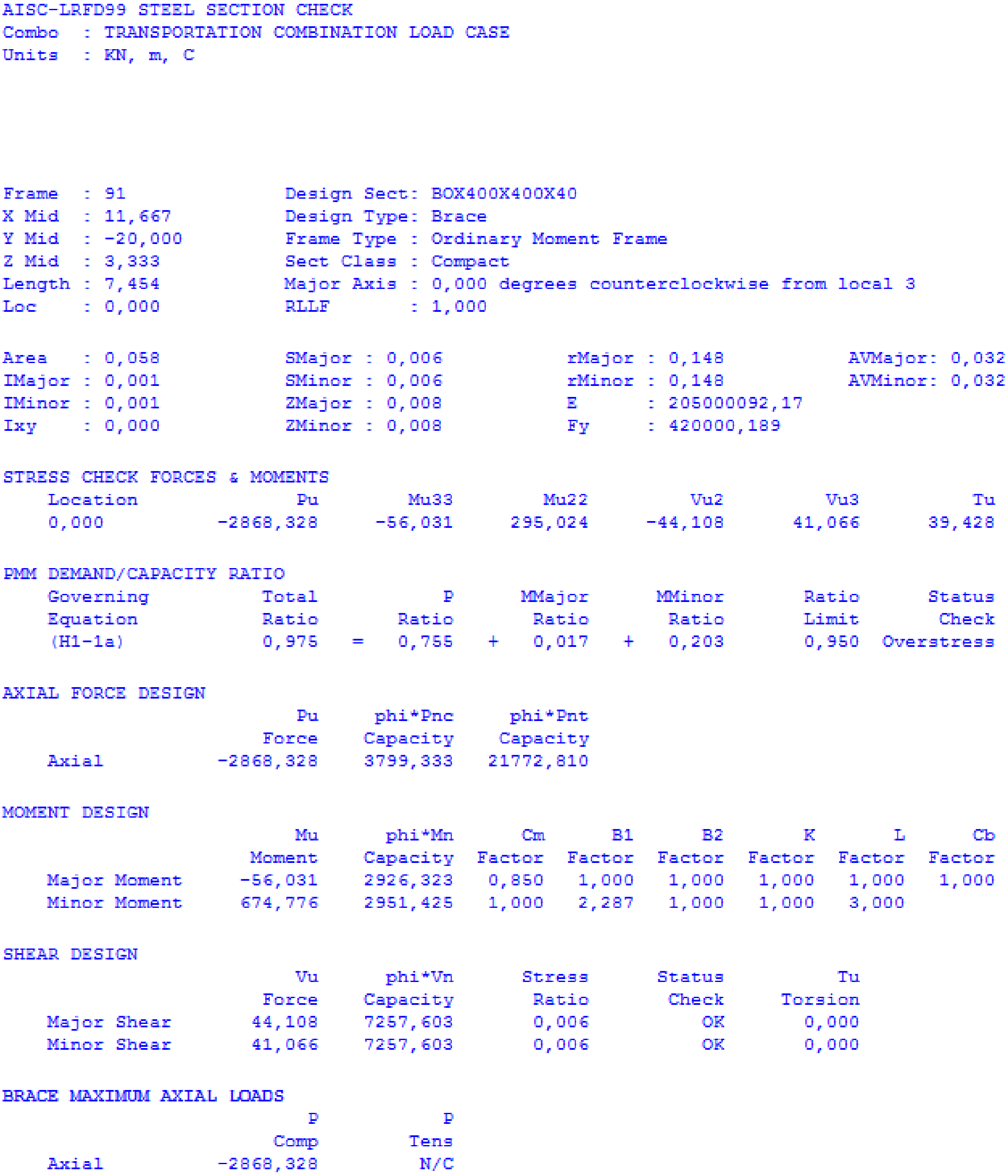
```
AISC-LRFD99 STEEL SECTION CHECK
Combo  : 100 COMBINATION LOAD CASE 100
Units  : KN, m, C



Frame  : 5                Design Sect: HE800B
X Mid  : 5,000            Design Type: Beam
Y Mid  : -20,000          Frame Type : Ordinary Moment Frame
Z Mid  : 0,000            Sect Class : Compact
Length : 10,000           Major Axis : 0,000 degrees counterclockwise from local 3
Loc    : 10,000           RLLF       : 1,000

Area   : 0,033            SMajor : 0,009          rMajor : 0,328          AVMajor: 0,014
IMajor : 0,004            SMinor : 9,933E-04      rMinor : 0,067          AVMinor: 0,017
IMinor : 1,490E-04        ZMajor : 0,010          E      : 205000092,17
Ixy    : 0,000            ZMinor : 0,002          Fy     : 420000,189


STRESS CHECK FORCES & MOMENTS
    Location              Pu        Mu33        Mu22         Vu2         Vu3          Tu
    10,000         -1127,983    -400,831       0,422     129,905       0,054      -0,097

PMM DEMAND/CAPACITY RATIO
    Governing          Total           P      MMajor      MMinor       Ratio      Status
    Equation           Ratio       Ratio       Ratio       Ratio       Limit       Check
    (H1-1a)            0,595   =   0,502   +   0,092   +   0,000       0,950          OK

AXIAL FORCE DESIGN
                          Pu     phi*Pnc     phi*Pnt
                       Force    Capacity    Capacity
    Axial          -1127,983    2247,287   12625,206

MOMENT DESIGN
                          Mu     phi*Mn       Cm       B1       B2        K        L       Cb
                      Moment   Capacity   Factor   Factor   Factor   Factor   Factor   Factor
    Major Moment    -400,831   3866,942    0,850    1,000    1,000    1,000    1,000    2,538
    Minor Moment       0,523    563,220    0,775    1,239    1,000    1,000    1,000

SHEAR DESIGN
                          Vu      phi*Vn      Stress      Status          Tu
                       Force    Capacity       Ratio       Check     Torsion
    Major Shear      129,905    3175,201       0,041          OK       0,000
    Minor Shear        0,054    3742,202   1,446E-05          OK       0,000

CONNECTION SHEAR FORCES FOR BEAMS
                      VMajor      VMajor
                        Left       Right
    Major (V2)       -27,566     129,905
```

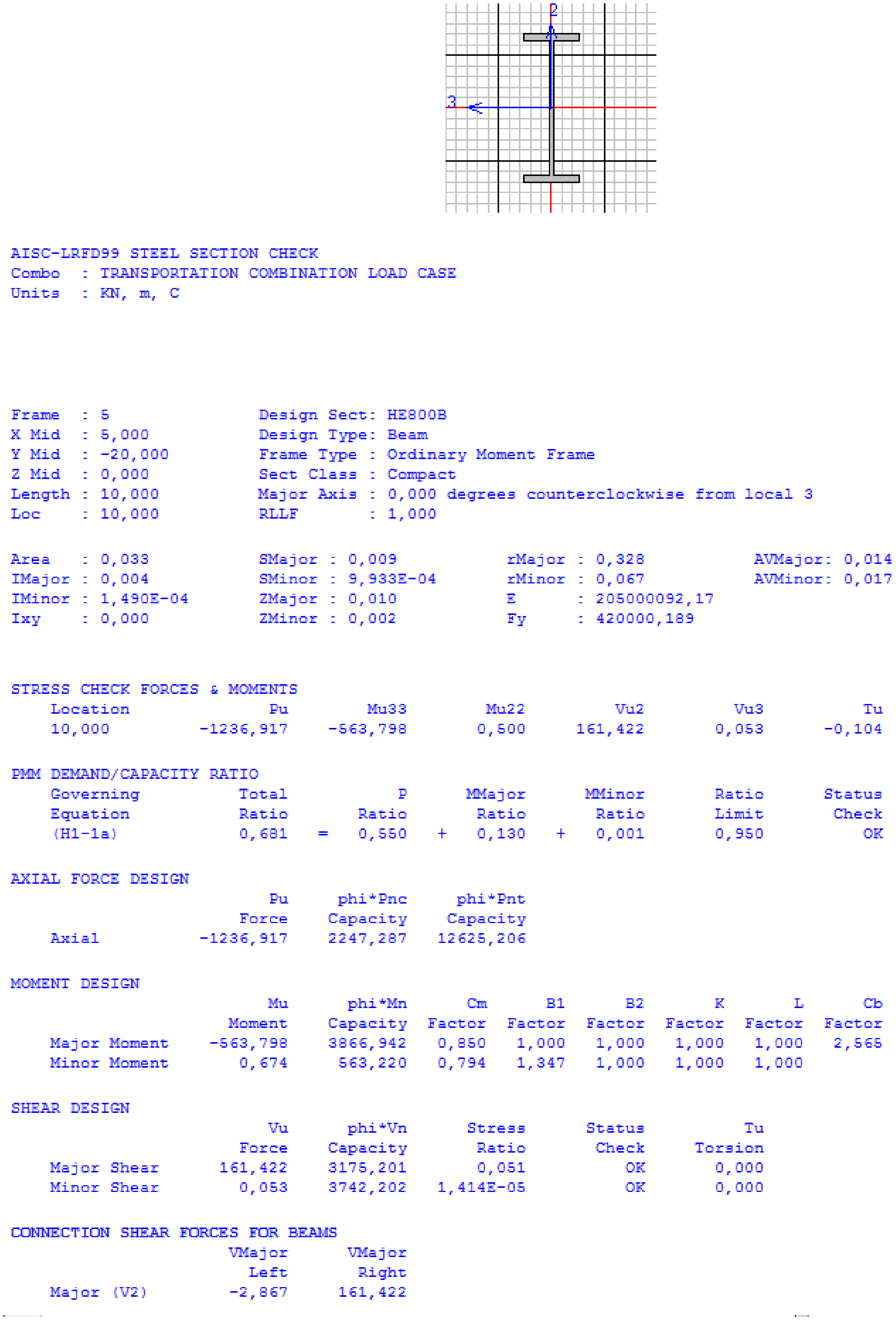
13.3 Transportation section details



```
AISC-LRFD99 STEEL SECTION CHECK
Combo   : TRANSPORTATION COMBINATION LOAD CASE
Units   : KN, m, C




Frame   : 59                 Design Sect: BOX500X500X50
X Mid   : 10,000             Design Type: Column
Y Mid   : -20,000            Frame Type : Ordinary Moment Frame
Z Mid   : 3,333              Sect Class : Compact
Length  : 6,667              Major Axis : 0,000 degrees counterclockwise from local 3
Loc     : 0,000              RLLF       : 1,000

Area    : 0,074              SMajor : 0,010           rMajor : 0,189           AVMajor: 0,040
IMajor  : 0,003              SMinor : 0,010           rMinor : 0,189           AVMinor: 0,040
IMinor  : 0,003              ZMajor : 0,013           E      : 205000092,17
Ixy     : 0,000              ZMinor : 0,013           Fy     : 420000,189


STRESS CHECK FORCES & MOMENTS
    Location                  Pu        Mu33        Mu22         Vu2         Vu3          Tu
    0,000              -6560,249      98,997   -1331,125      49,792    -342,295       0,714

PMM DEMAND/CAPACITY RATIO
    Governing              Total           P      MMajor      MMinor       Ratio      Status
    Equation               Ratio       Ratio       Ratio       Ratio       Limit       Check
    (H1-1a)                0,627  =    0,362  +    0,018  +    0,246       0,950          OK

AXIAL FORCE DESIGN
                              Pu    phi*Pnc     phi*Pnt
                           Force   Capacity    Capacity
    Axial              -6560,249  18107,917   27820,813

MOMENT DESIGN
                              Mu    phi*Mn      Cm      B1      B2       K       L      Cb
                          Moment  Capacity  Factor  Factor  Factor  Factor  Factor  Factor
    Major Moment          98,997  4811,186   0,430   1,000   1,000   1,179   1,000   2,160
    Minor Moment       -1331,125  4811,186   0,314   1,000   1,000   1,851   1,000

SHEAR DESIGN
                              Vu     phi*Vn      Stress      Status          Tu
                           Force   Capacity       Ratio       Check     Torsion
    Major Shear           49,792   9072,004       0,005          OK       0,000
    Minor Shear          342,295   9072,004       0,038          OK       0,000
```

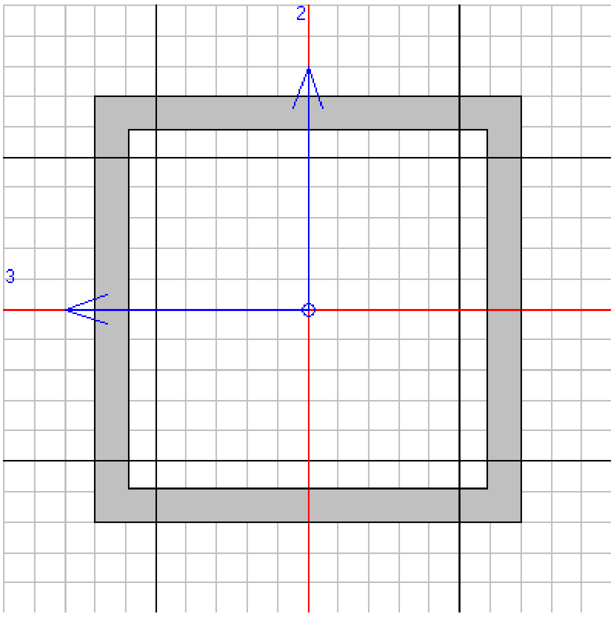



```
AISC-LRFD99 STEEL SECTION CHECK
Combo   : TRANSPORTATION COMBINATION LOAD CASE
Units   : KN, m, C



Frame   : 91               Design Sect: BOX400X400X40
X Mid   : 11,667           Design Type: Brace
Y Mid   : -20,000          Frame Type : Ordinary Moment Frame
Z Mid   : 3,333            Sect Class : Compact
Length  : 7,454            Major Axis : 0,000 degrees counterclockwise from local 3
Loc     : 0,000            RLLF       : 1,000

Area    : 0,058            SMajor : 0,006          rMajor : 0,148          AVMajor: 0,032
IMajor  : 0,001            SMinor : 0,006          rMinor : 0,148          AVMinor: 0,032
IMinor  : 0,001            ZMajor : 0,008          E      : 205000092,17
Ixy     : 0,000            ZMinor : 0,008          Fy     : 420000,189

STRESS CHECK FORCES & MOMENTS
    Location             Pu        Mu33        Mu22         Vu2         Vu3          Tu
    0,000         -2868,328     -56,031     295,024     -44,108      41,066      39,428

PMM DEMAND/CAPACITY RATIO
    Governing          Total           P      MMajor      MMinor       Ratio      Status
    Equation           Ratio       Ratio       Ratio       Ratio       Limit       Check
    (H1-1a)            0,975   =   0,755   +   0,017   +   0,203       0,950  Overstress

AXIAL FORCE DESIGN
                         Pu     phi*Pnc     phi*Pnt
                      Force    Capacity    Capacity
    Axial         -2868,328    3799,333   21772,810

MOMENT DESIGN
                         Mu     phi*Mn       Cm       B1       B2        K        L       Cb
                     Moment   Capacity   Factor   Factor   Factor   Factor   Factor   Factor
    Major Moment    -56,031   2926,323    0,850    1,000    1,000    1,000    1,000    1,000
    Minor Moment    674,776   2951,425    1,000    2,287    1,000    1,000    3,000

SHEAR DESIGN
                         Vu     phi*Vn      Stress      Status          Tu
                      Force   Capacity       Ratio       Check     Torsion
    Major Shear      44,108   7257,603       0,006          OK       0,000
    Minor Shear      41,066   7257,603       0,006          OK       0,000

BRACE MAXIMUM AXIAL LOADS
                          P           P
                       Comp        Tens
    Axial         -2868,328         N/C
```

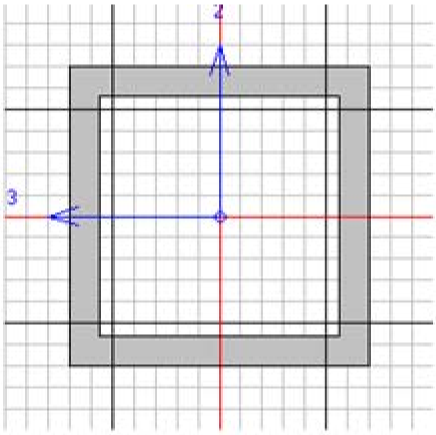


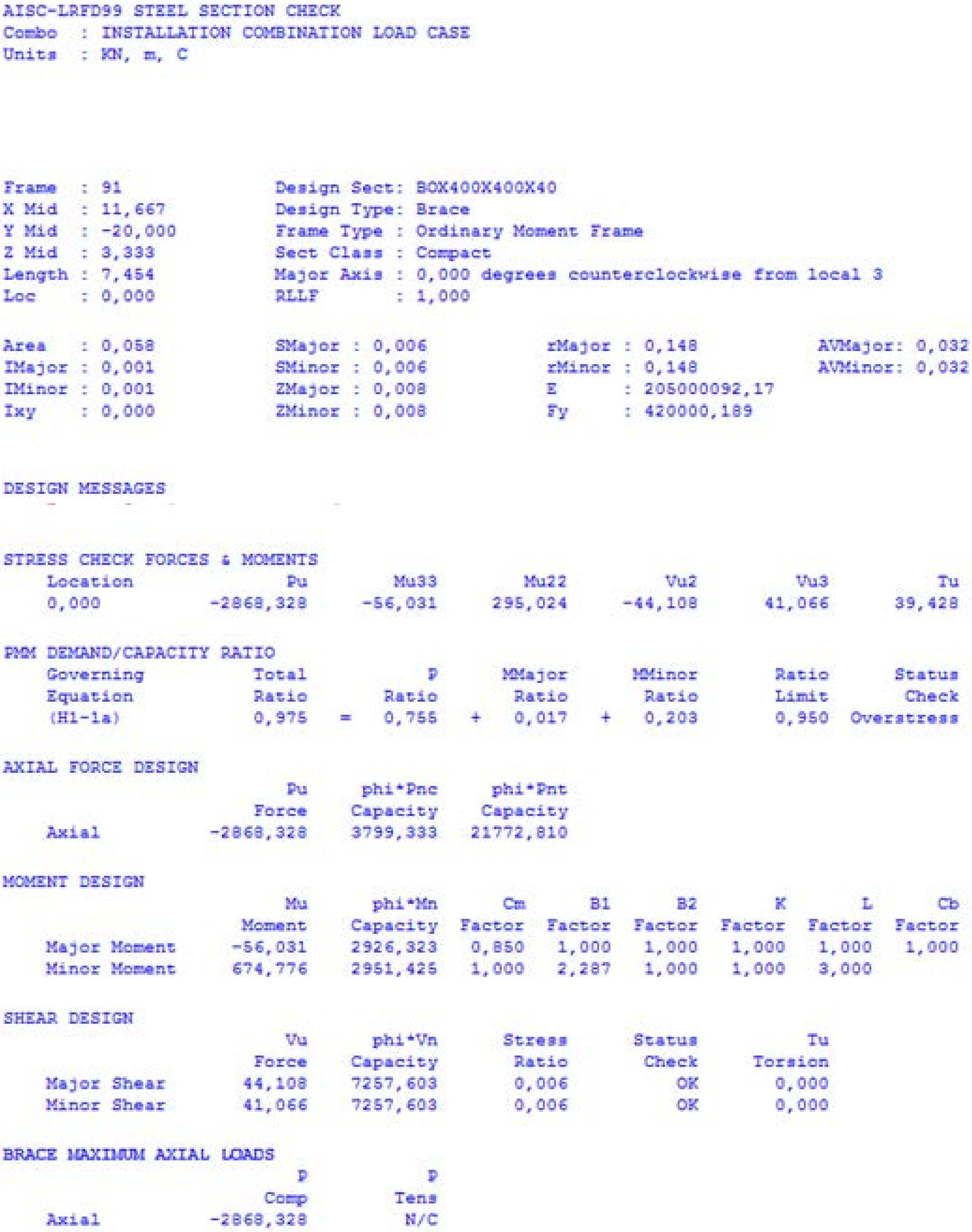
```
AISC-LRFD99 STEEL SECTION CHECK
Combo  : TRANSPORTATION COMBINATION LOAD CASE
Units  : KN, m, C




Frame  : 5                 Design Sect: HE800B
X Mid  : 5,000             Design Type: Beam
Y Mid  : -20,000           Frame Type : Ordinary Moment Frame
Z Mid  : 0,000             Sect Class : Compact
Length : 10,000            Major Axis : 0,000 degrees counterclockwise from local 3
Loc    : 10,000            RLLF       : 1,000

Area   : 0,033             SMajor : 0,009          rMajor : 0,328          AVMajor: 0,014
IMajor : 0,004             SMinor : 9,933E-04      rMinor : 0,067          AVMinor: 0,017
IMinor : 1,490E-04         ZMajor : 0,010          E      : 205000092,17
Ixy    : 0,000             ZMinor : 0,002          Fy     : 420000,189


STRESS CHECK FORCES & MOMENTS
    Location             Pu         Mu33        Mu22         Vu2         Vu3          Tu
    10,000        -1236,917     -563,798       0,500     161,422       0,053      -0,104

PMM DEMAND/CAPACITY RATIO
    Governing         Total            P      MMajor      MMinor       Ratio      Status
    Equation          Ratio        Ratio       Ratio       Ratio       Limit       Check
    (H1-1a)           0,681   =    0,550   +   0,130   +   0,001       0,950          OK

AXIAL FORCE DESIGN
                         Pu      phi*Pnc     phi*Pnt
                      Force     Capacity    Capacity
    Axial         -1236,917     2247,287   12625,206

MOMENT DESIGN
                         Mu      phi*Mn       Cm       B1       B2        K        L       Cb
                     Moment    Capacity   Factor   Factor   Factor   Factor   Factor   Factor
    Major Moment   -563,798    3866,942    0,850    1,000    1,000    1,000    1,000    2,565
    Minor Moment      0,674     563,220    0,794    1,347    1,000    1,000    1,000

SHEAR DESIGN
                         Vu      phi*Vn      Stress      Status          Tu
                      Force    Capacity       Ratio       Check     Torsion
    Major Shear     161,422    3175,201       0,051          OK       0,000
    Minor Shear       0,053    3742,202   1,414E-05          OK       0,000

CONNECTION SHEAR FORCES FOR BEAMS
                     VMajor      VMajor
                       Left       Right
    Major (V2)       -2,867     161,422
```

13.4 Installation section details

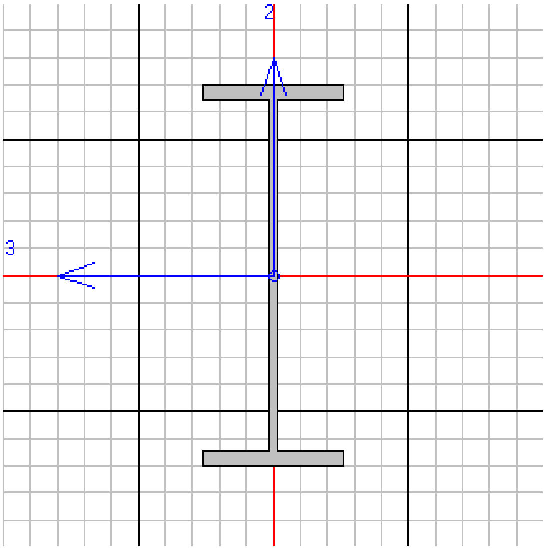


```
AISC-LRFD99 STEEL SECTION CHECK
Combo  : INSTALLATION COMBINATION LOAD CASE
Units  : KN, m, C



Frame  : 59              Design Sect: BOX500X500X50
X Mid  : 10,000          Design Type: Column
Y Mid  : -20,000         Frame Type : Ordinary Moment Frame
Z Mid  : 3,333           Sect Class : Compact
Length : 6,667           Major Axis : 0,000 degrees counterclockwise from local 3
Loc    : 0,000           RLLF       : 1,000

Area   : 0,074           SMajor : 0,010           rMajor : 0,189           AVMajor: 0,040
IMajor : 0,003           SMinor : 0,010           rMinor : 0,189           AVMinor: 0,040
IMinor : 0,003           ZMajor : 0,013           E      : 205000092,17
Ixy    : 0,000           ZMinor : 0,013           Fy     : 420000,189


STRESS CHECK FORCES & MOMENTS
    Location              Pu        Mu33        Mu22         Vu2         Vu3          Tu
    0,000          -6560,249      98,997   -1331,125      49,792    -342,295       0,714

PMM DEMAND/CAPACITY RATIO
    Governing          Total           P      MMajor      MMinor       Ratio      Status
    Equation           Ratio       Ratio       Ratio       Ratio       Limit       Check
    (H1-1a)            0,627   =   0,362   +   0,018   +   0,246       0,950          OK

AXIAL FORCE DESIGN
                          Pu     phi*Pnc     phi*Pnt
                       Force    Capacity    Capacity
    Axial          -6560,249   18107,917   27820,813

MOMENT DESIGN
                          Mu      phi*Mn      Cm      B1      B2       K       L      Cb
                      Moment    Capacity  Factor  Factor  Factor  Factor  Factor  Factor
    Major Moment      98,997    4811,186   0,430   1,000   1,000   1,179   1,000   2,160
    Minor Moment   -1331,125    4811,186   0,314   1,000   1,000   1,851   1,000

SHEAR DESIGN
                          Vu      phi*Vn      Stress      Status          Tu
                       Force    Capacity       Ratio       Check     Torsion
    Major Shear       49,792    9072,004       0,005          OK       0,000
    Minor Shear      342,295    9072,004       0,038          OK       0,000
```





```
AISC-LRFD99 STEEL SECTION CHECK
Combo  : INSTALLATION COMBINATION LOAD CASE
Units  : KN, m, C



Frame  : 91              Design Sect: BOX400X400X40
X Mid  : 11,667          Design Type: Brace
Y Mid  : -20,000         Frame Type : Ordinary Moment Frame
Z Mid  : 3,333           Sect Class : Compact
Length : 7,454           Major Axis : 0,000 degrees counterclockwise from local 3
Loc    : 0,000           RLLF       : 1,000

Area   : 0,058           SMajor : 0,006           rMajor : 0,148           AVMajor: 0,032
IMajor : 0,001           SMinor : 0,006           rMinor : 0,148           AVMinor: 0,032
IMinor : 0,001           ZMajor : 0,008           E      : 205000092,17
Ixy    : 0,000           ZMinor : 0,008           Fy     : 420000,189


DESIGN MESSAGES


STRESS CHECK FORCES & MOMENTS
    Location              Pu        Mu33        Mu22         Vu2         Vu3          Tu
    0,000          -2868,328     -56,031     295,024     -44,108      41,066      39,428

PMM DEMAND/CAPACITY RATIO
    Governing          Total           P      MMajor      MMinor       Ratio      Status
    Equation           Ratio       Ratio       Ratio       Ratio       Limit       Check
    (H1-1a)            0,975   =   0,755   +   0,017   +   0,203       0,950  Overstress

AXIAL FORCE DESIGN
                          Pu     phi*Pnc     phi*Pnt
                       Force    Capacity    Capacity
    Axial          -2868,328    3799,333   21772,810

MOMENT DESIGN
                          Mu      phi*Mn      Cm      B1      B2       K       L      Cb
                      Moment    Capacity  Factor  Factor  Factor  Factor  Factor  Factor
    Major Moment     -56,031    2926,323   0,850   1,000   1,000   1,000   1,000   1,000
    Minor Moment     674,776    2951,425   1,000   2,287   1,000   1,000   3,000

SHEAR DESIGN
                          Vu      phi*Vn      Stress      Status          Tu
                       Force    Capacity       Ratio       Check     Torsion
    Major Shear       44,108    7257,603       0,006          OK       0,000
    Minor Shear       41,066    7257,603       0,006          OK       0,000

BRACE MAXIMUM AXIAL LOADS
                           P           P
                        Comp        Tens
    Axial          -2868,328         N/C
```



```
AISC-LRFD99 STEEL SECTION CHECK
Combo  : INSTALLATION COMBINATION LOAD CASE
Units  : Kip, in, F



Frame  : 5               Design Sect: HE800B
X Mid  : 196,850         Design Type: Beam
Y Mid  : -787,402        Frame Type : Ordinary Moment Frame
Z Mid  : 0,000           Sect Class : Compact
Length : 393,701         Major Axis : 0,000 degrees counterclockwise from local 3
Loc    : 393,701         RLLF       : 1,000

Area   : 51,770          SMajor : 547,841         rMajor : 12,909          AVMajor: 21,700
IMajor : 8627,412        SMinor : 60,617          rMinor : 2,630           AVMinor: 25,575
IMinor : 357,974         ZMajor : 624,273         E      : 29732,747
Ixy    : 0,000           ZMinor : 94,770          Fy     : 60,916


STRESS CHECK FORCES & MOMENTS
    Location                Pu        Mu33        Mu22         Vu2         Vu3          Tu
    393,701           -278,070   -4990,033       4,429      36,289       0,012      -0,924

PMM DEMAND/CAPACITY RATIO
    Governing            Total           P      MMajor      MMinor       Ratio      Status
    Equation             Ratio       Ratio       Ratio       Ratio       Limit       Check
    (H1-1a)              0,681   =   0,550   +   0,130   +   0,001       0,950          OK

AXIAL FORCE DESIGN
                            Pu     phi*Pnc     phi*Pnt
                         Force    Capacity    Capacity
    Axial             -278,070     505,210    2838,259

MOMENT DESIGN
                            Mu      phi*Mn      Cm      B1      B2       K       L      Cb
                        Moment    Capacity  Factor  Factor  Factor  Factor  Factor  Factor
    Major Moment     -4990,033   34225,315   0,850   1,000   1,000   1,000   1,000   2,565
    Minor Moment         5,966    4984,919   0,794   1,347   1,000   1,000   1,000

SHEAR DESIGN
                            Vu      phi*Vn      Stress      Status          Tu
                         Force    Capacity       Ratio       Check     Torsion
    Major Shear         36,289     713,814       0,051          OK       0,000
    Minor Shear          0,012     841,280   1,414E-05          OK       0,000

CONNECTION SHEAR FORCES FOR BEAMS
                        VMajor      VMajor
                          Left       Right
    Major (V2)          -0,644      36,289
```