Structural Design of Helicopter Landing Platform on Offshore Ship

Wai Lin Tun

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Supervisor: Prof.Dr. Zbigniew Sekulski
West Pomeranian University of Technology, Szczecin

Reviewer: Prof.Marco Ferrando
Università di Genova

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ABSTRACT

There has been an increased of activities in exploration of oil and gas in offshore. Helicopters are used as a primary mean of personal transportation to offshore installations. Helicopter operations in offshore installations and vessels are risky and critical. Due to adverse weather conditions and space limitation, the design of the helicopter landing structures has to be considered carefully.

A design using rule-based approach is presented in this thesis. It is to be installed on offshore construction and drilling vessel of LOA 115.4 metre. Based on mission objectives of the vessel, the design is developed from the initial phase. Analysis of various loads and load combinations is made according to DNV offshore standard, OS-E-401. Sikorsky S-92 is used as the largest helicopter to land on the structure. 16 different landing positions are considered. 30 load combinations for stowage condition due to ship motions are modelled to ensure the adequacy of strength.

Aluminium alloy and high strength steel are used to save weight. Common structural arrangement and connections are applied and allowable stress level is checked according to Class requirements. The design is found to be less efficient compared to relevant designs from industry. The deficiency comes from the fact of using common structural arrangement as in steel constructions. Recommendations to improve the design features are presented finally.

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SYMBOL AND ABBREVIATIONS

σ_c	Critical buckling stress
$R_{p,0.2}$	Yield strength at 0.2% non-proportional elongation
R_m	Tensile strength
R_e	Yield stress
P	Axial force on pillar
η	Usage factor
ABS	American Bureau of Shipping
BV	Bureau Veritas
DNV	Det Norske Veritas
GL	Germanischer Lloyd
LR	Lloyds' Register
HAZ	Heat affected zone
HCA	Helideck Certification Agency
SOLAS	International Convention on Safety of Life at Sea
D-circle	A circle, usually hypothetical unless the helideck itself is circular, the diameter of which is the D-value of the largest helicopter the helideck is intended to serve.
D value	The largest overall dimension of the helicopter when rotors are turning
MTOM	Maximum Certified Take-Off Mass
Sigxx	Combined axial stress from axial force and bending moments
TauNxy	Shear stress due to shear force in local beam y-direction
TauNxz	Shear stress due to shear force in local beam z-direction
LOS	Limited Obstacle Sector
OFS	Obstacle Free Sector

CONTENTS

Declaration of Authorship

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

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

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

I have acknowledged all main sources of help.

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

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

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1 INTRODUCTION

1.1 General

Exploration and production activities for oil and gas in offshore water have been increased during the recent years. Helicopters are used as primary mode of personal transportation for offshore installations and vessels. According to available data in 2007, total fleet of offshore helicopter is 1147 with total flight hours of 986,010 [1]. Total 10 accidents occurred in 2007 with 5 fatal cases in world-wide scale for offshore helicopter operations [1]. On the other side, 5 helicopter accidents were recorded in other types of industry in 2007.

Therefore it can be stated in general that offshore helicopter operations are risky and critical.

There are some main causes of offshore helicopter accidents. Between 1997 and 2006, engine related causes were recorded 24 times, pilot mistake 16 times, tail rotor related problems 15 times and obstacle strike cases recorded 11 times as major causes [1].

During the accident, the helicopter might ditch into the sea or land; or crashed on the helipad or nearby facilities. If the helicopter crashes on the landing platform, secondary accidents may arise. The helicopter landing platforms should be arranged and constructed according to industrial guidelines to reduce the potential risks of secondary accidents from helicopter operations. Besides this, safe operation guidelines and procedures have to be followed all the time. This thesis will present the design of the helicopter landing platform on offshore ship taking into account of relevant industrial guidelines.

1.2 Objectives and Scope of Thesis

The objective of this thesis is to perform design and analysis of a helicopter landing structure on an offshore construction vessel. It is not intended for development a new technology or a specific deep research about structural analysis. It is developed as an example of engineering calculation and design procedure for helicopter landing structures. It is intended to realize the stages required for structural analysis such as modelling of loads, load combinations and required safety features. This thesis should be regarded as a basic document for analysis of helicopter landing structures and further researches and improvements should be made based on this thesis. It is intended to have better understanding about helideck (the general term “helideck” will be used to refer helicopter landing platform in this thesis) design and to make further improvement and research.

The author started the design from the initial phase. The design was evolved from many trials and errors and some observations from similar ships. The design is entirely based on Class Rules and loads are analyzed according to Class recommended practices. This might be a conservative approach.

The calculation and design presented in this thesis is only for the basic design. Detail design and local structural analysis is out of the scope of the thesis. The structure has been designed and improved by some trials. Therefore, it cannot be surely said that the design proposed in this thesis is the most optimal and efficient design. Optimization study is a broad topic and due to limited time and resources available, this topic is not presented in the thesis.

During the analysis of loads, most possible loads and combinations are taken into account. There is a specific kind of vibration induced loads due to the flow of wind over helideck structures. This is known as vortex shedding. Due to limited time, effect of vortex shedding is not considered for calculation.

As the helideck structure is subjected to various loadings from different sources, it is quite difficult to formulate and investigate the problem from classical structural theory. As in the case of ship structures, the complexity of the structure makes it impossible to analyze theoretically.

The helideck structure is designed with aluminium alloy and high strength steel. It is the common practice of design in the industry. The purpose is to save the weight of the structure. On the other hand, certain problems encountered due to the usage of aluminium alloy. During the modeling phase, aluminium structure is treated in the same way as the steel in the software. There is still lack of information available for finite element (FE) modeling of aluminium alloys [2]. Aluminium alloys show different strength properties near welded zones. This area is commonly called heat affected zone, HAZ. Some researches apply effects of welding on FE modeling though it is still difficult to add detail features during initial design phase. But all the guidelines related to aluminium alloy construction from Class are considered.

Nowadays, many commercial computer codes are available for structural analysis. Even in the case of helicopter landing platform structures, it is not easy to perform analysis manually. There are some commercial FE computer programs available for structural analysis. In this thesis, GeniE from DNV will be used for the modelling of the design and analysis will be carried out by Sestra package of DNV software. As this thesis is developed during the author's internship period at MT Poland, it is the intention of MT Poland to perform the work with DNV software package. (MT Poland is a subsidiary of Marin Teknikk AS which is an independent ship design and engineering company located in Norway. Please see www.marinteknikk.no for more information)

The strength requirements of the structure are checked according to DNV Rules. For primary structural members, the design approach is based on direct stress analysis applying different usage factors under different operational conditions. There is no specific requirement for checking induced stress level in the plating. There is still uncertainty about lateral loading condition on aluminium plantings. Therefore it is not possible to check the results of plating from the analysis and the result might not be relevant. The thickness of the plating strictly follows the requirement of Class and it is considered as sufficient in this thesis.

1.3 Overview of Available References

DNV defines helideck as a safe operation area for landing of helicopter on a ship with all necessary structures and equipment [3]. Therefore, the term helideck means not only about the structures but also other appliances and safety equipment necessary for safe helicopter operation on board a ship. There are very rare reference works available for engineering analysis of helideck structures. This might be due to a fact that the topic of this thesis relates directly to a common engineering design problem rather than a specific area of interest for research.

Most of the reference works available for this topic can be found in rules from Classification Societies, regulations and guidelines of some international bodies for aviation management. Normally, the Classification Societies have some criteria for structural strength requirement and some features related to safety of operation but the latter are usually adopted from those of aviation societies.

For the work in this thesis, the helideck structure is to be designed according to DNV Rules. As the ship has to be operated as offshore vessel, the main rule shall be DNV offshore standard OS-E-401. Besides this, the ship has to comply with IMO SOLAS regulations for safety related matters [4].

Another important reference for offshore helideck design consideration is CAP437. Civil Aviation Authority of UK publishes it as a standard regulation. CAP437 is applied particularly to UK registered helicopters operating within and outside of the UK Continental

Shelf areas [5]. But this CAP437 is widely accepted as minimum standard for offshore helicopter landing areas by other regulatory bodies. In fact, CAP437 consists of all necessary features for helideck design considerations although it does not reveal details about structural design requirements. But CAP437 represents the most resourceful document available for safety related features of helidecks. The design features in this thesis are based a lot on CAP437 requirements.

Jackson, R.I and Frieze, P.A conducted experiment on deck structures under wheel loads [6]. They created a steel flight deck grillage model with different frame spacing. Wheel load is idealized by a group of load cells transmitting through spheroidal pads. Numerical study was also made at the same time. The results of both studies were correlated and design curves are presented based on permanent set parameter, C_{sp}. An example of design curve for C_{sp} = 0.2 is shown in the Figure 1.1. C_b in the Figure is the plate slenderness parameter and C_p is the pressure parameter. If the panel width b, patch width B, applied load P and permanent set s_p is known, the requirement thickness can be estimated. Therefore, this kind of curve is very useful for designers.

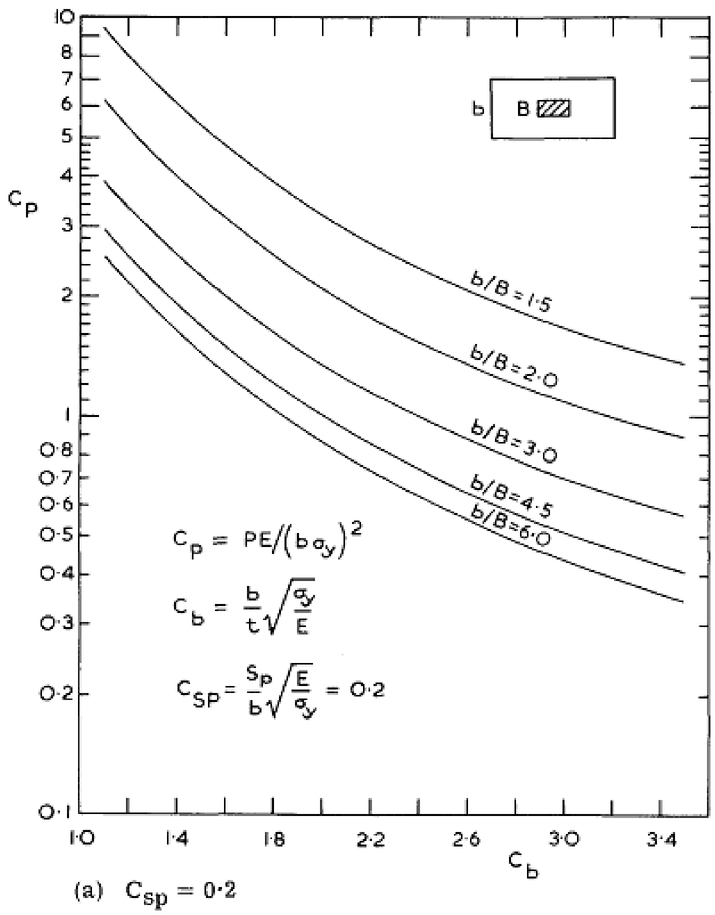

Figure 1.1 An example of wheel patch design curve of steel grillage model [5]

From this study, parameters such as plate slenderness and plate width to patch width ratio are found to be significant factors for wheel loading [6]. The presence of residual stresses is found to be less significant while that of aspect ratio is found to have little or no effect.

Stainback, J made a study about structural analysis of helicopter flight and hangar decks for US Navy [7]. Her work is, in fact, a detail guideline for the technical procedure (Structural Design of Aircraft Handling Deck, DDS 130-2, 1984) of the Naval Sea System Command to assess the ships for the helicopter operations. She explained about how to calculate landing loads, wheel loads and inertia forces acting on helicopter in association with ship motions. She mentioned that the procedure in DDS 130-2 had some limitations [7] and FE analysis needed to be performed to get extensive range of results. The work performed here gives good insight about the design procedure for integrated type landing pad. But both the works of Jessica and Jackson deal with ordinary steel flight decks.

When dealing with analysis of the design, there are some reference works to be cited. The structure is intended to design with aluminium alloy. There is significant difference between aluminium and steel design in the real case. In fact, there is still room to be explored for efficient aluminium design [2].

The main issue related to aluminium design is lack of research in some areas. Sielski [2] wrote a technical report to ship structural committee about research needs in aluminium structures. He described about previous researches from others that the yield strength of welded panel in tension was close to that of base metal in 5xxx series alloy while that of 6xxx series was closer to HAZ property (5xxx means aluminium alloy series start with 5). There are some differences in HAZ properties accepted by different Classification Societies. He also mentioned that the knowledge of how to consider effects of welds in finite element models is still limited. (During the initial design stage, it might be difficult to consider these effects in the analysis and modelling.) He also points out that fatigue analysis using civil engineering design codes is not so relevant for using in ship structures [2].

Plates on a ship experience axial compression, lateral loading or combined load of the previous ones. For the case of separate helicopter landing platform, lateral loading will be significant. The landing forces from the helicopter exert through the wheel to the plating. For the steel plates, some theories have been proposed and experiments have been carried out. The research carried out by Jackson, R.I and Frieze, P.A is one of those cases. But still, there is lack of experimental data for lateral loading of aluminium panels according to the author’s knowledge.

Regarding to lateral loading of plates, two approaches known as permanent set approach and the allowable stress approach, can be applied. Collette, M, et al [8] mentioned about these approaches but they said experimental results for later loading of aluminium plates were unavailable and hence validation of these approaches was impossible in the report of SSC-454 (2008).

1.4 Outline of Thesis

The thesis will be presented in a sequential order. Chapter one and two will introduce about the thesis and overview of the problem. The design is to be based upon Classification Society's Rule and therefore Chapter three will make short review about applicable codes and standards for the formulation of the solution. Then various loads will be analyzed and possible load combinations will be made according to Class requirements in Chapter 4. Important features of geometry, engineering data and results of analysis will be shown in Chapter 5. General design concept of the structure and initial design would be included in this chapter. All the work will be summarized and further recommendation will be given in the last section.

2 GENERAL DESCRIPTION OF THE PROBLEM

2.1 Introduction

Nowadays, helicopter landing operations on board a ship can be found for different purposes. Many naval vessels have landing platform for military operations. Helicopter landing platforms can be found on offshore barges, offshore drilling vessels and offshore construction and support vessels. Some of pleasure crafts also consist of landing pad to host small helicopters. Examples of helicopter landing decks on different ship types can be seen in Figure 2.1. The major problems and constraints for helicopter landing structure on a ship can be as follows:

- availability of space,
- safety requirement,
- strength requirement.

(source:http://www.naval- technology.com /contractors/data_management/cilas/cilas3.html, accessed 9 December 2012)

(source: http://www.mikeyscruiseblog.com /2012/04/20/allure-of-the-seas-fire/, accessed 9 December 2012)

(source: http://www.eventective.com/blog/wp-content/uploads/2008/04/2300521910_cdcc8295c2_b1.jpg, accessed 9 December 2012)

(source: http://www.boa.no/Default.aspx?ID=7&M =News&PID=121&NewsID=26, accessed 12 December 2012)

Figure 2.1 Examples of helicopter landing platforms on different ships

2.2 Major Constraints for the Design

Availability of space

There is always space limitation in offshore construction vessels. Normally, the deck area on the aft part is occupied by cranes, mast; and drilling and construction equipments. Except in seismic survey vessels, helideck structures on most offshore construction vessels are located on forward part of the ship. An example of seismic survey vessel with midship helideck can be seen in Figure 2.2.

Figure 2.2 Example of a helideck located in mid-ship area of seismic survey vessel (source: http://www.shipspotting.com/gallery/photo.php?lid=1117062, Accessed 20 October 2012)

Depending on the availability of space, the helideck is installed above the forecastle deck or above the wheel house. It is very important to think about the configuration of the structure so as to minimize the blockage of view on the wheel house. But in general, helidecks are fitted above the wheel house in most of the offshore vessels.

Safety Requirements

Helicopter operation on board a ship is a risky operation. The design has to be complied with strict safety rules and regulations. For example, there is minimum requirement for landing area depending on type of helicopter intended to use. Medium to large size helicopters are normally used in offshore due to operational and economical reasons (categorization of helicopter types can be found in Appendix A7). Therefore, the helipad size on offshore ship is normally bigger than those on tanker or cruise ships. The categorization of helicopter size according to UK's HCA can be found in Table A7. 1.

In addition to size of the pad, there must be sufficient safety equipment installed for operation support on board.

Strength Requirements

Offshore vessels are to operate under harsh environmental conditions. Various combinations of environmental loads can exert on the structure in addition to landing forces of helicopter and self-weight of the structure. In DNV offshore standard, there is additional forces need to impose in consideration of design compared to DNV rules for classification of ships [9]. Therefore, the helideck structures on offshore ships require higher strength and durability than those on other commercial vessels.

As the structures are mostly located on higher part of the ship, it is also desirable to reduce the weight as much as possible. Normally, aluminium alloys are used in conjunction with high strength steel. But there needs to think about fabrication related problems due to HAZ effects of aluminium alloys and connections between steel and aluminium parts.

Another difficulty arises is the uncertainty about load cases. Several load cases and combinations need to be considered to ensure that most severe load case will include in the analysis.

There are also certain areas of complexity in engineering analysis of helicopter landing. In fact helicopter landing is a dynamic engineering problem. There is also uncertainty of interactions between ship and helicopter due to ship motions, helicopter landing and wind forces.

2.3 Technical Data Required for the Design

The design of structure needs to be based on the some technical specifications. The general arrangement and layout of the working vessel is important for the design. Besides this, it is important to define the largest helicopter intended to use.

2.3.1 *Main Technical Parameters of the Ship*

The ship is a riserless drilling vessel type with Marin Teknikk MT6022XL design. It is designed for riserless well completion, wet tow and subsea construction work in both shallow and deep water. It can also perform slender well drilling and well intervention with riser.

Table 2.1Main technical parameters of ship for the design

Description	**Value**
Length Over All, LOA	115.4 m
Length Between Perpendiculars, LPP	107.95 m
Rule Length, L	105.6 m
Breadth, B	22 m
Depth to Main Deck	9 m
Draught	7.15 m
Depth to Summer Water Line	7.095 m
Block Coefficient	0.731
Displacement	12767.53 tonnes
Power of Propulsion	2X3000 kW
Trial Speed	14.5 knots

Due to copy right issues, the detail general arrangement of the ship is not included in this paper. Starting from the bottom, the decks are arranged in the following order: tank top, tween deck, main deck, shelter deck, forecastle deck, boat deck, captain deck and bridge deck. As seen in the Figure 2.3, the main engine room is located on tank top just aft of thruster room.
Moon pool is located approximately between frame 62 and 76 with heavy drilling mud tanks located on sides around moon pool. Cement tank room is located aft of moon pool. Stern thruster room is located next to cement tank room.
ROV hangar, crane and control room are located on main deck and shelter deck. Drilling mast is fitted above moon pool on main deck. The deck space on main deck is reserved for drilling pipes and pipe handling equipment. The main construction deck crane is located on shelter deck, port side around frame 46. Access to life boats will be located on boat deck. Total 4 life

boats are installed on both sides of the ship. Cabins, offices and wheel house are located in superstructure in the forward of the ship.

From initial observations, there are some free deck spaces available on forward part of the boat deck and top of the wheel house deck. The drawings are shown in Figure 2.4 and Figure 2.5 respectively. Support structures to helicopter landing platform can be constructed in these two areas.

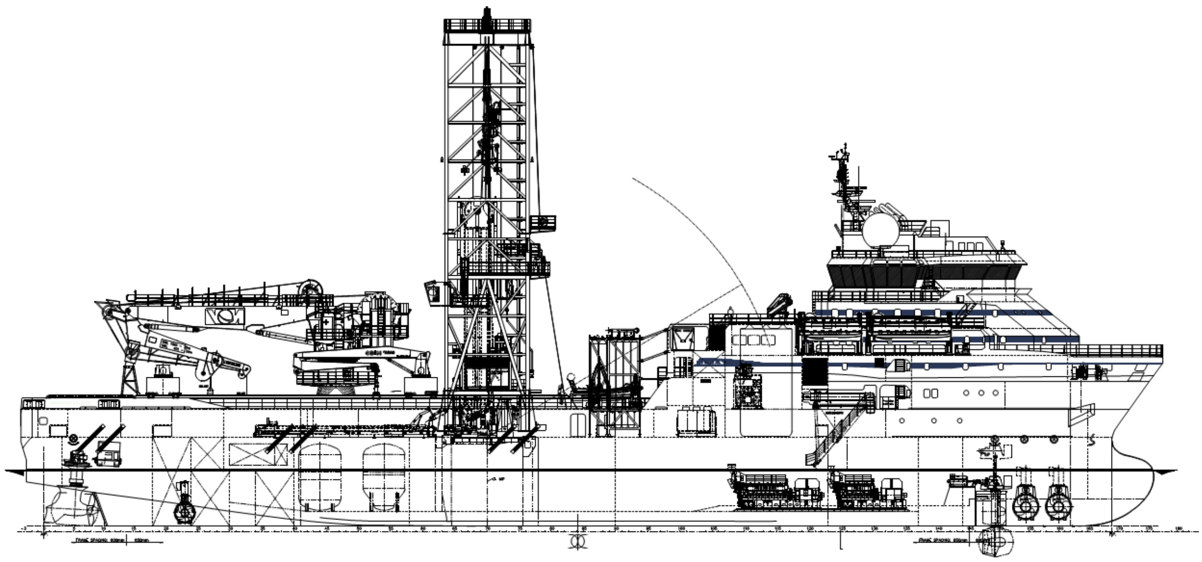

Figure 2.3 Profile view of the ship

(Marin Teknikk owns copy rights for all the ship drawings in this thesis)

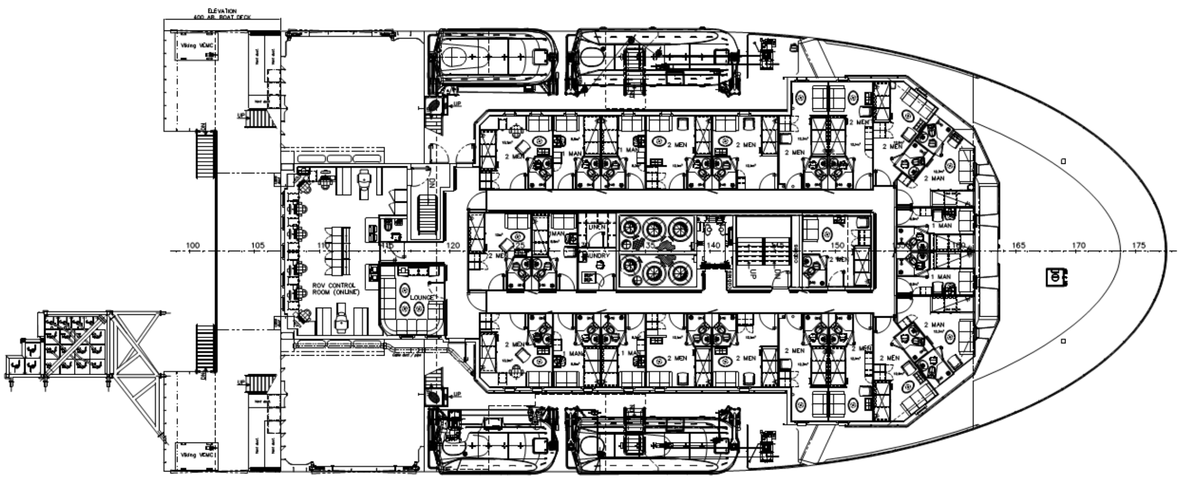

Figure 2.4 Plan view of boat deck

(Marin Teknikk owns copy rights for all the ship drawings in this thesis)

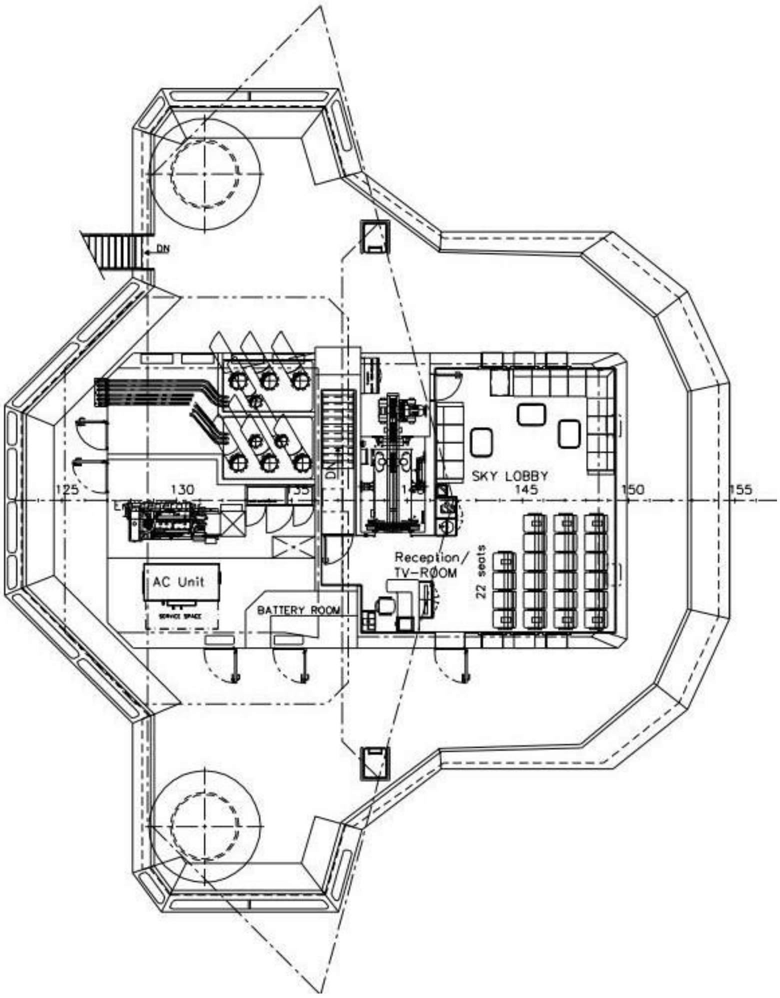

Figure 2.5 Top of the wheel house

(Marin Teknikk owns copy rights for all the ship drawings in this thesis)

2.3.2 Helicopter Data

The helicopter landing platform must be able to withstand the landing loads from the biggest helicopter intended to use. Sirkosky S-92 will be used as the largest helicopter that will land on board. Typical Sirkosky S-92 helicopter can be seen in Figure 2.6 and important technical parameters of S-92 helicopter are shown in Table 2.2.

Table 2.2 Technical data for Sirkosky S-92 helicopter [9]

Power plant and fuel system	
Description	**Value**
Number of Engines	2
Engine Type	GE CT7-8A
Take-off Shaft horsepower (5min)	1,897 kW
OEI Shaft horsepower (30 sec)	2,034 kW
Performance	
Maximum Gross Weight	12020 kg
Maximum Cruise Speed	280 kph
Maximum Range-No Reserve	999 km
Accommodations	
Cabin Length	6.1 m
Cabin Width	2 m
Cabin Height	1.8 m
Cabin Area	11.9 m^2
Cabin Volume	19.8 m^2
Baggage Volume	3.96 m^2

Figure 2.6 Typical S-92 Sikorsky type helicopter [9]

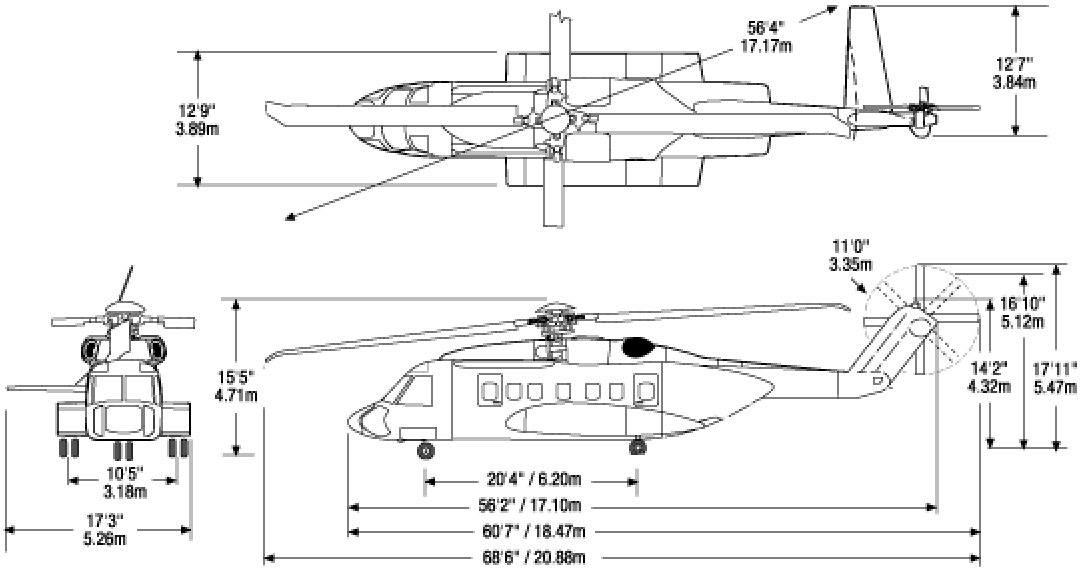

Figure 2.7 Main Dimensions of S-92 [9]

The weight of the helicopter is distributed between front wheel and rear wheels. The detail construction about the wheel is not available and it is assumed to have double wheel at each landing gear. The distribution of load on front and rear wheels is 37.72kN and 40.1 kN respectively (MT Poland design data).

The overall weight of the helicopter is distributed on front wheels as 32 percent and rear wheels 68 percent. The distribution of the loading is as follows:

- Maximum take-off mass = 12020 kg = 117.92 kN = 12.02 tonne,
- Load on front wheels = 37.72 kN = 3.84 tonne,
- Load on rear wheels = 40.1 kN = 4.09 tonne.

The illustration of load distribution and wheel spacing can be found in Figure 2.8.

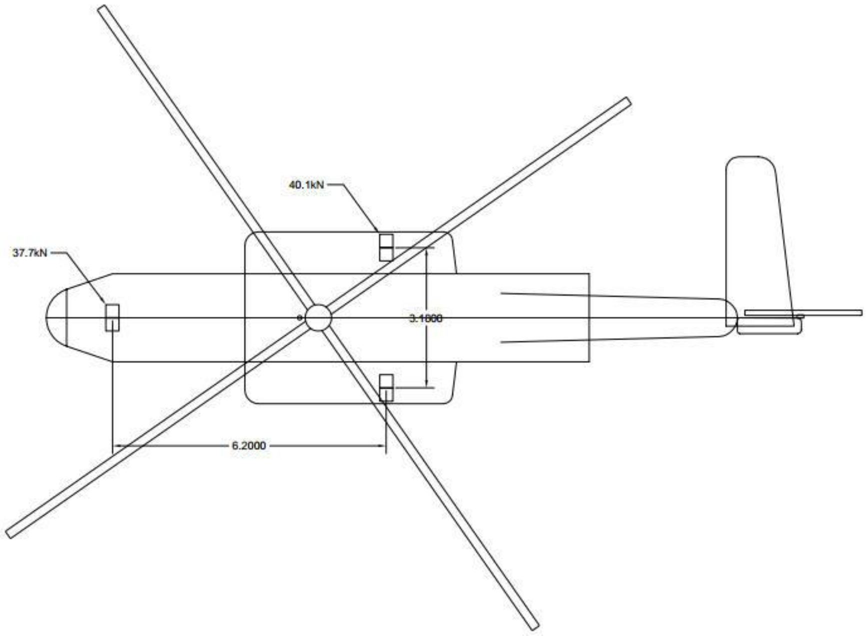

Figure 2.8 Description of load distribution and wheel spacing

2.3.3 Wheel Patch Load

There is no detail technical data available for consideration of wheel patch loading. In fact, for the modelling, the landing forces from the helicopter will be transmitted to plating as surface load. According to the requirement of Classification Society, the landing force will be at least two times the maximum take-off mass of helicopter [3]. Under this condition, a very large surface load will be acting on these surface patches.

In DNV's OS-E-401, there is no description about how to handle foot print area. There is similar kind of problem for wheel loaded vehicle and in this case DNV set out instructions to assume wheel footprint area. However, this should be seen as different case. The design thickness in these formulations is based on the tyre pressure and maximum axle load with the effect of vertical acceleration (heave motion). The wheel print obtained from these formulations is relatively small and it is not reasonable to apply big forces through this area.

Rules from Lloyds' Register [11], ABS [12] and Bureau Veritas [13] are also checked; and it is found that wheel patch area of 300mm x 300mm is recommended for unknown case. For Sirkosky S-92, there are two wheels under each landing gear. Therefore, tyre print area of 300mm x 600 mm will be applied for modeling in GeniE.

3 REVIEW OF APPLICABLE CODES AND STANDARDS

3.1 General

This section will make review of applicable codes and standards for offshore helicopter landing areas. Although the ship is to be classed under DNV Rules, it might be of great interest to see and compare other relevant rules. Classification societies have issued rules for helicopter landing area on ship. In addition to ship societies, relevant rules can be found in ISO standard and some regulations for aviation.

3.2 DNV Rules

DNV OS-E-401 gives requirements for offshore helicopter landing platforms. The design loads and load combinations need to comply with the requirements listed in DNV Rules for Classification of Ships Pt.6 Ch.1 Sec.2 B and these are to be combined with specific wind loads [3]. Inertia forces with a 100 year return period shall be applied [3].

The scantlings of structural elements shall be based on the most unfavourable of the following loading conditions:

- landing condition,
- stowed condition (helicopter lashed onboard at sea).

For landing conditions, there will be cases with normal landing and emergency landing. OS-E-401 does not mention about emergency landing case. But emergency landing case is listed in 2009th edition of OS-E-401 [14].

The following loads are to combine under landing conditions:

- landing impact forces,
- gravity and inertia forces of the structure with equipment,
- wind forces.

DNV Rule states that heel and trim do not normally need to be considered in landing condition [3]. So, only gravity forces of structure will be included in the analysis.

For the stowage condition, the following forces need to combine appropriately:

- gravity and inertia of the helicopter,
- gravity and inertia of the structure with equipment,
- hull bending loads (only applicable for integrated helicopter decks),

- sea pressure,
- ice loads on erected helicopter deck and supporting structure,
- green sea on pillars, supporting erected helicopter deck.

The detail of loads and load combinations will be explained in the next chapter. Regarding to safety features, the design must comply with SOLAS regulation and minimum shipboard safety requirements of CAP437 [3].

The strength requirements are based on operational condition and landing force. There is a Class formula for checking minimum thickness of plating and it depends on the landing forces. The stiffeners also need to have Class' recommended minimum section modulus. The scantlings of other structural elements are to be based on direct strength analysis with different allowable usage factors.

3.3 SOLAS and CAP437

Regulations concerning about helicopter landing structures can be found in Chapter II-2, Part G of 2008 Edition of SOLAS [4]. The main requirement that will have impact on structural design is the arrangement for emergency exit and locations for stowage of safety and fire fighting equipment.

There must be both a main and an emergency escape routes for a helicopter landing platform. These routes are intended for escape, rescue and fire fighting during an emergency condition and these should be located as far as possible [4]. In the proximity of helideck, there should be enough space to host fire fighting appliances. The items shown in Table 3.1are required as minimum.

CAP437 is the one of the most important documents for giving guidelines and rules for offshore helicopter landing areas. This standard covers the landing areas on fixed offshore installations, mobile offshore installations, vessels supporting offshore mineral exploitation or other vessels such as tankers, cargo vessels, and passenger vessels.

In DNV Rule, it is stated that the helideck must have minimum safety requirements from CAP437 [9]. Guidelines for structural design can also be found in CAP437 but for the current design, the strength requirements are defined according to DNV-OS-E401.

Extensive requirements about dimension, approach areas, marking, lighting, deck surface, rescue, fire fighting, communication and navigation can be found in CAP437.

Table 3.1 Minimum required safety and fire fighting equipment for helidck according to SOLAS [4]

No	**Item**	**No/Capacity**
1	dry powder extinguisher	2/total 45kg
2	carbon dioxide extinguishers	18 kg
3	foam fire fighting system	500 L/min for helicopter length between 15 to 24 m
4	Fire fighting nozzles and hoses	at least 2 with hoses long enough to reach every part of helideck
5	two set of fire fighter's outfits with following elements: • adjustable wrench, • fire resistant blanket • cutter, bolt 60 cm • hook, grab or salving • heavy duty hacksaw with 6 spare blades • ladder • lift line 5 mm diameter with 15 m in length • pliers • set of assorted screwdrivers • knife	

Sizing

The size of the landing platform varies depending on type of the largest helicopter intended to use. The size is normally judged by the term called "D-value." The size of the helideck should be large enough to have a circle of diameter equal to the D-value of the largest helicopter. In addition to this, the structure must be able to withstand the maximum weight of the helicopter. There may be slight difference between criteria for accepting the sizing. For example, the installations which need to classify under Norwegian Civil Aviation Authorities, need to have the size of 1.25 x *D* [15]. In helideck, it is mandatory to mark its D-value in metres and maximum weight in tons on the deck plating. Some examples of D-value, t-value of different helicopter types can be found in Table 3.2.

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Table 3.2 D-value and t-value of some helicopters [5]

Type	**D-value (metres)**	**Perimeter 'D' marking**	**Rotor diameter (metres)**	**Max weight (kg)**	**'t' value**	**Landing net size**
Bolkow Bo 105D	12	12	9.9	2400	2.4t	Not recommended
EC 135 T2+	12.2	12	10.2	2910	2.9t	Not recommended
Bolkow 117	13	13	11	3200	3.2t	Not recommended
Agusta A109	13.05	13	11	2600	2.6t	Small
Dauphin AS365 N2	13.68	14	11.93	4250	4.3t	Small
Dauphin AS365 N3	13.73	14	11.94	4300	4.3t	Small
EC 155B1	14.3	14	12.6	4850	4.9t	Medium
Sikorsky S76	16	16	13.4	5307	5.3t	Medium
Agusta/Westland AW 139	16.63	17	13.8	6800	6.8t	Medium
Bell 412	17.13	17	14.02	5397	5.4t	Not recommended
Bell212	17.46	17	14.63	5080	5.1t	Not recommended
Super Puma AS332L	18.7	19	15.6	8599	8.6t	Medium
Bell 214ST	18.95	19	15.85	7938	7.9t	Medium
Super Puma AS332L2	19.5	20	16.2	9300	9.3t	Medium
EC 225	19.5	20	16.2	11000	11.0t	Medium
Sikorsky S92A	**20.88**	**21**	**17.17**	**12020**	**12.0t**	**Large**
Sikorsky S61N	22.2	22	18.9	9298	9.3t	Large
EH101	22.8	23	18.6	14600	14.6t	Large

Approach Areas

Another area of concern is obstruction of objects near the landing area. These might not only have potential risks for clearance with helicopter operations but also creates problems with helicopter performance. There is a minimum requirement for space clearance near the landing area.

Within the D-circle of the landing area, there should be an obstacle free approach and take-off sector of at least 210 degree. Within the rest 150 degree space, certain objects with specific height are allowable and this area is called Limited Obstacle Sector (LOS). There is limitation of object heights located in limited obstacle sector depending on distance from the centre of the pad. Figure 3.2 shows the extent of measurement of LOS in octagonal landing pad. The segment for LOS is to be measured from circumference of D-circle. In the first segment of LOS located 0.62 D from hypothetical centre of D-circle, no object of height above 25 cm is allowed to exist. The second segment extends up to 0.83 D from the centre. The allowable height at the beginning of the sector is 0.05 D which increases with 1:2 slope to the end of the zone.

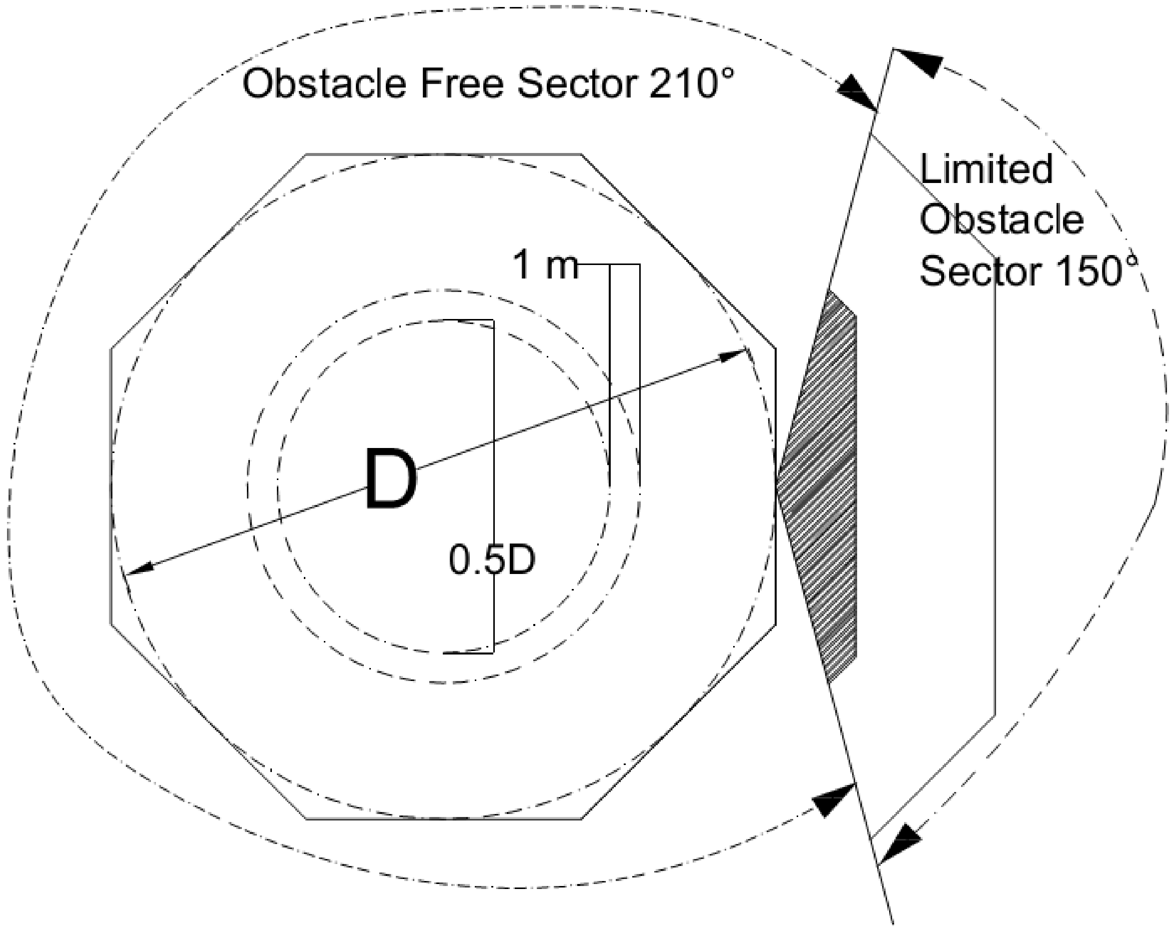


Figure 3.1 Description of OFS and LOS as per CAP 437 [5]

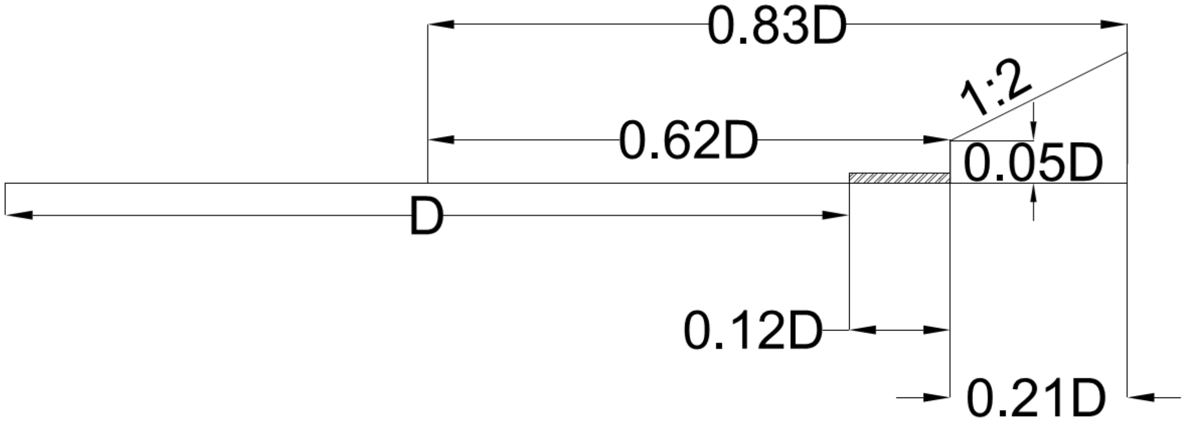


Figure 3.2 Description of Height Limitation in LOS [5]

OFS and LOS are applied to ensure clearance at landing area level. There is another criterion to consider in the case of helicopter loss of control due to power failure. These may happen during take-off and landing; and consequently the helicopter will fall from its operational elevation. If some facilities are located under helideck, the consequences are likely to be severe. Therefore, a clear zone has to be defined below the helicopter landing deck. The zone is to be at least 180 degrees wide, located within OFS, with a falling slope of 5:1. It can be assumed that the clearance sector for dropping objects below helicopter landing deck starts from the edge of the safety net due to practical reasons. The requirement of below deck level clearance is shown in Figure 3.3 and Figure 3.4.

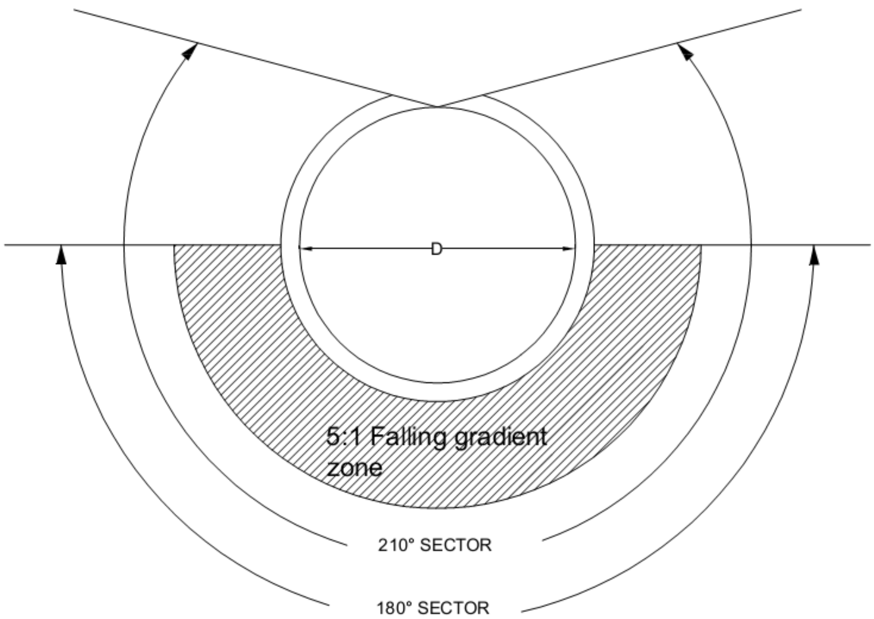


Figure 3.3 Plan view of Obstacle Free Areas below landing area level [5]

In certain helidecks, such as those located in the midship area, it is not possible to fulfil the obstacle free criteria below landing deck. In certain circumstances, when the ship approaches to offshore terminal or other ships by side, there would be infringement of this criterion. So the helicopter operation needs to be postponed under this condition.

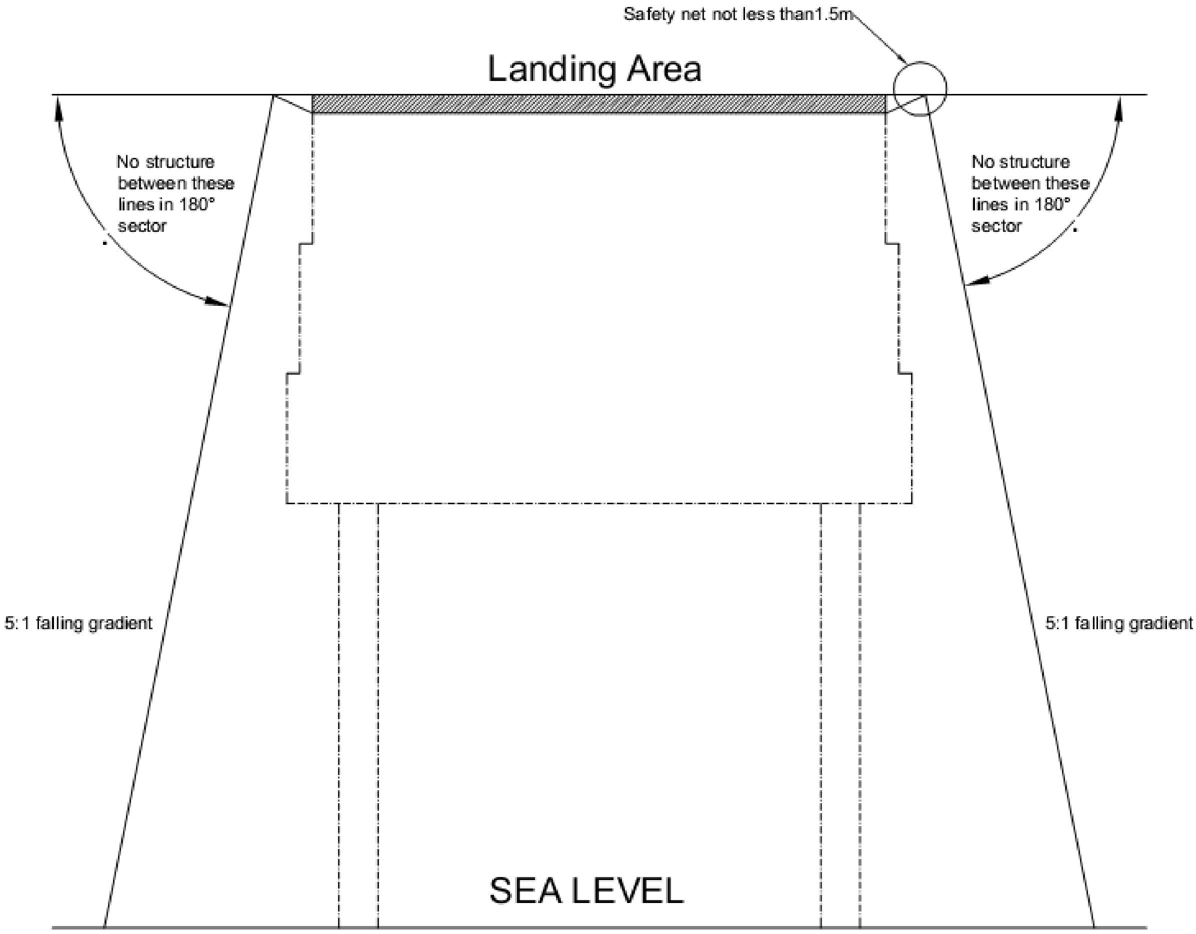


Figure 3.4 Profile view of Obstacle Free Areas below landing area level [5]

3.4 Summary of Different Regulations Related to Helicopter Landing Areas

Regulations from industry and Classification Societies have quite similar features for formulating loads and load combinations. It is difficult to judge which Class requirements are more conservative without proper case by case analysis. Societies formulated their regulations based on experience and research. These requirements should be seen as minimum barriers for safety. It might be interesting to compare some features from different Societies and it will assist in understanding more about main differences. PAFA Consulting Engineers made study about helideck structural requirements for Health and Safety Executive of UK in 2001 and similar kind of review can be found in that report [16].

An important area of interest is how landing loads are defined under different regulatory bodies. Normally, the landing load is based on the maximum certified take-off mass (MTOM) of the helicopter. The Societies apply at least safety factor of 1.5 to MTOM to define landing force. The safety factor will be 3 for emergency landing force in some cases.

Concerning to load cases, normally three conditions are separately considered. Conditions under landing, stowage and distributed loading are normally considered separately. But thickness of plating is normally formulated from landing load. It is quite common to use normal landing force as input for calculating thickness. For other structural elements, different load cases must be checked under stowage and landing conditions to identify most severe loading condition.

Under stowage condition, different loads are combined. Some Rules give more precise information. For example, DNV and GL Rules give detail wind profile velocity to consider while some only give general statement. Some Classification Societies ask for formulating different ship motion forces but some Rules only ask for vertical motion to include in load modelling.

Table 3.3 Comparison of Rules for landing condition

	ISO [17]	CAP [5]	ABS [12]	BV [13]	DNV [9]	GL [18]	LR [11]
			Pt.3Ch2 Sec11	Pt.3 Ch.2 Sec.11	OS-E-401	Ch1.Pt.6 Sec7 C	Pt.3Ch.9 Sec5
Landing	-	1.5M	1.5M	0.75M (through one group of wheel)	2M	1.5M	1.5M
Emergency Landing	-	2.5M	-	1.25M	-	2.5M	2.5M
Response factor	1.3	1.3	-	-	-	-	-
Area load [kNm^{-2}]	0.5	0.5	-	-	-	0.5	0.5
Horizontal action	0.5M	0.5M	-	-	-	0.5M	0.5M
Wind	yes	yes	yes	-	$30ms^{-1}$	$25\ ms^{-1}$	-

(M in the above table means maximum certified take-off mass of the designated helicopter)
All the ship Classification Societies treat landing force as static vertical load. This assumption makes analysis easier and less time consuming for practical purposes. ISO and CAP rules recommend in considering added response due to dynamic condition [5]. Structural response factor of 1.3 is recommended for analysis.

Table 3.4 Comparison of Rules for stowed condition

	ISO [17]	CAP [5]	ABS [12]	BV [13]	DNV [3]	GL [18]	LR [11]
Stowed	M	M	M	M	M	M	M
Area load [kNm^{-2}]	2	2	0.49	-	-	2	0.5
Tie down	yes	-	-	-	-	yes	-
Wind	yes	yes	-	-	$55ms^{-1}$	$50\ ms^{-1}$	-
Motion	storm condition, 10 yr return period	10 yr return period	yes	yes	yes	vertical only	vertical only

ABS [12] and Lloyds' Register [11] state that it is necessary to check for distributed loading of 2 kNm^{-2} on deck as separate load case.

3.5 Impact of Safety Requirements on Structural Design

In addition to analysis of load nature, safety requirements from Classification Societies, local and international authority have to be considered. The current design is considered under DNV Offshore Standard with type "HELDK-SH". According to DNV instructions, the design has to be complied with safety requirements of CAP 437 and SOLAS [3].
These safety requirements have influence in choosing the location and sizing of the structure.

Environmental Effects

The environmental effects have influence on choosing the location for the helideck. The location of the helideck is to have minimum requirement of clearance mentioned in CAP 437. These minimum requirements from CAP make sure the safety of helicopter operations. But to achieve optimal operational conditions, the effects from environment should also be considered. The general guidelines about environmental effects can be found in CAA Paper 2008/03 [19].

According to CAA paper, the effects can be classified as structural turbulence, thermal effects caused by exhaust emissions from generators and engines, hot and cold gas streams and vessel's motions [19]. In most cases, it is difficult to achieve perfect conditions according to guidelines. The design should always be a compromise between various factors to achieve optimal operational performance.

Structural Turbulence

The existence of tall and blunt structure nearby the landing area create turbulence field. This will have impact on helicopter performance and should be avoided. Another important aspect is to include an air gap between helideck and its supporting structure. The air gap creates better wind flow over helideck. For oil and gas production platforms, a research indicates that the gap should be between 3 and 5 metres [19]. But it might be difficult to include that range of air gap for offshore vessels.

Exhaust Emissions

Exhaust emissions from engines and turbine pose potential risks on helicopter operations. Exhaust gases are normally spread away on high points in the installations and stream of hot gases may exist invisibly in the proximity of landing area. Increased air temperature can cause less rotor lift and less engine power margin. Rapid air temperature increment can lead to engine surge and even compressor stall or flameout [19]. Therefore, it is important to arrange the exhaust stack to disperse these hot gases away from the helideck.

Vessel Motions

Severe ship's motions can cause helicopter operations difficult and risky. There should be certain operational limits for landing on a ship. Normally, heave acceleration is the most important one to consider [19]. These vessel motions vary along the length of the ship. Motions are more severe at bow and stern due to the combined effect of heave and pitch. Midship sections are likely to have relatively stable motions though it is sometimes difficult to define obstacle free sectors in these areas. So some vessels have platforms located in ship side as cantilevered structures. But the landing area suffers from the effect on roll in this kind of arrangement. In general, vessels have to install Helideck Motion System to monitor the helideck motion. Vessel's motions are to be within allowable range during landing operation.

The requirements may vary slightly according to respective authority. The operation limit of UK Helideck Certification Agency (HCA) can be found in Appendix A7.

4 ANALYSIS OF LOADS

4.1 General

The forces acting on the platform are analyzed and estimated according to DNV guidelines. There might be a lot of uncertainties about operating conditions in offshore. Sufficient level of safety is necessary under possible scenarios. The scantlings of the structural components have to be determined under most severe loading conditions.

On the other side, it is not always easy to predict the most severe loading case during initial phase of design. Therefore, possible worst loading scenarios have to be modelled and analyzed in the software.

According to DNV-OS-E401 [9] and DNV Rules Pt.6 Ch.1 Sec.2 B [3], the following loading conditions in general are considered:

- Landing condition,
- Stowed condition.

Different sources of loads are combined under these two conditions.

4.2 Landing forces

The total vertical force from the helicopter during landing shall be taken not less than [3]:

$$P_v = 2\ gM_H (kN) \tag{4.1}$$

where: P_v = total vertical force from helicopter; g = acceleration due to gravity; M_H = maximum take-off mass in tonnes of helicopter.

According to DNV guidelines, this total force, P_v is assumed to be distributed on helicopter's landing gear in the same manners as when the helicopter is resting on a horizontal surface and the helicopter's centre of gravity is in its normal position in relation to the landing gear. In fact, the landing impact force from helicopter is a dynamic load and it is necessary to use different analysis procedure. Due to time and modelling constraints, that kind of analysis is out the scope of this thesis. As per DNV guide, it can be treated as static vertical load in GeniE [3].

4.3 Inertia Forces

Inertia forces due to ship motions are calculated according to DNV Rules for classification of ships Part 3 Chapter 1 Section4. Inertia forces due to ship motions will be considered under stowed condition along with other environmental loads.

Surge, sway/yaw and heave accelerations can be calculated by DNV Rules [3].

Surge acceleration:

$$a_x = 0.2 g a_0 \sqrt{C_B}\ (ms^{-2}) \tag{4.2}$$

Combined sway/yaw acceleration:

$$a_y = 0.3\ g a_0\ (ms^{-2}) \tag{4.3}$$

Heave acceleration:

$$a_z = 0.7\ g \frac{a_0}{\sqrt{C_B}}\ (ms^{-2}) \tag{4.4}$$

Common acceleration parameter is given by:

$$a_0 = \frac{3C_w}{L} C_v C_{v1} \tag{4.5}$$

where: $C_v = \frac{\sqrt{L}}{50}, maximum\ 0.2; C_{v1} = \frac{v}{\sqrt{L}}, minimum\ 0.8;$

$C_w = 10.75 - [(300 - L)/100]^{3/2}$ for 100< L < 300.

Roll angle is given by:

$$\phi = \frac{50\ c}{B + 75}\ (rad) \tag{4.6}$$

where: c = (1.25-0.025 T_R) k; k = 1.2 for ships without bilge keel; B = breadth of ship.

Period of roll:

$$T_R = \frac{2\ k_r}{\sqrt{GM}}\ (s), \text{maximum } 30 \tag{4.7}$$

where: GM = metacentric height in metres; k_r = roll radius of gyration.

Tangential roll acceleration in general can be calculated as:

$$a_r = \phi (\frac{2\pi}{T_R})^2 R_R (ms^{-2}) \tag{4.8}$$

where: R_R = distance in metres from the centre of mass to the axis of rotation.

The pitch angle is estimated as:

$$\theta = \frac{0.25a_0}{C_B}\ (rad) \tag{4.9}$$

The period of pitch is taken as:

$$T_p = 1.8\sqrt{\frac{L}{g}}\ (s) \tag{4.10}$$

where: L = Rule length of the ship as per DNV definition.

Tangential pitch acceleration is given as:

$$a_p = \theta(\frac{2\pi}{T_p})^2 (ms^{-2}) \tag{4.11}$$

Combined vertical acceleration can be estimated as:

$$a_v = \frac{k_v g a_0}{C_B}\ (ms^{-2}) \tag{4.12}$$

where: k_v = variable between 0.7 and 1.5 for location between 0.6L from A.P and F.P.

Acceleration along the ship's transverse axis is given as the combined effect of sway/yaw and roll as:

$$a_t = \sqrt{a_y^2 + (gsin\phi + a_{ry})^2}\ (ms^{-2}) \tag{4.13}$$

In the same way, acceleration along the longitudinal axis can be given as the combined effect of surge and pitch as:

$$a_l = \sqrt{a_x^2 + (gsin\theta + a_{px})^2}\ (ms^{-2}) \tag{4.14}$$

a_{px} is the longitudinal component of pitch acceleration.

Then forces acting on supporting structures can be calculated using the above accelerations.

- vertical force alone acting can be estimated as:

$$P_v = (g + 0.5a_v)M(kN) \tag{4.15}$$

- vertical force in combination with transverse force:

$$P_{VC} = gM(kN) \tag{4.16}$$

- transverse force in combination with vertical force:

$$P_{TC} = 0.67a_tM(kN) \tag{4.17}$$

- vertical force in combination with longitudinal force:

$$P_{VC} = (g + 0.5a_v)M(kN) \quad (4.18)$$

- longitudinal force in combination with vertical force:

$$P_{LC} = 0.67a_l M(kN) \quad (4.19)$$

P_{TC} and P_{LC} may be regarded as not acting simultaneously.

M in these cases means the weight of the unit or structure considered. The calculation for acceleration experienced by helicopter landing structure due to ship motions can be found in Appendix A2.

Table 4.1 Possible inertia forces due to ship motions for load modelling

Forces Due to Ship Motions		**Equation**
vertical force alone P_v	14.611 M	**(4.15)**
vertical force in combination with transverse force, P_{VC}	9.81 M	**(4.16)**
transverse force in combination with vertical force, P_{TC}	3.8023M	**(4.17)**
vertical force in combination with longitudinal force, P_{VC}	14.611 M	**(4.18)**
longitudinal force in combination with vertical force, P_{LC}	4.338M	**(4.19)**

If forces due to ship motions in Table 4.1 are divided by acceleration due to gravity, acceleration factors are obtained as shown in Table 4.2.

Table 4.2 Acceleration factors due to ship motion forces

vertical acceleration only	1.49
vertical + transverse acceleration in combination	1
(transverse direction)	0.39
vertical + longitudinal acceleration in combination	1.49
(longitudinal direction)	0.44

The coefficients in table Table 4.2 will be used in GeniE to modify the acceleration field under stowed condition to simulate inertia forces resulted from ship motions.

4.4 Wind Load

According to DNV-OS-E4, wind loads on structural elements are to be combined with other loads mentioned in DNV Rules for Classification of Ships Pt.6 Ch.1 Sec.2B [9]. Wind load for structures is calculated according to DNV-RP-C205 [20]. Normal landing and stowed condition are considered. But wind forces acting on helicopter is neglected in this calculation. Form OS-E-401, wind load is to be calculated applying 'gust' wind (3 second averaging period). The recommended velocities from DNV are as follows:

$V_{1min,\,10}$ = 30 ms^{-1} for the landing condition,

$V_{1min,\,10}$ = 55 ms^{-1} for the stowed condition.

The wind for 3 second averaging time interval and height up to helicopter deck is to be predicted.

Mean wind speed *U* with averaging period at height *z* above sea level can be calculated as:

$$U(T,z) = U_{10}(1 + 0.137\, ln\frac{z}{H} - \; 0.047\, ln\frac{T}{T_{10}}) \tag{4.20}$$

where: U_{10} = 10 minute wind speed at height *H*.

The required wind profile for gust wind condition can be calculated using the reference velocities given for one minute period with 10 metre height.

The basic wind pressure can be calculated as:

$$q = \frac{1}{2}\rho_a\, U_{T,z}^2 \tag{4.21}$$

Wind loads from three directions have to be modelled separately and combined appropriately according to specific load case. Wind from aft, forward and starboard sides are modelled in GeniE. As the helicopter landing structure comprises of different small structural members, it is not as simple as predicting those of single structure. There are several members located in series both in longitudinal and transversal planes. Therefore, the effects of solidification and shielding have to be considered.

Solidification effect can be estimated as:

$$F_{W,SOL} = \; C_e\, qS\phi sin\alpha \tag{4.22}$$

where:C_e =the effective shape coefficient; *S*= projected area of the member normal to the direction of the force; α =anlge between the direction of the wind and the axis of the exposed member or surface; ϕ =solidity ratio.

For the structural members located behind those along wind direction, the effect from wind will be reduced. This force along with solidification effect can be estimated as:

$$F_{W,SHI} = F_{W,SOL}\,\eta \qquad (4.23)$$

where: η= shielding factor. The landing pad is a large area that is affected by wind. According to DNV practice, pressure coefficient of 2 is to be used at the leading edge of the deck, linearly reducing to zero at the trailing edge. The pressure may act both upward and downward. In the analysis, only downward pressure is considered as it will cause most severe loading condition on the structure.

The summary of load sums from wind loads are given inTable 4.3. During modeling in GeniE, it is assumed that wind from aft is taken directly as opposite from forward wind. This assumption might be conservative but it is not quite impossible to calculate the influence smoke funnel and navigation tower located aft to the helideck. Therefore, it is reasonable to assume that forward and aft winds as equal in magnitude and opposite in directions.

Table 4.3 Summary of wind loads

Landing condition			
	F_x [kN]	F_y [kN]	F_z [kN]
FWD Wind	-121.4	0	0
FWD Wind Pressure	0	0	-334.15
SB Wind	0	97.53	0
SB Wind Pressure	0	0	-334.15
Accidental stowed condition			
	F_x [kN]	F_y [kN]	F_z [kN]
FWD Wind	407.9	0	0
FWD Wind Pressure	0	0	-1122.74
SB Wind	0	327.7	0
SB Wind Pressure	0	0	-1122.74

The ratio of wind pressure between two conditions is: $q_{stowage}/q_{landing}$ = 2.816/0.837 = 3.36. Therefore, for stowed condition, the basic wind pressure modelled in landing case is multiplied by factor of 3.36 in GeniE.

4.5 Green Sea Load

The green sea pressure on supporting pillars of the helicopter landing structure is to be considered if it is located on the fore part of ship. The horizontal load caused by green sea can be predicted as:

$$p = 4.1 C_D a\,(1.79\, C_W - h_0)(kNm^{-2}) \tag{4.24}$$

where: C_D = drag coefficient; $a = 2+L/20$, maximum 4.5; L = length between perpendiculars; h_0 = vertical distance in m from the waterline at draught T to the load point; C_W = wave load coefficient.

The calculation for green sea load is shown in the Table 4.4.

Table 4.4 Calculation of green sea load on pillars

Parameters	**Value**
C_D	1 (circular section)
a	2.89
C_w	8.088
h_0	10.1 m
limiting height for green sea load (1.79 x C_w)	14.48 m
green sea affected height	4.56 m
green sea pressure	11.88 kNm^{-1} (assumes as line load)

Total green sea load on pillars is 104.07 kN acting in the X-direction.

4.6 Ice Load

Ice load on structure is considered under stowage condition. According to DNV's rule Pt.6 Ch.1 Sec.2, ice thickness of 5 cm is added for exposed area of structure [3]. This means added mass and inertia load for the structure. There is no automatic feature for modelling ice load in GeniE. Therefore, a virtual density depending on section type is calculated and defined in GeniE. The density of aluminium is 2.7 tonne.m^{-3} but with ice thickness of 5cm on its flanges and web, total density of W460X60 section becomes 11.58 tonne.m^{-3}. This virtual density can be calculated as follows:

actual mass of section = sectional area x 1m x density of material, mass of ice = ice sectional area x 1m x density of ice.

But in GeniE, the volume of section is assumed as ice volume and new density has to be considered. Therefore:

actual ice sectional area x density of ice = sectional area x new density.

So, the required virtual density is:

$$\rho_{virtual} = \frac{A_{ice} \times \rho_{ice}}{A_{section}} \tag{4.25}$$

.Virtual densities used for modeling in GeniE are shown in Appendix A3.

The effect of icing on stowed helicopter on the platform is neglected.

Total mass of ice for the whole structure is approximately 116.66 tonne.

4.7 Landing Positions

One difficulty with designing helicopter landing structure is uncertainty of landing position. Depending on weather and operation condition, the helicopter may approach the platform from ship’s sides or forward. The response of the structure will vary depending on landing location. Therefore, it is necessary to find out the specific location that will cause maximum loading condition on the structure.

In this thesis, 16 different landing positions are considered to figure out maximum response from the structure. There is no specific recommendation for landing position in DNV Rule. For the academic purpose, it is assumed that 16 positions considered here is sufficient. In this case one group of structural members might be at their maximum response while some are in normal condition.

Landing positions are considered in combination with appropriate wind directions. The abbreviation in landing positions mean A for Aft wind, S for Starboard wind and C for combined wind conditions or landing in oblique position relative to pad. Due to the symmetry of the structure, only starboard side wind condition is considered. Approach positions from outside of obstacle area are excluded. Landing positions with approach from bow and side are shown in Figure 4.1 and Figure 4.2 respectively. Landing in oblique positions are shown in Figure 4.3 under which combined wind conditions are exposed. Brief explanation about landing positions can be found inTable 4.5.

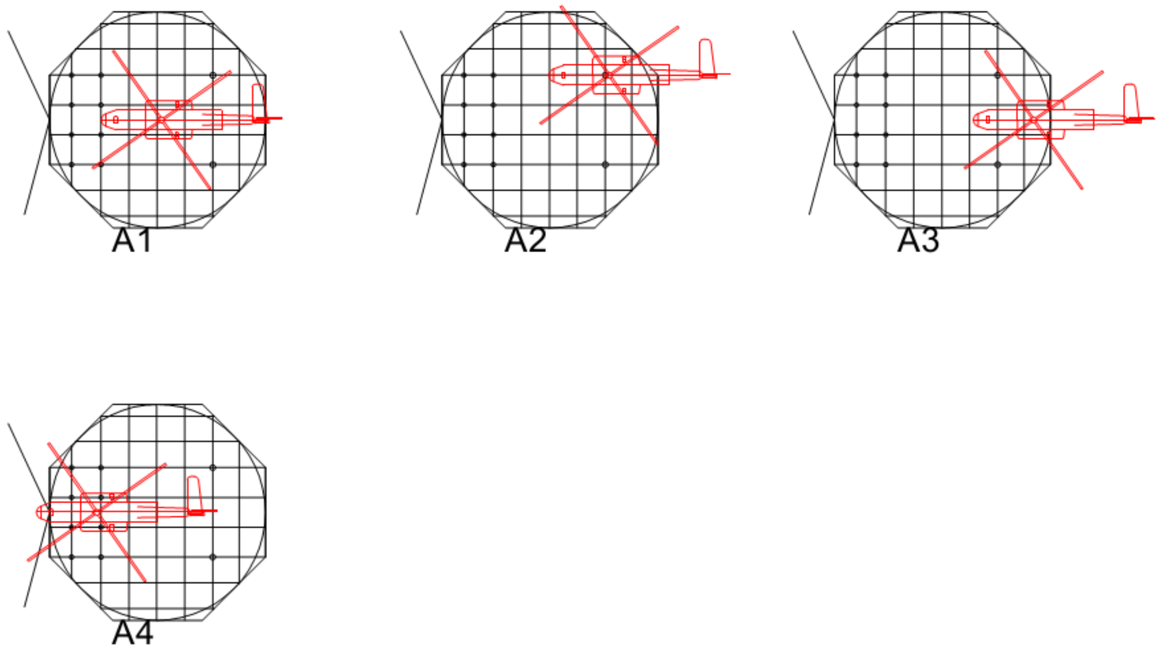


Figure 4.1 Landing positions with approach from bow

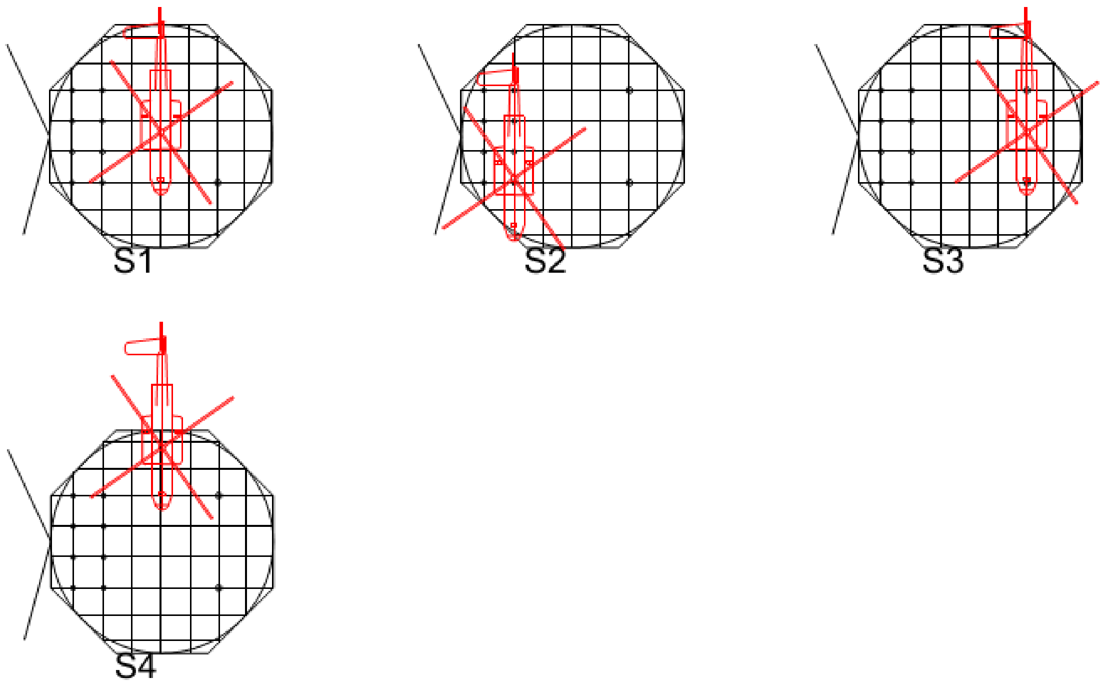


Figure 4.2 Landing positions with approach from side

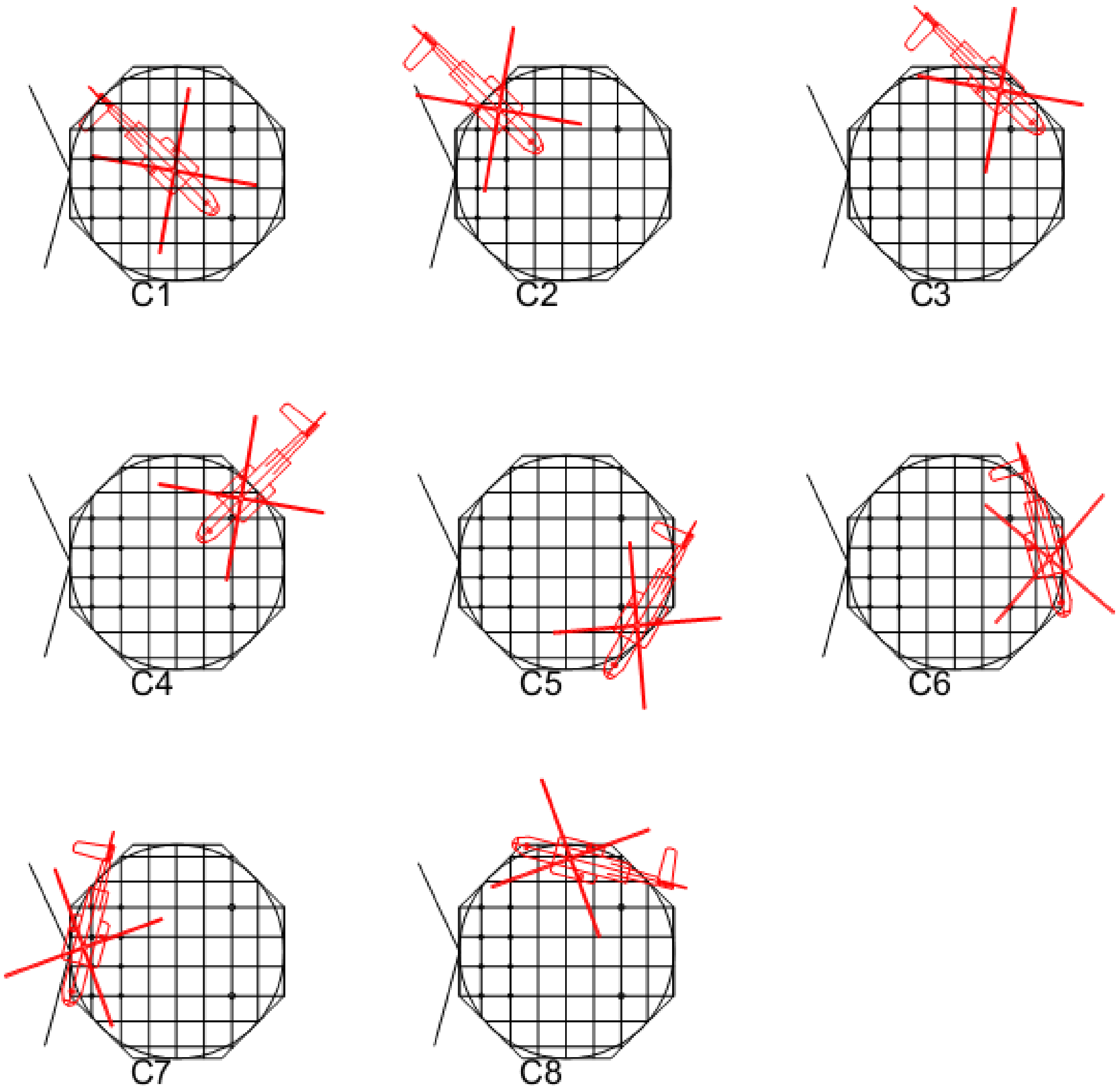


Figure 4.3 Landing in oblique position relative to pad

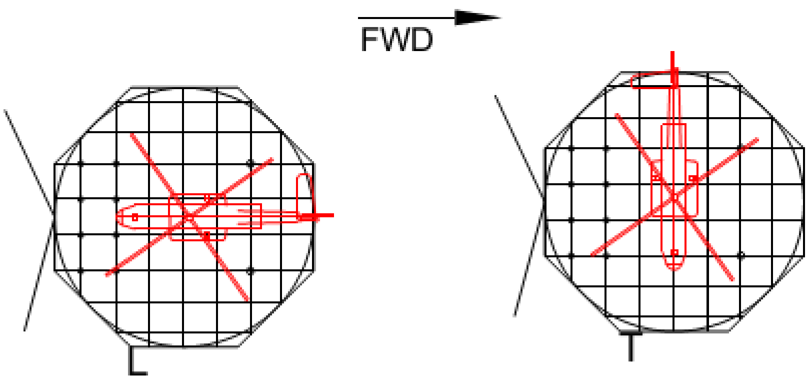


Figure 4.4 Helicopter orientations under stowed condition

Table 4.5 Description of landing positions illustrated in Figure 4.1, Figure 4.2 and Figure 4.3

Load Case	Description
A1	Helicopter in the centre of pad, landing longitudinally
A2	Helicopter over position above main pillar
A3	Helicopter in foremost location of the pad in longitudinal direction
A4	Helicopter in rearmost location of the pad
S1	Landing transversely in the centre of pad
S2	Helicopter over position above aft pillar
S3	Helicopter over position above transverse girder
S5	Helicopter on edge of the pad on side
	All the landing in case 'C' , helicopter land in oblique positions
C1	Helicopter in the centre
C2	Helicopter on the edge of port side
C3	Helicopter with only one set of rear wheels on the edge
C4	Helicopter on the edge of port side
C5	Helicopter with fwd and rear wheels acting on the edge
C6	Helicopter with fwd and rear wheels acting on the edge
C7	Helicopter on rearmost position of pad with front and rear wheels on edge
C8	Helicopter on edge of pad with front and rear wheels on edge

Some of the landing cases considered here might be hypothetical. It is very unlikely that the helicopter will land on the edge of the pad with two groups of wheels directly above the girders. It is to make sure that most severe condition will be included in the analysis.

For the stowed condition, only the helicopter resting longitudinally and transversely at the centre of the pad is considered as shown Figure 4.4. ‘L’ position means helicopter rests longitudinally along the centre line of pad and ‘T’ means that it rests transversally.

4.8 Load Combination

According to DNV's Rule, the strength of the structure has to be checked under combined condition of various loads. The strength has to be checked for landing condition and stowed condition.

For the landing condition, landing forces are combined with wind load and self-weight of the structure. In this initial design phase, the distribution of equipment is neglected. In other Class Rules, it is recommended to add extra deck pressure for equipment and moving personnel. DNV does not mention about this allowance.

For the stowed condition, it is assumed that helicopter would be parked under two positions along with different motion conditions. Parking loads, inertia forces, wind forces, ice loads and green sea load on pillars will be combined and checked as the most severe load combination.

In DNV-OS-E-401 2012th edition, the scantlings of girders and supporting structures are to be determined for operational conditions with usage factor of 0.67 for landing and 0.8 for stowage [9]. This 2012 edition of OS-E-401 contains quite short descriptions about Class requirements and it refers to DNV Rules for Classification of Ships Pt.6 Ch.1 for checking strength requirements. In DNV Rule, the landing forces are to be taken not less than that is given in Equation **(4.1)**.

Better explanation about different load combinations can be found in old version of OS-E-401. In Oct 2009 edition of OS-E-401, the scantling design is considered under operational and accidental conditions with allowable usage factor of 1 for the latter case [14].

According to OS-E-401 latest edition, it may not be necessary to check for accidental conditions. But DNV's expression about stowed condition is not so clear. So it might be better to model as accidental condition under which all possible loads will be acting simultaneously. In this case, the usage factor '1' can be applied for checking allowable stresses. In addition to this, it might be of interesting to see the response of structure under accidental case. Therefore accidental load cases are included in modelling.

Different load factors from various loads are combined as shown in Table 4.6, Table 4.7 and Table 4.8.

Table 4.6 Load factors for normal landing case

Normal Landing Case (Starts with 1)										
Load Case No	**101**	**102**	**103**	**104**	**105**	**106**	**107**	**108**	**109**	**110**
Self Weight	1	1	1	1	1	1	1	1	1	1
Wind AFT	1	1	1	1						
Wind FWD										
Wind SB					1	1	1	1	1	1
Position										
A1	2									
A2		2								
A3			2							
A4				2						
S1					2					
S2						2				
S3							2			
S4								2		
C1									2	
C2										2

Table 4.6 continued

Load Case No	**111**	**112**	**113**	**114**	**115**	**116**
Self Weight	1	1	1	1	1	1
Wind AFT				0.707	0.707	
Wind FWD	0.707	0.707	0.707			
Wind SB	0.707	0.707	0.707	0.707	0.707	1
Position						
C3	2					
C4		2				
C5			2			
C6				2		
C7					2	
C8						2

Table 4.7 Load factors for accidental landing case

Accidental Landing Case (Starts with 2)										
Load Case No	**201**	**202**	**203**	**204**	**205**	**206**	**207**	**208**	**209**	**210**
Self Weight	1	1	1	1	1	1	1	1	1	1
Wind AFT	1	1	1	1						
Wind FWD										
Wind SB					1	1	1	1	1	1
Position										
A1	3									
A2		3								
A3			3							
A4				3						
S1					3					
S2						3				
S3							3			
S4								3		
C1									3	
C2										3

Table 4.7 continued

Load Case No	**211**	**212**	**213**	**214**	**215**	**216**
Self Weight	1	1	1	1	1	1
Wind AFT				0.707	0.707	
Wind FWD	0.707	0.707	0.707			
Wind SB	0.707	0.707	0.707	0.707	0.707	1
Position						
C3	3					
C4		3				
C5			3			
C6				3		
C7					3	
C8						3

Table 4.8 Load factors for emergency stowed condition

Emergency Stowed Condition (starts with 3)										
AFT WIND										
Stowed position	L					T				
Load Case No	**301**	**302**	**303**	**304**	**305**	**306**	**307**	**308**	**309**	**310**
Structure Self Wt X-dirn		0.46	-0.46				0.46	-0.46		
Structure Self Wt Y-dirn				0.39	-0.39				0.39	-0.39
Structure Self Wt Z-dirn	1.49	1.49	1.49	1	1	1.49	1.49	1.49	1	1
Helicopter Wt X-dirn L			-0.46							
Helicopter Wt Y-dirn L				0.39	-0.39					
Helicopter Wt Z-dirn L	1.49	1.49	1.49	1	1					
Helicopter Wt X-dirn T							0.46	-0.46		
Helicopter Wt Y-dirn T									0.39	-0.39
Helicopter Wt Z-dirn T						1.49	1.49	1.49	1	1
Ice load X-drin		0.46	-0.46				0.46	-0.46		
Ice load Y-drin				0.39	-0.39				0.39	-0.39
Ice load Z-drin	1.49	1.49	1.49	1	1	1.49	1.49	1.49	1	1
Green sea load	1	1	1	1	1	1	1	1	1	1
Wind FWD										
Wind AFT	3.36	3.36	3.36	3.36	3.36	3.36	3.36	3.36	3.36	3.36
Wind SB										

Table 4.8 continued

FWD WIND										
Stowed position	L					T				
Load Case No	**311**	**312**	**313**	**314**	**315**	**316**	**317**	**318**	**319**	**320**
Structure Self Wt X-dirn		0.46	-0.46				0.46	-0.46		
Structure Self Wt Y-dirn				0.39	-0.39				0.39	-0.39
Structure Self Wt Z-dirn	1.49	1.49	1.49	1	1	1.49	1.49	1.49	1	1
Helicopter Wt X-dirn L			-0.46							
Helicopter Wt Y-dirn L				0.39	-0.39					
Helicopter Wt Z-dirn L	1.49	1.49	1.49	1	1					
Helicopter Wt X-dirn T							0.46	-0.46		
Helicopter Wt Y-dirn T									0.39	-0.39
Helicopter Wt Z-dirn T						1.49	1.49	1.49	1	1
Ice load X-drin		0.46	-0.46				0.46	-0.46		
Ice load Y-drin				0.39	-0.39				0.39	-0.39
Ice load Z-drin	1.49	1.49	1.49	1	1	1.49	1.49	1.49	1	1
Green sea load	1	1	1	1	1	1	1	1	1	1
Wind FWD	3.36	3.36	3.36	3.36	3.36	3.36	3.36	3.36	3.36	3.36
Wind AFT										
Wind SB										

Table 4.8 continued

SB WIND										
Stowed position	L					T				
Load Case No	**321**	**322**	**323**	**324**	**325**	**326**	**327**	**328**	**329**	**330**
Structure Self Wt X-dirn		0.46	-0.46				0.46	-0.46		
Structure Self Wt Y-dirn				0.39	-0.39				0.39	-0.39
Structure Self Wt Z-dirn	1.49	1.49	1.49	1	1	1.49	1.49	1.49	1	1
Helicopter Wt X-dirn L			-0.46							
Helicopter Wt Y-dirn L				0.39	-0.39					
Helicopter Wt Z-dirn L	1.49	1.49	1.49	1	1					
Helicopter Wt X-dirnT							0.46	-0.46		
Helicopter Wt Y-dirn T									0.39	-0.39
Helicopter Wt Z-dirnT						1.49	1.49	1.49	1	1
Ice load X-drin		0.46	-0.46				0.46	-0.46		
Ice load Y-drin				0.39	-0.39				0.39	-0.39
Ice load Z-drin	1.49	1.49	1.49	1	1	1.49	1.49	1.49	1	1
Green sea load	1	1	1	1	1	1	1	1	1	1
Wind FWD										
Wind AFT										
Wind SB	3.36	3.36	3.36	3.36	3.36	3.36	3.36	3.36	3.36	3.36

For modelling in GeniE, individual loads are created separately. For example, in A1 case, original weight of helicopter is modelled as surface load over the plate. Then for the landing case, new load combinations can be made with respective wind loads. In landing case, according to Equation **(4.1)**, load factor 2 is applied.

Different individual loads need to combine together under accidental stowed condition. For instance, in load case 421, the weight factor of structure and helicopter will be 1.49 due to heave motions which are combined with ice load, green sea and wind from starboard. For the stowed condition, the wind load will be 3.36 times that of landing condition and this is explained in sub-section 4.4.

5 STRUCTURAL DESIGN AND SCANTLING CHECK

5.1 The Basis of Structural Design Concept

The ship is a family of subsea construction and drilling vessel designed by Marin Teknikk. It is occupied by various drilling and construction equipment on aft part of the ship. Therefore, the appropriate location for helicopter deck is above the wheel house structure. It will be designed as a separate platform above the wheel house.

But the location is still awkward and there are some constraints on the design. For overall strength consideration of ship, the main support points for helideck structure are chosen directly above the ship's frames.

In this case, the helicopter landing structure may be seen as a separate deck in a raised location without rigid supports from ship. It must foresee the nature of various loads. Another problem is the uncertainty about landing positions. During normal operation, the helicopter might be able to land on landing circle of the platform. But during emergency cases, it is expected to land on some locations outside of the circle. At that time, the moment acting on the structure might be bigger. So, it is also important to think about the adequacy of strength at edges of the structure.

The structure will be designed in two parts. The first one will be the deck plate with its supporting structures underneath. The second part will be strong girders with supporting pillars from the ship. The deck plates and stiffeners will be designed using aluminium alloy. For the lower support structures, high strength steel will be used.

The landing forces and inertia loads from the structure have to be transmitted to the structure of the ship. The landing pad is, in fact, a large area subjected to various loading conditions. It cannot be surely said that only the centre of the pad will be used for landing. It is necessary to consider all possible locations of landing under severe weather or emergency conditions. Therefore, 16 landing positions are included in the analysis.

The maximum transverse space available above the wheel house is shown by dotted lines in Figure 5.1. The maximum length available is at frame 150 with 11.46 m. At frame 151 and 152, the transverse width is 10.485 m and 8.117 m respectively. At frame 150, as it is very close to deck structure, it is not possible to arrange pillar in the centre. For frame 152, there is not enough space and the aft pillars then should be located on frame 151.

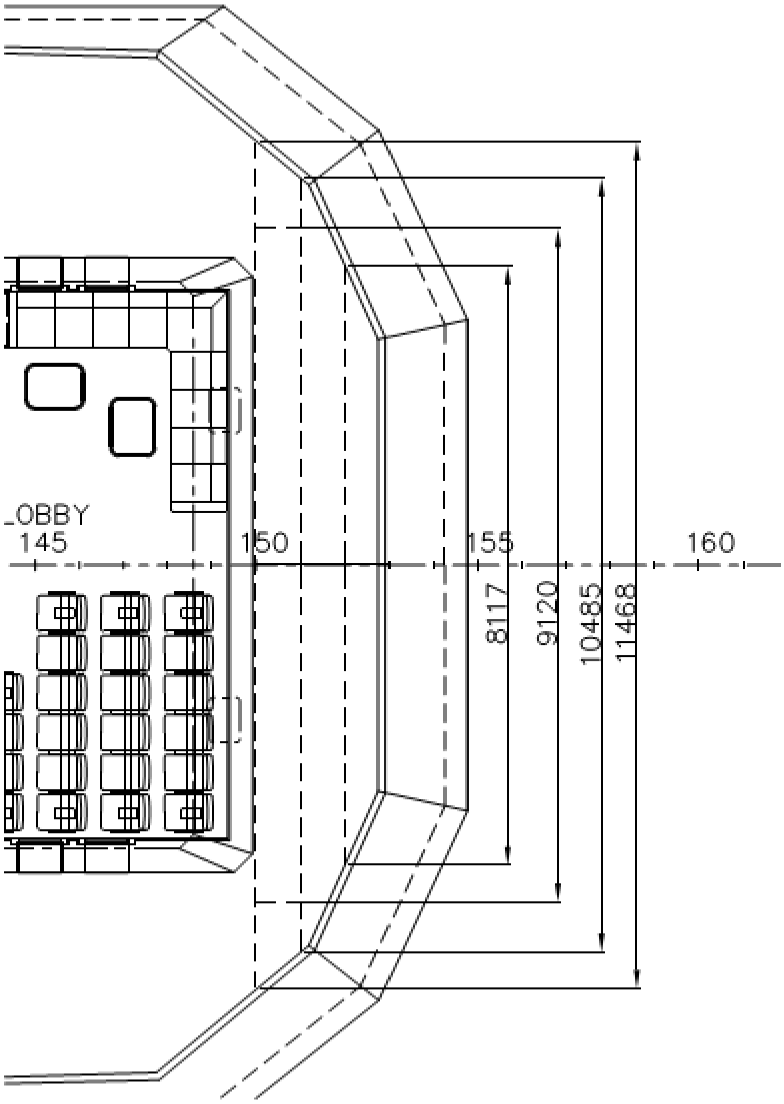


Figure 5.1 Availability of space above the wheel house deck for helideck

Depending on the available space, it is decided to locate the main support pillars evenly spaced over the entire dimension of the pad. And the locations must be above the ship's frame. As shown in Figure 5.2, the first row of pillars will be located at frame 146 with the support point above sky lobby and on the bridge deck; the second row will be at frame 151 on top of the wheel house and the main pillars at frame 170 on the boat deck.

Like in ordinary ship structures, the deck plate is continuously supported by series of stiffeners which in turn are attached to big girders.

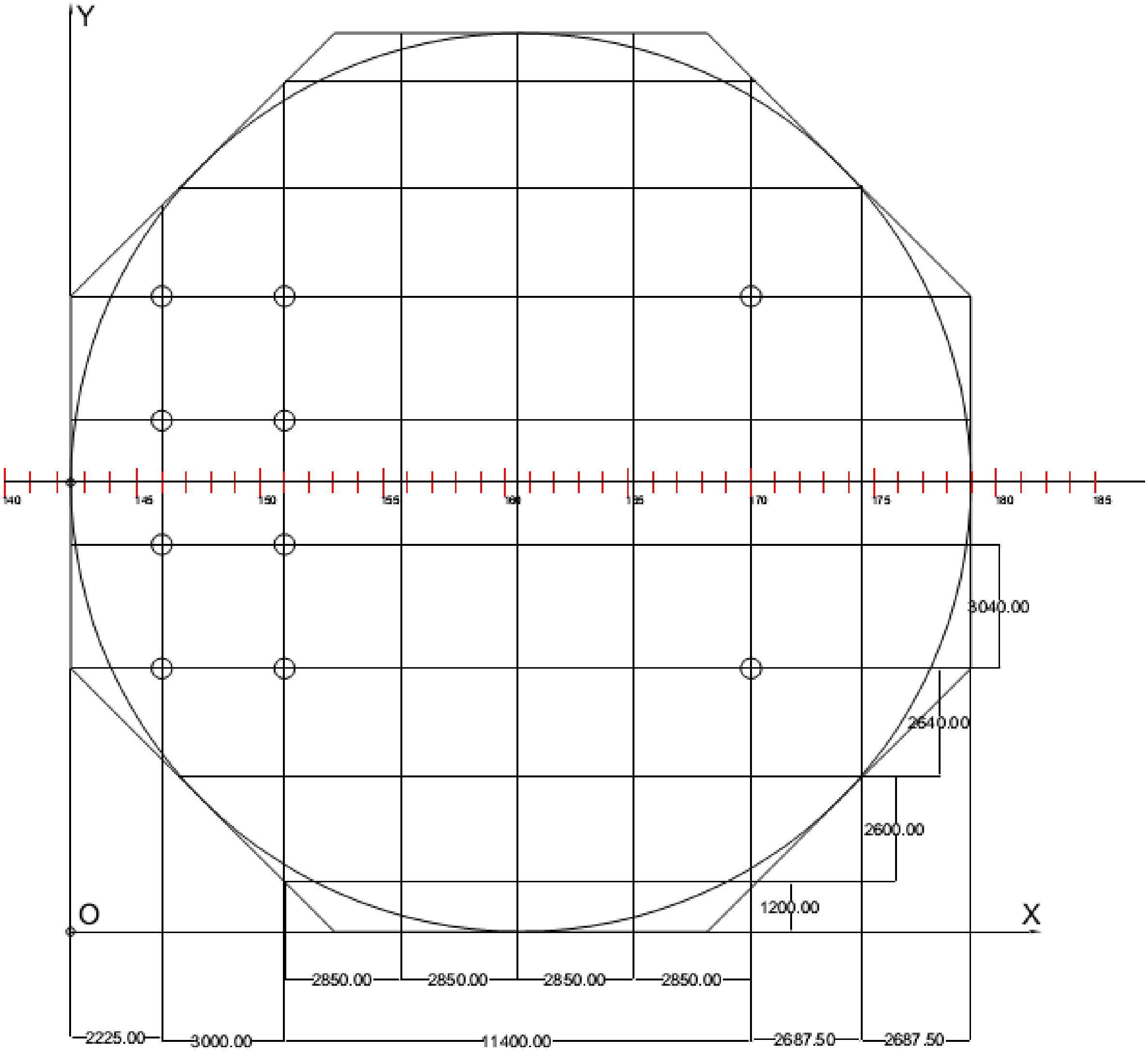


Figure 5.2 Location of support points and spacing of girders under plate of landing platform

The helideck can be imagined as a big stiffened panel subjected to large loadings and inertia forces. Functionally, it can be considered as a plate with support girders and stiffeners underneath. The overall second moment of inertia of the structure can be considerably improved by adding another layer of supporting structure below the primary layer. The concept is shown in the Figure 5.3. Another advantage of putting two layers is that there creates gap for air flow. This would be beneficial for wind flow over helideck and turbulence can be reduced [19].

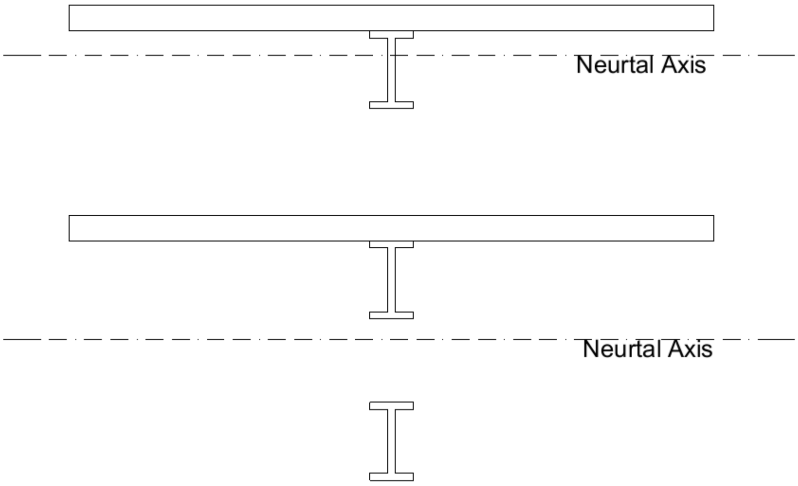


Figure 5.3 Concept of two beam layers

Normally, the arrangement of the structural elements for pancake structure has to consider carefully as the allowable stress for aluminium parts is relatively lower. On the other hand, the supporting steel structures below also need to have sufficient strengths and rigidity. During the early phases of design, there were certain problems in aluminium members while the author was trying to reduce the scantling of the all members. Although, the scantling of steel members can be further reduced, it is necessary to maintain at certain level to ensure the rigidity of the structure.

5.2 Nomenclature for Structural Components

The naming of bracings and short columns will be based on Figure 5.4. The abbreviations used for the each type of structural elements can be found in Table 5.1.

For transversely or longitudinally spanned members, the numbering is very simple. The numbering will be increased from aft to forward and starboard to port. So UTG1 will be located on extreme of starboard side and ULG1 will be on extreme of aft side on the structure.

For short columns, the name can be given by the coordinate system as shown in Figure 5.4. It will start with S and SC1 means short column located at coordinate (C, 1). For the bracing it will start with B and BC12 means bracing located in C, spanning transversely between 1 and 2.

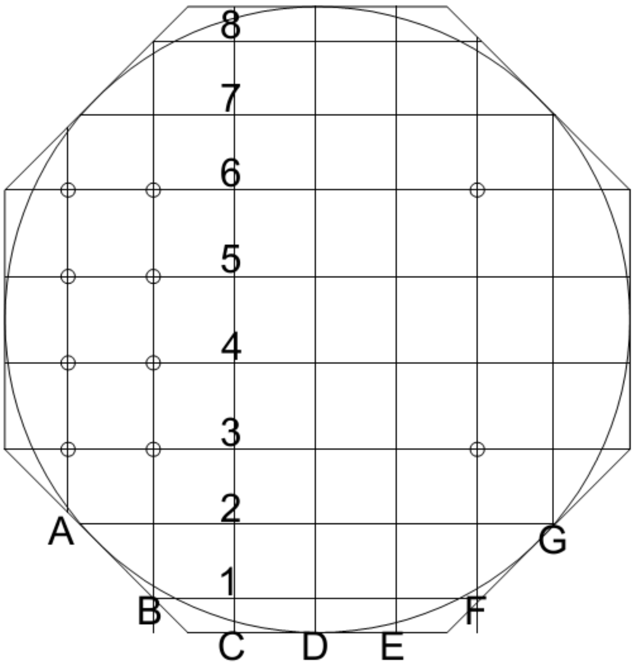


Figure 5.4 Reference coordinate for naming of structural elements

Table 5.1 Abbreviations for structural members

Symbol	**Meaning**
ST	Stiffeners
UTG	Upper transverse girder
ULG	Upper longitudinal girder
SP	Short columns connected between upper and lower structures
B	Bracing
P	Main pillar
LTG	Lower transverse girder
LLG	Lower longitudinal girder
RP	Support pillars in the middle of structures

5.3 Plates and Stiffeners

Based on the requirements of Rule, initial scantlings of the structure can be developed. The minimum thickness of the deck plating can be checked according to the DNV Rules for classification of ships Pt.6 Ch.1 Sec.2 C.

The thickness of aluminium plating shall not be less than:

$$t = \frac{k\,(1+s)\sqrt{P_w}}{\sqrt{f_1}} + 1\ (mm) \tag{5.1}$$

where: t = minimum thickness of plating; s = beam spacing (m); P_w = fraction of landing force P_v acting on the wheel[s] considered (kN); f_1= material factor ($f_1 = \frac{\sigma_f}{235}$); k = 0.6 in separate platforms.

For the calculation, loads will be taken as follows:

- Load on one group of rear wheel = 40.1 kN
- With the landing factor of 2, P_w = 80.2 kN

This assumption complies with requirement for minimum landing force given in Equation **(4.1)**. The calculation can be found in Appendix A4.

The minimum plating thickness is 12.05 mm. But for modelling in GeniE, the thickness is only taken as 12 mm. In this calculation, yield stress of the plate is taken as 125 MPa for the effect of HAZ from welding. So the whole deck plate is considered as HAZ area and this in fact is a conservative approach.

The minimum section modulus of the stiffeners is to be:

$$Z = 1000\,\frac{M}{\sigma}\ (cm^3) \tag{5.2}$$

where: M = bending moment (kNm) from the most unfavourable location of landing forces point loads. In most cases half fixed beam ends will be a reasonable assumption and $\sigma = 180\, f_1$ $\mathrm{Nmm^{-2}}$ in general. f_1 is the material factor as defined in subsection 5.5.

For the initial phase, it is difficult to predict most unfavourable bending moment. In 2009 version of OS-E-401, there is an empirical formula to check for this and it is more convenient compared to Equation **(5.2)**. The required section modulus is:

$$Z = \frac{1.34.\,10^6 k_z labp}{m\sigma_f}\,(mm^3) \tag{5.3}$$

where: k_z = 1.0 for $b/s \leq 0.6$ = (1.15 – 0.025b/s) for 0.6 <b/s < 1.0;

$m = \frac{r}{(\frac{a}{l})^2 - 4.7\frac{a}{l} + 6.5}$ = factor depending on the rigidity of girders supporting continuous stiffeners.

Support stiffeners to girders shall have a minimum shear area of:

$$A_s = 0.125\, p\, f \tag{5.4}$$

where: p = design pressure under wheel loading $= \frac{f\ P_v}{A}$ (kNm^{-2}); s = beam spacing in m; l = beam length in m; a = extent in m of the load area parallel to the stiffeners; f = fraction of load; b = extent in m of the load area perpendicular to the stiffeners; σ_f = minimum yield stress of the material.

The minimum section modulus of stiffer is 431.93 cm^3.

The shear area of stiffeners to girder should have 21.42 cm^2.

Checking of Plate Thickness by alternative Rule

The required plate thickness is also checked by Lloyds' Register Rule. The corresponding section for helicopter landing platform [11] can be found in Pt.3 Ch.9 Section 5. The purpose is to check whether the plating thickness required by DNV Rule is reasonable according to another Rule.

The thickness of aluminium plating is not to be less than:

$$t = 1.4t_1 + 1.5\ mm \tag{5.5}$$

where: $t_1 = \frac{\alpha s}{1000\sqrt{k}} mm$; α = thickness coefficient;

β = tyre print coefficient $\log_{10}(\frac{P_1 k^2}{s^2} \times 10^7)$.

Plating is to be designed for emergency landing case taking:

$$P_1 = 2.5\phi_1\phi_2\phi_3 f\gamma P_w(tonnes) \tag{5.6}$$

where: ϕ_1 = patch aspect ratio correction factor; ϕ_2 = panel aspect ratio correction factor;

ϕ_3= wide patch load factor; f = 1.15 for landing decks above manned spaces or 1.0 elsewhere;

P_h = the maximum all-up weight of the helicopter in tonnes; P_w = landing load, on the tyre print in tonnes; Υ = load factor (in this case 0.6).

The calculation of thickness is shown in Appendix A4.

The required plate thickness according to Lloyds' Register Rule is 11.83 mm.

So it can be seen that the difference between DNV and Lloyds' Rule is negligibly small.

5.4 Girders and Supporting Structures

The scantlings of girders and supporting structures are to be based on direct stress analysis. The basic allowable usage factor η_0 for operational conditions is:

Landing conditions: $\eta_0 = 0.67$

Stowed conditions: $\eta_0 = 0.8$

In 2009th version of OS-E-401, usage factor for accidental conditions can be found and thus:

Accidental conditions: $\eta_0 = 1.0$

According to DNV-OS-C201, the maximum permissible usage factor η_p can be obtained as:

$$\eta_p = \eta_0 \beta \quad (5.7)$$

Then maximum permissible stress can be calculated as:

$$\sigma_p = \eta_p \sigma_f \quad (5.8)$$

β is a coefficient depending on type of structure, failure mode and reduced slenderness. For the case of yield check, β can be taken as 1 [21].

5.5 Materials

Aluminium alloys will be used for the deck plates and upper structural members. For the upper longitudinal girders and the rest of the structure will be constructed with steel. General properties of material used for helideck construction can be found in Table 5.2.

Table 5.2 Properties of materials used in design [3]

Item	Grade	Yield Strength $R_{p0.2}$ / R_{eH} (MPa)	Tensile Strength R_m (MPa)
Deck Plate	NV 5083-H116	215	305
Stiffeners & Girders	NV 6082-T6, $t \leq 5$	250	290
	$5 < t \leq 50$	260	310
Lower structure	NV D36, (Steel)	355	440

As the helideck is located at high elevation on the ship, it is important to design the structure as light as possible. NV5083-H116 is used for deck plates as it is a commonly used grade for rolled products with relatively high strength. For structural shapes such as stiffeners and girders, NV6082-T6 will be used. This is also a popular extruded product for structural sections with high strength. High strength steel is also used for the rest of structural beams to achieve high strength and light weight.

There is an important issue while applying aluminium alloy as structural elements in the design. This is due to a fact that aluminium alloy shows different structural properties when it is welded. In fact this is a crucial fact to consider since the beginning of initial design phase. Different types of aluminium alloys show different amounts of reduction in strength in the welded region. This region is called heat affected zone (HAZ) and in some cases reduction up to 50 percent of original yield strength may happen. 6xxx series alloys have greater impact on strength reduction than that of 5xxx series [2].

In this thesis, deck plates, stiffeners and upper transverse girders are connected by welding. Welded aluminium strength properties will be used for these structures. In fact, this is a conservative approach. On the other hand, during the initial design stage it is difficult to decide and locate the welded spots.

For deck plates using 5083 alloy, temper 0 condition will be used while for 6082 alloy, properties under T4 state will be used. It is stated in Pt.3 Ch.1 Sec.2 of DNV Rules for classification of Ships that the most unfavourable properties due to welding correspond to T4 condition [3]. Strength of welded aluminium alloys used in this thesis is shown in Table 5.3.

Table 5.3 Welded aluminium alloy properties [3]

Item	Grade	Yield Strength $R_{p0.2}$ (MPa)	Tensile Strength R_m (MPa)
Deck Plates	NV 5083-0	125	275
Stiffeners & Girders	NV 6082-T4	110	205

The material factor f_1, is widely used in Rule formulas and it is defined as follows for aluminium alloy:

$$f_1 = \frac{\sigma_f}{235}$$

As the connections between aluminium members are assumed to be made by welding, the welded aluminium alloy properties in Table 5.3 will be used for calculating Class formulas.

For plates: f_1= 0.53

For stiffeners and girders: f_1 = 0.46

5.6 Permissible Stresses

After the analysis in GeniE, the induced stresses of structural members have to be checked whether those are within allowable limit or not. The basic usage factor and maximum permissible factor are explained in Section 5.4. In this section permissible stresses under various loading conditions will be calculated as per DNV Rules. The HAZ effect of welded aluminium is considered here. The summary of permissible stresses can be found in Table 5.4.

Table 5.4 Permissible stresses of different materials used in the design

	Material	η_0	η_p	σ_p **(MPa)**
Landing	NV 5083-0	0.67	0.67	83.33
	NV 6082-T4	0.67	0.67	73.33
	NV D36	0.67	0.67	236.67
Stowed	NV 5083-0	0.8	0.8	100
	NV 6082-T4	0.8	0.8	88
	NV D36	0.8	0.8	284
Accidental Landing/Stowed	NV 5083-0	1.0	1.0	125
	NV 6082-T4	1.0	1.0	110
	NV D36	1.0	1.0	355

5.7 Sectional Properties of Structural Components

Sectional properties of the components used in the design are shown in Table 5.5.

For the structural beam section, it should be read as follows:

T455_153_8.5_13 = Section type $\mathbf{d\_b_f\_t_w\_t_f}$.

The symbol for reading the dimensions can be found in Figure 5.5.

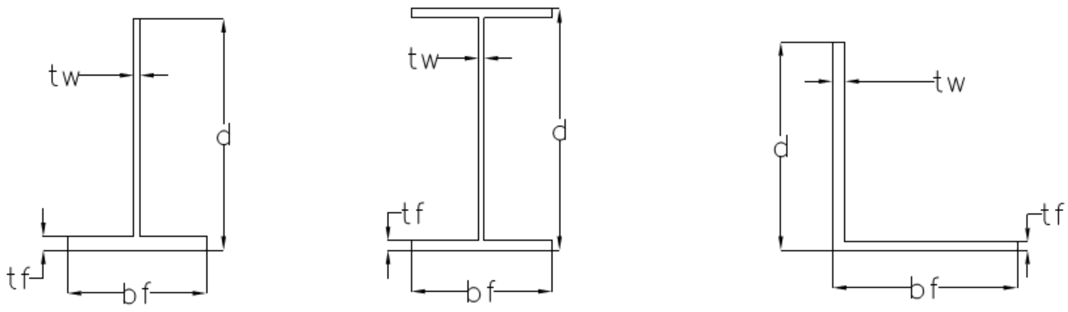


Figure 5.5 Symbols for beam section dimensions

For the circular sections, British Standard circular hollow sections are used and they should be read as follows:

CHS_219_1x5 = external diameter x thickness. Sectional properties of circular beams can be found in Table 5.6.

Table 5.5 Sectional property of beams

Item	**ID**	**Type/Material**	**Symbol**	**Sectional Area (cm^2)**
ST	ST 1 to ST43	L section/ Aluminium NV-6082-T6	L203_178_7_12.8	36.994
UTG	UTG 1, UTG 2, UTG 3, UTG 4, UTG 5, UTG 6, UTG 7, UTG 8, UTG 9, UTG 11, UTG 12, UTG 13, UTG 15,	T section/ Aluminium NV-6082-T6	T455_200_8.5_13.3	65.275
	UTG 10, UTG 14		T455_200_10_13.3	72.1
EB	EB1 to EB8	I section/ Aluminium NV-6082-T6	I353_128_6.5_10.7 (W360 x 39)	49.076
ULG	ULG1, ULG2, LG4, ULG5,ULG7, ULG8,	I section/ Steel NV D36	I455_153_8_13.3 (W460 x 60)	74.97
	ULG3, ULG6,		I450_152_7.6_10.8 (W460 x 52)	65.39

Table 5.5 continued

Item	**ID**	**Type/Material**	**Symbol**	**Sectional Area (cm^2)**
LTG	LTG2, LTG3, LTG4, LTG5, LTG6,	I section/ Steel NV D36	I353_128_6.5_10.7 (W360 x 39)	49.076
	LTG1		I347_203_7.7_13.5 (W360 x 64)	79.45
LLG	LLG1 to LLG8	I section/ Steel NV D36	I353_128_6.5_10.7 (W360 x 39)	49.076

Table 5.6 Sectional property of circular beams

Item	**ID**	**Type/ Material**	**Symbol**	**Sectional Area (cm^2)**
SP	SB3, SB4, SB5, SB6, SC1, SC2,SC4, SC7, SC8 SD1,SD2,SD4, SD5,SD7, SD8 SE1,SE2,SE4, SE5,SE7, SE8 SF1,SF2,SF4, SF5,SF7, SF8 SG2, SG3, SG4, SG5, SG6,SG7	Hollow circular section/ Steel NV D36	CHS_219_1x5	33.644
	SC3, SC6, SD3, SD6 SE3, SE6		CHS_219_1x10	65.72
	SF3, SF6		CHS_219_1X12_5	81.16

Table 5.6 continued

Item	ID	Type/ Material	Symbol	Sectional Area (cm^2)
MB	BB34, BB56, BF34, BF56, BD12, BF12, BD78, BF78, BD23, BF23, BD67,BF67, BBC4,BBC5, BCD1,BDE1,BEF1, BCD2,BDE2,BEF2,BFG2, BCD4,BDE4,BEF4,BFG4, BCD5,BDE5,BEF5,BFG5, BCD7,BDE7,BEF7,BFG7, BCD8,BDE8,BEF8, BBC1, BBC2, BBC7, BBC8	Hollow circular section/ Steel NV D36	CHS_219_1x5	33.644
	BCD3,BDE3,BEF3,BFG3 BCD6,BDE6,BEF6,BFG6 BG3, BG4, BG5, BG6 BBC3, BBC6		CHS_219_1x10	65.72
MP	AP1, AP4	Hollow circular section/ Steel NV D36	CHS_323_9x25	234.85
	P1, P2, AP2,AP3		CHS_323_9x20	191.02
	AP5,AP8,RP1,RP2		CHS_244_5x12_5	91.14
	AP6,AP7, PS1, PS2, PS3, PS4,PS5		CHS_219_1x5	33.644

5.8 Structural Model

The structure is modelled in GeniE software of DNV. The concept models developed in GeniE are shown in Figure 5.6.

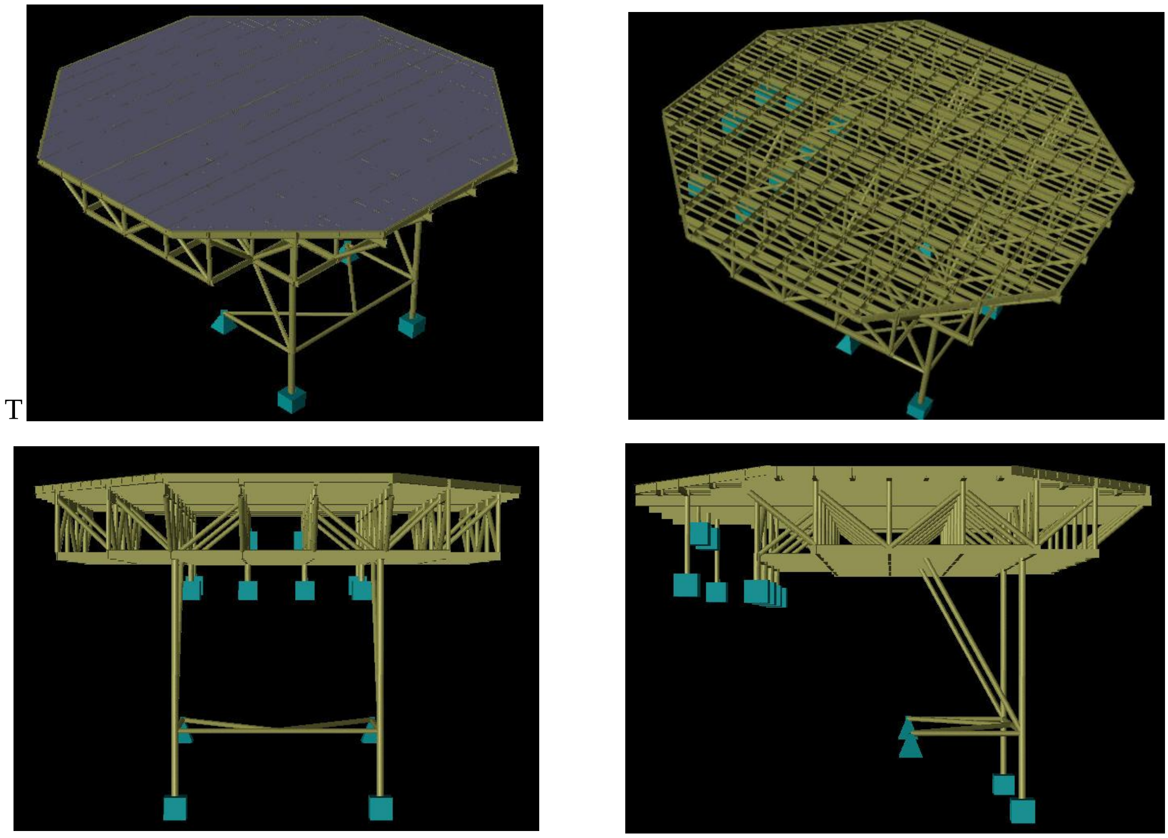


Figure 5.6 Concept models of helicopter landing platform in GeniE

The profile view of ship with installed helideck and side view of installed structure are shown in Figure 5.7 and Figure 5.8. The installed helideck as seen from front view can be found in Figure 5.9.

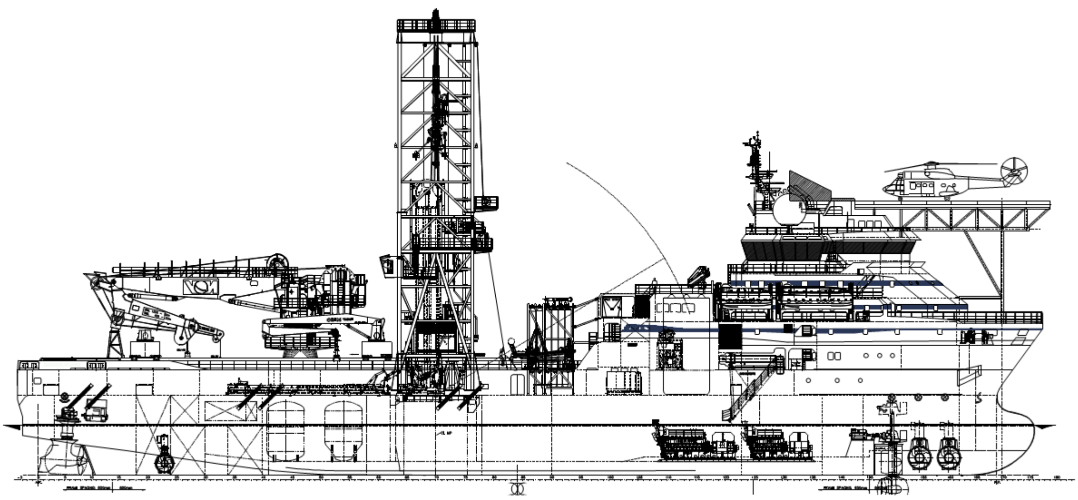


Figure 5.7 Profile view of ship with installed helideck

(Marin Teknikk owns copy rights for all the ship drawings in this thesis)

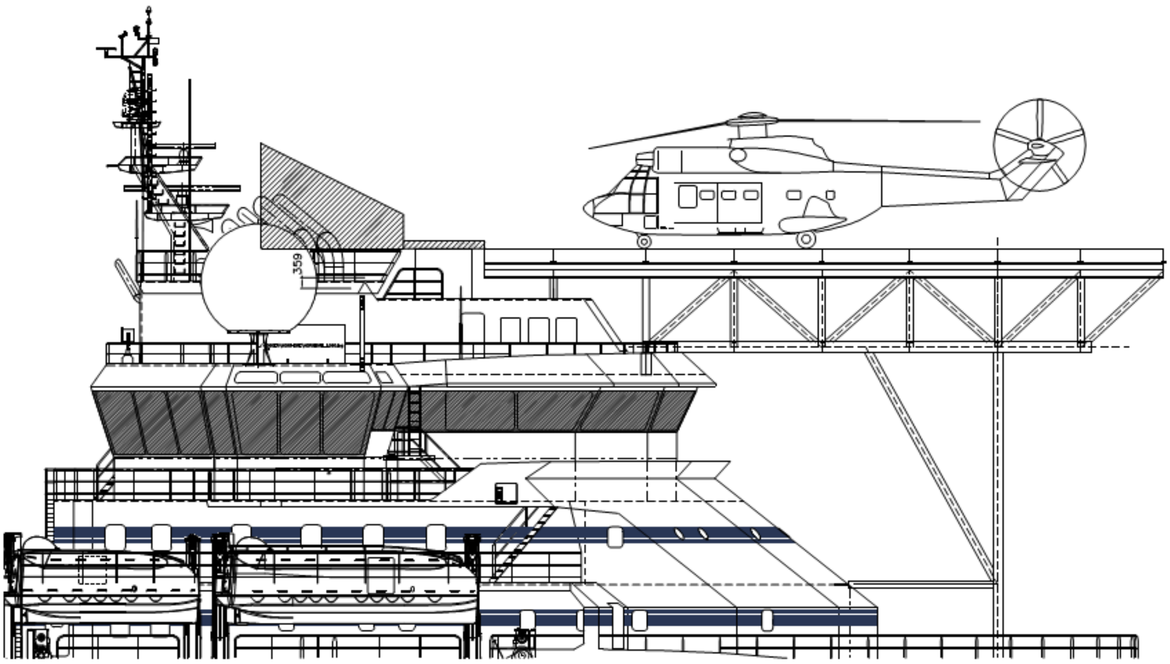


Figure 5.8 Side view of installed helideck
(Marin Teknikk owns copy rights for all the ship drawings in this thesis)

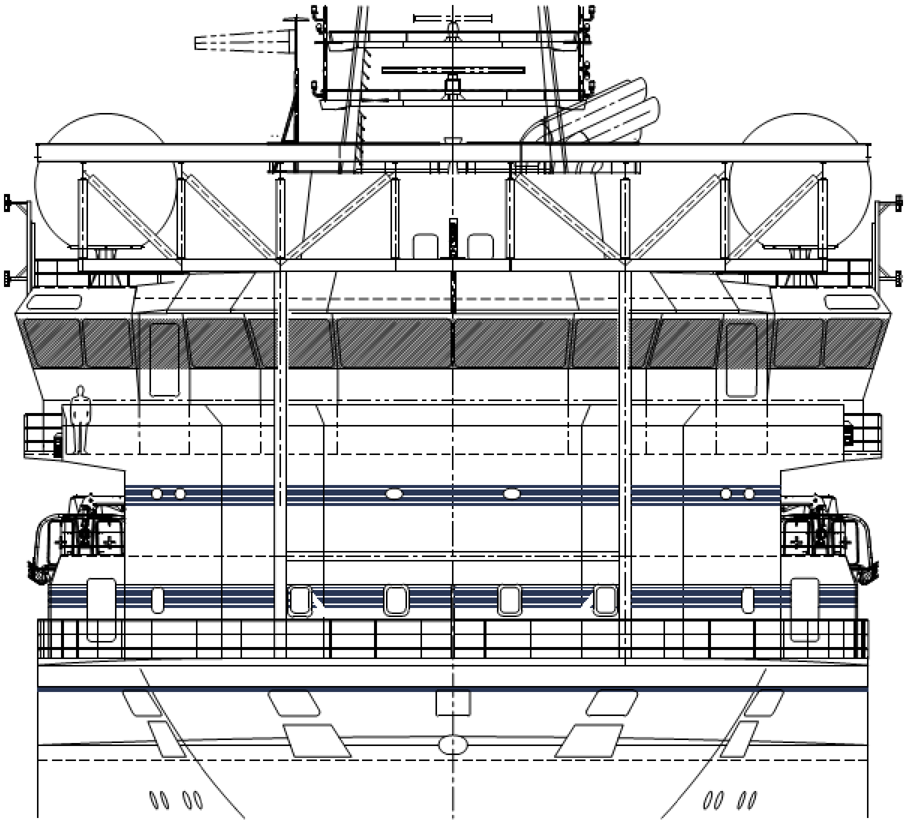


Figure 5.9 Installed helideck as seen from front of the ship
(Marin Teknikk owns copy rights for all the ship drawings in this thesis)

Longitudinal stiffeners (ST)

Aluminium stiffeners of ‘L’ profile will be installed to reinforce the deck plate. These will be positioned longitudinally and spaced evenly. Total 43 stiffeners will be installed with transverse spacing of 500 mm. Arrangement of longitudinal stiffeners in GeniE concpet model is shown in Figure 5.10. This stiffener spacing is an important parameter in calculating plate thickness according to Class’ formula.

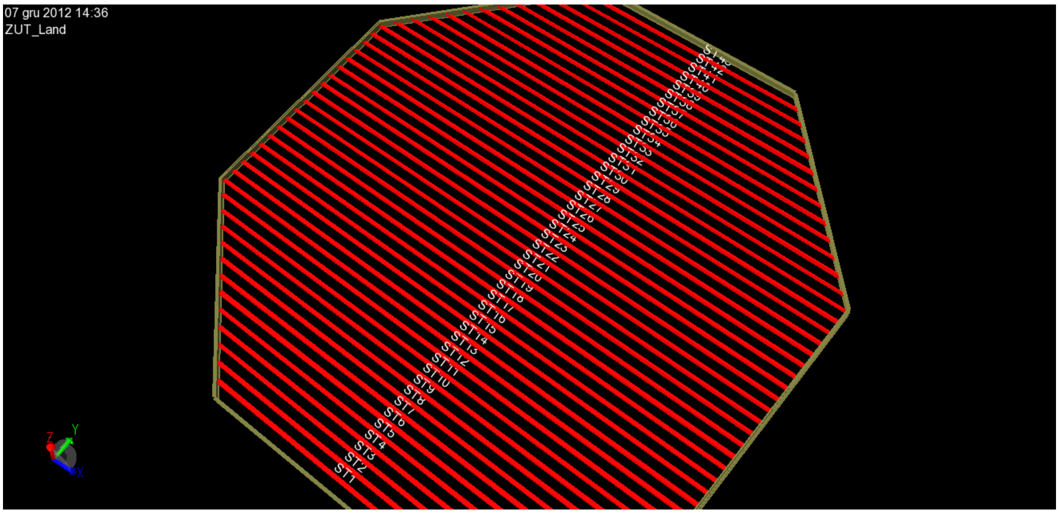


Figure 5.10 Arrangement of longitudinal stiffeners

Upper transverse girder (UTG)

15 ‘T’ profile aluminium beams are installed in the transverse direction underneath the plating to support longitudinal stiffeners. These beams will again transmit the loads to the steel beams installed longitudinally. Special bolted connections need to be used between these different materials. The spacing of UTG can be seen in Figure 5.2 and arrangement can be seen in Figure 5.11.

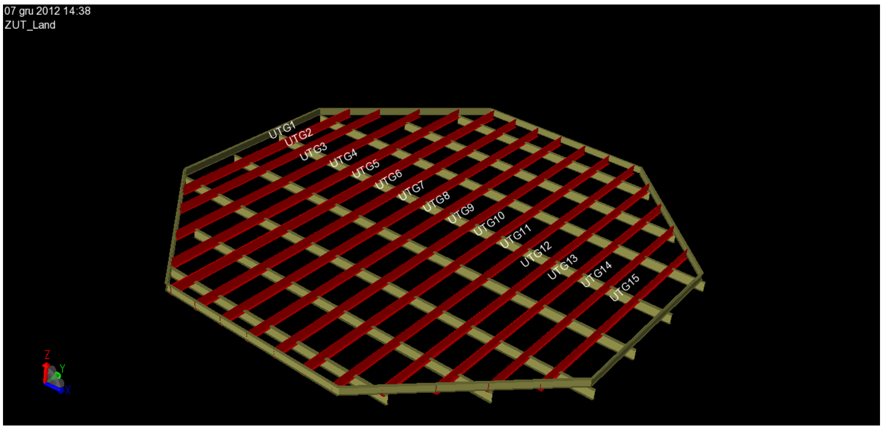


Figure 5.11 Arrangement of upper transverse girders

Upper longitudinal girders (ULG)

Total of 8 steel standard 'I' beams are constructed to bear the load from the aluminium structures above. Smaller sections are used for ULG 3 and ULG 6 which are located directly above the main pillar support. This is due to a reason that other beams, especially, those on the sides require more rigidity to control the bending of UTG. Orientation of ULG which respect to UTG and short columns can be seen in Figure 5.12.

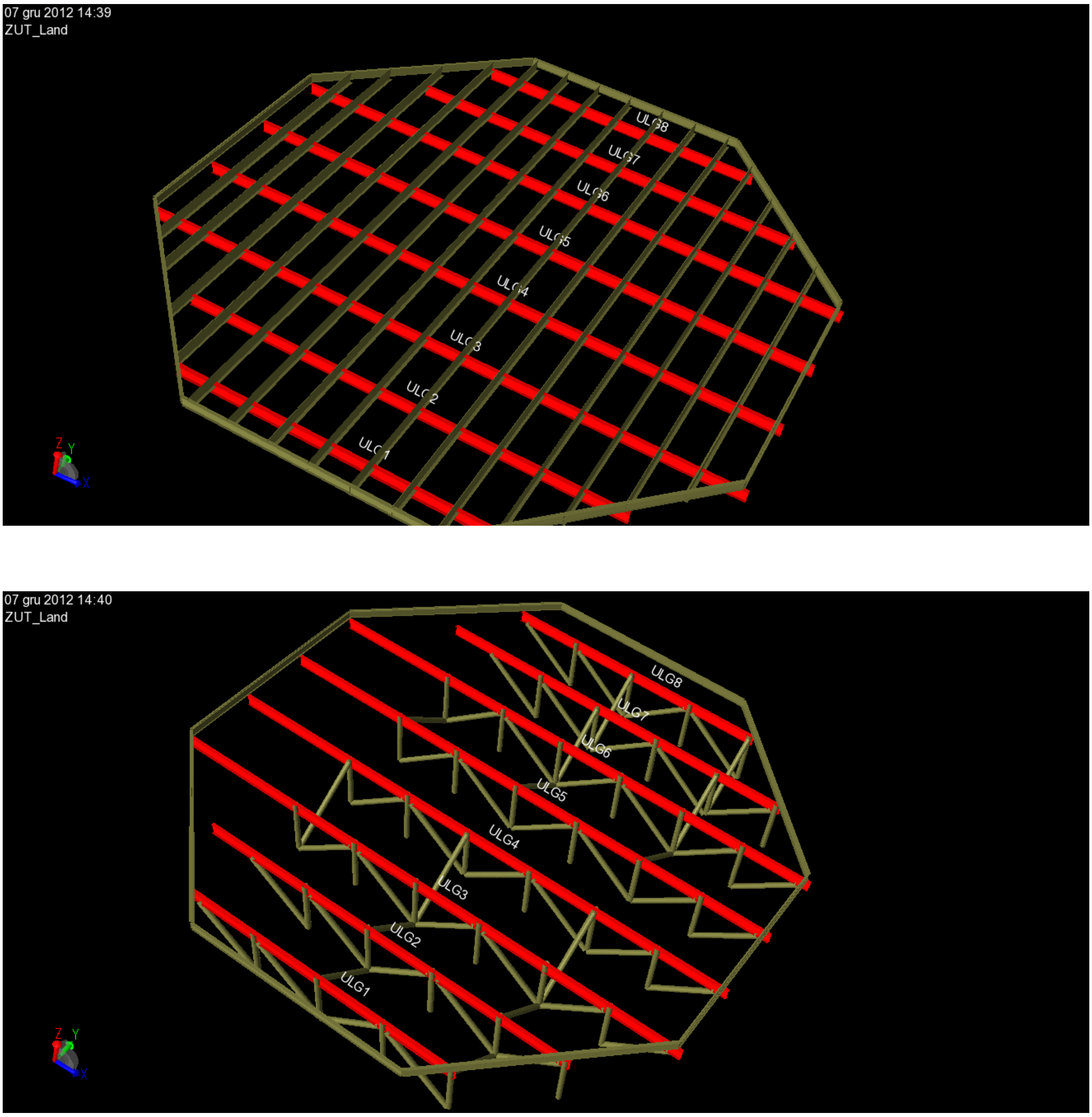


Figure 5.12 Arrangement of upper longitudinal girders

Edge beams (EB)

8 aluminium beams will be installed on the edges of the plate. These are not intended to carry heavy loads. Edge beams can be connected each other and with UTG in bolted connections. Edge beams are shown in Figure 5.13.

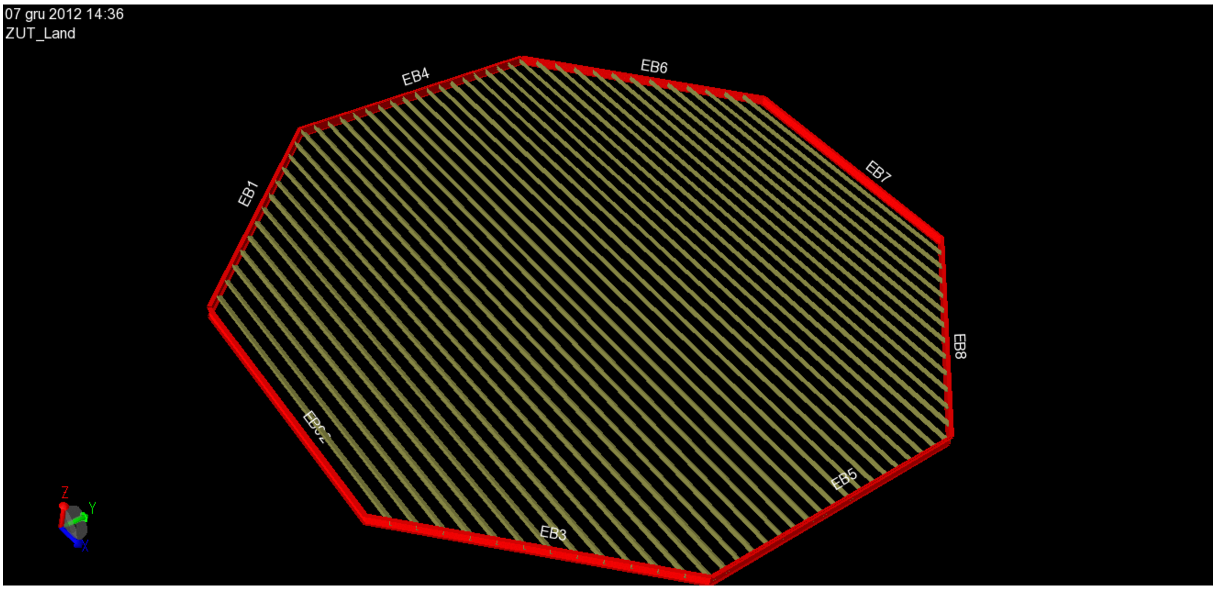


Figure 5.13 Arrangement of upper longitudinal girders

Short Pillars (SP)

Circular hollow columns will be used to transfer the load from the upper layer to lower layer. Depending on the locations, different sections are used. Locations of pillars which respect to lower girders can be seen in Figure 5.14.

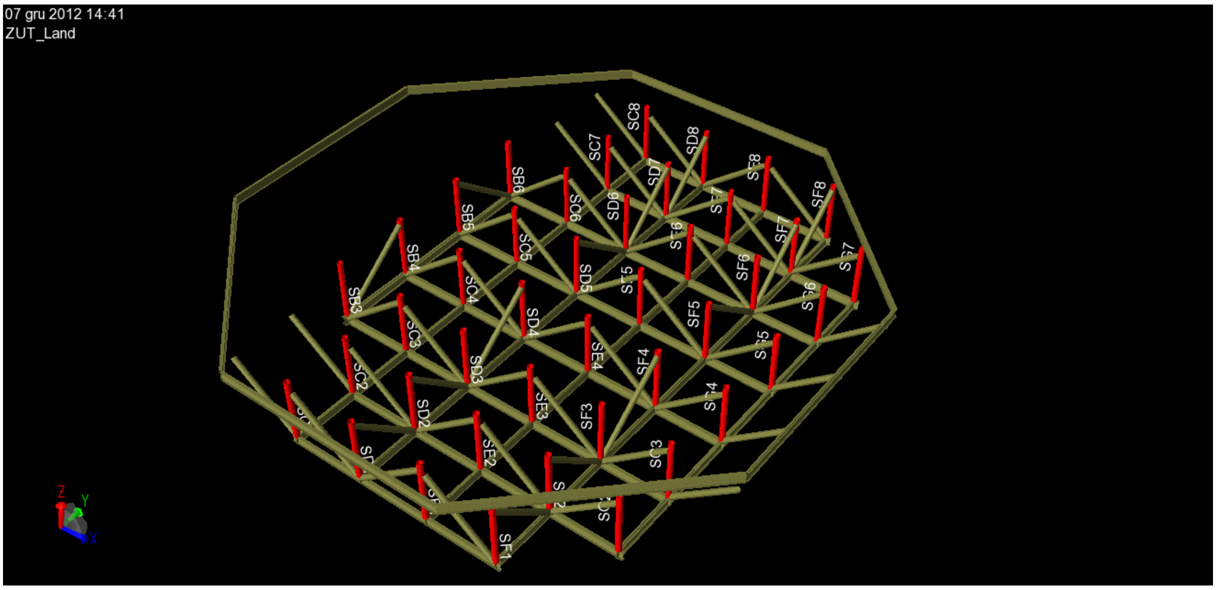


Figure 5.14 Arrangement of vertical short columns

Main bracing (MB)

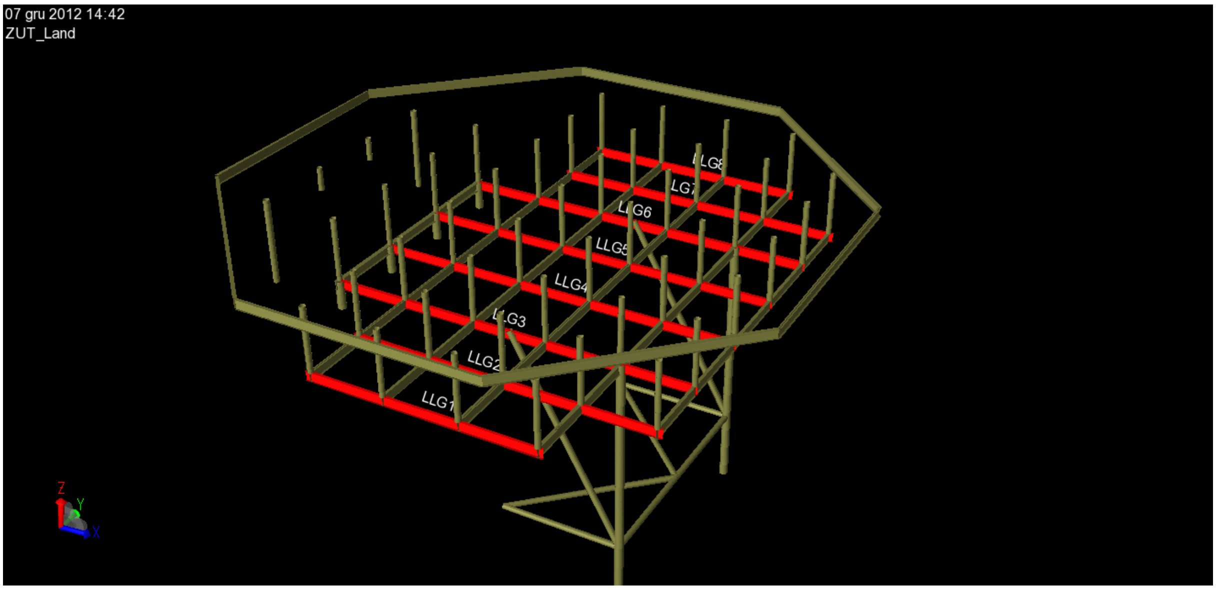
Short bracings will be installed in certain locations to transfer loads equally and to improve the stability of the structure. Bracing beams are installed as same pattern in longitudinal direction. Referring to naming system in Figure 5.4, transverse bracings will only be located at coordinate at B, D and F. The arrangement of all longitudinal and transverse bracings is shown in Figure 5.15.

Figure 5.15 Arrangement of bracing beams

Lower longitudinal and transverse girders (LLG & LTG)

These members will take the loads from short columns and bracing; and transfer to pillars. As all of these are steel sections, connection design will be relatively simple and easy. One important feature for transverse girders (LTG) is that these will need to have necessary strength to be able to resist the bending loads on sides.

Additional support points are required for LLG 3 and LLG6. Without, RP1 and RP2, these beams will have free span of 11.4 metre. Some problems encountered during the earlier designs and it is necessary to put RP1 and RP2. The connections of LTG and LLG can be found in Figure 5.16.



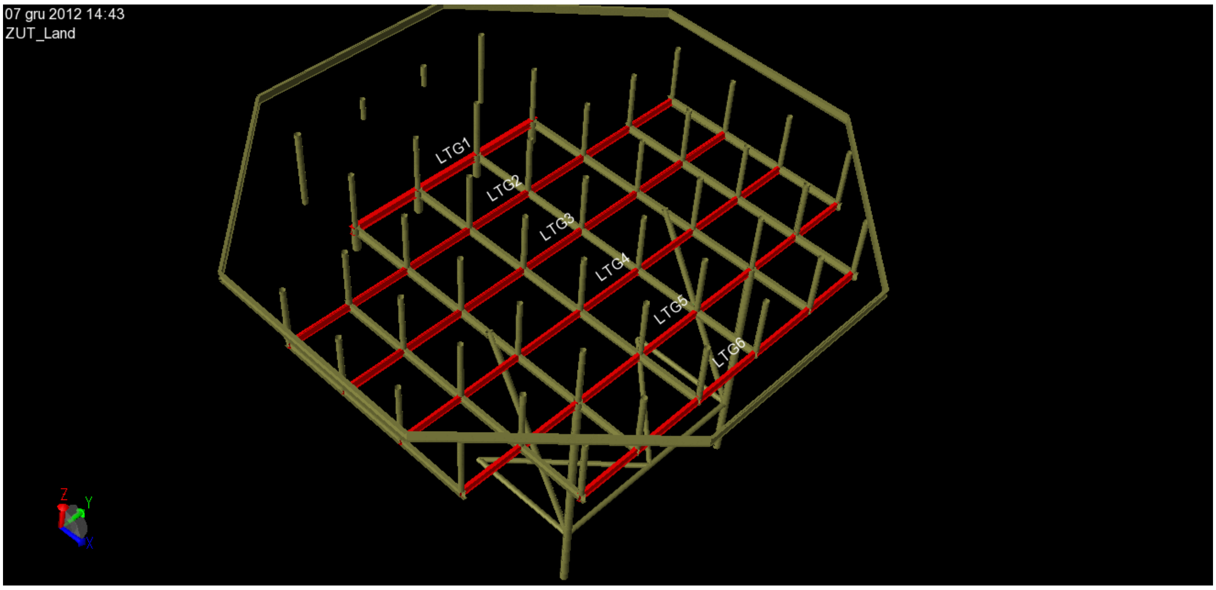


Figure 5.16 Arrangement of lower longitudinal and transverse beams

Referring to naming system in section 5.2, the structural members in row 3 and 6 normally bear larger loads under stowed conditions. These members are important as they transfer the loads to pillars. Bracings and short columns in these two rows are designed with bigger sections.

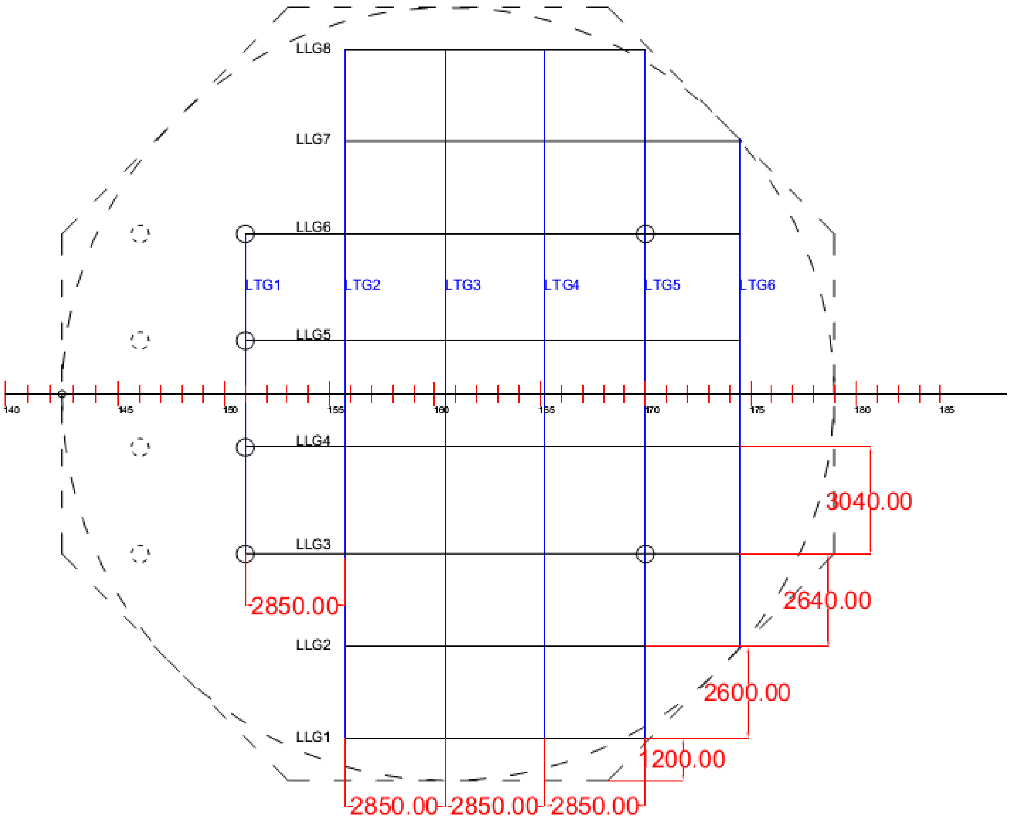
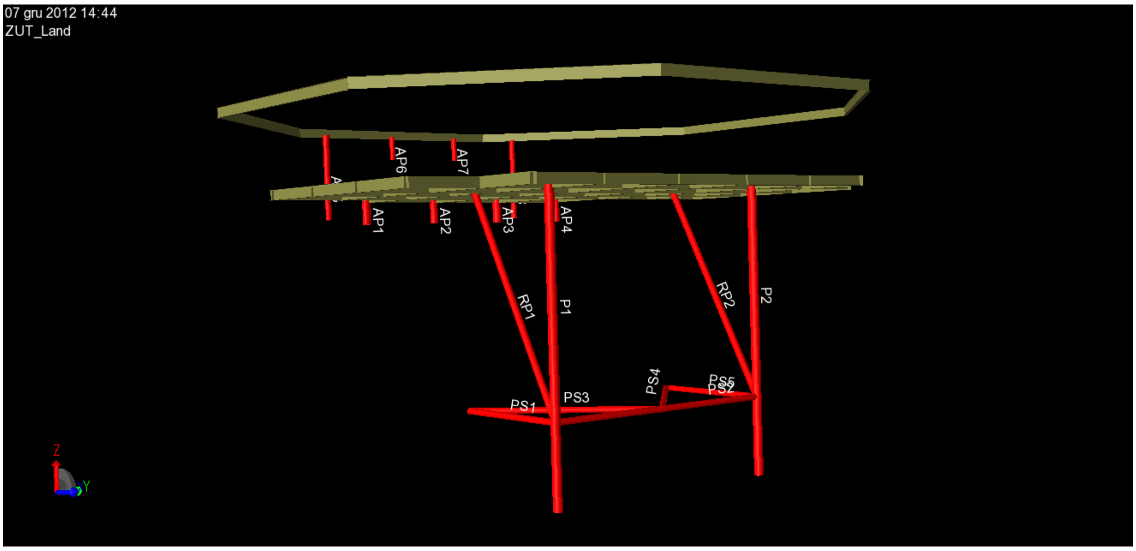


Figure 5.17 Spacing arrangement of lower longitudinal and transverse beams

Pillars

All the loads from the landing platform will be transmitted through 10 pillars to the underneath ship structures. 5 small bracings are installed at captain deck level to stabilize the two main pillars P1 and P2. Arrangement of forward and aft pillars can be found in Figure 5.18.



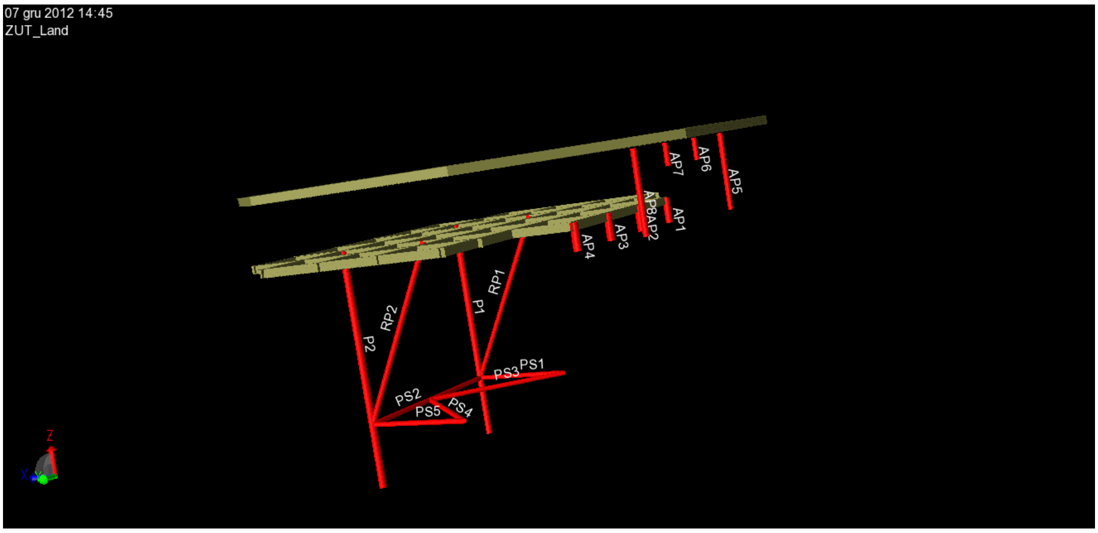


Figure 5.18 Arrangement of pillars

The mass of the whole helideck landing structure with individual group is obtained from GeniE as shown in the Table 5.7.

Table 5.7 Mass of structural element groups and centre of gravity

Item	**Mass [tonnes]**	
Plate	13.1866	
Longitudinal Stiffeners	7.84226	
Upper transverse girders	6.03171	
Edge beams	0.977813	
Upper longitudinal girders	8.13636	
Short pillars	3.34023	
Main bracings	6.20608	
Lower longitudinal girders	3.76637	
Lower transverse girders	4.19544	
Pillars	6.58358	
Total	60.26644	
Centre of mass		
x [mm]	y [mm]	z [mm]
11529.6	11001	-1617.38

For the model in GeniE, the coordinate system originates as shown in Figure 5.2 with top of plate as zero point in vertical system. Therefore, the centre of mass is located 29.75 m from the base line of ship and 4.496 m aft of forward perpendicular.

The main dimensions of the structure from side and front views are shown in Figure 5.19 and Figure 5.20. There will be slight difference between dimensions from concept model design to production drawings. The design for production is out of the scope of this thesis. The individual beam spacing can be found in Figure 5.2 and Figure 5.17.

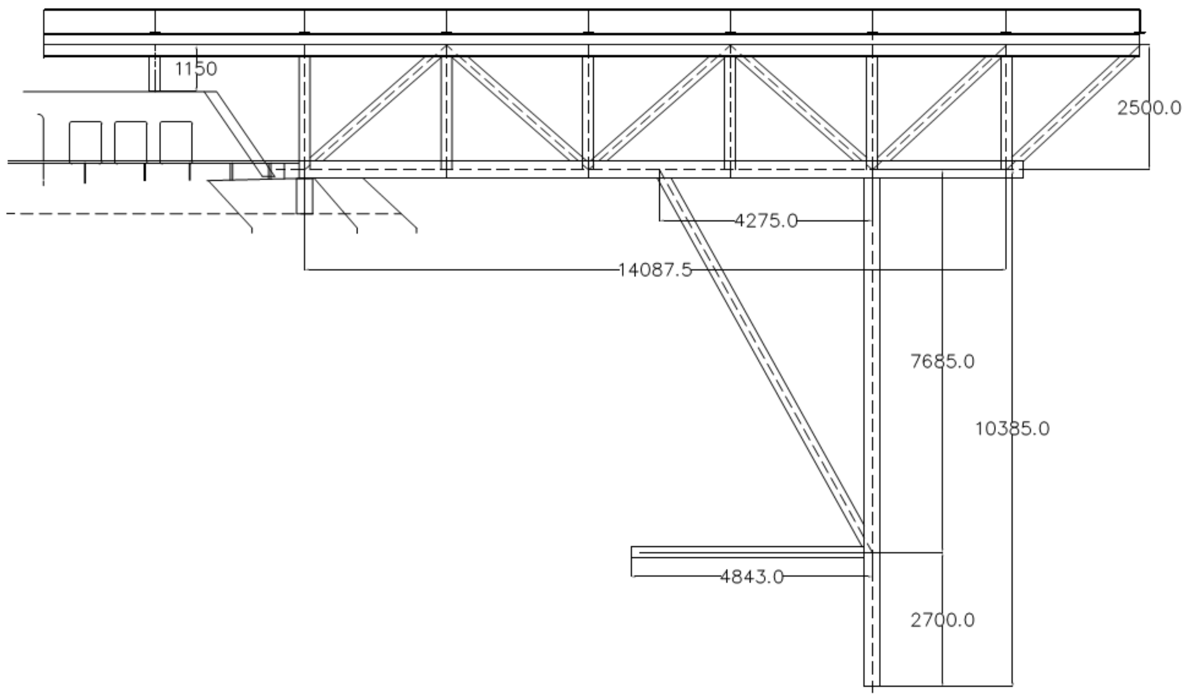


Figure 5.19 Main dimensions of helideck structure on side view

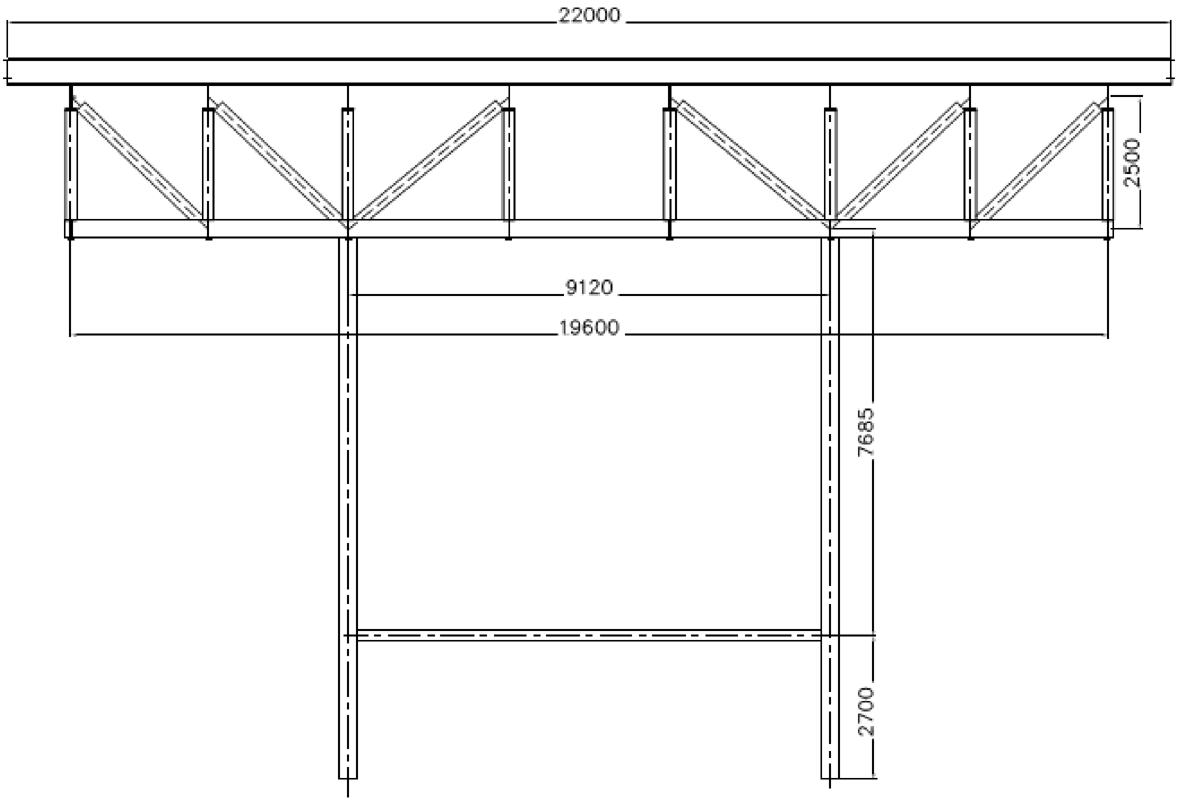


Figure 5.20 Main dimensions of helideck structure on front view

5.9 Aluminium and Steel Connection

Aluminium transverse girders and steel longitudinal girders are connected at intersection points. There needs to pay special attention for steel and aluminium connection points.OSE-401 mentions that non-hygroscopic insulation material must be applied between steel and aluminium [9]. Bolts with nuts and washers must be of stainless steel. One piece of steel plate is to be welded to steel girder. Threaded holes are to be made on that steel plate. Then aluminium girder is connected through the stainless bolts in its flange. One layer of insulation material is to be put between aluminium and steel. According to NORSOK standard M-001, the contacting surface of the carbon steel must be coated [22]. This type of connection is used in Kappa aluminium offshore helideck and it can be applied in the same way in current design.

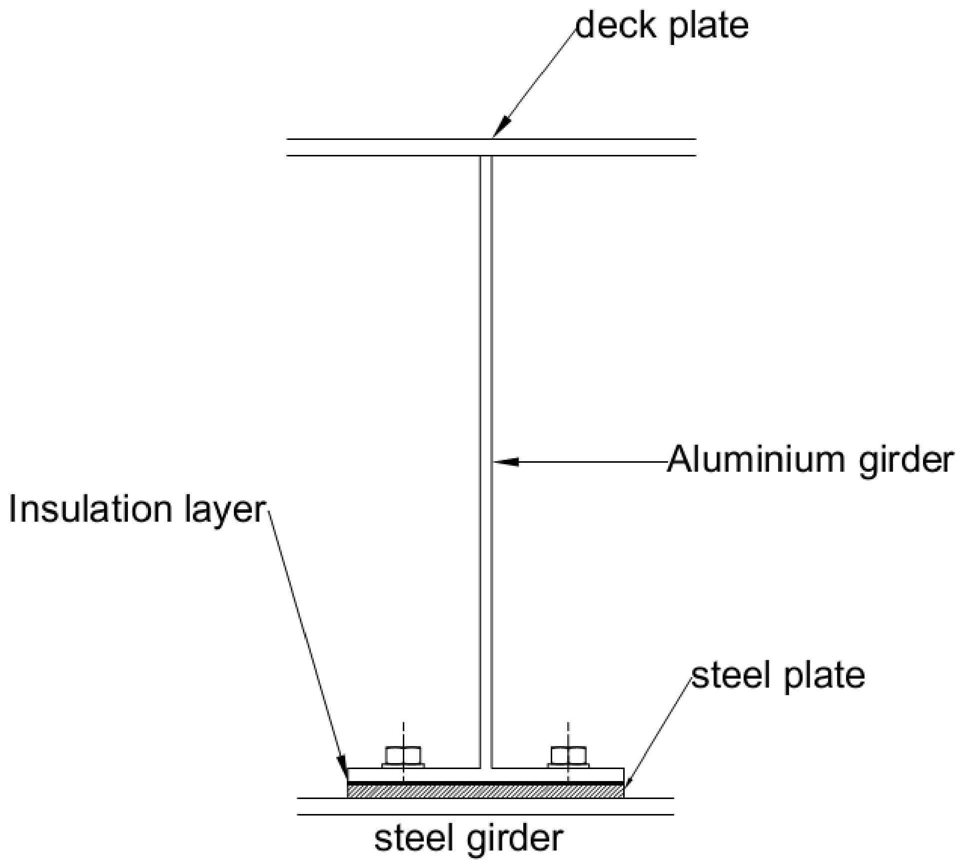


Figure 5.21 Connection between aluminium and steel girders [23]

5.10 Buckling Check

The structure is composed several of slender members and buckling check for those elements have to be performed. Buckling check is carried out according to DNV Rules for Classification of Ships Pt.3 Ch.1 Sec.13. Buckling control for vertical columns, bracings and main support pillars is carried out.

The critical buckling stress σ_c can be determined as follows:

$$\sigma_c = \sigma_{el} \text{ when } \sigma_{el} < \frac{\sigma_f}{2} \tag{5.9}$$

$$\sigma_c = \sigma_f \left(1 - \frac{\sigma_f}{4\sigma_{el}}\right) \text{ when } \sigma_{el} > \frac{\sigma_f}{2}$$

The ideal elastic lateral buckling stress may be calculated as:

$$\sigma_{el} = 0.001\, E\, \frac{I_A}{Al^2}\ (N/mm^2) \tag{5.10}$$

where: I_A = moment of inertia in cm^4 about the axis perpendicular to the expected direction of buckling; A = cross sectional area of member in cm^2.

For pillars, cross ties and panting beams the critical buckling stresses can be calculated as:

$$\sigma_c = \frac{10P}{A\eta}\ (N/mm^2) \tag{5.11}$$

where: $\eta = \frac{k}{(1+\frac{l}{i})}, minimum\ 0.3$, P = axial load in kN; l = length of member in m; i = radius of gyration in cm.

The critical buckling stress and allowable axial load for short columns, pillars and bracing can be found in Appendix A6.

5.11 Presentation of the Results

The results from analysis will be presented briefly in this section. As there are total 62 load cases, only significant cases and results will be shown here. The main criterion is to check whether the resulted normal stresses and shear stresses from the beams are within the allowable range. In GeniE, it is not possible to display normal and VonMises stresses in beams. So the results are extracted to excel file and individual load cases are checked. For the presentation, in each structural group, maximum cases are checked for normal stresses and shear stress as shown in Appendix A5.

For the slender members such as SP, MB and MP, in addition to normal stresses, buckling stresses and axial loads are checked. For pillars and columns, different groups are separated according to length and sectional properties. In each group, 3 maximum cases are checked and shown in Appendix A6.

For normal and emergency landing cases, as expected, most of the severe stresses occur under landing positions. Overall, the maximum responses for most structural members occur in emergency stowed conditions with heave acceleration. Some examples of beam plating stresses and beam stresses are shown in the following figures.

Figure 5.22 shows z-displacement of the structure under load case 213. The worst deflection occurs on the edge of the structure which is quite close to the front wheel patch load. Z-displacement under stowed condition of load case 326 is shown in Figure 5.23. Although the helicopter is parked in the centre of the pad, the maximum deflection still occurs on the starboard edge of the structure. Under this case, starboard wind pressure on the landing pad has certain degree of influence for causing this. Beside this, the structure is relatively weak on the edge as no direct support structures under the girders. But still, the stresses in beams are within allowable limits for all load cases.

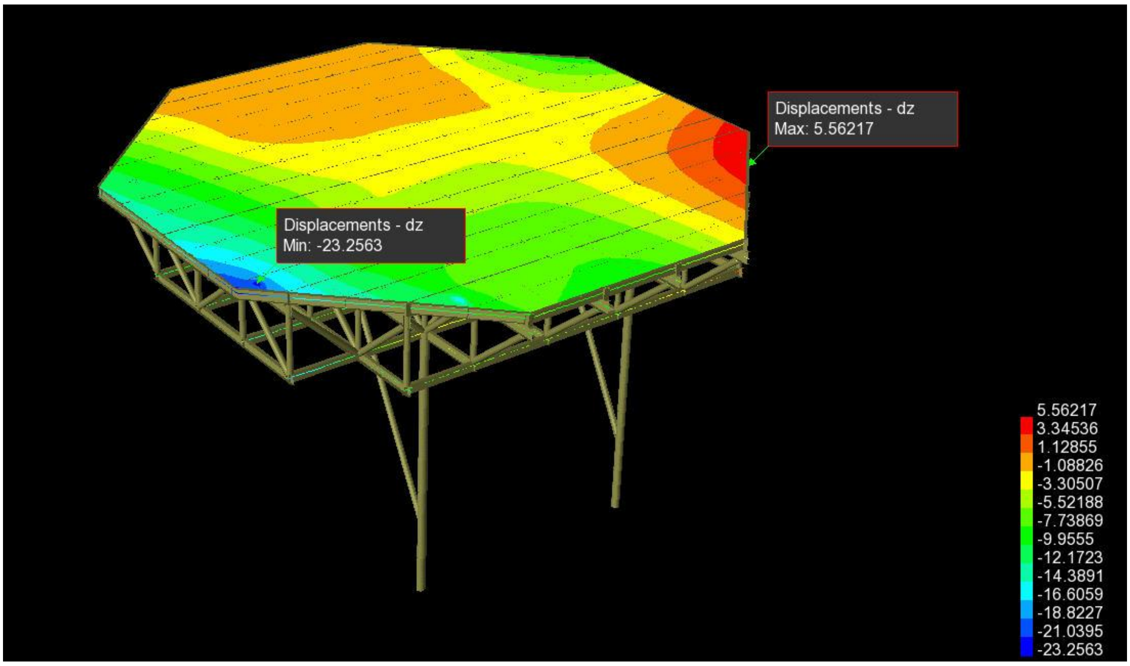


Figure 5.22 Z-component of displacement for load case 213

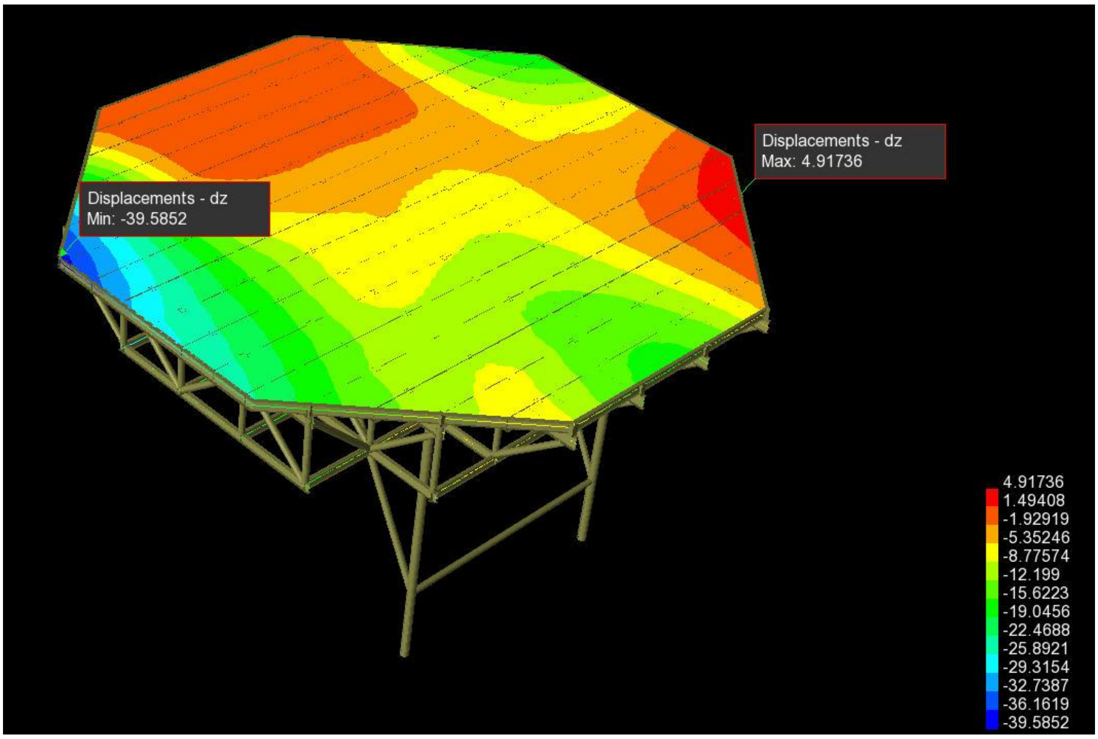


Figure 5.23 Z-component of displacement for load case 326

As mentioned earlier, it is not so convenient to check normal stresses directly in GeniE. But it is still possible to utilize the graphical presentation of results to check which ones are the most significant stress components in specific load case. Examples of axial and shear stress of beams under load case 326 are shown in Figure 5.24 and Figure 5.25.

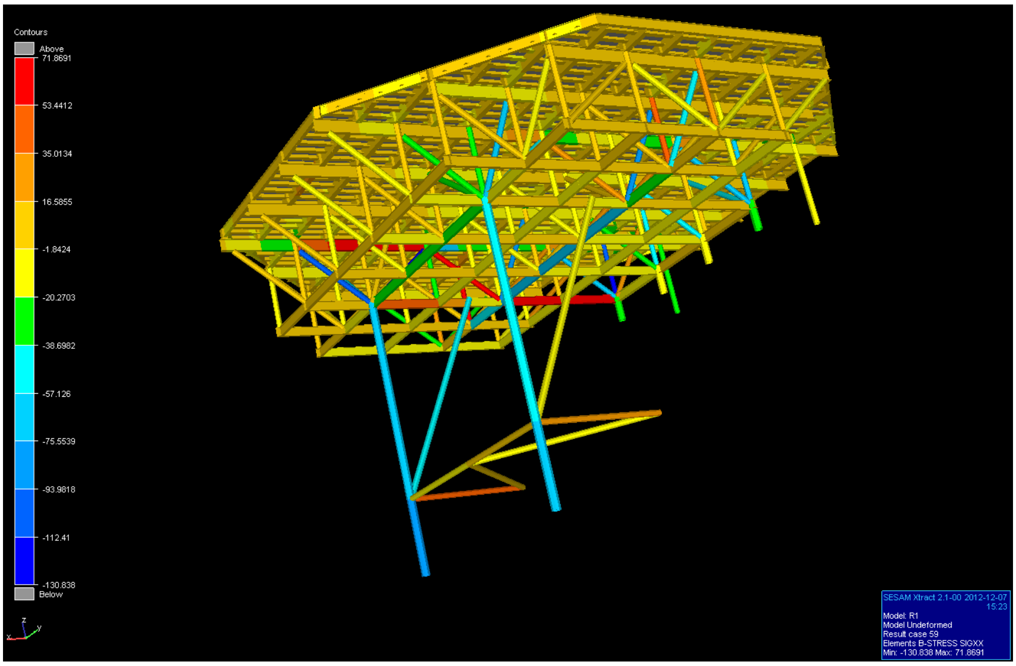


Figure 5.24 Axial stress (Sigxx) of beams under load case 326

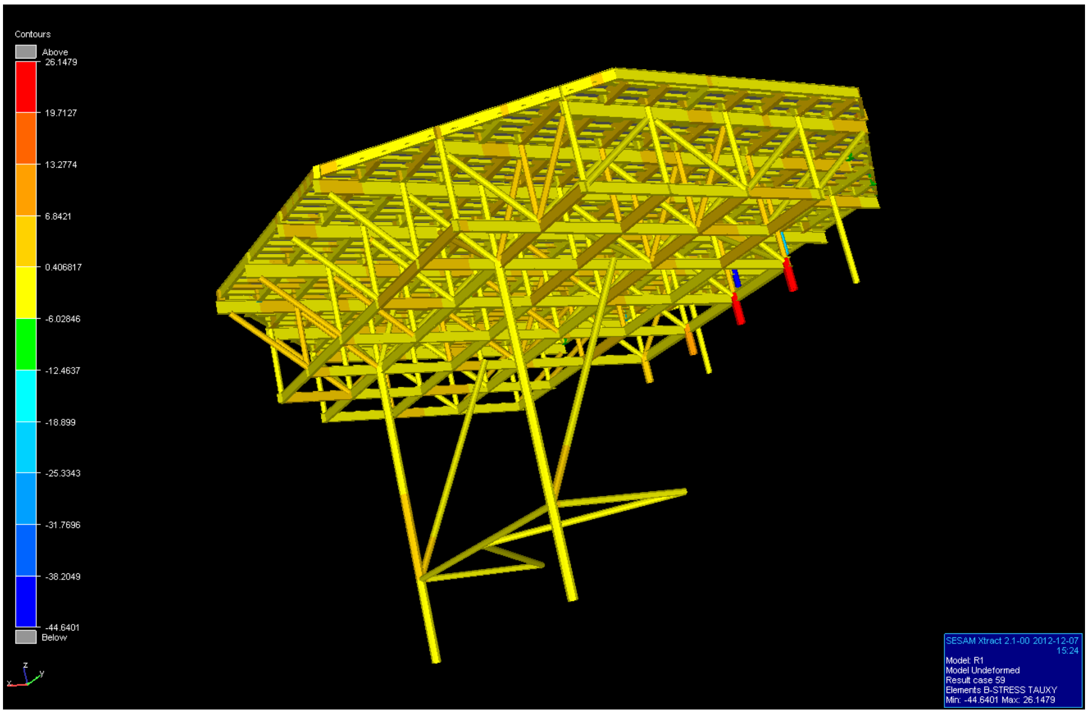


Figure 5.25 Shear stress (Tauxy) of beams under load case 326

5.12 Comparison with Industrial Designs

In this section, the design developed in this thesis will be compared with some relevant designs from industry. There are only few data available from two manufacturers. Here performance and capacity will be compared.

Aluminium Offshore AS shows some data about their helideck on their website. According to this site, the mass of pancake structure of three helidecks is shown in Table 5.8[24].

Table 5.8 Mass of pancake structure of three helidecks from Aluminium Offshore AS

Helicopter	**Helideck Diameter [metre]**	**Aluminium (Pancake) [tonne]**	**Steel (Pancake) [tonne]**
S-76	16	13	34
AS3321	19.5	18	50
S-61	22.2	24	70

Approximately, the last one in the above table has quite similar features to the design in the thesis. The maximum take-off weight of S-61 is 9.3 tonne with rotor diameter of 18.9 m. The helideck diameter is also quite similar. The mass of pancake structure of the design in this thesis can be seen in Table 5.9.

Table 5.9 Mass of pancake structure of helideck in current design

Helicopter	**Helideck Diameter [m]**	**MTOM [kg]**	**Rotor Diameter [m]**
S-92	22	12020	17.17
Weight [tonne]			
Plate			13.1866
Stiffeners			7.84226
Girders			6.03171
Edge beams			0.977813
Total			28.03838

By comparing these two designs, the author can validate his design. Although the current design cannot be stated as an efficient design, its weight and capacity are not so far reaching from industrial design.

Design features of Kappa Aluminium Offshore AS

The design concepts from two companies are available on web page. Both companies use special aluminium extrusions. Welding of the structure is avoided and only bolted connections are used. Due to the special design of extrusion, plate and stiffeners can be produced without welding. Figure 5.26 shows a typical section of extruded aluminium deck plank.

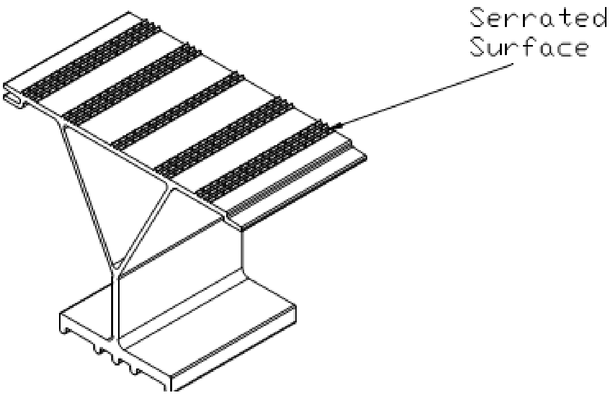


Figure 5.26 Typical aluminium extrusion design from Kappa Aluminium Offshore [23]

These deck planks are connected to aluminium girders by bolted connections. The deck planks have groove and tongue on each side. These deck planks are connected to each other by special seal and glue as shown in Figure 5.27. .

Therefore, this kind of design feature allows weld free connection and hence the full yield strength of aluminium can be utilized. Beside this, the companies state that the installation time is shorter than welded connections.

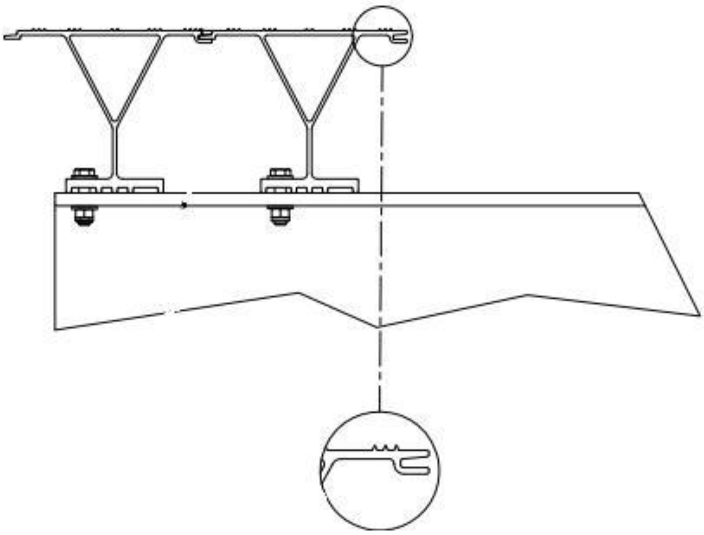


Figure 5.27 Connection of deck planks to girder [23]

6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The work in this thesis shows an approach to design of helicopter landing structure on board a ship. The design is developed using Rule based approach. For the commercial design, it is always necessary for designers to check that the design must be complied with Rules. Some important features are realized through this study.

Nowadays, it is very common to use aluminium alloy as construction material for pancake structure of the helideck. Aluminium alloy with marine grade has good corrosion resistance and relatively good strength level. But the worst drawback of aluminium is that its strength is reduced near the welding zone. So it is very important to consider about the material characteristics of aluminium alloy from the initial phase of the design.

In terms of structural mass, deck plate is found to be most significant one with 47 per cent of total mass of pancake structure. So the efficiency of the design is quite dependant on the required minimum plating thickness. If the original material property of the aluminium alloy can be utilized, under the same beam spacing arrangement, the minimum thickness will be about 9.5 mm. Then, plating mass about 2.7 tonnes can be saved. In addition to this, the scantling of other aluminium members can be reduced slightly.

Aluminium stiffeners account for about 28 per cent of total mass. The minimum section modulus required by Rule is 431.93 cm^3. The section modulus of the stiffener used in current design is only 298.8 cm^3 and the stress levels in all stiffeners are satisfactory for all load cases. Therefore, Rule based formula is found to be conservative. But HAZ property of aluminium is used for calculation of Rule based formula and this should be one of the reasons for giving conservative figures.

The structural efficiency of the aluminium pancake depends on the configuration of lower steel support structures. It is quite important that the arrangement of lower structures should not block the bridge deck's view. In current design, only two main pillars block the forward view of the bridge deck. But it is very important to ensure that the girders have the enough rigidity. In the current design, maximum deflections of the structure occur on sides. Therefore, the steel girders in the transverse direction must be strong enough to compensate this weak feature.

Total 62 load cases are analyzed in this thesis. The purpose is to identify the most severe loading condition. There are total 30 load cases for stowed condition. For most of the structural members, the maximum response occurs under vertical motion conditions (heave; and combined surge and heave). This fact can be clearly seen from calculation as vertical acceleration is 1.49 g while others are only 0.39g and 0.44g. To save time and work load, it is recommended to model only vertical acceleration cases in stowed condition. Germanischer and Lloyds' Register Rules consider only vertical motion case and therefore it can be assumed as an effective decision.

The design of the aluminium structure in this thesis is not efficient as the full yield strength capacity cannot be utilized. Although proper studies are not made here, it can be concluded that more efficient structure can be constructed if welding is not used. Therefore, it is very important to consider about the connection design and configurations to achieve optimal efficient design.

Most of the structural members show maximum response under accidental stowed condition. Under such loading criteria, the distribution from inertia forces is quite significant. The ice on the structure weighs around 116.7 tonne. This load is amplified due to the effect of heave motion. If the ship does not operate in North Sea area or other special area, Class' requirement can be reduced and structural weight can be smaller. Another option is to install de-icing equipment for the helideck.

6.2 Recommendations

There are still a lot of interesting areas to explore regarding to helicopter landing areas. Structural analysis and design would be one of those disciplines. But, recommendation regarding to structural analysis and design will be given here.

The landing of the helicopter is a dynamic engineering problem. It might be interesting to see the dynamic analysis of the landing and to make research on landing loads. Then the results should be compared with existing formulas from regulations and practicability of these formulas can be checked.

As mentioned in earlier sections, there were some experiments about wheel loading on deck plates. These previous works have only results for steel plates and hence new tests for aluminium plates and panels should be performed to fully understand the dynamic behaviour of the problem.

The current work use beam elements for structural analysis. During initial design phase it is not always easy to build full finite element model. It is recommended to carry out detail finite element analysis of the design selecting the most severe load cases.

Optimization studies should also be made. As mentioned above, the mass of the plating is the largest one among aluminium alloy structural members. According to Rule based approach, the thickness of the plating depends on stiffener spacing. If stiffener spacing is reduced, the required plate thickness will become smaller. On the other hand, this will increase the total mass of the stiffeners. So, proper analysis should be made to achieve optimal spacing, which in turn will give optimal plate thickness. Optimization studies should also be made on lower steel structures as the structural efficiency of the upper part also depends on the arrangement of lower support structures.

Another form of studies should be made using extruded profiles. The aim is to eliminate the effect of welding so that the full material properties of aluminium can be utilized. In this kind of study, emphasis should also be paid on connection design and in some cases detail analysis should be made for specific load cases. Optimization should also be carried out to achieve efficient sectional profile. In this type of design, the weight from extruded sections would be significant as there needs to use small stiffener spacing.

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APPENDIX

A1. Wind Loads

Table A1. 1 Calculation of wind velocities and pressures

Input Required		
Parameter	**Value**	**Unit**
ρ_{air}	1.226	$kg.m^{-3}$ for dry air at 15 $\dot{C}$
$V_{1min.10}$ (landing)	30	ms^{-1}
$V_{1min.10}$ (stowage)	55	ms^{-1}
$z_{.heli}$	22.1	m
z_r	10	m
z	10	m
t_{heli}	3	s
t	60	s
t_r	600	s
γ_a	0.0000145	m^2s^{-1}
Results		
Landing condition		
U_{10}	27.07	ms^{-1}
$U_{3,23.45}$	36.75	ms^{-1}
$q_{.landing}$	0.837	kNm^{-1}
Stowed condition		
U_{10}	49.69	ms^{-1}
$U_{3,23.45}$	67.37	ms^{-1}
$q_{.stowage}$	2.816	kNm^{-1}

The wind load over the structures is estimated as a single frame of elements located in the normal direction of the wind. Some dimensions used in wind load calculations are approximately taken and not the exact ones.

Table A1. 2 Calculation of forward wind forces on beams

Wind from FWD												
	L [m]	W [m]	Area [m²]	No	total A[m²]	Enclosed Area [m²]	κ	C_e	$F_{W,SOL}$ (Land) [kNm⁻¹]	$F_{W,SOL}$ (EMG) [kNm⁻¹]	$F_{W,SHI}$ (Land) [kNm⁻¹]	$F_{W,SHI}$ (EMG) [kNm⁻¹]
UTG	22	0.455	10.01	1	10.01	70.4	0.95	2.2	0.285	0.96	0.27	0.86
SP	2.5	0.2191	0.54775	8	4.382		1	0.8	0.052	0.176	0.0498	0.158
MB	3.6	0.2191	0.78876	4	3.15504		1	0.8	0.052	0.176	0.0498	0.158
LTG	19.6	0.313	6.18175	1	6.18175		0.95	2.1	0.187	0.627	0.177	0.56
MB	3.9	0.2191	0.85449	2	1.70898		1	0.8	0.052	0.176	0.049	0.158

frame spacing [m]	1.5
total length [m]	22
spacing ratio	0.068
Solidity ratio, Φ	0.36
a	0.6
Aerodynamics solidity ratio, β	0.217
η	0.95

Table A1. 3 Calculation of side wind forces on beams

Wind from SB												
	L [m]	*W* [m]	Area [m^2]	No	total A [m^2]	Enclosed Area [m^2]	κ	C_e	$F_{W,SOL}$ (Land) [kNm^{-1}]	$F_{W,SOL}$ (EMG) [kNm^{-1}]	$F_{W,SHI}$ (Land) [kNm^{-1}]	$F_{W,SHI}$ (EMG) [kNm^{-1}]
ULG	16.775	0.45	7.633	1	7.633	47.808	0.95	2.1	0.325	1.092	0.299	1.05
LLG	14.2	0.353	5.013	1	5.013		0.95	2.1	0.252	0.847	0.232	0.779
SP	2.5	0.2191	0.548	6	3.287		1	0.8	0.063	0.211	0.058	0.194
MB	3.6	0.2191	0.789	6	4.733		1	0.8	0.063	0.211	0.058	0.194
					20.664							
frame spacing[m]				2.6								
total length [m]				22								
spacing ratio				0.118								
Solidity ratio, Φ				0.432								
a				0.6								
Aerodynamics solidity ratio, β				0.259								
η				0.92								

Table A1. 4 Drawings for estimation of wind forces

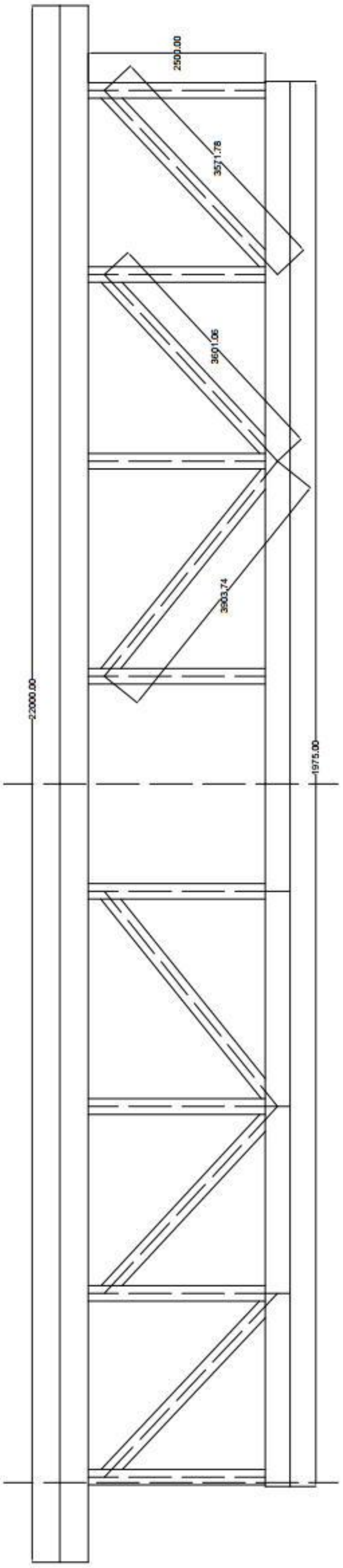

Figure A1. 1Main dimensions for estimation of forward and aft winds

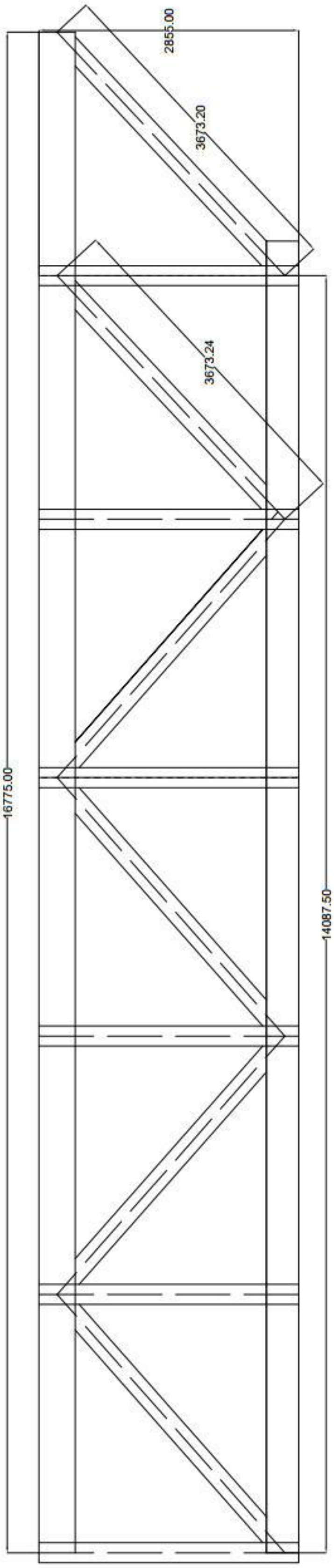

Figure A1. 2 Main dimensions for estimation of side winds (only the position between X-coordinate of 5225-22000 is taken to simplify the calculation)

A2. Inertia Forces

Table A2. 1 Calculation of ship's accelerations for estimation of inertia forces on helicopter landing structure

Input Required		
Length Over All, LOA	115.4	m
Length Between Perpendiculars, LPP	107.95	m
Rule Length, *L*	107.96	m
Breadth, B	22	m
Depth to Main Deck	9	m
Draught	7.15	m
Depth to Summer Water Line	7.095	m
Block Coefficient	0.731	
Height to axis of rotation from baseline (roll & pitch), z		4.5
Distance from the centre of mass of helideck to the axis of rotation (tangential roll), R_r		24.732
Distance from the centre of mass of helideck to the axis of rotation (pitch), R_p		55.18
Vertical projection of R_{pv}		24.732
Results		
Parameter	**Value**	**Equation used**
C_v	0.208	
C_{v1}	1.395	
a_0	0.5 ms^{-2}	**(4.5)**
a_x	0.845 ms^{-2}	**(4.2)**
a_y	1.483 ms^{-2}	**(4.3)**
a_z	4.047 ms^{-2}	**(4.4)**
k_r	8.58	
T_R	13.83 s	**(4.7)**
c	0.7234	

Table A2.1 continued

Parameter	**Value**	**Equation used**
ϕ	0.373 rad	**(4.6)**
a_r	1.904 ms^{-2}	**(4.8)**
θ	0.172 rad	**(4.9)**
T_p	5.97 s	**(4.10)**
a_p	10.57 ms^{-2}	**(4.11)**
k_v	1.42	
$\boldsymbol{a_v}$	9.61 ms^{-2}	**(4.12)**
$\boldsymbol{a_t}$	5.67 ms^{-2}	**(4.13)**
$\boldsymbol{a_l}$	6.475 ms^{-2}	**(4.14)**

A3. Virtual Densities of Sections

The virtual densities of various sections are calculated by using Equation **(4.25)**.

Table A3. 1 Virtual density used for modeling ice load

Item	**Section**	**Ice Area (mm^2)**	**Virtual Density ($tonne.m^{-3}$)**	**Total Density ($tonne.m^{-3}$)**
Plate (Al)	13 mm thickness	40105.28 $x10^6$	6.923	9.623
Long: Stiffeners (Al)	L203_178_7_12_8	38100	9.31	12.014
Up: Trans: Girders (Al)	T455_153_8.5_20	65500	7.49	10.19
Up: Long: Girders (Steel)	W460x60	68450	7.99	15.79
	W460x52	67800	9.1	16.9
Lower: Trans: Girders (Steel)	W360x39	60900	10.88	18.68
Lower: Long: Girders (Steel)	W360x39	60900	10.88	18.68
Short Columns (Steel)	CHS_219_1x5	42287.143	9.032	16.833
Bracings (Steel)	CHS_219_1x10	42287.143	5.791	13.591
	CHS_219_1x12_5	42287.143	4.689	12.489
Pillars (Steel)	CHS_323_9x20	58755.714	2.768	10.568
Pillar Supports (Steel)	CHS244x12_5	46278.571	4.569	12.37
	CHS_219_1x5	42287.143	9.032	16.833
Aft Pillars (Steel)	CHS_323_9x25	58755.714	2.252	10.052

Total density is calcuated by adding virtual density by material density.

A4. Plate thickness and stiffeners

Table A4. 1 Calculation for minimum thickness of plating according to DNV Rule

Input Required		
Parameters	**Value**	**Unit**
σ_f	125	Nmm^{-2}
k	0.6	
s	0.5	m
f_1	0.532	
Load on one group of wheels	40.1	kN
P_w	80.2	kN
Result		
t	12.05	mm ,Equation **(5.1)**

Table A4. 2 Calculation for section modulus of stiffener according to DNV Rule

Input Required		
Parameters	**Value**	**Unit**
a	0.6	m
b	0.3	m
s	0.5	m
l	3	m
k_z	1	
r	38	
σ_f	110	Nmm^{-2}
m	6.78	
p	445.56	kNm^{-2}
Result		
Z	431.93	cm^3, Equation**(5.3)**
A	21.42	cm^2, Equation **(5.4)**

Table A4. 3 Calculation for minimum thickness of plating according to Lloyds' Register Rule

Input Required		
Parameters	**Value**	**Unit**
u	600	mm
v	300	mm
v/s	0.6	
s	500	mm
l	1500	mm
P_w	4.09	tonne
f	1.15	
Υ	0.6	
k	0.9	
ϕ_1	1	
ϕ_2	1	
ϕ_3	1	
Results		
P_1	7.055	tonne
β	2.35	
α	14	
t_1	7.378	mm
t	11.83	mm

There should be another case in which the wheel axle is positioned parallel to the direction of stiffener. But that is not the case for giving out maximum thickness.

The required plate thickness according to Lloyds' Register Rule is 11.83 mm.

A5. Results

The most severe stresses for each group of structural elements can be found in the following tables. There is no specific requirement for allowable shear stress in DNV guideline. Therefore, in the case of maximum shear stresses, VonMises stresses are checked whether they are within allowable range.

Table A5. 1 Most severe stresses for longitudinal stiffeners under normal landing conditions

LC No	**VonMises**	**VonMises [MPa]**	**Sigxx [MPa]**	**TauNxy [MPa]**	**TauNxz [MPa]**
114	ST25	**73.8053**	-16.1375	-1.23602	-39.467
		60.5148	-50.2245	-1.76936	-17.3222
		31.0265	30.6302	-0.620819	-1.92312
	Normal Stress				
113	ST13	62.7954	-53.8204	6.46996	11.2607
		62.7954	**-53.8204**	6.46996	11.2607
		43.6417	**43.6109**	0	0
	Shear Stress				
109	ST22	49.5577	-2.3919	**-9.25718**	-16.8392
		41.6866	-30.5627	-6.23829	-9.13858
		42.5066	42.4721	0	0
114	ST25	73.8053	-16.1375	-1.23602	**-39.467**
		60.5148	-50.2245	-1.76936	-17.3222
		31.0265	30.6302	-0.620819	-1.92312

Table A5. 2 Most severe stresses for upper transverse girders under normal landing conditions

LC No	**Normal Stress**	**VonMises [MPa]**	**Sigxx [MPa]**	**TauNxy [MPa]**	**TauNxz [MPa]**
110	UTG2	**62.3229**	-62.3229	0	0
		62.3229	**-62.3229**	0	0
		40.6533	40.6533	0	0
	Shear Stress				
113	UTG13	31.0453	-8.68823	**13.9757**	2.71947
		25.1682	-25.1583	0	0
		11.6827	11.6613	0	0
115	UTG3	31.522	1.22446	0	**17.8365**
		23.9195	-23.9168	0	0
		10.2756	10.1767	0	0

Table A5. 3 Most severe stresses for edge beams under normal landing conditions

LC No	**Normal Stress**	**VonMises [MPa]**	**Sigxx [MPa]**	**TauNxy [MPa]**	**TauNxz [MPa]**
114	EB5	**94.3107**	-94.2496	0	0
		94.3107	**-94.2496**	0	0
		92.1415	92.079	0	0
	Shear Stress				
110	EB4	34.1236	-7.49325	**-16.3602**	-0.17788
		25.6777	-25.3423	0	0
		18.935	18.4776	0	0

Table A5. 4 Most severe stresses for upper longitudinal girders under normal landing conditions

LC No	**Normal Stress**	**VonMises [MPa]**	**Sigxx [MPa]**	**TauNxy [MPa]**	**TauNxz [MPa]**
113	ULG3	**115.041**	-115.041	0	0
		115.041	**-115.041**	0	0
		85.5176	**85.5166**	0	0
	Shear Stress				
103	ULG6	60.5279	-56.4202	0	**12.5439**
		60.0492	-60.0489	0	0
		38.046	38.0458	0	0

Table A5. 5 Most severe stresses for lower transverse girders under normal landing conditions

LC No	**Normal Stress**	**VonMises [MPa]**	**Sigxx [MPa]**	**TauNxy [MPa]**	**TauNxz [MPa]**
116	LTG2	**150.676**	-150.674	0	0
		150.676	**-150.674**	0	0
		140.142	140.14	0	0

Table A5. 6 Most severe stresses for lower longitudinal girders under normal landing conditions

LC No	**Normal Stress**	**VonMises [MPa]**	**Sigxx [MPa]**	**TauNxy [MPa]**	**TauNxz [MPa]**
116	LTG2	**126.046**	126.043	0	0
		92.2122	-92.2011	0	0
		126.046	**126.043**	0	0
	Shear Stress				
113	LTG5	100.898	93.5677	0	**-21.3571**
		96.588	-96.5789	0	0
		98.8738	98.8659	0	0

Table A5. 7 Most severe stresses for lower short pillars under normal landing conditions

LC No	Item	Sigxx [MPa]	Axial Force [kN]
106	SB3	-116.133	-186.523
107	SF6	-21.0917	-114.205
108	SC8	-114.411	-28.6473
110	SB6	-107.591	-162.589
	SC3	-36.0163	14.9537
	SF6	-20.4815	-94.8561
113	SF6	-27.3075	-69.9957
116	SB6	-119.539	-168.925
	SC7	-120.183	-11.7174
	SC8	-129.871	-13.6912
	SC3	-48.5472	13.4698

Table A5. 8 Most severe stresses for main bracings under normal landing conditions

LC No	Item	Sigxx [MPa]	Axial Force [kN]
103	BF56	-57.2434	-74.4853
	BFG4	-59.3292	18.8836
107	BF56	-52.1049	-78.3834
110	BBC7	-72.7803	-15.5475
	BBC8	-58.9292	-50.2345

Table A5.8 continued

LC No	Item	Sigxx [MPa]	Axial Force [kN]
111	BF56	-53.5909	-152.643
113	BF23	-93.7662	-134.675
	BFG4	-59.1579	-14.1953
	BEF3	-96.1431	-385.001
	BFG3	-102.645	-383.584
114	BFG4	-65.4206	-28.1014
	BFG3	-88.3558	-316.423
	BG6	-27.7866	-31.9506
116	BD67	-98.5683	-248.58
	BD78	-76.7947	-183.531
	BBC7	-61.8195	48.798
	BBC8	-90.0095	-6.76569

Table A5. 9 Most severe stresses for main pillars under normal landing conditions

LC No	Item	Sigxx [MPa]	Axial Force [kN]
101	PS1	-51.5707	51.029
	PS5	-51.2953	44.734
103	AP6	-108.743	-3.70999
	PS5	-52.0842	41.3864
104	AP6	-122.581	-65.7081
	AP7	-122.563	-64.7979

Table A5.9 continued

LC No	**Item**	**Sigxx [MPa]**	**Axial Force [kN]**
105	RP1	-59.2299	-146.195
	AP3	-36.1516	-90.8078
106	RP1	-60.2599	-153.395
107	PS4	-10.4202	-18.0831
108	AP4	-63.7407	-330.277
109	AP3	-42.0265	-103.104
	PS2	-61.8763	-10.1095
110	AP4	-54.5804	-355.304
	AP8	-73.8087	-171.357
111	P2	-53.4837	-747.515
	AP4	-56.6092	-229.958
112	PS2	-61.4068	-6.04597
113	P1	-67.8498	-848.806
	PS4	-12.4683	-23.8804
114	P1	-55.0349	-699.75
	AP3	-38.2575	-25.6068

Table A5.9 continued

LC No	Item	Sigxx [MPa]	Axial Force [kN]
114	PS4	-10.4755	-18.1913
115	AP5	-46.8619	-138.241
116	RP2	-61.1979	-151.379
	PS1	-54.1242	33.9319
	AP8	-42.6716	-97.3818

Table A5. 10 Most severe stresses for longitudinal stiffeners under accidental landing conditions

LC No	VonMises	VonMises [MPa]	Sigxx [MPa]	TauNxy [MPa]	TauNxz [MPa]
214	ST25	**110.7**	-24.3169	-1.85265	-59.1821
		90.9321	-75.5376	-2.65665	-25.9814
		46.4575	45.8465	-0.937543	-2.92811
	Normal Stress				
203	ST13	93.2821	-79.9025	1.41275	9.69816
		93.2821	**-79.9025**	1.41275	9.69816
		65.1377	**65.0919**	1.40978	0
	Shear Stress				
214	ST25	110.7	-24.3169	-1.85265	**-59.1821**
		90.9321	-75.5376	-2.65665	-25.9814
		46.4575	45.8465	-0.937543	-2.92811
209	ST22	74.1034	-3.49344	**-13.8803**	-25.1384
		62.2994	-45.6492	-9.34273	-13.6548
		63.845	63.7938	0	0

Table A5. 11 Most severe stresses for upper transverse girders under accidental landing conditions

LC No	Normal Stress	VonMises [MPa]	Sigxx [MPa]	TauNxy [MPa]	TauNxz [MPa]
210	UTG2	**92.1695**	-92.1694	0	0
		92.1695	**-92.1694**	0	0
		60.4274	60.4274	0	0
	Shear Stress				
213	UTG13	44.566	-11.6849	**20.2109**	3.96406
		35.8732	-35.8581	0	0
		18.2444	18.2146	0	0
215	UTG3	46.9445	2.02045	0	**26.5376**
		32.1603	-32.1541	0	0
		15.1921	15.0315	0	0

Table A5. 12 Most severe stresses for edge beams under accidental landing conditions

LC No	Normal Stress	VonMises [MPa]	Sigxx [MPa]	TauNxy [MPa]	TauNxz [MPa]
214	EB5	**134.528**	-134.438	0	0
		134.528	**-134.438**	0	0
		131.671	131.579	0	0
	Shear Stress				
210	EB4	50.6917	-11.1484	**-24.3086**	-0.25545
		38.103	-37.6039	0	0
		28.0755	27.3944	0	0

Local strengthening may be required in EB5. The maximum stresses occur at the edge of the beam where it crosses above UTG3 and UTG6. On the other hand, it can be regarded as hypothetical case because the wheels rest directly above the edge of the beam.

Table A5. 13 Most severe stresses for upper longitudinal girders under accidental landing conditions

LC No	Normal Stress	VonMises [MPa]	Sigxx [MPa]	TauNxy [MPa]	TauNxz [MPa]
213	ULG3	**157.924**	-157.924	0	0
		157.924	**-157.924**	0	0
		119.811	119.81	0	0
	Shear Stress				
203	ULG6	86.8064	-80.8204	0	**18.139**
		85.8859	-85.8856	0	0
		55.6848	55.6846	0	0

Table A5. 14 Most severe stresses for lower transverse girders under accidental landing conditions

LC No	Normal Stress	VonMises [MPa]	Sigxx [MPa]	TauNxy [MPa]	TauNxz [MPa]
216	LTG2	**218.269**	-218.266	0	0
		218.269	**-218.266**	0	0
		203.052	203.049	0	0

Table A5. 15 Most severe stresses for lower longitudinal girders under accidental landing conditions

LC No	Normal Stress	VonMises [MPa]	Sigxx [MPa]	TauNxy [MPa]	TauNxz [MPa]
216	LLG6	**177.213**	177.208	0	0
		131.108	-131.091	0	0
		177.213	**177.208**	0	0
	Shear Stress				
207	LLG3	141.107	132.381	0	**-27.9137**
		110.745	-110.739	0	0
		139.425	139.422	0	0

Table A5. 16 Most severe stresses for short pillars under accidental landing conditions

LC No	**Item**	**Sigxx [MPa]**	**Axial Force [kN]**
205	SB3	-101.108	-157.024
206	SB3	-157.047	-257.404
	SC2	-119.865	-5.74769
	SC6	-50.5059	14.5047
208	SC7	-140.909	-10.1973
	SC8	-169.17	-43.2152
	SC3	-55.6658	21.1062
210	SB6	-160.401	-238.318
	SC7	-124.772	17.8719
	SC3	-51.831	20.2751
211	SF6	-29.1288	-203.602
212	SF6	-28.6863	-189.127
213	SF6	-37.7874	-100.722
216	SB6	-169.287	-236.365
	SC7	-171.579	-16.1372
	SC8	-187.927	-20.2833
	SC3	-69.4078	18.6047
	SE6	-46.7004	-79.1088

Table A5. 17 Most severe stresses for main bracings under accidental landing conditions

LC No	Item	Sigxx [MPa]	Axial Force [kN]
203	BF56	-83.4881	-183.115
	BFG4	-87.652	-34.1949
207	BF56	-77.5236	-121.843
208	BBC6	-89.3579	-336.387
210	BBC6	-84.1906	-331.38
	BBC7	-105.408	-22.2801
	BBC8	-85.4841	-75.1152
213	BF23	-131.484	-192.689
	BFG4	-82.0783	-19.9785
	BEF3	-132.214	-529.87
	BFG3	-143.749	-542.492
214	BFG4	-91.7773	-40.8377
	BFG3	-122.14	-441.75
216	BD67	-140.903	-357.217
	BD78	-110.746	-264.873
	BBC6	-103.962	-344.298
	BBC7	-87.7509	71.0574
	BBC8	-129.94	-8.65142

Table A5. 18 Most severe stresses for main pillars under accidental landing conditions

LC No	**Item**	**Sigxx [MPa]**	**Axial Force [kN]**
202	PS1	-79.6952	57.2687
	PS5	-79.1747	58.7531
203	PS3	-80.358	11.3473
204	PS1	-79.3122	58.5154
	PS2	-81.4395	-6.25656
205	RP1	-85.8711	-192.795
	AP3	-46.9017	-135.501
206	RP1	-87.416	-203.596
207	PS4	-13.6625	-21.2493
208	AP4	-82.6054	-470.467
209	AP3	-52.2188	-150.499
	PS2	-92.2333	-12.1094
210	AP4	-67.8475	-503.684
	AP8	-110.04	-252.261
	PS2	-92.5228	-12.5964

Table A5.18 continued

LC No	**Item**	**Sigxx [MPa]**	**Axial Force [kN]**
211	P2	-78.0639	-1075.58
	AP4	-70.9007	-315.665
212	PS2	-91.5878	-6.26084
213	P1	-94.3359	-1182.52
	PS4	-16.842	-29.9453
214	P1	-75.4516	-958.935
	AP3	-50.0606	-37.6996
	PS4	-13.7455	-21.4117
215	AP5	-64.0253	-196.736
	AP7	-149.616	-184.691
216	AP8	-59.3012	-132.258
	RP2	-89.6137	-213.834
	PS1	-83.5254	43.0317

Table A5. 19 Most severe stresses for longitudinal stiffener under accidental stowed condition

LC No	Normal Stress	VonMises [MPa]	Sigxx [MPa]	TauNxy [MPa]	TauNxz [MPa]
323	ST19	71.2143	-20.5466	-1.70669	-36.5761
		69.2605	-69.2347	0	0
		68.0481	52.2184	-4.26514	-18.9248
	Shear Stress				
328	ST22	29.3436	-16.1121	-5.34048	-8.1023
		16.388	-16.374	0	0
		23.5817	23.5491	0	0

Table A5. 20 Most severe stresses for Upper transverse girders under accidental stowed condition

LC No	**Normal Stress**	**VonMises [MPa]**	**Sigxx [MPa]**	**TauNxy [MPa]**	**TauNxz [MPa]**
326	UTG14	**109.227**	-109.203	0	0
		109.227	**-109.203**	0	0
		58.2704	58.2454	0	0
	Shear Stress				
324	UTG7	30.3307	-7.96904	**14.6753**	0.721712
		30.0871	-29.9749	0	0
		20.2972	20.2953	0	0
326	UTG8	68.49	-35.9866	0	**33.5067**
		54.7636	-54.7613	0	0
		54.6395	54.6366	0	0

Table A5. 21 Most severe stresses for edge beams under accidental stowed condition

LC No	Normal Stress	VonMises [MPa]	Sigxx [MPa]	TauNxy [MPa]	TauNxz [MPa]
326	EB5	**125.846**	-125.81	0	0
		125.846	**-125.81**	0	0
		119.956	119.918	0	0
	Shear Stress				
316	EB8	59.9113	-17.9744	**-22.0063**	**-1.78389**
		58.9905	-56.7946	0	0
		44.7125	41.7726	0	0

Table A5. 22 Most severe stresses for upper longitudinal girders under accidental stowed condition

LC No	Normal Stress	VonMises [MPa]	Sigxx [MPa]	TauNxy [MPa]	TauNxz [MPa]
326	ULG3	**253.655**	-253.655	0	0
		253.655	**-253.655**	0	0
		150.192	150.192	0	0
	Shear Stress				
316	ULG6	118.658	-113.221	0	**20.1606**
		117.193	-117.192	0	0
		102.205	102.203	0	0

Table A5. 23 Most severe stresses for lower transverse girders under accidental stowed condition

LC No	Normal Stress	VonMises [MPa]	Sigxx [MPa]	TauNxy [MPa]	TauNxz [MPa]
306	LTG2	**194.513**	-194.511	0	0
		194.513	**-194.511**	0	0
		181.618	**181.615**	0	0
	Shear Stress				
313	LTG5	195.125	-54.0205	0	**1.9386**
		153.856	-153.856	0	0
		103.432	103.432	0	0

Table A5. 24 Most severe stresses for lower longitudinal girders under accidental stowed condition

LC No	Normal Stress	VonMises [MPa]	Sigxx [MPa]	TauNxy [MPa]	TauNxz [MPa]
329	LLG3	**313.761**	313.739	0	0
		273.833	-273.801	0	0
		313.761	**313.739**	0	0
	Shear Stress				
324	UTG7	254.422	239.75	0	**-48.9457**
		190.886	-190.885	0	0
		251.33	251.329	0	0

Table A5. 25 Most severe stresses for short pillars under accidental stowed condition

LC No	Item	Sigxx [MPa]	Axial Force [kN]
324	SB3	-224.463	-265.242
	SE3	-88.2564	-169.003
	SF6	-56.3398	-113.923
326	SB3	-252.379	-376.686
	SF6	-56.1217	-250.604
329	SB3	-226.455	-268.162
	SD3	-87.6589	-57.9754
	SE3	-87.3167	-171.429
	SF6	-56.3915	-113.637

Table A5. 26 Most severe stresses for main bracings under accidental stowed condition

LC No	**Item**	**Sigxx [MPa]**	**Axial Force [kN]**
306	BD23	-158.969	-392.88
	BBC1	-98.9211	-33.6036
	BBC7	-109.692	40.0306
	BBC8	-110.866	-17.5726
315	BB34	-122.497	-294.603
	BBC3	-148.755	-447.029
316	BFG4	-111.636	-39.6484
	BEF3	-187.987	-756.387
319	BBC6	-141.272	-434.689
320	BBC3	-151.139	-456.932
324	BB56	-164.31	-418.214
326	BD23	-184.588	-432.449
	BF23	-158.629	-192.633
	BEF4	-107.419	-17.0215
	BFG4	-117.318	-20.5568
	BEF3	-211.853	-857.293
	BFG3	-188.616	-640.798
	BBC1	-103.067	-28.2536
329	BB56	-163.32	-411.892

Table A5. 27 Most severe stresses for main pillars under accidental stowed condition

LC No	Item	Sigxx [MPa]	Axial Force [kN]
302	AP6	-298.082	3.65238
	AP7	-300.998	8.68344
303	PS1	-103.08	43.6546
	RP1	-109.408	-209.244
	PS2	-112.364	-8.59541
307	AP6	-297.753	3.3962
	AP7	-301.089	8.105
308	PS1	-99.9618	43.6027
313	AP2	-167.024	-171.113
	AP3	-160.648	-171.633
	PS1	-114.259	6.15978
	PS5	-108.518	29.4796
314	PS4	-25.9459	-60.6893
316	PS2	-111.418	-12.459
317	PS2	-111.352	-10.6836
318	AP2	-160.755	-478.551
	AP3	-160.66	-145.992
	PS1	-111.141	6.10792

Table A5.27 continued

LC No	Item	Sigxx [MPa]	Axial Force [kN]
318	PS5	-105.312	29.7488
320	AP1	-300.528	-670.882
322	AP6	-302.67	38.6632
323	RP1	-114.684	-297.459
324	AP4	-320.241	-698.967
	AP5	-95.8702	-93.9095
	PS4	-36.8588	-93.1878
	P1	-130.932	-1320.66
326	AP5	-90.0103	-204.811
	P1	-137.619	-1689.46
327	AP6	-302.341	38.407
328	RP1	-113.27	-296.644
329	AP4	-321.278	-703.389
	AP5	-96.1321	-95.0229
	PS4	-36.846	-93.1565
	P1	-131.059	-1321.3

A6. Buckling Check

The critical buckling stress of slender member is calculated by using Equations **(5.9)** and **(5.10)**. The axial load is checked by Equation **(5.10)**. The structural members are categorized depending on length and sectional properties as shown in Table A6. 1 and Table A6. 2.

Table A6. 1 Critical buckling stress and allowable axial load for short columns and pillars

Category	Tag	Length [m]	Sectional Properties	σ_c (Acc) [MPa]	P (Acc) [kN]	σ_c (Land) [MPa]	P (Land) [kN]
1	SB3, SB4, SB5, SB6, SC1,SC2,SC4, SC5,SC7, SC8 SD1,SD2,SD4, SD5,SD7, SD8 SE1,SE2,SE4, SE5,SE7, SE8 SF1,SF2,SF4, SF5,SF7, SF8 SG2, SG3, SG4, SG5, SG6,SG7	2.5	CHS_219_1x5	302	534	201.33	356
2	SC3, SC6 SD3, SD6 SE3, SE6	2.5	CHS_219_1x10	391	1036	260.67	690.67
3	SF3, SF6	2.5	CHS_219_1X12_5	301	1274	200.67	849.33
4	P1, P2	7.68 (only length above captain deck)	CHS_323_9 x 20	277	2163	184.67	1442
5	RP1, RP2	8.85	CHS_244_5x12_5	177	545	118.00	363.33
6	AP1, AP4	1.15	CHS_323_9x25	352	1957	234.67	1304.7
7	AP2,AP3	1.15	CHS_323_9x20	353	5236	234.67	3490.7
8	AP5,AP8	3.384	CHS_244_5x12_5	329	1486	219.33	990.7

Table A6.1 continued

9	AP6,AP7	0.934	CHS_219_1x5	355	739	236.67	492.7
10	PS1,PS5	4.8	CHS_219_1x5	294	423	196.00	282
11	PS3,PS4	6.62	CHS_219_1x5	238	299	158.67	199.3
12	PS2	9.12	CHS_219_1x5	142	152	94.67	101.3

Table A6. 2 Critical buckling stress and allowable axial load for main bracings

Category	Tag	Length [m]	Sectional Properties	σ_c (Acc) [MPa]	P (Acc) [kN]	σ_c (Land) [MPa]	P (Land) [kN]
13	BB34, BB56 BD34,BD56 BF34,BF56	3.65	CHS_219_1x5	319	507	212.67	338
14	BD12, BF12 BD78, BF78 BD23, BF23 BD67,BF67 BBC4,BBC5	3.3	CHS_219_1x5	326	534	217.33	356
15	BCD1,BDE1,BEF1 BCD2,BDE2,BEF2,BFG2 BCD4,BDE4,BEF4,BFG4 BCD5,BDE5,BEF5,BFG5 BCD7,BDE7,BEF7,BFG7 BCD8,BDE8,BEF8	3.5	CHS_219_1x5	322	519	214.67	346
16	BCD3,BDE3,BEF3,BFG3 BCD6,BDE6,BEF6,BFG6	3.5	CHS_219_1x10	321	1002	214.00	668
17	BG3, BG4, BG5, BG6 BBC3, BBC6	3.4	CHS_219_1x10	323	1017	215.33	678
18	BBC1, BBC2, BBC7, BBC8	3.5	CHS_219_1x5	322	519	214.67	346

A7. Helicopter Limitation List (HLL) [1]

According to UK's HCA, there are certain limitations applied to operational condition of helicopter on offshore platforms and ships. The limitations are based on the category of platforms. Three categories are dived as follows:

- Category 1 : Mobile offshore drilling units such as FPSO's with good visual references
- Category 2: Vessels with stern or mid-ships mounted helidecks giving good visual references
- Category 3: Vessels with bow mounted helidecks with poor visual references

In addition to these, helicopters are classified as Category A (heavy) and B (medium); and the list is shown in

Table A7. 1 Types of helicopter according to UK's HCA

Type	D Value	't' Value	Category
S61	22.2	9.3	A
S92	20.88	12.0	A
EC225	19.5	11.0	A
AS332L2	19.5	9.3	A
AS332L	18.7	8.6	A
Bell214ST	18.95	8.0	A
Bell412	17.13	5.4	B
Bell212	17.46	5.1	B
AW139	16.6	6.8	B
S76	16.00	5.3	B
EC155	14.3	4.9	B
AS36 5N/N2/N3	13.68	4.3	B
EC135	12.0	2.7	B
A109	12.96	2.6	B

Table A7. 2 Summary of HAC's Pitch, Roll and Heave Limitations

AIRCRAFT		HELIDECK CATEGORY											
		1				2				3			
		P/R	*INC*	*H/R*	*H/A*	*P/R*	*INC*	*H/R*	*H/A*	*P/R*	*INC*	*H/R*	*H/A*
Heavy	Day	±3	3.5	1.3	5.0	±2	2.5	1.0	3.0	±2	2.5	1.0	3.0
	N	±3	3.5	1.0	4.0	±2	2.5	0.5	1.5	±1	1.5	0.5	1.5
Medium	Day	±4	4.5	1.3	5.0	±3	3.5	1.0	3.0	±3	3.5	1.0	3.0
	N	±4	4.5	1.0	4.0	±2	2.5	0.5	1.5	±1.5	2.0	0.5	1.5

where: *P/R* = Pitch and Roll (deg); *INC* = Helideck inclination (deg); *H/R* = Heave Rate (ms^{-1}); *H/A* = Heave Amplitude (metres) i.e. peak to trough distance.