Structural Design and Stability of a 6,000 ton Capacity Floating Dock as per DNV-GL Rules

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LIST OF SYMBOLS & ABBREVIATIONS

A_g - Gross cross-sectional area of member (mm^2)
A_{gv} - Gross area subject to shear (mm^2)
A_n - Net cross-sectional area of member (mm^2)
A_{nv} - Net cross-sectional area of member (mm^2)
B - Breadth or beam (m)
BM_L - Longitudinal metacentric radius (m)
BM/ BM_T - Transverse metacentric radius (m)
C_f - Slenderness coefficient for the flange plate
CL - Centreline
CoG - Centre of Gravity
C_w - Slenderness coefficient for the web plate
D - Depth (m)
d_h - Bolt hole diameter (mm)
FEA - Finite Element Analysis
F_y - Yield strength (N/mm^2)
F_u - Ultimate strength (N/mm^2
g - Acceleration due to gravity (m/s^2)
GM_l - Longitudinal metacentric height (m)
GM/ GM_t - Transverse metacentric height (m)
GZ - Righting arm/ righting lever (m)
h_s - Vertical distance from the load point to the top of the tank (m)
I - Moment of inertia (mm^4/ cm^4/ m^4)
LCB - Longitudinal Centre of Buoyancy
LCG - Longitudinal Centre of Gravity
k - Effective length constant (slenderness check)
k_a - Correction factor for aspect ratio of plate field
L or l - Span or length of the member (m)
L_D - Length of the dock (m)
m - Bending moment factor
f_1, f_2 - DNVGL material factors
r - Radius of gyration (m)
R_{eh} - Minimum yield stress in N/mm^2

s - Spacing (mm)

s_w - Spacing of web stiffeners (mm)

T - Draught (m)

t - Thickness (mm)

TCG - Transverse Centre of Gravity

t_{gross} - Gross thickness (mm)

t_k - Corrosion allowance (mm)

t_{net} - Net thickness (mm)

t_p - Thickness of plate (mm)

t_w - Thickness of web (mm)

t_f - Thickness of flange (mm)

VCG - Vertical Centre of Gravity

Z - Section modulus (cm^3)

σ - Stress (N/mm^2)

σ_{av} - Average axial compressive stress (N/mm^2)

σ_{cr} - Minimum critical buckling stress (N/mm^2)

Δ - Displacement (t)

TERMS AND DEFINITIONS

i. The *light displacement* of the dock is its complete weight including all machinery, lifting appliances, equipment, full supply of consumables for operation of the dock (fuel oil, fresh water etc.), compensating ballast water (if necessary) and rest-water.

ii. The *rest-water* is remaining ballast water which the pumps cannot discharge.

iii. The *compensating ballast water* is ballast water for reduction of stresses and deflections in the dock structures and for adjustment of the trim and heel of the dock.

iv. The *pontoon bottom* is the bottom of the pontoon structure.

v. The *pontoon deck* is the deck of the pontoon structure supporting the docking blocks.

vi. The *safety deck* is a watertight deck in the wing walls, located at such distance below the upper deck as to provide a satisfactory freeboard to upper deck when all compartments below the safety deck are flooded, but with no load on the docking blocks.

ABSTRACT

This thesis work is focusing on the design and analysis of a Floating Dry Dock complying with DNV-GL Rules with emphasis on the structural design and stability. The mentioned work was carried out during the internship in Nelton Sp. z o.o. located in Szczecin from July 3 till November 8 in the year 2017.

Floating Dry Docks are being widely used for the construction of ships, docking of ships for inspection and repairs and also for ship launching. One of the major advantage of floating dry docks from the graving docks is mobility. And a floating dry dock doesn’t require any yard space. Floating dry docks are built to different lifting capacities, and there are different types of designs available as well based on the requirements. With the requirement for a pontoon type floating dry dock with 5 modules of pontoons and 2 dock wings which can be dismantled, the design is carried out for the same with an appropriate connection between the pontoons and the wing tanks.

Just like any other structure, the safety is of prime concern and hence various classification societies developed rules for the design of floating dry docks with regard to the structural design, stability, machinery, other safety and protection systems and survey requirements. Current work is based on the rules developed by DNV-GL.

With a stability check based on approximated weights available, the work carried out involves the global structural design, with adequate connections between different modules. With structural design in place, more or less actual weights of the structure is calculated and then the stability check is done based on that. Based on a feasibility check, the capacity and dimensions of this floating dry dock is found suitable for the construction of all the types of submarines which are currently under consideration by the Polish Navy.

Keywords: floating dry-docks/ floating docks, design, docking, structure, load, stability, ballast

1 INTRODUCTION

1.1 General

A dry-dock is a narrow basin or a vessel which can be flooded to make a marine craft resting on the docking blocks on it to float and vice versa, i.e., water can be drained off by some mechanism to make the structure rest on the docking blocks. These can be used for the construction and repair of ships by docking and then by floating. This thesis work involves the structural design and stability of a floating dry-dock. Floating dry-dock as the name suggests, itself is floating. Since it is a floating structure, it works on controlled buoyancy to lift any structure out of water for any kind of repair works or inspections. It needs to be stable floating, carrying the intended load during the docking operations and should also have the strength to withstand the intended loads.

Floating dry-docks are generally U-shaped or channel like structures, with less complex geometry. The common structure is pontoon type consisting of water tight chambers, the pontoon and wing walls. The draft of the floating dock is adjusted by controlling the water ballast during the docking operations.

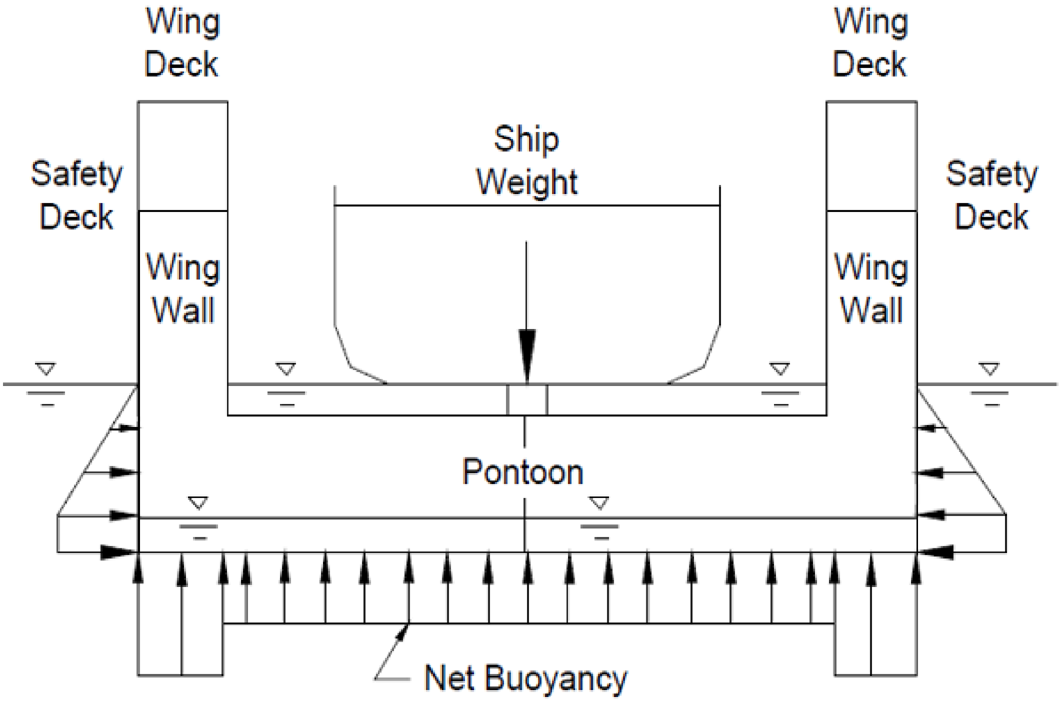


Figure 1: Floating dry dock components

Source: Dock Master Training Manual, Heger Dry Dock Inc.

There are different types of floating dry-docks based on the structural assembly mainly the unit dock which has continuous wing walls and pontoon, the composite dock which has sectional pontoon but the wing walls are continuous and the sectional dock which is made up of different longitudinal sections and without longitudinal structural continuity.

The structure can be made of materials like steel, concrete, timber, etc. different classification societies have developed rules regarding the design of floating dry docks. The floating docks are not designed for harsh environments. These are normally designed to be operated close to the harbour and mobility is also possible. These can be used for salvage operations also. As the main purpose of these structures is not related to transport, these are normally not provided with any propulsion units, neither the structural hull is designed in a way to enhance smoother movement. But these can be towed to the required locations and is one of the advantages of the floating docks. As the structure is floating these experience motions due to the wind and currents. So proper mooring arrangement is required for the dock. The hull, machinery, electrical installations, etc. are covered by class certification but the mooring system has to be considered separately.

The dock construction should consider water-tight compartments. Most of these tanks will be used for water ballast. Ballasting is needed to get immersion of the dock to ensure free movement of the vessel to be docked on to the docking space. The compartment and spaces are designed based on the requirements of intact and damage stability, and also considering an economical pumping system to easily attain the trim and list desired.

1.2 Project Inputs

The basic inputs to the design include the type and geometry, main dimensions, and capacity of the dock. The main dimensions have been fixed based on a concept stability analysis performed by Nelton. A number of typical offshore vessel types have been analysed for the dimensions and capacities and the dock dimensions have been fixed based on the feasibility of docking those vessels. The dock dimensions like the internal width and the length are decided purely based on the maximum dimensions of the vessels intended to be docked with enough space for access around. But the width of dock wings and the depth of pontoon was decided based on the stability requirements of the dock. The height of the dock wing is influenced by the draft of the vessel to be docked. A concept GA developed was also provided which helps understand the geometry and the various space arrangements. The basic inputs to the structural design are listed below. The given data and GA has been used to develop the structural design.

Table 1: Main Particulars

Design	Floating Dock
Type	Sectional Pontoon Type
Material	Steel
Capacity	6,000 tons
Length Overall	92.4 m
Width Overall	30 m
Width Inside	23 m
Depth Overall	15 m
Depth of Pontoon	4.5 m
Minimum Draught	1.69 m
Maximum Loaded Draught	13.5 m
Class	DNV-GL

1.3 Objectives

The main objective of the work is to design and analyse the floating dry dock structure and to check the stability criteria. The overall work break down is listed below:

i. Design the structural scantlings based on DNV-GL Rule requirements,

ii. Estimation of the weights and CoG,

iii. Global/ local strength analysis of the structure in docking,

iv. Design the connection concepts between the continuous wing tanks and sectional pontoons,

v. Check for stability,

vi. Feasibility study considering the proposed submarine projects for the Polish Navy.

1.4 Outline of the Work

This thesis work for the design of a floating dry-dock is based on the inputs provided by design company Nelton Sp. z.o.o., Szczecin. A concept GA was provided by Nelton along with the preliminary stability checks based on which this work is developed. With the available inputs on the main dimensions, the scantlings are calculated based on the DNV-GL requirements and based on the assumed spacing and span of members.

For structural sections, the required section moduli are calculated and the sections are chosen higher than the minimum required calculated from the class requirements. With the calculated scantlings and sticking to the GA, the structure is modelled to perform the various Finite Element Analysis. DNV-GL guidelines has been referred to and followed in the modelling and FEA. The results from the FEA are verified with the general conditions given in DNV-GL rules. The reactions at the connections between the pontoons and the wing walls are obtained from the FEA which is further used to design the connection details. Based on the FEA, the scantlings are finalised, and a weight report is prepared, capturing the steel weight and other major weights with enough contingency level. The hull and tanks are modelled in maxsurf and a stability check for the various required conditions of draft are then performed. To have a better representation of the resulting design, a 3D model is then developed in Rhino3D.

1.5 Case Study

The structure consists of 5 sections of pontoons of maximum external dimensions 30m x 18m x 4.5m each. The assembly of the dry dock is as such, the 30m length of pontoon will be the breadth of the dry dock assembly. The pontoons are arranged with 600mm spacing between each and the pontoon decks will be connected to the dock wings through suitable bolting arangement and there is no direct strength connection between the pontoons. Hence the pontoon girders will be taking part in the transverse strength of the dry dock. As is the case, the global transverse bending will be much critical for each pontoon and the global longitudinal bending will be influenced by the dock wing structure.

This drydock is meant for operation in the harbor for the dry docking of ships for inspection, repairs or even new building of ships. In fact the design assumes the docks port of operation is sheletered against waves. As such any dynamic pressure resulting from wave actions has not been considered in the design. A very basic design is performed considering only normal operating conditions.

Strength and stability are equally important for the smooth operation of a dry dock. Rather than the integrity of the structure, special care has to be taken always while performing the docking and undocking operations and needs to have personnel with good expertise to perform such operations. Considering the very basic case, the most critical loadings that act on the structure other than the selfweight would be the hydrostatic pressure, the load from the tank fluids and the maximum capacity docking load. While the former are distributed loads over the exposed structural area, the latter can be considered linearly distributed along the length of the dock and the loading is along a critical location which enhances the bending, that is along the centerline or centre of the beam of the dry dock. There occurs the longitudinal bending and transverse bending as well, which would create strain in the structure and results in stresses. In order to reduce the stresses. The deflection has to be reduced and for that either the structure has to be strengthened or arrangements have to be modified or capacity is to be reduced which is not the desired solution. The stress and deflection are related and there is the maximum deflection associated with the allowable or design stresses. So in the docking operation, the deflections are monitored to ensure that the limit is not reached. This is the basic ideology behind the structural design of the floating dry dock.

1.6 Literature Review

In order to carry out the work a lot of references were sourced which are closely related to the work to be done. Several of those include the operational aspects, testing aspects, and also design aspects.

Volney E. Cook (1957, [1]) has presented a paper which summarizes the history and development of the floating drydocks in terms of design, construction, operation and maintenance. In his paper, he gives an overview of the earlier methods used in drydocking of vessels with all the advantages and disadvantages and the reason why there was an increase in the need for floating dry-docks. His paper is more on to the operational aspects, and it is very important to know the exact operational requirements before the designing of such structures.

This paper is found to be very useful and informative and one of the earliest of such publications related to the floating dry-docks.

Arsham Amirikian (1957, [2]) in his paper presents useful data and guidelines on the design of floating dry-docks. A first look in to the conventional approach and then a detailed discussion is given on the most advanced concepts of analysis of that time. Arrangements and framing details are provided for steel-framed structure and as well as concrete and timber structures. And this paper could be a useful reference considering the design aspects for the design of the floating dock.

Helmut J. Warnke (1973, [3]) in his paper describes the way in which the installation of a new 33,000 ton floating dock enabled Jacksonville Shipyards, Inc., of Jacksonville, Florida greatly to enlarge their service and repair capacity. In this paper he explains the considerations which were taken in to account to decide the type of floating dock like the expenditure, ease of construction, towage from the construction yard to the intended location, etc. the details on the load testing of the dock is described and the details of the design and various installations on that floating dock are also detailed. The tests and trials performed are also included. These are important information to be kept in mind while designing.

Paul Stuart Crandall (1974, [4]) in his paper has focused on large floating docks for large ships. Due to the vast changes in the worldwide Shipping and introduction of a number of large cargo vessels during those times, he talks about the importance of having new ways of building, launching and accommodating new ships. He talks about the overall advantages of having floating docks for large vessels. The various aspects he has discussed in his paper are helpful in coming up with an efficient design.

B. Rapo (1981, [5]) in his paper presents a short review of the various types of drydocking facilities. He discusses the different docking circumstances and also the causes of damages during docking. The criteria to be fulfilled to prevent these damages are also summarized. His paper focuses on block loadings and the ship strength and dock type considerations. The importance of stability during docking is also discussed.

Brandon M. Taravella (2003, [6]) in his paper presents the method for accurately predicting the block reactions in case of dry docking. He discusses the method presented by Paul S. Crandall (called as Crandall's trapezoidal method), calculates the results for an existing dry-docked vessel. This result is compared with the computational methods like FEM by Euler beam theory and Timoshenko beam theory. He also takes actual measurements. From his comparisons of the various results obtained, he concludes that FEM by Timoshenko method is superior in predicting the block reactions, but the FEM by Euler beam theory can also be applied with a correction factor for the blocks at the aft and forward overhangs of the vessel. It is important have a better idea of the various block reactions at various points, so that the structure can be designed considering the maximum probable loads at each of those locations.

Tyler Morra (2011, [7]) in his Master thesis, explains in detail, the evolutionary development of floating dry-docks. His research covers the primitive floating dry-docks and the technological developments and the needs that brought about those developments. His studies is based on the earliest available articles on floating docks. He does an analysis of the floating dock facility from the earliest known type to the latest ones. The various issues and the reason for the advancements are also studied.

Heger Drydock Inc. (2015, [8]) in the document issued on the vessels transfer concepts describes the various methods which can be used for the transfer of vessel from on and off the dock and the shore. Various provisions will have to be provided for different methods and the type of method used also depends on the total load to be handled. This information would be useful in recommending the ideal method and also do a strength analysis considering the same concept.

Valery V. Korotaev, Anton V. Pantiushin, Mariya G. Serikova, Andrei G. Anisimov (2016, [9]) in their article details different deflection measuring systems on floating dry-docks. They have developed a camera-based system and is explained in this paper. They give some insight in to the various deflections occurring on the floating dry-docks. More specifically it is the new method developed for measuring, which they have explained in this paper. Though this is not design related paper, the information is useful considering the importance of deflection control in floating dry-docks.

1.7 Calculation and Design Tools

Various calculation and design tools are used in this thesis work. Spreadsheet calculations are developed for the scantlings design, built-up sections check, weight calculation, etc. A trial version of FEMAP with NX NASTRAN solver is used for the FEA, RHINO3D is used for the modelling and MAXSURF is used for the stability calculations.

2 SCANTLINGS DESIGN

2.1 General

The scantlings design is based on DNV-GL Rules for Floating Dry-docks. The minimum required scantlings are estimated here. The calculations are based on the various formulae developed by DNV-GL. The structure is made up of stiffened plates with frames and girders providing the transverse and longitudinal strength respectively. The scantling calculation in general for the case of subject floating dry dock can be divided in to the pontoon structure scantlings and the dock wing structure scantlings. The pontoons are longitudinally framed which in the assembly be transversely framed structure. The dock wings are longitudinally framed and in the assembly too it act as longitudinally framed.

- → The type of structure: Pontoon type with 5 pontoons connected to 2 wing structures which can be dismantled,
- → Material of construction: The hull structure is to be made of mild steel of minimum yield strength 235MPa. The materials used has to comply with Pt.2 Ch.2 of the DNV-GL Rules for Classification of Ships,
- → Main dimensions: The main dimensions of the structure including the minimum and maximum drafts as mentioned in section 1.2,
- → Frame spacing and span of members: Frame spacing is assumed as 600mm and the span of different members assumed as well,

Using the above basic details, various other parameters are assumed or calculated using the formulae given in the rules.

2.2 Geometry

The scantling calculation is based on the geometry of the structure represented in the figures 2 to 7. Figure 2 shows the various deck levels, figure 3 is a 3D geometry of the dock as per the GA provided. Specific details needed in the scantling calculation are mentioned in figures 4, 5, 6 and 7.

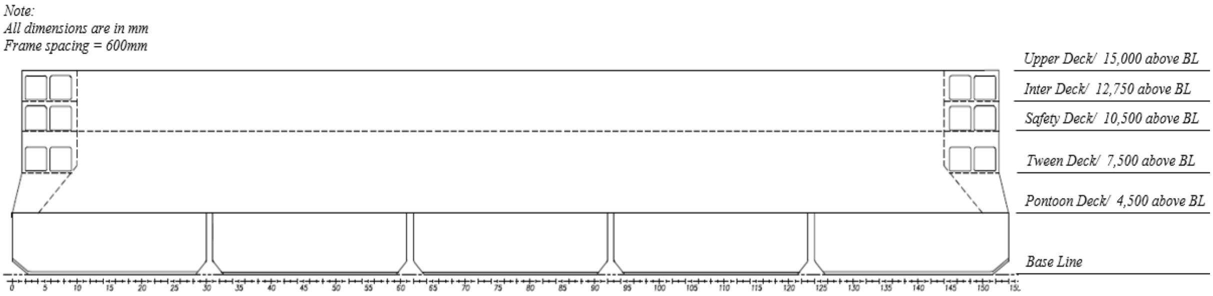

Note:
All dimensions are in mm
Frame spacing = 600mm

Figure 2: A generic sketch of the floating dock profile view

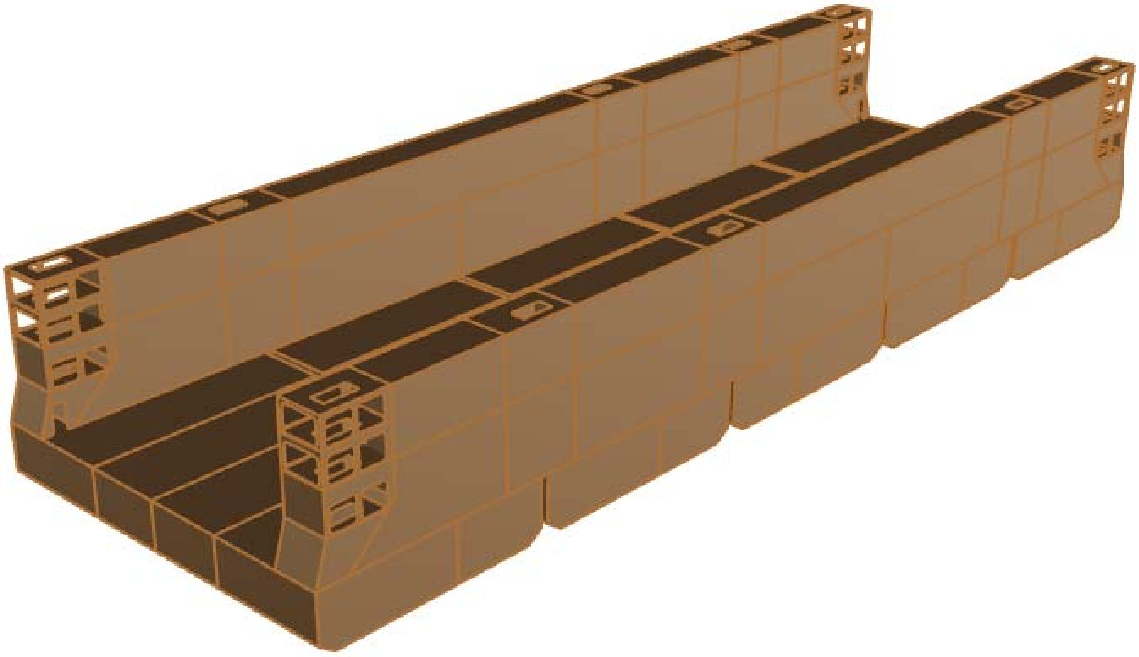


Figure 3: 3D Geometry

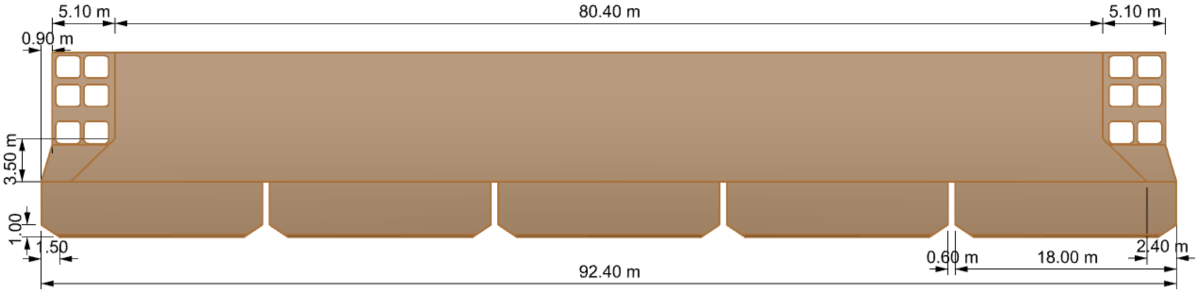


Figure 4: Profile view

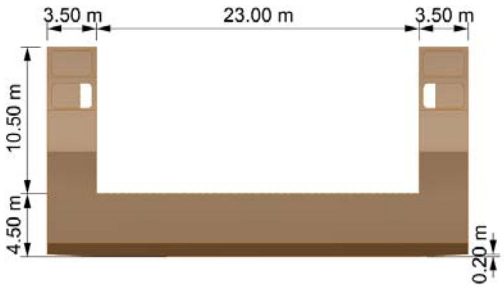


Figure 5: End view

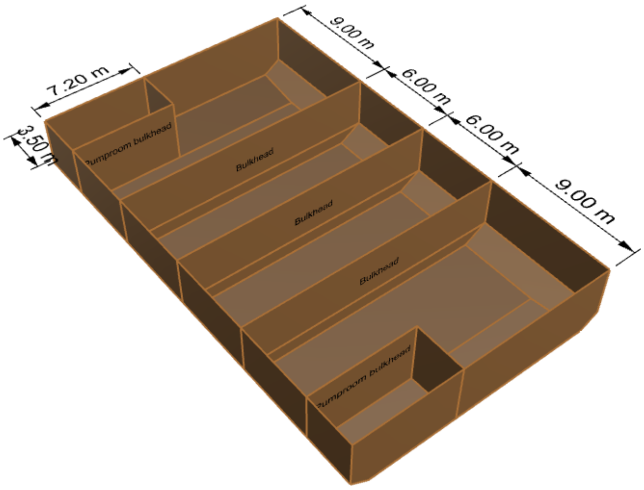


Figure 6: Typical pontoon structure arrangement

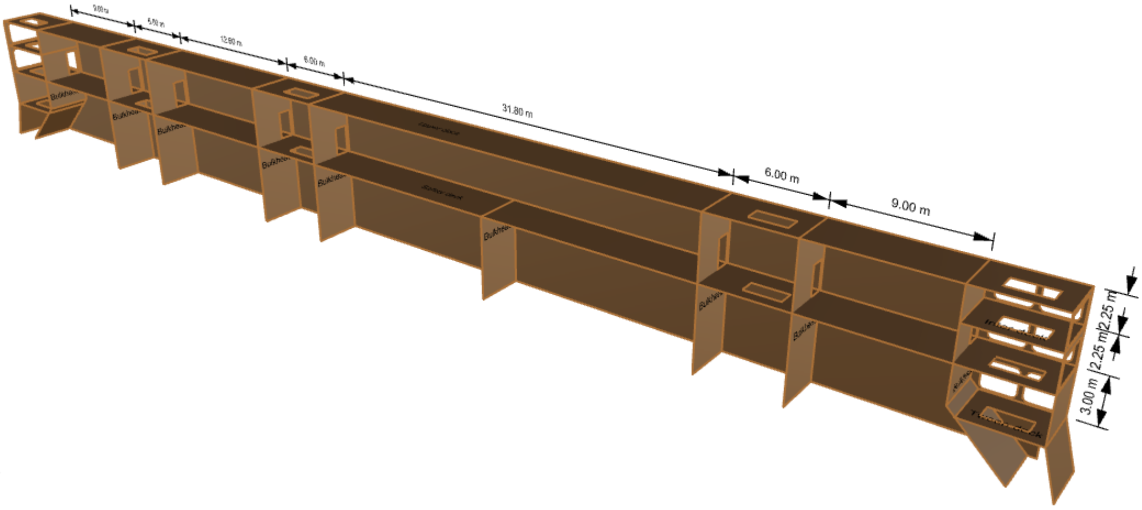


Figure 7: Typical dock wing structure arrangement

The geometry of a typical pontoon and a typical dock wing structure are given in figure 6 and 7. The longitudinal strength for the dock is imparted through the continuous dock wings. Each sectional pontoon of length 30m and width 18m are arranged as such the length of the pontoon makes the width of the dock. The longitudinal girders of the pontoons impart transverse strength to the dock. In the scantlings design, pontoon girders refer to the longitudinal girder of the pontoon which is transversely arranged in the dock assembly and the web frames vice versa.

2.3 Pontoon Structure

2.3.1 Plating

The minimum plating thickness at any location is given by DNVGL-RU-FD-Sec. 7.3.1.1

$$t = s\sqrt{\frac{L_D}{f_1}}\ (mm) \tag{1}$$

Minimum yield strength chosen as 235 MPa, hence $f_1 = 1.0$

$$t = 5.8\ mm$$

2.3.2 Bottom Plating

The minimum bottom plate thickness is calculated as per DNVGL-RU-FD-Sec. 7.3.1.2

$$t = 15.8k_a s\sqrt{\frac{P}{\sigma}} + t_k\ (mm) \tag{2}$$

$$s = 0.6\ m;\ l = 1.5\ m; t_k = 3\ mm;\ h_s = 13.55\ m,\ f_1 = 1.0$$

$$\frac{s}{l} = 0.4$$

$$k_a = (1.1 - 0.25\frac{s}{l})^2 = 1\ (min. 0.72, max. 1.0)$$

$$P = \rho g h_s = 136.25\ kPa$$

$$\sigma = 160f_1 = 160\ MPa$$

$$\therefore t = 11.75\ mm$$

Bottom plate of thickness **12 mm** and yield strength **235 MPa** is chosen.

2.3.3 Deck Plating

The minimum deck plate thickness is calculated as per DNVGL-RU-FD-Sec. 7.3.1.2

$$t = 15.8k_a s\sqrt{\frac{P}{\sigma}} + t_k\ (mm) \tag{3}$$

$$s = 0.6\ m;\ l = 1.5\ m; t_k = 3\ mm;\ h_s = 9.05\ m,\ f_1 = 1.0$$

$$\frac{s}{l} = 0.4$$

$$k_a = (1.1 - 0.25\frac{s}{l})^2 = 1\ (min. 0.72, max. 1.0)$$

$$P = \rho g h_s = 91\ kPa$$

$$\sigma = 160 f_1 = 160\ MPa$$

$$\therefore t = 10.15\ mm$$

Deck plate of thickness **12 mm** and yield strength **235 MPa** is chosen.

2.3.4 Side Plating

The minimum side plate thickness is calculated as per DNVGL-RU-FD-Sec. 7.3.1.2

$$t = 15.8 k_a s \sqrt{\frac{P}{\sigma}} + t_k\ (mm) \tag{4}$$

$$s = 0.6\ m;\ l = 1.8\ m\ (max.); t_k = 3\ mm;\ h_s = 11.3\ m,\ f_1 = 1.0$$

$$\frac{s}{l} = 0.33$$

$$k_a = (1.1 - 0.25\frac{s}{l})^2 = 1\ (min. 0.72, max. 1.0)$$

$$P = \rho g h_s = 113.63\ kPa$$

$$\sigma = 160 f_1 = 160\ Mpa$$

$$\therefore t = 10.99\ mm$$

Side plate of thickness **12 mm** and yield strength **235 MPa** is chosen.

2.3.5 Bulkhead Plating (longitudinal)

The minimum bulkhead plate thickness is calculated as per DNVGL-RU-FD-Sec. 7.5.2.1

$$t = 15.8 k_a s \sqrt{\frac{P}{\sigma}} + t_k\ (mm) \tag{5}$$

$$s = 0.6\ m;\ l = 1.8\ m\ (max.); t_k = 3\ mm;\ h_s = 2.25\ m,\ f_1 = 1.0$$

$$\frac{s}{l} = 0.0.33$$

$$k_a = (1.1 - 0.25\frac{s}{l})^2 = 1\ (min. 0.72, max. 1.0)$$

$$P = 10(h_s + 2.5) = 47.5\ kPa$$

$$\sigma = 120 f_1 = 120\ Mpa\ (min.)$$

$$\therefore t = 8.96\ mm$$

So pontoon bulkhead plate of thickness **10 mm** and yield strength **235 MPa** is chosen.

2.3.6 Bottom Girder

The minimum section modulus of the bottom girder is calculated as per DNVGL-RU-FD-Sec. 7.3.2.1

$$Z = \frac{1000}{\sigma m} l^2 spw_k \ (cm^3) \tag{6}$$

$$s = 1.8\,m;\ l = 4.0\,m\ (max.); t_{kw} = 3\,mm;\ t_{kf} = 3\,mm; h_s = 13.55\,m;\ f_1 = 1.39;$$

$$m = 10$$

$$w_k = 1 + 0.05(t_{kw} + t_{kf}) = 1.3$$

$$P = \rho g h_s = 136.25\,kPa$$

$$\sigma = 160 f_1 = 222.4\,MPa$$

$$\therefore Z = 2294\,cm^3$$

A T- section of the following dimensions and yield strength **355 MPa** with combined section modulus of **2364 cm^3** is chosen.

$web\ height = 380\,mm; web\ thickness = 12\,mm$

$flange\ width = 250\,mm; flange\ thickness = 20\,mm$

2.3.7 Bottom Frame

The minimum section modulus of the bottom frame is calculated as per DNVGL-RU-FD-Sec. 7.3.2.1

$$Z = \frac{1000}{\sigma m} l^2 spw_k \ (cm^3) \tag{7}$$

$$s = 1.5\,m;\ l = 1.8\,m\ (max.); t_{kw} = 3\,mm;\ t_{kf} = 3\,mm; h_s = 13.55\,m;\ f_1 = 1.39;$$

$$m = 10$$

$$w_k = 1 + 0.05(t_{kw} + t_{kf}) = 1.3$$

$$p = \rho g h_s = 136.25\,kPa$$

$$\sigma = 160 f_1 = 222.4\,MPa$$

$$\therefore Z = 387\,cm^3$$

A T- section of the following dimensions and yield strength **355 MPa** with combined section modulus of **658 cm^3** is chosen.

$web\ height = 240\,mm; web\ thickness = 12\,mm$

$flange\ width = 100\,mm; flange\ thickness = 16\,mm$

2.3.8 Bottom Stiffeners

The minimum section modulus of the bottom stiffener is calculated as per DNVGL-RU-FD-Sec. 7.3.2.1

$$Z = \frac{1000}{\sigma m} l^2 s p w_k \ (cm^3) \tag{8}$$

$$s = 0.6\,m;\ l = 1.5\,m\ (max.); t_{kw} = 3\,mm;\ h_s = 13.55\,m;\ f_1 = 1.0; m = 10$$

$$w_k = 1 + 0.06 t_{kw} = 1.18$$

$$p = \rho g h_s = 136.25\,kPa$$

$$\sigma = 160 f_1 = 160\,MPa$$

$$\therefore Z = 136\,cm^3$$

A bulb- section of **160x11.5 mm** and yield strength **235 MPa** with combined section modulus of **146 cm^3** is chosen.

2.3.9 Deck Girder

The minimum section modulus of the deck girder is calculated as per DNVGL-RU-FD-Sec. 7.3.2.1

$$Z = \frac{1000}{\sigma m} l^2 s p w_k \ (cm^3) \tag{9}$$

$$s = 1.8\,m;\ l = 4.0\,m\ (max.); t_{kw} = 3\,mm;\ t_{kf} = 3\,mm; h_s = 9.05\,m;\ f_1 = 1.39; m = 10$$

$$w_k = 1 + 0.05\left(t_{kw} + t_{kf}\right) = 1.3$$

$$p = \rho g h_s = 91.00\,kPa$$

$$\sigma = 160 f_1 = 222.4\,MPa$$

$$\therefore Z = 1532\,cm^3$$

A T- section of the following dimensions and yield strength **355 MPa** with combined section modulus of **2147 cm^3** is chosen.

$web\ height = 350\,mm; web\ thickness = 12\,mm$

$flange\ width = 250\,mm; flange\ thickness = 20\,mm$

2.3.10 Deck Frame

The minimum section modulus of the deck frame is calculated as per DNVGL-RU-FD-Sec. 7.3.2.1

$$Z = \frac{1000}{\sigma m} l^2 spw_k \ (cm^3) \tag{10}$$

$$s = 1.5\ m;\ l = 1.8\ m\ (max.);\ t_{kw} = 3\ mm;\ t_{kf} = 3\ mm;\ h_s = 9.05\ m;\ f_1 = 1.39;\ m = 10$$

$$w_k = 1 + 0.05(t_{kw} + t_{kf}) = 1.3$$

$$p = \rho g h_s = 91.00\ kPa$$

$$\sigma = 160 f_1 = 222.4\ MPa$$

$$\therefore Z = 259\ cm^3$$

A T- section of the following dimensions and yield strength **355 MPa** with combined section modulus of **531 cm^3** is chosen.

$web\ height = 220\ mm; web\ thickness = 12\ mm$

$flange\ width = 100\ mm; flange\ thickness = 16\ mm$

2.3.11 Deck Stiffeners

The minimum section modulus of the deck stiffener is calculated as per DNVGL-RU-FD-Sec. 7.3.2.1

$$Z = \frac{1000}{\sigma m} l^2 spw_k \ (cm^3) \tag{11}$$

$$s = 0.6\ m;\ l = 1.5\ m\ (max.);\ t_{kw} = 3\ mm;\ h_s = 9.05\ m;\ f_1 = 1.0;\ m = 10$$

$$w_k = 1 + 0.06 t_{kw} = 1.18$$

$$p = \rho g h_s = 91.00\ kPa$$

$$\sigma = 160 f_1 = 160\ MPa$$

$$\therefore Z = 91\ cm^3$$

A bulb- section of **140x10 mm** and yield strength **235 MPa** with combined section modulus of **99 cm^3** is chosen.

2.3.12 Side Frame

The minimum section modulus of the side frame is calculated as per DNVGL-RU-FD-Sec. 7.3.2.1

$$Z = \frac{1000}{\sigma m} l^2 spw_k \ (cm^3) \tag{12}$$

Dock port and starboard sides:

$$s = 1.8\ m;\ l = 3.7\ m\ (max.);\ t_{kw} = 3\ mm;\ t_{kf} = 3\ mm;\ h_s = 11.3\ m;\ f_1 = 1.39;\ m = 10$$

$$w_k = 1 + 0.05(t_{kw} + t_{kf}) = 1.3$$

$$p = \rho g h_s = 113.63\ kPa$$

$$\sigma = 160 f_1 = 222.4\ MPa$$

$$\therefore Z = 1637\ cm^3$$

Other sides:

$s = 1.5\ m;\ l = 4.0\ m\ (max.); t_{kw} = 3\ mm;\ t_{kf} = 3\ mm; h_s = 11.3\ m;\ f_1 = 1.39; m = 10$

$$w_k = 1 + 0.05(t_{kw} + t_{kf}) = 1.3$$

$$p = \rho g h_s = 113.63\ kPa$$

$$\sigma = 160 f_1 = 222.4\ MPa$$

$$\therefore Z = 1594\ cm^3$$

A T- section of the following dimensions and yield strength **355 MPa** with combined section modulus of **1863 cm^3** is chosen.

$web\ height = 360\ mm; web\ thickness = 12\ mm$

$flange\ width = 250\ mm; flange\ thickness = 16\ mm$

2.3.13 Side Stiffeners

The minimum section modulus of the side stiffener is calculated as per DNVGL-RU-FD-Sec. 7.3.2.1

$$Z = \frac{1000}{\sigma m} l^2 s p w_k\ (cm^3) \tag{13}$$

Dock port and starboard sides:

$$s = 0.6\ m;\ l = 1.8\ m\ (max.); t_{kw} = 3\ mm;\ h_s = 11.3\ m;\ f_1 = 1.0; m = 10$$

$$w_k = 1 + 0.06 t_{kw} = 1.18$$

$$p = \rho g h_s = 113.63\ kPa$$

$$\sigma = 160 f_1 = 160\ MPa$$

$$\therefore Z = 163\ cm^3$$

Other sides:

$$s = 0.6\ m;\ l = 1.5\ m\ (max.); t_{kw} = 3\ mm;\ h_s = 11.3\ m;\ f_1 = 1.0; m = 10$$

$$w_k = 1 + 0.06 t_{kw} = 1.18$$

$$p = \rho g h_s = 113.63\ kPa$$

$$\sigma = 160 f_1 = 160\ MPa$$

$$\therefore Z = 113\ cm^3$$

A bulb- section of **180x10 mm** and yield strength **235 MPa** with combined section modulus of **178 cm³** is chosen for the dock port and starboard sides.

A bulb- section of **160x9 mm** and yield strength **235 MPa** with combined section modulus of **127 cm³** is chosen for the other sides.

2.3.14 Bulkhead Stiffeners (longitudinal)

The minimum section modulus of the bulkhead stiffener is calculated as per DNVGL-RU-FD-Sec. 7.3.2.1

$$Z = \frac{1000}{\sigma m} l^2 s p w_k \ (cm^3) \tag{14}$$

$$s = 0.6\ m;\ l = 1.8\ m\ (max.); t_{kw} = 3\ mm;\ h_s = 2.25\ m;\ f_1 = 1.0; m = 12$$

$$w_k = 1 + 0.06 t_{kw} = 1.18$$

$$p = 10(h_s + 2.5) = 47.5\ kPa$$

$$\sigma = 160 f_1 = 160\ MPa$$

$$\therefore Z = 57\ cm^3$$

A bulb- section of **120x8 mm** and yield strength **235 MPa** with combined section modulus of **62 cm³** is chosen.

2.4 Dock Wing Structure

2.4.1 Plating

The minimum plating thickness at any location is given as per DNVGL-RU-FD-Sec. 7.4.1.2

$$t = s\sqrt{\frac{L_D}{f_1}}\ (mm) \tag{15}$$

Minimum yield strength chosen as 235 MPa, hence $f_1 = 1.0$

$$t = 5.8\ mm$$

2.4.2 Upper Deck Plating

The minimum upper deck plate thickness is calculated as per DNVGL-RU-FD-Sec. 7.4.2.2

$$t = 7.5 + (s - 0.6)7.5\ (mm) \tag{16}$$

$$s = 0.6\ m;$$

$$\therefore t = 7.5\ mm$$

Also by considering the design pressure, the minimum upper deck plate thickness is calculated as per DNVGL-RU-FD-Sec. 6.2.1.2

$$t = 15.8k_a s\sqrt{\frac{P}{\sigma}} + t_k\ (mm) \tag{17}$$

$$s = 0.6\ m;\ l = 1.8\ m; t_k = 1\ mm;\ P = 5\ kPa,\ f_1 = 1$$

$$\frac{s}{l} = 0.33$$

$$k_a = (1.1 - 0.25\frac{s}{l})^2 = 1.04\ (min.0.72, max.1.0)$$

$$\sigma = 160f_1 = 160MPa$$

$$\therefore t = 2.7\ mm$$

Upper deck plate of thickness **8 mm** and yield strength **235 MPa** is chosen.

2.4.3 Safety Deck Plating

The minimum safety deck plate thickness is calculated as per DNVGL-RU-FD-Sec. 6.2.1.2

$$t = 15.8k_a s\sqrt{\frac{P}{\sigma}} + t_k\ (mm) \tag{18}$$

$$s = 0.6\ m;\ l = 1.8\ m; t_k = 1\ mm;\ P = 5\ kPa,\ f_1 = 1$$

$$\frac{s}{l} = 0.33$$

$$k_a = (1.1 - 0.25\frac{s}{l})^2 = 1.04\ (min.0.72, max.1.0)$$

$$\sigma = 160f_1 = 160MPa$$

$$\therefore t = 2.7\ mm$$

Safety deck plate of thickness **8 mm** and yield strength **235 MPa** is chosen

2.4.4 Tween Deck Plating

The minimum tween deck plate thickness is calculated as per DNVGL-RU-FD-Sec. 6.2.1.2

$$t = 15.8 k_a s \sqrt{\frac{P}{\sigma}} + t_k \ (mm) \tag{19}$$

$$s = 0.6\, m;\ l = 1.8\, m; t_k = 2\, mm; h_s = 5.55\, m,\ f_1 = 1$$

$$\frac{s}{l} = 0.33$$

$$k_a = (1.1 - 0.25\frac{s}{l})^2 = 1.04\ (min. 0.72, max. 1.0)$$

$$P = \rho g h_s = 56\ kPa$$

$$\sigma = 160 f_1 = 160 MPa$$

$$\therefore t = 7.6\, mm$$

Tween deck plate of thickness **8 mm** and yield strength **235MPa** is chosen

2.4.5 Intermediate Deck Plating

The minimum intermediate deck plate thickness is calculated as per DNVGL-RU-FD-Sec. 6.2.1.2

$$t = 15.8 k_a s \sqrt{\frac{P}{\sigma}} + t_k \ (mm) \tag{20}$$

$$s = 0.6\, m;\ l = 1.8\, m; t_k = 1\, mm; P = 5.0\ kPa,\ f_1 = 1$$

$$\frac{s}{l} = 0.33$$

$$k_a = (1.1 - 0.25\frac{s}{l})^2 = 1.04\ (min. 0.72, max. 1.0)$$

$$\sigma = 160 f_1 = 160 MPa$$

$$\therefore t = 2.7\, mm$$

Intermediate deck plate of thickness **8 mm** and yield strength **235 MPa** is chosen.

2.4.6 Side Wall Plating

The minimum side plate thickness is calculated as per DNVGL-RU-FD-Sec. 7.4.1.1

$$t = 15.8 k_a s \sqrt{\frac{P}{\sigma}} + t_k \ (mm) \tag{21}$$

$$s = 0.6\, m;\ f_1 = 1$$

$$\frac{s}{l} = 0.33$$

Below safety deck level_longitudinal wall:

$$l = 1.8\,m;\ t_k = 3\,mm; h_s = 6\,m$$

$$\frac{s}{l} = 0.33$$

$$k_a = (1.1 - 0.25\frac{s}{l})^2 = 1.04\ (min. 0.72, max. 1.0)$$

$$P = \rho g h_s = 60.33\,kPa$$

$$\sigma = 120 f_1 = 120\,MPa\ (minimum)$$

$$\therefore t = 9.7\,mm$$

Below safety deck level_transverse wall:

$$l = 3.5\,m;\ t_k = 3\,mm; h_s = 6\,m$$

$$\frac{s}{l} = 0.17$$

$$k_a = (1.1 - 0.25\frac{s}{l})^2 = 1.12\ (min. 0.72, max. 1.0)$$

$$P = \rho g h_s = 60.33\,kPa$$

$$\sigma = 160 f_1 = 160\,MPa\ (minimum)$$

$$\therefore t = 8.8\,mm$$

Side wall plate of thickness **10 mm** and yield strength **235 MPa** is chosen below safety deck level.

Above safety deck level_longitudinal wall:

$$l = 1.8\,m;\ t_k = 2\,mm;\ h_s = 1.5\,m$$

$$\frac{s}{l} = 0.33$$

$$k_a = (1.1 - 0.25\frac{s}{l})^2 = 1.04\ (min. 0.72, max. 1.0)$$

$$P = \rho g h_s = 15.10\,kPa$$

$$\sigma = 120 f_1 = 120\,MPa\ (minimum)$$

$$\therefore t = 5.4\,mm$$

Above safety deck level_transverse wall:

$$l = 3.5\,m;\ t_k = 2\,mm;\ h_s = 1.5\,m$$

$$\frac{s}{l} = 0.17$$

$$k_a = (1.1 - 0.25\frac{s}{l})^2 = 1.12\ (min. 0.72, max. 1.0)$$

$$P = \rho g h_s = 15.10\,kPa$$

$$\sigma = 160f_1 = 160\ MPa\ (minimum)$$

$$\therefore t = 4.5\ mm$$

Side wall plate of thickness **8 mm** and yield strength **235 MPa** is chosen above safety deck level.

2.4.7 *Bulkhead Plating (transverse)*

The minimum bulkhead plate thickness is calculated as per DNVGL-RU-FD-Sec. 7.5.2.1

$$t = 15.8k_a s\sqrt{\frac{P}{\sigma}} + t_k\ (mm) \qquad (22)$$

$$s = 0.6\ m;\ l = 2.9\ m\ (max.); t_k = 2\ mm;\ h_s = 3\ m,\ f_1 = 1.0$$

$$\frac{s}{l} = 0.21$$

$$k_a = (1.1 - 0.25\frac{s}{l})^2 = 1\ (min.\,0.72, max.\,1.0)$$

$$P = 10(h_s + 2.5) = 55\ kPa$$

$$\sigma = 160f_1 = 160\ Mpa\ (min.)$$

$$\therefore t = 7.6\ mm$$

So wing bulkhead plates of thicknesses **8 mm** and **6 mm** and yield strength **235 MPa** are chosen below safety deck level and abve safety deck level respectively

2.4.8 *Bottom Frame*

The minimum section modulus of the bottom frame is calculated as per DNVGL-RU-FD-Sec. 6.2.2.2

$$Z = \frac{1000}{\sigma m} l^2 spw_k\ (cm^3) \qquad (23)$$

$$s = 1.8\ m;\ l = 3.5\ m\ (max.); t_{kw} = 3\ mm;\ t_{kf} = 3\ mm; h_s = 5.7\ m;\ f_1 = 1.39; m = 10$$

$$w_k = 1 + 0.05\left(t_{kw} + t_{kf}\right) = 1.3$$

$$p = \rho g h_s = 57.32\ kPa$$

$$\sigma = 160f_1 = 222.4\ MPa$$

$$\therefore Z = 739\ cm^3$$

An I- section of the following dimensions and yield strength **355 MPa** with section modulus of **756 cm^3** is chosen.

$web\ height = 294\ mm; web\ thickness = 8\ mm$

$flange\ width = 200\ mm; flange\ thickness = 12\ mm$

2.4.9 Upper Deck Frame

The minimum section modulus of the deck frame is calculated as per DNVGL-RU-FD-Sec. 6.2.2.2

$$Z = \frac{1000}{\sigma m} l^2 spw_k\ (cm^3) \tag{24}$$

$$s = 1.8\ m;\ l = 3.5\ m\ (max.); t_{kw} = 1\ mm;\ t_{kf} = 1\ mm; p = 5\ kPa;\ f_1 = 1.0; m = 12$$

$$w_k = 1 + 0.05(t_{kw} + t_{kf}) = 1.1$$

$$\sigma = 160 f_1 = 160\ MPa$$

$$\therefore Z = 45.5\ cm^3$$

A T- section of the following dimensions and yield strength **235 MPa** with combined section modulus of **404 cm^3** is chosen.

$web\ height = 250\ mm; web\ thickness = 8\ mm$

$flange\ width = 100\ mm; flange\ thickness = 10\ mm$

2.4.10 Upper Deck Stiffeners

The minimum section modulus of the deck stiffener is calculated as per DNVGL-RU-FD-Sec. 6.2.2.2. Actual required strength has to be assessed based on longitudinal strength requirement.

$$Z = \frac{1000}{\sigma m} l^2 spw_k\ (cm^3) \tag{25}$$

$$s = 0.6;\ l = 1.8\ m\ (max.); t_{kw} = 1\ mm;\ p = 5\ kPa;\ f_1 = 1.0; m = 10$$

$$w_k = 1 + 0.06 t_{kw} = 1.06$$

$$\sigma = 160 f_1 = 160\ MPa$$

$$\therefore Z = 7\ cm^3$$

A bulb- section of **120x6 mm** and yield strength **235 MPa** with combined section modulus of **52 cm^3** is chosen.

2.4.11 Safety Deck Frame

The minimum section modulus of the deck frame is calculated as per DNVGL-RU-FD-Sec. 6.2.2.2

$$Z = \frac{1000}{\sigma m} l^2 spw_k \ (cm^3) \tag{26}$$

$$s = 1.8\,m;\ l = 3.5\,m\ (max.); t_{kw} = 2\,mm;\ t_{kf} = 2\,mm; p = 5\,kPa;\ f_1 = 1.0; m = 12$$

$$w_k = 1 + 0.05\left(t_{kw} + t_{kf}\right) = 1.2$$

$$\sigma = 160 f_1 = 222.4\,MPa$$

$$\therefore Z = 69.5\,cm^3$$

A T- section of the following dimensions and yield strength **235 MPa** with combined section modulus of **655 cm^3** is chosen.

$web\ height = 300\,mm; web\ thickness = 8\,mm$

$flange\ width = 150\,mm; flange\ thickness = 10\,mm$

2.4.12 Safety Deck Stiffeners

The minimum section modulus of the deck stiffener is calculated as per DNVGL-RU-FD-Sec. 6.2.2.2. Actual required strength has to be assessed based on longitudinal strength requirement.

$$Z = \frac{1000}{\sigma m} l^2 spw_k \ (cm^3) \tag{27}$$

$$s = 0.6\,m;\ l = 1.8\,m\ (max.); t_{kw} = 2\,mm;\ p = 5\,kPa;\ f_1 = 1.0; m = 10$$

$$w_k = 1 + 0.06 t_{kw} = 1.12$$

$$\sigma = 160 f_1 = 160\,MPa$$

$$\therefore Z = 7\,cm^3$$

A bulb- section of **120x6 mm** and yield strength **235 MPa** with combined section modulus of **50cm^3** is chosen.

2.4.13 Tween Deck Frame

The minimum section modulus of the deck frame is calculated as per DNVGL-RU-FD-Sec. 6.2.2.2

$$Z = \frac{1000}{\sigma m} l^2 spw_k \ (cm^3) \tag{28}$$

$$s = 1.8\,m;\ l = 3.5\,m\ (max.); t_{kw} = 3\,mm;\ t_{kf} = 3\,mm; h_s = 3\,m;\ f_1 = 1.0; m = 12$$

$$w_k = 1 + 0.05(t_{kw} + t_{kf}) = 1.3$$

$$p = \rho g h_s = 30.17\,kPa$$

$$\sigma = 160 f_1 = 160\,MPa$$

$$\therefore Z = 450.4\,cm^3$$

A T- section of the following dimensions and yield strength **235 MPa** with combined section modulus of **666 cm^3** is chosen.

$web\ height = 300\,mm; web\ thickness = 8\,mm$

$flange\ width = 150\,mm; flange\ thickness = 10\,mm$

2.4.14 Tween Deck Stiffeners

The minimum section modulus of the deck stiffener is calculated as per DNVGL-RU-FD-Sec. 6.2.2.2

$$Z = \frac{1000}{\sigma m} l^2 s p w_k\ (cm^3) \tag{29}$$

$$s = 0.6\,m;\ l = 1.8\,m\ (max.); t_{kw} = 3\,mm;\ h_s = 3\,m;\ f_1 = 1.0; m = 10$$

$$w_k = 1 + 0.06 t_{kw} = 1.18$$

$$p = \rho g h_s = 30.17\,kPa$$

$$\sigma = 160 f_1 = 160\,MPa$$

$$\therefore Z = 44\,cm^3$$

A bulb- section of **120x6 mm** and yield strength **235 MPa** with combined section modulus of **52 cm^3** is chosen.

2.4.15 Inter Deck Frame

The minimum section modulus of the deck frame is calculated as per DNVGL-RU-FD-Sec. 6.2.2.2

$$Z = \frac{1000}{\sigma m} l^2 s p w_k\ (cm^3) \tag{30}$$

$$s = 1.8\,m;\ l = 3.5\,m\ (max.); t_{kw} = 1\,mm;\ t_{kf} = 1\,mm; p = 5\,kPa;\ f_1 = 1.0; m = 12$$

$$w_k = 1 + 0.05(t_{kw} + t_{kf}) = 1.1$$

$$\sigma = 160 f_1 = 222.4\,MPa$$

$$\therefore Z = 63.9\ cm^3$$

A T- section of the following dimensions and yield strength **235 MPa** with combined section modulus of **655 cm^3** is chosen.

$web\ height = 300\ mm; web\ thickness = 8\ mm$

$flange\ width = 150\ mm; flange\ thickness = 10\ mm$

2.4.16 Inter Deck Stiffeners

The minimum section modulus of the deck stiffener is calculated as per DNVGL-RU-FD-Sec. 6.2.2.2

$$Z = \frac{1000}{\sigma m} l^2 spw_k\ (cm^3) \tag{31}$$

$$s = 0.6\ m;\ l = 1.8\ m\ (max.); t_{kw} = 1\ mm;\ p = 5\ kPa;\ f_1 = 1.0; m = 10$$

$$w_k = 1 + 0.06t_{kw} = 1.06$$

$$\sigma = 160f_1 = 160\ MPa$$

$$\therefore Z = 7\ cm^3$$

A bulb- section of **120x6 mm** and yield strength **235 MPa** with combined section modulus of **50 cm^3** is chosen.

2.4.17 Side Wall Frame

The minimum section modulus of the side wall frame is calculated as per DNVGL-RU-FD-Sec. 7.4.1.4

$$Z = \frac{1000}{\sigma m} l^2 spw_k\ (cm^3) \tag{32}$$

$$s = 1.8\ m;\ f_1 = 1.39; m = 10$$

$$\sigma = 160f_1 = 222.4\ MPa$$

Below safety deck level:

$$l = 5.0\ m\ (max.); t_{kw} = 2\ mm;\ t_{kf} = 2\ mm; h_s = 6\ m$$

$$w_k = 1 + 0.05\left(t_{kw} + t_{kf}\right) = 1.2$$

$$p = \rho g h_s = 60.33\ kPa$$

$$\therefore Z = 1465\ cm^3$$

A T- section of the following dimensions and yield strength **355 MPa** with combined section modulus of **1522 cm^3** is chosen.

$web\ height = 500\ mm; web\ thickness = 10\ mm$

$flange\ width = 100\ mm; flange\ thickness = 16\ mm$

Above safety deck level:

$$l = 4.0\ m\ (max.); t_{kw} = 1\ mm;\ t_{kf} = 1\ mm; h_s = 1.5\ m$$

$$w_k = 1 + 0.05(t_{kw} + t_{kf}) = 1.1$$

$$p = \rho g h_s = 15.08\ kPa$$

$$\therefore Z = 215\ cm^3$$

A T- section of the following dimensions and yield strength **355 MPa** with combined section modulus of **238 cm^3** is chosen.

$web\ height = 150\ mm; web\ thickness = 8\ mm$

$flange\ width = 100\ mm; flange\ thickness = 12\ mm$

2.4.18 Side Stiffeners

The minimum section modulus of the side wall frame is calculated as per DNVGL-RU-FD-Sec. 7.4.1.3

$$Z = \frac{1000}{\sigma m} l^2 s p w_k\ (cm^3) \tag{33}$$

$$s = 0.6\ m;\ f_1 = 1.0; m = 12$$

$$\sigma = 160 f_1 = 160\ MPa$$

Below safety deck level_longitudinal wall:

$$l = 1.8\ m\ (max.); t_{kw} = 2\ mm;\ t_{kf} = 2\ mm; h_s = 6\ m$$

$$w_k = 1 + 0.05(t_{kw} + t_{kf}) = 1.2$$

$$p = \rho g h_s = 60.33\ kPa$$

$$\therefore Z = 74\ cm^3$$

A bulb- section of **140x8 mm** and yield strength **235 MPa** with combined section modulus of **86 cm^3** is chosen.

Below safety deck level_transverse wall:

$$l = 3.5\ m\ (max.); t_{kw} = 2\ mm;\ t_{kf} = 2\ mm; h_s = 6\ m$$

$$w_k = 1 + 0.05(t_{kw} + t_{kf}) = 1.2$$

$$p = \rho g h_s = 60.33\ kPa$$

$$\therefore Z = 277\ cm^3$$

A bulb- section of **220x10 mm** and yield strength **235 MPa** with combined section modulus of **283 cm^3** is chosen.

Above safety deck level_longitudinal wall:

$$l = 1.8\ m\ (max.); t_{kw} = 1\ mm;\ t_{kf} = 1\ mm; h_s = 1.5\ m$$

$$w_k = 1 + 0.05(t_{kw} + t_{kf}) = 1.1$$

$$p = \rho g h_s = 15.08\ kPa$$

$$\therefore Z = 17\ cm^3$$

An angle-section of **75x50x8 mm** and yield strength **235 MPa** with combined section modulus of **23 cm^3** is chosen.

Above safety deck level_transverse wall:

$$l = 3.5\ m\ (max.); t_{kw} = 1\ mm;\ t_{kf} = 1\ mm; h_s = 1.5\ m$$

$$w_k = 1 + 0.05(t_{kw} + t_{kf}) = 1.1$$

$$p = \rho g h_s = 15.08\ kPa$$

$$\therefore Z = 64\ cm^3$$

An angle-section of **100x65x8 mm** and yield strength **235 MPa** with combined section modulus of **70 cm^3** is chosen.

2.4.19 Bulkhead Stiffeners (transverse)

The minimum section modulus of the bulkhead stiffener is calculated as per DNVGL-RU-FD-Sec. 6.2.2.2

$$Z = \frac{1000}{\sigma m} l^2 s p w_k\ (cm^3) \tag{34}$$

$$s = 0.6\ m;\ l = 2.4\ m\ (max.); t_{kw} = 2\ mm;\ h_s = 3\ m;\ f_1 = 1.0; m = 10$$

$$w_k = 1 + 0.06 t_{kw} = 1.12$$

$$p = 10(h_s + 2.5) = 55\ kPa$$

$$\sigma = 160 f_1 = 160\ MPa$$

$$\therefore Z = 133\ cm^3$$

A bulb- section of **200x8.5 mm** and yield strength **235 MPa** with combined section modulus of **201 cm^3** is chosen below safety deck level.

An angle-section of **100x65x8 mm** and yield strength **235 MPa** with combined section modulus of **70 cm^3** is chosen above safety deck level.

2.5 2D Section Drawings

Based on the scantlings designed, 2D drawings are developed for understanding the typical structure. Figure 8, 9 and 10 has to be read in conjunction with table 2. Item descriptions corresponding to the item numbers mentioned in the drawings are listed in table 2.

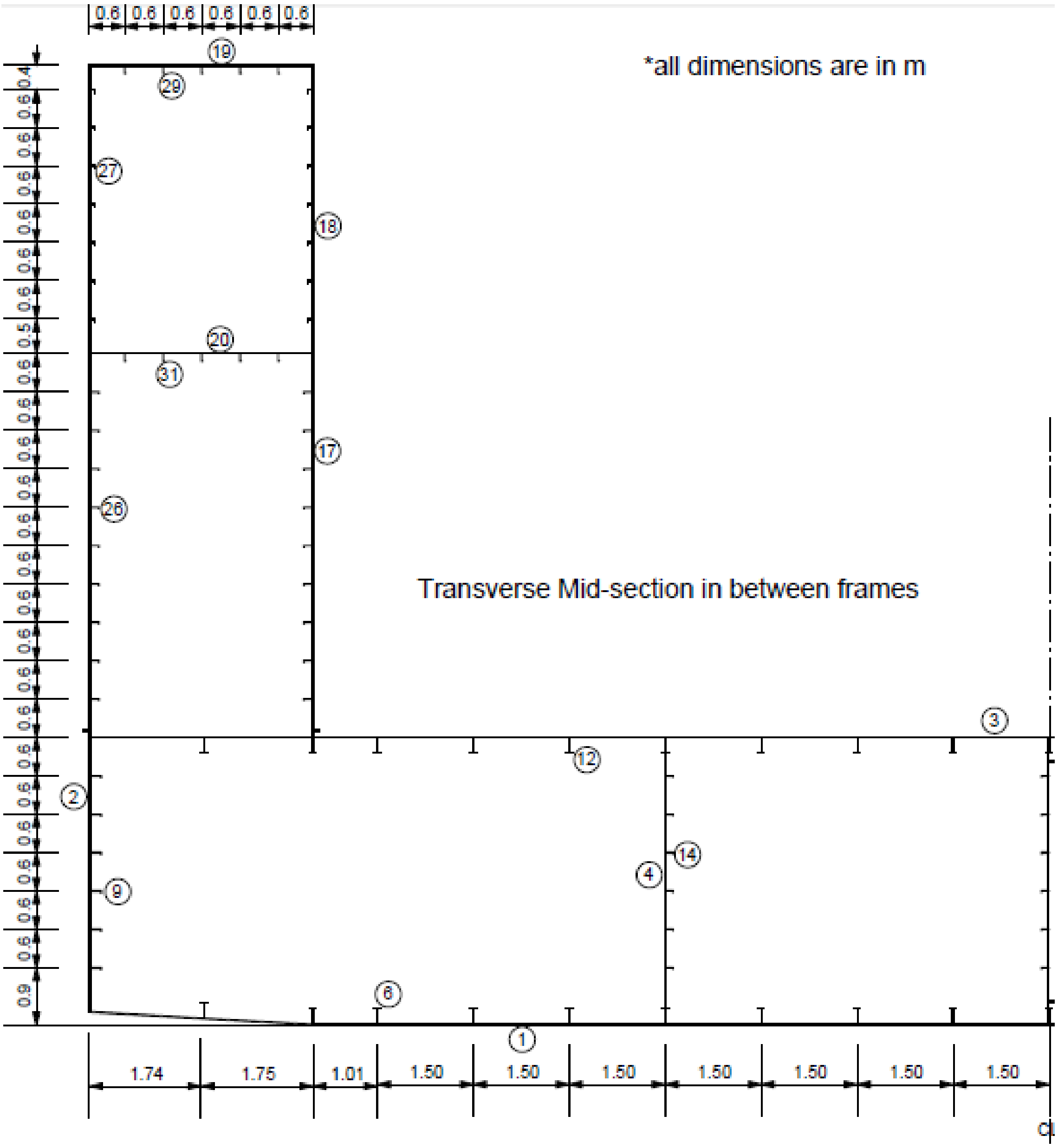


Figure 8: Mid-section view between frames (CL-Port)

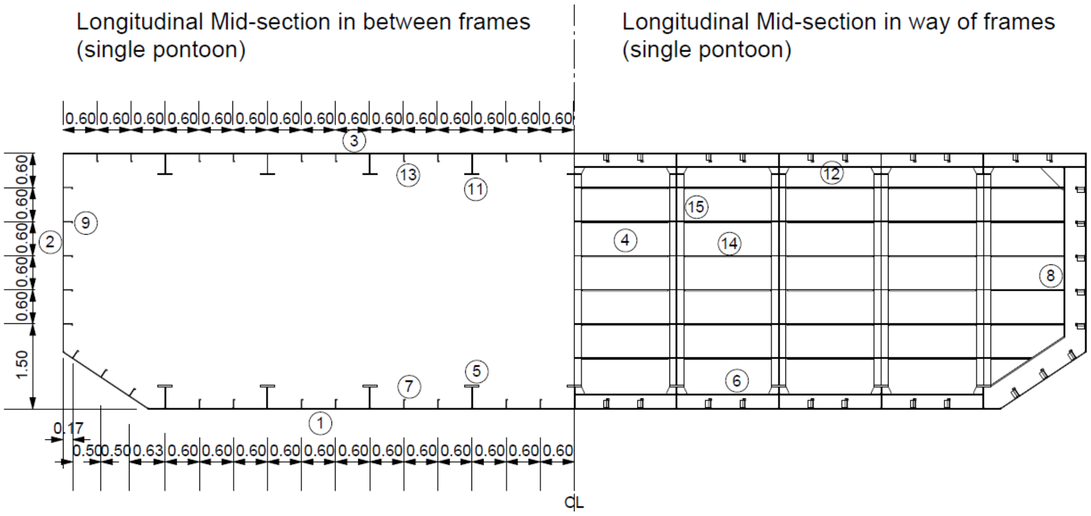


Figure 9: Typical pontoon section

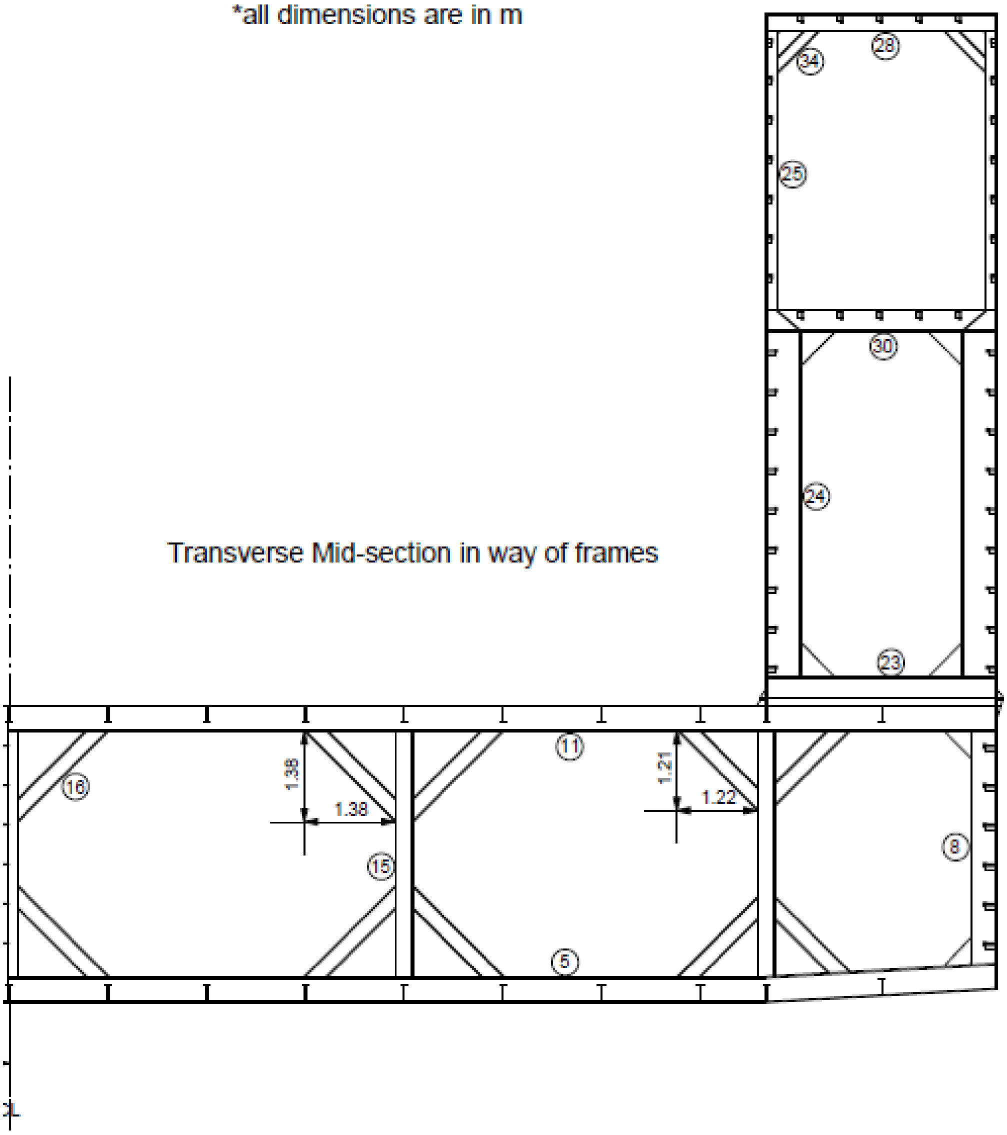

*all dimensions are in m

Figure 10: Mid-section view in way of frames (CL-Starboard)

Table 2: Items list from the drawings

Item no.	Item description	Scantlings in mm
	Pontoon	
1	Bottom plate	12 thick
2	Side Plate	12 thick
3	Deck plate	12 thick
4	Longitudinal bulkhead	10 thick
5	Bottom Girder	T section: W380x12 F250x20
6	Bottom Frame	T section: W240x12 F100x16
7	Bottom stiffeners	BP 160x11.5
8	Side frame	T section: W360x12 F250x16
9	Side stiffeners	BP 180x10
10	Side stiffeners	BP 160x9
11	Deck girder	T section: W350x12 F250x20
12	Deck frame	T section: W220x12 F100x16
13	Deck stiffeners	BP 140x10
14	Bulkhead stiffeners	BP 120x8
15	Pillars	UC 250x250x71.8 kg/m
16	Pillar brackets	UC 250x250x71.8 kg/m
	Dockwing	
17	Side plate (below safety deck)	10 thick
18	Side plate (above safety deck)	8 thick
19	Upper deck plate	8 thick
20	Safety deck plate	8 thick
21	Transverse bulkhead (below safety deck)	8 thick
22	Transverse bulkhead (above safety deck)	6 thick
23	Bottom frame	UB 300x200x55.8 kg/m
24	Side frame (below safety deck)	T section: W500x10 F100x16
25	Side frame (above safety deck)	T section: W150x8 F100x12
26	Side stiffeners (below safety deck)	BP 140x8
27	Side stiffeners (above safety deck)	LP 75x50x8
28	Upper deck frame	T section: W250x8 F100x10
29	Upper deck stiffeners	BP 120x6
30	Safety deck frame	T section: W300x8 F150x10

31	Safety deck stiffeners	BP 120x6
32	Bulkhead stiffeners (below safety deck)	BP 200x8.5
33	Bulkhead stiffeners (above safety deck)	LP 100x65x8
34	Upper bracket	UB 150x100x20.7 kg/m

2.6 Slenderness Check

The dock is subjected to hogging and sagging bending and at various stages, the structural members are subjected to variable loads which could be tensile or compressive. Slenderness of a structural member is directly related to the length or free span of the member and limiting the free span could avoid potential buckling and also constructional deformations. Hence the slenderness check ensures the member will yield locally before it could buckle. A member under compression is critical to buckling than a member in tension.

The general formula for slenderness ratio is,

$$Slenderness\ ratio = \frac{kl}{r} \tag{35}$$

The subject design requires a slenderness check to be done on the structural members to decide if a local stiffening is required to limit the slenderness ratio. The guidelines as per Part 3 Chapter 8 of the DNV-GL Rules for Classification of Ships is followed.

In doing the slenderness check, a minimum of the yield stresses is considered and only the net scantlings are considered in order to have higher factor of safety.

2.6.1 Net thickness of Plate Panels

The net thickness requirement of the plate panels in mm as per DNVGL-RU-SHIP Part 3 Chapter 8 Section 2.2 is below,

$$t_p \geq \frac{b}{C} \tag{36}$$

$b = distance\ in\ mm\ between\ stiffeners\ at\ mid\ length\ of\ the\ the\ plate\ field$

$C = Slenderness\ coefficient\ as\ per\ the\ slenderness\ coefficient\ for\ plates\ given\ in\ table\ 1\ of\ Chapter\ 8\ of\ the\ DNVGL\ Rules\ for\ Classification\ of\ Ships$

In general for all plates forming the outer shell,

$b = 600mm$

$C = 100\ (for\ shell\ plates)$

$C = 125\ (for\ other\ plates)$

Table 3 shows the net thickness and thickness required as per slenderness check for the various plate panels used in the design.

Table 3: Slenderness check for plates

Location	t_{gross} (mm)	t_k (mm)	t_{net} (mm)	b (mm)	C	t_p (mm)
Pontoon						
Bottom	12	3	9	600	100	6
Side	12	3	9	600	100	6
Deck	12	3	9	600	100	6
Bulkhead	10	3	7	600	125	4.8
Dock Wing						
Side (below safety deck level)	10	3	7	600	100	6
Side (Above safety deck level)	8	2	6	600	125	4.8
Upper deck	8	1	7	600	125	4.8
Safety deck	8	1	7	600	125	4.8
Tween deck	8	2	6	600	125	4.8
Intermediate deck	8	1	7	600	125	4.8
Bulkhead (below safety deck level)	8	2	6	600	125	4.8
Bulkhead (above safety deck level)	6	1	5	600	125	4.8

Table 3 shows that the thicknesses considered are more than the minimum required as to provide enough stiffness.

2.6.2 Net thickness of Stiffeners

The minimum thickness requirement as per DNVGL-RU-SHIP Part 3 Chapter 8 Section 3.1.1 are as follows,

$$stiffener\ web\ plate, t_w \geq \frac{h_w}{C_w}\sqrt{\frac{R_{eh}}{235}} \tag{37}$$

$$stiffener\ flange\ plate, t_f \geq \frac{b_{f-out}}{C_f}\sqrt{\frac{R_{eh}}{235}} \tag{38}$$

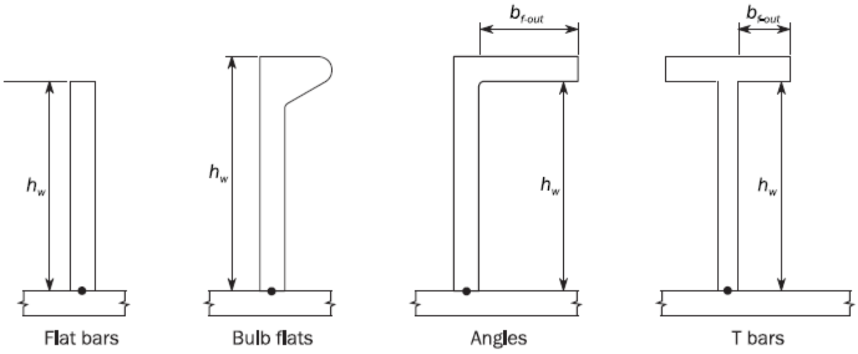


Figure 11: Stiffener Scantling Parameters

Source: DNVGL-RU-SHIP Part 3 Chapter 8 Figure 1

R_{eh} for stiffeners is taken as 235 N/mm^2.

Table 4: Slenderness check for stiffeners

Location		t_{gross} (mm)	t_k (mm)	t_{net} (mm)	h_w or $b_{f\text{-}out}$ (mm)	C_w or C_f (mm)	t_w or t_f (mm)
Pontoon							
Bottom (bulb bar)	Web	11.5	3	8.5	160	45	4
	Flange	-	-	-	-	-	-
Side (bulb bar)	Web	9	3	6	160	45	4
	Flange	-	-	-	-	-	-
Deck (bulb bar)	Web	10	3	7	140	45	3
	Flange	-	-	-	-	-	-
Bulkhead (bulb bar)	Web	11.5	3	8.5	160	45	4
	Flange	-	-	-	-	-	-
Bottom (bulb bar)	Web	8	3	5	120	45	3
	Flange	-	-	-	-	-	-
Dock Wing							
Upper deck (bulb bar)	Web	6	1	5	120	45	3
	Flange	-	-	-	-	-	-
Safety deck (bulb bar)	Web	6	2	4	120	45	3

	Flange	-	-	-	-	-	-
Tween deck (bulb bar)	Web	6	3	3	120	45	3
	Flange	-	-	-	-	-	-
Intermediate deck (bulb bar)	Web	6	1	5	120	45	3
	Flange	-	-	-	-	-	-
Side (below safety deck level) (bulb bar)	Web	8	2	6	140	45	3
	Flange	-	-	-	-	-	-
Side (above safety deck level) (angle bar)	Web	8	1	7	67	75	1
	Flange	8	1	7	42	12	4

Referring to the slenderness check results as per table 4, the net scantlings chosen for stiffeners in the design are adequate.

2.6.3 *Net thickness of Primary Supporting Members*

The net thicknesses of web plate and flange plate shall satisify the following conditions as per DNVGL-RU-SHIP Part 3 Chapter 8 Section 4.1.1,

$$Web\ plate, t_w \geq \frac{s_w}{C_w}\sqrt{\frac{R_{eh}}{235}} \tag{39}$$

$$Flange\ plate, t_f \geq \frac{b_{f-out}}{C_f}\sqrt{\frac{R_{eh}}{235}} \tag{40}$$

Table 5: Slenderness check for primary supporting members

Location		**t_{gross} (mm)**	**t_k (mm)**	**t_{net} (mm)**	**s_w or b_{f-out} (mm)**	**C_w or C_f (mm)**	**t_w or t_f (mm)**
Pontoon							
Bottom girder	Web	12	3	9	750	100	9
	Flange	20	3	17	117	12	12
Bottom frame	Web	12	3	9	600	100	7
	Flange	16	3	13	44	12	5
Deck girder	Web	12	3	9	750	100	9
	Flange	20	3	17	119	12	12
Deck frame	Web	12	3	9	600	100	7

	Flange	16	3	13	44	12	5
Side frame	Web	12	3	9	600	100	7
	Flange	16	3	13	119	12	12
Dock Wing							
Upper deck frame	Web	8	1	7	600	100	7
	Flange	10	1	9	46	12	5
Safety deck frame	Web	8	2	6	400	100	5
	Flange	10	2	8	46	12	5
Tween deck frame	Web	8	3	5	400	100	5
	Flange	10	3	7	46	12	5
Intermediate deck frame	Web	8	1	7	600	100	7
	Flange	10	1	9	46	12	5
Side frame (below safety deck level)	Web	10	2	8	600	100	7
	Flange	16	2	14	45	12	5
Side frame (above safety deck level)	Web	8	1	7	600	100	7
	Flange	12	1	11	46	12	5

Slenderness check results for the primary supporting members as per table 5 shows that the scantlings chosen are adequate if the webs are properly stiffened at intervals, S_w.

2.6.4 Net thickness of Pillars

The minimum thickness requirement as DNVGL-RU-SHIP Part 3 Chapter 8 Section 6.1 are as follows,

$$pillar\ web\ plate, t_w \geq \frac{h_w}{C_w}\sqrt{\frac{R_{eh}}{235}} \tag{41}$$

$$pillar\ flange\ plate, t_f \geq \frac{b_{f-out}}{C_f}\sqrt{\frac{R_{eh}}{235}} \tag{42}$$

Table 6: Slenderness check for pillars

Location		**t_{gross} (mm)**	**t_k (mm)**	**t_{net} (mm)**	**h_w or b_{f-out} (mm)**	**C_w or C_f (mm)**	**t_w or t_f (mm)**
Pontoon							
Pillar (I-section)	Web	9	3	6	222	75	3

	Flange	14	3	11	120	12	10

The pillar sections chosen are sufficient considering the slenderness requirements.

2.7 Summary

The scantling design has been done based on the worst condition of design pressure which is for the maximum submersion draft. Normal grade steel of yield strength 235 MPa is chosen for all members except the pontoon girders, frames and pillars. This is to reduce the material scantlings and to ensure higher strength with lesser scantlings. Longitudinal framing is adopted in the pontoons as the pontoon structure needs more strength in the longitudinal direction (along the transverse of the dock). Longitudinal framing is adopted in dock wings to resist the longitudinal bending of the dock. The scantling design done is based on the local hydrostatic pressures and the structure has to be analysed globally for the strength to withstand the global loads. This is done by FEA. All the scantlings designed is including the corrosion allowance requirements as per DNVGL-RU-FD-Table 3.

The slenderness check carried out for the scantlings prove that the scantlings chosen are equal to or higher than the minimum required to satisfy the slenderness criteria. For the T section girders and frames used, web stiffeners have to be provided at intervals as mentioned in table 5 (column S_w for webs) to satisfy the slenderness criteria.

3 WEIGHTS AND CoG ESTIMATION

3.1 General

An accurate weight calculation is essential to have an optimized design. An estimation of the various weights and their corresponding Centre of Gravity is done as per the available data. Based on the scantlings and arrangement of the various structural members, the steel weight is estimated. Since this is a preliminary stage of design, the weight could be expected to be higher from the estimated value by about 10% (a nominal value based on experience). This is to account for the stiffening or strengthening required in the structure, and the weight of welding and also some tertiary structural members which were not considered.

From the concept GA available, approximate weights of major architectural items are estimated with a marginal contingency of 20%. Major architectural weights considered include the weight of insulation, panels, bulkheads, wet units, doors. B15 fire rating is the requirement as per the DNVGL Rules. Most of the other architectural items shown in the drawings (refer Appendix A) are included in the weight estimation. The additional items which are not considered is assumed to cover with in the 20% contingency. The weight of such items constitute less than 10% of the total weight. Although there could be some local stiffening required to support these loads in specific areas, there is no heavy concentrated loading expected. So the impact of such weights is not much on the global strength.

The major electrical and HVAC weights are considered as lump sum quantities and considered distributed over the area of the accommodation. The distributed weight is estimated based on the weight in similar kind of accommodations. Again these won’t constitute the weights which could be deciding factor in the strength of the structure. The assumed weights are again added with a safety margin of 20%.

The equipment and outfit loads including the docking blocks, cranes, swing bridges, generator and ballast pumps as a minimum are considered and applied as point loads considering the most critical cases. These constitute heavy concentrated loads and based on the load transfer from the equipment to the base, the foundation has to be designed and stiffened. In the absence of proper data, the detailed design of foundation in such case has not been performed. Any additional loads from the stiffening structural members and items which are not accounted are expected to be covered in the additional 10% of load considered in the steel weight. Contributing further to the loading is the weight from the fresh water and fuel oil tanks, the maximum filled capacity is considered in the lightweight calculation or initial weight of the structure. There is rest water expected to be present at the bottom of the pontoon ballast tanks as the pumps can’t drain the tank completely. As per recommendations, this can be 2 to 3 feet high. So marginal value of 600mm (i.e; 2 feet) high rest water is considered in the pontoon tanks bottom at lightship conditions.

The CoG of various items based on their locations in the GA are calculated and the overall CoG is estimated. The most critical of the CoG would be the VCG as more or less the arrangement has the longitudinal and transverse CoG at the center. But VCG could be important from the stability perspective. So from the known weights and locations, wherever contingency is applied, a 20% increase in VCG is applied for the added weight as a standard engineering practice. This is because the higher VCG could decrease the stability and the design should be done for the worst case.

For the weights and CoG calculation, the origin of the coordinate system is fixed at the aft bottom corner of the starboard side. All measures to the fore part is positive. All measures to the port side is positive and upward from the base line is positive.

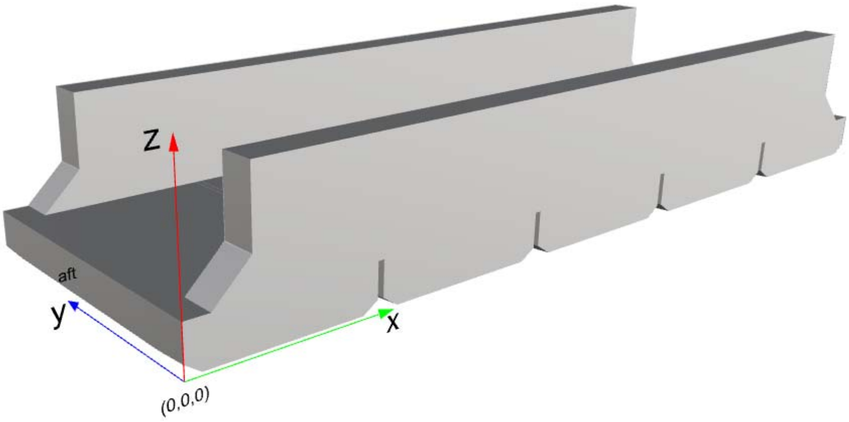


Figure 12: Coordinate system

A summary of the estimated weights of the empty structure is given in Table 7. A detailed weight report is attached as Appendix B.

Table 7: Summary of weights

Sl. No	Item Description	Contingency	Total Weight	CoG			Moments		
				X	Y	Z	M-x	M-y	M-z
			(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)
1	Structural Steel	10%	2207	46.34	15.00	4.36	102258	33100	9620
2	Architectural and misc	20%	165	45.68	15.40	10.13	7524	2536	1668
3	Outfitting and equipment	20%	323	48.45	14.33	7.86	15667	4634	2541

2695	**46.55**	**14.94**	**5.13**	**125449**	**40271**	**13829**
	CoG			Moments		
Total Weight	X	Y	Z	M-x	M-y	M-z
(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)

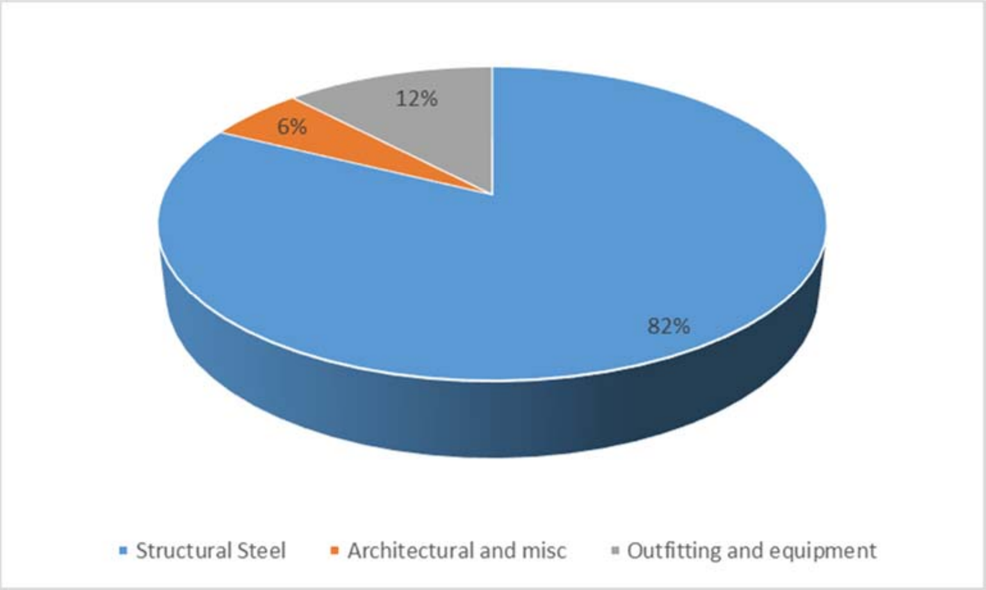


Figure 13: Percentage distribution of weights

From table 7, the VCG of the empty structure is obtained as 5.13 m and the LCG and TCG are very close to the centre. More than 80% of the weight is contributed by steel.

3.2 Summary

All the weights considered in this section except the steel weight are based on the datasheets sourced for various major equipment and few assumptions based on some similar items in the absence of actual design. The contingencies considered are based on standard engineering practice and not a documented one and is assumed to include items which were not considered and also for additional supports and other unexpected increases in weights.

4 GLOBAL STRENGTH ANALYSIS

4.1 General

The major operational loads that act on a floating dry dock include the docking load, ballast water pressure inside the tanks and the external sea water pressure acting on the immersed part of the hull. The dock strength has to be analysed for longitudinal as well as transverse bending. The various such critical loading cases are considered in the strength analsysis of the dock. The minimum of the cases as required by DNV-GL is checked here. A linear static FEA is carried out using FEMAP structural modelling and analysis software with NX Nastran solver. The FEA modelling is done based on the gross scantlings estimated.

The various ship loading cases include:

i. Sagging ship
ii. Hogging ship

The vaious docking stages include:

i. Lightship condition where only the selfweight, weight of consumables and rest water/ compensating ballast water acts, and externally the hydrostatic pressure.

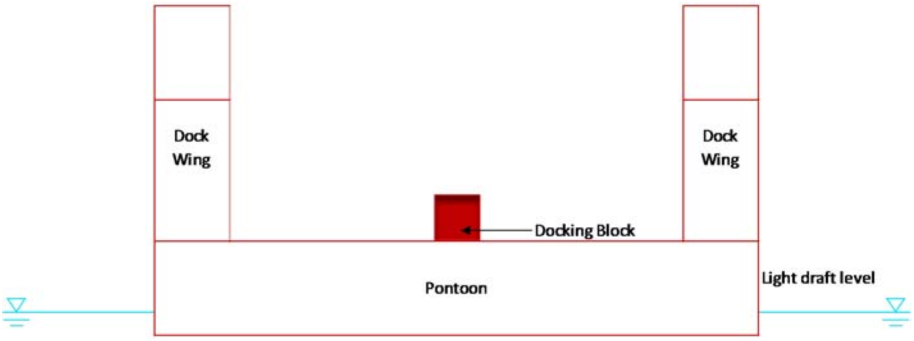


Figure 14: Lightship condition

ii. Fully submerged condition where the dock is immersed to the maximum draft by ballasting.

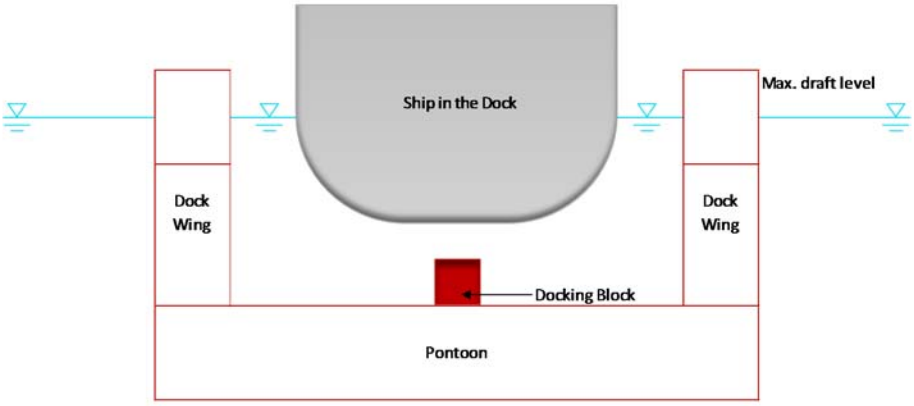


Figure 15: Fully submerged condition

iii. Docking or undocking conditon where the docked ship is completely supported by the docking blocks and the draft level is just below the docking block height.

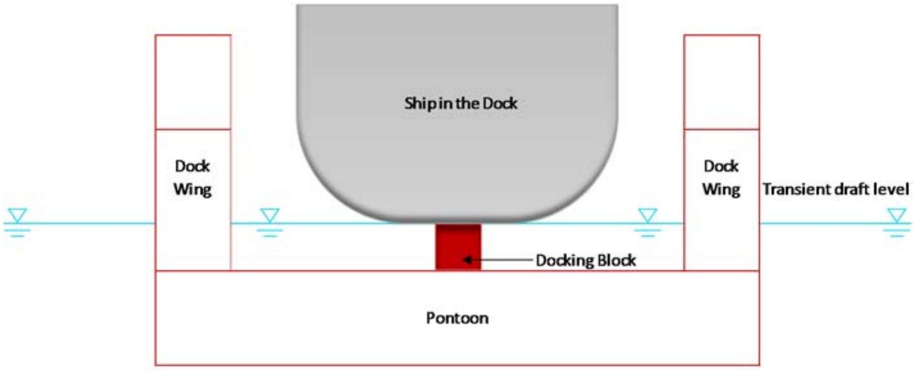


Figure 16: Docking/ undocking condition

iv. The working draft condition where the docking load is completely supported on the docking blocks and in addition only the weights mentioned in the initial case acting with an increased draft.

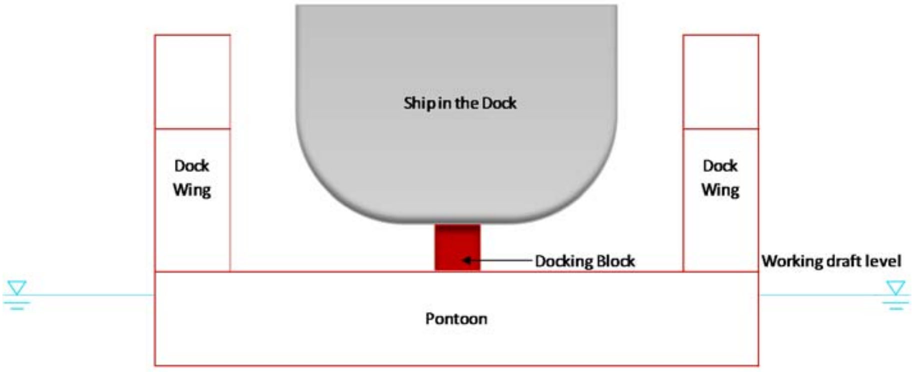


Figure 17: Working condition

The strength is expected to be critical when docked to maximum capacity, when on full sinkage and the stability is expected to be critical when the dock load is 100% plus the weight of water up to the docking block height.

4.2 Loads and Load Distribution

Based on the GA available, the weights of major architectural, outfitting items, machinery are approximately estimated to have a more or less realistic loading case. These loads are either applied as areal pressure loads or point loads. The sea pressure is applied as linearly varying elemental loads along the length, breadth and depth of the structure.

The ships docking load is assumed to be along blocks arranged at the centerline of the dock, with the mid-ship positioned at half the length of the dock. There can be supporting side blocks as well but the load concentrated at the center alone is the most critical case to be considered.

4.3 Sagging and Hogging Ship Load

The weight distribution in a ship is not uniform, and as a result the ship structure can be said to be sagging if more weights are concentrated towards the midship and hogging if otherwise. Infact this loading conditon of the docked ship has a great effect on the dock deflection or structural response. Docking is always based on a docking plan prepared based on the weight distribution of the ship. The ship where ever possible is docked with the center of gravity aligned with the center of gravity of the dock in the longitudinal and transverse directions, so that there is no additional moments acting due to the docked ship. a docking plan can be prepared when there is data regarding the ships to be docked. In the absence of actual data of ships to be docked, and for the purpose of designing in general, the load distribution pattern as recommended by DNVGL-RU-FD is followed. The recommeded load distributions considered are the worst cases. But in case of an increased load distribution, case-by-case analysis will be needed to ensure the strength of the dock.

The standard sagging ship for the most unfavourable loading is assumed to have a weight equal to the capacity of the dock and this load is assumed to be distributed over a length not more than,

$$L_S = 0.8L_D$$

The weight distribution curve in this case is assumed to be symmetrical and is in the form of a rectangle with a parabola on top, such that the area of the rectangle is twice the area of the parabola.

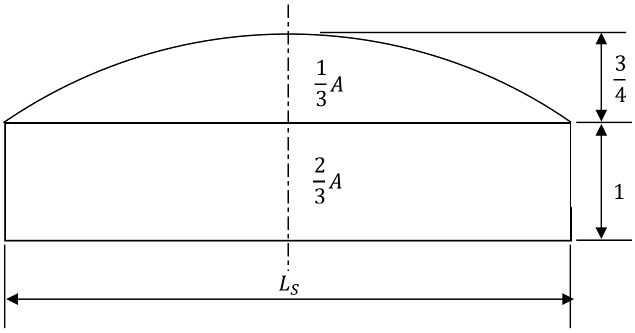


Figure 18: Weight distribution of standard sagging ship

Source: DNVGL-RU-FD Figure 1

The standard hogging ship for the most unfavourable loading is assumed to have a weight equal to the capacity of the dock and this load is assumed to be distributed over a length not less than,

$$L_H = 1.2L_D$$

The weight distribution curve in this case is assumed to be symmetrical and is in the form of a rectangle along the length and two small rectangles at the ends on top of it, such that the area of the larger rectangle is twice the sum of the areas of the smaller ones.

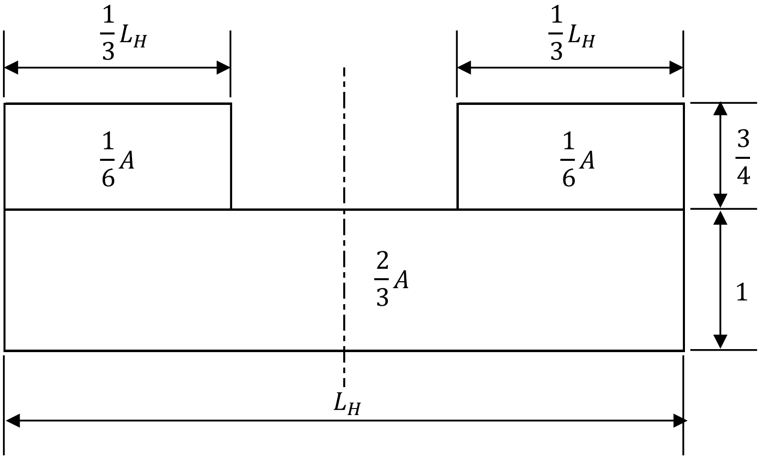


Figure 19: Weight distribution of standard hogging ship

Source: DNVGL-RU-FD Figure 2

4.4 Finite Element Model

A finite element model is developed for the global strength analysis of the structure as per the guidelines in DNV-GL-CG-0127. All major structural members which contribute to the longitudinal and transverse strength are modelled. These include the hull plates, bulkhead plates, girders, frames and stiffeners. The gross thickness of members are considered in this case as per the guideleines of DNVGL-CG-0127. All the plates, girder and frame webs are modelled with 4-noded quadrilateral meshes wherever possible and otherwise 3-noded triangular meshes are applied. The flanges of girders and frames and the stiffeners are modelled as beam elements. An ideal mesh size of 300 mm x 300 mm is followed wherever possible. The aspect ratio of the elements is kept closer to 1 wherever possbile and less than 3 the maximum. All the major structural cut-outs, for example, for the doors, windows, hatches etc are considered in the model. A summary of the FE model is given in the table below.

Table 8: FEM data

No. of nodes	234899
No. of elements	358705
Plate elements	Plates, girder and frame webs
Beam elements	Girder and frame flanges, stiffeners, pillars, brackets
Spring elements	Bolted connections

The material properties were chosen based on the recommendations in DNVGL-CG-0127. Table 9 lists the properties of the material considered in the analysis.

Table 9: Material properties

Material	Young's Modulus	Poisson Ratio	Shear Modulus	Density
	kN/m^2		kN/m^2	t/m^3
Steel	2.06 x 10^8	0.3	0.792 x 10^8	7.8

Coordinate system:

A rectangular coordinate system is adopted for the global model with the origin (0, 0, 0) located at the one corner such that, the length of the dock is along the positive x-axis (aft to foreward), the breadth of the dock is along the positive y-axis (starboard to port) and the height of the dock is along the positive z-axis from the baseline. The results ae sometimes represented in a generated coordinate system with the origin located at the base and the longitudinal and transverse center of the dock.

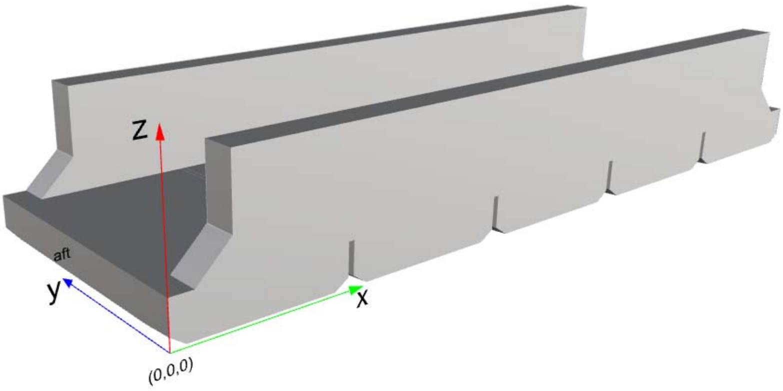


Figure 20: Rectangular coordinate system

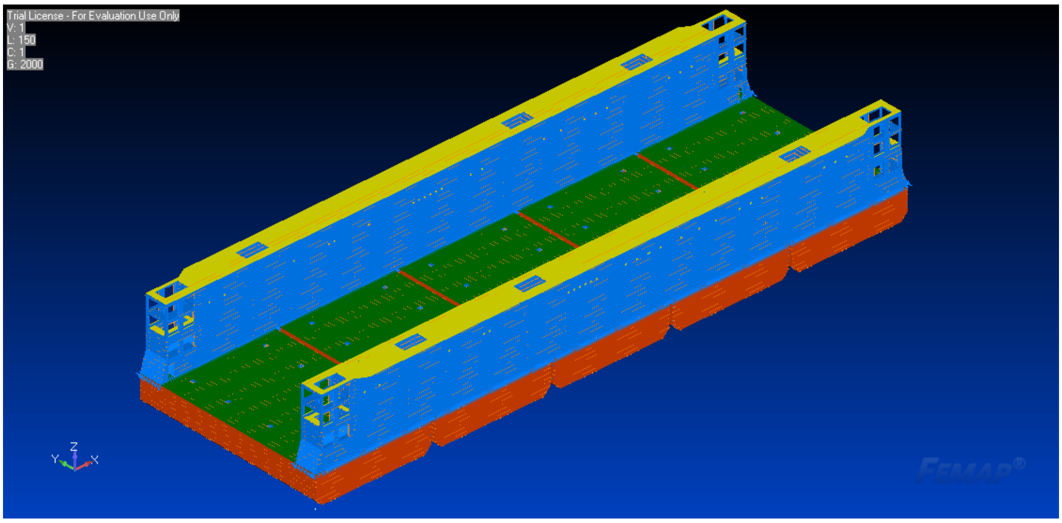


Figure 21: Global finite element model perspective view

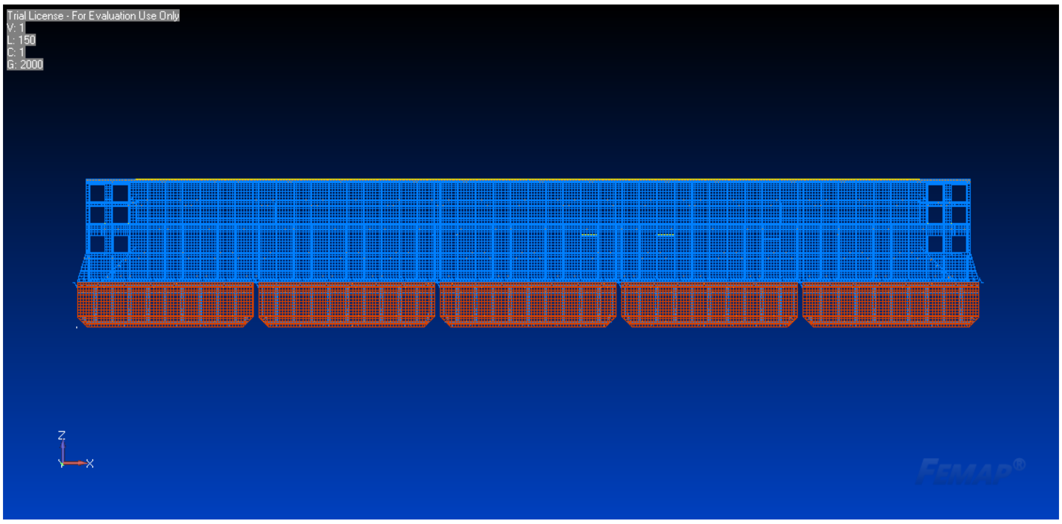


Figure 22: Global finite element model side view

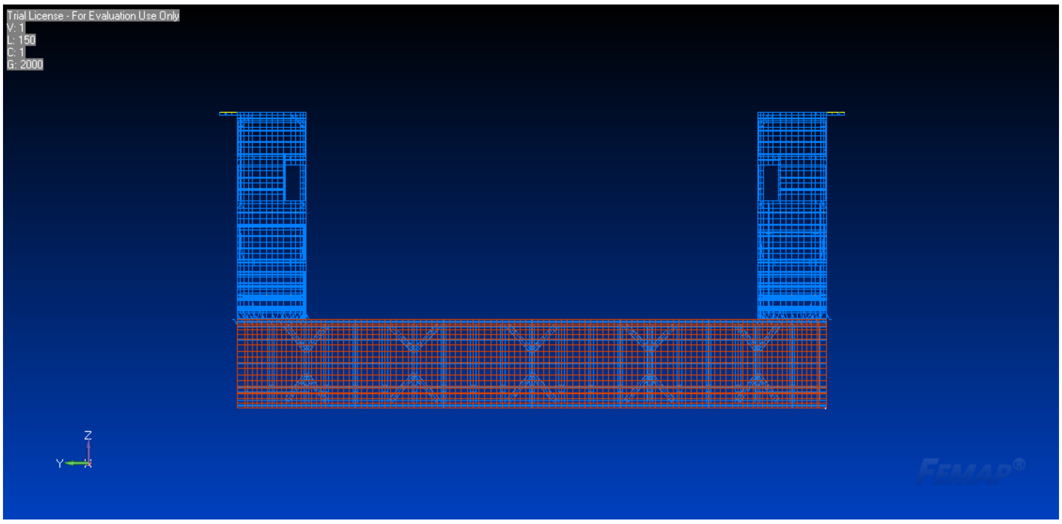


Figure 23: Global finite element model end view (enlarged)

4.5 Boundary Conditions and Connections

The dock as a floating body is not rigidly fixed in any direction. The stability and motion restraint is achieved through the balancing hydrostatic forces acting on the hull. All the nodes in FEMAP model is free to translate and rotate and has six degrees of freedom. So it is needed to restrain the xyz translations at first hand and then restrain the rotations about x, y and z axes of the global model to achieve a state of equilibrium.

To achieve near realistic conditions, one point each at the aft end wall and the foreward end wall are completely restrained against translational motions. As the ends are not restrained against the rotation, another point is fixed in the y-direction so that stability is attained against rotation. The same restraints are applied at the aft end and foreward end as the structure is discontinuous along the pontoon structure. A single point cosntraint can cause stress concentration at those nodes due to structural imbalances, which is not happening in actual case. So to overcome that a rigid node respresenting the nodes along the end surface are modelled and the boundary condtiions are applied to these nodes. The result is that it acts as single point supports, but the resulting forces will be shared equally on to the member nodes. Figure 24 shows the restraint locations and restraint directions considered in the analysis.

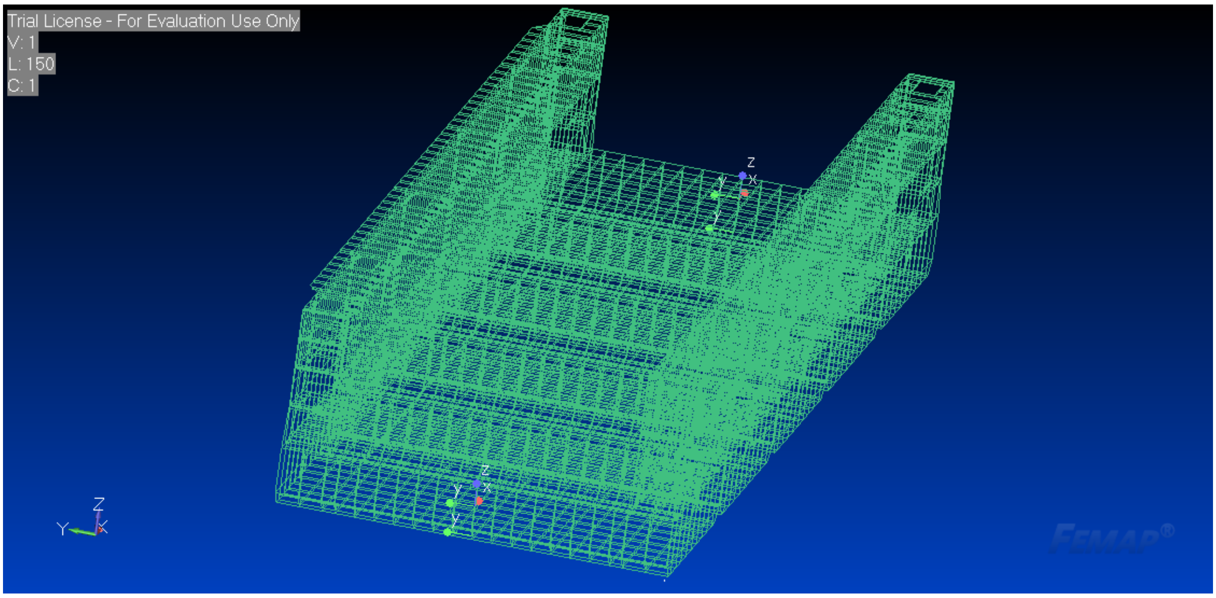


Figure 24: A wire frame view of the model with boundary constraints

Since the dock wings and sectional pontoons are seperate structures which are assembled through bolting, a proper connection has to be considered in the analsyis which could replicate the bolting connections. As the bolts are designed for tension and shear, and less moments, a connection which doesnt transfer moments but only translational forces are considered. This is enabled through spring supports of sufficient stiffness constants close to that of the bolts. Springs of stiffness constant 10^6 N/mm are assumed and provided in the x, y and z directions. A minimum rotational stiffnes of 10 N/mm is applied to achieve stability of the model.

4.6 Finite Element Analysis

4.6.1 Working Draft Condition

Based on the weight of the dock and the weights acting on the dock, the draft will be self-adjusted to give the required uplift or balancing force. The external hydrostatic pressure acting depend on this draft. The working draft of the dock is estimated between 1.69 m and 4.2 m in a preliminary stability check purely based on assumed weight. With the estimated weights and full lifting capacity, the required draft obtained is 3.9 m and this is assumed to be the working draft, where as the maximum working draft can be up to 4.2m. the various loads that act in this condition are:

i. The lightweight including the full load of consumables and rest water of 2 feet high at the bottom of the pontoon.

ii. The docking load of the ship which can be either in sagging state or in hogging state.
iii. The external hydrostatic pressure for which the magnitude is dependend on the draft.

The analysis is done considering a sagging ship first and then a hogging ship. In both cases, the longitudinal and transverse strengths are checked. The results are then compared and the highest of the values are considered to be representing the stresses on the dock.

Table 10: Stress results- Longitudinal bending and shear- Sagging ship

Longitudinal Member	f_1	Max. Bending Stress (MPa)		Mean Shear Stress (MPa)	
		Allowable	Actual	Allowable	Actual
Dock Wing					
Side Plate	1	140	107	100	71
Upper Deck Plate	1	140	151	100	71
Safety Deck Plate	1	140	74	100	40
Upper Deck Stiffener	1	140	116	100	23
Safety Deck Stiffener	1	140	107	100	37

Table 11: Stress Results- Longitudinal bending and shear- Hogging ship

Longitudinal Member	f_1	Max. Bending Stress (MPa)		Mean Shear Stress (MPa)	
		Allowable	Actual	Allowable	Actual
Dock Wing					
Side Plate	1	140	113	100	57
Upper Deck Plate	1	140	139	100	67
Safety Deck Plate	1	140	69	100	42
Upper Deck Stiffener	1	140	118	100	24
Safety Deck Stiffener	1	140	114	100	38

Table 12: Stress results- Transverse bending and shear- Sagging ship

Transverse Member	f_1	Max. Bending Stress (MPa)		Mean Shear Stress (MPa)	
		Allowable	Actual	Allowable	Actual
Pontoon					
Bottom Plate	1	170	160	100	96
Side Plate	1	170	192	100	99
Deck Plate	1	170	191	100	93

Bottom Girder	1.39	236	119	139	85
Deck Girder	1.39	236	107	139	69

Table 13: Stress results- Transverse bending and shear- Hogging ship

Transverse Member	f_1	Max. Bending Stress (MPa)		Mean Shear Stress (MPa)	
		Allowable	Actual	Allowable	Actual
Pontoon					
Bottom Plate	1	170	80	100	47
Side Plate	1	170	97	100	50
Deck Plate	1	170	95	100	44
Bottom Girder	1.39	236	54	139	43
Deck Girder	1.39	236	43	139	27

From the results in table 10, the maximum longitudinal stresses on the dock wing upper deck is found to be higher than the allowable as per DNVG-RU-FD Sec. 4.3.1.1. As the upper deck is subjected higher stresses, a high grade plate of yield strength 355 MPa can be used, so that the resulting requirement will be as per table 14 below.

Table 14: Revised longitudinal bending stress results

Longitudinal Member	f_1	Max. Bending Stress (MPa)		Mean Shear Stress (MPa)	
		Allowable	Actual	Allowable	Actual
Dock Wing					
Upper Deck Plate	1.39	194.6	151	139	71

The results from table 12 shows that, when a sagging ship of full capacity is docked, the maximum actual stresses acting on the pontoon side plate and pontoon deck plate at specific regions are more than the allowable transverse bending strength as per DNVGL-RU-FD Sec. 5.3.1.1. These regions are the fore and aft ends of the central pontoon at the center of the connecting edges of the deck and the side plates. A higher stress plate of 355 MPa can be used in this region to mitigate the problem. Then the result would be as per the table 15 below.

Table 15: Revised transverse bending stress results

Transverse Member	f_1	Max. Bending Stress (MPa)		Mean Shear Stress (MPa)	
		Allowable	Actual	Allowable	Actual
Pontoon					

Side Plate	1.39	194.6	192	139	99
Deck Plate	1.39	194.6	191	139	93

Figure 25 shows the location of maximum Von Mises Stress plot in case of a sagging ship of full capacity docked.

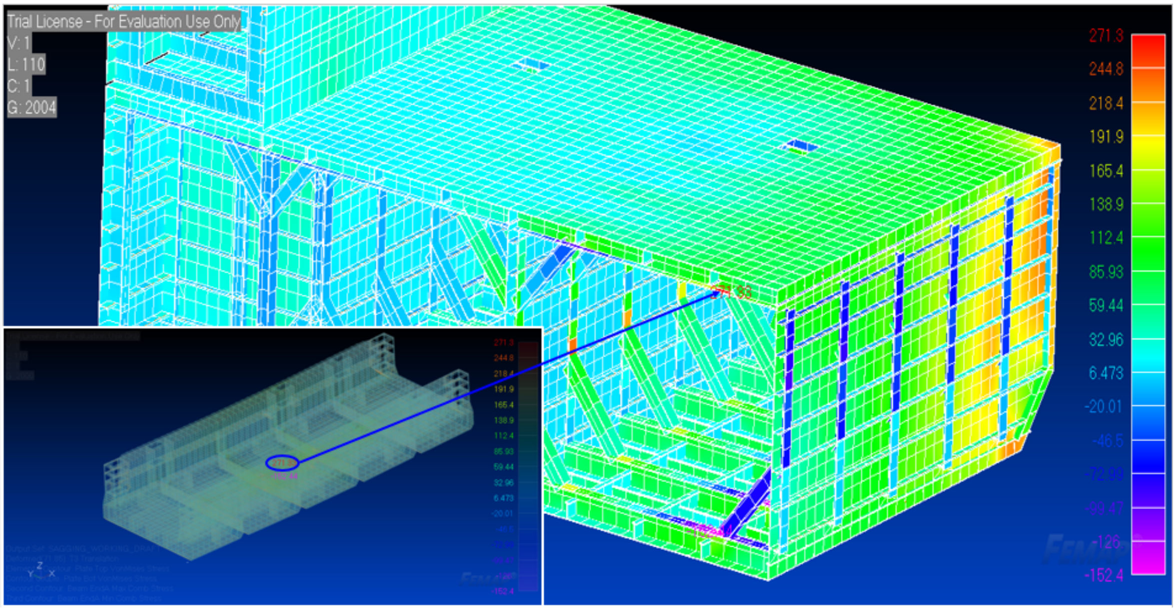
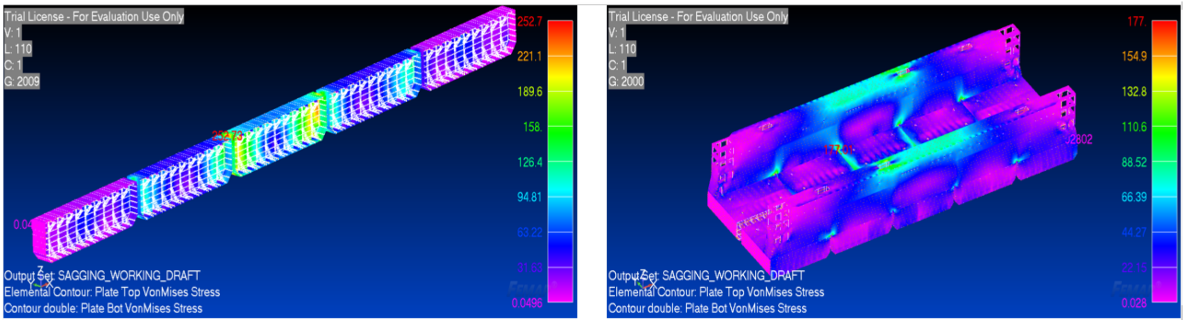


Figure 25: Max. Von Mises stress plot- Sagging ship

From figure 25, the maximum stresses element is seen on the flange of the pontoon deck girder, where the bracket from the central pillar is connected. The maximum value obtained is 271.3 MPa and the allowable value as per DNVGL-RU-FD Sec. 5.3.1.1 is 278 MPa. So the peak stress is found to be with-in the limits of combined stress. From the stress contour, it is clear that the peak stresses are much localised and all other elements can be seen in very reasonable range of stresses. So the structure as a whole is very much safe in carrying the stipulated loads in this condition. A closer view on the high stressed regions on the low yield strength members initially considered is shown in figure 26 below.



Output Set: SAGGING_WORKING_DRAFT
Elemental Contour: Plate Top VonMises Stress
Contour double: Plate Bot VonMises Stress

Output Set: SAGGING_WORKING_DRAFT
Elemental Contour: Plate Top VonMises Stress
Contour double: Plate Bot VonMises Stress

Figure 26: Von Mises Stress excluding high yield strength members

The first plot of figure 26 shows the section of the pontoons with in the adjacent frames on either sides of the centreline and the second plot shows the remaining section. The limit for the stresses for low yield members used is 200 MPa. Von Mises stresses above 200 MPa is obtained on the central pontoon bulkhead and the pontoon deck, side and bottom edges at the region. But all these higher values are less than 278 MPa which is the limit in case of a plate of high yield strength. So it is advisable to use high yield plates at those regions of expected high stresses. So the central pontoon deck, side and bottom plates along the length, with in one frame on the port and starboard sides and the central pontoon bulkhead are advisable to be replaced with plates of yield strength 355 MPa.

Figure 27 below, shows the maximum Von Mises Stress plot in case of a hogging ship of full capacity docked.

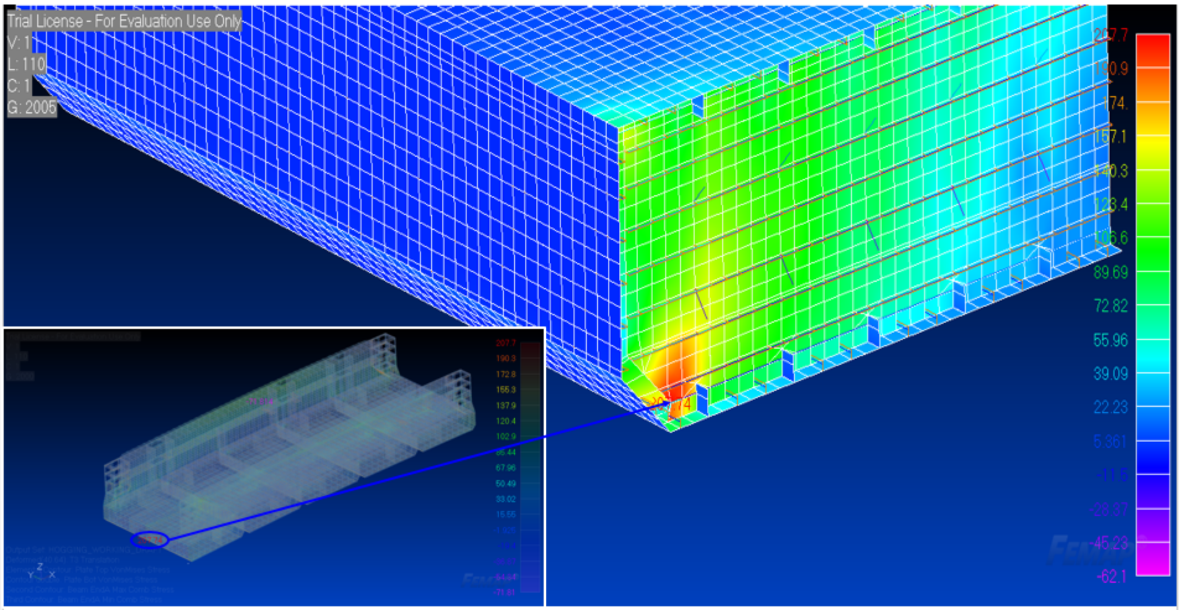


Figure 27: Max. Von Mises stress plot- Hogging ship

From figure 27, the maximum Von Mises stress plot shows the peak stress occurs at the pontoon central bulkhead at aft end bottom. The maximum value obtained is 207.7 MPa. Allowable value as per DNVGL-RU-FD Sec. 5.3.1.1 is 200 MPa. A high yield strength plate of 355 MPa is recommended for this region so that the allowable stress is increased to 278 MPa. A closer view on the high stressed regions on the low yield strength members initially considered is shown in figure 28.

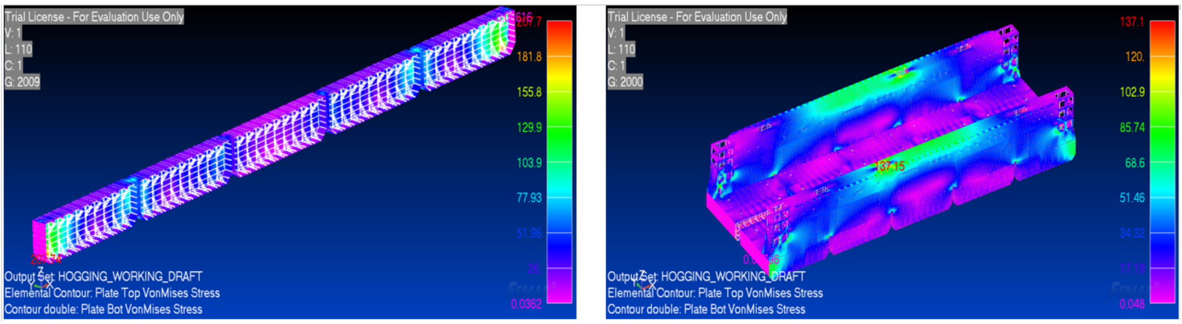


Figure 28: Von Mises Stress plot excluding high yield strength members

The first plot of figure 28 shows the section of the pontoons with in the adjacent frames on either sides of the centreline and the second plot shows the remaining section. The limit for the stresses for low yield members used is 200 MPa. Von Mises stresses above 200 MPa is obtained on the central pontoon bulkhead. But all this higher value is much less than 278 MPa which is the limit in case of a plate of high yield strength. So it is advisable to use high yield plates at those regions of expected high stresses. So the central bulkhead at the aft and fore end pontoons are advisable to be replaced with plates of yield strength 355 MPa.

The deflection plots for the dock along the longitudinal and the transverse are shown in the figure 29 and 30 respectively. Both sagging and hogging cases are considered.

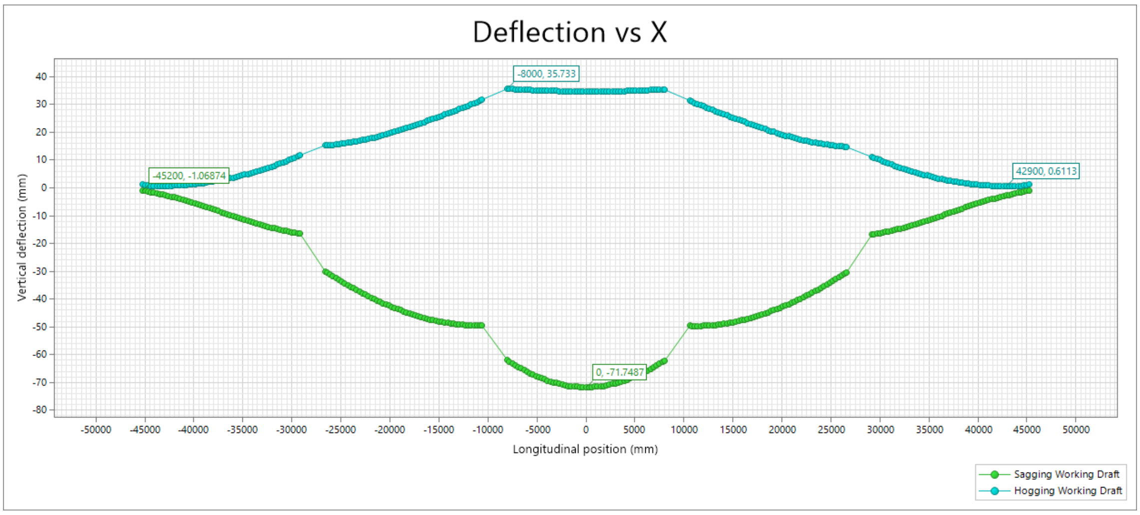


Figure 29: Vertical deflection along the length in sagging and hogging working condition

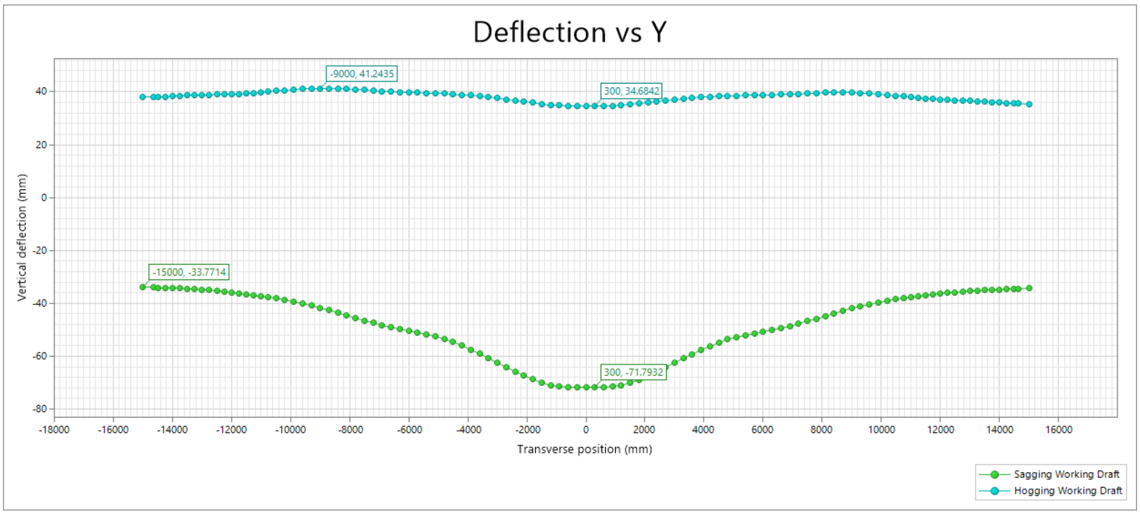


Figure 30: **Vertical deflection along the breadth in sagging and hogging working condition**

The maximum deflections as shown in figure 27 and 28 are found to be with-in acceptable limits compared to the length and breadth of the deck. The worst case of deflection occurs in case of a sagging ship docked. These deflections can be monitored in real case using some deflection monitoring systems and these values represent the strength limits while undergoing these loading conditions.

4.6.2 Maximum Submerged Condition

Based on the draft of the ship to be docked, the dock will be ballasted to get enough immersion, so that the ship can be towed in between the dock wings. The maximum draft will be the maximum draft calculated for the dock. Since the dock wings are also immersed in this case, there is large hydrostatic forces acting in the dock walls as well. So the local stiffeners experience large pressure forces. The various loads that act in this condition are:

i. The lightweight including the full load of consumables.
ii. The ballast loads.
iii. The external hydrostatic pressure for which the magnitude is dependend on the draft.

There is no docking load acting in this case. Full ballast loads is considered in the analysis, but the hydrostatic forces to balance all the downward loads requires the draft to be 12.1 m only. That means with the full available loading, the dock is not able to meet the maximum submersion of 13.5 m. So the analysis is carried out with the maximum possible submersion of 12.1 m. The results are compared with the permissible values.

Table 16: Stress results- Longitudinal bending and shear

Longitudinal Member	f_l	Max. Bending Stress (MPa)		Mean Shear Stress (MPa)	
		Allowable	Actual	Allowable	Actual
Dock Wing					
Side Plate	1	140	35	100	28
Upper Deck Plate	1	140	47	100	21
Safety Deck Plate	1	140	43	100	25
Upper Deck Stiffener	1	140	41	100	16
Safety Deck Stiffener	1	140	104	100	39

Table 17: Stress results- Transverse bending and shear

Transverse Member	f_l	Max. Bending Stress (MPa)		Mean Shear Stress (MPa)	
		Allowable	Actual	Allowable	Actual
Pontoon					
Bottom Plate	1	170	39	100	42
Side Plate	1	170	65	100	53
Deck Plate	1	170	61	100	25
Bottom Girder	1.39	236	117	139	58
Deck Girder	1.39	236	102	139	65

From the results in table 16 and 17, it is understood that the dock is less stressed in this condition and all the scantlings and yield stress of materials chosen satisfy the strength requirements. Unlike the condition where the docking loads are acting, the higher loads which include the hydrostatic and ballast loads are distributed over the exposed areas. Hence no high concentration of loads as in case of docking.

Figure 31 shows the location of maximum Von Mises Stress in case of a fully submerged dock.

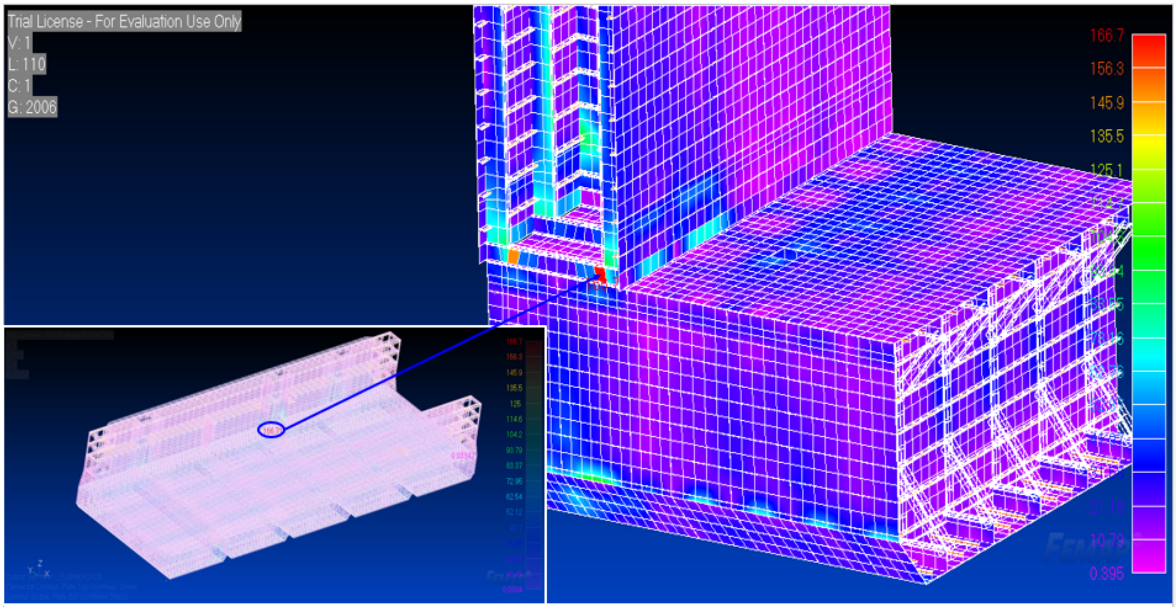


Figure 31: Max. Von Mises stress plot

From figure 31, the maximum Von Mises stress is seen on the dock wing bottom web at the location in the figure. The maximum stress value is 166.7 MPa and the allowable value as per DNVGL-RU-FD Sec. 5.3.1.1 is 200 MPa. So the peak stress is found to be with-in the limits of combined stress. The peak stress here is much localised and no way affecting the global strength of the structure. The stress contour shows the stresses on the majority of the elements comes in a very lesser range.

The deflection obtained is very less and not critical in this case.

4.6.3 Docking and Undocking Condition

As the ship to be docked is towed in to position, between the dock wings of the fully submerged dock, the lifting of the dock and docking of the vessel is achieved through de-ballasting of the dock. As the dock emerges out of water, the vessel to be docked is positioned as such the keel rests on the docking blocks arranged linearly along the length of the dock. Once there is contact between the keel of the ship and the docking blocks, the weight of the vessel starts to be carried on to the dock. The vessel in immersed state, the initial loading will be less as there is the buoyancy forces acting due to the immersed hull of then vessel. When the draft of the dock is decreased further, it passes through a state when the docked vessel hull is completely out of water, which means the load of the vessel in full is acting on the dock. since the docking block has a height of 1.2 m (assumed in this case), a draft level just below the dock block level would be critical as there is the load of the docked vessel plus the hydrostatic pressure acting on the deck. This case of loading would be critical for a dock and needs to be carefully analyzed. This section analyses such a condition.

The various loads that act in this condition are:

i. The lightweight including the full load of consumables
ii. The docking load of the ship which can be either in sagging state or in hogging state.
iii. The external hydrostatic pressure for which the magnitude is dependend on the draft.

The analysis is done considering a sagging ship first and then a hogging ship. In both cases, the longitudinal and transverse strength are checked. Ballast loads are considered which is enough to balance the buoyancy forces created at the draft level of 5.7 m (just below the docking blocks). The results are then compared and the highest of the values are considered to be representing the strength of the dock.

Table 18: Stress results- Longitudinal bending and shear- Sagging ship

Longitudinal Member	f_1	Max. Bending Stress (MPa)		Mean Shear Stress (MPa)	
		Allowable	Actual	Allowable	Actual
Dock Wing					
Side Plate	1	140	108	100	73
Upper Deck Plate	1	140	145	100	69
Safety Deck Plate	1	140	72	100	38
Upper Deck Stiffener	1	140	113	100	22
Safety Deck Stiffener	1	140	107	100	37

Table 19: Stress results- Longitudinal bending and shear- Hogging ship

Longitudinal Member	f_1	Max. Bending Stress (MPa)		Mean Shear Stress (MPa)	
		Allowable	Actual	Allowable	Actual
Dock Wing					
Side Plate	1	140	122	100	57
Upper Deck Plate	1	140	147	100	70
Safety Deck Plate	1	140	75	100	43
Upper Deck Stiffener	1	140	125	100	25
Safety Deck Stiffener	1	140	114	100	38

Table 20: Stress results- Transverse bending and shear- Sagging ship

Transverse Member	f_1	Max. Bending Stress (MPa)		Mean Shear Stress (MPa)	
		Allowable	Actual	Allowable	Actual
Pontoon					
Bottom Plate	1	170	164	100	101
Side Plate	1	170	203	100	105
Deck Plate	1	170	201	100	98
Bottom Girder	1.39	236	122	139	89
Deck Girder	1.39	236	113	139	78

Table 21: Stress results- Transverse bending and shear- Hogging ship

Transverse Member	f_1	Max. Bending Stress (MPa)		Mean Shear Stress (MPa)	
		Allowable	Actual	Allowable	Actual
Pontoon					
Bottom Plate	1	170	86	100	51
Side Plate	1	170	105	100	53
Deck Plate	1	170	103	100	48
Bottom Girder	1.39	236	56	139	47
Deck Girder	1.39	236	47	139	36

From the results in table 18 and 19, the maximum longitudinal stresses on the dock wing upper deck is found to be higher than the allowable as per DNVG-RU-FD Sec. 4.3.1.1. As the upper deck is subjected higher stresses, a high grade plate of yield strength 355 MPa can be used as explained in section 4.6.1.

The results from table 20 shows that, when a sagging ship of full capacity is docked, the maximum actual stresses acting on the pontoon side plate, pontoon deck plate and pontoon bottom plate at specific regions are more than the allowable transverse bending strength as per DNVGL-RU-FD Sec. 5.3.1.1. These regions are the fore and aft ends of the central pontoon at the center of the connecting edges of the deck and the side plates and the bottom and the side plates. A higher stress plate of 355 MPa can be used in this region to mitigate the problem as explained in section 4.6.1.

Figure 32 shows the Maximum Von Mises stress plot during the docking or undocking condition of a sagging ship.

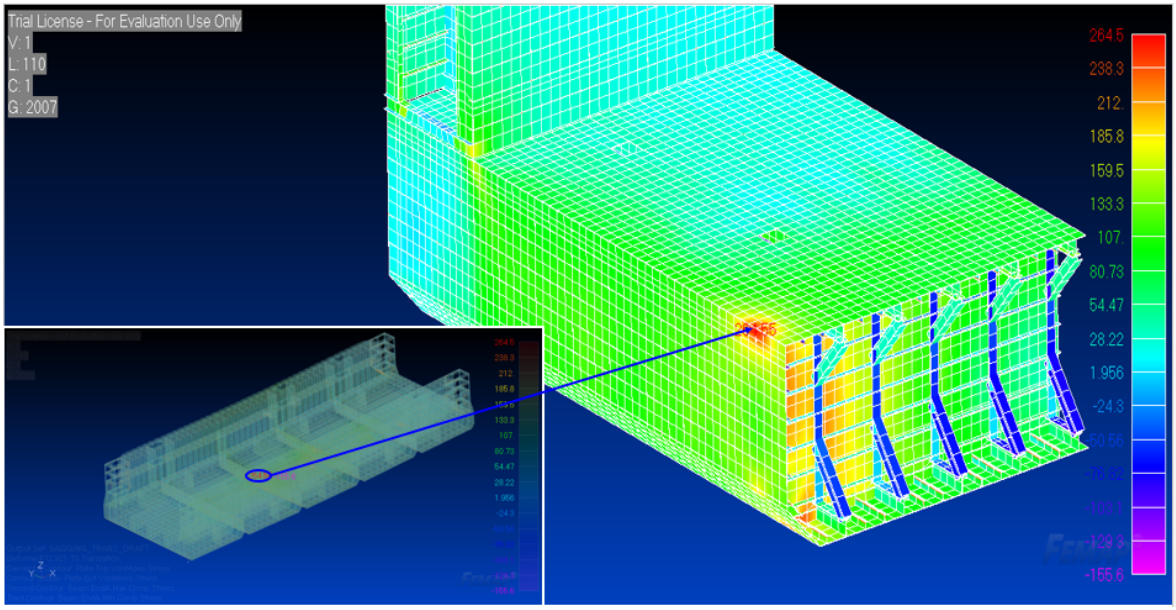


Figure 32: Max Von Mises stress plot- Sagging ship

From figure 32, the maximum stresses element is seen on the central pontoon side top edge at the about the centre-line as shown. The maximum value obtained is 264.5 MPa and the allowable value as per DNVGL-RU-FD Sec. 5.3.1.1 is 200 MPa**.** So the peak stress is found to be higher than the limits of combined stress. A high yield plate of 355 MPa and allowable stress of 278 MPa can be used in this region. From the stress contour, it is clear that the peak stresses are much localised and all other elements can be seen in very reasonable range of stresses. So the structure as a whole is very much safe in carrying the stipulated loads in this condition. A closer view on the high stressed regions on the low yield strength members initially considered is shown in figure 33 below.

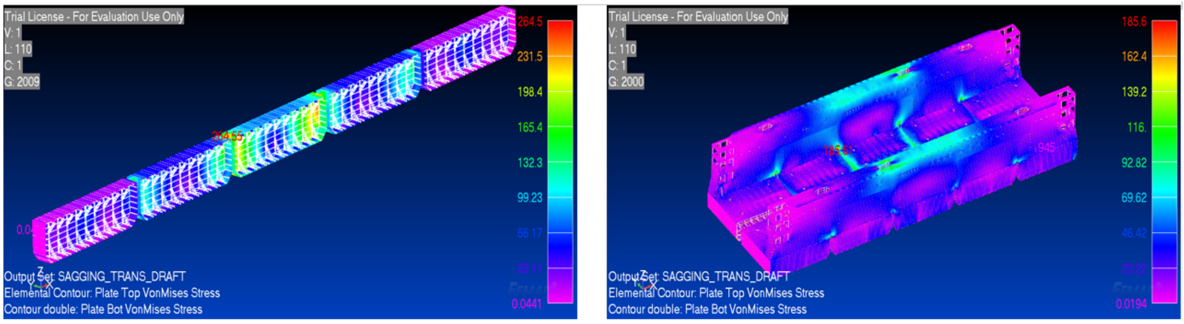


Figure 33: Von Mises Stress plot excluding high yield strength members

Similar case is explained in section 4.6.1 for sagging ship, and it is advisable to replace the pontoon bottom, deck and side plates with in the adjacent port and starboard frames about the centre line with high yield plates of 355 MPa.

Figure 34 shows the location of Maximum Von Mises stress during the docking or undocking condition of a hogging ship.

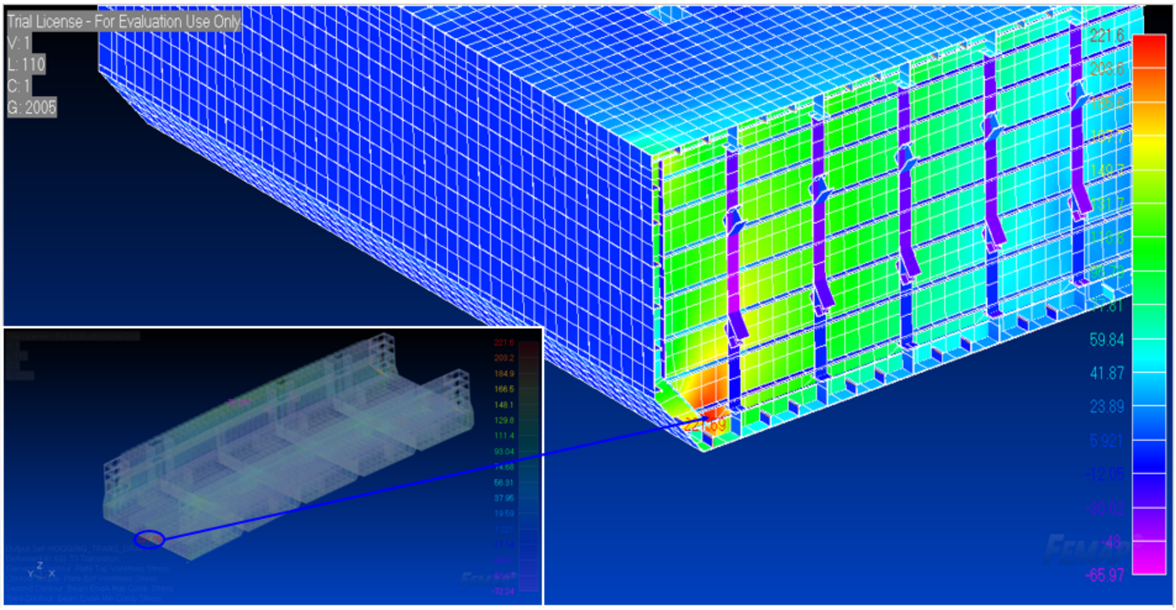


Figure 34: Max. Von Mises stress plot- Hogging ship

From figure 34, the maximum Von Mises stress plot shows the peak stress occurs at the pontoon central bulkhead at aft end bottom. The maximum value obtained is 221.6 MPa. Allowable value as per DNVGL-RU-FD Sec. 5.3.1.1 is 200 MPa. A high yield strength plate of 355 MPa is recommended for this region so that the allowable stress becomes 278 MPa.

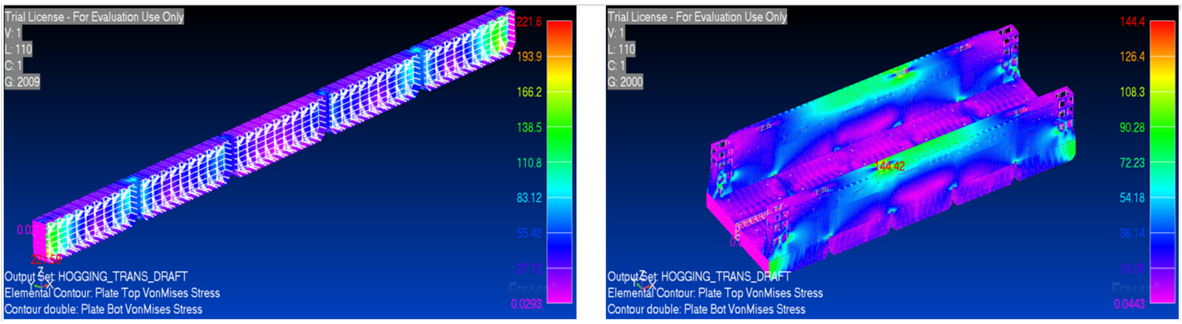


Figure 35: Von Mises Stress excluding high yield strength members

Similar case is explained in section 4.6.1 for hogging ship, and it is advisable to replace the pontoon central bulkhead at the fore and aft end pontoons with high yield plates of 355 MPa.

The deflection plots in the docking and undocking condition is shown in figure 36 and 37.

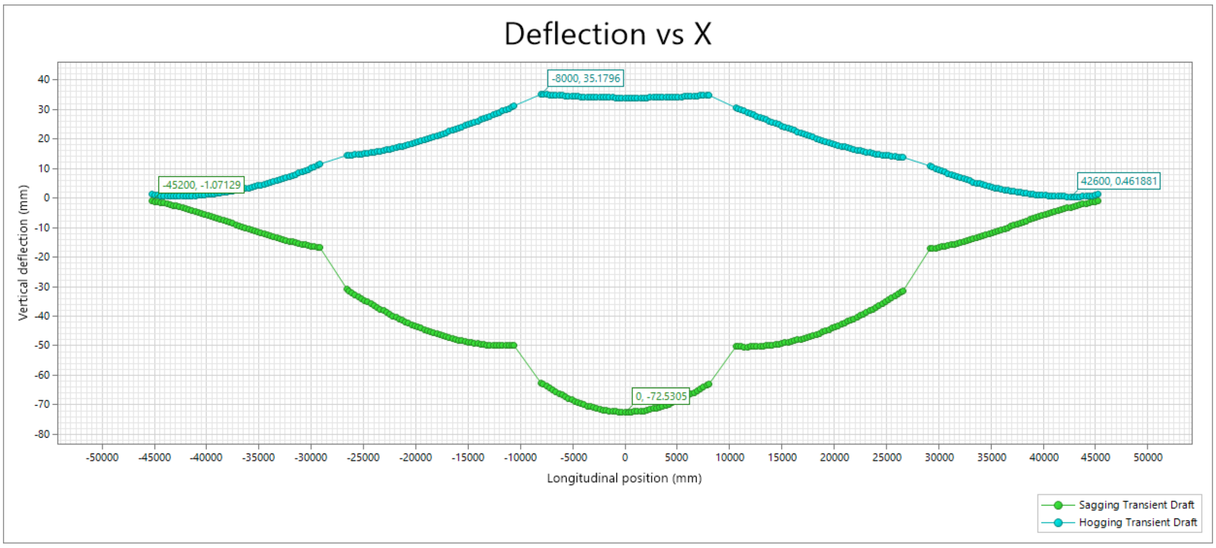


Figure 36: Vertical deflection along the length in sagging and hogging docking condition

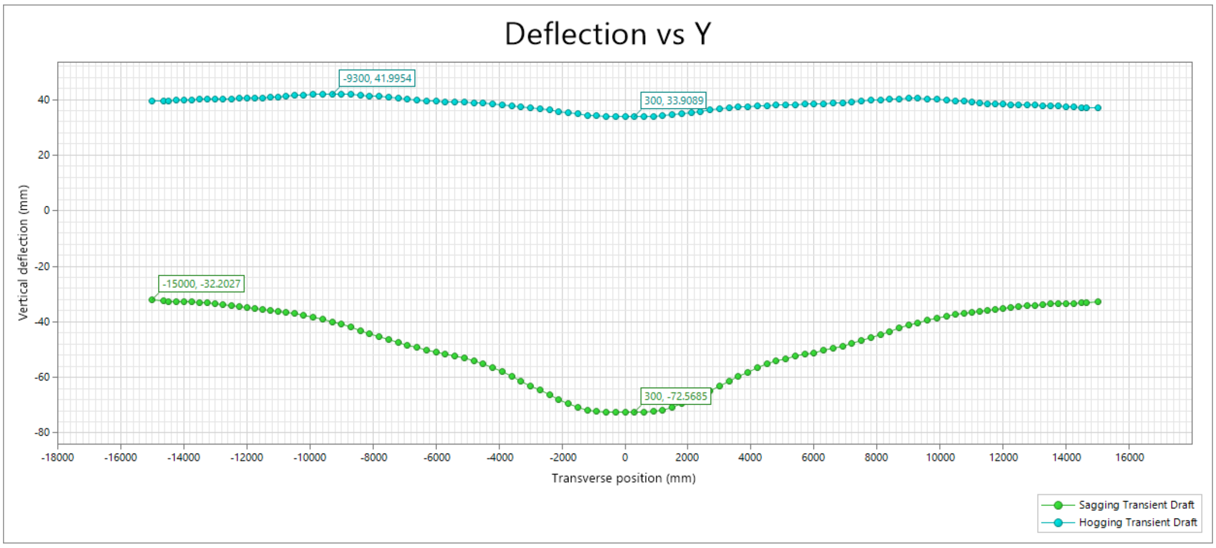


Figure 37: Vertical deflection along the breadth in sagging and hogging docking condition

The maximum deflections as shown in figure 36 and 37 are found to be with-in acceptable limits compared to the length and breadth of the deck. The deflections seem to be a little higher than that in the working condition.

4.7 Summary

From the FEA performed for various loading conditions, a comparison of the stress results show that the maximum stresses on the members is expected to occur in the case of a sagging ship on dock. The stresses are a little higher in the stage when the water level is just below the docking blocks with the full ship weight carried by the dock, that is, in the docking or undocking stage. A closer study of the high stressed regions show that these high stresses are occurring on elements at the corners or where there is point loads applied or stress concentration taking place. And the neighboring elements has stress values lesser by about 30% or more. Figure 38 is the plot of maximum Von Mises stresses on the deck plate. Marked in the picture are the 2 elements which has high stress concentration. These areas need to be locally analyzed and these will not be deciding the global structural strength. But in case of the subject design, the peak stresses calculated are with-in the specified limits. So the structure can be deemed safe. But a detailed analysis could help optimizing, by using lesser grades of steel which has an influence on the cost.

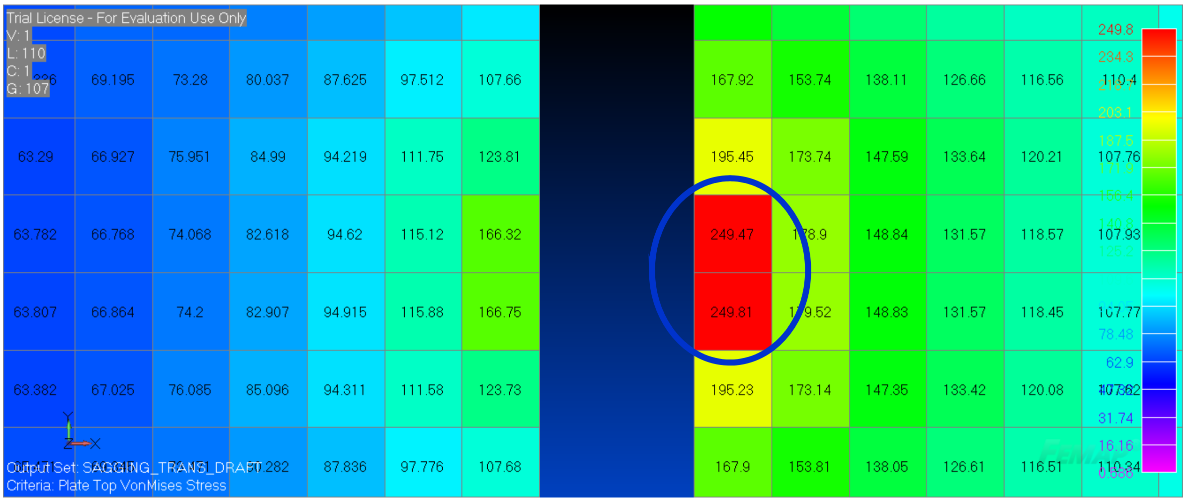


Figure 38: Stress Concentration

The stresses experienced by the structure seems to be very less with enough factor of safety except for those stress concentrated regions.

Based on the results from FEA, the following changes to the scantlings is made:

1. High yield plate of yield strength 355 MPa is used for the pontoon deck, side and bottom between the first frame to the port and to the starboard.
2. High yield plate of yield strength 355 MPa is used for the pontoon central bulkhead.
3. High yield plate of yield strength 355 MPa is used for the dock wing upper deck plate.

The stress is related to the strain and the deflections, and as such deflection is also an important parameter in assessing strength. The deflection of the dock are divided in to the dockwing deflection and the pontoon deflection. All the deflection values obtained in different analyses are found acceptable. The maximum deflection can be regarded as representing the maximum stress value and the deflection has to be monitored while docking operations and proper ballasting has to be done to control the deflection and thereby stresses.

The worst condition for the dock is found to be for docking a sagging ship of full capacity and at a stage when the water level is just below the docking block level, with the full docking load supported by the dock.

5 BUCKLING CHECK

5.1 General

Buckling is the sudden sideways deflection of a structural member. Buckling can occur due to compressive or shear stresses. A member subjected to buckling fails to carry any more of compressive or shear loads and is considered an ultimate failure. This failure can happen even when the stresses developed within are well below the yield stresses. So in addition to bending and shear stress checks an additional check on the buckling is necessary so that any probabilities can be eliminated by suitably stiffening or increasing the sections.

In the subject design buckling has to be checked for the pontoon pillars which suffer high axial forces. The stress values are taken from the FEA and the buckling is checked based on the DNV-GL Rules for buckling.

The buckling acceptance criteria as defined by DNV-GL is,

$$\eta_{act} \leq \eta_{all} \tag{43}$$

Where,

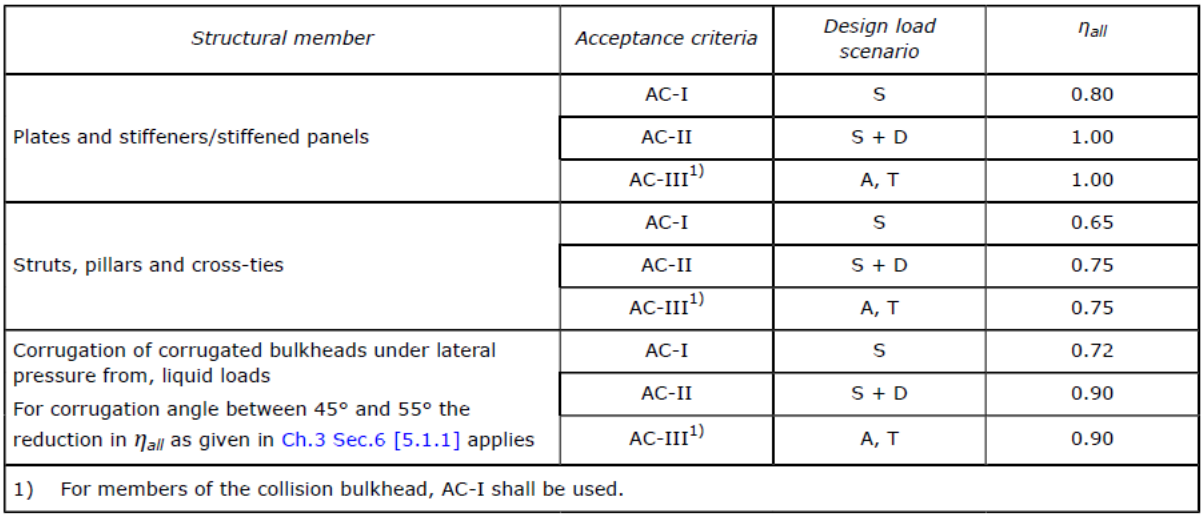
$\eta_{act} = buckling\ utilisation\ factor\ based\ on\ the\ applied\ stress$

$\eta_{all} = allowable\ buckling\ utilisation\ factor$

η_{all} value is given below.

Table 22: Buckling acceptance criteria

Source: DNVGL-RU-SHIP Part 3 Chapter 8 Table 3



Structural member	*Acceptance criteria*	*Design load scenario*	η_{all}
Plates and stiffeners/stiffened panels	AC-I	S	0.80
	AC-II	S + D	1.00
	AC-III$^{1)}$	A, T	1.00
Struts, pillars and cross-ties	AC-I	S	0.65
	AC-II	S + D	0.75
	AC-III$^{1)}$	A, T	0.75
Corrugation of corrugated bulkheads under lateral pressure from, liquid loads For corrugation angle between 45° and 55° the reduction in η_{all} as given in Ch.3 Sec.6 [5.1.1] applies	AC-I	S	0.72
	AC-II	S + D	0.90
	AC-III$^{1)}$	A, T	0.90
1) For members of the collision bulkhead, AC-I shall be used.			

The above table provides the allowable buckling utilisation factor for various structural parts critical to buckling for different loading scenarios namely, static (S), dynamic (D), accidental (A) and temperature loadings (T). The subject design doesn’t take in to consideration any dynamic, temperature or accidental loading conditions. So the buckling check is based on the acceptance criteria I (AC-I).

5.2 Buckling of Pillars

The pillars transferring the deck loads to the bottom structure used in the pontoons is subjected to high axial loading especially in case of docking. The strength of pillars to resist any buckling failure is of utmost importance.

The buckling utilization factor for axially compressed pillars is given by,

$$\eta = \frac{\sigma_{av}}{\sigma_{cr}} \tag{44}$$

Figure 39 shows the gross section of the main load bearing pillars used in the pontoons. The corrosion allowance is 3 mm each for web and flange. The net section properties is considered in the buckling check.

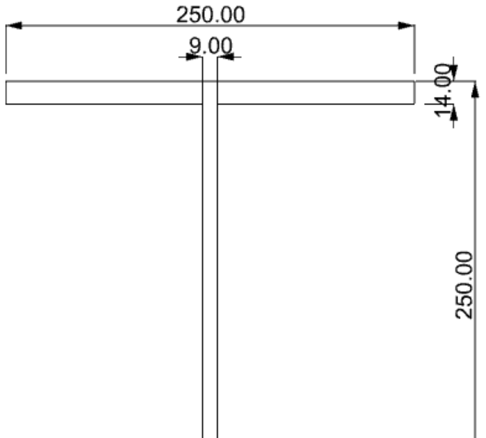


Figure 39: Typical I-section pillar

Table 23: Gross section properties

Height	Sectional Area	Weaker moment of inertia
(m)	(cm^2)	(cm^4)
3.77	91.4	3648

Table 24: Net section properties

Height	Sectional Area	Weaker moment of inertia
(m)	(cm^2)	(cm^4)
3.77	68.7	2865

σ_{cr} is taken equal to the elastic column buckling stress if its value is less than or equal to half the minimum yield stress or else, it has to be calculated as per the formulation given in DNVGL-CG-0128 section 3.4.1 and 3.4.2.

The calculated value is given below,

$$\sigma_{cr} = 302\ N/mm^2$$

The maximum average axial stress obtained from the axial forces acting in various loading cases in tabulated below,

Table 25: Axial stress result

Loading case	Max. σ_{av}
	(N/mm^2)
Sagging Working Condtion	120

$$\therefore \eta_{act} = 0.40$$

As per AC-I, for static loading case, $\eta_{all} = 0.65$

$\eta_{act} < \eta_{all}$, hence the condition that the member yields before buckling is satisfied.

6 CONNECTION DESIGN

6.1 General

The subject design has 7 major structural sections which include 5 symmetrical pontoons and 2 symmetrical dock wings. There is no strength connection between the pontoons but the pontoons are bolted on to the dock wings. So in general, the pontoons actively take part in transverse bending strength and the dock wings in longitudinal strength. The structure responds globally to the loads acting through transverse and longitudinal bending. The differences in curvature of the bending of the dock wings and the pontoons causes high tension and shear at the connections at specific regions. These values of tension and shear are considered in the design of the connection. The maximum spacing between bolts is decided based on the water tightness requirement.

6.2 Bolt Loads Calculation

In the FEM, spring elements are modelled to ensure connection between the pontoon decks and the dock wing walls. A spring constant of 10^6 N/mm is assumed as the stiffness of the joint. From the FEA carried out, the maximum forces acting on the connecting members modelled as spring are taken out. These values are assumed to be the actual forces acting on the bolted connection. A bolt has been considered at every 300 mm along the length of each dock wing wall in the FE model. The purpose of this bolting is to provide strength connection as well as water tight connection between the dock wing base and the pontoon deck. To have water tightness and better integrity, bolt spacing is reduced to 200 mm (max.).

Flanged bolting connections are preferred in this case to have enough water tightness. A typical connection is shown in figure 40.

Figure shows the bolt is in tension. The subject design experiences both tension and shear in the bolted connections due to the differential bending and also due to the local pressures acting due to the loaded dock wing tanks and the hydrostatic pressure loads. The bolts are preloaded to ensure clamping between the joining plates or in other terms to enhance shear transfer between the plates by friction. The gasket or sealant used in between the connecting surfaces could reduce the stiffness of the connection joint. The thickness of the gasket has to be restricted to as small as possible to have better contact stiffness of the joint. The preloading value depends on the bolt size and bolt grade. As per AISC ASD Specification for Structural Steel Buildings, the pretension/ preload shall be 0.7 times the minimum tensile capacity of the bolt.

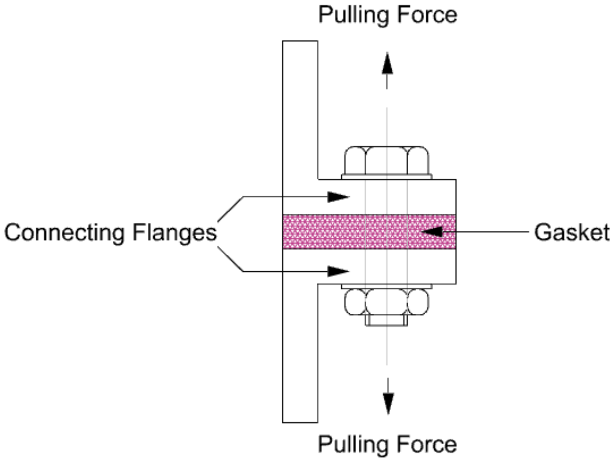


Figure 40: Typical bolting

Bolt preload creates a compressive force between the contact surfaces and a tension on the bolt. The idea behind this to reduce the external tension acting in the bolt especially in case of cyclic loadings to prevent fatigue of the bolts. When an external tension force acts on the joint, the applied tension is used to relieve the compression forces generated by the bolt preload and when the compression forces are completely removed, there will be separation of the surfaces in contact and hence the bolt gets more tensile load. That means up to 80% to 90% of the external tension load passes through the joint and only the remaining through the bolt. Preload also enhances slip resistance.

Bolt selection is done as per the guidelines of *AISC ASD Specification for Structural Steel Buildings.*

Maximum bolt load obtained from FEA,
$Maximum\ tensile\ load = 131\ kN$
$Resultant\ shear\ load = 71\ kN$
Galvanized carbon steel bolt M24 and grade 8.8 as per ISO 898-1 is chosen.

As per AISC ASD Section J3.6, for the chosen bolt,

$Allowable\ tensile\ strength = 146\ kN$

$Allowable\ shear\ strength = 105\ kN$

M24 bolt chosen satisfies the allowable strength requirements.

6.3 Connecting Elements Calculation

The required plate thickness for the connection is based on the design check as per AISC ASD Section J4-1.

The selected bolt is M24 bolt and the size of the hole required in 26 mm.

6.3.1 Design for Tension

Since the plate elements are subjected to tension, the strength of the elements in yielding and rupture has to be checked and the lower value is considered as the design strength in tension.

Table 26 gives the parameters needed in the design for tension and table 27 and 28 shows the design checks for shear yielding and shear rupture respectively.

Table 26: Connecting plate parameters in tension

Thickness	Width	F_y	F_u	d_b	A_g	A_n
(mm)	(mm)	(N/mm^2)	(N/mm^2)	(mm)	(mm^2)	(mm^2)
12	90	355	480	26	1080	744

Table 27: Tensile yielding

AISC ASD J4.1		
Tensile yielding	Safety factor	Allowable strength
$R_n = F_yA_g$ (N)	Ω	R_n/Ω (N)
383400	1.67	229581

Table 28: Tensile rupture

AISC ASD J4.2		
Tensile rupture	Safety factor	Allowable strength
$R_n = F_uA_n$ (N)	Ω	R_n/Ω (N)
357120	2.00	178560

So from the tables 27 and 28, the lowest allowable strength is considered as the strength of the plates in tension which is 178 kN. Since this value is higher than the allowable bolt strength in tension (146 kN), the considered thickness of plate in connection is acceptable.

6.3.2 Design for Shear

There will be shearing forces acting through the cross section of the connecting plates in the horizontal directions. Friction between the connecting flanges can reduce the effect of shearing forces. The forces considered in this section are without friction reduction.

Table 29 gives the parameters involved and table 30 and 31 shows the design checks for shear yielding and shear rupture respectively.

Table 29: Connecting plate parameters in shear

Thickness	Width	F_y	F_u	d_b	A_{gv}	A_{nv}
(mm)	(mm)	(N/mm^2)	(N/mm^2)	(mm)	(mm^2)	(mm^2)
12	100	355	480	26	1200	864

Table 30: Shear yielding

AISC ASD J4.3		
Shear yielding	Safety factor	Allowable strength
$R_n = 0.6F_yA_{gv}$ (N)	Ω	R_n/Ω (N)
230040	1.5	153360

Table 31: Shear rupture

AISC ASD J4.4		
Tensile rupture	Safety factor	Allowable strength
$R_n = 0.6F_uA_{nv}$ (N)	Ω	R_n/Ω (N)
214272	2.00	107136

So from the tables 30 and 31, the lowest allowable strength is considered as the strength of the plates in shear which is 107 kN. Since this value is higher than the allowable bolt strength in shear (105 kN), the considered thickness of plate in connection is acceptable.

6.4 Bolting Arrangement

The bolting arrangement has to be carefully considered for the strength and water tight integrity and the ease of installation as well. Three proposals for the connection arrangement are shown in figures 41 to 43. The figures show section at the port side dock wing to pontoon connection region with minimum of details for better clarity.

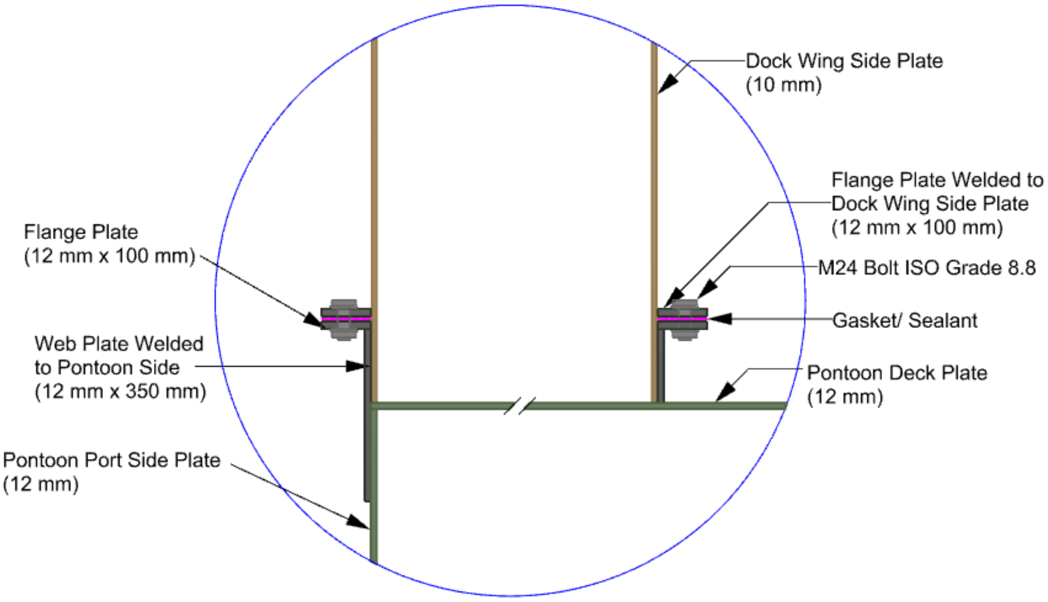


Figure 41: Bolting Option 1

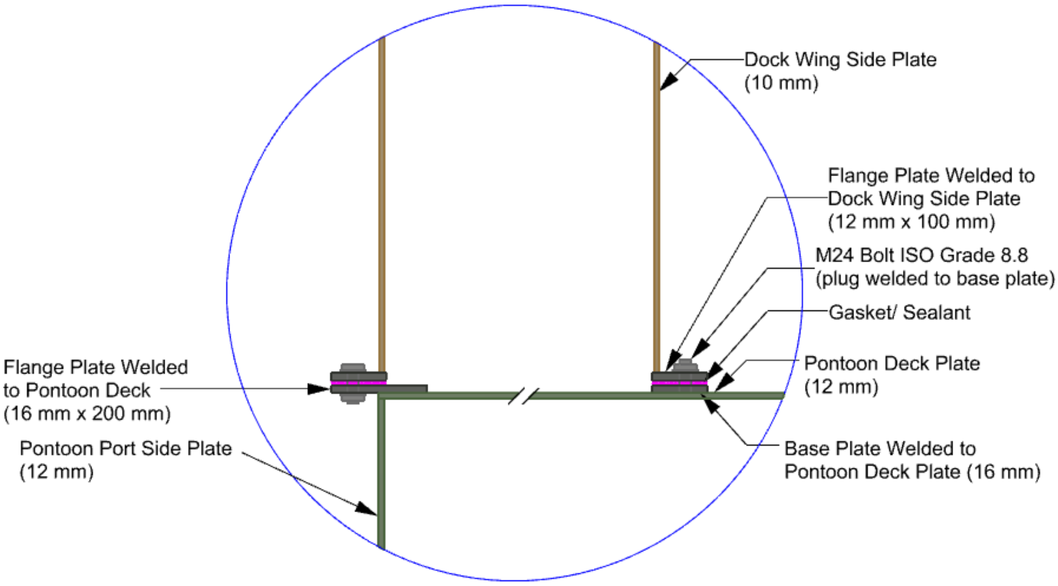


Figure 42: Bolting Option 2

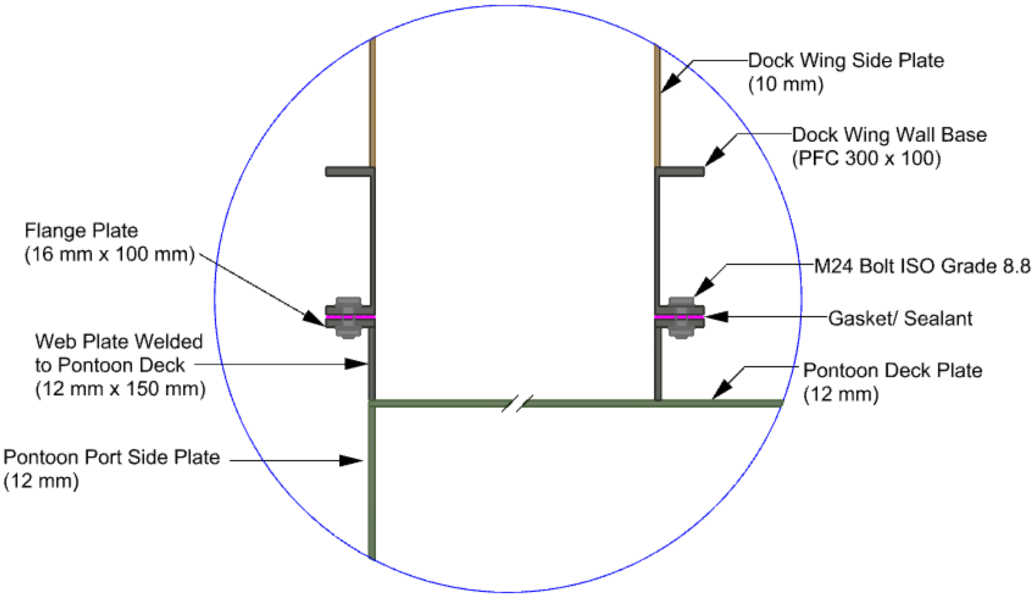


Figure 43: Bolting Option 3

Local stiffening will be required for the webs of connecting parts along the length. Bolt holes of 26 mm diameter are provided on the flanges for the bolting with a spacing not more than 200 mm. Water-tight gasket is sandwiched between the connecting flanges to ensure water-tightness. The dock wing to pontoon is bolted continuously along the length and also along the width at the edges of the pontoon.

The arrangement shown in figure 41 (option 1) and 43 (option 3) could be better in terms of water tight integrity. Connection plates are welded on the pontoon deck for both the options and connecting plates are welded on dock wing for option 1 but for option 3, parallel flange channels of 300 mm x 100 mm are welded to the dock wing base, which could give more stiffness to the dock wing base. For option 3, bottom flanges of the PFC are used in bolting.

The arrangement shown in figure 42 has bolts plug welded on to a 16 mm plate which is welded on to the deck to at the inner wall region. The mating plate on the dock wing is provided with slots for the bolts. The position can be aligned and bolted together. These require comparatively less steel for the connection plates as there is no web plate needed to be welded on to the pontoon deck.

From the arrangements considered, option 3 is better in terms of water tightness, ease of installation and strength.

7 INTACT STABILITY CHECK

7.1 General

Stability of a floating structure can be defined as the ability to get back to the upright position which is favorable when the external forces or internal forces are changed, added or removed. The various forces include the gravitational loads, the balancing buoyant forces, wind, waves, free surface moments, etc.

The basic theory behind is that equilibrium is attained when the weight assumed to be acting down through the center of gravity of the structure is balanced by an equivalent upward buoyant force assumed to be acting through the center of buoyancy and the center of buoyancy is vertically in line with the center of gravity. Figure 44 shows the basic position of various stability parameters for an upright dock.

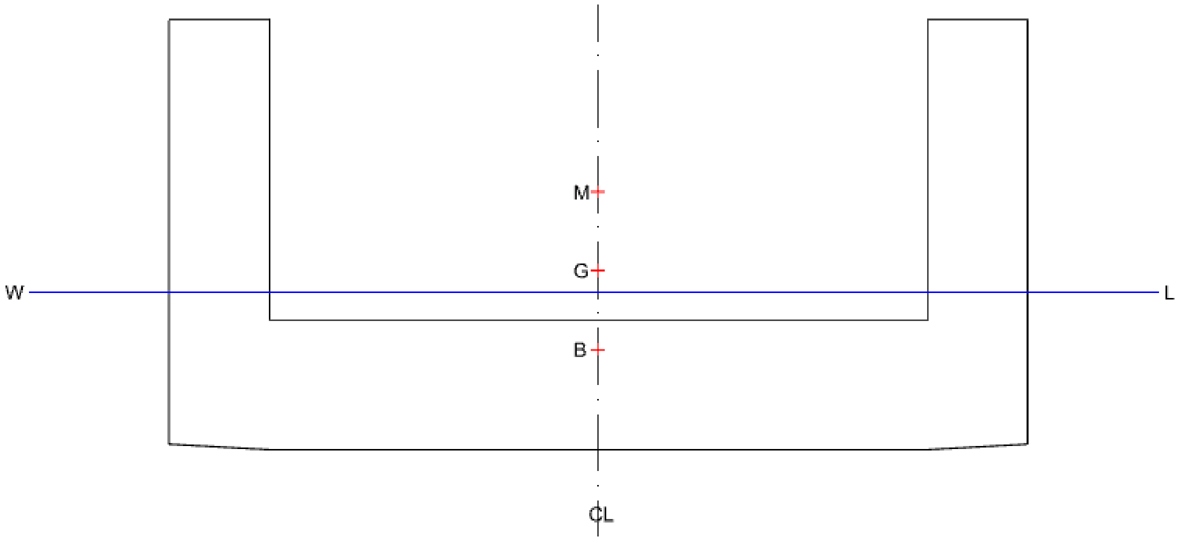


Figure 44: Upright dock

When the structure is heeled due to an imbalance in the forces, the underwater volume of the dock changes and the apparent point where the vertical through the initial buoyancy and the new buoyancy intersects is termed as metacenter and metacentric height or GM is a measure of the initial stability of the structure (up to 15 degrees). The structure tends to get back to position with a righting moment of ΔGZ where Δ is the displacement of the structure and GZ is the righting arm calculated as GM.Sin θ where θ is the angle of heel.

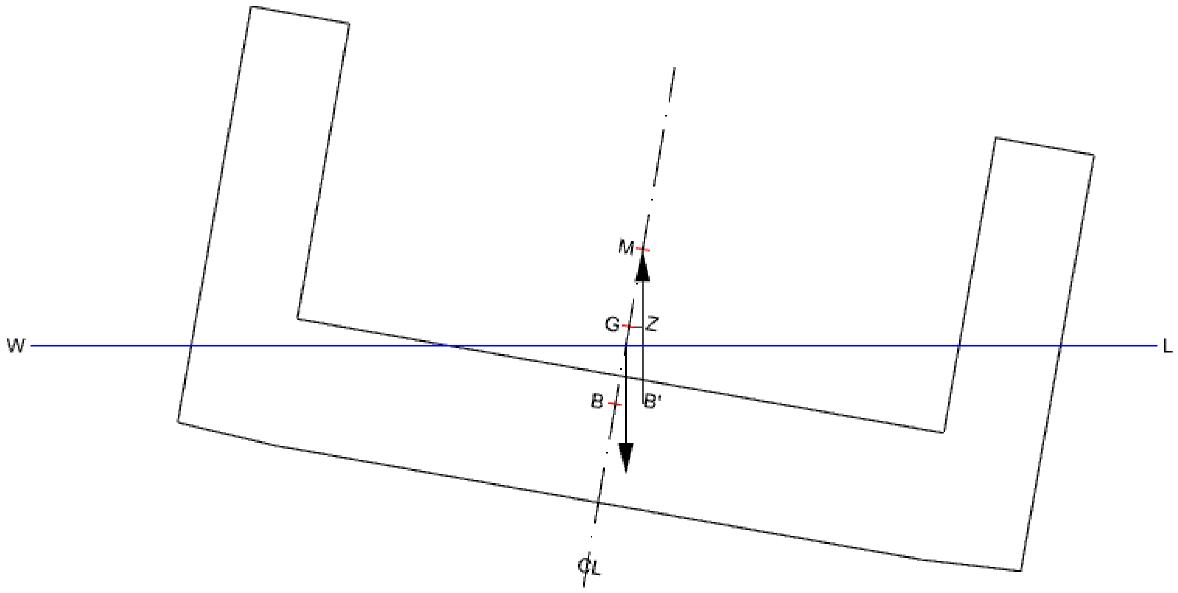


Figure 45: Heeling dock

There can be positive, neutral or negative equilibrium based on the position of M. If it falls above G, the structure is said to be in positive equilibrium or the righting moment tends to bring back the ship to the upright position. If M falls below G, then the structure is in negative equilibrium or then there is no righting moment but an additional heeling moment which tends the ship to heel more. And another case is that of neutral equilibrium in which M falls on G, or GM=0, GZ=0, there is no righting or additional heeling moment.

To have an initial stability GM must be positive. Too high GM gives a very high righting moment, which makes the rolling period faster which is not a comfortable condition. A very low GM, makes the rolling period slower which is also not a preferred case. Optimum cases are defined by IMO criteria for intact stability.

The stability of a ship is related to the hydrostatic particulars, those parameters which depend on the draft of the vessel.

7.2 Case of Floating dock

A basic study on the particulars of the vessels which can be docked on this dock was performed when the preliminary or concept design was made.

From the types of vessel data compared, the mean values of the ships' main particulars obtained is listed in the table 32.

Table 32: Mean values from typical ship data

LOA	LBP	B	T	D	Lightweight
(m)	(m)	(m)	(m)	(m)	(t)
92.6	83.2	19.5	6.4	8.02	4798

The dock capacity is fixed. So the design has to have enough dimensions to contain the ships which comes with in the range. So a study on the required dimensions was needed to fix the main dimensions of the dock. The height and maximum draft of the dock depends on the draft requirements of the vessels to be docked. The maximum draft of the ship data compared was 7.7 m and the average draft was 6.4 m. So to meet the purpose, the dock must be designed to have a maximum draft such that it would be able to dock the vessel with the maximum draft.

The stability of a floating dock has to satisfy the stability criteria with its own weight and also with the combined weights of the dock and the ship. Each case by case basis, the stability of the vessel being docked has to be carefully considered for safe docking operations.

There are different stability cases on a minimum to be considered.

1. Fully submerged condition of the dock.
2. Submerged until the level of docking blocks.
3. Final working condition with the typical ships on the blocks.

The guidelines of DNVGL-RU-FD has been followed for the stability calculations. Weight of the dock and the VCG are two important parameters needed for the stability calculation. As per table 7, the calculated weights is 2695 tons and VCG is 5.13 m. So a rounded of value of 2700 tons weight and 6 m VCG are considered in the analysis. Higher VCG considered makes the design conservative. In all cases fully loaded fresh water and fuel oil tanks are considered. Due to the presence of partially filled tanks, the free surface correction has to be applied to the calculations. Wind heeling moments is included based on the formula given as,

$$F = 0.5\Sigma C_H \rho V^2 A \tag{45}$$

Table 33: Wind force and parameters

F	Wind force in N	702436.8
Z	height above the waterline of the centre of gravity of the exposed member in m	8.585
C_H	Height coefficient	0.97
ρ	Air mass density in kg/m^3	1.204
V	Wind velocity in m/s	29.95
A	Lateral exposed area (dock+ship) in m^2	1335

A wind velocity of 29 m/s can be considered as a conservative case based on DNVGL-RU-SHIP Part 3 Chapter 15 Section 4.2.1. But since a higher wind velocity was considered in the preliminary analysis as per the data provided by Nelton, which is even more conservative, the same is followed.

From the above data, the wind pressure to be applied on the exposed side is calculated as,

$$P = 526\,Pa$$

7.3 Stability Analysis Tool

The tool used for stability analysis is MAXSURF STABILITY MODULE. The modelling of the surfaces is done in RHINO 3D and imported in to MAXSURF MODELLER further to the MAXSURF STABILITY MODULE for further analysis.

MAXURF is a powerful tool for the naval architectural calculations of all types of marine vessels. It has got different modules for hull modelling, stability, motions and resistance prediction, structural modelling, structural analysis and export to vessel detailing.

MAXSURF Advanced can be used for both intact and damage stability checks and further more. A plane water surface or user defined wave form can be considered for the calculations. It has got a library of comprehensive stability criteria as defined by statutory and regulatory bodies. There is this advantage for the users to define stability criteria as well.

7.4 Coordinate System

The origin of the coordinate system is placed at baseline intersecting the centerline and the mid-section. X-coordinates in the fwd. direction from the mid-section of the dock is positive and the x-coordinates to the aft direction is negative. Similarly, the y-coordinates towards the starboard side from the centerline is positive and the y-coordinates towards the port side is negative. The z-coordinates measured from the base line to the up is taken as positive.

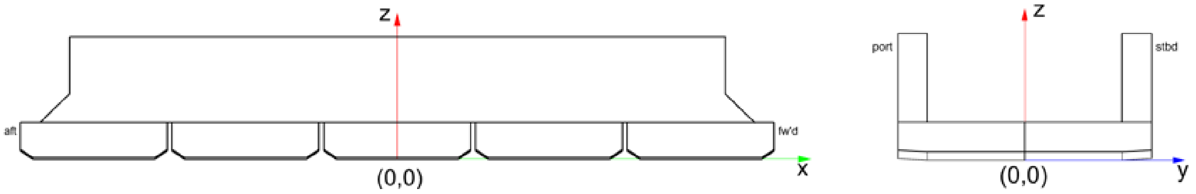


Figure 46: Coordinate system for stability analsysis

7.5 Hydrostatic Parameters

The basic hydrostatic parameters calculated from MAXSURF for the dock in maximum allowable working draft condition, which is 4.2 m, is given in the table 34:

Table 34: Hydrostatic particulars for maximum working draft

Displacement t	**11348**
Heel deg	0
Draft at FP m	4.2
Draft at AP m	4.2
Draft at LCF m	4.2
Trim (+ve by stern) m	0
WL Length m	92.4
Beam max extents on WL m	30
Wetted Area m^2	3604.004
Waterpl. Area m^2	2707.4
Prismatic coeff. (Cp)	0.956
Block coeff. (Cb)	0.951
Max Sect. area coeff. (Cm)	0.994
Waterpl. area coeff. (Cwp)	0.977
LCB from zero pt. (+ve fwd) m	0

LCF from zero pt. (+ve fwd) m	0
KB m	2.149
KG m	4.9
BMt m	18.341
BML m	175.621
GMt m	15.589
GML m	172.869
KMt m	20.489
KML m	177.769
Immersion (TPc) tonne/cm	27.751
MTc tonne.m	212.311
RM at 1deg = GMt.Disp.sin(1) tonne.m	3087.46

These particulars influence the stability of the dock in this loading case. GM_t or transverse metacentric height determines the initial stability condition of the dock. As the height of the centre of gravity increases, the stability decreases. The hydrostatic particulars refers to all those parameters which are dependent on the draft. So these values vary for different draft conditions.

7.6 Tank Capacities

From the concept tank plan available, few modifications have been made to include the tank spaces for fuel oil, fresh water and sewage. Below figures give an idea about the various tank spaces and their arrangements and based on which the stability and loading is dependent. The drawings provided by Nelton is modified to include the additional tank spaces and is shown in figures 47 to 49.

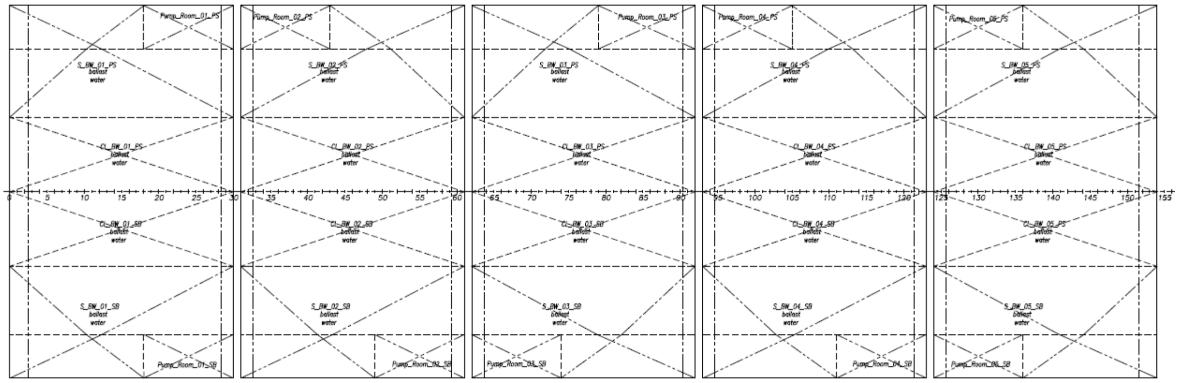


Figure 47: Tank plan- pontoon

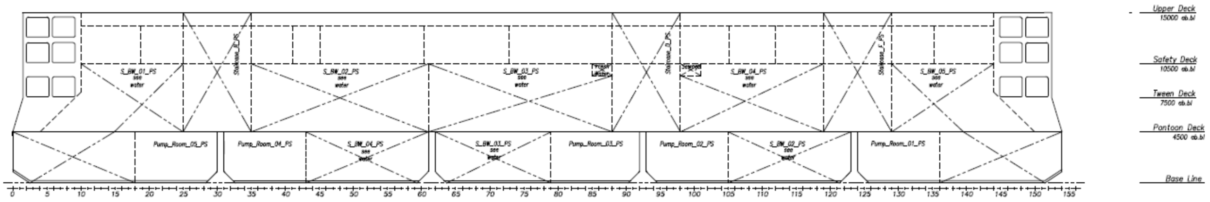


Figure 48: Tank plan- view of port side

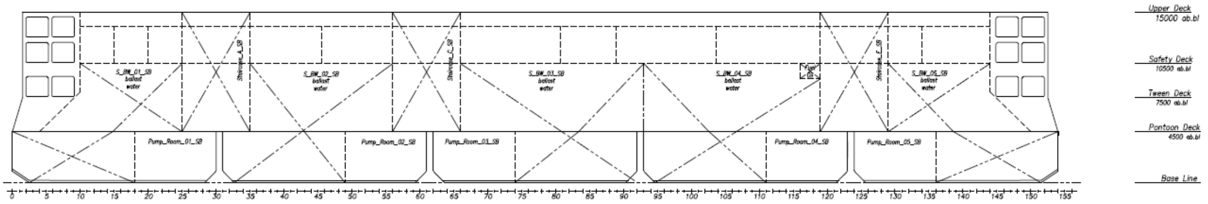


Figure 49: Tank plan- view of stbd side

The pontoon bottom has tank spaces through-out the enclosed volume for ballast water, leaving the spaces for pump rooms. There are 3 longitudinal bulkheads provided in the pontoon, one at the centreline and 2 others on either parts of the centreline 6m apart. So there are two ballast tanks provided on either sides of the centreline and per pontoon and it makes a total of 20 ballast tanks. Table 35 is the list of tank capacities:

Table 35: Tank capacities

Tank name	Capacity	Capacity
	(m^3)	(t)
CL_BW_01_PS	467	480
CL_BW_01_SB	467	480
CL_BW_02_PS	467	480
CL_BW_02_SB	467	480
CL_BW_03_PS	467	480
CL_BW_03_SB	467	480
CL_BW_04_PS	467	480
CL_BW_04_SB	467	480
CL_BW_05_PS	467	480
CL_BW_05_SB	467	480
S_BW_01_PS	797	818
S_BW_01_SB	797	818
S_BW_02_PS	910	933
S_BW_02_SB	848	870

S_BW_03_PS	915	939
S_BW_03_SB	921	945
S_BW_04_PS	841	863
S_BW_04_SB	901	924
S_BW_05_PS	797	818
S_BW_05_SB	797	818
Fuel oil	8	7
Fresh water	6	6
Sewage	6	-
Total capacities	**13219**	**13548**

7.7 Stability Analysis

7.7.1 Case I: Lightship Condition

The light draft condition of the vessel is based on the displacement obtained due to the self-weight, rest water in the ballast tanks and the full load of consumables. The rest water assumed is of 0.6 m height. All the ballast tanks are uniformly filled to 12% by volume each to match the 0.6 m rest water height. The stability analysis is run and the various results obtained is summarized below.

Table 36: Summary of results (Lightship condition)

Draft amidships		1.59 m		
Displacement		4039 t		
Reference	**Criteria**	**Required**	**Actual**	**Result**
	General:			
DNVGL-RU-FD Sec 1.3.11	Initial GMt after free surface correction	>1 m	43.9 m	pass
IMO MSC 267(85) Sec 2.2.2	Angle of max. GZ	>25 deg	17.3 deg	fail
DNVGL-RU-FD Sec 1.2.1	Minimum freeboard to the pontoon deck	>0.3 m	2.9 m	pass
DNVGL-RU-FD Sec 1.1.1	Minimum freeboard to the upper deck	>1 m	13.4 m	pass
	Wind criteria:			
IMO MSC 267(85) Sec 2.3.1.2	Angle of steady heel	≤16 deg	0.2 deg	pass
IMO MSC 267(85) Sec 2.3.1.2	Angle of steady heel/ deck edge immersion angle	≤80%	1.89%	pass

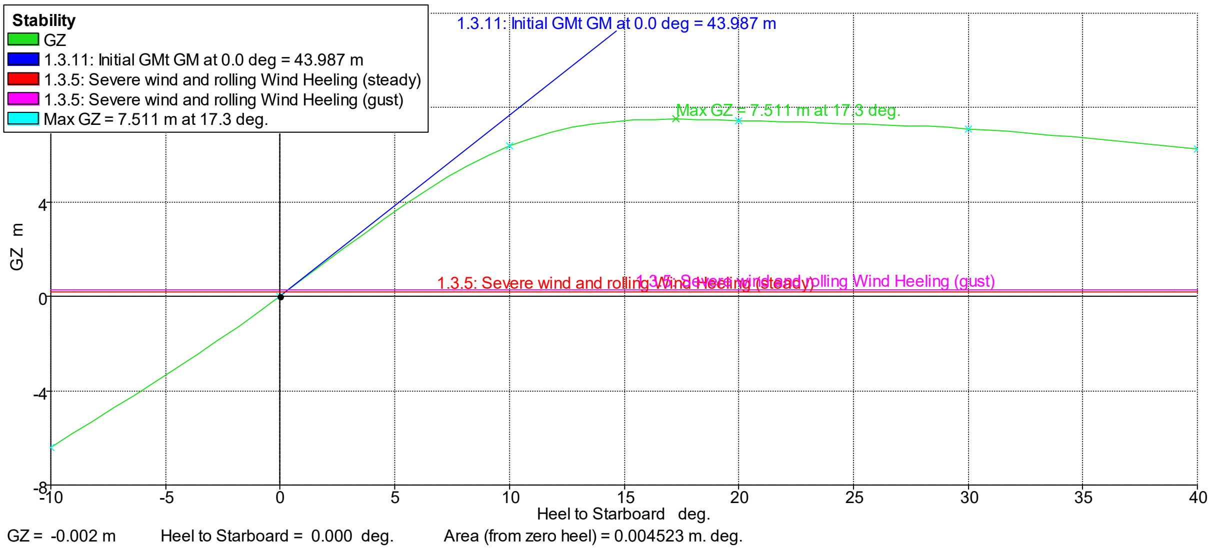


Figure 50: Intact stability curves (Lightship condition)

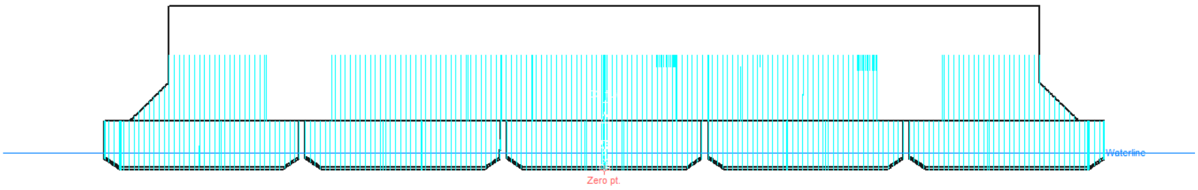


Figure 51: Profile view showing the Lightship waterlevel

From the results of intact stability criteria at lightship condition, the dock fails the mandatory criteria for the angle of heel for maximum GZ. In specific cases where it is not possible to meet this requirement, other criteria could be provided by the approving authority. Otherwise in case of this design, the compensating ballast water can be used or the rest water level in the tanks can be increased to achieve the required buoyancy. Due to increase in buoyancy of the vessel with the weight and centre of gravity unchanged, the metacentric height reduces and then higher GZ can be achieved at higher angles only.

A basic check proves that when the ballast tanks are filled to 21% by volume (around 1m height) by sea water, a maximum GZ of 7.4 m can be achieved at 25.5 degree angle of heel.

7.7.2 Case II: Fully Submerged Condition

Full submersion of a dock in docking operations is achieved by filling the ballast tanks to the required level. If there is no reserve ballast capacity the ballast tanks have to be filled to the maximum level. In the case of subject design, the ballast tanks are filled to maximum capacities to ensure maximum submersion. The stability of a floating body depends on the water-plane area. As soon as the pontoon deck is submerged during the ballasting of the dock, the water plane area shifts. The buoyancy is now supported on the water plane area of the dock wings. As the water plane area is less, the moment of inertia which reduces, thereby causing a sudden decrease in the metacentric height and hence the stability of the dock. As such this is a critical stability condition of the dock. The results of the analysis carried out are summarized below.

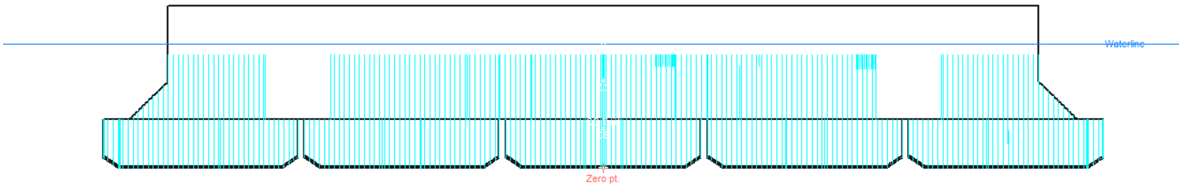


Figure 52: Profile view showing the fully submerged water level

Table 37: Summary of results (Fully submerged condition)

Draft amidships		12.1 m		
Displacement		16518 t		
Reference	**Criteria**	**Required**	**Actual**	**Result**
	General:			
DNVGL-RU-FD Sec 1.3.11	Initial GMt after free surface correction	>1 m	6.4 m	pass
IMO MSC 267(85) Sec 2.2.2	Angle of max. GZ	>25 deg	19.1 deg	fail
DNVGL-RU-FD Sec 1.1.1	Minimum freeboard to the upper deck	>1 m	2.9 m	pass

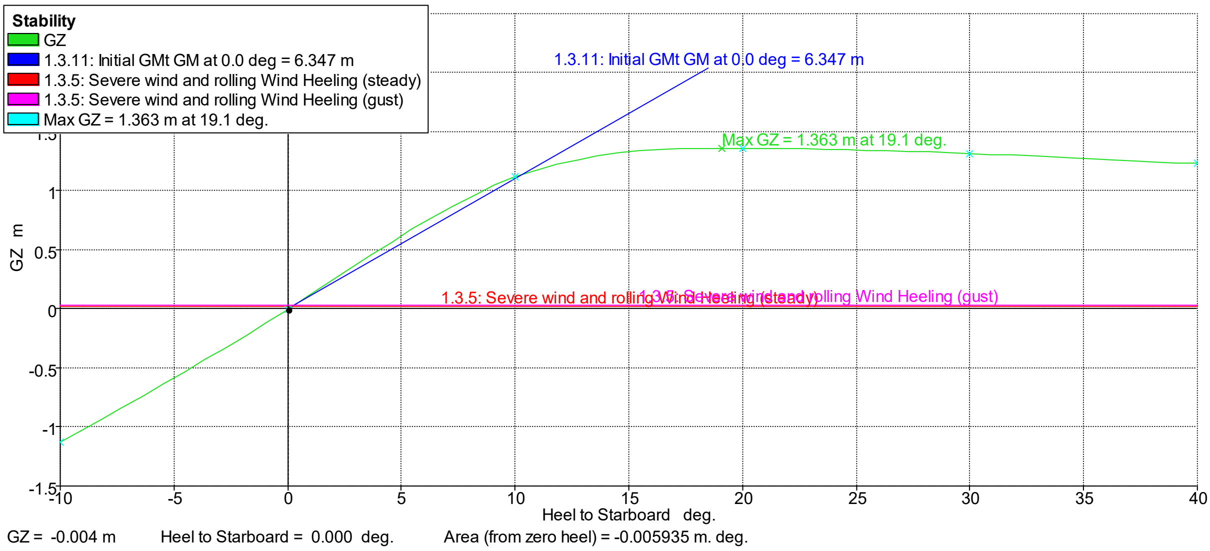


Figure 53: Intact stability curves (Fully submerged condition)

In this case of docking operation, the wind criteria is invalid as the surface exposed to wind is very less, and the height above the water level is less as well. From the checks on the mandatory stability criteria, the minimum angle of heel for the maximum GZ is lesser than the requirement by a smaller margin. Since this operation is not a frequent one and the duration the dock remains in this state is very less this value could be specially considered.

The draft achieved is less compared to the draft requirements of the vessels to be docked. So more of submersion of the dock is needed which can only be achieved in this case by increasing the ballast capacities. A draft of only 12.1 m is achieved whereas the requirement in 13.5 m.

7.7.3 Case III: Docking Condition (water level just below the dock blocks)

To attain the docking condition draft, the ballast water is removed in a controlled manner so that the ship weight slowly start to transfer some load on to the docking blocks. As draft is further decreased such that the water level is reduced to just below the docking block height, the ship weight is completely transferred on to the dock. This condition of docking can be considered similar to that of a vessel engaged in heavy lift. So the stability criteria is checked for the same as per relevant standards. The results are summarized as below.

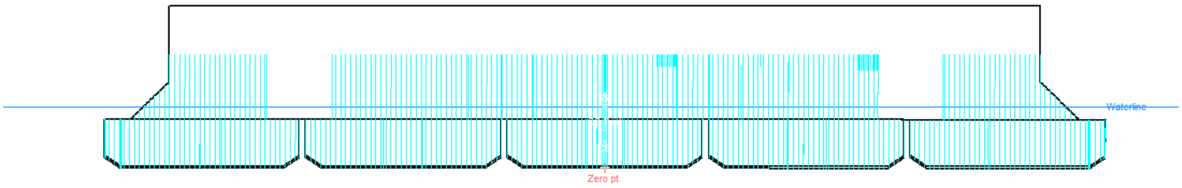


Figure 54: Profile view showing the docking water level just below the dock blocks

Table 38: Summary of results (Docking condition)

Draft amidships		5.7 m		
Displacement		12751 t		
Reference	**Criteria**	**Required**	**Actual**	**Result**
	General:			
DNVGL-RU-FD Sec 1.3.11	Initial GMt after free surface correction	>1 m	7.1 m	pass
IMO MSC 267(85) Sec 2.2.2	Angle of max. GZ	>25 deg	32.7 deg	pass
DNVGL-RU-FD Sec 1.1.1	Minimum freeboard to the upper deck	>1 m	9.3 m	pass
	Wind criteria:			
IMO MSC 267(85) Sec 2.3.1.2	Angle of steady heel	≤16 deg	0.3 deg	pass
	Lifting criteria:			
DNVGL-RU-SHIP Pt 5 Ch 10 Sec 4.	Angle of steady heel	<10 deg	0 deg	pass
DNVGL-RU-SHIP Pt 5 Ch 10 Sec 4.	Areas below righting lever curve A1 and A2, A1/A2	>40%	55.2%	pass

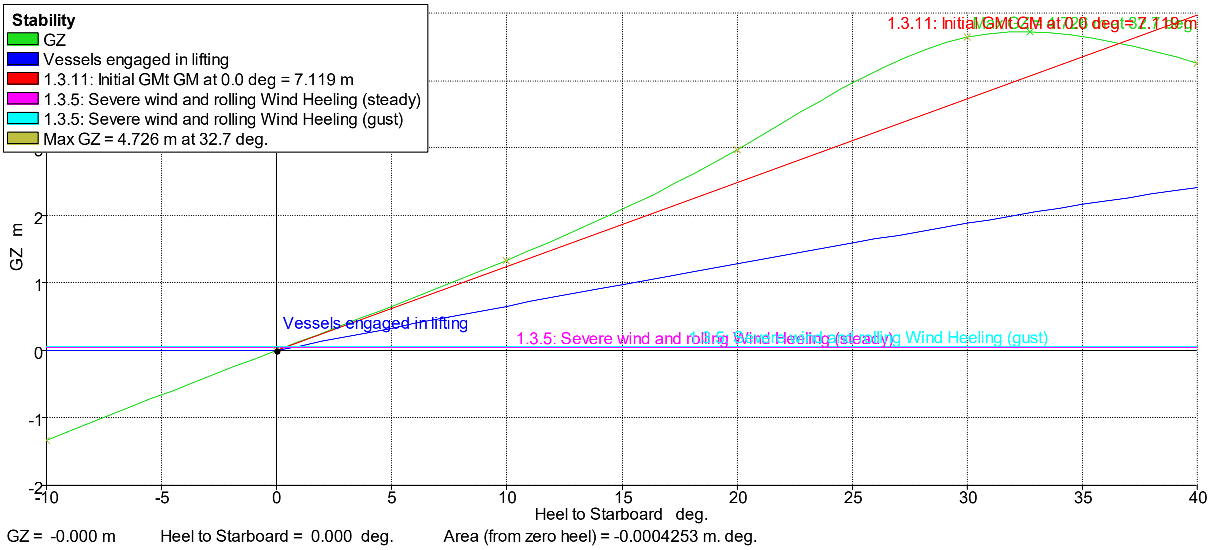


Figure 55: Intact stability curves (Docking condition)

At docking condition, all the mandatory and additional stability criteria are satisfied and the dock is deemed safe for lifting a maximum capacity ship of 6,000 tons with a conservative VCG of 8 m measured from the top of the docking blocks.

7.7.4 Case IV: Working Condition

After safe docking is ensured, further de-ballasting can reduce the draft to a value less than the maximum allowable draft as per the freeboard requirement. In this analysis, the minimum draft is considered which includes the influence of rest water in the tank bottom and the docked ship weight. The results of the analysis are summarized below.

Table 39: Summary of results (Working Condition)

Draft amidships		3.7 m		
Displacement		10039 t		
Reference	**Criteria**	**Required**	**Actual**	**Result**
	General:			
DNVGL-RU-FD Sec 1.3.11	Initial GMt after free surface correction	>1 m	11.4 m	pass
IMO MSC 267(85) Sec 2.2.2	Angle of max. GZ	>25 deg	28.2 deg	pass
DNVGL-RU-FD Sec 1.2.1	Minimum freeboard to the pontoon deck	>0.3 m	0.7 m	pass
DNVGL-RU-FD Sec 1.1.1	Minimum freeboard to the upper deck	>1 m	11.3 m	pass
	Wind criteria:			
IMO MSC 267(85) Sec 2.3.1.2	Angle of steady heel	≤16 deg	0.4 deg	pass
IMO MSC 267(85) Sec 2.3.1.2	Angle of steady heel/ deck edge immersion angle	≤80%	16%	pass

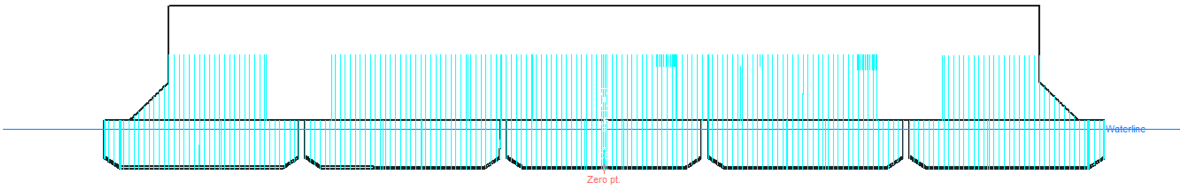


Figure 56: Profile view showing the working condition draft level

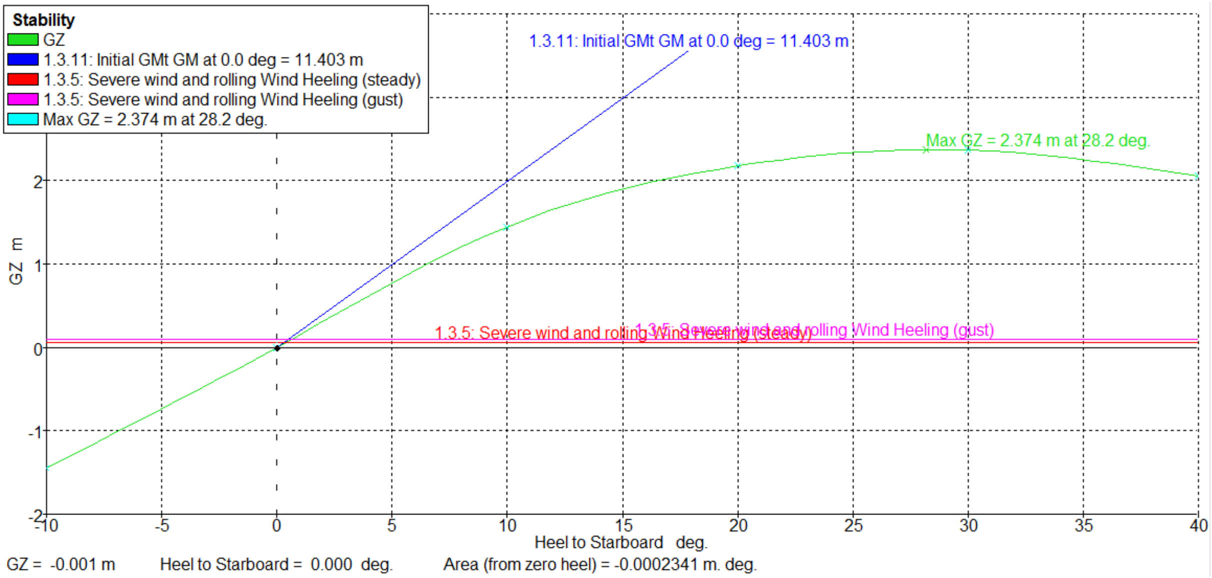


Figure 57: Intact stability curves (Working condition)

Above results prove that the dock is stable in working condition. The GM_T has reduced from the same draft condition earlier during the submersion operation, as there is the combined weight and VCG of the ship and dock acting together because the ship is fully resting on the dock. VCG in this case is raised by much.

7.7.5 Case IV: Undocking Condition

During undocking process, the ballast weights are increased so as to get sufficient immersion of the dock. At the start of undocking, the water level will be just below the docking blocks. The complete weight is supported on the dock and the water plane area is reduced explains the criticality in the undocking process. A stability analysis of the same is performed and the results are as below.

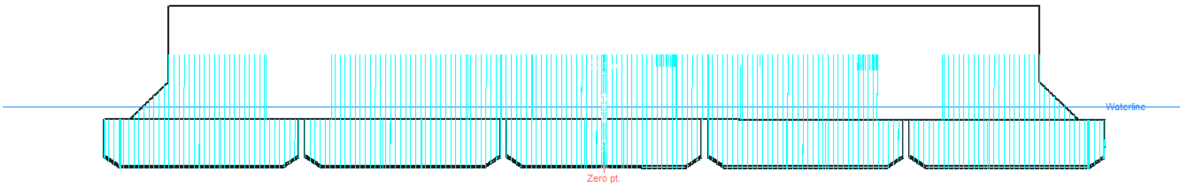


Figure 58: Profile view showing the water level at undocking condition with water level just below docking blocks

Table 40: Summary of results (Undocking condition)

Draft amidships		5.7 m		
Displacement		12744 t		
Reference	**Criteria**	**Required**	**Actual**	**Result**
	General:			
DNVGL-RU-FD Sec 1.3.11	Initial GMt after free surface correction	>1 m	1.9 m	pass
IMO MSC 267(85) Sec 2.2.2	Angle of max. GZ	>25 deg	30 deg	pass
DNVGL-RU-FD Sec 1.1.1	Minimum freeboard to the upper deck	>1 m	9.3 m	pass
	Wind criteria:			
IMO MSC 267(85) Sec 2.3.1.2	Angle of steady heel	≤16 deg	1.1 deg	pass

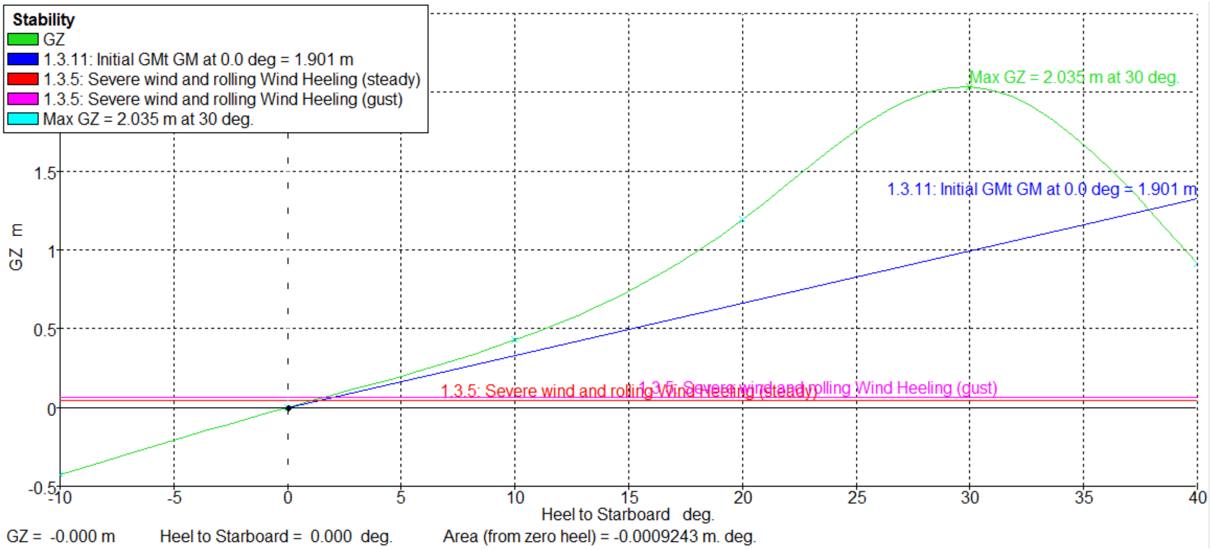


Figure 59: Intact stability curves (Undocking condition)

We can see from the results that the initial GM_t is just higher than the minimum required. And compared with the various other conditions analysed, this value is much lesser. So the condition of undocking of a ship can be considered the deciding condition of stability of the dock.

7.8 Limiting vessel VCG

For docking capacity assessment of a dock and to select the ships to be docked other than based on their dimensional limits, an important factor which comes in is the position of VCG of the vessel to be docked. Based on the critical stability condition, which is the undocking stage, an analysis is done for a range of docking weights acceptable different VCGs' of the vessel. Based on the results obtained a graph has been plotted to easily understand the range of a combination of the weight and VCG acceptable.

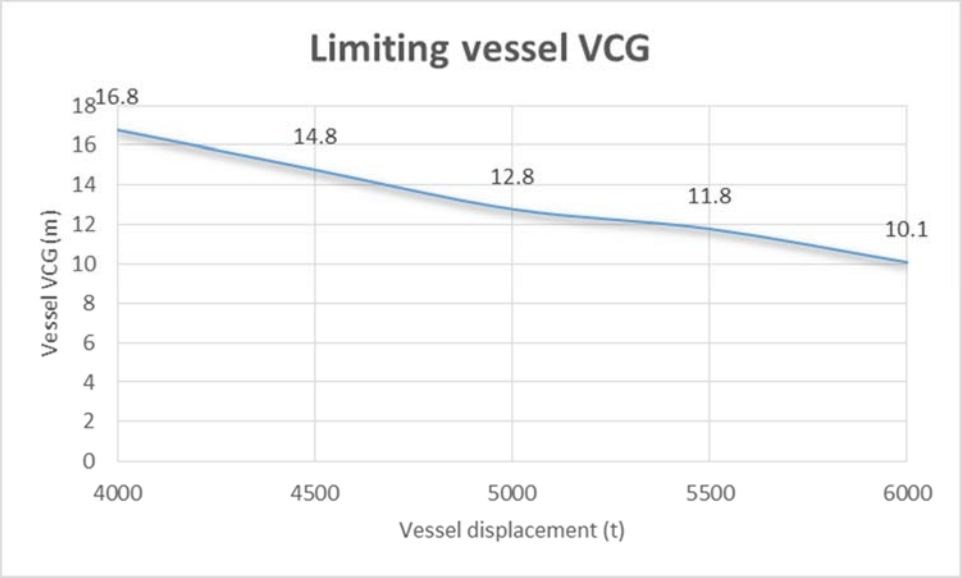


Figure 60: Limiting VCG curve

In the above plot, the maximum VCG acceptable for a range of weights from 4000 ton to 6000 ton is shown. The significance of this graph is that the category of vessels which comes below limiting VCG curve can be safely docked. The curve slopes down linearly shows that as the weight of the vessel increases, the acceptable VCG decreases. A careful consideration of this data is important to decide on the actual capacity of the dock.

7.9 Summary

From the various intact stability checks carried out, the dock does not experience any serious threats in terms of stability. The only issue prevailing is with respect to achieving the maximum submersion to the desired level. As per the current results, the maximum submersion is less by 1.4 m. This limits the capability of the dock. This result has direct impact from the estimated weight of the dock. If more weight on the structure is expected the submersion would increase. With the estimation not expected to vary much, additional ballast capacity would be needed to increase the loads for maximum submersion.

8 FEASIBILITY STUDY FOR SUBMARINES CONSTRUCTION

Floating docks can be used for the repair as well as construction of ships with in its carrying and containing capacity. This section of this report presents the basic study done to check the feasibility of the planned submarines construction for the Polish Navy. This is a basic study which is only concerned about the docks carrying capacity.

(News source: www.navyrecognition.com)

The Polish Navy has planned procurement of 3 new submarines as part of the Orca Submarine Program. Poland's Polish Armament Group (Polska Grupa Zbrojeniowa - PGZ SA) has signed a MoU with French Naval Ship builder DCNS which could lead to joint construction of submarines in Poland. Poland is currently considering proposals from Saab, DCNS and TKMS for the Orca Submarine Program. Saab is offering its A26, DCNS its Scorpene and TKMS the Type 212A. Under the plan, three new submarines are to be delivered by 2023.

Above is a brief of the news published regarding the submarine projects. There has been proposals from 3 different companies for their specific class of submarines. The first part of this study is to collect basic data regarding the classes of submarines on offer.

Table 41: Basic data for study

Builder	Submarine Class	L	B	T	Δ
		(m)	(m)	(m)	(ton)
Saab	A26	63	6.4	6	1930
DCNS	Scorpene	75	6.2	5.8	2000
TKMS	Type 212A	57.2	6.8	6.4	1830

The above basic information have been collected from the internet sources. As for classes with more than one design, the one with maximum measures and quantity is chosen.

8.1 Lifting Capacity in Strength

The floating dock has been designed for lifting 6,000 tons of docking load. The highest of the weights of the submarines for study is only 2,000 tons which is 66% less than the maximum lifting capacity. So the dock will be able to carry the maximum load of the fully constructed submarine.

When we do check on the linear load density, assuming the docking load is uniformly distributed along the length of the submarine, the maximum load per length is obtained for the Type 212A which is 32 tons/m. the dock strength check was done considering 81 tons/m load (even conservative load). So the dock is safe for operation.

8.2 Space Requirements

The space requirement refers to the clearances possible with in the docking space. The length of the dock is 92.4 m without considering the extended platforms. The maximum length of the submarines in consideration being 75 m, there is no issue with length constraints. Figure 61 shows the longer submarine docked.

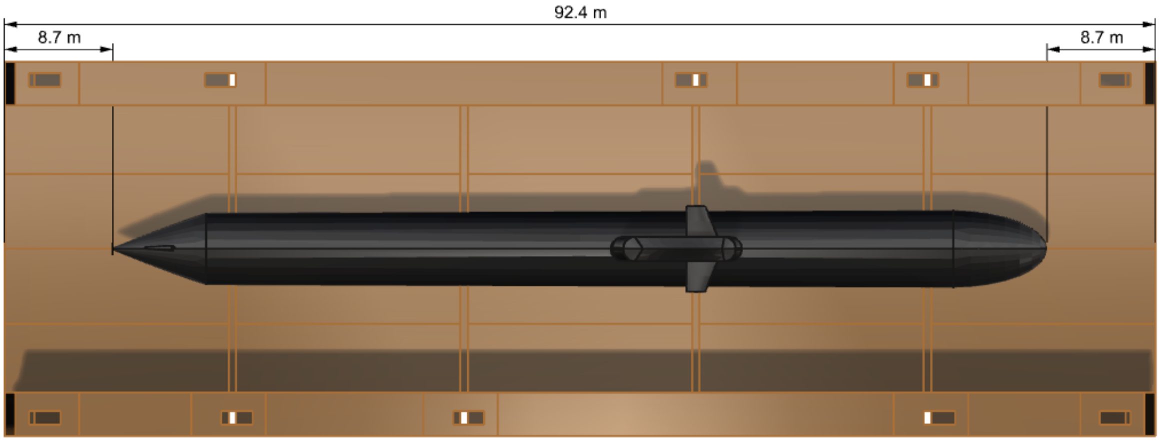


Figure 61: Scorpene Class Submarine in dock (top view- representative model)

The maximum internal width of the dock (between the dock wings) is 23 m. The maximum beam of the submarines in consideration being 6.8 m, there will be a clearance of 8 m on either sides to give enough working space. A case of two submarines docked side-by-side is also possible. Figure 62 shows the submarines with lower beams docked side-by-side.

Another important parameter in docking and undocking operations is the draft of the vessel. Though for construction, this has no influence, launching by undocking will need sufficient submersion of the dock to have the submarine float freely.

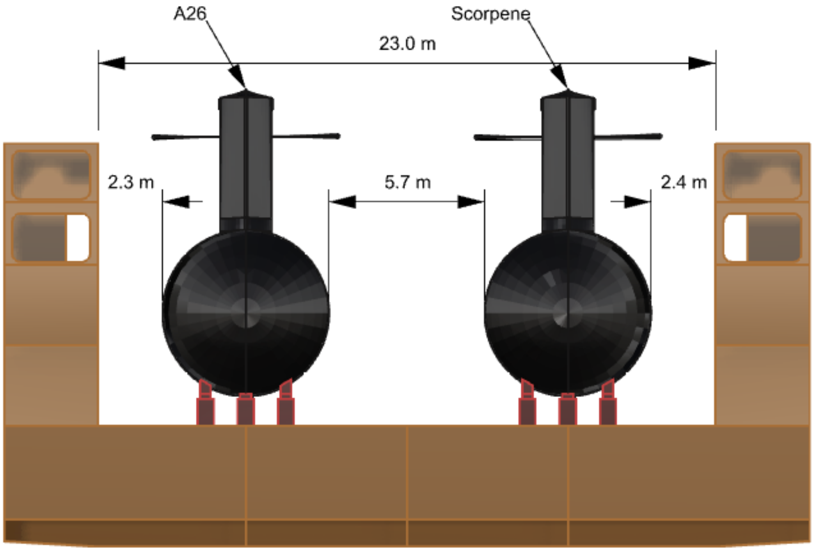


Figure 62: Submarines docked side-by-side (view from front- representative model)

The required maximum draft of the dock is 13.5 m with this draft and docking blocks of height 1.2 m and a safe clearance of 0.3 m, docking and undocking of vessels up to 7.5 m is possible. The maximum draft of the submarines in consideration being 6.4m, there is enough clearance possible.

After a preliminary cycle of the design, the maximum draft achieved by the design is only 12.1 m. This means, a safe clearance of only 6.1 m. Except for Type 212A class submarine, this draft is safe. But the design modification to suit the requirements is possible without much harm.

8.3 Lifting Capacity in Stability

Lifting capacity in stability is more directed to the weight and VCG of the docked vessel. The critical condition would be the undocking phase. Referring to the figure 60 for the limiting VCG curve, it is understood that as the weight of the vessel decreases, higher VCG is acceptable. For a vessel of 4,000 tons, a maximum VCG of 16.8 m is acceptable. For the submarines in consideration, the weight is less and would be the VCGs referring to the geometry. So it is safer to undock any of those submarines constructed on the subject floating dock.

9 CONCLUSION

The complete work intended to be part of this thesis has been carried out and are open for discussions and further improvements. The work was developed based on the concept General Arrangement provided by the internship company, Nelton. The stage by stage conclusions from the work are briefed below:

The scantlings were chosen based on the local strength requirements as per DNVGL-RU-FD. The material of construction as per the requirement was steel, but there was flexibility in choosing the grade of steel to be used. As and where possible, normal grade steel is used for the structural members. High grade steel was considered initially for only the pontoon girders, frames and pillars. This was because the use of normal grade steel results in the requirement for sections which have a section modulus higher by 39% and results in higher sections for these members. From the economical point of view, the cost of higher grade of steel is little higher than the normal grade steel. But otherwise we can save on the material weight. So the decision is dependent on whether there is any weight limitation. In this scenario there is no study done on the cost and weight comparisons, but the importance is given to the flexibility that if normal grade steel is considered in the design, in case of non-availability of the same grade, a higher grade can be chosen without the need for a re-analysis.

The arrangement of members, like the span and spacing are also to be decided by the designer. In the case of this design, arrangement was decided as such to make use of the standard sections or built-up sections which are easier to fabricate as possible. While choosing a section or thickness of plate, the availability in the market has to be known by the designer. This design has chosen all standard sections available in market.

Another important aspect is the ease for production, like the handling, cutting and welding easiness and also accessibility for welding and inspection in assemblies.

Foreseeing all the above mentioned challenges makes avoid any changes or rework at later stages of the design. To the best possible extend everything is taken in to consideration in this design.

A slenderness check was also carried out as per DNVGL-RU-SHIP Part 3 Chapter 8, to ensure the plates and sections have enough thickness to resist local buckling, or else local stiffening is provided.

After the scantlings design, more or less it was possible to get the exact steel weight with less contingency. But for the other weights including architectural, electrical, HVAC, piping, outfitting etc. for which design is not done yet the only possibility of getting weights is to refer to any similar designs and base on a rule of thumb to estimate the approximate weights expected in our design. In this design, the weights other than steel weight was calculated based on the items in the GA. The maximum of weights of items available or shown in the GA are captured either referring to the data sheets of similar items or a rule of thumb based on experience is followed. There can be variations expected in the final weight which could be an increase of weight only. That contingency is considered in the design for any expected increases in weight other than calculated. As a step to move further, these weights and CoG were calculated with enough contingencies, which are assumed to be ok.

A finite element model was prepared and analysis was done for all the loading conditions prescribed in DNVGL-RU-FD. The steel weight is automatically generated from the model and this weight is compared to the weight calculated to know if there is any major discrepancies. The weight were found to be closer. Other loads calculated earlier was then applied to the model as point, line or element loads. It was noticed that enough submersion as required was not possible with full ballast loads acting and a modification to the ballast spaces is needed to carry more ballast and hence enough submersion. Based on the analyses performed, the structure was found to be fit for purpose with minor modifications needed in the design. The major stresses and deflection are caused in the pontoon structure near where the docked vessel weight acts. The structure as a whole is capable of carrying more payload if the loading is not along the center-line.

The connection design of the dock-wings to the pontoon deck was done based on the maximum forces at the connections obtained from FEA analysis. The bolting is arranged with a watertight gasket in between the connecting parts to ensure watertight integrity.

Intact stability checks were performed based on the requirements of relevant codes and standards. The critical condition of stability is found to be the undocking stage with water level just below the docking blocks level. With regard to the maximum submersion, it was found that additional ballast capacity has to be provided to ensure maximum required submersion. Approximately 800 m^3 more of ballast is needed to attain the maximum required submersion.

The dock design was checked for its feasibility in constructing the submarines for the Polish Navy’s Orca Submarine Program and found to be feasible except for the draft clearance for Type 212A class submarine being less by a small margin. This correction of draft or submersion of the dock is intended in the considered design. So it can be assumed that the subject dock is able to perform the construction and launching of the submarines needed to be constructed.

This being a concept stage of design, modifications or design changes are expected to happen and one more cycle of the process could give much refined results.

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I take this opportunity to thank all the professors and my friends for all the help and guidance and special thanks to my friends **Mr. Kailas Cheriyan** and **Mr. Adarsh E K** for imparting necessary help and guidance at the most needed times.

I must express my very profound gratitude to my Parents for their love and invaluable support throughout. Above all, I do strongly believe that God Almighty’s blessings are the prime motivation for the successful completion of my project.

Kodathoor Gangadharan Midhun

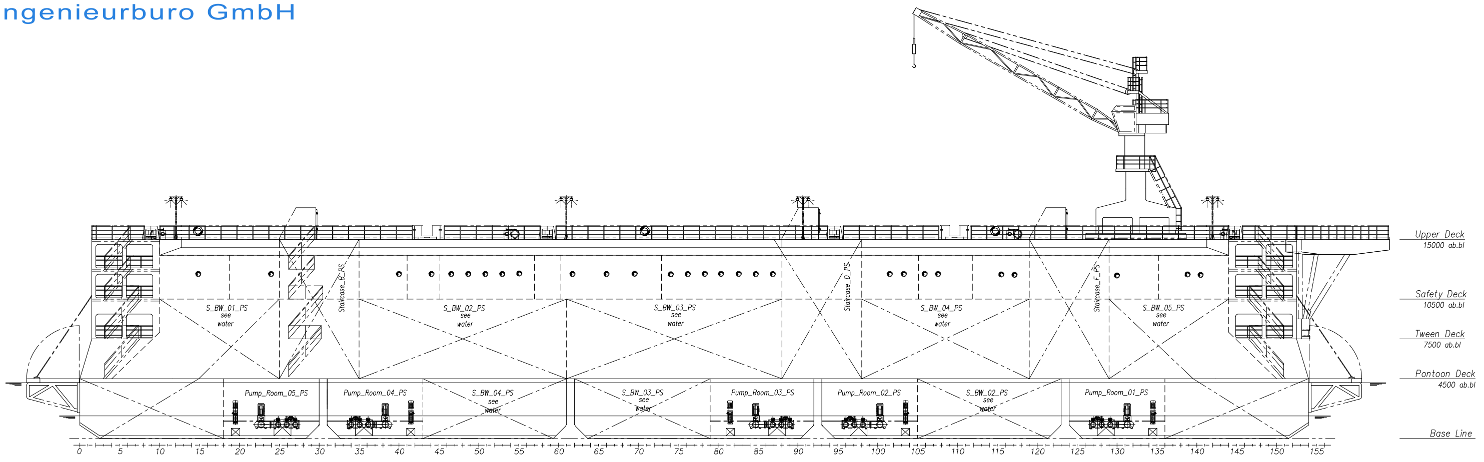
APPENDIX A

CONCEPT GENERAL ARRANGEMENT DRAWING OF THE DOCK

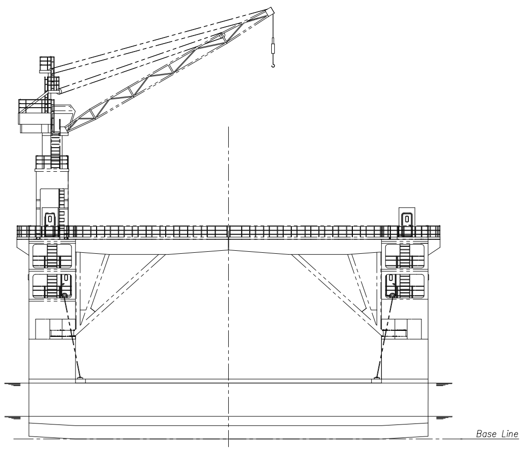
(Provided by NELTON/ KABE)

KABE
Ingenieurburo GmbH

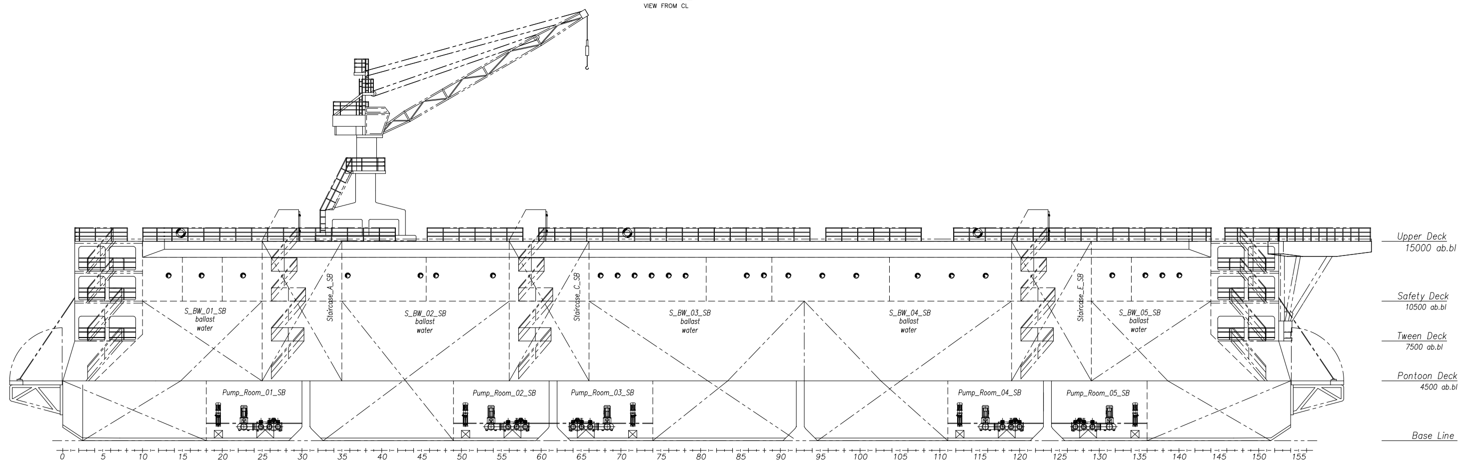
KB-022 FLOATING DOCK



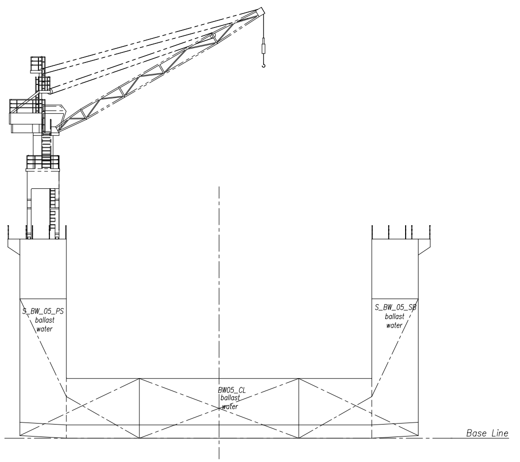
PROFILE VIEW
PORTSIDE
VIEW FROM CL



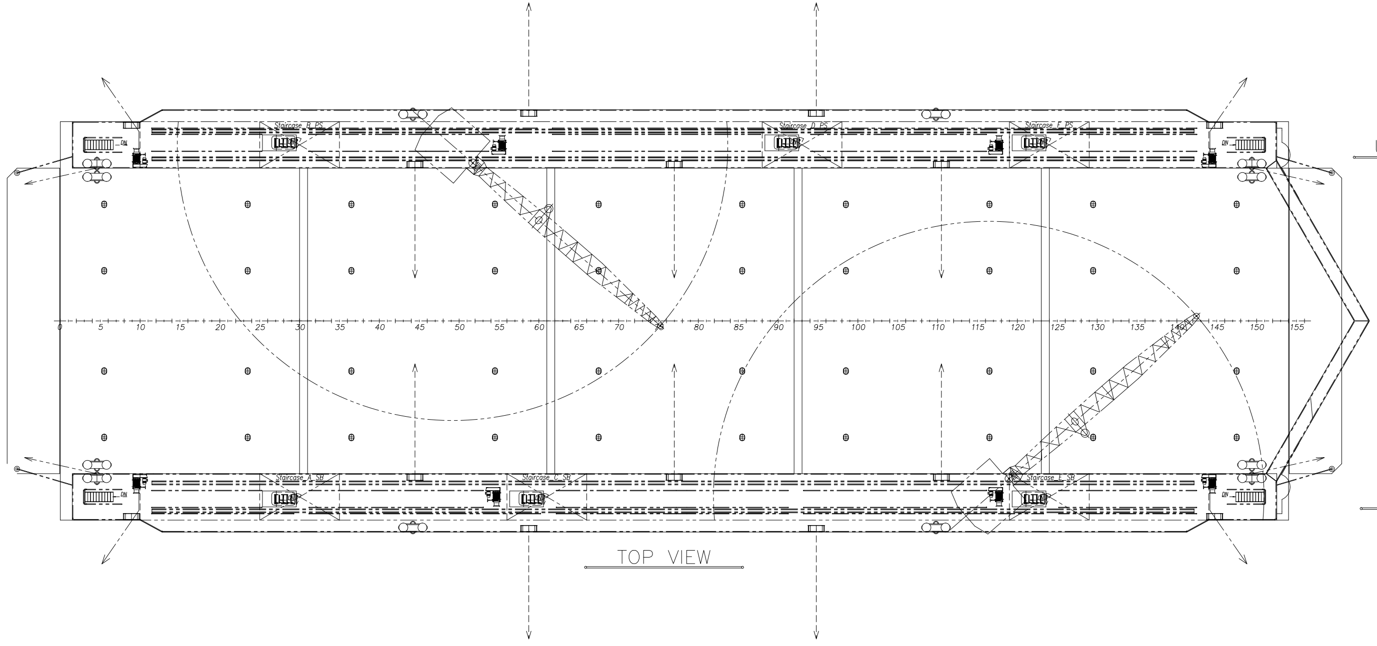
FRONT VIEW



PROFILE VIEW
STARBOARD SIDE



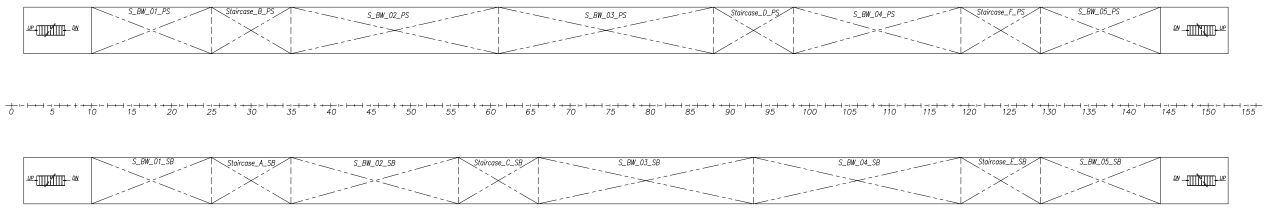
TRANSVERSE SECTION
TYPICAL



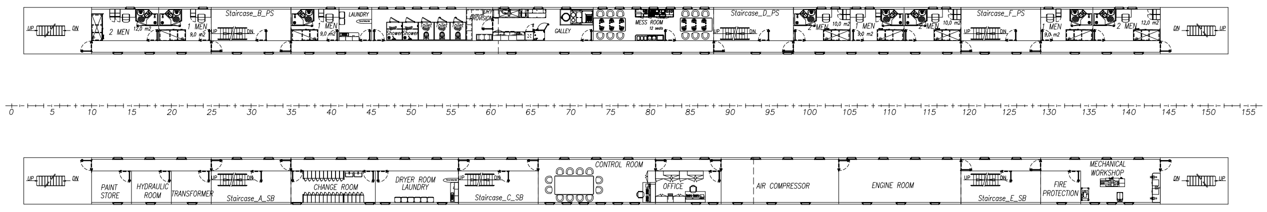
UPPER DECK
PORTSIDE

UPPER DECK
STARBOARD SIDE

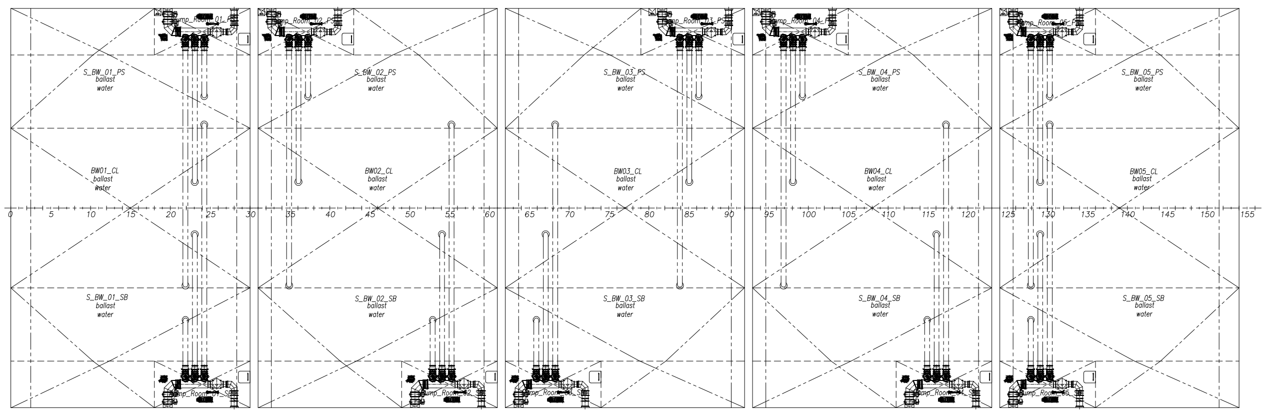
TOP VIEW



TWEEN DECK



SAFETY DECK



PONTOON DECK

KB-022 CHARACTERISTICS

MAIN DIMENSIONS

Length (o.a.):	92,40m
Length (w.l.):	92,40m
Bmax (breath out side of side towers):	30,00m
Bi (breath inside of side towers)	23,00m
B1 (breath of side tower):	3,50m
Hd (height of pontoon):	4,50m
D (depth of top deck):	15,00m
Tmin (draught of empty structure):	1,70m
Tmax (draught of structure with max payload):	4,20m
Tdrown (max draught):	13,50m
Frame span	0,6m
P (max payload):	6000t
Crane tonnage	10t
Ballast pumps capacity	1200 m3/h

REV.	DATE/NAME	REVISION TEXT
B	2017.03.28	General update

TITLE:
GENERAL ARRANGEMENT

DESCRIPTION:
FLOATING DOCK

PROJECT NO.:
KB-022-01

DESIGNER:
KABE
Ingenieurburo GmbH
www.kabe-hamburg.de

CUSTOMER:
Ha Long Shipbuilding Co. Ltd.
Gieng Day ward
Ha Long city
Vietnam

DRAWING NO.:			REVISION:
100-100			B
DRAWN:	DATE:	SCALE:	SHEET:
ANS/SCH	2017.03.10	1:200	1 OF 1
CHECKED:	PLOTTED:	FORMAT:	
AG	2017.03.10	A0	⊕

APPENDIX B

WEIGHTS AND CoG CALCULATION

Weight Estimate- 6000 tons Floating Dock
Steel

									CoG			Moments		
Sl. No.	Item Description	t	L	B or H	A	Qty.	Density	Total Weight	X	Y	Z	M-x	M-y	M-z
		(mm)	(m)	(m)	(m^2)		(kg/m or m^2 or m^3)	(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)
	Pontoon													
1	Deck plate	12.00	18.00	30.00	540	5	94.20	254.34	46.20	15.00	4.49	11750.51	3815.10	1143.00
2	Bottom plate	12.00	16.00	30.00	480	5	94.20	226.08	46.20	15.00	0.01	10444.90	3391.20	1.36
3	Side plate (upper)	12.00	18.00	3.50	63	10	94.20	59.35	46.20	15.00	2.75	2741.79	890.19	163.20
4	Side plate (lower)	12.00	17.00	1.00	17	10	94.20	16.01	46.20	15.00	0.50	739.85	240.21	8.01
5	End plate (upper)	12.00	30.00	3.50	105	10	94.20	98.91	46.20	15.00	2.25	4569.64	1483.65	222.45
6	End plate (lower)	12.00	30.00	1.41	42	10	94.20	39.85	46.20	15.00	0.50	1840.91	597.70	19.92
7	Bkhd plate (center)	10.00	17.40	3.31	58	5	78.50	22.61	46.20	15.00	2.27	1044.38	339.08	51.25
8	Bkhd plate (sides)	10.00	17.40	3.31	58	10	78.50	45.21	46.20	15.00	2.27	2088.76	678.17	102.49
9	Bkhd plate (pump room)	8.00	9.98	3.78	38	10	62.80	23.69	46.20	15.00	2.27	1094.52	355.36	53.78
10	Bottom girder	-	30.00	-	-	45	75.05	101.31	46.20	15.00	0.31	4680.62	1519.68	30.90
11	Bottom frame	-	17.00	-	-	95	35.17	56.80	46.20	15.00	0.18	2623.99	851.94	10.11
12	Deck girder	-	30.00	-	-	45	72.22	97.50	46.20	15.00	4.24	4504.36	1462.46	413.39
13	Deck frame	-	18.00	-	-	95	33.28	56.92	46.20	15.00	4.35	2629.50	853.73	247.30
14	Side frame_1	-	3.77	-	-	90	65.31	22.16	46.20	15.00	2.25	1023.81	332.41	49.86
15	Side frame_2	-	4.35	-	-	190	65.31	53.98	46.20	15.00	2.24	2493.89	809.71	120.92
16	Bottom stiffener (bulb section 160x11.5)	-	30.00	-	-	90	17.30	46.71	46.20	15.00	0.10	2158.00	700.65	4.82
17	Deck stiffener (bulb section 140x10)	-	30.00	-	-	100	13.00	39.00	46.20	15.00	4.42	1801.80	585.00	172.42
18	Side stiffener (port and stbd) (bulb section 180x10)	-	18.00	-	-	70	17.60	22.18	46.20	15.00	2.40	1024.53	332.64	53.22
20	Bulkhead stiffener (bulb section 120x8)	-	17.28	-	-	105	9.19	16.67	46.20	15.00	2.70	770.35	250.12	45.02
21	Bulkhead stiffener_pump room (bulb section 120x8)	-	9.98	-	-	70	9.19	6.42	46.20	15.00	2.70	296.61	96.30	17.33
22	Pillars_central (UC 250x250x71.8)	-	3.77	-	-	45	71.80	12.18	46.20	15.00	2.26	562.76	182.71	27.53
23	Pillars_sides (UC 250x250x71.8)	-	3.36	-	-	190	71.80	45.78	46.20	15.00	2.26	2115.15	686.74	103.47

									CoG			Moments		
Sl. No.	Item Description	t	L	B or H	A	Qty.	Density	Total Weight	X	Y	Z	M-x	M-y	M-z
		(mm)	(m)	(m)	(m^2)		(kg/m or m^2 or m^3)	(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)
24	Pillar brackets (UC 250x250x71.8)	-	1.50	-	-	470	71.80	50.62	46.20	15.00	2.26	2338.60	759.29	114.40
	Dock Wing													
25	Side plate (below safety deck)	10.00	92.40	6.00	527	4	78.50	165.38	46.20	15.00	7.50	7640.44	2480.66	1240.33
26	Side plate (above safety deck)	8.00	90.60	4.50	387	4	62.80	97.29	46.20	15.00	12.75	4494.96	1459.40	1240.49
27	End plate (extreme)	8.00	3.50	10.63	27	4	62.80	6.77	46.20	15.00	8.77	312.79	101.56	59.38
28	End plate (inner)	8.00	3.50	12.00	42	4	62.80	10.55	46.20	15.00	9.37	487.43	158.26	98.86
29	Upper deck plate	8.00	3.50	90.60	8	2	62.80	1.00	46.41	15.00	15.00	46.63	15.07	15.07
30	Safety deck plate	8.00	3.50	90.60	285	2	62.80	35.80	46.50	15.00	10.55	1664.51	536.94	377.65
31	Tween deck plate	8.00	3.50	4.50	11	4	62.80	2.73	52.80	15.00	7.55	143.91	40.88	20.58
32	Interdeck plate	8.00	3.50	5.10	11	4	62.80	2.86	46.20	15.00	12.80	131.95	42.84	36.56
33	Bulkhead plate (above safety deck level)	6.00	3.20	4.35	14	12	47.10	7.87	42.80	15.00	12.75	336.73	118.01	100.31
34	Bulkhead plate (below safety deck level)	8.00	2.50	5.40	14	14	62.80	11.87	55.80	15.00	7.50	662.30	178.04	89.02
35	Bottom frame	-	3.50	-	-	102	55.80	19.92	46.20	15.00	4.77	920.33	298.81	95.08
36	Upper deck frame_1	-	4.30	-	-	92	23.55	9.32	45.96	15.00	13.25	428.18	139.75	123.46
37	Upper deck frame_2	-	3.50	-	-	12	23.55	0.99	45.96	15.00	13.25	45.46	14.84	13.11
39	Upper deck frame_4	-	1.70	-	-	4	23.55	0.16	46.20	15.00	13.25	7.40	2.40	2.12
40	Upper deck frame_5	-	3.60	-	-	20	23.55	1.70	45.96	15.00	13.25	77.93	25.43	22.47
41	Safety deck frame_1	-	4.30	-	-	92	18.84	7.45	45.96	15.00	10.42	342.54	111.80	77.66
42	Safety deck frame_2	-	3.50	-	-	12	18.84	0.79	45.96	15.00	10.42	36.37	11.87	8.25
43	Safety deck frame_3	-	2.60	-	-	6	18.84	0.29	45.96	15.00	10.42	13.51	4.41	3.06
44	Safety deck frame_4	-	1.70	-	-	4	18.84	0.13	46.20	15.00	10.42	5.92	1.92	1.33
45	Safety deck frame_5	-	3.60	-	-	20	18.84	1.36	45.96	15.00	10.42	62.34	20.35	14.13

Weight Estimate- 6000 tons Floating Dock
Steel

									CoG			Moments		
Sl. No.	Item Description	t	L	B or H	A	Qty.	Density	Total Weight	X	Y	Z	M-x	M-y	M-z
		(mm)	(m)	(m)	(m^2)		(kg/m or m^2 or m^3)	(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)
46	Tween deck frame_1	-	3.50	-	-	12	30.62	1.29	46.20	15.00	7.33	59.41	19.29	9.42
47	Tween deck frame_2	-	1.70	-	-	4	30.62	0.21	46.20	15.00	7.33	9.62	3.12	1.53
48	Tween deck frame_3	-	1.80	-	-	10	30.62	0.55	91.50	15.00	7.33	50.42	8.27	4.04
49	Tween deck frame_4		3.60	-	-	8	30.62	0.88	91.50	15.00	7.33	80.68	13.23	6.46
50	Inter deck frame_1	-	3.50	-	-	12	30.62	1.29	91.50	15.00	12.53	117.65	19.29	16.11
51	Inter deck frame_2	-	1.70	-	-	4	30.62	0.21	91.50	15.00	12.53	19.05	3.12	2.61
52	Inter deck frame_3	-	3.60		-	8	30.62	0.88	91.50	15.00	12.53	80.68	13.23	11.05
53	Side frame upper	-	4.20	-	-	212	18.84	16.78	46.20	15.00	12.66	775.01	251.63	212.31
54	Side frame lower	-	5.40	-	-	212	51.81	59.31	46.20	15.00	7.55	2740.22	889.68	447.81
55	Brackets_upper top (UC 150x100x20.7)	-	0.75	-	-	160	20.70	2.48	46.47	15.00	14.49	115.43	37.26	36.00
56	Upper deck stiffener (bulb section 120x6)	-	90.60	-	-	9	7.31	5.70	46.63	15.00	14.97	265.59	85.43	85.26
57	Safety deck stiffener (bulb section 120x6)	-	90.60	-	-	9	7.31	5.70	46.63	15.00	10.47	265.59	85.43	59.64
58	Tween deck stiffener (bulb section 120x6)_1	-	4.50	-	-	4	7.31	0.13	46.20	15.00	7.47	6.08	1.97	0.98
59	Tween deck stiffener (bulb section 120x6)_2	-	0.90	-	-	8	7.31	0.05	1.35	15.00	7.47	0.07	0.79	0.39
60	Inter deck stiffener (bulb section 120x6)_1	-	5.10	-	-	4	7.31	0.15	46.20	15.00	11.82	6.89	2.24	1.76
61	Inter deck stiffener (bulb section 120x6)_2	-	0.90	-	-	16	7.31	0.11	46.20	15.00	11.82	4.86	1.58	1.24
62	Inter deck stiffener (bulb section 120x6)_3	-	0.60	-	-	16	7.31	0.07	46.20	15.00	11.82	3.24	1.05	0.83
63	Side stiffener_lower_long (bulb section 140x8)	-	740.0	-	-	2	10.80	15.98	46.22	15.00	7.50	738.83	239.76	119.88
64	Side stiffener_lower_trans (bulb section 220x10)	-	56.0	-	-	2	20.10	2.25	46.22	15.00	7.50	104.05	33.77	16.88
65	Side stiffener_upper_long (L 75x50x8)	-	850.0	-	-	2	7.39	12.56	46.20	15.00	12.75	580.41	188.45	160.18
66	Side stiffener_upper_trans (L 100x65x8)	-	63.0	-	-	2	9.40	1.18	46.20	15.00	12.75	54.72	17.77	15.10
67	Bulkhead stiffener_above safety deck (L section 100x65x8)	-	147.00	-	-	2	9.40	2.76	43.90	15.00	12.75	121.32	41.45	35.24
68	Bulkhead stiffener_below safety deck (bulb section 200x8.5)	-	221.00	-	-	2	17.80	7.87	46.20	15.00	8.30	363.48	118.01	65.30

Weight Estimate- 6000 tons Floating Dock
Steel

									CoG			Moments		
Sl. No.	Item Description	t	L	B or H	A	Qty.	Density	Total Weight	X	Y	Z	M-x	M-y	M-z
		(mm)	(m)	(m)	(m^2)		(kg/m or m^2 or m^3)	(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)
	Misc													
69	Connection supports	12.00	220.00	0.75	165	2	94.20	31.09	46.20	15.00	4.60	1436.17	466.29	143.00
70	Stiffening at crane rail base	10.00	90.00	0.50	45	4	78.50	14.13	46.20	15.00	15.06	652.81	211.95	212.80
71	Extended platforms	10.00	23.00	4.00	92	2	12000.00	24.00	46.20	15.00	4.50	1108.80	360.00	108.00

2006.09	**46.34**	**15.00**	**4.28**	**92961.96**	**30091.33**	**8588.87**
	CoG			Moments		
Total Weight	X	Y	Z	M-x	M-y	M-z
(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)

Additional Weight **Contingency** = **10%**

200.61	**46.34**	**15.00**	**5.14**	**9296.20**	**3009.13**	**1030.66**
	CoG			Moments		
Total Weight	X	Y	Z	M-x	M-y	M-z
(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)

**20% safety margin in VCG for additional weight considered*

Weight Estimate- 6000 tons Floating Dock
Architectural, Electrical, HVAC

									CoG			Moments		
Sl. No.	Item Description	t	L	B	A	Qty.	Density/ unit wt	Total Weight	X	Y	Z	M-x	M-y	M-z
		(mm)	(m)	(m)	(m^2)		(kg/m(m^2/m^3/no.))	(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)
	Insulation													
1	Floor Insulation (PAROC Marine Floor Slab 140)	50.00	80.40	3.50	281	2	140.00	3.94	45.28	15.00	10.58	178.39	59.09	41.66
2	Wall insulation (Paroc Marine Slab 220)_long sides	15.00	80.40	4.50	362	4	220.00	4.78	45.28	15.00	12.80	216.25	71.64	61.13
3	Wall insulation (Paroc Marine Slab 220)_short sides	15.00	-	-	16	4	220.00	0.21	46.20	15.00	13.02	9.76	3.17	2.75
4	Wall insulation (Paroc Marine Slab 220)_bulkheads	15.00	-	-	16	12	220.00	0.63	45.28	15.00	12.80	28.69	9.50	8.11
5	Deck insulation (Paroc Marine Slab 80)	70.00	80.40	3.50	281	2	80.00	3.15	45.28	15.00	15.00	142.71	47.28	47.28
	Linings and panels													
6	Floating floor plate	3.00	80.40	3.50	281	2	23.55	13.25	45.28	15.00	10.60	600.14	198.81	140.49
7	Floor vinyl sheet	3.20	80.40	3.50	281	2	2.30	1.29	45.28	15.00	10.60	58.61	19.42	13.72
8	Wall lining (MOS)_long sides	25.00	80.40	2.20	177	4	18.00	12.74	45.28	15.00	11.70	576.66	191.03	149.04
9	Wall lining (MOS)_short sides	25.00	-	-	16	4	18.00	1.15	46.20	15.00	11.92	53.22	17.28	13.73
10	Wall lining (MOS)_bulkheads	25.00	-	-	16	12	18.00	3.46	45.28	15.00	11.70	156.49	51.84	40.44
11	Ceiling panels (MOS)	50.00	80.40	3.50	281	2	6.00	3.38	45.28	15.00	12.85	152.90	50.65	43.39
12	Partition (MOS)_longitudinal	50.00	80.40	2.20	177	2	22.60	7.99	46.20	15.00	11.70	369.37	119.92	93.54
13	Partition (MOS)_transverse_1	50.00	4.50	2.50	11	14	22.60	3.56	40.40	18.93	11.70	143.80	67.38	41.66
	Other architectural items													
14	B15 door	45.00	2.05	0.80	2	46	60.00	2.76	46.20	15.00	11.58	127.51	41.40	31.95
16	Common shower/ toilets (port side only)	-	-	-	-	5	200.00	1.00	31.20	28.20	10.65	31.20	28.20	10.65
17	Bunk beds (port side only)	-	-	-	-	8	250.00	2.00	50.59	27.98	11.80	101.17	55.95	23.60
18	MDF tables in acc. Cabins (port side only)	18.00	-	-	-	8	35.00	0.28	50.59	29.20	11.00	14.17	8.18	3.08
19	MDF Dining tables (port side only)	18.00	-	-	-	2	55.00	0.11	48.27	28.70	11.00	5.31	3.16	1.21

Weight Estimate- 6000 tons Floating Dock
Architectural, Electrical, HVAC

									CoG			Moments		
Sl. No.	Item Description	t	L	B	A	Qty.	Density/ unit wt	Total Weight	X	Y	Z	M-x	M-y	M-z
		(mm)	(m)	(m)	(m^2)		(kg/m(m^2/m^3/no.))	(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)
20	Control room table	18.00	-	-	-	1	80.00	0.08	41.40	1.43	11.00	3.31	0.11	0.88
21	Chair (normal)	-	-	-	-	23	8.00	0.18	46.20	15.00	11.00	8.50	2.76	2.02
22	Chair (control room)	-	-	-	-	12	16.00	0.19	41.40	1.43	11.00	7.95	0.27	2.11
23	Watertight hatch covers on pontoon deck	-	-	-	-	50	100.00	5.00	46.20	15.00	4.50	231.00	75.00	22.50
24	Watertight hatch covers on wing bulkheads	-	-	-	-	17	100.00	1.70	45.28	15.00	5.15	76.98	25.50	8.76
	Misc													
25	Electrical cabling and accessories and supports	-	277.20	-	-	2	50.00	27.72	46.20	15.00	12.50	1280.66	415.80	346.50
26	HVAC ducting and accessories and support	-	80.40	-	-	2	80.00	12.86	46.20	15.00	13.00	594.32	192.96	167.23
27	Paint (3 coat)	-	-	-	17898	1	0.20	3.58	46.20	15.00	4.44	165.38	53.69	15.89
28	Piping	-	90.00	-	-	5	45.00	20.25	46.20	15.00	0.60	935.55	303.75	12.15

137.25	**45.68**	**15.40**	**9.80**	**6269.98**	**2113.75**	**1345.47**
	CoG			Moments		
Total Weight	X	Y	Z	M-x	M-y	M-z
(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)

Additional Weight **Contingency = 20%**

27.45	**45.68**	**15.40**	**11.76**	**1254.00**	**422.75**	**322.91**
	CoG			Moments		
Total Weight	X	Y	Z	M-x	M-y	M-z
(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)

**20% safety margin in VCG for additional weight considered*

EMship intern
Nelton

Weight Estimate- 6000 tons Floating Dock
Outfitting and Equipment

Prepared by MKG
on 21 Aug 2017

									CoG			Moments		
Sl. No.	Item Description	t	L	B	A	Qty.	Density/ unit wt	Total Weight	X	Y	Z	M-x	M-y	M-z
		(mm)	(m)	(m)	(m^2)		(kg/m or m^2 or no.)	(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)
1	Docking blocks	-	-	-	-	100	1200.00	120.00	46.20	15.00	5.10	5544.00	1800.00	612.00
2	Swing bridge	-	-	-	-	2	3400.00	6.80	92.34	15.00	13.65	627.92	102.00	92.82
3	Handrails (wing upper deck)	-	374.00	-	-	2	26.20	19.60	46.20	15.00	15.60	905.41	293.96	305.72
4	Handrails (safety deck)	-	27.80	-	-	2	26.20	1.46	46.20	15.00	15.60	67.30	21.85	22.72
5	Handrails (tween deck)	-	20.40	-	-	2	26.20	1.07	46.20	15.00	15.60	49.39	16.03	16.68
6	Handrails (inter deck)	-	27.80	-	-	2	26.20	1.46	46.20	15.00	15.60	67.30	21.85	22.72
7	Handrails (stairs)	-	140.00	-	-	2	26.20	7.34	44.28	15.00	9.80	324.84	110.04	71.89
8	Stairs	-	70.00	-	-	2	55.50	7.77	44.50	15.00	9.80	345.77	116.55	76.15
9	Crane	-	-	-	-	2	22000.00	44.00	46.2	15.00	4.00	2032.80	660.00	176.00
10	Crane rail (SD100)	-	90.00	-	-	4	75.00	27.00	46.20	15.00	15.10	1247.40	405.00	407.65
11	Generator	-	-	-	-	1	13400.00	13.40	70.00	1.50	12.00	938.00	20.10	160.80
13	Ballast pumps	-	-	-	-	10	1500.00	15.00	46.20	15.00	1.00	693.00	225.00	15.00
14	Fire pumps	-	-	-	-	2	300.00	0.60	46.20	15.00	15.00	27.72	9.00	9.00
11	Capstan	-	-	-	-	2	2000.00	4.00	46.20	15.00	15.00	184.80	60.00	60.00

269.49	**48.45**	**14.33**	**7.60**	**13055.64**	**3861.39**	**2049.15**
	CoG			Moments		
Total Weight	X	Y	Z	M-x	M-y	M-z
(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)

Weight Estimate- 6000 tons Floating Dock
Outfitting and Equipment

Additional Weight **Contingency** **=** **20%**

53.90	**48.45**	**14.33**	**9.12**	**2611.13**	**772.28**	**491.80**
	CoG			Moments		
Total Weight	X	Y	Z	M-x	M-y	M-z
(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)

**20% safety margin in VCG for additional weight considered*

Weight Estimate- 6000 tons Floating Dock
Consumables and Rest Water

									CoG			Moments		
Sl. No.	Item Description	t	L	B	A	Qty.	Density/ unit wt	Total Weight	X	Y	Z	M-x	M-y	M-z
		(mm)	(m)	(m)	(m^2)		(kg/m or m^2 or no.)	(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)
1	Fuel oil					9	840.00	7.94	71.10	1.75	9.80	564.39	13.89	77.79
2	Fresh water					6	1000.00	6.30	55.80	28.25	7.55	351.54	177.98	47.57
3	Rest water at pontoon bottom					1310	1025.00	1342.75	46.20	15.00	0.30	62035.05	20141.25	402.83

1356.99	**46.39**	**14.98**	**0.39**	**62950.98**	**20333.12**	**528.18**
	CoG			Moments		
Total Weight	X	Y	Z	M-x	M-y	M-z
(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)

Additional Weight **Contingency** **=** **2%**

27.14	**46.39**	**14.98**	**0.47**	**1259.02**	**406.66**	**12.68**
	CoG			Moments		
Total Weight	X	Y	Z	M-x	M-y	M-z
(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)

**20% safety margin in VCG for additional weight considered*

Weight Estimate- 6000 tons Floating Dock
Summary

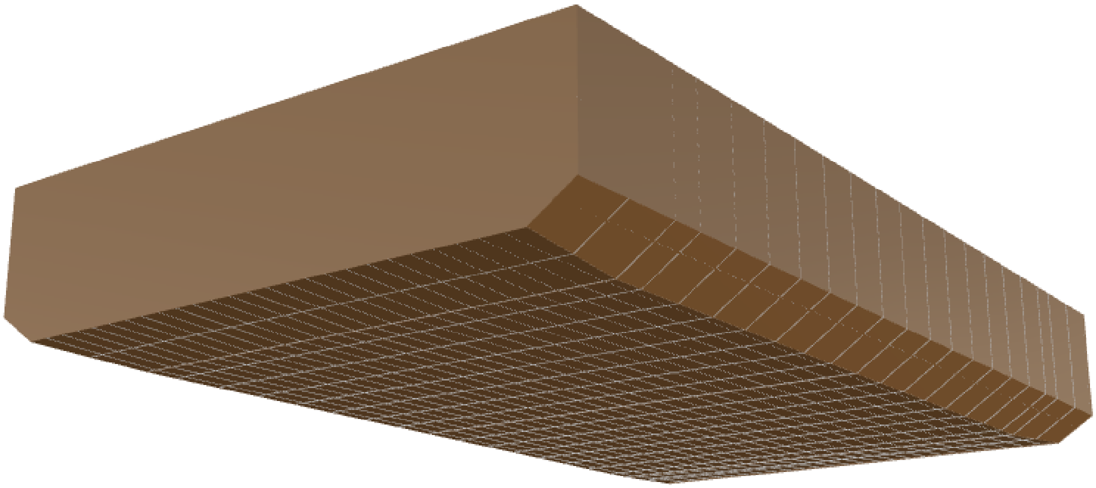
Sl. No.	Item Description	Contingency	Total Weight	CoG			Moments		
				X	Y	Z	M-x	M-y	M-z
			(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)
1	Structural Steel	10%	2207	46.34	15.00	4.36	102258	33100	9620
2	Architectural and misc	20%	165	45.68	15.40	10.13	7524	2536	1668
3	Outfitting and equipment	20%	323	48.45	14.33	7.86	15667	4634	2541
4	Consumables and rest water	2%	1384	46.39	14.98	0.39	64210	20740	541

4079	**46.50**	**14.96**	**3.52**	**189659**	**61010**	**14370**
	CoG			Moments		
Total Weight	X	Y	Z	M-x	M-y	M-z
(tons)	(m)	(m)	(m)	(t.m)	(t.m)	(t.m)

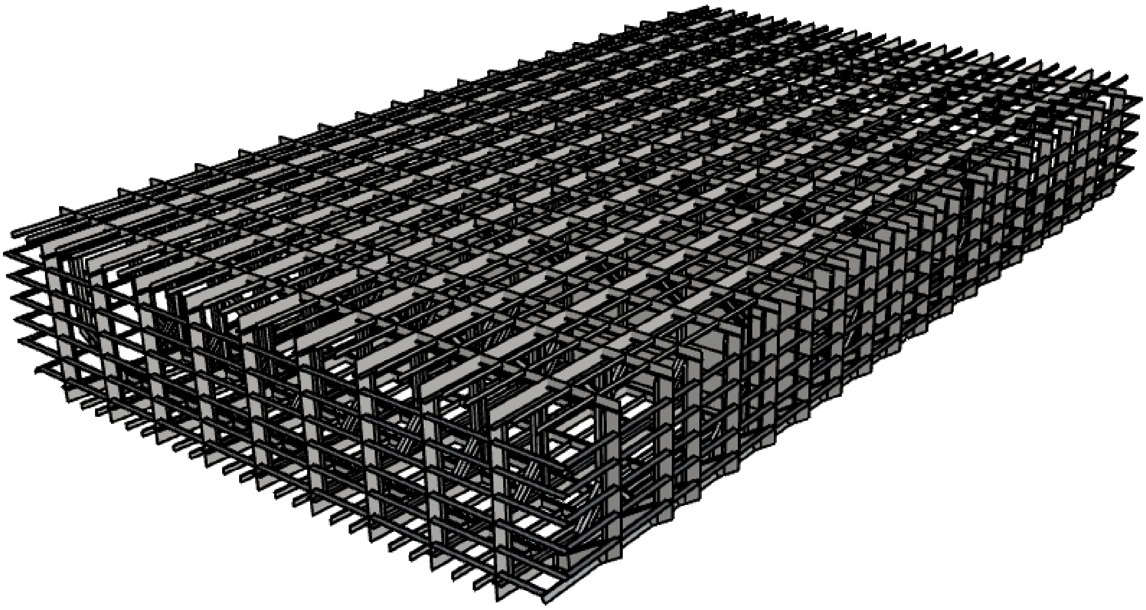
APPENDIX C

3D VISUALIZATION

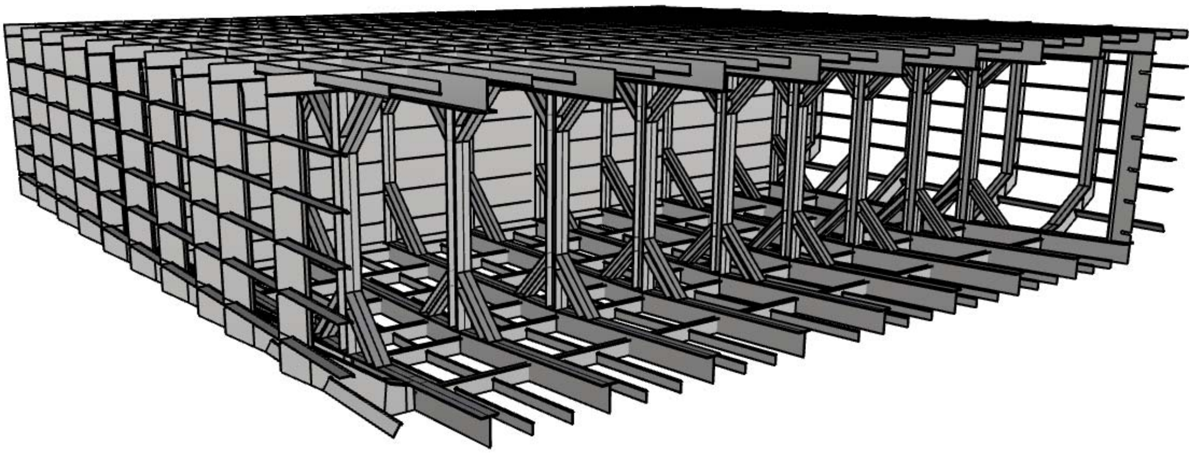
Isometric View



Pontoon Isometric View from Bottom

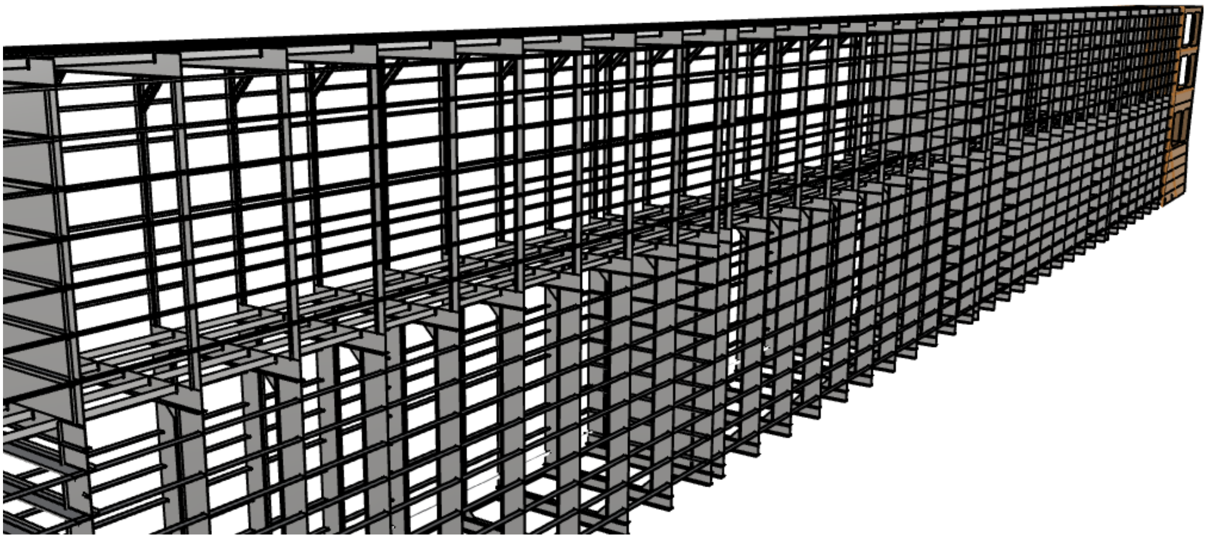


Pontoon Structure Frame Work



View Inside Pontoon

View Inside Dock Wing



Dock Wing Steel Frame Work