Structural design of a multi-role support offshore vessel of 100m long

Oluwafemi A. Adelere

Master Thesis

presented in partial fulfillment
of the requirements for the double degree:
“Advanced Master in Naval Architecture” conferred by University of Liege
"Master of Sciences in Applied Mechanics, specialization in Hydrodynamics, Energetics and Propulsion” conferred by Ecole Centrale de Nantes

developed at West Pomeranian University of Technology, Szczecin
in the framework of the

“EMSHIP”
Erasmus Mundus Master Course
in “Integrated Advanced Ship Design”

Ref. 159652-1-2009-1-BE-ERA MUNDUS-EMMC

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

Reviewer: Prof. D. Boote,
University of Genova.

Szczecin, February 2014

ABSTRACT

Offshore support vessels are in various specialized design, to meet or fulfill specific offshore operations, however the need for just one vessel capable of fulfilling all these specialized function arises in the multi-role offshore support vessels.

This work present a structural design of multi-role offshore support vessel capable of operating in the gulf of Guinea, with design Criteria Sea state 4m significant wave height. The design process involves achieving multiple objectives at the same time, while conforming to structural, economic and production constrains. Every step forward needs to be checked by the previous stages to enhance best combination between design requirement in all stages and the final results.

The design meets or fulfill multiple operation requirements of wide range of offshore support activities, including diving, survey, cable lay, construction and maintenance support. And also, the requirements of the classification society.

Detail analysis of the local loads and stresses on the main deck and tween deck, is carried out using Nauticus 3D beam, a Det Norske Veritas (DNV) finite element software, using the beam theory assumptions, from Marin Teknikk Poland.

The design is based on the Det Norske Veritas (DNV) classification rules, with the aid of Nautical hull software, the global scantling is done.

However, the local and global loads, stresses are compared with the standard values from the classification society (DNV), and total adherences to the rules are ensured. The regions, joints, nodes of higher stresses are identified and necessary steps are taken to ameliorate these stresses to the confinement of the stated rule values.

Furthermore, comparison is made between designed optimized structure and the owner structural or operation requirements, in terms of mass in kilograms.

The vessel is constructed all of mild steel, except for the helicopter landing platform deck which is made of aluminum, round bilge hull form, flare bulbs bow, with a large and clear working area on the main deck for the offshore activities.

ACKNOWLEDGEMENTS

This thesis was developed in the frame of the European Master Course in "Integrated Advanced Ship Design" named "EMSHIP" for "European Education in Advanced Ship Design", Ref.: 159652-1-2009-1-BE-ERA MUNDUS-EMMC.

The author is grateful for the support from MT Poland during the period of internship and Special thanks to, Mr. Piotr Sedzimir for giving valuable advices with technical problems.

I am deeply indebted to Mr. Marcin Przybylski for the support and supervision of this work.

The assistance from Prof. Zbigniew Sekulski of West Pomeranian University of Technology Szczecin, is unquantifiable.

Finally, special thanks to Professor Philipe Rigo for his restless effort in organizing and managing this EMShip Program.

CONTENTS

Declaration of Authorship

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

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

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

I have acknowledged all main sources of help.

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

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

I cede copyright of the thesis in favour of West Pomeranian University of Technology Szczecin.

Date: *Signature*

Definitions of symbols and abbreviations

a= arm length of bracket (mm)

f1=material factor

g_o= 9.81 m/ s^2

h_b = vertical distance in meters from the load point to the deepest equilibrium waterline in damaged condition obtained from applicable damage stability calculations.

h_0 = vertical distance from the waterline at draught T to the load point (m)

horz = horizontal

i.e= that is

t_k= corrosion addition (mm)

t= thickness (mm)

t_b= bracket thickness (mm)

w_k= corrosion factor (mm)

y = horizontal distance from the centre line to the load point, minimum B/4 (m)

z = vertical distance from the baseline to the load point, maximum T (m)

AP= aft perpendicular

AHC = Active heave Compensation

B= beam.

C_B = Block coefficient

C_W= 0.0792L1 wave coefficient.

DNV =Det Norske Veritas

FP= fore perpendiculars.

FCL= From centre line

FL=Flange

HP = HP bulbs type 20

L= rule length of ship.

L1 = ship length

MT = Marin Teknikk

PS= port side

ROV= Remote operated vehicle

SB= starboard

V= maximum service speed in knot.

T = draft.

W=web

Z= section modulus (cm^3)

ρ = density of ballast, bunkers or liquid cargo in t/m^3, normally not to be taken less than 1.025 t/m^3

σ_{Nx} = Axial stress

τ_{Mx} = Torsional stress

τ_{Qy} = Shear stress in local y-direction

τ_{Qz} = Shear stress in local z-direction

τ_{Qz} = Shear stress in local z-direction

φ= circular pillar

σ_{My}= Bending stress about local y-axis

σ_{Mz} = Bending stress about local z-axis

σ_{Ny} = Normal stress in local xz-plane

1. INTRODUCTION

1.1. Background

Offshore support vessels are vessels that regularly carry goods, supplies, individuals in addition to the crew, and equipments in support of explorations, production of offshore minerals or energy resources. They are with sufficient accommodations and installations to meet the subsea project.

However, need for a single vessel that can perform all the functions of specialized offshore operations arises, hence, the mult-irole support vessel is designed to meet all these specialized functions all in one vessel. The structures of the multi-role support vessel is designed, such that it meets it multiple services needs, and also conform to the owner and classification requirements.

The Support Vessel is equipped with Remote Operated Vehicle (ROV), this is a computer-controlled, precision, position-keeping capabilities (unmanned submarines) with arms camera accessories for underwater functions, and other subsea operations, with additional cabins, mess room facilities and Client offices, to comfortably accommodate the Client's ROV support crews. Also, equipped with subsea service installations, such as winches, fire fighting equipments. The design is also, for a light construction work, with 100 tones offshore cranes, with a large deck creating access to working platform.

Hence, this work focus on the structural design to meet the service conditions and also special equipments onboard for some special service need, such as the moon pool, which is an opening in the floor of the hull to enhance underwater functions to lunch and retrieve equipments, diving bell e.t.c.

1.2. Scope and Limitations of Work

The aim of this work is to understudy, an existing mult-role offshore vessel, understand her unique structural features, and applying this uniqueness for this design project .Therefore, this work is not intended at developing a novel approach to structural design. A detail comparison is to be made between the designed vessel, and an optimized vessel fulfilling basic requirement from the classification society for ship. Simply, because DNV offshore standard in part 5 chapter 7 section3 B 100, there are additional forces needed to be imposed on offshore vessel design, as compared to DNV rules for classification of ordinary ships [1].

The rule base design approach is used, which is mainly based on the rules define by the classification society [2]. However, according to Hughes (1988) the limitation of this approach to design is that, since the mode of structural failure are numerous, complex and inter dependent so, for the simplified formulas the margin against failure is unknown [2].

Chapter two of this work describes existing support offshore vessels, chapter three gives description of the understudied vessel.

While four give detail technical descriptions of the designed ships, chapter five further describe the hull, materials; chapter six presents, the scantlings, seven the finite element analysis, chapter eight is the weight estimations and comparison with the optimized structure.

Chapter nine is the conclusions of the work and recommendations.

It should be noted that this work emphasis the structure of the hull structure to the main deck, and shelter deck, alone, other structural part like the main propulsion unit, helideck is not shown in detail in this work.

1.3. Methodology

Structural design of a ship consists of two distinct levels, the preliminary design and the detailed design. The preliminary determines the location, spacing, of the principal structural members. The detailed design determines the geometry and scantlings of local structure, such as, the brackets end connections, cut-outs, reinforcements, etc.

A similar multi-role support offshore vessel MT 6016 and MT 6020 from MT Poland was studied to understand structural arrangements and needs of the multi-role support vessel. See figure 1.0 for picture and drawing of MT 6016 and 3.1 for MT 6020.

The methodology employed in this design is the semi probabilistic method, Load, strength, dimensions are random parameters but their distribution is basically not known. To overcome this, partial safety factors are used. Each factor corresponds to load type, failure mode [2].

The design is done by performing four sections scantling one at the moon pool region, two sections forward of the mid ship, and the last one, at the aft of the mid ship. Similarly, the same sections are designed for an ordinary ship satisfying basic classification rule, and a detail comparison is made between these designs.

Figure 1.0 ship MT 6016 Source Marin Teknikk

2. OVERVIEW OF OFFSHORE SUPPORT SHIPS

2.1. Offshore Vessels

Offshore vessels as the name implies are vessels for offshore activities. The term offshore support and supply are often mistakenly used to mean the same, but are different even if they are interwoven sometimes in there functions. Offshore supply vessels are vessels designed to meet the needs of an offshore activities by transporting equipment, personnel from the coast/shore to the deep water site where the offshore activity is taken place, and also from the site back to the coast/shore. According to DNV, supply vessels are offshore service vessels intended for supply services to offshore units or installations [1]. While the offshore support vessel goes beyond transportation of goods, personnel's and equipments to installations, it also helps or participate actively in the offshore activities, they are stationary at the offshore site, to perform their functions such as helping to position properly equipments/object to the sea bed, to lift or drop object where the oil platform crane cannot reach as in the case of oil exploration.

Offshore support vessels are of different types and forms, depending on the designed applications.

However, since offshore support vessels can also perform the functions of a supply vessel, overviews of some supply vessels in addition to support are presented in the preceding sections.

2.2. Anchor Handling Towing and Supply (AHTS) Vessels

These are vessels for deep water anchor handling and towing operations, equipped with a winch capable to lift a barge or other offshore vessels. The main duty is to move rigs, tow barges, setting anchors, and provide supply. They are equipped with large cranes, winches, and large open deck space. Winch and engine capacity determines power. See figure 2.1 below, for a drawing of a general arrangement of an Anchor Handling Towing and Supply vessels.

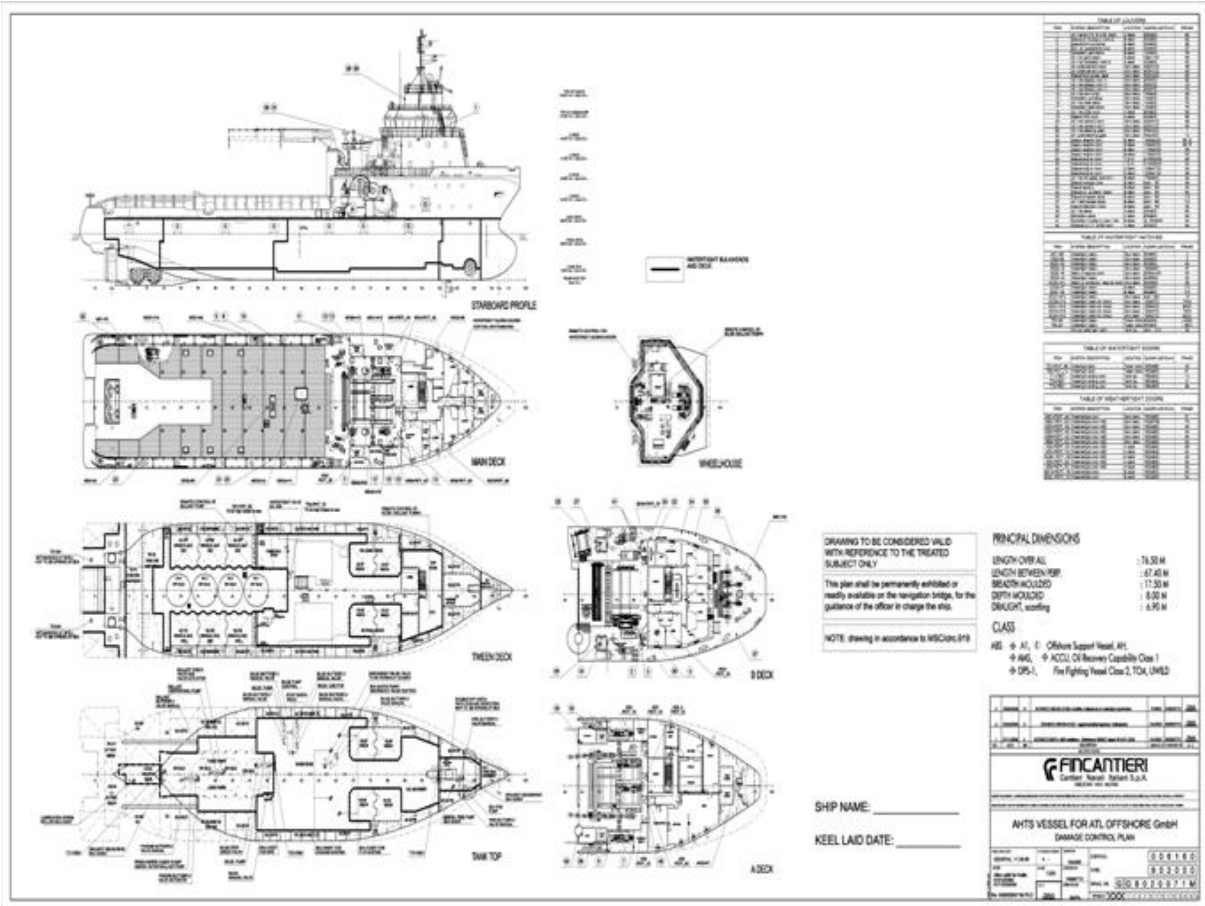

Figure 2.1 General arrangement of Anchor Handling Towing and Supply source Hartmann offshore

2.3. Platform Supply Vessels (PSV)

They are ships specially designed to supply offshore oil platform. These vessels serve a positioned oil rigs by delivering staff, food, equipment and waste removal [10]. Figure 2.2 is a view of a platform supply vessels.

Figure 2.2 A view of platform supply vessels
(http://en.wikipedia.org/wiki/File:Northern-Genesis.jpg access 6.11.2014)

2.4. Diving Support Vessels (DSV)

Diving support vessels are vessels which serve as floating bases for professional diving work. They are equipped with diving support equipment such as a large Cranes, pressure chamber, diving bells and may also be used as a standby/support vessel, with fire fighting, rescue operations, or oil recovery equipment, see figure 2.3 for view of a Diving support vessels.

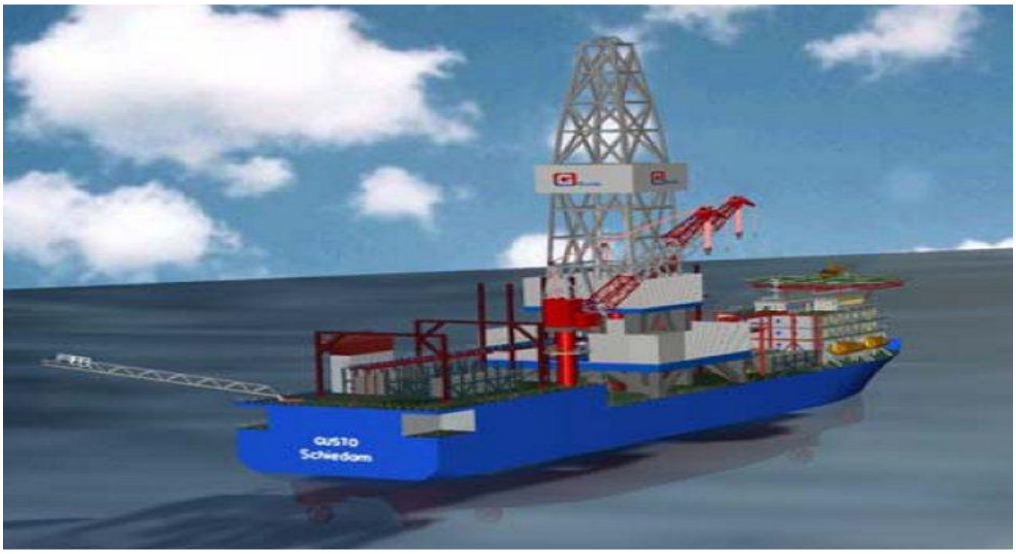

Figure 2.3 A view of Diving Support Vessels
(http://www.globalsecurity.org/military/systems/ship/offshore-dsv.htm access 12.11.2014)

2.5. Emergency Response and Rescue Vessels (ERRV)

These are offshore support vessel with the main function of being on permanent standby at offshore installations for the rescue and evacuation of offshore facilities, other functions may be to monitor the Safety Zone, and warn approaching vessels and the installation of the risk of collision in the exploration site.

2.6. Remote Operating Vessels (ROV) Support Vessels

They are often equipped with a moon pool, an opening in the floor of the hull giving access to the sea, to facilitate ROV launching. ROVs are used for underwater activities, equipped with cameras and arms for underwater duties. Remotely Operated Vehicles are unoccupied, highly manoeuvrable underwater robots operated by a person on board the vessel.

2.7. Well Servicing Vessels

These are Vessels built for well intervention servicing and work on existing wells. See figure 2.4 for a picture of well servicing vessel

Figure 2.4 A view of Well servicing vessels
(http://www.rovworld.com/article5494.html access 2.11.2014)

2.8. Multi-Purpose Service Vessel (MPSV)

Multi-Purpose vessels are equipped for sub-sea service, with large crane, winches, and/or fire fighting equipment installed. These vessels may have other equipment, such as ROV support, diving support, etc.

2.9. Seismic Survey Vessel

Survey vessels are vessels with seismic prospecting equipment, called seismic streamers, they are used as survey vessels to explore and locate potential area for oil drilling and other mineral in the oceans. See figure 2.5 for a picture of Seismic Survey Vessels.

Figure 2.5 view of Sterling Seismic Survey Vessels,
(http://gcaptain.com/releases-notation-specific-seismic/ access 1.11.2013)

2.10. Fast Supply Intervention Vessel (FSIV)

This is a type of crew boat with high speeds, to enable fast delivery of personnel and cargo. Fitted with fuel and water cargo capabilities, often equipped with a fire fighting capabilities. See figure 2.6 for a fast supply vessel in operation.

Figure 2.6 Fast supply intervention vessels
(http://dehoop.net/Examples-Design-Offshore-Vessels.php access 12.11.2013)

2.11. Floating Production Systems FPSO

Floating production systems are designed such that they contain petroleum or drilled oil products, as well as drilling equipment. Ships can also be used as floating production systems. The platforms can be kept in place through large and heavy anchors. The oil is stored from nearby oil platforms, until it ready to be transported through pipeline or with the tanker, in floating production system, once the drilling has been completed, the wellhead is actually attached to the seafloor. The extracted petroleum is transported through risers from this wellhead to the production facilities on the semi-submersible platform.

2.12. Maintenance Support Vessels

These are vessels design for the transportation of liquid cargo, stores, materials and equipments. They are also used for transporting personnel and materials between platforms and are capable of continuous operation and could remain on station for lengthy days, also used for construction work. See figure 2.7 for a general arrangement of a Maintenance support vessel from megalodon marine.

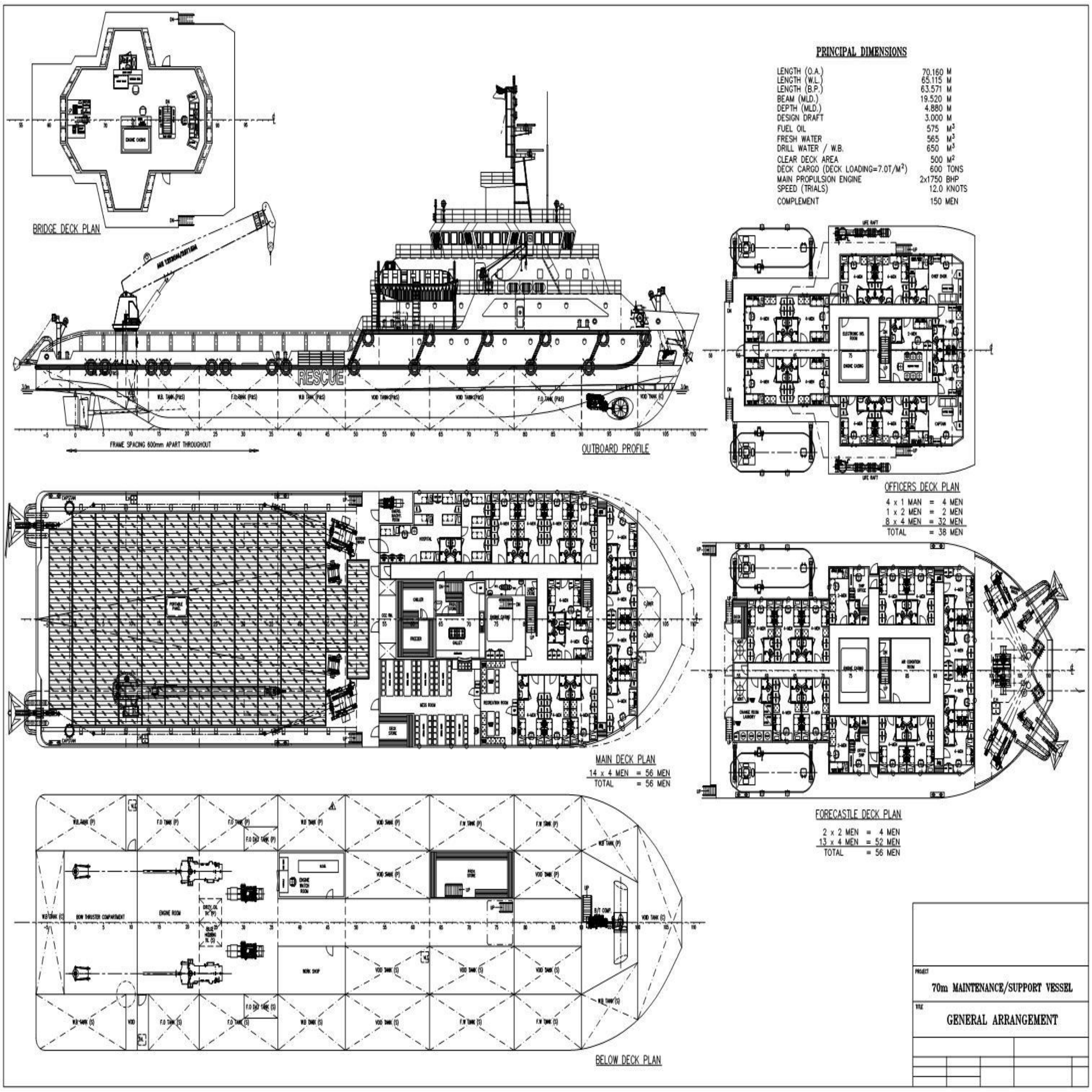

Figure 2.7 Maintenance support vessels

(http://www.megalodonmarine.com/store/pic/megalodonmarine/MB7001%20GA.JPG access 20.11.2013)

2.13. Utility Support Vessels (USV)

The utility vessels are ships design to supply all offshore oil platform needs, they transport personnel and goods to and from the oil production platform and other offshore structure or marine vessels. Figure 2.8 presents a general arrangement drawing for a Utility vessels from Maglodon marine.

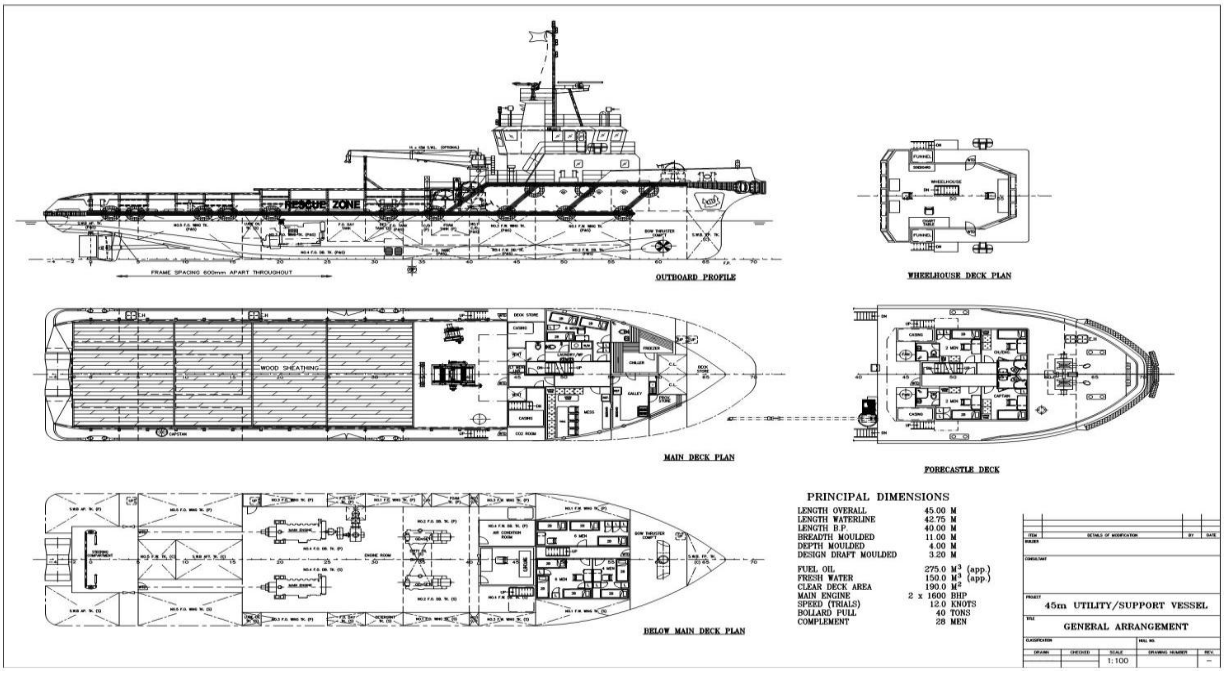

Figure 2.8 Utility support vessel (http://www.slideshare.net/thtsai77/overview-offshore-support-vessels-final-presentation-863127 access 21.12.2013)

2.14. Pipe Lay Support Vessels

These are vessel equipped with heavy crane for the installation of pumps, valves and equipments for laying pipes between subsea marine structures. It connect oil production platform to the onshore refineries see figure 2.9 for a picture of pipe lay support vessel with a large fore helideck.

Figure 2.9 pipe lay support vessel source Korea marine equipment

2.15. Fire Fighting Support Vessels

These are specialize vessel for fire fighting, they are designed to extinguish fire on ships and other offshore installations; they are often stationed in the production site. See figure 2.10 for one in operation from marine connector.

Figure 2.10 fire fighting support vessels source maritime connector

3. DESIGN ASPECT OF MULTI-ROLE SUPPORT OFFSHORE SHIP HULL STRUCTURE

3.1. Technical Knowledge of the Ship

The Multi-role support vessel combines the functions of all the offshore vessels described above in chapter 2; It functions as a Diving support vessel, Emergency response, Rescue, Remote operating and maintenance support vessel, having a dynamic positioning system, with some special feature such as the moon pool which serves as opening for the subsea operations.

The moon pool deck regions to the port and starboard plates are exceptionally thick of thickness 20mm to suit the operation requirements, since heavy and sharp construction equipment will often be placed at this region of the vessel. So many dynamic damages are caused due to the operation, and during severe weather condition, this equipments are often welded to this part of the deck. And this welded equipment may be remove from this point, to the final point or place of application, by using the torch to cut or burn it off the deck, hence this actions reduce the plating thickness during the life cycle of the vessel to an approximate thickness of 12mm over the life cycle of the vessel.

Due to this opening in the hull, there is buoyancy lost, while on the moon pool plates are cut out or perforations which act as dampers to absorb some energy from the sea water, to prevent splashing of water on the main deck, due to sloshing of the water in this confined opening.

Ventilating channels are connected to the top corners above the deck, to give air exit from enclosed moon pool. The moon pool cover may be explosively open in high wave crest or broken in trough due to suction pressure, if the ventilating opening is too small or not designed.

Another distinctive feature of the multi-role support vessel is the Compensators in the winches of the crane.

During the lifting operation in deep water installations heave motion compensation system are employed to prevent vertical resonance motion of the lifted equipment, which in turns reduce the dynamic load on the vessel, through the crane, these compensators are in form spring damper or hydraulic pistons.

Also are longitudinal fender are fitted on the ship at free board cargo deck and deck above to prevent obstructions.

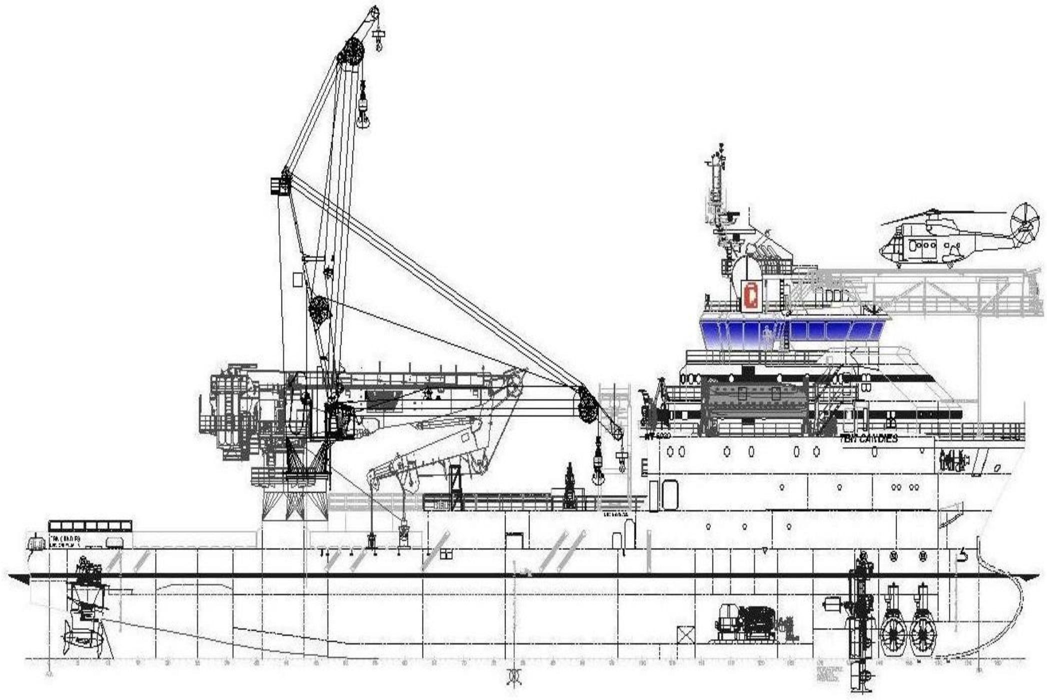

Figure 3.1 Section Drawing of the ship MT 6020-2290 source Marin Teknikk Poland

3.2. Design Loads

The loads acting on the ship structure can either be local or global load, when the ship is considered as single beam the load action on it is classified as primary or global load. And the loads acting on the stiffened panels, single beams and plate panels, they are regarded as the local loads.

Local loads are loads acting on the tertiary and secondary members, such as the point load on the deck plating, pressure load from the tank pressure on plates, sea pressure load on the outer shell.

The waves and still water bending moment applied to obtain the section modulus, and shear area of the hull girder as result of the global loads.

3.2.1 Pressures

The pressure acting on the ship's side, bottom and weather deck are taken as the sum of the static and the dynamic pressure according to DNV part 3 chapter2 sec 4 B 100[9].

Load point below summer load waterline:

$$P_1=10h_o+p_{dp}\ (kN/m^2) \quad (1)$$

For load above summer waterline:

$$P_2= h_o(p_{dp} - (4 + 0.2\ k_s)\ h_0)\ \ (kN/m^2) \quad (2)$$

= minimum 6.25 + 0.025 L1 for sides

= minimum 5 for weather decks.

Where

$p_{dp} = p_l + 135(y/B+75)-1.2(T-z) \quad (kN/m^2)$

$p_l = k_s C_W + k_f$

$=(k_s C_W +k_f)(0.8+0.15V/\sqrt{L})$ If $V/\sqrt{L}>1.5$

$K_s=3C_B +2.5/\sqrt{C_B}$ at A.P and aft

=2 between 0.2L from AP

$=3C_B+4.0/C_B$ at F.P and forward

kf = the smallest of T and f

The design pressure on watertight bulkheads (compartment flooded):

$$p = 10\, h_b \; (kN/m^2) \tag{3}$$

The design pressure on inner bottom (double bottom flooded) shall not be less than:

$$p = 10\, T \qquad (kN/m^2).$$

Liquid in tanks:

The pressure in full tank shall be taken as the greater of :

$$p =\rho g_0 h_s \qquad (kN/m^2) \tag{4}$$

$$p=\rho g_o\, h_s + p_0 \qquad (kN/m^2) \tag{5}$$

$$p=\rho g_o(h_s+0.3\, b) \qquad (kN/m^2) \tag{6}$$

$$p = 0.67\, (\rho\, g_0\, hp + \Delta\, p_{dyn}) \qquad (kN/m^) \tag{7}$$

$$p = \rho\, g_0\, (h_s + 0.1l) \qquad (kN/m^2) \tag{8}$$

Where

p_0 = 25 kN/m² in general,

$c = (1.25 - 0.025\, T_R)\, k \quad T_R=2k_r/\sqrt{GM}$

a_v = vertical acceleration taken in centre of gravity of tank.

H = height in m of the tank

b = the largest athwart ship distance in m from the load point to the tank corner at top of the tank which is situated most distant from the load point. For tank tops with stepped contour, the uppermost tank corner will normally be decisive

l= the largest longitudinal distance in m from the load point to the tank corner at top of tank which is situated most distant from the load point. For tank tops with stepped contour, the uppermost tank corner will normally be decisive.

The design pressure on inner bottom (double bottom flooded) shall not be less than:

$$p = 10\, T \qquad (kN/m^2). \tag{9}$$

Deck cargo units, Deck equipment

The forces acting on supporting structures and securing systems for heavy units of cargo, equipment or structural components (including cargo loads on hatch covers) are normally to be taken as:

Vertical force alone:

$$P_V = (g_o + 0.5\ a_v)\ M \qquad (kN) \qquad (10)$$

Vertical force in combination with transverse force

$$P_{VC} = g_o\ M \qquad (kN) \qquad (11)$$

Transverse force in combination with vertical force

$$P_{TC} = 0.67\ a_t\ M \qquad (kN) \qquad (12)$$

Vertical force in combination with longitudinal force

$$P_{VC} = (go + 0.5\ a_v)\ M \qquad (kN) \qquad (13)$$

Longitudinal force in combine force with vertical force

$$P_{LC} = 0.67\ a_l\ M \qquad (kN) \qquad (14)$$

a_t = combine transverse acceleration ; a_l =combine longitudinal acceleration; M= mass of unit in tone.

Dry cargo store equipment and accommodation:

The pressure on inner bottom, decks or hatch covers shall be taken as**:**

$$p = \rho\ (g0 + 0.5\ a_v)h \quad (kN/m^2) \qquad (15)$$

Where h= stowage height (m.)

3.3. Longitudinal Strength

With respect to bending and shear in the hull girder due to loadings, in ballast and cargo condition by waves and other loads, the following probabilistic approaches are employed.

3.3.1 Still Water Condition

$$M_{SO} = 0.0052\ L^3\ B\ (CB + 0.7)\ (kNm) \qquad (16)$$

If the still water bending moment M_{SV} is not determined by a direct calculation, that is, if it not at the mid ship, following approximate calculation method is applied [9];

$$M_{SV} = 5\ [(\Delta - DW)\ z + S\ (p\ y) - D\ x\ ]\ (kNm) \qquad (17)$$

where

Δ = displacement of ship in tones

DW = deadweight of ship in tones

Σ p = DW

p = individual weights in tones

y = distance in meters from L/2 to centre of gravity of the respective individual weights. Weights extending beyond L/2 are divided at L/2 and each part is considered separately

x= 0.18 (C_B + 0.35) L in meters

z = 0.2 L for ships with machinery amidships

= 0.24 L for ships with machinery at quarter length aft

= 0.27 L for ships with machinery aft

L = length of ship in meters.

The expression for M_{SV} may be positive or negative, and the moments are defined as follows:

— M_{SV} positive = hogging moment

— M_{SV} negative = sagging moment.

3.3.2 Wave Load Condition

Vertical wave bending moment amidships in sagging condition; DNV part 3 chapter2 section 4 B 200[9].

$$M_{ws} = -\ 0.11 C_W L^2 B (C_B + 0.7) \quad (kNm) \tag{18}$$

Vertical wave bending moment amidship in hogging condition:

$$M_{wh} = 0.19\ C_w L^2 C_B \qquad (kNm) \tag{19}$$

Design wave bending moment at any arbitrary position is given as follows

$$M_W = k_{wm}\ M_{WO} \qquad (kNm) \tag{20}$$

k_{wm} = 1.0 between 0.40 L and 0.65 L from A.P.

= 0.0 at A.P. and F.P.

Increase Linearly from 0 at k_{wm} =0 to 0.40L at k_{wm} =1.0 and decrease linearly from 0.65L at k_{wm}=1 to L at k_{wm}= 0.

3.4. Structural Arrangements and Models of Case Study Vessel

Models of some sections of the of understudy vessel (MT6029) structure, from Marin Teknikk Poland is described in the following figures, with the mass(kg), position of center of gravity (m), the stiffeners, plates and other structural members orientation.

3.4.1 Fore of the Mid Ship MT 6020

A section of a multi-role support offshore vessel fore of the mid ship, shown upside down in figure 3.2

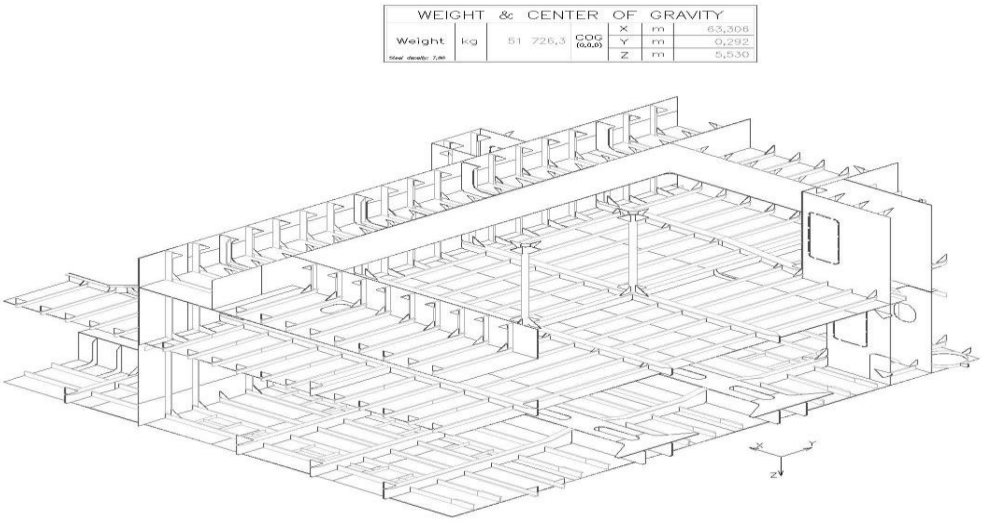

Figure 3.2. Fore of the moon pool source MT Poland

Above is a section of the main deck with longitudinal stiffeners, tween deck transversely stiffened, and a circular pillar of diameter 292mm and thickness of 20mm φ 292x20, with some end connecting brackets, and also the girders, with a water tight bulkhead, 14m to 28m forward of the moon pool.

3.4.2. The Moon Pool MT 6020

The moon pool is double skin type of dimension 7000X7000mm within frame 64 and frame 76. With deck plate of thickness 22mm around it, and the corners of the openings is of special thickness of 25mm. Figure 3.3 shows the moon pool plate cut out or perforations is 350x800mm within 1350mm above the tank top, and 350x650 in size within the distance of 1350mm to 2250mm above the tank top, and cut out of 350 x 800mm within 2250mm to 3200mm above the tank top. Similarly, an opening 350x800mm is at a distance within the tween deck and 1325mm above the tween deck, so also is within 1325mm above the tween deck to 2375mm throughout the frames of the moon pool opening, which serves as energy absorbers to prevent water on the deck, in severe weather working condition.

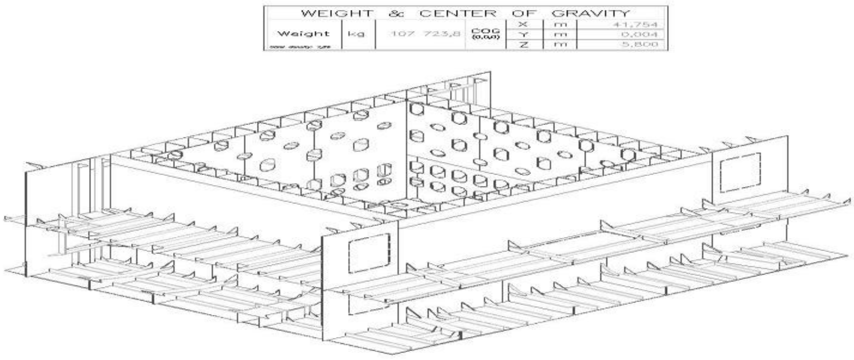

Figure 3.3. The moon pool source MT Poland

3.4.3. Bottom Structure

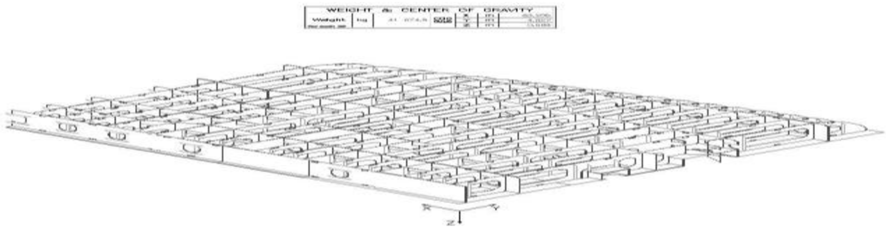

Figure 3.4 Bottom structure source MT Poland

The figure 3.4 is the bottom structure viewed upside down of the hull, in a section fore of the moon pool, with cut out in the plates, with a flat bar transverse stiffener, also with longitudinal bottom girder. The section is at distance 63m from the aft of the ship

3.4.4. The Port Side of the Moon Pool MT 6020

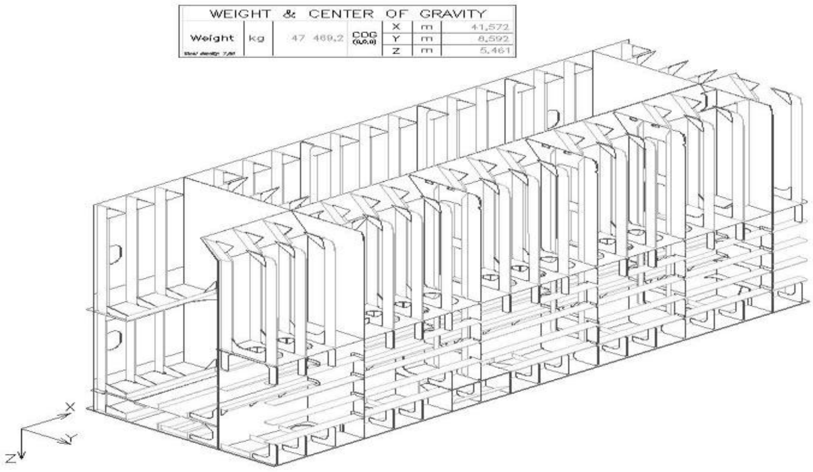

Figure 3.5 Port side of the moon pool

Figure 3.5 show a section of the port side of the moon pool region upside down view, within frame 62 to frame 78, the stiffeners and mainframes on the longitudinal bulkhead at position 6600mm from the centre line which is transversely stiffened from the tank top to the main deck with ends connections, that is the brackets. Also stiffeners and main frame for the bulkhead at position 9150mm from the centre line longitudinally stiffened from the main deck to the tween deck and transversely stiffened from the tween deck to the tank top.

Also, at the shell 10300mm from the center line, transversely stiffened from the tank top to the tween deck and longitudinally stiffened from the tween deck to the main deck of the outer shell, with the brackets at the end connection.

3.4.5. Water Tight Bulkhead MT 6020

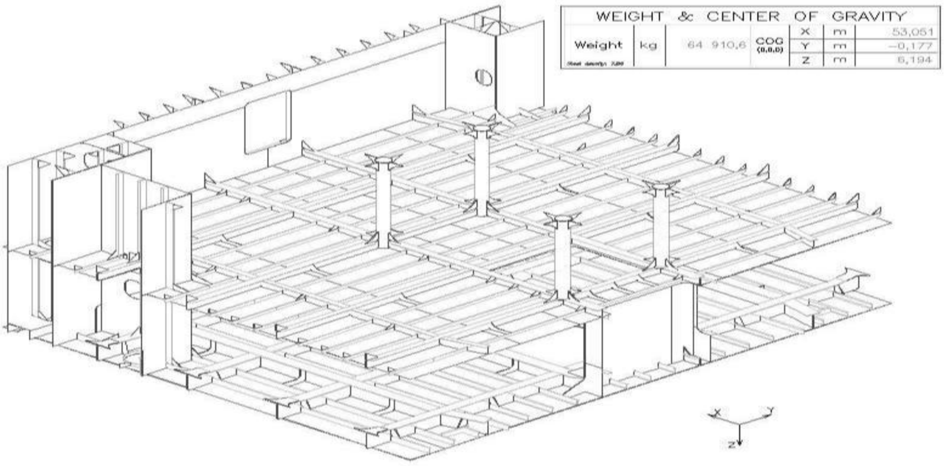

Figure 3.6 A water tight Bulkhead frame 77

The figure 3.6 above shows a section of the water tight bulkhead at frame 77 which is transversely stiffened and twin pillar at frame 80 and frame 88 at position 1.30 and -1.30 from the centre line respectively with end connecting brackets on the pillar, and transverse stiffeners on the deck.

3.5. Propellers

The vessel apply the dynamic positioning system which is a mathematical model of the vessel ,wind, position of the thrusters, combined with other information from sensors ,to estimate required thruster output. Two off R-R Azipull 100 thrusters, each 2500 kW, frequency controlled.

3.6. Deck equipment

Windl/Mooring: 2 off Rauma or similar, minimum of 10 T and Capstan 2 off or similar, minimum 10TDeck crane: 1 off Knuckle jib crane 5 T at 15 m,1 off NOV/ TTS offshore crane and 100 T at 10 m wire cap. 2100 m

3.7. Helicopter Deck

Helicopter deck of aluminium for sikorsky S92

3.8. Main Engines/Generator

Four of Caterpillar, type 3516 TA, each 2100 kW, 1800 rpm.4 off Siemens /ABB generators, each 2625 kVA, 690V/60Hz, 1800 rpm 1 off Cat C32 of 910 eKW, 1800 rpm, 1 off ABB.

Generator**:** Diesel electric propulsion system.

The generators are located at frame 115, the engine is connected to switch board which help to transmit electrical energy to the aft propeller, hence the use of a long shaft to the aft part of the ship is not required.

3.9. Accommodation

Accommodation for 98 persons + 12 divers ;20 x 1 man cabins ; 39 x 2 men cabins; 1 hospital; Superintendent office; Survey room; Customer project room**;** Saturation control room **;**Mess; Dayroom; Dayroom smokers lounge**;** Sky lobby**;** Ship conference room / office

3.10. Main switchboard

Since a shaft is not used in the transmission of mechanical power/energy from the engine to the propeller, the power is converted to electrical power/energy by switch board through cable to the aft, where it is again converted to mechanical power, the brand used is Hareid Elektriske / Siemens/ ABB.

3.11. Cargo tank Capacities

This is the allotted space in the hold for a specified item

Table xx cargo tank capacities.

Name	Capacity
Fuel Oil	1100m^3
Fresh Water	660m^3
Water Ballast	2900 m^3
Anti Heeling	300 m^3
Lubricating Oil	40 m^3
Bilge Water storage	90 m^3
Cement Capacity 4 x 66 m^3	264 m^3

4. TECHNICAL DESCRIPTIONS OF THE SELECTED SHIP

4.1. Ship Equipments

The equipments are designed to meet general offshore needs, in addition to operation field support duties, the vessel is designed for light construction work with about 100T AHC crane, ROV handling.

The vessel is equipped with diesel electric frequency controlled propulsion, azimuth thrusters.

A moon pool and hangar facilitate a comprehensive diving. The construction deck and offshore crane with active heave compensation and the bulwalk which give a good working platform.

4.2. Main dimensions

These are the characteristics of the vessel, it define the geometry and size of the vessels, and also topology of some key element parts. This also defines the category in the classification rules. From table 4.2 the overall length of the vessel is given as 100m, and the length between perpendiculars is 94.2m, hence, the category of less than 100m vessel is used to define this ship.

Table 4.2 main dimensions of the ship.

parameters	**symbols**	**values**
Length overall (m)	L.o.a	100.2
Rule length (m)	L	93.323
Breadth (m)	B	20.6
Depth Main Deck (m)	H_m	8
Depth Shelter Deck (m)	H_s	10
Depth Tween deck (m)	H_T	4.7
Depth tank top (m) at mid ship	H_{TT}	1.15
Draft (m)	T	6.25
Speed (knots)	V	16
Length between perpendiculars (m)	Lbpd	94.20

4.3. Cargo capacity

The load on the main deck and tween deck is presented in table 4.2 stating the positions on the main deck with regards to the frames and for the tween deck the load is uniform throughout the deck while the tank loads are defined by the density of the fluid.

Table 4.3 load distribution on the decks

Main deck load t/m2	Frame 0 - 90	Frame 90 - 96	Frame 96 -109
	10	5	2
Tween deck	2	2	2

General arraignment drawing

See section 3.1 and figure 3.1, for a section drawing of the ship, with all equipments onboard

5. CONCEPT OF THE HULL STRUCTURE

5.1. General on Hull

The hull is a water tight body, outermost part of any water craft, and needs to be reinforced adequately to withstand all loads or pressure it is subjected to. The type of reinforcements defines the framing system. A good knowledge of the environmental condition in which the ship will operate dictates the kind of materials used for the hull.

5.2. Framing system

The frame describes the positions on the hull, structural members and compartments arranged along the longitudinal direction of ship, the numberings are from aft to the fore part of the ship.

On the other hand, a ship framing system describes the orientations of the stiffening members of the ship structures.

Framing system can be longitudinal, transverse, or sometimes mixed framing system. This has a great impact on the production, weight resistance, among others. The transverse framing system is used in ships of relatively less length since the hull girder bending moments are not so large, the primary structural loads are hydrostatic or impact load. The longitudinal framing system is normally used for ships over 100 meters. Longitudinal framing system vessels, can withstand longitudinal bending moments more efficiently.

However, for this design, the bottom, inner bottom, tween deck, and the inner and outer side shell from the tween deck to the tank top are transversely stiffened, since the transverse compression are lower at this region, only hydrostatic load, that is, sea and tank pressure act on this part of the structure. While the main deck is longitudinally stiffened, it experiences more transverse compressive load due to its offshore activities, this part is more susceptible to bending by local loads since heavy production or offshore equipments are placed on the main deck and outward bending of the wing tank, which tend to increase the normal stress resulting from bending of large stiffened panels between longitudinal and transverse bulkheads due to this local loads.

Frame 0 is at distance 0 from the aft perpendicular AP, 2400mm as the typical longitudinal stiffener spacing and frame are spaced 600mm forward.

5.3. Topology

The hull structure should be adequately strengthen to withstand the entire loads or pressures it is been subjected to, this requires good material selections, appropriate framing or support system as stated earlier in section 5.1. Figure 5.1 is the front view of the moon pool section of the ship stiffened with HP stiffener, however, detail descriptions and definition of some element parts is as follows;

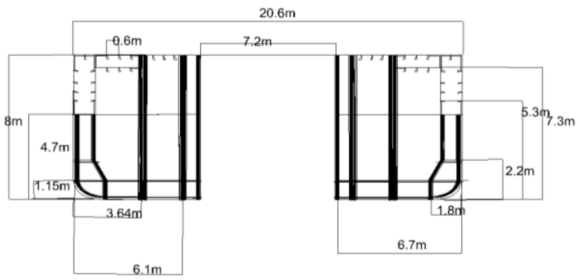

Figure 5.1 Front view of a section of the ship.

The main deck, cofferdam, inner and outer side shell plates above the tween deck are longitudinally stiffened, due to the compressive stresses in the transverse direction imposed by the offshore operations on these parts of the vessel.

On the main deck the longitudinal stiffeners are spaced 600mm forward, from 0mm to 3.6m FCL on the deck is a cover for the moon pool which is not part of the main deck, it is employed when there are no subsea operations. The cofferdam is situated at 7.3m from the baseline, the tween deck and the tank tops are located at 4.7m and 1.15m above the baseline respectively.

Figure 5.2, 5.2.1, 5.2.2, and 5.2.3 presents perspective views of the mid ship, front view of a section in the aft with the stiffening systems orientation specified frame 30 to 40, a perspective view of the aft section from frame 30 to 40, and a sections fore of the moon pool within frame 105 to frame 110, while figure 5.2.4 is the perspective view of the section from frame 115 to 125.

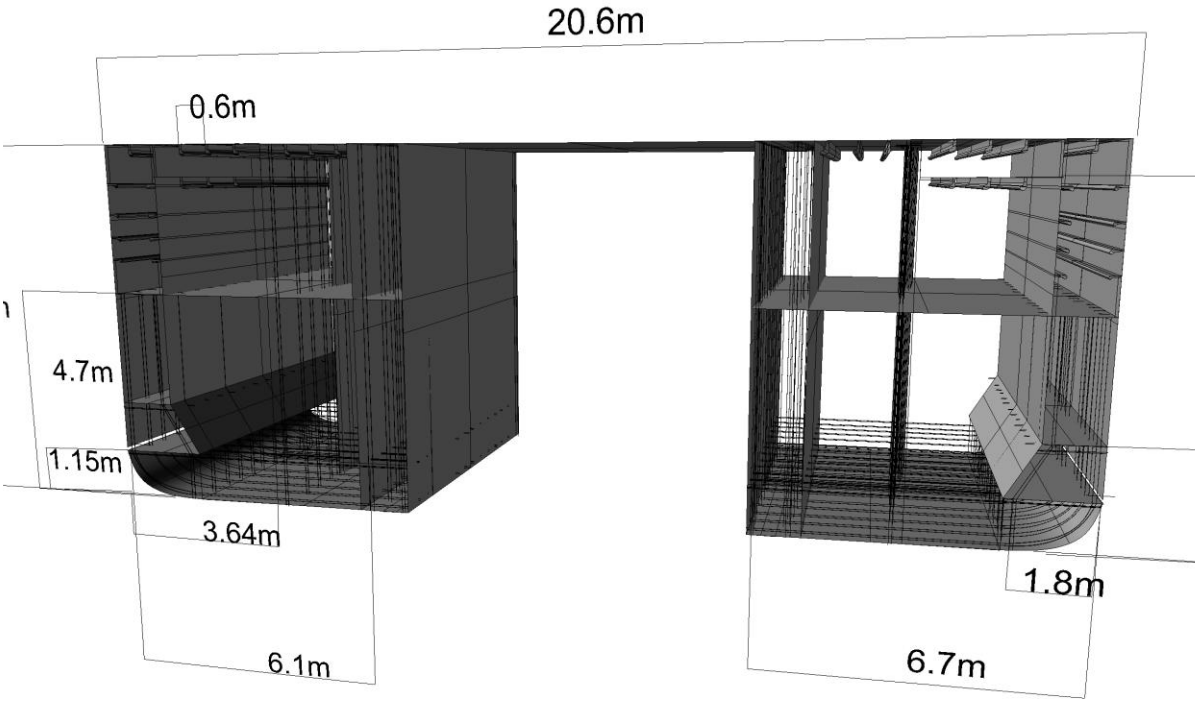

Figure 5.2 Section of the ship with the moon pool

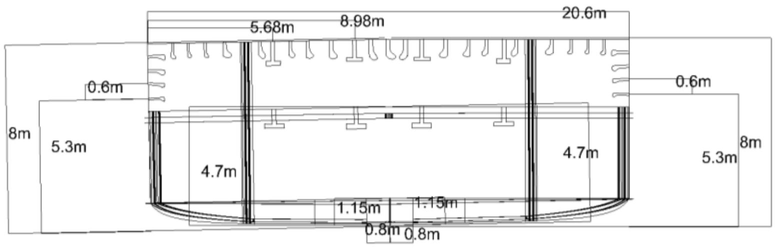

Figure 5.2.1 front view of aft Section of the ship frame 30 to frame 40

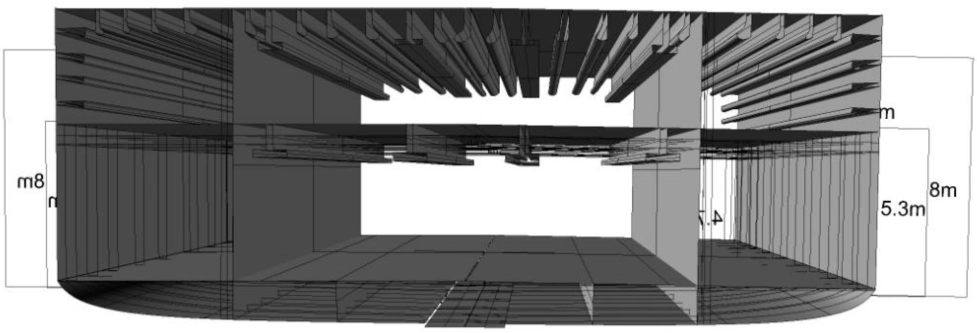

Figure 5.2.2 Section of the ship frame 30 to frame 40

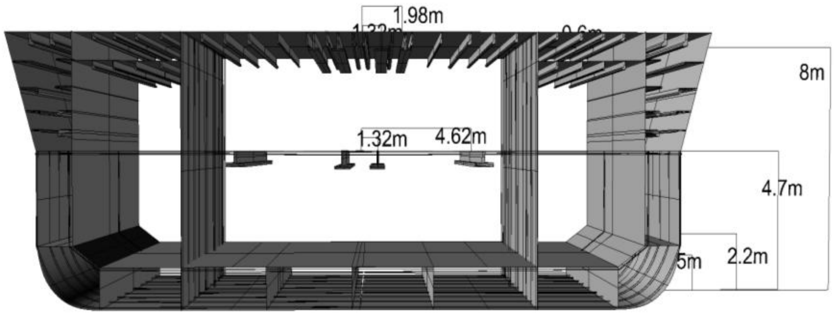

Figure 5.2.3 A perspective view of a section fore of the mid ship frame 105 to 110

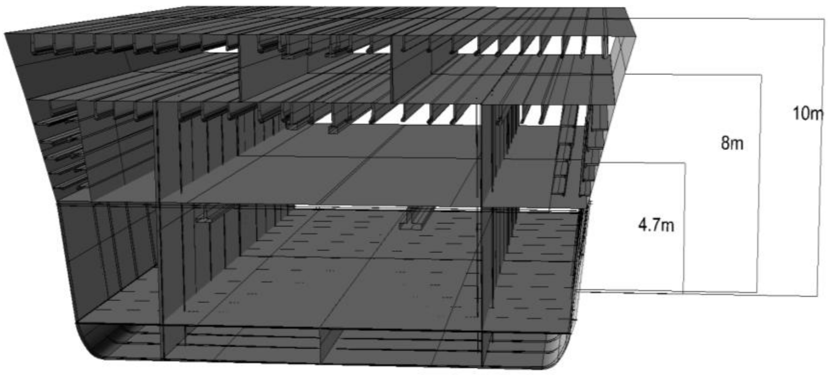

Figure 5.2.4 A perspective view of a section fore of the mid ship frame 115 to 125

5.3.1. The Hull Structure Description

The hull structure is a double skin, with inner shell at 9150mm FCL and outer shell of 10300mm FCL in the amidships, with double bottom.

The bottom is at the base line, with plate thickness good enough to withstand the sea pressure and tank pressure. With exceptional thickness in the region with opening to the sea water such as the moon pool, the propeller opening , sea chest and sheer strake.

5.3.2. Main Deck

Main deck structure is made up of the deck plating with stiffeners, girders and supporting pillars.

The main deck is at 8m from the baseline of the ship with longitudinal stiffener spacing of 600 mm, with transverse and longitudinal girder from the aft to the fore frames, the deck is longitudinal stiffened by stiffener type HP.

5.3.3. Tween Deck

The tween deck is basically 4.7m above baseline at the mid ship, transversely stiffened, from the stern to frame 3 the floor is raised so that the height from base line here is5.050m.Similarly,from frame 3 to frame 18 the tween deck is transversely stiffened with a bulkhead at frame 18 . From frame 18 to 31 and beyond transverse stiffening continue.

5.3.4. Water Tight Bulkhead

Bulkheads generally represent demarcations or partition within the ship that separate different compartments. They are designed to block fire and water from going to other compartments water (tight), also it increases the structure rigidity of the ship. See figure 5.3 for comprehensive description on the water tight bulkhead at the main deck and tween deck.

A water tight transverse bulkhead is at frame 3, frame 18 Frame 25, frame 31, frame 47, frame 63, frame 77, frame 96, frame 109, frame 123 and frame129.

And the longitudinal bulkheads span from frame 47 to frame 109 from a distance 9.15m from the centre line and from frame 47 to frame 119 for the bulkhead at 6.6m frame the centre line for the main deck.

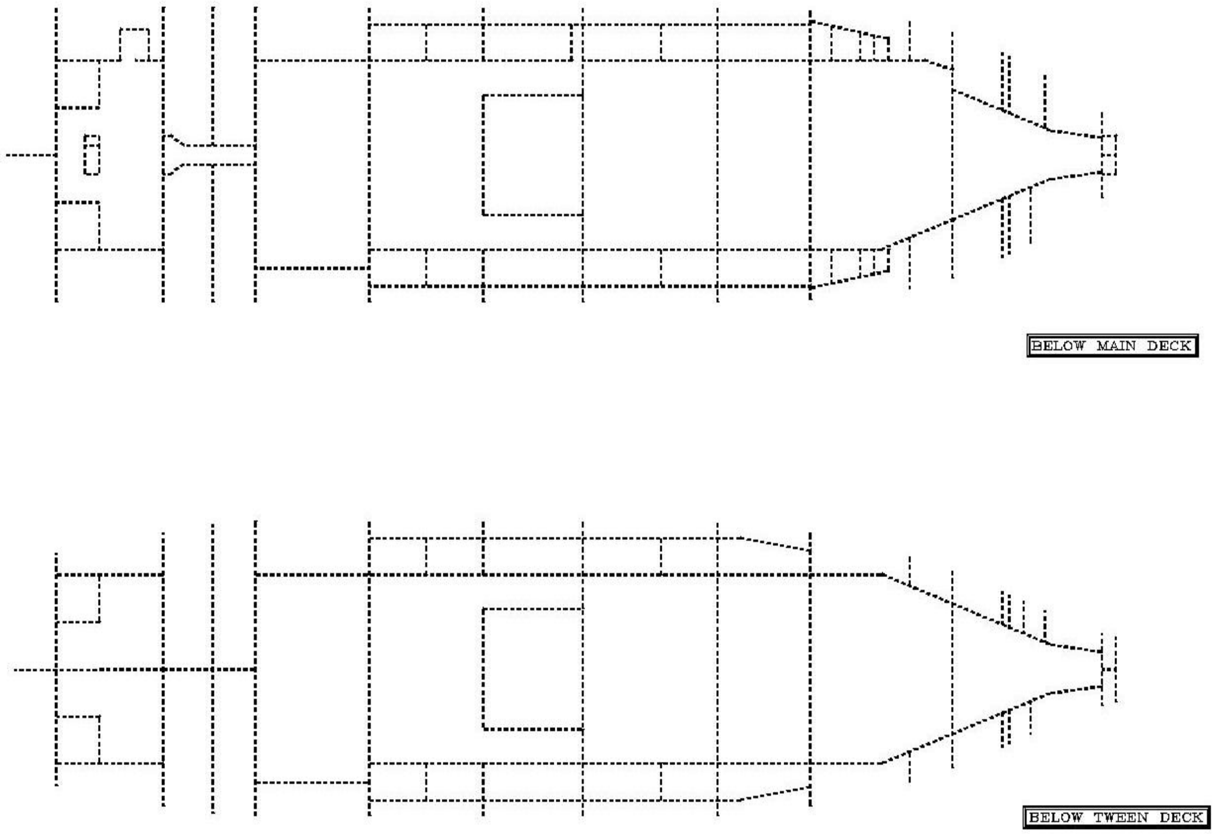

Figure 5.3 water tight bulkheads

5.3.5. The Tank Top/Inner Bottom

The inner bottom or the tank top height is 1.15m above the base line, transversely stiffened, at the amidships, within frame 50 to frame 129, and sloped to 2.295 m from frame 31 to 50.
Inner bottom height is 2.295m above the base line, from the aft frame 17 to frame 31,
The inner bottom height is 2.200m from frame 129 to frame 141 and 2.750m from frame 141 to the fore part.

5.3.6. Cofferdam

700mm below the main deck at 6600mm FCL to 9150mm FCL is in mini deck with void or empty space and large enough for the passage of personnel and equipments, it separate the main deck where welding and other flammable operation is taking place from the fuel oil tank to prevent explosion, according to DNV rule part 3 chapter2 section3 A700 [9]. However, it does not extend beyond section 9150mm FCL to 10300FCL since this section contains water ballast which is not explosive or flammable.

5.4. Materials

Due to its stiffness, strength, ductility, damage tolerance and availability, steel is the material of choice for the ship structure. Steel grade NV-NS 235 which is, mild steel with yield point 235N/mm^2 and modulus of elasticity of 206000 N/mm^2 of category B, is selected because of the relative high or moderate temperature of operation in the gulf of Guinea, hence the temperature cannot be so low that the steel becomes brittle for the operation condition. However, in regions with high stresses concentration, that is, openings, where crack can easily be initiated, such as the moon pool, higher category of NV is used, for the moon pool edges NV D with fine treated grain is used as the material, due to it toughness, that is, its ability to absorb more energy even at low operating temperature, while for category B the brittleness properties increases at very low temperature, it loses ductility as the temperature decreases. In addition, the sheer strake plate NV D category is used, so as to absorb some stress from the main deck.
The thickness of the plates for offshore vessels are not like the convectional ships plate, they are given additional thickness allowance.

6. HULL STRUCTURE SCANTLING CALCULATIONS ACCORDING TO CLASSIFICATION RULES

6.1. Basis for structural scantling

In the previous section, chapter 5 the structural concept of the ship was presented in details, positions of key structural members were specified, a detail description of these members in terms of the size and types are obtained in the following steps;

6.2. Initial Scantling

The scantling calculations are presented in two parts according to DNV rules with the aid of Nauticus hull DNV software. The first is to meet operation or owner requirements, and the second is to meet minimum requirement by rules (optimized structure). These two structures are compared in respect to their masses. Based on the requirements of Rule, initial scantlings of the structure are developed. The minimum thickness of the plates, and other members are checked according to the DNV Rule part 3chapter 2 section 5 C200, section 6 C 100[9].

6.3. Frame 30 to Frame 40

A cross-section is created in the aft part of the ship in frame 30 to frame 40 as shown in figure 6.1, at a distance 18m from the AP, to 24m from AP.

6.3.1. Section Scantling at Frame 31

The deck plate thickness according to the scantling is12mm stiffened by HP 220x10, sheer strake thickness 22mm and the side shell is stiffened by HP140x9 from the main deck to the tween deck longitudinally and transversely to the tank top with plate thickness of 11mm , bottom plate 15mm with transverse stiffenerHP260x11, bilge strake 13mm and garboard strake of 15mm with HP200x10 transverse stiffener, tank top plate 10mm with HP240x10 transverse stiffener, tween deck plate 7mm transversely stiffened by HP240x10, with bottom girders at 0 FCL,4620mm FCL at PS and SB 15mm,12mm thick respectively stiffened by HP 200x10. Longitudinal girders at 1.32m, 4.62m FCL PS and SB of type W250x8FL150x12 shown in figure 6.1. See Annex A1 for Nauticus Hull report for details.

The section is further optimized base on the rule minimum requirement as the constrain, not considering any special operation requirements of her multi-role needs. The sole objective function is the mass of the structure. See figure 6.2 for optimized structure scantling diagram. For details see Annex A1 and A1´ for Nauticus Hull reports for the section scantling.

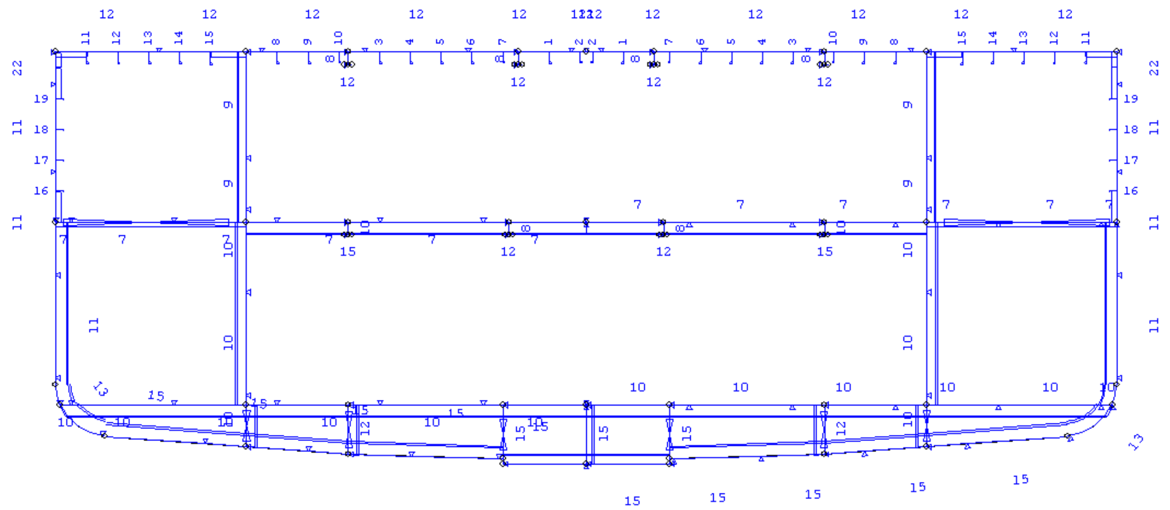

Figure 6.1 Operation requirement scantling at frame 31

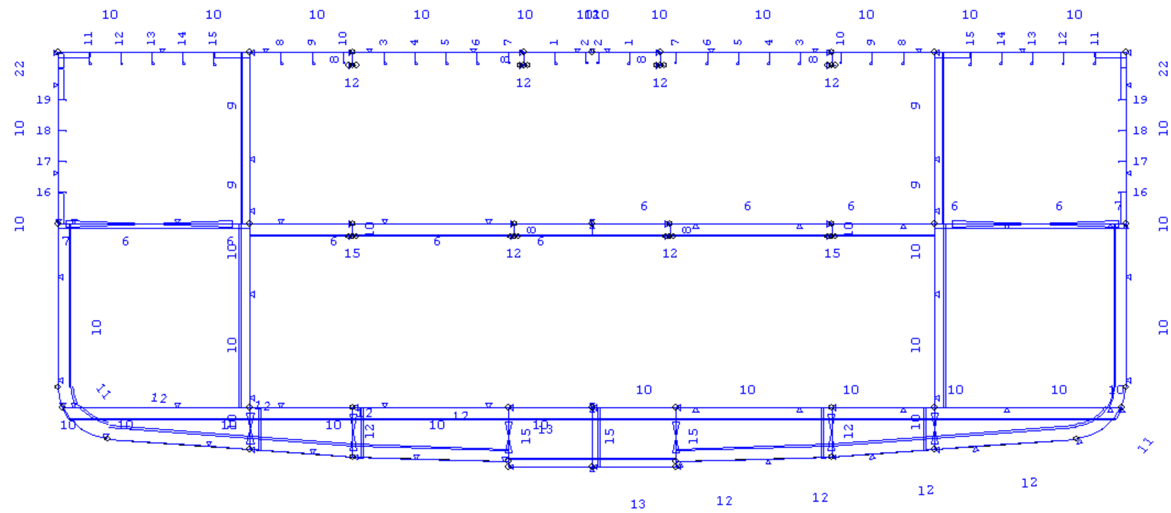

Figure 6.2 Optimized structure scantling at frame 31

6.3.2. Compartments and Load

The double bottom and the side tanks are filled with water ballast and main deck and tween deck load stowage rate of 10t/m^3 and 2t/tm^3 per 1000 mm stowage height.

6.4. Frame 63 to Frame 77

Cross-sections within frame 63 to frame 77, been the region where the moon pool is situated. The model is created by defining the outer shell, position of double bottom, plate thickness and position and spacing of stiffener.

6.4.1. Section Scantling Frame 65

The plate thickness at the main deck is 20mm, and the thickness of the side shell from the tip of main deck is 22mm (sheer strake), which help to absorb some excessive stress on the main deck. While, the side shell below and above the tween deck is 11mm .The bilge plate (bilge strake) thickness is 13 while the bottom plate is 18mm thick, while the 0.5mm bottom plate thickness is an opening to sea, it is only meant to fool the software there is no plate at all at this region. The side shells are stiffened longitudinally from the main deck to the tween deck by HP200x10, and transversely from the tween deck height to the tank top, by stiffener HP220x10, while the bilge plate stiffeners are HP200x12. For the tank top plates, HP 200x10 transverse stiffeners are used. The longitudinal bulkhead at 6.66m FCL PS and SB are stiffened transversely by HP 220x10 stiffeners from the tank top to the tween deck, and from tween deck to the cofferdam below the main deck are HP200x10 transverse stiffeners, while from the bottom of the cofferdam to the main deck, the stiffener is HP 200x11.5.

The bulkhead at 4.2m FCL PS and SB are transversely stiffened to the tween deck from the tank top by HP220x10 and from the tween deck to the main deck by HP 180x8.

At 3.6m FCL PS and SB, the bulkhead plates are transversely stiffened from tank top to tween deck by HP 240 x11, and from the tween deck to the main deck by HP220x10. The main deck plates are stiffened longitudinally by HP200x11.5. The cofferdam plate is stiffened by HP160x7.

However, from the above description it is obvious that the upper part of the structure in this region is heavier than the bottom part which tends to push the position of the neutral axis a bit up toward the deck and increase the bottom bending stress. But since the area of this region or section is small compared to the total area of the main deck, it is not considered as the global scantling of the structure. See figure 6.3 the geometry.

The main deck plates are exceptionally high in this section due to her operational use described in chapter3, section 3.1, and the 0.5mm thickness is open floor to the sea where diving, and other subsea equipments are lunch in to the sea from the main deck. Stringer are situated at 2.2m above the base line with plate thickness of 10mm and stiffener HP180x8

Similarly, the section is further optimized base on the basic rule requirement as the constrain, not considering any special operation requirements of her multi-role needs. The sole objective function is the mass of the structure. See figure 6.4 for the scantling of the optimized structure. For details see Annex A2 and A2´ for Nauticus hull report for operational and optimized reports.

6.4.2 Effect of Openings

The effect of openings are assumed to have longitudinal extensions on structural element,

That is, inside tangents at an angle of 30° to each other, according to DNV rules part 3chapter 2 section 4 D200 [9].

Hence, the bulkhead structure at 3.6m and 4.2m FCL respectively have 0% bending efficiency and 100% shear efficiency, so also, is the 700mm deck below the main deck (cofferdam). While the bulkhead at 6660mm, 9150mm and 10300mm have 100% bending and shear efficiency.

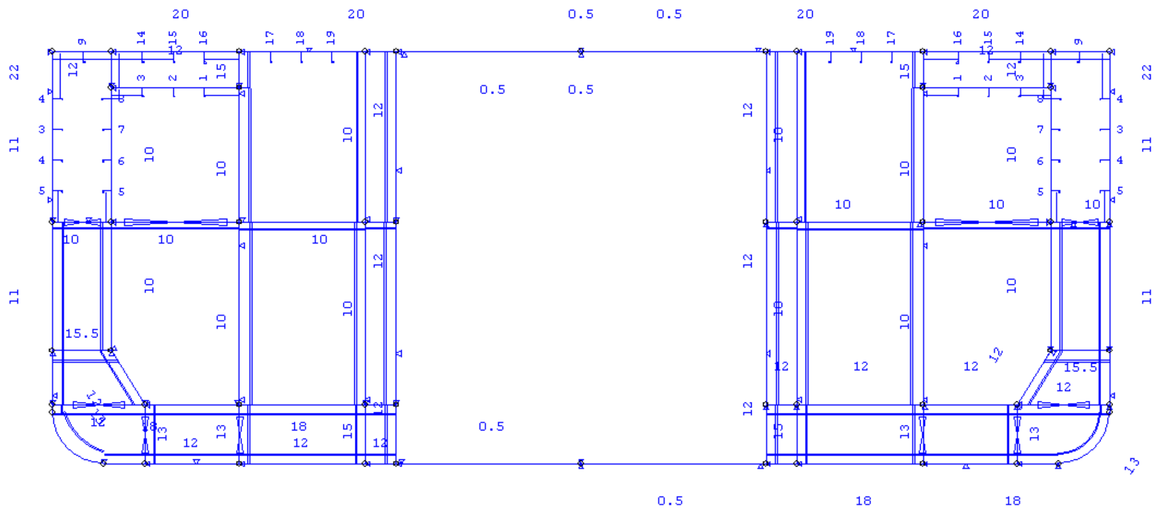

Figure 6.3 Operation requirement scantling at frame 65

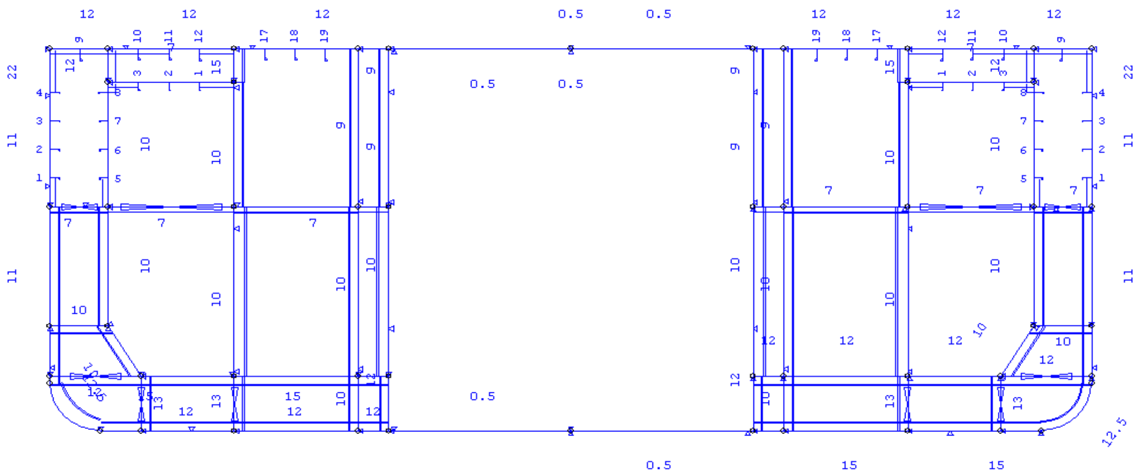

Figure 6.4 Optimized structure scantling at frame 65

6.4.3. Compartments and Load Frame 63 to Frame 77

The middle section of figure 6.3 and 6.4 is the moon pool, modelled as water ballast, the compartment 3.6m FCL to 4.2m FCL also water ballast and the side tank, and from 6.6m FCL to 9.15m FCL is modelled as fuel oil and above it is void space, the cofferdam. Also the main deck load, and tween deck of $10t/m^2$, $2t/m^2$ with stowage height of 1000m.

6.5. Frame 105 to Frame 110

The section scantling of frame 105 to frame 110 is depicted in frame 106 as shown in figure 6.5 and 6.6, 63m AP to 66m AP. This is section fore of the moon pool.

6.5.1 Section Scantling Frame 106

The deck plate thickness is 9mm, and 13mm for crane, bottom, tank top plates are 14mm and 12mm respectively, while sheer strake is 22mm thick, side shell and bilge strake are 11mm and 12mm.

Outer side shell from the deck main deck to the tween deck is stiffened longitudinally by HP 260x10 also, top of the side tank on the main deck. From tween deck to the tank top HP 200x10 transverse stiffener is used. The bottom and tank top plates are stiffened transversely by HP 240x10 and HP 220x12, the tween deck plate 8mm is transversely, stiffened by HP 200x10.

For the inner side shell HP 220x 10 transverse stiffeners from the tween deck to the tank top, also HP 220x10 from tween deck to the main deck longitudinally.

Bulkhead at 6.6m FCL PS and SB are transversely stiffened by HP 200x10. Longitudinal girder at 4.62m ,1.32m FCL PS and SB on tween deck W350x10/FL150x15 and on the main deck at position,1.32and1.98m FCL PS and SB on main deck is W350x10/FL150x15 and W400x10/FL400x15.Bottom girders at 0, 1.32, 4.62 of thickness 12mm and HP 200x10 respectively.

The section is further optimized base on the rule minimum plate thickness requirement as the constrain not considering any special operation requirements of her multi-role needs. Figure 6.6 and 6.5 is the optimized structure and operation requirement diagram. See Annex A3 and A3` for details from Nauticus hull reports for details.

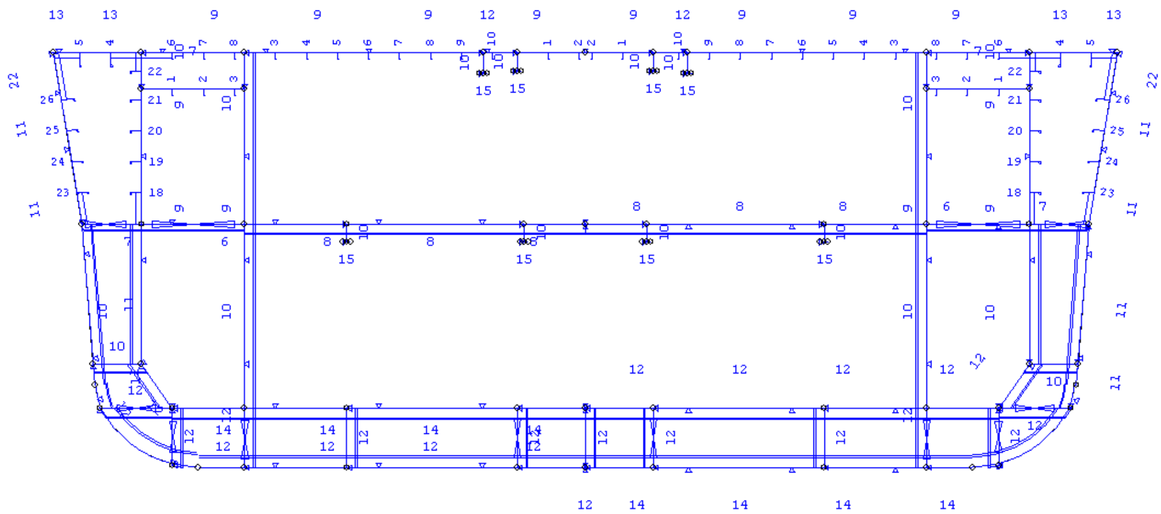

Figure 6.5 Operation requirement scantling at frame 106

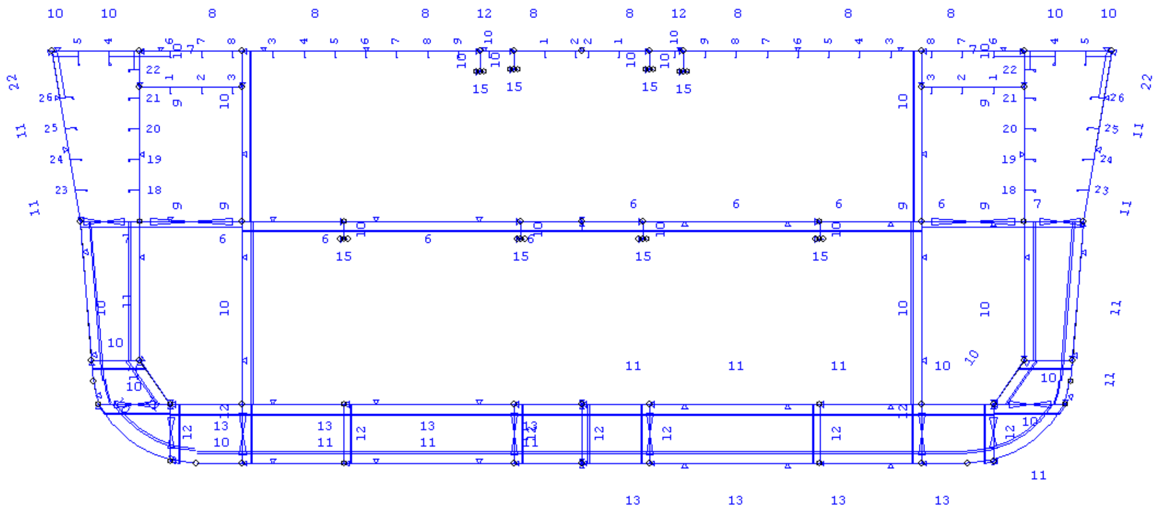

Figure 6.6 Optimized structure scantling at frame 106

6.5.2. Compartment and Load Frame 106

The tank at extreme side (side tanks) between the outer shell and the inner shell contains water ballast, so also, is the double bottom tanks, and from, 6.6m to 9.15m FCL at both PS and SB side contains fuel oil and separated from the deck by the cofferdam void space, and the main deck load stowage rate of 5t/m^3 per 1000 mm stowage height.

6.6. Frame 115 to Frame 125

These are cross-sections within 69m from AP to 75m AP, these sections includes the shelter deck 10m from the base line, the main deck 8m above the base line, tween deck 4.7m above the base line and tank top is 1.15m from the base line.

6.6.1. Section Scantling Frame121

A cross-section of frame 121 gives scantling as follows;

The shelter deck plate thickness is 8mm. The main plate of thickness 7mm,sheer strake plate thickness of 22mm,side shell plate 11mm thick, bilge strake plate thickness of 12mm and bottom plate of 14mm thick as shown in figure 6.7. Shelter deck plates are stiffened longitudinally by HP 140x7, main deck by 120x6, while the tween deck, tank top, bilge strake and bottom plate are stiffened transversely by HP220x10, HP220x10,HP 260x10 and HP 260x10 respectively.

The outer and inner side shells are stiffened longitudinally from the main deck to the tween deck by HP200x9 and HP220x10. And transversely from tween deck to tank top by HP260x10.

Bulkhead at 6.6m FCL PS and SB are of plate thickness 10mm from the tank top to the tween deck and 8mm from the tween deck to the main deck, stiffened transversely by HP200x11.5

And bottom girders at 0m, 1.32m, 4.62m 6.6m FCL PS and SB, 12mm thick with HP180x10 stiffeners respectively.

The structure is further optimized base on the basic rule requirement not considering any special operation requirements, just only the deck load and compartment/local loads from tanks, since some additional plate thick is included in the operation requirements to meet her multi-role and peculiar needs. See figure 6.8 and 6.7 for the diagrammatic descriptions of the optimized and operation requirement structures.

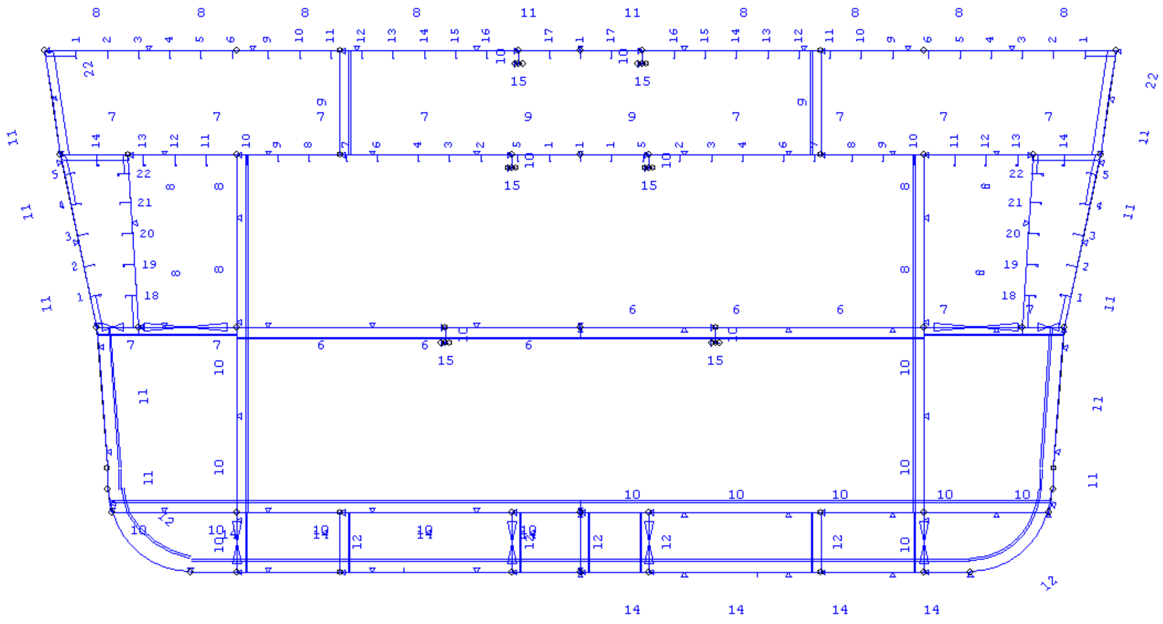

Figure 6.7 Operation requirement scantling at frame 121

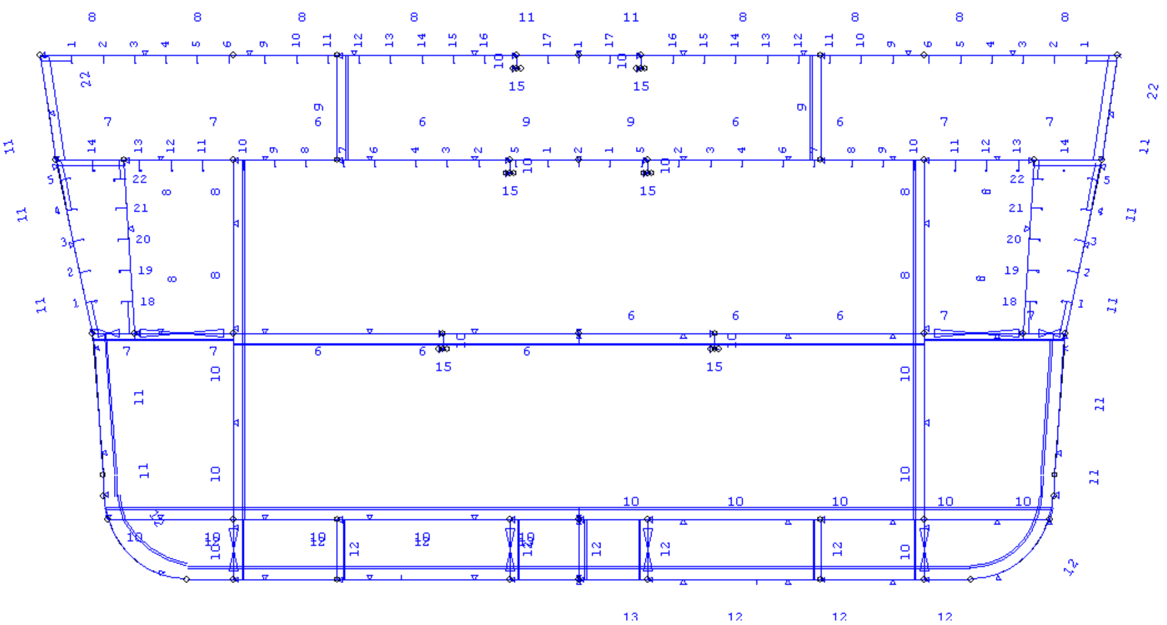

Figure 6.8 Optimized structure scantling at frame 121

6.6.2. Compartment and Load Frame 121

The double bottom if filled with water ballast, the tank at the PS and SB side are water ballast and above the tank top are machinery model as deck load on the tank top, and the compartment below the shelter deck and the main deck is model void space, and main deck load of 1t/m^2. See Annex A4 and A4' for report from Nauticus hull.

6.7. End Connections of Stiffeners

The end connections designs are equally of great importance as any other part, since this where cracks are initiated from, and in turns have great effect on the fatigue life of the structure. Stiffeners may be connected to the web plate of girders in the following ways:

— welded directly to the web plate on one or both sides of the frame

— connected by single- or double-sided lugs

— With stiffener or bracket welded on top of frame

— a combination of the above.

However, location determine the end connections, in locations with great shear stress a single or double-sided lugs connection are required, e.g longitudinal stiffener connecting transverse girder in a longitudinally stiffened deck, while in the middle where the shear stress is negligible, the stiffeners can be directly welded on the plate.

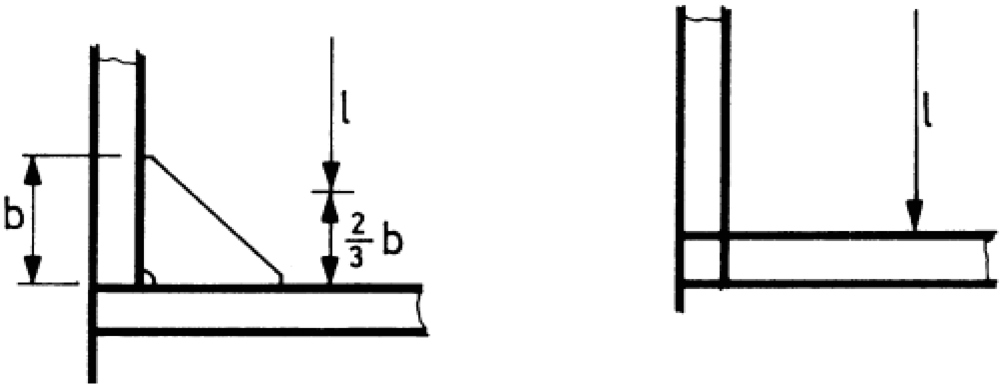

Figure 6.10 Rule length with and without end connections.

According to DNV rules part 3 chapter1 section 3 C200 [14].

Thickness of bracket :

$t_b=(3+k\sqrt{Z/w_k})+t_k$ *(mm)* (21)

where k = 0.2 for brackets with flange or edge stiffener and 0.3 for brackets without flange or edge stiffener,

Arm length of brackets :

$a=c\sqrt{((Z/w_k)/(t_b-t_k))}$ *(mm)* (22)

c = 63 for bottom and deck girders brackets

7. STRENGTH OF THE GRILLAGE STRUCTURE OF THE MAIN DECK AND TWEEN DECK UNDER LOCAL LOADS ON VESSEL

7.1. The Grillage Structure

The ship is made up of networks of cross stiffened plates, welded together, inform of plate been stiffened by girders or stiffener. For the quantitative evaluation of the strength capability of the initial design, a check is performed on the integrity of the structure, by evaluating the loads cases for the design draft. Complex girders are design from direct stress analysis calculations according to DNV rule chapter 3 part2 section D300 301 [9],since they are not all obtainable directly from rules, that is, scantling from Nautical hull, the calculations are as follow for the deck.

7.2. Load on the Main Deck

The model of the deck is created in a 3D beam figure 7.1, the transverse and longitudinal girder with their profile defined see Annex F for all the profiles. Loads are applied to the design draft of 6.25m, figure 7.2.3 shows the main deck beams, in red, load in green, and the beam element numbers are presented in figure 7.2.

Since the deck is longitudinally stiffened the loads on it are carried mainly by the transverse beam as shown in the figure 7.3. Also, are the deflections of the beams as a result on the load in figure 7.4.

The stiffeners, plates and simple girders are not modeled, since these are designed based on the rule, from scantling in Nauticus hull see chapter 6 for details. Load of $10t/m^2$ on the main deck from aft to frame 90 and $5t/m^2$ from frame 90 to frame 96 and $2t/m^2$ from frame 96 to 112.

And a dynamic factort of 1.3 is also considered when loading the structure, DNV part 3 chapter 2 section 3 B800 1103,[9].

The load is applied on the beam in t/m by multiplying the load in t/m^2 by the breadth of the girder see Annex A for the load on the maind deck beams. The poison’s effect is ignored, since for beam element the length is large compared to the width.

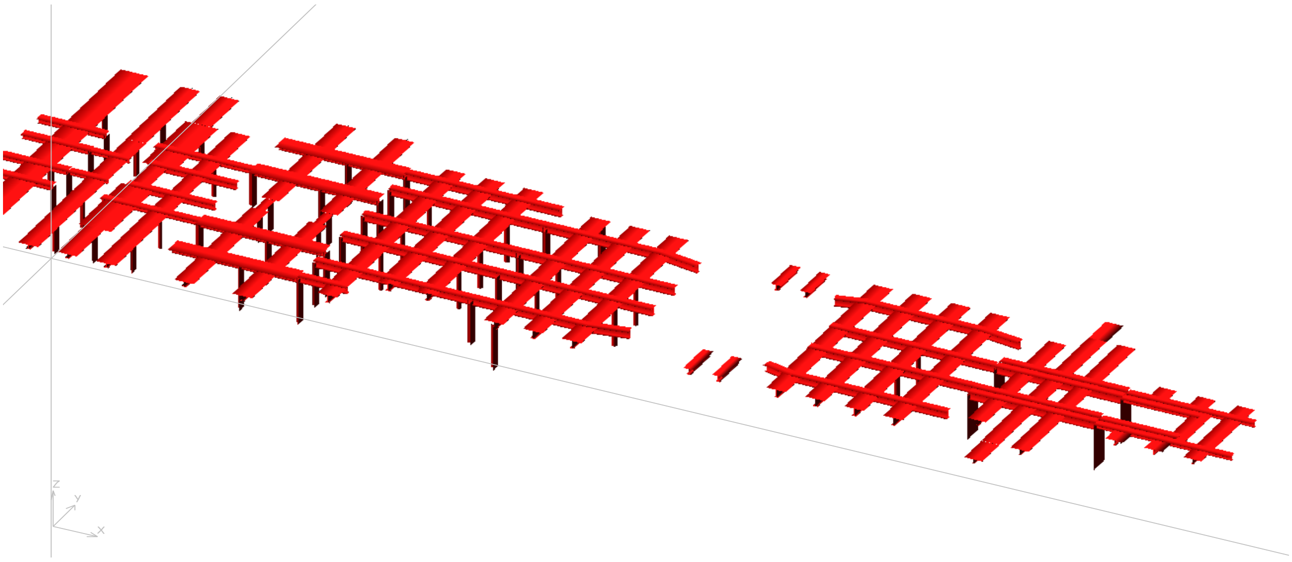

Figure 7.1 The main deck beam girder model in 3D beam

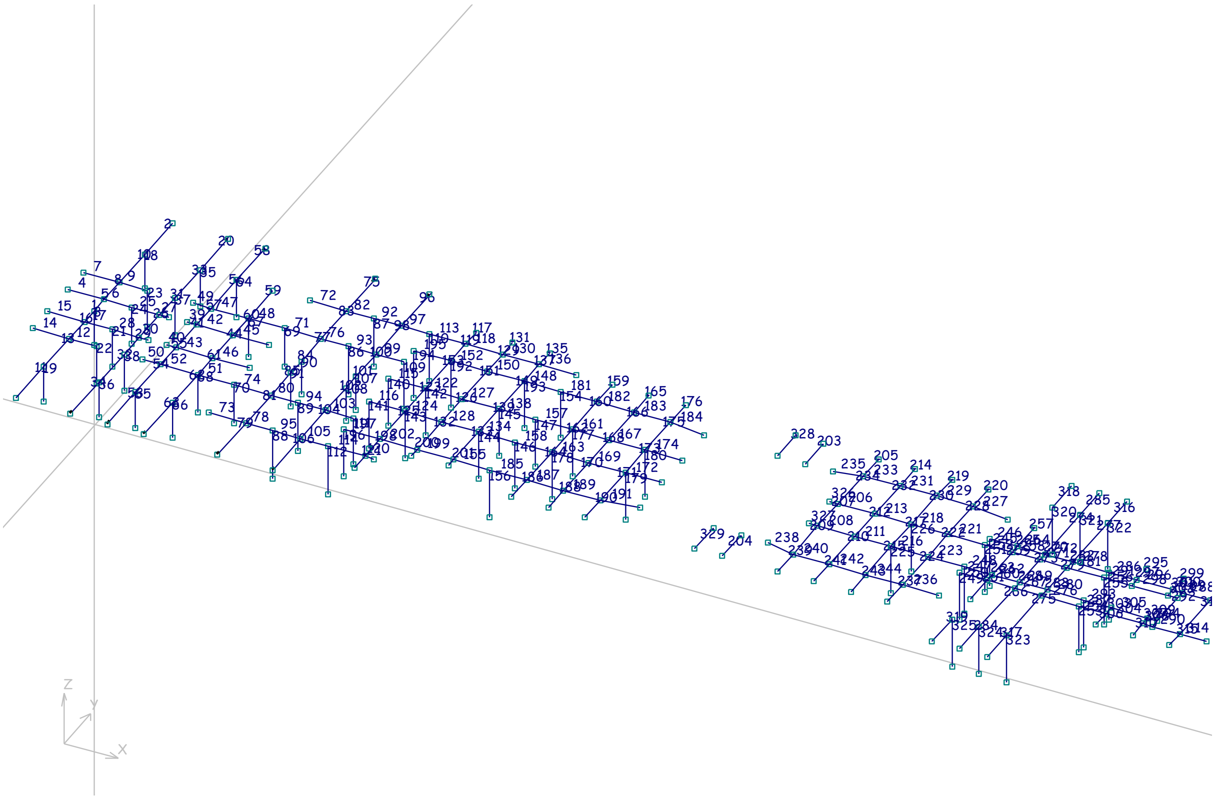

Figure 7.2 Main deck numbered beam girder elements

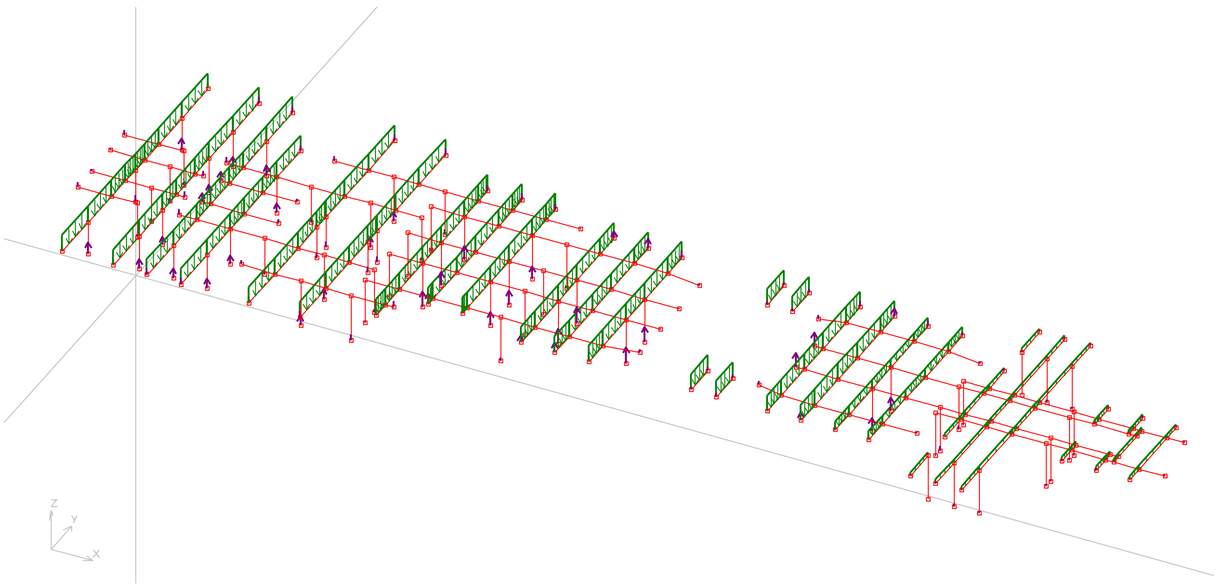

Figure 7.3 Loads on the main deck

7.2.1. Boundary Conditions for Main Deck

Nodes of sections away from analysis is fixed in all direction, that is, in x,y,z translation and rot x ,rot y and rotz, (x, y, z rotation) respectively, The pillars and mainframes node below the main deck on the tween deck are fixed for x, y and z translation and free in rotation.

Beams supported by vertical bulkhead are fixed in x and y translation.

Figure 7.2.4 is the main deck with all it boundary nodes defined, and deflection modes.

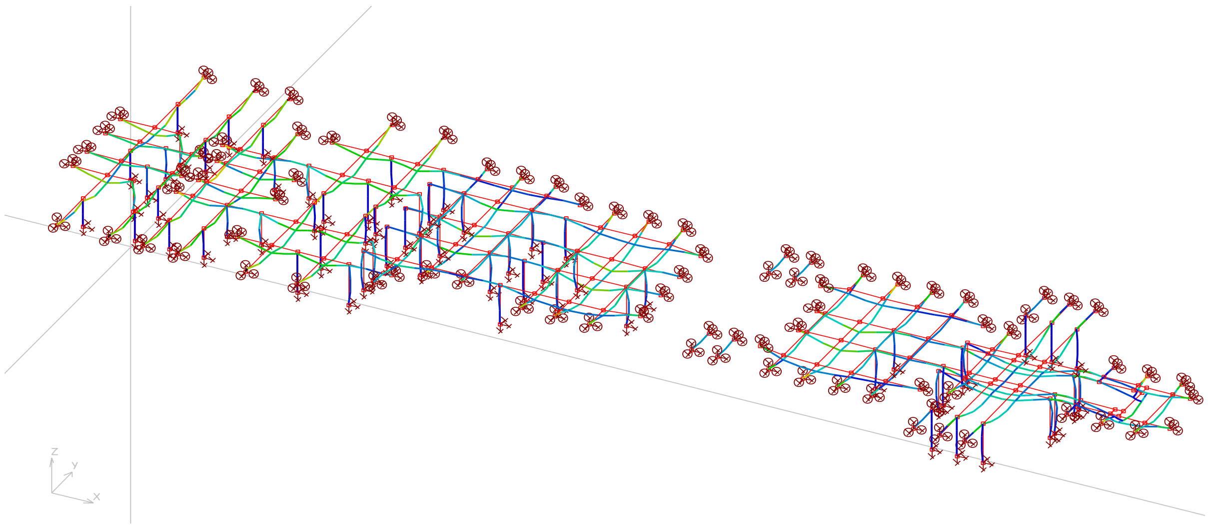

Figure 7.4 Deck beam deflection mode structure with boundary condition

7.3. Load on the Tween Deck

Similarly, the tween deck model is created in a 3D beam with load applied to the designed draft, and below is a figure of the deck beam in red and load in green, since the tween deck is transversely stiffened the loads are carried mainly by the longitudinal beam as shown in figure

7.6, shows all stiffeners and other transverse beam only transfer load to the longitudinal beam or girder. Consequently, only the longitudinal girders are loaded. On the tween deck the load is 2t/m^2.

However, the load is applied on the tween deck in t/m on the beams by multiplying the load in t/m^2 by the breadth of the girder see Annex E for the load on the tween deck beams.And figure 7.5 presents the tween deck model in 3D beam, figures 7.6 for the tween deck loads and figure 7.7 the deflections, from frame 30 to frame 98.

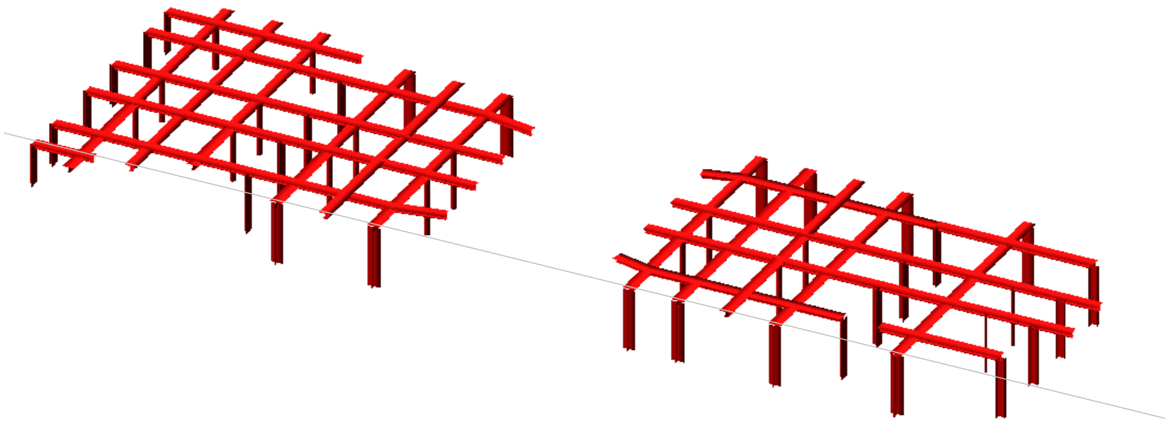

Figure 7.5 model of the Tween in frame 30 to frame 98 3D beam.

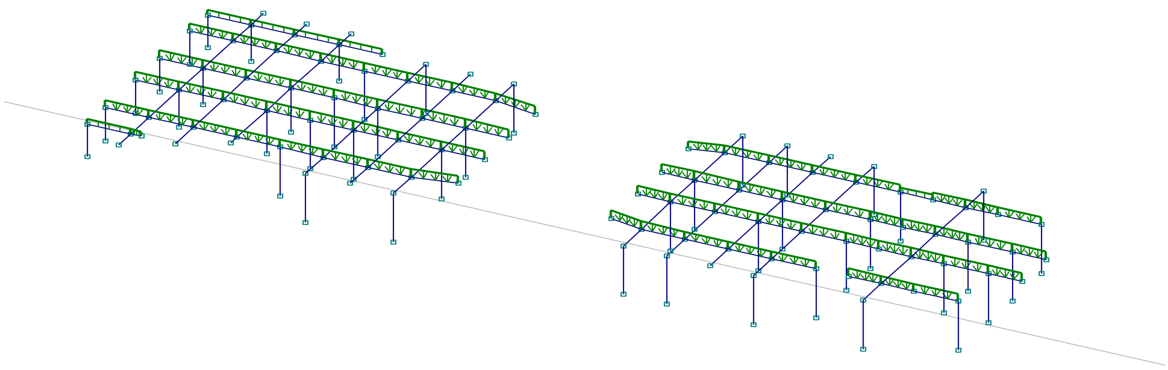

Figure 7.6 Tween deck load

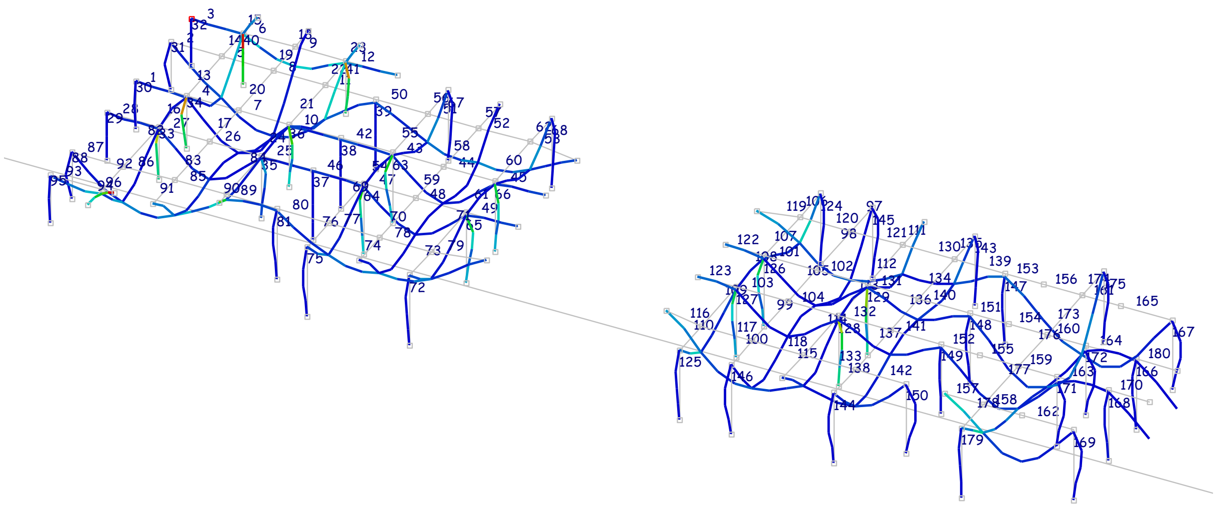

Figure 7.7 The tween deck deflection under loads

7.3.1. Boundary Conditions on Tween Deck

A discontinuous pillar are fixed only the x,y translation, and free in the z translation, roty, rot x and z rot (x, y, z rotation).The node of continuous pillar and mainframe below the tween deck is fixed in x, y, z translation and free in x, y, z rotation that is ;

-vertical beam on Tank top are fixed in all degree of freedom,

-all deck beams ending bulkhead are fixed in all degree of freedom,

-deck beams supported by vertical bulkhead are fixed in x and y translation.

7.4. The Mesh

The model has coarse mesh; horizontal beam elements represents longitudinal and transversal girders; vertical beams represents pillar or bulkhead support. Since the analysis is based on beam theory, a coarse mesh gives good estimation of shear forces / bending moments induced in grillage elements.

The local transverse strength need occasionally to be specially considered. With dynamic factor considered.

The strength analysis is based on a beam model within the following context

Longitudinal x-direction from the aft/stem to frame 129

Transverse in y- direction maximum 10.3m FCL PS to 10.3m,

Vertical z-directions is from the main deck to the tween deck and from the tween deck to tank top respectively.

Simple girder and plates are not included.

7.5. Results from the Main Deck Analysis

The local stresses in each of the beam member obtained from 3D beam software are critically examine to check the integrity of the structure to the local load applied, and the value beyond acceptable values are sorted in table 7.2. See Annex C for a detail report from 3D beam for all the local stresses value in each beam member.

Acceptable stress levels according to DNV rules part 3 chapter 1 section 12 B400 403 [14] for mild steel should be less than the follows:

σ = 160 f1 N/mm². Shear strain τ = 90 f1. σ_e = 245 f1 N/mm².

Where,

f1 is material factor =1 for NV NS 235 steel. From DNV rule part 3 chapter 2 section 2 B 200 203 [9].

Table 7.1 Acceptable stress

material	Local bending stress σ	Shear stress τ	Equivalent stress σ_e
NV mild steel yield strength R_e = 235 MPa	160 MPa	90 MPa	245 MPa

Table 7.2 Stress values above recommended rule values on the main deck.

Beam No.	σ_{Nx} [N/mm2]	τ_{Qy} [N/mm2]	τ_{Qz} [N/mm2]	τ_{Mx} [N/mm2]	σ_{My} [N/mm2]	σ_{Mz} [N/mm2]
327	-1	6	120	2	241	31
326	-1	-6	120	-2	240	31
165	-0	-0	-77	0	211	1
188	-0	-0	77	-0	211	1
241	-0	-0	76	0	207	4
214	-0	0	-75	-0	203	4
200	-0	3	90	-3	187	15
219	0	-1	-74	1	182	8
243	0	1	88	-1	-201	10
50	0	2	77	2	-193	21
49	0	-2	77	-2	-193	21
39	0	-3	92	-2	-161	16
40	0	3	92	2	-160	17
186	0	-1	77	1	-169	18
159	0	1	-76	-1	-168	17
161	-1	0	41	1	-160	5
167	-1	-0	-42	-0	-160	6
163	-1	-0	41	-1	-160	5
169	-1	0	-42	0	-160	6

Where

σ_{Nx} is axial stress; σ_{My} is Bending stress about local y-axis; σ_{Ny} is Normal stress in local xz-plane; τ_{Qz} Shear stress in local z-direction; τ_{Qy} Shear stress in local y-direction τ_{Mx} Torsional stress.

Beam 327; Frame 80-79,

Figure 7.8 present the main deck grid with stressed beam values above the acceptable value in red colour, beam 327, from frame 79 to 80 at a distance 1320mm FCL SB, and distance 47.4m to 48m AP and figure 7.8.1 depicts the stresses along the length of the beam in millimetres.

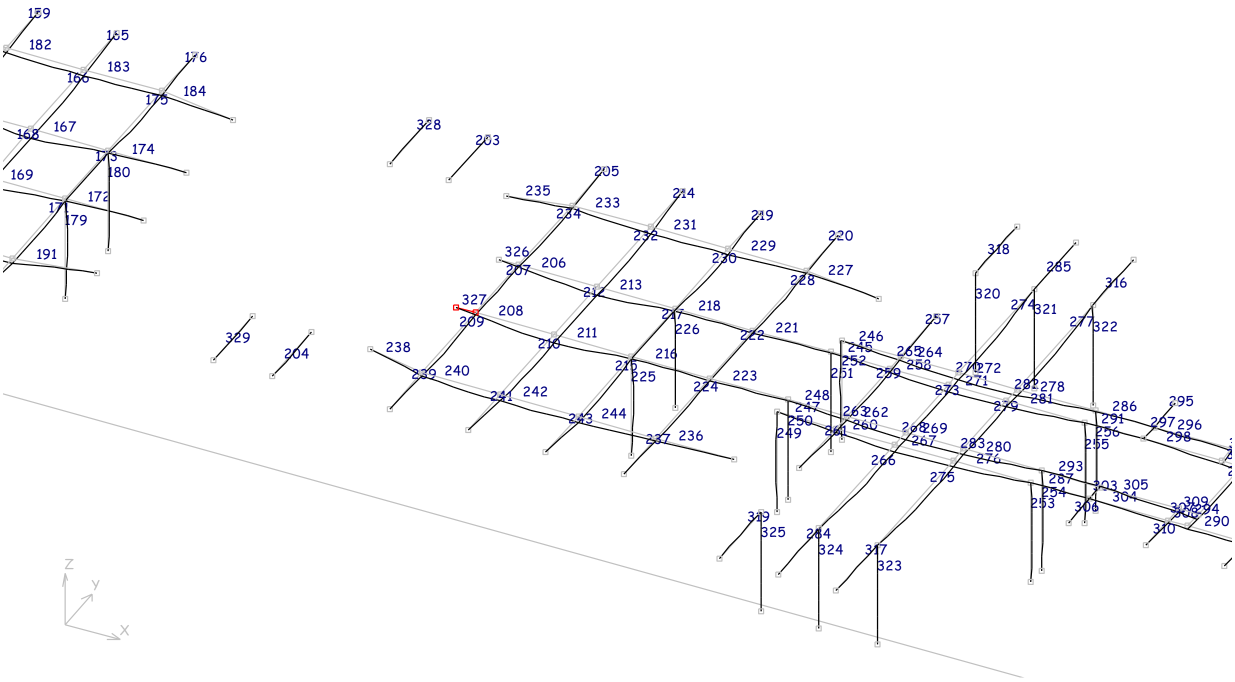

Figure 7.8 Main deck element with stress above rule value in red beam 327

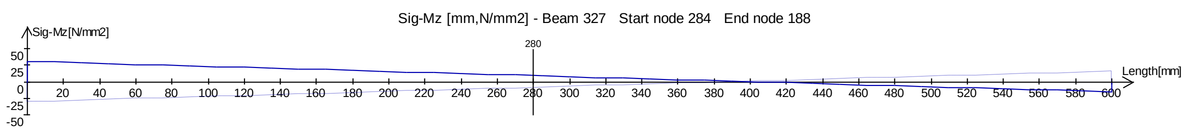

Figure 7.8.1 Stresses along beam 327length

Deck girder is to be supported by a large bracket of radius arm of about 500mm or a vertical with web height large enough, to reduce the stress by increasing the section modulus. Table 7.3 presents stress at a mentioned distance from end of the beam.

Table 7.3 stress at a local distance in beam 327

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
341	341 (327)	-1	2	120	144	-134	143	-135

***Beam 326; Frame 80-79**,*

This beam is more of mirror to beam 327 on the PS, Figure 7.9 is a section of the main deck grid with over stressed beam 326 in red colour from frame 79 to 80 at a distance 1320mm FCL PS, and at 47.4m to 48m AP and figure 7.9.1 shows the stresses along the length of the beam in millimeters, and the deflection in black and numbering in blue.

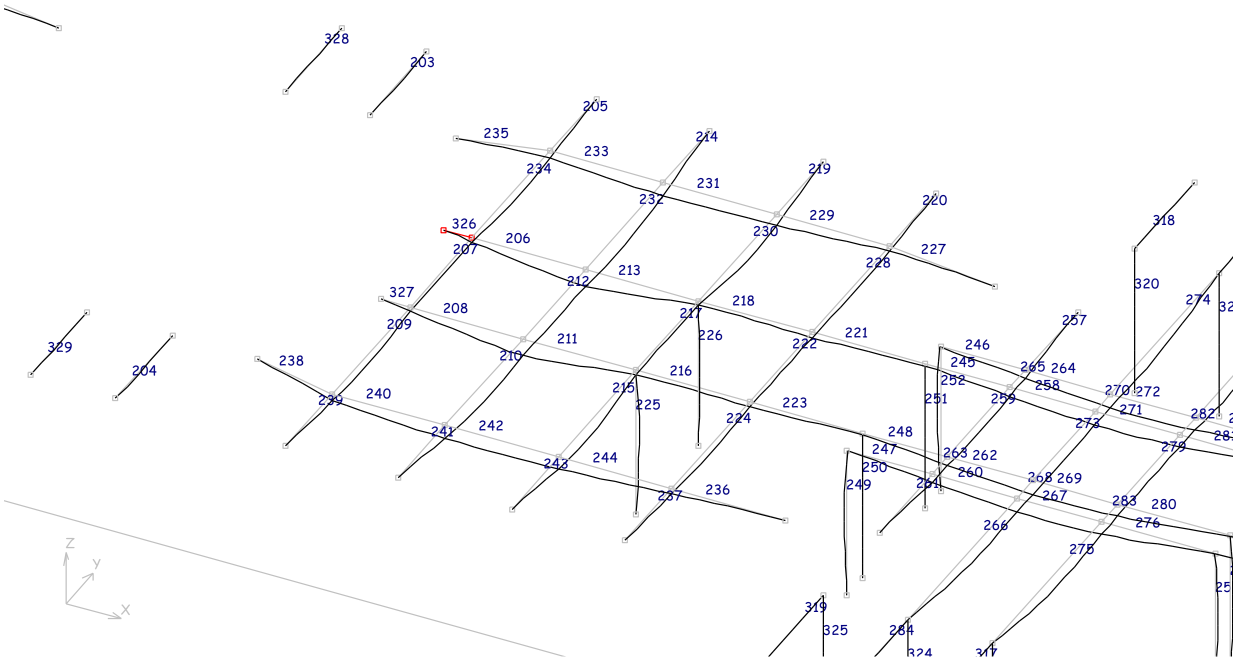

Figure 7.9 Main deck element with stress above rule value in red beam 326

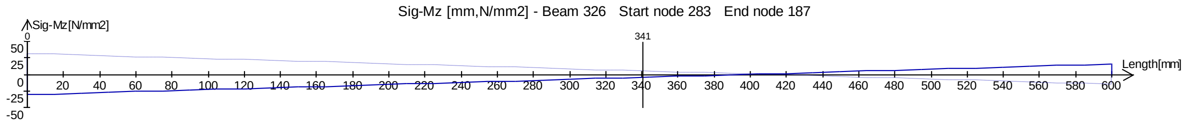

Figure 7.9.1 stresses along beam 326 length

Deck girder is to be supported by a bracket 500mm arm, which decreases the bending moment as a result of increase in the section modulus at this end. Table 7.4 presents stress at a mentioned distance from end.

Table 7.4 stress at a local distance in beam 326

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
341	341 (326)	-1	-2	120	143	-133	143	-134

Beam 165; Frame 55

Figure 7.10 shows a section of the main deck grid, with over stressed beam 165 in red and deflections in black colour in frame 55 at a distance 33m AP, 4.62m to 6.6m FCL PS and figure 7.10.1 shows the stresses along the length of the beam 165 in millimeters.

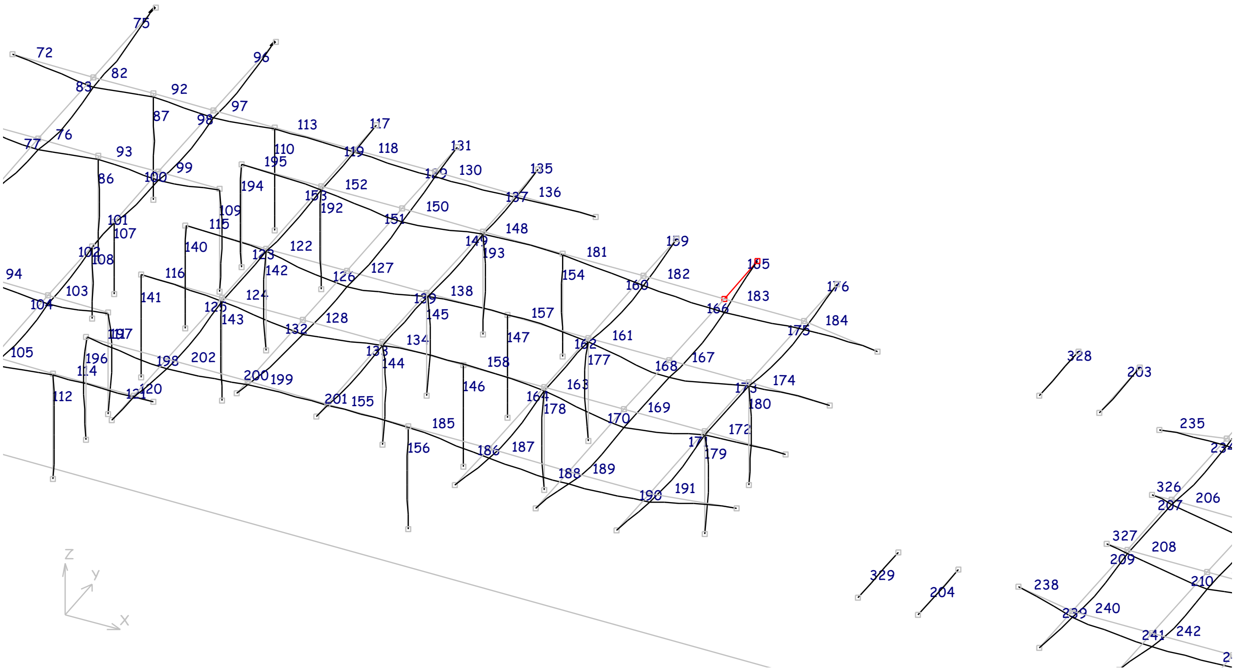

Figure 7.10 Main deck element with stress above rule value in red beam 165

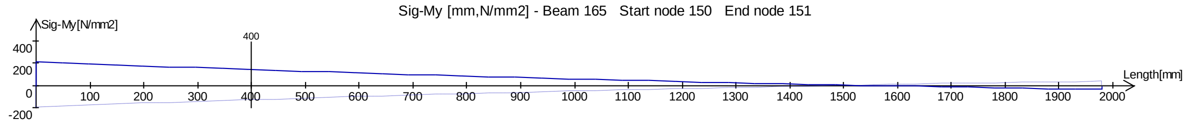

Figure 7.10.1 stresses along beam 165 length

A bracket with 400mm arm is used to support the deck; Table 7.5 presents stress at a mentioned distance from end, the bracket reduces the beam length, and also increases the section modulus.

Table 7.5 stress at a local distance in beam 165

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
400	400 (165)	-0	0	-67	143	-133	143	-134

Frame 55 Beam 188

Figure 7.11 presents a section of the main deck grid, with highly stressed beam 188, above the acceptable value specified by the rules in red and the deflections in black colour in frame 55 at a distance 33m AP, 4.62m to 6.6m FCL SB and figure 7.11.1 shows the stresses along the beam length.

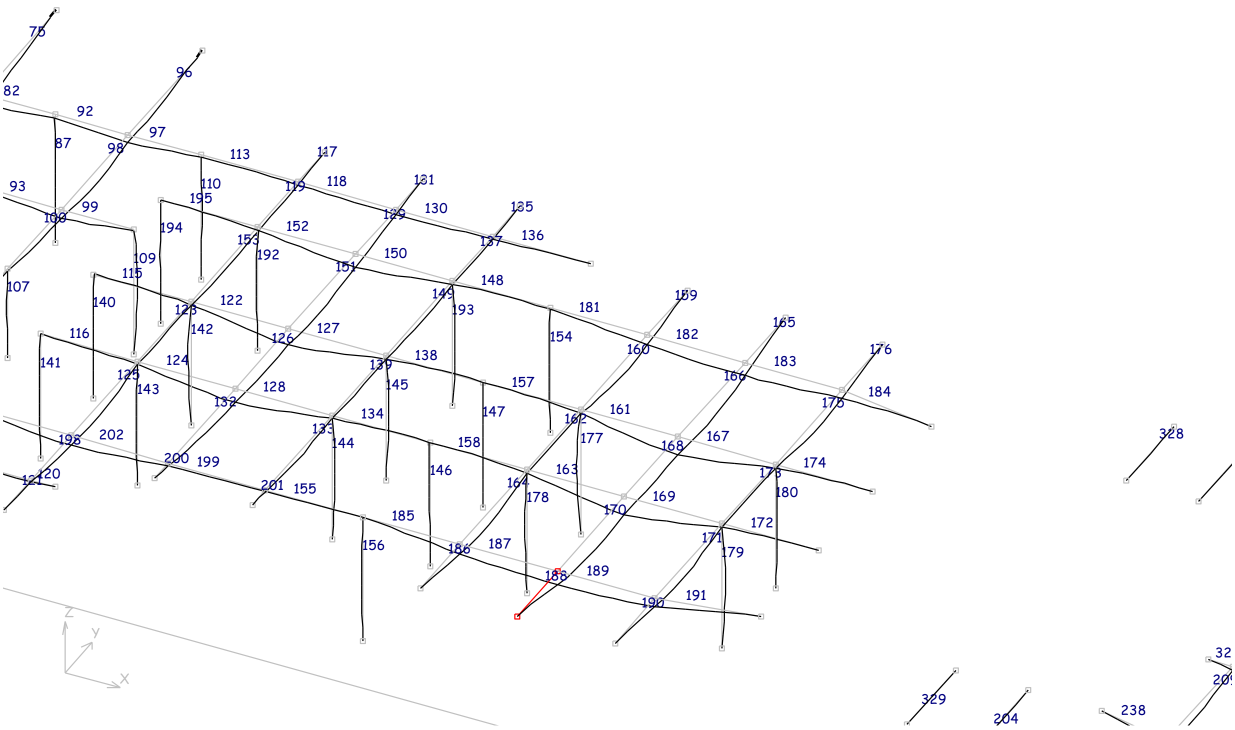

Figure 7.11 Main deck element with stress above rule value in red beam 188

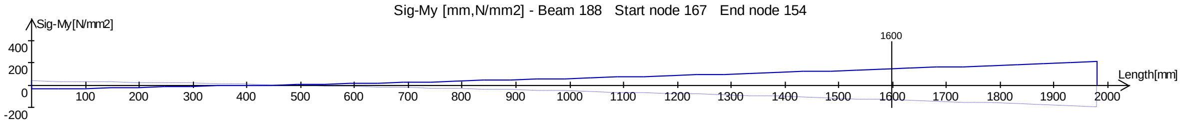

Figure 7.11.1 stresses along beam 188 length

A bracket with 400mm arm is used to support the deck; Table 7.6 presents stress at mentioned distance from end. The bracket increases the section modulus at this point so the bending stress is reduced.

Table 7.6 stress at a local distance in beam 188

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
1600	1600 (188)	-0	-0	68	146	-136	146	-137

Beam 241 ;Frame 84,

Figure 7.12 shows a section of the main deck grid, with high stressed beam 241 in red colour in frame 88 at a distance 50.4m AP, 4.62m to 6.6m FCL SB, with beam deflections in black colour and figure 7.12.1 shows the stresses along the length of the beam 245 in millimeters.

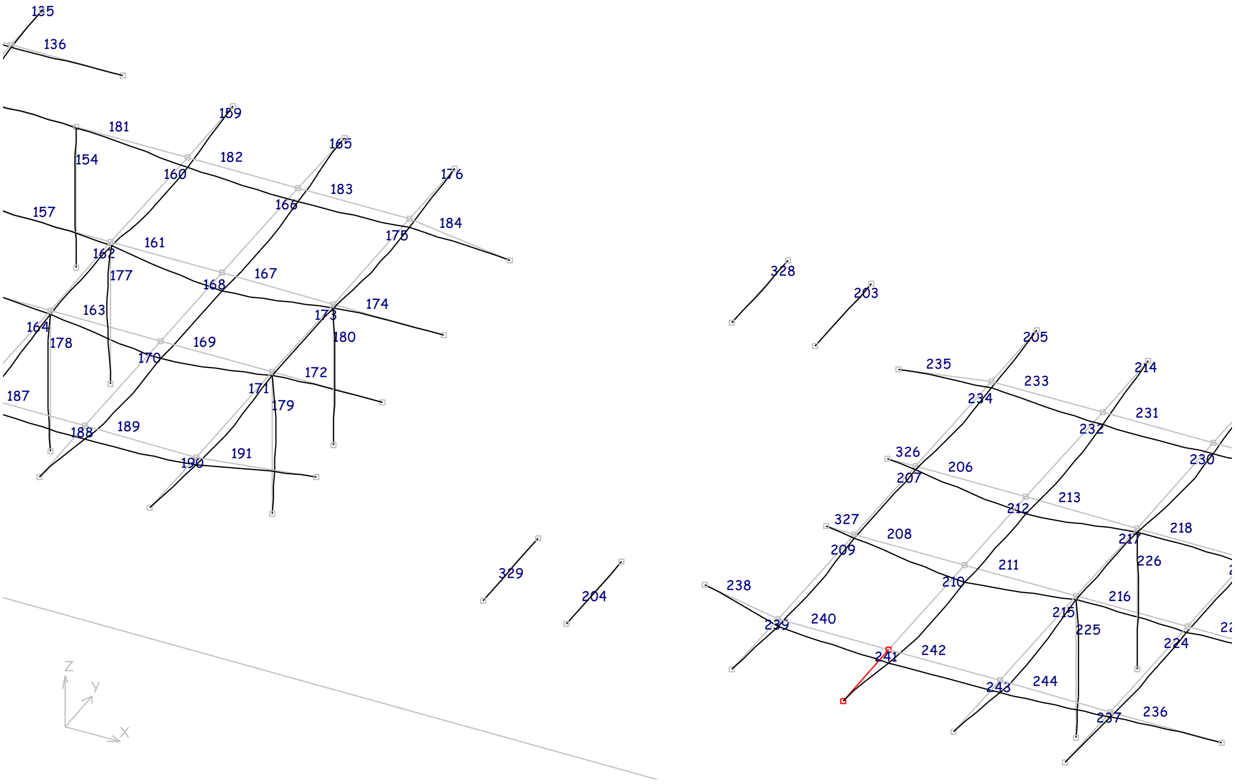

Figure 7.12 Main deck element with stress above rule value in red beam 241

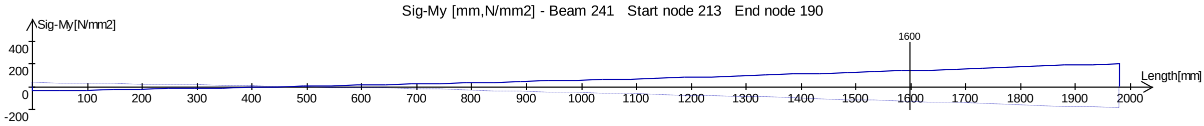

Figure 7.12.1 stresses along beam 241 length

Deck girder is to be supported at end by bracket with 450mm arm. Table 7.7 presents stress at mentioned distance from end. The added bracket increases the section modulus which in turns reduces the bending stress.

Table 7.7 stress at a local distance in beam 241

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
1600	1600 (241)	-0	0	67	143	-133	143	-134

Beam 214; Frame 84

Figure 7.13 is a section of the main deck grid, with over stressed beam 214 in red colour in frame 84 at a distance 50.4m AP, 4.62m to 6.6m FCL PS and figure 7.13.1 present the stresses along the length of beam 218 in millimeters.

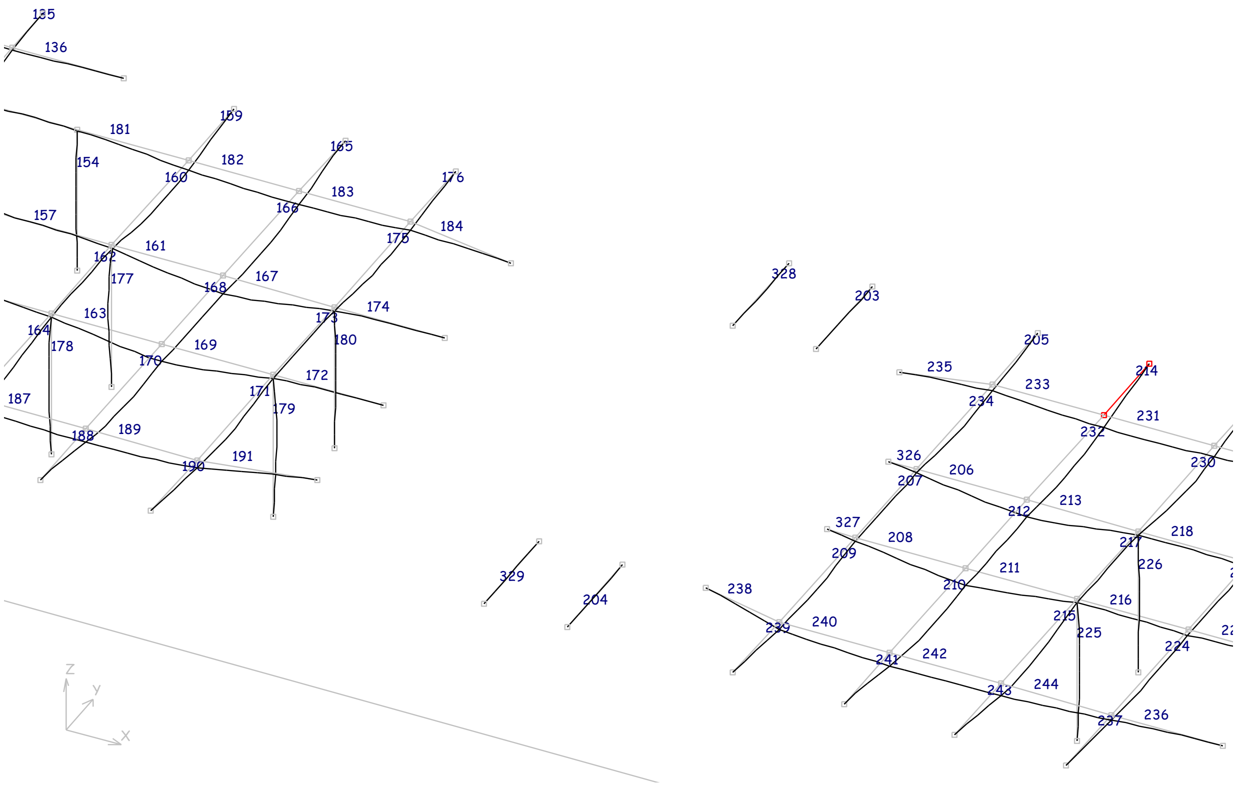

Figure 7.13 Main deck element with stress above rule value in red beam 214.

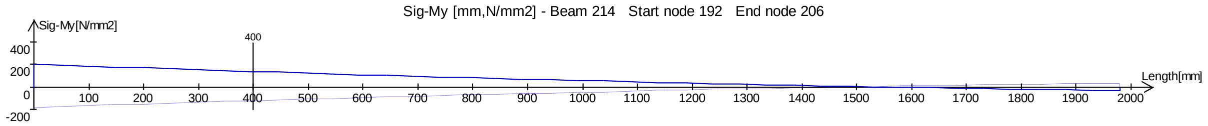

Figure 7.13.1 Stresses along beam 214 length

Deck girder is to be supported at end by bracket with 450mm arm lenght, hence the section modulus in this end is increased. Table 7.8 presents stress at mentioned distance from end. For bracket arm design see section 6.7.

Table 7.8 stress at a local distance in beam 214

Distance [mm]	**Local Distance [mm (Beam)]**	**σ_{Nx} [N/mm2]**	**τ_{Mx} [N/mm2]**	**τ_{Qz} [N/mm2]**	**σ_{My} (top) [N/mm2]**	**σ_{My} (bottom) [N/mm2]**	**σ_{Ny} (top) [N/mm2]**	**σ_{Ny} (bottom) [N/mm2]**
400	400 (214)	-0	-0	-65	138	-128	137	-128

Beam 200; Frame 39 4620mm to 6.6m FCL SB

Figure 7.14 present a section of the main deck grid, with beam number 200 with stress value higher than acceptable value the in red and the deflections in black colour, in frame 39 at a distance 23.4 m AP, 4.62m to 5.28m FCL SB and figure 7.14.1 is the stresses along the length of beam 200 in millimeters.

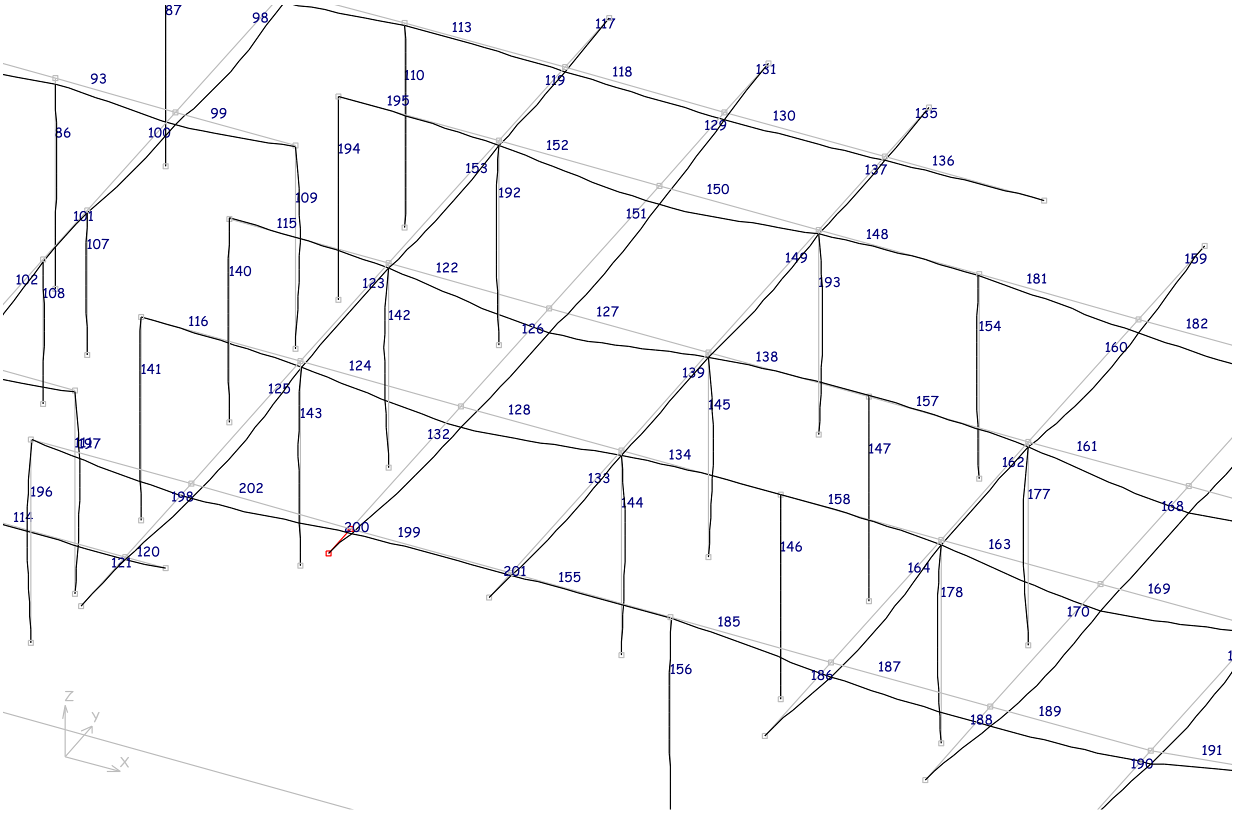

Figure 7.14 Main deck element with stress above rule value in red beam 200

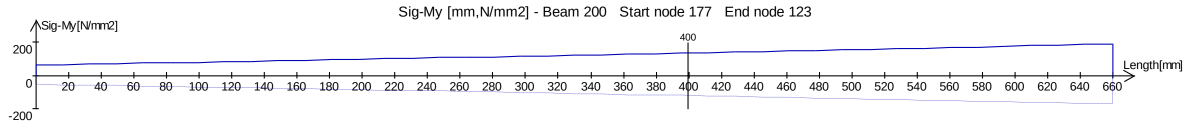

Figure 7.14.1 Stresses along beam 200 length

Deck girder is to be supported at end by bracket with 400mm arm. Table 7.9 presents stress at mentioned distance from end. Hence as result of the increase in the section modulus the bending stress at this point is reduced.

Table 6.9 stress at a local distance in beam 200

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
400	400 (200)	-0	-3	83	135	-125	134	-126

Frame 88 Beam 219

A section of the deck grid is presented in figure 7.15A below, with beam 219 stress value above the recommended value from the rules in red colour and the deflection of the beam in black and the other parts in light blue colour,

The beam is positioned at frame 88, 52.8m from the AP and 4.62m to 5.28m FCL on the PS, while figure 7.15.1A is the plot of the stresses along the length of the beam

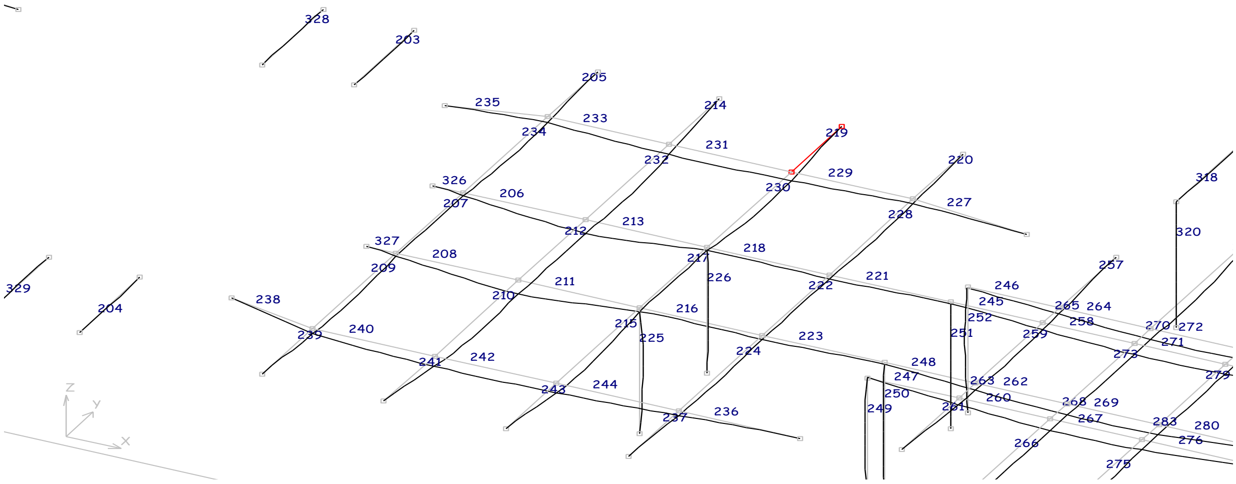

Figure 7.15A Main deck element with stress above rule value in red beam 219

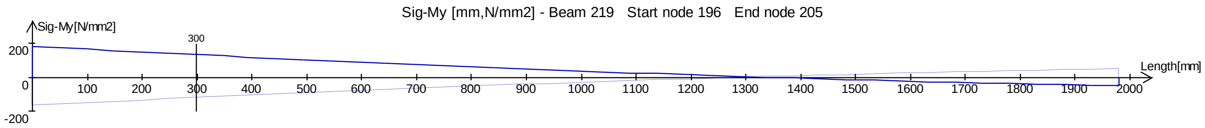

Figure 7.15.1A Stresses along beam 219 length

Deck girder is to be supported at end by bracket with 300mm arm. Table 7.10A presents stress at a mentioned distance from end. The bracket increases the section modulus and reduces the bending stress at this end, see section 6.7 for bracket design.

Table 7.10B stress at a local distance in beam 243

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
300	300 (219)	0	1	-67	132	-123	132	-123

Frame 88 Beam 243

Figure 7.15B presents a section of the main deck grid, with high stressed beam 243 in red colour in frame 88, at a distance 52.8 m AP, 4.62m to 5.28m FCL SB and figure 7.15.1B is the plot of the bending stresses along the length of beam 243 in millimeters.

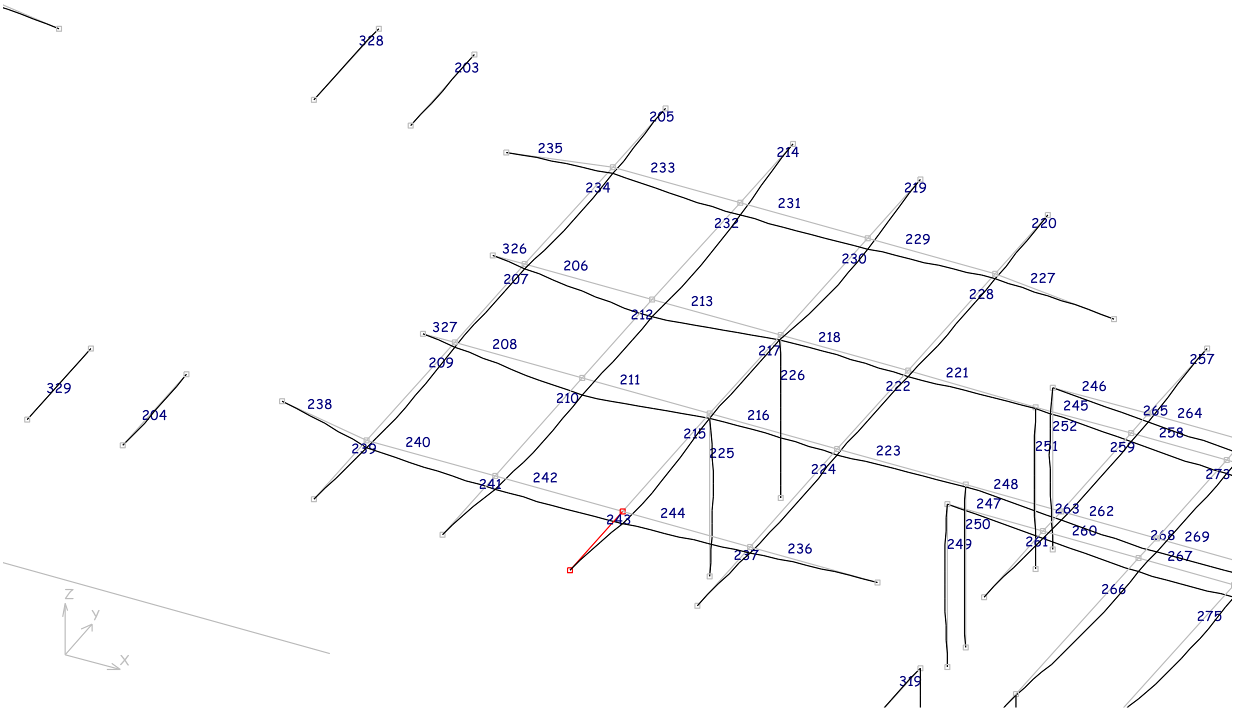

Figure 7.15B Main deck element with stress above rule value in red beam 243

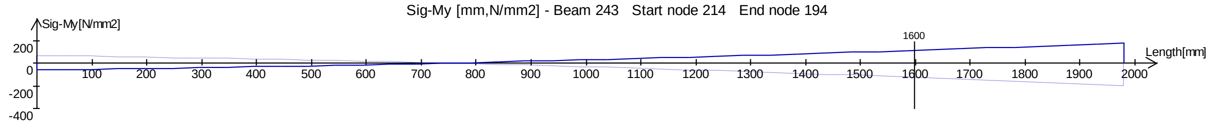

Figure 7.15.1B Stresses along beam 243 length

Deck girder is to be supported at end by bracket with 300mm arm. Table 7.10B presents stress at a mentioned distance from end. The bracket increases the section modulus, and as a result, the bending stress at this end is reduced, see section 6.7 for bracket design.

Table 7.10B stress at a local distance in beam 243

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
1600	1600 (243)	0	-1	76	115	-128	115	-128

Beam 50 Frame 8-10

The figure 7.16 is a section of the main deck grid, with highly stressed beam 50 in red in and the deflections is black colour in frame 8 to 10 at a distance 4.8 m to 6m AP, 3.3m FCL SB and figure 7.16.1 is the bending stresses along the length of beam 50 in millimeters.

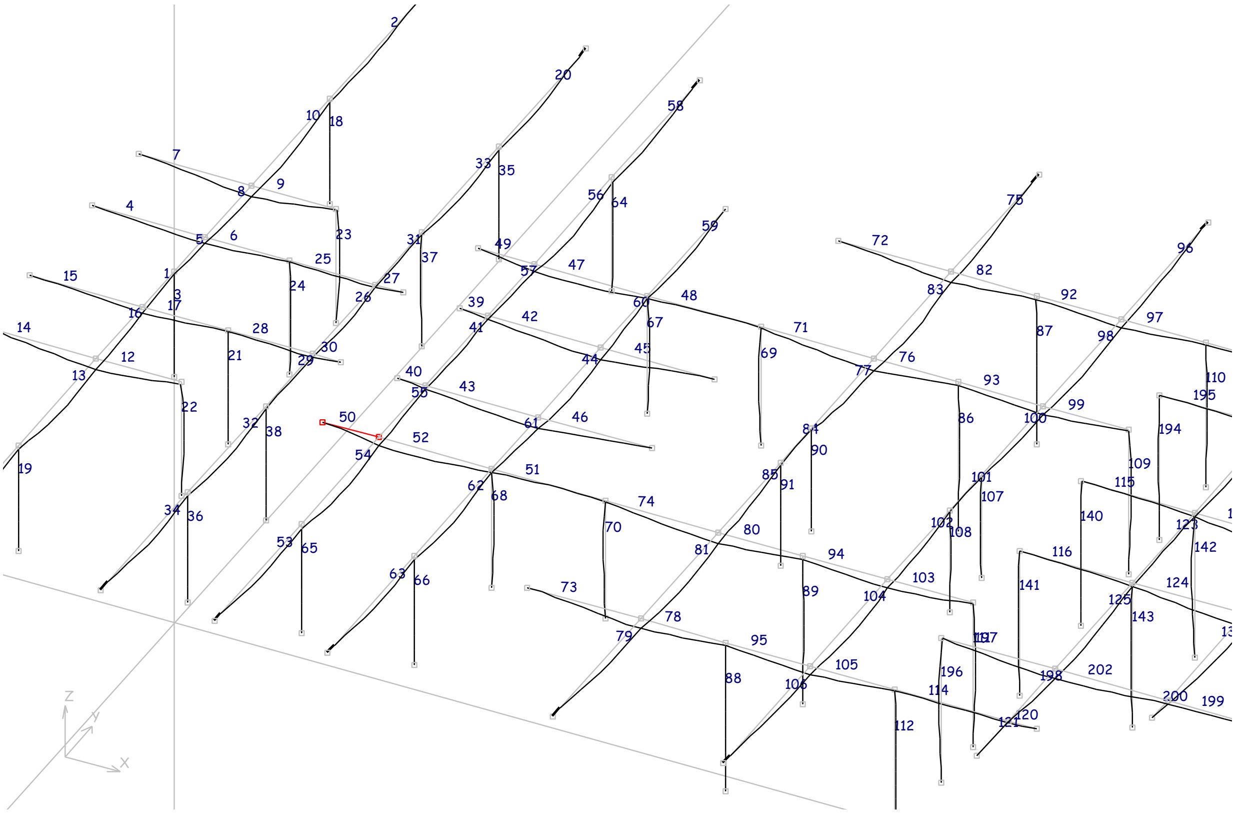

Figure 7.16 Main deck element with stress above rule value in red, beam 50

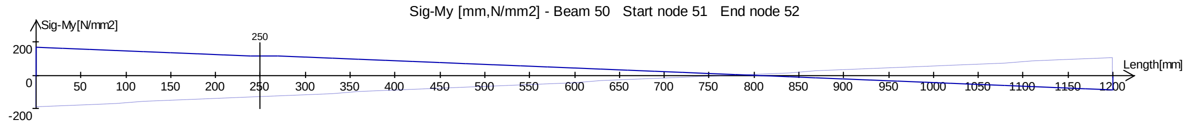

Figure 7.16.1 Stresses along beam 50 length

The deck girder at this end is increased with bracket 450mm arm lenght, so that, the sectional modulus is increased. See table 7.11 for stresses at this end.

Table 7.11stress at a local distance in beam 50.

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
250	250 (50)	0	2	77	116	-132	116	-132

Beam 49 Frame 8-10

Figure 7.17 shows a section of the main deck grid, with highly stressed beam 49 in red and deflections in black colour in frame 8 to 10 at a distance 4.8 m to 6m AP, 3.3m FCL PS and figure 7.17.1 is the stresses along the length of beam 49 in millimeters.

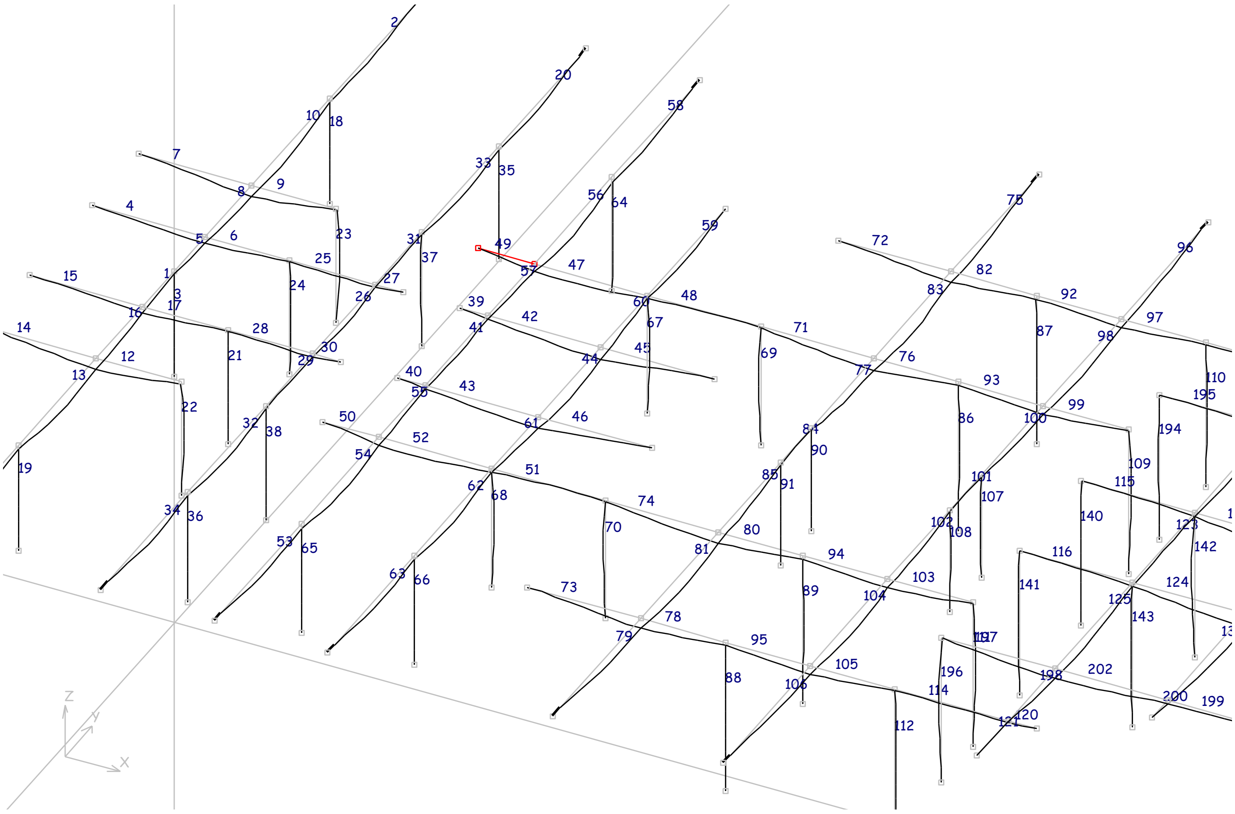

Figure 7.17 Main deck element with stress above rule value in red, beam 49

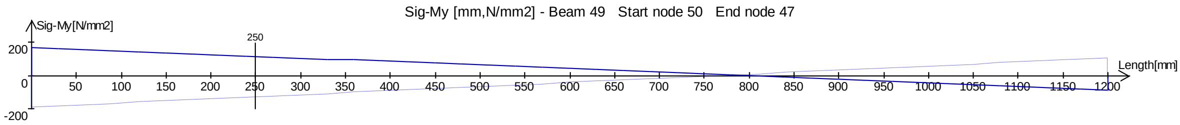

Figure 7.17.1 Stresses along beam 49 length

Height of web at this deck girder at this end is increased with bracket radius 450mm. See table 7.12 below for stresses at a position from the end. The bracket increases section modulus and reduce the bending stress at this end, for details about bracket design see section 6.7.

Table 7.12 stress at a local distance in beam 49

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
250	250 (49)	0	-2	77	116	-131	116	-131

Beam 39 Frame 9-10

The figure 7.18 represents a section of the main deck grid, with highly stressed beam 39 in red colour in frame 9 to 10 at a distance 5.4 m to 6m AP, 1.32m FCL PS and figure 7.18.1 is the stresses along the length of beam 39 in millimeters. The beam numbering is in blue, deflection in black and beam in light blue.

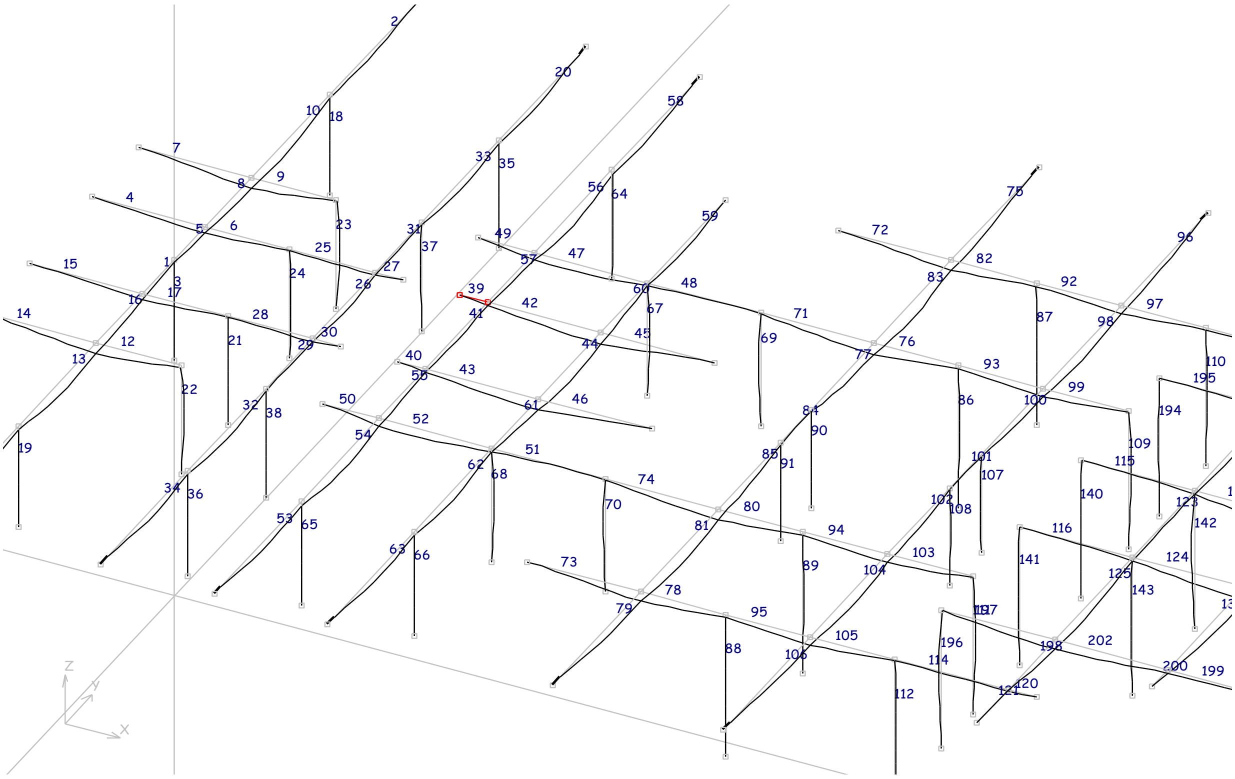

Figure 7.18 Main deck element with stress above rule value in red beam 39

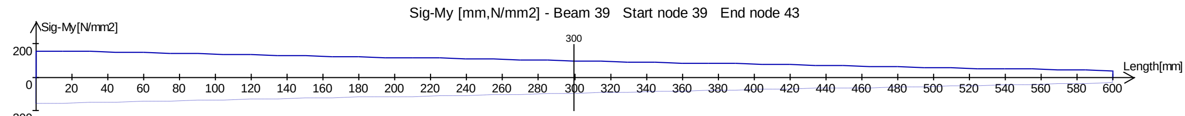

Figure 7.18.1 Stresses along beam 39 length

Height of web at this deck girder at this end is increased with bracket 400mm arm lenght. Hence, the stress is reduced significantly as shown in table 7.13 for stress at a position from the end. And the section modulus is increased.

Table 7.13 stress at a local distance in beam 39

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
300	300 (39)	0	-2	92	97	-100	97	-100

Beam 40 Frame 9-10

Representing the main deck grid is figure 7.19, with highly stressed beam 40 in red colour in frame 9 to 10 at a distance 5.4 m to 6m AP, 1.32m FCL SB, while black colour is the deflection of the beam and figure 7.19.1 is the stress along the length of beam 40 in millimeters.

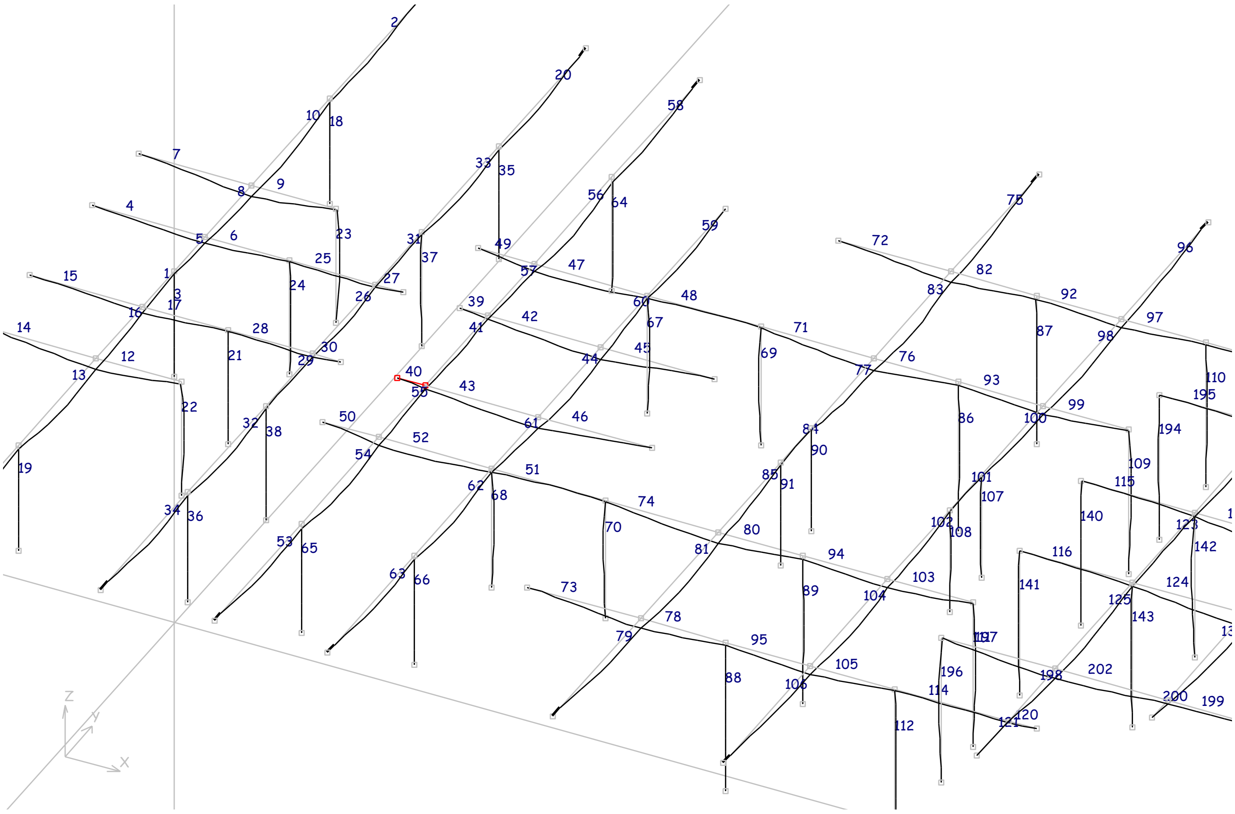

Figure 7.19 Main deck element with stress above rule value in red beam 40

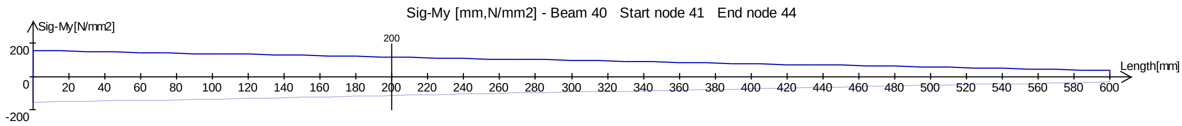

Figure 7.19.1 Stresses along beam 40 length

Height of web at the deck girder at this end is increased with bracket of 400mm arm. see table 7.14 below for stress at a position from the end. As result of increased section modulus the bending stress at this end is reduce significantly.

Table 7.14 stress at a local distance in beam 40

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
200	200 (40)	0	2	92	116	-119	116	-119

Frame 51 Beam 186

The figure 7.20 shows a section of the main deck grid, with highly stressed beam 186 in red colour in frame 51 at a distance 30.6 m AP 4.62m to 6.6m , FCL SB and figure 7.20.1 is the stress along the length of beam 186 in millimeters.

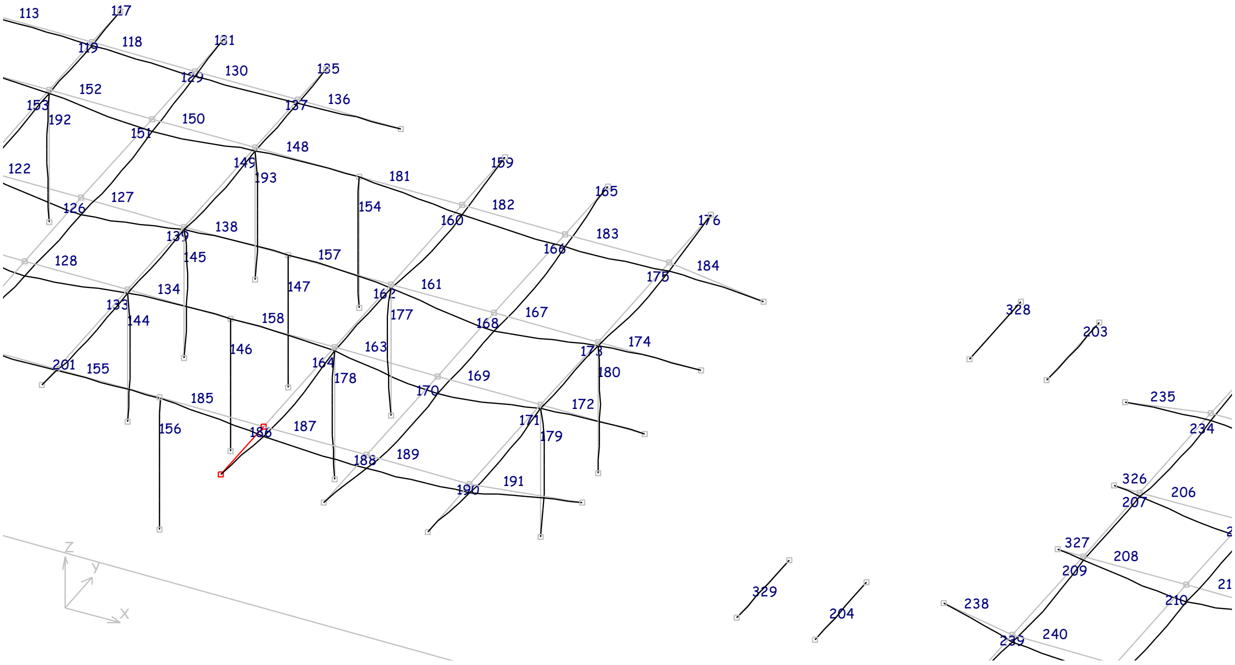

Figure 7.20 Main deck element with stress above rule value in red beam 186

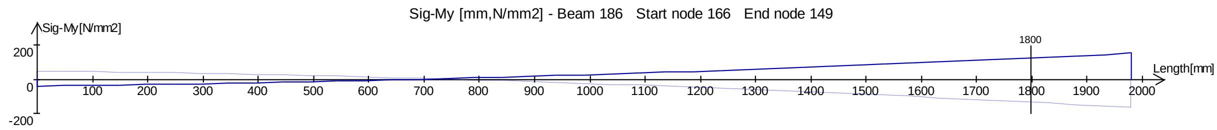

Figure 7.20.1 Stresses along beam 186 length

Deck girder is supported at end by bracket with 450mm arm. Table 7.15 presents stresses at mentioned distance from end. The bracket increases the section modulus and the bending stresses at this end, see section 6.7 for bracket design.

Table 7.15 stress at a local distance in beam 186

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
1800	1800 (186)	0	1	71	124	-138	124	-138

Frame 51 Beam 159

The figure 7.21 represents a section of the main deck grid, with highly stressed beam 159 in red colour in frame 51 at a distance 30.6 AP, 4.62 to 6.6m FCL PS and figure 7.21.1 is the bending stresses along the length of beam 159 in millimeters.

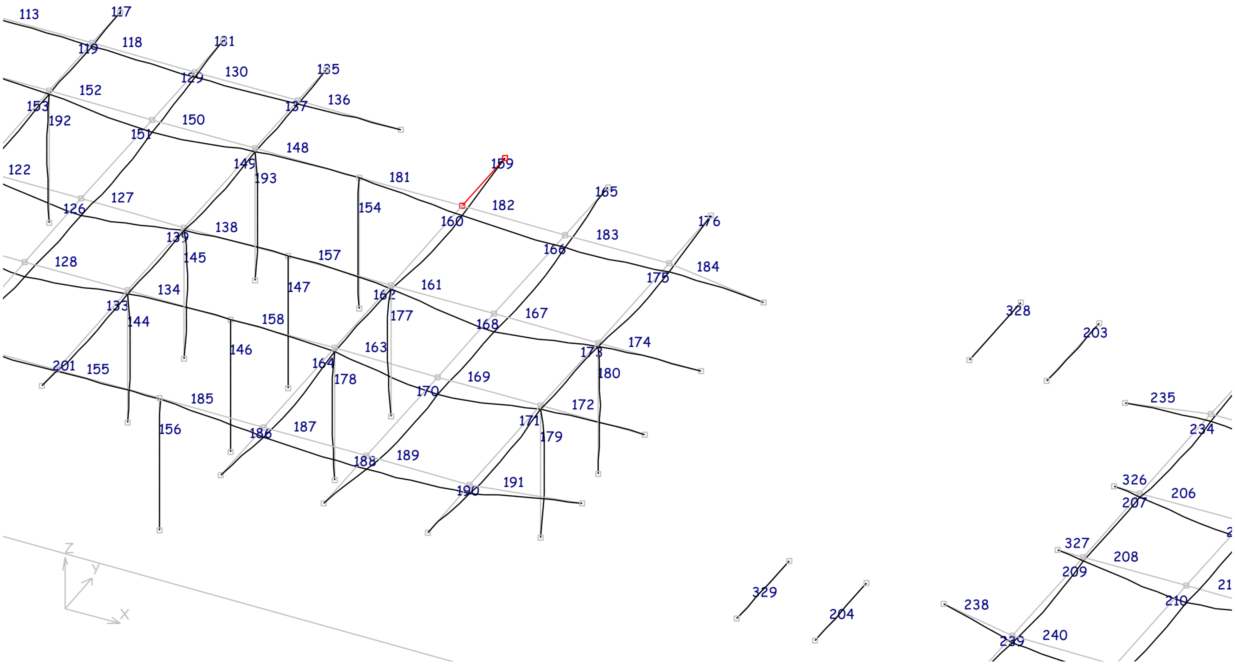

Figure 7.21 Main deck elements with stress above rule value in red beam 159

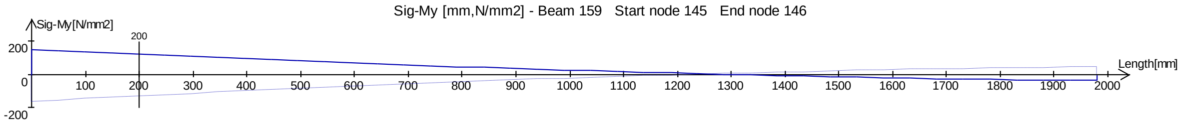

Figure 7.21.1 Stresses along beam 159 length

Deck girder is supported at end by bracket with 450mm arm. Table 7.16 presents stresses at mentioned distance from end.

Table 7.16 stress at a local distance in beam 159.

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
200	200 (159)	0	-1	-70	120	-134	120	-134

Frame 55 to Frame 59 Beam 167

The figure 7.22 represents a section of the main deck grid, with highly stressed beam 167 in red colour and the deflections of the beam in black colour in frame 55to frame 59 at a distance 33 m to 35.4m AP, 1.32m FCL PS and figure 7.22.1 is the bending stresses along the length of beam 167 in millimeters.

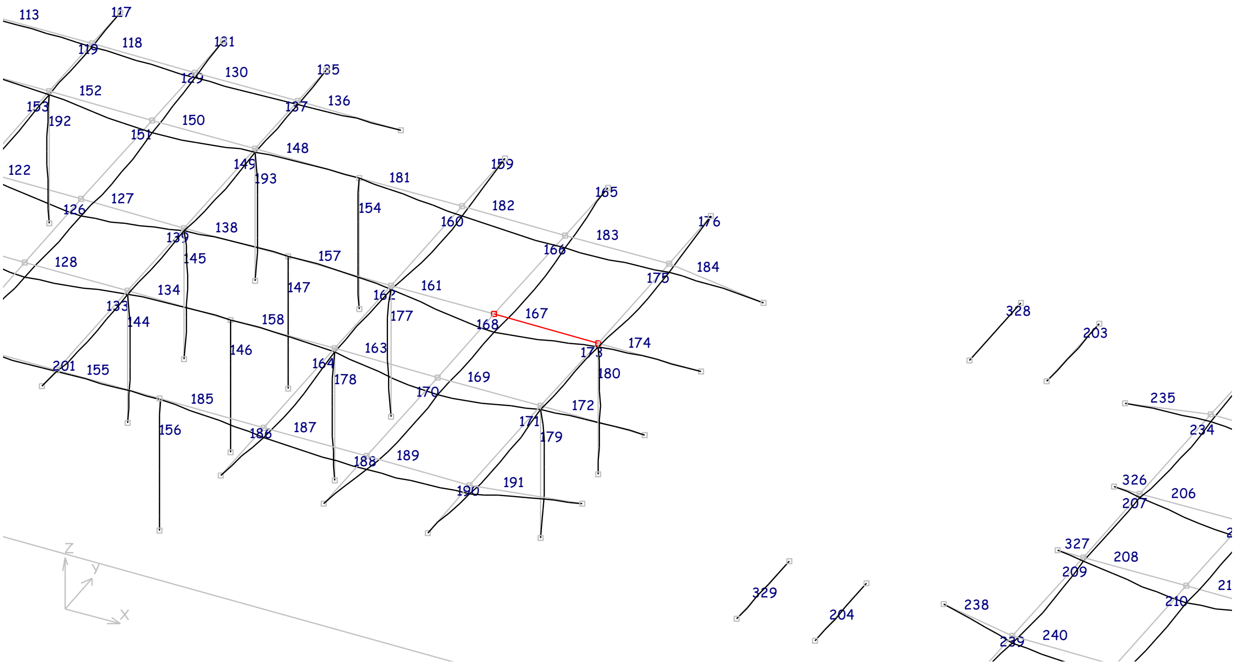

Figure 7.22 main deck element with stress above rule value in red beam 167

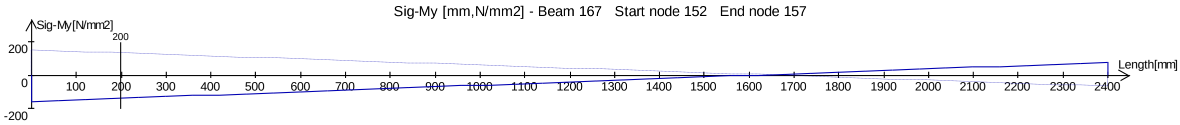

Figure 7.22.1 stresses along beam 167 length

The deck is to be supported by a pillar at frame 55, 35.4 AP and 1.32 FCL to the PS, alternatively beam 172 is to be supported by a bracket of 400 arm, to the longitudinal girder through beam 167 as shown in the above diagram. Table 7.17 presents stresses at mentioned distance from end.

Table 7.17 stress at a local distance in beam 167

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
200	200 (167)	-1	-0	-42	-140	130	-141	130

Frame 51 to Frame 55 Beam 161

Figure 7.23 shows a section of the main deck grid, with the highly stressed beam 161 in red colour, frame 51 to 55 at a distance 30.6 m to 33m AP, 1.32m FCL, PS and figure 7.23.1 is the plot of the stresses along the length of beam 161 in millimeters.

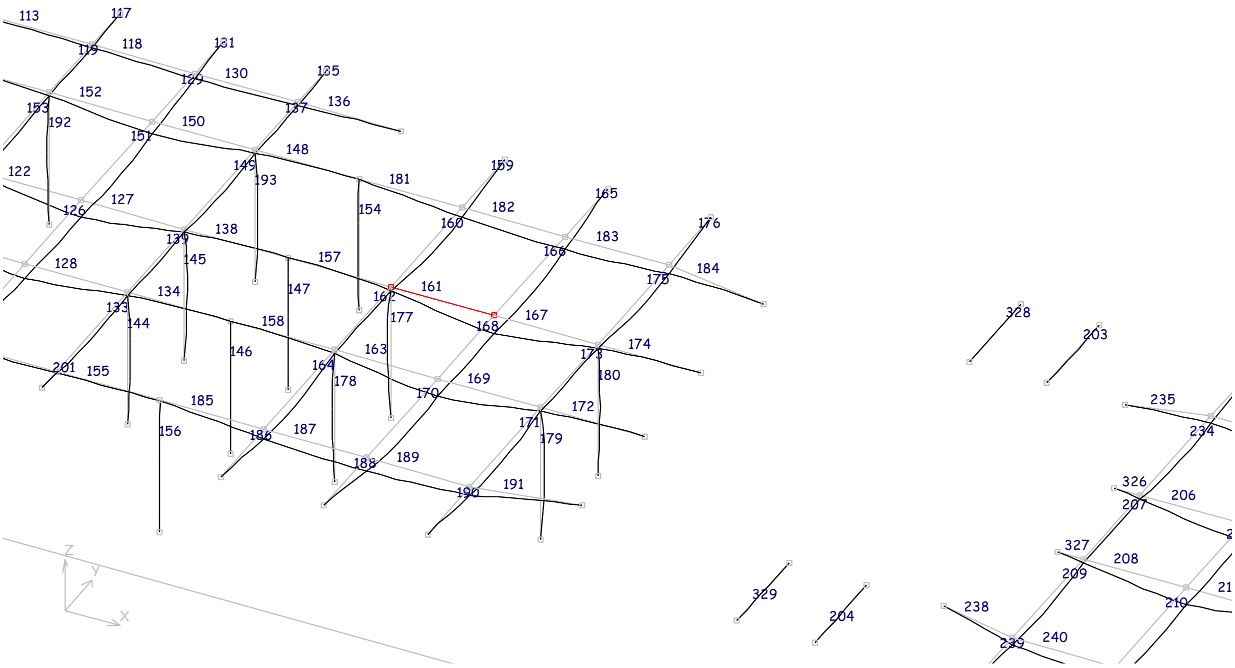

Figure 7.23 Main deck element with stress above rule value in red beam 161

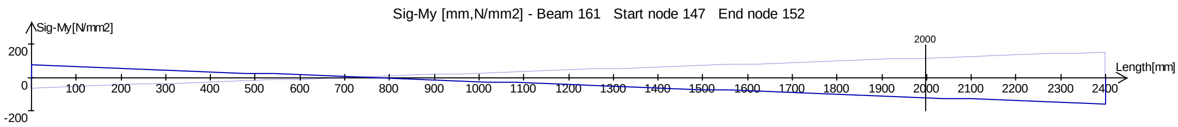

Figure 7.23.1 Stresses along beam 161 length

A bracket arm of 400mm is to be used to support the beam 167 to the pillar at end 177 as show in the above figure 7.23. Alternatively, a pillar could be erected at frame 55 at 1.32m FCL, PS. Table 7.18 below presents stresses at mentioned distance from end.

Table 7.18 Stress at a local distance in beam 161

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
2000	2000 (161)	-1	1	41	-121	113	-122	112

Frame 51 to Frame 55 Beam 163

The figure 7.24 depicts a section of the main deck grid, with the highly stressed beam 163 in colour red in frame 51 to frame 55 at a distance 30.6 m to 33m AP, 1.32m FCL ,SB and figure 7.24.1 is the plot of the bending stress along the length of beam 163 in millimeters.

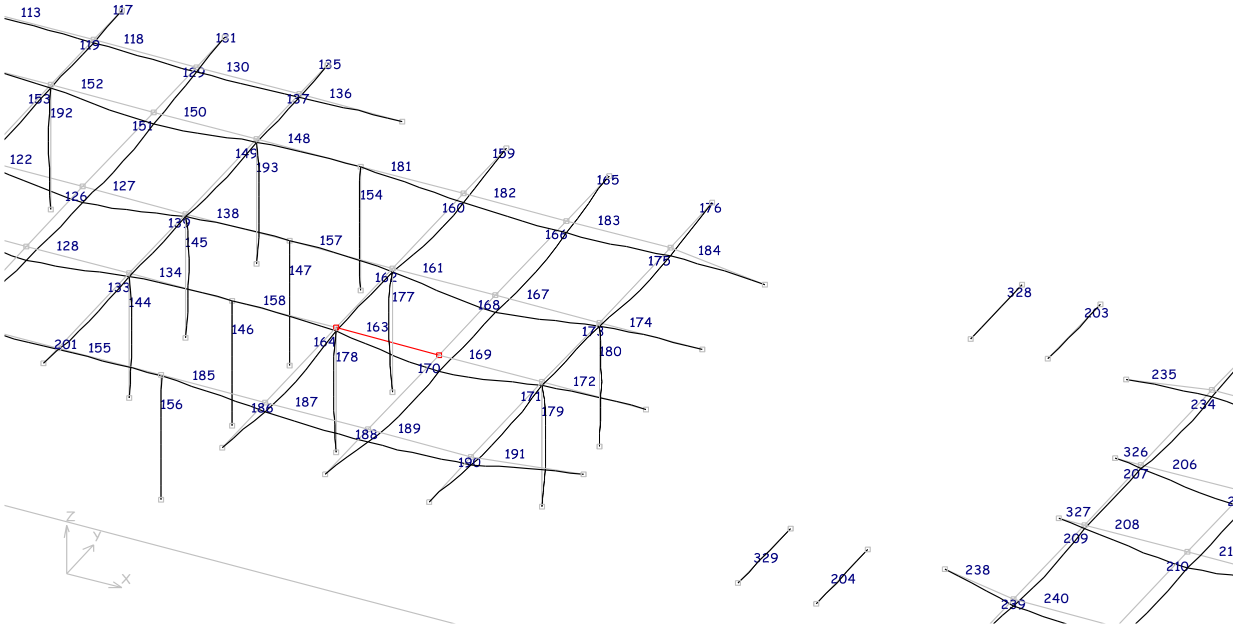

Figure 7.24 Main deck element with stress above rule value in red beam 163

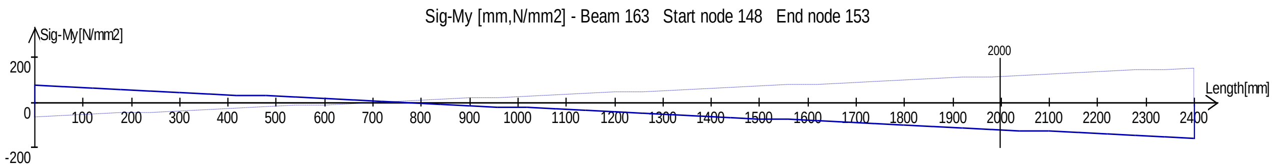

Figure 7.24.1 Stresses along beam 163 length

Similarly, a bracket arm of 400mm is to be used to support the girder at the end of beam 163 to the pillar at end 178 as show in the above figure 7.24. Alternatively, a pillar could be erected at frame 55 that is33m AP, at 1.32m FCL, SB. Table 7.19 shows bending stress at mentioned distance from end.

Table 7. 19 Stress at a local distance in beam 163

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
2000	2000 (163)	-1	-1	41	-121	113	-122	112

Frame 55 to Frame 59 Beam 169

The figure 7.25 is a section of the main deck grid, the high stressed beam 169 in red colour in frame 55 to frame 59 at a distance 33m to 35.4 AP, 1.32m FCL, SB and figure 7.25.1 is the stress along the length of beam 169 in millimeters.

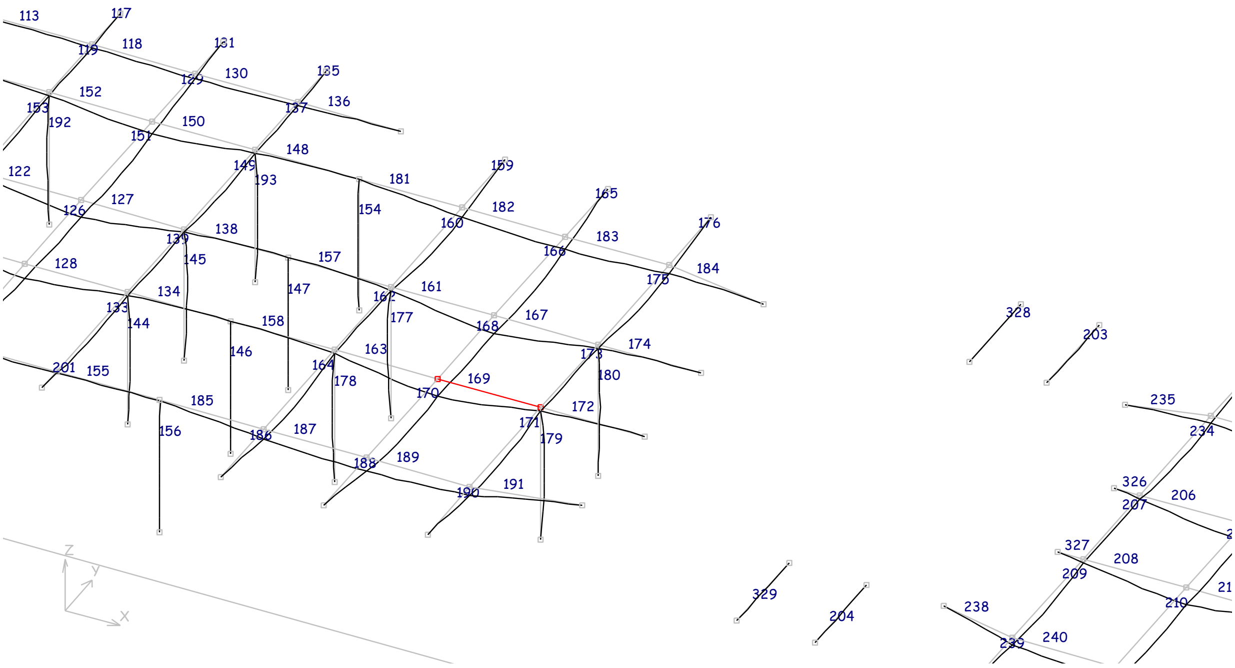

Figure 7.25 Main deck element with stress above rule value in red (beam 169)

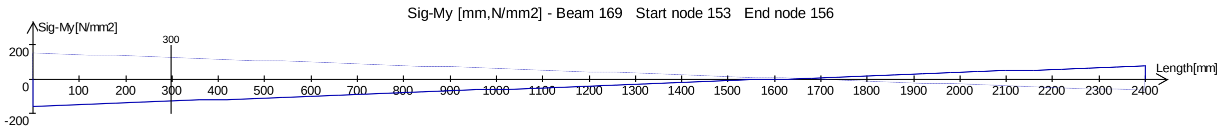

Figure 7.25.1 Stresses along beam 169 length

A pillar support at frame 55 33m AP, or a large bracket arm of 400mm at the end of pillar in frame 59, that is, beam 179 in figure 7.25. Table 7.20 presents stress at mentioned distance from end.

Table 7. 20 Stress at a local distance in beam 169

Distance [mm]	Local Distance [mm (Beam)]	σ_{Nx} [N/mm2]	τ_{Mx} [N/mm2]	τ_{Qz} [N/mm2]	σ_{My} (top) [N/mm2]	σ_{My} (bottom) [N/mm2]	σ_{Ny} (top) [N/mm2]	σ_{Ny} (bottom) [N/mm2]
300	300 (169)	-1	0	-42	-130	121	-131	121

Remarks

The procedure to ameliorate the stress for all the Beams with high bending stresses are the same; The highly stressed positions are identified, and the section modulus at this point is increased, by the addition of brackets or increase the web height, hence the bending stress is reduce, since they are inversely proportional. See equation 21 and 22 for bracket design.

7.6. Tween Deck Local Stress

The tween deck is loaded by 2t/m^2 are the reaction force and stresses are obtained. See Annex D for local stresses and Annex E for beam load, and the bending stresses are sorted in descending order of magnitude as follows in table 7.21, and the maximum local stress is 137N/mm^2

Table 7.21 The tween deck Beam Stresses, values, sorted by Sig-My in Descending order

Beam No.	σ_{Nx} [N/mm2]	τ_{Qy} [N/mm2]	τ_{Qz} [N/mm2]	τ_{Mx} [N/mm2]	σ_{My} [N/mm2]	σ_{Mz} [N/mm2]
13	-0	0	19	0	137	4
14	0	-1	-39	-1	137	12
145	-7	-0	8	-0	122	0
31	-9	-0	11	-0	121	0
88	-11	0	11	0	120	0
146	-7	-0	7	0	119	0
22	-0	1	-32	1	115	14
174	-0	-0	-34	-1	115	8
21	0	-0	16	-0	115	4
173	0	0	12	1	114	7
175	-10	0	14	0	113	1

Table 7.21 shows the local stresses on the tween deck, it is obvious that the local stresses are all below the 160 N/mm^2 rule value. See Annex D for detail report from Nauticus 3D beam.

7.7. Buckling of Pillars

The pillars allowable buckling loads are calculated by specifying the type, location and length in the Nauticus hull excel software as shown in figure 7.21, and the allowable loads are compared with the deck beam column in loaded conditions which is the reaction force values obtained in from the 3D beam software.

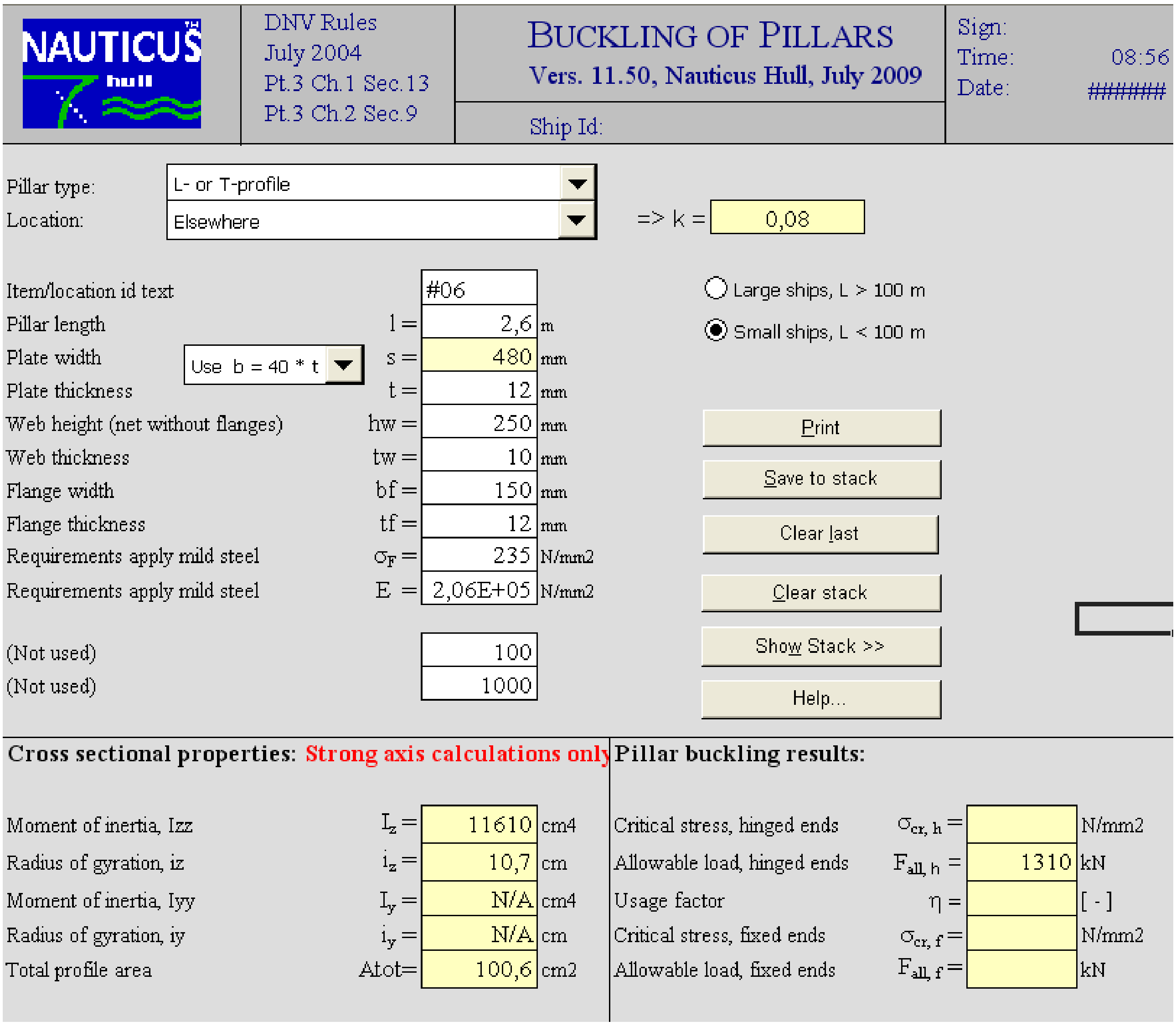

Figure 7.21Nauticus hull buckling of pillars interface

Table 7.22 Allowable loads of a defined Pillar

Profile type	Location id text	Length [m]	Profile scantlings, s*t / hw*tw / bf*tf	k-factor	(Hinged ends) F_{all} [kN]	σ_{cr} N/mm2	Return >> η [–]
O	#14 pillar	2,7	260*20	0,1	1317		
L/T	#14 d6600	2,7	480*12/300*10/150*15	0,1	1045		
L/T	#18d3960	2,7	480*12/300*12/150*15	0,1	1100		
HP	#22d660	2,7	480*12/220*10	0,1	738		
L/T	#25d6600/3300	2,7	480*12/200*15/120*20	0,1	991		
L/T	#31d3300	2,7	480*12/200*15/120*20	0,1	991		
L/T	#31d6600 MD	3,3	480*12/200*15/120*20	0,1	942		
L/T	#31d6600 TD	2,5	480*12/200*15/120*20	0,1	1006		
L/T	#31d3300TD	2,2	480*12/200*15/120*20	0,1	1031		
O	#35 pillar	2,7	292*25	0,1	1876		
O	#43 pillar	2,7	292*25	0,1	1876		
L/T	#47 66/33	2,8	480*12/250*20/150*20	0,1	1261		
L/T	#47 66/33TD	3,3	480*12/250*20/150*20	0,1	1221		
O	#59 pillar	2,7	292*25	0,1	1876		
O	#59 pillarTD	3,3	292*25	0,1	1787		
L/T	#59	2,5	480*12/250*12/120*15	0,1	981		
L/T	#59 TD	3,5	480*12/250*12/120*15	0,1	915		
O	#88 pillar	2,6	292*25	0,1	1890		
L/T	#96	2,6	360*9/125*15/150*15	0,1	593		
L/T	#96 TD	3,195	360*9/250*15/150*20	0,1	896		
L/T	#102	3	360*9/250*12/120*15	0,1	726		
L/T	#102 TD	3,5	360*9/250*12/120*15	0,1	702		
L/T	#105	2,985	360*9/300*10/150*15	0,1	795		
O	#102	3,2	139,7*12	0,2	313		
L/T	#109	2,6	360*9/125*15/150*15	0,1	593		
L/T	#06	2,6	480*12/250*10/150*12	0,1	1310		

See Annex B for the load reactions in each beam node and figure 7.2.2 for beams numbers. However, the value of reaction force on a pillars obtained from the 3D beam Nauticus software in Annex B, is compared with a the standard in table 7.22 to check if the value is within or below the allowable load, while values above this values are to sorted and redesign. Large brackets are recommended to reduce the length and increase the sectional modulus. While a lesser value to the F_{all} , value in the table 7.22 are consider good design.

7.8. Plate Buckling

The plate buckling strength for a plate subjected to longitudinal compressive bending stress of a given thickness, length and spacing is calculated and compared to the critical buckling strength, the longitudinal compressive stress should be less than the critical buckling strength.

From the interface in figure 7.22, the plot of figure 7.23 is obtained which represents the buckling strength for a given plate thick, length and spacing.

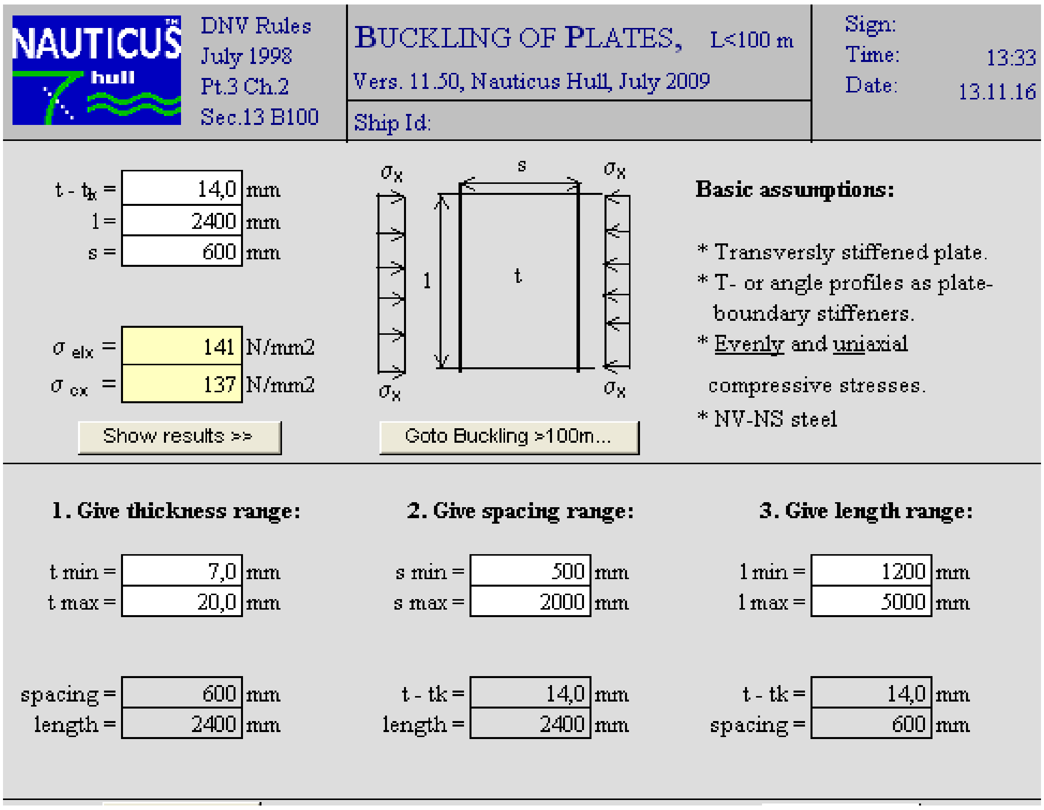

Figure 7.22 Nauticus hull buckling of plate interface

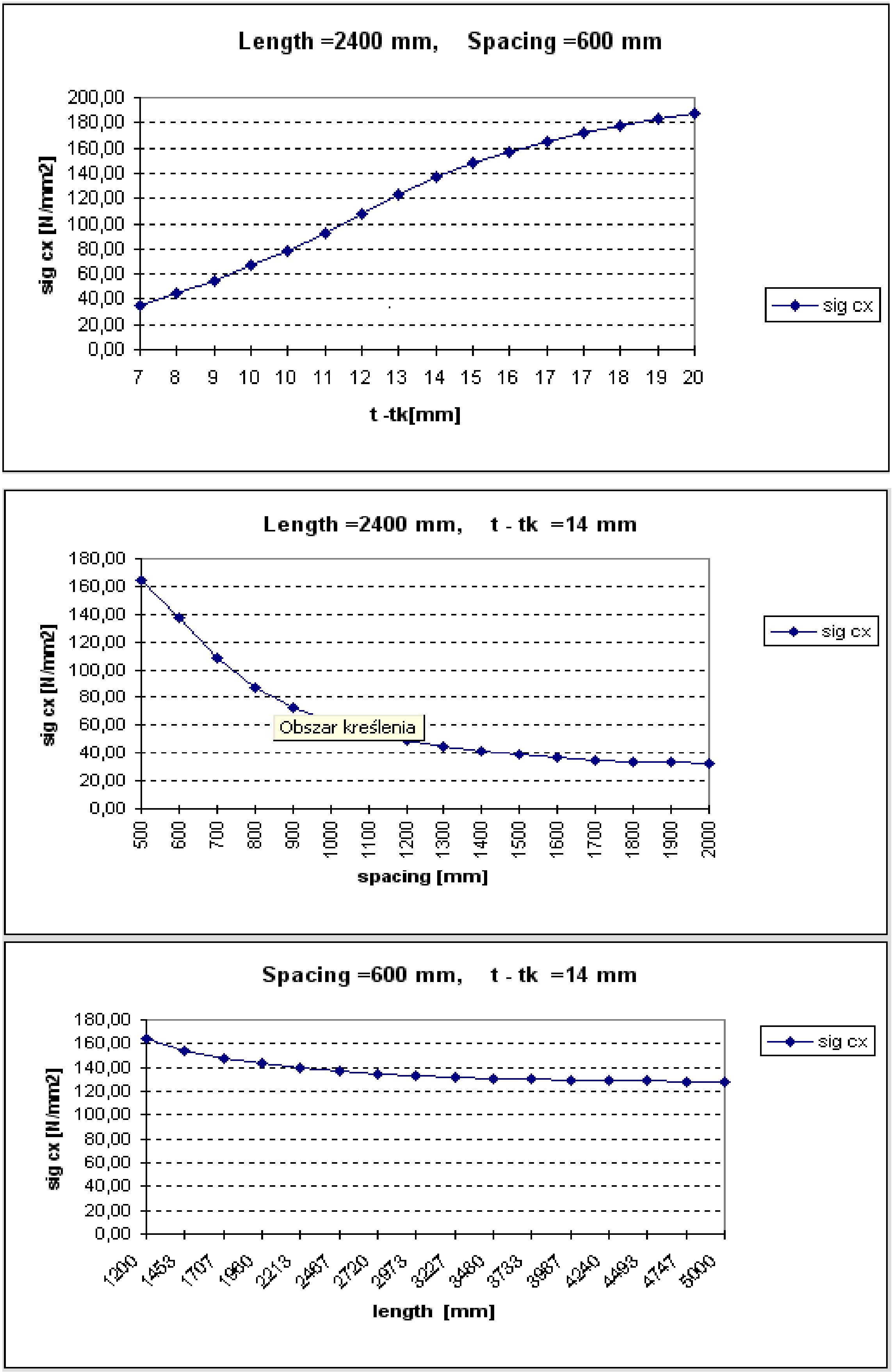

Figure 7.23 Plate buckling strength for a given length, spacing and thickness.

Slamming and bow flare loads

During a severe weather, the ship may be subjected to heave motion, and at the fore body of the ship could be out of water, and fall back to water. Creating a great impact pressure on the hull. However, since the size of the ship according to rules is less than 100 metres, this cannot be a treat, so it is not analyzed for slamming.

7.9. Effective Flanges

Due to shear lag effect the effectiveness of the plating acting as flange for deck girders which support crossing stiffeners is reduced and should have a satisfactory buckling strength.

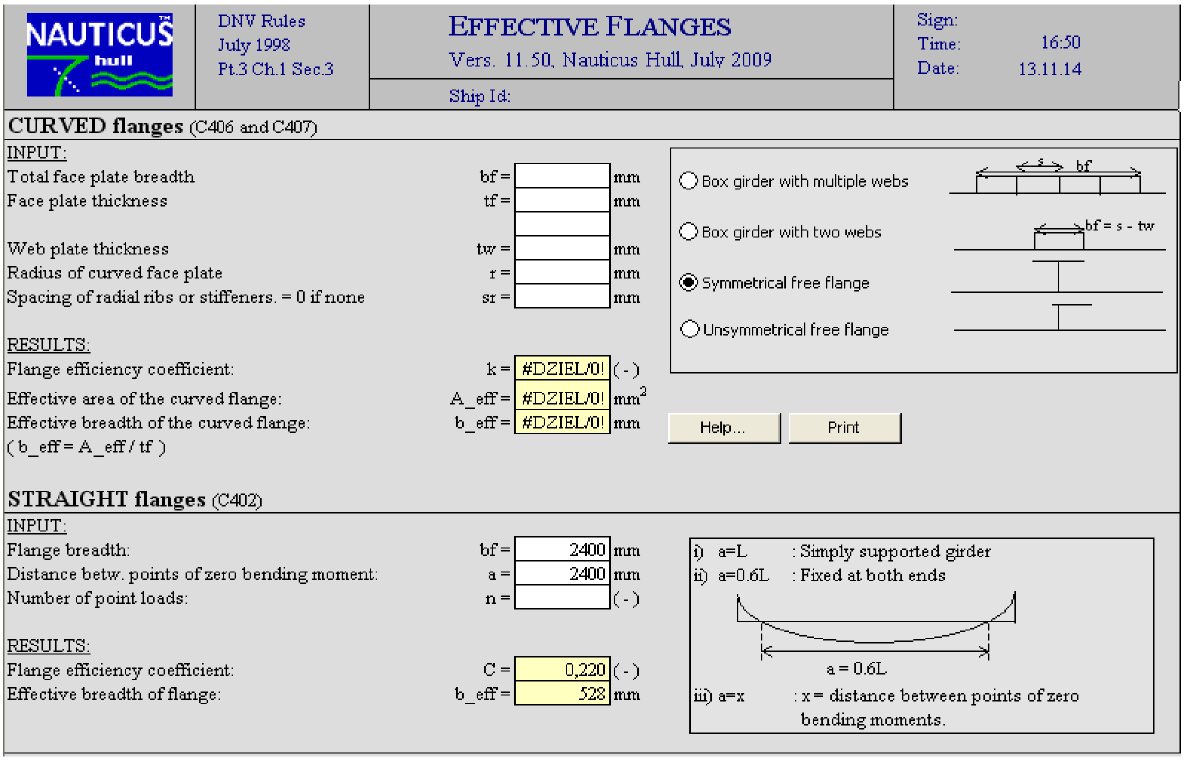

Figure 7.24 Nauticus hull effective flanges interface

The effective breadth of flange is defined as the cross-sectional area of plating within the effective flange width, which helps in carrying load.

Figure 7.24 is a calculation of deck plate effectiveness for frame 47 and frame 51without bracket at end. However, it should be noted that this is already taken into consideration in the scantling.

7.10. Detail Description of Girder Design on Main Deck from 3D Beam

Longitudinal girder W350 x 15/ FL150 x 20 and transverse girder of W350 x20/FL200 x25 are the size of the girder within frame 3 and frame 19.

From frame 19 to frame 31 the size of the longitudinal and transverse girders are W450 x22 FL300 x30 and W350 x18 /FL250 x25, at 3.3m PS and SB and frame 22 and 28 respectively.

The size of the longitudinal and transverse girder from frame 32 to 62 are W550x 20/FL 300x30 and W550x20/FL250x25, at 1.32m and 4.62m FCL PS and SB respectively and at frame 35,39,51,55, and 59 respectively.

In the region of the moon pool opening from frame 63 to frame 77 the girders are only transverse of the type W400 x20/ FL250 x 25 at position of frame 71 and 74. The girder type for the longitudinal and transverse at frame 79 to 96 are W550x 20/FL 300x30 and W550x20/FL250x25. At 1.32m and 4.62m FCL PS and SB respectively at frame 80, 84, 88, and 92 respectively.

From frame 96 to 109 the girders are of the type W300 x10/ FL150 x 15, at positions 1.32m and 1.98m FCL PS and SB respectively. Beyond 109 are simple girders that can be designed from Nauticus hull scantling.

7.11. Description of Designed Tween Deck Girders

At frame 31 to 63 the girder types are W300x9 /FL 150x12 transverse at positions at frame 35,39,43, 51,55, and 59. The longitudinal types are W300x10/FL150x15 at position 1.32 and 4.62m FCL at PS and SB respectively.

While, the girders from frame 63 to frame77 are W250 x8/ FL150 x12 transversely positioned girder at frame 71 and 74.

The girders between frame 77 to frame 96, are W300x9/150x12 transverse and W300x10/FL150x15 longitudinal at position 1.32m and 4.62m FCL PS and SB, and transverse at frame 80,84, 88 and 92.

From frame 96 to 109, tween deck plating are with the longitudinal girder of W300 x10/ FL150 x15 and transverse of W300 x10/ FL150 x15. At positions 1.32m and 4.62m FCL PS and SB respectively, and transversely at frame 102.

7.12. Detail Description of Pillars and Webframes from 3D Beam

The pillars below the main deck are of the diameter and thickness, φ292x25 in frames 35, 43, 51, 59, 80, 88 at position 1320mm FCL PS, and SB respectively.

The span of the pillars at frame 35 is of length 5400mm, 43 is of length 5860mm, 51 is length 6200mm, 88 is of length 6200mm above the tank top to the main deck respectively. While the pillar at frame 80 is to the tween deck with length 3125mm.

And web frames at transverse bulkhead structure in frame 31, at a position 1320mm, 4620mm, 6600mm from centre line on port and starboard respectively, on frame47 at 1320mm, 4620mm, the size of the web frame is W250x20/FL150x20 at PS and SB, above the tween deck and W300x15/FL150x20 below the tween deck ,while at frame 51 and 59 the frame size is W250x12/FL150x15 at 6600mm PS and SP respectively.

Frame 96 the web frame is position at 1320mm, with size W125x15/FL150x15 above the tween deck and W250x15FL150x20.

Longitudinal bulkhead 6600mm FCL with mainframe of W250x12/FL 150x15 at frame 51,59,67,71,74, 80,84,92 ,99,102,105,112,116,120,from the tween deck to the tank top and W250x12/FL 120x15 above the tween deck to the cofferdam.

8. WEIGHT ESTIMATION OF OPERATION REQUIREMENT STRUCTURE AND COMPARISON WITH OPTIMIZED STRUCTURE

8.1. Weight of Section

The tool used for the scantling (Nauticus hull software) does not calculate the weight of the section, so this has to be done manually, to estimate weight of the section, the total solid is considered, by calculating the volume and multiplying with density of mild steel 7850kg/m^3, the ship material. The tool only give area for longitudinal member alone, the transverse area and volume has to be calculated manually see Annex 1,2,3and 4 for excel calculations for section of frame 63to 77, 30 to 40, 105 to 110,and 115to 125.

The longitudinal members volumes are estimated by multiplying the area (web x thickness) by the total length of the section.

Transverse member volumes are calculated thus:

1. Length of the transverse member x the web height x thickness x the number of frames (if found in each frame)
2. Total volume = volume of plates + volume of profiles + volume of bottom girders +volume of stringers + bulkheads volumes +volume of girders.
3. Mass in kg = total volume (m^3) x density of mild steel kg/m^3. ………...........(7.1)
4. Total mass = mass of transverse girder obtained from 3D beam calculations + (7.1)

For 3D mass estimation see appendices F1.

8.2. Results from Nauticus Hull Software

The figures and tables in this section present the result from the design. The convections used are positives for tension and negatives compression. For details see report from Nauticus hull in Annex A1, A2, A3, and A4.

8.2.1. Frame 65

Figure 8.1 shows the global stress distributions and table 8.1 and 8.2 presents the summary of result obtained from Nauticus hull for frame 65 in the moon pool region, for operation requirement structure and the optimized structure.

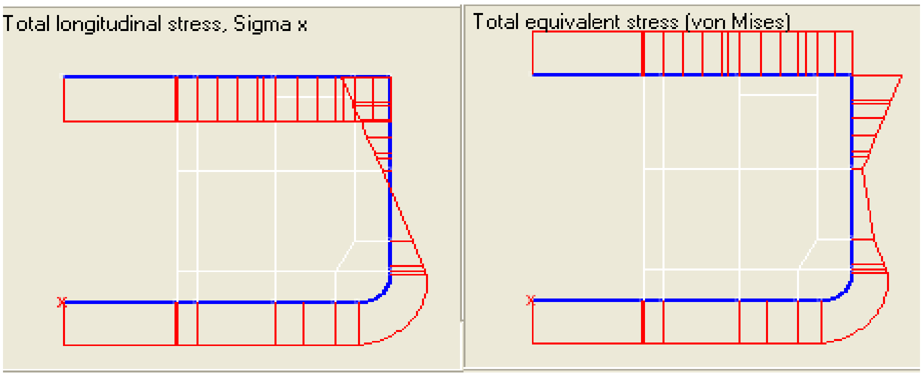

Figure 8.1Longitudinal and total equivalent stress distribution

Table 8.1 local stress in frame 65

global longitudinal stresses operation structure (N/mm^2)	Sagging	Hogging
	105.6	-97.5
Sagging(N/mm^2)	Bottom	Deck
	105.6	-98.6
Hogging (N/mm^2)	Bottom	Deck
	-97.5	91.0
global longitudinal stresses optimized structure (N/mm^2)	Sagging	Hogging
	123.1	-113.05
Sagging(N/mm^2)	Bottom	Deck
	123.1	-128.2
Hogging (N/mm^2)	Bottom	Deck
	-113.7	118.2

Table 8.1.2 Hull Girder Strength Summary frame 65

Parameters	**Operation requirement Structure**	**Optimized structure**
Mass of frame 30 to 40 (kg)	157806.2	130524.4
Moment of inertial (m^4)	12.972	10.676
Moment of inertial about the horz.Neutral axis, effective (m^4)	12.9772	10.676
Moment of inertial about the vertical.Neutral axis,efective (m^4)	84.178	75.060
Section modulus, deck line at z=8000mm) (m)	3.358	2.635
Section modulus bottom	3.135	2.704
Distance from AP to considered section(m)	39	39
Height from base line to the neutral axis (m)	4.137	3.948
Still water bending moment, sagging(KNm)	123804	123804
Still water bending moment hogging(KNm)	123804	123804
Wave bending moment sagging(KNm)	207420	207420
Wave bending moment Hogging (KNm)	181906	181906

8.2.2. Frame 31

This is a section aft the mid ship, figure 8.2 is the global stress table8.2 present the global bending moment at this section and table 8.2.2 shows the hull girder summary, for both the optimized structure and the operation requirement structure.

The figure 8.2 presents the longitudinal stress

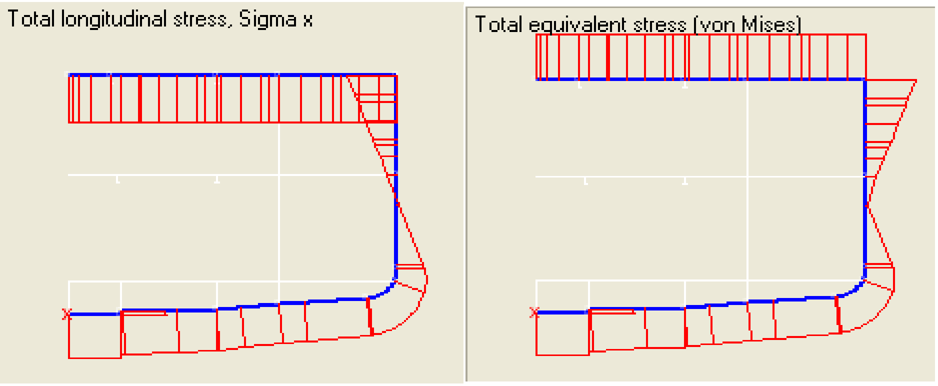

Figure 8.2 Longitudinal and equivalent stress distribution

Table 8.2 local stress in frame 31

global longitudinal stresses structure (N/mm²)	Sagging	Hogging
	50.2	-46.8
Sagging(N/mm²)	Bottom	Deck
	50.2	-54.5
Hogging (N/mm²)	Bottom	Deck
	-46.8	50.7
global longitudinal stresses optimized structure (N/mm²)	Sagging	Hogging
	56.7	-52.9
Sagging(N/mm²)	Bottom	Deck
	56.7	-61.1
Hogging (N/mm²)	Bottom	Deck
	-52.9	56.9

Table 8.2.2 Girder Strength Summary frame 31

Parameters	**Operation requirement Structure**	**Optimized structure**
Mass of frame 63 to 77 (kg)	86237.08	79346.56
Moment of inertial (m^4)	13.442	11.939
Moment of inertial about the horz.Neutral axis (m^4)	13.442	11.938
Moment of inertial about the vertical.Neutral axis (m^4)	56.983	51.789
Section modulus,	3.229	2.878

deckline(z=8000mm)		
Section modulus bottom	3.503	3.099
Distance from AP to considered section(m)	18.6	18.6
Height from base line to the neutral axis (m)	3.837	3.852
Still water bending moment, sagging(KNm)	77930	77930
Still water bending moment hogging(KNm)	77930	77930
Wave bending moment sagging(KNm)	97922	97922
Wave bending moment Hogging (KNm)	85878	85878

8.2.3. Frame 106

This is a section fore of the mid ship, table 8.3.1and 8.3.2 are the summaries of the hull girder strength for the operation requirement structure and the optimized structure in terms of the bending moment, section modulus, mass e.t.c, while figure 8.3 presents the stress distribution.

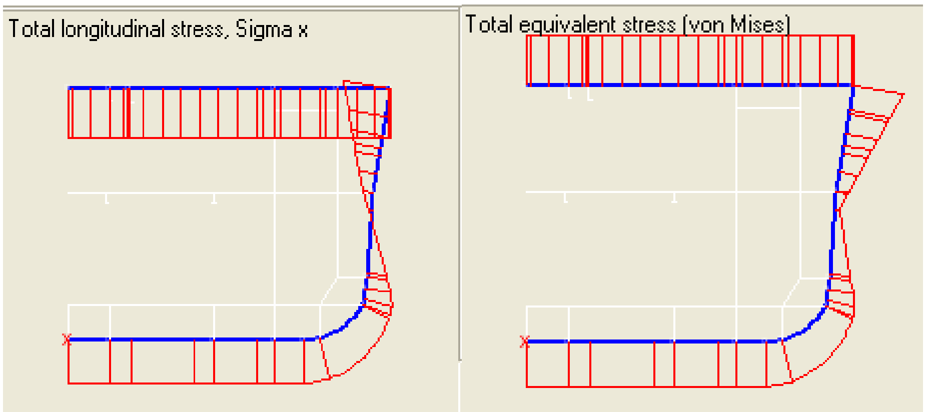

Figure 8.3 Longitudinal and equivalent stress distribution

Table 8.3.1 local stress in frame 106

global longitudinal stresses structure (N/mm^2)	Sagging	Hogging
	87.4	-80.9
Sagging(N/mm^2)	Bottom	Deck
	87.4	-99.8
Hogging (N/mm^2)	Bottom	Deck
	-80.9	92.4
global longitudinal stresses optimized structure (N/mm^2)	Sagging	Hogging
	94.4	-87.4
Sagging(N/mm^2)	Bottom	Deck
	94.4	-106.7
Hogging (N/mm^2)	Bottom	Deck
	-87.4	98.8

Table 8.3.2 Hull Girder Strength Summary frame 106

Parameters	**Operation requirement Structure**	**Optimized structure**
Mass of structure ,frames 105to 110 (kg)	46095.99	43039.59
Moment of inertial (m^4)	13.149	12.225
Moment of inertial about the horz.Neutral axis (m^4)	13.149	12.255
Moment of inertial about the vertical.Neutral axis (m^4)	65.295	62.2669
Section modulus,deckline(z=8000mm)	3.103	2.905
Section modulus bottom	3.490	3.24
Distance from AP to considered section(m)	64.8	64.8
Height from base line to the neutral axis (m)	3.768	3.782
Still water bending moment, sagging(KNm)	123804	123804
Still water bending moment hogging(KNm)	123804	123804
Wave bending moment sagging(KNm)	187334	187334
Wave bending moment Hogging (KNm)	164291	164291

8.2.4. Frame 121

Figure 8.4 shows the global stress distributions and table 8.4.1 and 8.4.2 presents the summary of result obtained from Nauticus hull for frame 121, for operation requirement structure and the optimized structure.

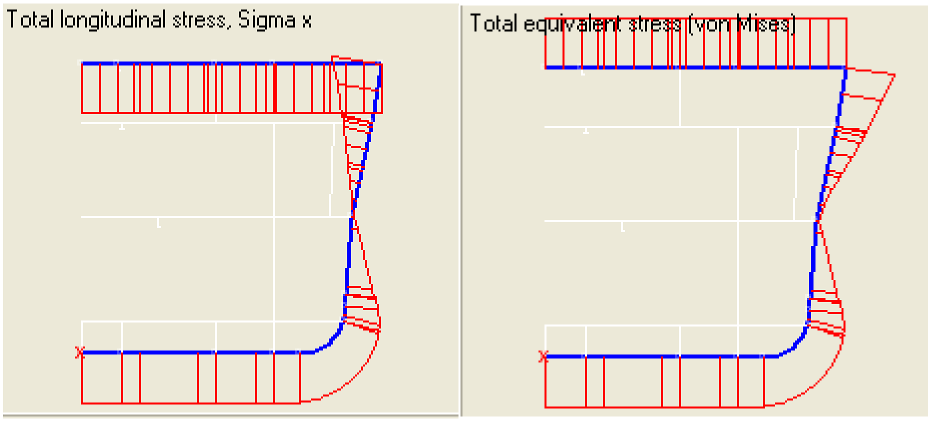

Figure 8.4 Longitudinal and equivalent stress distributions

Table 8.4.1 local stress in frame 121

global longitudinal stresses structure (N/mm^2)	Sagging	Hogging
	55.9	-51.8
Sagging(N/mm^2)	Bottom	Deck
	55.9	57.7

Hogging (N/mm^2)	Bottom	Deck
	-51.8	53.5
global longitudinal stresses optimized structure (N/mm^2)	Sagging	Hogging
	58.6	-54.4
Sagging(N/mm^2)	Bottom	Deck
	58.6	-58.6
Hogging (N/mm^2)	Bottom	Deck
	-54.4	54.3

Table 8.4.2 Hull Girder Strength Summary frame 121

Parameters	**Operation requirement Structure**	**Optimized structure**
Mass of structure, frame 115 to 125 (kg)	92844.25	91902.47
Moment of inertial about the vertical.Neutral axis (m^4)	63.36	63.151
Moment of inertial about the horz.Neutral axis (m^4)	20.543	19.907
Section modulus shelter deck z=10000(m)	4.052	3.989
Section modulus,deckline(z=8000mm)	6.657	6.650
Section modulus bottom	4.18	3.989
Distance from AP to considered section(m)	72.6	72.6
Height from base line to the neutral axis (m)	4.92	5.00
Still water bending moment, sagging(KNm)	95959	95959
Still water bending moment hogging(KNm)	95959	95959
Wave bending moment sagging(KNm)	137801	137801
Wave bending moment Hogging (KNm)	120852	120852

8.3. Remarks

The mass differences in percentage with respect to the operation requirement structural mass are presented in table 8.4.1 for each of the considered sections.

Table 8.4.1 percentage difference of mass

sections	Percentage difference of the optimized design structure to operation requirement structure (%)
Frame 30-40	-7.99
Frame 63-77	-17.28
Frame 105-110	-6.63
Frame 115-125	-1.01

In the fore part of the vessel where little or no offshore operation is done, the difference to the optimized structural mass is not much such as in frame 115-125.

However, in the region with opening, that is, the moon pool, a large difference is expected due to the large difference in the plate thickness. And also in the open deck in the aft of the moon pool. But the difference does not commensurate with the plate thickness because of the opening.

It is observed that position of the neutral axis for frame 63 to frame 77 operation requirement is high,closer to the deck, which give a higher section modulus at the deck .However, the high modulus is as a ressult of higher mass or thickness of the deck struture which reduces over time, durring the life cycle of the ship due to welding and unwelding activities of the offshore equipments, as explained earlier in chapter 3 section 3.1 paragraph 2. This area is less than 4% of the total deck area.

In addition, other parts of the structure is designed such that the bottom parts are stronger than the deck part, and the neutral axises are below the midle of vertical height from the base line, so the deck strain is higher than the bottom strain. Hence, buckling of the deck in sagging wave condition take place earlier than the bottom under hogging condition. So the ultimate hull girder strenght under sagging condition is lower than the hogging condition.

Finally, the longitudinal combined stress taken as the sum of hull girder and longitudinal bottom, side or deck girder bending stresses, is normally not to exceed 190f1N/mm^2 accordonig to DNV rules in part 3 chapter 1 section 12 B 400 406 [14], and the shear stress not to exceed 90f1N/mm^2 structure is found to have sufficient capability since the values does not far below this rules values.

9. CONCLUSSIONS AND RECOMMENDATIONS

9.1. Conclusions

The design tools used are appropriate, and Nauticus 3D beam software proved to be excellent tool for the finite element analysis since the meshing time is not required after defining the profile type.

In addition, the structure integrity conforms to the requirements of the classification society, the global strengths are found to be good for the operational use. And the structures, in general are found to have sufficient capability to withstand local loads and global loads.

Designing a multi-role support vessel requires experience and using an existing vessel as a reference is a good starting point.

Good designs of multi-role offshore vessels are not only to meet the minimum requirements stated by the classification society for ships, the operational and condition of services is of great influence on the design.

However, the design is such that, the region of the moon pool is exceptionally thick to meet her rugged offshore applications.

The objective function in the optimization is the weight and the constrain is the minimum rule thickness requirement.

Furthermore, the structures have little or no effect on the ability of the vessel to operate in 4m sea state or any other severe sea state, it the compensator in the crane winches that significantly influences this.

The weight of the vessel around the moon pool region is 173.95 tones and the neutral axis is 4.137m from the base line, at the frame 30 to 40 is 95.06 tones, with neutral axis height from the base line as 3.229m, at frame 105 to frame 110 is 49.23 tones with a neutral axis distance of 3.768m to the base line, and frame 115 to 125 is 102.34 tones with neutral axis at a position at 4.92m from the base line.

9.2 Recommendations

Since the section modulus at the bottom and the deck is above the rule for the optimized design, which implies that this design can be optimized further to save cost using an automatic optimization technique such as LBR-5 or any other optimization tools.

The double bottom strength assessment is another area that can be explore, and detail design of the Helicopter deck (Helideck), propulsion unit would be an interesting part to look into.

REFERENCES

[1]. DNV 2012 Rules for classification of ships *Offshore service vessels Tugs and Special Ships*, Det Norske Veritas, July.

[2]. Hughe O.F., 1988. ship structural design: A rationally based, computer-Aided Optimization Approach, *SNAME*, New Jersey.

[3]. Rigo, P. and Rizzuto, E., 2004. Analysis and Design of Ship Structure. In: *Ship design and construction*. SNAME, 18.1-18.9.

[4]. Yao Tetsuga., 2009. *Buckling/Plastic collapse behaviour and strength of ship structure* Osaka.

[5]. Paik J K and Mansour 1995 A simple formulation for predicting the ultimate strength of ships . *Marine Science and Technology*. 1, 52-62.

[6]. Rahman M. K and Chowdhury M. 1996 Estimation of ultimate Longitudinal Bending Moment of ships and Box Girders. *Journal of ship Research.* 40(3), 244-257.

[7]. DNV 2011 Offshore Standard DNV-OS-C101 *Design of Offshore Steel Structures, General (LFRD Method).* Det Norske Veritas, April.

[8]. Park, J. K, Thayamballi A.K and Jung S.C. 1996. Ultimate strength of ship hull under Combined Vertical Bending Horizontal and Shearing Forces, *SNAME* 104,31-59.

Veritas, April 2011.

[9]. DNV. 2001 Rules for classification of ships, *Hull Structural Design, Ships with Length less than 100 metres* Det Norske Veritas, January.

[10]. Worldyards. 2011 Offshore Segment *Definitions for Offshore Vessels and Structures* ‘February.

[11]. Park, J. K et al 2011. Modified Paik-Mansour formula for ultimate strength calculations of ship hulls. *In*: Mansour A.E. and Caldwell J.B., eds. *Proceedings of MARSTRUCT 2011*, Hamburg, Germany.

[12]. Rigo P, 2011. A Module-Oriented Tool for Optimum Design of Stiffened Structures, *Marine Structures*, 14(6): 611-629.

[13]. Overview of Offshore support vessels Available from http://www.slideshare.net/thtsai77/overview-offshore-support-vessels-final-presentation-863127

[14]. DNV 2011 Rules for classification of ships, *Hull Structural Design, Ships with Length 100 metres and above*, Det Norske Veritas, July.

Appendices

F1. Nauticus 3D beam mass calculation

from 3D beam mass estimations

mass frame 30-40 = 617+ 463+308+154+126+629+503+629+378+252+771x2= 5601 kg

mass frame 63-67 = 491+491+491+491 =1964 kg

mass frame 105-110 = 212+420+240+420+212+120 =1624 kg

frame 115-125 = 115 +344+ 115= 574 kg

fomular for scantling

F2. Plating thickness.

For plating exposed to lateral pressure the thickness requirement is given as function of nominal allowable bending stress as follows:

$t= t_k+ (15.8k_a s\sqrt{P})/\sqrt{\sigma}$

k_a = correction factor for aspect ratio of plate field

$= (1.1 - 0.25 s/ l)^2$

= maximum 1.0 for s/ l = 0.4

= minimum 0.72 for s/ l = 1.0

s = stiffener spacing in m. l = stiffener span in m. P = design lateral pressure in kN/m^2. σ = Von mises tress t_k = corrosion addition.

The thickness is not to be less than:

$t = 5,0 + 0,04 L + t_k$ (mm) bottom and bilge plate

$t = 7,0 + 0,05 L + t_k$ (mm) for keel plate

$t=t_0 + 0,03 L + t_k$ (mm) inner bottom plate

$t = 5,0 + k L + t_k$ (mm) side strucure

$t=t_0 +kL+t_k$ (mm) deck plate

$t = 5,0 + k L + t_k$ (mm) bulkhead plates

t_o= 5,5 for unsheathed, weather and cargo decks

=5 for accommodation deck weather cargo

K = 0.02 in vessels with single continuous deck

= 0.01 in vessels with two continuous decks above 0,7 D from the baseline

F3. Web and flange

The thickness of web and flange is not to be less than the

Larger of:

$t = 5,0 + 0,02 L + t_k$ (mm) …..bottom structure

$t=t_k+h/g$

$t = 5,0 + k L + t_k$ (mm) …..deck

$t = t_k + h/g$

$t = 5.0 + k L + t_k$ (mm) …. side structures bulkhead

$t = t_k + h/g$

k = 0.01 in general;= 0,02 in peaks and in cargo oil tanks and ballast tanks in cargo area

h = profile height in mm

g = 70 for flanged profile webs

= 20 for flat bar profiles

F4. Simple Girder thickness

The web plate thickness and the thickness of flanges, brackets and stiffeners on girders is not to be less than:

$t = 5.0 + k L + t_k$ (mm)

k = 0.03 for peak tank girders

= 0.02 for girders in cargo/ballast tanks in liquid cargo tank areas

= 0.01 for other girders and for stiffeners on girders in general.

Mainframe

$Z = 0{,}55\, l^2$ spwk (cm3) and

k = 6,5 for peak frames

= 4,0 for ' tween deck frames

The section modulus requirement is given by the greater of

$Z = 0{,}5\, l^2$ spwk (cm3) side structure

$Z = 6.5\sqrt{L}$ (cm3 =)

F5. Shear force diagram