Structural design of a container ship approximately 3100 TEU according to the concept of general ship design B-178

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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

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Szczecin, February 2012

ABSTRACT

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By **Wafaa Souadji**

The initial design stage is crucial for the ship design, including the ship structural design, as the decisions are here taken fundamental to reach design objectives by establishing basic ship characteristics. Consequently, errors which may appear have the largest impact on the final design. Two main aspects related to the design of structures are typically addressed in the initial design: analysis of strength and cost estimation.

The design developed in the dissertation is based on the conceptual design of general containership B-178 built in the Stocznia Szczecińska Nowa, providing its main particulars, hull form as well as the general arrangement.

The general objective of the thesis is to carry out the hull structural design based on the functional requirements of the containership. The design was developed according to the Rules and Regulations of Germanischer Lloyd.

The thesis is started with definition of the structural concept of one complete cargo hold located at midship. At this stage the topology of the structure, which comprises location of primary and secondary structural members, including their material, was carried out by highlighting first the important factors which may affect the dimensioning of structural members such as defining the unit cargo, the stowage of containers inside holds, their securing and handling devices. Afterwards, the numerical structural model was build using the Poseidon ND 11 computer code to evaluate the scantlings of the structural members under the design criteria loads. Two approaches were considered; the first one analytical, where dimensioning of the structural elements has to conform the requirements of the GL rules. The structural mass was estimated, location of centre of gravity, section modulus, moment of inertia, was also calculated. In the second approach direct calculations are carried out with the use of the finite element method to verify the ship hull strength under the selected load cases. It was carried out by introducing the model resulting from the first approach, defining the boundary condition, adjustment of the global load cases and finally the evaluation of the results.

Another analysis using the finite element method was made to verify the structural strength of one complete watertight bulkhead subject to flooding. It was performed using another FE model in the GL frame software, based on the beam theory. The evaluation of results indicated the necessity of application of the high tensile steel for the structural elements of the bulkheads.

Drawings of the midship section, bulkheads as well as longitudinal section of one complete cargo hold located in the middle of the ship as well as technical description are also given in the dissertation. The 3D visualisation of a part of the ship located in the middle of the ship using the Tribon software is also presented.

CONTENTS

LIST OF SYMBOLS

a_v	Acceleration vector
B	Moulded breath of the ship, m
C_B	Block coefficient of the ship
D	Depth of the ship, m
g	Gravitational acceleration, m/s²
f_Q	Probability factor for a straight-line spectrum of seaway-induced loads
f_F	Weighting factor for the simultaneousness of global and local loads
k	Material factor
L_{oa}	Length over all of the ship, m
L_{pp}	Length between perpendicular of the ship, m
M_{ST}	Static Torsional moment, N.m
M_{WT}	Torsional moment coaming from Wave, N.m
M_{SW}	Still Water vertical bending moment, N.m
M_{WV}	Vertical bending moment coaming from Wave, N.m
M_{WH}	Horizontal bending moment coaming from Wave, N.m
M_{xx}	Torsional moment around the X-axis, N.m
M_{yy}	Bending moments around the Y-axis, N.m
M_{zz}	Bending moments around the Z-axis, N.m
q_i	Distributed force, KN/m
R_{eH}	Yield stress, N/mm²
t	Thickness, mm
t_{red}	Reduced thickness, mm
T	Draught scantling, m
V	Service speed, m/s
X_A	Frame at where the engine room front bulkhead is located
W	Section modulus, m^3
τ_L	Shear stress, N/mm²
σ_L	Normal stress, N/mm²
σ_v	Von Mises stress, N/mm²
σ_y	Normal stress component in the transversal direction, N/mm²
σ_x	Normal stress component in the longitudinal direction, N/mm²

LIST OF ACRONYMS

ABS	American Bureau of Shipping
GL	Germanischer Lloyd
IACS	International Association of Classification Societies
IMO	International Maritime Organisation
ISO	International Organization for Standardization
NKK	Nippon Kaiji Kyokai
SOLAS	IMO convention for Safety Of Life At Sea

LIST OF ABBREVIATIONS

DK_1	Upper Deck
DK_2	Second Deck
DK_STO	Deck Stool
IB	Inner Bottom
LB_1	First Longitudinal Bulkheads located at y = 14100 mm
LB_2	Second Longitudinal Bulkheads located at y = 11550 mm
LG_00	Longitudinal Girder N °1, at the centre line
LG_02	Longitudinal Girder N °2, at Y = 1350 mm
LG_05	Longitudinal Girder N °2, at Y = 3900 mm
LG_08	Longitudinal Girder N °1, at Y = 6450 mm
LG_11	Longitudinal Girder N °1, at Y = 9000 mm
LG_14	Longitudinal Girder N °1, at Y = 11550 mm
LG_17	Longitudinal Girder N °1, at Y = 14100 mm
LS_1	Longitudinal Stringer N °1, at Z = 4295 mm
LS_2	Longitudinal Stringer N °2, at Z = 6890 mm
LS_3	Longitudinal Stringer N °3, at Z = 9485 mm
LS_4	Longitudinal Stringer N °4, at Z = 12080mm
CO_1	Vertical plate of the Coaming
CO_2	Top Coaming
Shell	Outer Shell
Bottom	Outer Bottom
FL1	Plate of the Floor limited by LG_00, Shell, LG_02 and IB
FL2	Plate of the Floor limited by LG_02, Shell, LG_05 and IB
FL3	Plate of the Floor limited by LG_05, Shell, LG_08 and IB
FL4	Plate of the Floor limited by LG_08, Shell, LG_11 and IB
FL5	Plate of the Floor limited by LG_11, Shell, LG_14 and IB
FL6	Plate of the Floor limited by LG_14, Shell and IB
WF1	Plate of Web Frame limited by LG_17, Shell and LS_1
WF2	Plate of Web Frame limited by LS_1, Shell, LS_2 and LB_1
WF3	Plate of Web Frame limited by LS_2, Shell, LS_3 and LB_1
WF4	Plate of Web Frame limited by LS_3, Shell, LS_4 and LB_1
WF5	Plate of Web Frame limited by LS_4, Shell, DK_2 and LB_1
WF6 or PW	Plate of Web Frame (Passage Way) limited by DK_1, Shell, DK_2 and LB_1
WF7	Plate of Web Frame limited by LS_1, LB_1, IB and LB_2
WBH	Watertight Bulkhead
NWBH	Non Watertight Bulkhead

LIST OF FIGURES

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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 the West Pomeranian University of Technology, Szczecin.

Date: *Signature*

15/01/2012 Souadji

1. INTRODUCTION

1.1. Background

1.1.1. Marine Structural Design

Ship structural design represents one of the most challenging tasks during the ship design process, as in the preliminary design phase certain basic objectives must be fulfilled. One of the most important objectives is to ensure that the ship structure being designed is capable of withstanding the different kind of loading acting on it in all time of service. Another very important objective is to design the hull structural members as economically as possible.

Design of the ship hull structure is a very important part of the ship design as a whole. It is especially important at the initial stages of the ship design when the basic characteristics of the ship are defined. The typical ship hull structural design involves through distinct phases: project requirements, structural material, structural topology, and analysis of structural strength.

The ship project starts with series of requirements specified by the owner, where the intended service and the specifications of the ship are well clarified.

Afterwards the process of structural design begins by selecting the structural materials, the size and the arrangement of the structural members.

The actual structure is subjected to many types of loading: deadweight, cargo, ballast, and fuel, equipment resulting in the shear forces, bending moments and torsional moment acting in the ship hull girder. The structural strength of the ship hull structure should be verified against all these types of loading; internal forces in the girder at the level of overall capacity and external loading at the level of local strength and the strength of the primary girder systems. Hence the next step in the structural design is the evaluation of all of these loads. In fact the knowledge of the basic concepts of waves, motions and design loads are essential for the design because it defines the behaviour of the environment where the ship will navigate.

Once the structural topology is specified and the load is calculated, an initial scantling of the structural members may be identified based on the classification societies rules. The initial structural members scantling is determined based on stress analysis of beams, plates and shells under hydrostatic pressure, bending and concentrated loads. Three levels of marine structural design have been developed:

- design by rules;
- design by analysis ;
- design based on performance standards.

Traditionally the structural design of ships has been based primarily on rules formulated by the classification societies on the basis of experience employing empirical equations, sometimes referred to as "rule of thumb". However with the increasing sizes of ships since 1970, there were no existing rules to guide the designer who looked forward to the methods based on first principles. It was necessary to search for a new tool capable to assess and analyze the structure of the ship, the formulas based on rules and empirical studies have been followed by direct calculations of hydrodynamic loads and finite element analysis.

The analysis using the finite element method allows knowing the deflections and the distribution of the stresses over the hull structure which may verified against the permissible stresses. Hence, at this stage changes in the material used and the sizing of the structural elements can be made in certain structural regions which need to be more strengthened.

The structural design is an iterative process; the analysis can be proceeding until reach satisfactory scantling which fulfils the project criteria. Therefore the structure is ready for the final design and can be presented for the fabrication and the construction.

1.1.2. Approach for Structural Design of Container Ships

Due to the property of the intended service of the containership which is built specially to carry containers, there are many factors which influencing the dimensioning and the arrangement of the hull structural members. The selection of the structure is mainly affected by the size and the stowage of containers.

The structure of the containership is characterized by large deck opening; hence the hull girder strength cannot be treated in the traditional way by taking only into account the vertical bending moment and the shear forces. Other loads strongly affect the deformation and stresses of the ship hull girder: the internal forces such as the torsional moment as well as the horizontal bending moment, and the external load represented by the external water pressure and cargo loads.

1.2. Objective

The general objective of the thesis is to carry out the hull structural design of a containership has a capacity of 3100 TEU. The presented design is based on the general design of the containership B-178 built in Stocznia Szczecińska Nowa, providing its main particulars, hull form as well as the general arrangement.
The dissertation proceeds throughout a set of steps in where the following secondary objectives are attained.

- ✓ Selection of the structural concept of one complete cargo hold located at the middle of the ship. At this stage the structural material as well as the structural primary members are selected.

- ✓ Performing of the structural members' scantling according to GL rules, with the assistance of Poseidon computer code where two approaches are considered pre-sized structure according to construction rules and pre-sized structure according to first principle. The building of the structural model is based on the structural concept.

- ✓ Estimation of the hull steel mass;

- ✓ Providing the technical description as well as the drawings of the midship section, bulkheads, longitudinal section. Use of Tribon software for the visualisation in 3 D of a part of the ship located in the middle.

1.3. Thesis Outlines

The present dissertation consists of ten sections including necessary background and objectives in Section 1.
Sections 2 and 3 are dedicated to the state of the art of the design of containerships summarized from a literature review: Section 2 contains general information about the types of containership, freight containers as well as stowage method of containers; section 3 highlights the design aspects of the containership hull structures.

The general arrangement, main dimensions as well as the technical description of the containership B-178 is given in Section 4.

Section 5 covers the selection of the structural topology, including the material and the arrangement of the primary structural members.

In the Section 6, the structural model is build based on the structural topology selected in Section 5, and the initial scantling according to the GL rules is obtained after iterative process in Poseidon software. Estimation of the mass of hull steel is also given in this section.

Two finite element analyses are carried out in the section 7: the analysis of the structure of one complete bulkhead in order to verify the strength of its primary members against the flooding condition; the cargo hold analysis to check the adequacy of the structural members scantling resulted from Section 6 under two load cases: Homogeneous 40 ft containers and heavy 20 ft containers.

Section 8 contains the 2D and 3D views of the midship section realized with the assistance of Tribon software.

Section 9 contains the necessary structural technical description resulted from the previous sections.

Finally conclusions are provided in Section 10.

References, Appendixes including the drawing plans are provided in the end of the presented dissertation.

2. OVERVIEW OF CONTAINERSHIPS AND FREIGHT CONTAINERS

2.1. Developments of Containership Concept

In the 1960's and 1970's remarkable changes in the design of general cargo ships took place. The relatively small hatches of the cargo holds became larger and larger, so that finally these cargo ships could only be designated as "open deck" ships. One great advantage of these “open” container ships is the fact that all the containers carried are in cells and no lashing is needed. A second advantage is the fact that no time need to be spent for the opening and the closing of hatch covers. The absence of hatch covers lowers the centre of gravity of the upper tiers of containers enabling more of these to be carried within a stability limit. There is a cost saving for the hatch covers but this is offset by the cost of the increased depth of the ship and of the additional safety features required (Watson, 1998).

The "open deck" cargo ship type was proposed much earlier, e.g. by Wendel already in the 1950's (Wendel, 1958), but its feasibility was doubted, particularly with respect to structural problems.

Finally, the introduction of containers in the 1960's as well as the establishment of calculation methods, especially the finite element method, supported the development of "open deck" ships. In just a few years evolved into three "generations" of container ships up to 3,000-TEU Panamax container ships (Albert, 1978). Nowadays the largest new-Panamax containership has a carrying capacity of over 14000 TEU, and even the ultra large container vessels are well over the class of the new Panamax containership by the carrying capacity higher than 15000 TEU (http://en.wikipedia.org/wiki/Container_ship).

2.2. Containerships Definition and Types

Containership is specifically build for transporting containers inside cargo holds and exposed deck. Containerships can be categorized by ship size, container stowage methods, loading and unloading facilities, etc (Nippon Kaiji Kyokai, 2009).

The typical categories of containerships are:

1) Categorization by ship Size:

These containerships are known as *big intercontinental containerships*, divided into:

a) Ultra large containerships (http://en.wikipedia.org/wiki/Container_ship): Containerships with dimensions over the limits of the new Panamax containerships, their length is about 397m, breadth 56m, and draft of 15.5m. These types of containerships, which are of the *Emma Maersk* class, are able to carry over 15,000 TEU of capacity.

Figure 2.1. Ultra large containerships. Available from http://en.wikipedia.org/wiki/File:Edith_Maersk_Suez.jpg [Accessed 22 October 2011].

b) Over- Panamax type containerships: These ships are too large to pass through the Panama Canal. An over-Panamax ship with a breath of around 40 m is capable of stowing up to 18 rows of containers on the exposed deck and up to 16 rows in cargo holds. Their capacity is 4,000 TEU. A new Panamax with breadth of 43m able to carry from 10,000 to 14,500 TEU.

c) Panamax Type containerships: Containerships that have a maximum width (less than 32.25 m) capable of passing through Panama Canal. These ships can normally stow containers between 2,000 TEU to 3,500TEU. Up to 13 rows of containers and 5 tiers can be stowed on exposed deck, inside holds up to 11 rows and 8 tiers.

Figure 2.2. Panamax Type containerships, Norasia Polaris. Availble from http://shumsw5.tripod.com/norasia/norasiapolaris050406.jpg [Accessed 22 October 2011].

d) Feeder containerships: Containerships feeders are small or medium-sized ships starting at 200 TEU that specialize in transporting cargo from small ports to large ports and vice versa, or for use in services which are not profitable for the larger container vessels. The feeders may be equipped with cargo gear. Often, multipurpose ships are employed as container feeders (Van Dokkum, 2003).

Figure 2.3. Container feeder. (Van Dokkum, 2003).

2) Categorization by loading and unloading facilities:

a) Containerships with cargo gear: The majority of this type of containership can stow containers less than 3,000 TEU. These containerships have cranes such as jib cranes for cargo handling.

b) Gearless containership: This type of containership is not installed with onboard cargo handling cranes, see Figure 2.4. Containers are handled by the cargo handling equipment located on the quays of container terminals.

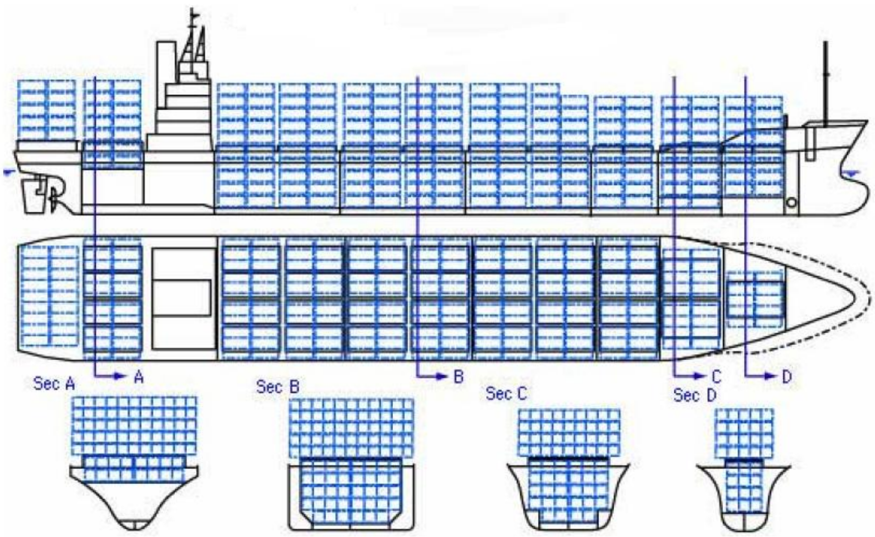


Figure 2.4. Gearless containerships. (Nippon Kaiji Kyokai, 2009).

c) Hatch coverless containerships or Open-Top containerships: This type of containership is not equipped with any hatch covers expect in the ship bow as shown in Figure 2.5. In this type of ship, containers stowed on the exposed decks are fixed by cell guides which are installed insides holds from the inner bottom to the uppermost container tier level. The advantage of this kind of containership is the reduction of the work required for the lashing system and the opening and the closing of the hatch cover, in addition to the efficiency of the cargo handling devices because of the easing of the constraints on the mixed stowage of high-cube containers.

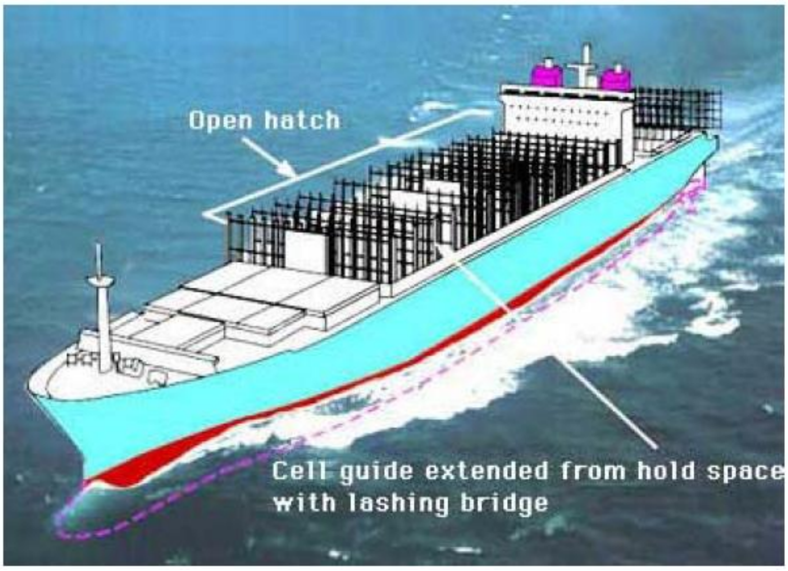


Figure 2.5. Open top containership. (Nippon Kaiji Kyokai, 2009).

2.3. Fright Containers

Containers used for marine transportation are defined according to the terms and definitions provided by the International Organization for Standardization (ISO). Table 2.1 contains a brief description of the principle terms and definitions specified by ISO for shipping containers.

Table 2.1. Terms and definitions of containers; according to (Nippon Kaiji Kyokai, 2009)

Terms	Definitions
General cargo container	Freight container that is not intended for use in air transport, Primary intended for The carriage of a particular category of cargo such as a cargo, requiring temperature control, liquid or gas cargo, dry solids in bulk or cargoes such as automobiles (cars) or livestock.
General purpose container	General cargo container which is totally enclosed and weather-proof, all its side and end walls are rigid including the floor and roof, at least one of its ends should equipped with doors. This kind of container is intended to carry cargo of greatest possible variety.
Specific-purpose container	General cargo container that has constructional features either for the "specific purpose" of facilitating packing and empting other than by means of doors at one end of container, or for other specific purposes such as ventilation.
Open-top container	Specific-purpose container that has no rigid roof but may have a flexible and movable or removable cover, made e.g. of canvas or plastic or reinforced plastic material, normally supported on movable or removable roof bows.
Platform Container	Specific purpose container that has no superstructure whatever, but has the same length, width, strength requirements and handling and securing features as required for interchange of its size within the ISO family of containers.
Platform-based container with incomplete superstructure and fixed ends	Platform-based container without any permanently fixed longitudinal load-carrying structure between ends other than at the base.
Thermal container	Freight container built with insulating walls doors, floors and roof, designed to retard the rate of heat transmission between the inside and the outside of the container.
Refrigerated container	(1) Mechanically Refrigerated Container: Thermal container fitted with a refrigeration unit and a heat-producing appliance. (2) Refrigerated and Heated Container: Thermal container fitted with a refrigerating appliance (mechanical or expendable refrigerant) and heat-producing appliance.
Tank container	Freight Container comprises two basic elements, the tank or tanks and the framework.

Figure 2.6 shows some of the types of containers defined in Table 2.1.

a) 20 ft Dry cargo ISOcontainer

b) 20 ft open top ISO container

c) 20ft Refrigerated ISO container

d) 20 ft container Flat Rack

Figure 2.6. Types of containers. Available from http://www.francecontainertrading.fr/htfr/0003.htm [Accessed 23 October 2011].

2.4. Containership General Arrangement

The general arrangement of the containerships is affected by several factors as the size of containers, the containers handling facilities, etc. For self-sustaining feeder ship, under the exposed deck the hull is divided into compartments by watertight bulkheads. The compartments which are located from the collision bulkhead till the front bulkhead of the engine room are specified to the cargo containers, they are known as cargo holds. The superstructure is situated above the aft peak in the aft part of the containership, as depicted in Figure 2.7, which is different in the case of mid-size container ship where the superstructure located straight above the engine room, as depicted in Figure 2.8. The structure of the watertight bulkheads is generally extended over four or five frames to give the possibility to the installation of the handling devices such as the cranes, as shown in Figure 2.7, the contrary for the mid-size containership where there is no handling devices, see Figure 2.8.

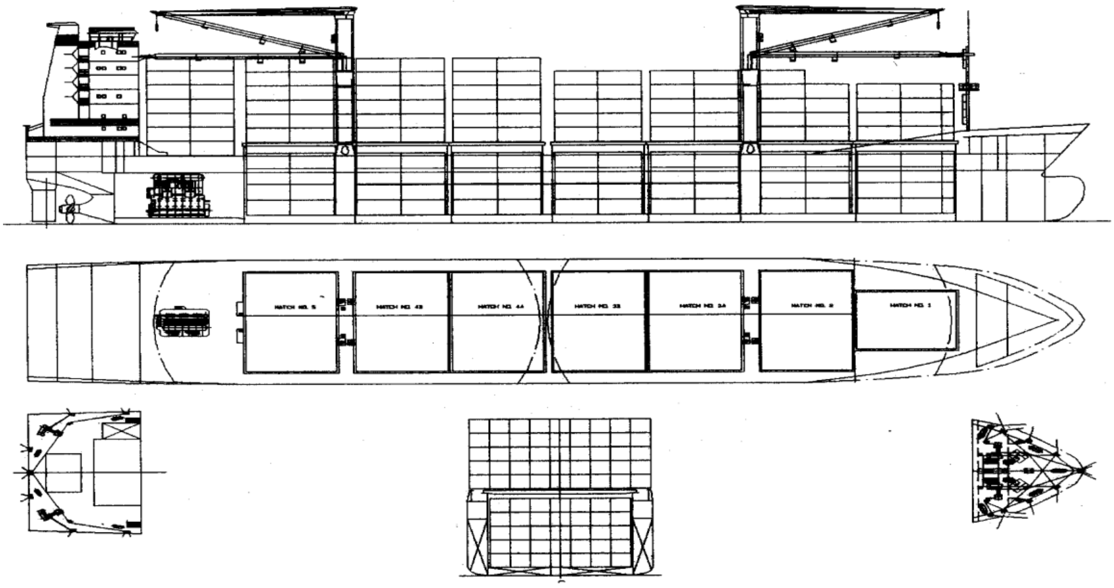


Figure 2.7. Self-sustaining feeder ship. (Zink and Van Rynbach, 2004).

For the big Post Panamax containers ships the superstructure, located above the engine room, is moved a bit towards 1/3 the length of the ship to improve the navigation bridge visibility, as is shown in Figure 2.9, so that other compartments can be dedicated to the stowage of cargo containers in the aft part of the ship between the aft peak and the engine room

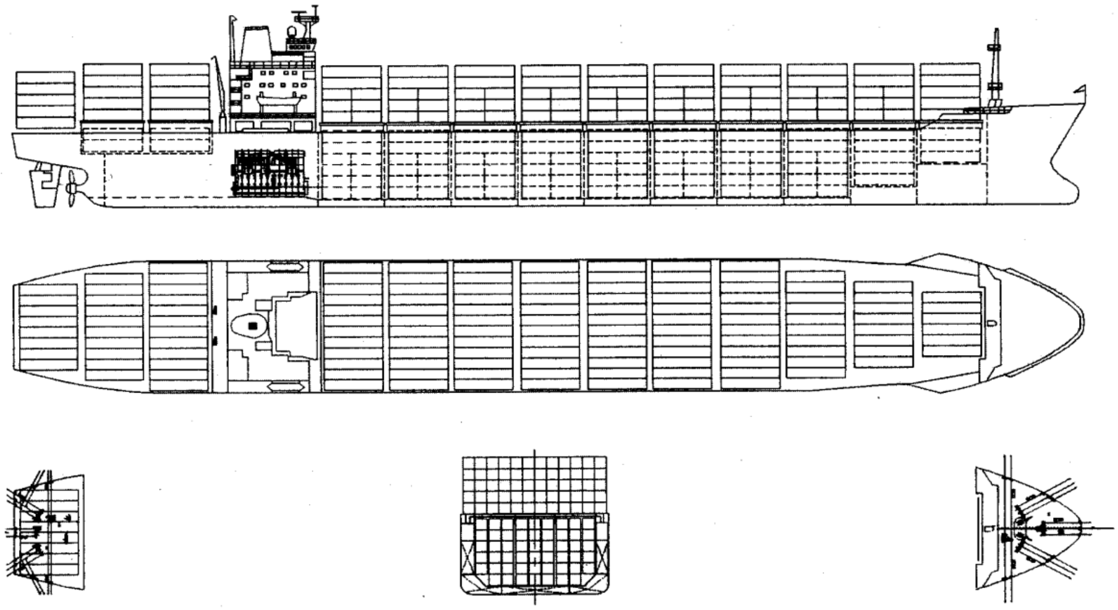


Figure 2.8. Mid-size containership. (Zink and Van Rynbach, 2004).

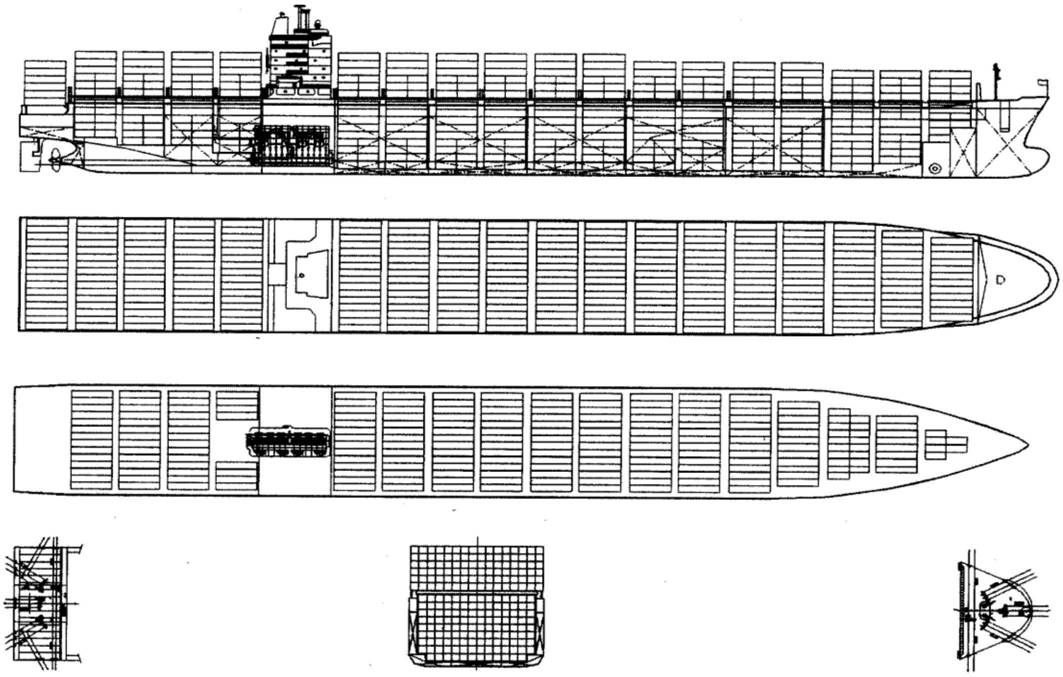


Figure 2.9. Post-Panamax size containership. (Zink and Van Rynbach, 2004).

2.5. Containers Stowage Method and Securing

2.5.1. General

Containerships take maximum advantage of space inside holds and on the exposed deck for the stowage of containers. Figure 2.10 shows the stowage of containers for a typical containership.

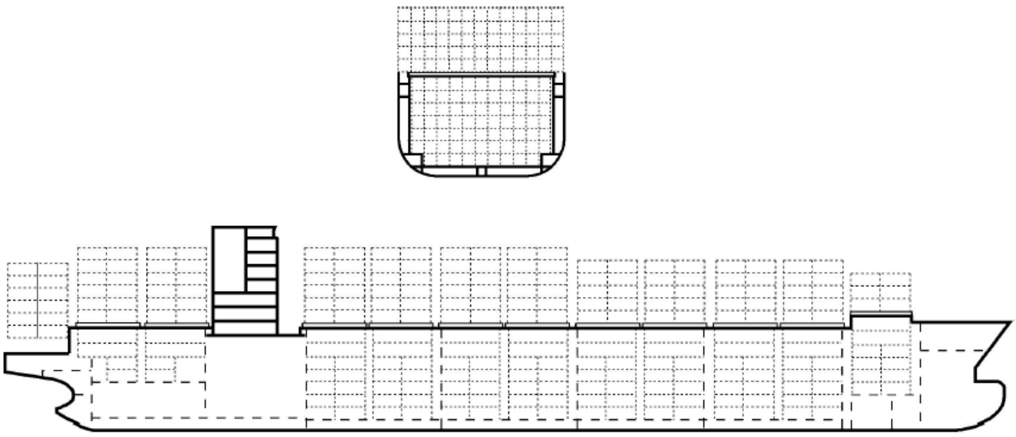


Figure 2.10. General view of a typical container carrier. (IACS, 2005).

The stowage of containers on board the ship is depended on the principle of bay-row-tier coordinates which is a system of numerical coordinates related to the length, breadth and height (http://www.containerhandbuch.de/chb_e/stra/stra_01_03_03.html), see Figure 2.11. The stowage space of the container on board the ship is unambiguously stated in numbers and is (almost always) recorded in the shipping documents. It is then also possible to establish at a later date where the container was carried during maritime transport. According to this principle, bays are the container blocks in the transverse direction, rows are the lengthwise rows and tiers are the vertical layers.

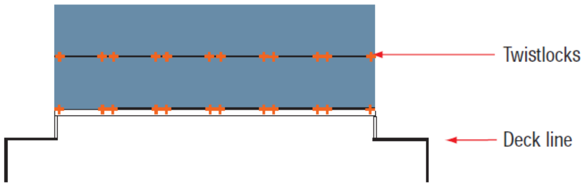
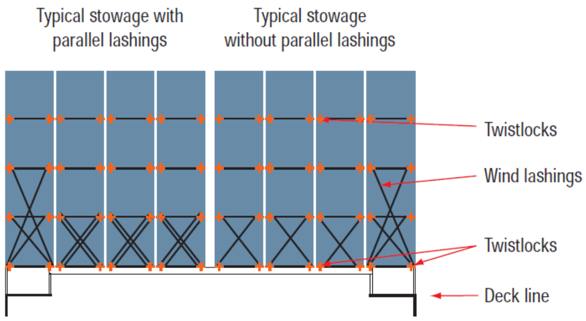
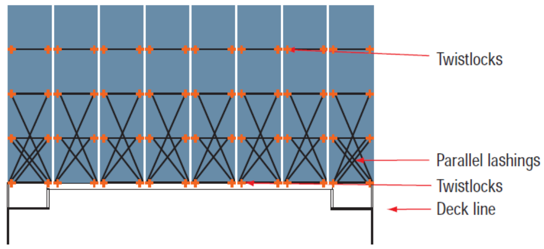
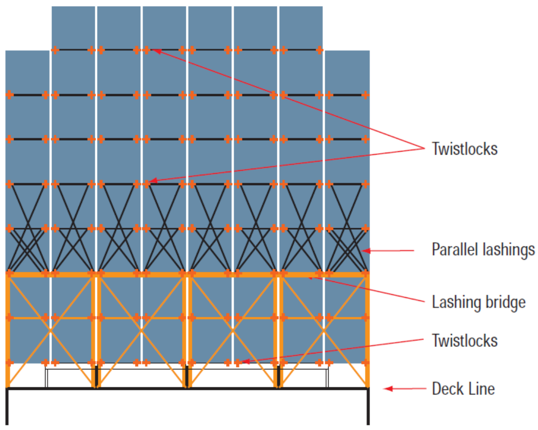
Figure 2.11. Principle of bay-row-tier coordinates; Available from http://www.containerhandbuch.de/chb_e/stra/stra_01_03_03.html [Accessed 10 November 2011].

2.5.2. Stowage of Containers on the Exposed Deck

Above the weather deck, containers are typically stowed in stacks in the longitudinal direction. The stacks are spaced about 20 to 25 mm apart as well as athwartship. Containers stacks may be secured in order to prevent them from moving and falling down. The most common method utilizes lashings to secure each stack independently. There are a variety of lashing methods; most of them are listed in Table 2.2. A detailed description of the lashing components is provided in the sub-section 2.5.4.

Containers stowed on exposed decks need to be stowed in such a way so that they do not hinder vision from the Navigation Bridge (Nippon Kaiji Kyokai, 2009). The requirements regarding navigation bridge visibility are specified in SOLAS. In Figure 2.12 the area designated by A is to be ensured by more than two ship lengths, or 500 m. Additionally to SOLAS requirements, there are also requirements regarding navigation bridge visibility for navigation through the Panama Canal, which are stricter than the SOLAS requirements.

Table 2.2. Lashings methods. (Lloyd Register, 2011)

Lashing methods	Description
	Containers secured by Twistlock. Usually for two tiers only
	Containers secured by Twistlock and Lashing Rod. Lashing rods to bottom of second tier. Wind lashings to bottom of third tier.
	Containers secured by Twistlock and Lashing Rod. Lashing rods to bottom of third tier.
	As described above, but lashings originate from a Lashing Bridge. Lashing rods to bottom of fifth tier.

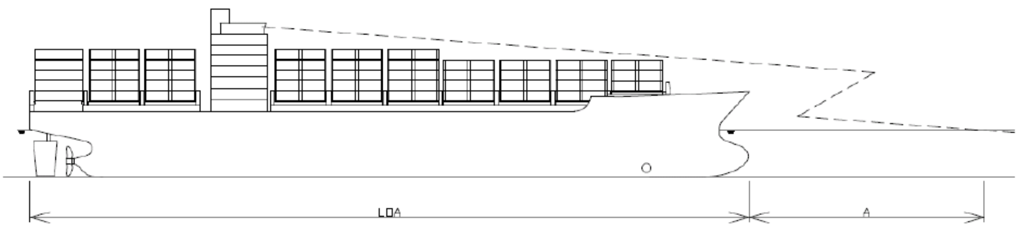


Figure 2.12. Navigation bridge visibility. (Nippon Kaiji Kyokai, 2009).

2.5.3. Stowage of Containers in Side Holds

In recent years, the cargo holds in most of containerships are designed to the carriage of 40 ft containers, means the length of one cargo hold, limited by two watertight bulkheads, is equivalent to the length of 40 ft container. Containers are stowed using cell guides. The cargo hold space provided for the stowage of 40 ft bays gives the possibility to stow two bays of 20 ft containers in the longitudinal direction. In this case, according to (Nippon Kaiji Kyokai, 2009) the containers corners which are not supported by cell guides need to be fixed using container guides and stackers in order to prevent the horizontal movement of containers. In addition, at least one or more tiers of 40 ft containers are generally stowed on the top of 20' containers stacks to prevent the deformation of 20 ft containers. Figures 2.12, 2.13 and 2.14 show different possibilities of the stowage of 40 ft and 20 ft containers inside holds of 40ft container bay.

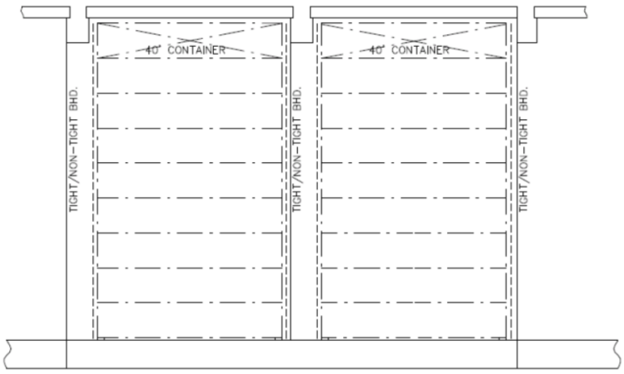


Figure 2.13. Stowage example of 40ft containers into 40ft container bays.
(Nippon Kaiji Kyokai, 2009).

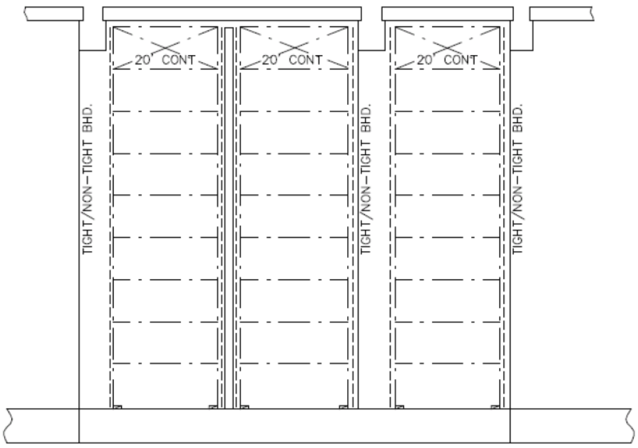


Figure 2.14. Example of 20ft container into 20ft container bays.
(Nippon Kaiji Kyokai, 2009).

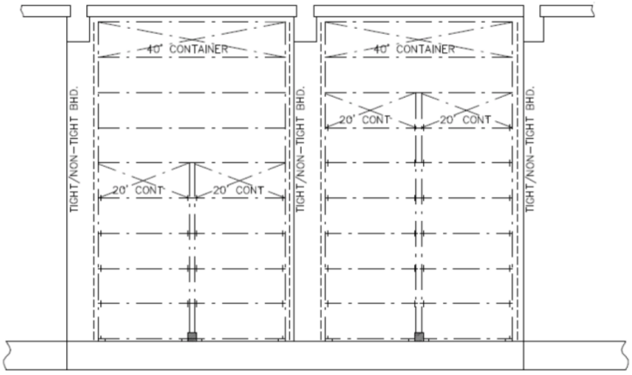
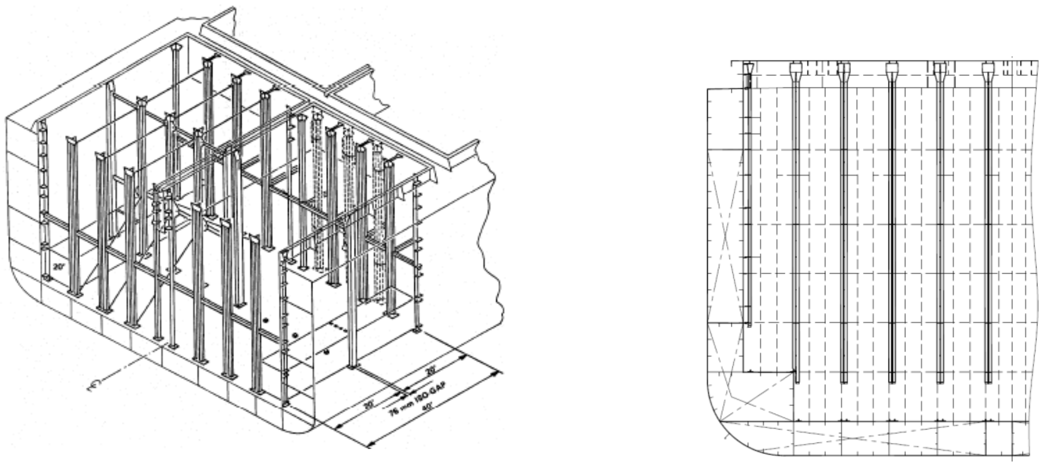


Figure 2.15. Stowage example of 20ft container and 40ft container into 40ft container bays. (Nippon Kaiji Kyokai, 2009).

Container cell guide systems may include features to provide flexibility for stowing different size containers. Moveable cell guide structures may be installed to enable alternate length stowage, as is shown in Figure 2.16a.

A typical cell guide system consists of groups of four vertical guides constructed from steel angle bars into which the containers are lowered running the full depth of the vessel from hatch coaming level down to the top tank. The Typical hold cell guide arrangement is shown in Figure 2.16b.



a) b)

Figure 2.16. a) Cell guide arrangement for the stowage of 20 ft and 40 ft containers. b) Typical hold cell guide arrangement. (American Bureau of Shipping, 2010).

2.5.4. Securing Devices

Deck container-securing systems are most often comprised of fixed and portable lashing fittings that restrain the container stacks from tipping and from translation in the horizontal plane. Securing components for the stowage of containers inside holds and on the exposed deck are shown in Figure 2.17 and listed in table 2.3.

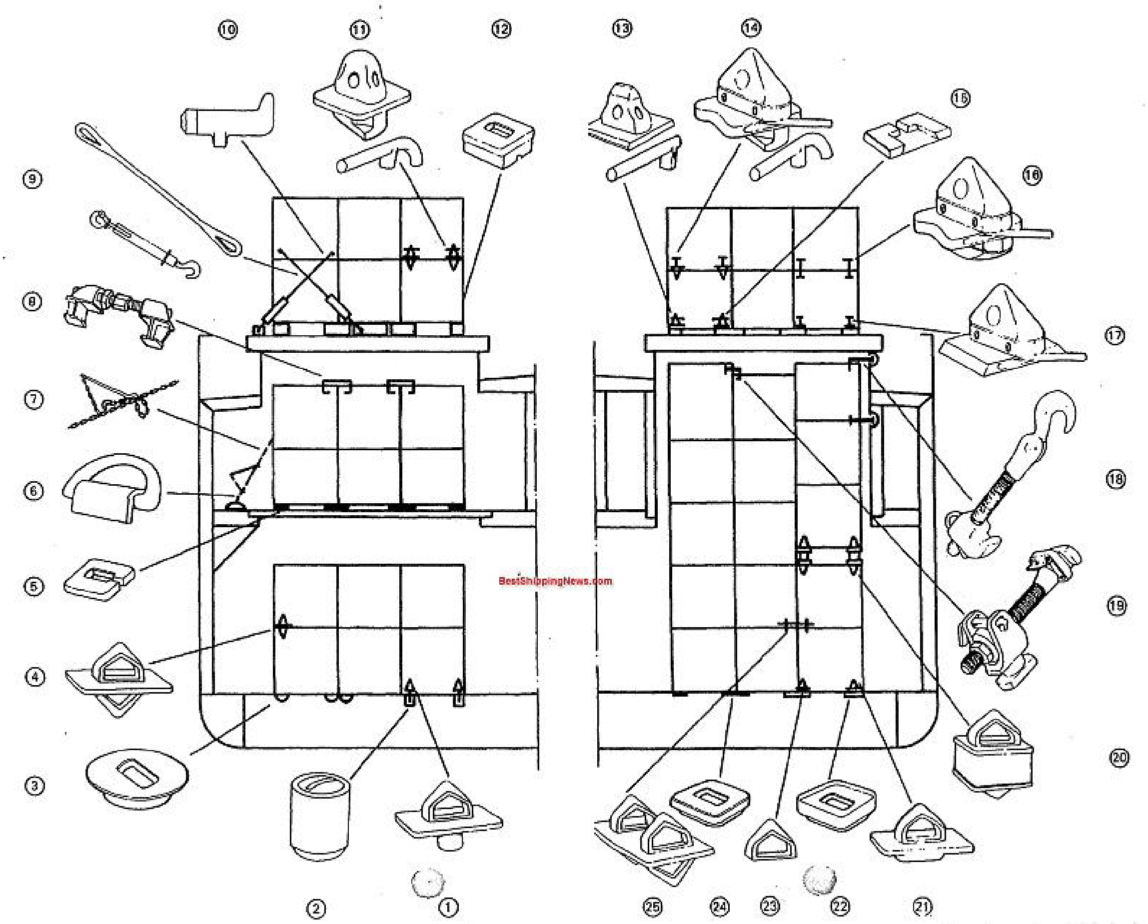


Figure 2.17. Container securing devices. Available from http://forshipbuilding.com/ship-types/container-ship/ [Accessed 29 May 2011].

Table 2.3. Container securing devices. Available from (http://forshipbuilding.com/ship-types/container-ship/)

Deck fitting	
2	Flush deck fitting, flush deck insert, flush foundation, circular foundation, stud bushing with plugging screw, screw plug.
5	socket, base stowing plate, base (to be used with 21).
15	U-frame, shoe fitting, dovetailed base, companion fitting, dovetailed foundation (to be used with 13, 17).
22 & 24	keyhole inserts (sunken, flush, raised).
Stacking and locking fittings	
4	Stacking cone, intermediate stacking cone, stacker, stacking stud.
11	Tocking cone, Pinstacker (with locking pin).
14, 16 & 17	Twistlock, twist locking cone.
20	Spacer stacking cone, compensating cone, spacer fitting (with cone top and bottom),
8, 19 & 25	Bridge fittings.
8	Adjustable bridge fitting, clamp.
19	Offset height clamp, compensatory bridge fitting, variable height clamp.
25	Non-adjustable bruise fitting, double stacker, double intermediate stacking.
Bottom fitting	
1	Pin bottom fitting, base stacking cone, cone plate, bottom stacking cone, bottom locator (to be used with 2).
21	Bottom stacking cone (to be used with 5, 12, 22, and 23).
23	Guide cone.
Lashing equipment	
7 & 9	Loadbinders,
7	Chain lashing with chain lever.
9	Lashing wire and turnbuckle.
18	Bulkhead bridge fitting.
Lashing points or lashing terminal	
6	D-ring, lashing eye.
Other lashing equipment	
10	Lashing rod or bar, securing pads (penguin hook, elephant’s foot, eye hook), webbing.

3. DESIGN ASPECTS OF CONTAINERSHIPS HULL STRUCTURE

3.1. Unique Features and Capabilities

Unique feature of the containership is the stowage of the rectangular container units within the fuller rectangular portion of the hull and their arrangement in tiers above the main deck level. The previous section mentioned some of these features such as the stowage of containers inside holds and on deck associated with detailed description of the required securing devices and the lashing system needed for that. Additionally, a set of other features are listed in the following sub-sections.

3.1.1. Container Cell Guides

In the cargo holds of containerships cell guides are arranged with vertical guide rails, as shown in Figure 2.16 in the previous section, consisting of equilateral angles of dimensions 150 x 150 and thickness between 12 to 15 mm. The distance between two angles is from 30 to 80 mm, so that the distance between the containers, taking into account the tolerances and the clearance, is from 80 to 150 mm as maximum value, as depicted in Figure 3.1.

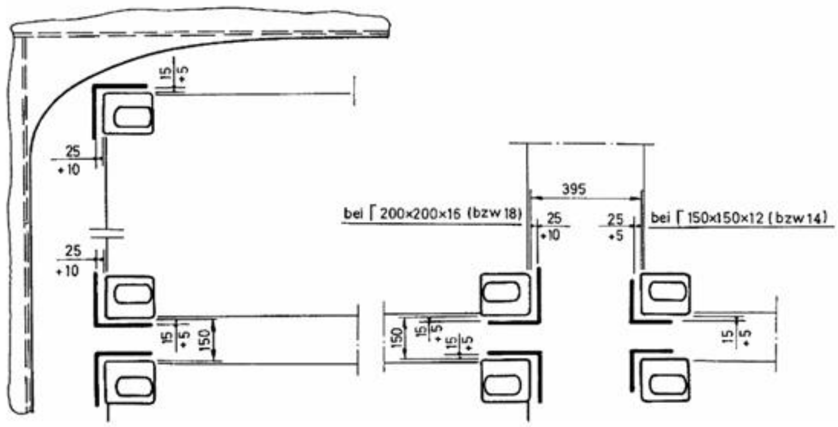


Figure 3.1. Location of container in a guidance cell. (Lücke and Lenk, 1970).

An important component of the cell guide system is the flared entry guide at the top of the cell angles, which assists the crane operator in lowering the containers into each cell or stack. A properly designed system will facilitate container stowage, speed up crane cycle time, and will minimize the potential for damage to the containers and the ship structure during loading operations.

3.1.2. Pontoon Hatch Covers Designed for Container Stowage

Containerships carry containers stowed on hatch covers. Most of the containerships are outfitted with pontoon type hatch covers. Typically, there are two or three hatch covers across the full breadth hatch opening. The construction and design of the hatch cover requires the consideration of various strength and deformation aspects associated particularly with the high weights of the stacks as well as with the torsion induced deformation of the ship hull.
The primary structural elements are typically longitudinal girders located web longitudinal girders under the plating, which are stiffened in the longitudinal direction because of safety against buckling. Occasionally, hatch covers are used with double-sided plating.

3.1.3. Container Pedestals

In order to maximize container stowage on deck and provide the fore and aft access on the weather deck for personnel, the outboard stacks of containers are often supported on pedestals fitted with lashing points, as shown in Figure 3.2. Elevated platforms are provided to facilitate handling and installation of the lashing equipment.

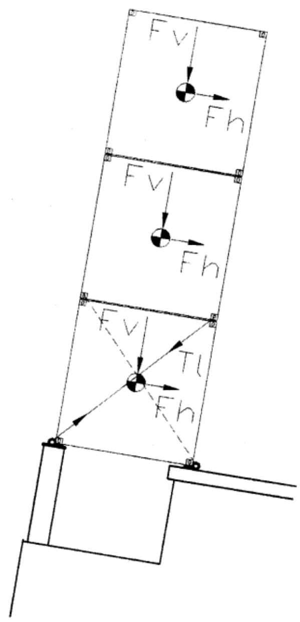


Figure 3.2. Design loads on container stack supported by outboard pedestals.
(Zink and Van Rynbach, 2004).

3.1.4. Refrigerated Container Stowage

Depending upon the trade route, containerships may transport large numbers of refrigerated boxes, commonly specified as *reefer containers*. This type of containers is able to control temperatures, allowing every type of product. Reefer containers are available as 20ft and 40ft containers (http://www.shipping-container-housing.com/refrigerated-containers.html). During the transportation, integral units are connected to the power system of the ship. The number of reefers which are allowed to be connected to the system depends on the capacity of the ship's power supply system. One more cargo holds may be outfitted with large ventilation systems to provide ambient air for cooling and with access for inspection and maintenance. Such reefer loads require a large supply of electrical power and the ship's generators must be sized accordingly.

3.1.5. Provisions for Self-loading and Self-unloading Capability

Container ships that serve ports without crane facilities must have the capability to load and discharge cargo containers and thus be *self-sustaining*. Such ships may be outfitted with either pedestal type jib cranes or gantry cranes.

3.2. Container Ship Structure

3.2.1. General

Container ship structure is designed to suit cargo containers that have fixed dimensions and discrete support points, and to provide special features that facilitate cargo stowage, such as large hatch openings. Many structural components need to be designed with care to avoid problems in service. Figure 3.3 illustrates some of the potential problem areas.

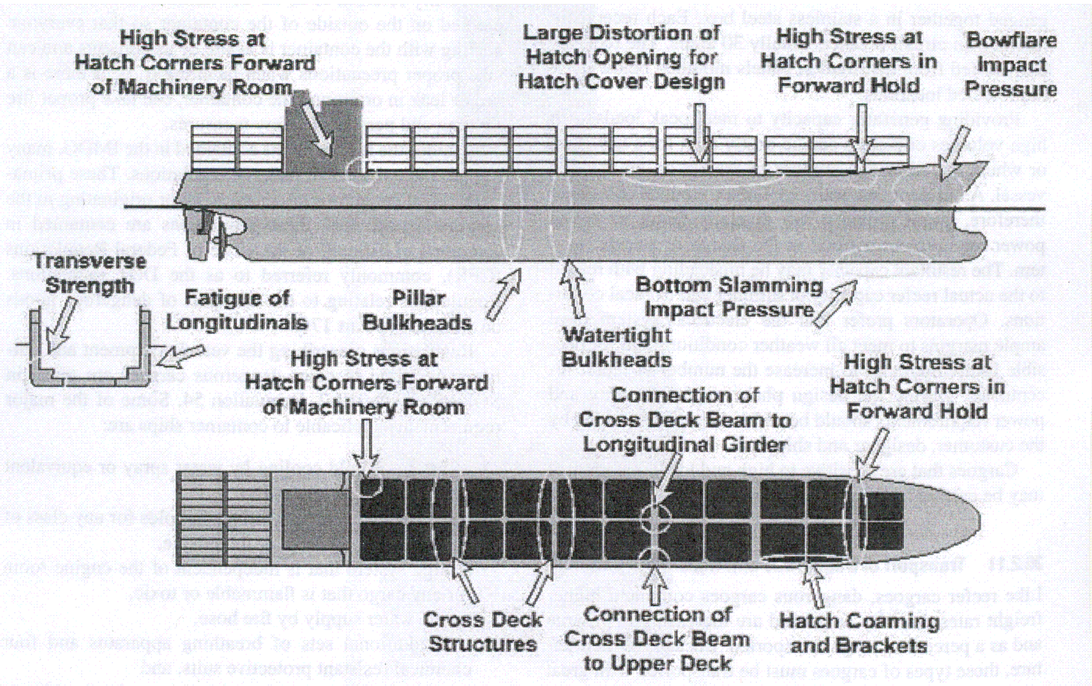


Figure 3.3. Areas of interest for container ship structure. (Zink and Van Rynbach, 2004).

3.2.2. Midship Section of a Typical Panamax Containership

A midship section of a typical Panamax containership which is constructed with a single deck, double bottom as well as double side shell is presented in Figure 3.4. The width of the double side shell is about 2 to 2.5 mm in order to provide sufficient space to the passage way and to the tanks. However, some designs reduce this width to 1 to maximum 1.5m in order to increase the number of container cells within the existing beam. The resulting narrow side tank creates many structural issues that need to be carefully considered. The space provided by the double bottom height is dedicated to tanks.

The arrangement of the structural members is mainly influenced by the arrangement of containers which have fixed dimensions. The frequently framing system adopted for this kind of ships is longitudinal throughout the midship section. In the double bottom, the spacing of the bottom longitudinal side girders matches the spacing of the containers in the hold above, in this way the containers land on or adjacent the girders. The bottom longitudinal side girders and floors form a grillage type structure that supports cargo hold container loads and external hydrostatic forces between bulkheads. Similarly, the web frames and stringers in the side shell structure form a grillage to support the ship's side between bulkheads.

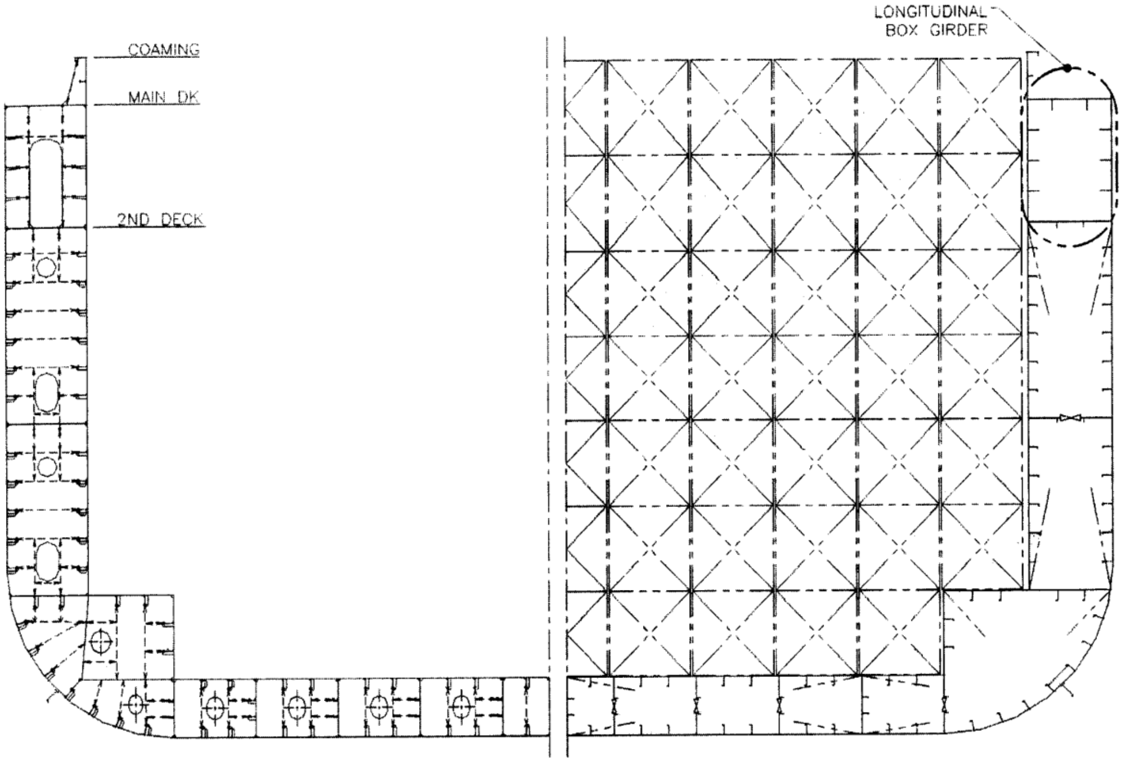


Figure 3.4. Typical midship section of Panamax containership. (Zink and Van Rynbach, 2004).

3.2.3. Longitudinal Box Girders

Containerships are characterized by large hatch openings which reduce the available width of continuous main deck plating or top flange of the hull girder. Longitudinal strength is provided by a continuous box girder that runs the full length of the hatch openings. It is formed by thick plates which are the deck plate, the sheer strake, the upper plate of the longitudinal bulkhead and the second deck. These plate are reinforced by a flat bar stiffeners. For most modern containerships, the high tensile steel is used for the plates as well as the stiffeners of the longitudinal box girders in order to reduce their thickness.

3.2.4. Longitudinal Hatch Coamings

Continuous longitudinal hatch coamings are adopted for most modern containership; these members will contribute to longitudinal strength and permit a reduction in main deck thickness. It is important to design the coaming with good continuity, well rounded corners and tapered longitudinal transitions to avoid cracking. High tensile steel is adopted for these plates.

3.2.5. Longitudinal Hatch Girders

Containerships which have two or three hatch covers spanning across the hatch opening require the arrangement of one or two longitudinal hatch girders to support the inboard sides of the covers. The tops of the longitudinal hatch girders are coincided with the level of the tops coamings. The girders can be either structurally continuous or non-continuous. Non continuous hatch girders are preferable in order to avoid the potential cracking problem resulted from the connection of the transverse bulkheads and the continuous girders. Elimination of the hatch girders allows an additional container cell and increase below deck stowage.

3.2.6. Hatch Corners

In the case where the longitudinal coamings or hatch girders are continuous, a radius should be provided to the hatch corner to reduce the high stress concentration. The common hatch corner designs are shown in Figures 3.5 to 3.7.
Circular and elliptical hatch corner with a thicker plate inserted in the main deck in way of the corner reduces the stress concentration; the inserted plate is typically 10% to 40% thicker than the surrounding main deck plate. Hatch corner design is particularly important on post-Panamax ships to avoid the high warping stress coaming from the torsion load.

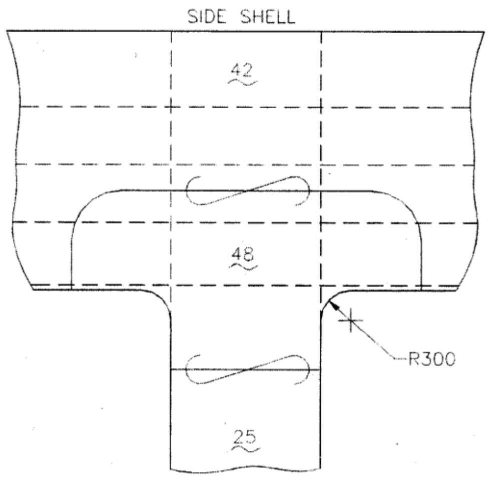


Figure 3.5. Typical hatch corner with deck insert and 300 mm radius.
(Zink and Van Rynbach, 2004).

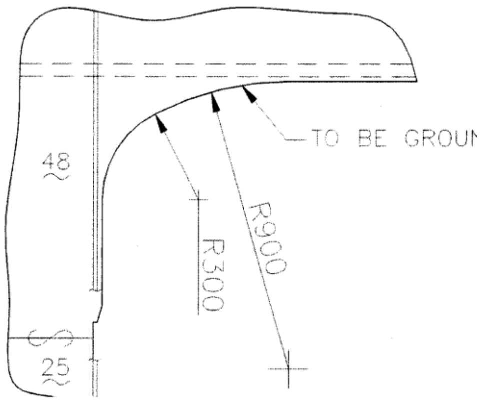


Figure 3.6. Typical elliptical design with a large initial radius of 900 mm.
(Zink and Van Rynbach, 2004).

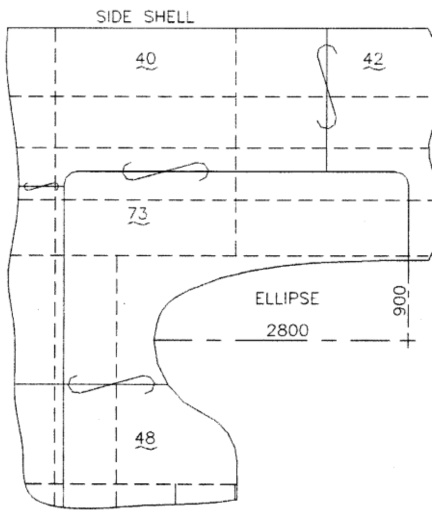


Figure 3.7. Typical *keyhole* type design for highly stressed corners such as forward of the engine room. (Zink and Van Rynbach, 2004).

3.2.7. Transverse Bulkhead

In the cargo holds the transverse bulkheads are arranged to suit stowage of the containers and to support both the double bottom and the side structure. Adequate subdivision for 40 ft container holds is commonly used; each complete cargo hold is divided into two parts by the use of Pillar bulkhead, so that each part is dedicated to the stowage of one 40 ft container of two 20 ft containers. Only the transverse bulkhead which limited the holds should be watertight. The structure of the bulkhead is composed by vertical frameworks and stringers as shown in Figure 3.8 which shown the arrangement of the two type of transverse bulkheads.

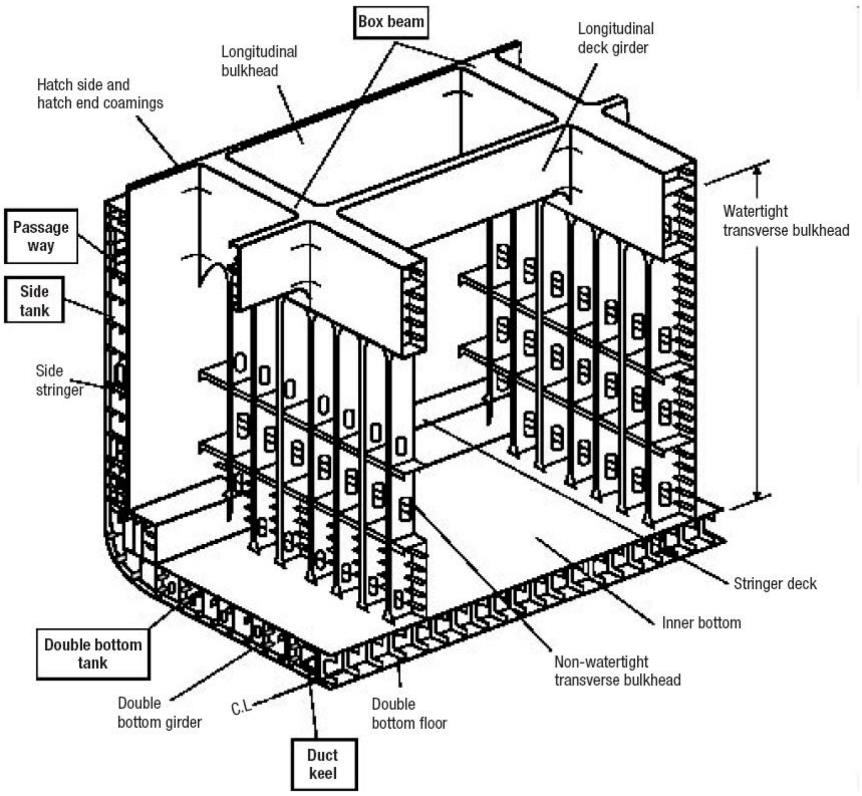


Figure 3.8. Typical cargo hold configuration for a container carrier. (IACS 2005).

3.2.8. Structural Material

The increasing in the size of containerships during the last years is accompanied by using steels of increased plate thickness up to 85 and even 100 mm in some cases. Higher tensile steel of yield strength exceeding 390 N/mm² is adopted in certain structural regions of the containership such as the deck and the coamings; this chosen is aimed at reducing steel weight as well as avoiding thicker plates and the associated welding problems.

Figure 3.9 shows the application of the high tensile steel in the structure of containership.

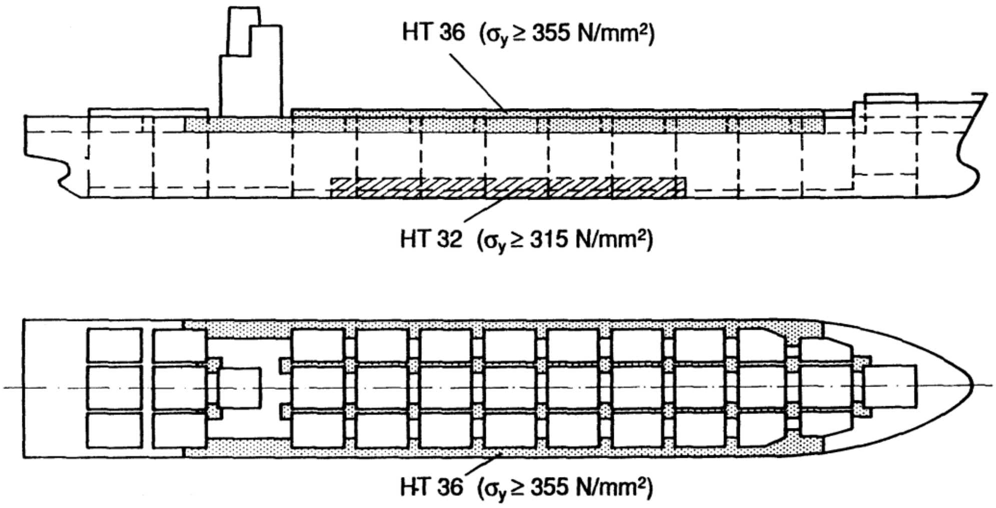


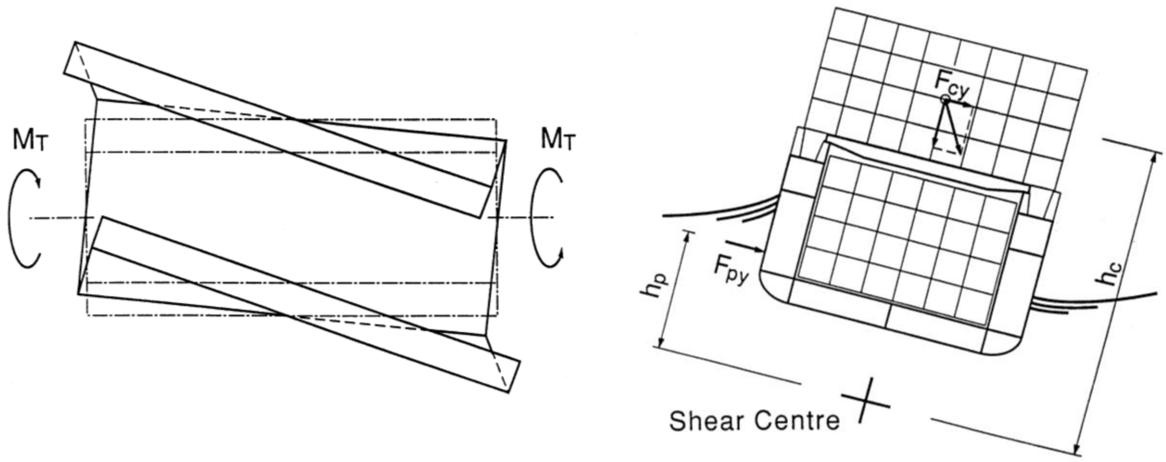
Figure 3.9. Example of the use of high tensile steel in a containership. (Fricke and Koster, 1990).

Additionally to the deck and coamings plates, the plates of the outer bottom as well as the bottom longitudinal sides are built also of high tensile steel where the focus is on the strength against buckling in the dimensioning.

3.3. Structural Design and Dimensioning of Container Ship

3.3.1. Design Loads of the Structure of Containership

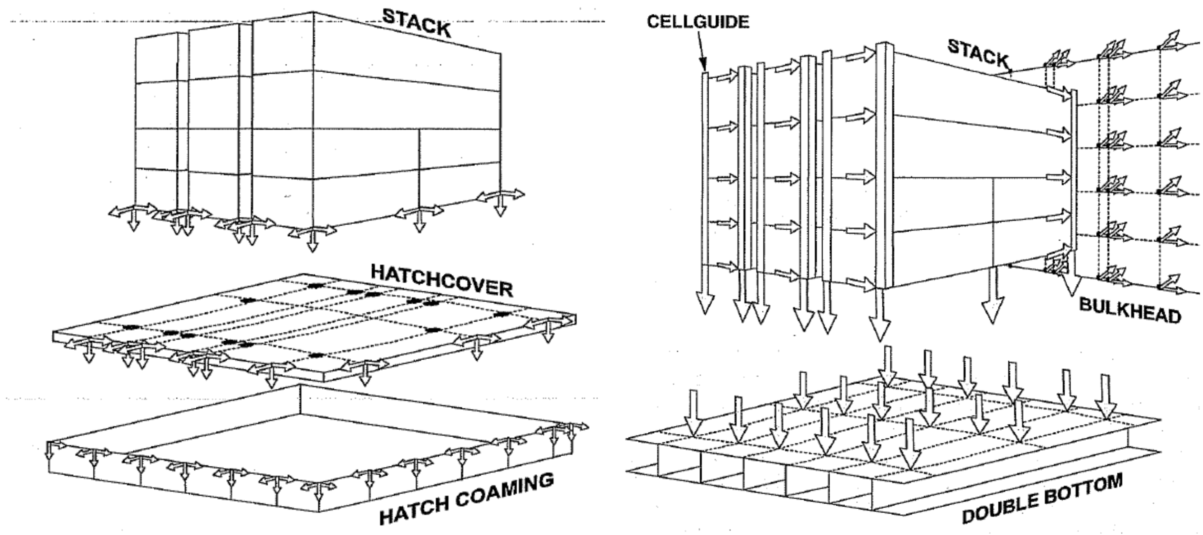
In addition to the vertical bending moment, the structure of the containerships is subjected to different kind of loads which strongly affect the deformation and stresses of the ship hull girder: the internal forces such as the torsional moment as well as the horizontal bending moment, and the external load represented by the external water pressure and cargo loads.
- The torsional moment: It is well known that an open box section subjected to a torsional moment behaves very differently from a closed section. Applied to containerships, the torsional moment is due to the large deck opening which cause relative displacements between port and starboard deck strip in longitudinal direction, as shown in Figure 3.10a. additionally the shear centre of an open cross sections is normally located below the bottom, in this case the torsional moment resulted from the transverse forces, Figure 3.10b illustrates this effect; the resultant transverse force F_{py} due to the different pressures between the port and starboard shell, and the transverse acceleration load F_{cy} due to rolling acting at the deck containers.



a) b)

Figure 3.10. a) Warping displacement of an open section. b) Increased torsional moments due to transverse forces about shear centre. (Zink and Van Rynbach, 2004).

- The horizontal bending moment: this is caused by the large deck opening.
- External water pressure and cargo loads: in practical application, the cargo container loads are usually assumed to consist of three parts: static weight of cargo container in upright condition, added static load due to roll and pitch of the vessel, and inertial forces due to accelerations of the vessel (Mansour, 2008). Figure 3.11 shows the distribution of the containers load stowed in hold and on the hatch cover.



a) b)

Figure 3.11. a) Hatch-stowed stack load distribution scheme. b) Hold-stowed stack load distribution scheme. (Mansour, 2008).

3.3.2. Approaches for Structural Design of Containerships

For the calculation and the assessment of deformations and stresses due to the combined action of vertical and horizontal hull bending as well as torsional moments, different methods has been used by and classification societes (Fricke & Koster, 1990).

a) the determination of the hull structural scantling and the calculation of the deformations based on formulas given in the rules of the classification societies, this method known as Design by rules

b) Calculation of the stresses and deformations due to hull bending moments on the basis of the classical beam theory. Estimation of the warping displacements on the basis of similar ships for which refined calculations have been performed. Determination of the stresses in the deck structure (deck strips and/or box girders) using a model in which the warping displacements are applied as input data.

c) This method is similar to the previous one, except for the torsional distortions of the hull (twist angles and warping displacements) which are calculated by the extended beam theory, including the torsional behaviour of open and closed cross sections.

d) Determination of the stresses and deformations for several individual load cases using the finite element method using a global finite element model of the hull.

Among the four method described above, method d) gives a good insight about the deformations and stresses in the structural

It has been found that method d) is preferable, particularly in case of new and unconventional designs as well as optimized and highly-stressed structures. This method is called the direct calculation approach.

4. TECHNICAL CHARACTERISTICS OF THE CONTAINERSHIP B178

The presented design is based on the concept of the general design of the containership B178 which was build in Stocznia Szczecińska Nowa. The presented section provides general technical description of the containership B178.
All the data and the information of the structure listed in this section are provided from the West Pomeranian University of Technology, Szczecin as well as the GL Office, Szczecin.

4.1. Main Characteristics of the Containership B-178

The main dimension, the speed as well as other characteristics of the containership B-178 is given in Table 4.1.

Table 4.1. Main characteristics of the containership B-178

Length Over All L_{oa} , m	220.5
Length Between Perpendiculars L_{bp}, m	210.2
Breath moulded B, m	32.24
Depth to main deck D, m	18.7
Draught scantling T, m	12.15
Deadweight capacity , t	41,850
Block coefficient C_B	0.67
Speed (service) at 10,50 draught V, kn	22.30
Tonnage abt., GT	35,881
Tonnage abt., NT	14,444
Total container capacity	3091
Container capacity in holds	1408
Container capacity	1683
Crew	24 + 1 pilot

4.2. Type of the Ship and Destination

The containership B-178 is a cellular, geared container vessel intended for the carriage of:

- 20 and 40 ft ISO containers in holds and on deck;
- 45 and 49 ft containers on deck;
- dangerous cargo containers in holds No 1-6;
- reefer containers (self-contained air cooled type) on deck and in hold No 2- 5;
- Break bulk cargoes in hold No 2-5.

The containership has a single screw motor ship with excessive freeboard, fitted with one fixed pitch propeller, driven by slow-speed engine.
The ship has six cargo holds dedicated to the stowage of containers, the engine room and the accommodation which is situated at the aft part, transom stern as well as bulbous bow, in addition to one transverse bow thruster.
The total capacity of containers is 3091 TEU; 1408 TEU in holds and 1683 TEU.

Figure 4.1 shows the longitudinal section of the containership B178:

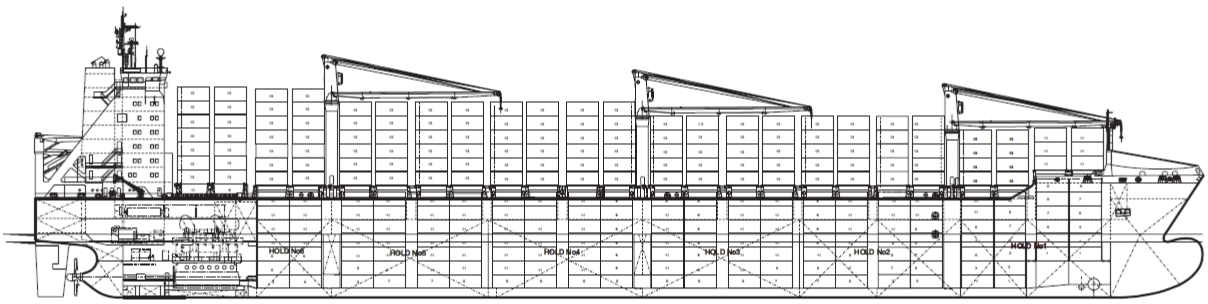


Figure 4.1: Longitudinal view of the containership B178. (Stocznia Szczeciñska Nowa).

4.3. Containership Hull Structure

4.3.1. General

The scantling and the arrangement of the structural members are determined in accordance with the requirement of the GL rules and with ship yard’s standard. The hull structure is of all welded construction.
Transverse and longitudinal framing system is adopted with the frame spacing is 790 mm in the hold area and engine room, and 800 mm in the after peak. Longitudinal stiffener and

transverse web frames are used in cargo area. Outside cargo area longitudinal and transverse framing is used.

Higher tensile steel 355 N/mm² is used for about 40% of the hull weight. Mild steel grade A, B, D and E is used elsewhere.

4.3.2. Double Bottom Structure

The double bottom is extended from the after peak bulkhead to the fore peak bulkhead. The height of the double bottom in the cargo hold is 1730 mm.

Longitudinal bottom framing extends fore and aft as far as practicable. Their arrangement is according to the distribution of containers. The floors adopted generally at every four frames in the cargo holds area, their arrangement is depends on the containers stowage inside holds in the engine room the floors are adopted each frame.

Bottom structure forward adequacy reinforced against slamming depending on ballast draught.

4.3.3. Transverse Bulkheads

The distribution of the transverse bulkhead is as shown in Figure 4.1.

All transverse watertight bulkheads are extended up to the main deck. The plates of all bulkheads are plane construction with vertical stiffeners made of rolled steel sections.

Between hatch N°1 and 2, 3 and 4, 5 and 6, 7 and 8, 9 and 10 cross tier of big construction are arranged. They extend from second deck to the top of transverse hatch coaming.

Adequate reinforcements for columns of 3 cranes are provided in the construction of the bulkheads.

4.3.4. Main Deck

The longitudinal framing system is adopted for the main deck in way of holds and engine room. The rest parts are framed transversely.

Continuous longitudinal hatch coamings supporting steel pontoon covers arranged on main deck.

Exposed main deck has camber about 50mm/m but no sheer. Forecastle deck has about 35 mm/m.

4.3.5. Engine Room and Stern Structure

The engine room area is arranged with a continuous double bottom with main engine foundation integrated with bottom structure and platform deck.

Double bottom in engine room is built with full height floor on each frame with longitudinal girders under main engine seating and divided into tanks, cofferdams and other compartment.

Platforms are supported by transverse webs and pillars. Pillars in the engine room are continuous through the depth of the vessel, as far as practicable.

The containership has transom type, single screw stern structure.

5. CONCEPT OF THE HULL STRUCTURE, MATERIAL AND TOPOLOGY

This section is dedicated to the development of the initial concept of the structure, which considered among the first steps in the design process, of course after the conceptual design phase. This latter should provide overall characteristics of the ship, such as the general arrangement, main dimensions, and hull form. Besides other parameters which define the intended service of the ship including its speed and destination.

As mentioned before, the developed design is based on the concept design of the containership B-178, providing its general arrangement, main dimensions as well as hull form. This data represents the results of ship designers work performed in the previous steps, as an example of that, the hull form which may provided from the hydrodynamic department.

Therefore, this section is focused on the structural concept of the ship hull structure, starting by the selection of the material and the definition of structural topology, of one complete cargo hold, which needs to meet the specified ship mission requirements. At the end of this Section, concept sketch of the midship section will be provided and ready to be used for the followed Section.

5.1. Material Selection of the Hull Structure

The choice of the material is among the most important structural consideration which should be defined and taken into account during the earliest stage of the structural design, regarding to the goal which play in the strength and the preliminary cost estimation.

The selection of the material has been based on the earlier experience and theoretical background collected in the section 3. It is known that for certain areas in the structure of containerships; such as deck, side shell and bottom structures, thicker plates are adopted to resist against the existing higher stresses in these regions. Therefore high tensile steel have to be used for such plates and profiles to reduce their thicknesses.

At this first stage, for the developed design, steel has been adopted for the entire hull structure, where two categories have been selected to be considered in different structural regions of the hull structure; normal hull structural steel grade A and high tensile hull structural steel grade AH. This choice, for the mild steel, is aimed at its splendid properties such as tough, strong, high weldability and low price.

Special attention is paid to the application of the high tensile steel regarding to its high price and low weldability comparing with the mild steel. Therefore, high tensile steel has been adopted in such areas where there is need to reduce thicknesses and profile dimensions.
The mechanical proprieties as well as structural members in which the mild and higher steel is selected to be used are listed in Table 5.1.

Table 5.1. Material selection for ship hull structural members

Steel grade	R_{eH} , N/mm²	Structural members
AH	355	Shell plating ,including keel, outer bottom and side plates; Inner bottom, deck plates, and longitudinal bulkhead strakes; Bottom longitudinal girders; Longitudinal hatch coamings including their longitudinal stiffeners.
A	235	Transverse members, including floors, web frames, and plates forming transverse bulkheads; Longitudinal stringers in the side shell as well as transverse bulkheads structures; Longitudinal stiffeners for the whole structure.

Moreover discussion and modification of the material selected may take place during the next stages of this work, after the evaluation of the scantling and strength analysis results.
The developed containership is not intended to operate in the ice zone. Therefore, the material for the ice strengthening is not included.

5.2. Factors Influencing the Selection of the Ship Hull Structure Topology

The design of containerships hull structure is essentially influenced by the stowage of containers that have fixed dimensions. The length of the cargo space is among the main parameters which should base on for the determination of the total length of the ship. Also the subdivision of the cargo space is depended on the size of the single container. From the structural concept point of view, there are a set of factors which may affect the selection and the dimensioning of the structural elements, such as the sufficient space which should provided to the stowage of containers and to other devices, which have to be installed inside holds and along the cargo space for the safety and the handling of containers. Therefore it is important to highlight the technical feasibility of these factors before dealing with the structure selection.

At this stage, it is useful to collect the necessary information about the following items:

- size of containers and the number of bays, which may to be stowed inside holds;
- the size and the thickness of container securing devises such as the cell guide angles;
- the sufficient space provided to the cargo handling appliances such as cranes.

In the following, a detailed description about the unit cargo container size and its appropriate devises, which have been chosen for the presented design.

On the base of referenced containership concept, the developed containership is dedicated to the stowage of 20 and 40 ft ISO standard containers, where their external size is cited in Table 5.2.

Table 5.2. External size of containers. Available from (http://www.carucontainers.com/be/fr/les-dimensions-d-un-conteneur) [Accessed 23 October 2011]

Container	External size, mm		
	Length	Width	Height
20 feet	6058	2438	2591
40 feet	12192	2438	2591

According to the typical general arrangement of container ships, the cargo space is divided into holds by watertight bulkheads. One complete hold itself is divided into two parts by the use of so called pillar bulkheads; where inside of each part two bays of 20 or one bay of 40 ft containers may be stowed. Hence each part may have more than 12.192 m of length; which is equivalent to the length of one 40 ft container. In the ship transverse direction, the breadth of the ship allows the stowage of eleven rows of containers, and the depth allows the stowage up to 7 tiers below the deck, as shown in Figure 5.2.

The security of the containers inside holds is assured by the installation of cell guides. For that, containers have been shifted from each other in order to provide sufficient space to the installation of cell guides. This spacing has been taken equal to 76 mm in the longitudinal direction and 100 mm in the transversal direction. These values are calculated based on the size of cell guides and the tolerances of the containers. In the case where 40 ft containers are stowed, the length of one 40 ft container is equivalent to the sum of the length of two 20 ft containers plus the spacing between them, as depicted in Figure 5.1.

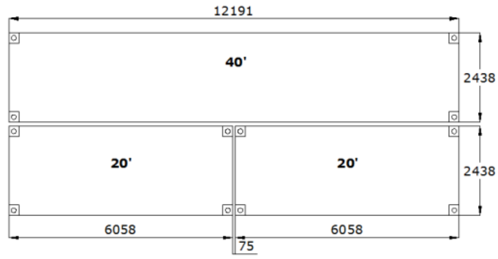


Figure 5.1. Equivalent length of 40 ft container.

In this case, the cell guides is taken movable to give the flexibility to the containership to carry 20 ft and 40 ft containers. Figure 5.2 shows the stowage of 20 ft container in one part of one complete cargo hold (half cargo hold), taken into account the space provided for the installation of the cell guides.

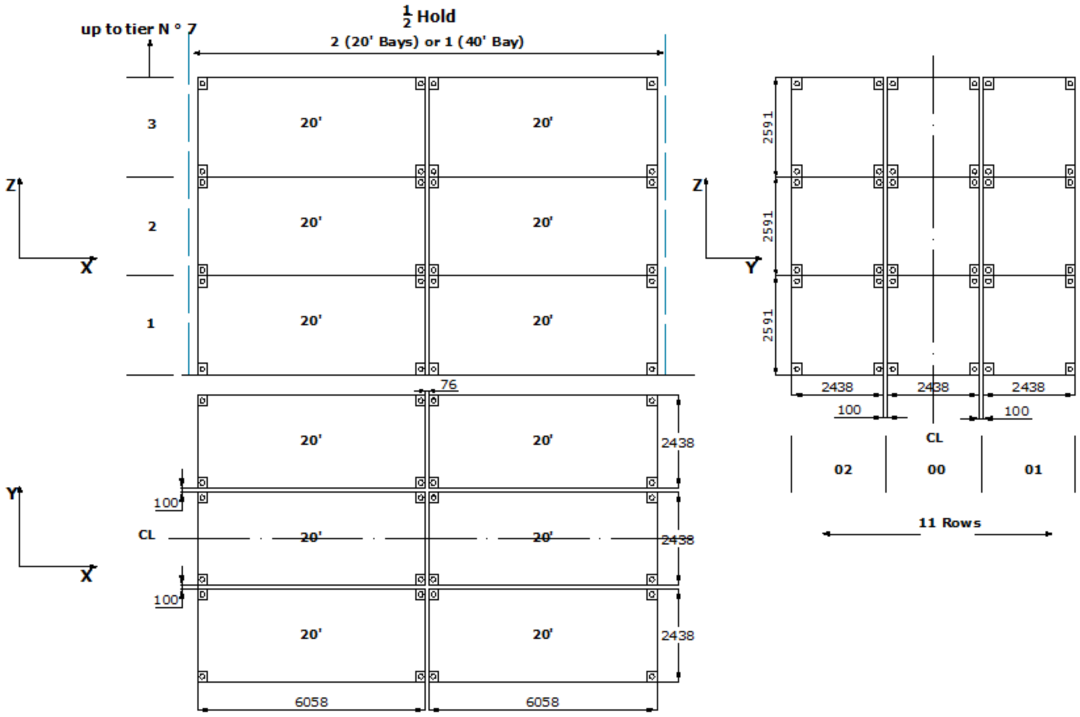


Figure 5.2. Stowage of containers inside half cargo hold.

The handling of containers is ensured by the installation of handling devises such as cranes. The location of this latter is adopted above the main deck, between holds. The space limited by the structure of watertight bulkheads, provides sufficient space for the installation of the cranes equipment. For the developed containership, this spacing is taken extended over 2 frames as a first approximation, which can be changed afterwards depends on the requirement of the owner, in the case where he will require more space for the installation of other equipment as pumps, etc.

5.3. Structural Topology Selection

As mentioned before, the selection of the structural topology is based on the knowledge of the main feature of the unit container, its devices and its arrangement inside cargo holds, which has been done previously. Therefore, an initial structural topology of one cargo hold is defined; starting by the identification of the arrangement of the primary structural members, the location of watertight and pillar bulkheads, besides of other construction notes such as the inner hull spaces, and the arrangement of the elements of each structure. Figure 5.3 shows the first concept sketch of one cargo hold limited by two watertight bulkheads.

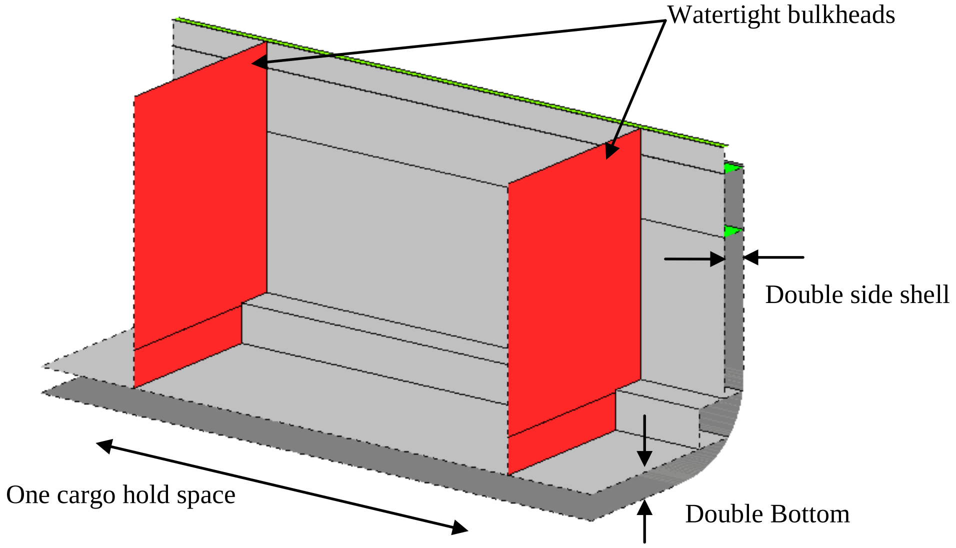


Figure 5.3. First concept sketch of one cargo hold.

The determination of the spacing of double side shell will be provided after the calculation of the necessary spacing lifted to the stowage of containers and its appropriate securing devices, taken into account also the sufficient width which should provided to the passage way.
In the following sub-sections, a structured detail about the framing system adopted, and the arrangement of the primary elements of the double bottom, double side shell, deck and transverse bulkheads structures.

5.3.1. Framing System

Along the cargo space, the longitudinal framing system is adopted for structures of double bottom, deck, and double side shell. The spacing between primary members is matched with the stowage of containers inside the hold. This choice is aimed at providing a rigid support to the stowage of containers. For example the rigid support for the seat of containers in the double bottom area is achieved by the grillage results from the arrangement of longitudinal girders and floors. Another example and similarly to the double bottom structure, the grillage formed by the web frames and the longitudinal stringers in the double side structure contribute at supporting ship's sides structure between transversal bulkheads.

The plates are arranged in a way to avoid the coincidence of their welding butt with the location of the structural elements. Hence, knowledge the framing spacing in the longitudinal and transversal directions is necessary to know the location of all structural elements such as web frames, longitudinal girders, floors and longitudinal stiffeners. The spacing of the primary structural elements is based on the elementary framing spacing in the longitudinal direction and the stiffener spacing in the transversal direction. In the developed design the framing spacing in both longitudinal and transversal direction is adopted as follow:

- the longitudinal framing spacing is taken equal to 790 mm, along the cylindrical part, this choice has based on ship yard standard;
- the transversal stiffener spacing in the double bottom area is taken equal to 850 mm, and 865 mm in the double side shell area.

5.3.2. Subdivision and Transverse Bulkheads Structure

Each cargo hold which is limited by two watertight bulkheads is divided into two parts by the use of pillar transverse bulkhead, where the length of each part is equivalent to the length of 40 ft container, as shown in Figure 5.4. The structure of these bulkheads is extended over two frames, may be up to 4 frames for the watertight bulkheads, in order to provide sufficient space to the installation of containers' handling devices and its equipments such as pumps. However, in the developed design the structure of all transverse bulkheads (watertight and pillar) is extended over 2 frames, as it concerns preliminary design. This choice can be modified afterwards (as mentioned before in Sub-section 5.2).

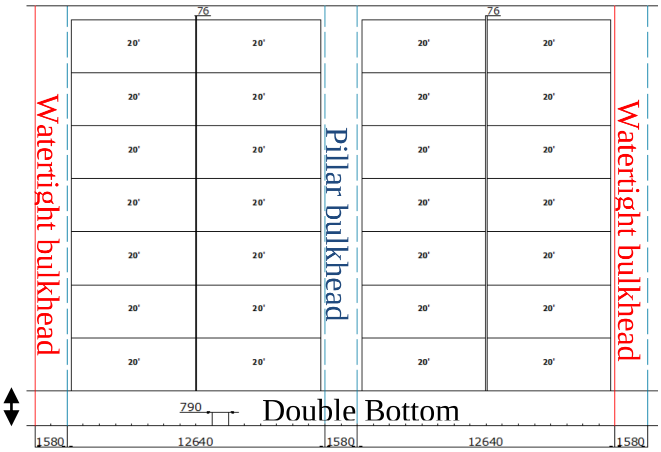


Figure 5.4. Subdivision inside one cargo hold.

The structure of watertight bulkheads is formed by watertight plates located at the frame dedicated to the location of watertight bulkheads, and by vertical framework and horizontal stringers. However the structure of non watertight bulkheads (pillars) is composed only of vertical frameworks and horizontal stringers. These elements are extended over 2 frames. In the vertical direction, between the double bottom and the upper deck, four horizontal stringers are arranged; the spacing between them is matched to the four first containers' tiers.

At the same level with the second deck, one more stringer has been placed. Between the second deck and the upper deck, stool plate is arranged.

In the horizontal direction, one vertical framework is arranged in the centreline above the bottom centre longitudinal girder located in the double bottom structure, and two others are placed athwartship. The both structures of watertight and pillar bulkheads are depicted in Figures 5.5 and 5.6 respectively.

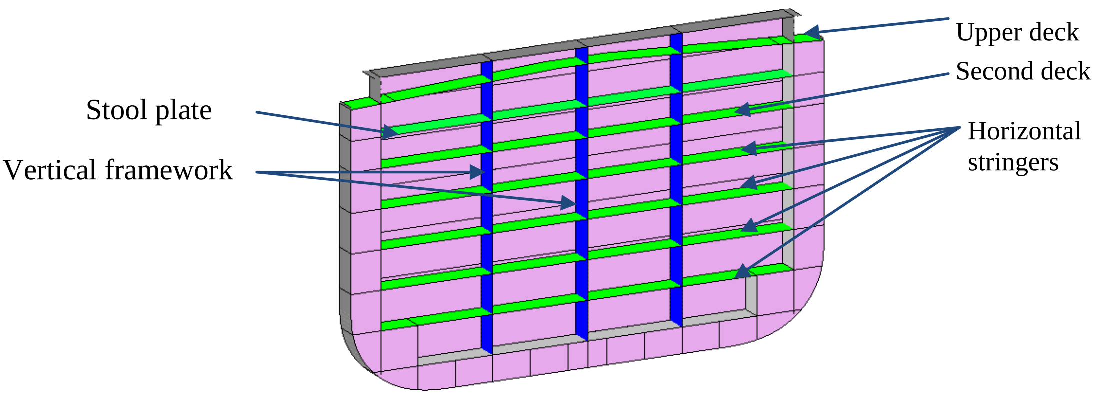


Figure 5.5a. Watertight bulkhead structure: open side (non watertight side) of the watertight bulkhead.

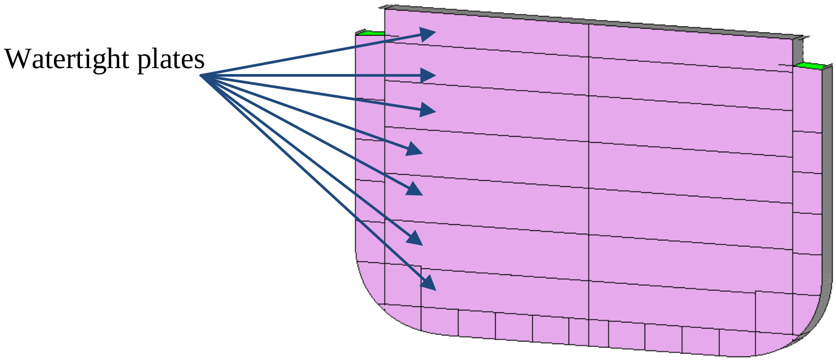


Figure 5.5b: Watertight bulkhead structure: watertight side of the watertight bulkhead.

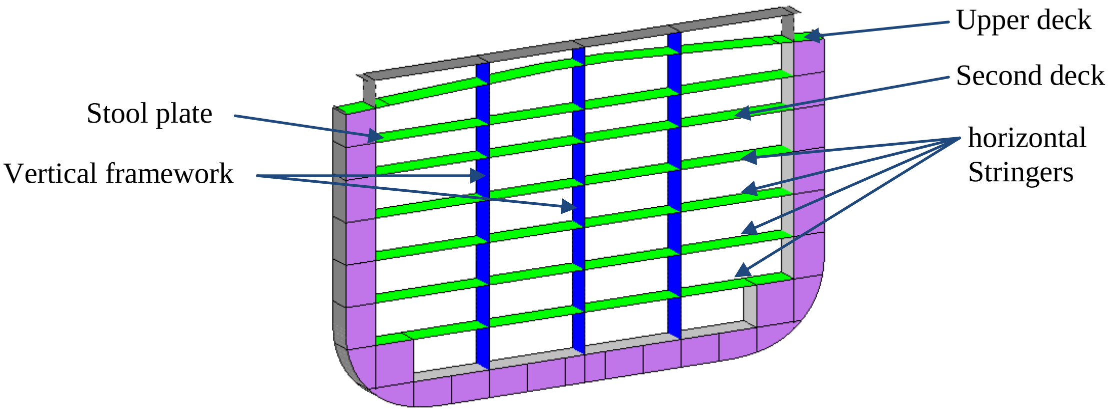


Figure 5.6. Pillar bulkhead structure.

5.3.3. Double Bottom Structure

The height of the double bottom is taken equal to 1700 mm, in order to provide sufficient space to the ballast tanks and to facilitate the access during the fabrication process, inspection and in case of reparation. The space provided for the duct keel is 2700 mm, it is limited by watertight bottom longitudinal girder in each side. From these latter the arrangement of the other longitudinal bottom side girders is based on the stowage of containers in the hold above, in a manner to give the possibility to the cell guides to be land or adjust the longitudinal side girders. Therefore the location of the longitudinal side girders is matched to the spacing of containers stowed in the hold above, with a spacing is taken equal to 2550 mm, which is equivalent to three stiffener spacing. Also under each longitudinal bulkhead, longitudinal side girders are arranged. The arrangement of all these longitudinal girders as well as the longitudinal stiffeners is shown in Figure 5.7.

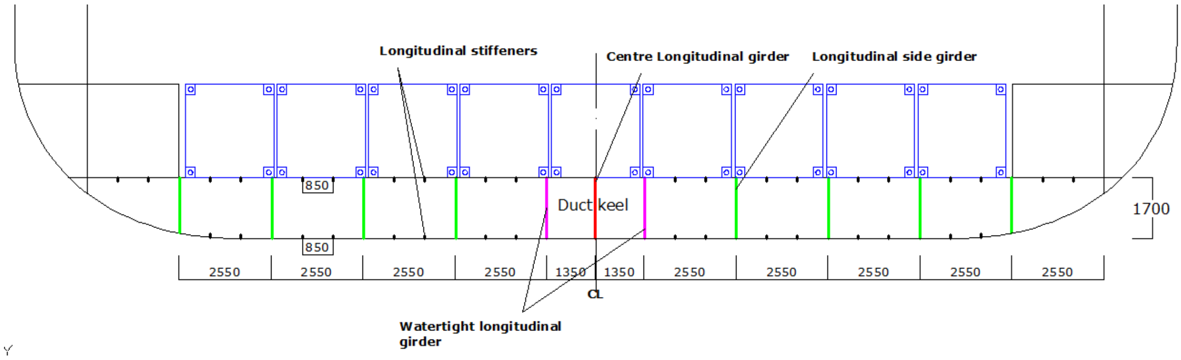


Figure 5.7. Double bottom structural element arrangement in the transverse direction.

Floors are arranged under each transversal bulkhead, despite its type. Between two adjacent bulkheads floors are arranged each ¼ the distance between these bulkheads, as shown in Figure 5.8.

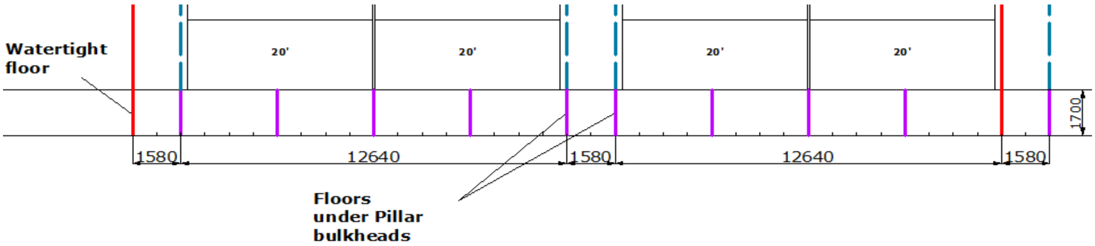


Figure 5.8. Floors arrangement in the double bottom structure (in the longitudinal direction).

Figure 5.9 shows 3D visualisation of the arrangement of bottom longitudinal girders and the floors in the double bottom structure.

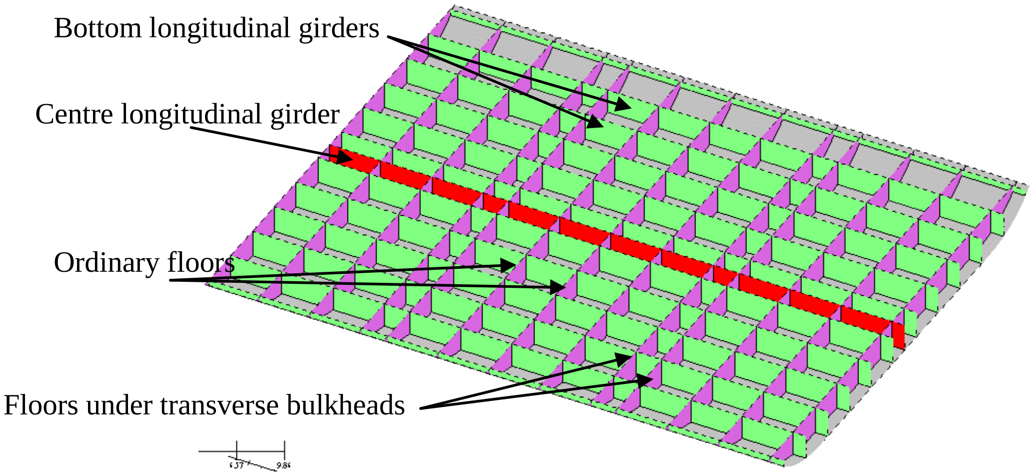


Figure 5.9. 3D view of the bottom structure.

5.3.4. Deck Structure

Camber for about 700 mm has been adopted for the exposed main deck, but no sheer.

Longitudinal hatch coamings are arranged athwartship in order to support the hatch covers, they are running along the cargo holds. Each of them is composed by two plates, vertical and horizontal; the vertical one limited the plate of the main deck and seat above the longitudinal bulkhead. The horizontal one is called Top coaming, which is used to support the edges of hatch covers. It extends over two frames, in the longitudinal direction, at the level of each transversal bulkhead. Deck structure is shown in Figure 5.10 afterwards.

5.3.5. Double Side Shell Structure

The structure of double side shell is limited by the shell and longitudinal bulkhead, the space lifted for this area is equal to 2020 mm, in order to provide sufficient space to the passage way. In this area, the arrangement of the web frames is coincided with the arrangement of floors in the double bottom structure. Horizontal stringers are arranged at the same level with those of the bulkhead structure. Due to the hull form at the level of the bilge, second longitudinal bulkhead is arranged, it has shifted about 2590 mm from the first longitudinal bulkhead, in order to give the possibility to stow one row of containers above the first stringer. This latter has been extended till the second longitudinal bulkhead. As shown in Figure 5.10.

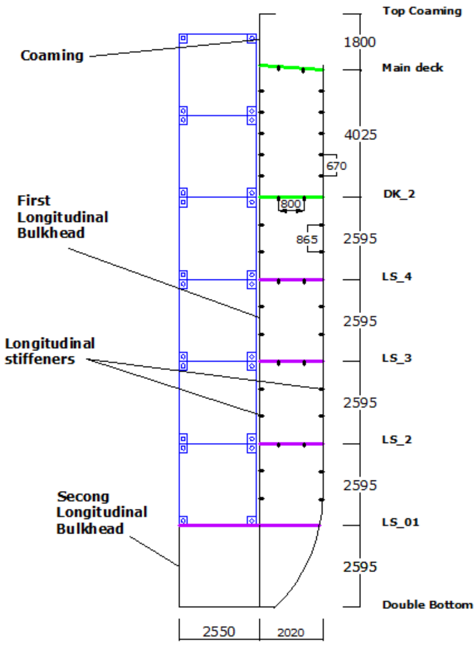


Figure 5.10a. Double side shell and deck structures: 2D visualisation.

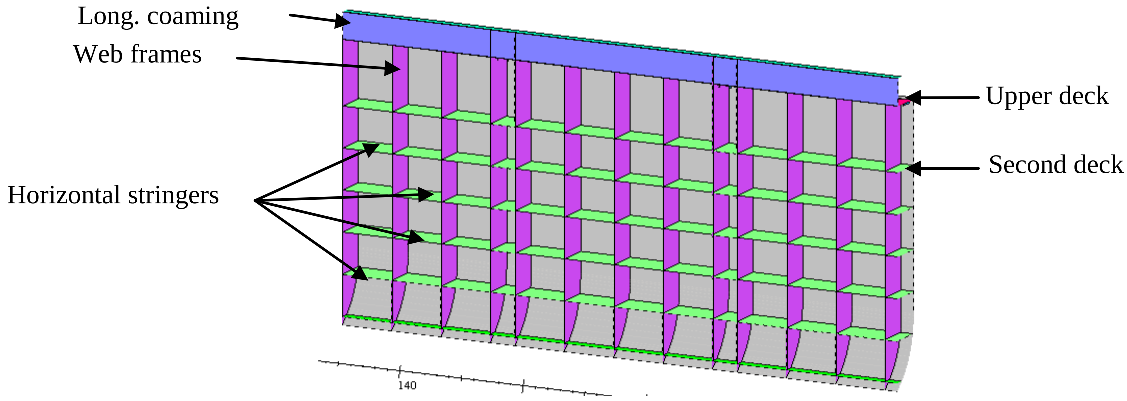


Figure 5.10b. Double side shell and deck structures: 3D visualisation.

The passage way is provided by making an opening in the upper part of the web frame, between the second and the main decks, as it is depicted in Figure 5.11, where its dimensions are 2600 × 780 mm × mm.

Stay is adopted each 4 frames in the holds area, and each 2 frames at the level of transverse bulkheads, in order to provide a rigid support to the coming.

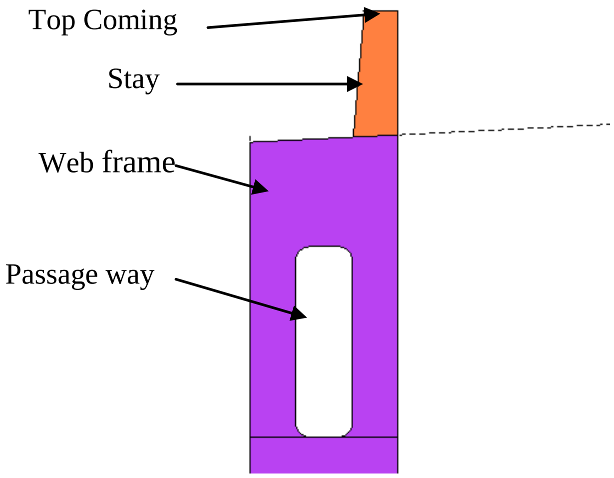


Figure 5.11. Passage way.

5.4. Midship Section Concept Sketch

Concept sketch, given by Figure 5.12, is made up to provide the necessary information about the arrangements and the spacing adopted for the structural elements of the ship structures detailed in the previous sub sections. Additional information about the space provided to the tanks as well as the necessary opening for the access is given in the sketch.

The 3D view of the arrangement of the structural elements inside one complete cargo hold is shown in Figure 5.13.

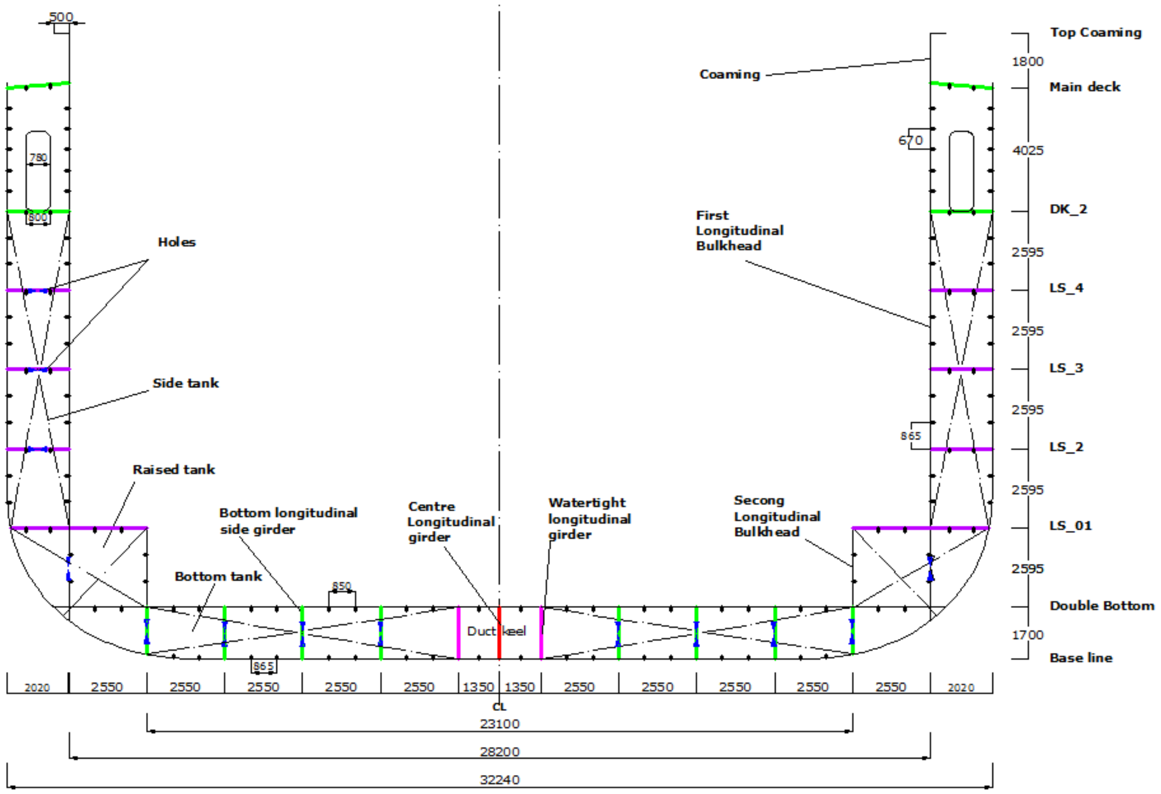


Figure 5.12. Midship section concept sketch.

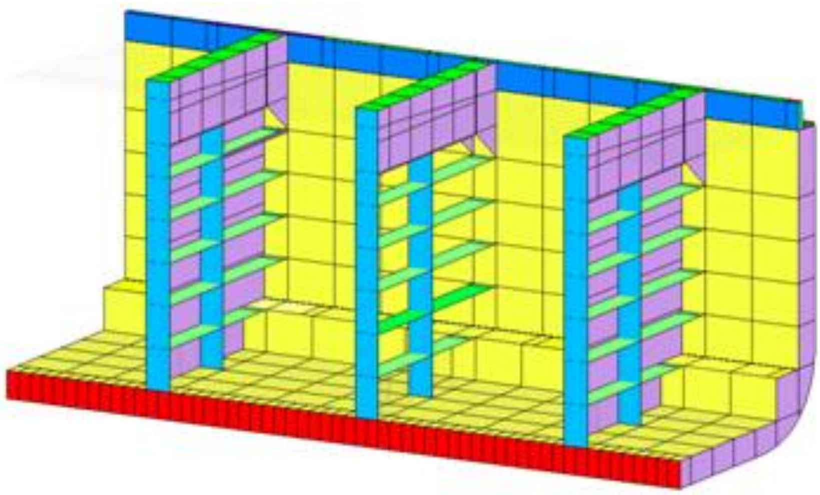


Figure 5.13. 3D view of one complete cargo concept sketch.

6. HULL STRUCTURE SCANTLING ACCORDING TO GL RULES

Ship hull structural scantling represents one of the most important and challenging tasks during structural design of the ship, regarding to its process which is complicated and iterative.

For the developed design, the structural scantling is performed according to GL rules, with the assistance of Poseidon computer program.

This chapter represents the procedure considered for dimensioning the hull structure, starting from the creation of the structural model till the sizing of its structural elements.

The following outline, Figure 6.1, illustrates the process of the structural modelling and sizing used by Poseidon, which will be presented in this section.

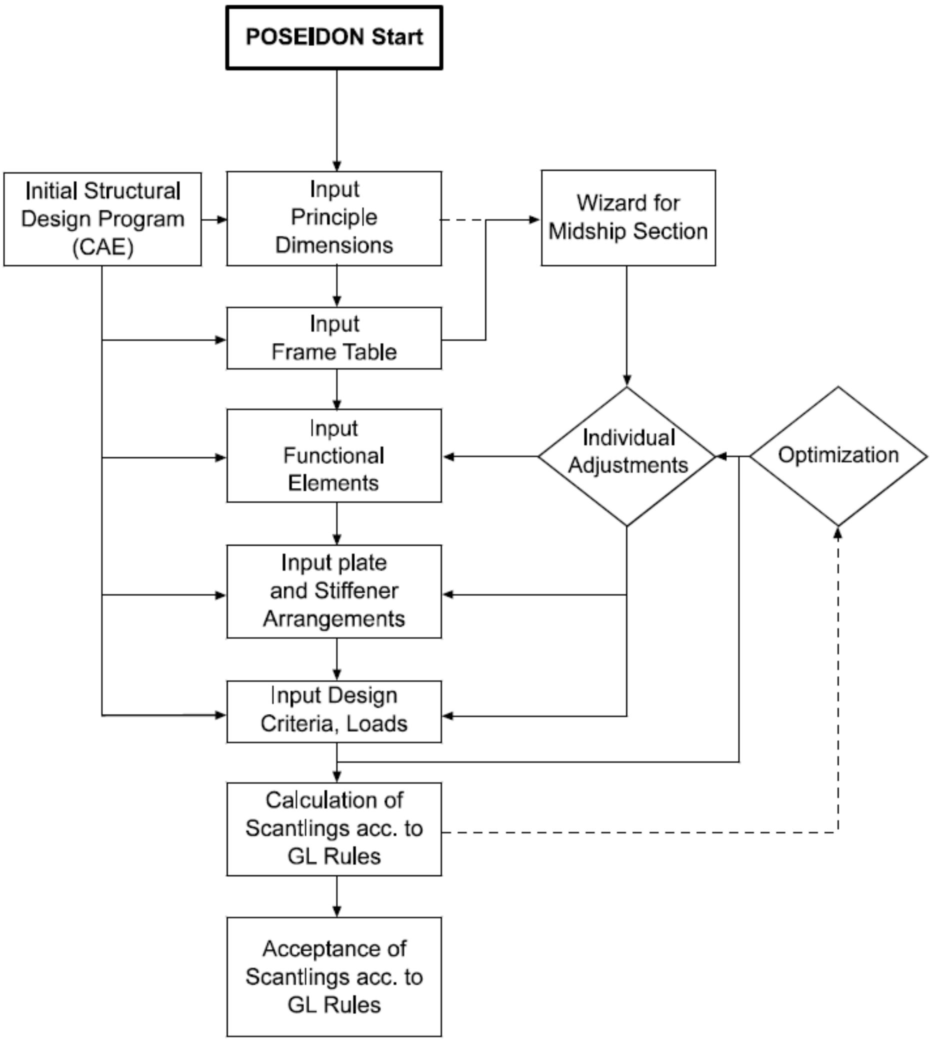


Figure 6.1. Structural modelling and sizing according to GL rules in Poseidon ND 11 computer code (Germanischer Lloyd, 2011).

6.1 Hull Structural Modelling Using Poseidon Software

6.1.1. Ship Hull Structural Modelling According to Poseidon Computer Code

A structural model is a set of structural elements which are distinguished by their function. In Poseidon computer code, these elements are divided into the following main groups. (Germanischer Lloyd, 2011)

Longitudinal members: all longitudinal elements which are extend over the ship length and contribute to the longitudinal strength, such as shell, inner bottom, decks, stringers, longitudinal bulkheads (inner skin), longitudinal girders and hatch coaming.

Transverses members: all elements which are not contribute to the longitudinal strength such as web frames, floors and stay. Besides, *transverse bulkheads* may be also considered as transverse members.

All of the structural elements listed above are considered as plates during the modelling, which have holes and stiffeners. The way to model these elements differs from one to another; in fact each category has its own section in the tree view in Poseidon. However, the modelling of all elements is based on the same principle, which is:

1- define the geometry of the element, that known as *Functional Elements* for the longitudinal members, and Cells for the transverses members and Bulkheads;
2- arrange plates for the functional elements or cells, which had already defined;
3- create the holes and stiffeners of the selected plate.

In Poseidon, there exist three different methods for define the structural model:
- ➢ manual input of the structural elements' data;
- ➢ import of structural data from external design program;
- ➢ using Wizard provided by Poseidon, which can generate a typical cross section for different type of ships from the input of few key parameters.

In this work, the first and the third methods have been adopted to build the structural model.

6.1.2. Structural Modelling Process

The model is adopted from the front bulkhead of the engine room (frame 58) till the collision bulkhead (frame 254). The creation of Poseidon model needs to follow several steps, starting by the generation of the typical midship section of a containership using Wizards, this step is considered as the first version of the model, which is enhanced during the progress of the modelling process. After that, the cylindrical part is created in parallel with the creation of transverse bulkheads. The modelling process is subdivided into the following steps:

- input the ship characteristic data including the principal dimensions of the ship as well as the material adopted;
- input of a frame table in the ship's longitudinal direction (*X* Axis);
- generation of the typical cross section of a containership with the help of a Poseidon Wizard;
- input of a frame table in the ship's transverse direction (*Y* and *Z* Axis);
- checking of all structural elements (longitudinal, transversal elements) provided by Wizard, creation the camber and input of the missing data as first assumptions for the scantling;
- extending of the structural elements over the cylindrical part of the ship;
- arrangement of the transversal bulkheads.

Figure 6.2 shows some outlines taken from the structural modelling process.

The above mentioned steps of the structural modelling process are detailed in the Appendix A.6.1.2.1.

The developed hull structural model resulted from the structural modelling process is shown in Figure 6.3.

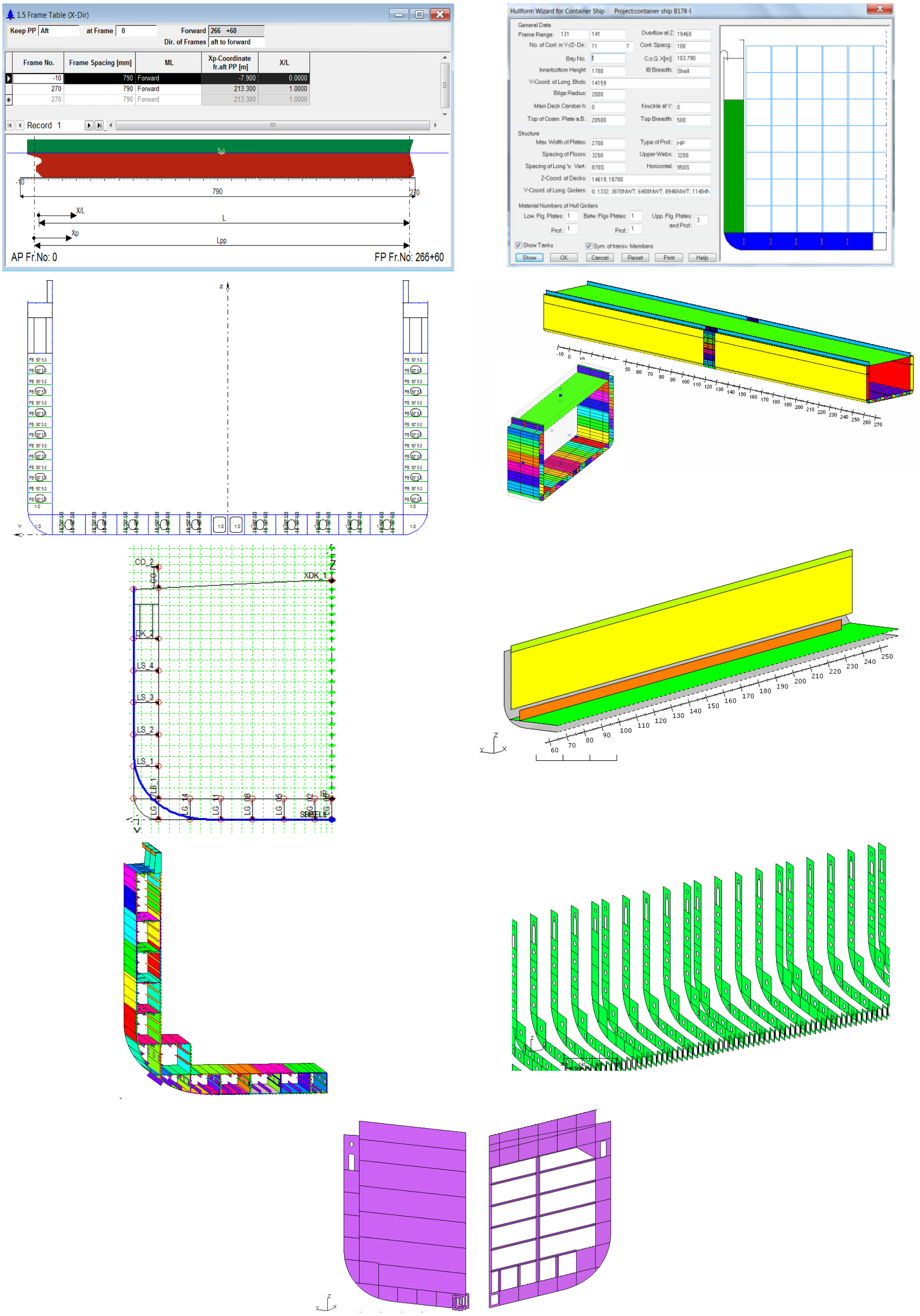


Figure 6.2. Outlines from the structural modelling process.

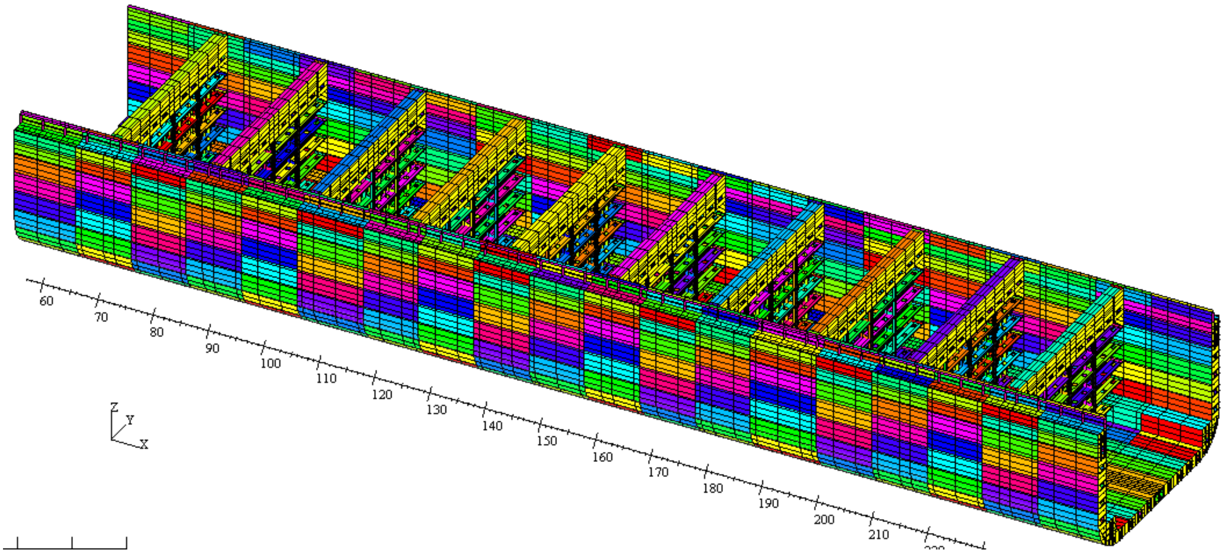


Figure 6.3a. The ship hull structural model developed in Poseidon computer code :the whole ship hull structural model

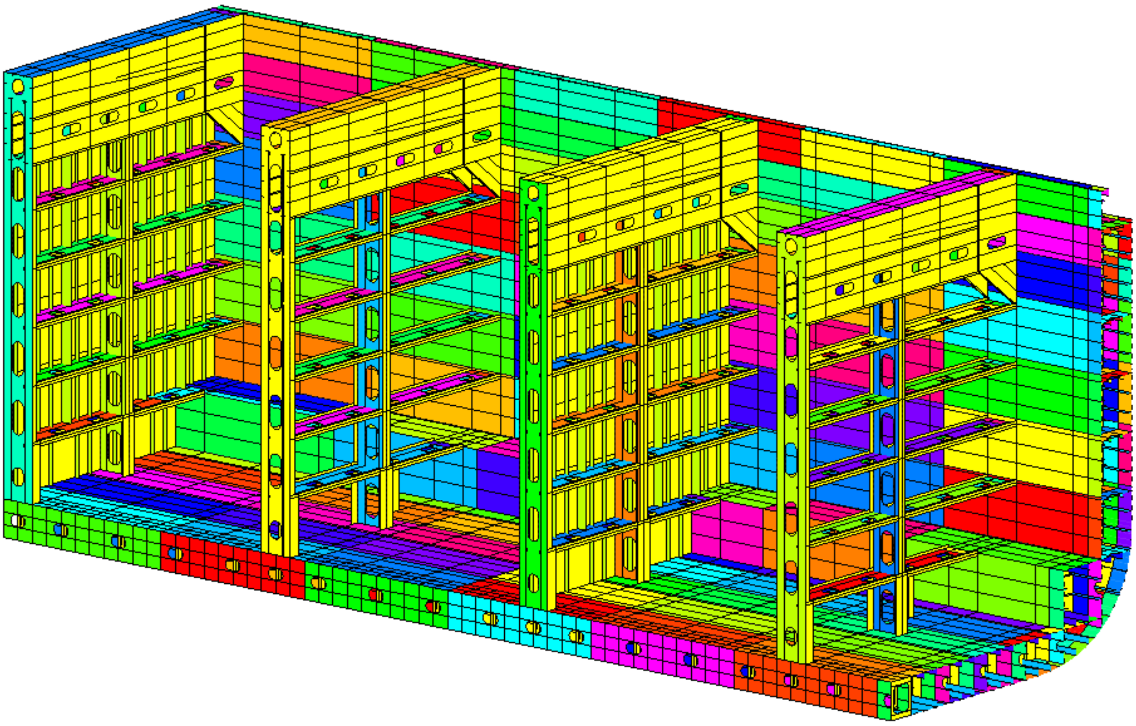


Figure 6.3b). The ship hull structural model developed in Poseidon computer code: complete hold located at the middle of the ship hull structural model

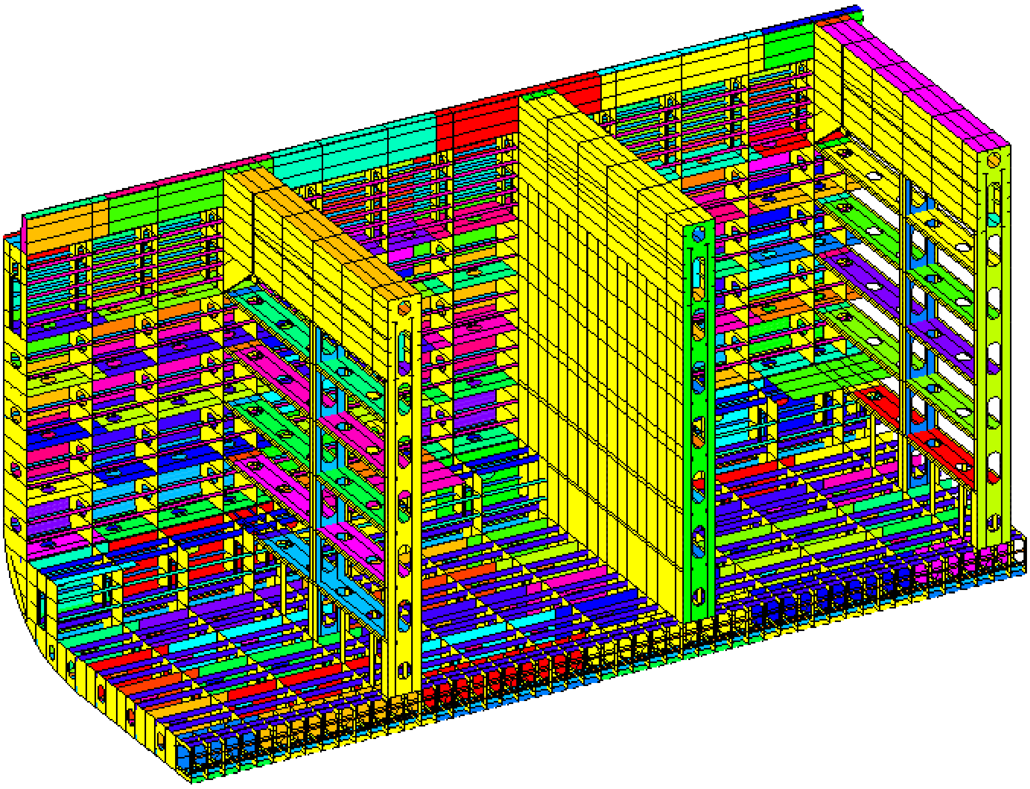


Figure 6.3c). The ship hull structural model developed in Poseidon computer code: Primary and secondary structural element arrangement.

6.2. Design Criteria Loads

The sizing of structural members in Poseidon is based on design loads, which contain the following items:

- tanks load;
- still water bending moment and sheer forces.

6.2.1. Tank Load

The arrangement of the tanks is carried out using the compartment method. In the double side shell area as well as in the double bottom; compartment are arranged, that serve to ballast and fuel tanks. These compartments are separated by the watertight floors and web frames at the level of watertight transverse bulkheads. Their arrangement over the cylindrical part is defined in table 6.1.

Table 6.1. Arrangement of tanks with the use of compartments method

Tank's Type	Double Bottom Compartment		Side compartment		Start Frame (bulkhead)	End Frame (bulkhead)
	Port Side	Start port	Port Side	Start port		
Fuel Tank	TFOB6P	TFOB6S	TFOS6P	TFOS6S	58	74
Ballast water	TWB5P	TWB5S	TWS5P	TWS5S	74	110
Ballast water	TWB4P	TWB4S	TWS4P	TWS4S	110	146
Ballast water	TWB3P	TWB3S	TWS3P	TWS3S	146	182
Ballast water	TWB2P	TWB2S	TWS2P	TWS2S	182	218
Ballast water	TWB1P	TWB1S	TWS1P	TWS1S	218	254

Cells are used to arrange each compartment; it is defined in the compartment worksheet, as shown in Figure 6.4.

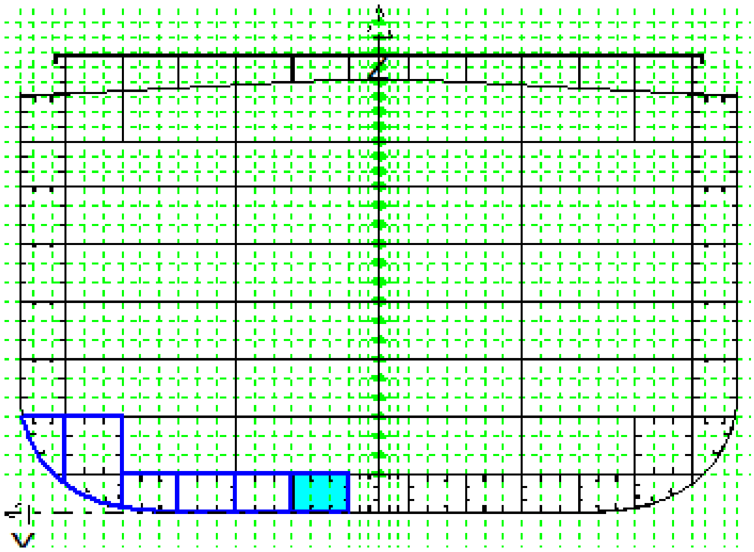
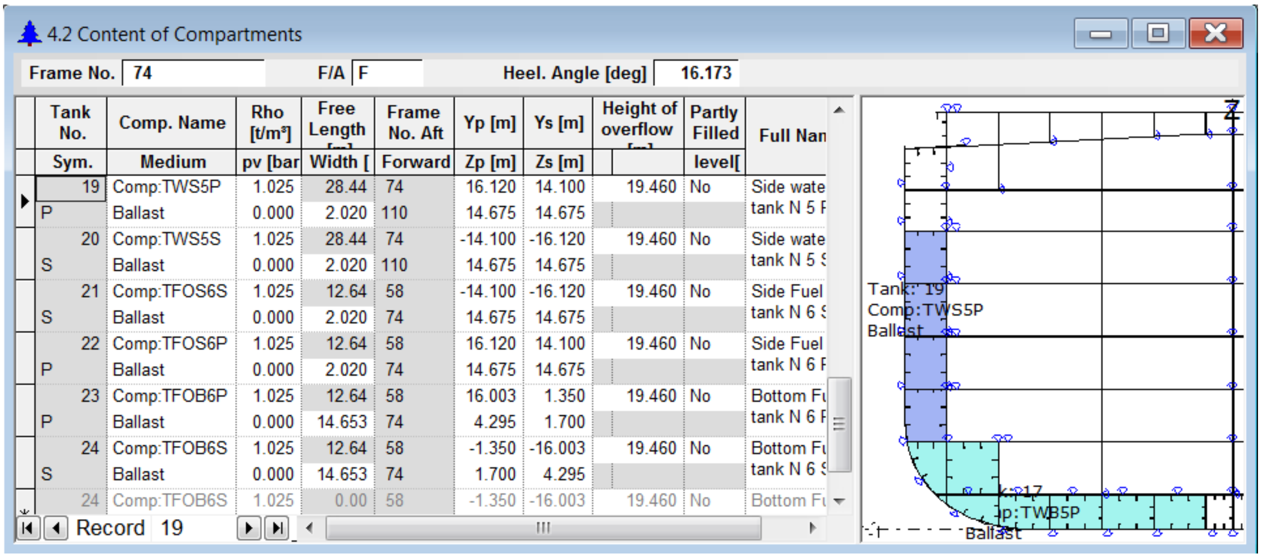


Figure 6.4. Example of the arrangement of one completed tank located in the double bottom.

After the creation of the compartment, it was checked using the Info command, this later provides information about the volume and the emplacement of the compartment. If no red common appear means the compartment is well arranged.

After that, content of compartments worksheet was used to specify the content of each compartment. In this later each tank was referred to its compartment and specified, if it is ballast or fuel tank, by selecting its type from the medium choices. Once the type has been defined the other parameters such as Rho, location of the tank, and height of over flow has been done automatically. Besides the free length and the width of the tank was calculated by the use of Calculate Tank Dimensions command (Ca). As an example, see Figure 6.5.



Tank No. / Sym.	Comp. Name / Medium	Rho [t/m³] / pv [bar	Free Length / Width [	Frame No. Aft / Forward	Yp [m] / Zp [m]	Ys [m] / Zs [m]	Height of overflow	Partly Filled / level[	Full Nan
19	Comp:TWS5P	1.025	28.44	74	16.120	14.100	19.460	No	Side wate
P	Ballast	0.000	2.020	110	14.675	14.675			tank N 5 F
20	Comp:TWS5S	1.025	28.44	74	-14.100	-16.120	19.460	No	Side wate
S	Ballast	0.000	2.020	110	14.675	14.675			tank N 5 S
21	Comp:TFOS6S	1.025	12.64	58	-14.100	-16.120	19.460	No	Side Fuel
S	Ballast	0.000	2.020	74	14.675	14.675			tank N 6 S
22	Comp:TFOS6P	1.025	12.64	58	16.120	14.100	19.460	No	Side Fuel
P	Ballast	0.000	2.020	74	14.675	14.675			tank N 6 F
23	Comp:TFOB6P	1.025	12.64	58	16.003	1.350	19.460	No	Bottom Fu
P	Ballast	0.000	14.653	74	4.295	1.700			tank N 6 F
24	Comp:TFOB6S	1.025	12.64	58	-1.350	-16.003	19.460	No	Bottom Fu
S	Ballast	0.000	14.653	74	1.700	4.295			tank N 6 S
24	Comp:TFOB6S	1.025	0.00	58	-1.350	-16.003	19.460	No	Bottom Fu

Figure 6.5. Tank description with the use of compartment.

The Figures 6.6 and 6.7 show the arrangement of the tanks in both; double side shell and double bottom areas.

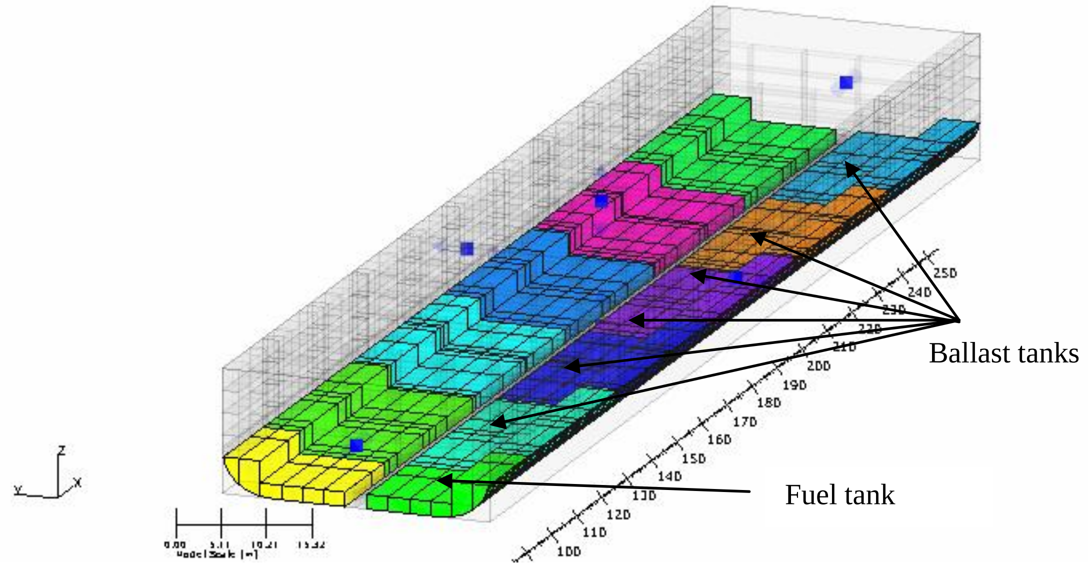


Figure 6.6. Arrangement of the Tanks in the double bottom region (Ballast and fuel).

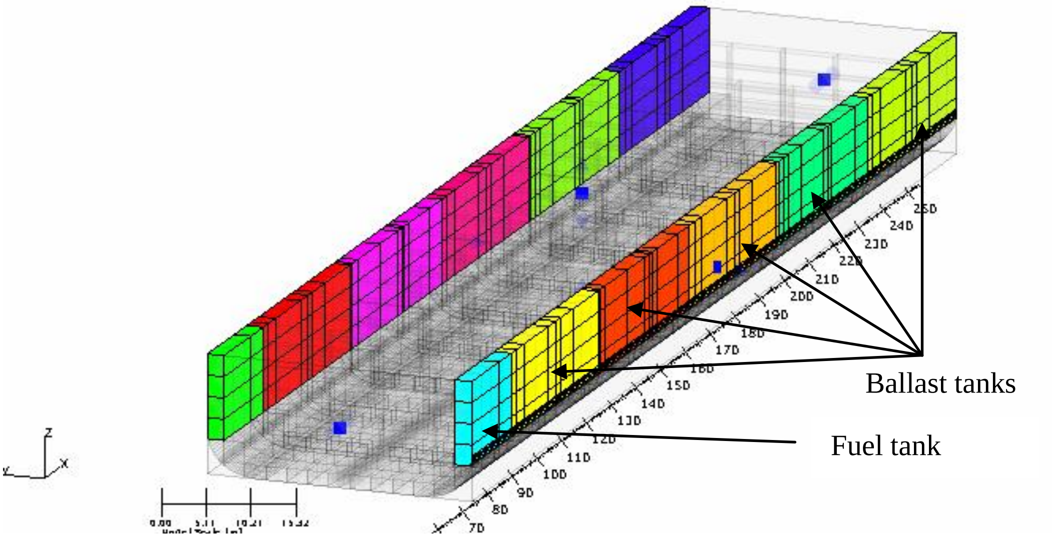
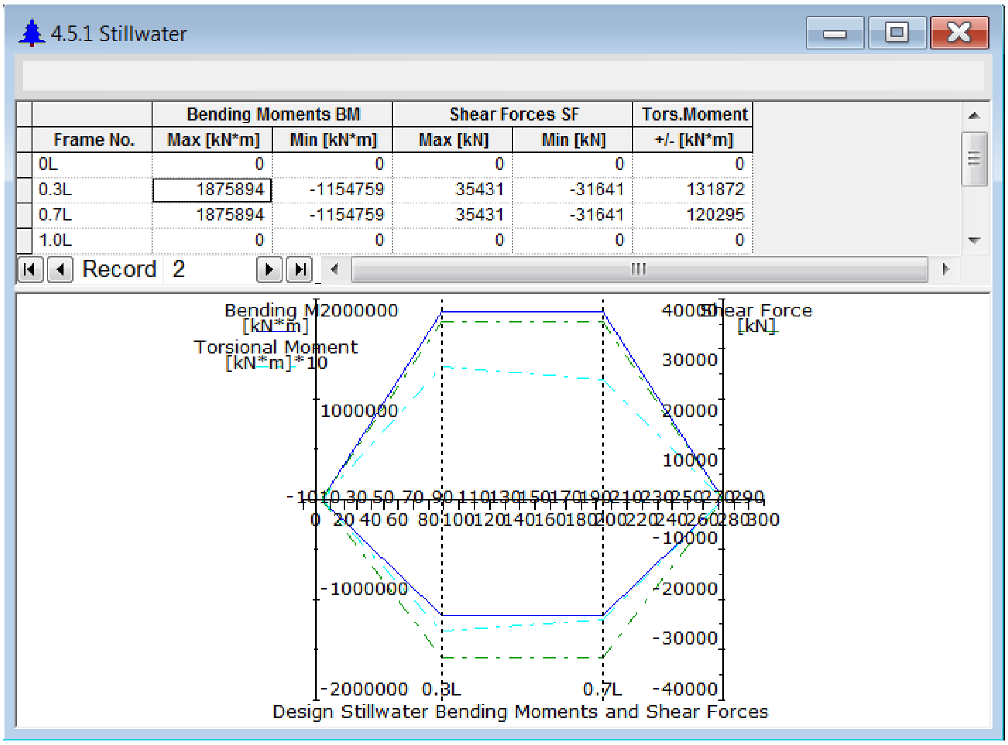


Figure 6.7. Arrangement of the Tanks in the double side shell (Ballast and fuel).

6.2.2. Stillwater Bending Moments Shear Forces and Torsion Moment

The scantling of the longitudinal structural elements is to be determined on the basis of the maximum value of the still water bending moment and shear forces. Default values, which is based on GL construction rules, is provided by Poseidon as shown in Figure 6.8.



	Bending Moments BM		Shear Forces SF		Tors.Moment
Frame No.	Max [kN*m]	Min [kN*m]	Max [kN]	Min [kN]	+/- [kN*m]
0L	0	0	0	0	0
0.3L	1875894	-1154759	35431	-31641	131872
0.7L	1875894	-1154759	35431	-31641	120295
1.0L	0	0	0	0	0

Figure 6.8. Still water bending moment, shear forces and torsional moment values.

6.3. Scantling of the Structural Elements and Material Discussion

6.3.1. Scantling of Longitudinal and Transversal Plates and its Stiffeners

The first proposed scantling was checked with the use of Rules Check command which has been applied at several frames by entering the frame number each time, as shown in figure 6.9.

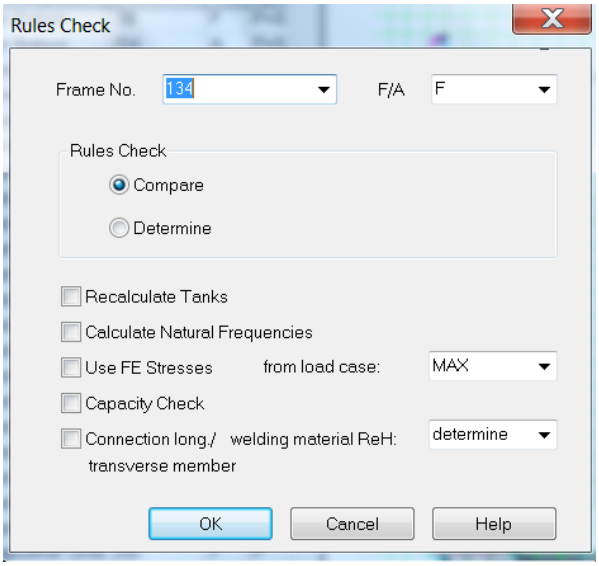


Figure 6.9. Rules check command applied for the midship section (frame 134).

The results of this command give information about the frame as the inertia moment, bending moment and the permissible stress. Besides, red comments and warnings was appeared for the existing scantling in certain plates and stiffeners, which gives the opportunity to correct the errors. The configuration of the results in the midship section after the use of the check command is given in Figure 6.10.

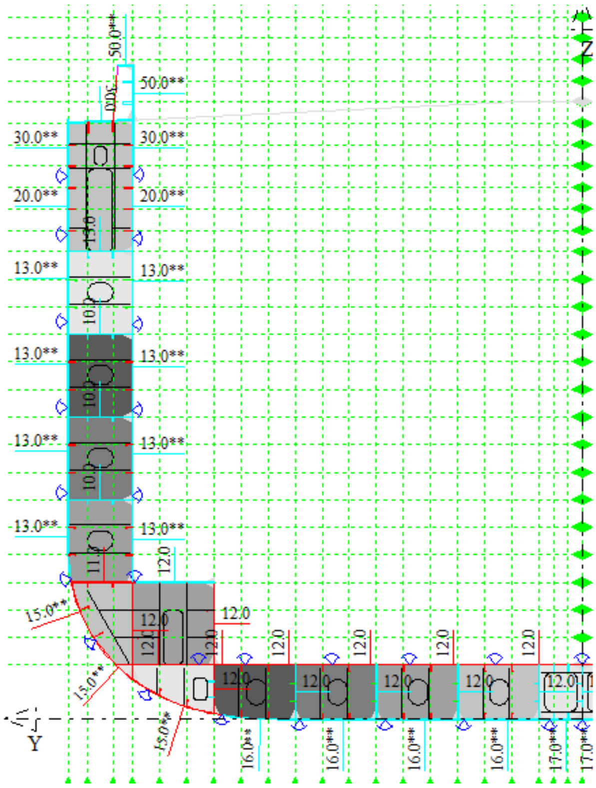


Figure 6.10. Results from the check command.

In order to correct errors and making scantling within the limits of the required dimensions, the build values have been changed several times until the required values have been reached.
The use of the mild steel for the longitudinal stiffeners requires the selection of profile which have significant dimension, for example in the double bottom structure the HP chosen of mild steel reaches the dimension of 360*15. In this case the high tensile steel of R_{eh} =355N/mm² is decided to be adopted for the longitudinal stiffeners of the structures: double bottom, shell, deck and longitudinal bulkhead in order to reduce the dimensions and the thicknesses of the profiles.
The resulted data and the configuration of the scantling of the longitudinal plates and its stiffeners which fulfils GL rules are given in Table 6.2 and Figure 6.11 respectively.
In the Table 6.2, the material defined by number 3 referred to high tensile steel of R_{eh}=355N/mm² and number 1 referred to the mild steel of R_{eh} =235N/mm², see Figure A.6.2 where the material number is defined during the first steps of the modelling.

Table 6.2. Final scantling of the longitudinal plates and its longitudinal stiffeners which fulfils the GL rules

Longitudinal plates			Stiffeners on long. plates		
	t, mm	material	profile type	dimension	material
Shell; Keel	17.5	3	FB	220*15	3
Shell B1:B4	16	3	HP	280*11	3
Shell; bilge 5	17	3	HP	280*11	3
Shell Side; S6	17	3	HP	260*11	3
Shell Side; S7	14	3	HP	240*12	3
Shell Side; S8	14	3	HP	240*11	3
Shell Side; S9	14	3	HP	200*11	3
Shell Side; S10	14	3	HP	200*9	3
Shell Side; S11	20	3	FB	260*20	3
Shell; Sheer	30	3	FB	260*20	3
IB;pl1	14	3	HP	120*12	1
IB;pl1:pl6	14	3	HP	260*11	3
DK_01	35	3	FB	360*30	3
DK_02	12.5	3	HP	140*9	3
LB_1; pl1	12	3	HP	240*11	3
LB_1; pl2	12	3	HP	220*11	3
LB_1; pl3	12	3	HP	200*11	3
LB_1; pl4	12	3	HP	200*9	3
LB_1; pl5	20	3	FB	260*20	3
LB_1; pl6	30	3	FB	260*20	3
LB_2	12	3	HP	260*10	3
LS_1	12	3	HP	240*12	3
LS_2	10	1	HP	140*9	1
LS_3	10	1	HP	140*9	1
LS_4	10	1	HP	140*9	1
LG_00	12	3	FB	150*12	1
LG_02	12	3	FB	150*12	1
LG_05	12	3	FB	150*12	1
LG_08	12	3	FB	150*12	1
LG_11	12	3	FB	150*12	1
LG_14	12	3	FB	150*12	1
LG_17	14	3	FB	180*9	3
CO_1	35	3	FB	200*30	3
CO_2	50	3	FB	300*50	3

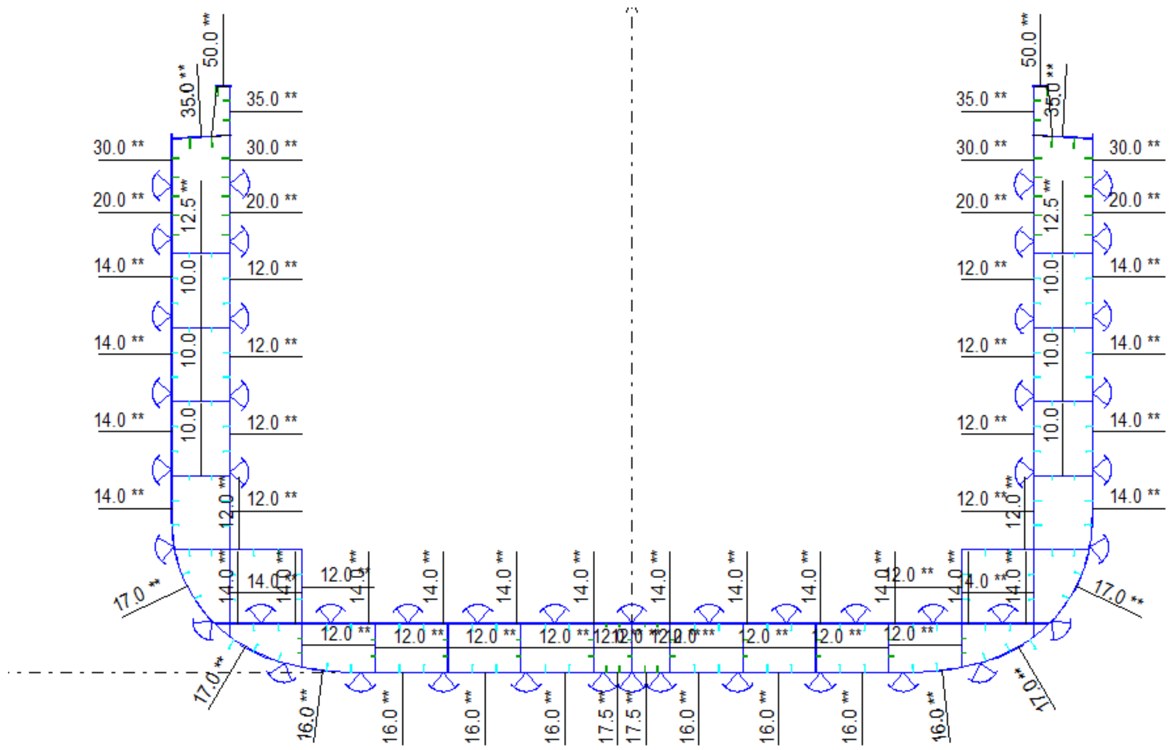


Figure 6.11. First scantling of the longitudinal plates based on construction rules.

The final sizing of the transverse members based on construction rules is shown in Table 6.3.

Table 6.3. Sizing of transverse plates and its stiffeners

Transverse plates			stiffeners		
	Thickness *t*, mm	Material	profile type	Dimensions mm × mm	Material
FL1	13	3	FB	150×12	3
FL2:FL6	12	1	FB	150×12	1
WP1:WP7	10	1	FB	150×10	1
PW6	12	1	FB	150×10	1

6.3.2. Scantling of Bulkheads' Structural Elements

The thickness of each plate has been determined according to GL rules; the calculation was performed in watertight bulkheads section, by selecting bulkhead plating. For that the design criteria Watertight (**WT**) was considered for each plate. Besides, the height of load centre for each plate is determined. According to GL rules; this latest may taken as the vertical distance from the base line to the lower edge of plate, the results are given in Table 6.4.

Table 6.4. Breadth and load centre of the bulkhead plates

Bulkhead Plate	Breath m	Load center Lolc (z), m
BHD1	2.45	1.7
BHD2	2.95	4.15
BHD3	2.95	7.1
BHD4	2.95	10.05
BHD5	2.95	13
BHD6	2.45	15.95
BHD7	2.1	18.4

Figure 6.12 shows the input field of the necessary data for calculation of the thickness of the plate BHD1.

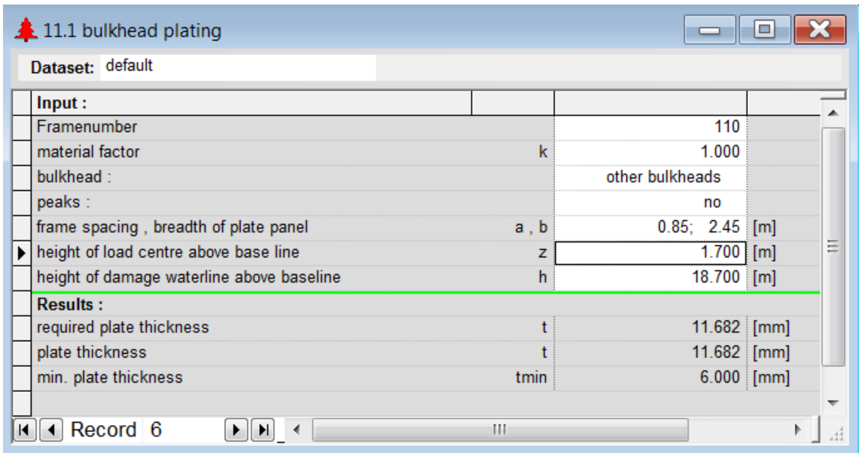


Figure 6.12. Input field for the calculation of the thickness of the plate BHD1.

The results for the other plates are given in Table 6.5.

Table 6.5. Bulkhead plates' Thickness

Plate	Required thickness, mm	Thickness as build, mm
BHD1	11.68	12
BHD2	10.94	11.5
BHD3	10.3	10.5
BHD4	8.943	9
BHD5	7.702	8
BHD6	6.14	6.5
BHD7	6	6

The same calculation was performed for the other bulkheads, the results was the same except for the plates of the collision bulkhead. However in the present work the collision bulkhead is not modelled.

Bulkhead Stiffeners are arranged from the IB till the DK_STO in the first scantling.

Since the distribution of the load is not uniform over the vertical direction of the bulkhead and it is higher in the lower part, the sizing of Stiffener which is located in the lower part has to be more rigid than the one which is located in the upper part. In order to reach an optimisation in the sizing of the stiffeners, the length of these latter has been divided into two parts, where their scantling has been based on the difference of the centre load in each part.

The load centre of each part and its scantling are given in Table 6.6.

Table 6.6. Scantling of the transverse bulkhead Stiffeners

	Z, m	*W*, cm^3	Profile mm × mm
IB to Z=9285	2.9975	248.5	HP 220*10
Z=9285 to D ST	10.5825	232.9	HP 200*11

6.3.3. Permissible Still Water Values

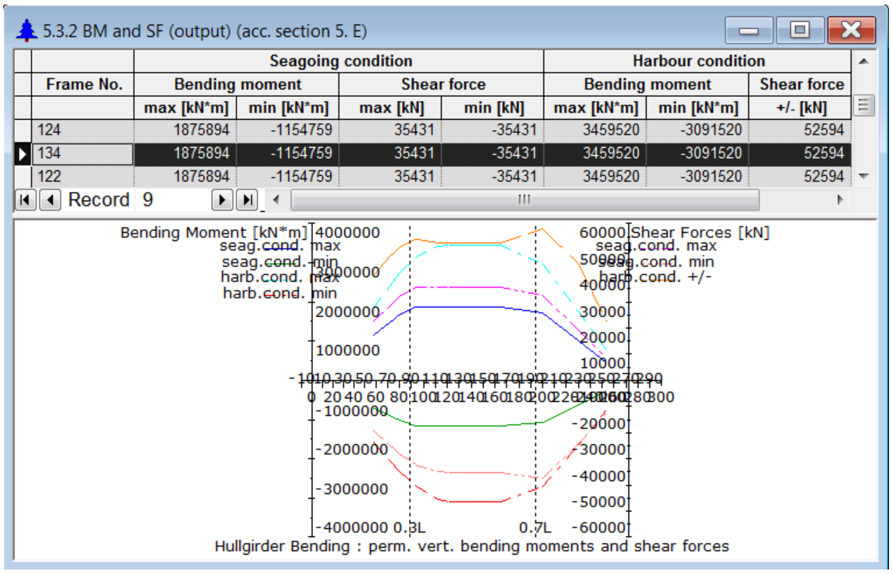
The verification of the midship section, using the check commend, provides the necessary information about the existing values of the moment of inertia, the neutral axis as well as the section modulus. Therefore, these parameters was inputted to the Section Modulus, BM and SF (input) command in order to calculate the permissible still water stresses at the deck and the bottom, as is shown in Figure 6.13.

5.3.1 Section Moduli,BM and SF (input)

Frame No.	Moment of Inert. [m4]	Z co-ord. N. Axis	Y co-ord. Top	k Top	Cs Rules	Cs hogg actual	Sigma p-D'	Tau p	Wact. Top	Wreq Top
X/L	Shear Fact. [N/mm²/kN]	Z co-ord. Bottom	Z co-ord. Top	k Bottom	Fact. in Harb. C.	Cs sagg actual	Sigma p-B	Tau L	Wact. Bottom	Wreq Bottom
		[m]					[N/mm²]		[m³]	
134	188.463	7.888	14.580	0.720	1.000	0.000	242	80	15.028	14.957
0.472	0.00146459	0.000	20.550	0.720	0.100	0.000	152	73	23.892	14.957

Figure 6.13. Calculation of the permissible still water stresses.

From the above table the permissible stress in the top is equal to 242 MPa, and 152 MPa in the bottom. The values of the bending moment and shear forces in both seagoing condition and harbour condition are also provided in the results section, see Figure 6.14.



Frame No.	Seagoing condition: Bending moment max [kN*m]	Seagoing condition: Bending moment min [kN*m]	Seagoing condition: Shear force max [kN]	Seagoing condition: Shear force min [kN]	Harbour condition: Bending moment max [kN*m]	Harbour condition: Bending moment min [kN*m]	Harbour condition: Shear force +/- [kN]
124	1875894	-1154759	35431	-35431	3459520	-3091520	52594
134	1875894	-1154759	35431	-35431	3459520	-3091520	52594
122	1875894	-1154759	35431	-35431	3459520	-3091520	52594

Figure 6.14. Permissible still water bending moment and shear force.

6.3.4. Results Evaluation

The evaluation of the results is carried out by the verification of the stress combinations represented by the normal stress σ_L and shear stress τ_L due to the hull girder loads. According to the section *Longitudinal Strength* of the GL rules, the following load cases have to be considered:

- load case 1: load caused by vertical bending and static torsional moment;
- load case 2: load caused by vertical and horizontal bending moment as well as static torsional moment;
- load case3: load caused by vertical and horizontal bending moment as well as static and wave induced torsional moment.

For each load case listed above, the von Mises stress σ_v has been checked and compared with the permissible stress represented by the equivalent stress from σ_L and τ_L which should not exceed the following value:

$$\sigma_v = \sqrt{\sigma_L^2 + 3 \times \tau_L^2} \leq \frac{190}{k} \;, \frac{N}{mm^2}$$

The analysis of the values of the normal stress σ_L as well as the shear stress τ_L for all the longitudinal plates and their stiffeners indicates that for the three load cases the normal stress is always high in the top coaming comparing with the other elements. However the maximum magnitude is in the load case 1 and 2 where the normal stress reaches the values of 218 MPa and 217.4 MPa respectively, as an example the distribution of the normal stress for the load case 1 is given in Figure 6.15.

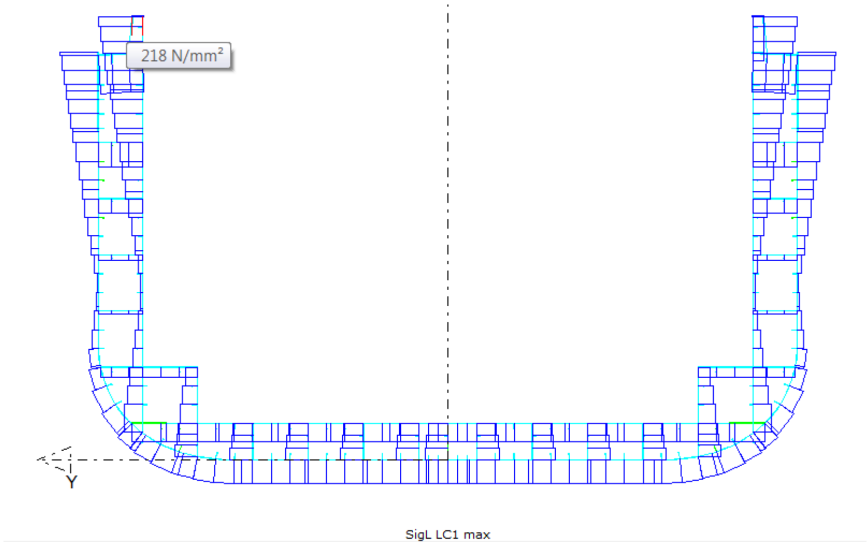


Figure 6.15. Normal stress distribution for load case 1, frame 134.

The shear stress is higher in the shell plates, its magnitude is almost the same for the three load cases; it is varied between 42 MPa in the load case 1 and 2, and 46 MPa in load case 3. The distribution of the shear stress for the load case 1 is given in Figure 6.16.

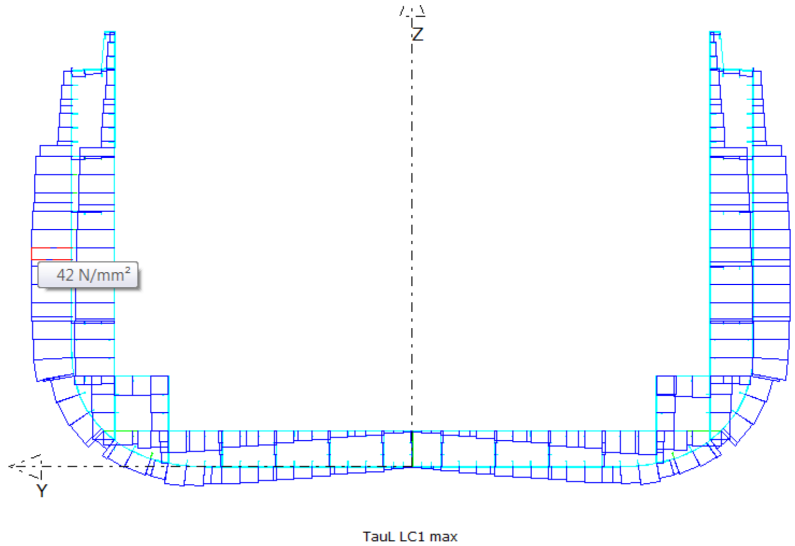


Figure 6.16. Shear stress distribution for load case 1, frame 134.

The equivalent von Mises stress for all the load cases is below the limit. The maximum value is observed in the load case 1, where it reached 218 MPa in the top coaming.

The distribution of the von Mises stress for the load case 1 is given in Figure 6.17.

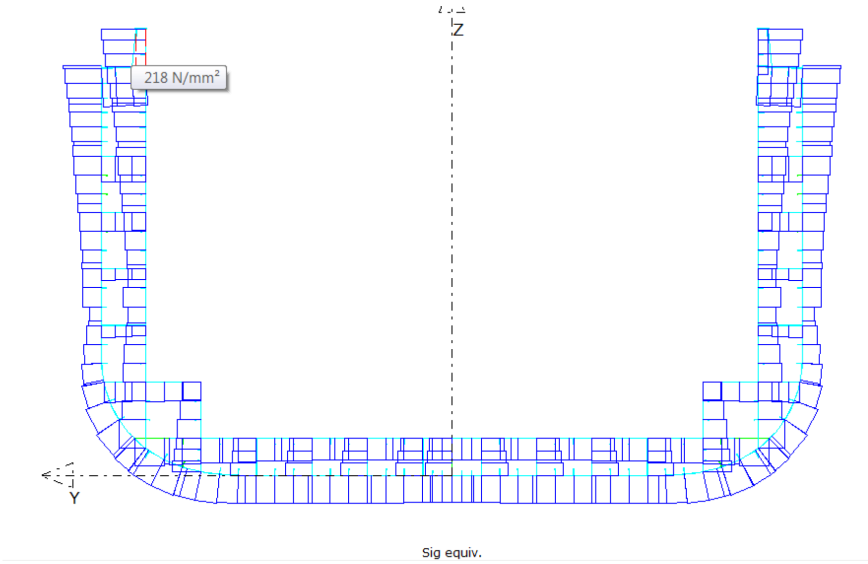


Figure 6.17. von Mises stress distribution for load case 1.

6.4. Hull Steel Mass Estimation

The prediction of the mass is an essential part of the ship design. The reason is that the estimation of the mass during the earliest steps of the project is necessary to quoting the cost. Additionally during the structural design the weight of the hull steel is important because it allows knowing which elements in the structure should deal with in order to save the mass so that the optimum scantling can be reached.

In the present sub-section, the mass of the hull steel for the whole ship is estimated based on the volume density. This latter is determined by calculating the ratio between the total weight of the structural elements in one complete cargo hold and the volume of this latter.

The mass of the structural elements is calculated manually, starting from the calculation of the areas then the volumes of the structural elements, and finally multiplying the volume by the density of the steel which equal to 7.85 t/m^3.

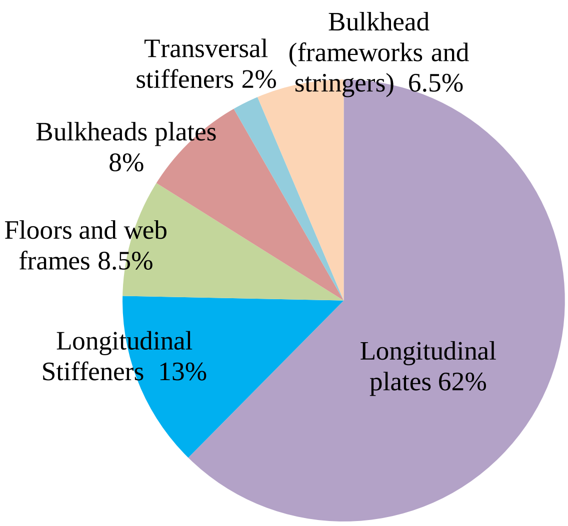
The total mass of the structural elements in one cargo hold comprises the mass of the longitudinal and transversal plates, bulkhead members as well as the longitudinal and transversal stiffeners.

The total mass of the entire structural elements in one cargo hold is given in Table 6.7.

From the results given in Table 6.7, the high mass is the mass of the longitudinal plates which represents 62 % of the total steel mass of the structural elements in one cargo hold, followed by the mass of the longitudinal stiffeners 13%. Comparing with the transverse elements, it is clear that the longitudinal elements have the biggest mass from the total mass in one cargo hold. This means that the total mass is influenced by the mass of the longitudinal elements especially the longitudinal plates; hence the save in the total weight can be reached by saving in the mass of the longitudinal plates. Both the longitudinal plates and stiffeners are made by high tensile steel (except some ones, however their percentage is low), which means that their mass is also the mass of the high tensile steel needed. Since the cost of the high tensile steel is higher than the mild steel, then the saving in the mass of the longitudinal plates is also saving in the cost.

Table 6.7. Total mass of the structural elements in one cargo hold.

	W, t	W, % W_t
Longitudinal plates	654.3	62.4
Longitudinal Stiffeners	135.5	12.9
transverse plates (floors and web frames)	90.0	8.5
Bulkheads plates	81.7	7.7
transversal stiffeners	20	1.9
Bulkhead (frameworks and stringers)	66.8	6.3
Total Mass in one cargo hold, W_t	**1048.5**	



The total mass of the steel hull ship is estimated by:

- Calculation of the density d: $d = \frac{M_c}{V_c}$;
- Calculation of the volume of the ship: $V_s = C_B \times L \times B \times D$;
- Calculation of the mass of the ship hull steel : $M_s = d \times V_s$

The total displacement of the containership B178 is calculated by multiplying the underwater volume with the volume density of the water.

The results of the calculation are given in Table 6.8.

Table 6.8. Calculation of the total hull steel mass of the developed containership

Volume of one cargo hold V_c, m^3	16903.08
Mass of the structural elements in one cargo hold M_c, t	1048.54
Density d, t/m^3	0.062
Total volume of the ship V_s , m^3	55660.96
Hull steel mass of the ship M_s, t	3452.78
Displacement of the container B178, t	56996.83

The total hull steel mass of the ship is found equal to 3452.78 t, which represent 6.05% the total displacement of the ship. Because of the lack of the data concerning mass assessment for hull steel, no comparison of the value found is made.

6.5. Conclusion

As seen throughout this section, reaching such a target scantling which fulfils the GL rules is carried out through a set of steps such as the building of the model, inputting of the proposal scantling and finally modification of the elements dimensions until the values of the sectional modulus in the midship section become within the limits of the permissible values provided by Poseidon software. This latter provides also a good insight on the normal stress, shear stress and von misses stresses in the midship section due to the combined vertical bending moment, horizontal bending moment, tensional moment as well as the shear forces, which allows to know the behaviour of the structure and to verify the sufficiency of the scantling.

The results from the combined stresses indicate that the final scantling reached which based on the GL rules is sufficient against the combined loads listed previously. Hence the model is ready for the finite element analysis provided also by Poseidon.

7. STRENGTH ANALYSIS USING FINITE ELEMENT METHOD

7.1. Bulkhead Analysis Using Finite Element Method

The structural strength of the transverse watertight bulkheads is verified using the finite element method. The analysis is made in the GL frame software, where the structure of one complete watertight bulkhead is modelled. The results provide an over estimation of the bulkhead structure behaviour, as the calculation of deflections, reacting forces and moments as well as stresses.

7.1.1. Analysis Method

The knowledge of the reason behind the requirement of the watertight bulkhead, allows afterwards the decision about which method of analysis has to be considered. There are two main aspects to use the watertight bulkheads; safety and strength aspects.

- ✓ Divided the ship into watertight compartments;
- ✓ Provide reserve of buoyancy in case of flooding;
- ✓ Transverse strength;
- ✓ Torsional rigidity.

Once clarifying the use of the bulkheads, it depicts that there are two main types of loads which applied to the structure of the bulkhead: in-plane load and out-of-plane load.
In-plane load, represented by the following items.

- ✓ In plane compressive forces resulting from the hydrostatics pressure;
- ✓ In plane shear forces resulting from the torsion.

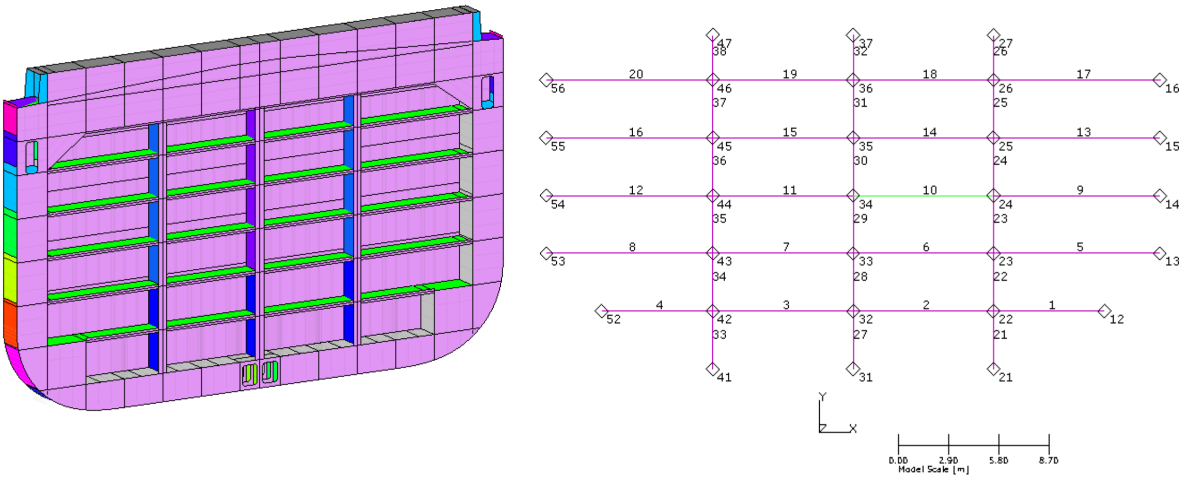
Out-of-plane load, represented by:

- ✓ In-out-of plane bending forces, in the case of flooding compartment.

In the presented model the only load which is considered is flooding loading, because of the stresses generated in that case is more larger than the stresses generated due to the hydrostatic pressure. The analysis is based on the beam theory.

7.1.2. Description of the Model

A model of one complete watertight bulkhead structure is built in GL frame software. The bulkhead Plates, vertical frameworks and horizontal stringers were modelled using beams which are linked between nodes, as shown in the Figure 7.1. Stiffeners and holes were not considered in this analysis.



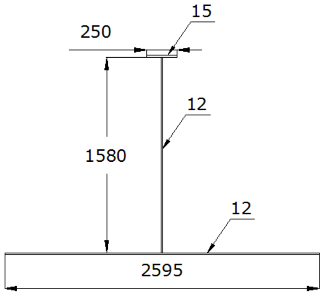
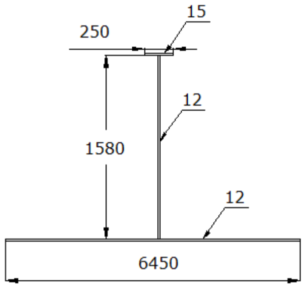
(a) Structure of one complete watertight bulkhead

(b) Model of the watertight bulkhead in GL frame computer code using beams

Figure 7.1. Bulkead structure modelling.

Afterwards the cross sections of these beams have been defined; cross sections for the horizontal beams which represent the horizontal stringers, and cross sections for the vertical beams which represent the vertical framework. The dimensions of these sections are based on the first scantling which was defined previously. Because of the thickness of the bulkhead plates are changed from the lower beams to the upper beams, several cross sections are defined. Table 7.1 gives the cross sections of the lower horizontal beam and the lower vertical beam.

Table 7.1. Cross section definition for the lower horizontal and vertical beams

Beams	Cross section
Lower horizontal beams: from 1 to 4	
Lower vertical beams from 21 to 33	

7.1.3. Define the Boundary Condition

The spring stiffness is prescribed in the nodes which are located at the edge of the model in all degree of freedom except the rotation around the *Z* axis as shown in Figure 7.2.

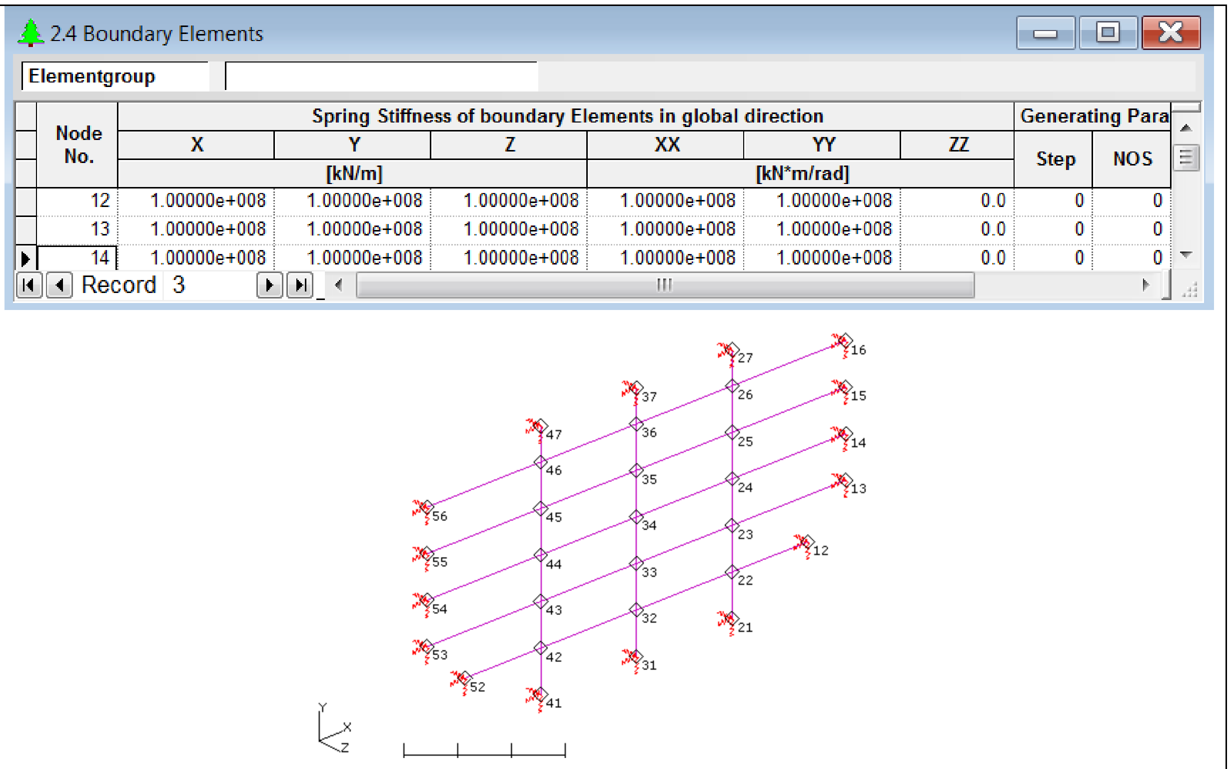


Figure 7.2. Input field for the definition of the boundary condition of the model.

7.1.4. Calculation of the Load Acting on the Structure of the Bulkhead

As mentioned before the structure is subjected to the flooding load. The calculation of the load is based on the following formula.

$$q = \rho g h$$

Where the damage water line is taken at the level of the bulkhead deck; h=18.7 m.

In the present model, the horizontal beams are considered as a support for the vertical beams hence the loads is inputted only to the vertical beams. The calculation of the load at each level of the vertical beams is given in Table 7.2.

Table 7.2. Calculation of the load acting on beams of the model.

	h_i, m	q_i, KN/m
IB	1.7	1102.558
LS_01	4.295	934.2559
LS_02	6.89	765.9536
LS_03	9.485	597.6514
LS_04	12.08	429.3491
DK_02	14.675	261.0469
DK_st	16.69	130.3613

7.1.5. Results Evaluation

The maximum deflection of the model 20 mm is observed in the vertical beams which are located in the middle, as shown in Figure 7.3.

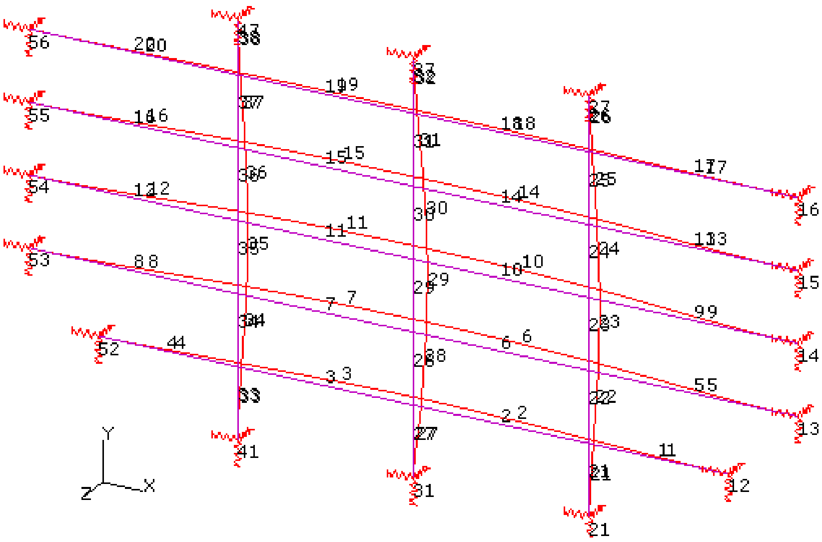


Figure 7.3. Deformation of the model beams under the flooding load.

According to the GL rules, the permissible stress of the primary structural members, in the case of flooded hold is referred to the nominal yield stress R_{eH} which equal to 235 N/mm² in this case as the mild steel is used.

Higher von Mises stresses are observed at the level of the flanges of the frameworks represented by the vertical beams in the model. The magnitude of these stresses are significant at the lower vertical beams 21, 27 and 33, as shown in Figure 7.4, which represents the cross section of the beam 27.

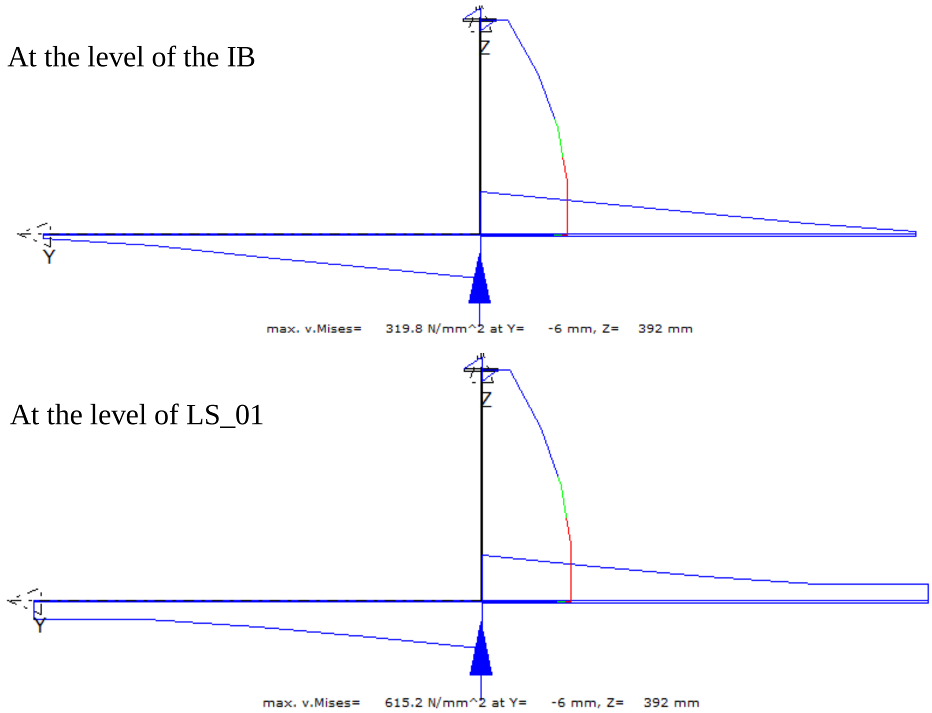
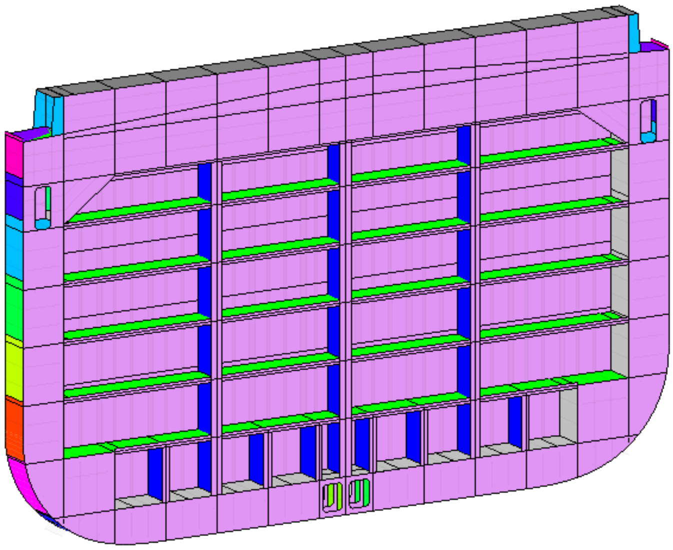


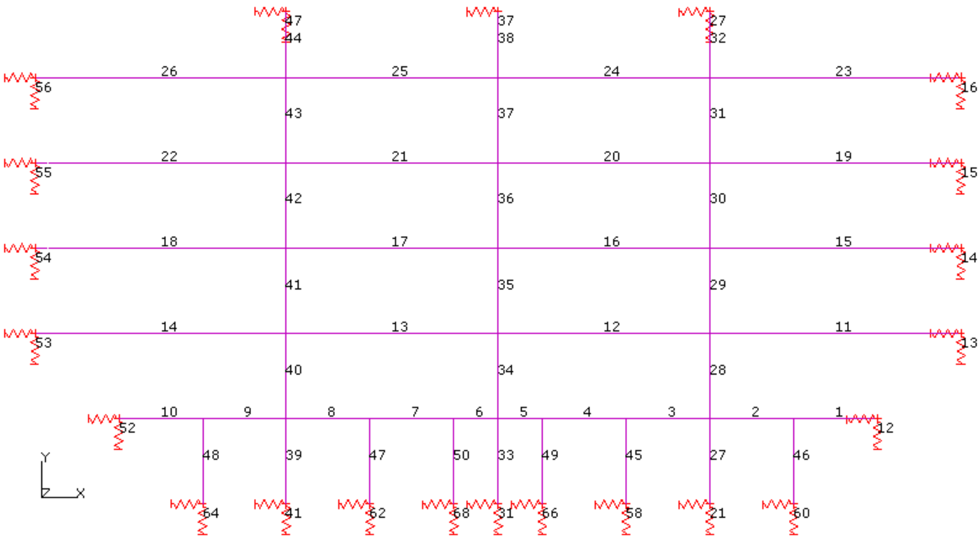
Figure 7.4. Distribution of the von Mises stress in the cross section of the beam 27.

The first trial to decrease the magnitude of the von Mises stresses is to increase the thickness of webs and flanges of the lower vertical beams. After the analysis, the von Mises stresses at the level of the vertical beams which are located between the LS_1 and DK_STO are decreased under the limits. However the magnitude of the von Mises stress at the lower vertical beams remains high. Therefore additional vertical beams were added between the inner bottom and the first longitudinal stringer as depicted in Figure 7.5. The arrangement of the additional beams is matched with the arrangement of the bottom longitudinal girders.

The material chosen for the lower beams (from IB to SL_1) is the high tensile steel; this solution is adopted in order to decrease the thicknesses of lower vertical beams.



(a) Structure of the bulkhead with additional vertical webs from IB to LS_1



(b) Model of the watertight bulkhead in GL frame computer code with additional vertical beams from IB to LS_1

Figure 7.5. Bulkhead structure model with the additional lower beams.

The cross section of the vertical beams 45 to 50 is shown in Figure 7.6.

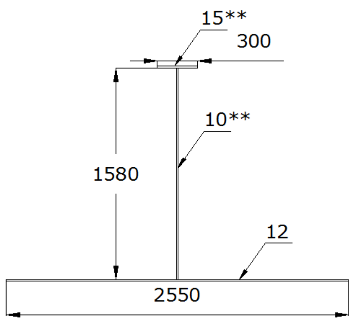
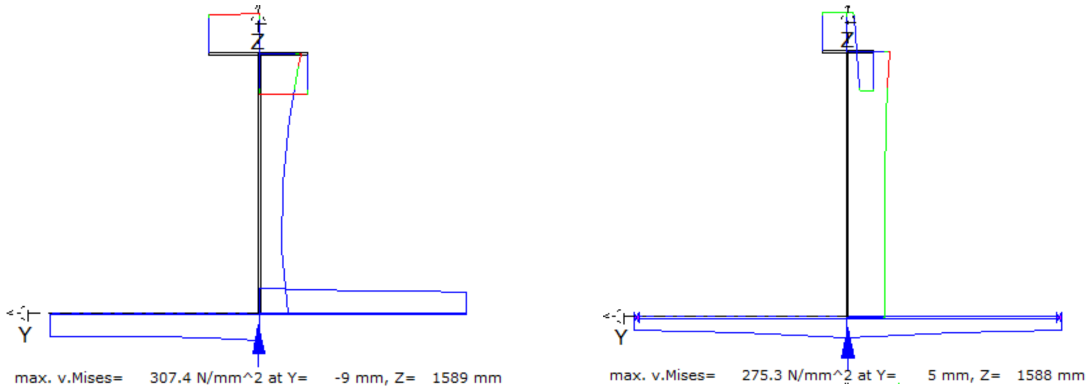


Figure 7.6. Cross section of the additional vertical beams, from 48 to 50.

The results of the finite element analysis after the change made at the level of the lower beams shows that the magnitude of the von Mises stresses is decreased below the limits of the permissible von Mises stress. The values shown in Figure 7.7 were compared with the permissible von Mises stress equal to 355 N/mm² (because of the application of high tensile steel). This proves that the additional vertical beams provide a good support to the bulkhead structure at the lower part.

The distribution of the von Misses Stress in the cross section of the beams 33 and 45 and is given in Figure 7.7.



(a) Cross section of beam 33 (b) Cross section of beam 45

Figure 7.7. Von Misses Stress distribution in the cross section of the beams 33 and 45, at the level of the inner bottom.

7.1.6. Conclusion

The analysis of the watertight bulkhead structure using the GL frame software provides an overall estimation of the distribution of the stresses in the primary elements of the bulkhead which allows selecting the areas in where the stresses are more significant.

The evaluation of the results indicates that the thicknesses of the bulkhead plates are sufficient except for the two upper plates which are dedicated to be contributed to form the transversal box, hence thickness of 12.5 mm is adopted for these two plates instead of 6 mm. Additionally, the results designate the necessity of adding additional vertical beams at the lower part of the watertight bulkhead, from IB to LS_1, in order to reinforce its structure against the significant stresses in this area. The use of the high tensile steel for a part of the webs and the flanges in the vertical frameworks is taken place in order to decrease the thicknesses of these parts.

Since the stresses are important in the lower part of the watertight bulkhead, the size of the lightening holes in the web of the frameworks is decreased to 700×500 mm×mm.

The final scantling of the watertight bulkhead is given in the appendix, Plan sheet N°2 "Watertight bulkhead structure".

7.2. Cargo Hold Analysis

The cargo hold analysis performed in the presented section is aimed at analyse the final scantling, which is defined in the previous section, under the realistic load cases required by the GL rules. The standard load cases are given Figure A.7.25.

For the developed containership, two load cases have been considered:

- ✓ homogeneous 40 ft;
- ✓ heavy Loading 20 ft.

7.2.1. Description of the Model

The finite element model is generated based on the previously defined geometrical and topological information as well as the final scantling of the structural elements. According to the requirement given in the section *Cargo hold analysis* of the GL rules , the model considered is located at about amidships, and it shall extend over one complete cargo hold and two half cargo holds. All The structural elements have been included in the model, the plates and the stiffeners are idealised using mode 3, in which the plates are modelled as shell elements, and the stiffeners are modelled as beam element. Figure 7.8 shows the necessary input field to generate the mesh.

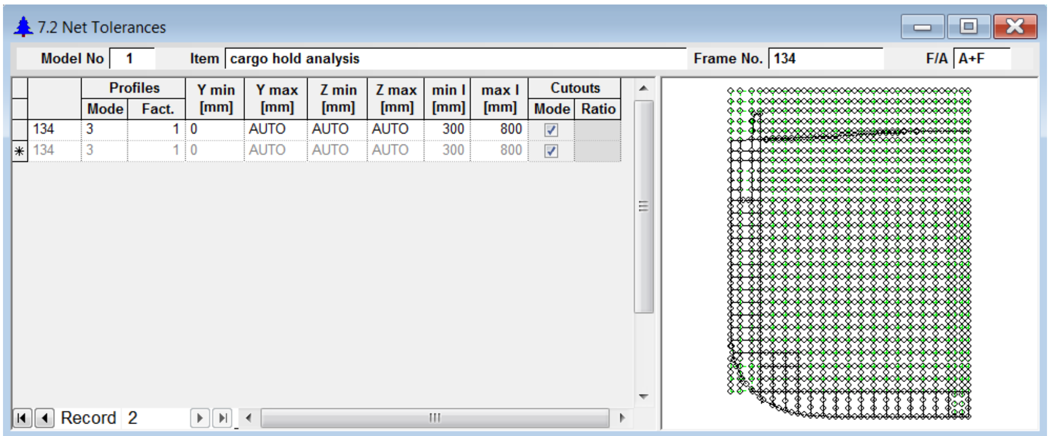


Figure 7.8. Net tolerance input field for the generation of mesh.

The holes in the plates of the longitudinal and transverse members are considered in order to calculate the realistic shear stress. The reduction in the stiffness of the plate due to the presence of the holes is considered by the corresponding reduction in the element thickness. Therefore the reduced thickness is calculated for all the elements which containing holes, based on the following formula:

$t_{red}\ (y) = \frac{H-h}{H} t_0\ ;\ t_{red}\ (x) = \frac{L-l}{L} t_0\ ;$

$t_{red} = \min\left(t_{red}\ (x), t_{red}\ (y)\right).$

Where H, L, h and l represent the dimensions of the plate and the hole, given in Figure 7.9.

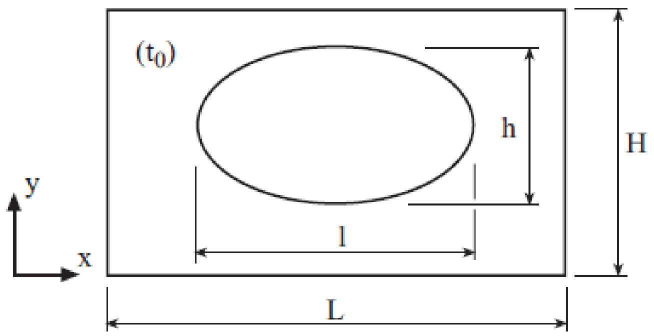


Figure 7.9. Cut-out. GL rules, section "*Cargo Hold Analysis*"

The results of the calculation of the reduced thickness for the corresponding plates are detailed in Table 7.3.

Table 7.3. Reduced thickness calculation

Elements		t_0 mm	t_{red} mm	hole dimension mm×mm
Bottom longitudinal girders	LG_00; LG_14	12	8.5	800*500
	LG_17	14	10	800*500
Floors	Fl2;FL6	12	6	800*600
Web frames	WF1;WF7	10	9	800*600
Longitudinal stringers	LS_2;LS_4	10	7.5	650*500
Bulkhead stringers	LS_1;DK_2	10	6	750*600

The generation of the finite element model based on the parameters defined previously is depicted in Figure 7.10.

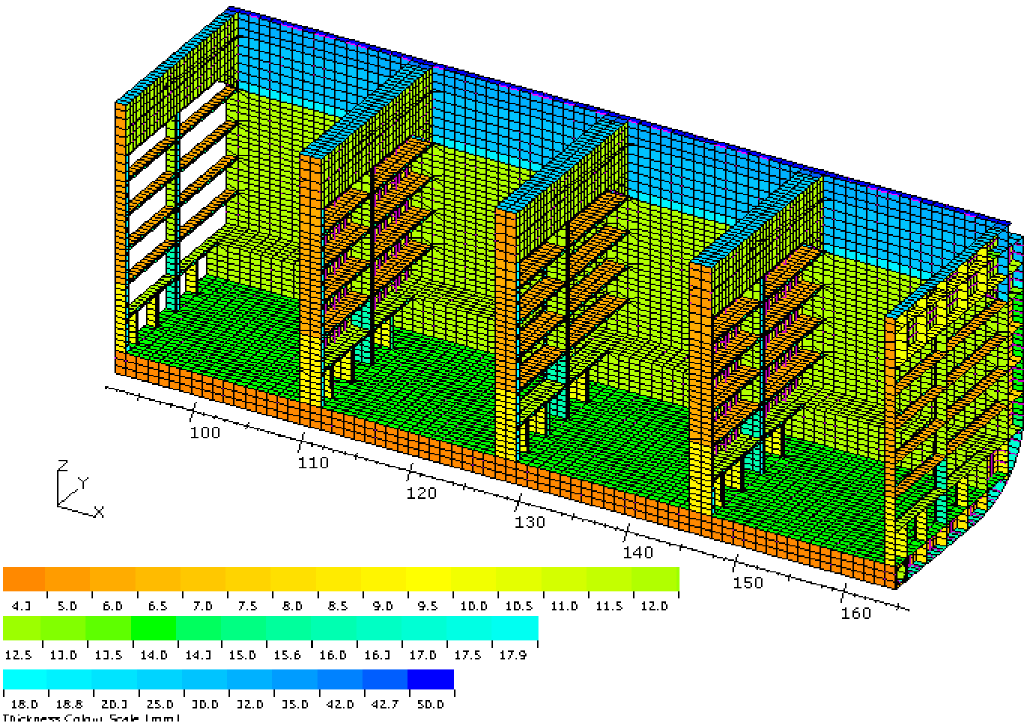


Figure 7.10. Mesh generation of the finite element model.

7.2.2. Define the Boundary Condition

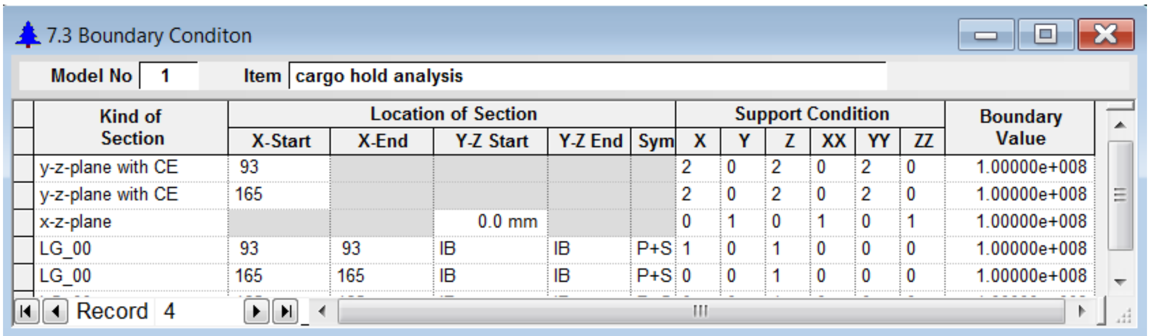
In order to determine the full loads acting on the cargo hold model of the ship, appropriate boundary forces and moments have been applied at the fore and the aft ends of the model.

The structure of the cargo model is supported at its boundaries by applying the following supports at the centre line:

- two supports in the vertical direction at the fore and aft ends;
- one support in the longitudinal direction at only the aft boundary.

In the transverse direction the symmetry conditions was applied.

The definition of the boundary condition for the FE analysis as well as its configuration is given in Figures 7.11 and 7.12 respectively.



7.3 Boundary Conditon

Model No 1 Item cargo hold analysis

Kind of Section	Location of Section					Support Condition						Boundary Value
	X-Start	X-End	Y-Z Start	Y-Z End	Sym	X	Y	Z	XX	YY	ZZ	
y-z-plane with CE	93					2	0	2	0	2	0	1.00000e+008
y-z-plane with CE	165					2	0	2	0	2	0	1.00000e+008
x-z-plane			0.0 mm			0	1	0	1	0	1	1.00000e+008
LG_00	93	93	IB	IB	P+S	1	0	1	0	0	0	1.00000e+008
LG_00	165	165	IB	IB	P+S	0	0	1	0	0	0	1.00000e+008

Record 4

Figure 7.11. Input field for the boundary condition of the model for FE analysis.

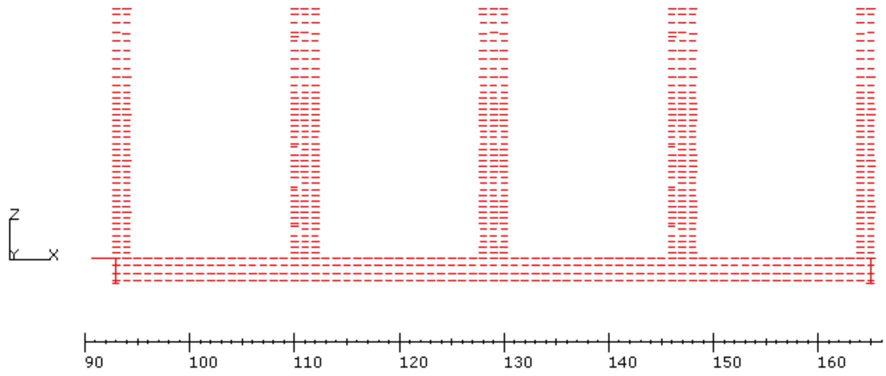


Figure 7.12. Generation of the boundary conditions.

7.2.3. Definition of the Loads to Generate

The loads for the finite element model were defined according to the specification of each load case in Loads section in the Poseidon file. The generation of the loads for the homogeneous 40 ft containers load case is detailed in the following:

External sea loads:

This command allows defining the static and the dynamic water pressure, as shown in figure 7.13.

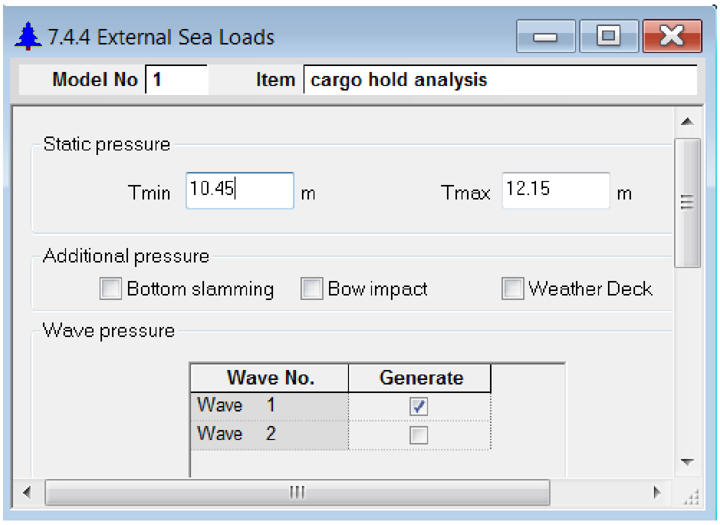


Figure 7.13. External sea loads.

According to the Rules, the maximum amplitude of the wave extends over the full length of the cargo hold model, as shown in Figure 7.14.

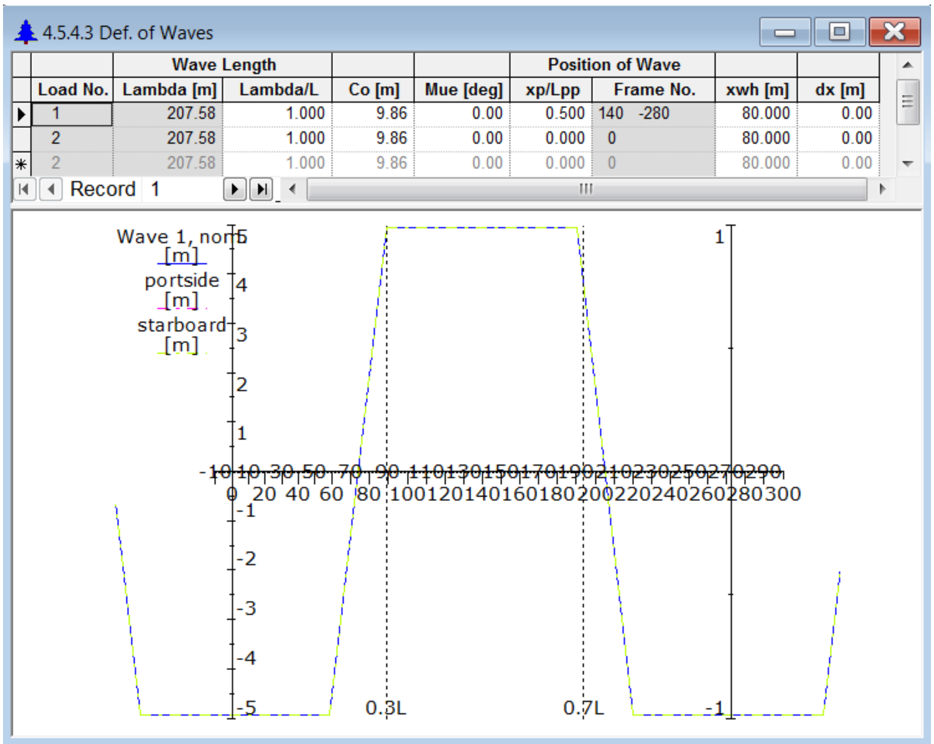


Figure 7.14. Input field for the definition of the wave profile (Hogging wave).

Remark: the wave load number 2 represents the sagging wave is depicted in Figure 7.15, to be generated for the heavy 20 ft container load case.

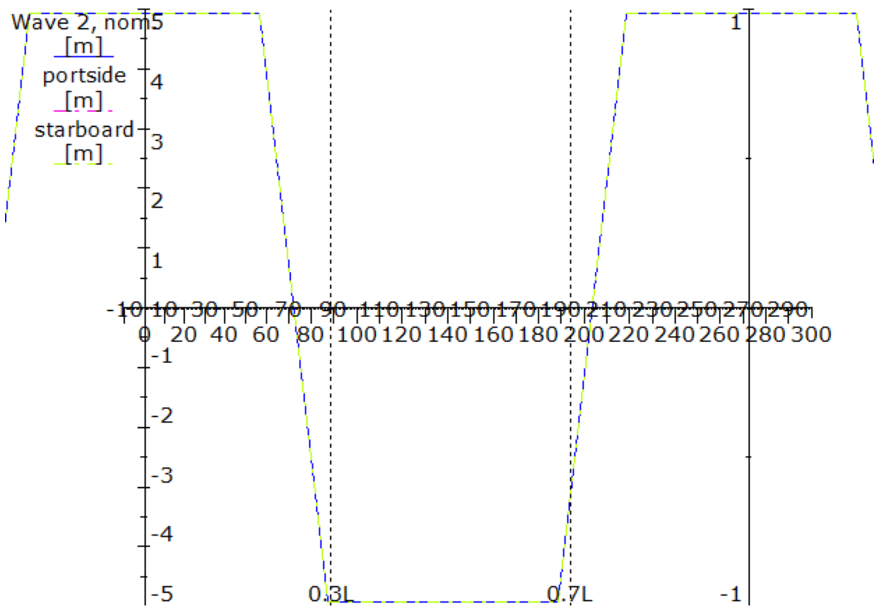


Figure 7.15. Profile of the sagging wave.

Containers load

Container load has been defined by creating 20ft containers bays, as shown in Figure 7.16.

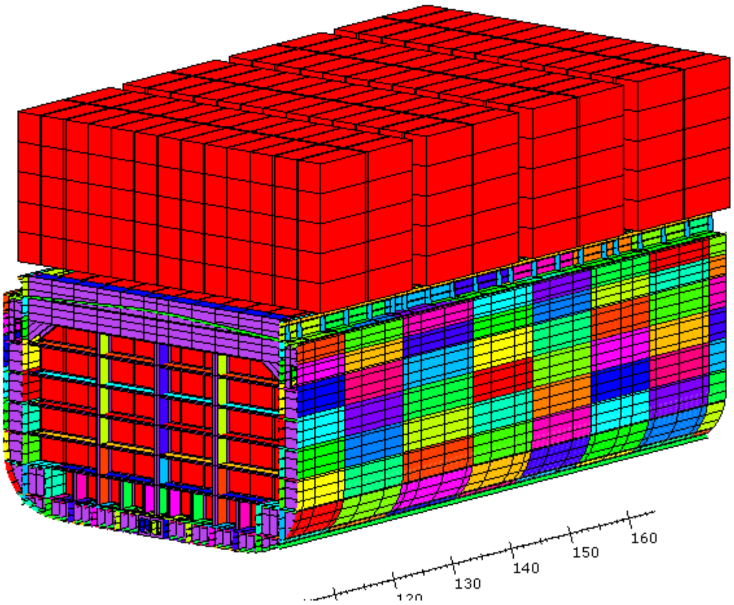
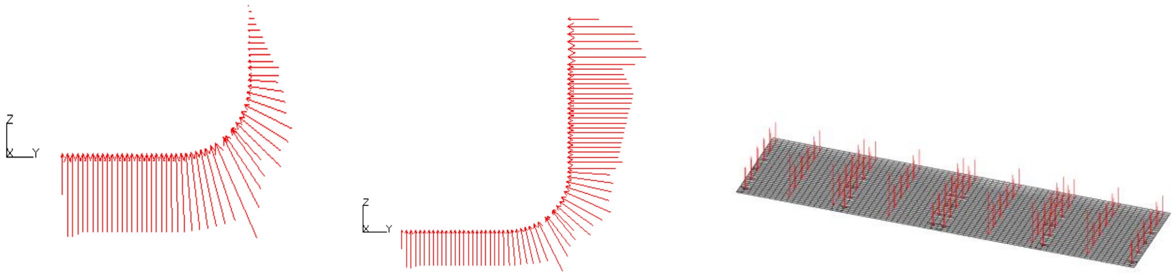


Figure 7.16. Containers arrangement.

The generation of the unit loads described above are given in Figure 7.17.



Static pressure load *Wave pressure load* *Container load on the inner bottom*

Figure 7.17. Unit Load generation.

7.2.4. Global Load Adjustment

After the generation of the finite element model and the unit loads, the global load case is adjusted in order to produce the target hogging or sagging scenarios and obtain the equilibrium of the full balanced model (Germanischer Lloyd, 2011). This is achieved by applying the sectional forces and moments at the forward and aft ends of the model. The target hogging and sagging values which were inputted during the adjustment are given in Table 7.4.

Table 7.4. The target hogging and sagging values

	Bending moment Hogging, KN.m	Bending moment Sagging, KN.m
Still water	1875894.00	-1154759.00
Waves	1759584.34	-2144119.25
Target value	3635478.34	-3298878.25

The adjustment need to input load factors for the unit load group, these factors are given by *Cargo hold analysis* section of the GL rules. For example, for the wave crest or trough the probability factor is taken 0.6.

Factors were calculated and inputted for the containers loads in order to get the required forces. The dead weight of the structure is taken into account, increased by 20 % to include the weight of the lashing equipment accessories and structural components such as brackets which are not modelled. The calculation for the both load cases are given in Table 7.5.

Table 7.5. Calculation of the dead weight factors

Load case	Factor formula	Factor value
Homogeneous 40 ft	$(1-\boldsymbol{a}_v*)\times g\times 1.2$	9.77
Heavy 20 ft	$(1+\boldsymbol{a}_v)\times g\times 1.2$	13.77
* $\boldsymbol{a}_v$ represents the acceleration vector, taken equal to 1.7.		

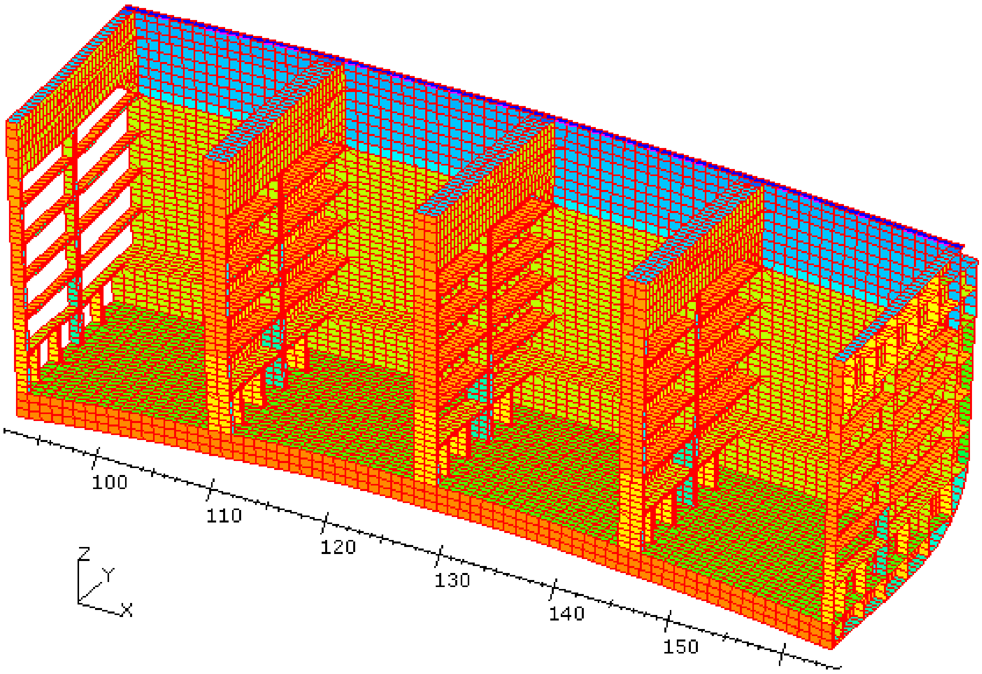
The necessary factors inputted as well as the adjustment for the both load cases with the resulted bending moment and shear force curves are given in the Figures A.7.26 and A.7.27.

7.2.5. Evaluation of the Results

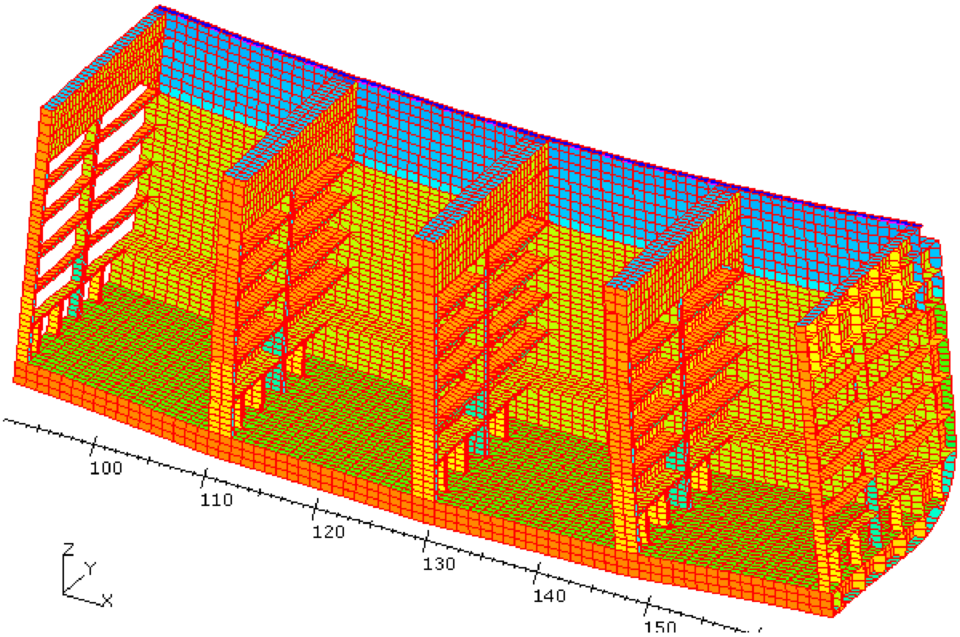
Deflections: Maximal deflections of the model under the considered loading cases are given in table 7.6. The deformations of the model under the two first load cases are shown in Figure 7.18. The magnitude of the deflection in the first load case is higher than in the second load case. This can be explained by the magnitude of the total bending moment due to the hogging condition in the first load case which is higher than the magnitude of the total bending moment in the second load case where the sagging condition is applied.

Table 7.6. Maximum deflection of the model under the considered load cases

Load case	Maximum deflection in *Z* direction, mm
Homogeneous 40 ft;	92
Heavy Loading 20 ft;	-33



(a) Homogeneous 40 ft load case



(b) Heavy 20 ft load case.

Figure 7.18. Deformation of the model under the realistic load cases.

Permissible stresses: The permissible stresses of the primary structural members are calculated according to the values given in Table A.7.4. The results of the calculation are listed in Table 7.7.

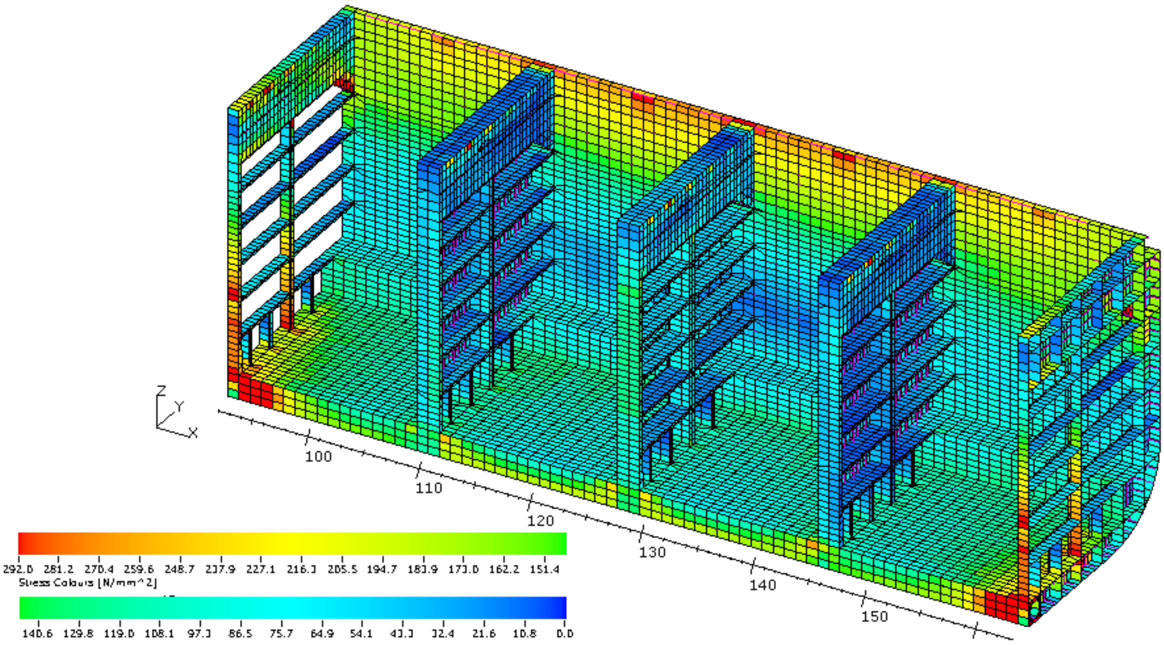
Table 7.7. Calculation of the permissible stresses

	k	Normal stress σ_N, N/mm²	Shear stress τ, N/mm²	Equivalent stress σ_v N/mm²
Longitudinal members	0.72	264	138	292
Transverse members	1	150	100	180

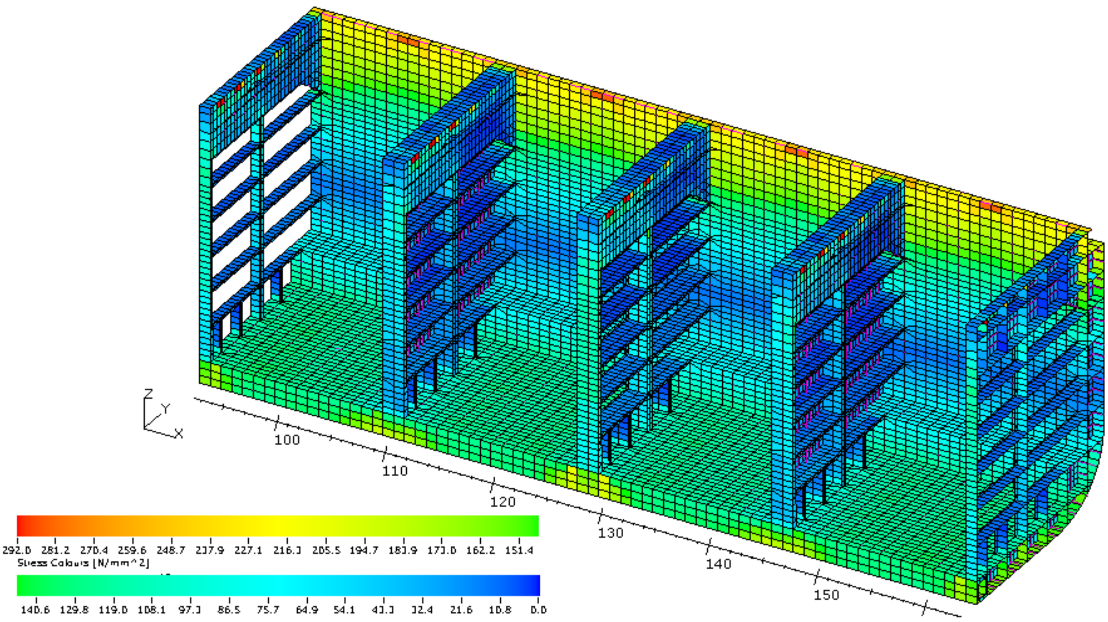
Since the permissible stresses is not the same for all the primary structural members, this latter have been checked separately. In the following the distribution of the von Mises stress, normal stress as well as shear stress in the structural elements subjected to the homogeneous 40 ft and heavy 20 ft load cases are given.

- ✓ *Von Misses stress:*

The distribution of the von Misses' stresses in the structural elements is given in Figure 7.19.



(a) Homogeneous 40 ft load case



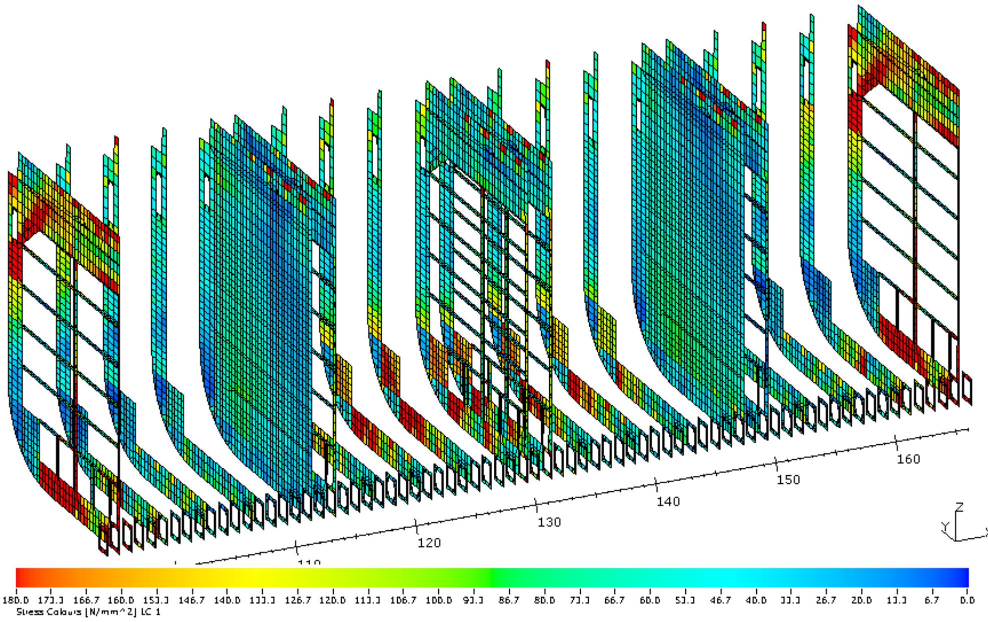
(b) Heavy 20 ft load case

Figure 7.19. Distribution of the von Mises stresses in the whole model.

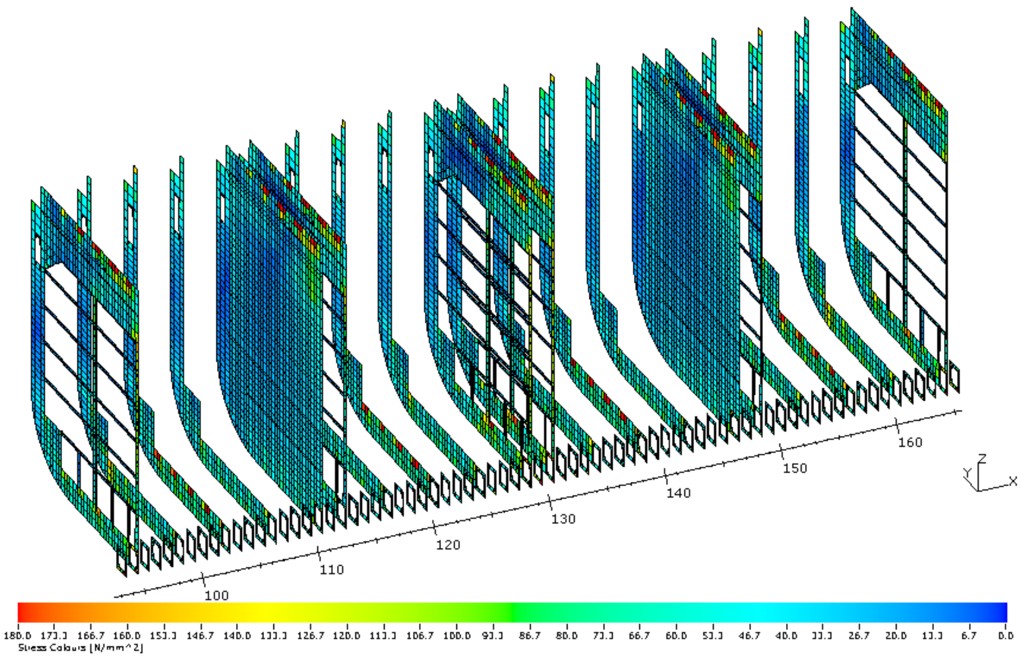
From the distribution of the von Mises stress given in the above figure, in the both load cases considered the stresses tend to zero at the neutral axis, and start to increase from this latter until reach their maximum values at the structural elements which are located far from the neutral axis such as the top coaming and the outer bottom. The magnitude of the stresses is higher in the top coaming than in the bottom. This is because the top coaming is far from the neutral axis comparing with the outer bottom. This distribution conforms to the hull girder theory. The model in homogeneous 40 ft load case is subjected to the hogging bending moment which is higher in the middle of the model; the reason to appear higher stresses in the middle of the top coaming (from the frame 127 to the frame 131), about 300 MPa which exceeds the permissible stress 292 MPa.

In the homogenous 40 ft load case, the significant stresses which are depicted in the fore and aft ends at the level of the double bottom of the model cannot be considered absolutely trustful because of the magnitude of the moments and forces applied at these boundaries are higher.

The distribution of the von misses stresses in the transverse members is given in Figure 7.20.



(a) Homogeneous 40 ft load case



(b) Heavy 20 ft load case

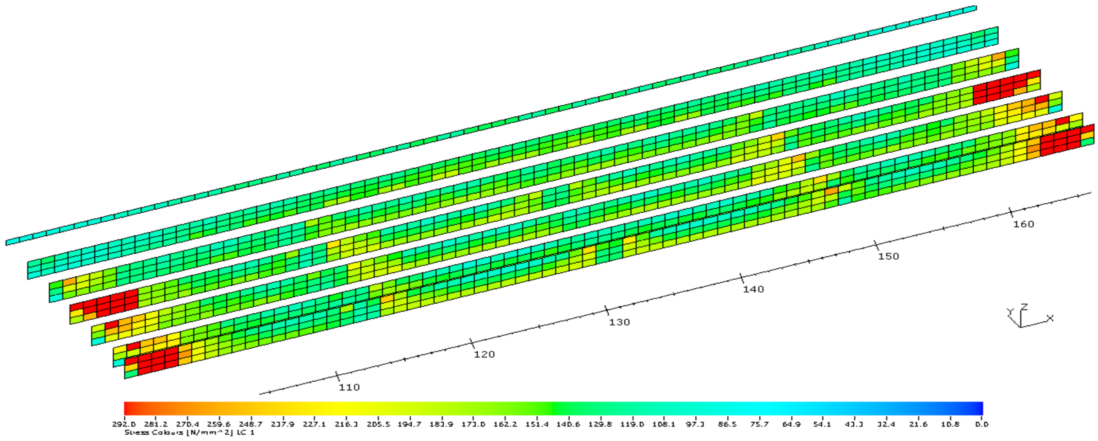
Figure 7.20. Distribution of the von Mises stresses in the transverse members.

From Figure 7.20, higher stresses appear in the floors FL4 and FL5 as well as in the plate WF7 at the middle of the model in the homogeneous 40 ft load case. This will be explained later on after discussing the shear stress distribution given in Figure 7.26.

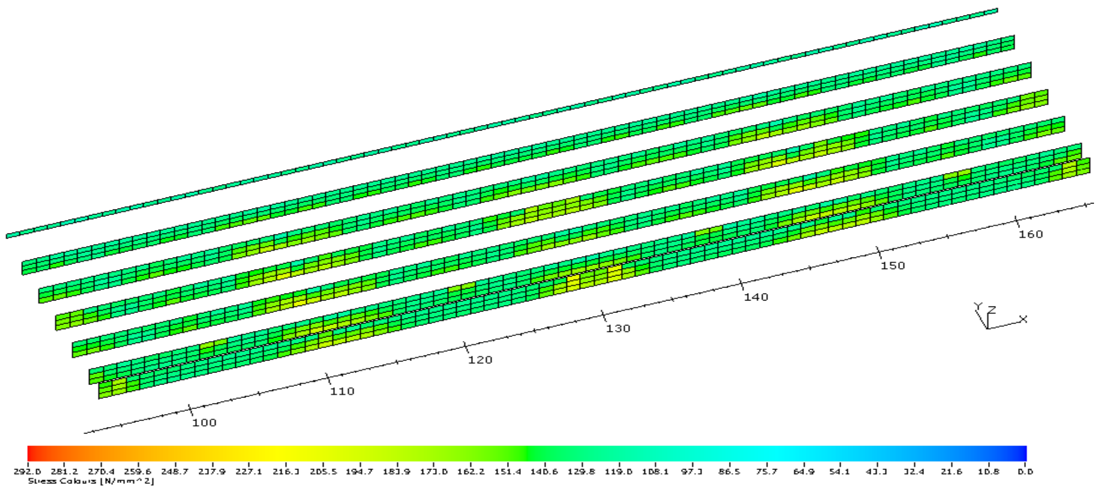
Concerning heavy 20 ft load case, the von misses stresses are uniformly distributed over the model. Additionally, the concentration of the stresses is observed at the level of the containers seat. The maximum values of the von Mises stresses in this load case are within the permissible stress 180 MPa.

As mentioned before the higher stresses depicted at the boundaries of the model is due to the higher moments and forces, its magnitude is not realistic hence it can be neglected.

The distribution of the von misses' stresses in the bottom longitudinal girders is given in Figure 7.21.



(a) Homogeneous 40 ft load case



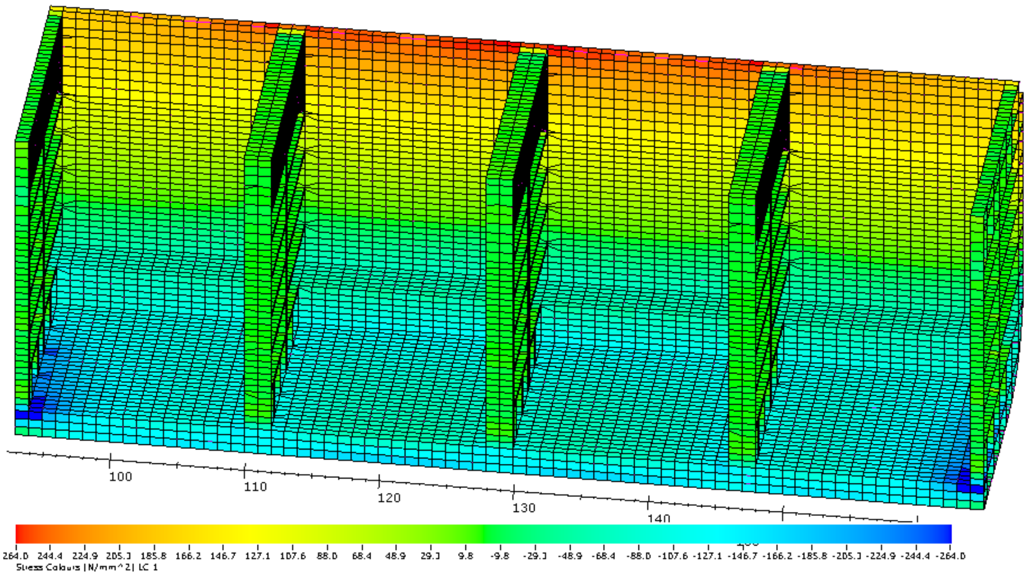
(b) Heavy 20 ft load case

Figure 7.21. Distribution of the von Mises stresses in the bottom longitudinal girders.

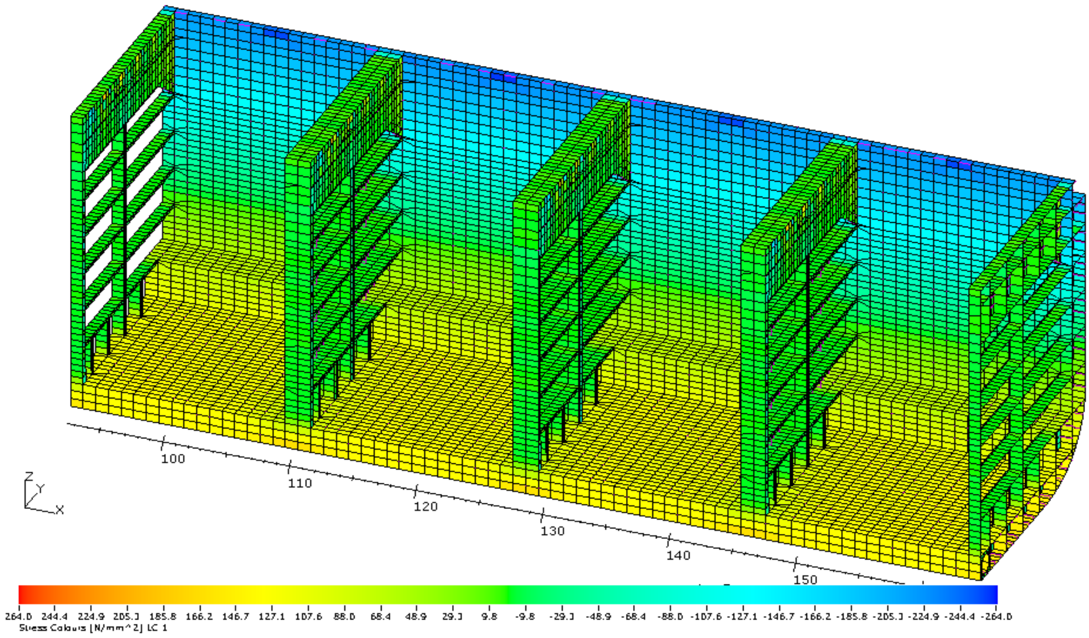
Concerning the distribution of the von Mises stress in the bottom longitudinal girders, the stresses are slightly increase near to the transverse bulkheads where the seat of containers exisit. This is mainly resulted from the shear stress components; see distribution of the shear stress given later on in Figure 7.27.

- ✓ *Normal stress:*

The distribution of the normal stress in the model is represented in the Figure 7.22.



(a) Homogeneous 40 ft load case



(b) Heavy 20 ft load case

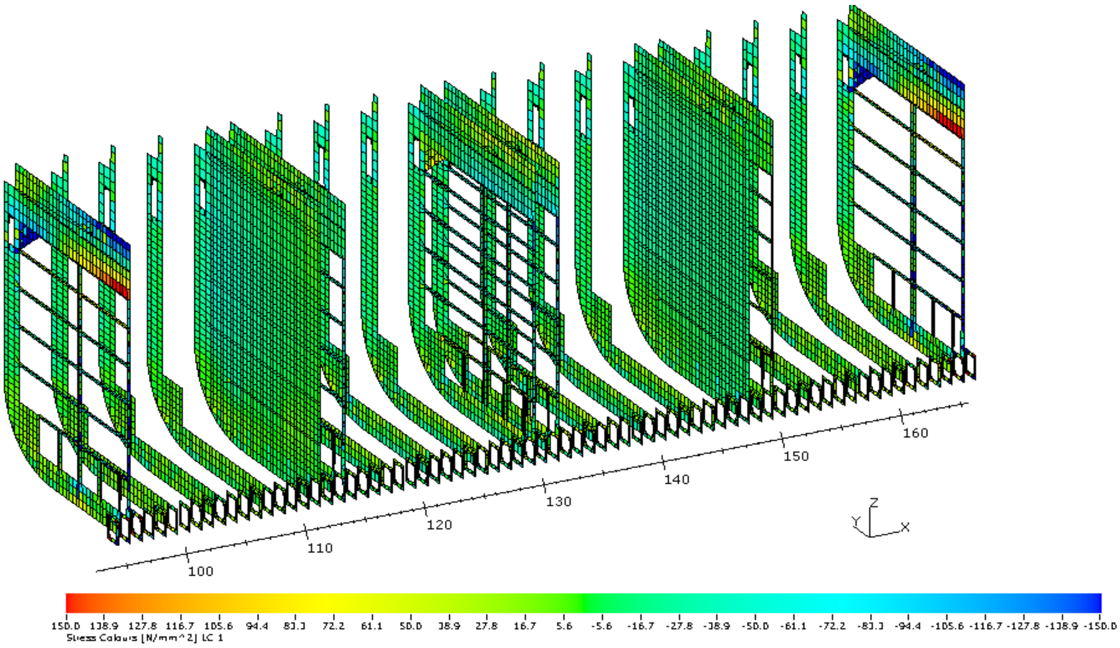
Figure 7.22. Distribution of the normal stresses in the model.

In the homogeneous 40 ft load case, the stresses are higher in the middle of the model and decrease slightly at the ends; this can be explained by the bending moment curve given in Figure A.7.26 where the magnitude of the bending moment is significant in the middle of the model than at the ends. The distribution of the normal stress due to the longitudinal bending moment given in Figure 7.22 is conforming to the hull girder theory, since the stresses tend to zero at the level of the neutral axis and reach their maximum values at the top coaming and bottom areas. In fact it confirms the discussion of the results the von Mises stress distribution mentioned previously in Figure 7.19. The largest value of the normal stress due to the bending moment is occurring in the coaming for the homogeneous load case, it equal to 280 MPa which exceed the permissible stress 264 MPa. This explains the appearance of higher von Mises stress in the coaming previously, since the normal stress is a component of the von Mises stress. In the bottom the value of the normal stress is about -210 MPa (the sign minis is because the bottom is in compression).

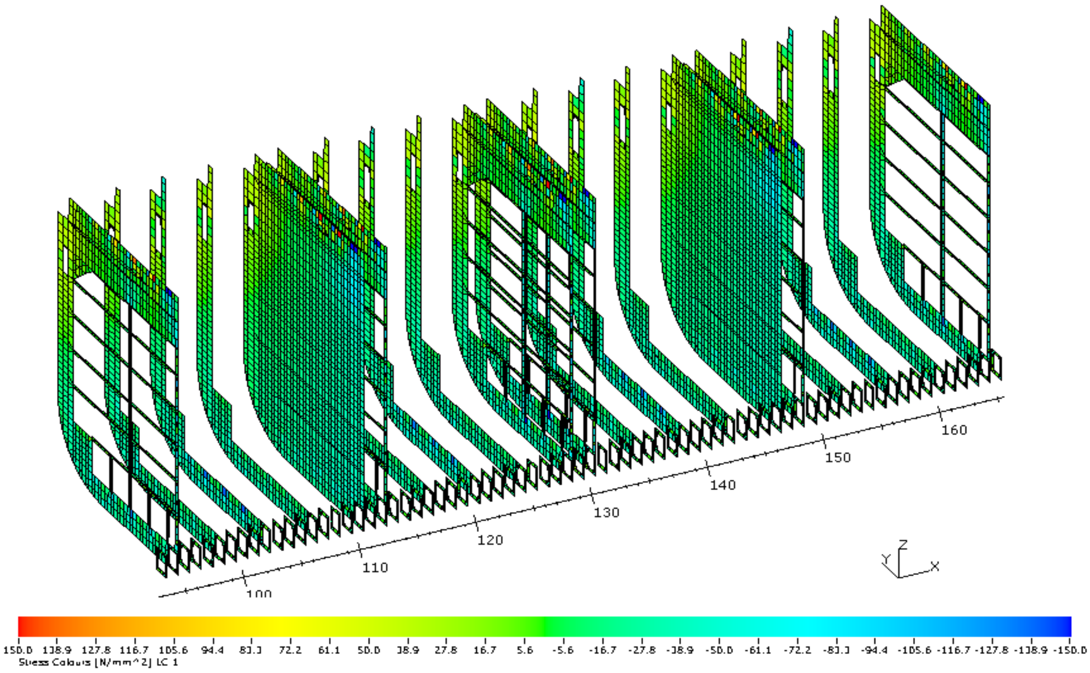
Concerning the heavy 20 ft load case the stress at the top coming is equal to -230 MPa, and 170 Mpa in the plates of the outer bottom, which are under the permissible stress 264 Mpa.

In the both load cases the largest values of the stresses are occurring in the coaming as the distance of this latter and the neutral axis is more than the distance between the bottom and the neutral axis.

The distribution of the normal stress in the transverses members is represented in Figure 7.23.



(a) Homogeneous 40 ft load case

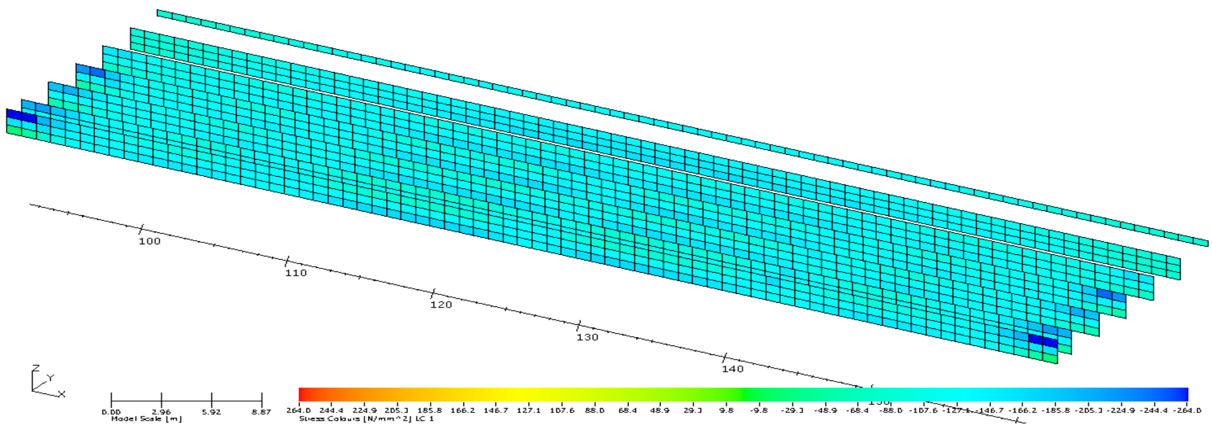


(b) Heavy 20 ft load case

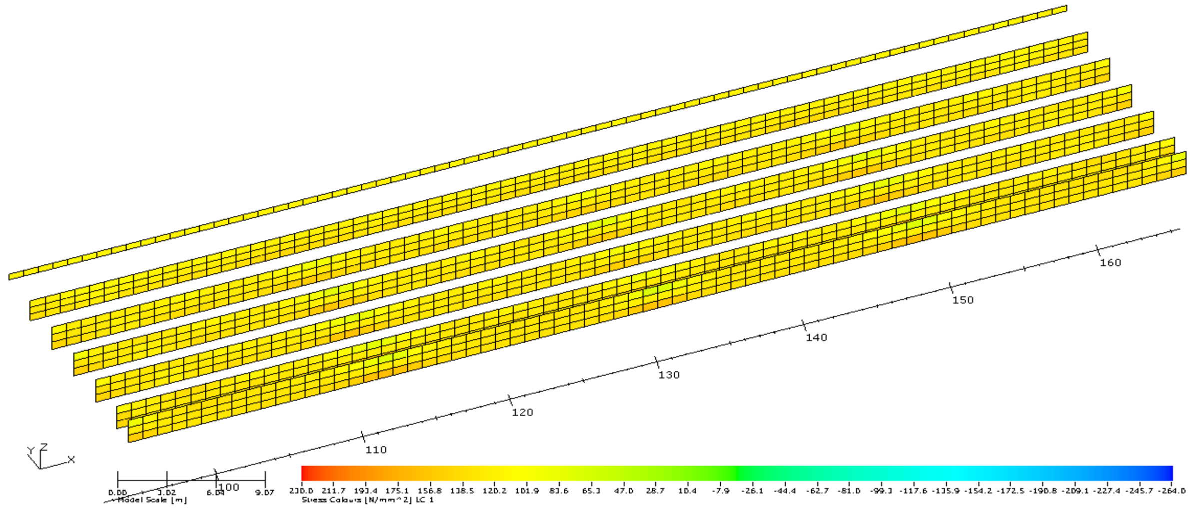
Figure 7.23. Distribution of the normal stresses in the transverse members.

The normal stress due to the longitudinal bending moment in the transverse members is low, since these elements do not contribute to the longitudinal strength, which confirms with the hull girder theory.

The distribution of the normal stress in the bottom longitudinal girders is represented in Figure 7.24.



(a) Homogeneous 40 ft load case



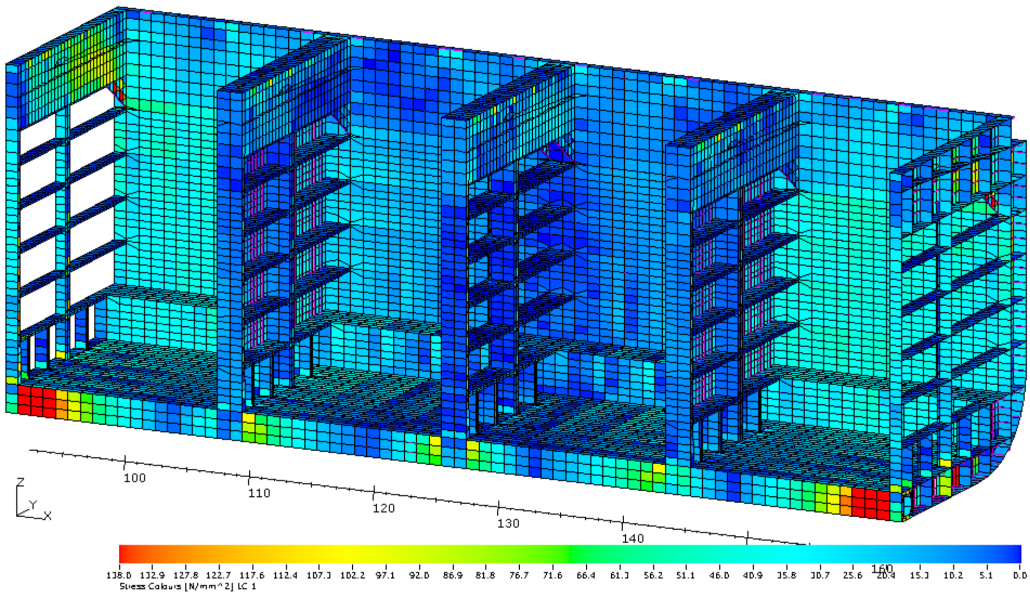
(b) Heavy 20 ft load case

Figure 7.24. Distribution of the normal stresses in bottom longitudinal girders.

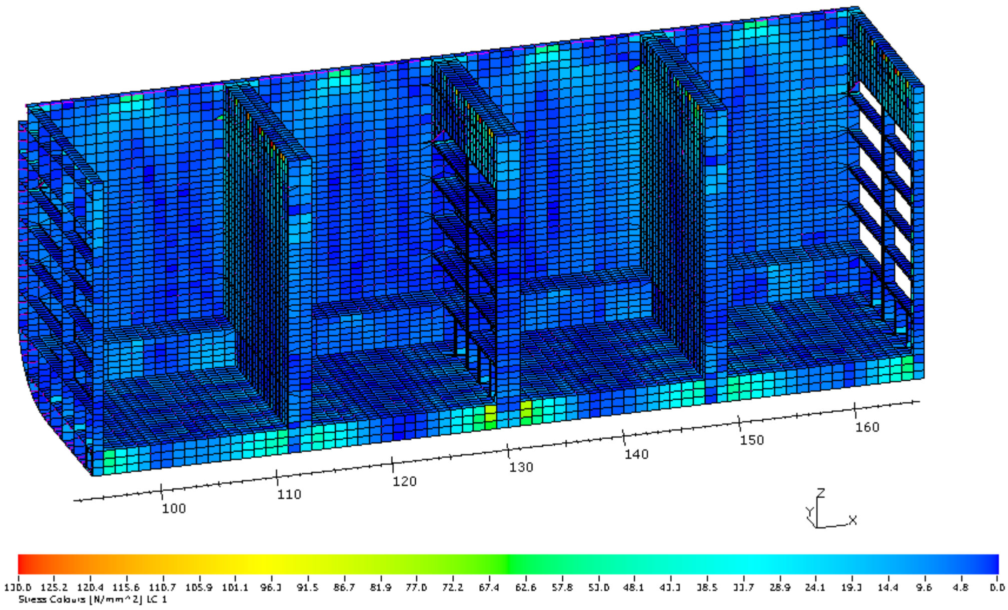
In the both load cases the normal stresses are under the permissible stresses. It is remarkable that the maximum stresses are occurring in the lower edge of the girders; 170 MPa for the homogeneous 40 ft load case and 162 MPa for the heavy 20 ft load case

- ✓ *Shear stress:*

The distribution of the shear stress in the model is represented in Figure 7.25.



(a) Homogeneous 40 ft load case

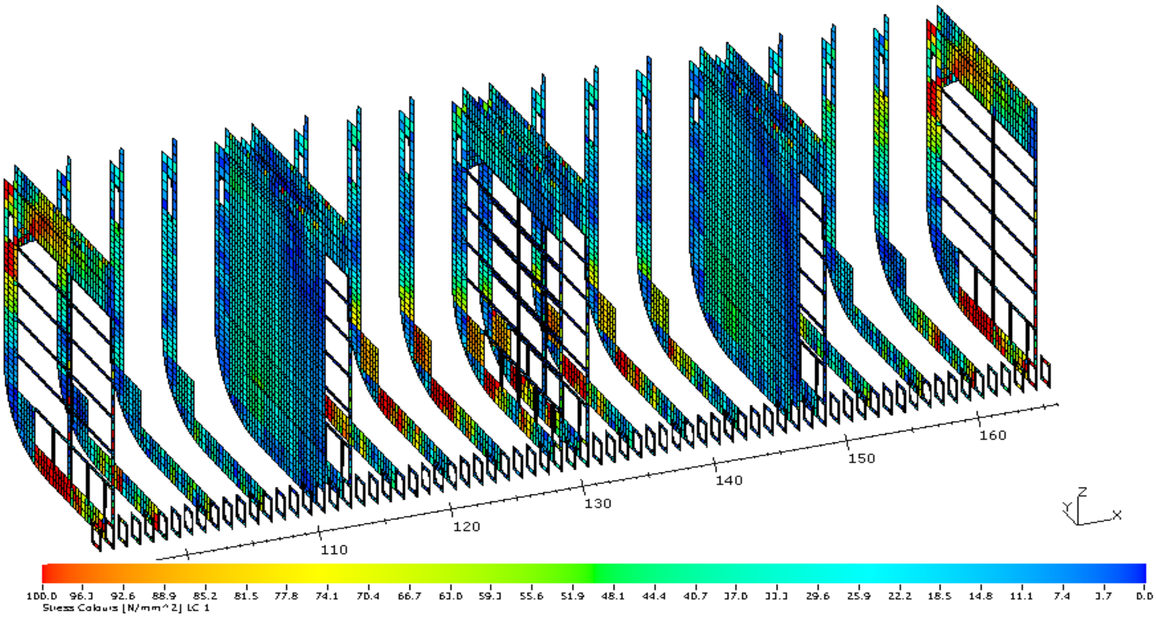


(b) Heavy 20 ft load case

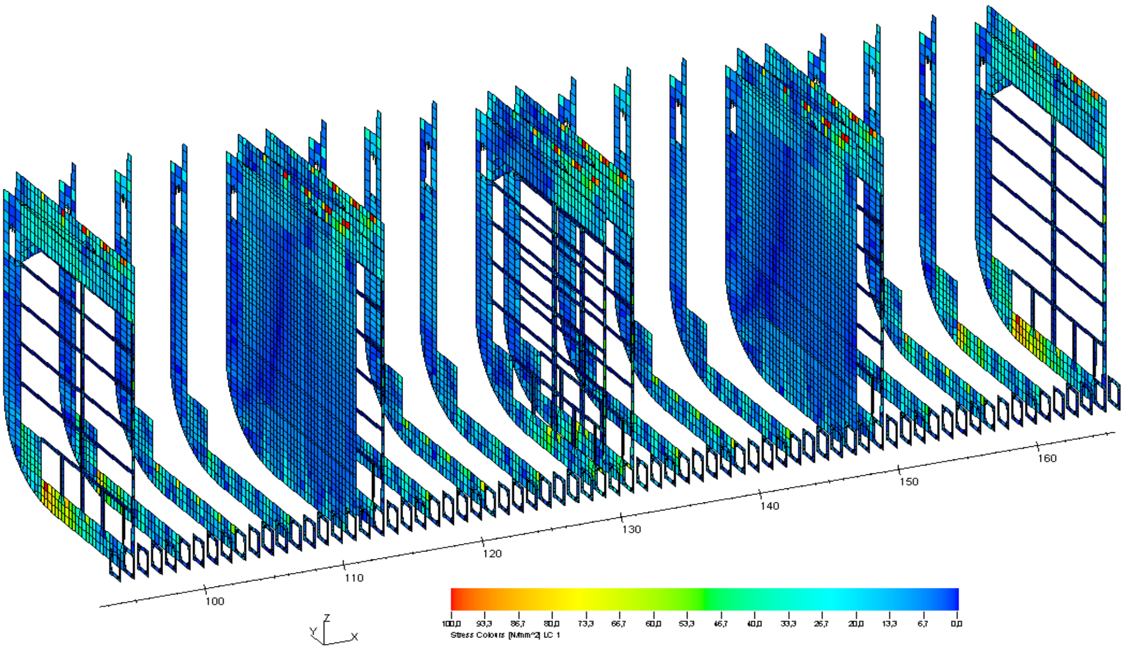
Figure 7.25. Shear stress distribution in the model.

The distribution of the shear stress in Figure 7.25 for both load cases can be explained by the shear forces curves given in Figures A.7.26 and A.7.27 respectively. For the homogeneous load case the shear stress is almost zero in the middle of the model and starts to increase at the regions which are close to the boundaries. That conforms to the distribution of the shear force over the model which its magnitude is almost null at the centre and more important at the boundaries. Concerning the heavy 20 ft containers the shear stress is uniformly distributed over the length of the model in similar manner to the distribution of the shear force given in Figure A.7.27.

The distribution of shear stress in the transverse members is represented in Figure 7.26.



(a) Homogeneous 40 ft load case



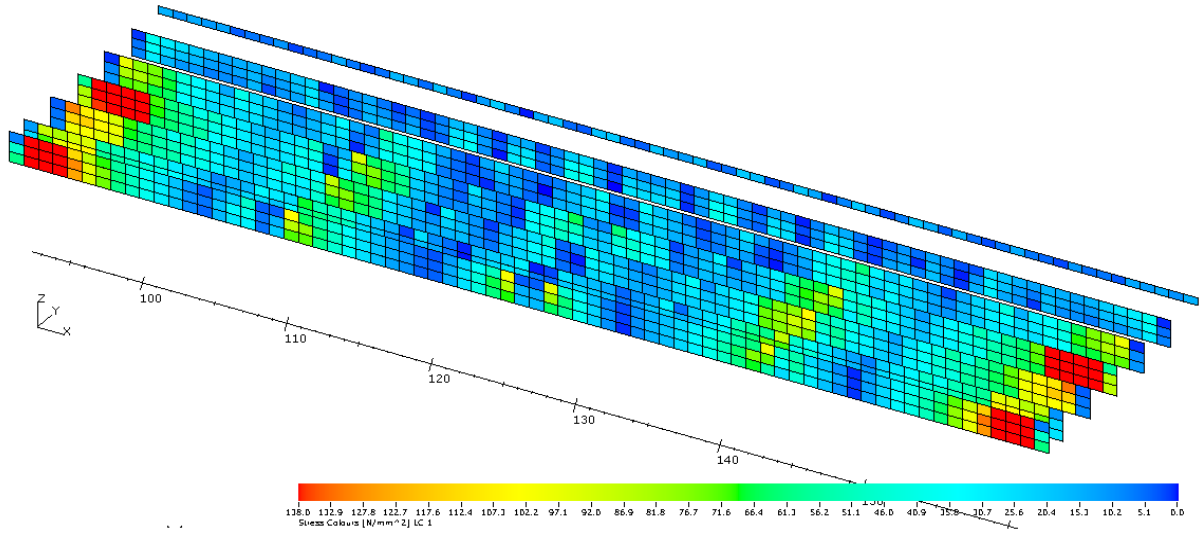
(b) Heavy 20 ft load case

Figure 7.26. Shear stress distribution in the transverse members.

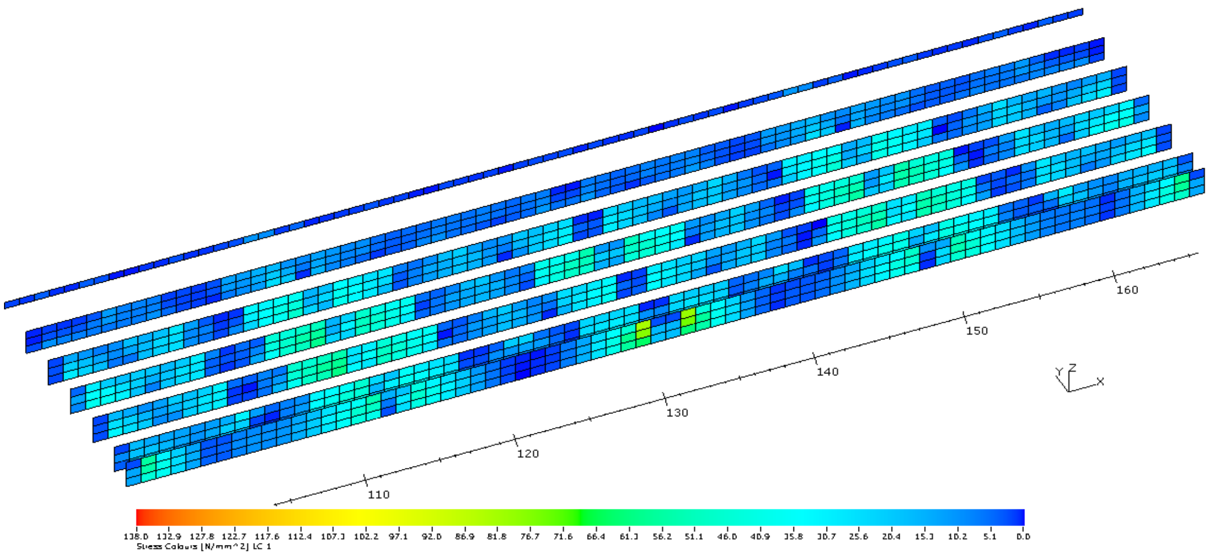
In the homogeneous 40 ft load case high shear stress that exceeds the permissible stress of 100 MPa is occurring in the floors FL4 and FL5 as well as the plate WF7 at mid hold of the model. This distribution proves that the high von Mises stresses occurring at the same elements discussed previously in Figure 7.19 is mainly resulted from the high shear stress component.

In the second load case the values of the shear stress is small in the centre area and slightly increased at the edge of the model as well as at the level of containers seat in the floors, this can be explained by the distribution of the shear force given in the Figure A.7.27.

The distribution of shear stress in the bottom longitudinal girders is represented in Figure 7.27.



(a) Homogeneous 40 ft load case



(b) Heavy 20 ft load case

Figure 7.27. Shear stress distribution in the bottom longitudinal girders.

The shear stress in the bottom longitudinal girders is not significant generally as in the both cases the values of the shear stress is under the permissible stress.

In the homogeneous 40 ft load case, it is remarkable that the shear stresses are near to the bulkheads area due to the seat of containers.

The buckling strength is checked for compliance with Section 3, Design principle of the GL rules which corresponding to the plate field evaluation in Poseidon software.

In the homogeneous 40 ft load case where the model in subjected to the hogging condition, the plates of the outer bottom are in compression, the maximum normal stress σ_x is -218 MPa. Hence these plates are critical to the buckling. These plates are shown in Figure 7.28.

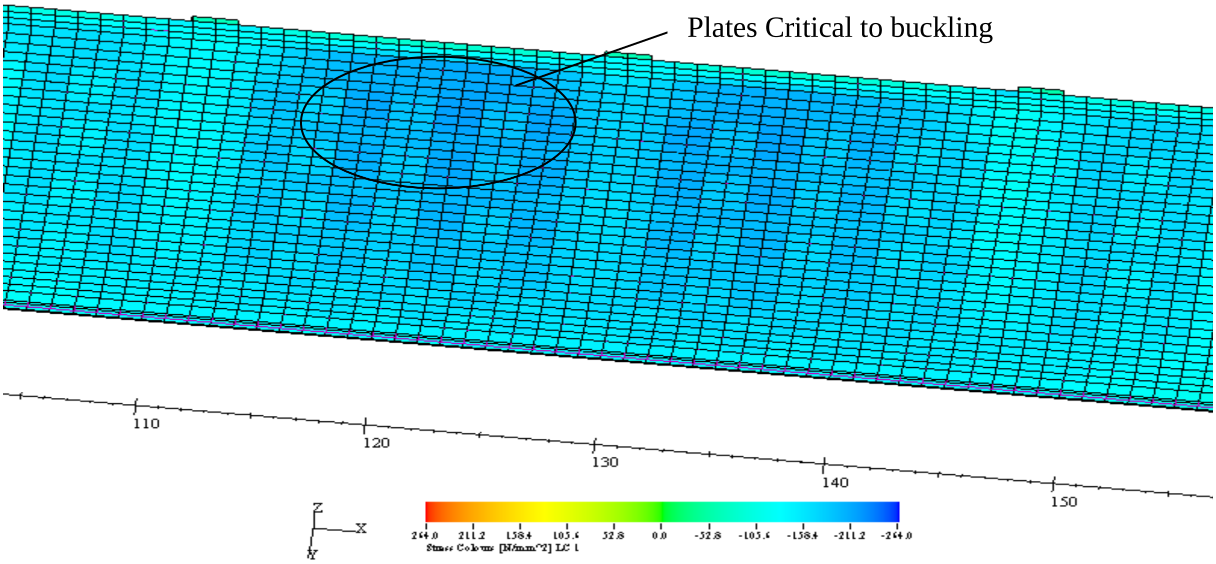
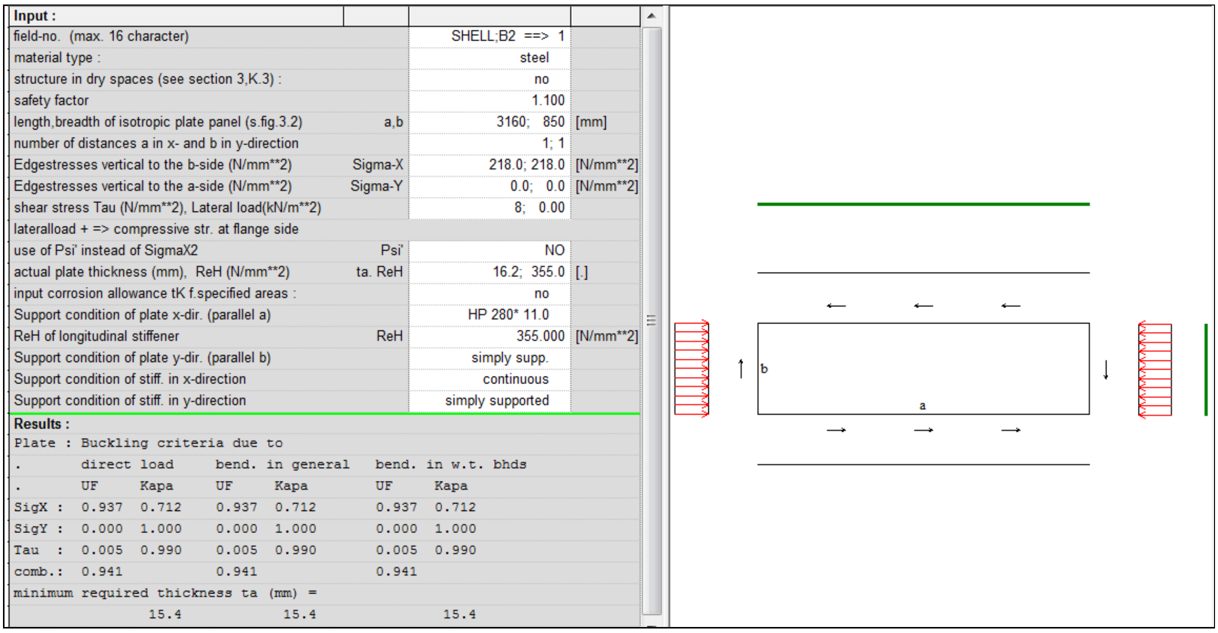


Figure 7.28: Outer bottom plating critical to buckling at mid model.

The value of the longitudinal normal stress component -218 MPa is input to the buckling strength section in Poseidon software to verify the minimum thickness required for the plate.

The stress component in the transverse direction σ_y has been calculated using the Poisson effect. However, since $\sigma_y < 0.3\ \sigma_x$ than according to the rules, the stress component σ_y tend to zero and only σ_x should be considered. The buckling checking is given in Figure 7.29.

The result indicates that the minimum thickness under the specified conditions should not be less than 15.4 mm. Hence the thickness 16 mm as well as stiffeners 280×11 are sufficient against buckling.



Input :			
field-no. (max. 16 character)		SHELL;B2 ==> 1	
material type :		steel	
structure in dry spaces (see section 3,K.3) :		no	
safety factor		1.100	
length,breadth of isotropic plate panel (s.fig.3.2)	a,b	3160; 850	[mm]
number of distances a in x- and b in y-direction		1; 1	
Edgestresses vertical to the b-side (N/mm**2)	Sigma-X	218.0; 218.0	[N/mm**2]
Edgestresses vertical to the a-side (N/mm**2)	Sigma-Y	0.0; 0.0	[N/mm**2]
shear stress Tau (N/mm**2), Lateral load(kN/m**2)		8; 0.00	
lateralload + => compressive str. at flange side			
use of Psi' instead of SigmaX2	Psi'	NO	
actual plate thickness (mm), ReH (N/mm**2)	ta. ReH	16.2; 355.0	[.]
input corrosion allowance tK f.specified areas :		no	
Support condition of plate x-dir. (parallel a)		HP 280* 11.0	
ReH of longitudinal stiffener	ReH	355.000	[N/mm**2]
Support condition of plate y-dir. (parallel b)		simply supp.	
Support condition of stiff. in x-direction		continuous	
Support condition of stiff. in y-direction		simply supported	

Results :

```
Plate : Buckling criteria due to
.        direct load      bend. in general      bend. in w.t. bhds
.        UF      Kapa     UF      Kapa          UF      Kapa
SigX :   0.937   0.712    0.937   0.712         0.937   0.712
SigY :   0.000   1.000    0.000   1.000         0.000   1.000
Tau  :   0.005   0.990    0.005   0.990         0.005   0.990
comb.:   0.941            0.941                 0.941
minimum required thickness ta (mm) =
                 15.4             15.4                  15.4
```

Figure 7.29. Buckling strength checking.

The verification of the torsional strength is performed using the option of *the stress evaluation in the cross section* which is provided by Poseidon software; this latter allows plotting the distribution of stresses in the cross section after the input of the moments and forces. The checking is carried out through two load cases:

- ✓ Load induced by the total torsional moment which comprises the static torsional moment and wave induced torsional moment;

- ✓ Load induced by vertical and horizontal bending moment as well as static and wave induced torsional moment.

The first load case is aimed at indicating the structural elements which are affected by the torsion moment. The magnitude of total torsional moment is calculated as follow.

$$M_T = M_{ST} + f_Q \times M_{WT}$$

Where: f_Q=0.75, represents the probability factor for a straight-line spectrum of seaway-induced loads.

The second load case is a combination of the moments listed previously, for that two factors have been used: f_Q and f_F. The factor f_F is the weighting factor for the simultaneousness of global and local loads, it equals 0.8. The still water vertical bending moment and the static torsional moment are multiplied by the factor f_F, and remaining moments which are caused by waves are multiplied by the f_Q. Afterwards the total magnitude of the moments in the three directions is calculated. Table 7.8 gives the resulted values of the moments which are inputted to the model.

Table 7.8. Combination of vertical bending moment, torsional moment and horizontal bending moment

	Moment M, KN.m	$\times f_Q$	$\times f_F$
$M_{xx\ ST}$	131872		105497.6
$M_{xx\ WT}$	321408.8	241056.6	192845.3
$M_{yy\ SW}$	1875894		1500715
$M_{yy\ WV}$	1759584.34	1319688	1055751
$M_{zz\ WH}$	1433942.86	1075457	860365.7
Total moments in the three directions			
Mxx	298342.88		
Myy	2556465.804		
Mzz	860365.716		

The distribution of the von Mises stress due to the static torsional moment as well as the torsional moment induced by the wave is given by Figure 7.30.

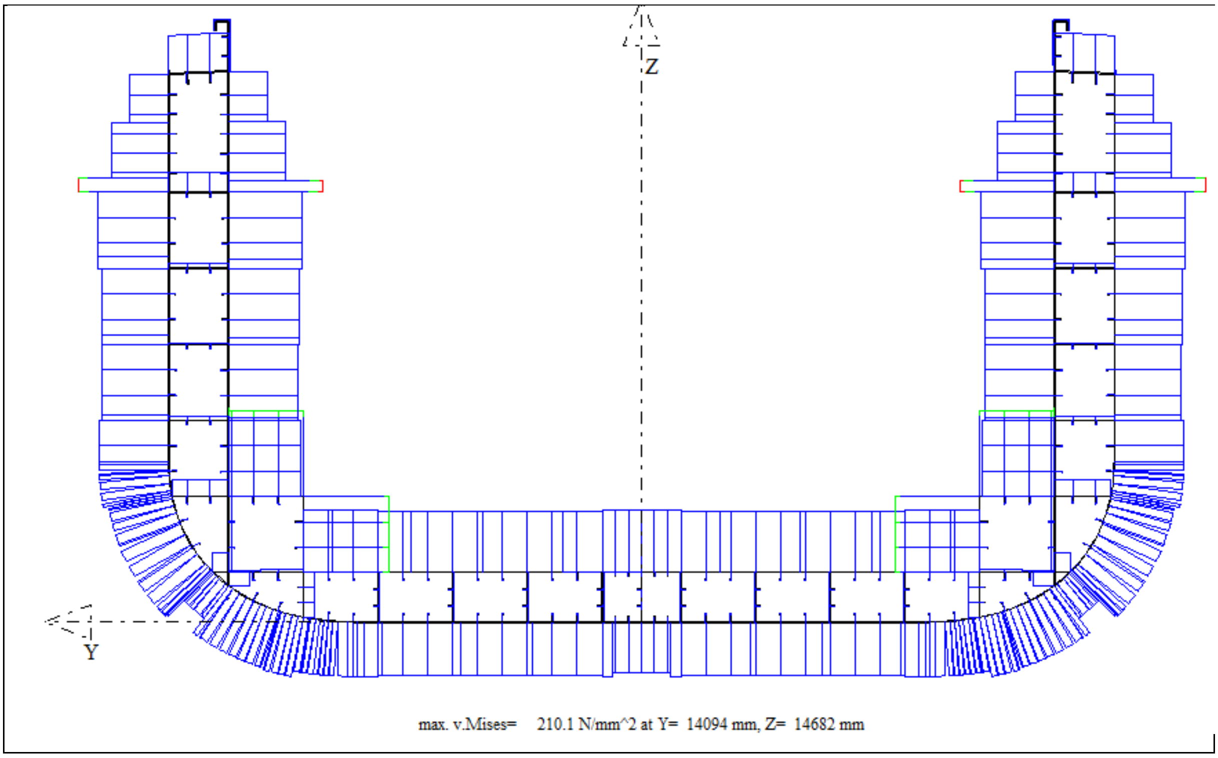


Figure 7.30. Distribution of the von Mises stress due to the global torsional moment.

From the distribution of the von Mises stress presented in Figure 7.30, the stresses in all structural elements are below the limit 292 N/mm². However higher stresses are observed at the upper part of the plates S11 and pl5 of the Side Shell and BL_1 respectively, what can be explained by the thickness of these plates at that level as given in Figure 7.31.

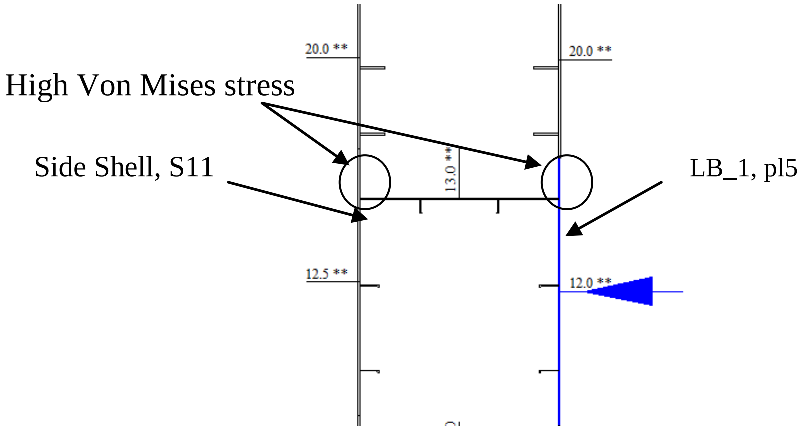


Figure 7.31. Plates critical to the high von Mises stresses due to the global torsional moment.

To mitigate the higher stresses at the level of the upper part of the Shell and LB_1, correction in the arrangement of the plates is made, see 7.2.6.

The distribution of the von Mises stress due to the combined loads due to the vertical and horizontal bending moment as well as static and wave induced torsional moments is given by Figure 7.32:

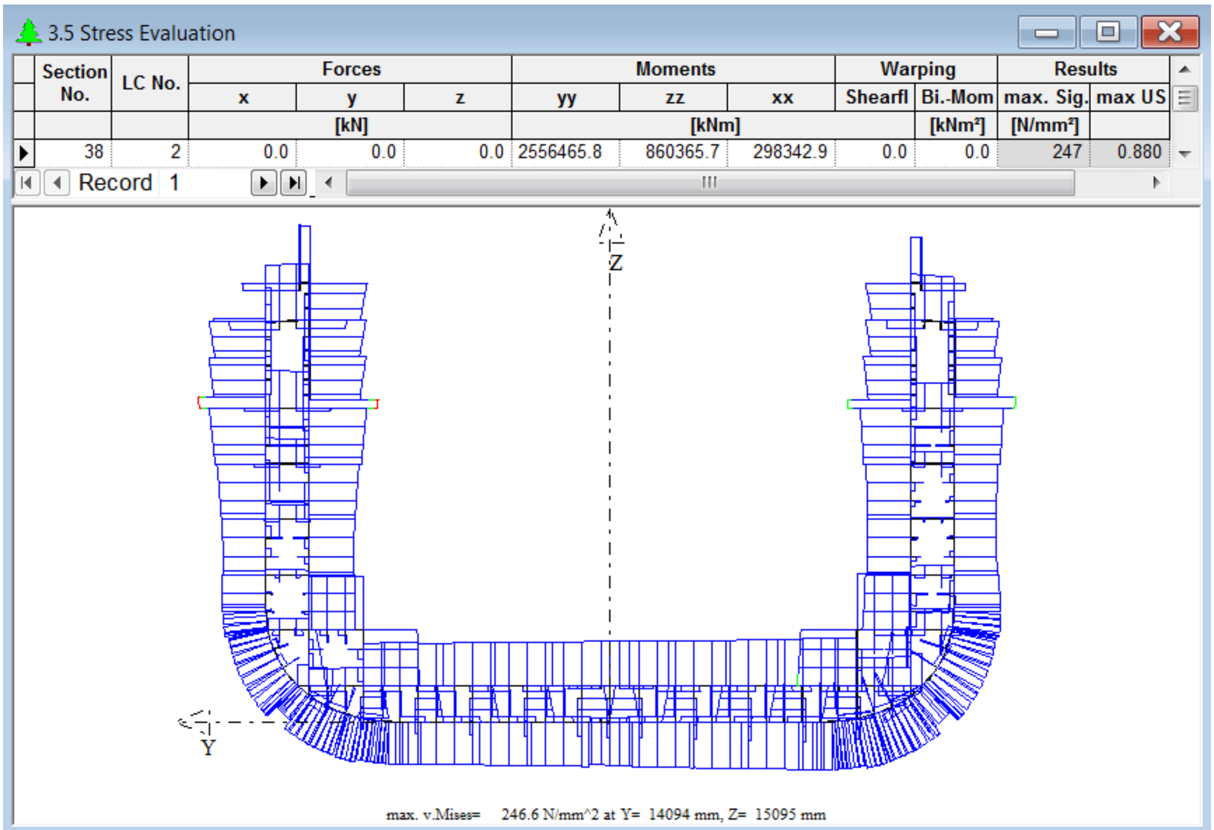


Figure 7.32. Distribution of the von Mises stress due to the vertical and horizontal bending moment as well as static and wave induced torsional moments.

From Figure 7.32, it can be seen that the von Mises stresses are larger important in the upper plates of the Shell and LB_1, S11 and pl5 respectively, but still below the permissible stress. The value of the stresses at the level of the top coaming due to the vertical bending moment is 205 N/mm². It is remarkable that the stresses are not distributed symmetrically what can be explained by the existing horizontal bending moment.

7.2.6. Conclusion:

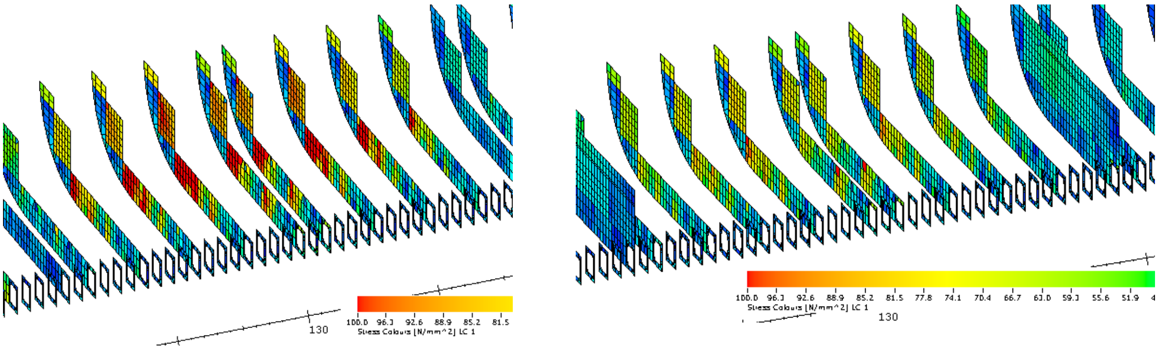
The previous discussion of the results, from the generation of the finite element method given in the Figures 7.20-7.28 as well as torsional strength verification, indicates the necessity to the following modification:

- ✓ In order to reinforce the top coaming against the high normal stress due to the longitudinal bending moment, its thickness is increased to 60 mm from the frame 127 to the frame 131.
- ✓ Change the final scantling of floors FL3 to FL5 and the plate WF7 in order to reinforce it against the high shear stress. The change made for these elements comprise the increasing of the thickness and decreasing the size of the holes to the minimum values in these elements since the holes affect the shear stress. Table 7.9 contains the updated thickness and the holes size in the plates FL3 to FL5 as well as WF7.

Table 7.9: new scantling of the FL3-FL5 and the plate WF7

Elements		***t***, mm	hole dimension mm×mm
Floors:	FL3	13	500*700
	FL4	14.5	400*600
	FL5; FL6	15	400*600
Web frames	WF7	14	1200*600

The change in the shear stress magnitude in these elements after the above updated thicknesses and holes size is represented in Figure 7.33.



a) Shear stress first distribution b) Shear stress final distribution

Figure 7.33: Shear stress distribution in the floors FL3-FL5 and the plate FL7.

- ✓ The breadths of the plates S11 and pl5 of the Shell and LB_1 are decreased 600 mm in order to make the above plates which have 20 mm thickness surrounding the upper box, as shown in Figure 7.34, so that the stresses due to the torsional moments is decreased in this area, as depicted in Figure 7.35.

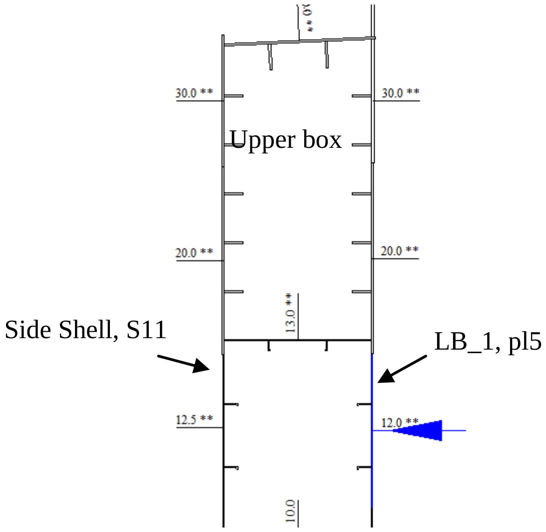


Figure 7.34. Correction in the plates surrounding the upper box.

The new distribution of the von Mises stresses in the both load cases are shown in Figures 7.35 and 7.36 respectively.

The maximum von Mises stress is decreased at the upper box. Appearance of other areas which have higher von Mises stress such as the box surrounded by the two longitudinal bulkheads LB_1 and LB_2 as well as the LS_1 and IB. However the magnitude of the stresses is within the limits of the permissible stress.

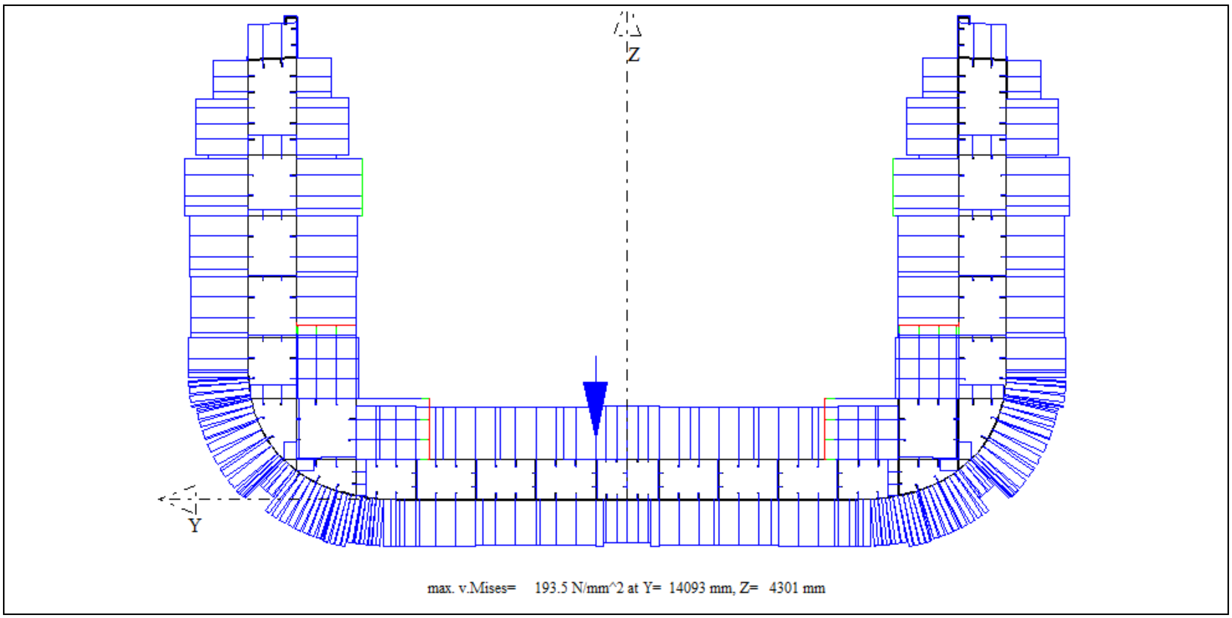


Figure 7.35: Distribution of the von Mises stresses due to the Global torsional moment after the correction in the thicknesses of plates surrounding the upper box.

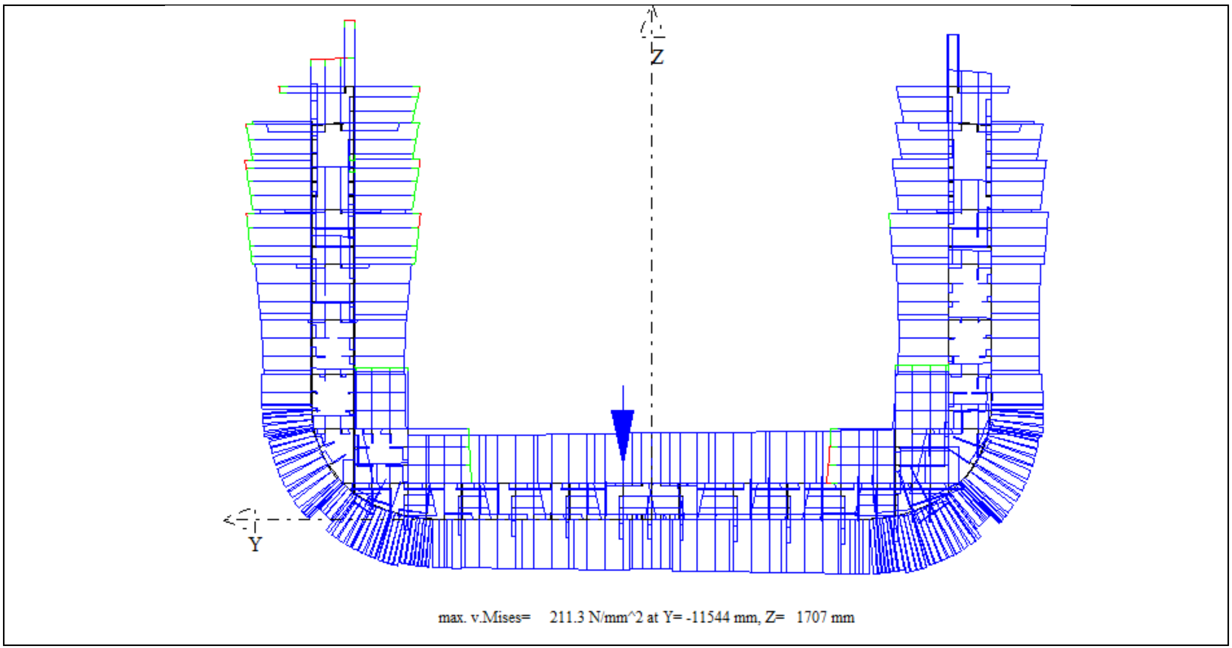


Figure 7.36. Distribution of the von Mises stresses due to the vertical and horizontal bending moment as well as static and wave induced torsional moments after the correction in the thicknesses of plates surrounding the upper box.

The midship section plan with the sufficient scantling against the realistic load cases resulted from the finite element analysis is represented in the appendix, plan sheet N° 1 “Midship section, frame 134.

8. THREE-D VISUALISATION OF A PART OF THE HULL STRUCTURE IN TRIBON SOFTWARE

The present section dedicated to the visualisation of the resulted structural members scantling from the finite element analysis. For that, a part of the structure is modelled in Tribon software. The part selected is located at the middle of the ship as shown in Figure 8.1, in this figure the picture is taken without the inner skin to allow the visualisation of the arrangement of the primary and secondary structural members in the double side shell as well as double bottom structures.

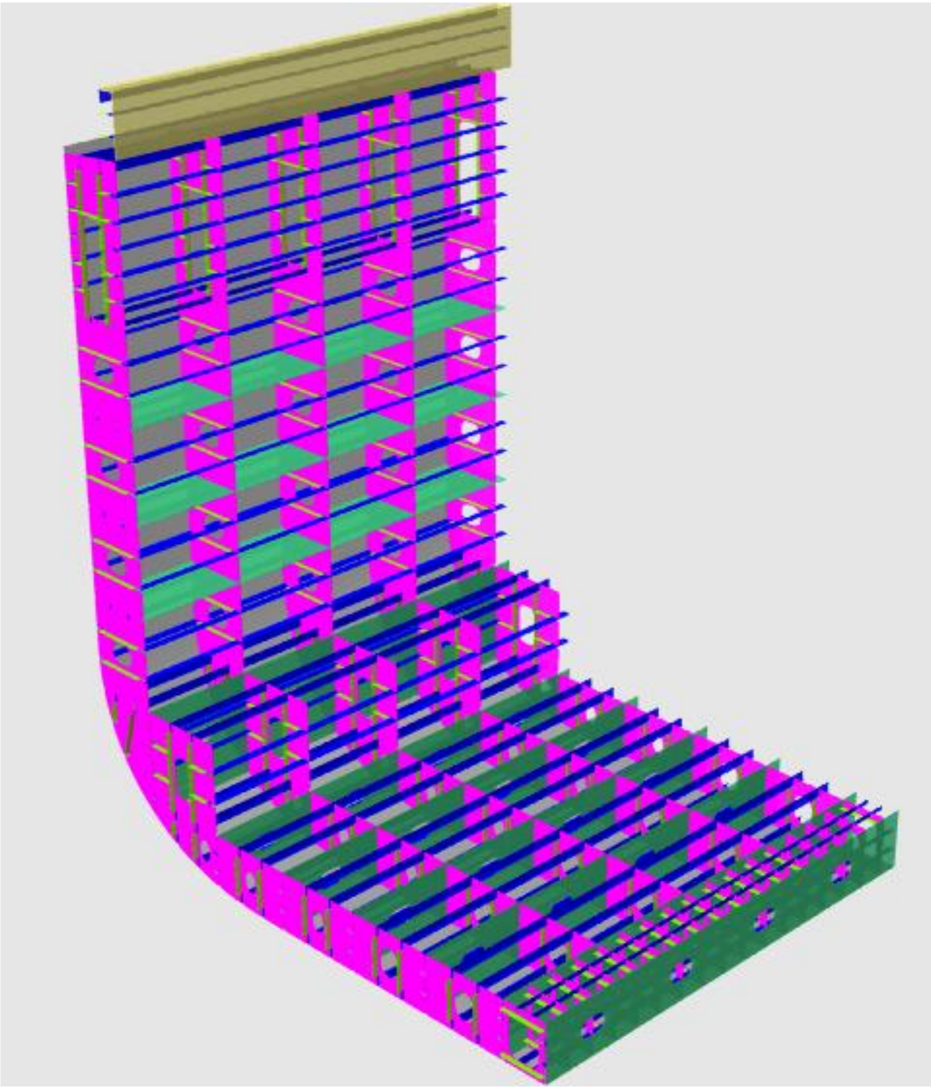


Figure 8.1. 3D Visualisation of a part of the ship modelled using Tribon software.

Figure 8.2 shows 2 D midship section drawing. The version with a scale of 1/50 is in the Appendix, Plan sheet N°1 “MIDSHIP SECTION, frame 134”.

The 3D visualisation of the structural elements of the model is given in Figure 8.3. The

Figure 8.3 contains a set of outlines resulted from the model developed in Tribon software. The same outlines with a big size are in the Appendix, Figure A.8.28.

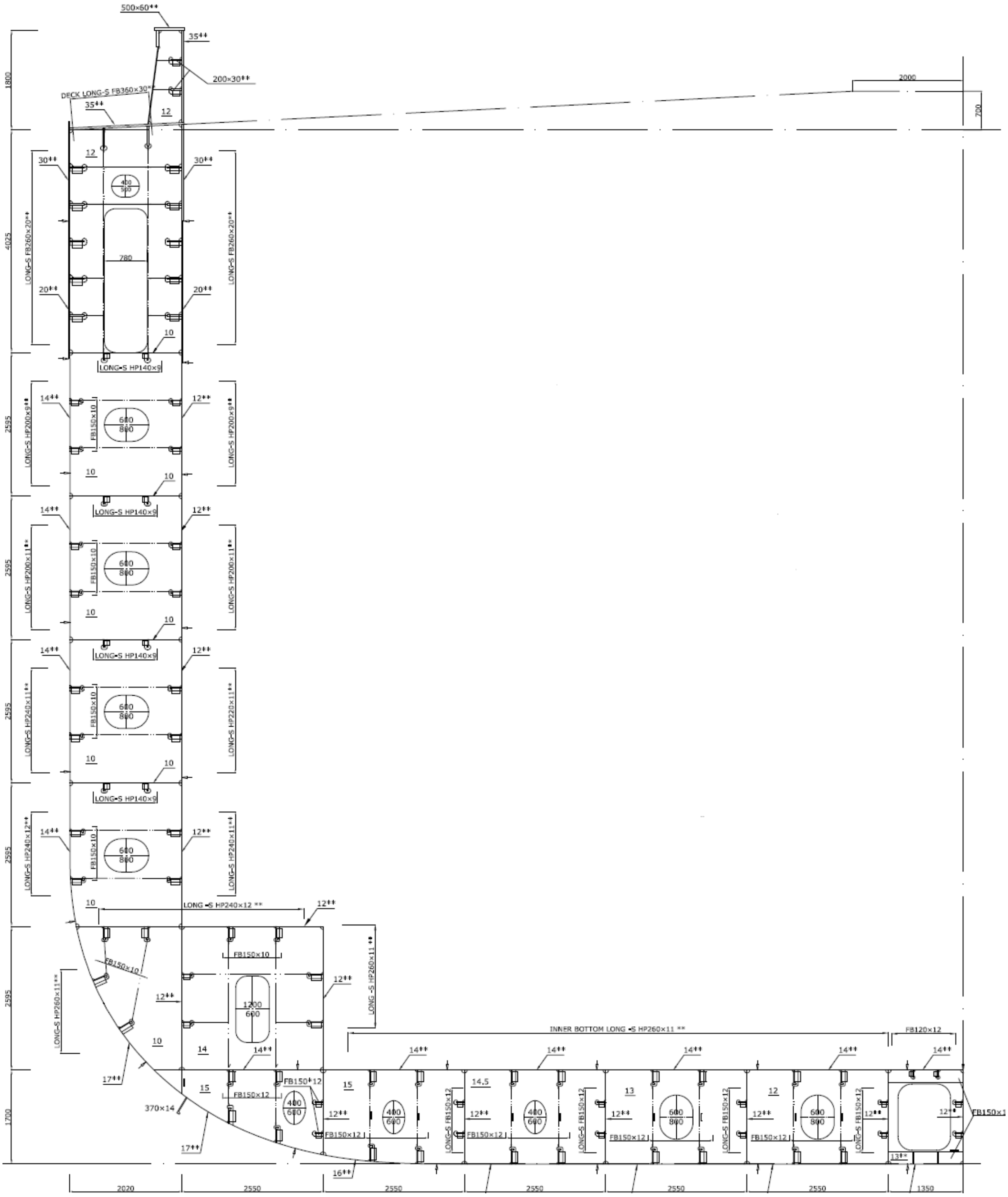


Figure 8.2. Midship section, frame 134 developed in Tribon software.

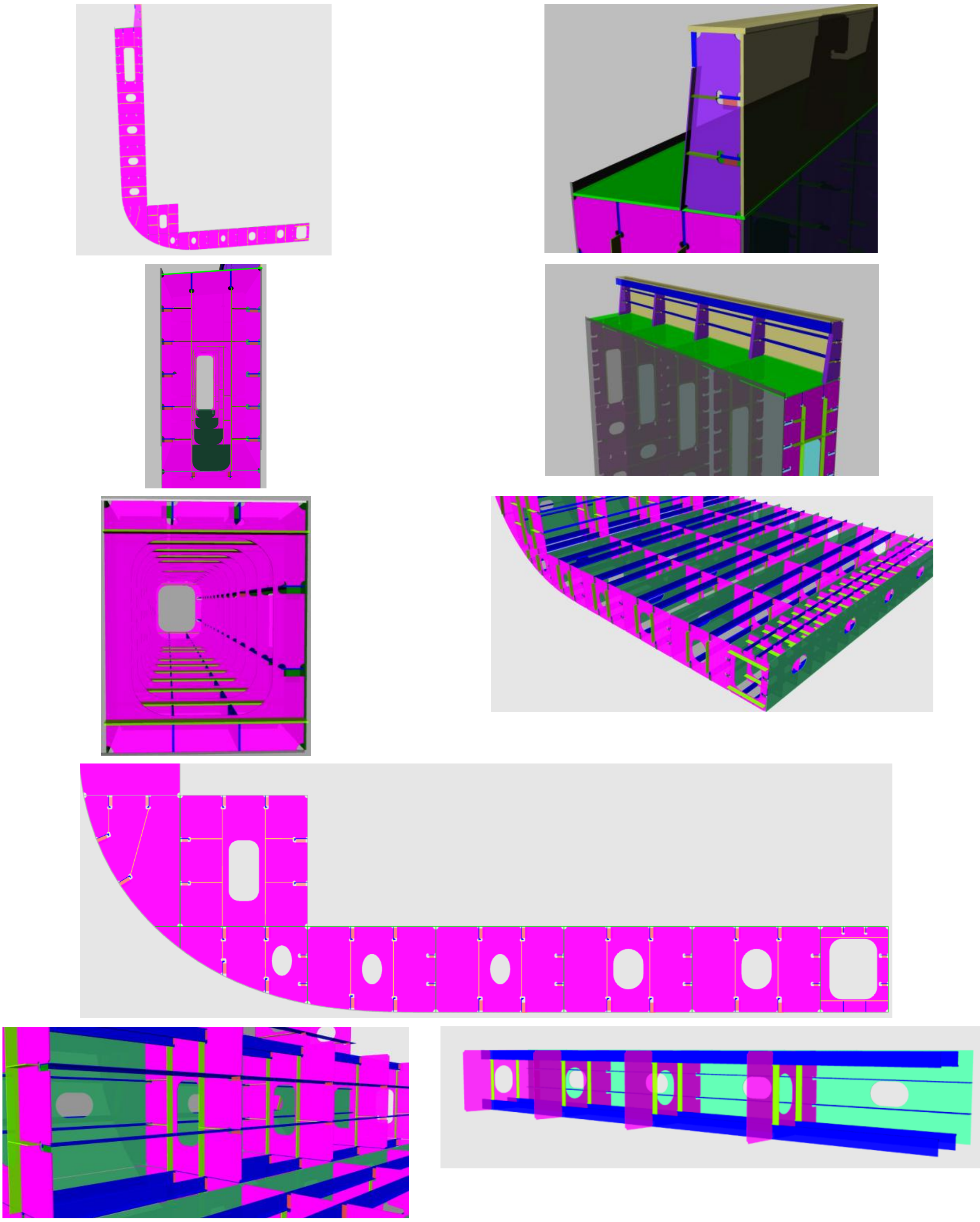


Figure 8.3. Visualisation of the arrangement of the structural elements using Tribon software.

In the outlines given in Figure 8.3, the inner skin plates are removed to allow seeing the arrangement of the structural elements.

9. TECHNICAL DESCRIPTION OF THE DEVELOPED SHIP HULL STRUCTURE

This section is dedicated to the technical description of the structure of the developed containership. In the following the important structure note which was adopted during the first steps of this work as well as the solution resulted from the analysis.

- The hull structural scantling is in accordance with the rules of Germanischer Lloyd.
- Both mild steel of Re is 235 N/mm² and High tensile steel of R_e is 355 N/mm² are used for the building of the structural elements. The application of these two types of steel in the structural regions is given in Table 9.1.

Table 9.1. Application of the mild steel and high tensile steel in the structural elements

Steel grade	R_{eH}, N/mm²	Structural members
AH	355	Shell plating: keel, outer bottom and side plates; Inner bottom, deck plates, and longitudinal bulkhead strakes; Bottom longitudinal girders and the first stringer in the double side structure; Lower vertical framework of the transverse bulkheads; Longitudinal hatch coamings including their longitudinal stiffeners. Longitudinal stiffeners in the plates of shell, longitudinal bulkheads, double bottom and the first longitudinal stringer of the double side structure.
A	235	Transverse members, including floors, web frames, and plates forming transverse bulkheads; Longitudinal stringers in the side shell structure except the first stringer as well as in the transverse bulkheads structures; Longitudinal stiffeners in the plates of the stringers in the double side structure and the bottom longitudinal girders.

- The longitudinal framing system is adopted in the holds area; the frame spacing is 790 mm. Floors are arranged each four frames and under each transverse bulkhead.
- The plates of the floors are strengthened by the flat bar stiffeners around the holes, The size of the holes is varied between 800×600 in the plates which are close to the centre

line and 600*400 for the rest of the plates. The thickness of the floors is changed from 12 mm to 15 mm, see in the Appendix Midship section plan

- The frame spacing in the transverse direction is: 450 mm from the centre line to the second bottom longitudinal girder, 850 mm between the bottom longitudinal girders and 800 mm in the double side structure.
- The height of the double bottom is 1700; the space of the double bottom is reserved to the ballast and fuel tanks. The duct keel is limited by the second watertight longitudinal girder; the width of the duct keel is 1350 mm. The spacing of the bottom longitudinal girders is 2550, all the bottom longitudinal girders, except the ones which limit the duct keel, contain holes for the lightning of their mass and provide the access in the double bottom in case of reparation or inspection, the size of these holes is 500 × 800.
- The transverse watertight bulkheads are flat and strengthened by the use of vertical frameworks, horizontal stringers as well as HP profiles.
- The width of the double side shell is 2020mm; the space of the double side is reserved to the ballast and fuel tanks, except the upper box dedicated to the passage way. The plates surrounding the upper box are strengthened by flat bar stiffeners of high tensile steel of 260 × 20.
- The total mass the structural elements in one complete cargo hold is 1048.54 t, 62 % is dedicated to the longitudinal plates, 13 % is dedicated to the longitudinal stiffeners and remaining percentage is dedicated to the transverse members including the structure of the transverse bulkhead.
- The total hull steel mass estimated is 10628.33 t, which is about 18% the total displacement of the ship.

10. CONCLUSIONS

The objective of the ship hull structural design reside in achieving such hull structure capable of sustaining the different kind of loads which the ship may encounters during her life, and to serve its intended purpose. Among the keys to reaching the objective; is the correct dimensioning of the structural members.

In the thesis, dimensioning the structural members of the assumed containership is performed. The structural model was built based on the structural concept defined in Section 5. The modelling is started from the generation of the midship section and then the whole structural model.

As it can seen in Sections 6 and 7, dimensioning the structural members is carried out using two approaches provided by Poseidon software: pre-sized structure according to construction rules and pre-sized structure based on direct calculation (first principle).

Looking at the results of the first approach, an initial scantling which fulfils the requirement of the GL rules with the minimum thickness is obtained in an iterative process, since the change in the dimensions and material of specific structural elements was making until the section modulus in the top and the bottom of the midship section turned out to be within the limits of the permissible values of the section modulus required by the GL rules. Additional information about the neutral axis, the inertia moment as well as the distribution of the normal stress, shear stress and von Mises stress due to the combined vertical bending moment, horizontal bending moment, tensional moment as well as the shear forces were provided. The evaluation of the results proves that the structure can resist all of these forces.

The resulted structural scantling from the first approach was verified using the second approach which is based on the direct calculation and carried out by performing the finite element analysis of one cargo hold located at the middle of the ship. At this stage, two load cases were based on for the assessment of the combined stresses and deformation; homogeneous 40 ft containers and heavy 20 ft containers.

The results of the finite element analysis provides a good insight about deflection, normal stress, shear stress and von Mises stress in the structural members which allows selecting the critical structural regions such as the middle part of the top coaming and some parts of the floors. These structural regions were strengthened by increasing their thicknesses and decreasing the size of the holes in the selected floors. The buckling verification in some structural members such as the outer bottom plates ensures the adequacy of the thickness of the plates and the dimensions of the longitudinal stiffeners against the high normal stresses in the outer bottom.

The verification of the torsional strength represented by the distribution of the von Mises stresses in the midship section indicated the necessity to change the thicknesses of certain plates of the shell and the longitudinal bulkhead at the level of the upper box (passage way).

Except that, the values of the combined von Mises stresses in the midship section due to the combination of the vertical bending moment, horizontal bending moment and the torsional moment are all within the limits of the permissible von Mises stress required by the GL rules. This proves the sufficiency of the hull structural scantling against the selected load cases.

11. ACKNOWLEDGEMENTS

First of all, I am so grateful to my sponsor, Erasmus Mundus EMSHIP program, for providing me the opportunity to upgrade my knowledge in Ship Design field. I would like to express my sincere appreciation to all my professors in the University of Liège, Ecole Centrale Nantes and West Pomeranian University of Technology, Szczecin.

I would like to express my deepest gratitude to my advisor Dr. Zbigniew Sekulski for his guidance and constant support in helping me to conduct and complete this thesis. Many thanks to Dr. Maciej Taczala for his assistance and advices during the progress of this thesis.

I would like to express my sincere gratitude to Eng. Wojciech Stecewicz and Eng. Arek Dabrowski for providing me the necessary tools and the comfortable conditions during my internship in GL Office, in Szczecin.

Many Thanks to Dr. Alfred Jazukiewicz and Eng. Piotr Gutowski from Genfer Design Company in Szczecin for their assistance to solve a technical problem related to this thesis.

Many thanks to all the people I have come to know in Liege, Nantes, Gdansk and Szczecin, especially my EMSHIP colleagues, whose friendship and companionship I will always enjoy. I owe my sincere appreciation to my family and relatives who have supported and encouraged me. I especially want to thank Prof. Hamoudi Ben Ameur for his continuous encouragement during my study in EMSHIP program.

Finally, I want to extend my profound appreciation to my beloved parents for their love, and invaluable support during my life and studies.

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APPENDIX

- **Section 6**

A.6.1.2.1. Input of the Data of the Ship

The required data comprises the main dimensions, service speed and other parameters of the ship have been entered as shown in Figure A.6.1.

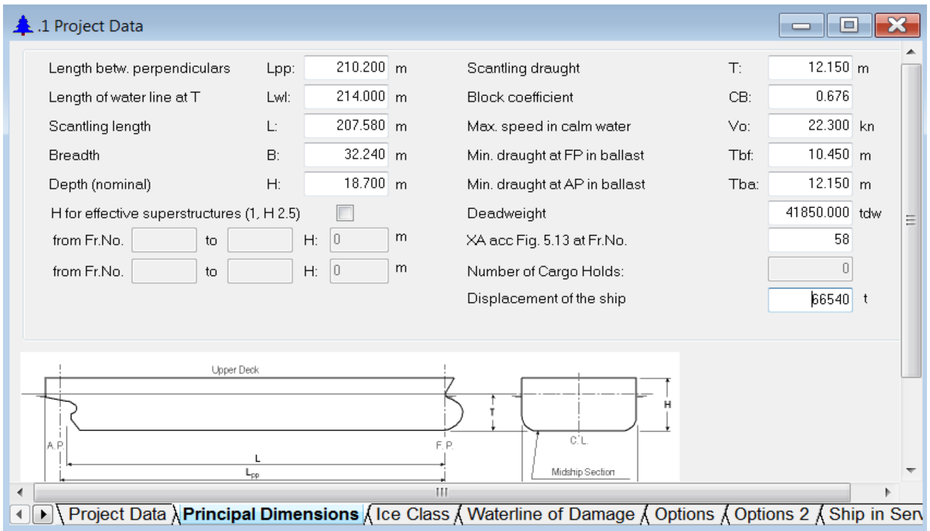


Figure A.6.1. Input field of the data of the ship.

The minimum draught at fore and aft peaks in ballast are taken as estimated value.

X_a, according to the section Longitudinal Strength of the GL rules, is the frame at where the engine room front bulkhead is located.

A.6.1.2.2. Material Definition

The categories of the material are referred to numbers which have been defined as shown in Figure A.6.2. For each material E-modulud, G modulus, Material density as well as Yield stress are needed

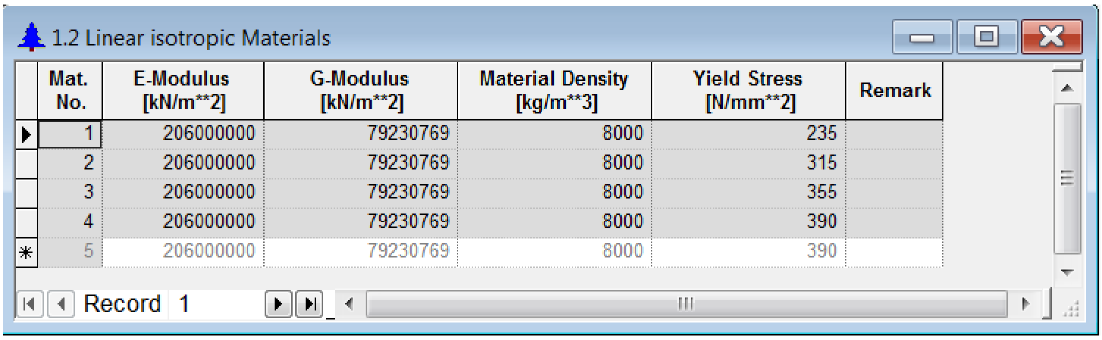


Figure A.6.2. Input the Material properties.

A.6.1.2.3. Generation of the Frame Table in the Ship's Longitudinal Direction

The frame spacing, a, is taken equal to 790 mm over the length of the ship. As the aft and fore parts are not modelled, there was no need to define the spacing at these parts. The input field of the frame spacing in the longitudinal direction is given in Figure A.6.3.

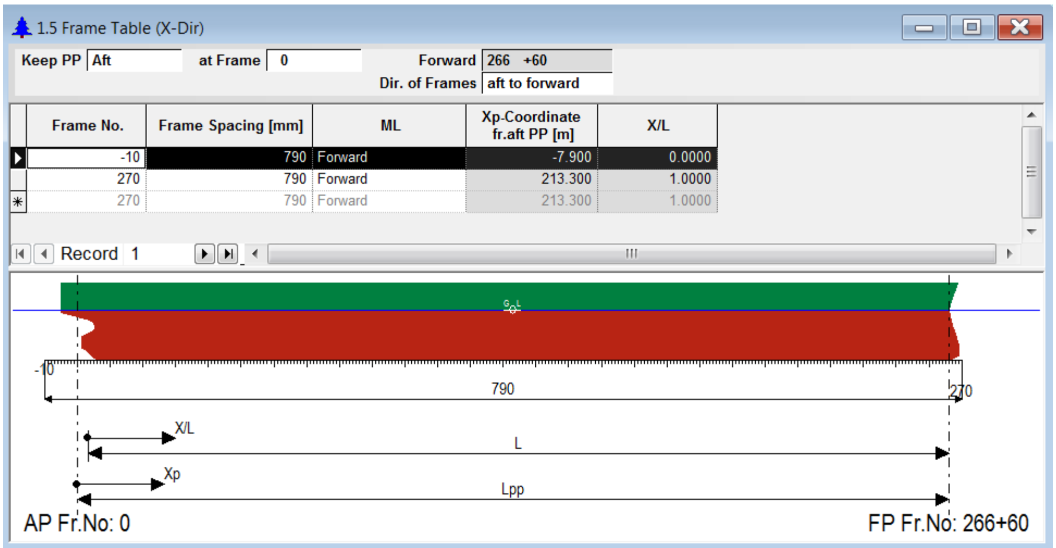


Figure A.6.3. Frame table in the ship's longitudinal direction (*X* Axis).

A.6.1.2.4. Generation of the Containership Typical Cross Section Using Poseidon Wizard

The generation of the midship section using Poseidon -Wizard required the input of some key parameters such as the inner bottom height, frame spacing and spacing of the floors and longitudinal girders and other parameters, as is shown in Figure A.6.4. The input of these parameters is based on the structural concept defined in the previous section.

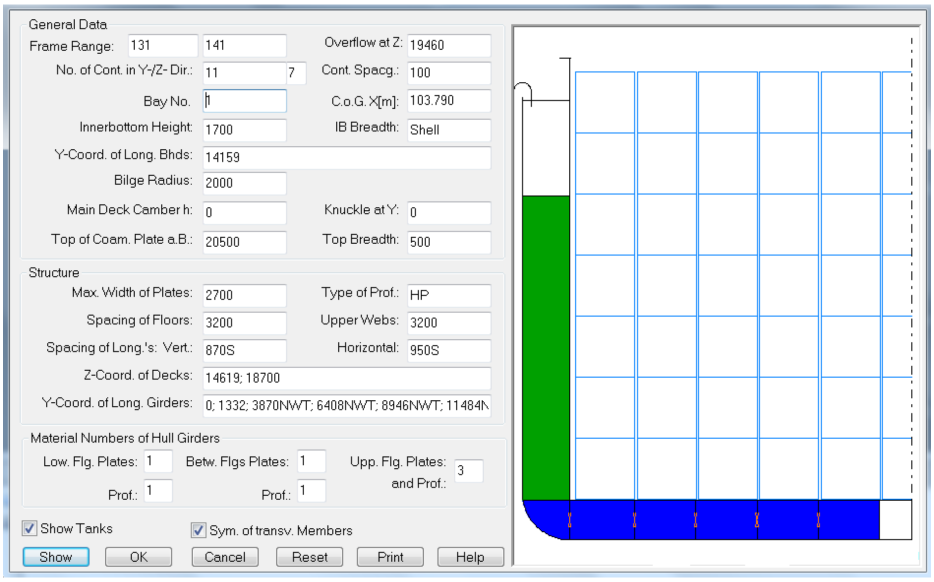


Figure A.6.4. Input field key parameters of the midship section.

Due to the lack of the midship section coordinates at the beginning of this work, its shape has taken by default referring to wizard, where the bilge radius was equal to 2000 [mm]. The 2 D and 3D view of the midship section generated by Wizard is depicted in Figures A.6.5 and A.6.6.

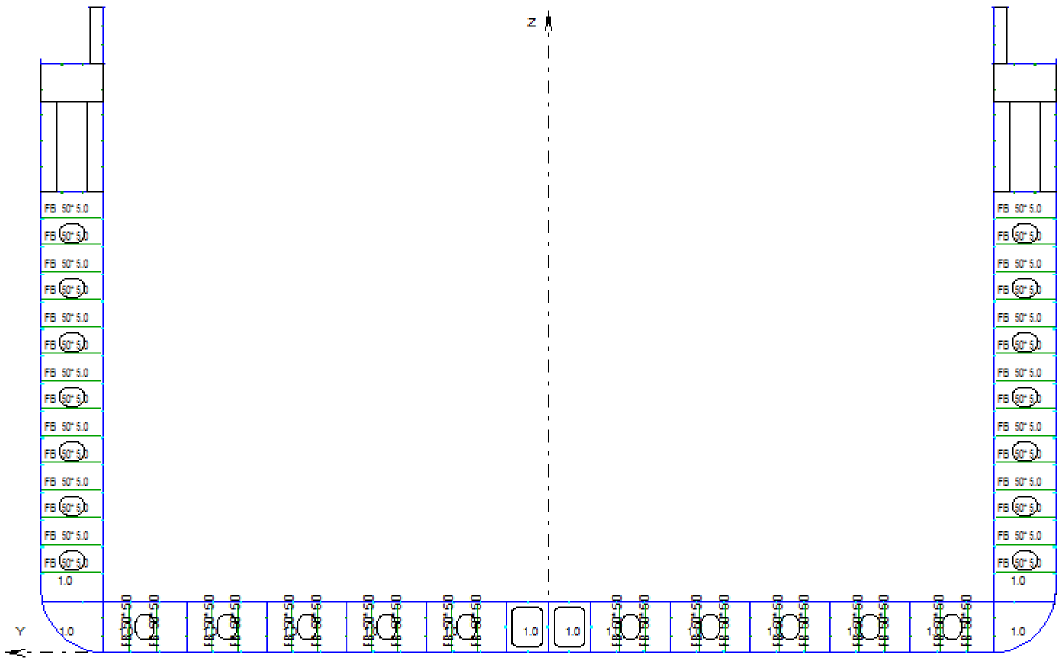


Figure A.6.5. 2D view of the midship section of the containership generated by Wizard-Poseidon.

In addition that Wizard-Poseidon generated the midship section very fast; it provides also a well structured description of all structural elements, as shown in Figure A.6.7, which represents the functional element worksheet. From the longitudinal view of this later, it is clear that Wizard-Poseidon defines all the primary longitudinal elements as an extended surface over the length of the ship, see Figure A.6.6. As an example of that, the arrangement of the main deck functional element is shown in Figure A.6.7. The plates of the functional elements, the transversal members, the holes, and the stiffeners are extended within the frame interval [131-141] as depicted in the 3D view given by Figure A.6.6.

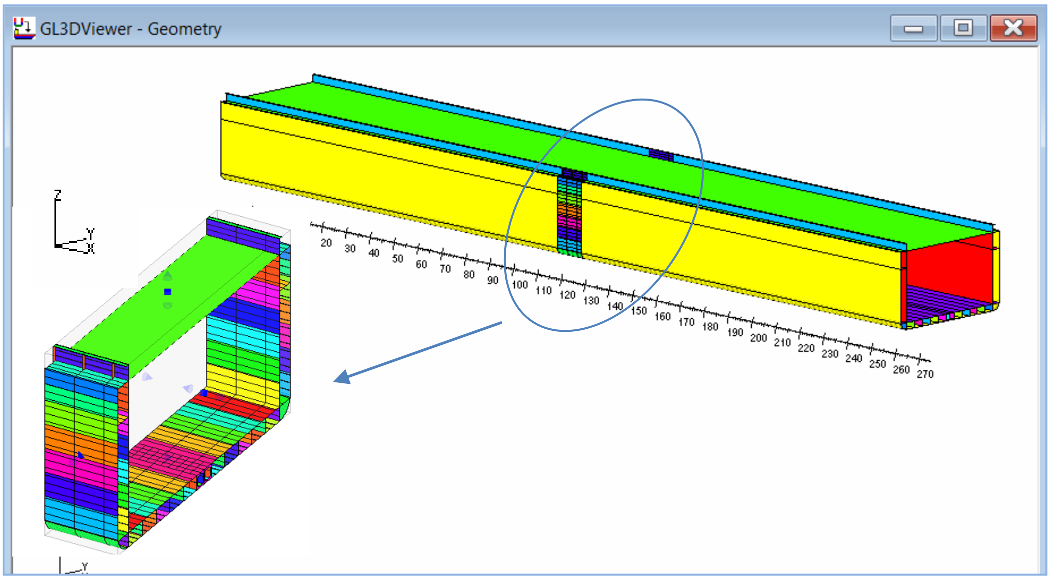


Figure A.6.6. 3D view of the midship section generated by Wizard.

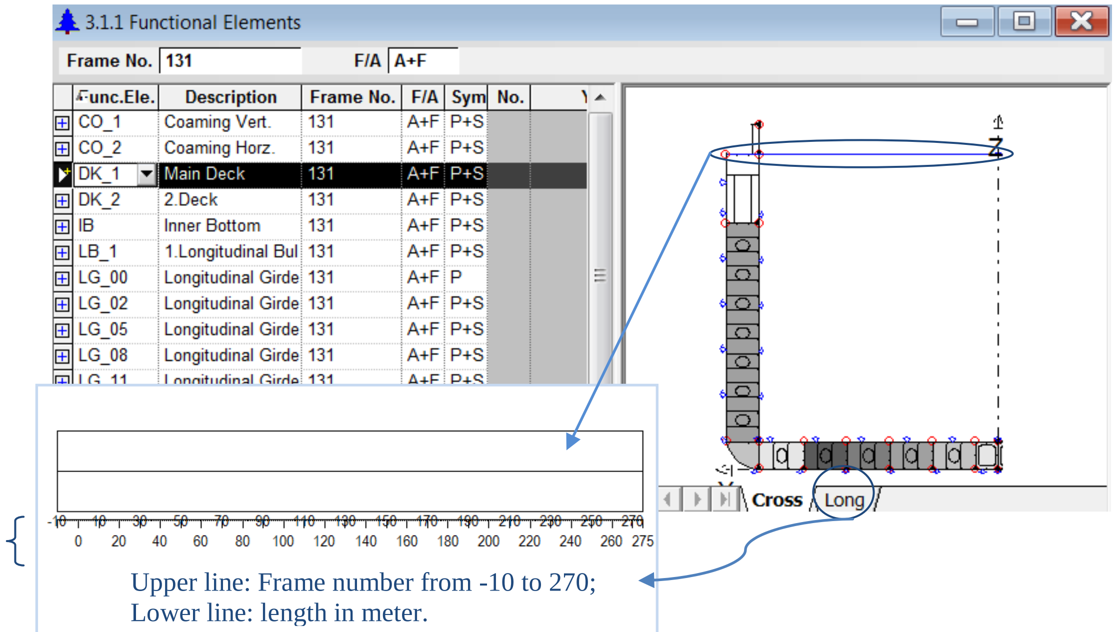


Figure A.6.7. Arrangement of the main deck functional element over the length of the ship.

Wizard-Poseidon generated the plates of the functional elements from the frame 131 to the frame 141in the Plate arrangement worksheet as shown in Figure A.6.8.

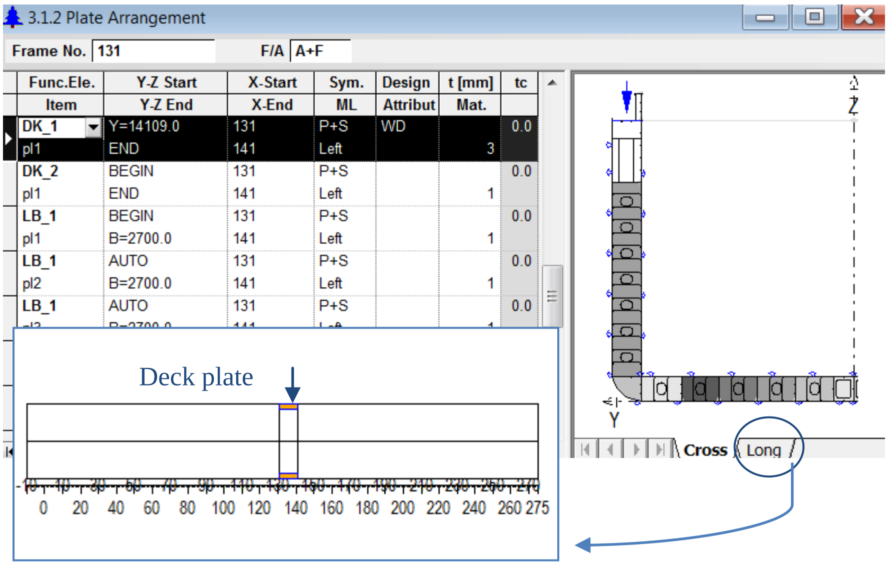


Figure A.6.8: Plate arrangement worksheet view.

A detailed 3D view of the arrangement of the longitudinal members, transversal members and longitudinal stiffeners, provided by Wizard-Poseidon is given in Figure A.6.9. The transversal web plates and the floors are defined at the frame 131 and arranged each 4 frames.

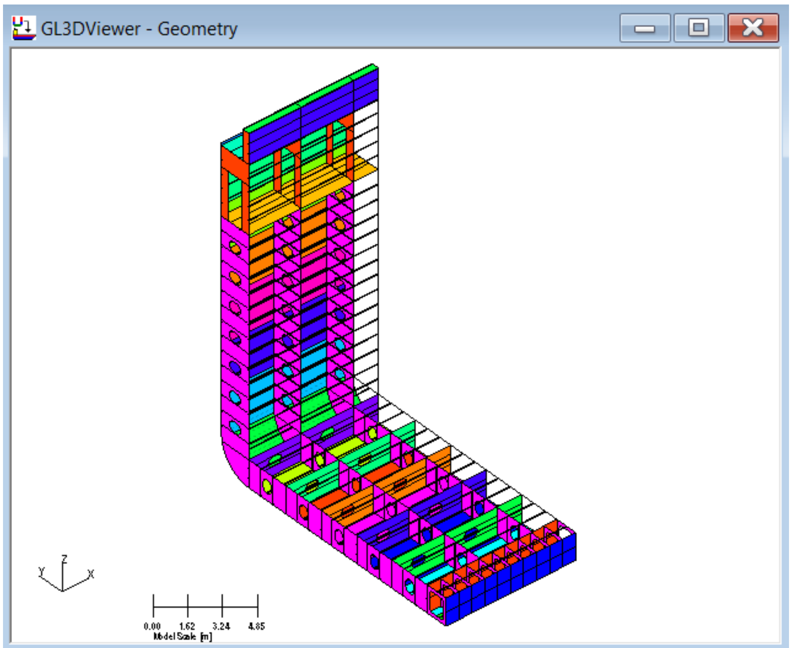


Figure A.6.9. Arrangement of structural elements generated by Wizard-Poseidon.

Remark: the difference in colour in the longitudinal plates is because Poseidon differentiates between the longitudinal plates by giving each plate colour different to the adjacent plate despite the plates have the same thickness.

A.6.1.2.5. Generation of a Frame Table in the Ship's Transverse Direction (Y and Z Axis)

After the creation of the midship section using a Wizard-Poseidon, the frame table in the ship's transverse direction has been created. This latest is made up by horizontal and vertical lines, the result is a grid which gives a good accuracy and can be used also as a reference to other elements during the arrangement of the structural elements afterwards.

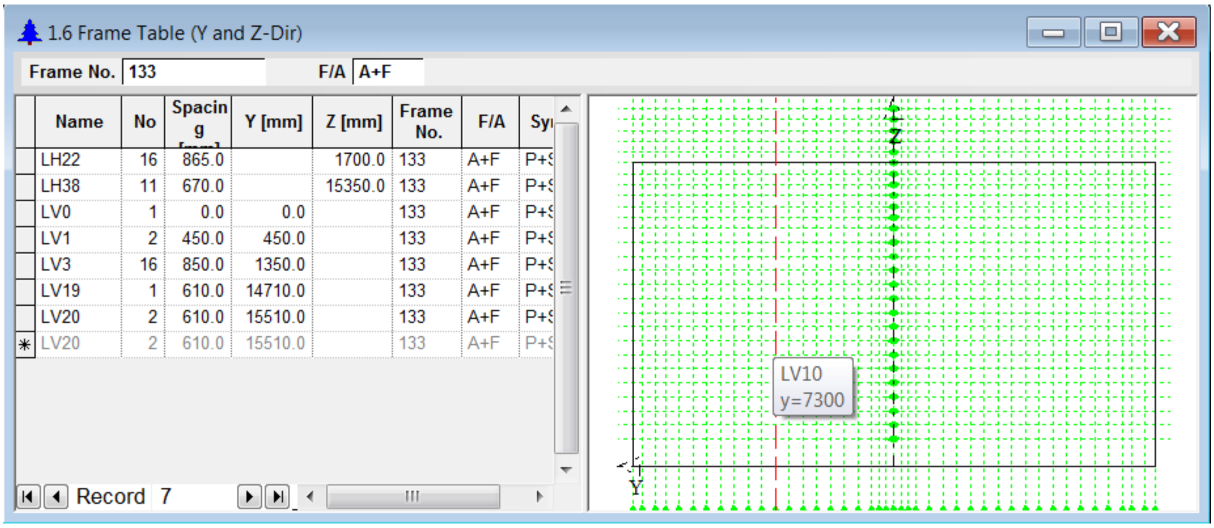
Vertical lines represent the spacing between longitudinal elements in the ship's transverse direction (*Y* axis); they are marked from LV0 to LV21. Horizontal lines represent the spacing between longitudinal elements in the vertical direction (*Z* axis); they are marked from LH22 to LH46. The origin point is located at the centre line, as depicted in Figure A.6.10.

The location of vertical and horizontal lines is taken according to the location of the structural elements in the midship section provided by Wizard. However, some modification has been made for the spacing of the structural elements, provided by wizard, in order to get the same arrangement defined in the structural concept defined in the section five.

The spacing between the vertical lines has been taken equal to 850 mm, excepts in the double side shell region (between shell and longitudinal bulkhead) where the passageway is planned, consequently the distance between the vertical line at this region is referred to the width of this latter which taken equal to 800 mm, therefore the spacing of the vertical line is taken successively 610, 800, 610 mm.

In the vertical direction the spacing between the horizontal lines has been taken equal to 865 mm from HL22 which is the location of the inner bottom. LH22 is located at a distance 1700 mm above the keel which represents the high of the double bottom.

The frame table in the ship's transverse direction is represented in Figure 6.10.



Name	No	Spacing [mm]	Y [mm]	Z [mm]	Frame No.	F/A	Sy
LH22	16	865.0		1700.0	133	A+F	P+S
LH38	11	670.0		15350.0	133	A+F	P+S
LV0	1	0.0	0.0		133	A+F	P+S
LV1	2	450.0	450.0		133	A+F	P+S
LV3	16	850.0	1350.0		133	A+F	P+S
LV19	1	610.0	14710.0		133	A+F	P+S
LV20	2	610.0	15510.0		133	A+F	P+S
LV20	2	610.0	15510.0		133	A+F	P+S

Figure A.6.10. Definition of the frame table in the ship's transverse direction.

A.6.1.2.6. Checking and Enhancing the Midship Section Generated by Wizard-Poseidon

In the following, corrections that have been made, in order to enhance the midship section provided by Wizard-Poseidon.

a) - Longitudinal members

The developed structural model is based on the structural concept defined in the previous section. Therefore in order to obtain such a similar model; other structural elements have been added, such as horizontal stringers in the double skin area. Thus between the inner bottom and the second deck, four stringers have been defined in the Functional Elements input task as depicts in Figure A.6.11.

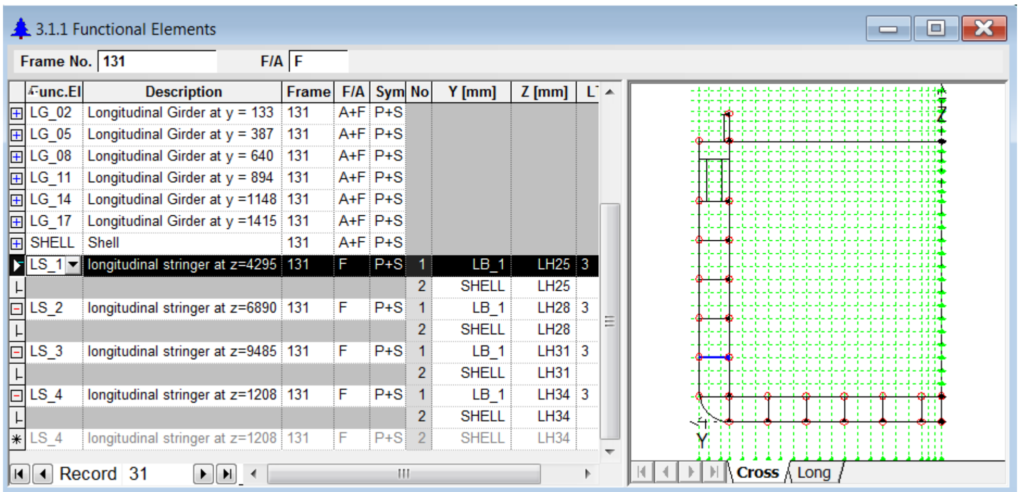


Figure A.6.11. Input field for the creation of the longitudinal stringers in the double side areas.

The plates of stringers have been defined afterwards in the plate arrangement worksheet, where the thickness chosen for all of them has been taken equal to 10 mm.

b) - Transverse members

After the creation of the stringers, correction has been made for the plate of web frame in the double side shell structure, the plate which is running from inner bottom till the second deck is replaced by five plates, which is created between horizontal stringers.

As mentioned before in the sub section 6.1., the creation of Transverse Members' plates needs first the generation of their cells, which describe the plates contour. The description of cell has referred to the functional elements, which are surrounding the cell. Between stringers, cells have been defined as shown in Figure A.6.12, which represents the geometry of cells worksheet. The cells from WF1 to WF5 are permanents cells.

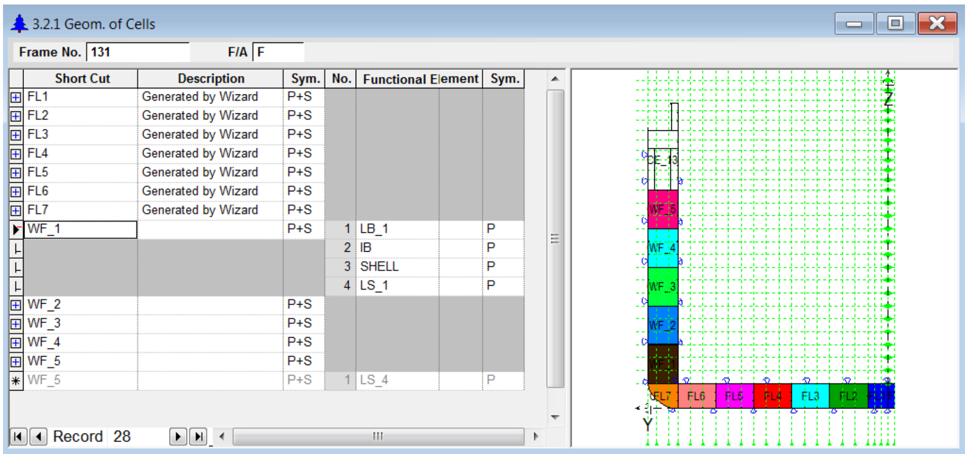


Figure A.6.12. Generation of cells needed for defining the web frames and the floors.

The cells FL1 to FL7, which have been generated by wizard-Poseidon, represent the floor plates contour; the cells WF1 to WF5 represent the web frame plates contour.

After the generation of the cells, the plates of these cells have been defined in the Plates worksheet as shown in Figure A.6.13.

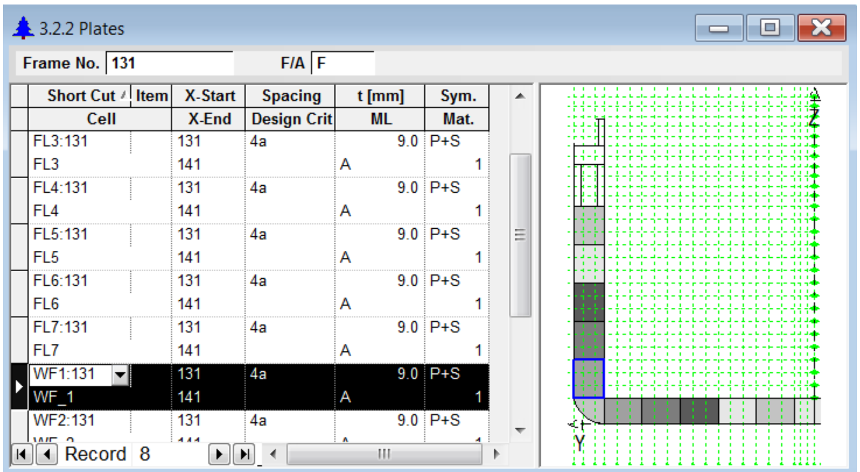


Figure A.6.13. Input field for defining the web frame and floors plates.

c) - Stiffeners and holes

The arrangement of longitudinal stiffeners as well as transversal stiffeners on the longitudinal and transversal plates has been already provided by Wizard. However, their sizing wasn't significant, which required the suggestion of a first scantling, which will be checked and corrected according to GL rules afterwards. The holes and cut-outs in longitudinal members and transverse web plates have already provided by Wizard.

d) - Creation of the camber

The camber can be created by Wizard or manually input data as it was made in this work.

The idea was to create a virtual main deck XDK_1 as functional element defined by three nodes which has the coordinate of the camber, as shown in Figure A.6.14, and after that refer the main deck DK_1 to this later.

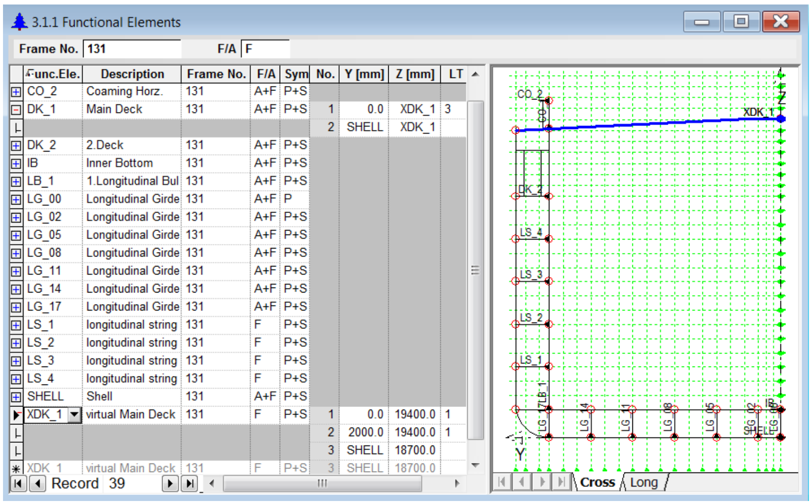


Figure A.6.14. Input field for the creation of the XDK_1 needed for creating the camber.

6.1.2.7. Import of the Midship Section Shape

In this step the real shape of the midship section has been entered. The file gl.frm, which was provided by GL office, contains the hull shape data of the containership B-178. This file has been imported to the Poseidon file, the coordinates of the frame 131, which represents the frame at which the midship section is located, has been taken for define the new shape of the shell as depicted in Figure A.6.15. Coordinates of the Shell functional element has been replaced by the coordinates of Shell 1.

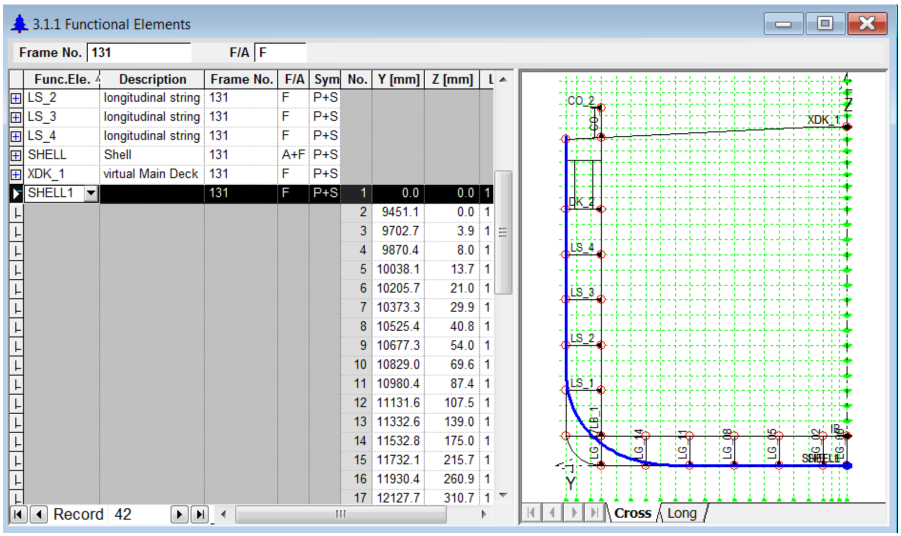


Figure A.6.15. Import of the midship section shape.

Because of the specification of the shape of Shell 1 at the level of the bilge, the importation of the midship coordinates caused some errors, mentioned as red comments by Poseidon, which required necessary modifications of the arrangement of the structural elements at the level of the bilge, such as:

- creation of a second longitudinal bulkhead LB_2 above the longitudinal girder LG_14 from the inner bottom till the high of the stringer LS_1;
- extend the stringer LS_1 till the second longitudinal bulkhead LB_2.
- move the bulkhead LB_1 from the inner bottom IB to the LS_1, and extend LG_17 till LS_1. The above modifications are depicted in Figure A.6.16:

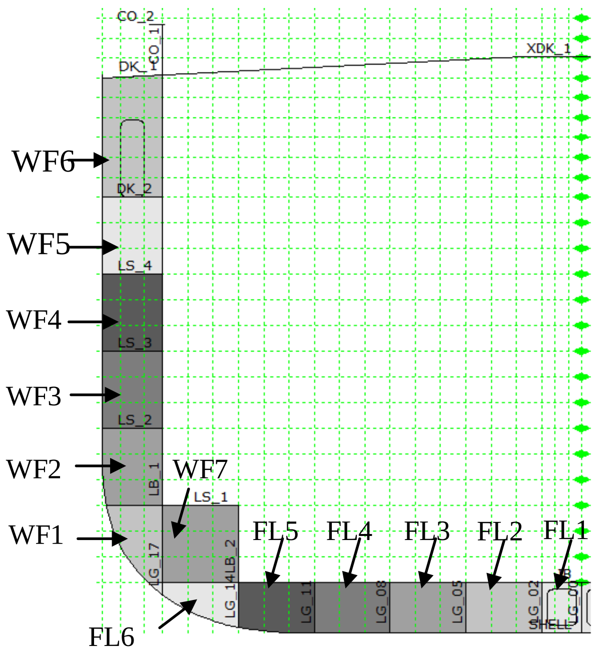


Figure A.6.16. Midship section with a new shell shape after modification.

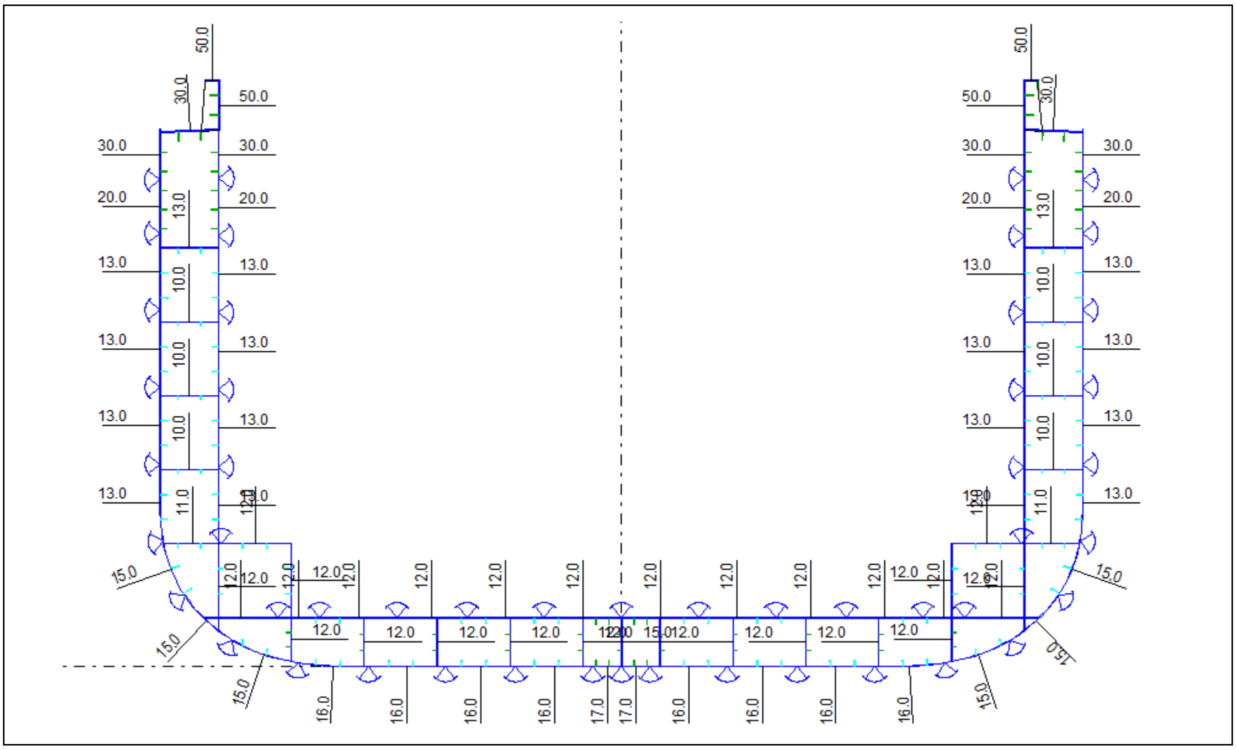
A.6.1.2.8- Input of the Proposed Scantling

It was remarkable that Wizard-Poseidon didn't provide all the dimensions of the structural elements, such as plates' thickness of the longitudinal and the transversal members, which required the input of the missing dimensions manually. In addition, and as mentioned before the sizing of the stiffeners was not significant, hence a first scantling has been suggested and inputted. That will be checked and corrected based on GL rules afterwards.

Table A.6.1 contains the data as well as the configuration of the proposed scantling which has been inputted for the sizing of the longitudinal plates and their stiffeners. For the transversal plates, the thickness adopted for all of them is 12 mm, as first input which will be check afterwards.

Table A.6.1. Proposed scantling data and configuration

Plates			Stiffeners on longitudinal plates		
	t, mm	material	profile type	dimension mm*mm	material
Shell; Keel	17	3	FB	220*15	1
Shell B1-B5	16	3	HP	220*12	1
Shell; bilge ; S7	15	3	HP	220*12	1
Shell Side; S8; 11	13	3	HP	220*12	1
Shell Side; S12	20	3	FB	240*12	1
Shell; Sheer S13	30	3	FB	240*20	1
IB ; pl1:pl6	12	1	HP	220*12	1
DK_01	30	3	HP	340*28	1
DK_02	13	1	HP	140*9	1
LB_1; pl1	13	1	HP	200*10	1
LB_1; pl5	20	1	HP	200*10	1
LB_1; pl6	30	1	FB	200*10	1
LB_2	12	1	HP	200*10	1
LS_1: LS_4	10	1	HP	140*9	1
LG_00 : LG_17	12	1	FB	150*14	1
CO_1	50	3	FB	200*20	1
CO_2	50	3	FB	300*50	1



A.6.1.2.9. Creation of the cylindrical part and arrangement of the transversal bulkheads

According to the general arrangement of the ship, the cargo space is defined from the forward bulkhead of the engine room (located at the frame 58), until the collision bulkhead (located at the frame 254). The cylindrical part has been divided into holds by five watertight bulkheads; one hold itself has been divided into two parts by non watertight bulkhead. The arrangement of the bulkheads as well as their structure in Poseidon model is based on the structural concept defined in the previous section. The table 6.2 contains the calculation of the numbers of frames needed for the stowage of containers, the determination of the location of the transverse bulkheads in the table 6.3.

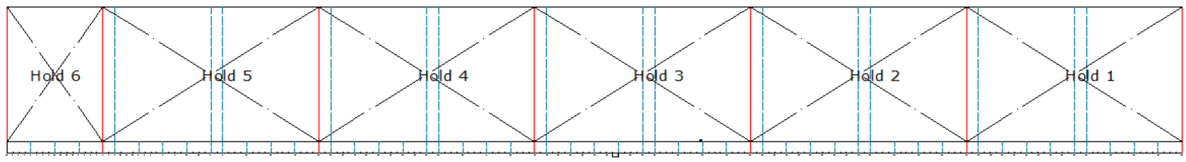
Table A.6.2. Calculation of the space needed to the stowage of containers into one complete cargo hold.

20 ft container bay	Space needed [m]	Number of frames needed
1	6.095703	8
2	12.19141	16

Table A.6.3. Location of the bulkheads.

		Start frame	End frame
Hold 6		58	74
WBh		74	76
Hold 5		76	92
	NWBh	92	94
		94	110
WBh		110	112

Hold 4		112	128
	NWBh	128	130
		130	146
WBh		146	148
Hold 3		148	164
	NWBh	164	166
		166	182
WBh		182	184
Hold 2		184	200
	NWBh	200	202
		202	218
WBh		218	220
Hold1		220	236
	NWBh	236	238
		238	254



After the determination of the location of the bulkheads, all the structural elements have been extended over the cylindrical part.

Because of the distinction in the function of these elements not all of them have been extended in the same way. Following, a brief explanation of the methodology followed with examples for the extension of the structural members and the creation of the structure transverse bulkheads.

a) - Extension of the longitudinal members

For *The elements: Shell, longitudinal bulkheads, Inner bottom and top coaming,* create successive blocs of length between 8 and 12 m by:

First, define the start frame and the end frame of these elements in the Functional Element worksheet as shown in the Figure 6.18a. Thus, arrange successive plates for these elements in Plates Arrangement worksheet. The length of plates varied from 8 to 12 m depends on the arrangement of the transverse frames, means that the join of two adjacent plates should not coincide with the location of transversal member, such as floors and web frames. The arrangement of plates is shown in figure 6.18b. Poseidon differentiates between the plates by given each plate colour different from the adjacent plate despite that they have the same thickness.

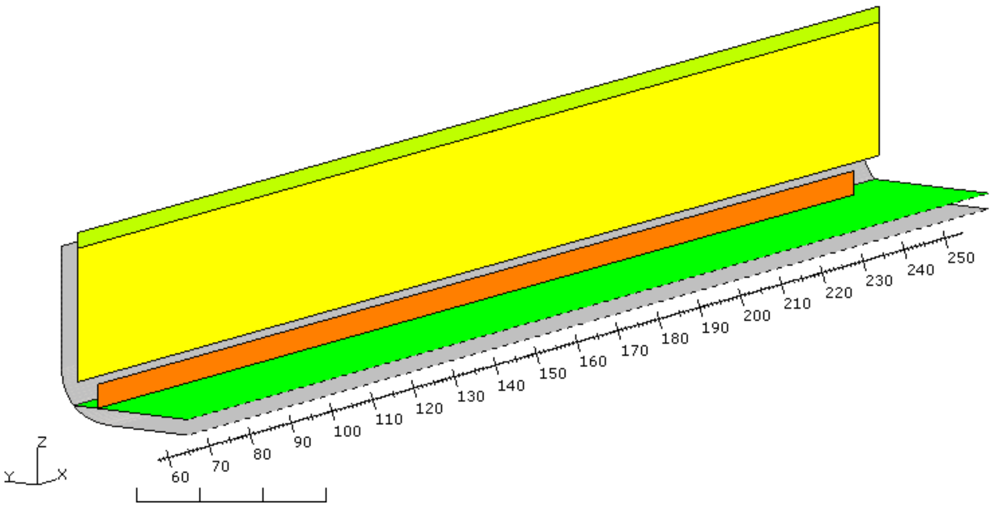


Figure A.6.17a. Extension of the longitudinal members (*Shell, longitudinal bulkheads, Inner bottom and top coaming):* Functional Element definition

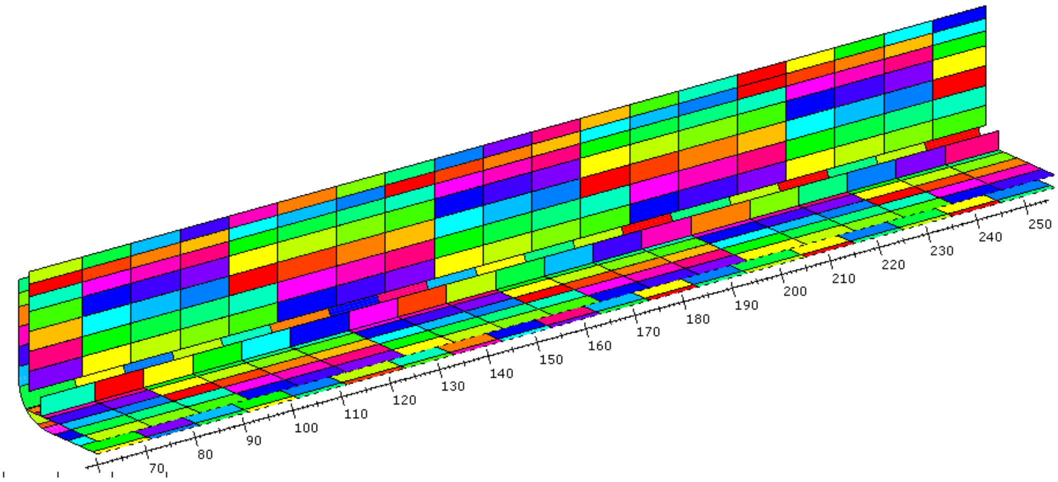
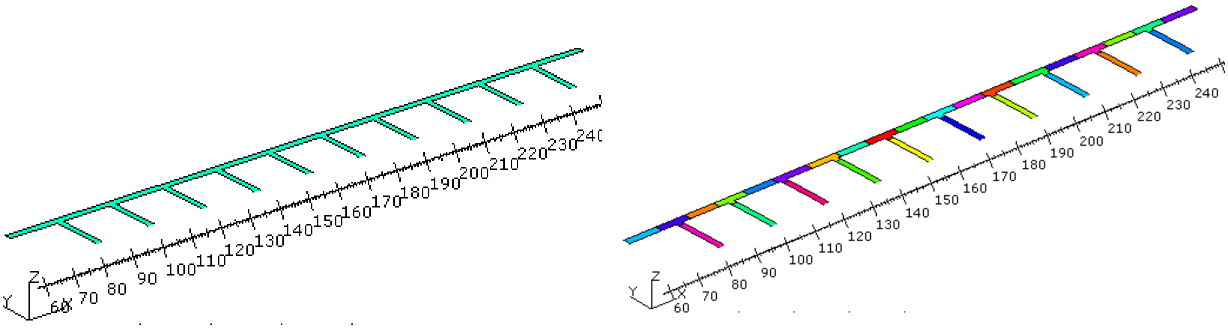


Figure A.6.17. Extension of the longitudinal members (*Shell, longitudinal bulkheads, Inner bottom and top coaming:* Arrangement of the plates

For the elements: stringers, decks, and longitudinal girders. Their plates have been stretched over the length of the cylindrical part. Besides, these elements have been used to contribute to create an initial structure of transverse bulkheads, to be detailed afterwards.

In addition that the main deck is stretched over the length of the cylindrical part (From the LB_1 to Shell), it is defined also over the full breadth at each frame where located the both watertight and non watertight bulkhead, in order to create hatches. For that the new arrangement of the main deck has been defined in the Functional Element worksheet. Afterwards, plates of the main deck have defined in plate arrangement worksheet. Where their lengths have been varied between 8 and 12 m, and take the same arrangement as the plates of the elements listed above. The extension of the main deck is depicted in Figure A.6.18.



(a) Main deck functional element arrangement

(b) Arrangement of the plates of the main deck

Figure A.6.18. Arrangement of the main deck functional elements and plates over the model length.

As mentioned before, in order to create the initial structure of transverse bulkheads, the same procedure that have been considered for the extension of the main deck, has been taken for the extension of the other elements such as the stringers, longitudinal girders, the top coaming, and the second deck, as depicted in Figure A.6.19.

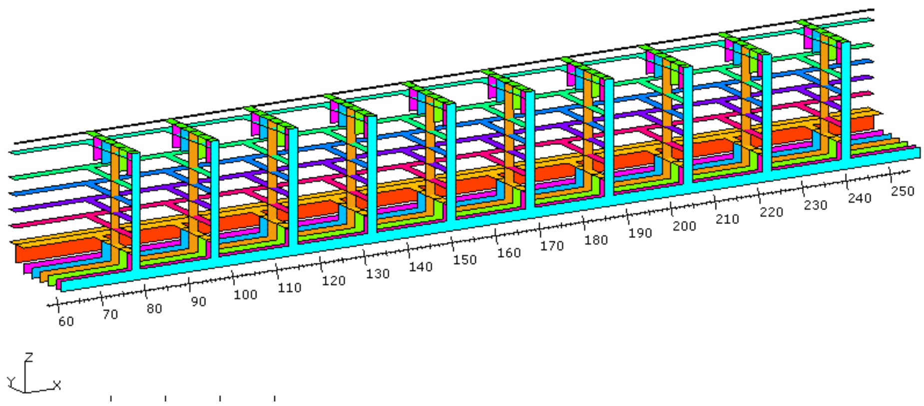
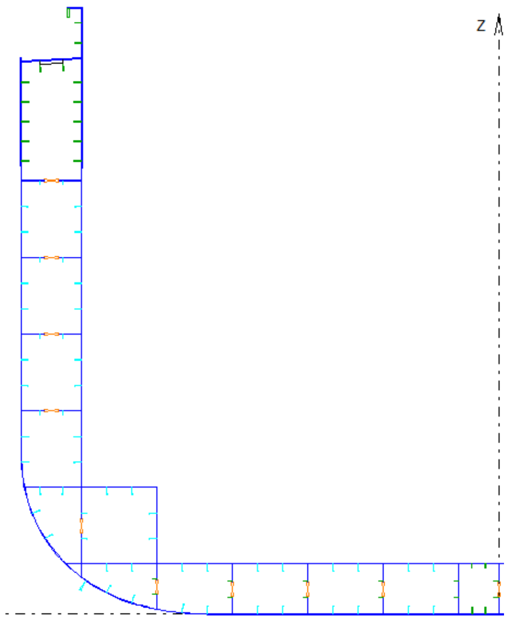
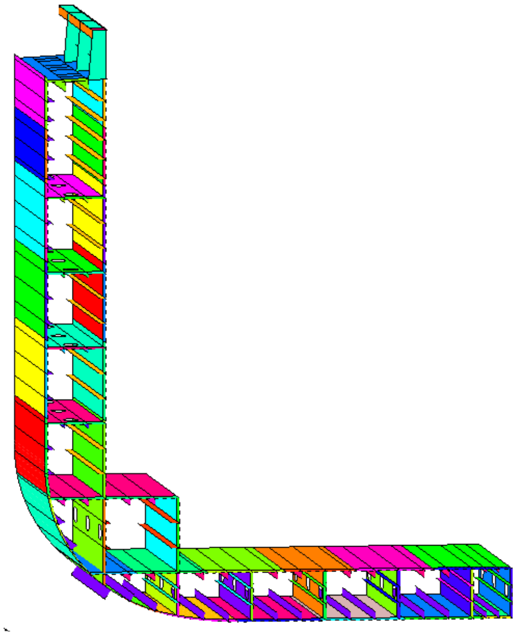


Figure A.6.19. Arrangement of the stringers, longitudinal girders and Top coaming over the length of the model.

After the creation of longitudinal members' plates, longitudinal and transverse stiffeners as well as holes on these plates have been created. Longitudinal stiffeners have been extended from the frame 58 to the frame 254 by using the magic command, in the stiffeners arrangement worksheet. Longitudinal members plates' holes have been defined in the worksheet Holes and cut out under longitudinal members in the tree view of Poseidon file. The arrangement of longitudinal stiffeners and holes are shown in Figure A.6.20.



(a) Frame 118



(b) From FR 98 to 109

Figure A.6.20. Longitudinal stiffeners and longitudinal members' holes arrangement

b) Extension of transverses members

Two types of transverse members have been considered; watertight and non watertight web frames and floors. In the holds area, at the level of each non watertight bulkhead, and under the open side of watertight bulkhead; non watertight web frames and floors has been arranged, where the spacing adopted at every four frames. At the frames which are dedicated to the location of watertight bulkhead; watertight web frames and floors have been arranged. Besides, the surrounding plates at the level of duct have been adopted each frame.

Figure A.6.21 shows the arrangement of the web frames and floors over the model.

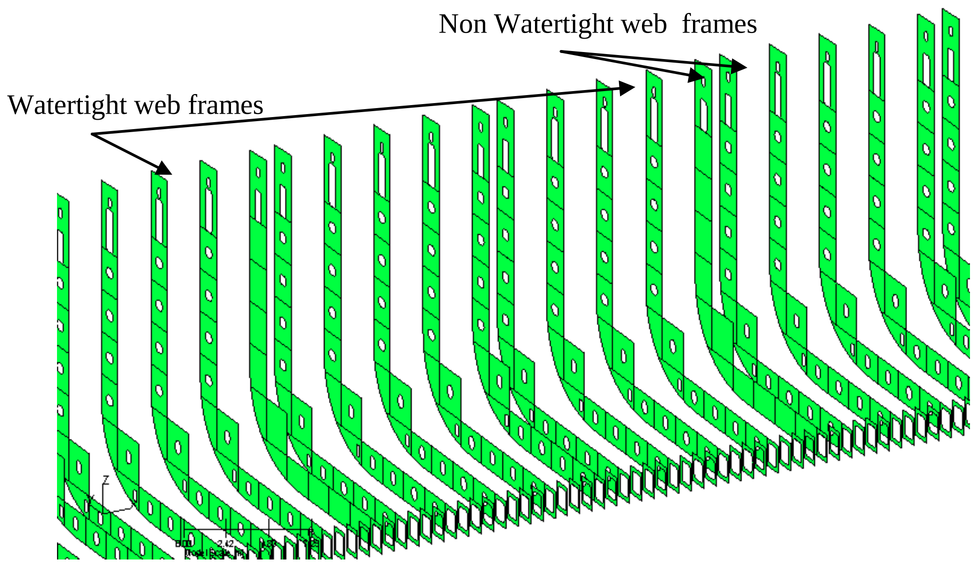
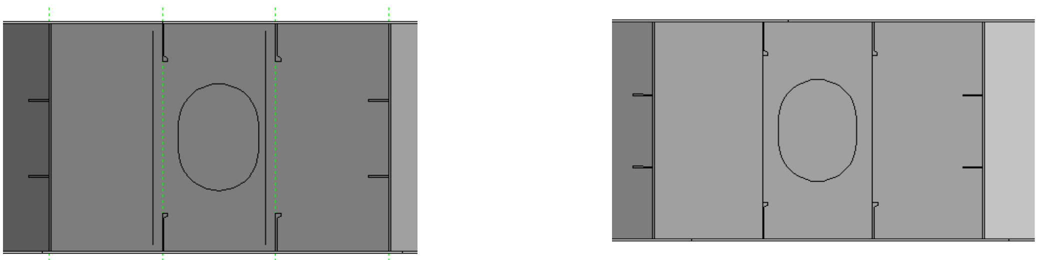


Figure A.6.21. Arrangement of the floors and web frames over the length of the model.

The stiffeners on the transverse plates are provided by wizard, their arrangement is depicted in Figure A.6.22a. The stiffeners are shifted 50 mm from the longitudinal stiffeners, which is preferable point of view fatigue strength as well as production process, this solution is adopted by the Korea shipyard. However as the present project do not address to the fatigue analysis; the arrangement of the stiffeners adopted is as shown in Figure A.6.22.b.



(a) Proposed by Wizard-Poseidon (b) Solution adopted in the present work

Figure A.6.22. Arrangement of the stiffeners on the transverse plates.

The arrangement of the stiffeners and the holes in the floors and the web frames is depicted in Figure A.6.23.

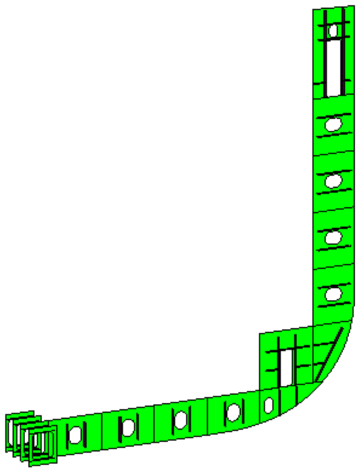


Figure A.6.23. Arrangement of the stiffeners and holes in the floors and Web frames.

A.6.1.2.10- Structure of Transverse Bulkheads:

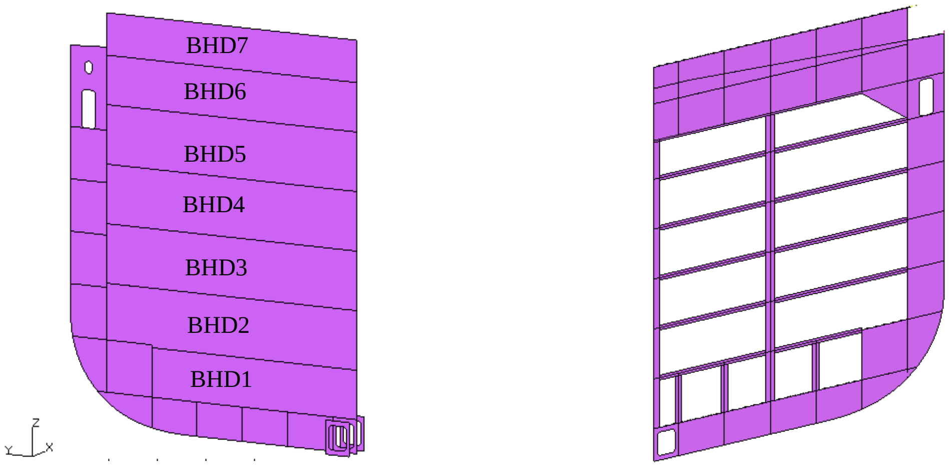
As mentioned before, two types of bulkheads have been adopted for divided the cylindrical part: watertight and non watertight bulkheads. In Poseidon, the transverses bulkheads can be created using the section Transverse Bulkheads from the tree view, or manually. In this work, the second method was adopted.

The structure of each transversal bulkhead, despite its type, has been extended over two frames. Also, each bulkhead has two sides:

- The first side is located at the start frame of the bulkhead, it can be watertight in the case of watertight bulkhead (means formed only by watertight plates), or not in the case of non watertight bulkheads. In this last case, it is called **open side**.
- The second side is always an open side despite the type of the transversal bulkhead.

The watertight side of the bulkhead is formed by plane watertight plates (BHD1 to BHD7) stretched from the inner bottom till the top coaming, as shown in Figure 6.24.a. These plates are transversal elements; therefore, there were created in the transversal web plate worksheet. Their thicknesses are different from plate to plate, to be defined afterwards according to GL rules.

The open side is composed by horizontal and vertical flanges at the level of the horizontal stringers and vertical web frames, from the deck stool till the top coaming, plate has been created in order to form the transversal box, as shown in Figure 6.24b.



(a) Watertight side. (b) Open side.

Figure 6.24.Watertight bulkhead structure.

- **Section 7**

	LC 1	LC 2	LC 3 [1]	LC 4 [1]	LC 5	LC 6 [2]
Load component	**Homo-geneous 40 FT**	**Heavy Loading 20 FT**	**Light Loading 40 FT**	**Light Loading 20 FT**	**Pitching Condition**	**Flooded Condition**
Static Water Pressure Draught	scantling	scantling	scantling	scantling	scantling	damage + 1 m
Dynamic Water Pressure	wave crest	wave trough	wave crest	wave crest	wave trough	none
Vertical Bending Moment Stillwater Wave	Max [3] Hogging	Min Sagging	Max Hogging	Max Hogging	Min Sagging	Min none
Vertical Acceleration	$(1-a_v)\,g$	$(1+a_v)\,g$	$(1-a_v)\,g$	$(1-a_v)\,g$	$(1+a_v)\,g$	g
Transverse Acceleration	0	0	0	0	0	0
Longitudinal Acceleration of all masses	0	0	0	0	$a_x \cdot g \approx 0{,}15\,g$	0
Deck Bay A	40' 20 t/FEU [4]	40' 30 t/FEU [4]	40' 16 t/FEU [5]	40' 16 t/FEU [5]	20' 100 t/Stack	40' 28 t/FEU [4]
Bay B	40'	40'	40'	40'	20'	40'
Bay C	40'	40'	40'	40'	20'	40'
Bay D	40'	40'	40'	40'	20'	40'
Hold Bay A	40' 20 t/FEU [4]	20' 15 t/TEU [4]	40' 16 t/FEU [5]	20' 8 t/TEU [5]	40' 30 t/FEU [4]	40' 28 t/FEU
Bay B	40'	20'	40'	20'	40'	Flooded
Bay C	40'	20'	40'	20'	40'	Flooded
Bay D	40'	20'	40'	20'	40'	40' 28 t/FEU

1 This load case depends on the technical building specification and the yard's standards respectively. It may be replaced by the load case 'Empty Bay'

2 The damage case resulting in the largest wetted area of the watertight bulkhead

3 Maximum still water bending moment of the following values:

- Still water bending moment corresponding to the minimum requirement for the section modulus of the midship section stated in the IACS UR S11.
- Still water bending moment corresponding to the loading condition chosen from the trim and stability booklet.

Alternatively, the maximum permissible still water bending moment may be used for design purposes.

4 The severest load case from the trim and stability booklet has to be considered

5 The loading condition with the lightest containers has to be considered.

Figure A.7.25. Standard load case, from the section Cargo Hold Analysis of the GL rules.

Loadgroup	Basic Loadcase Fx [kN]	Fy [kN]	Fz [kN]	CoGx [m]	CoGy [m]	CoGz [m]	Reference Type	Value [t]	Factor	Fx [kN]	Fy [kN]	Fz [kN]
93 N.x.	9981	0	0	0.000	9.096	11.015	Fx	0.0	0.000000	0.0	0.0	0.0
93 Sh.z.	0	-901	-9996	68.250	10.029	0.000	Fz	0.0	5.814230	0.0	-5238.9	-58117.9
93 Ben.yy	0	0	0	0.000	0.000	0.000	Fx	0.0	-28.223182	0.0	0.0	0.0
165 N.x.	9981	0	0	0.000	9.142	10.861	Fx	0.0	0.000000	0.0	0.0	0.0
165 Sh.z.	0	-963	-10007	125.130	10.041	0.000	Fz	0.0	5.811740	0.0	-5595.0	-58156.1
165 Ben.yy	0	0	0	0.000	0.000	0.000	Fx	0.0	28.224076	0.0	0.0	0.0
S Stat Tmin	0	-62109	183965	0.000	0.000	0.000	Fx	0.0	0.00000	0.0	0.0	0.0
S Stat Tmax	0	-83965	215140	96.690	7.821	0.000	Fz	21930.6	1.00000	0.0	-83964.9	215139.5
S WaveLNo 1	0	-91728	54046	96.690	8.283	0.000	Fz	3305.6	0.60000	0.0	-55036.6	32427.7
S WaveLNo 2	0	44074	-54046	96.690	8.283	0.000	Fz	0.0	0.00000	0.0	0.0	0.0
Dead W. X	2193	0	0	0.000	10.844	8.788	Fx	0.0	0.00000	0.0	0.0	0.0
Dead W. Y	0	2193	0	96.639	0.000	8.788	Fy	0.0	0.00000	0.0	0.0	0.0
Dead W. Z	0	0	2193	96.639	10.844	0.000	Fz	-2183.6	-9.77000	0.0	0.0	-21421.1
GPL 1	0	0	-7300	0.000	0.000	0.000	Fx	0.0	0.00000	0.0	0.0	0.0
Bay 21 H V	0	0	-7500	121.180	6.908	0.000	Fz	750.0	0.98100	0.0	0.0	-7357.5
Bay 21 D V	0	0	-6000	121.180	8.178	0.000	Fz	650.0	1.06275	0.0	0.0	-6376.5
Bay 23 H V	0	0	-7500	114.860	6.908	0.000	Fz	750.0	0.98100	0.0	0.0	-7357.5
Bay 23 D V	0	0	-6000	114.860	8.178	0.000	Fz	650.0	1.06275	0.0	0.0	-6376.5
Bay 25 H V	0	0	-7500	106.960	6.908	0.000	Fz	750.0	0.98100	0.0	0.0	-7357.5
Bay 25 D V	0	0	-6000	106.960	8.178	0.000	Fz	650.0	1.06275	0.0	0.0	-6376.5
Bay 27 H V	0	0	-7500	100.640	6.908	0.000	Fz	750.0	0.98100	0.0	0.0	-7357.5
Bay 27 D V	0	0	-6000	100.640	8.178	0.000	Fz	650.0	1.06275	0.0	0.0	-6376.5
Bay 29 H V	0	0	-7500	92.740	6.908	0.000	Fz	750.0	0.98100	0.0	0.0	-7357.5
Bay 29 D V	0	0	-6000	92.740	8.178	0.000	Fz	650.0	1.06275	0.0	0.0	-6376.5
Bay 31 H V	0	0	-7500	86.420	6.908	0.000	Fz	750.0	0.98100	0.0	0.0	-7357.5
Bay 31 D V	0	0	-6000	86.420	8.178	0.000	Fz	650.0	1.06275	0.0	0.0	-6376.5
Bay 33 H V	0	0	-7500	78.520	6.908	0.000	Fz	750.0	0.98100	0.0	0.0	-7357.5
Bay 33 D V	0	0	-6000	78.520	8.178	0.000	Fz	650.0	1.06275	0.0	0.0	-6376.5
Bay 35 H V	0	0	-7500	72.200	6.908	0.000	Fz	750.0	0.98100	0.0	0.0	-7357.5
Bay 35 D V	0	0	-6000	72.200	8.178	0.000	Fz	650.0	1.06275	0.0	0.0	-6376.5

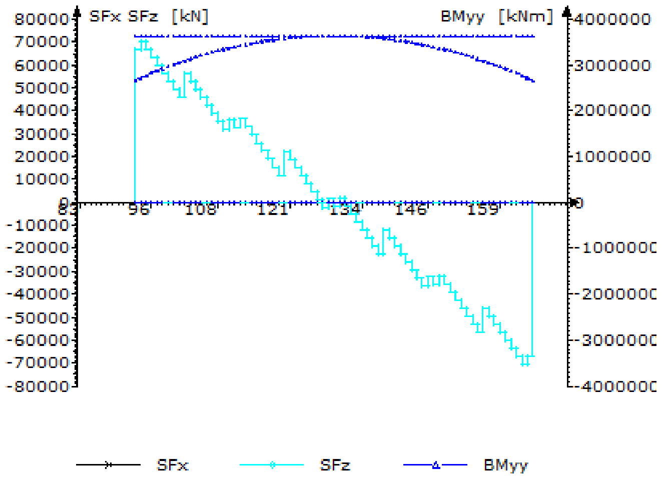


Figure A.7.26. Load adjustment for the homogeneous 40ft containers load case.

Loadgroup	Basic Loadcase Fx [kN]	Fy [kN]	Fz [kN]	CoGx [m]	CoGy [m]	CoGz [m]	Reference Type	Value [t]	Factor	Fx [kN]	Fy [kN]	Fz [kN]
93 N.x.	9981	0	0	0.000	9.096	11.015	Fx	0.0	0.000000	0.0	0.0	0.0
93 Sh.z.	0	-901	-9996	68.250	10.029	0.000	Fz	0.0	-0.605360	0.0	545.5	6051.1
93 Ben.yy	0	0	0	0.000	0.000	0.000	Fx	0.0	32.287715	0.0	0.0	0.0
165 N.x.	9981	0	0	0.000	9.142	10.861	Fx	0.0	0.000000	0.0	0.0	0.0
165 Sh.z.	0	-963	-10007	125.130	10.041	0.000	Fz	0.0	-0.599250	0.0	576.9	5996.5
165 Ben.yy	0	0	0	0.000	0.000	0.000	Fx	0.0	-32.288738	0.0	0.0	0.0
S Stat Tmin	0	-62109	183965	0.000	0.000	0.000	Fx	0.0	0.00000	0.0	0.0	0.0
S Stat Tmax	0	-83965	215140	96.690	7.821	0.000	Fz	21930.6	1.00000	0.0	-83964.9	215139.5
S WaveLNo 2	0	44074	-54046	96.690	8.283	0.000	Fz	3305.6	0.60000	0.0	26444.5	-32427.7
Dead W. X	2175	0	0	0.000	10.848	8.845	Fx	0.0	0.00000	0.0	0.0	0.0
Dead W. Y	0	2175	0	96.638	0.000	8.845	Fy	0.0	0.00000	0.0	0.0	0.0
Dead W. Z	0	0	2175	96.638	10.848	0.000	Fz	-3053.1	-13.77324	0.0	0.0	-29951.2
GPL 1	0	0	-7300	0.000	0.000	0.000	Fx	0.0	0.00000	0.0	0.0	0.0
Bay 21 H V	0	0	-7500	121.180	6.908	0.000	Fz	1125.0	1.47150	0.0	0.0	-11036.2
Bay 21 D V	0	0	-6000	121.180	8.178	0.000	Fz	975.0	1.59413	0.0	0.0	-9564.8
Bay 23 H V	0	0	-7500	114.860	6.908	0.000	Fz	1125.0	1.47150	0.0	0.0	-11036.2
Bay 23 D V	0	0	-6000	114.860	8.178	0.000	Fz	975.0	1.59413	0.0	0.0	-9564.8
Bay 25 H V	0	0	-7500	106.960	6.908	0.000	Fz	1125.0	1.47150	0.0	0.0	-11036.2
Bay 25 D V	0	0	-6000	106.960	8.178	0.000	Fz	975.0	1.59413	0.0	0.0	-9564.8
Bay 27 H V	0	0	-7500	100.640	6.908	0.000	Fz	1125.0	1.47150	0.0	0.0	-11036.2
Bay 27 D V	0	0	-6000	100.640	8.178	0.000	Fz	975.0	1.59413	0.0	0.0	-9564.8
Bay 29 H V	0	0	-7500	92.740	6.908	0.000	Fz	1125.0	1.47150	0.0	0.0	-11036.2
Bay 29 D V	0	0	-6000	92.740	8.178	0.000	Fz	975.0	1.59413	0.0	0.0	-9564.8
Bay 31 H V	0	0	-7500	86.420	6.908	0.000	Fz	1125.0	1.47150	0.0	0.0	-11036.2
Bay 31 D V	0	0	-6000	86.420	8.178	0.000	Fz	975.0	1.59413	0.0	0.0	-9564.8
Bay 33 H V	0	0	-7500	78.520	6.908	0.000	Fz	1125.0	1.47150	0.0	0.0	-11036.2
Bay 33 D V	0	0	-6000	78.520	8.178	0.000	Fz	975.0	1.59413	0.0	0.0	-9564.8
Bay 35 H V	0	0	-7500	72.200	6.908	0.000	Fz	1125.0	1.47150	0.0	0.0	-11036.2
Bay 35 D V	0	0	-6000	72.200	8.178	0.000	Fz	975.0	1.59413	0.0	0.0	-9564.8

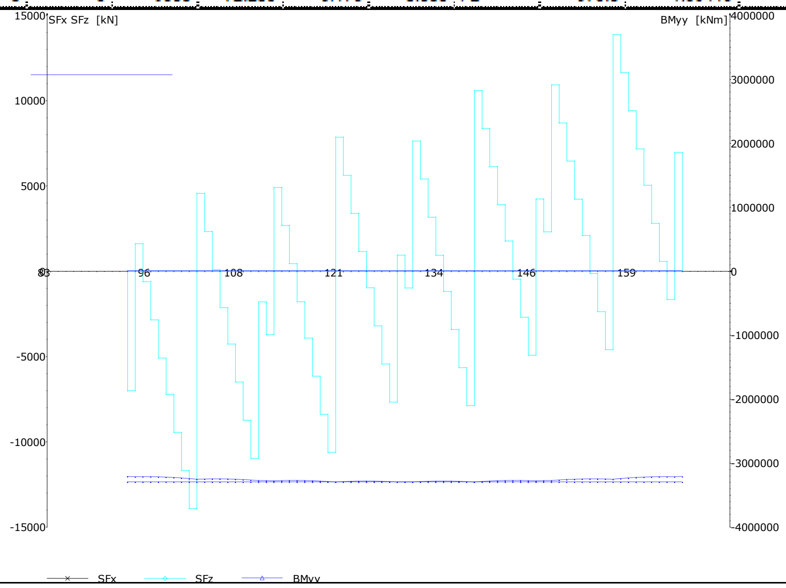
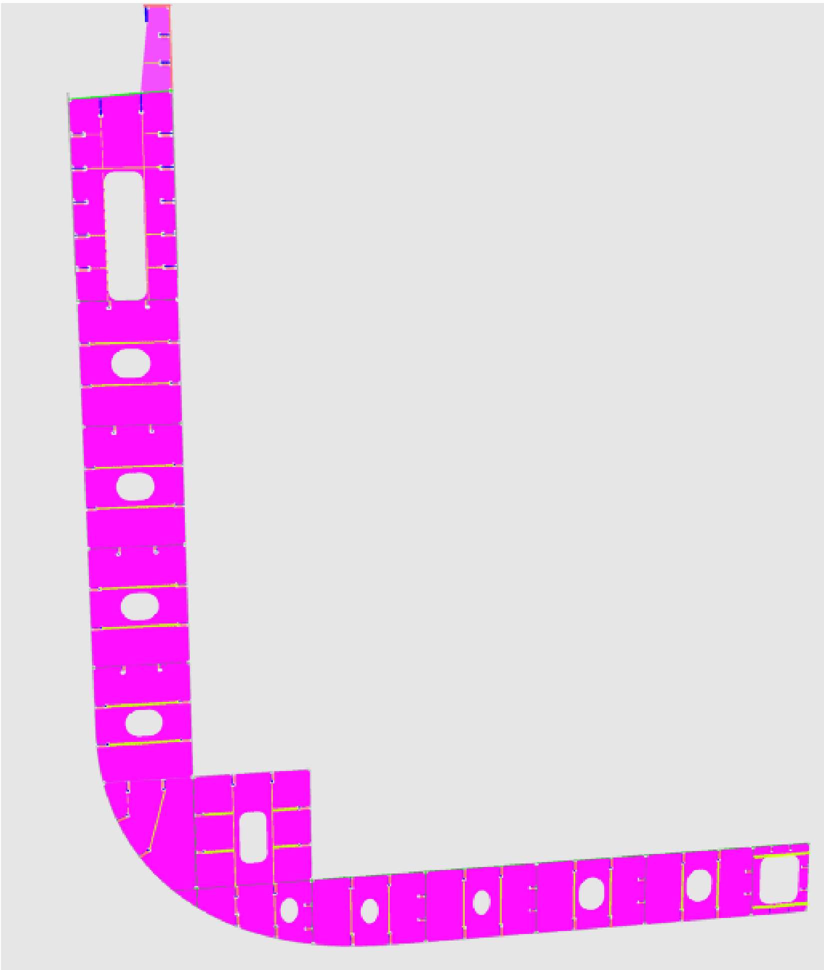


Figure A.7.27: Load adjustment for heavy 20 ft load case.

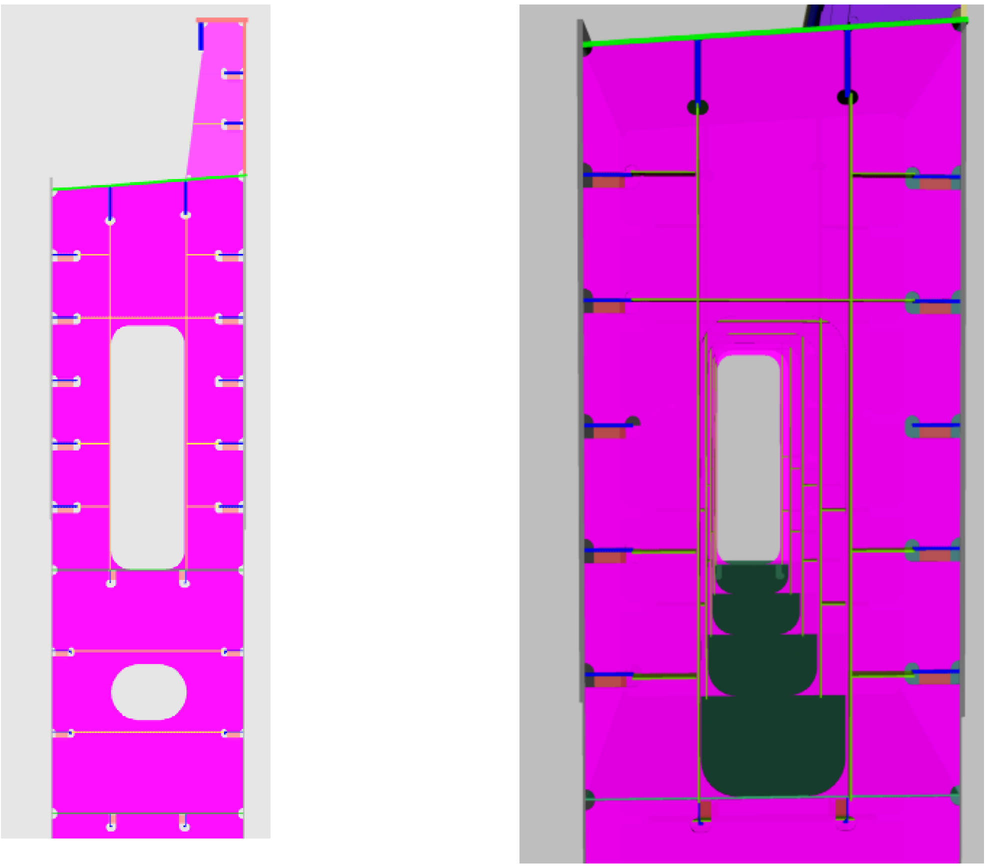
Table A.7.4: Allowable stress for the primary structural members, from the section Cargo Hold Analysis of the GL rules

Members/ beams type/load case	Normal stress σ_N	Shear stress τ	Equivalent stress σ_V
Longitudinal concentric beams	190/k	100/k	210/k
Longitudinal eccentric beams	210/k	100/k	210/k
Transverse	150/k	100/k	180/k
Flooded hold	-	-	R_{eH}

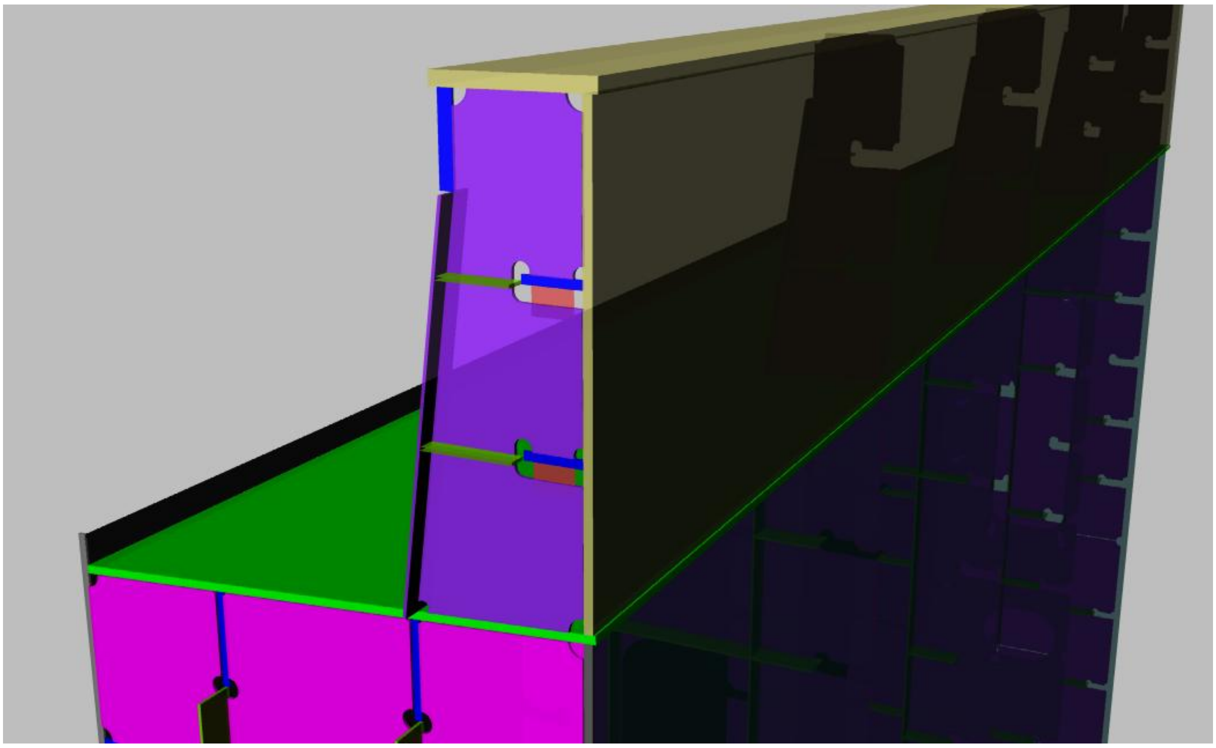
- **Section 8**



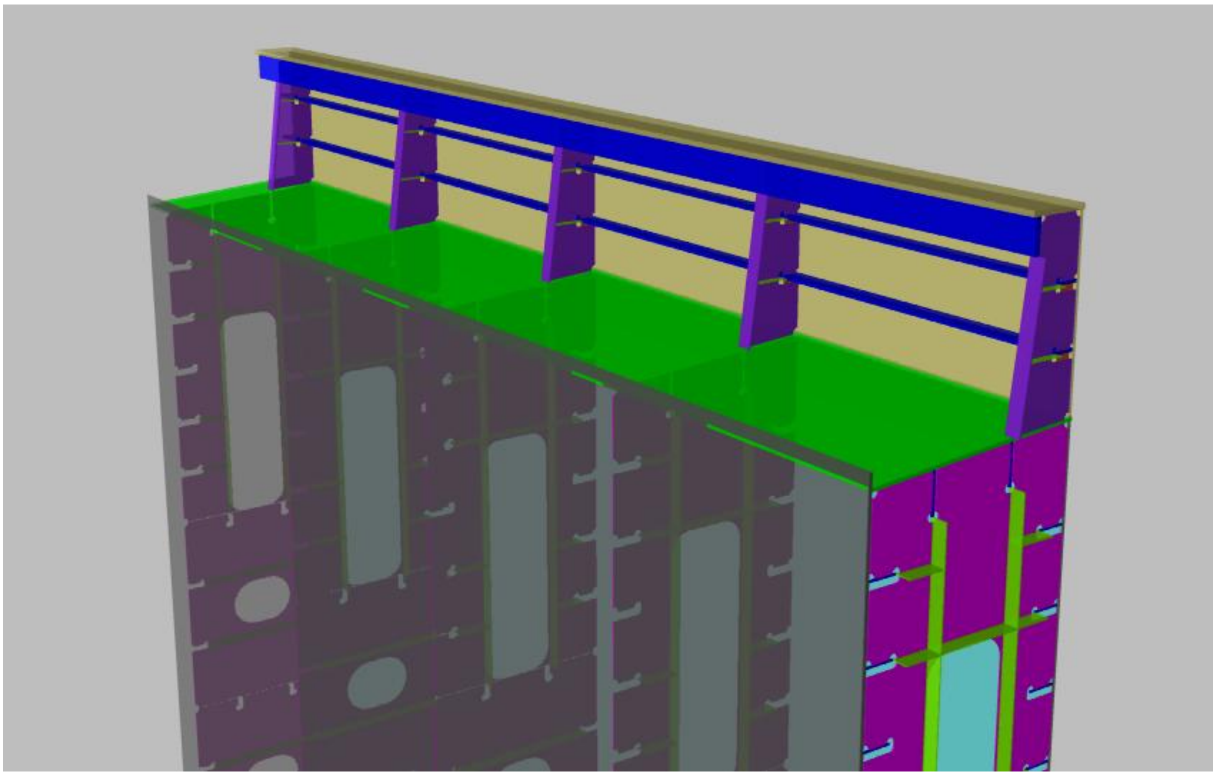
a) Midship section



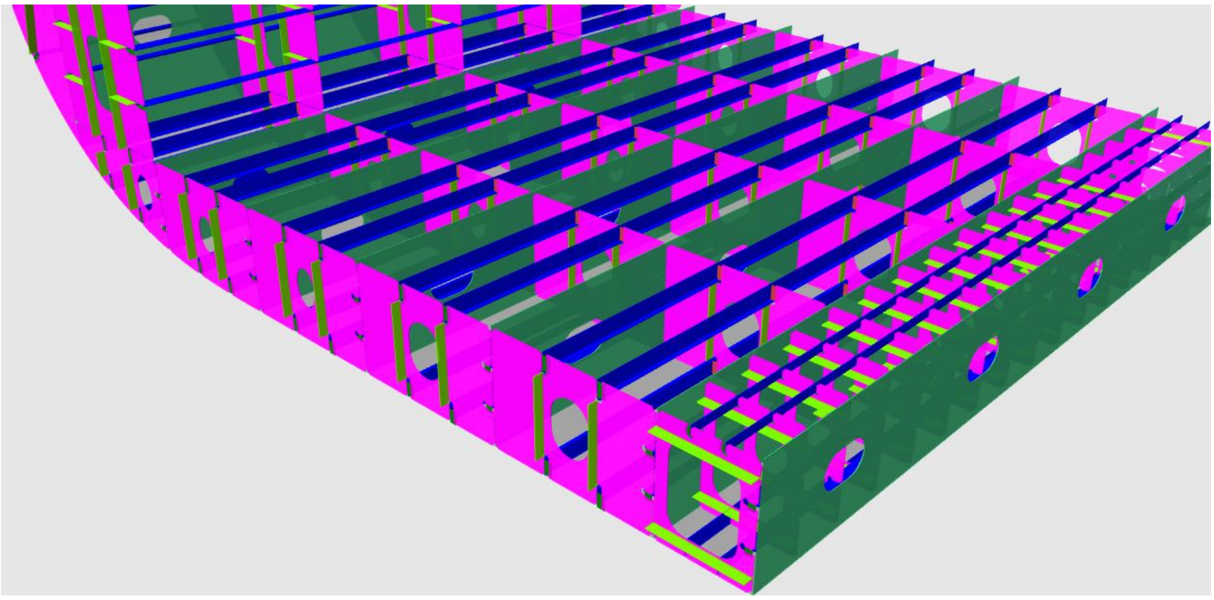
b) Passage way.



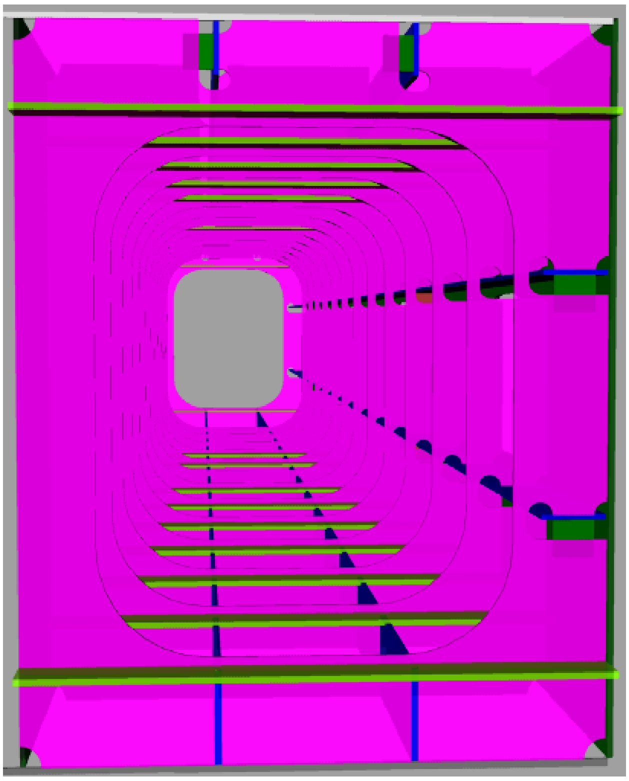
c) Stay.



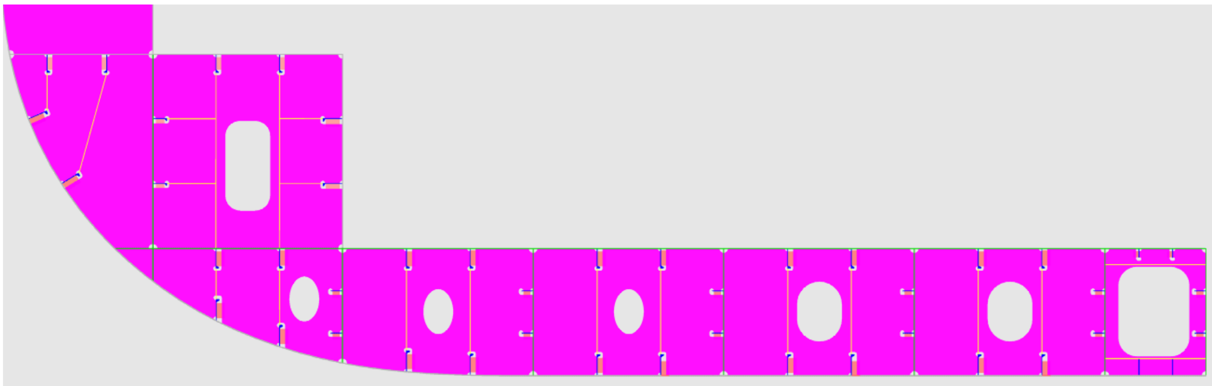
d) Arrangement of the stay at the level of the top coaming.



e) Double bottom structure



f) Half of the Duct keel



g) Ordinary floor

Figure A.8.28. Visualisation of the arrangement of the structural elements using Tribon software.

- Plans:

Attached to this thesis the following plans:

Sheet N°1: Midship section-frame134;

Sheet N°2: Watertight bulkhead structure;

Sheet N°3: Longitudinal section of one cargo hold located at the middle of the ship.