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Structural Design of a Containership Approximately 3100 TEU According to the Concept of General Ship Design B-178

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Abstract— The design developed in this work 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 this work 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 work 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: pre-sized structure according to construction rules and pre-sized structure according to direct calculations. In the first approach, dimensioning of the structural elements has to conform the requirements of the Germanischer Lloyd rules. 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 subjected to flooding. It was performed using another Finite Element model in the Germanischer Lloyd frame software, based on the beam theory. The evaluation of results indicated the necessity of application of the high tensile steel for some structural elements of the bulkheads.

Keywords— Containership, Finite Element Analysis, Ship Structural Design.

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I. Introduction

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, fuel and equipment resulting in the shear forces, bending moments and torsional moment acting on 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, 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 behavior 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 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 on the basis of experience employing empirical equations, sometimes referred to as "rule of thumb".

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.

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.

The general objective of this work is to carry out the hull structural design of a containership has a capacity of 3100 TEU. This work proceeds throughout a set of steps in where the following secondary objectives are attained.

1) 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.
2) Performing of the structural members' scantling according to Germanischer Llyod 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 direct calculations. The building of the structural model is based on the structural concept.
3) Estimation of the hull steel mass.
4) Providing the technical description as well as the drawings of the midship section, bulkheads, longitudinal section.
5) Visualisation in 3-D of a part of the hull ship structure located in the middle with the assistance of Tribon software.

II. The Selected Containership

The principal particulars of the containership B178 are given in Table I:

TABLE I
PRINCIPAL PARTICULARS OF THE CONTAINERSHIP B178

Length Over All L_{oa} , m	220.5
Length Between Perpendiculars L_{bp}, m	210.2
Breath 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

III. Concept of the Hull Structure, Material and Topology

A. Material Selection of the Hull Structure

For the developed design, steel is adopted for the entire hull structure. Two categories of steel are 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. The mechanical proprieties as well as structural members in which the mild and high tensile steel is selected to be used are listed in Table II.

TABLE II
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.

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

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 provided to the stowage of containers and to other devices that 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, rows and tiers 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.

C. Structural Topology Selection

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.

Fig. 1 shows the first concept sketch of one cargo hold limited by two watertight bulkheads.

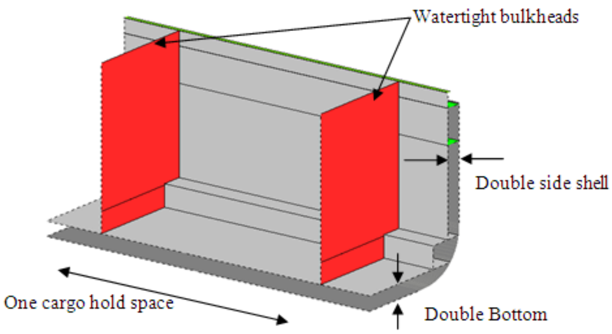


Fig.1 First concept sketch of one cargo hold

The longitudinal framing is taken for the whole structure.

Each cargo hold, limited by two watertight bulkheads, is divided into two parts by the use of pillar transverse bulkhead. The length of each part is equivalent to the length of 40 ft container, as shown in Fig. 2.

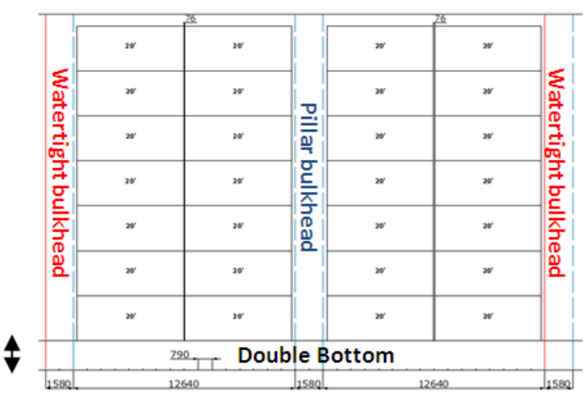


Fig. 2 Subdivision inside one cargo hold

The structure of watertight bulkhead 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.

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.

The arrangement of the floors and the longitudinal bottom side girders is based on the stowage of containers in the hold above, in order to provide a rigid support to the cell guides.

Camber for about 700 mm is 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.

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.

D. Midship Section Concept Sketch

Concept sketch, given by Fig. 3, is made up to provide the necessary information about the arrangements and the spacing adopted for the structural elements of the ship structure.

IV. Hull Structure Scantling According to Germanischer Lloyd Rules

The structural scantling is performed according to Germanischer Lloyd rules, with the assistance of Poseidon computer program.

The process considered for dimensioning the hull structure used by Poseidon, starting from the creation of the structural model till the sizing of its structural elements, is given in Fig4.

4.

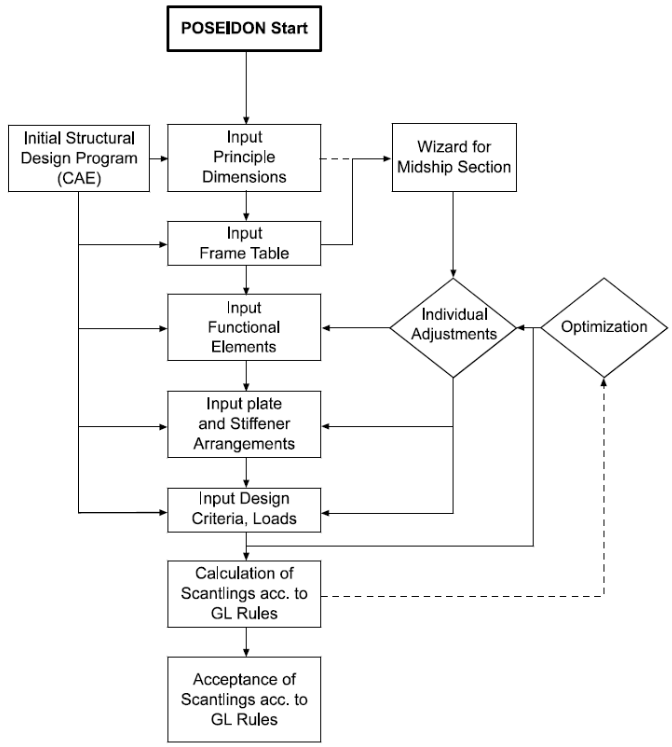


Fig. 4 Structural modeling and sizing according to Germanischer Llyod rules in Poseidon ND 11 computer code [1]

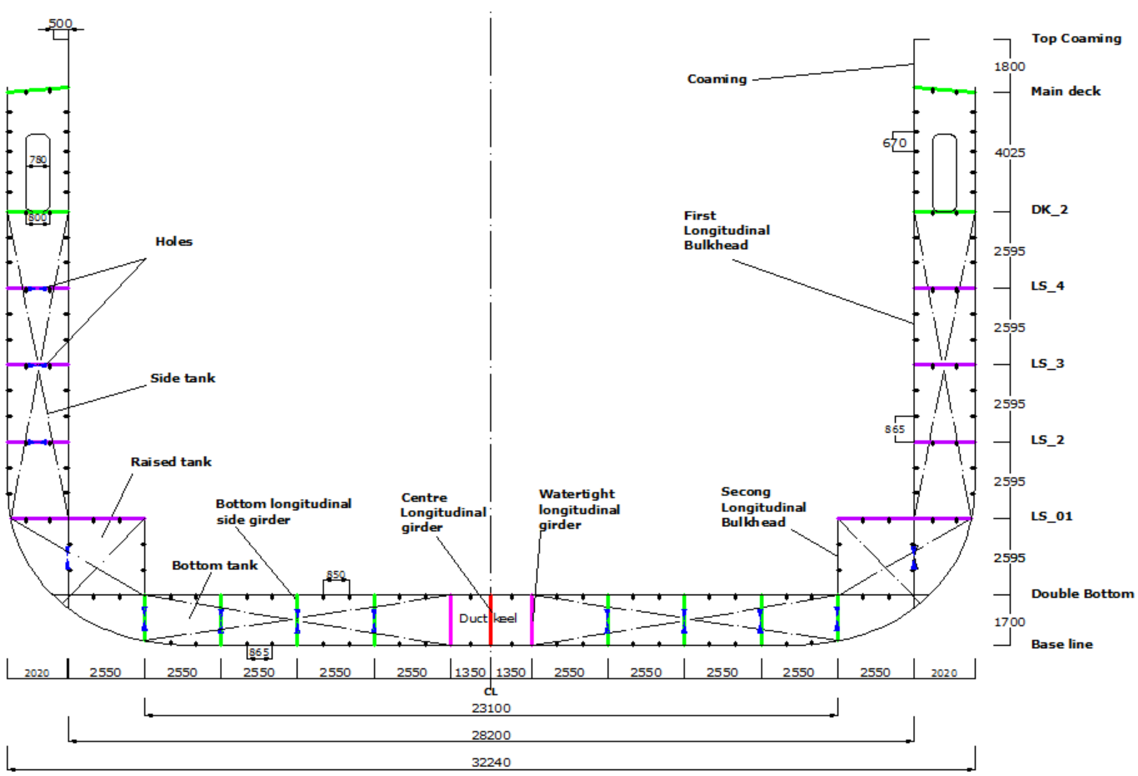


Fig.3 Midship section concept sketch

A. Hull Structural Modeling Using Poseidon Software

The building of the structural model is based on the structural concept defined previously.

The modeling process is subdivided into the following steps:

1) input the ship characteristic data including the principal dimensions of the ship as well as the material adopted;
2) input of a frame table in the ship's longitudinal direction (X Axis);
3) generation of the typical cross section of a containership with the help of a Poseidon Wizard;
4) input of a frame table in the ship's transverse direction (Y and Z Axis);
5) 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;
6) extending of the structural elements over the cylindrical part of the ship;
7) arrangement of the transversal bulkheads.

The resulted ship hull structural model is shown in Fig. 5.

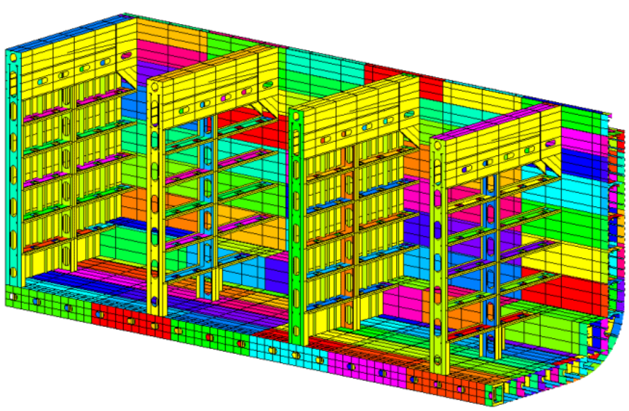


Fig. 5 The resulted ship hull structural model developed in Poseidon computer code

B. 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.

C. Evaluation of the Results

In order to reach the target scantling, which fulfils the Germanischer Llyod rules, the dimensions of the structural elements has been changed several times until the sectional modulus in the midship section became within the limits of the admissible sectional modulus required by the Germanischer Llyod rules. The resulted scantling of the longitudinal plates is represented in Fig. 6.

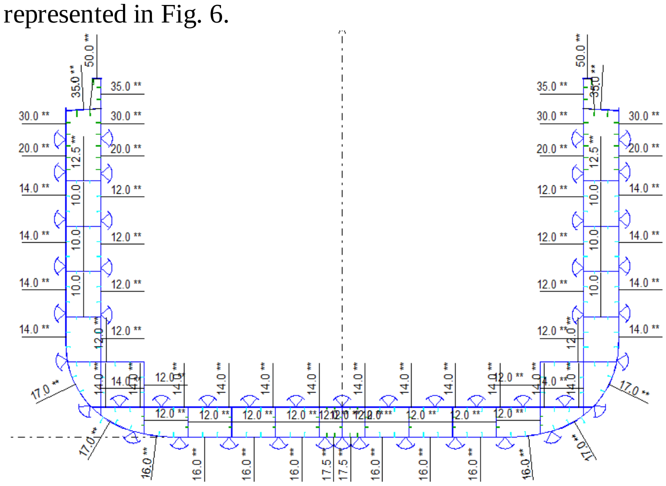


Fig. 6 Resulted scantling of the longitudinal plates based on construction rules

(**) designates the use of high tensile steel.

The distribution of the normal stress, shear stress and von Mises stress are plotted for each of the following load cases:

- 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 case 3: 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 is compared with the permissible stress represented by the equivalent stress σ_v from σ_L and τ_L, according to Germanischer Lloyd rules, it should not exceed:

$$\sigma_v = \sqrt{\sigma_L^2 + 3 \times \tau_L^2} \leq \frac{190}{k} \qquad (1)$$

Where:

k is the material factor (in the case of the high tensile steel k=0.72),

σ_L is the normal stress in the longitudinal direction,

τ_L is the shear stress in the longitudinal direction.

In this case: $\sigma_v = 263$ N/mm

The equivalent von Mises stress, the normal stress, and the shear stress for all the load cases are found below the limit which indicates that the final scantling reached is sufficient against the combined loads listed previously. Hence the model is ready for the finite element analysis provided also by Poseidon.

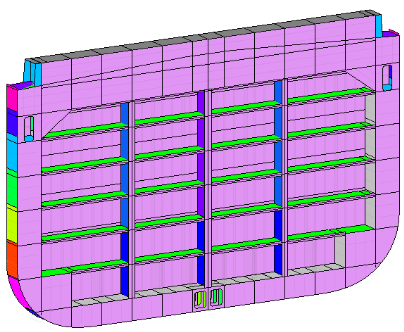
V. Strength Analysis Using Finite Element Method

A. Bulkhead Analysis Using Finite Element Method

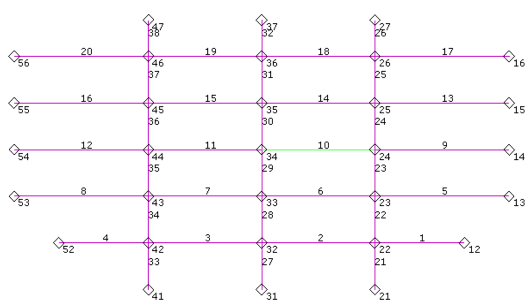
The structural strength of the transverse watertight bulkheads is verified using the finite element method. The analysis is made in the Germanischer Llyod Frame software, where the structure of one complete watertight bulkhead is modeled. The results provide an overall estimation of the bulkhead structure behavior, as the calculation of deflections, reacting forces and moments as well as stresses.

1. Build the Structural Model of One Complete Bulkhead

A model of one complete watertight bulkhead structure is built in Germanischer Llyod frame software. The bulkhead Plates, vertical frameworks and horizontal stringers are modeled using beams which are linked between nodes, as shown in the Fig. 7. Stiffeners and holes are not considered in this analysis.



(a) Structure of one complete watertight bulkhead



(b) Model of the watertight bulkhead in Germanischer Llyod Frame software

Fig. 7 Bulkhead structure modeling

2. Boundary Conditions

The spring stiffness is prescribed in the nodes located at the edge of the model in all degree of freedom except the rotation around the *Z* axis.

3. Load Input

The structure is subjected to the flooding load. The damage water line is taken at the level of the bulkhead deck; *h*=18.7 m.

The horizontal beams are considered as a support to the vertical beams hence the loads is inputted only to the vertical beams.

4. Evaluation of the Results

The analysis of the watertight bulkhead structure using the Germanischer Llyod 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, as shown in Fig. 8, 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 members.

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.

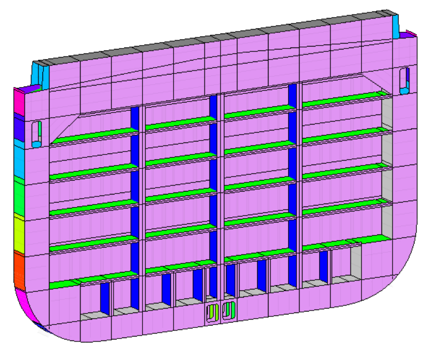


Fig. 8 Structure of the bulkhead with additional vertical webs from IB to LS_1

B. Cargo Hold Analysis

The performance of the cargo hold analysis is aimed at analyze the final scantling, resulted previously, under the realistic load cases required by the Germanischer Llyod rules.

For the developed containership, two load cases were considered:

- ✓ Load case 1: homogeneous 40 ft;
- ✓ Load case 2: heavy Loading 20 ft.

The specification of each load case is given in Fig. 9.

	LC 1	LC 2
Load component	**Homo-geneous 40 FT**	**Heavy Loading 20 FT**
Static Water Pressure Draught	scantling	scantling
Dynamic Water Pressure	wave crest	wave trough
Vertical Bending Moment Stillwater Wave	Max [3] Hogging	Min Sagging
Vertical Acceleration	$(1-a_V)\,g$	$(1+a_V)\,g$
Transverse Acceleration	0	0
Longitudinal Acceleration of all masses	0	0
Deck Bay A	40' 20 t/FEU [4]	40' 30 t/FEU [4]
Bay B	40'	40'
Bay C	40'	40'
Bay D	40'	40'
Hold Bay A	40' 20 t/FEU [4]	20' 15 t/TEU [4]
Bay B	40'	20'
Bay C	40'	20'
Bay D	40'	20'

Fig. 9 Standard load case [2]

1. Description of the Model

The finite element model is generated based on the geometrical and topological information as well as the final scantling of the structural elements defined previously. According to the requirement given in the section *Cargo hold analysis* of the Germanischer Lloyd rules, the model considered is located at about amidships, and extended over one complete cargo hold and two half cargo holds (Fig.10). All The structural elements are included in the model, the plates and the stiffeners are idealized using mode 3: the plates are modeled as shell elements, and the stiffeners are modeled as beam elements.

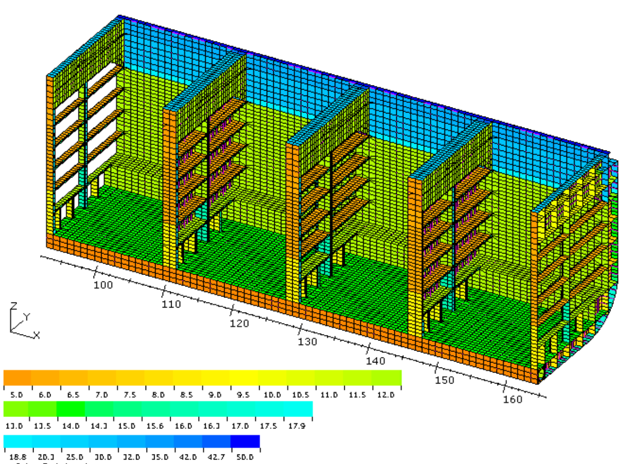


Fig.10 Mesh generation of the finite element model

2. Boundary Conditions

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 is applied.

3. Unit Load Input and Global Load Adjustment

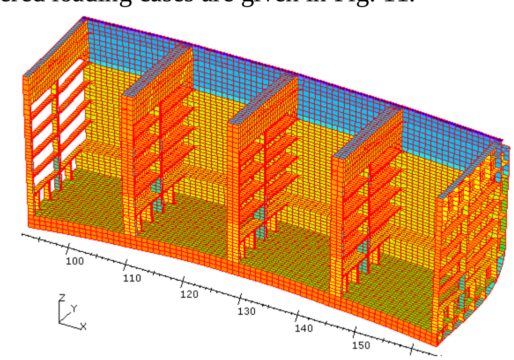
After the generation of the unit load (static pressure load, wave pressure load , and container load), the global load case is adjusted in order to produce the target hogging or sagging scenarios and to obtain the equilibrium of the full balanced model. This is achieved by applying the sectional forces and moments at the forward and aft ends of the model. The target hogging and sagging values are calculated and given in Table III.

TABLE III
THE TARGET HOGGING AND SAGGING VALUES

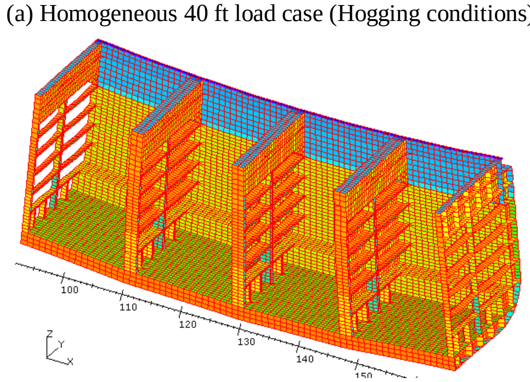
	Load case 1: Bending moment Hogging, KN.m	Load case 2: Bending moment Sagging, KN.m
Still water	1875894.00	-1154759.00
Waves	1759584.34	-2144119.25
Target value	3635478.34	-3298878.25

1. Evaluation of the Results

Deflections: Maximal deflections of the model under the considered loading cases are given in Fig. 11.



(a) Homogeneous 40 ft load case (Hogging conditions)



(b) Heavy 20 ft load case (Sagging condition)
Fig. 11 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 the Germanischer Lloyd rules. The results of the calculation are listed in Table IV.

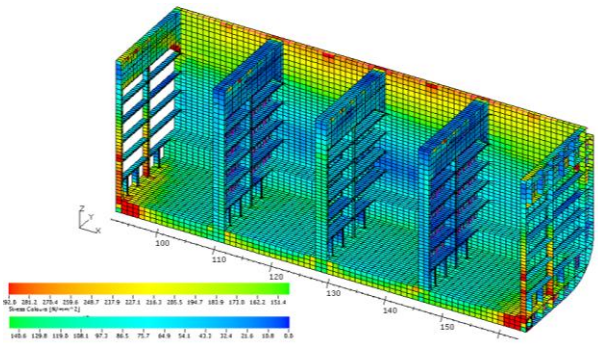
TABLE IV
CALCULATION OF THE PERMISSIBLE STRESSES

	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

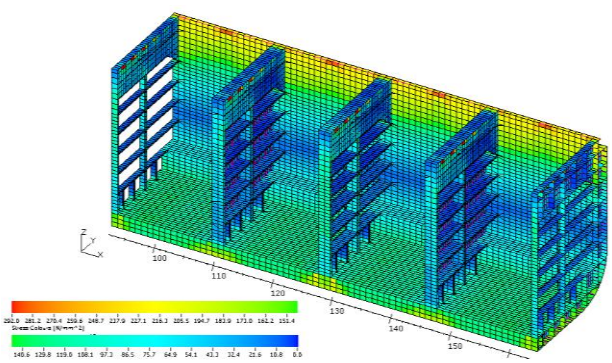
k is the material factor
0.72 for the high tensile steel, 1 for the mild steel

Since the permissible stress is not the same for all the primary structural members, it has been checked separately.

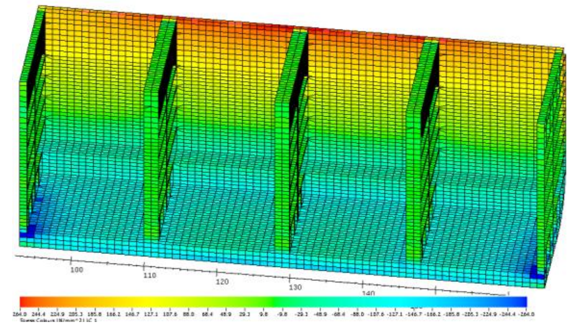
The distribution of the von Mises stress, normal stress as well as shear stress in the structural elements is given in Figures 12 to 14.



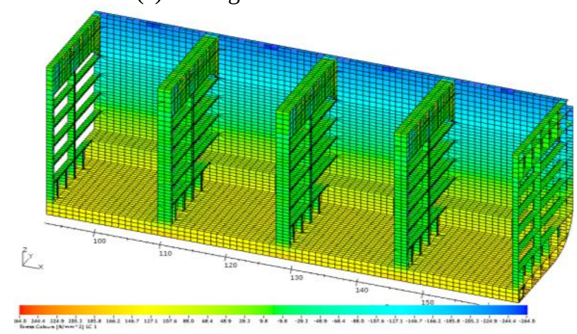
(a) Homogeneous 40 ft load case



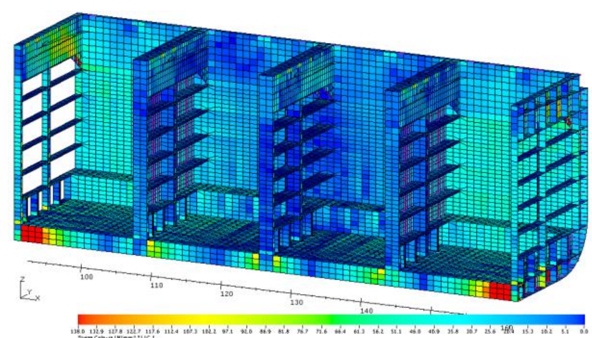
(b) Heavy 20 ft load case
Fig. 12 Distribution of the von Mises stresses in the whole model



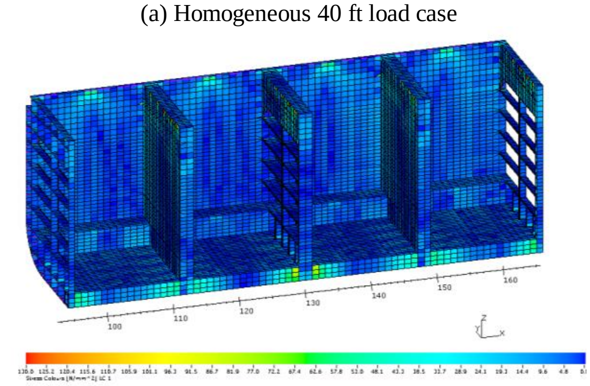
(a) Homogeneous 40 ft load case



(b) Heavy 20 ft load case
Fig. 13 Distribution of the normal stresses in the whole model



(a) Homogeneous 40 ft load case



(b) Heavy 20 ft load case
Fig. 14 Shear stress distribution in the whole model

Buckling strength: the buckling strength is checked for compliance with Section 3, *Design principle* of the Germanischer Lloyd 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 Fig. 15.

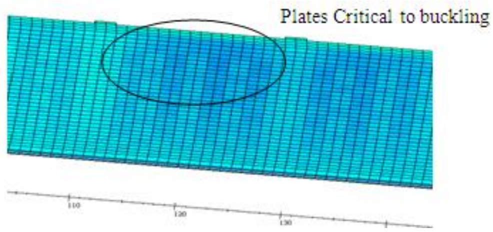


Fig. 15 Outer bottom plating critical to buckling at mid model

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 is calculated using the Poisson effect. However, since σ_y is less than 0.3 σ_x, than according to the rules, the stress component σ_y tend to zero and only σ_x should be considered.

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.

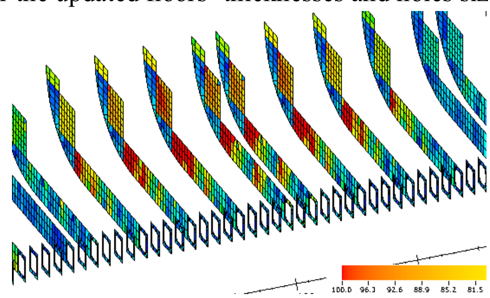
Torsional strength: The verification of the torsional strength is performed using the option of *the stress evaluation in the cross section* provided by Poseidon; this latter allows plotting the distribution of stresses in the cross section after the input of the moments and forces. The selected load case is the one induced by vertical and horizontal bending moment as well as static and wave induced torsional moment.

VI. Results And Discussions

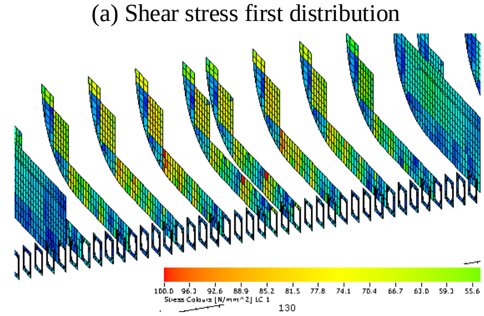
From the results of the first approach, it can be seen that reaching such a target scantling is carried out through a set of steps such as: the building of the model, inputting of the proposal scantling and finally modification of the elements dimensions until the values of the sectional modulus in the midship section become within the limits of the permissible values, required by the Germanischer Lloyd rules and 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 behavior of the structure.

The distribution of the stresses resulted from the generation of the finite element analysis (second approach) allows selecting the critical structural regions, and therefore, indicates the necessity to the following modification:

1) In order to reinforce the top coaming against the high normal stress due to the longitudinal bending moment, its thickness is increased locally (in the middle part of the ship).
2) Increasing of the thickness of the floors located at the bilge area in order to reinforce it against the high shear stress. Besides of the decreasing of the size of the holes made in these floors to the minimum values. Fig. 16 shows the change in the distribution of the shear stress after the updated floors' thicknesses and holes size.



(a) Shear stress first distribution



(b) Shear stress final distribution

Fig.16 Shear stress distribution in the floors

3) Increasing of the thickness of the plates surrounding the upper box in the double side shell in order to decrease the magnitude of the stresses due to the torsional moment.

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.

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 Germanischer Lloyd rules. This proves the sufficiency of the hull structural scantling against the selected load cases.

VII. Conclusions

The objective of the ship hull structural design resides 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 this work, dimensioning the structural members of the assumed containership is performed. The structural model was built based on the structural concept. The modeling is started from the generation of the midship section and then the whole structural model.

As it can be seen in this work, 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 using finite element analysis.

Looking at the results of the first approach, an initial scantling which fulfils the requirement of the Germanischer Lloyd 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 Germanischer Lloyd rules. 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 and strengthened against the selected load cases.

REFERENCES

[1] Germanischer Lloyd, 2011, POSEIDON Tutorial for Containerships.
[2] Germanischer Lloyd, 2011, Structural Rules for Container Ships.