INVESTIGATION OF HULL STRENGTH OF RIVER SEA CONTAINER VESSEL

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SUMMARY

River sea vessels are ships for inland navigation and suitable for restricted navigation at sea in regions where, - significant wave height does not exceed 2m, according to Bureau Veritas Rules for the classification of inland vessels. In a container vessel structure, almost the entire deck space is occupied by hatches, leaving a narrow strip of deck plating outboard. This calls for a topside structure of heavy plating or a double hull to provide material in tension, stiffness against lateral and torsional loads, and resistance to buckling in compression when the vessel is in sagging condition. For sea going open deck vessels, torsional loading plays a predominant part to the hull girder strength and for inland navigation open deck vessels; the effect of torsion is rather negligible. Keeping this scenario in mind, the aim of this project is to investigate the hull strength of a river sea container vessel under combined bending and torsional loading to study the effect of torsion on river sea open deck vessel. To perform the strength analysis, firstly, a finite element model is created using Femap with NX Nastran software for the investigated vessel. Therefore, still water and wave loads are calculated using direct calculation. To find out the still water loads Argos software is used and for the wave induced loads potential flow software Hydrostar is used. Next, Finite element model is verified with classical beam theory and thin wall girder theory. Then the effect of various loading conditions on structural response is investigated. After, structural response of different hull configurations are scrutinized under combined bending and torsional loading. Finally, some recommendations are proposed for structural response of river sea container vessel subjected to combined bending and torsional loading.

1. INTRODUCTION

A river-sea vessel, is subjected to various load patterns with many magnitudes which cause deformation of its structure, as well as stresses. The first design step is to calculate exact loads acting on the structure concerned, in order to estimate the structural strength in a reasonable way and consequently to develop the design. Container vessels are characterized by exceptionally wide hatch coamings and are sometimes often called open deck vessels. The use of wide hatches has significant effects on torsional strength and rigidity of hull girder. Due to its particular construction, vessel hull structure can be considered as thin walled structures. Axial (warping) stresses as well as shear stresses are normally- assessed using the thin-walled theory with open cross sections subjected to torsion. The torsional strength and rigidity of open deck vessels depend mainly on the structural arrangements of both vessel ends. All vessels are subjected to torsional moments which tend to twist the hull girder along its length. In general, torsional stiffness is more than adequate to prevent undue distortion of the structure. Torsional loading induces additional stresses, usually called warping stresses, near hatch corners. Wave induced torsion loading results from motion of a vessel in oblique waves. When the vessel is sailing obliquely into the predominant waves the vertical wave bending moments are reduced but the horizontal bending moments and torsional moments are increased.

For sea going container vessels, torsional stress plays an important part to the hull strength. Torsion induced stresses and deformation is generally negligible on inland vessels solely operated on inland waterways. But when inland container vessels are operated in restricted maritime water stretches, the impact of torsion on vessel's hull strength has not yet deeply been investigated. It is thus of importance to better understand the torsional strength as well as bending strength and hull girder deformation characteristics of river-sea vessels with large hatch openings. Keeping this scenario in mind, this paper attempts to investigate the hull strength of a river-sea container vessel.

2. LITERATURE REVIEW

Ship structure design and analysis has always been a very important and active field of scientific research, making those structures more reliable and cost effective. A lot of research and studies have been performed regarding the structural response under combined bending and torsional loading in both analytical and numerical (mainly FE) approaches. At first, Elbatouti et al. (1974) investigated the structural analysis of SS-7 containership under combined loading of vertical, lateral and torsional moments using finite element techniques. They analyzed the hull structure and found that local deformation due to non-prismatic nature of the structure and the deck openings can cause considerable increase of global stress level in the inner bulkhead plating. Next Vernon et al. (1987) compared the St. Venant and warping based thin walled beam theories and their application in the torsional analysis and suggested that warping based theory provides a better model of the behavior of prismatic thin walled sections because of the account of longitudinal deformation. The non-localized axial and secondary shear stresses associated with warping restraint can significantly add the overall stress distribution, particularly in open sections with low St.

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Venant stiffness. Thereafter Lijima et al. (2004) developed a practical method for torsional strength assessment, including a wave load estimation method and a proposal of design loads by a dominant regular wave condition. Chirica et al. (2009) proposed both numerical and experimental methodology to analyze the ship hull torsion and found that the thin wall beam theory proposed for torsion analysis of the ship hull may be considered as a good tool for a very quick torsion calculation. Senjanovic et al. (2012) presented the direct response assessment of a 11,400 TEU container vessel by a beam model subjected to rule based load distributions i.e. pure torque and horizontal shear force induced torque and suggested that torsional response in waves is considered to be one of the most important in structural design of ultra large container vessels. Pelvazza et al. (2012) studied the theory of torsion of thin walled beams with influence of shear for open sections and suggested that the beams with single symmetrical section, such as U section or closed open sections, as container ship sections, loaded to torsion by couples in the cross section planes are also subjected to bending. For modern container ship structures, the shear influence on displacements is small but for container ships with single side structures, this influence could be significant. Carvalho (2015) analyzed the structural behavior of open deck ship hull structures subjected to bending, shearing and torsion by using analytic and finite element solutions and proposed that the simplified thin walled girder application, within the predefined boundary conditions, provides an almost perfect envelope for the axial warping stresses verified in the FE analysis.

3. INVESTIGATED VESSEL WITHIN THE STUDY

The evaluation of structural strength of a river-sea container vessel has been carried out complying with the BV rules for the Classification of Inland Navigation Vessels [8]. Main features of the vessel are given in Table 1.

Table 1: Main particulars of the vessel

Length overall	134.05m
Length between perp.	131.55m
Breadth mld	14.5m
Depth	5.7m
Draught	3.6m (Estuary)
Range of navigation	IN (1.7)
Loading sequence	2R (2 Runs)
Propulsion	Self-propelled

The vessel has longitudinal framing system on deck, inner side shell, side shell, inner bottom and bottom shell. The hatch coaming plate, main deck plate and shear strake plate has constructed with high tensile steel-grade AH36 (R_{eh}= 355 MPa). Whereas, the other hull structure is made of mild steel grade A (R_{eh}=235 MPa). There are four cargo holds separated transversely by bulkheads. There are three ordinary frames arranged between two consecutive web frames (Figure 1).

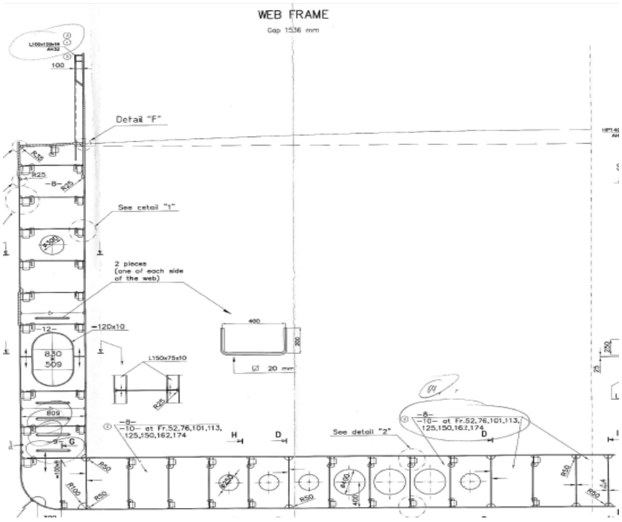

Figure 1: Midship section of the investigated vessel

4. PARTIAL SHIP STRUCTURAL ANALYSIS

The partial ship structural analysis, respectively cargo hold analysis, is used for the strength assessment of hull girder structural members, primary supporting members and bulkheads.

4.1 STRUCTURAL MODEL

The finite element model is extended up to four cargo holds. The ship is modelled by so called “coarse mesh” model, where the principal finite element type employed is the quadrilateral orthotropic shell element defined by four nodes, each with six degrees of freedom. The element mesh has to follow the local stiffener system as far as practicable; hence this mesh system is characterized by following parameters:

- one shell element between every stiffener,
- at least 3 elements over the depth of girders, floors, web frames and stringers
- all stiffeners are to be represented by eccentric beams

“Net” thickness approach has been used in the analysis, which means that the analysis is performed on thicknesses reduced due to corrosion. Corrosion deduction thickness is taken according to BV rules. In this way, it is ensured that the cargo ship will have satisfactory structural strength not only in “as-built” condition, but also at the end of her design life.

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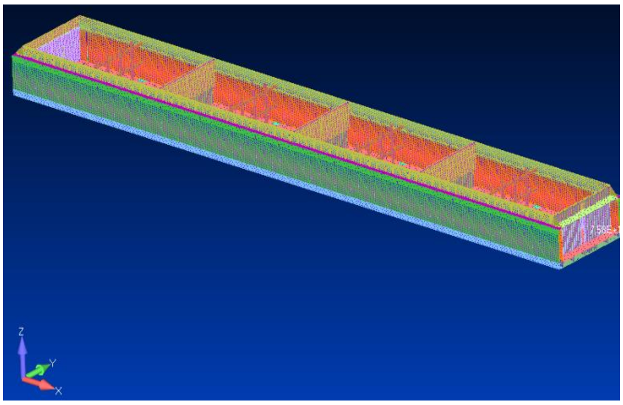

Figure 2: Finite element model of the investigated vessel

4.2 STANDARD LOADING CONDITIONS

A loading condition is a distribution of weights carried in the vessel spaces arranged for their storage. According to BV rules for the Classification of Inland Navigation Vessels, NR 217, Part B, Chapter 3, Section 1, [8] the loading conditions can be divided into the following categories for self-propelled container vessels:

1. Lightship

The light standard loading conditions are:
- Supplies: 100%
- Ballast: 50%

2. Fully loaded vessel

The vessel is considered to be homogeneously loaded at its maximum draught with 10% of supplies, without ballast.

3. Transitory conditions

The vessel, without ballast, is assumed to carry the following amount of supplies:
- In hogging condition: 100% of supplies
- In sagging condition: 10% of supplies
- Loading/unloading sequence

Loading and unloading are performed uniformly in two runs of almost equal masses, starting from one end of the cargo space and progressing towards the opposite end.

4.3 HYDROSTATIC ANALYSIS

For each of loading condition, the hydrostatic calculations of the FE model are performed in order to check if displacement, trim and still water bending moment are in accordance with the loading manual. In this project, Argos (BV) is used to compute still water bending moment (Figures 3 and 4).

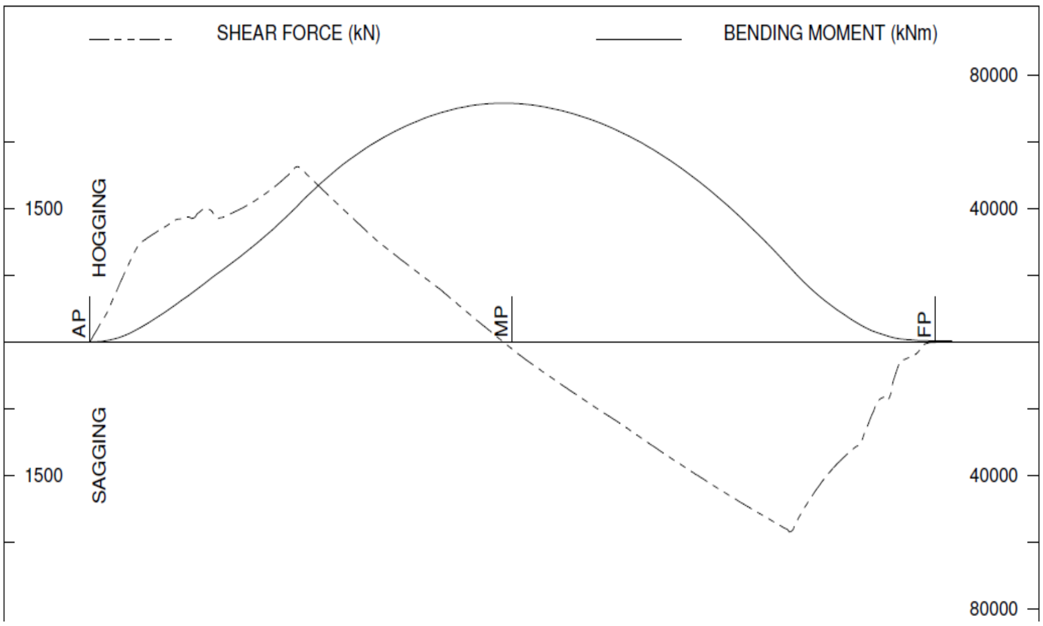

Figure 3: Still water bending moment (Hogging) of the investigated vessel

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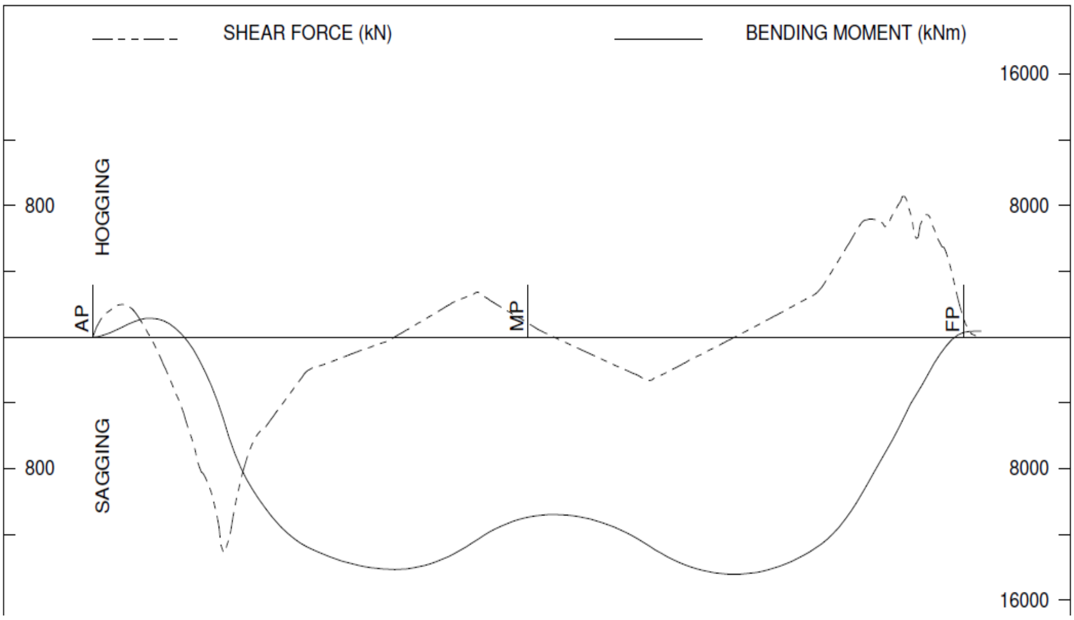

Figure 4: Still water bending moment (Sagging) of the investigated vessel

4.4 HYDRODYNAMIC ANALYSIS

The wave load is taken into account by Equivalent Design Wave Method. The principle of the method is that various load components which occur simultaneously are combined by setting the characteristics of regular waves that maximise the dominant load parameters. The parameters of design waves are selected based on the results of hydrodynamic analysis.

In this project, Hydrodynamic analysis is performed by Hydrostar (potential flow software), which is used to perform frequency-domain simulations of a rigid ship in extreme waves. The numerical method is based on potential flow theory. It can be used to calculate global responses and local loads on ship hulls at any forward speed. It solves the linear 3D radiation/diffraction problem by the Rankine Panel method by taking into account these forward speed effects (Figure 4). In this project, Belgian scatter diagram and JONSWAP spectrum has been used in order to compute long term response.

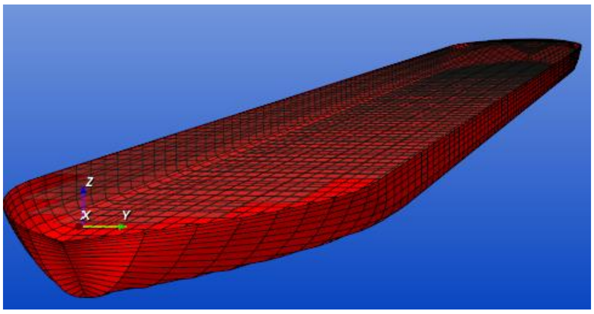

Figure 5: Hydrodynamic model of the investigated vessel

The scheme presented below is followed to model the investigated vessel:

1) For a maximum draft mesh is built.
   From bodylines
   From drawings: general arrangements and transversal sections.
2) Mesh quality and hydrostatic properties are checked.
3) Weight distribution is input.
4) Radiation/diffraction calculations are performed for a range of ω_e = [0.2-2.2] rad/s at 10 knots and 360º incident regular waves of unit amplitude.
5) Correction due to viscous effects on roll motion are imposed.
6) Calculations of motions, velocities and accelerations for radiation-diffraction conditions imposed.
7) Definition of locations on the ship where loads and relative wave elevations are desired to be calculated.
8) Ships Response amplitude operator (RAO) are built for every mode of motion and load response at given locations imposed on the hull.
9) Long-term extreme values are obtained (in double amplitude) for a given response.

4.5 LOAD CASES

Load cases are combinations of still water loads and wave loads. Load cases are selected aiming to maximise dominant load effects having dominant influence on the strength of some part of the structure. For each load case, design wave is determined based on the results of the hydrodynamic analysis and rule value of dominant load effect. Each load combination requires the application of the structural weight, internal and external pressures and hull girder loads. According to BV Rules, NR 217, Part B, Chapter 3, Section 1 [8], the

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load cases can be divided into the following categories for self-propelled container vessels:

1. Upright vessel condition

The hull girder loads are: Vertical still water bending moment and vertical wave bending moment.

2. Incline vessel condition

When the vessel is in oblique waves then the vessel will experience the following hull girder loads: Vertical still water bending moment, Vertical wave bending moment, Horizontal wave bending moment, Still water torsional moment and Wave induced torsional moment.

Figures 6 and 7 illustrate wave induced bending moment in oblique sea conditions for full load and ballast load conditions respectively.

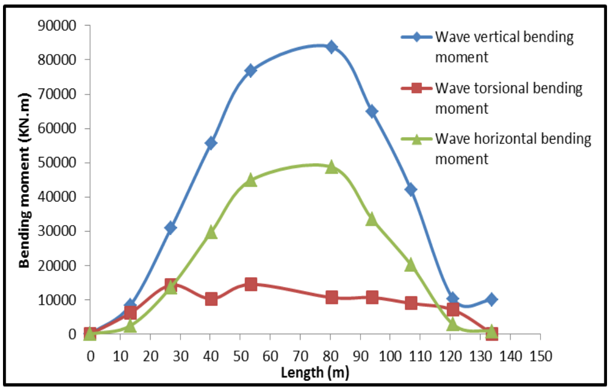

Figure 6: Wave bending moment in oblique sea (Full load condition)

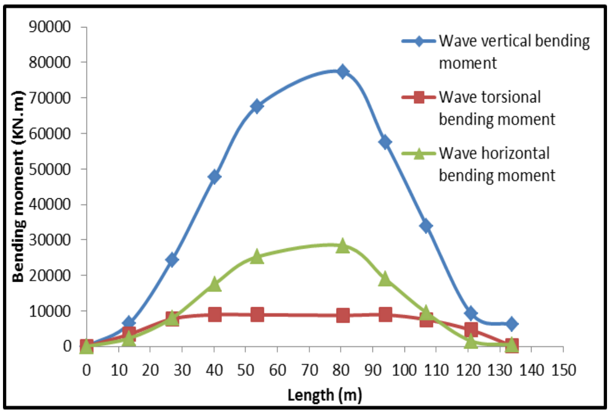

Figure 7: Wave bending moment in oblique sea (Ballast load condition)

From Figures 6 and 7 it is observed that wave bending moment is larger for full load condition than ballast load condition. One of the reasons for that is in full load condition the displacement volume is higher than the ballast load condition.

4.6 GLOBAL STRENGTH ANALYSIS

The objective of a global strength analysis is to obtain a reliable description of the overall hull girder stiffness and to assess the global stresses and deformations of all primary hull members for specified load cases resulting from realistic loading conditions and the wave-induced forces and moments. Generally, the purpose of the global analysis is not to judge on local stresses due to stiffener or plate bending, whereas the focus is at realistic stiffness and deformation characteristic of the hull girder. Global strength analysis may be required if the structural response of the hull girder cannot be sufficiently determined by simple beam theory, e.g. for ships:

- with large deck openings subjected to overall torsional deformation and stress response, as for container ships
- without or with limited transverse bulkhead structures over the vessel length, as for Ro-Ro vessels and car carriers
- with partly effective superstructure and/ or partly effective upper part of hull girder, as for large Passenger vessels

4.7 BOUNDARY CONDITIONS

If a cantilever beam is considered with a bending moment on one side, the moment will be the same in all sections along the length of the beam. The same concept has been employed in the FE model to study the stresses developed on the hull midship section. Maximum bending moments (Sagging/Hogging) (upright condition) are applied on one side of the FE model and the other side is imposed with fixed constrains (Table 2).

Still water bending moment and wave bending moment is applied in the fore end of the model and aft end is clamped. Rigid elements are created under main deck, which allows transfer of load to various nodes. Rigid element connects free edge nodes and other nodes in the same plane, so that they act together as a single element. Thus, two rigid elements are required to create two boundary conditions:

1. Constraint: a rigid element at the aft of the model with zero DOF to clamp
2. Moment: Bending Moment is applied on a rigid element at the fore part of the model in positive y direction to create hogging/Sagging condition.

Table 2: Boundary conditions

Boundary conditions	Translations in directions			Rotation around axes		
	X	Y	Z	X	Y	Z
Node at aft end	Fixed	Fixed	Fixed	Fixed	Fixed	Fixed
Node at fore end	Free	Free	Free	Free	Free	Free

4.8 REFERENCE VESSEL STRUCTURAL ANALYSIS – WITHOUT TORSION

The most severe case is observed for hogging case (upright condition) due to higher bending moment value. Since the applied maximum bending moment corresponds to the value in the midship section, the stress values in the midship areas are studied.

A comparison of global stress values obtained from beam theory and the finite element model is carried out for validation (Figure 8).

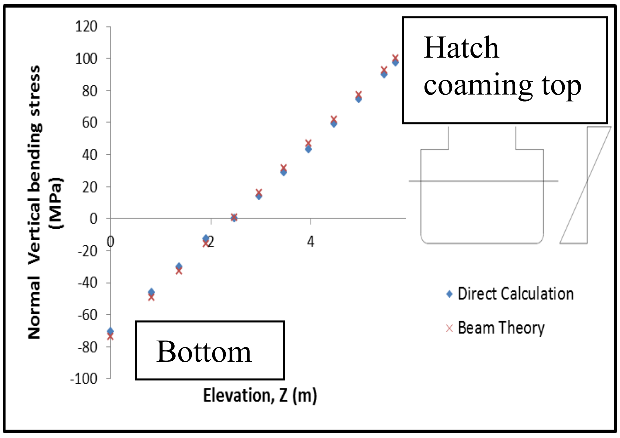

Figure 8: Comparison of normal stress between beam theory and direct calculation at X=61m (Hogging-Upright condition)

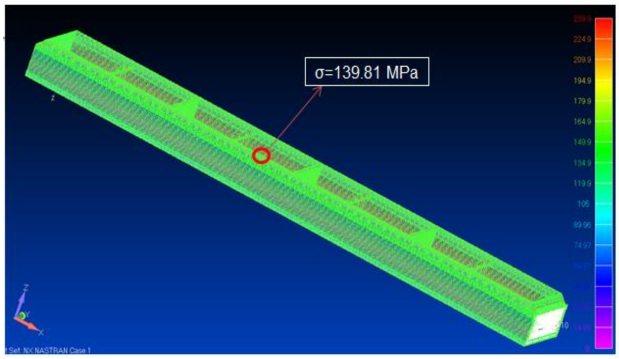

Figure 9: Maximum Von Mises stress for hogging condition (Upright loadcase)

In order to fulfil the strength checking criteria, Von-Mises stress in critical areas should be lower than the master allowable stress. From Figure 9, it is observed that maximum Von Mises stress values are indicated on hatch coaming top plate which is lower than the master allowable stress.

4.9 REFERENCE VESSEL STRUCTURAL ANALYSIS – WITH TORSION

For the structural analysis with torsion, cantilever boundary condition is also considered. Vertical bending moment (still water and wave), Horizontal wave bending moment, torsional moment (still water and wave) is applied in the fore end of the model and the aft end is clamped. Rigid elements are created under main deck, which allows transfer of load to various nodes.

Firstly, only torsional moment is applied and normal stress due to torsion is checked. Then a comparison of normal stress due to torsion values obtained from the thin walled girder theory and the finite element model is carried out for validation (Figures 10 and 11).

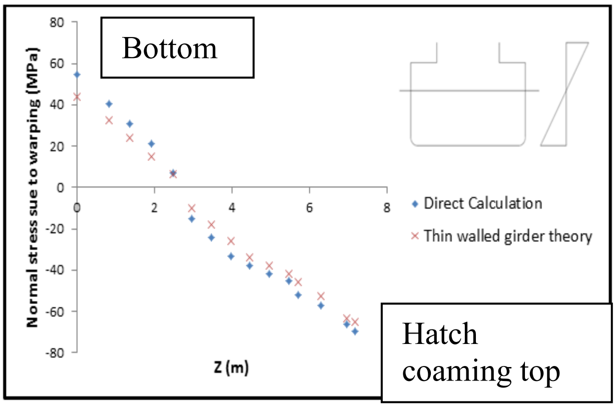

Figure 10: Comparison of normal stress due to torsion between thin wall girder theory and direct calculation (along vertical side plate)- Sagging condition

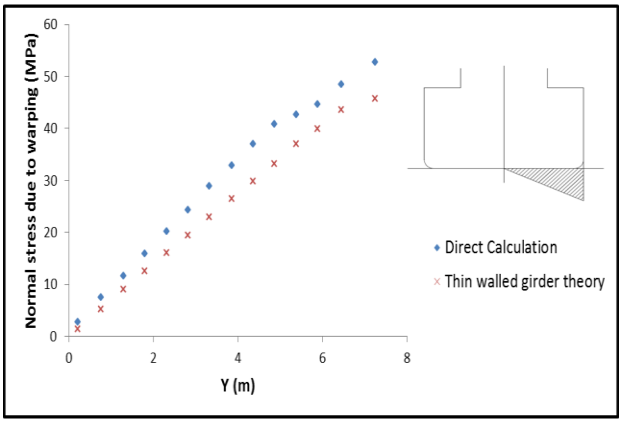

Figure 11: Comparison of normal stress due to torsion between thin wall girder theory and direct calculation (along bottom plate)-Sagging condition

From Figures 10 and 11, it is observed that the difference of stress between thin wall girder theory and direct calculation is nearly 10 %. This difference is acceptable considering the hypothesis of the thin wall theory.

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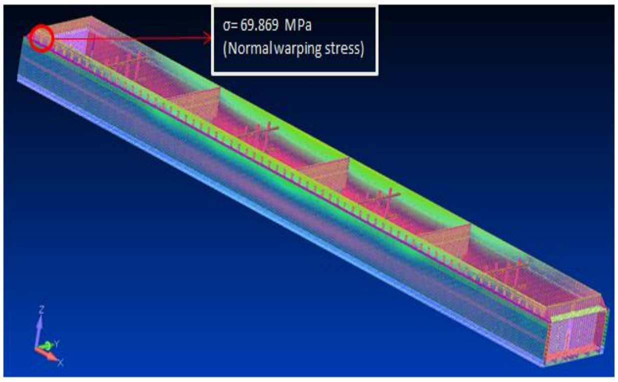

Figure 12: Maximum normal stress due to torsion (Sagging condition)

From Figure 12, it is seen that normal stress due to torsion is maximum at near cargo hold bulkheads. From Figure 10, it is also observed that maximum normal stress due to torsion occurs at the hatch coaming top.

4.10 INFLUENCE OF DIFFERENT LOADING CONDITIONS

Full load and lightweight conditions for the investigated double hull-open deck river-sea container vessel is considered for combined bending and torsional structural response analysis.

The influence of different loading conditions is shown in Figures 13 and 14.

From Figures 13 and 14, it is observed that in both conditions normal stress due to torsion is maximum at near the aft and forward cargo hold bulkheads. In full load condition, the effect of torsion is much predominant at aft and forward cargo hold bulkhead ends. Still in both conditions, the maximum normal stress value is less than the allowable value. It is also seen that in both cases normal stress due to horizontal bending moment does not have significant impact. So, for further combined bending and torsional strength analysis for different hull configurations full load condition is considered.

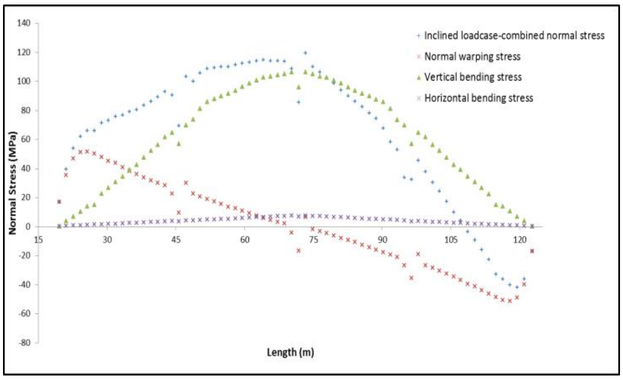

Figure 13: Combined bending and torsional structural response of lightweight condition

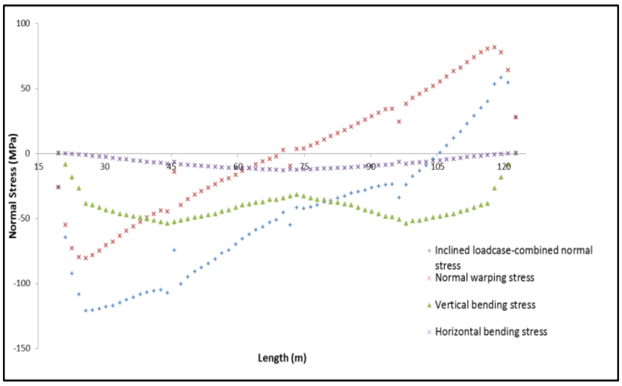

Figure 14: Combined bending and torsional structural response of full load condition

4.11 INFLUENCE OF DIFFERENT HULL CONFIGURATIONS ON COMBINED BENDING AND TORSION EFFECTS

In this section, the difference between different hull configurations on combined bending and torsional structural strength is presented. Change of hull configuration induces change of hull girder transverse section geometric properties. Hull strength check should be performed for each configuration.

For this purpose, 3D FE model for different hull configurations are prepared using FEMAP. Comparison of stress distribution is shown in Figures 15 to 19 along the length and depth of the vessel for various hull configurations. In this analysis, incline load case has been considered to investigate the combined effect of vertical bending, horizontal bending and torsion upon different hull configurations. For the combined bending and torsion stress distribution along the length, hatch coaming top has been selected because maximum stress occurs at hatch coaming top.

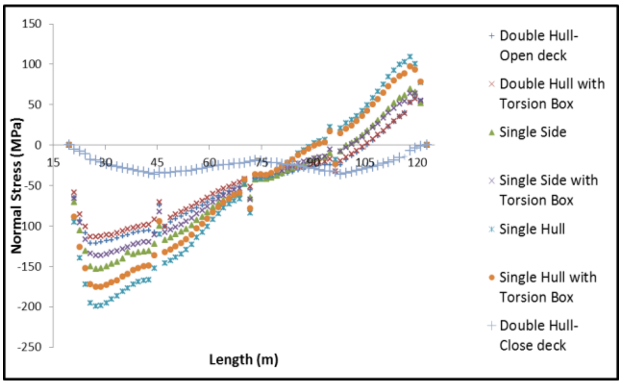

Figure 15: Combined bending and torsion stress along the length for different hull configurations

From Figure 15, it is observed that among the different hull configurations the highest combined bending and torsion stress value is found for single hull vessel which is 199.1 MPa at X=25.744m near the aft cargo hold bulkhead but still it is under the allowable stress limit

(331MPa). Moreover, it is seen that torsion box does not have significant impact on normal stress value.

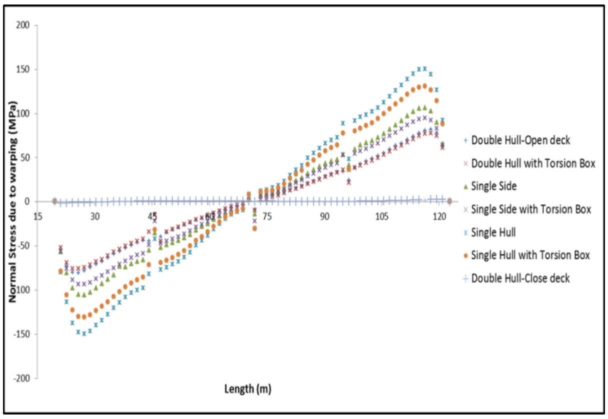

Figure 16: Warping normal stress along the length for different hull configurations

Combined bending and torsion stress integrates three components of stress. These are: warping normal stress due torsion, normal vertical bending stress and normal horizontal bending stress. In order to investigate which stress effects most in combined bending and torsion stress, torsional moment, vertical bending moment and horizontal bending moment applied separately for different hull configurations (Figures 16-18). For this analysis, along the length section X=25.744m is selected because maximum combined bending and torsion stress is found in this section.

Also, it is seen from Figure 16 that normal warping stress due to torsion for closed deck vessel has rather small value and can be negligible. It is also visible from Figures 15 to 18 that in combined bending and torsion stress, most contributed factor is normal warping stress due to torsion for different hull configurations.

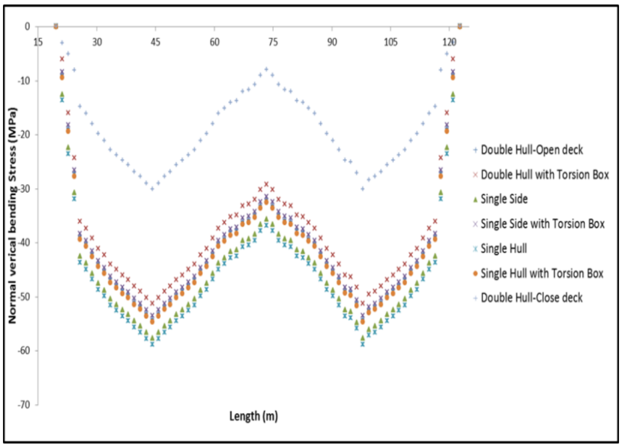

Figure 17: Normal vertical bending stress along the length for different hull configurations

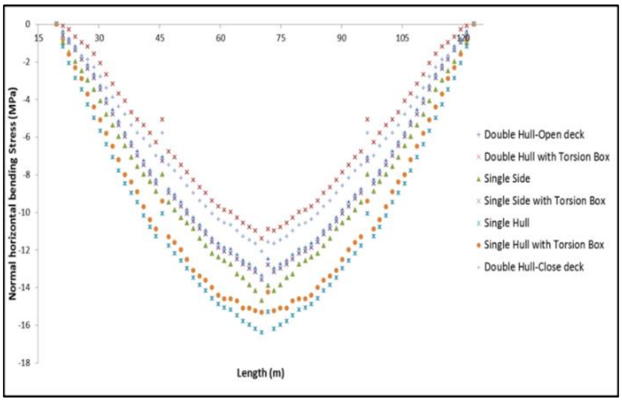

Figure 18: Normal horizontal bending stress along the length for different hull configurations

The normal stress distribution from shear strake to bottom plate is shown in Figure 19 for different hull configurations. For this analysis, along the length section 25.744m is selected because maximum combined bending and torsion stress is found in this section (Figure 15). It is seen from Figure 19 that among different hull configurations combined bending and torsion stress is maximum for single hull vessels at shear strake and the value is 148 MPa which is also under allowable limit (331 MPa).

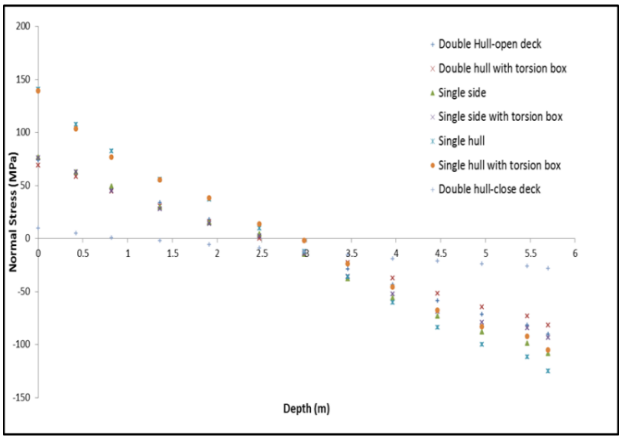

Figure 19: Combined bending and torsion stress along the depth for different hull configurations at x=25.744m

5. CONCLUSIONS

Structural analysis of the investigated vessel shows that:

- The hull scantling of river sea container vessel under combined bending and torsional loading complies with current Bureau Veritas Rules for the classification of inland navigation vessels – NR 217.
- The impact of the warping stresses induced by the torque and the normal stresses due to horizontal bending moment on the hull scantling remains negligible.
- Investigation of the impact of the structural configuration on the level of warping stresses shows that among different hull configurations considered,

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highest warping stresses values are found for single hull vessel.

- As a recommendation, combined effect of vertical bending, horizontal bending and torsion should be taken into account when analysing hull strength of vessels with hull structural configuration other than double hull, i.e with double bottom and double side, fitted with open deck.

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