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Direct Strength Analysis of Container Ships

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Abstract:- Direct Strength Analyses are meant for evaluating the yield strength and buckling strength using net dimensions of primary strength members of the container carrier. The paper deals about the automation of direct strength analysis procedure using ANSYS. The stresses at different locations are calculated due to internal cargo load, ballast load, and the external hydrodynamic sea pressure for specific load cases. The still water bending moment (SWBM) has been picked from loading manuals. The wave bending moments (WBM) are calculated from JBP Rules. The effects of SWBM & WBM are applied to the structure with proper load combination factor and local hull girder moment correction. The results are extracted using general post-processor of ANSYS for checking yielding, buckling and ultimate strength. The overall safety of the vessel is checked.

Keywords:- direct strength, finite element analysis, cargo, ship hull

I. INTRODUCTION

Function of a ship is to transport commodities or people from one place to another. There are different classification of ships such as cargo carriers, passenger carriers, industrial ships, service vessels and container ships. Analysing ship as a whole is quite tedious and time consuming. Normally studies are carried out on individual primary structural members for various cases. Container ships are open deck ships because of the fact that there are large hatch openings in the deck to permit the stowage of containers in the holds. The hatchways are enclosed by flush hatch covers and additional containers are stored on the open deck. The fact that a large portion of the deck is cut away, creates structural problems, and it is often necessary to use high strength steel to obtain the required structural strength. Container ships are much faster than normal cargo ships. They are ships of the linear type in that they work on fixed schedules and between fixed ports. Because of their high speeds and complicated arrangements they are of necessity very costly, but apparently large sums of money which have been spend on them are justified by the speed with which cargo can be dispatched,[1].

Fig.1 shows general view of a container ship. It is a double bottom container ship. It is divided into different compartments by transverse bulkheads. Each compartment is called as hold. The arrangement of containers is as shown in the Fig.1. It is a 4500 TEU (Twenty foot equivalent unit) capacity container ship.

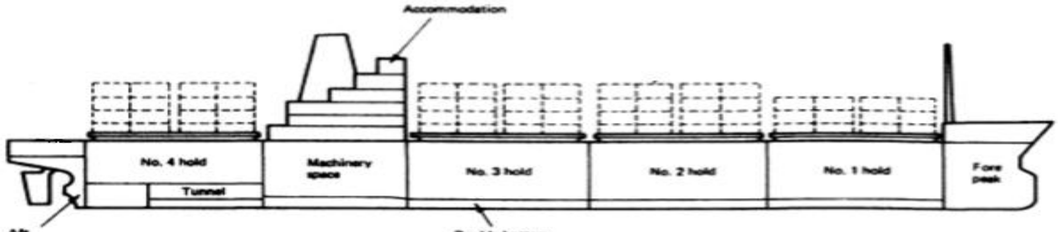

Fig.1: Container ship

II. FUNCTION OF THE SHIP STRUCTURE

The primary requirement of the ship structure is that it should resist longitudinal bending, necessitates that a considerable amount of material should be distributed in the fore and aft direction. This longitudinal material is provided by the plating of decks, sides and bottom shell and tank top and any girders which extend over an appreciable portion of the length. Additional longitudinal strength is provided by longitudinal girders in the bottom of the ship. The centre girder is an important member in this respect. It is a continuous plate running all fore and aft and extending from the outer bottom to tank top. Side girders are also fitted, and they are usually intercostals, that is cut at each floor and welded to them. Longitudinal deck girders, even though in general not completely effective for the longitudinal hull girder strength, are also subject to high longitudinal stresses. Advantages of the longitudinal system are that the longitudinals take part in the longitudinal strength of the ship. The bottom and side shell plating has to resist water pressure in addition to providing overall longitudinal strength of the structure. Thus local stresses can arise due to bending of the plating between frames or floors, [2]. The side shell, bottom shell, deck plating, longitudinal girders, centre girders, floors, longitudinal frame, transverse frame etc are as shown in Fig. 2

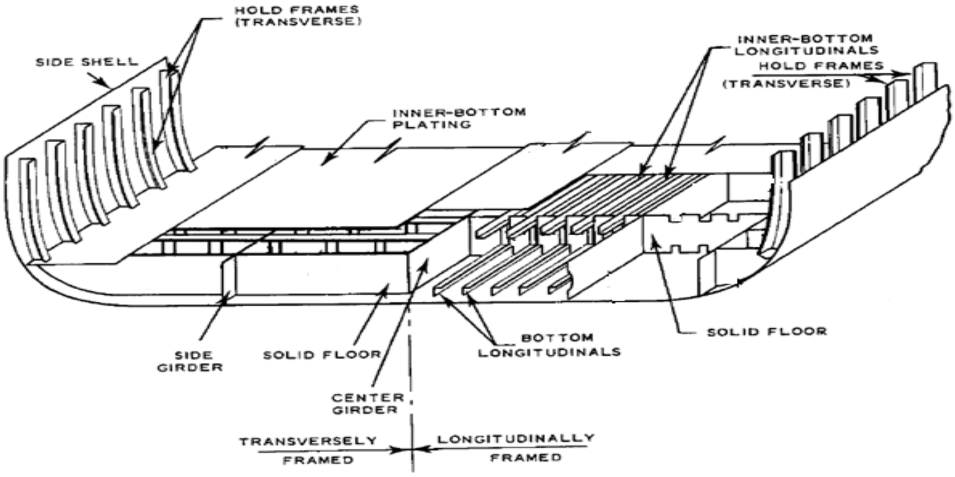

Fig. 2: Transverse and longitudinal framed section

In general, container ships have double hull side structure in the cargo hold area. Additional transverse strength is provided in all ships by water tight or oil tight bulkheads. The bulkheads serve as main transverse strength elements in the structural design of the ship. The plating is thin relative to the principal dimensions of the transverse section of the structure and would buckle under compressive loads very easily if it was not stiffened. It is therefore necessary that there should be transverse stiffening of decks, shell and bottom. The stiffening is provided in transversely framed ships by rings of material extending around the ship. In the bottom the stiffening consists of vertical plates extending from the outer bottom to the inner bottom, the plates being called floors. The sides and decks are stiffened by rolled sections such as angles or channels called side frames and beams. The transverse material so provided has the dual function of maintaining the transverse form of the structure that is providing transverse strength and preventing buckling of the longitudinal material. The spacing of the transverse material in relation to the plating thickness is an important factor both in resisting the compressive stresses and in preventing local deformation due to water pressure, so that the span thickness ratio cannot be allowed to be too great,[4].

III. MOTION OF SHIP

The motion of the sea generates motion of the ship. They are heaving, surging, and swaying which are linear motions, heaving being vertical motion of the ship, whilst surging and swaying are the longitudinal and transverse motion of the ship. Rolling, pitching, and yawing which are rotations all involve accelerations which generate forces on the structure. Rolling is rotation about a longitudinal axis, while pitching is rotation above a transverse axis and yawing is rotation about vertical axis, [5]. The motions of the ship are as shown in the Fig.3.

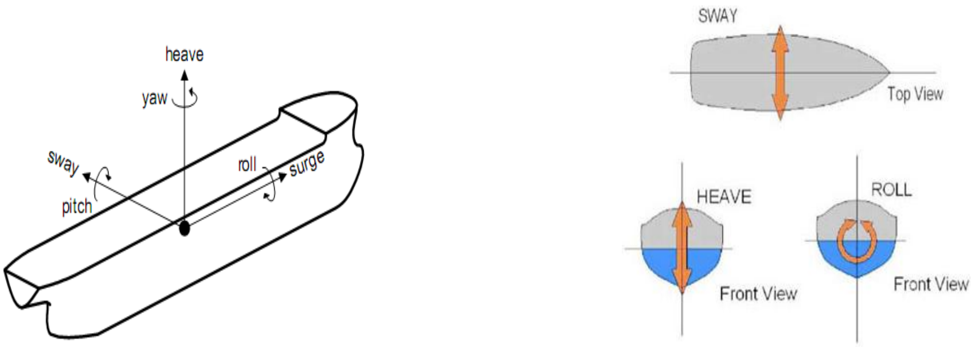

Fig.3: Motion of the ship

IV. LOADS ON SHIPS HULL

The hull of ships is subjected to a number of loads.

- Even when sitting at dockside or at anchor the pressure of surrounding water displaced by the ship presses in on its hull.
- The weight of the hull and of cargo and components within the ship bears down on the hull.
- Wind blows against the hull, and waves run into it.
- When a ship moves, there is additional hull drag, the force of propellers, water driven up against the bow.
- When a ship is loaded with cargo, it may have many times its own empty weight of cargo pushing down on the structure.

If the ships structure, equipment, and cargo are distributed unevenly there may be large point loads into the structure, and if they are distributed differently than the distribution of buoyancy from displaced water then there are bending forces on the hull [6].

A. Primary Hull Loads, Strength, and Bending

The primary strength, loads, and bending of a ship's hull are the loads that affect the whole hull, viewed from front to back and top to bottom. Though this could be considered to include overall transverse loads (from side to side within the ship), generally it is applied to Longitudinal loads (from end to end) only. The hull, viewed as a single beam, can bend, (shown in Fig.4)

- Down in the centre, known as sagging
- Up in the centre, known as hogging.

This can be due to:

- hull, machinery, and cargo loads
- wave loads, with the worst cases of:
  - sagging, due to a wave with length equal to the ship's length, and peaks at the bow and stern and a trough amidships
  - hogging, due to a wave with length equal to the ship's length, and a peak amidships (right at the middle of the length)

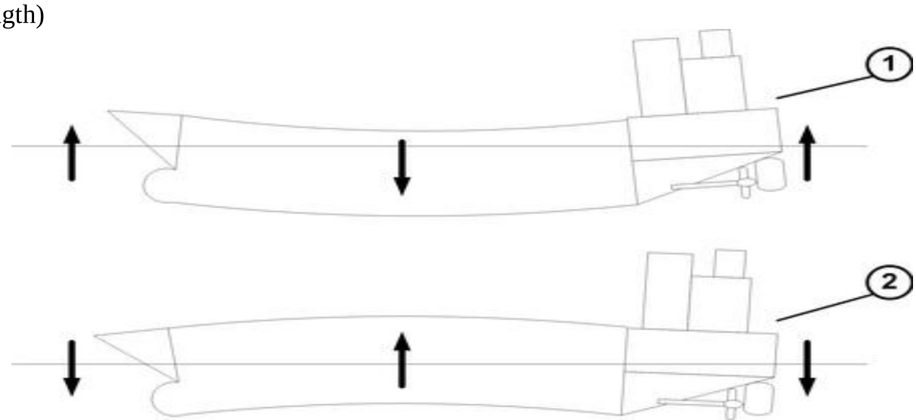

Fig. 4: Ship hull (1) Sagging and (2) Hogging under loads.

Primary hull bending loads are generally highest near the middle of the ship, and usually very minor past halfway to the bow or stern. Primary strength loads calculations usually total up the ships weight and buoyancy along the hull. Cargo weight is then added in to that section depending on the loading conditions being checked.

Primary strength calculations generally consider the midship cross section of the ship. These calculations treat the whole ships structure as a single beam, using the simplified Euler-Bernoulli beam equation to calculate the strength of the beam in longitudinal bending. The moment of inertia of the hull section is calculated by finding the neutral or central axis of the beam and then totalling up the quantity for each section of plate or girder making up the hull.

The total **still water bending moment** is then calculated by integrating the difference between buoyancy and total weight along the length of the ship. For a ship in motion, additional bending moment is added to that value to account for waves it may encounter. Standard formulas for wave height and length are used, which take ship size into account. The worst possible waves are, as noted above, where either a wave crest or trough is located exactly amidships.

Those total bending loads, including still water bending moment and wave loads, are the forces that the overall hull primary beam has to be capable of withstanding.

B. **Secondary Hull Loads, Strength, and Bending**

The secondary hull loads, bending, and strength are those loads that happen to the skin structure of the ship (sides, bottom, and deck) between major lengthwise subdivisions or bulkheads. Unlike primary loads, secondary loads are treated as applying to a complex composite panel, supported at the sides, rather than as a simple beam.

Secondary loads, strength, and bending are calculated similarly to primary loads. Stress in the structure is calculated from the loads and bending.

C. **Tertiary Hull Loads, Strength, and Bending**

Tertiary strength and loads are the forces, strength, and bending response of individual sections of hull plate between stiffeners, and the behavior of individual stiffener sections. Usually the tertiary loading is simpler to calculate. First, maximum hydrostatic load or hydrostatic plus slamming load is to calculate. The plate is supported against those loads at its edges by stiffeners and beams. The deflection of the plate (or stiffener), and additional stresses, are simply calculated from those loads.

D. **Total Loads, Bending, and Strength**

The total load on a particular section of a ship's hull is the sum total of all primary, secondary, and tertiary loads imposed on it from all factors. This is generally calculated at the middle of a hull bottom plate section between stiffeners, close or at the midsection of the ship, somewhere midways between the keel and the side of the ship.

V. SCOPE AND OBJECTIVES

There are various classification societies, which are non-governmental organizations or groups of professionals that establish and apply technical standards in relation to the design, construction, survey, safety and protection of marine related facilities including the ships and offshore structures. Earlier ships are designed as per the rule of different classification societies. To eliminate competition between class societies with respect to structural requirements and standards, the International association of classification societies (IACS) has developed a standard set of rules called Common Structural Rule. Ships having length equal to or greater than 90m signed for construction on or after April 1st, 2006 should follow this rule. This gives standardization of ships constructed in any part of the world in terms of scantlings and structural strength. It is important to give a standardization of the ship's structural strength following the common structural rule by IACS. The present work is aimed to find the strength of hatch coverless container ship according to IACS.

For the analysis a complex model of a ship hull structure including all the structural components incorporated is required in order to retrieve the exact response of the ship structure under severe loads. The modeling requires to be done by a finite element tool such as ANSYS.

The objectives are

- To develop finite element model of the container ship with all its complexities in finite element package ANSYS [8].
- To perform the direct strength analysis by considering various load combinations as per common structural rule of IACS.

VI. DIRECT STRENGTH ANALYSIS OF SHIP STRUCTURES

The direct strength analysis of container ship is carried out to check the structural adequacy of the design. Using 3-D Shell and beam elements, FE model of container ship of three-hold length (1 + 1 + 1) has been simulated using pre-processor of ANSYS 10.0. For this project only two loading conditions are considered. They are the following:

- Empty load condition
- Full load condition

In empty load condition no cargo load is considered. But in full load condition cargo load is considered. In both cases hydrostatic and hydrodynamic loads are considered. Direct strength analysis is to be carried out by applying design loads calculated according to the IACS rule. IACS decided to develop a set of Common Structural Rules (CSR'S) for both bulk carriers and oil tankers, on the basis of the work done by two pilot projects: Joint Bulker Project (JBP), and Joint Tanker Project (JTP). It gives Standardization of ships constructed in terms of scantlings and structural strength. Loads are calculated according to IACS common structural rule for double hull oil tankers 2006. The objective of the common structural rule is to issue a set of rules and procedures for the determination of structural scantlings of container ship. It is used to check guide lines given in the rule and their universal application to the tanker structures. Combinations of static and dynamic loads are to be applied to the 3D FE model. The load values are calculated in the midship section. At each of these points the applicable design loads were calculated. In the below mentioned situations i.e., at static sea pressure, roll motion ,pitch motion ,dynamic wave pressure ,cargo load calculation

A. Design Load Application and Finite Element Analysis

Load is applied as pressure. Hydrostatic, Hydrodynamic, cargo load are applied. In order to make the application easy we create components out of ship structure. This component creation is necessary to apply different pressure at different location and for viewing and extracting the result. These components consists of inner bottom shell, outer bottom shell, side shell etc. static analysis is done to solve the model. Linear static analysis is carried out [9].

B. Results and Discussions

After the analysis the stresses are checked with respect to the reference stresses. Results are extracted at various locations in terms of components for checking yielding. The von Mises stress at each structural member obtained from the analysis is compared with the actual yield value in order to check whether the values are within the limit or exceeds the limit. The final stress distributions at various regions for empty and full load condition are as shown in Tables 1 and 2. The table also shows whether the values are within limit or exceeds the limit.

Table1: Results of Evaluation of Yield strength for empty load condition

Sl. No	Structural Member	Von-Mises stress(N/mm^2)	Allowable stress(N/mm^2)	Remarks
1	Web frame	214.974	235	With in limit
2	Outer bottom shell	371.736	345.5	Exceed limit
3	Inner bottom shell	368.283	345.5	Exceed limit
4	Side shell	177.91	235	Within limit
5	Bulkhead	57.265	235	Within limit

Table2: Results of Evaluation of Yield strength for full load condition

Sl. No	Structural Member	Von-Mises stress(N/mm^2)	Allowable stress(N/mm^2)	Remarks
1	Web frame	204.291	235	Within limit
2	Outer bottom shell	325.051	345.5	Within limit
3	Inner bottom shell	320.489	345.5	Within limit
4	Side shell	176.063	235	Within limit
5	Bulkhead	57.222	235	Within limit

The von Mises plots of various structural members are given subsequently. It can be seen that in which portions the stresses are within the allowable limit, wherever it is exceeding, the stress variation etc.

Fig. 4 & Fig. 5 shows von Mises plot of web frame in N/mm^2 in empty and full load conditions

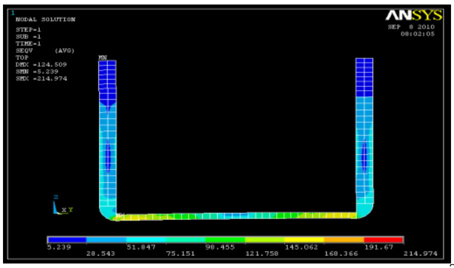

Fig.5: von Mises plot of web frame in N/mm^2 in empty load condition

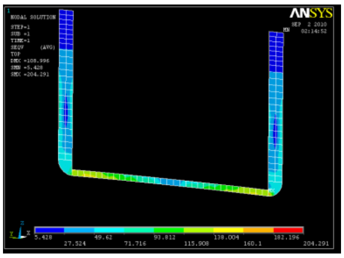

Fig.6: von Mises plot of web frame in N/mm^2 in full load condition

The values obtained are 214.97 N/mm^2 & 204.29 N/mm^2 in empty load condition and in full load condition. It can be seen that the stresses in the web frame are within the allowable limit.

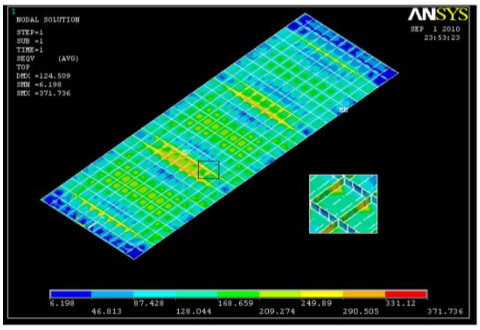

Fig.7: von Mises plot of outer bottom shell in N/mm^2 in empty load condition

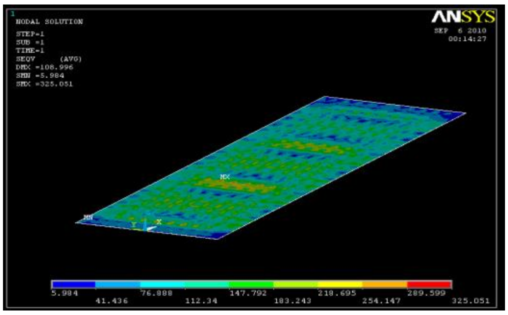

Fig.8: von Mises plot of outer bottom shell in N/mm^2 in full load condition

Fig.7 & Fig.8 shows the stress variations in the outer bottom. After analysing the values obtained are 371.74 N/mm^2 & 325.05 N/mm^2 in empty load condition and in full load condition. It was found that the stress in the outer bottom exceeds the allowable limit in empty load condition. It can be seen that maximum stress occurs in the outer shell below the portions were the bulkhead is present in the inner bottom. In order to keep the stress within the allowable limit increase the bottom shell thickness nearer to the stress concentration is required. The plate thickness is modified as per the IACS rule. The required plate thickness is given by,

$t_{required}$ for outer bottom shell $= t_{provided} \times \sqrt{\sigma_{ansys}} / \sqrt{\sigma_{allow}}$

$=16 \times \sqrt{371.736} / \sqrt{345.5} = 16.59$ mm

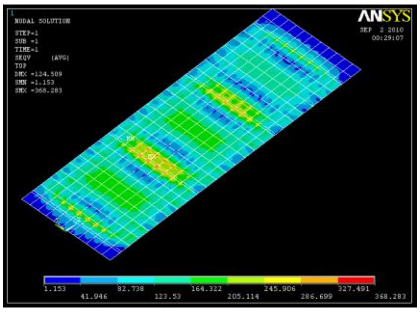

Fig.9: von Mises plot of inner bottom shell in N/mm^2 in empty load condition

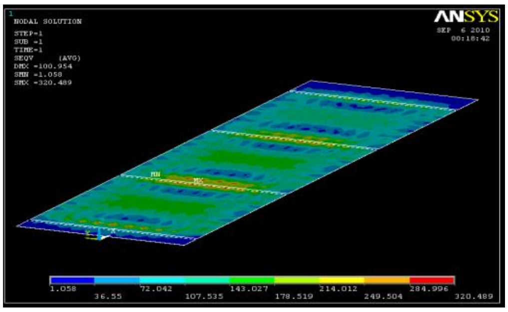

Fig.10: von Mises plot of inner bottom shell in N/mm^2 in full load condition

Fig.9 & Fig.10 shows the stress concentration of inner bottom. The values obtained are 368.28 N/mm^2 & 320.49 N/mm^2 in empty load condition and in full load condition. It was found that the stress exceeds the allowable limit in empty load condition. We can see that maximum stress occurs nearer to the portions where the bulkhead and inner shell meet and also below the portions of bulkhead. Only at small portions of the area the high stress value occurs. In order to reduce the stress concentration we can increase the shell thickness nearer to the stress concentration.

The plate thickness is modified as per the IACS rule. The required plate thickness is given by,

$t_{required}$ for inner bottom shell $= t\ provided \times \sqrt{\sigma_{ansys}} / \sqrt{\sigma_{allow}}$

$=16 \times \sqrt{368.28} / \sqrt{345.5}$

$=16.51$ mm

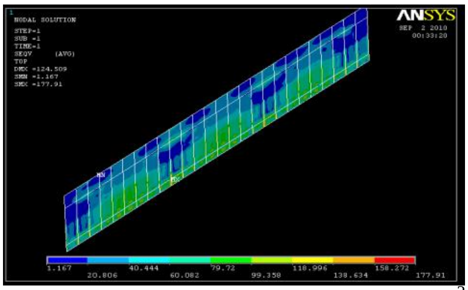

Fig.11: von Mises plot of side shell in N/mm^2 in empty load condition

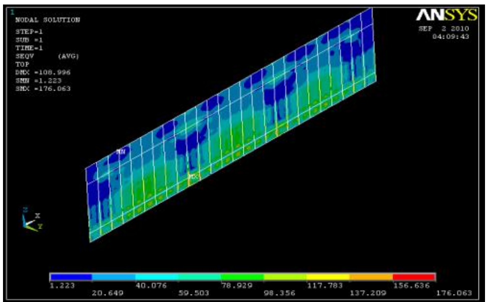

Fig.11: von Mises plot of side shell in N/mm^2 in full load condition

Fig.11 & Fig.12 shows the stress concentration of side shell. The values obtained are 177.9 N/mm^2 & 176 N/mm^2 in empty load condition and in full load condition. It was found that the stress within the allowable limit.

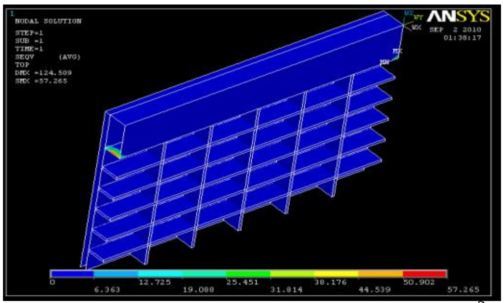

Fig.13: von Mises plot of bulk head in N/mm^2 in empty load condition

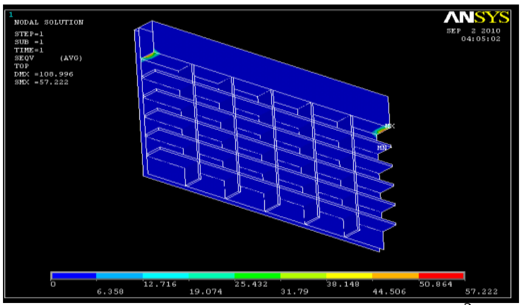

Fig.14: von Mises plot of bulk head in N/mm^2 in full load condition

The stress concentration of bulkhead is shown in the Fig.13 & Fig.14. The values obtained are 57.26 N/mm^2 & 57.22 N/mm^2 in empty load condition and in full load condition. It is a cargo carrier so no hydrostatic pressure coming in to the bulkhead. It can be seen that only small stresses are coming over the bulkhead. So it is preferable to decrease the thickness of bulkhead. If it is an oil tanker then much larger pressure coming over here hence high thickness is needed.

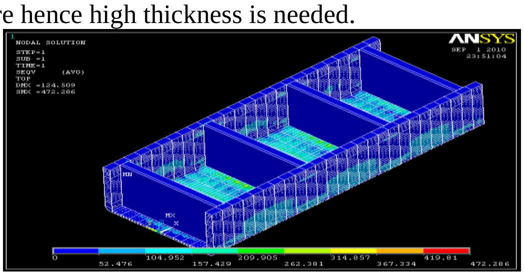

Fig.15: von Mises plot of three hold model in N/mm^2 in empty load condition

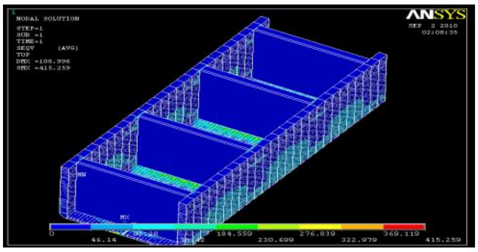

Fig.16: von Mises plot of three hold model in N/mm^2 in full load condition

From the final stress distributions at various regions we can see that some portions of the outer bottom shell, inner bottom shell are getting stressed more than the allowable stress value. These are the critical areas where care is to be taken because more loads come over it or because of the connection part.

B. **Check for deflection**

Maximum allowable deflection from CSR,

Longitudinal direction = 25280/150= 168.5 mm

The comparison of deflections in empty load condition and in full load condition is shown in the below Tables 3 and 4

Table 3: Comparison of Deflection values (mm) in Empty load condition

Sl.No	Structural Member	ANSYS results Deflection (mm)	Allowable deflection from CSR (mm)	Remarks
1	Web frame	124.5	168.5	Within limit
2	Outer bottom shell	124.5	168.5	Within limit
3	Inner bottom shell	124.5	168.5	Within limit
4	Side shell	124.5	168.5	Within limit
5	Bulkhead	124.5	168.5	Within limit

Table 4: Comparison of Deflection values (mm) in Full load condition

Sl.No	Structural Member	ANSYS results Deflection (mm)	Allowable deflection from CSR (mm)	Remarks
1	Web frame	108.9	168.5	Within limit

2	Outer bottom shell	108.9	168.5	Within limit
3	Inner bottom shell	108.9	168.5	Within limit
4	Side shell	108.9	168.5	Within limit
5	Bulkhead	108.9	168.5	Within limit

D. Modifications

The results also show that some of the outer bottom shell, inner bottom shell, and bulk head areas are getting stressed more than the allowable stress value. So where ever it is exceeding necessary modifications should be done to bring down the stresses within allowable limit.

Modifications can be done in the following,

- Increase the plate thickness of that particular panel.
- Decrease the stiffener spacing.
- Use higher grade of steel.
- Refining the stressed area by finer mesh using separate sub-models.

The modification is done on plate thickness. The revised thickness obtained after the calculation is represented as Table 5.

Table 5: Revised thickness

Sl No.	Structural Member	Thickness (mm)	
		$t_{provided}$	$t_{required}$
1	Outer bottom plate	16	16.59
2	Inner bottom plate	16	16.51

VII. CONCLUSION

In this paper of project on ship structural safety, which has been carried out by following **Common Structural Rule (CSR's)** issued by **IACS** is a practical assessment method of ship structural strength. The hydrostatic and hydrodynamic loads enabled to evaluate the maximum stresses of the primary members and also helped to assess the areas of its occurrence and failure. Practical formulae to determine the design loads and to estimate the corresponding dynamic loads developed based on an extensive series of hydrodynamic and structural analyses of full ship models were used in this analysis. Care is taken while selecting the element types also. Plate structures were modeled using 4 nodded shell elements. It is not possible to model all the stiffeners in the structure, so to account for it line members were given stiffener property using 2-D, 3 nodded beam elements. Yielding strength of the structural member is easily estimated by performing linear FEM analysis. From the viewpoint of practical use, it is preferable to evaluate the strength of the member based on yielding.

The modeling is done in such a way that it will include all the structural components in the model. The accuracy of the displacements and the stresses are directly related with meshing. In this project, the container ship has been analysed using (Common Structural Rule) issued by IACS using finite element software ANSYS. The results are extracted in the form of deflection and stresses. It is found that the stresses are within allowable limit in most of the cases and wherever it is exceeding necessary measures are taken to bring down to its permissible limit. Thus the overall safety of the vessel is checked for yielding.

It is concluded that, the guidelines mentioned in the common structural rule of IACS of ship structures are of universal application to tankers with different hull constructions and under different loading conditions. Hence, they are useful in developing naval ships as well as in rationally designing ships that have limited service experience such as container ships of double side skin.

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