Analysis and modification of existing design of a ship to improve its stability: A case study

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Abstract— It has become obvious that modern ships suffer from problems related to their sea keeping behavior, which is related to large amplitude roll motion. The intact stability is very important for the behavior of a ship in the sea going conditions. In present case of 150 Ton oil barge requires to improve the stability of ship and minimize the effect of heeling by modification in existing design of a ship to solve the current ship problem. The buoyancy force has to be increased by the addition of stabilizing tanks to the ship in such that increase the stability of ship and also reduce the effect of heeling. The ship requires to improve its metacentric height and to increase the buoyancy force to minimize heeling of ship. The ship requires working in safe condition as per the guidelines of IRS class. The IMO requirement also has to consider for safe sea keeping condition. The ship must have less than 100 angle of heel for its sea running condition by doing inclining test.

Index Terms— Ship stability, design of a ship, buoyancy force minimizes, Healing angle.

1. INTRODUCTION

A ship may be disturbed from rest by conditions which tend to make it heel over to an angle. These conditions include such things as wave action, wind pressures, turning forces when the rudder is put over, recoil of gunfire, impact of a collision or enemy hit, shifting of weights on board, and addition of off-center weights. These conditions exert heeling moments on the ship that may be temporary or continuous. When a disturbing force exerts an inclining moment on a ship, there is a change in the shape of the ship's underwater body. The underwater volume is relocated, its bulk being shifted in the direction of the heel. This condition causes the center of buoyancy (B) to leave the ship's centerline and shift in the direction of the heel. (The center of buoyancy moves to the geometric center of the new underwater body.) As a result, the lines of action of the forces of buoyancy and gravity separate and in doing so exert a moment on the ship. This moment tends to restore the ship to an even keel. If we study figure 1.1, you will notice that a righting or restoring moment is present. This righting moment is caused by the two equal and opposite forces, each of W tons (displacement) magnitude, separated by a distance GZ, which constitutes the lever arm of moment. Figure 1.1 shows that the ship is stable because the center of buoyancy (B) has shifted far enough to position the buoyant force where it tends to restore the ship to an even keel or an upright position.
A moment is the product of a force tending to produce a rotation about an axis times its distance from the axis. If two equal and opposite forces are separated by a distance, the moment will become a couple which is measured by one of the forces times the distance that separates them. The righting moment of a ship is therefore the product of the force of buoyancy times the distance GZ that separates the forces of buoyancy and gravity. It may also be expressed as the force of gravity (weight of the ship) times GZ. The distance GZ is known as a ship's righting arm. Putting this into mathematical terms, you have the following:

Righting moment = W x GZ (expressed in foot-tons)

Where: W = Displacement in tons,
GZ = Righting arm in feet

However, it is possible for conditions to exist which do not permit B to move far enough in the direction in which the ship rolls to place the buoyant force outboard of the force of gravity. The moment produced will tend to upset the ship, rendering it unstable. Figure 1.2 shows an unstable ship in which the relative positions of B and G produce an upsetting moment. In this illustration it is obvious that the cause of the upsetting moment is the high position of G (center of gravity) and the geometric center of the underwater body (B—the center of buoyancy).
A bilge keel is a long fin of metal, often in a "V" shape, welded along the length of the ship at the turn of the bilge. Bilge keels are employed in pairs (one for each side of the ship). A ship may have more than one bilge keel per side, but this is rare. Bilge keels increase the hydrodynamic resistance when a vessel rolls, thus limiting the amount of roll a vessel has to endure.

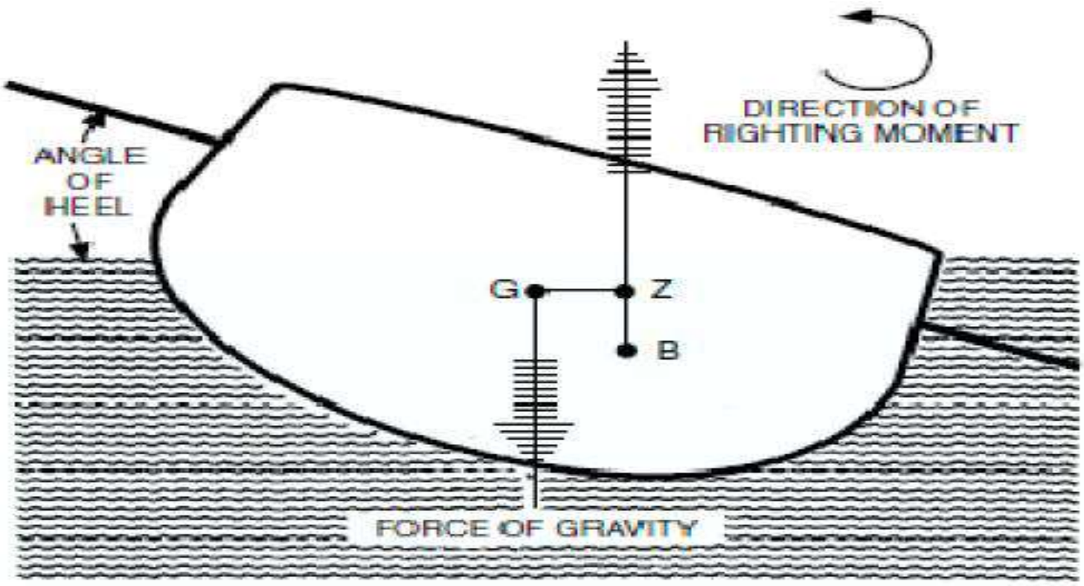

Fig. 1.1: Development of Righting Moment when a Stable Ship Inclines

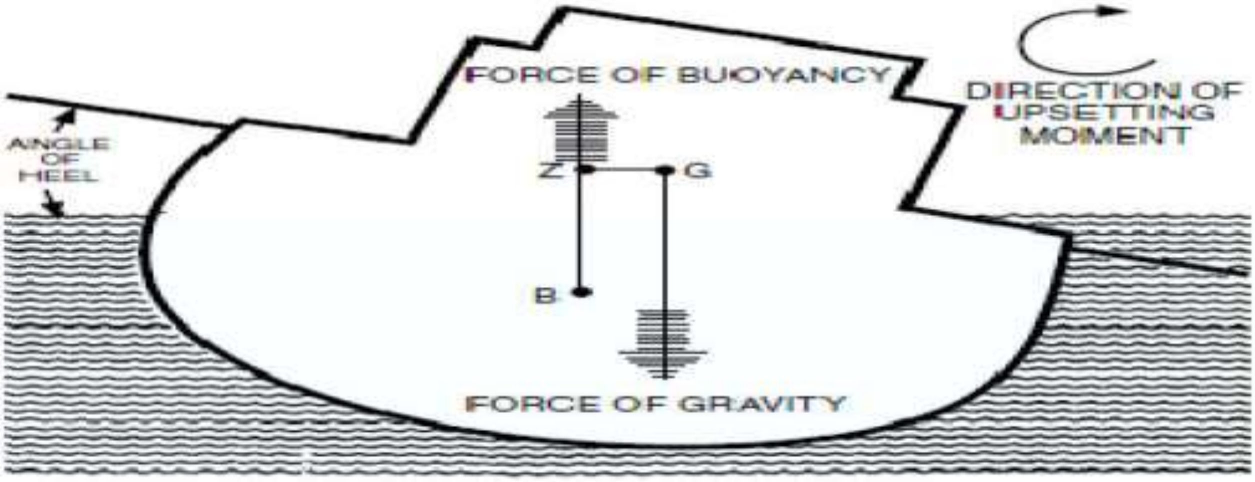

Fig. 1.2: Development of an Upsetting Moment when an Unstable Ship Inclines

The angle of heel on account of should not exceed 10^0, for that calculation the below formula should be used:

$$MR=0.02\ V_0^2/L\ (KG- d/2)$$

Where
MR= Heeling Moment (M-T)
VO= Service Speed (m/s)
L= Length of Ship at Waterline (m)
KG= Height of centre of gravity above keel (m)
Δ=Displacement (t)
d= Mean Draught (m)

Tim Gourlay, Tim Lilienthal [1] "Dynamic Stability of Ships in Waves" Proc. Pacific 2002 International Maritime Conference, Sydney, Jan 2002 A method is proposed for evaluating the overall dynamic stability of an intact vessel in a seaway. We use an existing ship motions program to study the motion of a vessel with a certain loading condition, speed and heading, in given wave conditions. A deterministic method is discussed for looking at the stability of a vessel over a wide range of these parameters. This is done with a view to giving operators advice on the safest headings and speeds to adopt in extreme conditions, as well as gauging the overall safety of a particular vessel. It is hoped that eventually such dynamic stability analysis can be used to modify the present IMO stability criteria for ships. We have outlined a method for assessing the overall dynamic stability of a ship in waves. The method is based on regular wave simulations, over a range of wavelengths whose heights are chosen to correlate with an irregular sea. The advantages of this method over the full probabilistic method are greatly decreased computing time; a simplified analysis and increased understanding of the essential capsize phenomena.

Florian Kluwe [2] "Development of an intact stability criterion for avoidance of capsizing in following seas" Hamburg University of technology, Institute of ship design and ship safety, Hamburg, Germany" It has become obvious that modern ships suffer from problems related to their sea keeping behavior, which is mainly related to large amplitude roll motion in head and following seas. As these effects are not covered by the existing intact stability criteria, an additional concept is developed. This new concept allows quantifying the risk of the occurrence of large roll angles by calculating a capsizing index based on the results of numerical simulations. This paper presents the ideas and concepts behind the new approach. Additionally to the simulation based approach a simplified criterion is developed which addresses the same hazards but without the need to carry out numerical simulations. For validation and the determination of suitable threshold values a number of capsizing accidents, which occurred during the last 50 years were analyzed.

Alberto Francescutto [3], "The Intact Ship Stability Code: Present Status and Future Developments" University of Trieste, Italy. We have outlined a method for assessing the overall dynamic stability of a ship in waves. The method is based on regular wave simulations, over a range of wavelengths whose heights are chosen to correlate with an irregular sea. The advantages of this method over the full probabilistic method are greatly decreased computing time; a Simplified analysis and increased understanding of the essential capsize phenomena. This research paper has been developed in the frame of contract open problems and hints for future developments in the field of Intact Stability have been presented in this paper. The code has been restructured in two parts, one of which designed to become mandatory, and it will be adopted under SOLAS and ILLC conventions. A rational updated plan of action has however been prepared within a time range of five years. It will consider prioritary the development of vulnerability criteria able to distinguish ships sensible to additional dangerous phenomena to the present stability criteria, so that full calculations/testing can be limited to these ships. In this paper the general stability criteria and weather criteria discussed based on ideas, concepts and ship typologies/ dimensions, existing long before their adoption, so that the need of their upgrading and of implementing the important developments of ship dynamics, with particular emphasis on nonlinear aspects.

2. TECHNICAL SPECIFICATION

2.1 Ship particulars:

Ship type: 150 Ton oil barge
Official number: 3891
Port of registry: India
Flag: India
Type of vessel: Oil barge (>60^0)

Principal dimensions: Length OA – 41.6 meter
Length BP – 38.3 meter
Breadth (Mld.) – 08.4 meter
Depth – 4.0 meter
Design Draft – 2.5 meter
Summer draft – 2.722 meter
Displacement at SLWL – 575.49 metric tons
Deadweight at SLWL – 245 metric tons
Gross Tonnage – 474 metric tons

Classification: Indian register of shipping
Class notation: Oil barge for carriage of liquid having flash point above 60^0
Longi. center of buoyancy: 0.018 forward from center of ship
Vertical center of buoyancy: 1.404 meter from baseline
Longi. center of gravity: 0.577 aft from center of ship
Vertical center of gravity: 3.296 meter above baseline
Metacenter of ship: 3.947 meter from baseline
Metacentric height: 0.651 meter

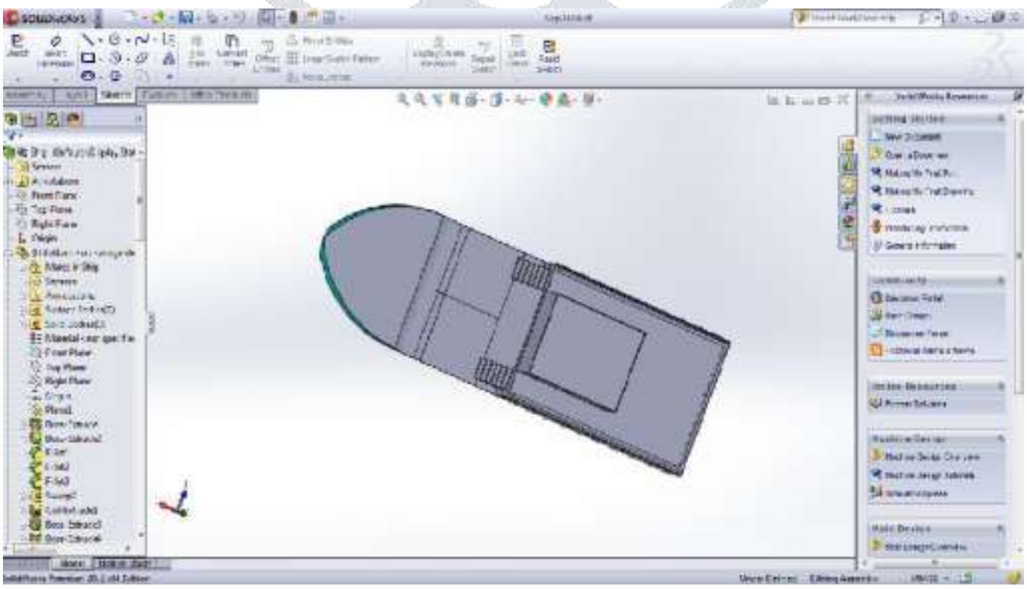

Figure -2.1: Ship model main deck plan view in solid works

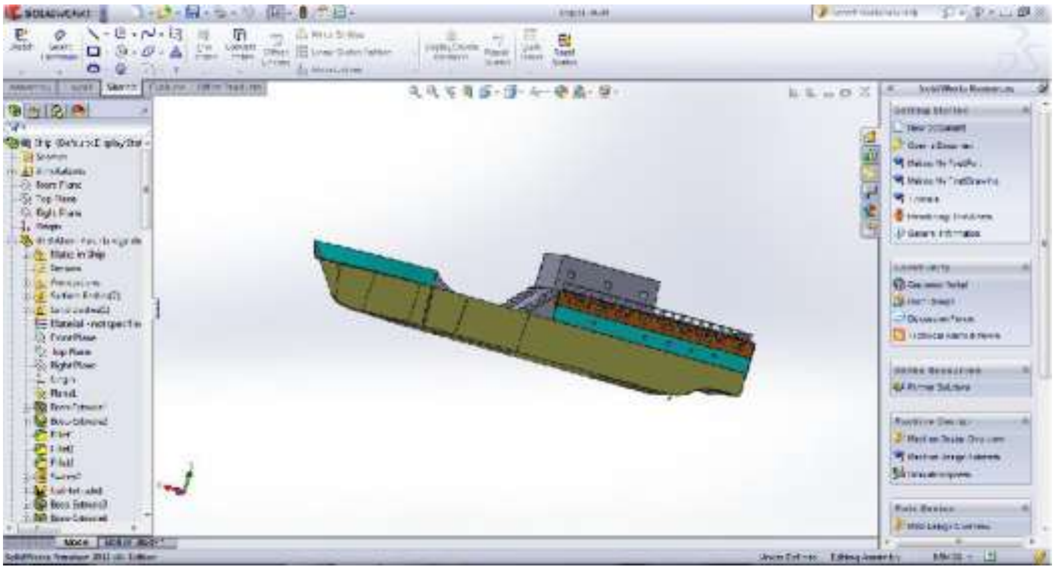

Figure 2.2 Ship portside view in solid works

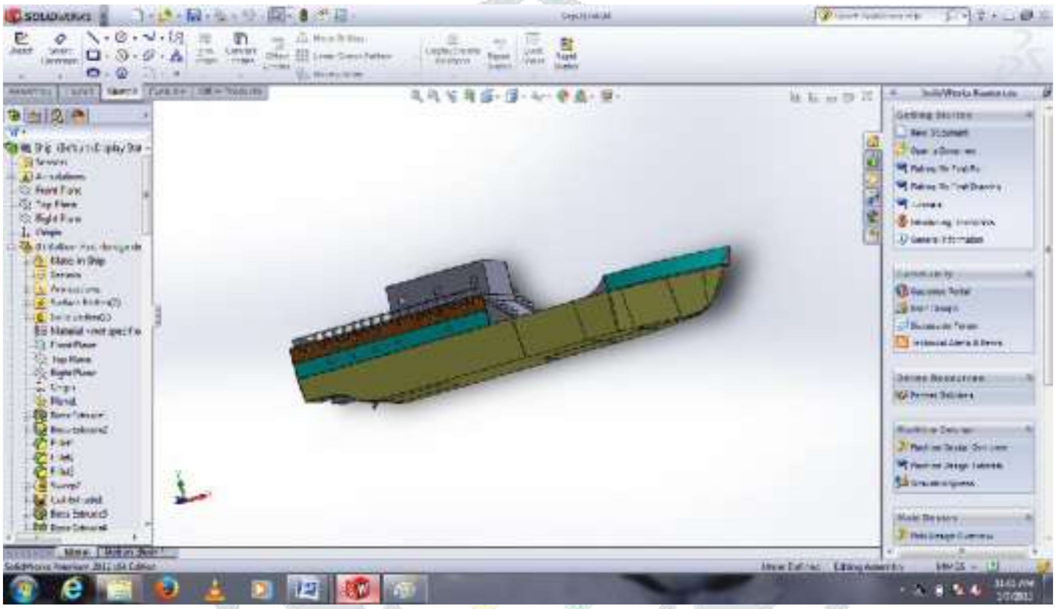

Figure 2.3 Ship outside view in solid works

2.2 Effects of wind and weather criterion on ship

The ability of a ship to withstand the combined effects of beam wind and rolling shall be demonstrated for each loading condition as follows:

1. The ship is subjected to a steady wind pressure acting perpendicular to the ship's center line which results in a steady wind lever (lw1)
2. From the resultant angle of equilibrium (θo), the ship is assumed to roll owing to wave action to an angle (θ1) to windward.
3. The ship is then subjected to a gust wind pressure which results to a gust wind heeling lever (lw2)
4. Under these circumstances, area b in the GZ curve shall be equal or greater that area a.
5. Free Surface Effect shall be accounted for.

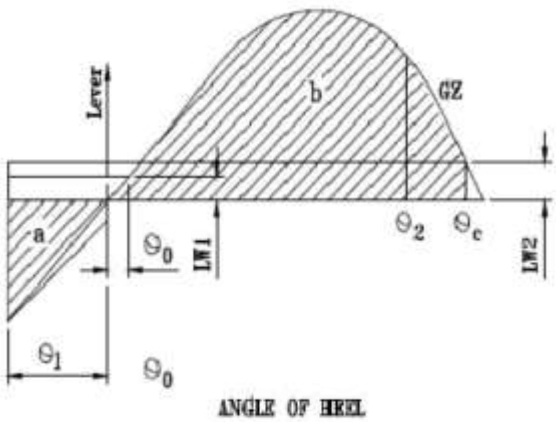

Figure 2.2.1 Angle of heel Vs. Lever

θo = Angle of heel under section of steady wind
θ1 = Angle of roll to windward due to wave action

θ2 = Angle of down flooding or 50 degree or θc whichever is less
θc = Angle of second intercept between wind heeling lever (lw2) and GZ curves.

Calculation of wind heeling lever:

lw1 = (P x Ax Z) / (1000x g x D)
lw2 = 1.5 x lw1
Where, P = 504 N / sq.m
A = projected lateral area of the ship and deck cargo above LWL
g = 9.81 m / sq.sec
D = Displacement in tons.
Z = vertical distance from center of A to the center of underwater lateral area

Description	Displacement (Tons)	Trim (Meter)	Actual VCG (Meter)	Maximum VCG(Meter) [IMO 749(18)]	Maximum VCG (Meter) [Weather]
Light Ship (Condition-1)	**400**	**3.525 a**	**4.15**	**4.19**	**4.22**
Loaded Departure (Condition-2)	**645**	**0.65 a**	**3.29**	**3.60**	**3.49**
Loaded Arrival (Condition-3)	**578**	**1.26 a**	**3.58**	**3.75**	**3.65**
Ballast Departure (Condition-4)	**582**	**0.09 a**	**3.31**	**3.70**	**3.59**
Ballast Arrival (Condition-5)	**517**	**0.48 a**	**3.63**	**3.85**	**3.74**

Table 2.2.1 Maximum VCG Vs Displacement

3 Methodology

3.1 Ship particulars:

Ship type: 150 Ton oil barge
Official number: 3891
Port of registry: India
Flag: India
Type of vessel: Oil barge (>60o)

Principal dimensions: Length OA – 41.6 meter
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Depth – 4.0 meter
Design Draft – 2.5 meter
Summer draft – 2.722 meter
Displacement at SLWL – 640.99 metric tons
Deadweight at SLWL – 268 metric tons
Gross Tonnage – 497 metric tons

Classification: Indian register of shipping
Class notation: Oil barge for carriage of liquid having flash point above 60o
Longi. center of buoyancy: 3.53 meter aft from center of ship
Vertical center of buoyancy: 1.431 meter from baseline
Longi. center of gravity: 1.33 meter aft from center of ship
Vertical center of gravity: 3.359 meter above baseline
Metacenter of ship: 4.6855 meter from baseline
Metacentric height: 1.326 meter.

3.2 System implementation:

Stabilizing tanks:

These form of stabilizing tanks used to improve the stability of a ship. These tanks can be used as internal tanks in the compartment or at the external side of the ship the tanks have been attached to improve the stability of a ship.
1. By adding stabilizing tanks we have greater intact stability due to more under water volume of a barge that gives generates more buoyancy force.
2. This increase in buoyancy force will increase the stability of ship.
3. The stabilizing tanks which are empty tanks increase the stability of a ship.
4. The improved stability of ship will minimize the heeling angle and improves the resistance to heeling impact while the small weight can be positioned at different places on the main deck area.

3.3 Calculation for stabilizing tank:

As per IRS requirement with cargo oil tank 90% full, FO tanks 98% full and fresh water tanks 100% full, the displacement of water must be above 630 tons.

The volume of stabilizing tank for one side will be 50.2113 M3. So the total volume of ship to be increased will be 100.42 M3.

We can see from below model of ship that the stabilizing tanks of 0.950mtr width and depth from 1mtr to 3.3mtr. Length of tanks is 22.98mtr.

We have to only consider the volume which will be in water so it will be considered from 1mtr to 2.5mtr water level draft only.

The volume of stabilizing tank for our interest is only up to 2.5mtr water level. So volume of stabilizing tank for our consideration is 32.75M^3 one side and for both side of ship it is considered as 65.5M^3.

3.4 Modified model of ship:

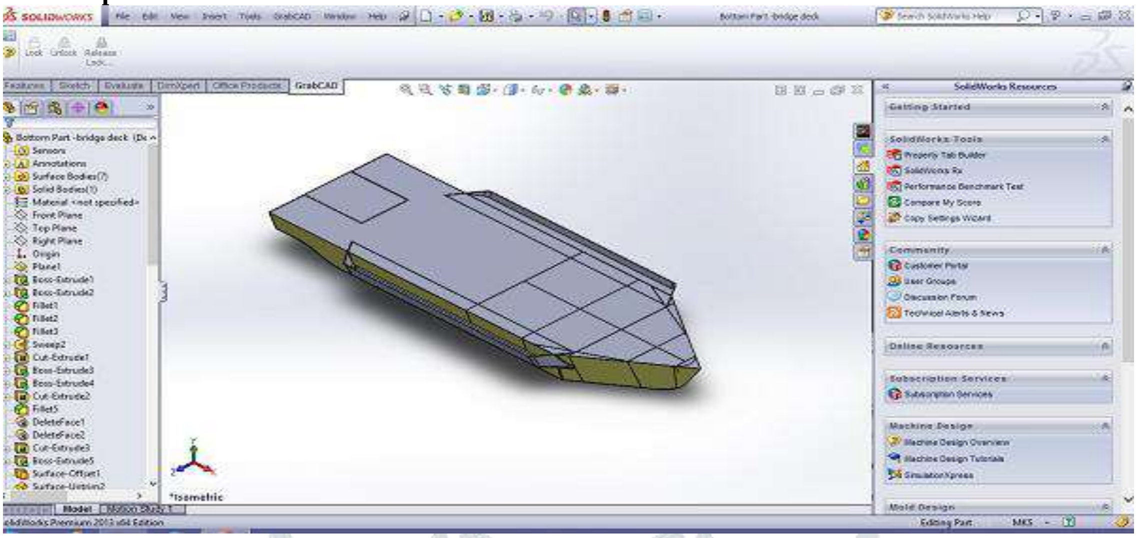

Figure 3.4.1 Ship with Stabilizing Tank

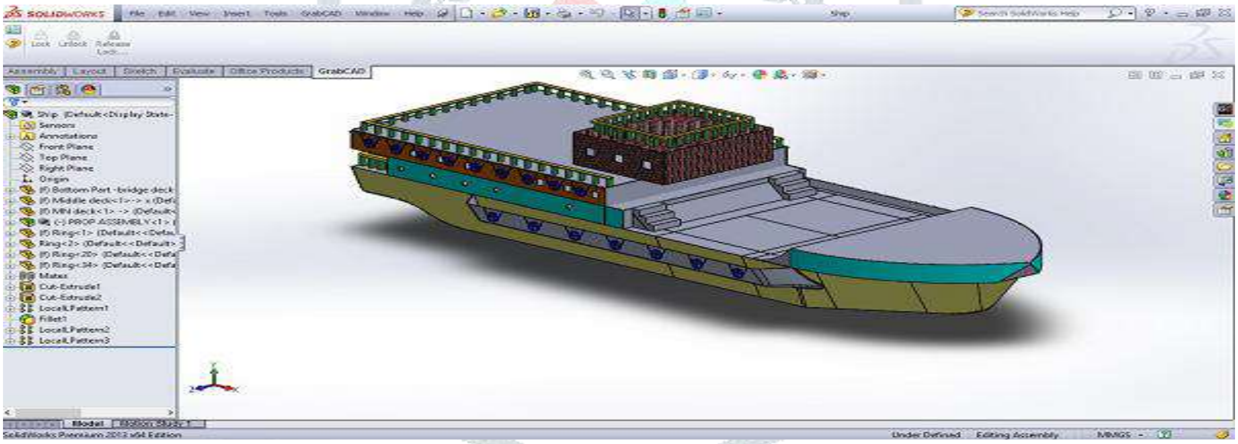

Figure 3.4.2 Ship STBD Side View

Description	Displacement (Tons)	Trim (Meter)	Actual VCG (Meter)	Maximum VCG (Meter) [IMO 749(18)]	Maximum VCG (Meter) [Weather]
Light Ship (Condition-1)	441.16	2.524 a	4.295	4.59	4.38
Loaded Departure (Condition-2)	731.53	0.277 a	3.35	3.67	3.54
Loaded Arrival (Condition-3)	640.27	0.452 a	3.611	3.78	3.68
Ballast Departure (Condition-4)	662.3	0.009 a	3.3891	3.78	3.57
Ballast Arrival (Condition-5)	571.05	0.143 a	3.67	3.89	3.78

4. Result and Analysis

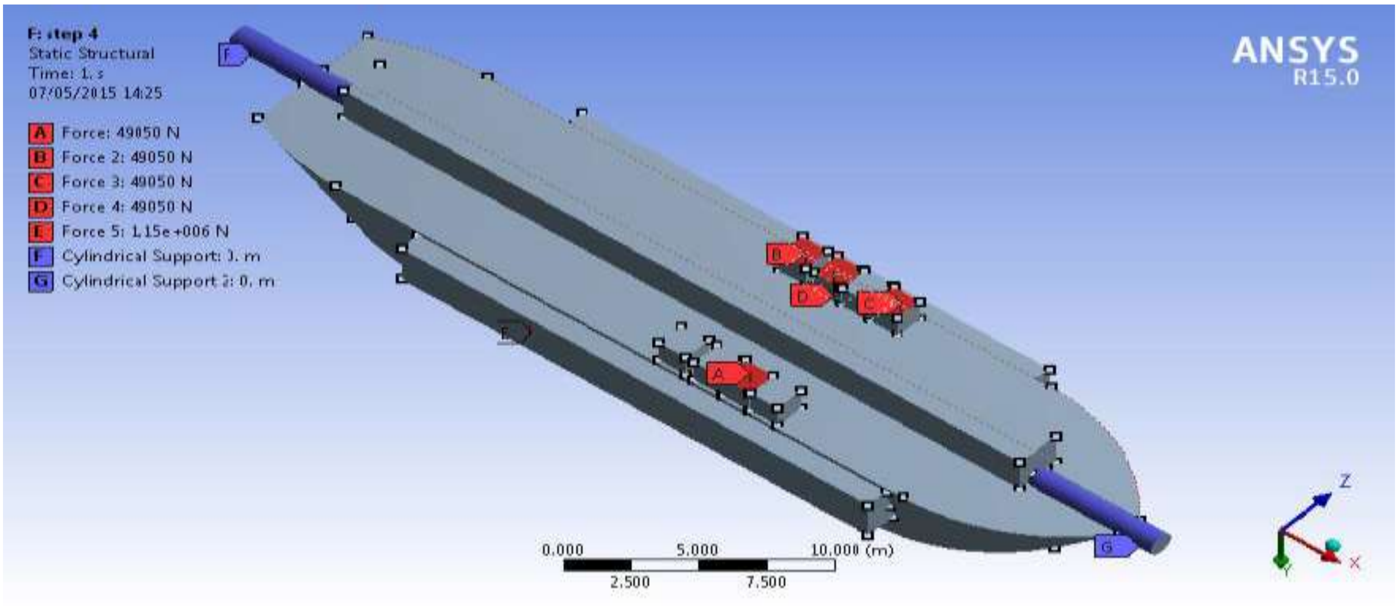

Figure -4.1: **Inclining test**

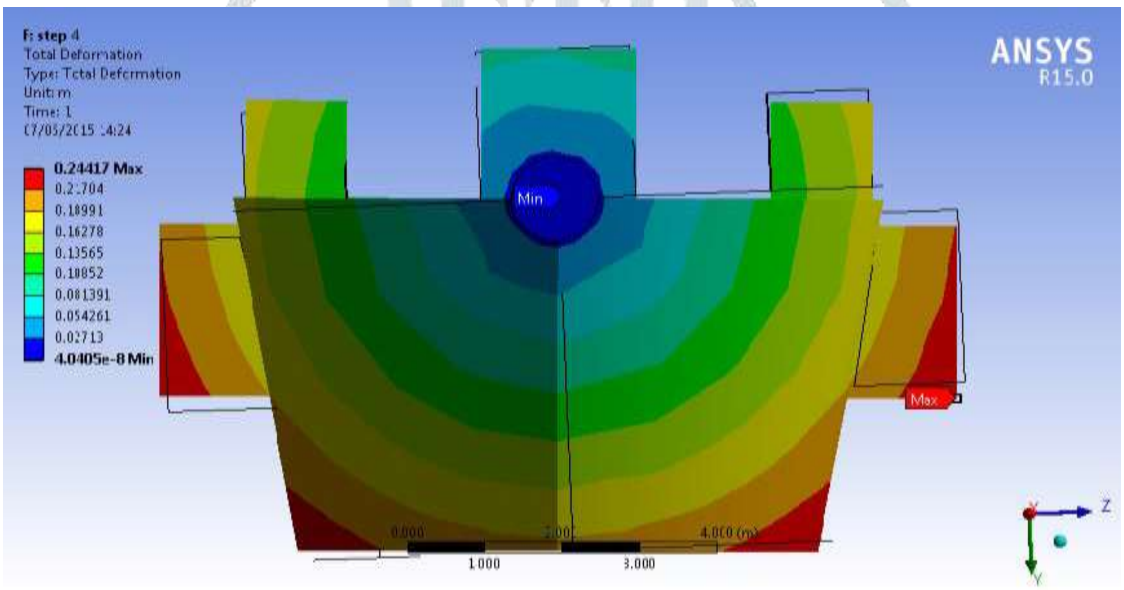

Figure -4.2: **Deformation analysis of load condition 1**

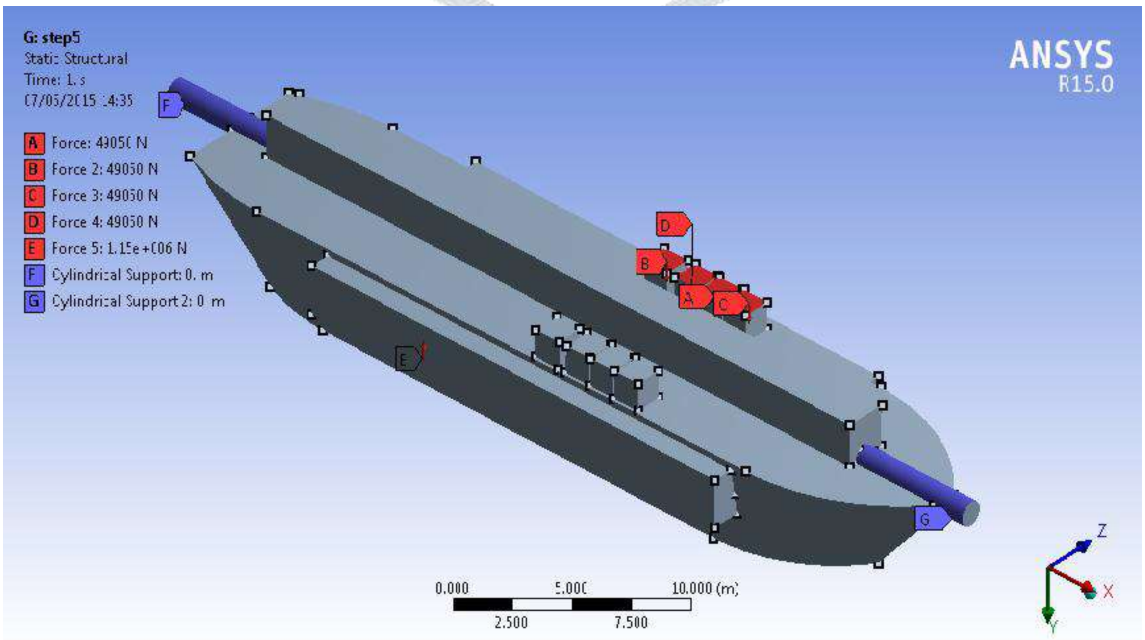

Figure -4.3: **Load condition**

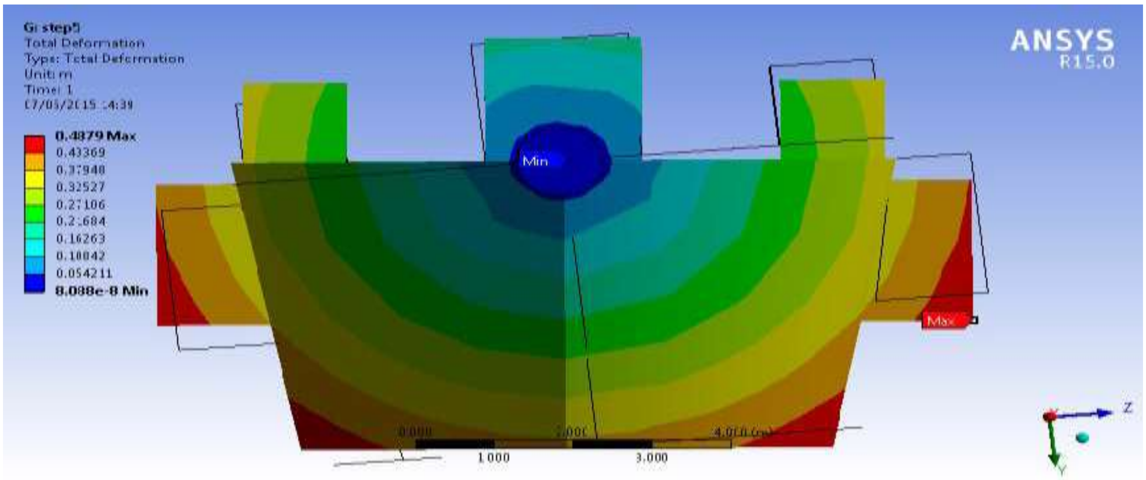

Figure -4.3: **Deformation analysis of load condition 2**

Step	Applied load at Port side in N	Applied load at STBD side in N	Deformation in meter	Heeling angle
1	49050	147150	0.24403	3.9^0
2	0	196200	0.48857	7.72^0
3	98100	98100	0.000085	0.0013^0
4	147150	49050	0.24417	3.88^0
5	196200	0	0.4879	7.717^0

4.2 Inclining test calculation:

1. Heeling angle:

Tan Ѳ = Deformation / Distance between center of applied load to centerline

All dimensions are in meter

Where Ѳ = Heeling angle of ship

2. Buoyancy force:

F = Volume of sea water displaced by ship x Density of sea water

= 640.99 m3 x 1.025

= 657.014 MT

= 6445307 N

3. Weight of each block for inclining test:

W = Density x Volume of block (1.3 m x 1.3 m x 1.3 m)

= 2275.83 Kg/ m3 x 2.197 m3

= 5000 kg

= 49050 N

Sr. No.	Parameters	Existing model	Modified model
1	Gross tonnage	474 MT	497 MT
2	Displacement of water at SLWL	575.49 MT	640.99 MT
3	Buoyancy force	589.877 MT	657.014 MT
4	Maximum displacement in inclining test	0.5380 Mtr	0.48857 Mtr
5	Maximum inclining angle	8.5^0	7.72^0

Table 4.1: Comparison of existing model with modified model of ship

5. CONCLUSION

The goal of this project work was to obtain minimum heeling angle of ship when the inclining test of ship carried out with minimum efforts. The intact stability of ship has also required increasing.

In this dissertation work, Solid works and PTC CREO 3 software used for preparation of model and for static analysis of that model ANSYS software used.

In ANSYS software different types of static loads applied for doing the static analysis of ship model for its inclining test. For inclining testing of model in ANSYS various parameters like buoyancy force, static loading condition, load of weight of the ship itself, metacenter, metacentric height, etc has been considered for the testing.

From this entire work, it can be concluded that, due to modification in existing design of 150 Ton oil barge, now it will have safe heeling angle condition and more stability as well as it will have more safe sea going conditions.

6. FUTURE WORK

In future, this dissertation work will provide the basic information about to increase the intact stability and solution for avoiding large heeling angle of small ship or barges.

It will give information about how to conduct an inclining experiment of ships in ANSYS software, so that companies of ship building can consider this as basic guideline. Software's like solid works and PTC CREO 3 can be used for modeling of ship which may give better idea than AUTOCAD.

This dissertation will give idea about inclining test requirement can be simulated by using ANSYS software for any ship.

This dissertation work will also give basic idea about how to give a ship more stability by introducing stabilizing tanks in the existing design of ship by the minimum efforts and by not changing the existing inside area of the ship and also not any kind of change in the transportation capacity of the ship. The ship has more stabilized sea going condition also.

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