Comparative analysis of different loading conditions on large container ships from the perspective of the stability requirement

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Abstract. Container ships carry cargoes that are considered light from the weight point of view, compared to their volumetric capacity. This fact makes the still water vertical bending moment to be in hogging condition. Thus, the double bottom structure is permanent subject to compressive load. With the enlargement of container ships to the Post Panamax vessels, the breadth to depth ratio tends to be increased comparative to those of Panamax container ships that present restriction related to maximum breadth of the ship. The current studies on new build models reveal the impossibility for Panamax container ships to comply with the minimum metacentric height value of stability without loading ballast water in the double bottom tanks. In contrast, the Post-Panamax container ships, as resulted from metacentric height calculation, have adequate stability even if the ballast water is not loaded in the double bottom tanks. This analysis was conducted considering two partially loaded port-container vessels. Given the minimization of ballast quantities, the frequency with which the still water vertical bending moment reaches close to the allowable value increases. This study aims to analyse the ships’ behaviour in partially loaded conditions and carrying ballast water in the double bottom tanks. By calculating the metacentric height that influences the stability of the partially loaded port container vessels, this study will emphasize the critical level of loading condition which triggers the uptake of ballast water in the double bottom tanks, due to metacentric height variation.

1. Introduction

The Post Panamax vessels fitted with double bottom structure are required to gain greater flexibility in loading more containers while fulfilling the stability and cross stability requirements. Thus, various loading scenarios that were not possible on Panamax vessels, now are being applied to Post Panamax ships that can stack lighter weight containers inside the holds [1, 2]. On the other hand, the breadth of the Post Panamax ship increased, along with the increase of lateral loads due to water pressure, while the weight of containers even under normal circumstances is reduced, to balance these loads. Therefore, the prompt that appears in the double bottom structure occurs in the double bottom and tends to increase as far as weight of loaded containers in the storage decreases [3].

An empty loading section, along with the adjacent sections, is one of the loading scenarios (particularly in terms of the tensions that arise due to inhomogeneity load) required by designers of port container ship structure. The MOL Comfort ship accident resulted in various loading scenarios to be investigated and, after analysing the results, answered to the query whether applications on the
double bottom structure are close to or exceeding in value those of the one-bay empty loading conditions. Investigations are carried out for 21 loading scenarios [1] as set forth in the table below.

**Table 1.** One bay empty condition.

|                       | One-bay empty | All loaded compartments/roster |
|-----------------------|---------------|--------------------------------|
| Storage loaded        | 30.0 Ton/FEU  | 0 la 30.0 Ton/FEU (7 scenarios at | (design load)                     |
| containers            |               | 5 Ton interval)                 |
| On caps loaded        | 130.0 Ton/stack| Design load (130 Ton/Stack)     |
| containers (Design    |               | 2/3 Design load (87 Ton/Stack)  |
| load for 40" containers) |           | 1/3 Design Load (43 Ton / Stack) |

The results are shown in the graph below where on the horizontal axis is represented the container loads in the hold, while the transverse stress occurring in the bottom shell plates are represented on the vertical axis. Maximum transverse stress for each load condition is shown by the three lines for the three container loading scenarios on the hatch cover. (at the design value, at 1/3 of design value, and at 2/3 of design value).

For comparison, under one bay empty condition, the maximum transverse stress present in the bottom shell plates is between 85 and 90 N/mm² and is represented by the red zone.

![Figure 1. Comparison of transverse stresses from bottom floor tables for load conditions [1].](image)

As emphasized in figure 1, the value of transverse stress is equal to that of one-bay empty condition in the area where the line cuts the red zone.

For example, when the container load on the hatch cover is between 1/3 and 2/3 of design load and the load inside the hold is about 15 tons/FEU, the transverse stress is equal to that one, due to the one-bay empty load condition.

The result reinforces the idea that Post Panamax ships, while winning in terms of load capacity, might meet conditions where the transverse stress from the bottom floor tables equal those from one-bay empty condition even when loading scenario is very similar to that from current operating real conditions.
2. Loads acting on the structure of the double-bottom structure of port container ships

Generally, port container ships are regularly subject to hogging that induce stress in both the deck and the bottom shell plates area throughout the ship’s operation. It is a feature of the port container ships with a capacity greater than 10,000 TEU to have the engine room and the accommodation located in the ships’ semi-aft.

The bottom sea pressure, container load, ballast water and the fuel from the double bottom fuel tanks are factors acting on the structure of the double bottom structure.

The upward load due to bottom sea pressure is a major load, as well as the lateral load acting on the structure of the double bottom, because the weight of goods is relatively small in relation to load due to the bottom sea pressure. Bottom sea pressure is determined by the hydrostatic pressure corresponding to the draft and the pressure induced by the waves.

This pressure is compensated to some extent when the double bottom tanks are ballasted or the fuel tanks are filled, because the loads induced by their weight is opposite to that due to bottom sea pressure (to a greater extent in the case of ballast, due to higher specific gravity).

Compressive loads due to side water pressure acts upon the side shell of the ship in a transverse direction.

We can structure the three loads acting on the double-bottom as shown below:

1. Compression loads due bending moments
2. Vertical loads due to water pressure
3. Transverse loads compression due to lateral pressure water

![Figure 2. Acting forces on the double-bottom space [4].](image)

Loads due to bending moment induce longitudinal compressive stress in the bottom shell plates and the transverse induce transverse compressive stress. On the other hand, the upward load due to bottom sea pressure causes convex deformation in the structure of the double bottom structure, consisting of bottom shell plate and longitudinal, girder and floor. The result is that the compressive stress in the double-bottom structure area arises in the central area; deformation structure is maximized near partial bulkhead in the longitudinal direction.

![Figure 3. Transverse Compressive stress [4].](image)
In conclusion, the combination of two forces at the middle area (centreline) and near partial bulkhead overlap in the longitudinal direction 1 and 2, and transverse, 2 and 3.

Increasing of loading capacity of Post Panamax port container ships was given by removing the width restriction (32m) so that the ratio B/D (width/height) of the ship increased accordingly, especially for the ships over 8,000 TEU. However, this coefficient is directly related to ship stability, specifically to the GM metacentric height (G_{M} considering free surface).

The reference literature related to Post Panamax container vessels [4] calculated the B/D values for port container ship generations and values of GM in case the ship is or not ballasted in double bottom tanks.

3. Case studies

This study aims at analysing the ships’ behaviour in different conditions loaded/unloaded and carrying ballast water in the double bottom tanks. By calculating the metacentric height that influences the port container vessel stability for vessels carrying containers in a limited number, different by maximum allowed for that type, this study will emphasize the level of loading capacity where the Post Panamax vessels require to take ballast water in the double bottom tanks, due to metacentric height variation.

The study concerns two vessels, Panamax and Post-Panamax, for which the Draught and the metacentric height was calculated using the loading program for port-container ships, MACS3 developed by Interschalt, figure 5. The program was applied for different situations of loading ballast water in the double bottom tanks.

The first vessel is a Panamax with the following characteristics:

- Length overall: 207.46 m
- Breath overall: 29.80 m
- Draught (max): 11.40 m
- Capacity: 2,474 TEU

Results 1. There were calculated two situations: for 1729.4 m³ of ballast water in double bottom space and without ballast water. The results are presented in table 2.
Table 2. The results for Panamax vessel.

| Scenario                  | A1                  | A2                  |
|---------------------------|---------------------|---------------------|
| Water ballast in double bottom tanks | 1729.4 to ballast | 0.0 to ballast      |
| Draught Mean              | 9.69 m              | 9.33 m              |
| GM'(corrected)            | 0.989/0.400 m limit | 0.376 m/0.400 m limit |

The second vessel is a Post Panamax with the following characteristics:
- Length overall: 366.08 m
- Breath overall: 48.20 m
- Draught (max): 15.50 m
- Capacity: 12.552 TEU

Results 2. For the second vessel, there were loaded different quantities of ballast water in double ballast tanks: first scenario 517.9 m³ of ballast water in double bottom space and the second scenario 352.9 m³ of ballast water. This quantity cannot be unloaded due to the size of the vessel, and represents the minimum amount remaining distributed on the 18 ballast water tanks. The results are presented in table 3.

Table 3. The results for Post Panamax vessel.

| Scenario                  | A1                  | A2                  |
|---------------------------|---------------------|---------------------|
| Water ballast in double bottom tanks | 517.9 to ballast | 352.9 to ballast |
| Draught Mean              | 13.71 m              | 13.71 m              |
| GM'(corrected)            | 2.4049/0.802 m limit | 2.398 m/0.802 m limit |

4. Conclusions

The results of the two scenarios emphasized the variation of Panamax and Post Panamax vessels’ metacentric heights in different conditions carrying ballast water in the double bottom tanks. The values show the small variation of metacentric height 0.069 m, while varying the amount of ballast water in the double bottom tanks.

References

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