Design for Safety and Stability

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ABSTRACT

Safety and stability are two key aspects for the successful design of ships while keeping the balance between efficiency and performance of the ship. In the past the main drivers for safety improvements have been catastrophic accidents but a change of mind is needed to enhance safety and stability within the given envelope of design constraints. This can only be achieved when beside comprehensive calculation tools basic design methods will be developed and used in the daily design work. A method to predict the attained subdivision index has been developed and has been shown here as an example for a simplified design method.

Keywords: *design, safety, cruise ships, stability index*

1. INTRODUCTION

The design of complex ships, like cruise ships, is an everlasting quest to find the right balance between the performance of the ship, for cruise ships this is the satisfaction of the guests on board, efficiency of operation and safety and environmental protection. Obviously the compliance with rules and regulations are the basis for each design, but the development of technologies and new design ideas challenging the application of regulations.

2. DESIGN TO SAFETY

Shipbuilding and design of ships has a very long tradition and is mainly built on experience. Main drivers for design changes towards a safer ship have been in the past mainly accidents or near-accidents and experiences of the designers as well as operational feedback. Very popular examples are the capsize of the VASA, the sinking of TITANIC or the foundering of ESTONIA. In the past such kind of accidents also influenced the rule making process and based on the IMO rules the current state-of-the-art has been defined.

Merchant ships are designed, built and operated to be part of an enterprise to generate profit. This main objective together with the challenge to find the right balance with rules and regulations is usually the motivation not to design to safety but to squeeze the rules and their interpretation to the limits and maximizing the profit for shipbuilder and operator. By maximising the nominal capacity of a ship and designing the ship for the date of delivery only by ignoring the life time of the ship and the operational needs the strategy for design will fail on the long run. A change of mind is needed for the whole industry to maximize the safety within the given envelope in close cooperation with the operator and for the life-time of the ship.

Another important factor for the design process is the available time. Decisions influencing the global safety of a ship, like the watertight subdivision, are defined at an very early stage of design and needs to be kept unchanged until delivery. Hence, the methods you may apply to determine the safety needs to be fast and robust. Complex tools like parametric optimizations may be used from time to time to expand the level of experience but they are unsuitable for the daily design work. The industrialization of outcome of research projects is very important to take new technologies into use, but it also worth to reconsider experiences and knowledge from the old days.

3. STABILITY RELATED TOPICS FOR DESIGNERS

There are many different topics which may influence the stability or general safety of a ship which needs to be considered during the design. The following figure illustrates a possible accident scenario.

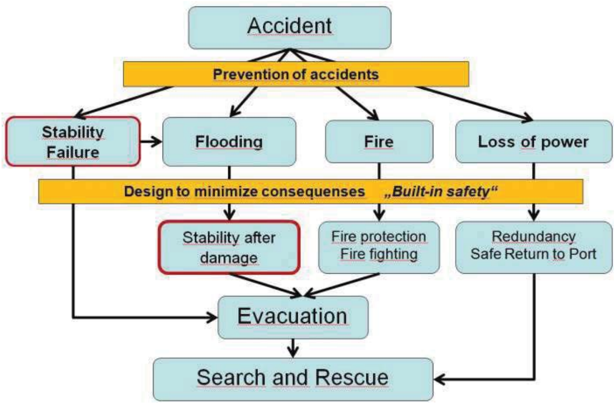

Figure 1 Accident Scenario

Although the best way to improve the safety is the prevention of any accident the focus of most of the designers and researchers is the mitigation of any accident. In particular the extensive discussion about stability after flooding during the recent years, which is still ongoing, is leading somehow in the wrong direction.

In the daily work of ship designs some basic elements like a accurate estimation of light weight and centre of gravity is much more important than a fancy flooding simulation. Proper weight and COG estimations together with the reasonable account for future growth and service based loading conditions form the basis for the hull form and thus the stability behaviour of the ship during its life time. The constant verification of weight and intact stability, including dynamic stability behaviour, ensures that the ship will meet the requirements from the regulations as well as for the performance.

The detailed investigation for stability after flooding is the second focus during the design. To find the best subdivision is again a huge iterative process to align the different demands of space requirements, operability and survivability after damage. Also other safety rules, like escape routes are challenging parameters in this process.

As explained before this needs to take place within a very short time frame and the following presentation of a method to judge on the damage stability capabilities for different hull forms in an easy way is a good example how modern first-principle tools together with basic knowledge can be combined to form a powerful design tool.
During the development of a new hull form it was recognized, that the normally used hard points for the hull form designer will not reflect all different demands a hull form has to fulfil. Therefore an algorithm has been developed to compare different hull forms under special interest of the demands of the damage stability calculation.

4. DESIGN OF A NEW HULL FORM

During the design process different hull forms are developed to find the best for the given design. Hard points for the hull designer are defined to reflect any constraints, which are the following:

- Geometry
    - Lpp
    - Bmax
    - Design draught
- Hydrostatics
    - Minimum KM on design draught
    - LCB
    - Displacement

A new kind of hard point has been searched for the hull designer that guarantees the same level of the attained index.

4.1The Stability Energy Index

The fundamental idea was formulated by RAHOLA already in 1923. He invented the stability energy of a vessel which was used for the stability rating of different vessels. Based on these principles the following algorithm was developed.

Contributing Factors

The area under the righting lever arm curve is calculated from the upright to a certain range of heel. This area is been called E_{phi}.

To reflect the influence of the damage stability calculation E_{phi} is only calculated for the design draught of a vessel but for all three draughts relevant for the calculation of the attained subdivision index:

- Light service draught (D_l)
- Deepest subdivision draught (Ds)
- Partial subdivision draught (D_p)

Basic Calculations

A variation of different hull forms with the same KG on the different draughts is calculated according the above mentioned principles. The watertight subdivision for the calculation of the attained index has been the same for all four hull forms.
The below diagram show the resulting attained index in comparison with the computed area under the GZ-curve from upright to 22° of list.

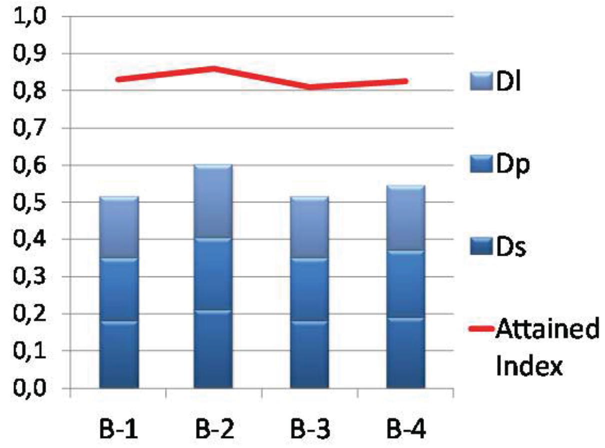

Figure 1 Area under the GZ curve compared with the Attained Index A_i

As the ship is not floating on the three initial draughts after damage anymore, an additional draught has been considered to reflect the situation of the vessel after flooding. This 'over' draught (D_o) is the deepest subdivision draught D_s plus 40% of the difference between D_s and D_l. In addition a weight factor 0.5 for D_l is used to adjust for the minor influence of this draught. Figure 2 show the improvement driven by these decisions.

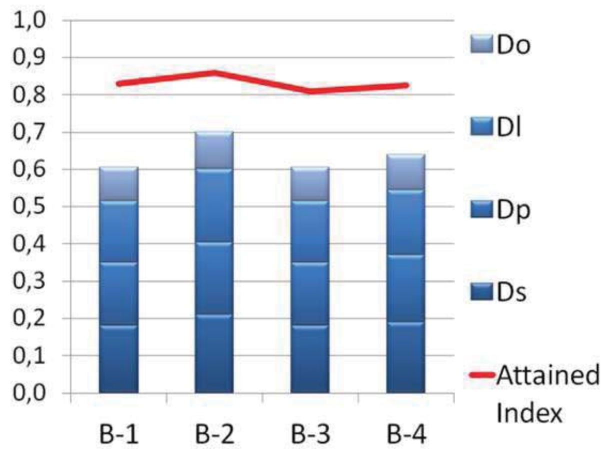

Figure 2 Area under the GZ curve compared with the Attained Index A_i with an additional draught Do

Calculation Rule for the Stability Energy Index

Based on the findings an easy algorithm for the hull form designer has been developed to verify if his hull form will reach the Stability Energy

Index and to calculate the Required Stability Energy Index as a hard point for the hull for designer based on a given Attained Index reached in the damage stability calculation

The hull form designer will get the draughts D_l, D_p, D_s and D_o with their corresponding KG values. For each draught the corresponding area under the GZ curve has to be calculated from 0° to 22° list and summed up according the following formulae.

$$SE_{phi} = 0.5 \times E_{phi-l} + E_{phi-p} + E_{phi-s} + E_{phi-o}$$
$$with:$$
$$\begin{aligned} E_{phi-l} &= E_{phi}(D_l; KG_l; 0° - 22°) \\ E_{phi-p} &= E_{phi}(D_p; KG_p; 0° - 22°) \\ E_{phi-s} &= E_{phi}(D_S; KG_S; 0° - 22°) \\ E_{phi-o} &= E_{phi}(D_o; KG_o; 0° - 22°) \end{aligned} \qquad [1]$$

<u>Stability Energy Index versus given Attained Index</u>

Based on further calculations a simple calculation rule for SE_{phi} at a given Attained Index could be derived statistically.

$$SE_{phi}(RAI) = 2 \times RAI - se_{ship} \qquad [2]$$

with: RAI = Required Attained Index and
se_{ship} = correction factor for different ships [approx. 0.96-1.06[1]]

The following diagram shows the results by using the above introduced formula. For the same KGs and watertight subdivision the attained index has been calculated as well as the SE_{phi} indicated as the Real SE_{phi} in the diagram. A very good correlation has been found and with this prove this method has been used during parametric optimizations of hull forms resulting in the optimum compromise between hydrodynamic performance, space requirements and sufficient stability after flooding.

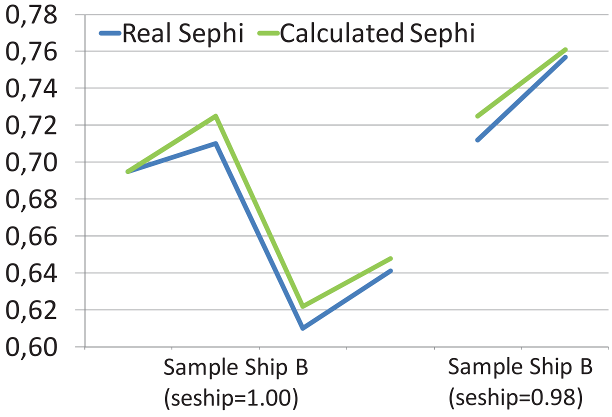

Figure 3 congruence between the real and the calculated SE_{phi}

5. EXAMPLE DESIGN TO SAFETY

One other example for design to safety is the arrangement of watertight doors in a passenger ship. The space below the bulkhead deck is subdivided into watertight compartments and on cruise ships, each square meter is used for the accommodation of the crew and technical spaces like workshops and laundries or storage areas. Each of the watertight compartments requires two means of escape, one of them needs to be a vertical stair or escape leading to the embarkation deck, the second one is usually a watertight door leading into the adjacent compartment.

If operational needs are not considered in the right way at an early design stage the purpose of the spaces may cause that watertight doors are required to be open during normal service and not only as an emergency escape. Typical examples are the laundry and the connected linen stores. In the past laundry and linen stores have been located in adjacent watertight compartments, but recent designs have shown that this can also be placed on top of each other. With this vertical flow the watertight doors may be kept closed during normal operation and this really increases the safety level.

[1] To be further investigated

6. RISK MANAGEMENT AND FUTURE CHALLENGES

The safety related design process requires a high degree of transparency and close cooperation between the stake holders. Not only shipyard and operator are required to cooperate, also the regulatory bodies, like flag administration and classification societies, and technical experts need to be part of the team.

This approach has a number of positive effects. One is of course that the design is of outstanding quality, usually with a proven higher safety level than required by the rules and regulations, on the other hand the lack of knowledge about the special challenges for large cruise ships can be communicated in a better way to a wider audience.

A basic challenge however remains new designs and also new rules and regulations improve the safety of new ships significantly in a continuous way, however it takes about 30 to 40 years to get a whole fleet renewal. The question how to upgrade the safety of the existing fleet is one of the major tasks for the industry and the regulatory bodies in the coming years. Otherwise the gap in safety level between old and new ships will become unacceptable. The introduction and quantification of active safety measures may be one possible way to solve this problem.

7. CONCLUSIONS

Ship design always focus on safety and stability, however instead of interpreting gien rules and regulations to their limits a change of mind is needed to maximize safety within the given design constraints. A proper holistic approach based on close cooperation between regulators, designers and operators is the way ahead, while using highly sophisticated calculation tools together with experience and traditional simple design methods to avoid the repetition of mistakes which have happened in the past. A method has been shown how this combination of modern tools with old experiences can be used in the daily design process.

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