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The Impact of the new DMS-1030 Stability Standard on the Future Design of Navy Ships

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ABSTRACT

In 2022, the German BAAINBw launched a revised issue of their 1030-1 stability regulations for Navy surface vessels. The improvements of the revised code concerned (inter alia) a new stability criterion for minimizing the effect of parametric rolling combined with pure loss of stability on the wave crest and revised damage stability calculation assumptions, which mainly focus on the submergence of openings and a special treatment of watertight doors. The improvements of the code were found to be necessary to keep track of recent developments in IMO for commercial ships and to update the safety level represented by the code. At the same time, the revised code gives more freedom to the ship designer, a fact which may allow novel and more cost effective concepts of Navy Ships in the near future, provided, the evaluation of the stability according to the code takes place immediately during the very early design phase of the ship. The present paper gives insight into the important updates of the code and it demonstrates at the same time how the design of Navy Ships may benefit from the revised code, if it is applied throughout the very first design phase of the ship. The paper will further present an improved design regime for the early design stage.

KEY WORDS

Navy Ship Design, Navy Ship Stability

INTRODUCTION

Due to their mission profile, Navy Ships encounter more and different threats compared to commercial vessels. As a consequence, Navy Ships require higher safety levels with respect to the survivability in intact and damaged conditions. Consequently, commercial safety standards such as the International Code on Intact Stability or the SOLAS, which define minimum requirements only, cannot be applied to Navy Vessels, as one of their core abilities is to survive extreme situations. This holds for the intact stability in adverse weather conditions as well as for the survivability after a damage. For this reason, Navy Ships have to comply with other, more demanding stability standards compared to commercial ships. Navy Ships may be in principle subdivided into surface ships and submarines. The present paper addresses solely Surface Vessels, which may be further subdivided into Navy Combatants and Auxiliary Ships. In 2022, the German Federal Office of Bundeswehr Equipment, Information Technology and in Service Support (Bundesamt für Ausrüstung, Informationstechnik und Nutzung der Bundeswehr), abbreviated BAAINBw) published a revised version of their stability standard for surface ships of the German Navy. The revision of this well proven and established stability standard, which was developed by Wendel in the mid-sixties of the last century (Wendel 1964) seemed to be necessary for the following reasons:

- New hull forms of Navy Ships lead to a higher risk of experiencing large roll angles due to parametric rolling. This was not explicitly addressed by the standard.
- Recent developments in damage stability assessment of the SOLAS 2009 and the SOLAS 2020 showed that the consideration of intermediate flooding stages and the treatment of openings should be reconsidered.

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- In some aspects, the existing stability standard was found to be unnecessarily prescriptive, and it was suspected that this might prevent novel designs of Navy Surface Ships.

When reviewing recent developments in the stability assessment of commercial ships, the following problems were identified which should be definitively avoided when assessing the stability of Navy Vessels:

- Due to the more demanding damage stability requirements in the SOLAS, the limiting GM is strongly dominated by damage stability, but the ships shall operate most of the time in intact conditions, and they should be designed for intact conditions.
- Some types of ship (e.g. large Container vessels) operate with GM- Values which are far away from those the ship was designed for.
- The commercial standard allows to make use of additional operational guidance if problems in the fulfilment of the stability are identified (2^{nd} Generation Intact Stability Criteria). This is certainly not an adequate option for Navy Ships.

Overall, there were several reasons identified which made a revision of the Navy Stability Code necessary. The following sections explain why certain amendments of the code became necessary and how the identified problems were solved. These amendments are compared with existing stability standards and it is shown where elements of these standards (e.g. SOLAS, IS-Code) could be used and where alternatives needed to be developed. The impact of these amendments on the future design of Navy Surface Ships is demonstrated afterwards.

INTACT STABILITY

A brief Introduction into the Intact Stability Part of the BV 1030-1

A detailed description of the BV 1030-1 (now DMS 1030-1) is given by Russel (2024). Explanations about the development of the original stability code are given by Wendel (1964). The governing principle of the BV1030-1 is the determination of ship specific individual heeling levers, which are then checked against the righting levers of the ship as lever balances. The code does not make explicit differences between Auxiliaries and Combatants, but it specifies service categories where a ship is intended to operate. Depending on the defined service area, loading conditions, external forces and groups of stability criteria are then defined. If any German Navy Ship shall operate in a region which is characterized by a higher service category than the one the ship was originally designed for, a decision of the German Parliament (Deutscher Bundestag) is required to permit the operation of the ship. For ships in unrestricted service, which are solely treated in this paper, these lever balances have to be determined for the still water condition as well as for the ship in waves, where the two situations “ship on wave crest” and “ship in wave trough” are to be analysed. Several loading conditions including reserve deadweight for future service have to be analysed during the stability assessment, and, before each voyage, the individual loading condition has to be individually checked against the criteria by the crew by making use of the stability booklet and, if available, the loading computer. It should be noted in this context that typically, the stability booklet and the loading computer are not provided by the industry, but by the German Navy Arsenal. As the BV 1030-1 deals with explicit loading conditions, no $GM_{required}$ (or KG_{max}) curves are in use. For the still water condition (see Fig. 1, top right), the following heeling levers have to be determined:

- Shifting of fluids by heeling levers for each tank (the maximum permissible filling level for any tank is 95%)
- Beam Wind of 40 knots
- Turning circle at full speed (eventually, the permissible speed is limited during the operation of the ship)
- Icing
- Unsymmetrical loading
- RAS supply, if applicable

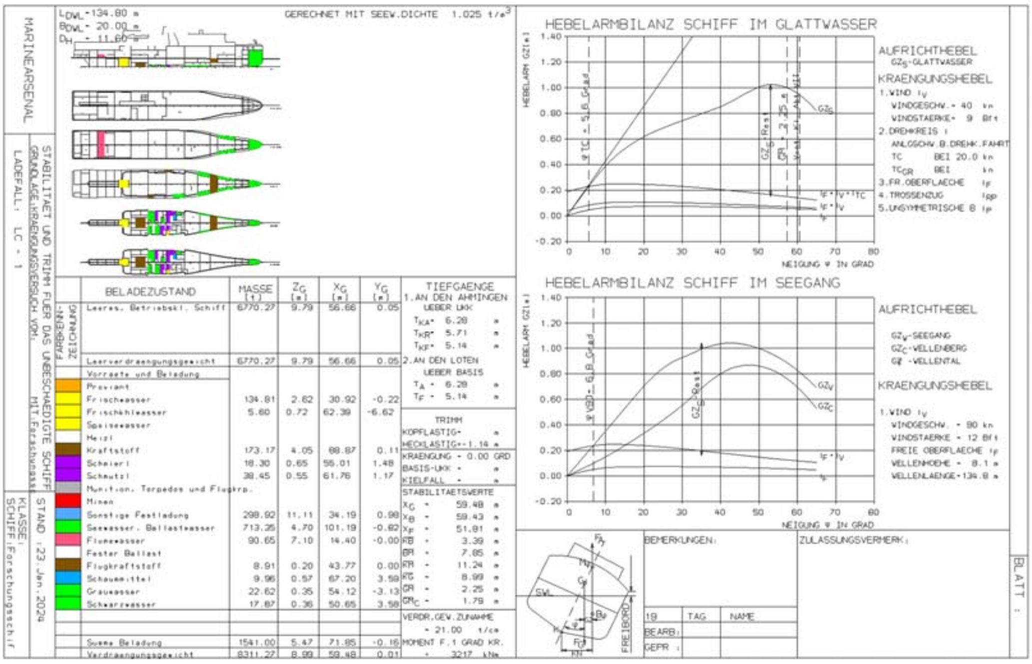

Figure 1: Lever arm balance still water (top right) and in waves with the crest curve (GZ_C) and the crest-trough average (GZ_V)

For Navy Auxiliary Ships, additional loading conditions may be defined and must be investigated. The sum of these heeling levers is compared with the righting lever of the ship, see Russel 2024. Additionally, a lever balance of the ship in waves has to be determined, where the wave length λ equals ship length, and the related wave height H has to be taken from the formula $H=\lambda/(10+0.05\lambda)$ (Wendel 1964, Russell 2024). For this design wave, the two situations “ship on crest” and “ship in trough” have to be computed, see Fig. 1, bottom right. For the “ship on the crest” condition (which is typically the weaker of the two curves), the maximum stability must equal at least 0.05m in minimum to prevent a pure loss of stability failure. The reference curve in waves for the lever balance is computed as the average of the crest and the trough curve, and the following heeling levers have to be computed (for ships in unrestricted service):

- Beam wind of 90 knots
- The shifting of fluids in tanks

For this lever balance, the same limiting criteria as for the still water condition apply, see Fig. 1 bottom right. The BV 1030-1 stability standard includes a stability criterion against the “pure loss of stability” failure mode, but righting lever alterations in waves which are responsible for parametric rolling (or a combination of parametric rolling and pure loss of stability on the wave crest) are only indirectly addressed when taking into account the crest-trough average for the lever balance.

Improvements the BV 1030-1 Intact Stability Part

Parametric roll and pure loss of stability. It is a general understanding in the commercial ship stability community that the existing stability regulations -represented by the International Code on Intact Stability- have not solved all relevant problems concerning ship safety (IMO 2008, Preamble Para 4, P. 9). As a consequence of this insight, the IMO has initiated the development of the so called 2nd Generation Intact Stability Criteria (SGIT), which are presently part of the recommended Intact Stability criteria of the IMO. In parallel, investigations by Krüger et al (Krüger 2014) have shown that the safety level against large roll angles represented by the BV 1030-1 is indeed substantially larger compared to the safety level of the IS code (due to the fact that the BV 1030-1 already includes pure loss of stability on the wave crest), but there remains a nonnegligible probability of encountering large rolling angles for hull forms which have substantial righting lever alterations in waves, even for ships designed according to the BV 1030-1. Therefore, it was concluded to integrate a criterion into the code which takes into account the identified problem. When analysing the SGIT, namely the criteria suggested for parametric rolling, it was found that too many physical problems existed which prohibited to make further use of any of these criteria in the context of the BV 1030-1. The problems identified were the following (e.g. Krüger 2013, Gualeni 2015):

- The SGIT- Criteria do not sufficiently take into account that the real GZ-curve may deviate substantially from its linearization by GMφ. As a consequence, it is neglected that the natural roll period of the ship varies with the amplitude of the roll motion.

- The natural roll period of the ship is calculated from the still water stability, but it should be calculated from the stability in waves. And it does additionally vary in waves, as the stability permanently changes.

- The criteria do not take into account any combination of parametric rolling and pure loss of stability on the wave crest, and they additionally fail if the initial stability on the wave crest becomes negative. But that is exactly the failure mode which is to be addressed by the BV 1030-1 (in following seas).

- The computation of the righting lever curve in waves in the SGIT-regulations is incorrect, as it shall be computed for several longitudinal positions of the wave crest with free trimming at the same time. This is certainly not correct, as the real trim of a ship in longitudinal wave comes from the pitching motion. And this has a strong effect on the phase shift between heeling and pitching motion and therefore on the stability alterations.

Besides the above mentioned deficiencies of the SGIT, the BV 1030-1 already includes a stability regime in waves, and the newly developed criterion should be developed as an addendum to the existing code.

The newly implemented addendum is explained in the following, and it is now a mandatory part of the new DMS 1030-1 which has replaced the BV 1030-1.

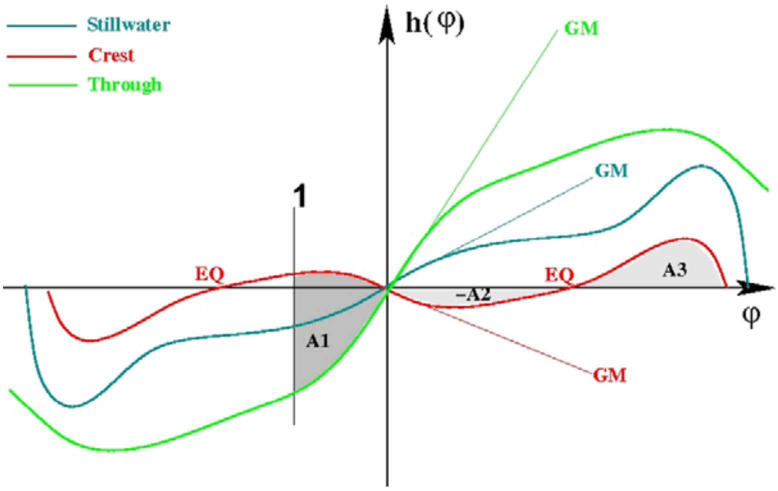

Figure 2: Stability in waves (following seas)

As the BV 1030-1 aims on minimum stability requirements, the critical situation for surface ships is certainly their operation following seas. This is due to the following reasons:

- The most critical resonances (two or one pitch cycle(s) per roll cycle) occur only in following seas if the stability is low or moderate.

- In following seas, the ship stays sufficiently long on the wave crest which makes a large roll angle more probable.

- Due to the low relative velocity between ship and waves, roll damping (e.g. from bilge keels) is less effective.

For these reasons, the addendum shall focus on the stability behavior in following seas. Fig. 2 shows a typical stability situation in following seas, and it shows the righting lever curves for crest (red), trough (green) condition as well as the still water condition (blue). The latter is not relevant for the problem addressed, nor is the linear representation of this curve. In Fig. 2, the initial stability on the wave crest has become negative, which means that the upright equilibrium is not stable anymore. If we assume for a moment that the wave crest situation would remain forever, then the ship will start to heel towards the stable equilibrium on the wave crest (EQ). If the ship reaches this equilibrium, she has taken up an energy level which is equivalent to the area under crest curve A2 (if dissipation by roll damping is neglected). As the remaining energy under the crest curve (A3) is larger than |A2|, the ship will not heel over the angle of vanishing stability and she will (after some time, damping included) return to the stable equilibrium EQ and she will then remain there. A long as A3 is larger than |A2|, the ship will not capsize due to pure loss of stability alone. The relation of A2 and A3 is mainly dominated by the wave height (for a given stability).

If one takes into account now that the ship is permanently oscillating between the wave crest and the wave trough situation, it is well known that this oscillation can build up a large and sudden roll motion (parametric roll). If the ship experiences such a roll motion, she sees the maximum roll angle when she is in the wave trough situation (green) and she is always close to the upright position when she is on the wave crest. In Fig. 2 we assume that when the ship is in the wave trough condition, she may have rolled to a certain roll angle, denoted by “1” in Fig. 2. If the ship is accelerated from the heeled position (1) to the upright position again, the wave passes by until the ship stays on the wave crest again in the upright position. During this heeling motion toward the upright position, the sea state feeds energy into the ship which can be expressed as the difference of the areas under the crest and the trough curve. In Fig. 2, this area difference is denoted by “A1”. When the ship reaches the upright position on the wave crest, she has taken up an energy equivalent to A1. When the ship now heels on the wave crest towards the crest equilibrium EQ, her energy level equals A1 + |A2| when she reaches this equilibrium. As the sum A1 + |A2| is certainly larger than A3, the ship will be forced over the angle of vanishing stability and she will capsize due to a combination of parametric rolling and pure loss of stability on the wave crest.

This concept was for the first time put forward by Kluwe (Kluwe 2009). He suggested 15 Degrees for the roll angle denoted by “1” in Fig. 2 and 40 Degrees as the maximum permissible roll angle. It is of further interest to underline that the Area A1 solely depends on the individual hull form of the ship and not on the stability (as this area is basically a difference between two righting lever curves, the ZCGsinφ and YCGcosφ- terms cancel out themselves), whereas the areas A2 and A3 depend on both the hull form and the stability. This criterion is therefore a strong motivation for the ship designer to minimize the righting lever alterations in following seas during hull form design. If he is not able to do so, the designer has to accept that the ship requires larger values of stability (on the crest) as a consequence.

In the context of the BV 1030-1 this criterion can easily be implemented if it is applied for the design wave which is already included in the BV. Rinke (Krüger 2014) has applied this criterion to several existing Navy Ships of the German Navy and he concluded that the Area A3 should have twice the value of the sum of the areas A1 and |A2|. Further, it was found that the GM on the wave crest must never become negative, which does then result in a crest righting lever which must be positive from zero to 40 degrees. (A3 then disappears, and A3 should amount 2A1). Concluded, the revised requirements of the DMS 1030-1 are the following (Russell, 2024):

- For the given design wave of λ equalling ship length, and the related wave height $H=\lambda/(10+0.05\lambda)$, the area under the wave crest curve up to 40 Degrees must amount to two times the area difference between trough and crest up to 15 Degrees (where the wave crest righting lever curve must be corrected for free surface effects).

- The stability on the wave crest (including free surface corrections) must meet a minimum value of 0.05m, which must occur before 40 Degrees. From the equilibrium up to 40 degrees, the righting lever on the wave crest must be positive.

It is further recommended to present the stability results in form of GM_{Required} -Curves. This is to prevent the situation that only one single criterion dominates the whole ship design or that damage stability deviates significantly from intact stability.

Openings. Originally, the treatment of openings was not foreseen in the BV 1030-1 as the hull (and the superstructure) needed to be watertight up to 60 degrees. During all stability calculations the only criterion was that the side of the bulkhead deck must never be submerged in any equilibrium (intact or damaged). This requirement was found to be too stringent, impeding to many interesting design alternatives. Consequently, the side of deck criterion was deleted and replaced by exactly the same opening concept as it is part of the SOLAS. Openings are subdivided into weathertight and not weathertight openings. During any equilibrium (the balance between heeling and righting levers), no openings are allowed to be submerged. Not weathertight openings may limit the range of stability if they become submerged. For the stability evaluation in waves, the freeboard of weathertight openings in the equilibrium is calculated as the average value between the crest and the trough condition. The means that a weathertight opening may be submerged either in crest or trough condition, provided, that the sum of both freeboards is clearly positive.

Ballast water. The DMS 1030-1 requires that no additional ballast water shall be taken in any loading condition for stability reasons. This means that the designer of a Navy Ship must be aware of the operational profile of the ship.

$GM_{Required}$-Curves. The DMS 1030-1 requires that curves of $GM_{Required}$ are to be computed for the intact and the damaged ship during the planning phase of any Navy Ship. These curves shall be computed without taking into account fluid shifting moments. It must be demonstrated that the limiting GM- values for the damaged condition do not differ significantly from those obtained for the intact condition. If there is a significant difference found, the design should be revised, otherwise it must be demonstrated by appropriate calculations that in none of desired operational conditions, excessive accelerations do occur.

DAMAGE STABILITY

A brief Introduction into the Damage Stability Part of the BV 1030-1

Other than the SOLAS, the damage stability part of the BV 1030-1 examines the same predefined loading conditions as the intact part (or part of them). This includes not only the exchange of fluids in case a filled tank is damaged, but also the correction for the free surface effects of all partly filled tanks which are not damaged. One should note that the BV does not permit filling levels of more than 95% of a tank, which results in the fact that especially Auxiliary Navy Vessels may have large initial free surface corrections. The BV 1030-1 damage stability standard is a deterministic standard with a maximum damage length L_l of

$$L_l = 0.18\ L_{DWL} - 3.6\text{m, but not more than 18m.} \qquad [3]$$

The maximum penetration depth is assumed not to breech the center line of the ship, the damage height is infinite. Like the SOLAS, any combination of lesser extent is to be examined. The BV generally requires to minimize the amount of longitudinal bulkheads, as the flooding should be kept as symmetrical as reasonably possible. During the damage stability evaluation, the following heeling levers have to be computed:

- Beam wind of 40 knots
- The shifting of fluids in tanks

The resulting equilibrium (including the heeling levers) must be less than 25 Degrees, and the residual righting lever must be larger than 0.05m up to 40 degrees or the submergence of a not weathertight opening. The range of positive stability from the equilibrium must be larger or equal to 15 degrees, for details see Russell 2024. Fig. 3 shows an example of the damage stability assessment according to BV 1030-1. It should be noted that the output of the stability assessment (both intact and damage) is quite extensive as this information is not only part of the stability booklet of the ship, but it is also used for crew training purposes in stability matters.

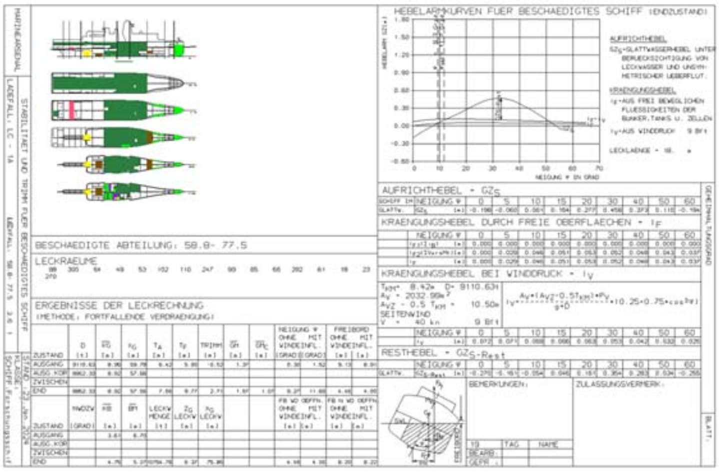

Figure 3: Damage stability assessment according to BV 1030-1

Improvements the BV 1030-1 Damage Stability Part

Intermediate stages of flooding. In the BV 1030-1, the assessment of intermediate stages of flooding was not explicitly mentioned. Nevertheless, the BAAINBw could request that intermediate stages should be analysed, but this was typically not done. The reason is that the BV requires that flooding shall be kept as symmetrical as ever possible, and the use of longitudinal bulkheads was restricted to the absolute minimum. For the same reason, cross flooding devices were not fitted. Another assumption was that the investigation of lesser extent damages was typically restricted to investigate only the effect of double bottom compartments. The effect of A- class bulkheads on the possible flooding sequence was never requested to analyse, although Navy Ships have quite complex internal subdivisions in this respect, see Fig. 4.

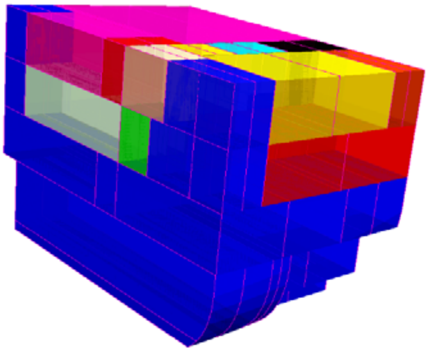

Figure 4: A-class sub-compartments of a single watertight compartment

The revision of the SOLAS with the 2009 and 2020 edition has put more emphasis on intermediate stages of flooding (see Russell 2024), and now, also cross flooding arrangements of cargo ships have to be checked against intermediate stages of flooding. Consequently, it was found that there was a certain gap between the commercial standard, represented by the SOLAS 2020, and the damage stability part of the BV 1030-1. In contrast to the IS-Code developments, it was found to be useful to integrate the most important updates of the SOLAS 2020 more or less directly into the damage stability part of the BV 1030-1 as follows:

- If cross- flooding devices are fitted, intermediate stages shall be considered and cross flooding times shall be computed. The procedure is equivalent to the former A266.
- If A-class bulkheads are fitted, the most critical lesser extent combination of not flooded sub compartments has to be determined and investigated, eventually together with cross flooding examinations.
- In cases of large compartments with unrestricted floodwater flow, these may be additionally investigated as being partly filled.

The maximum permissible heeling angle of any intermediate stage must not exceed 25 degrees (including wind and shifting of fluids in partly filled tanks), the maximum residual righting lever must be 50mm. This is roughly equivalent to the SOLAS 2020 requirement for passenger ships.

Openings. The consideration of openings was originally not foreseen in the BV as it was required to design the complete hull and superstructure watertight until 60 degree. During the stability assessment (both intact and damage) it had to be checked that the deck edge must never be submerged. This concept was replaced by the opening concept which is used in the SOLAS 2020 standard, distinguishing between weathertight and not weathertight openings. None of these openings might be submerged during any equilibrium floating, but weathertight openings are allowed to submerge during the calculation of the righting levers.

Watertight doors. The new stability standard DMS 1030-1 does generally not permit the installation of watertight doors below the bulkhead deck.

APPLICATION TO NAVY SHIP DESIGN

Intact stability

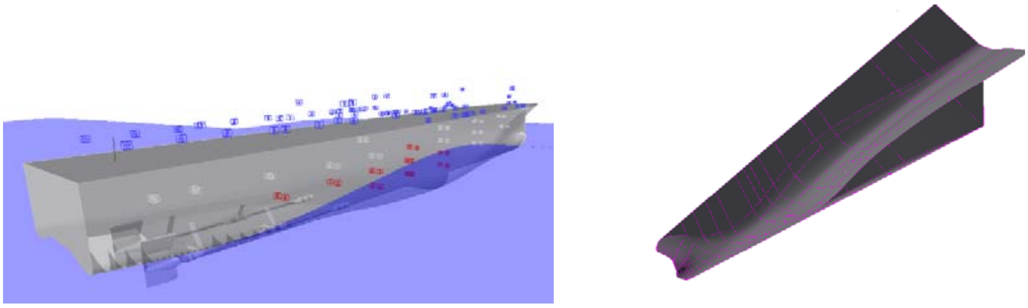

Figure 5: Navy Ship in wave crest condition of the design wave and a hull form optimized for righting lever alterations

The newly implemented stability criterion puts an additional challenge on the hull form design of all Navy Ships built according to this new standard. Besides optimizing the hydrodynamics with respect to minimum speed power requirement and optimal underwater pressure signature, the designer must now additionally try to minimize the righting lever alterations in waves (see Fig. 5, left, and Fig. 2). This is certainly an additional design constraint for the development of the hull form and the subdivision. To keep the good hydrodynamics (also with respect to the underwater noise signature) of existing designs, it was found beneficial to conduct the following strategy during hull form design, which increases the stability on the wave crest and reduces the stability in the trough at the same time, while keeping the basic hydrodynamic efficiency of the hull:

- The LCB should be as far aft as reasonably possible. This leads to an increased trim down by stern in the wave crest condition and this increases the phase shift between rolling and pitching motion. At the same time it is also beneficial to design the ship in such a way that the ship will always operate with slight trim down by stern. This should be taken into account when optimizing the hydrodynamics of the aft body.

- The bilge radius should be as large as reasonably possible. This increases the immersion of the ship on the wave crest and increases the effective water plane moment of inertia.

- Where ever possible, buoyancy should be moved to the outer parts of the hull which are immersed in the crest condition.

Hulls which have been designed according to this strategy easily comply with the area ratio requirement. An additional problem now arises for all Navy Supply Vessels: As these ships have large tank capacities for aircraft fuel and marine diesel, this results in substantial free surfaces at small heeling angles, resulting in a righting lever curve which immediately deviates from its initial GM (see Fig. 6).

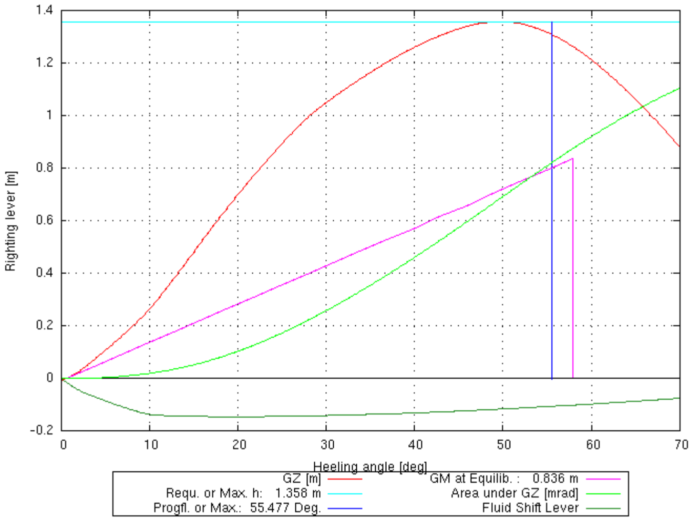

Figure 6: Righting lever curve (red) of a Navy Auxiliary for a loading condition with large free surfaces

In this context it must be noted that all fluid shifting moments have to be directly calculated, taking into account heel and free trimming. As the maximum permissible filling level of all tanks is 95%, this leads to large initial free surfaces which decrease with larger heeling angles. The wave crest curve in the area ratio criterion must be corrected for free surface effects. This may result in a situation where it is reasonable to subdivide large tanks to reduce the initial free surface.

It is further well possible that the ship may be sensitive with respect to trim. This mostly holds for Navy Auxiliaries which have a larger variety of possible loading conditions compared to Navy Combatants. For these ships, the tank arrangement must be well designed for all possible operating conditions as only limited possibilities exist to use extra ballast water.

Damage stability

The revised damage stability regulations of the DMS-1030 result in two major challenges and opportunities for the design of the hull and the internal subdivision: First of all, the position of the bulkhead deck can be selected freely now, as it is explicitly allowed that the bulkhead deck becomes submerged during a damage case, provided, no openings become submerged. Secondly, it puts a hard challenge on the ship design if no water tight doors are allowed below the bulkhead deck. This is hardly a problem for Navy Combatants, but some Navy Auxiliaries are strongly restricted in their operability when heavy goods need to be transferred longitudinally below the bulkhead deck.

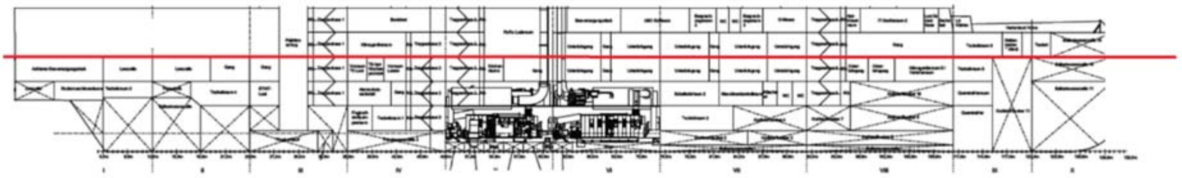

Figure 7: Possible location of the bulkhead deck (red)

This leads to one possible solution that the bulkhead deck must not necessarily be the uppermost water tight deck. It is now well possible to lower the bulkhead deck and to extent the watertight transversal bulkheads into the superstructure, see Fig. 7. This leads to an increased reserve buoyancy on one hand and allows the installation of water tight doors on the bulkhead deck and the superstructure decks. Due to the increased reserve buoyancy, the compartments can become longer which is cost effective. Below the bulkhead deck of Navy Auxiliaries, there may exist the possibility to install water tight doors in the main traffic routes, provided, the ship fulfils all damage stability requirements when the doors of interest are assumed to be open, see Fig. 8.

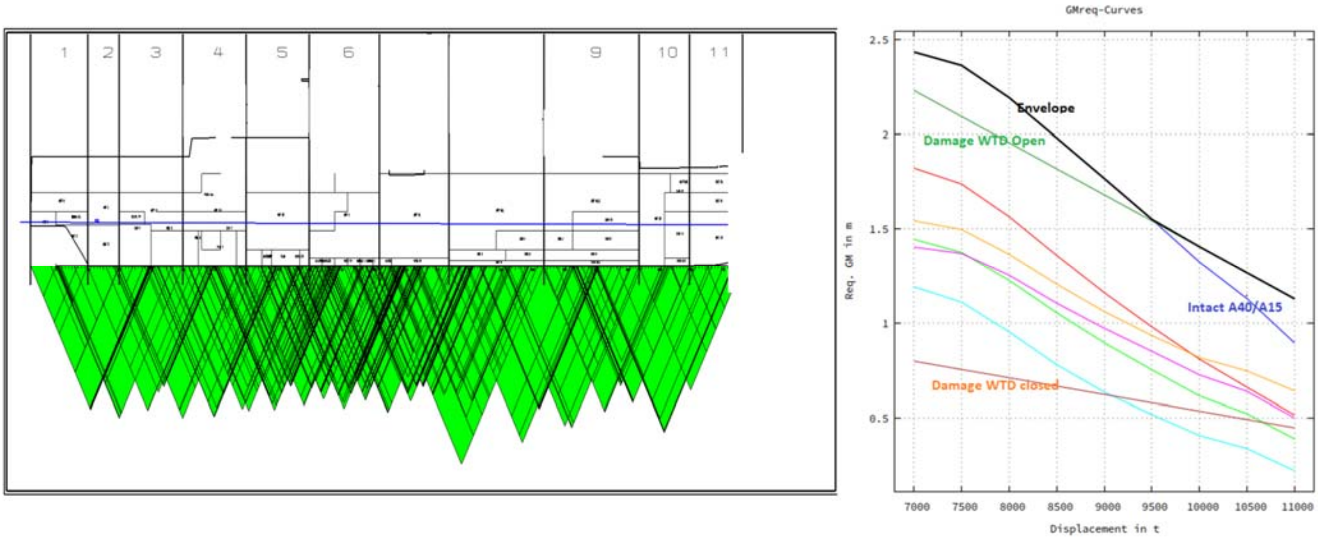

Figure 8: Damage stability assessment and GM$_{\text{Required}}$- Curves

Fig, 8, left, shows the results of the damage stability assessment where it is assumed that the most critical water tight door is open. Due to the large reserve buoyancy, this does not pose large problems for the damage stability assessment. The curves of $GM_{Required}$ (Fig. 8, right) show that the required values of GM are not substantially larger compared to the intact stability values, even if the most critical water tight door is assumed do be open. The damage stability curve denoted by “Damage WTD closed” shows the effect of the most critical open watertight door on the damage stability.

CONCLUSIONS

The present paper has given an insight into recent developments of the German Navy Stability Code DMS 1030-1 (former BV 1030-1) and to the resulting effects on Navy Ship design. The necessity to update the code was shown, and it was also discussed when it seemed to be reasonable to integrate well proven elements of stability standards for commercial ships into the BV code. It was also shown that for the problem of intact stability in waves, it seemed to be useful to deviate from available commercial standards. The idea that the limiting values of GM shall not differ substantially between intact and damaged condition, which is not reflected in commercial standards, assures that the design of a Navy Ship is well balanced with respect to stability. For typical ship design problems, recommendations have been presented how to deal with this new standard. Most important is that the stability assessment of a Navy Ship is thoroughly performed during the very first stages of the planning phase.

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