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Introduction to the Concept of the German Navy Stability Standard DMS 1030-1

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ABSTRACT

Following World War II and the founding of the German Armed Forces, lessons learned from ship accidents as well as scientific advancements called for a new stability regulation specific to the Federal German Navy, the BV 103. While certain minor modifications have been made through the years since then, the basic concept behind this standard still remains effective up to the succeeding regulation DMS 1030-1 of this day. With the most recent additions it has been proven to keep up with and even outclass the safety levels of current civilian stability regulations. The key to this success is early adaptation of available scientific techniques outside the usual constraints of large regulatory bodies.

KEY WORDS

Stability; Standard; German Navy; Regulation; Code

INTRODUCTION

Just by their designed purpose, naval vessels are subject to use cases and loads different from regular civilian merchant craft. At the same time, they still have to work on a day-to-day basis during peacetime operations. As sufficient stability and floatability form the necessary baseline of any functioning ship, having an appropriate regulation for these parameters has a major impact on the viability of a ship design and needs to accommodate both scenarios.

Therefore, the German Armed Forces (Bundeswehr) decided early after its (re)founding past World War II, that a specific stability standard was needed for the new Federal German Navy (Bundesmarine), especially since existing regulations at that time considered stability issues very simplified, if at all. This code was originally called BV (Bauvorschrift, meaning construction regulation) 103. It was later renumbered to BV 1033-1, according to the numerical identifier for "intact stability" as per the structured breakdown in the official German list of naval components and assemblies, "-1" denoting the applicability for surface vessels.

In 2001, it was again renumbered to BV 1030-1, referring to the numerical identifier for "stability" as a whole, as it also integrated inclining test requirements now. Following a recent new approach in requirement engineering of the 2020s within the German procurement organization BAAINBw (Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support), the code was renamed DMS (Deutscher Marinestandard, meaning German Navy Standard) 1030-1.

This paper explains the rationale behind the creation of the original standard in the 1960s, its philosophy of stability criteria and the principal steps in its further development into the most recent edition DMS 1030-1 of 2023. A short comparison of safety levels with respect to current civilian standards is also outlined within the paper. It thereby provides the necessary basic understanding, given by the actual regulatory body responsible for said regulation, to further evaluate its impact on current as well as future navy ship designs. These design impacts themselves and the improvements to the standard derived from them are then presented by Krüger (2024).

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HISTORICAL CONTEXT

Early Regulation Efforts

Historically, the very first regulations for seagoing ships established in the 19th century considered reserve buoyancy, i.e. sufficient freeboard, to be of most importance for ship safety. In principle, these early considerations still remain in effect up to today in form of the International Convention on Load Lines (ICLL), with every ship above a certain size being subject to corresponding calculations and markings.

Stability issues were of course also considered, at least academically, over the course of several past centuries. However, most of the time this work focused on the initial stability in form of the metacentric height GM. While it was found around the same time as the first local freeboard regulations entered into force, that ships with the same GM might have different stability issues at higher heeling angles (Reed, 1868), no mandatory rules for stability were established for quite some time after that.

Regulation efforts at those times were of course also impeded by choosing international competition rather than cooperation. Following the TITANIC disaster for example, a very early version of SOLAS was discussed for the first time internationally, but was thwarted by the outbreak of World War I. Both the impact of TITANIC as well as the World Wars also meant, that the safety of damaged ships got a lot more focus than intact stability. And even then, the safety of damaged ships was mostly considered a problem to be solved rather with freeboard and subdivision than with stability requirements – that might have developed differently if TITANIC had capsized before it sunk due to progressive flooding.

Therefore, safe ship design from a stability point of view relied mostly on experience and best practice by naval architects and generally not on mandatory requirements. Even after Rahola (1939) came up with his famous basic intact stability criteria, it was not until late into the 1960s that the Inter-Governmental Maritime Consultative Organization (IMCO, todays International Maritime Organization IMO) finally adopted these officially, albeit first as a recommendation (!) for fishing vessels only, becoming mandatory for all ships as late as with the 2008 International Code on Intact Stability (IS Code). Mandatory damage stability criteria also were not available until 1960 at the earliest, and even then, they were very basic and not applicable for all ship types.

Rationale for a New German Navy Stability Standard

The Federal German Navy was founded on January 2, 1956 after the reestablishment of the German Armed Forces in late 1955. In its very early days, it consisted mostly of ship designs from World War II as well as ships bought from allies. However, the new role of Germany within NATO as well as technological advancements soon required a new quality and quantity of naval ships and corresponding designs.

On the other hand, rebuilding efforts after World War II lead to an increase in commercial shipbuilding activity around the world, now trying to keep to the non-mandatory Rahola criteria as the newest best practice as far as reasonably possible. Having lost the war, Germany was limited to a certain size of ships under its flag, which then were designed and operated with very little regard even to these still very basic criteria to maximize payload. As a result of this, a lot of stability accidents including capsizings of undamaged German-flagged merchant ships happened in the 1940s and 1950s, which were noticed especially in the German scientific community of the time (Wendel, 1958).

The German government as the responsible flag authority of course had to investigate these accidents and therefore cooperated closely with these scientific institutions, in this case the Technical University of Hanover and the University of Hamburg. Implementing the German lessons learned from these investigations on an international level for the merchant navy had to wait due to the number of nations involved, as described above. Germany however took initiative trying to avoid the failure modes leading to said accidents at least for its new military, as regulations for warships were in the own interest of each nation and therefore excluded from IMO regulations up to this day. Furthermore, the special stability needs due to the varying military usage of navy ships are not accounted for by civilian standards, e.g. maneuvering a tight turning circle at full speed for example.

Therefore, it was decided to create a new stability standard for the Federal German Navy together with the mentioned German scientific institutions. Ironically, the first ship these rules were applied to was the sail training vessel GORCH FOCK of 1958, a modified design of the 1930s and in service up to this day. A preliminary version of the standard then became official in 1961, incorporating full-scale stability measurements and experiences from designing and operating the GORCH FOCK, and applied to other vessels as well.

As a baseline, the German researchers looked at the Rahola criteria (Arndt, 1965), as they were best practice at the time. While they appreciated that these took the whole righting lever curve beyond the initial stability GM into account, they reasoned that general safe criteria for the righting lever curve cannot be formulated without considering the individual inclining levers for each ship and load case as well. In principle, they also looked back into the work of Reed (1868), who had already found out about decisive effects of the same inclining lever acting on ships with different righting levers, and argued to combine his approach (with modified and additional inclining levers) with modified criteria of Rahola.

In addition, and as their investigations into the post-war accidents had shown, it was also deemed necessary to formulate requirements for stability in a seaway. Due to the failure modes encountered in these accidents, stability in longitudinal waves had been found especially important to consider.

These two main factors, comparison of individual righting versus inclining levers and consideration of stability in a seaway, form the successful backbone of the German Navy stability standard up to this day and are at least in combination still somewhat unique to other regulations.

REGULATORY FRAMEWORK OF THE DMS 1030-1

Every basic concept explained in this section applies to the original edition of BV 103 of the 1960s as well as its later variants BV 1033-1/1030-1 in several following editions and the newest DMS 1030-1. For ease of readability however, within the text the regulation referred to will always be DMS 1030-1, with differences to earlier editions being outlined as they apply.

Universal Design Assumptions

The starting point for applying DMS 1030-1 is given by the so-called operating area group, see Table 1, which has to be chosen depending on the use cases of the ships by the navy and by the procurement organization. Historically, larger ships like frigates, destroyers and tankers were assigned to the highest operating area group A, medium-sized ships like corvettes and squadron tenders were designed for operating area B, while operating area C was intended for small combatants like minehunters and offshore patrol vessels. These three operating areas were already present in the first version of the standard and have remained unchanged to this day. The operating areas D to F were added later and are used for small craft, which will not be subject of this paper.

Table 1: Operating area groups in DMS 1030-1 (BAAINBw, 2023)

Operating area group	Operating area	Design wind speed in knots	Additional limitations
A	Worldwide, unlimited	90	n/a
B	Worldwide, outside tropical storms	70	n/a
C	Coastal	50	n/a
D, E, F	Shore-based, harbors, inland	20 - 40	restricted wave height and distance to the shore, decreasing from D to F

Nowadays, the military focus of the German Navy has generally shifted from operating mainly in the Baltic and North Sea to being able to perform missions worldwide, while relying more on single ships per mission rather than small squadrons. Thereby range and endurance considerations have made former small ship types bigger and so operating area group A is demanded more and more as a de-facto default for most of the ongoing newbuilds of the German Navy.

Then there are several standard load cases defined in DMS 1030-1, the most important ones are given in Table 2. These have been heavily modified in their total extent, numbering structure and detailed definition since the original BV 103, but the principles shown in Table 2 have always been implemented in the standard. These standard load cases consider the special purpose of navy ships with many details, e.g. with respect to endurance requirements and ammunition depletion during the mission they are designed for. There are some additional standard load cases defined for special mission requirements, but they are seldom design-driving and therefore omitted in this paper.

Each of the seagoing load cases 1, 1A, 2 and 2A however also has a variant with heavy ice accretion of up to 15 cm thickness, depending on the operating area group. As Figure 1 shows, this is not an academic problem, because being able to operate all-year around also in colder regions is mission-critical for a navy faced with potential adversaries in said cold regions. These ice load cases do not have to fulfil damage stability requirements, but are regularly design-driving for intact stability, as several hundred tons of ice mass at a very high center of gravity have to be considered in the calculations.

Table 2: Standard load cases in DMS 1030-1 (BAAINBw, 2023)

Load case ID	Designation	Explanation
0	Light displacement	Non-seagoing, empty vessel with crew and specified equipment and system fillings
0V	Short move displacement	Same as load case 0, but with additional ballast due to trim restrictions for docking and warping
1	Limit displacement	End of mission, ammunition only partly depleted, other consumables fully depleted
1A	End-of-life limit displacement	Same as load case 1, but with commissioning reserves
2	Full-load displacement	Begin of mission
2A	End-of-life full-load displacement	Design load case, same as load case 2, but with commissioning reserves

Another factor not to be overlooked is the commissioning reserve, which started at 2 to 6 percent of the light ship weight at delivery (depending on the ship type) in older versions of the standard. It has now been increased to 10 percent of this value and at a higher center of gravity, as the lifetime of German Navy ships tends to be extended more and more and lots of weight-intensive retrofits accumulate over this period, so that several older ship classes now operate at their stability limits and can only be modified further with expensive countermeasures, if at all. As a side note, the German Navy also uses a realistic person weight derived from several actual measuring campaigns resulting in 91 kg per soldier, which of course is also used in other areas such as the design of life saving equipment.

Figure 1: Ice accretion (Source: NATO)

Especially for naval auxiliaries carrying large amount of supplies, additional variants and/or intermediate stages of the mentioned load cases need to be added. As per DMS 1030-1 all tank fillings are assumed at a maximum of 95% filling of the net tank volume and the tanks are actually built to physically achieve only this limit. This is done to achieve at least a basic protection against hull ruptures from underwater explosion shock pressures by allowing the incompressible fluids to move. As a side effect, this also leads to a clearly defined maximum free surface moment of the tanks.

In this context, it is important to note that in DMS 1030-1 the effect of free surfaces is always considered as an inclining lever l_f with the actual tank moments, not some simplification using the surface moment of inertia, see Equation 1 with p denoting the individual tank masses and b(φ) denoting the tank cross-curves of stability.

$$l_f = \frac{\sum_i p_i \cdot b_i(\varphi)}{\Delta} \qquad [1]$$

This inclining lever is always present in all load and damage cases and used in every stability criterion. In addition, all hydrostatic calculations are to be done with free instead of fixed trim.

As a consequence, this also means that the actual righting lever curve has to be treated and presented separately without free surface correction in the German Navy stability documentation. This documentation follows a unified approach for every ship class designed according to DMS 1030-1 and presents a lot of data at a quick glance on a single page per load or damage case, which is useful for training purposes as well as quick decision making under pressure in combat. For this purpose and some ship classes, a stability computing software with decision making support is developed by the Bundeswehr itself and supplied to the contractors responsible for the automation software, whose hardware (operating station and sensors) it then uses.

The complications mentioned in the paragraphs before had to be argued for quite a lot back in the 1960s – and even today for some projects –, as they meant a calculation effort at the yards hitherto unknown, and later also made a solid business case for the increasing use of computers and corresponding software programs in naval architecture developed in cooperation with the German scientific community.

General Criteria Approach

As a first step for every load or damage case to be investigated according to DMS 1030-1, a lever balance with the applicable righting and inclining levers has to be established. Then, all of the stability criteria follow the same basic concept, as two conditions have to be satisfied. Firstly, the inclining angle has to stay below a certain value, depending on the condition (still water, seaway, damaged, special) and operating area group. Secondly, a reference angle is determined, at which a minimum residual righting lever "GZ_S-Rest" has to be reached, see Figure 2. The reference angle Φ_{ref} for the intact condition is then determined by

$$\phi_{ref} = max\left(2 \cdot \phi_{equi} + 5°; 35°\right) \qquad [2]$$

from the inclining angle at the equilibrium Φ_{equi}, while the reference angle for damaged conditions is derived from

$$\phi_{equi} + 15° \leq \phi_{ref} \leq min\left(40°; \phi_{df}\right) \qquad [3]$$

with Φ_{df} denoting the angle of downflooding. The limit for the residual righting lever depends on the inclining angle in the equilibrium, but is never lower than 0.1 m in the intact and 0.05 m in the damaged condition.

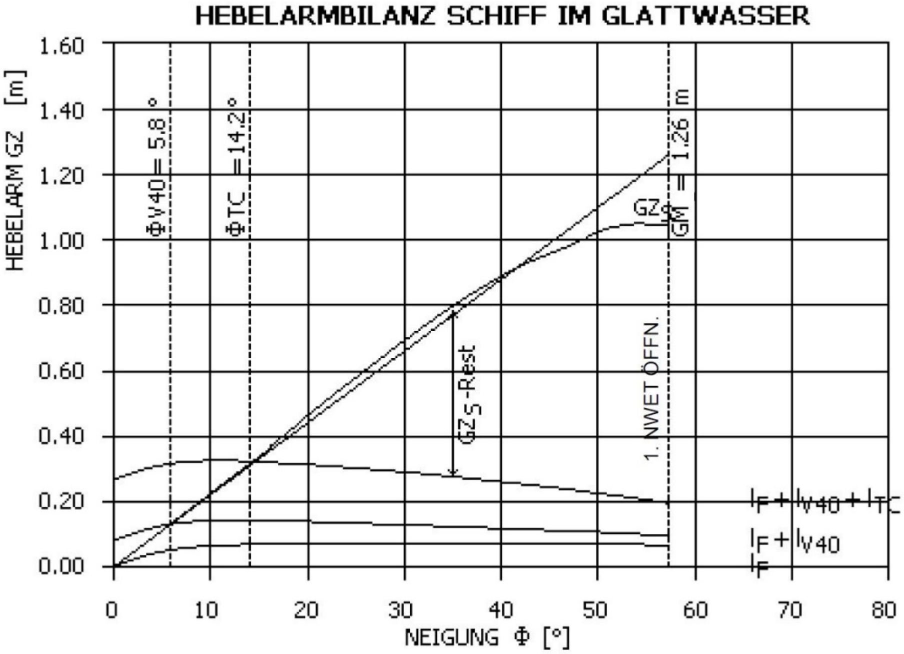

Figure 2: Typical DMS 1030-1 lever balance with inclining levers, reference angle and residual righting lever (BAAINBw, 2023)

This two-part approach allows to account for several requirements. First off, the inclining angle part of the criteria is able to consider limits set by the crew and operations on board and is in itself not primarily driven by safety concerns. The necessary safety is then given by the residual righting lever part of the criteria, which is intelligently coupled with the inclining angle at the equilibrium resulting from the applied inclining levers. Due to the third factor, the use of minimum values for the reference angle, at which the residual righting lever is to be achieved, a minimum safety level is always guaranteed, even for very little inclining levers. Lastly and maybe most importantly, the reference angle concept implicitly also leads to restoring energy reserves in addition to the pure static requirements, as should be immediately clear from Figure 2, if the areas between the righting and inclining lever curves left and right of the equilibrium angle (in this case Φ_{TC}) up to the reference angle (in this case 35°) are compared.

As a boundary condition of course, sufficient freeboard with regard to watertight and weathertight integrity has to be achieved for the stability assessment. Historically, the revisions of BV 103/1033-1/1030-1 up to 2015 required the bulkhead deck to be not submerged in any condition. Since per the standard and in difference to civilian regulations the bulkhead deck had to be completely watertight anyway and as a result of investigations explained further down below, it was decided for the 2015 revision of BV 1030-1 to review this approach and now allow consideration of individual watertight and weathertight openings in the same way as in civilian standards.

Intact Stability in Still Water

The intact stability requirements of DMS 1030-1 for still water conditions focus on the main use cases of navy ships in general as well as the individual ship type. This means, that as a baseline every ship subjected to the regulation has to be able to perform a turning circle at maximum speed and maximum rudder angle in every seagoing standard load case, while at the same time being subjected to a steady cross wind of 40 knots and the actual fluid shifting moments, with sufficient stability. This means that a maximum heeling angle of 15° and a minimum residual righting lever at the reference angle of in this case 35° have to be complied with. These criteria have to be met even with up to 15 cm of ice accretion, depending on the operating area group. Until BV 1030-1 was revised in 2015, this criterion with ice accretion often was design-driving in the intact condition.

Figure 3: High speed turning circle (Source: Bundeswehr / Carsten Vennemann)

As Figure 3 shows, the actual turning circle at full rudder can be quite tight, while the speed loss might be quite significant. Because the actual turning circle parameters can be quite difficult to compute properly (and were nigh impossible to do back in the 1960s), DMS 1030-1 uses an equation with an empirical factor C_D derived from a range of real ship types (Arndt, 1965):

$$l_{TC} = \frac{C_D \cdot v_{max}^2 \cdot (\overline{KG} - 0.5 \cdot T)}{g \cdot L_{DWL}} \cdot \cos \Phi \tag{4}$$

As a matter of fact, and despite all shifts in naval design since the 1960s, this factor (default value 0.3) holds up quite well until this day if no other data is available. The wind inclining lever is then derived from Equation 5, the factor 0.25 ensuring proper developing of values at higher angles (Arndt, 1965).

$$l_V = \frac{A_V \cdot (A_{VZ} - 0.5 \cdot T)}{\Delta \cdot g} \cdot p_V \cdot (0.25 + 0.75 \cdot \cos^3 \Phi) \tag{5}$$

Explicit values for the wind pressure are prescribed in the standard for every 10 knots increase of wind speed. To determine the windage area A_V, individual drag coefficients for different shapes are required in the standard, e.g. for lattice structures often found on radars in older navy ship designs.

Factors other than turning circle, wind and free surfaces in still water conditions are then considered depending on the ship type. Replenishing ships for example need to be able to withstand an inclining lever of its replenishment-at-sea (RAS) gear, basically a pulling force (equivalent to the breaking strength of the gear already including safety margins) acting very high up in the supply mast. This is because for technical reasons the RAS gear is fastened much higher on the supplying ship than on the supplied ship, see Figure 4. The criterion for the RAS residual righting lever at the reference angle of 35° remains the same as for other criteria, the permissible inclining angle however is project-specific to the type of supply ship, but generally lower than 15°.

Figure 4: RAS maneuver (Source: Bundeswehr)

Tugs are designed using a similar approach to the RAS inclining lever, albeit with slightly modified parameters. In addition, smaller ships (operating area group E especially) are generally subject to unsymmetrical loading criteria in DMS 1030-1 as they are vulnerable to persons shifting positions, but are as mentioned omitted in this paper. Lastly, if the ship type calls for it, project-specific inclining levers can very easily be integrated using the described criteria philosophy.

Intact Stability in a Seaway

In addition to the intact stability requirements in still water, DMS 1030-1 requires every ship in intact condition to be resistant to lateral wind pressure as per Table 1, while at the same time being underway in longitudinal waves. This combination of longitudinal and lateral influences might seem contradictory and too conservative at first, but in conditions with such high wind speeds, wind direction might change much quicker than wave direction (Arndt, 1965).

The design wave length λ in DMS 1030-1 is set to the length between perpendiculars L_{PP} of the ship, while the wave height H is derived from this length as per Equation 6 and both are then combined to a sinusoidal wave. It should be noted that the aft perpendicular (AP) of German Navy ships usually is defined by the intersection of the design waterline with the transom instead of the civilian definition with AP at the rudder post.

$$H = \frac{\lambda}{10 + 0.05 \cdot \lambda} \qquad [6]$$

Using Equation 6, for a typical navy ship of 120 m in length a wave height of 7.5 m is the result, resulting in a wave steepness of 1/16. On the one hand, this is quite a large design wave for this ship size, especially compared to some other standards. On the other hand, this steepness is close to the breaking limit of natural waves, so the approach is also very conservative.

With this wave length, righting and inclining levers for three conditions have to be calculated and evaluated for different criteria: ship on wave crest, ship in wave trough and the average of these two, called “ship in a seaway”. Historically, the investigation of different wave phases between these extrema as well as trochoidal waves had also been used in the standard, but were omitted at some time in favor of the current conservative approach of just these three conditions.

In the condition “ship in a seaway”, the inclining levers due to free surfaces and wind pressure as per Equation 1 and 5 are combined and then subjected to the general criteria approach explained above. The permissible inclining angle is depending on the operating area group and can be up to 25° for operating area group A, leading to a reference angle of up to 55°, which then can be of consequence design-wise for the placement of non-weathertight openings such as large gas turbine air intakes.

In a second requirement, the worst of these three righting lever curves, usually ship on wave crest, has to be subjected to the inclining lever curve from free surfaces. It then still has to achieve positive residual righting lever values all the way from the equilibrium with this inclining lever up to 45° inclining angle, reaching 0.05 m at least once during this range. Both requirements have to be reached including ice accretion also, although the wind speeds for the first requirement may be reduced in this case to as low as 40 knots, depending on the operating area group.

With these two steps, the German Navy stability standard had already considered two out of the five failure modes as per the IMO Second-Generation Intact Stability Criteria, namely “dead ship” and “pure loss of stability”, back in the 1960s, i.e. several decades beforehand. This was only possible due to the circumstances mentioned in the historical summary above, which presented Germany with the opportunity to come up with something better than what was (insufficient) best practice at that time. One decisive factor to achieve this was of course also the relatively small and at the same time scientifically open-minded regulatory body responsible for the German Navy stability, being able to make quick decisions, which has continued to be like that until this day. In that sense, in the early 2010s it was decided to enhance the German Navy stability standard, finally resulting in BV 1030-1 of 2015 with an additional criterion for the intact stability in waves (Krüger, 2012).

This was deemed necessary because the design of German Navy ships had changed quite a bit over the 50 years since its founding. These design changes can be attributed to a number of factors. One major step was the increased use of helicopters now requiring large flight decks, a trend which also afflicted supply vessels. Another one was the introduction of more complex gun systems requiring more space on deck as well as below deck at the bow. Both trends are illustrated by Figure 5 with two ship pairs, each of a comparable base type but several decades apart.

Then there was a general trend to increase the endurance of ships, leading to larger tank volumes. With growing endurance – and also increasing demands for more comfort on board, i.e. bigger and less crowded rooms, by crews of younger generations – the ship hulls got bulkier and have much more enclosed decks now. At the same time service speed requirements were lowered from 35+ knots down to 20 to 30 knots due to changes in mission profiles, allowing for this increase in block and midship section coefficient in the first place.

Figure 5: Development of German Navy ship types (Sources: Bundeswehr / Christian Klöcking, Marcel Kröncke and Carsten Vennemann)

As a consequence of more flared frames and increased bulkiness, German Navy ships got generally more susceptible to righting lever alterations in waves and therefore parametric excitation of roll motions, which called for an additional criterion to limit these. The scientific background applied for this is described in more detail by Kluwe (2009), Krüger (2012) and Krüger (2024). Using the conditions ship on wave crest GZ_C and ship in wave trough GZ_T in DMS 1030-1, the criterion is then formulated using Equation 7 with the areas defined in Figure 6.

$$A_2 \overset{!}{\geq} 2 \cdot A_1 \qquad [7]$$

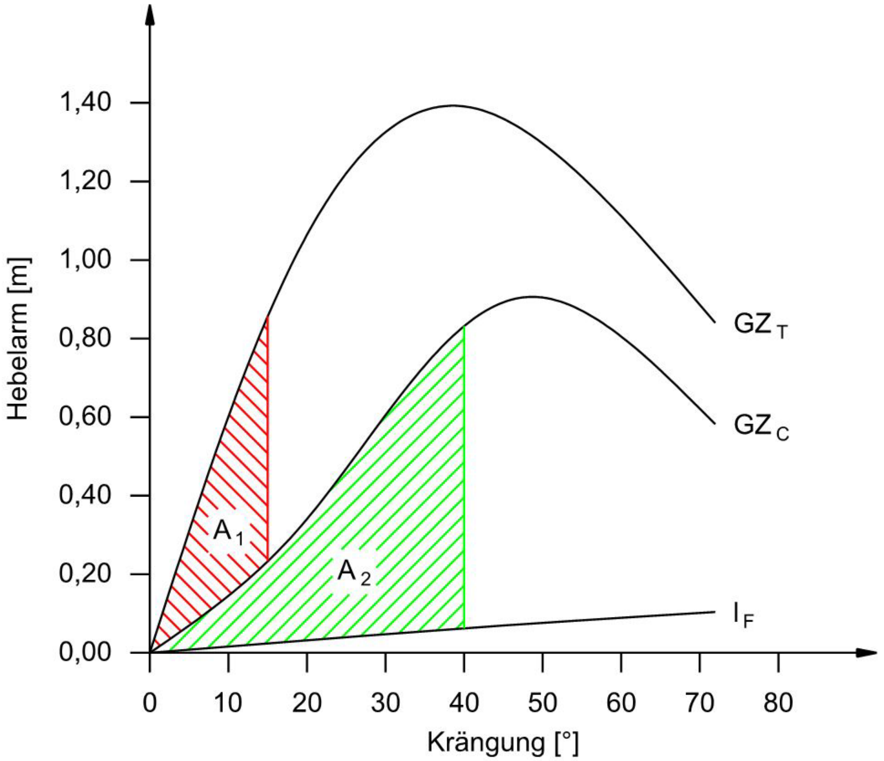

Figure 6: DMS 1030-1 area criterion (BAAINBw, 2023)

With this new area criterion, DMS 1030-1 now also directly addresses a third failure mode of the IMO Second-Generation Intact Stability Criteria, namely "parametric rolling". Ever since its introduction in 2015, it has now become the design-driving intact stability criterion of DMS 1030-1 in several projects, especially if ice accretion is involved. This then leads designers to rethink their approaches and reintroduce some features from older proven hull forms, such as V-hulls, larger bilge radii and lines with less flare of frames and buttocks (especially in the bow area), because the righting lever alterations in waves are primarily governed by the change of waterplane area in vertical direction.

Damage Stability

The damage stability in DMS 1030-1 follows a deterministic approach with a given damage length as per Equation 8. Keeping an absolute upper limit for the damage length is considered to be a sufficient compromise as a result of investigations into the safety levels described further down below, even for larger ship types.

$$L_l = min(0.18 \cdot L_{DWL} - 3.6\ m; 18\ m) \qquad [8]$$

This damage length is then to be applied with half the ships breadth penetration depth (up to centerline and excluding centerline bulkheads, if applicable) and unlimited penetration height at any given point (!) in longitudinal direction. That means there is not a specific number of compartments to be damaged like in some civilian standards, which could be directly derived from the damage length, but instead the actual damage resulting from the described cuboid is to be assumed, so compartment-internal additional subdivisions are also of importance. If a lesser extent of this baseline damage at one position leads to a more severe condition, this condition is to be evaluated with regard to the damage stability criteria and shown in the stability documentation. The same principle holds true for several cases of intermediate flooding stages differentiated in DMS 1030-1.

With respect to watertight integrity, there has to be one defined bulkhead deck as a horizontal watertight barrier to prevent up- and downflooding, which means any staircase or elevator casing penetrating the bulkhead deck also has to be watertight at minimum at that deck, but not necessarily below the bulkhead deck. Doors and hatches below the bulkhead deck are not permitted since the 2022 revision of DMS 1030-1 and are assumed open if above the bulkhead deck (no V-lines). This has two main reasons derived from experience: firstly, in general operation of the ship and especially in combat any existing opening will generate traffic of persons and often remain open, when it should not be. This has been proven time and again to be a contributing factor to many total losses including ships of foreign navies. Secondly, it presents an immense challenge to design a door or hatch, which can uphold its integrity even after a shock incident from weapon damage. For these reasons, if a door or hatch is to be fitted below the bulkhead deck as an exemption, it will be considered open in the damage stability evaluations. From experience, ammunition and cold storage rooms provide a sufficient pressure resistance to be assumed watertight in DMS 1030-1.

The DMS 1030-1 damage stability criteria follow the same general concept as the intact stability criteria, i.e. a lever balance has to be established first, in this case with the inclining levers from free surfaces and 40 knots of wind pressure. It should be noted in this context, that ice accretion as well as waves are not considered in the damaged condition in DMS 1030-1. Damage stability however is required for every seagoing load case of the intact condition, with an exchange of fluids in damaged tanks to sea water, if applicable.

The maximum permissible inclining angle at the equilibrium from this lever balance has to be less or equal than 25°. Cross-flooding devices to achieve this angle are generally not permitted in the standard. The latter also implicitly drives designers to choose a more symmetrical layout, which has additional value beyond stability in combat situations, where situational awareness and short routes are beneficial. The reference angle then has to be reached as per Equation 2, with at least 0.05 m of residual righting lever in the range between the equilibrium and 40° inclining angle and at the same time a minimum righting lever range of at least 15° before reaching 40° heeling angle or the downflooding angle. Again, the applied reference angle concept also means that there is an inherent level of safety against residual energy from rolling motion even in the damaged condition.

With regard to freeboard requirements, until 2015 any submergence of the bulkhead deck described above was the permissible limit within the standard. Starting with the 2015 revision of BV 1030-1, it was then decided to switch freeboard requirements from considering a whole deck, which had to be completely watertight anyway, to considering individual openings. This had been deemed acceptable from a safety point of view (see also below), allowed designers more freedom of arrangement for new ships, while at the same time making no discernible difference in evaluating already existing designs. Since then, the minimum freeboard in the damaged condition required in DMS 1030-1 is 0.5 m for weathertight openings. With the latest revision of DMS 1030-1, it was decided to enhance this approach with a requirement of half the height of the design wave as per Equation 6 for non-weathertight openings to consider the effect of a seaway also in the damaged condition.

SAFETY LEVELS

Comparison with 2008 IS Code

The safety level of intact ships in a seaway can be quantified using the so-called Insufficient Stability Event Index (ISEI), developed by the Institute of Ship Design and Ship Safety at Hamburg University of Technology (Kluwe, 2009). A summarized introduction into the concept is given by Krüger (2022). In very short terms, an ISEI value indicates the probability of a specific failure criterion of a ship – generally a special criterion for capsizing is used, but the concept allows for other criteria also – to be reached during a calculation of a significant timeframe in a seaway with a significant statistical parameter distribution.

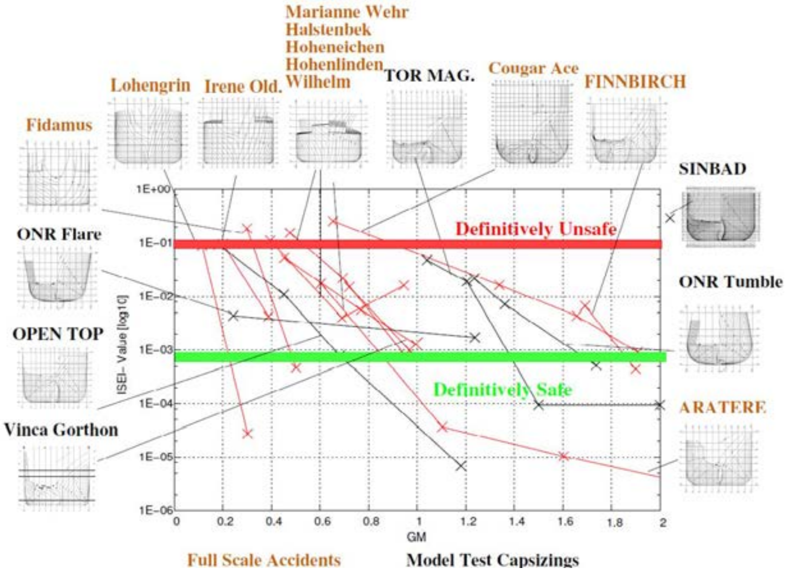

Figure 7: Safety levels of different civilian ships in a seaway (Krüger, 2022)

Figure 7 shows the ISEI values derived from several full-scale accidents and later model tests for ships designed according to the six Rahola criteria and the later added weather criterion, i.e. the minimum set of criteria as per the 2008 IS Code applied to any civilian ship nowadays. In a first step, the ISEI values for the actual stability – represented by the value of GM – in each accident condition are computed, resulting in the upper threshold of definitely unsafe values at 0.1 and above. In a second step, the same calculations are done after raising the stability in several steps until all of the mentioned IS Code criteria are only just fulfilled. Using the assumption that the ship loss rate resulting from applying these criteria is deemed socially acceptable, the lower threshold of definitely safe values of 0.001 and below is then determined.

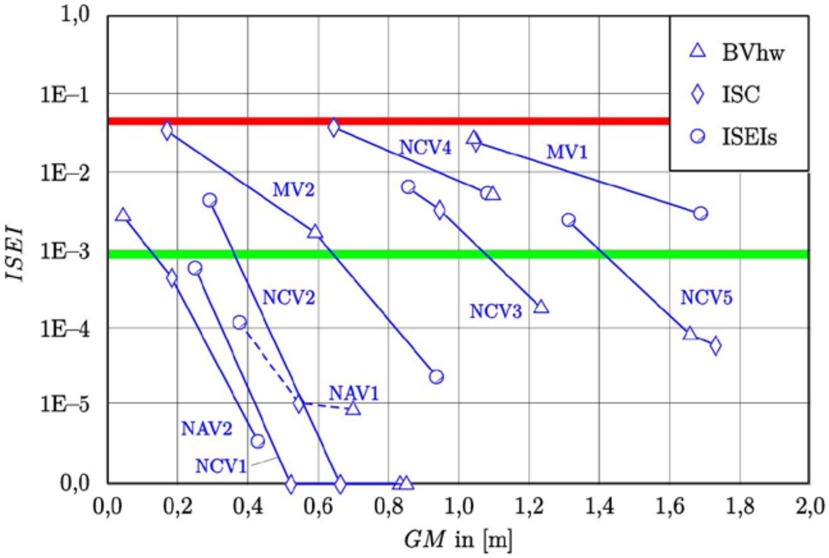

Figure 8: Safety levels of ships designed to different standards in a seaway (Krüger, Hatecke, Rinke & Tammen, 2014)

The same concept is applied by Krüger et al (2014) to determine the safety level of BV 1030-1 for a select number of ship types of combat vessels (NCV) and auxiliary vessels (NAV) designed to said standard and compared to two merchant vessels (MV), see Figure 8. These ship types are then given stability values to only just fulfil the minimum stability criteria for the IS Code (diamonds in Figure 8) and BV 1030-1 (triangles in Figure 8) respectively.

As a result, ISEI values for ships designed and operated according to BV 1030-1 are found to be two to three order of magnitudes smaller than those designed and operated according to the 2008 IS Code. This implicitly means that the probability of capsizing in heavy weather is lower by said magnitude, which is underlined by the fact that there has never been a single loss of any German Navy ship over 60 years since the introduction of the first BV 103 and with a sizeable fleet especially during the Cold War. Even if these naval ships were to be operated with the lower stability values according to IS Code, they still would be a lot safer than any merchant vessel thanks to their design according to BV 1030-1.

However, two particular naval ship types are identified, which get a lot closer to the investigated merchant vessels with regard to safety levels than the rest of the group, even if given BV 1030-1 stability values. Looking into the source of this, the reasons described above (see around Figure 5) are found and counteracted by the introduction of the new area criterion. This means that the picture painted by Figure 8 will look even with the most recent edition of DMS 1030-1 applied for future ships. In return of course this also means, that the 2008 IS Code without the application of Second-Generation Intact Stability Criteria presents a severe safety deficit for civilian vessels, which is only somewhat healed by stability values required for damage stability – which, mind you, generally only apply for ships over 80 m in length.

Comparison with SOLAS 2009

As described above, DMS/BV 1030-1 follows a deterministic approach to damage stability, opposed to SOLAS, which since 2009 uses a probabilistic damage stability approach for all types of ships. The damage safety index in SOLAS is determined by using the probability of a specific damage condition derived from accident statistics, then evaluating the survivability of this damage condition by fulfilment of SOLAS stability criteria to a value between 0 and 1, multiplying probability and survivability of this damage condition and then repeating the process for additional damages by adding up damage safety index until a minimum index at several draughts is reached. As the potential damage suffered by navy ships is not just inflicted by collision or grounding, which are statistical events, but by weapon impact, which is impossible to predict and can be aimed at any part of the ship, the mentioned deterministic approach is the only viable solution for evaluating the damage stability of navy ships.

However, to compare the two standards, a theoretical design of a civilian RoPax vessel only just fulfilling the minimum damage stability requirements of SOLAS 2009 B1 is used by Krüger (2012). The damage safety index resulting from this then forms the baseline for the comparison, see the uppermost line in Figure 9. Using a comparable set of damages and damage probability, but now evaluating the survivability of each damage case with the damage stability criteria from DMS/BV 1030-1 described above, results in less than half the damage index than as per SOLAS 2009 B1 for the same ship, see the lowermost line in Figure 9. In other words, even the minimum damage stability criteria of DMS/BV 1030-1 result in more than double the safety compared to SOLAS 2009 B1.

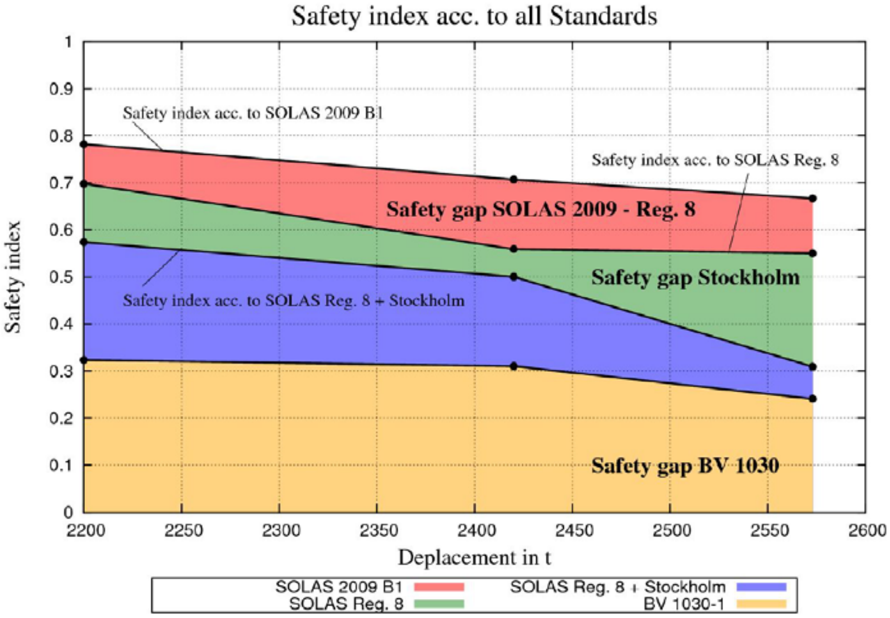

Figure 9: Damage safety index of the same ship design assessed by different standards (Krüger, 2012)

In the same investigation, the survivability of a recent German Navy ship beyond its design damage cases is investigated. As a result, it is found that the default scope of deterministic damage cases to be investigated as per DMS/BV 1030-1 covers about 82% of all theoretically possible probabilistic damage cases. The same ship however was able to survive about 95% of all theoretical damage cases beyond its design, even with DMS/BV 1030-1 stability criteria applied, which implies a lot of implicit additional safety generated by the deterministic approach used in DMS/BV 1030-1.

CONCLUSIONS

This paper has presented the basic principles of the German Navy Standard DMS 1030-1 as well as the rationale behind individual criteria decisions and their development over the years. Furthermore, the main reasons for its technical success were discussed upon in detail and related to the historical background during the creation of the standard. The safety levels achieved by the standard have been quantitively shown and compared to civilian regulations. As a result, it should be clear that proper stability regulations will drive a ship design to work well in everyday civilian usage first before it then will be a good warship in combat usage as well. This is achieved by naval administrations being able and willing to react quickly to scientific developments in working closely with competent academic communities. Finally, it is found that the standard remains valid and up to date until this day and with relatively minor improvements – compared to civilian standards over the same timeframe – will continue to provide successful designs for the foreseeable future.

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