Operational Evaluation of Damage Stability for Tank Vessels

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ABSTRACT

This paper attempts to highlight some of the technical and administrative issues currently hampering the proper and consistent enforcement of the various international tanker stability requirements. The paper describes the main technical issues surrounding the application of MARPOL, IBC, BCH and IGC Codes intact and damage stability requirements and it concludes by stressing the timely need to officially recognise the fundamental role played by onboard loading software in assuring that such proper and consistent enforcement of the various tankers' stability requirements are achieved in operation as well as during design.

BACKGROUND

The Issue

All tank vessels on international voyages must meet the International Maritime Organization's (IMO) requirements for damage stability. These deterministic two-compartment regulations are contained in the MARPOL Convention [MARPOL] for general purpose tankers, the IBC and BCH Codes for bulk chemical carriers and the IGC for gas carriers. Unlike dry cargo ships the damage survivability of tank vessels is highly dependent on the liquid cargo and ballast loading pattern, tank runoff after damage, and the cargo density. Typically compliance with these regulations is demonstrated only for the standard loading conditions in the vessels stability booklet.

In 2005 several Port States, led initially by the UK's Maritime and Coastguard Agency (MCA), recognized that many tank vessels carried onboard documentation to demonstrate compliance with these damage stability requirements *only* when the ships were loaded in accordance with the ships standard loading conditions in the approved Stability Booklet. However, during actual operations many tank ships are loaded to conditions which significantly differ from these standard loading conditions. A survey by the MCA indicated that "more than 50% of vessels are operating to conditions which are not in the approved Stability Information Booklet" [MSC 2006, 1] and are therefore unable to demonstrate compliance with the IMO damage stability requirement during Port State inspections.

This issue was initially brought to the attention of the IMO-Maritime Safety Committee (MSC) by the UK delegation at its 81st session. In 2006 at its 82nd session the MSC considered a joint report from the United Kingdom, Denmark, Germany, Norway and Sweden [MSC 2006, 2] proposing corrective action for this problem, as well as commentary papers from INTERTANKO [MSC 2006, 3] and from the International Parcel Tankers Association [MSC 2006, 4]. This topic was again considered by MSC at its 83 session in 2007 is now scheduled to be considered at the upcoming SLF meeting (SLF 51) in July 2008.

Loading Computers

It is generally understood that since nearly all tank vessels use computer programs to evaluate stability and longitudinal strength for any loading condition, there is no longer a practical incentive to stay with the standard loading conditions to comply with damage stability regulations. It is also recognized that modern double hull tankers are generally more vulnerable to damage stability scenarios, and the new regulations (including recently introduced bottom raking damage) [MARPOL – Annex I, Regulation 28] are generally are more onerous then past damage stability regulations. For these reasons the use of approved loading computers is often considered to be the only practical solution to demonstrate compliance with the damage stability regulations for non-standard loading conditions.

Loading computer programs with this feature are referred to as "IACS Type 3 Loading Instruments" as specified in IACS URL 5 [IACS 2005], which defines Type 3 as "software calculating intact stability and damage stability by direct application of pre-programmed damage cases for each loading condition".

In practice the application of an IACS Type 3 Loading Computer to demonstrate operational compliance with the IMO damage stability requirements has brought to light several significant problems and interpretation issues which are the subject of this paper.

CLASS, FLAG & PORT STATE AUTHORITY

The Damage Stability Study, as approved by the Flag State, is currently the only official stability document that can be used to demonstrate compliance with the IMO requirements for damage stability. However, recent experience has shown that Damage Stability Studies are often inadequate to demonstrate operational compliance with the IMO damage stability requirements.

IACS Type 3 Loading Computers, as approved by the Classification Society, if provided, are required to be developed in accordance with approved stability information and must "include all calculations necessary to ensure compliance with the stability requirements". Also the loading computer "is not a substitute for the approved stability information" and "should be easily comparable with the approved stability information".

The above IACS requirements are nearly impossible, in practice, to comply with. Firstly there are often differing interpretation between the original Flag State approved calculations and the Class approved software regarding the application of MARPOL; additionally the new Loading Computer can differ from the Damage Stability Study due to errors or omissions in the original study (especially for older ships).

It is the authors' opinion that if direct calculation of damage stability is to be performed by onboard loading computer, the approval should be the responsibility of Flag Administration. Whenever the approved documentation is demonstrated as deficient by approved onboard software, either the software should be approved by the Flag as an equivalent means to prove compliance in place of the old deficient documentation, or alternatively a new damage stability study should be mandated.

It should however be noted that the current "lower tier" status of Type 3 loading software affirmed by the words "is not a substitute for the approved stability information" is hard to defend in the light of the fact that – strictly speaking – this would imply the inability of Type 3 software to prove compliance for any loading condition other than those contained in the Damage Stability Study. Of course, this defies the very purpose of having a Type 3 loading computer onboard to allow the use of loading conditions different from the standard ones.

INTREPRETATION ISSUES

There are a number of technical interpretation issues between software and traditional methods of demonstrating IMO compliance, between Flag and Class, and between different IACS Class Societies. These issues should be addressed by IMO's SLF Sub-Committee in order to avoid conflicting requirements and make the damage stability information "easily comparable" and to "avoid confusion and possible misinterpretation by the operator relative to the approved stability information" as mandated by IACS L5. In the following a few of these issues are examined in some detail.

Lesser Extents of Damage

When a tank vessel's arrangement is very simple (old single skin tankers), or when considering homogeneously loaded ships, it is normally safe to assume that the greatest extent damages will govern survivability. For other cases, especially for product, chemical, and parcel tankers with very non-homogeneous and multi-port loadings, there are large combinations of lesser damages extents some of which, in some loading conditions, can become more onerous and thus determine the value of the required GM. In most damage stability studies only a few dozen damages are normally taken into consideration, mostly covering only the largest extents of damage. Onboard loading software is instead often, but not consistently and uniformly, required by Class to include all minor and L-shaped damages totalling, in most cases, several hundreds of damages.

The approval process of onboard loading software often implies a direct comparison of the results obtained by the customised software with those reported in the approved damage stability studies. In a significant number of cases, this exercise has revealed that the governing damage cases found by the onboard software were not included in the original approved damage stability study. For some marginally compliant tankers, this sometimes means that loading conditions approved as compliant are, in fact, proven to be not so by the onboard software.

Even when different parties agree that minor damages should be included in the generated list, the treatment is not always consistent. For instance, one Class indicates that minor damages in the engine room area, but not including damage to the engine room itself are not relevant, and that "lesser extent" need not be considered literally in way of the numerous small tanks in the engine room where they would result in too many individual damages. Also some Class Societies indicate that lesser extents need not be considered for dry spaces since damage to an empty dry space will always be conservative.

Uniform application of the same regulations cannot be attained if different parties have different definitions of minor damages and preconceived ideas of which damage cases are more onerous for the vessel. One such idea is that the larger the extent, the more onerous the damage. This is false in stability sensitive cases where damage not extending to the DB can lead to a more onerous damage case. Another such idea is that flooding of tanks near the keel is always beneficial to the ship: this is also false in cases that are sensitive to immersion of the downflooding openings, where additional flooding might imply the submergence of a critical downflooding points.

Treatment of Outflow of Tank Contents

There are differing interpretations amongst IACS Class Societies on the treatment of a damaged ship's displacement for the determination of the residual GZ lever arm curve when considering outflow from damaged tanks.

It is generally agreed that calculations should be based on "constant displacement" and "lost buoyancy" methods. And the term "constant displacement" generally means that the residual GZ lever should be obtained dividing the restoring moment by the weight of the ship with the flooded compartments considered as part of the sea and no longer part of the intact buoyancy of the ship. With this approach the displacement of the vessel does not change as the ship is heeled over through the range of angles considered for the calculation of the GZ curve while the volume of flooding water (which is not considered part of the ship displacement) changes at each heel angle.

It is the treatment of the outflow in the constant displacement calculation that is based on different interpretations. In other words, while some consider the intact displacement of the ship after run-off from damaged tanks as the correct ship weight to be used for the calculation of the residual GZ lever from the residual restoring moment, others consider instead the intact displacement of the ship before damage, including therefore in it the weight of the contents of damaged tanks.

It seems clear to the authors that if the ship is at equilibrium in a damaged condition (when the restoring moment is zero) her displacement will be equal to the intact displacement minus the weight of the fluid cargo lost from 100% run-off. It is therefore this value of displacement that should be kept "constant" and used to calculate GZ from the residual restoring moment.

It should be noted that some regulations for passenger or dry cargo ships explicitly stipulate the use of the intact displacement prior to damage (as opposed to the damaged, non-constant displacement including flooding water). For non-tank vessels, the exclusion or inclusion of the fluid outflow weight makes very small difference to the resulting GZ value obtained since the weight of lost fluids from a cargo or passenger ship is typically very limited. For tank vessels these two methods give substantially different results. Unlike passenger or dry cargo ships – the weight of lost fluid cargo for these types of ships can reach very large values accounting, in some cases, to 25% of the total intact displacement.

Nevertheless, it should also be noted that the use of the intact displacement for the calculation of GZ from the residual restoring moment is not mandated by any of the tank ship regulations.

In the authors opinion the correct calculation method would therefore be as follows:

1. Specify the initial draught, trim and heel (or displacement and centre of gravity) of the intact loading condition

2. If the damaged tank contains liquids, allow all the contents to spill out completely and re-calculate the new draught, trim and heel (or displacement and CG).

3. Re-calculate the damage stability from this heeled and trimmed starting point, using the standard lost buoyancy method with the damaged tank open to the sea allowing flood-water to the external water level.

4. Calculate the residual GZ at each heel angle accordingly by dividing the residual restoring moment by the damaged ship displacement (equal to the intact ship displacement minus fluid outflow, with the damaged compartments considered as part of the sea and no longer part of the intact buoyancy of the ship).

Intermediate Phases (Stages) of Flooding

None of the IMO tank vessel regulations explicitly require intermediate phases (or stages) of flooding. The MARPOL regulation simply states that "The Administration shall be satisfied that the stability is sufficient during intermediate stages of flooding" [MARPOL Annex I, Regulation 28]. Of course, this entails that each Flag State administration and each class society will apply whichever standard they deem appropriate. This often causes inconsistent application of the rule. It should be noted that, almost universally for tank vessels, the intermediate phases of flooding do not govern the value of the required GM, since the final equilibrium is almost always more onerous.

It is the authors' opinion that intermediate phases and stages should not be required at all in Type 3 Loading Instrument for conventional tank vessels and for standard IMO tanker damage stability studies.

If intermediate stages should be considered, there must be a clear, uniformly applied and

IMO mandated method to verify them. If IMO or IACS were to implement intermediate stages in the requirements, the following items would require clarification and amplification in guidance notes:

- How many phases are required, bearing in mind that each phase substantially increases the required operational calculation time?

- How are phases related to multi-stage flooding (e.g. Cross flooding connections)?

- What GZ and immersion standards are required for intermediate stages? Some criteria use a reduced standard as compared to the final stage while other use the full final stage criteria.

- Since intermediate stages are by definition 'added weight', how should outflow be treated in the determination of the displacement to be used for the development of the GZ levers from the heeling moments?

- Are the damage compartment treated a one common macro-compartment with a single free surface or independent intermediate fluid levels in each of the damage compartments?

- How should the intermediate stages be defined? At present some calculate the floodwater and outflow at each stage as a percentage of the difference between initial and final (equilibrium) volumes. Others attempt instead to link the intermediate floodwater and outflow volumes to the relative height of the internal and external free surfaces, mimicking the method often used in time-domain simulations. When used in coarse steps (as it always is the case given that the number of intermediate phases has to be limited), the latter method often creates physical absurdities such as a higher level of floodwater in the damage tanks in the final stage before equilibrium as illustrated in **Figure 1**.

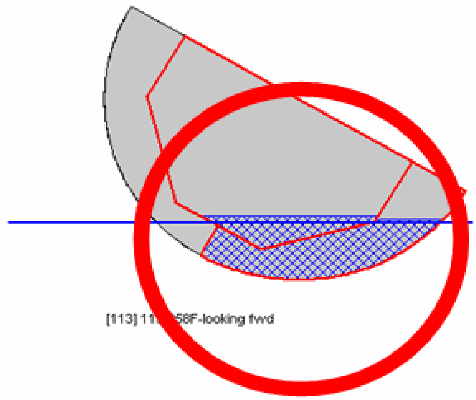

Figure 1: Internal floodwater level rising above the sea free surface as a result of coarsely stepped pseudo-time-domain intermediate flooding phase generation.

IMO Permeability vs. Actual Structural Permeability

IMO regulations specify standard permeability values that should be applied to the various compartment types [MARPOL, Annex I, Regulation 28]. For instance, all tanks and voids should have a permeability of 0.95, machinery spaces should have a permeability of 0.85 and stores should have a permeability of 0.60. One gray area in the regulations is what determines which group a given compartment should belong to. For instance, often pump rooms (a machinery space) and bosun stores (a store area) are assigned a permeability of 0.95, typically because these spaces are large and the machinery or stores actually kept in them do not take a sufficiently large amount of space to justify the standard 0.85 and 0.6 permeability values that IMO stipulates. Of course, this grey area allows arbitrary choices to be made and potentially different results in calculations performed by two separate parties.

Perhaps of greater concern, large tanks with actual structural permeability values close to

0.98-0.99 always use these larger structural permeability values to accurately calculate the tank capacity and the amount of oil/water loaded in them in the intact condition. When calculating the outflow from these tanks, some parties apply the standard 0.95 IMO value to calculate it (thus retaining some of the original onboard load, as a result of the difference (potentially up to 4% of the original content) while some others use the actual structural permeability value (thus running off all original content).

The latter method might appear more straightforward at first glance, and in line with the note to MARPOL [Reg. 28.4.2] reading: "The permeability of partially filled compartments shall be consistent with the amount of liquid carried in the compartment. Whenever damage penetrates a tank containing liquids, it is assumed that the contents are completely lost from that compartment and replaced by salt water up to the level of the final plane of equilibrium.", this actually leads to the odd result of a change in equilibrium position when a salt water tank is damaged, which was originally loaded so that the internal free surface is co-planar with the intact waterline. A simple check of the physics of this example will show that no change in static equilibrium should instead occur.

It is the opinion of the authors that either the note to MARPOL [Reg. 28.4.2] or the standard permeability should be changed since they lead to calculations that are clearly physically incorrect and inconsistent. The authors believe that realistic permeability should be used for both structural and flooding permeability. Alternatively, if standard permeability values are to be mandated, floodwater and outflow should be calculated on the same basis.

Free Surface Treatment for the Intact Tanks

MARPOL Reg. 28.4.4 and MARPOL Reg. 28.4.5 are meant to regulate the application of free surface correction values for all tanks that are left intact in a damaged tanker. It is unclear from these regulations if the direct calculation of the CG location of the contents of these intact tanks (as the ship is heeled to evaluate the GZ curve) is an acceptable alternative to the use of fixed free surface correction values for all angles of heel. In particular, it is unclear whether or not the direct calculation of intact tanks' CG's is applicable to consumables tanks since the spirit of Reg. 28.4.5 is to impose a minimum free surface correction for each consumables tank group, to take into account the variation of fill levels that these tanks experience during a trip.

It should be noted that the practice of calculating the CG location of the contents of the intact tanks as the ship is heeled to evaluate the GZ curve was brought about by the difficulty for tankers to satisfy the new MARPOL raking damage [MARPOL Annex I , Regulation 28) using fixed free surface correction values for all angles of heel as seemingly mandated by MARPOL Reg. 28.4.4. In practice, most Flag and Class Societies have allowed the direct calculation of the intact tanks CG's at each evaluated heel angle instead of the use of fixed free surface values for all those tanks that are not expected to see their content level vary during a trip. This practice, if deemed an acceptable interpretation of MARPOL Reg. 28.4.4, should be spelled out in guidelines on the application of MARPOL and similar guidelines on the same subject should also be given for the rest of the IMO tanker regulations (IBC, IGC etc.).

The treatment of free surface is often the source of significant differences in the application of both intact and damage stability. Even if one restricts the field to damage stability only, the application of FS corrections vary from using a fixed maximum slack value for all fill levels of all tanks (normally unless the tanks are completely empty or full, but there are exceptions and variations even for this simple treatment), to using FS values varying with tank fill (perhaps with minima required for consumable groups) to the direct calculation of the CG location for the fluid in each tank.

If one wanted to strictly apply MARPOL, an additional problem would also come to surface, since the regulations pertaining to FS treatment for damage stability [MARPOL Reg. 28.4.4 and MARPOL Reg. 28.4.5] are NOT the same as those applicable to intact stability [MARPOL Reg. 27.1]. It is difficult to see how to simultaneously satisfy these requirements without calculating two separate GM (corrected), one to be used to check intact stability regulations and one to be used to check damage stability regulations. In practice, this would also rule out the possibility of combined required GM curves including both intact and damage stability requirements. It would be highly recommended that IACS/IMO give guidance on whether these checks should be done separately with different GM(corrected) values. In our experience this is often not been the case.

Ship Symmetry vs. Loading Symmetry

Traditionally, damage stability studies have only considered one of the sides of a ship to apply damage cases because of geometrical symmetry. It should be noted, however, that such way of proceeding is only valid if the loading conditions analysed are also perfectly symmetrical. In other words, in its intact loaded state the ship needs to have essentially no heel and for every loaded tank on one side there must be an equally loaded tank on the other side. Clearly, this is hardly ever the case in actual operational loading conditions, where a certain amount of heel (however small) is always present and often tanks are not loaded symmetrically.

Of course, if a loading computer is meant to be able to calculate the required GM for any loading condition, the damage case selection needs to include both ship sides to handle any potential cargo asymmetry. It is to be noted, however that in many cases the damage stability studies do not observe the restriction on loading symmetry mentioned above, ending up analysing heeled ships using one side only; or analyzing upright ships in the damage stability study when the intact condition has an initial heel. This is something that should not be accepted, especially if the ship is marginally compliant, where with any significant operational intact heel the ship will be out of compliance with the regulations. In fact, for marginally compliant ships, even slight asymmetries in the tank or down-flooding point geometry will have an impact on the damage stability and the need to consider both ship sides in all damage stability studies exists even for perfectly symmetrical load cases.

L5 Accuracy Requirements

URL 5 gives a broad framework that all IACS class societies should follow when approving onboard stability software. Although it is not the role of IMO to regulate the internal workings of the class societies, it would be advisable that the guidelines that SLF might develop for the uniform application of the regulations might contain some reference on what level of accuracy should be considered acceptable. Some of the IACS URL5 tolerance values are questionable. For example:

- For small FS corrections like 10cm or less, the URL stipulates a 2% tolerance equal to only 2 mm. This level of accuracy is not attainable in practice nor is it inductive to any meaningful increase of safety.

- How can one define in a computer program with “close to zero” tolerance on Type 1 systems? Is a millimeter or a centimeter off in KM acceptable or not?

- Also, what is the precise meaning of the slash between tolerances in Table 1 defined both in terms of % and maximum absolute value? Does one have to meet both or either one?

GM/KG Curves vs, Direct Calculation

It is unclear whether dual-type software (Type 2 or Type 3, depending on user’s choice) is a valid alternative. Often a simple a quick check on a pre-programmed required GM curve with specified loading restrictions might be preferable to the run time requirements of a direct damage calculation if the loading condition does not require any detailed analysis to demonstrate compliance. This is the reason why ship operator requires the Type 3 capabilities *in addition* to those of Type 2 software. In these cases, should the results be displayed in significantly different fashion? How can this be achieved without creating confusion in the interpretation of the results and/or unduly increasing the complexity of the interface?

In other words, what should a Type 3 show to the Master who are used to the concept of required GM and GM margin? Should a required GM be calculated and displayed at all by a Type 3 loading instrument or should Type 3 systems simply supply a comply/non-comply warning?

CONCLUSIONS

It is evident to the authors that the current state of affairs in the interpretation and implementation of the tankers' intact and damage stability requirements needs a timely and wide-sweeping review aimed at producing clear guidelines on how these rules should be applied to ensure consist application. We think that it is very possible that this review will require the re-examination of the current wording of the tankers' intact and damage stability regulations, particularly when the current form of these regulations promotes analyses which are physically improbable.

This process is finally begun at IMO, as initiated by the Maritime Safety Committee and to be continued by the SLF Sub-Committee, but will require the active participation of IACS members so that the application of MARPOL, IBC, BCH and IGC Codes intact and damage stability requirements to prove design (T&S Books and Damage Stability Studies) and operational (Onboard Loading Software) compliance is finally achieved consistently, without penalising ship operators, and clearly indicating where the responsibility lie for approving any of these means to demonstrate compliance.

In view of the above, it is the opinion of the authors that whatever the result of the current process, the approval of the means to demonstrate compliance with stability requirements at design and operational stage should be performed by the same body and that both means of compliance should be treated as equivalent. Relenting on the latter requirement would simply mean persisting in allowing the current unsatisfactory lack of proper enforcement of these stability regulations.

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