Implications of different alternatives for damage stability analysis in decision support

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ABSTRACT

A decision support system for passenger ships in flooding casualty has been recognized as an important tool on modern cruise ships. There are several applications already at the market and in the use, some of which have been developed during the years without a direct link to any compelling requirement set forth in the international rule framework. After the Costa Concordia accident, the rule requirements have been developed at the IMO. These requirements form the minimum solution for a decision support system, based on the extension of the existing loading or stability computer system. However, there are systems that have been developed purely from the end users' needs, and which have functionality exceeding the rule-based minimum requirements. This paper presents different alternatives for a decision support system for flooding emergencies. Technical background, accuracy, usability and usefulness of the two approaches are compared with, taking into account the important statutory approval point of view.

Keywords: *Damage stability, Decision support system, loading computer, passenger ship.*

1. INTRODUCTION

Ship flooding accident requires rapid and correct decisions onboard the ship. The situation may evolve fast, leaving the crew with a tight time-frame for organizing appropriate actions. A decision support system is thus an essential tool in a distressed accident situation. Jasionowski (2011) proposes a monitoring tool informing the crew about the current status of the ship, in this way improving the awareness of the crew and thus helping the decision making in case of a flooding accident. Varela et al. (2014) emphasize the need to provide the crew with prediction of the progression of flooding and present an initial on-board decision support system. A more elaborate system providing means of communicating the status of the situation is presented by Nordström et al. (2016).

The IMO has taken the decision that all passenger ships of certain size, built after 2014, need to be equipped with a stability computer capable of providing the master with operational information after a flooding casualty and/or shore based support proving the same. The requirement is included in the SOLAS text and more detailed guidelines are given as MSC Circulars 1400 and 1532 (IMO 2011, 2016). In the recent SDC subcommittee working group, the relation of the guidelines was made clear, meaning that the Circular 1400 only affects ships built between 01 Jan 2014 and 13 May 2016, whereas the revised circular 1532 affects ships built after 13 May 2016. In its report to the parent committee MSC, the subcommittee also proposes this requirement to be applied on all existing passenger ship, built before 2014. For this purpose, a new guideline will be developed, taking into account the characteristics of older tonnage.

Passenger ships built before 2014 represent a vast amount of different ships, including pure passenger ships and ropax vessels, covered by many editions of SOLAS conventions in use at the time of their construction. Many of the ships have been designed to meet the deterministic damage stability requirements and majority of the ships do not have flooding sensors, which are mandatory on ships built after 2010.

Modern passenger ships built after 2016 all have flooding sensors in place. If an adequate number of well-placed flood level sensors are installed, it makes the calculation of time-domain flooding prediction possible, provided that some other conditions are met, as discussed in Takkinen et al.

(2017). These ships are also well documented in way of compartmentation details and usually have automation systems ready to provide all needed data for the damage stability computer directly through interfaces. On the contrary, the installation of the flood level sensors to older ships is complicated or nearly impossible in practice.

Taking into consideration these fundamental differences in equipment, it seems obvious that it is possible to develop more enhanced decision support for modern ships than for older ships. All systems, however, need to fulfill the rule requirements, as well as the end users' expectations.

2. ALTERNATIVES FOR DAMAGE STABILITY ANALYSIS

Conventionally, the damage stability information onboard is provided by calculating the final equilibrium of the damaged ship in the current loading condition. Loading computer software relying on static damage stability method is used for this purpose. International Association of Classification Societies defines three different types of stability software in the Unified Regulations regarding Onboard Computers for Stability Calculations (IACS, 2006) depending on the vessel's stability requirements. Type 1 is only for intact stability and Types 2 and 3 cover also the damage stability. More recent developments of the onboard software include time-domain damage stability prediction (Varela et al. 2014 and Ruponen et al. 2015 & 2016). Such solutions are installed on the newer passenger ships for better operational information of damage stability and to provide time perspective of the evolution of the stability for enhanced decision support.

Static damage stability

The method applied on some of the existing loading computer systems, widely installed on cruise ships, is to give the user possibility to manually define rooms and compartments damaged (open to sea). The system utilizes a 3-D model of the ship and calculates the final equilibrium position, usually with a few intermediate stages.

The calculation is based on the current loading condition, prepared using the loading computer. This system differs from the direct damage analysis (IACS Type 3 loading computer), since the Type 3 calculates all rule-based, deterministic damage cases (for example SOLAS 1974/90) using the current loading condition. Type 3 is suitable for checking the design rule compliance before sailing but the same is achieved using the GM limiting curves (IACS Type 2 loading computer). In real life, the damages occurring naturally are deterministic but the extent of the damage may differ from those defined in the rules (for example two-compartment damages).

This fact also rules out the systems based on pre-calculated damage scenarios since the number of loading/damage condition permutations is infinite. It is important that the calculations always are based on the real, current loading condition, as stipulated in the rules.

It is understood that the IACS is preparing a definition for Type 4 loading computer, which would be able to calculate the results of any damage extent for a given loading condition and reflect the requirements presented in Circular 1532. The information of the damage definition would be based on sensor information about detected flooding extent and/or manual breech definition by the user. The definition of the Type 4 is, however, not yet available.

The result of damage stability calculations is traditionally presented as the GZ curve, possibly with deterministic criteria comparison (MET/NOT MET), as shown in Figure 1.

Based on the GZ curve and some knowledge of the specific ship in question, an experienced captain (on board) or naval architect (shore based support) can estimate the severity of the flooding case. This information still needs to be combined with the information of the prevailing weather and geographic conditions, when evaluating the need of evacuation compared to Safe Return to Port (SRtP). Furthermore, it is impossible to define the time frame until the equilibrium will be reached. It may also be difficult to judge how the situation will evolve, for example due to progressive flooding.

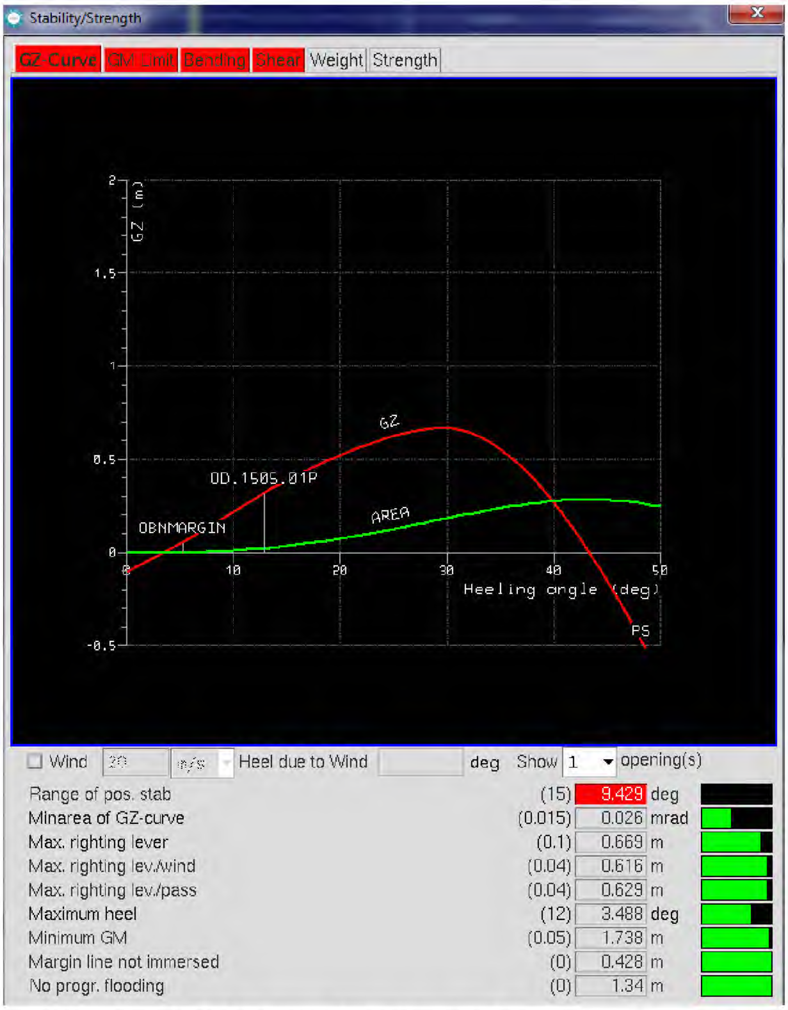

Figure 1: Example of typical damage stability output from a Type 4 Loading Computer

Time-domain damage stability prediction

An advanced approach to decision support is to use time-domain flooding simulation, combined with the measurement data from the automation system. The concept is introduced in Pennanen et al. (2015), and details of the applied calculation methods are presented in Ruponen et al. (2015, 2017). The Vessel TRIAGE system (Nordström et al. 2016) is used to present the severity of the situation, based on the latest measurement data and prediction of progressive flooding.

The time-domain prediction for progressive flooding and quasi-stationary ship motions is constantly updated, using the latest measurement data from the automation system. For practical reasons, each prediction is done for three hours, based on the Safe Return to Port requirements. Instead of informing the user on the stability at the intermediate stages of the flooding, the system communicates the severity of the situation to the user and provides the predicted evolution of the situation, and the important time perspective of the consequences.

3. CASE STUDY

A potential, realistic damage case of a 125 000 Gross Tonnage passenger ship is presented here in order to demonstrate some of the differences of the alternative approaches of damage stability analysis of the decision support systems. It should be bore in mind that in some damage cases the differences might not be so pronounced, and that it is difficult, if not impossible, to make a fully comprehensive study of all the potential cases.

Damage scenario

In the presented case the breach is a long and narrow raking damage near the waterline, which could be caused by ice for instance, or in collision with another ship or even side grounding. The breach extends over seven WT compartments, including

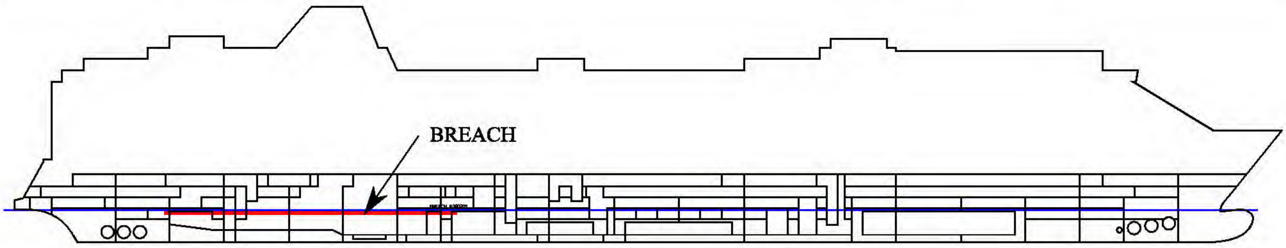

Figure 2: Small breach extending to several compartments

both main engine rooms, Figure 2. In this damage case the ship will be eventually lost, but the flooding takes several hours.

Reference results for the progression of flooding and the evolution of the stability are calculated in calm water with time accurate simulation. The ship is equipped with flooding sensors, which are taken as fully operational in this case, thus providing the onboard system with the information on the current status of the flooding. The floodwater does not immediately reach the sensors in all damaged compartments. In this case, about 10 min after damage, the flood level sensors indicate that the total of 7 compartments are flooded.

Flooding prediction results

Examples of the results from time-domain flooding prediction are presented in Figure 3. About 10 min after damage, the level sensors have detected all breached WT compartments, and the second prediction provides information that the ship will remain stable afloat for 3 hours. About 3 h after the damage the updated predictions start to indicate that eventually the heeling will start to increase. Finally, the prediction started 5 h after damage provides a reasonable estimate that the ship will capsize.

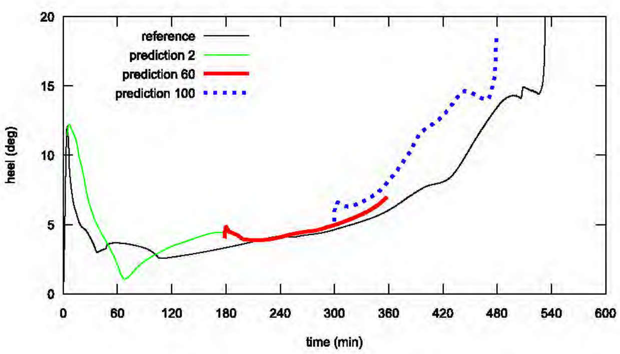

Figure 3: Time-domain flooding prediction results for the small but extensive breach

Loading computer results

The loading computer indicates the detected flooding, and the user can breach also additional compartments manually. The final equilibrium condition is calculated by considering the damaged compartments as lost buoyancy. In addition, typically 5 intermediate stages of flooding are calculated. In the studied damage scenario the ship capsizes during the intermediate flooding, and the last stable floating position for the 3rd stage is shown in Figure 4. The loading computer can only calculate the final condition and a number of intermediate stages, but the time-scale cannot be evaluated.

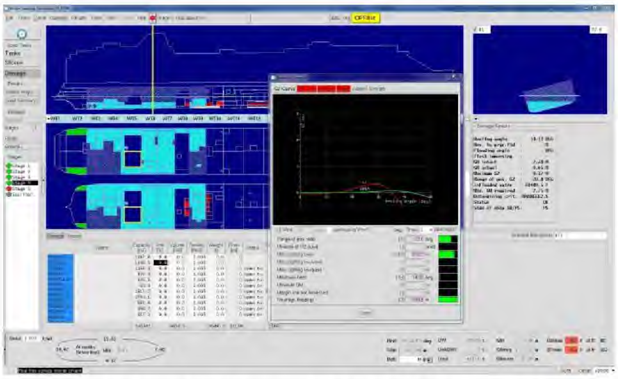

Figure 4: Example of damage stability results from a loading computer

Analysis of results

Both the loading computer and the time-domain flooding prediction indicate that the situation is extremely serious, and eventually the ship will sink or capsize. An experienced captain could tell this result also based on the fact that the flooding is detected in seven WT compartments.

The major benefit of the time-domain flooding prediction is the estimate of the time-to-sink. In this damage scenario there is plenty of time for orderly evacuation and abandonment. Also assistance from the nearby ships can be waited for. In addition, the flooding is very slow and active counteractions, such as pumping could be used to further increase the available time.

4. DISCUSSION

In the presented damage case the flooding and capsize of the ship took nearly 9 hours, leaving the crew with sufficient time for orderly evacuation. However, the results obtained from the static loading computer give an impression of a more severe case. The lack of information on the available time may lead to rushed evacuation actions, jeopardizing unnecessarily the safety of the people on board. In some other case the situation may evolve more rapidly, and fast decisions and actions are required. Also in such a case, the immediate results from the time-domain simulation are valuable.

IMO Circ. 1532 states that the "shore based support should be operational within one hour". In practice the gathering of the information of the situation may take a substantial amount of time. After this, with a full awareness of the situation, the shore based support will be able to provide results on the evolution of the situation and possible recommended actions. For serious damage cases this may be too long a time for efficient decision making for orderly evacuation and abandonment. Taking all this into account, an onboard decision support system with automatically launched time-domain prediction of progressive flooding would appear useful in addition to the loading computer and shore based support.

Statutory approval

The approval of the onboard stability computer is in practice conducted by the classification societies, which need to implement the Type 4 (or Circular 1532) requirements in their rules. This will most likely restrict the scope of approval of the damage stability analysis to those provided by the loading computer.

At least one classification society has defined a more advanced system to be installed onboard, consisting of flood level sensors and a loading computer with appropriate damage stability functionality. This definition exceeds the Circular 1532 requirements, and there is an approval procedure in place. In the future, it should be discussed, if also time-domain prediction based systems could be checked and approved by the classes – at least at the algorithm level – in order to increase credibility and trust.

5. CONCLUSIONS

Taking into consideration the pace of evolvement of the damage cases, like the Costa Concordia case, it is utmost important that there is a system onboard the ship, capable of giving immediate alert as well as rapid view of the severity and progress of the scenario.

A loading computer based system will provide an estimation of the situation at end of the flooding. The evaluation of the severity may require expert level interpretation of the results, but it can be done. This kind of system is also suitable for training and drills, as it provides the user with understanding of the extent and type of damages the ship eventually can or cannot survive.

Taking one step further in the user friendliness and usefulness of the system, is provision of time-domain prediction of the flooding scenario. Getting a view to the time scale of the damage scenario helps in the decision making. The severity of the case can also be based on the evolvement of the events, and thus be dynamic and easily communicable. In order to keep the loading computer functional for its primary purpose for planning and checking the loading condition for rule compliance, the time-domain prediction should run as a separate, dedicated system. This separate system can be complemented with other safety-related functions, like vulnerability monitoring, without causing problems in the class approval of the loading computer.

Although shore based support seldom can response rapidly in the early stages of flooding, it can provide valuable support for the master in course of a slowly progressing flooding case. Shore based support can concentrate on analyzing the case and calculate alternative scenarios to cope with it. According to the rules, shore based support is anyway required for the provision of post-damage residual strength information.

In order to increase maritime safety, all passenger ships should be equipped with a loading computer capable of performing damage stability analysis onboard. In addition to this, shore based support should be provided for increased safety and redundancy. Consequently, new ships equipped with properly located, good quality flood water level sensors will benefit of complementing the loading computer with a time-domain prediction based decision support system installed onboard.

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