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Probability of capsizing in dead ship condition

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The nature of the contemporary intact stability regulations is prescriptive. They are based mostly on requirements to the righting arm curve (GZ curve) on calm water. This approach is further development of Rahola's work which was conducted in the 1930s. The first intact stability resolutions were approved by IMO in the 1960s.

At present, IMO works on development of new regulations which are to be largely based on the probability approach. The SLF subcommittee proposed four main capsizing scenarios: dead ship condition, pure loss of stability on wave crest, parametric roll and surf-riding with broaching. These scenarios are the starting points for changing the current regulations. Many scientific centres have undertaken the work on creating the new stability criteria.

This paper presents the computations of the capsizing probability for RoPax ship in the case of Dead Ship Condition scenario. The non-linear model of ship motion for regular wave was applied in the calculations.

Keywords: capsizing, dead ship condition, probability

1. NEW INTACT STABILITY CRITERIA BASED ON THE PROBABILITY METHODS

In 1968 the intact stability rules were approved as the A.167 resolution (ES. IV). Then, in 1993, this resolution was replaced by another one – A.749 (18). In July 2010, the new revision of IS Code is to come into force. During the 85th session of Martine Safety Committee (MSC) it was agreed that part A of IS Code will be obligatory as it is defined in SOLAS Convention.

However, all above mentioned amendments are not followed by any crucial changes in the text of IS Code. The Code is still based on the same assumptions, according to which the ship indicator of stability safety is the righting arms curve on calm water.

The discussion about new generation of stability rules took place during the 50th (SLF 50/4, 2006), 51st (SLF 51/4, 2008) and 52nd (SLF 52/3, 2009) sessions of the Sub-committee on Stability, Load Lines and on Fishing Vessels (SLF) of IMO. It was proposed that the new generation of regulations should be based on four intact stability failure scenarios.

- Dead Ship Condition, i.e. ship without forward speed, exposed to action of waves and wind
- Pure-loss of stability
- Parametric roll
- Surf-riding and broaching

In order to present a new approach to the stability issue, it is necessary to define the intact stability failure. The definition can be found in SLF document 51/WP.2 (SLF 52/WP.2, 2008):

“Intact stability failure is a state of inability of a ship to remain within design limits of roll angle and combination of rigid body accelerations”.

Two types of the intact stability failure can be recognized (SLF 50/4/4, 2006):

- Partial intact stability failure – the partial loss of the operation abilities of a ship, additionally combined with the potential danger for people as well as for cargo and equipment.
- Total intact stability failure – the total loss of a ship, additionally combined with the loss of lives.

A process of determining the new intact stability regulation began during the 50th session of SLF IMO subcommittee. The delegations from Japan, the Netherlands, the USA (SLF 50/4/4, 2006) and from Italy (SLF 50/4/12, 2006) presented their conceptions concerning the new intact stability regulations. The subcommittee presented four definitions of criteria which deal with the assessment of the intact stability failure in different ways:

- "probabilistic performance-based" – this criterion is based on the physical model of intact stability failure considering the probability of an event;
- "deterministic performance-based" – this criterion resembles the previous one, except the fact that an event does not have the probability nature but is the determined one;
- "probabilistic parametric criterion" – this criterion is based on the value measurement connected with an occurrence but it does not encompass the physical model of the occurrence. It exploits one or more stochastic values;
- "deterministic parametric criterion" – this criterion also does not contain the physical model but is based on one or more deterministic values which take part in measuring the values connected with the occurrence. This criterion is applied to present regulations.

The new generation of stability regulation is to be a multi-stage process connected with two types of criteria (additionally IS Code is used):

- Performance based criteria – criteria combined with attaining the performance; they can be based on the model test or numerical simulations and can have probabilistic or deterministic nature;
- Vulnerability criteria – criteria connected with a ship susceptibility to intact stability failure for particular scenario; these criteria can be divided into two or more levels:
    - level 1 is based on the simple criterion combined with the ship geometry
    - level 2 is based on the simple physical model of an occurrence of dangerous phenomenon

Figure 1 presents the diagram of the concept of new stability regulations. Two levels of criteria, "vulnerability" level and the one based on performance, are different for disparate ship capsizing scenarios.

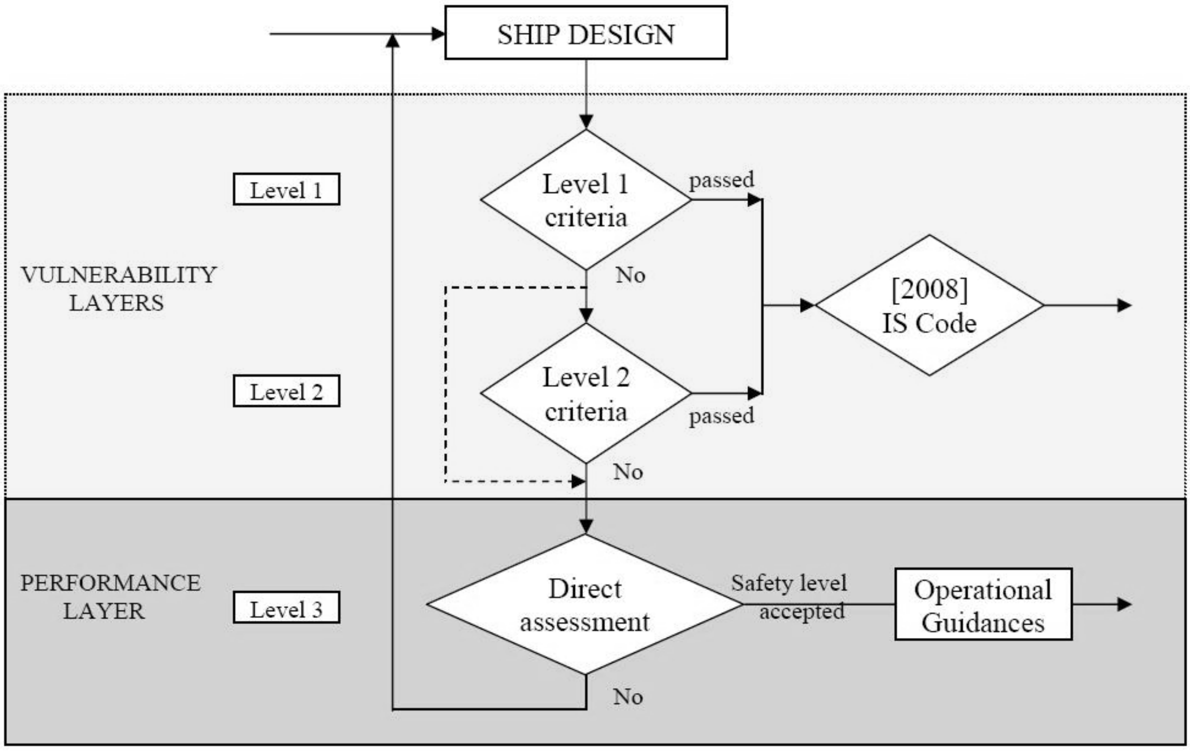

Figure 1. Process of assessing in the new generation of stability (SLF 52/3/3, 2009)

The probability of ship capsizing is the main part of the probabilistic criteria.

The model which is described by the formula below is the most popular probability model (Mc Taggart, 1995) (Mc Taggart, 1998), (Mc Taggart, 2000), (Lee et al., 2009):

$$\begin{aligned} P(C_{annual}) &= \sum_{i=1}^{N_{v_s}} \sum_{j=1}^{N_\beta} \sum_{k=1}^{N_{\widehat{H/\lambda}}} \sum_{l=1}^{N_\chi} \frac{1}{N\chi} p v_s(v_{s-i}) \\ &\times \quad p_{\beta_j}(\beta_j) p_{\widehat{H/\lambda}}(\widehat{H/\lambda}) \\ &\times \quad [Q_{H_{s,annual}}(H_C | v_s, \beta, \widehat{H/\lambda}, \chi)] \end{aligned} \tag{1}$$

where:

- $P(C_{annual})$ – probability of ship capsizing during one year
- v_s – ship speed
- β – heading
- $\widehat{H/\lambda}$ – wave steepness
- $H_{s,annual}$ – maximal significant height of wave

- $H_C|v_s, \beta, \widetilde{H/\lambda}, \chi$ – minimal significant height of wave which causes the capsizing in the presence of parametrical data

The formula presented is valid but only and exclusively under of the assumption that the heading and ship speed are independent of wave condition. This assumption is not totally correct in the light of existing recommendations for captains to change the course and the speed depending on the weather conditions.

The probability is often calculated by the Monte Carlo method (Mc Taggart, 2000). However, not only the probability of ship capsizing can be calculated this way, but also the probability of the critical maximum roll angle $\left(Q_{\phi_{max}}\right)$.

Instead of calculating the probability of capsizing in the direct way, Mc Taggart (2000) suggested using the method based on the probability of the critical roll angle. This method is based on the calculation of the distribution of the critical roll angel for different sea conditions.

According to this approach, it is possible to calculate the probability of capsizing by applying the formula (2):

$$P(C_{annual}) = Q_{\phi_{max}(\phi_C)} \quad (2)$$

2. THE PROBABILITY OF SHIP CAPSIZING IN DEAD SHIP CONDITION

Monte Carlo method was used to calculate the probability of ship capsizing for the Dead Ship Condition scenario. It was conducted with reference to the probability of critical maximum roll angle, where, the capsizing probability was defined with the usage of formula 2.

Monte Carlo method can be described with the formula 3:

$$Q_{\phi_{max}(\phi_C)} = \frac{N_{\phi_C}}{N_S} \quad (3)$$

- N_{ϕ_C} – number of simulations where the intended angle was reached
- N_S – number of all simulations

“LAIDYN” program was used to conduct all simulations. The program was created and developed at Aalto University in Espoo, Finland (Matusiak, 2000), (Matusiak, 2002). “LAIDYN” method is based on the assumption that the complete answer of a ship equals the sum of linear and non-linear parts. Such division results from the fact that the linear computation methods are well-known. It causes the situation where the radiation and diffractive forces are presented by linear equations quite well. In this method, the main part of the first order load is calculated with the linear approximation, based on the current heading and location in relation to a wave. Defining the non-linear part, such elements as non-linearity as a result of ship shape, hydrostatics, wave force, propeller and ruder forces, were taken into consideration.

3. COMPUTATIONS AND RESULTS

RoPax type of ship was chosen as the example for the calculations of capsizing probability for the Dead Ship Condition scenario. The basic parameters for this type of ship are presented in Figure 2. The centre of gravity of the ship was located on the height ZG = 11.5 [m].

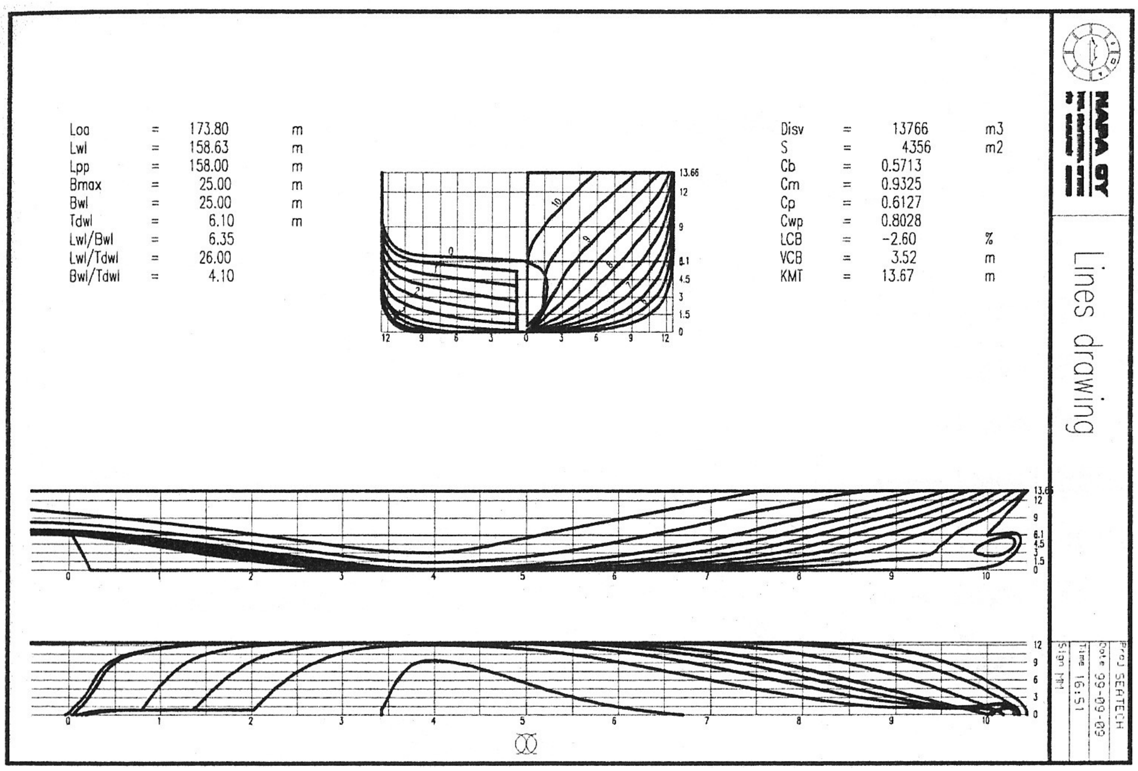

Figure 2. Lines drawing for RoPax ship (Mattila, 1999)

The sea wave statistics data were chosen for the seas around the European continent and were taken from “Global Wave Statistics” BMT Ltd (1986).

All, together 66911 computations of ship motions in waves were conducted. This sum matches about 1/3 life of a ship. The analysis of results shows that the increase of computation number for particular ship does not affect the scale of probability significantly.

Table 1. Probability of capsizing for Dead Ship Condition scenario

Critical roll Angell	Probability of reaching the critical angel
25	1.971E-3
30	1.421E-3
35	5.886E-4
45	3.286E-4
60	1.196E-4
75	1.928E-5

Table 1 presents the results of the probability computations for different angles where the LOSA accident can appear. The angel of hell equal 60 deg has been chosen as the critical heel in the final estimation of capsizing probability.

4. CONCLUSIONS

The probability of capsizing of RoPax ship during one year operation is found to be 1.196E-4. This is very low probability which means that the capsizing may occur once in 10000 years for single vessel, or one ship in populations 10000 ships during in one year period. This is very low probability which may be considered as acceptable.

The Dead Ship Condition scenario is considered at IMO as one of main scenarios for stability accidents. It is assumed as especially dangerous for ships with big “superstructures”, e.g. RoPax or loaded container ship. The results of the computations performed here do not support this opinion.

Monte Carlo method as a tool for the probability computations has some disadvantages. The most serious one is its time-consuming nature. This method gives better results when the number of computations increases.

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REFERENCES

Bassler, C. C., Belenky, V., Bulian, G., Francescutto, A., Spyrout, K., Umeda,N., 2009, "A review of available methods for application to secend level vulnerability criteria". In: 10th International Conference on Stability of Ships and Ocean Vehicles. pp. 111_128.

BMT Ltd (Ed.), 1986. "Global Wave Statistics", BMT Ltd, London.

Lee, S.-K., Long, Z.-J., Jeong, J.-H., Cheon, S.-J., 2009. "Risk assessment method of simulation-based for the intact ship stability", In: Proceedings of ICCES 09.

Mattila, M., 1999. "Experimental study on transverse stability of fast RoPax vessels in waves". Master's thesis, Helsinki University of Technology, Espoo, Finland.

Matusiak, J., 2000. "Two-stage approach to determination of non-linear motions of ship in waves". In: 4th Osaka Colloqium on Seakeeping Performance of Ships. Osaka University, Osaka Prefecture University, pp. 326_332.

Matusiak, J., 2002. "Towards an unified theoretical model of ship dynamics", In: The Maritime Research Seminar. Sjokulla, Finland.

Matusiak, J., 2007. "On certain types of ship responses disclosed by the two stage approach to ship dynamics" Archives of Civil and Mechanical Engineering VII (4).

McTaggart, K., 1995. "Wind effects on ship capsize risk", Tech. rep., National Defence. Research and Development Branch.

McTaggart, K., 1998. “Ongoing work examination capsizing risk of intact frigates using time domain simulation”, In: Proceedings of 4th International Stability Workshop.

McTaggart, K., 2000. “Improved modelling of capsize risk in random seas”, Tech. report, National Defence. Research and Development Branch.

SLF 50/4, 2006. “Revision of the intact stability code. Report of the working group on intact stability at SLF49 (part 2). Submitted by the chairman of the working group”, In: 50st session of IMO Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety. IMO

SLF 50/4/12, 2006. “Comments on SLF 50/4/4. Submitted by Italy”. In: 50st session of IMO Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety. IMO

SLF 50/4/4, 2006. “Framework for the development of new generation criteria for intact stability. Submitted by Japan, Netherlands and USA”. In: 50st session of IMO Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety. IMO

SLF 51/4, 2008. “Revision of the intact stability code. report of the working group (part 2). Submitted by the chairman of the working group”. In: 51st session of IMO Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety. IMO, p. 5.

SLF 52/3, 2009. “Revision of the intact stability code. report of the working group (part 2). Submitted by the chairman of the working group”. In: 52st session of IMO Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety. IMO

SLF 52/3/3, 2009. “Two-layered vulnerability criteria and direct assessment of ships’ stability

Submitted by Poland”. In: 52st session of IMO Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety. IMO

SLF 52/WP.2, 2003. “Revision of the intact stability code”. In: 51st session of IMO Sub-Committee on Stability and Load Lines and on Fishing Vessels Safety. IMO

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