Examination of IMO Weather Criterion in the Light of Capsizing Probability Calculation

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Key Words: Intact Stability, beam wind and waves, IMO, Weather criterion, capsizing probability

1. INTRODUCTION

International Maritime Organization (IMO) started to review Code on Intact Stability for All Types of Ships Covered by IMO Instruments (IS Code) adopted as the Resolution A. 749(18) and amended by the resolution MSC. 75(69) at the 45th session of the sub-committee on stability, load lines and fishing vessel safety (SLF45). In particular, high priority is given for the review of the weather criterion in the IS Code, which is based on the current Japanese stability standards and Soviet Union’s standards. This is because some European countries face difficulties to design with the current weather criterion large passenger ships and RoPax ships, which have large windage areas. However, the weather criterion is not only for these vessels but also for all other passenger and cargo ships of 24 m in length or above. Therefore, it is necessary to carefully evaluate the roles of the current weather criterion for guaranteeing the safety of ships other than large passenger ships and RoPax ships as rationally as we can. For such purpose, one of the authors had proposed to examine the safety level of the existing or draft stability criteria by using capsizing probability calculation with some examples applied to high-speed craft. Then this methodology was applied to 29 passenger ships and 46 non-passenger ships flying the Japanese flags for examining the IMO IS code. This paper describes outcomes relevant to the weather criterion from this comprehensive works.

2. OVERVIEW OF CALCULATION METHOD

Capsizing probability is usually defined as the probability that a ship capsizes within a certain time duration. In case the duration is one year, it is called as the annual capsizing probability, and calculated with long term wave and operational statistics. In this paper the time duration is set to be the wave period and the wave state is assumed to be stationary. The resultant probability can be regarded as capsizing probability per wave cycle.

The method used here considers the ship drifting in irregular beam wind and waves like the weather criterion but uses a more reasonable procedure to predict the ship motion than the weather criterion. The wind velocity is assumed to change with time around the average velocity with the Davenport spectrum. Further it is assumed that the wind generates fully developed waves, whose spectrum is ITTC (1978) one. The ship roll motion is modelled with one degrees of freedom one, which implicitly considers coupling with sway.

Based on the above mathematical model, the capsizing probability for a stationary sea state can be calculated by several methods such as the piece-wise linear method. In this study it was calculated by integrating a joint probability density function of Gaussian roll and roll rate in waves over the capsizing domain on the phase plane of roll motion without time-varying external forces. This approach is based on a theoretical conclusion that effect of time-varying excitation is negligibly small. It is noteworthy here that the weather criterion was also derived from this fact. The main drawback here is that roll motion outside safe region could be non-Gaussian in details. However, this difference could be minor for the current purpose because latest works based on the more rigorous one, e.g. the piecewise linear one, provided similar outcomes.

3. SAMPLE SHIP DATA

To examine the weather criterion, 29 passenger ships and 46 non-passenger ships with fully loaded departure conditions were selected from the Japanese fleet. This covers pure passenger ships, RoRo passenger ships, cargo and passenger ships, crude oil tankers, LPG tankers, container ships, general cargo ships, cement carriers, car carriers, tag boats and so on.

The metacentric heights are adjusted to marginally comply with the IS code, in other words, both the general criteria (Chapter 3.1 of the IS Code) known as A.167 and the weather criterion (Chapter 3.2 of the IS Code) known as A.562. In the calculation of the restoring arm curves non-water tight superstructures and down-flooding are ignored. The natural roll periods are estimated with the data from full-scale natural roll tests. The effective wave slope coefficients are estimated by Watanabe’s simplified formula because most of offset data are not available for direct calculation. Bertin’s roll damping coefficients are also assumed to be 0.02 because of the same limitation. The aerodynamic drag coefficients are assumed to be 1.17 as the IMO weather criterion assumed. The average wind velocity are set to be 26.5 m/s for ships used for international or ocean-going service, while that for domestic ships used only for coastal or smooth water service is reduced as the Japanese stability standards.

4. RESULTS AND DISCUSSION

The numerical results of capsizing probability are shown as functions of ship length in Figs. 1-2. Here the metacentric
heights are specified by the most stringent requirements of Chapters 3.1-3.2 of the IS Code and the white symbols indicate the cases the weather criterion is the most stringent. Thus these figures demonstrate that the weather criterion is dominant for about one third of passenger ships and for only two cargo ships, which are car carriers. This is approveable because they have large windage areas.

![Capsizing Probability of Passenger Ships](image1)

**Fig. 1** Capsizing probability of passenger ships marginally complying with the IS Code. Here the black symbols indicate the ships for which the general criteria are dominant and the white ones do the ships for which the weather criterion is dominant. The dotted line indicates the probability of one capsize for 20 years under the same sea state.

![Capsizing Probability of Non-Passenger Ships](image2)

**Fig. 2** Capsizing Probability of non-passenger ships marginally complying with the IS Code. Here the black symbols indicate the ships for which the general criteria are dominant and the white ones do the ships for which the weather criterion is dominant.

In general, the capsizing probability decreases when the ship length increases. This trend coincides with similar work done by Belenky\(^9\) for 16 ships. This is because larger ships have longer natural roll periods and then wave energy leading to harmonic resonance decreases. In particular, for the ships of 150 m or over in length, capsizing probability is too small to be plotted here. These large ships have no possibility of significant harmonic rolling under the sea state of 26.5 m/s in wind velocity. However, it is noteworthy that there is some possibility of harmonic resonance in following and quartering seas because of the Doppler effect. And even in beam seas sub-harmonic resonance may happen with parametric excitation. For smaller passenger ships capsizing probability seems to be too large. This is due to the simplified formula's overestimation of the effective wave slope coefficients, which was often reported for hard-chine craft.\(^9\) If the effective wave slope coefficients are correctly obtained, capsizing probability for these smaller passenger ships can be significantly lowered. Apart from these extreme cases, higher risk group situates around the dotted line, which shows probability of one capsize for 20 years under the same sea state assumed here. If the occurrence probability of such sea state is taken into account, the obtained values of capsizing probability specified by the weather criterion can be regarded as acceptable. It is also important that the combination of the general and weather criteria provides reasonably smooth upper envelope for passenger ships. In addition, the level of safety for passenger ships is comparable to that for cargo ships.

### 5. CONCLUSIONS

(1) The current IMO weather criterion could be dominant mainly for passenger ships and car carriers, while it is not so for cargo ships other than car carriers.

(2) The capsizing probability required by the current IMO weather criterion is generally acceptable.

(3) The combination of the general criteria and the weather criterion provides reasonable safety level for passenger ships at least up to 150 m in length.

(4) Capsizing probability with harmonic roll motions in beam wind and waves could be extremely small for larger ships having very long natural period.

### ACKNOWLEDGEMENTS

This paper is mainly based on the work executed in the fiscal years of 1994-1995 as a part of the RR32 research panel of the Shipbuilding Research Association of Japan, supported by the Nippon Foundation. The authors express their gratitude to these organisations as well as Professor M. Fujino, the chairman of this panel.

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