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Comparison of Proposed Stability Criteria
with the Results of Model Tests.

This report contains the results of a series of capsizing tests with a fishing vessel. The outcomes of the tests are compared with the requirements contained in Regulations 2 and 4 of Chapter IV of the Draft Text of the 1977 Convention as given in IMCO Document PFV XIX/2/4. The work described in this report was sponsored by the Bundesminister für Verkehr, Abt. Seeverkehr, Hamburg.
1. Introduction

The mechanism of capsizing of ships in waves is not yet fully understood. Therefore stability criteria can be determined on an empirical base only. For that purpose ship characteristics as e.g. righting levers, differences between the righting levers and the levers of heeling moments, areas under the righting lever curve etc. have to be defined which are supposed to assume different values for ships which are safe or unsafe with regard to capsizing. In order to judge the discriminating efficiency of such criteria information on the real behaviour of ships is necessary. It can be get from the casuality history of ships as well as from model experiments. Information on real ships has the advantage to include - at least in principle - realistic combinations of all capsize hazards. But practically it is impossible to get sufficient full scale data for a systematic investigation of stability criteria. Capsizing experiments with ship models are necessarily restricted to less realistic situations but can provide systematic information on the relationship between ship characteristics and occurrence or non-occurrence of capsizing in defined situations. Therefore they are suited to define efficient measures of stability rather than the required level of such measures. It seems that the combined use of model experiments and full scale information is the best way to develop criteria for the safety against capsizing: the first to establish formulations for the criteria, the latter to determine a sufficient level of safety.

In this paper stability criteria contained in Chapter IV of the draft text of an International Convention for the Safety of Fishing Vessels (IMCO-Documents PFV XIX/2/4 and PFV XVI/8) are compared with the results of model tests in order to state their relevance with respect to a situation which relatively often has been observed at actual casualties.
2. Investigated Capsize Situation and Ship Conditions.

The model tests have been carried out with the model of a fishing vessel operating in long-crested irregular quartering waves at a Froude number of about 0.3. The sea-state has been kept constant during the whole test series. The model was investigated at three freeboards (created by draft variation at unchanged depth) and with three variants of the deck well (1. completely free deck aft of the forecastle; 2. with a transverse squared volume body extending from side to side in the middle of the deck aft of the forecastle and 3. with a longitudinal squared volume body not extending from side to side; the area covered by the volume body was about 20 % of the free deck area in both cases). For each freeboard and each variant of the deck well the GM-value has been varied in order to determine the limiting values at which just capsizing occurs.

Details of the model, of the waves and of the testing procedure as well as information on each of 128 runs are given in the Appendix.

3. Results of Capsizing Tests.

Capsizing of ships in irregular seas is a random event. Therefore the safety against capsizing should be stated in terms of probability. Because of the big number of runs that would have been necessary to determine significant values of the probability of capsizing the decision whether a model is to be considered safe or unsafe against capsizing was based on its behaviour during several runs: A model condition was labelled "safe" if the model did not capsize in a series of four to eight runs. It was labelled "unsafe" when capsizing did occur.

In Fig. 1 the lowest righting arm curves of "safe" cases and the highest righting arm curves of "unsafe" cases are shown. In the following the curves of the "safe" cases are taken as capsize limits. This choice has been made because righting levers derived by interpolation between those of unsafe and safe cases would not have differed much from the chosen levers. It should also be kept in mind, that the tests did not include heeling moments from wind or gusts. Therefore actual stability
criteria should be based on even higher righting levers. In spite of this fact it seems fully justified to use the capsize limits for comparisons of the investigated model conditions.

It can be seen from Fig. 1 that the righting arms which are necessary to prevent capsizing increase with increasing freeboard (or decreasing draft). This holds for the ship with free deck area behind the forecastle as well as for the ship with volume bodies on the deck. The ship where the volume body on deck extends from side to side needs higher righting levers in order to be safe than the ship without or with a longitudinal volume body. There is no significant difference in the righting levers of the ship with free decks and of the ship with the longitudinally arranged volume body on deck.

4. Comparison of Proposed Stability Criteria with the Results of Model Tests.

For the capsize situation for which the model tests have been carried out only Regulations 2 and 4 of Chapter IV - Stability - of the draft text of an International Convention for the Safety of Fishing Vessels (IMCO-Document PFV XIX/2/4) apply.

In Fig. 2 the area under the righting lever curve up to 30° angle of heel as required in Regulation 2 (1) (a) is compared with the corresponding values which have been found necessary in the model tests in order to prevent capsizing. It can be seen that compliance with the requirement of the Regulation would not prevent capsizing in all investigated cases. The same holds with respect to the area under the righting lever curve up to 40° angle of heel as can be seen from Fig. 3.

When considering the curves derived from the model tests in Fig. 2 and 3 it should be kept in mind that they do not provide any allowance for wind heel and other influences not present in the model tests. If an allowance for influences not present in the model tests is made, the requirements of Regulation 2 (1) (a) can be considered sufficient for cases with low freeboard (or deep draught) only.
A comparison of the required righting lever at an angle of heel of 30° according to the model tests on the one hand and according to Regulation 2 (1) (b) on the other hand is shown in Fig. 4. For small freeboards the righting lever required by the Regulation seems to provide a sufficient safety margin; but this margin decreases with increasing freeboard.

The provision of Regulation 2 (1) (c) with respect to the angle of heel at which the maximum righting lever shall occur is more severe than has been found necessary in the tests for the cases with low freeboard. But it hardly suffices in the low draft conditions.

The GM requirement in Regulation 2 (1) (d) is far below what has been found necessary in the model tests.

Regulation 4 requires that every vessel shall be able to withstand the effect of water on deck to the satisfaction of the Administration. As guidance for the investigation of this effect the method described in PFV XVI/8, Annex II p. 47/50 has been used. The levers $GZ_w$ of the heeling moment due to water on deck determined according to this method are shown in Fig. 5. There is not much difference between the heeling levers $GZ_w$ for the case without and with a longitudinal volume body on deck. As to be expected the minimum righting levers necessary to prevent capsizing are about the same for both these cases. The heeling levers $GZ_w$ for the case with the transverse volume body on deck are significantly lower than those for the other two cases. The corresponding minimum righting levers however are higher than those for the other two cases. This unlogical result can only be explained by the fact that the method for the determination of the heeling moment due to water on deck is not realistic enough. The same conclusion is reached if the difference between the area under the righting lever curve up to 40° angle of heel and the area under the heeling lever curve is considered (this difference is equal to the area under the righting lever curve between the dynamic heeling angle due to water on deck and 40° angle of heel). Fig. 6 shows that the excess area under the righting lever curve which is necessary to prevent capsizing is much higher in the case with the transverse volume body on deck than in the cases without or with the longitudinal volume body on deck. Therefore, the proposed method is - at least for the investigated capsizing situation - not suited to take account of the effect of water on deck.
5. Conclusions

- Regulation 2 (1) (a) and (b) does not provide sufficient safety against capsizing in cases of high freeboard (or low draught). As yet it is not possible to state the limits of applicability of these requirements. For vessels similar to the investigated one some information on the dependency of the stability criteria on the freeboard can be taken from the test results reported above.

- The GM requirements of Regulation 2 (1) (d) do not directly influence the safety against capsizing. But they limit the initial heel due to wind or other moments and may thereby prevent the generation of situations from which it is more likely that a ship capsizes. In this connection it does not make sense that the GM can be reduced for vessels with complete superstructure (for which the heeling moment due to wind is usually higher than for a single deck vessel).

- With respect to Regulation 4 - Effect of water on deck - it has to be stated that at the time being, no method is available to judge reliably the effect of water on deck. Therefore, it is not possible to demonstrate compliance with this regulation. As a consequence this regulation should be deleted.

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