Development of Threshold Values for a Minimum Stability Criterion based on Full Scale Accidents.

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1 Scope and Conclusions

In [45] an intact stability criterion was developed which aims at the determination of sufficient intact stability of a ship in heavy weather. The aim of this dynamic intact stability criterion was to establish a minimum level of stability which should ensure that the remaining capsizing risk in heavy weather shall be as low as reasonably possible. The proposed criterion results in the computation of an index value (the insufficient stability event index ISEI). To make the criterion practically applicable, threshold values need to be defined for this index to distinguish between safe and unsafe ships or conditions on the one hand and to establish a required minimum level of safety in heavy weather on the other.

To establish such a threshold value for the ISEI, we have investigated several full scale capsizing events with appropriate numerical methods and procedures. These methods or procedures are based on the direct computation of the non linear roll motions of the ship in time domain in a natural (short crested irregular) seaway [74], [27]. Such kind of methods or procedures have been developed during several decades with the special intention to analyze full scale capsizing events for German authorities.

If these methods or procedures we have used in our analysis were found to give a reliable prediction of the ship’s behaviour in the accident condition, it was then assumed that these methods or procedures will also deliver reliable results in other conditions (which must still be covered by the mathematical formulation of the problem and the related assumptions). This results in the possibility to analyze many situations that might be potentially as dangerous for the ship as the accident condition.

Such kind of computations can be used to find the required threshold values for our dynamic intact stability criterion. An accident is an event which definitively proved that the stability condition was dangerous. Therefore, given that our numerical methods deliver the correct answer to the accident situation, then we can assume that the same type of computations for other conditions will give also a reliable answer. If we now use these methods to determine the ISEI-value for a loading condition which has been identified to be unsafe, then we can establish a relationship of the ISEI-value and stability conditions which are not acceptable.

Further, we must not neglect the fact that over decades in different countries, a lot of useful knowledge has been generated which resulted in many types of stability criteria. Based on the knowledge of the time when such criteria were developed, and also based on the ship types that did exist in those times, these stability criteria represent a sufficient and practical level of safety for those ship types.

Therefore, we have also collected some common stability criteria, and for each accident condition we have also checked whether these criteria were fulfilled or not. Our analysis has shown that for most of the older capsizing accidents, these criteria were not or hardly fulfilled, which shows that these criteria indeed represented a level of safety which might be considered as reasonable. Therefore we can conclude that the well established intact stability criteria represent a reasonable level of safety, provided that they are applied to ships for which they are valid. Some accidents we have investigated have happened because the relevant stability criteria were in fact not fulfilled.

On the other hand, we have also found (more recent) accidents where the ship fulfilled the relevant criteria (or recommendations) when it capsized in heavy weather. This has lead us to the conclusion that some modern ship types are not reflected by these well established criteria anymore.
In this respect, the computed ISEI- value may give assistance in judging upon the fact whether a loading condition is dangerous for ships which are not covered by the existing stability criteria. If the ISEI- value computed for such a loading condition is of approximately the same magnitude as computed for a real accident, we have good reasons to assume that this situation will potentially lead to an insufficient stability event, even if all relevant existing stability criteria are fulfilled. As most of the existing stability criteria are based on a very famous work of Rahola [62], we will call them Rahola- criteria in the following.

But it must also be the aim of a limiting stability criterion to ensure a certain consistent level of safety against insufficient stability events. Simply computing that a specific situation is dangerous is not enough. In this respect, the existing knowledge of the well established stability criteria is of a very high value, as the safety level these criteria represented was generally accepted to be reasonable at the time they were introduced. This knowledge can help to determine a threshold value for the ISEI which may represent a sufficient level of safety. To come to such a threshold value, the following steps have to be performed: If a ship capsized in a specific situation, and if this event is well represented by our computations, we can check whether the ship did fulfill the Rahola stability criteria. This is in particular valid for those ships and accidents where we can assume that they are indeed covered by the Rahola stability criteria. Therefore, we have analyzed many older capsizing events, because we can assume that the ships in those days were actually covered by the Rahola-criteria. If it now turns out that the ship did not comply with the Rahola criteria, it is useful to check the accident situation with a limiting stability value that fulfills these criteria. If it then turns out by the analysis that the ship would have survived the accident, then we have determined a level of stability which would have prevented that particular accident.

For such a loading condition, we can again compute the ISEI, which then represents a value that is connected to a safety level which is in general seen as sufficient. If we repeat this procedure for other ships covered by the Rahola- criteria, we come to a first impression for an ISEI- threshold value.

It has also been put forward by other groups of authors that the Rahola- criteria were not seen as sufficient for some ships, and alternative criteria have been developed, which represented the state of the art of the time. Therefore, for some accidents we have also investigated the application of these criteria and their effect on the ISEI. When all criteria converged to classify a loading condition as being safe, we have no reason to assume the opposite. Again, we can compute an ISEI- value which then also represents situations of generally accepted safety.

Following this procedure, we can identify a range of ISEI- values which represent a loading condition of a sufficiently accepted level of safety with respect to insufficient stability events in heavy weather. This information obtained from the analysis of full scale accidents can be completed by the analysis of special capsizing model tests, provided they were performed carefully and that they can be recomputed.

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1These are mentioned in the sense of the six criteria of IMO- intact code applicable to all types of ship.
Fig. 1 gives an overview about the cases we have studied. The abscissa denotes the GM-value of a ship, the ordinate shows the computed ISEI-value. The graph also shows model test results or investigations of other authors (e.g. ONR or ARATERE) which we have taken from literature and analyzed with our methods. Each curve represents an individual ship at different stability conditions. The first condition of each curve (the smallest GM-value) always represents the accident condition (or definitive capsize in a model test). Therefore it is obvious that the first value of each ship represents a condition which has clearly proven to be unsafe.

All accidents we have analyzed happened in following seas and resulted in capsizing. It is interesting to note that hardly any capsizing events\textsuperscript{2} are known to us which did not happen in following seas.

\textsuperscript{2}In this respect we refer to the sources available to us, and these are mainly accidents of German flagged vessels, and they might not be representative. A good summary of German capsizing events during the 60s or earlier can be

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Section 1: Scope and Conclusions

Those few capsizing accidents with insufficient stability which happened in head seas (e. g. E.L.M.A. Tres) would have - according to our computations- also happened in following seas. Some other accidents happened in beam (VINCA GORTHON) or bow quartering seas (MORMACKITE), but in these cases the cause of the accident accident did not seem to be insufficient stability but cargo shift. Head seas may lead to accidents with large accelerations. For capsizing events due to insufficient stability, the following sea scenario is the dominant failure mode. We have tried to select a couple of accidents in following seas with a variety of failure modes, but they all have in common a generally insufficient stability level.

It is now interesting to note that most of the unsafe conditions group in an ISEI- range about 0.1. These are all accidents which - in the accident condition - did not or only hardly fulfill the Rahola-Criteria. Therefore we have very good reasons to assume that an ISEI- value in the order of about 0.1 represents a situation which can clearly be defined as dangerous.

Further, we have some accidents for ships that did fulfill the Rahola- criteria in the accident condition, but nevertheless capsized (e.g. FINNBIRCH). These cover the ISEI- range from 0.1 to about 5E-3. Therefore we can conclude that such values of ISEI do represent situations which still have a non negligible risk of an insufficient stability event.

The last value of each curve (with the highest value of GM) was always computed for stability values which seemed to represent a situation which was considered as reasonably safe according to the procedure stated above. From Fig. 1 the fact can be derived that these situations are represented by an ISEI- value at or below 1.E-3. Therefore, we can conclude that an ISEI- value of or below 1.E-3 represents a situation which we can assume to be acceptably safe.

This information can be used to define reasonable threshold values which assure a sufficient safety level against insufficient stability events. It may be assumed that the stability of the ship in a loading condition to be evaluated shall meet an ISEI- value of about 1.E-3 to ensure a level of safety which is equivalent to the safety level of the Rahola- criteria for those ships where they are valid. It is further assumed that this well established safety level is sufficient for all realistic operating conditions.

Further information about the individual accidents and the circumstances is given in the following sections.