TOWARDS THE DIRECT ASSESSMENT OF A SHIP'S INTACT STABILITY

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Abstract

Based on the increasing reliability and experience with direct assessments via model test and/or numerical simulations there is a clear trend in the development of rules and regulations towards performance based criteria and alternative direct assessments. For the evaluation of a ship's intact stability expert knowledge and many tools are internationally available. But so far validated and standardized methodologies for a complete direct assessment are still missing. This paper aims at providing a basis for discussions of future concepts by describing an example of a design methodology for qualitative assessments currently in use at the FSG (Flensburger Schiffbau-Gesellschaft) and by briefly outlining some possible approaches for direct assessments.

1 Introduction

At present, the assessment of the stability of ships – intact or damaged– is confined to the fulfilment of empirical criteria related to the static lever arm curve for still water condition only. The IMO intact stability criteria (Resolution A 749, IS-Code) are prescriptive rules which were developed based on the experience with ships quite some years ago.

A current observation from ship design is, that some measures taken to improve the dynamic intact stability of a design are not rewarded or in some cases even punished by the current rules, even if model tests or direct dynamic simulations show a clear improvement. This is not surprising, as due to market demands ship designs change very rapidly and the old criteria being based solely on the static lever arm curve for still water condition, are not and can not represent the (dynamical) physical characteristics of modern vessels sufficiently well.

Some of the large Container ships recently suffered from parametric excitation, loosing and/or damaging a lot of cargo and being in the danger of capsizing. Many more of the modern designs are susceptible to parametric excitation, not only Container ships, but also RoRo-, RoPax-, Ferry and Cruise vessels, but luckily have not yet encountered such a dangerous situation - or we have not heard about it. Also quite a few vessels are endangered by pure loss of stability and combinations of parametric excitation and pure loss of stability. Currently the intact stability rules do not cover these dangerous mechanisms and other unfavourable and dangerous seakeeping characteristics many ship operators of RoRo, RoPax, Ferry, Cruise and Container vessels complain about, e.g. very short roll periods leading to high accelerations, especially if combined with insufficient roll damping as well as insufficient course-keeping capabilities of vessels in rough weather.

Due to these problems with the current IS-Code a revision process was started at the last IMO-SLF meeting. It was decided that next to some short term amendments the code should be completely revised with two major aims:

1. all new criteria shall be formulated as performance based criteria
2. alternative direct assessments via model test and/or numerical simulations shall be possible

Consequently the following steps have to be performed in the revision process:

- Identification of safety related situations/mechanisms endangering the intact ship
- Collection of existing related knowledge and further research with respect to the physical phenomena endagering a ship and the assessment of ships performance in dangerous situations
- Development of a framework of performance based intact stability criteria
- Definition of criteria with appropriate standards

2 Direct assessments in general

In other areas of ship design and approval alternative direct assessments are used to prove suffiencient safety or strength (e.g. stress analysis in structural design or evacuation). With respect to the intact stability approval, there are so far no alternative approaches established next to the "simple" fulfilment of the current empirical criteria with its already mentioned deficiencies.

It was shown many times, that the numerical tools which are available today allow for an evaluation of dangerous and even fatal scenarios, e.g. Söding (1987a) investigated the loss of the "E.L.M.A. Tres" and France et al. (2001) investigated the problem of parametric excitation of C11 Class Container ships. Furthermore it can be shown that the use of a "design for safety methodology" based on direct numerical simulations and a qualitative assessment allows to increase the safety of ships in severe seas without impeeding the economical ship's performance, Cramer and Krüger (2001). So despite the known deficiencies the numerical tools still have, they can be used to assess a ships safety, when being used appropriately. And the same is of course valid for model test methodologies, France et al. (2001), Clauss et al. (2002), and other.

Still, next to approval problems with most national authorities there is one basic problem when developing or applying direct approaches today: it is unknown what kind of safety level the existing empirical rules represent and which safety level would reach international acceptance. In order to allow a quantitative direct assessment of a ship's intact stability it is therefore necessary to develop methodologies for those alternative approaches and to estimate the internationally tolerable safety level. Those developments are indispensible for the future ship approval and design, as empirical formulations will never be able to provide a sufficiently broad and fair evaluation basis to cover all possible new design developments. This is also reflected in the IMO's decision towards performance based criteria and alternative direct assessments.

3 Qualitative evaluations already in use in ship design

The aim in the design process is, to improve the ship's safety with respect to intact stability together with all other design tasks (e.g. speed performance and cargo capacity). In order to allow for an efficient design process direct calculation methods are implemented into FSG's design software "E4". For the evaluation of the ship's intact stability and seaworthiness numerical motion simulation programs are used, Cramer (2001). As the safety level which has to be met by a design as such is unknown and a methodology for a quantitative assessment is not yet established, an "equivalent safety" approach was developed and is adopted for the time being. "Equivalent safety" means here, that an approach is used which allows a qualitative comparison of different ship designs with respect to their safety in severe seas. The methodology is as follows:

Several simulations are carried out for different speeds and encounter angles for each loadcase of interest and different significant wave length'. The seaways are modelled irregular and short crested according to a given spectrum. For all those conditions the significant wave height is increased until the limit between safe and unsafe according to a criterion developed by Blume (1987) for model testing is found. Blume developed this criterion because simply distinguishing between the ship did capsize or did not is not an adequate criteria to decide whether a ship can be considered as save in certain environmental conditions or not, as results then depend on the number and the duration of the tests. The Blume-criterion works as follows:

Whenever the ship did not capsize in the respective run (or here simulation) the area E_R under the calm water curve of righting arms between the maximum roll angle φ_{max} encountered in the run and the vanishing point is calculated (illustrated in figure 1). Whenever the ship did capsize, or in cases where φ_{max} is larger than the vanishing point, E_R is set equal to zero for the particular run. Then the mean $\bar{E}_R$ of all runs (or simulations) in the same condition and the standard deviation s of the E_R's are determined. A ship is regarded as save when

$$\bar{E}_R - 3s > 0 \tag{1}$$

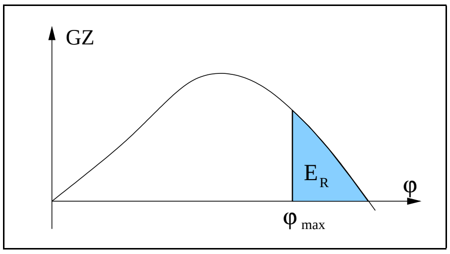

Figure 1: Area E_R

The results are presented as polar plots for each combination of load case and significant wave length. Figure 2 shows a polar plot for a 190m RoRo-Ship design. In this example the significant wave length of the short crested irregular seaway is equal to the ship's length'.

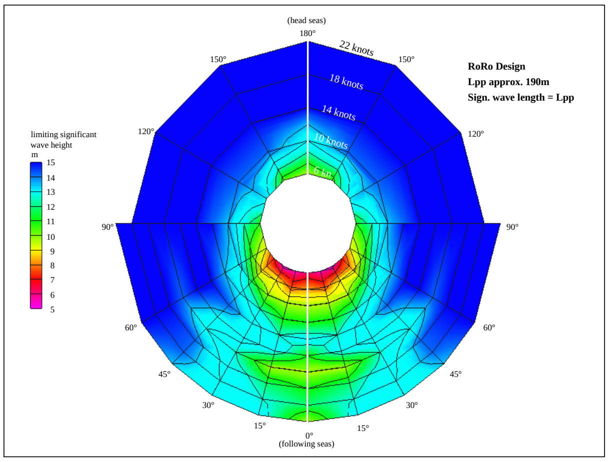

Figure 2: Polar plot for a 190m RoRo-Ship design

For this example a dangerous zone can be identified at small speeds in following seas where the vessel encounters parametric excitation. Also the region where the ship's natural roll period equals the period of encounter can be identified in following seas at around 18 knots ship's speed. This diagram can now be compared with diagrams of other loadcases and/or wave length', design alternatives or other ships. Figure 3 shows an example for such a comparison. In this case the design load case on even keel (left hand side) is compared to a case were the ship was additionally trimmed aftwards by 1m (right hand side). It can be seen that due to the aftward trim the region where parametric excitation occurs is a lot less pronounced while the region where the ship's natural roll period equals the encounter period the ship's roll motion increases. Also both regions are shifted to smaller speeds compared to the condition on even keel due to the shorter natural roll period.

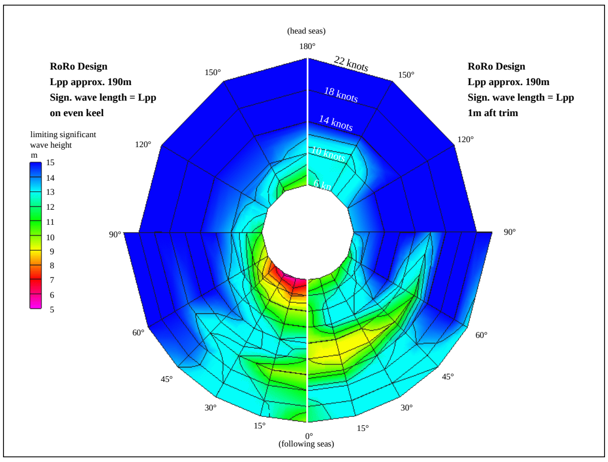

Figure 3: Polar plot for a 190m RoRo-Ship design, comparing the design loadcase on even keel with the design loadcase trimmed aft by 1m

Those polar plots provide valuable informations and decision support in the early design stages. The dangerous zones can be efficiently identified and analysed and once the underlying physical phenomena are understood, it is usually possible to improve the ship's stability in those critical conditions by design modifications, e.g. local hull form changes.

Additionally, those polar plots provide an excellent basis for the development of ship specific guidance to the master. And there is a strong demand for such guidance in the market. A first set of ship specific guidelines for operation is currently compiled at the FSG for one of our customers, including ship specific information regarding manoeuvring, fuel economy and sea keeping, with all those informations being derived via direct asessments, i.e. numerical simulations and model tests.

But while the described procedure is well suited to improve a ship's seaworthiness and give decision support for ship operation, it is still only a qualitative evaluation. And once these diagrams are calculated for several wave length' and loading conditions the ranking ("better" or "worse") of two design alternatives sometimes becomes difficult. In order to overcome this problem methodologies for a quantitative evaluation are necessary.

4 Concepts for quantitative evaluations

There are two general concepts how direct assessments could be performed:

1. the overall probability of intact survival could be calculated, taking into account the environmental conditions, ship conditions, operational restrictions, etc.

2. scenarios for all relevant physical phenomena endangering the intact ship could be assessed with appropriate criteria to be met.

The calculation of the overall probability of survival has several advantages compared to the rather deterministic assessment of certain scenarios. The most important advantage is, that the ranking of the different physical mechanisms endangering a ship during its lifetime are implicitely ranked via their probability of occurence and can be weighted with respect to their consequences. Furthermore knowing the probability of intact survival these probabilities can be directly compared to other means of failure, e.g. damage stability. So the development of methodologies and tools for such assessments is very important.

On the other hand the assessment of defined scenarios is very likely to be easier in application and especially for approval purposes for the near future. Because combinations of numerical simulations (where sufficiently validated) and model tests (where numerical simulations might not be good enough yet) are in this case easier to implement and standardize. Also a set of scenarios would provide the better frame for the development of empirical formulae for the assessment of a ships intact stability via the "rule book". But of course the most important question here is: Which scenarios need to be looked at and what are appropriate criteria to be met? Here again an analysis of overall probabilities of survival could help.

4.1 Probability of survival

There are different methodologies how an overall probability of survival for intact vessels can be calculated. In the following two methodologies currently under investigation within a research project carried out at the FSG and the TUHH (Technical University of Hamburg, Germany) are very briefly outlined.

Based on the polar plots

Based on the in section 3 described methodology for qualitative assessments, the estimated limiting significant wave heights according to the Blume-criterion in combination with seaway statistics and assumptions with respect to a ship's speed distribution etc. can be used to answer the question "How much time does a ship spent in potentially fatal conditions". This approach is charming because the polardiagrams proved to be a very practical, illustrating support for design decisions. Additionally all necessary numerical tools are already implemented and thus available. First trials with such a procedure are currently run for several ships at the TUHH, Hamburg, under supervision of Prof. Krüger. One disadvantage of this procedure is, that in order to calculate the overall likelyhood of potentially fatal conditions all possible combinations of environmental conditions, speed, etc. need to be simulated. In oder to reduce the computing effort, possibilities to narrow the calculation domain are also investigated.

Via Monte-Carlo Simulations

Another approach currently under development is to calculate the probability of survival or the likelihood of potentially fatal conditions for intact ships based on results from numerical motions simulations within the framework of Monte-Carlo Simulations. Here not every possibly combination of environmental conditions, speed, etc. is simulated but a sufficiently large random sample. An example for the use of the Monte-Carlo-Simulations for damage stability is given in Tellkamp and Cramer (2002) (this workshop). The advantage of this approach is, that the safety level is explicitely calculated and the level of confidence is known.

Figure 4 illustrates the computing effort and possible short comings of different approaches.

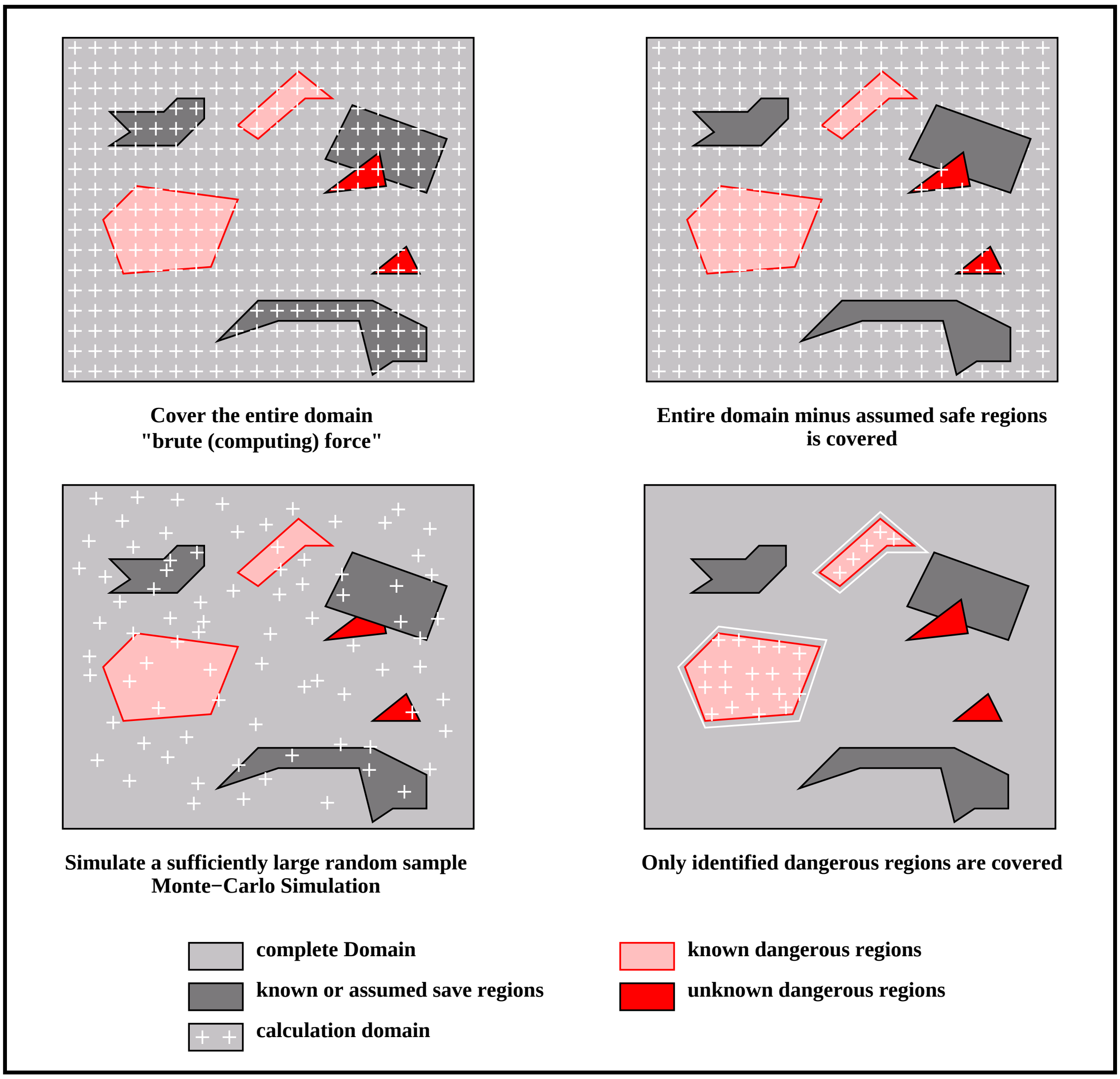

Figure 4: Different approaches towards safety evaluation

Potentially fatal versus capsizing probabilities

For the quantities to be evaluated there are numerious possibilities, and methodologies are not necessarily equally suitable for all kinds of quantities.

The calculation of the probability of survival brings the very important advantage, that the results can be directly compared to other means of failure, e.g. damage stability. But there are many problems in the actual calculation of the probability of failure or survival already for distinct combinations of environmental conditions, speed, etc. – within a Monte-Carlo framework for the random samples as such, e.g.:

- What is an intact failure, 50 degrees of roll? 90 degrees? Accelerations which induce cargo shifts? ...?
- How do we calculate failure periods of several years sufficiently accurately? Do concepts which allow an extrapolation of capsizing probabilities from high waves to lower waves, e.g. by Söding (1987b) help in this respect?
- What about the influence of operational measures?

Instead of the probability of survival or intact failure the probability of potentially fatal conditions could be calculated. For this option the periods to be calculated are smaller compared to the probability of an intact failure, and therefore with a good chance easier to evaluate. On the other hand a criterion or criteria which are good distinguishers between safe and potentially fatal need to be developed. The above used Blume criterion is an example for such a criterion, though its reliability and applicability has not yet been assessed and is therefore questionable for quantitative evaluations.

General questions to be answered

In all cases there are further questions to be answered:

- How sensitive are the results with respect to the applied sea statistics, speed and encounter angle distributions, etc., or the human factor in operating?
- How do we judge whether a numerical tool is appropriate or not?
- How do we decide whether the environmental conditions were modeled appropriately?
- etc.

Further research will show which of the above mentioned concepts allow for reliable quantitative assessments and which do not.

4.2 Assessment via deterministic scenarios

The difficult task when adopting such an approach is of course the definition of the scenarios and appropriate criteria. In order to ensure a sufficient intact safety of a vessel all dangerous mechanisms and phenomena potentially endangering a ship need to be taken into account and assessed appropriately. In an attempt to start a list this would include:

- Roll motions in severe seas due to large exciting moments
- Large heeling moments imposed on the ship other than waves like wind, loading and unloading, turning circles at full speed, movement of cargo and passengers, etc.
- Parametric excitation
- Stability losses in wave crest condition
- Severe accelerations and excessive roll angles when travelling at sea due to very short roll periods, insufficient roll damping, etc.
- Broaching and other course-keeping problems in rough conditions which can trigger large roll angles and capsizings
- etc.

And of course combinations of the above mentioned.

Now while the definition of appropriate criteria is difficult, this approach brings several advantages when adopted in rules and regulations, at least as long as the calculation of an overall probability of survival is not standardized and internationally available and agreed upon. Compared to the current intact stability criteria, this approach would bring the intended change towards performance based criteria, while it would still be possible to develop conservative empirical criteria applicable to most ships for approvals "via the rule book". As far as alternative direct approaches are concerned it is also very likely that, at least in the near future, they will be more easily accepted when they focus on certain scenarios, because standards are more easily defined and the problem at hand (the scenario) is also well defined. Examples like the Stockholm agreement and evacuation analysises are examples for this kind of methodology.

The most important disadvantages of this concept and problems when adopting this approach are:

- How do we ensure that the scenarios will be appropriate and sufficient for the evaluation of future design?

- How can be assured that all dangerous scenarios are covered?
- How do we include possible new dangerous phenomena?
- And how can be assured that the chosen scenarios and adopted direct assessments allow for a good distinction between sufficiently safe and unsafe?

5 Conclusions

A revision process of the IMO intact stability code was started and aims at new intact stability rules which are performance based and allow for alternative direct assessments. This change in philosophy is very important for future developments in ship design, as experience shows, that purely prescriptive, empirical formulae often can not assess future designs sufficiently well.

There are many examples which show, that todays numerical tools and model test methodologies are well suited to investigate physical phenomena endangering intact ships, to evaluate the causes of accidents and to improve a ship's sea keeping performance. But up to now this knowledge could not be used for ship approval purposes. With the intented change towards performance based criteria and alternative direct assessment this is very likely to change substantially.

Figure 5 illustrates the different components and approaches towards the assessment of a ships safety.

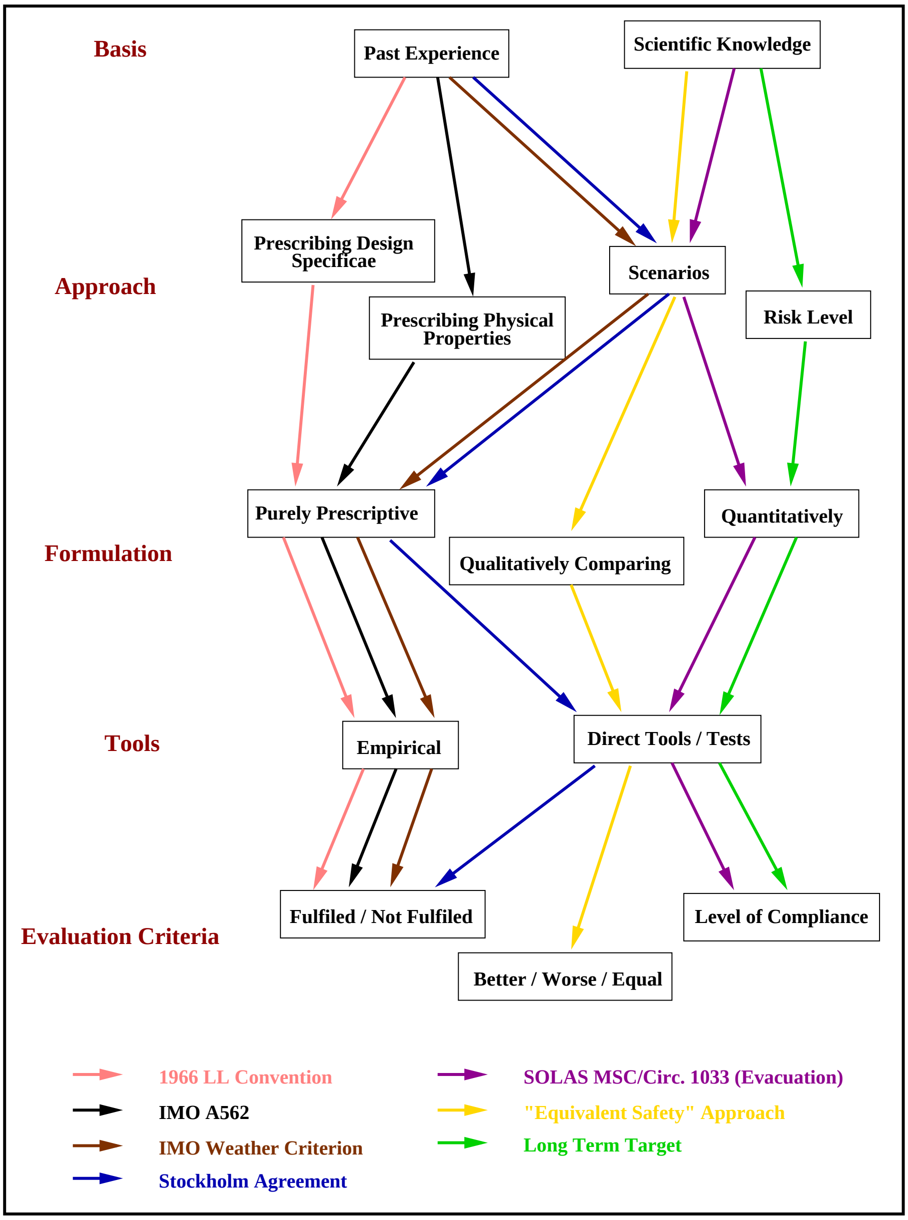

Figure 5: Different ways towards the assessment of a ships safety

For the development of new intact stability criteria and methodologies for direct assessments two things are needed:

1. Numerical Simulations and model test methods need to be validated and further developed to allow for an evaluation of a ship's performance in rough and severe conditions. In this respect the ability to assess the reliability of a method is very important, i.e. what are the limitations, and what is the accuracy of the results, because only when the accuracy is known the tools can be chosen appropriately.
2. Methodologies have to be developed and validated which provide a framework for an assessment of the ship's survivability based on numerical tools and/or model tests. And again it is of utmost importance that the reliability of the results can be assessed.

Last but not least, based on these methodologies a minimum internationally acceptable level of safety needs to be defined. So at some stage there needs to be an answer to the question:

With which frequency or in which kind of conditions is a ship allowed to capsize?

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