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Stability Criteria - Present Status and Perspectives of Improvement

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ABSTRACT: Short historical development and present status of stability criteria is presented. Current work of the International Maritime Organisation on second generation stability criteria is critically assessed showing the advantages and week points of the project. Perspectives for improvement of the safety against stability failure are discussed, including risk assessment methods and goal oriented approach to stability problems.

1 INTRODUCTION

History of stability criteria is a long one. It is assumed that first stability criteria were proposed by Denny in 1884 and adopted by British Admiralty after the CAPTAIN disaster. Few years later German professional Mariners Association recommended minimum righting arms curve after foundering of 15 fishing vessels during the stormy night 22 to 23 December 1894in North Sea. Benjamin in 1913 proposed minimum dynamic stability arms curve that was used by British Admiralty. During the period before the First World War several other proposals were advanced, e.g. by Anderson, Holt, Bruhn, Niedermair and Pierrotet. [1].

The most important proposal was however advanced in 1939 by Rahola, [2] who on the basis of comparison of stability characteristics of ships which capsized with those which were operated safely proposed set of criteria that were unofficially in use in several countries until international stability criteria developed by the Intergovernmental Maritime Consultative Organisation (IMCO)were adoptedin 1968.

Development of internationally adopted stability criteria was one of the basic tasks of IMCO since the establishment of this organization. At the International Conference on the Safety of Life at Sea (SOLAS) in 1960 this task was recommended for the Organization. The work on developmentof stability criteria started at the first meeting of the Sub-committee on Stability and Subdivision (STAB) of IMCO in 1962.

2 DEVELOPMENT OF THE INTACT STABILITY CODE

The current stability criteria are included in the International Code on Intact Stability 2008 adopted by the expanded Marine Safety Committee of the International Maritime Organisation (IMO) on 4 December 2008 [3](IMCO changed its name to IMO in 1982).

The short history of the Code is as follows. The first internationally accepted stability criteria were statistical criteria developed by the STAB Sub-committee of IMCO in the years 1962-67 and adopted in 1968 by IMCO Assembly by resolutions A.167(AS.IV) and A.168(ES.IV). Then, during the period 1978-82STAB Sub-committee developed so called "Weather Criterion" for passenger and cargo vessels that was adopted ultimately in 1985 by IMO Assembly by ResolutionA.562(14) and later on, for fishing vessels in 1991 by Resolution A.685(17).There were also adopted in the meantime several other resolutions related to various aspects of stability, amongst them resolutions related to stability of vessels of different types. All criteria included in these resolutions were recommended only, none of them was considered compulsory.

The criteria developed were criticised from the very beginning after they were adopted. During the discussions at STAB Sub-Committee and also in other places it was stressed that in development of those criteria several assumptions were made making those criteria non-rigorous. According to many opinions those criteria hardly could be assessed as "rational", because they were not based on probabilistic approach. In late eighties with no realistic proposals of how to base the criteria on probability of capsizing, and in order to make at least some step forward, IMO decided to make one comprehensive document that would include all resolutions and criteria already developed and split between several different documents. The idea of development of Intact Stability Code was advanced and finally, after discussion, the Code was developed. It was also agreed that this code should be based on system approach [4].

Finally Intact Stability Code was adopted in 1993 by IMO Assembly by resolution A.749(18). The Code was subsequently amended in 2002. Since then, however, discussion started again on the possibilities to improve level of safety against capsizing and to revise the criteria. It was agreed by the IMO that the most important motion would be to make stability criteria compulsory. This was achieved by drafting new edition of the Code, that was adopted ultimately in 2008.Both editions of the Code included stability criteria virtually unchanged from the original criteria recommended by the above mentioned resolutions.

3 PRESENT STATUS OF STABILITY CRITERIA

Present status of stability requirements is represented by the 2008 edition of the International Intact Stability Code [3].This editionof the Code consists of three parts: Part A, Part B and Explanatory Notes.

Part A of the Code was made compulsory by proper reference in the SOLAS Convention. It includes basic criteria: statistical criteria and weather criterion for both passenger and cargo ships and fishing vessels. Only minor improvements from the previous editions were included.

Part B of the Code includes provisions for specific types of ships and other provisions that are recommended only. That makes possible to amend this part of the Code more often as deemed necessary and to include criteria and provisions that may be not entirely sufficiently validated for a trial period. This part of the Code includes provisions for:

- Fishing vessels
- Pontoons
- Container ships greater than 100m
- Offshore supply ships
- Special purpose ships
- Mobile offshore drilling units (MODUs).

Part B of the code includes also chapters on:

- Guidance in preparing stability information
- Stability calculations performed by stability instruments
- Operational provisions against capsizing
- Icing considerations
- Considerations for watertight and weathertight integrity
- Determination of lightship parameters.

Two Annexes include detailed guidance for the conduct of an inclining test and recommendation for skippers of fishing vessels on ensuring a vessel's endurance in conditions of ice formation. Finally the Code includes third part comprising explanatory notes to the stability criteria.

4 IMO CURRENT WORK ON IMPROVED STABILITY CRITERIA

Having prepared the 2008 edition of the Intact Stability Code, the SLF Sub-Committee was, however, not satisfied with the stability criteria in force. The point was raised by some delegations, that several situations dangerous from the point of view of stability are not covered by the criteria. According to some delegations the following situations or stability failure modes should be considered:

- Parametric resonance in following and head seas
- Loss of stability in the wave crest
- Broaching to and surfing
- Dead ship condition, and
- Excessive accelerations when rolling

Actually the proposals were not new. Those situations were considered by the Sub-committee during late seventies and early eighties of the last century. At that time Polish delegation to IMO proposed to consider those situations [5], apart from the last one, but after brief discussion the Subcommittee decided that it was unable to work out usable recommendations in that respect. Problem of excessive accelerations was included recently following the proposal of the German delegation. The Sub-committee agreed to consider those situations under the agenda item "Second generation stability criteria".

Table 1. Three levels vulnerability approach within second generation stability criteria

	Level 1	Level 2	Direct stability assessment	operational guidance
Stability failure mode	Simple and conservative criteria based on geometry of hull and speed	Less conservative criteria, based on simplified physics and involving simplified	Numerical simulation of physical phenomena based on computer codes developed	Based on experience

Work on second generation stability criteria started in 2008 [6]. After rather lengthy discussion of the matter during several sessions the Subcommittee agreed that with regard of those situations safety assessment based on the three-levels vulnerability check have to be applied. The idea of this approach is that vulnerability to those stability failures at three levels have to be checked, as shown in the table 1.[7].

Fig.1 shows schematically process of checking vulnerability to all four stability failure modes.

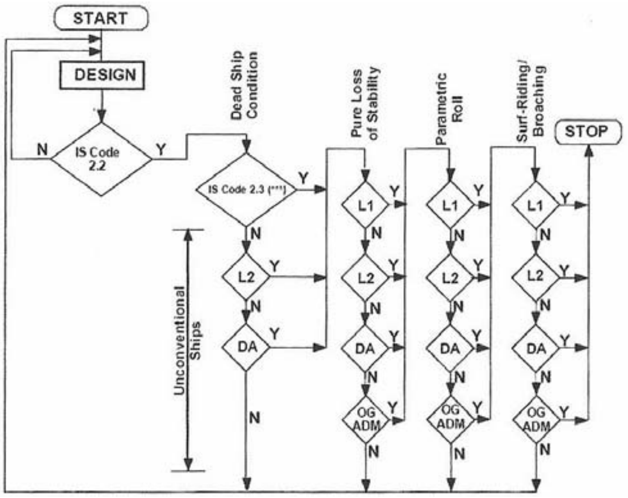

Figure 1. Schematic presentation of the process of checking vulnerability to four stability failure modes (from [8])

The SLF Subcommittee assumed that three to four years maybe sufficient to complete the criteria, however when the work started the Subcommittee realized that this is not an easy task. After six years of discussion and extensive work even the most simple criteria of the level 1 have not been finalized and although preliminary draft of those criteria was prepared, they are still under discussion. It is assumed now that at least three to five years more are needed to complete the second generation stability criteria. It appears that this approach is charged by some disadvantages and even some countries expressed now the view that the criteria proposed until now are too complicated and in particular at level three they require application of the rather sophisticated computer programmes that are not commercially available. Because of that in their opinion the whole task has to be abandoned.

5 CRITICAL OBSERVATIONS REGARDING SECOND GENERATION STABILITY CRITERIA

Attempt to improve safety against stability failure as deemed to be accomplished by development of the second generation stability criteria has some advantages but also some weak points. The second generation stability criteria as they are considered now are basically design oriented. Their concept is based on the assumption that improvement of ship construction and lay out will increase level of safety against stability failure. That is so, but only to the certain extent.

Analysis of causes of casualties reveals without doubt that in almost all cases the casualty scenario is very complex and several factors contribute to the end result. Casualties where one single cause may be identified are extremely rare. Usually, apart from design faults, also operational factors, including human factor, play important part. Therefore improvement of the design characteristics of the ship or even eliminating all possible causes where faulty design is the main cause of casualty may affect only small percentage of casualties. Concentrating main effort on design characteristics of ships is therefore not the most important task.

IMO current work on second generation stability criteria consisting of taking into account some stability failure scenarios identified as important will certainly increase the level of safety from the stability point of view. However, analysis of stability casualties reveals that chosen stability failure modes are not the most frequent ones. Although current approach to second generation stability criteria includes consideration of some important hazards it does not take into account hazards probability.

One of the stability failure modes chosen is parametric resonance. Extremely large effort to investigate parametric resonance was devoted during recent years and a great number of important papers were published on this subject (e.g. [7, 9]). Also a large number of documents containing studies of the effect of parametric resonance on stability were submitted to IMO. This resulted in preparation of preliminary draft of few options of vulnerability criteria to parametric resonance of the level 1 and 2.

Actually, the main reason of taking parametric resonance into consideration was one casualty of large container ship [10] where due to parametric resonance in head waves serious damage to the container staples leading to loss of several containers and some damage to the ship hull happened. Careful analysis of a number of casualty reports reveals however, that cases where the casualty may be attributed solely to parametric resonance are extremely rare and usually associated with other hazards.

If we consider, for example, proposed first level criteria on avoiding parametric resonance we may discover that they are most conservative. However if the designed ship is meeting those criteria it does not mean that occurring parametric resonance is impossible. Under certain combination of wave characteristics, speed and heading parametric resonance may occur and with no reaction from the crew it may be dangerous causing excessive rolling. It is true, that parametric resonance is rare event, and there are extremely rare situations where parametric resonance actually led to stability failure.

Within second generation criteria hazards were identified, however probability of hazard is not considered. It seems, that if the probability of hazard is lower than certain assumed value, such hazard may not be considered further. How to assess hazard probability is another matter. Obviously probability of hazard depend to some extent on ship design, but more on ship operation and human factor. Parametric resonance may be easily avoided by following by the master operational guidance. Within second generation stability criteria operational guidance was included in the scheme, therefore it was deemed that this may be necessary, but at present there was no attempt made to discuss this problem. Operational guidelines are proposed however as alternative to direct stability assessment as shown in the table 1.

Another hazard considered, loss of stability in wave crest happens more often, however both effects, parametric resonance and loss off stability in wave crest may be easily avoided with proper handlingof the ship and not putting the ship in situation when those phenomena may occur (e.g respecting recommendation MSC.1/Circ.1228). The same reasoning is applicable to surf riding and broaching, hazards in fact dangerous for rather fast small ships.

Different situation is regarding the hazard defined as dead ship condition. The present weather criterion as it appears in the IS Code in fact covers the situation of the dead ship condition. In general opinion weather criterion is working well for the majority of ships, However some unconventional ships, e.g. ships with large windage area and large B/L ratio, as for example large cruise vessels and similar, often have difficulty to meet this criterion. On the other hand experience shows that large passenger ships are reasonably safe.

IMO SLF Subcommittee already took care of this effect developing guidelines for alternative assessment of the weather criterion adopted by resolution MSC.1/Circ.1200. In the view of the author, problem of dead ship condition, that is virtually problem of the weather criterion could be considered as solved, at least for the time being.

6 EFFECT OF HUMAN FACTOR AND OPERATIONAL FACTORS

Human factor is an essential element of the system of safety against stability failure. According to many sources human factor constitutes main cause of casualty in about 80 to 90 per cent of casualties and even more [12,13]. The system of safety where human factor is included is shown in fig 2 [12], In the system there are numerous interrelations between various sub-systems. But restricting only to ship operation it would be necessary to consider only the part of it as marked in fig 2 by thick lines that encapsulates human and organisational errors (HOE).

Human and organisation error may be the result of design and construction faults (bad characteristics of ships) and force majeure, that are responsible for about 20% of all HOE casualties, the rest may be attributed to operational factors that include the following:
– society and safety culture
– organization
– system
– human performance (individual).

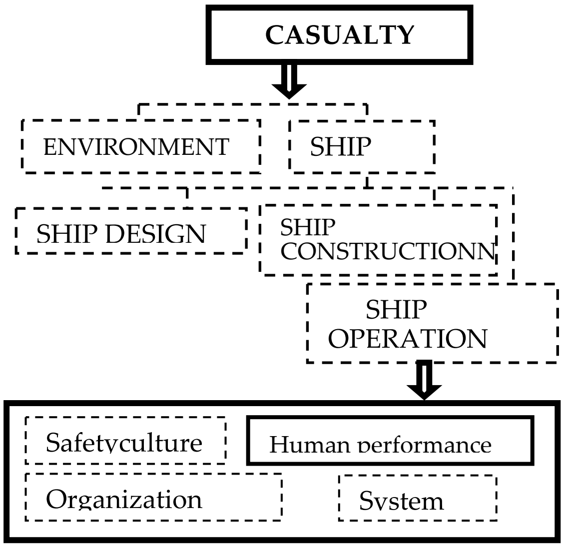

Figure 2. Safety system for CRG casualties (after [12])

Amongst other factors human performance and safe operation depends strongly on operator understanding of physical phenomena governing vessel motions in confused seas, This understanding may be achieved by proper education and training.

7 IDEAS HOW TO IMPROVE SAFETY AGAINST CAPSIZING

In the opinion of the author it is now time to apply different, more universal procedures to stability criteria. These are already considered widely and in particular in IMO higher bodies. Two approaches that are not charged with the above discussed deficiencies: risk analysis and goal oriented approach are proposed.

7.1 *Risk analysis*

Application of risk analysis is considered for some time and actually recommended by the IMO higher bodies. There is basic dichotomy between prescriptive regulations and risk analysis, and risk analysis has some advantages in comparison with prescriptive regulations [14].It was righty pointed out in the comprehensive paper on second generation stability criteria [7] that risk analysis have gained greater acceptance and become standard tool in other industries. Why not to use this approach to safety against stability failure?

The essential element of the risk analysis and risk based requirements is assessment of risk. Risk, according to the definition is equal to product of probability of failure (P) and its consequences (C):

$$\mathbf{R = P \times C}$$

IMO recommends to use in the risk assessment the logarithmic scale in the form:

$$\mathbf{\log R = \log (P) + \log (C)}$$

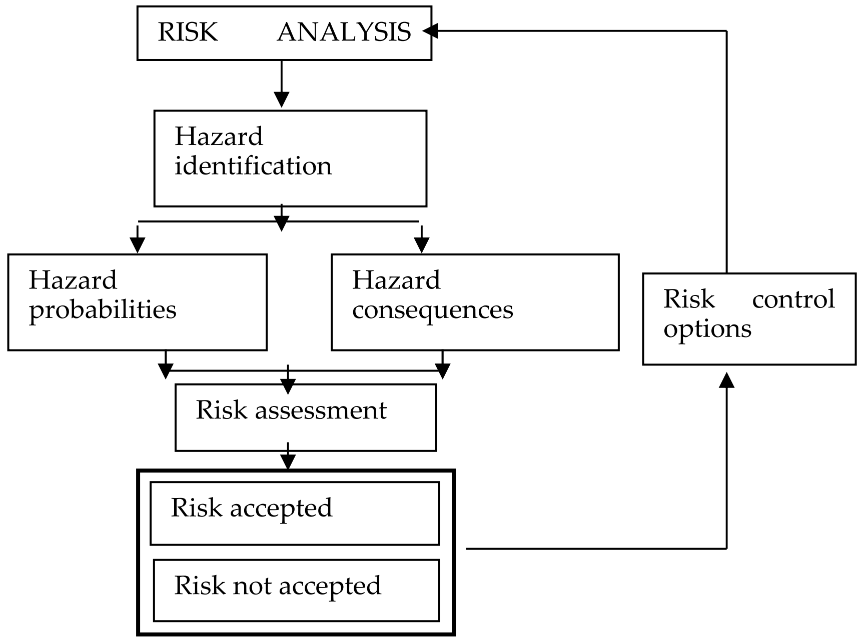

Figure 3. Steps of risk analysis

This formulation is more easy to apply and to construct a risk matrix where for probabilities (frequencies) of failure ranking is adopted from FI = 1 (extremely rare) to FI = 7 (frequent) and for consequences ranking is adopted from SI = 1 (negligible) to SI = 4 (catastrophic) with associated probabilities [14]. Risk analysis includes the following steps (fig.3):

Risk analysis is at present a well-established procedure used as a rule, when planning sophisticated systems. IMO recognized the advantages of using risk-based approach as an alternative to the prescriptive criteria in different areas of ship safety and ultimately the Marine Safety Committee of IMO recommended this approach as Formal Safety Assessment (FSA), in MSC/Circ.1023. Since then many papers were published on this subject, however only few concerning stability. Also the author in several papers discussed possibilities of application of the risk assessment methodology to intact stability criteria (e.g. [14, 15]), but in practice existing IMO rules on stability do not include possibility to apply such methods.

Obviously it would be impractical to apply this method to conventional ships that are reasonably safe, but the method could be effectively applied to important and large ships of non-conventional design. This on one hand may be the way to improve safety level when applying existing criteria and on the other hand the way to assure sufficient level of safety for non-conventional ships where clause for alternative methods already included in the SOLAS Convention may be used.

7.2 *Goal oriented approach*

The most recent concept of assuring safety is goal-based approach. Goal based approach does not specify the means of achieving safety but sets goals that allow alternative ways of achieving safety[16]. Goal-based requirements are for some time considered at IMO and appraised by some authors [17, 18], and they were introduced in some areas, albeit not in the systematic manner. Marine Safety Committee of IMO commenced in 2004 at MSCC 78 its work on goal-based standards in relation to ship construction adopting five-tier systems shown in the table 2. Goal oriented approach was recently suggested to be applied to subdivision and damage stability [19].

Table 2. Five-tier system for goal-based requirements

Tier I:	Goals
Tier II:	Functional requirements
Tier III:	Verification criteria of compliance
Tier IV	Technical procedures and guidelines, classification rules and industry standards
Tier V	Codes of practice and safety and quality systems for shipbuilding, ship operation, maintenance, training etc

The advantage of goal-oriented approach is that in order to achieve goal which is to make shipping safer, various means have to be used, not only prescriptive regulations or even risk analysis. All means that may contribute to safety have to be used as is specified in the table 2. This approach does not exclude risk analysis, which is one of the most important method to achieve compliance.

Conclusion. Perspectives of improvement of the safety level.

It seems that the best way to enhance safety would be to put stress on the goal-oriented approach. Using this approach with respect to intact stability two paradigms have to be taken into consideration:

- In general opinion existing criteria are working well for conventional ships. Experience of application of the existing intact stability requirements as in the IS Code 2008 reveals that stability failures with ships meeting the criteria are extremely rare.

– For non-conventional ships the existing requirement of the IS Code 2008 may be inadequate and alternative ways of assuring safety should be used. Applying alternative means is allowed under the provisions of SOLAS Convention. Alternative means may include risk assessment.

Bearing this in mind the future ways of improving safety with regard to stability failures could be as proposed in theTable 3.

In the table distinction is made between conventional and non-conventional ships. There is obviously the problem how to define non-conventional ships. Traditionally under the term "non-conventional ships", ships revealing novel design features are understood. However this is very vague definition because of the difficulty which features may be classified as "novel". It seems that the best way to classify ships as non-conventional would be to include in this category all ships to which requirements of the existing IS Code are considered non applicable in the view of designers, ship owners or administrations. Experts opinion may be used when assessing this category.

Table 3. Methods of safety assurance

Ships	Method of stability safety assessment
Conventional, not sophisticated	Prescriptive criteria as in the IS Code
Novel types, large sophisticated ships	Goal oriented approach including risk analysis under the provision allowing application of alternative means of assuring safety

Application of existing IS Code criteria to conventional ships is in the opinion of the author substantiated by the experience gained with the wide application of those criteria. Those criteria are well known world-wide, are reasonably simple and working quite well. There are really no reasons for abandon them.

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