FUTURE GENERATION STABILITY CRITERIA – PROSPECTS AND POSSIBILITIES

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ABSTRACT

Recently the Sub-committee SLF of IMO adopted revised version of Intact Stability Code, part A of which comprising basic stability criteria will be made compulsory by way of the.reference in the SOLAS convention. The first step of action intended to enhance safety of ships against capsizing was thus completed. At the same time, however, the SLF Sub-committee of IMO decided to start work on development of future generation stability criteria, with the intention to enhance further the safety of ships against capsizing The discussion on how to approach this difficult problem was already initiated during its 50th session in 2007. With this decision it is necessary to start work as soon as possible. The author considers different possible approaches including performance oriented criteria, criteria based on risk analysis and goal-oriented approach. The possible approaches are critically reviewed and practical prospects of developing required new generation stability criteria are assessed bearing in mind that they should be developed in the foreseeable future.t.

Keywords: *stability of ships, ship safety requirements, risk analysis*

1. INTRODUCTION

With the development of the revised Intact Stability Code (2008 IS Code) the first step of programme of improving stability criteria with which the SLF Sub-committee of IMO was charged was completed. The most important change in comparison with the original version of the Code adopted in 1993 is that part of the Code incorporating basic criteria is made compulsory via reference in the SOLAS Convention. The revised Code will come into force on 1 July 2010. The stability criteria as included in the revised 2008 Intact Stability Code are virtually the same as in the original IMO resolution A.167(ES.IV) adopted in 1968 (statistical criteria) and in resolution A.562(14) adopted in 1985 (severe wind and rolling criterion) with small amendments and some relaxations. From the point of view of ship safety this is however, not the final solution. From time to time, stability casualties happen in spite of the fact that ships meet all existing IMO criteria. The existing criteria may also be not applicable to some types of modern ships incorporating novel design features especially because original criteria as in resolution A.167(ES.IV) developed more than forty years ago were based on casualty statistics that included mainly vessels under 100m in length. With many modern ships there is no previous experience in relation to safety and stability and satisfying existing criteria may not assure required level of safety. Because of this, Maritime Safety Committee of IMO has recently included in its work programme the development of new generation criteria.

Currently work has already started on the development of new generation stability criteria, however, there are no clear indications how to proceed in order to solve this difficult problem and to achieve results in the form of requirements.

2. RECENT DECISIONS OF THE IMO SLF SUBCOMMITTEE

At its 51st session in 2008 the SLF Subcommittee agreed upon the Framework for the new generation stability criteria (IMO 2008). The Framework includes definitions of stability failures (total or partial), definitions of types criteria (deterministic or probabilistic, parametric or performance based) and vulnerability criteria that would check for the susceptibility to various modes of stability failure and are based on simplified models, simple mathematical formulations, analytical solutions or statistical data. Vulnerability criteria are intended to distinguish between conventional and non-conventional ships.

According to the decision of the Sub-Committee, new generation stability criteria are intended basically for non-conventional ships and should be used as alternative or supplement to existing criteria. The new generation stability criteria should take into consideration primarily three modes of failure:

- restoring arm variation problems such as parametric excitation and pure loss of stability
- stability under dead ship condition, and
- manoeuvring related problems in waves such as broaching-.to

The adopted Framework does not specify how the new criteria should be developed and what form the may take.

The above short description of the task was little more elaborated in the Framework for new generation stability criteria and associated terminology included in (IMO 2008a) with further explanation in the paper by Belenky, de Kat and Umeda (2008).

3. REQUIREMENTS CRITERIA AND STANDARDS

In the above mentioned documents there are included definitions of criteria and standards with the intention to use those definitions in the future work. According to the definitions proposed by Belenky et al (2008) and supported by the IMO Working Group on stability within the SLF Sub-committee (IMO 2008a), criterion is “a procedure, an algorithm or a formula used for judgement of likelihood of failure” and standard is “a boundary separating acceptable and unacceptable likelihood of failure.” Standards used to be of the binomial type with the strict boundary. This formulation requires, however some comments, especially that words “criterion” and standard” are being used in many IMO documents as well as in many publications interchangeable. Sometimes even word “norm” is used” that according to Webster Dictionary is “an authoritative standard”, whether“ “criterion” is “ a standard on which a judgement may be based” and “standard” is “something set by authority or by general consent as a rule” (the same source). It seems that there is no point to dwell upon the above definitions because certainly everybody understands what it is all about and perhaps better use word requirement, that in a broader sense is a concept that may be formulated in the descriptive or numerical form, it could be either standard or criterion or norm, generally something that is required.

Requirements may be of the prescriptive nature, or based on risk analysis. The basic dichotomy in the conception of safety requirements is between these two approaches (Kobyliński 2005).

Prescriptive requirements are formulated in the way where a ship dimension or other parameter (e.g. metacentric height) must be greater (or smaller) than certain prescribed quantity. In the broader sense any other quantity could be used, for example probability of capsizing estimated in a prescribed way. Prescriptive requirements could be parametric or performance based and both could be deterministic or probabilistic.(Fig.1)

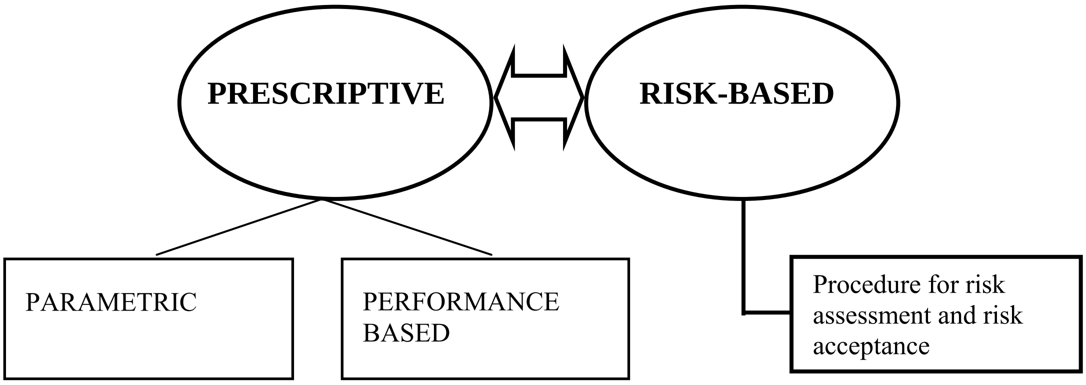

Figure1. Prescriptive versus risk-based requirements.

Parametric criteria are based on a measure of a quantity which is related to the phenomenon but does not contain a physical model of the phenomenon. Performance oriented criteria are criteria based on a physical model of phenomenon. Both could be deterministic or probabilistic.(IMO 2008). At the opposite of the prescriptive regulations, there is risk-based approach. In the risk-based approach the regulations do not require meeting certain specific measures, they are based on assessment of risk involved that may or may not be accepted. The risk analysis inherently includes factor of uncertainty and there is no fixed boundary for the risk acceptance and special consideration is given to the problem of risk acceptance in each case. The advantages of risk-based approach are obvious. They give free hand for the designer to develop new solutions, they actually allow taking optimal decisions from the point of view of economy and safety and the risk to the public and to the environment is assessed and accepted. Risk-analysis inherently involves holistic and system approach and allows taking into account all elements of safety system including operational aspects and human factor.

4. BASIC PHILOSOPHICAL APPROACH TO SAFETY

As mentioned existing criteria were developed more than forty years ago. They are of prescriptive (or parametric) character and are virtually design-oriented. This was the standard approach at that time. They are intended to be applied during the design stage of a ship. From the preliminary discussion at IMO forum it seems that the intention of the working group is to develop future stability criteria in the same manner, i.e. in the form of prescriptive criteria applicable at the design stage of the ship, possibly, however, in the probabilistic terms.

Since the time when existing criteria were developed, there was important development in the basic philosophy of ensuring safety of technical systems. In early eighties safety assessment (SA) was already widely used in some areas, and also system approach was recommended, where safety was considered as a system consisting of several elements mutually interconnected The use of the system approach to stability criteria was proposed by the author and it was partly applied in development of the Intact Stability Code albeit not in the systematic manner. (Kobyliński 1984). In the fall of the last century the Marine Safety Committee of IMO considered introduction of safety and risk assessment procedures (e.g. IMO 1977) and ultimately recommended Formal Safety Assessment (FSA) (IMO 2002). as a procedure to assess the adequacy of safety rules and regulations. The most recent concept of safety regulations is a goal-based approach. Goal-based regulations do not specify the means of achieving compliance but set goals that allow alternative ways of achieving safety (Hoppe 2006). The goal-based approach is a concept that was introduced in IMO work at 89th session of the Maritime Safety Committee.

Either FSA or goal-oriented approach involve risk analysis as a method where the ultimate result is assessment of risk in probabilistic terms considering all elements of the safety system.

5. PERFORMANCE ORIENTED APPROACH

The Framework for development of new generation stability criteria agreed by the SLF Sub-committee (IMO 2008) does not include any hints as to the form of the future criteria nor as to the tools that should be used. The general layout of the document leads however to the conclusion that the intention is to develop future criteria as performance based criteria and basically design oriented. According to the definition included in the above document performance based criterion is "a criterion based on a physical model of stability failure."

However there is still another, broader definition of performance based criterion (Kobyliński 2005a):

- "The performance based approach is the approach where the behavior of vessel is analyzed in a set of environmental and operational scenarios taken as realistically as possible on the basis of her performance in terms of safety against capsizing. The performance-oriented criteria should be based on calculations or measurements of performance of the vessel in deterministic or probabilistic terms in the analysed scenarios".

In the opinion of the author the above definition reflect better the essence of performance oriented criteria.

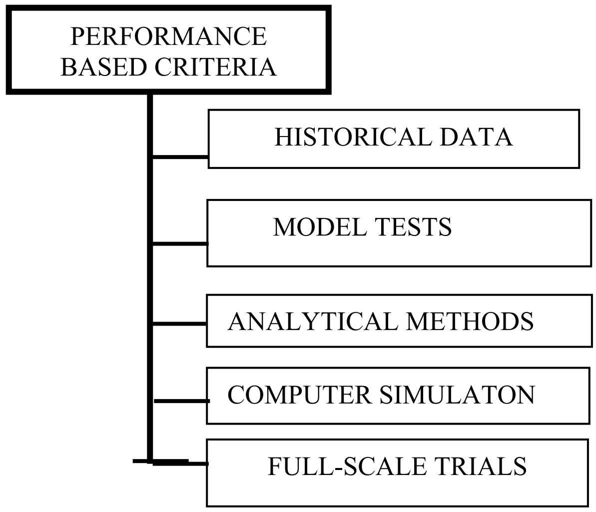

Figure 2. Tools for development of performance based criteria.

When developing performance based requirements different tools may be used. They are shown in fig.2. Performance based approach could be used to develop prescriptive requirements as well as it could be used for the purpose of risk analysis.

6. RISK BASED REQUIREMENTS

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:

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

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. Risk analysis includes the following steps (fig.3):

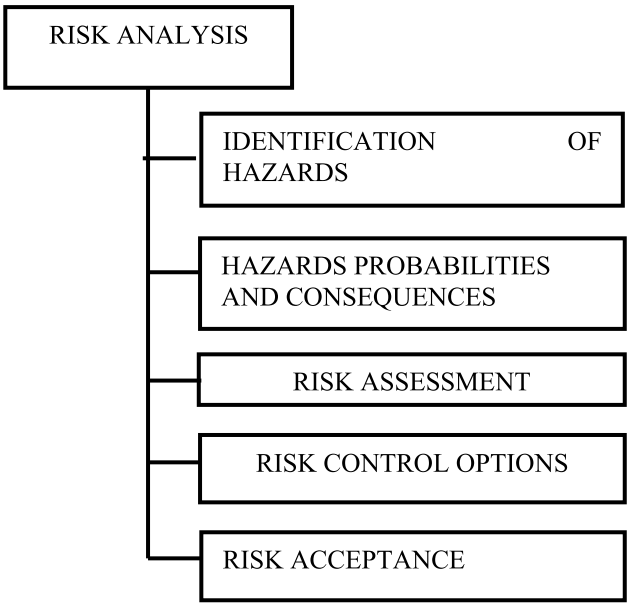

Figure 3. Steps of risk analysis.

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 (IMO 2002). 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 FSA methodology to intact stability criteria (e.g. Kobylinski 2004, 2005), but in practice existing IMO rules on stability, either intact or damaged, 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 overcome difficulties with application of existing criteria and on the other hand the way to assure sufficient level of safety for non-conventional ships.

7. PROSPECT OF DEVELOPING PERFORMANCE BASED CRITERIA

7.1. Capsizing scenarios, vulnerability stuies.

As stated above, performance oriented criteria are based on the physical model of capsizing. This is a very broad definition covering different modes of capsizing, or in other words, stability failures. It is evident that many existing requirements included in the present IS Code are actually based on performance oriented criteria, albeit the physical models of capsizing are rather simple (examples: crowding of passengers on one side, weather criterion etc).

In order to develop criteria the set of capsizing scenarios should be considered. It seems, however, that the number of possible scenarios leading to capsizing is extremely large. When using simple physical models in many cases analytical solutions may be adequate and in consequence simple deterministic criteria are developed. However simple scenarios are rare in reality and analysis of historical data on casualties almost always revealed that stability failure is the result of sequence of event that may be attributed to different causes and where human factor usually played predominant role.

The recent analysis of 364 stability casualties performed by the author (Kobyliński 2008) allowed to draw only very general conclusions showing that in the great majority of cases human factor was most important. Usually it is associated with some other factors such as shifting of cargo – the most frequent event - or with water inrush. Most accidents took place in rough sea, although forces of the sea were not always the primary event. Several casualties happened in comparatively calm sea.

In order to assure safety against capsizing and to identify possible ways of stability failure system approach should be adopted. Ship stability system is rather complicated. However, in most cases it could be considered as consisting of four basic elements: ship, environment, cargo and operation [Kastner 1986]. Those elements are strongly interconnected.

Analysis of stability casualties reveals that the causes of casualty may be attributed to functional aspects operational aspects,external causes and cargo related aspect

In order to achieve sufficient level of safety with respect of stability, all elements creating stability system have to be taken into account. Taking into account the fact, that less than 20% of all casualties are caused by faulty or bad design of the ship, the existing safety requirements that refer mainly to design features of the ship can not ensure sufficient level of safety, in particular with regard to ships having novel design features.

The diagram showing possible causes of stability failure is shown in fig. 4. This may be also considered also as first level of hazard identification tree in risk analysis. No probabilities ware attached at this stage to various hazards, however.

7.2. Potential of different types of tools

Tools that can be used in order to develop performance based criteria are shown in fig 2. However the potential of these tools is widely different.

Historical data and statistics. Analysis of historical data and statistics of stability accidents was used in developing existing basic criteria as in the IS Code (originally in the Resolution A.167(ES.IV)). It seems however, that statistic of stability accidents is not the suitable tool for development of any future stability requirements and that the possibilities of this method are exhausted. Stability casualties are rare, they happen with different types of ships in different situations and they are usually result of the sequence of events where human factor usually plays paramount role.

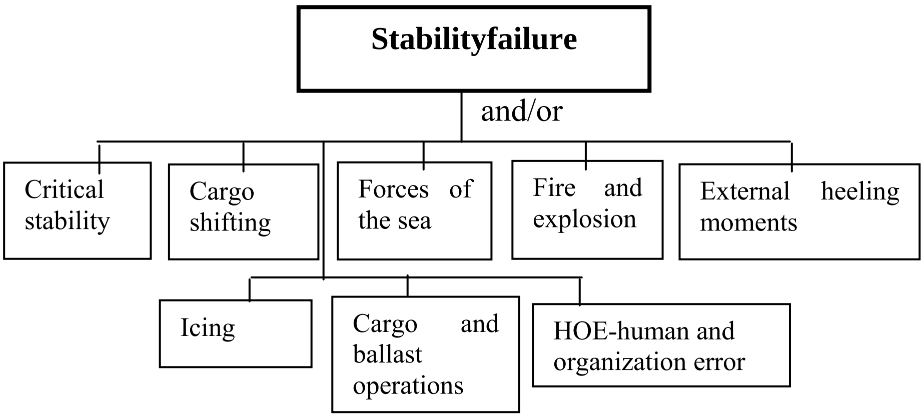

Figure 4. Basic hazards to stability (HOE –human and organisation.

With regard to the statistics of stability accidents it is obvious that collecting data on casualties suitable for estimation of risk function required in the probabilistic analysis would be extremely difficult, because not only precise stability characteristics of the ship capsized and environmental conditions at the time of casualty have to be known, but also data and time history of the ship operation

Historical data are extremely useful for the purpose of identification of capsizing scenarios. Descriptions of many stability casualties are available in different sources, but majority of the information, apart of few casualties that were investigated thoroughly enough, does not include necessary and accurate enough descriptions that may serve this purpose. However historical data and casualty statistics may be useful for vulnerability studies (hazard identification) although probability of different capsizing scenarios can nor be estimated this way.

Model tests. Model tests of capsizing were performed in towing tanks or in open waters as reported for example By Kobyliński & Kastner (2003). It appears, however, that although model tests of capsizing may provide valuable information on physics and possible modes of capsizing and also may serve as validation method of any mathematical simulation of capsizing, there is no hope that they may be used as a basis for development of stability criteria.

This is because conducting systematic model tests of capsizing in a realistically simulated environment poses extreme difficulties and might be enormously costly and time-consuming enterprise. Realization of more complex scenarios, where other than environmental factors is of importance, is hardly possible in model tests.

Analytical methods Analytical methods may be used in cases of rather simple capsizing scenarios, mainly when static or quasi-static approach may be adequate. Actually simple analytical models were used in developing existing criteria, but because of complicity of phenomena of behaviour of the ship in seaway, particularly when additional external forces are present analytical methods do not provide necessary solutions. However analytical methods might be useful at the stage of vulnerability studies (hazard identification).

Computer simulation. Computer simulation and analysis remains as the only tool that may lead to the development of performance-oriented criteria for the ship in a seaway. In the most mathematical models available at present only environmental effects are considered, mainly waves, sometimes wind is also considered in a simplified way as additional factor. The other factors that may cause capsizing, except of some attempts to include the effect of water on deck (see: Laranjinha et al 2002, Shin et al 2002), are not taken into account. To simulate more complex capsizing scenarios might be even more difficult. The 23rd ITTC Specialist Committee on Prediction of Extreme Motions and Capsizing (ITTC 2002) reviewed at depth available mathematical models of capsizing and reached the conclusion that: “only a few of these models consistently agree qualitatively with all the extreme motions and modes of capsize identified in free running model experiments. None of the models does so quantitatively.” Apparently much more effort must be put in order to achieve results applicable in practice and in particular mathematical models of capsizing scenarios that include several factors except of the effect of seaway have to be developed.

Nevertheless the author believes that in not very far future reliable mathematical models and computer codes for basic capsizing scenarios will be available. But calculation of the probability of capsizing in certain assumed seaway conditions will not solve the problem of safety criteria.

Full-scale trials. Full-scale trials have never been considered as a tool for development stability criteria. That is simply because full-scale ships cannot be artificially subjected to heeling moment that may cause capsizing. Only in few cases when considering, for example, static heeling moments caused by ballast operations or crowding passengers, full-scale trials may be used as a method for validation analytical models. Full-scale trial may be also of use for validation of model tests of seakeeping characteristics by assessing scale effect and in particular for estimation damping coefficients.

7.3. Conclusions regarding possibilities of development performance based criteria

The review of different tools available for development of performance based criteria leads to the conclusion that the possible method would be computer simulation and, to some extent also analytical methods. This may, however, require further effort in order to develop suitable computer codes covering different scenarios. It seems that some scenarios may be treated quite easily, the others, including most important scenarios where the ship sailing in heavy seas is subjected to additional heeling moments caused by wind, water on deck etc taking also into consideration master tactics may be very difficult to tackle.

Short-term probability of stability failure in given seaway pattern might be calculated. but still remains the problem of how to solve the rarity problem and how to choose appropriate climatic conditions for the particular ship. This would require assessment of probability that certain wave formation will happen.

Calculated values of short-term probability may be used to calculate long-term probability and there are even possibilities to take account of shipmaster tactics. The author advocated this procedure quite a long time ago in several papers, (e.g. Kobylinski 2004, 2005), but now, he is feeling that this is not good solution from some reasons. This problem needs thorough consideration, however, and due to lack of space is not discussed here further.

8. RESTORING ARMS VARIATION ON WAVE CREST PROBLEM

Considering capsizing scenarios caused by the forces of the sea only, the number of scenarios worth considering may be more than 20 (Kobyliński 2007. de Kat et al 1994). From those the IMO SLF Subcommittee selected only three. Are they really most important or more frequently met? There is no answer to that at present, because there are no results of any vulnerability (or hazards identification) studies available. Vulnerability criteria mentioned in the already mentioned Framework (IMO 2008)) may provide partial answer, but strictly speaking vulnerability criteria, if systematically analyzed, are nothing else but hazard and operability studies (HAZOP) that are routinely performed in the risk analysis.

With regard to the first scenario selected for further studies included in the Framework it may be recalled that problem of stability loss in the wave crest was considered by the SLF Subcommittee in early eighties, The SLF Sub-committee agreed at that time that three modes of capsizing in the wave crest should be considered, namely pure loss of stability, parametric resonance and broaching. Numerous papers were then presented to the Sub-committee. and consideration was given mainly to the paper by German Democratic Republic and Poland (IMO 1981) where criterion related to the pure loss of stability on the wave crest was proposed. After extensive discussion of the problem the Sub-committee decided that this problem must be relegated to the future work and at the time being, the best solution would be to develop some operational guidance in order to avoid the three modes of capsizing advising ship master on the dangers involved and to develop relevant operational guidance (IMO 1985, 1988). Ultimately such guidance was developed (IMO 1995).

During recent years a number of studies of the effect of parametric resonance in following as well as in head seas were performed and numerous papers presented, however parametric resonance depends mainly on two factors: magnitude of variations of restoring arm in waves and on the ratio of wave encounter period and natural period of roll. The first one is the design problem the second is mainly operational problem that can not be considered without taking into account human factor. One, possibility to take human factor into account is by performing risk analysis. Risk analysis uses construction of fault and events trees and assessing probabilities. This kind of analysis was performed by the author in the paper (Kobylinski 2007) to which reference is made and where samples of event trees and fault trees for parametric resonance could be found.

9. GOAL-BASED STANDARDS

The most recent concept of safety regulations is goal-based standards. Goal based requirements do not specify the means of achieving compliance but sets goals that allow alternative ways of achieving compliance (Hoppe 2006). 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 system where tier 1 was formulated as follows: "Ships are to be designed and constructed for a specific design life to be safe and environmentally friendly, when properly operated and maintained under specified operating and environmental conditions, in intact and specified damage conditions, throughout their life"**.** Goal-based standards are for some time considered at IMO and appraised by some authors and they were introduced in some areas, albeit not in the systematic manner. The concept of the goal-based standard that includes holistic approach involving risk analysis is an alternative to prescriptive standards. Due to lack of space application of goal based requirements is not discussed further and reference is made to author's paper (Kobyliński 2007a).

10. CONCLUSIONS

It seems that there is some consensus on the need to apply holistic and risk-based approach to safety of ships at sea. The possibilities to use this approach in the rule-making process are still under investigation

It is the opinion of the author that when considering possibilities of developing future generation stability criteria in many stages of consideration we are coming to the conclusion that risk analysis might be really the best solution. Considering for example vulnerability criteria as proposed by the working group one may conclude that it is clearly the matter of identification of hazards which is the first step of risk analysis. The procedures for hazards identification are well established within the risk analysis and they may be used. In the risk analysis holistic approach and assessment of probabilities of all possible capsizing scenarios is needed, where consequences of stability failure are also considered. This, in turn, makes assessment of safety level measured by risk possible. The Framework agreed advocating the need to assess safety level actually does not provide such possibility. It seems that recent proposal by the SLF Sub-commmittee indirectly leads to application of risk analysis not, however, referring to this method point-blank.

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