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# Examples of weaknesses of the 2nd Generation Intact Stability Criteria

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**Abstract**
One of the main tasks of the Sub-committee on Ship Design and Construction (SDC) of the International Maritime Organization (IMO) is development of the 2nd Generation Intact Stability Criteria. The paper presents the framework and the approach agreed by the Sub-committee. The framework bases on the concept of stability failure and vulnerability assessment. However, the criteria, standards and regulations developed so far have weaknesses that may prevent some IMO Member States from adoption of the regulations on the Maritime Safety Committee (MSC) level. The paper presents some of the weaknesses that are the most important from the Author's point of view. Awareness of the weaknesses may facilitate the future work of the Sub-committee and its working groups.

## Introduction

Sufficient intact stability is one of the most fundamental requirements for any type of vessel. While different stability criteria have been developed since the 1930s, the first international stability regulations were formulated in the International Code on Intact Stability (2008 IS Code), which came into force in July 2010, adopted through resolution MSC.267(85) of the Maritime Safety Committee (MSC) of the International Maritime Organization (IMO) [1]. Actually, the existing criteria and regulations were developed in sixties and eighties of the previous century. Before 2010 they had status of recommendations for administrations and classification societies for national and class regulations. They were widely applied to ship design and ship operation, sometimes with slight modifications. The history of development and the background of these criteria are described by Kobylinski and Kastner [2].

The criteria and standards contained in the 2008 IS Code are perceived as "the first generation of the stability criteria". At the time of their adoption, the criteria, standards and finally regulations were criticized by the international community. The main arguments were:

1. Existing criteria are of the prescriptive nature. They are based on the statistics of the stability accidents of the ships that were designed, constructed and operated more than fifty years ego. The hydrodynamics was not applied for this purpose.
2. Existing criteria do not take into account such phenomena like ship's speed, roll damping, mass moments of inertia, waves statistics, human element and other. At present it is possible due to developments in ship theory and technology (e.g. model tests, computer simulations).
3. It is not known what level of safety is secured if "old" criteria are applied for novel designs.
4. The parameters of the weather criterion were „tuned" using a certain sample population of ships, which limits the applicability of the weather criterion.

IMO's approach to the stability regulations between 2002 and 2008 may be described in such a sentence: "Let's adopt and make mandatory recommended so far stability criteria that are actually used by the shipping industry and then develop new criteria that take into account the latest research, are based on hydrodynamics rather than statistics, take into account the progress of the technology". That new criteria have been named: The Second Generation Intact Stability Criteria (2nd GISC) following the proposal from Poland [3].

## Planned framework for the Second Generation Intact Stability Criteria

The actual work on the second generation of intact stability criteria started at the 48th session of the Sub-committee on Stability and Load Lines and on Fishing Vessels Safety (SLF), in September 2005. A significant starting point for SLF was general agreement that the second generation criteria should be based on physics of the phenomena leading to intact stability failure and the criteria should be performance based. Also, there was general agreement of the desirability of relating the new criteria to probability, or some other measures of the likelihood of stability failures, as methods of risk analysis have gained greater acceptance and become standard tools in other industries. At the 51st session of SLF (July 2008), the intact stability working group agreed on the framework of the second generation intact stability criteria [4] and on the terminology list. The framework contains a set of assumptions, definitions, ideas and rules for further development. Some of them are presented in this chapter. Both the framework and the terminology list still are considered as working documents. The documents made a clear distinction between a criterion and a standard. There was also distinction between performance-based and parametric criteria, and between probabilistic and deterministic criteria. Special attention was paid to probabilistic ones.

### Definitions

For the purpose of the development of the 2nd GISC, the following definitions of general terms are assumed:

1. *Criterion* is a procedure, an algorithm or a formula used for judgement on likelihood of failure.
2. *Standard* is a boundary separating acceptable and unacceptable likelihood of failure.
3. *Rule* (or regulation) is a specification of a relationship between a standard and a value produced by a criterion.
4. *Stability*: a ship is stable if, upon being inclined by external forces, it returns to the initial upright position when action of these forces ceases to exist.
5. *Intact stability* is the stability of a ship without any damage to its watertight buoyant space, hull structure or to any onboard system that could lead to loss of buoyancy due to water ingress.
6. *Intact stability failure* is a state of inability of a ship to remain within design limits of roll (heel, list) angle and combination of rigid body accelerations. Two types of intact stability failures are distinguished:
   a. *Total stability failure*, or capsizing, results in total loss of a ship's operability with likely loss of lives. Capsizing could be formally defined as a transition from a stable nearly upright equilibrium that is considered safe, or from oscillatory motions near such equilibrium, to another stable equilibrium that is intrinsically unsafe (or could be considered unacceptable from a practical point of view).
   b. *Partial stability failure* is an event that includes the occurrence of very large roll (heel, list) angles and/or excessive rigid body accelerations, which will not result in loss of the ship, but which would impair normal operation of the ship and could be dangerous to crew, passengers, cargo or ship equipment. Two subtypes of partial stability failure are intended to be included in the development:
      - roll angles exceeding a prescribed limit;
      - combination of lateral and vertical accelerations exceeding prescribed limits.
7. *Unconventional ships* are ships that are vulnerable to stability failures neither explicitly nor properly covered by the existing stability regulations.
8. *Vulnerability criteria* are criteria intended to distinguish between conventional and unconventional ships.
9. *Operational guidance* is the recommendation, information or advice to an operator (in particular to ship master) aimed at decreasing the likelihood of stability failures and/or their consequences.
10. *Safety level* is a quantity related to a likelihood of failure, including, but not limited to a probability of failure during finite period of time. The term Safety level is understood as a level of safety from stability failure. Safety level is a standard for probabilistic performance-based criterion.
11. *Loading condition* is the characterization of the components of a ship mass and its distribution. A typical description of a loading condition includes mass displacement, coordinates of the centre of gravity and radii of inertia for three central axes and tanks with free surfaces and corresponding inertia effects.

12. *Operational parameters* are parameters that can be controlled; for a self-propelled ship which may include, but not limited to, commanded course angle, commanded propeller revolution, trim, heel, rudder angle, operational GM.
13. *Environmental conditions* are a set of parameters and functions describing wind, waves and currents and that are sufficient for an adequate modelling of possible stability failures, including but not limited to:
    – waves: significant wave height, characteristic period (modal/peak, mean, zero-crossing period), directional spectrum;
    – wind: direction, mean speed, spectrum of wind speed fluctuations, spectrum of transversal fluctuations, profile, coherence;
    – current: direction, mean speed, width and speed profile.
14. *Direct safety assessment* is a mean of assessing risk of stability failure from theoretical calculation or model experiments.
15. *Assumed situation* is a combination of loading conditions, environmental conditions and operational parameters as well as time of exposure.

One of the shortcomings of the framework for 2nd GISC is the lack of the definition of Performance Based Stability Criteria that were intended to be the main development. There were proposals put forward [5, 6, 7] actually being more or less in line with each other but the proposals were not adopted by SLF Sub-committee. The definition proposed by Szozda [7] is quoted below.

*„Performance Based Stability Criteria" (PBSC) are ship stability criteria used to secure sufficient level of safety for intact ships during sea voyage. PBSC relate to phenomena depending on intensity of a ship oscillations or magnitude of heel angles in specific operational and environmental conditions: loading, waves, wind and navigation. Quantities describing intensity of oscillations (amplitudes, accelerations, forces, energy and other) may be obtained as a result of numerical simulations, model tests or other appropriate methods. Not appearance of dangerous events causing loss of ship functions is the subject of performance based approach to stability assessment. PBSC are to be applied to ship design, stability assessment before each voyage and at sea.*

As the consequence of the definitions agreed by SLF in 2008 it may be said that 2nd Generation Intact Stability Criteria are tools for judging the likelihood of capsizing or exceeding prescribed limits of rolling angles and/or rigid body accelerations of an unconventional ship in assumed situations. Furthermore, the idea hidden behind the definitions may be described as follows: "Compliance with a regulation (*proper relation between the value produced by the criterion and the standard*) shall prevent the ship from capsizing or very large rolling (angles and/or accelerations)".

#### Criteria types

Description of the types of the criteria are given below in table 1. These definitions distinguish the criteria on the basis of how they judge stability failure – that is, whether they **judge on stability failure directly** (performance-based) or indirectly (empirical), and how the environment is described. Four criteria types were defined:
– probabilistic performance-based criterion;
– deterministic performance-based criterion;
– probabilistic parametric criterion;
– deterministic parametric criterion.

Table 1. Description of the types of the criteria

| | Performance-based (judge on stability failure directly) | Parametric |
|---|---|---|
| Probabilistic | A criterion based on a model of a stability failure considered as a random event | A criterion based on a measure of a quantity related to a phenomenon, but does not contain a model of the phenomenon, and includes one or more stochastic values for this criterion |
| Deterministic | A criterion based on a model of a stability failure considered in a deterministic manner | A criterion based on a measure of a quantity related to a phenomenon, but does not contain a model of the phenomenon, while all the input values are deterministic |

All intact stability criteria used in current 2008 IS Code are deterministic. The Code uses mainly parametric criteria related to righting arm curve properties and initial metacentric height values. Performance based criteria are also used but the models of the assumed events are very simplified. Performance based criteria in current 2008 IS Code are:
– weather criterion;
– criterion due to crowding of passengers (for passenger ships only);
– criterion due to turning (for passenger ships, this criterion is also applied to container ships).

#### Stability failure modes

Ships' behaviour at sea in different assumed situations is very complex. Taking into account current state-of-the-art in ships' hydrodynamics this complex behaviour shall be divided into separate dynamic modes, which are still complex enough to create serious problems while developing mathematical models of a ship motions and environment. The major dynamic modes (stability failure modes) that are taken into account by SLF Sub-committee so far are as follows:

1. *Parametric rolling* that is roll motion amplified by parametric resonance (caused by stability changes in waves or coupling with other degrees of freedom).
2. *Surf-riding* that is a phenomenon where mean speed of a floating body is shifted from the original one to wave celerity because of wave actions which may be associated with *Broaching-to* that is a phenomenon where a ship cannot keep constant course despite maximum steering efforts and experiences a significant yaw motion in an uncontrolled manner.
3. *Dead-ship condition* that is a condition under which the main propulsion plant, boilers and auxiliaries are not in operation due to the absence of power (SOLAS regulation II-1/3-8).
4. *Pure loss of stability* that is a phenomenon of prolonged one-time decrease of stability in waves, particularly in the wave crest.
5. *Excessive stability* that is a phenomenon of unaccepted intensity of rolling caused by large restoring arms.

#### Structure of the 2nd Generation Intact Stability Criteria

A multi-tiered approach to the 2nd GISC has been agreed so far and employed by the working and correspondence groups at subsequent SLF and SDC meetings. Three tiers were proposed, as shown in the figure 1. Stability failure mode *Excessive stability* is not shown in the figure 1 because this failure mode was added by SLF after the structure has been discussed and agreed.

The structure may be explained as follows:

1. The intention of the first level of vulnerability criteria is to separate non-vulnerable ships (conventional ships) from those which are **supposed to be vulnerable** (unconventional ships) for each stability failure mode. A ship which does not pass the first level criteria is recognized as vulnerable for specific mode of stability failure. The criteria at this level are expected to be relatively simple – as simple as present stability criteria.
2. The second level is expected to be more sophisticated than the first level and to employ more complex and physics based methods which consider the dynamics of the relevant phenomena. The aim of the second level is to confirm the assessment made at the first level. The second level shall be used if a ship fails to pass the first level.
3. A ship which fails to comply with two levels of vulnerability criteria is requested to be examined with Direct Assessment procedure (DA) – the third level criteria. The third level should be as close to physics as practically possible taking into account limitations of accessible tools. The outcome of DA could be changes in ship design or development of an Operational Guidance (OG).

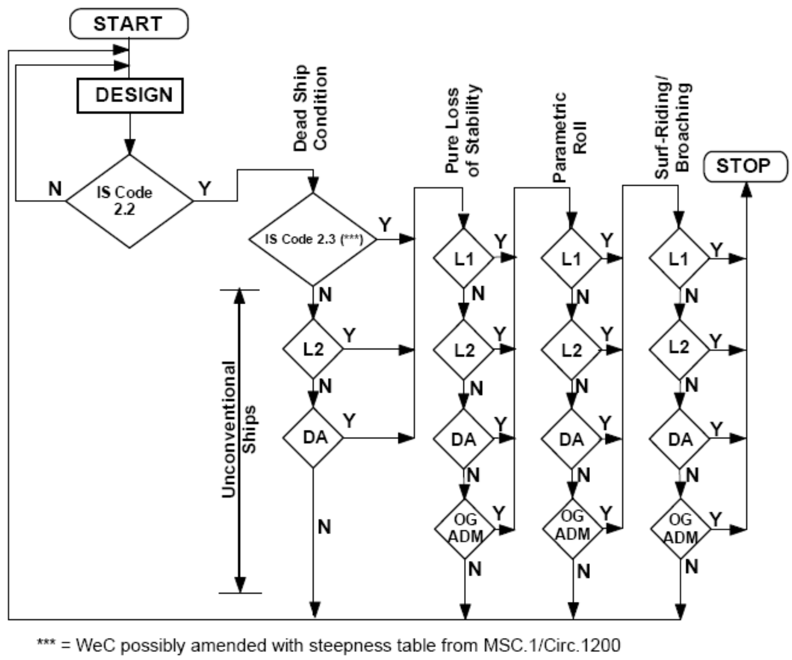


Fig. 1. Possible final structure after gaining sufficient experience in the application of the 2nd GISC

Table 2. Complexity of methods used for failure modes assessment on different levels

| | 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 computations | Numerical simulation of physical phenomena (computer codes) or model tests | Based on experience from numerical simulations or model tests |

In the opinion of the Author of this paper the structure presented in the figure 1 should not be finally agreed by the Sub-committee (*SDC in this case after reorganization of IMO*). The Operational Guidance for the Master should be issued after Direct Assessment resulted with positive judging of the safety level – the Administration is satisfied with the safety level demonstrated by DA.

Table 2 presents description of the assumed complexity of methods used for different stability failure modes assessment on different levels.

## Proper relation between Level 1 and Level 2 criteria

Multi-tiered approach will serve the shipbuilding industry effectively in terms of safety level if there will be proper relation between the Level 2 and the Level 1 criteria. There are at least three rules concerning relation between the Level 1 and the Level 2 criteria that shall be met in practice. The rules are given in the table 3.

Table 3. Rules for proper relation between Level 1 and Level 2 criteria

| | |
|---|---|
| Rule 1 | A ship that has been found vulnerable on Level 2 (which is more precise than Level 1) has to be found vulnerable on Level 1 as well |
| Rule 2 | A ship that has been found non-vulnerable on the Level 1 has to be found also non-vulnerable on the Level 2 |
| Rule 3 | A ship which suffers from particular stability failure mode in service shall be found vulnerable both on the Level 1 and the Level 2 |

Graphical interpretation of the rules 1 and 2 is shown in the figure 2 and may be explained as follows. Three circles represent three ships having different stability parameters: $r_1$ – a ship that has low value of the parameters; $r_2$ – a ship that has high value of the parameters; $r_3$ – a ship that has medium value of the parameters. "Holes" in planes represent standards: $R_1$ – standard on Level 1; $R_2$ – standard on Level 2. According to the vulnerability concept following relation shall be satisfied: $R_1 > R_2$. A circle (a ship) that goes through the "hole" (standard) is found as vulnerable on particular level (it corresponds to "N" in the figure 1).

A ship represented by $r_2$ is found not vulnerable on Level 1 ($r_2 > R_1$) but at the same time ships represented by $r_1$and $r_3$ are supposed to be vulnerable ($r_1 < R_1$ and $r_3 < R_1$). A ship represented by $r_3$ after more sophisticated analysis on Level 2 is found not vulnerable ($r_3 > R_2$) but a ship represented by $r_1$ has been confirmed to be vulnerable. In this case Direct Assessment (DA) is required.

How to prove before making practical use of particular criterion that criteria and standards developed by the Sub-committee satisfy the rules shown in table 2? It has to be proved by mathematical considerations based on hydrodynamics and ship behaviour rather than by comparison of the results of calculations performed on limited sample of ships – as it is being done by the Intersessional Correspondence Group. But of course the criteria are under development and the discussions during next Sub-committee's sessions and other stability conferences and workshops obviously will put new light on this issue. The core element here is to use well recognized and described accidents of ships suffering for particular failure mode and check whether the criteria would judge these ships as vulnerable (confirmation of the Rule 3 in the table 2).

## Current status of the 2nd Generation Intact Stability Criteria

The Intersessional Correspondence Group coordinated by Japan submitted to the Sub-committee on Ship Design and Construction for its first session in January 2014 (SDC 1) two reports [8, 9]. The second is titled "*Information collected by the Correspondence Group on Intact Stability regarding the second generation intact stability criteria development*". Developed draft rules, developed draft working version of explanatory notes, updated draft guidelines and relevant sample calculation results as well as comments on these have been attached at annexes to this document. The document is rather bulky one – consists of 130 pages.

The Sub-Committee considered the reports of the correspondence group at the plenary session and approved them in general. During that session, due to time constraints and the work overload, the Sub-committee limited its work to the preparation of the *Updated plan of action for the second generation intact stability criteria*, identifying the priorities, time frames and objectives for the work to be accomplished. The Sub-Committee agreed to

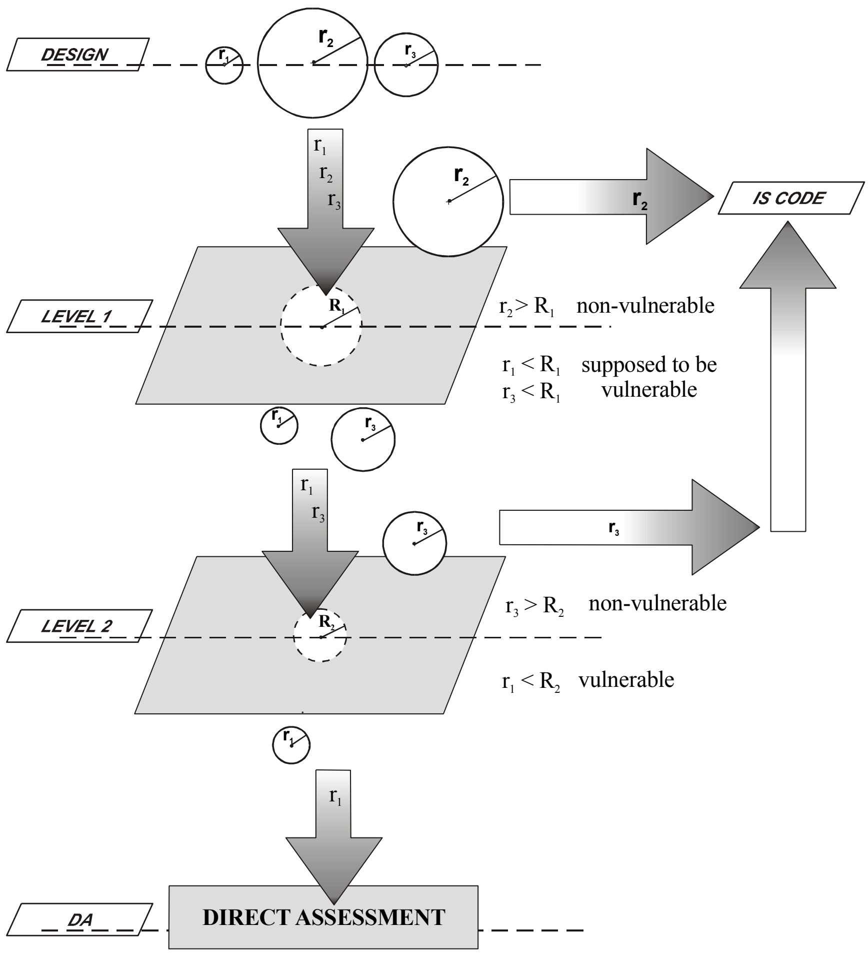


Fig. 2. Graphical interpretation of the 3 tiers approach and relation between Level 1 and Level 2

establish a Correspondence Group on Intact Stability for 2014, under the coordination of Japan, and instructed it to continue to work on the items contained in the *Updated plan of action for the second-generation intact stability criteria* (document SDC 1/WP.5), taking into account relevant documents from previous sessions, and to:

1. Finalize the draft amendments to the 2008 IS Code regarding vulnerability criteria and the standards (levels 1 and 2) related to parametric roll resonance, pure loss of stability and broaching-to.
2. Further develop the draft amendments to the 2008 IS Code regarding vulnerability criteria and standards (levels 1 and 2) related to dead ship condition and excessive accelerations.
3. Further enhance the working version of the Explanatory Notes for vulnerability criteria.
4. Further enhance the working version of the guidelines for Direct Assessment.
5. Submit a report to SDC 2 (February 2015).

It should be stressed that in the view of the Sub-committee only three stability failure modes were at enough matured stage so far that enabled execution of comparable sample calculations and making further developments in the draft texts of the rules with the view to finalize them within one year: parametric roll, pure loss of stability and broaching. Furthermore, these failure modes contain a number of options and values of standards that need decisions at later stage on the base of sample ships calculations. Other defined stability failure modes (dead ship condition and excessive stability) would need more work in the next future.

During SDC 1 session one delegation, supported by others, questioned whether it is feasible to continue the work on 2nd GISC at this point in time and suggested to discontinue the work to allow the Sub-committee to focus on more pressing issues [10]. They raised following arguments:

– There is limited evidence of an industry-wide problem of incidents where intact stability is identified as the cause.
– The mathematical complexity of proposals for the criteria will require the significant time to fully validate the regulations.
– The pressing workload of SDC Sub-Committee.
– 2nd GISC will be non-mandatory.

## Some weaknesses of the 2nd Generation Intact Stability Criteria

Inclusion of the new agenda item "Development of the 2nd Generation Intact Stability Criteria" into the work programme of former SLF and present SDC Sub-committee opened the door for international discussion and created opportunity for collection of the information, ideas, proposals, calculation methods and finally for development of new stability criteria that will be free (to possible and practical extend) from shortcomings of existing ones. But the process of the development of the 2nd GISC demonstrates both strong and weak features of the vulnerability concept.

From practical point of view the most serious problem appears with consistency between Level 1 and Level 2 criteria (rules 1 and 2 mentioned in the table 3) and judging the vessels that are not vulnerable for particular failure mode in operation as vulnerable taking into account developed criteria and standards. Also judging the vessel that is vulnerable in operation as not vulnerable creates similar problem – to what extent newly developed criteria and standards fit to the reality. Furthermore setting standards on the base of consistency between Level 1 and Level 2 neglecting the physical features of the phenomena related to particular failure mode (in terms of the intensity of rigid body oscillations) raises concerns due to the methodology. Citations from the report of the correspondence group [9] are quoted below:

1. "Vulnerability for pure loss of stability was not expected based on known behaviour of cruise vessels. However, three of the cruise vessels show vulnerability for pure loss of stability".
2. "Still two vessels are found to be vulnerable according to option 6A, whereas none of the vessels is vulnerable according to option 6B".
3. "It is noteworthy that for Ship 11 (both laden and ballast) and Ship 12 (ballast only) the vessel passes the first level criterion but fails the second level".
4. "For the 2nd check of Level 2 criterion, results of six loading conditions are judged as vulnerable and conflict with the lower level criteria. Therefore, it is proposed to amend the standard value on the basis of 0.25. In order to solve the consistency problem, maybe 0.3 is more reasonable. Based on this assumption, all of the six loading condition could be judged as non-vulnerable and consistent with the lower level criteria".

Other observations (weaknesses) that may question the approach presented by the Sub-committee at this stage are listed below:

1. There are not many (just a few) references to documented stability accidents where particular stability failure was the cause of the accident (Rule 3 in the table 3).
2. The real performance of the ship in terms of the definitions mentioned in 2.1 has not been taken into account. Therefore, **it is not known what limits for rolling angles or rigid body accelerations are secured by the criteria** (except of parametric roll, Level 2).
3. The 2nd Generation Intact Stability Criteria at present stage are basically design oriented. "*Their concept is based on the assumption that improvement of ship construction will increase level off safety against stability failure. 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*" [11]. It has not been decided or even discussed how eventual application of the regulations will affect ship operation – stability assessment before departure or at sea – taking into account that human factor is an essential element of the system of the safety against stability failure.
4. Present set of stability failures developed by the Sub-committee does not cover all dangerous situations that ship may encounter in operation. This set has been established basing on scientific interest of some research centres (except of excessive stability) at the moment of development of the approach to the 2nd GISC. Furthermore, the probability of particular failure mode occurrence was not considered. For example, parametric roll is very rare phenomena what was not taken into account.
5. In the opinion of the Author of this paper none of the criteria does fulfil requirements to be judged as performance-based probabilistic criterion (a criterion based on a physical model of a stability failure considered as a random event), as it was supposed at the beginning of the work.
6. The criteria and regulations are rather complicated from the design point of view (apart from the assumption that they should be simple). It is

difficult and time consuming to check all the criteria one by one. Obviously, proper computer programs may solve this problem, but the programs have to be available worldwide after the regulations have been agreed and incorporated into 2008 IS Code, Part B (if so decided).

7. At present it is not decided how Direct Assessment (the third level in the figure 1) might be performed.

## Conclusions

Apart weaknesses presented above the approach to the 2nd GISC has also positives, like:

1. Introduction of the definition of "unconventional" ship and stability failure mode.
2. Introduction of reference waves to intact stability assessment.
3. Taking into account additional factors affecting safety from stability point of view, such as: waves (in terms of weighting factors that to some extent may be interpreted as the measure of probability), ship's speed, roll damping, mass moments of inertia.
4. Introduction of ship dependent Operational Guidelines focused on the stability failure mode that has been found dangerous for the ship.
5. Requirement for Direct Assessment when the ship is vulnerable for any stability failure mode.

Development of the 2nd Generation Intact Stability Criteria takes a lot of time. Year 2007 was the first deadline for the completion of this task set out by the Maritime Safety Committee (MSC). The Sub-committee on Ship Design and Construction shall at its 2nd or 3rd session (in 2015 or in 2016 respectively) complete the work on at least three stability failure modes (parametric roll resonance, pure loss of stability and broaching-to) in order to "deliver the product" to the Committee for their consideration and decisions. The weaknesses of the approach to the 2nd GISC presented in this paper **may prevent Member States from adoption** on MSC level regulations developed in the frame of the 2nd GISC.

In the opinion of the Author of this paper there are three possible options for the future:

– Level 1 and Level 2 criteria and regulations for defined stability failure modes will be adopted by MSC and included into Part B of the 2008 IS Code;
– MSC will develop a resolution inviting Member Governments to apply 2nd GISC Level 1 and Level 2 in ship design;
– MSC will delete the work on the 2nd GISC from SDC agenda before the work has been completed.

Possible inclusion of the developed regulations into Part B (recommendatory) of the 2008 IS Code may encourage some administrations to apply the regulations in ships design and to submit to IMO information on the experience gained from application of the criteria.

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