Alternative Stability Requirements Based on System and Risk Approach

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ABSTRACT

The IMO Intact Stability Code is currently under review and short-term and long-term tasks in this context were agreed. The short-term task is almost completed, but the long-term project aimed at development of performance oriented criteria is under discussion. For ships incorporating novel construction features the existing criteria may be inadequate, therefore the author proposed to allow administrations to apply alternative requirements ensuring sufficient level of safety. Those requirements should be based on safety assessment including risk analysis. The author considers in the paper how alternative method based on safety assessment could be applied.

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

1. BACKGROUND

Existing international stability requirements are included in the IMO Intact Stability Code for all types of ships (IS Code), adopted in 1993 by the Resolution A.749(18), that was amended later, in 1998 by the resolution MSC.75(69). Currently IS Code is under review and it was agreed that the review has to be performed in two stages:

Stage 1: Short- term task. Within short-term approach as proposed by Germany (IMO 2003), the Code should be divided in two parts. Part one will include basic stability criteria that will be made mandatory by inclusion or by reference to SOLAS Convention. Part two should remain as the recommendation and will include all other requirements and guidelines of the existing Code. Moreover, all the existing stability requirements included in the IS Code will be reviewed and amended if necessary in the view of experience gained since their adoption. This task is almost completed and it is anticipated that the revised IS Code may enter into force at the earliest revision of the SOLAS convention in 2009. The Code will be supplemented by explanatory notes containing explanation of the method of development of existing criteria

Stage 2: Long-term task. This task includes development of additional and improved stability criteria based on more accurate representation of physical phenomena leading to capsizing. Germany (IMO, 2004) proposed to develop such criteria under heading "performance oriented criteria". This task includes also development of criteria for ships not covered yet by the IS Code, e.g tugs, sail ships, cable ships etc.

After initial discussion on the possible approach to the solution of the long-term task, currently the attention of the SLF Sub-committee is concentrated almost solely on completing the short-term task. With most members of the Sub-committee satisfied with incorporating intact stability requirement into SOLAS making them compulsory it is not certain now whether long–term task will be included in the work programme of the SLF Sub-committee. If it would be not included, then development of additional criteria might be postponed to rather distant time.

It seems that the existing safety requirements provide in general sufficient level of safety for conventional ships. The criteria are working quite well and, in fact, the number of casualties has a tendency to reduce with the time. This paradigm may be, however, questioned. From time to time serious casualties happen with a number of fatalities. Few examples of such accidents are referred to in by Kobylinski (2004). Francescutto (1992) claims that modern ships in many cases are unsafe and gives several reasons why it is so.

Casualty of the postpanamax C11 containership (France et al 2001) where parametric resonance in head seas was discovered confirms this opinion. If the number of fatalities is large and the casualty happens in sensitive area, then, following the reaction of the public, governments involved and IMO are obliged to impose quickly additional safety measures. Casualty of ESTONIA in 1994 is a good example of this. Recently, some accidents where parametric resonance, loss of stability in wave crest and other effects were the main cause of capsizing, caused that within the revision of the IS Code the idea of including some performance oriented criteria was proposed.

2. CRITICAL VIEWS ON PRESENT STABILITY CRITERIA

The existing stability criteria are of prescriptive nature and already after the time they had been adopted, they were strongly criticised (Kuo & Welaya 1981). These critical views are now enhanced. Statistical criteria were based on data for ships capsized and on those operated safely during the period 1930-1960. The type of those vessels differs from the type of ships operated recently. The data on stability characteristics of ships that capsized in many cases were inaccurate and the circumstances of casualty vague. In general, the population of vessels of each category that capsized was rather small.

Weather criterion was based on rather very simplified physical model of the behaviour of a ship rolling in beam seas including wind heeling moment. Only one situation, where vessel is exposed broadside to the wind and waves was taken into account. The value of wind pressure was adopted in such a way, that the resulting critical KG value would correspond to average KG values of the population of vessels existing at the time of development of the criterion that were considered safe in operation. Trial calculations did show that the majority of existing at that time ships satisfied adopted weather criterion.

3. ALTERNATIVE APPROACH TO STABILITY REQUIREMENTS

The critical opinions regarding present criteria are well recognized and during the discussions within the IMO SLF Sub-committee views were expressed that the existing criteria should be reviewed and superseded or supplemented by “performance oriented criteria - POC”. The understanding of “POC is, however, not clear. The author proposed definition of the POC (Kobylinski 2005) which is probably in line with the work programme of the SLF Sub-committee. In the opinion of the author this approach is not solving the basic problem of the overall safety assessment. POC, as they are understood by the Sub-committee, may consist of some improvement or additions to already existing criteria, for example improvement of the weather criterion, addition of criteria related to parametric resonance, loss of stability on wave crest etc. This will lead to fragmentation of requirements and perhaps, overregulation. Bearing in mind that the number of possible scenarios of capsizing is large, it might be anticipated, that when another casualty will happen, new set of regulations will be necessary.

Characteristic feature of the present times is increasing number of ships constructed, which could hardly be defined as conventional ships. Large passenger cruise liners, large containerships with the capacity as much as 10000 TEU and over, various types off-shore support vessels, high-speed craft of various types, with more types to come in the future, are result of changes in the shipping world. There are no historical data regarding those ships and no past experience. Safety of those ships should be approached in the different way. The practical solution of the problem the author sees in the introduction of the provision allowing the Administrations to apply alternative goal-oriented approach instead or on top of convention regulations.

In fact, the text of the revised version of the IS Code under development includes provision allowing Administrations to apply for particular ship or group of ships criteria demonstrating that safety of the ship is sufficient (IMO 2006). This formulation does not mention specifically application of safety assessment. In the opinion of the author, however, it implies such possibility.

The proposal to include in the above mentioned provision safety assessment procedure was discussed by the author in more detail in two papers (Kobylinski 2005, 2005a) and is not repeated here. The focus of this paper is on problems that may arise with the application of SA procedure.

4. ADVOCATING SAFETY ASSESSMENT

The advantages of safety assessment and risk-based approach are obvious. It provides free hand for the designer to develop new solutions, it actually allows taking optimal decisions from the point of view of economy and safety, and risk to the public and to the environment is assessed and accepted.

Safety assessment is defined as a broad range of approaches, which could be applied to manage the safety of a vessel in a systematic manner [Spouge 1996]. SA is at present widely used in various branches of technology, sometimes as a standard procedure, first of all in the nuclear industry. In the last few years there have been increasing applications of SA approaches in the offshore industry, particularly in the post PIPER ALPHA disaster period (Fidgerald and Grant 1991) (see also: (Apostolakis et al 1998).

SA is used to identify potential hazards, evaluate frequency of hazardous incidents and then to calculate the resultant level of risk and to develop recommendations and requirements on this basis.

IMO did recognize the situation and considered possibilities of application of risk based approach to safety regime of ships and ultimately the Marine Safety Committee of IMO recommended this approach as Formal Safety Assessment (FSA) first in MCS/Circ. 829 (IMO 1997) and later in MSC/Circ.1023 (IMO 2002). Since then many papers were published on this subject.

Performing risk analysis following recommended FSA procedure with regard to safety against capsizing is not an easy task. Obviously, guidance to help Administrations to apply such a procedure may be necessary.

5. CAPSIZING OR LOSS OF STABILITY ACCIDENT

The important issue is to define the term capsizing. In common language, capsizing usually is understood as the passing of the ship from the upright position or zero angle of heel to the upside down position or 180 degrees heel. The above concept of capsizing is, however, not satisfactory from the point of view of studying safety against capsizing. When considering practical problems of safety from the stability point of view, it would be better to introduce a concept of loss of stability accident (LOSA) instead of capsizing, that betted describes situation occurring in reality when a ship considered as capsized may not necessarily be in the upside down position. This was discussed *inter allia* by Kastner [1969/70], Abicht [1972] and Odabasi [1982].

There was the prolonged discussion on the definition of capsizing during the second STAB conference in 1982 [Rakhmanin et al 1982] where several proposals were considered. Morall [1982] finally proposed to define capsizing, as a situation where amplitudes of rolling motion or heel exceed a limit that makes operation or handling the ship impossible for various reasons (loss of power, loss of manoeuvrability, necessity to abandon the ship) but not necessarily taking the position upside down. This situation might be better defined as the loss of stability accident (LOSA) and the definition might be suitable for assessing risk of capsizing.

LOSA could be subdivided in sub-categories. For example:

- sudden capsizing
- large heel with loss of power and manoeuvrability
- large heel with progressive flooding and eventually capsizing or foundering

The sub-categorisation is important from the point of view of consequences, because in category 2 and 3 part or all passengers and crew could be saved and number of fatalities reduced.

6. APPLICATION OF RISK ASSESSMENT TO STABILITY SYSTEM

IMO recommendation (IMO 2002, 2002a) provides guidance on how to apply FSA procedure to IMO rule making process. According to this, FSA can be used as tool to help evaluation of new or improved regulations. With application to stability assumption would be made that the ship analysed satisfies the established criteria, but in the opinion of decision makers the criteria do not assure sufficient level of safety. The FSA procedure may show the necessity to improve criteria.

It seems that there is consensus on application of (FSA) to stability problems, but in practice this method was little used.

There are only few known attempts of application of SA procedure to stability of ships. The author in several papers discussed possibilities of application of the FSA methodology to intact stability criteria (Kobylinski 2004, 2005). Erickson et al (1997), Mc Taggart & de Kat (2000) attempted to apply risk approach to intact stability. Risk approach is inherently involved in the total ship safety concept strategy proposed by Vassalos (2002). The only one known attempt to apply full FSA procedure was presented by Germany (IMO 2003) but it was directed solely to assess the consequences of making the intact stability criteria mandatory.

Application of FSA to assessment of existing general stability criteria for all types of ships seems rather unrealistic. With the variety of ship types, sizes and operation profile, performing full FSA analysis required for the large population of ships would need enormous effort with uncertain results. In such analysis it would be impossible to include human factor, because criteria could not be based on a priori assumption that the. master is incompetent or that the criteria are deliberately neglected by the authorities. Probably, with existing criteria working quite well for the great majority of ships, there would be no motivation to undertake such a difficult and time-consuming task.

On the other hand, there are recently in operation or under construction many large ships, some of them incorporating non-conventional features. The existing criteria for those ships may be inadequate and the solution may be to require application of safety assessment including risk analysis for each individual ship. For example, LOSA is unthinkable with the ship carrying three or four thousands of passengers and risk analysis must proof that probability of such accident is extremely low. This can not be proofed using existing prescriptive criteria developed for quite different population of ships many years ago.

The IMO guidance (IMO 2002) is, however, of the general nature and refers to overall safety of a ship. Safety against capsizing is only one of the elements of the overall system of safety, nevertheless, because of serious consequences of LOSA, this element is important and risk analysis of capsizing requires more specific guidance. Whether the guidelines have to be developed or not is to the decision of appropriate bodies of IMO.

The block diagram for the procedure of safety assessment is shown in fig.1. The most important parts of this procedure are: risk analysis, risk control and risk reduction measures.

In this case when performing risk analysis all relevant types of hazards must be taken into consideration – environmental, technical, operational and managerial. Human factor must be taken also into consideration. It is assumed, that the ship is satisfying the existing compulsory criteria (criteria that in near future will be included in SOLAS convention).

7. RISK ANALYSIS

The crucial element in the safety assessment is risk analysis. Risk is equal to the product of probability of hazard and its consequences. In order to assess risk both quantities must be evaluated. Fig 2 shows the general logical scheme of risk analysis.

In case of stability the analysis starts from the constructing of the generic model of ship type and its operation profile. Hazard is defined as a situation that can potentially result in LOSA. Hazards have to be identified on the basis of scenario leading to LOSA.

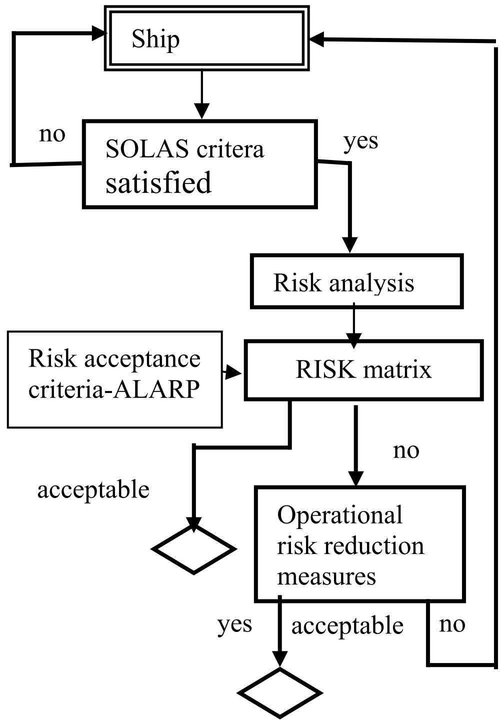

Fig.1. Block diagram of the safety assessment

With regard to stability, there are multiple possible scenarios that may lead to LOSA. They could be identified on four levels:

- Level I – design and construction
- Level II – approval
- Level III – managerial
- Level IV– operational

In each level there may be initiating events that start LOSA scenario. All these scenarios have to be considered and their probability estimated.

For example, in level I the ship designed meets established compulsory formal stability criteria, but there are hazards that were not taken care by the criteria that may lead to LOSA. In level II the appropriate authority may approve ship that does not meet the criteria for various reasons. In level III ship at departure has insufficient stability because of wrong assessment of loading condition, errors in ship data or in cargo information, negligence

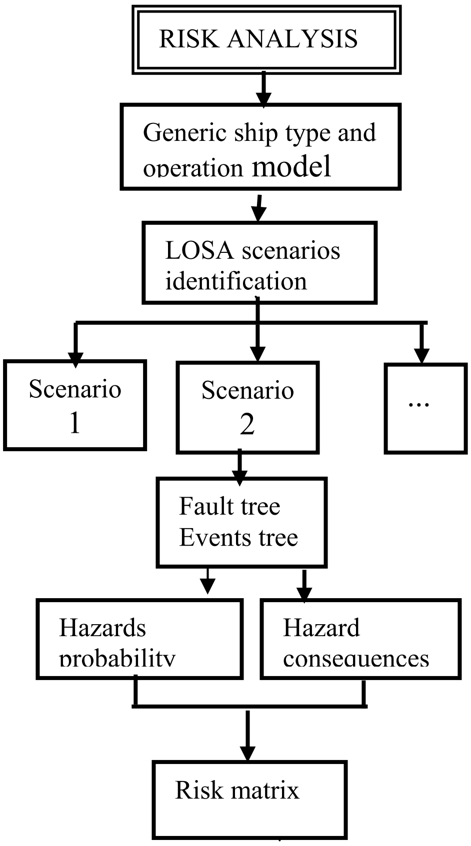

Fig.2 Block diagram of risk analysis

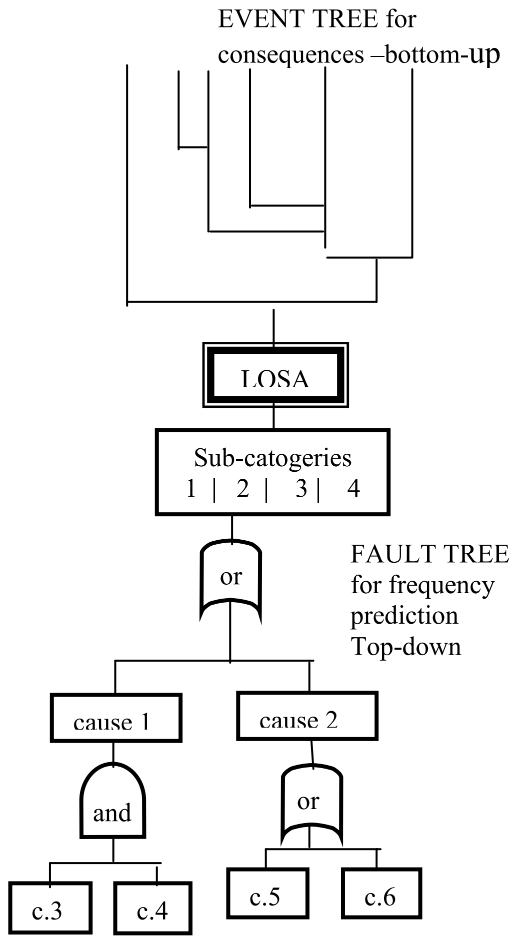

Fig.3. Fault tree and event tree

or other reasons. In level IV the ship may have insufficient stability because of insufficient departure stability, but also because wrong decisions of the master – misinterpreting data on stability, neglecting operational recommendations or wrong choice regarding speed, course etc.

In all levels human factor is crucial, in particular in managerial and operational level. There are certainly strong links between particular levels, for example design criteria may be inadequate, nevertheless ship may be operated safely; on the other hand negligence and bad operation may lead to casualty in spite of the fact that the ship meets established stability criteria. Obviously at the design level one must take into consideration also the way how the ship will be operated. Anticipated improper operation, however, should rather not influence design criteria; ships should not be designed on "fail safe" principle – no ship can be constructed that would not capsize because of faulty operation or negligence. Nonetheless, some measures prohibiting bad operation could be included (e.g. some automatic alarms such as signaling that doors are left open etc.). Ideal hypothetical alarm (although not yet realistic) would be an alarm signaling at sea that the ship is in dangerous situation.(e.g. not meeting established safety standard).

The problem of scenario identification was discusses by the author in (Kobylinski 2003). The suggested list of scenarios included, however, only scenarios on level I that are relevant to performing by the ship normal operations at sea. Scenarios on the level II to IV were not considered.

The method used for identification of scenarios and hazards is hazards and operability study (HAZOP). HAZOP is a basic analysis of procedures, events and possible deviations that may cause accidents. HAZOP methodology is based on fault tree analysis (top-down approach) and event tree analysis (bottom-up approach) (fig.3).

For identification of scenarios and construction of fault trees and event trees a team of experts have to be assembled. There are specific recommendations on how to organize work of such teams, in particular difference between expert judgment and engineering judgment is stressed (Hokstad et al 1998, IMO 2004a).

In the work of a team of experts the most advisable is to take proactive approach including probabilistic modelling of failures and ship behaviour at sea. Mathematical models and computer codes for evaluation of probability of LOSA when sailing in a seaway should be used. Analytical methods should be used to evaluate rare events, such as encountering extreme or freak waves. For evaluation of probability of some hazards deterministic models may be applicable. Model test results may be also taken into consideration for identification of some modes of capsizing, although evaluation of probability of capsizing based on model tests seems to be not possible.

Historical data and statistics should also be used, but with some reservation. Statistics of LOSA, if available, provides some information about the past, but can not be used to predict hazards relevant to non-conventional ships of the future. In general, statistical data should not be overestimated. On the other hand casualty records bank, such as e.g. collected by IMO in the years 1963-85 (IMO 1985) provides useful information on possible scenarios of LOSA.

8. RISK MATRIX

IMO recommended for validation o ranking to define probability and consequence indices on the logarithmic scale (IMO 2002):
Risk = probability x consequence
Log(risk)=log(probability)+log (consequences)

Frequency (probability) of LOSA is rated then from FI = 1 (extremely remote) to FI =7 (frequent), and severity (consequence) is rated from SI = 1 (Minor) to SI = 4 (catastrophic). With LOSA only catastrophic = (SI = 4, multiple fatalities, total loss of the ship) or severe (SI = 3, severe damage, single fatality) categories should be considered. Then the following risk index matrix could be obtained (Table 1):

It seems, that this type of ranking risk may be useful to evaluate LOSA. In the table insignificant and minor consequences were omitted, because they are not relevant to LOSA

9. ACEPTABILITY OF RISK

When one is considering risk, then the basic problem would be to decide whether the risk estimated is acceptable or not. This problem could be solved in the following ways (Brandowski 2002).

Table 1. Risk matrix

RISK INDEX (RI)			
FI	FREQUENCY	SEVERITY (SI)	
		3	4
		Severe	Catastrophic
7	Frequent	10	11
6		9	10
5	Reasonably probable	8	9
4		7	8
3	Remote	6	7
2		5	6
1	Extremely remote	4	5

1. by comparing the risk of LOSA calculated for the particular design with the risk calculated with the same method for existing ships (method of disclosed preferences)
2. investigating preferences of the public (by method of expressed preferences)
3. by risk-benefits assessment

The first method was applied when developing new safety requirements by IMO where the assumption was adopted that new requirements have to provide at least the same level of safety as the old ones. This method would require performing risk analysis for a number of existing ships that only just satisfy existing criteria and results of such exercise could be confusing because they may reveal that risk index for those ships may be widely different. This method is not suitable when the risk level of the new design has to be different (higher) than represented by current regulations.

The second method might lead to absurd results. The public behaviour is often irrational. Probably the most serious problems in accepting the probabilistic concept of safety result from the human nature. The realisation, for example, that safety is never absolute in the quantitative sense seems to disturb or even terrorise some people when the decisions on new enterprises have to be taken. Even if it has been proved that the probability of failure is extremely remote, the public might consider the undertaking as unsafe. From the other hand the public is not willing to resign from benefits which are related to higher risk.

Probably the best method that can be recommended is ALARP method. ALARP (as-low-as-reasonable-and-practicable) method is illus trated in fig 4

In the ALARP area risk-benefit analysis should be carried out using different methods. This problem is not discussed here. IMO guidelines on application of FSA provide respective recommendations.

10. CONCLUSIONS

The author believes that as an alternative solution to the stability requirements included in the compulsory part of the IS Code, the safety assessment methodology including risk assessment could be used. He also believes that

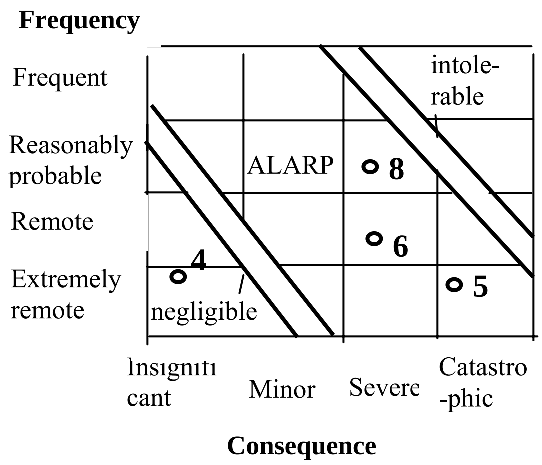

Fig. 4. ALARP principle.

some kind of guidelines to help administrations to use this approach should be developed. The paper shows that application of safety assessment and risk analysis to stability requirements in the design stage of a ship is feasible, although it requires quite considerable amount of work. The author believes that this methodology may be applied to large modern ships of complex design and to ships of novel type.

11. REFERENCES

Abicht, W., 1972, "Die Sicherheit der Schiffe im nachlaufender unregelmaessingen Seegang", Schiffbautechnik, Bd.19

Apostolakis, G.E., Guedes Soares, C., Kondo, S., Aven, T.(editors), 1998, "Special issue on offshore safety", Reliability Engineering & System Safety, Vol. 61.

Brandowski, A. 2002, "Criteria of safety for ships", 20 Sesja Naukowa Okrętowców, Gdańsk (in Polish)

Erickson, A., Person, J., Rutgerson, O., 1997, "On the use of formal safety assessment when analysing the risk for cargo shift in rough seas", International Conference on Design and Operation in Abnormal Conditions, Proceedings, Glasgow

Fidgerald, B.P., Grant, Mc.M., 1991, "A practical methodology for risk assessment of offshore installations", Offshore Operations Post Piper Alpha Conference, IME/RINA

France, W.N., Levadou, M., Treakle, T.W., Paulling, J.R., Michel, R.K., Moore, C., 2001, "An investigation of head sea parametric rolling and its influence on container lashing systems", SNAME Annual meeting.

Francescutto, A., 1992, "Is it really impossible to design safe ships?", RINA Spring Meeting 1992, paper No.3

Francescutto, A., 2003, "Sea waves and ship safety – state of art in current regulations", SLF Working Group Hamburg

Hokstad, P., Øien, K., Reinertsen, R., 1998, "Recommendations on the use of expert judgement in safety and reliability engineering studies, Two offshore case studies", Reliability Engineering & System Safety, Vol 61, No.1/2

IMO, 1985, "Analysis of intact stability casualty records", Submitted by Poland, Doc. SLF 30/4/4 and SLF/38

IMO, 1997, "Interim guidelines for the application of Formal Safety Assessment (FSA) to the IMO rule-making process", Doc.MSC/Circ.829;

IMO, 2002, "Guidelines for the application of formal safety assessment (FSA) to the IMO rule-making process", Doc. MSC/Circ. 1023;

IMO, 2002a, "Guidance on the use of human element analysing process (HEAP) and formal safety assessment (FSA) in the IMO rule making process", Doc. MSC/Circ. 1022;

IMO, 2003, "Revision of the code on intact stability", Submitted by Germany, Doc. MSC 78/24/1 and MSC 78/INF.5

IMO, 2004, "Review of the Intact Stability Code, Towards the development of dynamic stability criteria", Submitted by Germany, Doc SLF 47/6/4

IMO, 2004a, "Formal safety assessment, Expert concordance", Submitted by IACS, Doc. MSC 78/19/3

IMO, 2006, "Draft Restructured IS Code", To be presented to 49 session of the SLF sub-committee,

Kastner, S., 1969/70, "Das Kentern von Schiffen in unregelmaessiger langslaufender See", Schiffstechnik.

Kobyliński, L., 2003, "Capsizing scenarios and hazard identification", 8th International Conference on Stability of Ships and Ocean Vehicles STAB'03, Madrid,

Kobyliński, L., 2004, "Application of the FSA methodology to intact stability criteria", Marine Technology Transactions, Vol.15, Special issue – XXI SNO, pp. 319-329

Kobyliński, L., 2005, "Appraisal of risk assessment approach to stability of ships", 8th International Ship Stability Workshop, Istambul

Kobyliński, L., 2005a, "Performance oriented approach to stability criteria", Joint 16th International Conference on Hydrodynamics in Ship Design , 3rd International Symposium on Ship Manoeuvring, (HYDMAN), Ostróda

Kuo C., Welaya Y., 1981, "A review of intact stability research and criteria", Ocean Engineering, p.65

McTaggart, K., de Kat, J.O., 2000, "Capsize risk of intact frigates in irregular seas", SNAME Transactions.

Morrall, A., 1982, "Philosophical aspects of assessing ship stability", 2nd STAB Conference, Tokyo

Odabasi, A.Y., 1982, "A morphology of mathematical stability theory and its application to intact stability assessment", 2nd STAB Conference, Tokyo

Rakhmanin, N.N., Hormann, H., Morall, A., Bird, H., Cleary, W.A., Helas, G., 1982, "Panel discussion I: Philosophy and Research", 2nd STAB Conference, Tokio

Spouge J., 1996, "Safety assessment of passenger/ro-ro vessels", RINA International Conference on the Safety of Passengers in RO-RO vessels, London

Vassalos, D., 2002, "Total ship safety – a life-cycle risk-based DOR for safety", The Stability Research Centre, NAME, Universities of Glasgow and Strathclyde, Report, May