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Rational approach to ship safety requirements

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Abstract

Study of the history of the development of ship safety requirements reveals that work on the development of safety rules was always initiated as a result of tragic disasters. Public outcry at the lives lost forced the authorities to set up more stringent standards of ship construction. A classic example of this was the development of the first SOLAS Convention after the TITANIC disaster and also, quite recently, the establishment of new requirements for ro-ro vessels after the ESTONIA casualty. This method of establishing safety rules could be called "trial and error method". The author advocates a different approach to safety requirements. This approach entails relating safety considerations to the risk involved during the sea voyage. In the present situation actual risk for individual ships meeting all of the current safety standards may be widely different as has been shown by some examples. Moreover, present regulations relate mainly to the constructional features of ships, whereas the great majority of sea casualties are caused by human failure. At present, safety assessment is required in many fields of technology and this is used as a basis for the project's evaluation. The author shows how this approach could be used as a basis for ship survivability requirements and proposes a methodology for the simulation of the sea voyage taking into account the human factor and including risk assessment. In the opinion of the author the methodology described is fully feasible.

1 Introduction

History of development of shipping shows that during last two or three decades much more attention had been paid to safety problems in shipping as it was before. This manifests itself by the number of papers published, number of international conferences organised on safety, and the activity of the International Maritime Organisation the task of which is to promote safety at sea and sea environment protection, and which developed enormous amount of requirements related to ship construction.This activity had remarkable impact on shipbuilding industry which had to design and build ships complying with succession of more and more stringent requirements. This made certainly ships safer, but the question arises whether more stringent and more detailed requirements related to the construction of ships is a right solution? and whether safety regulations should be developed in the same way as they have been developed up to now? Both questions require consideration and this paper is mainly devoted to discussion of the second one, although some consideration is also given to the first question. As the author is working mainly on ship survivability of flooding, which includes stability problems, example given is related to this particular aspect of safety of ships. However, the conclusions are, according to the opinion of the author, applicable also to other aspects of ship safety.

2 Present situation with safety standards

From the oldest times shipbuilders were fully aware that ships they built must be safe. The knowledge how to build safe ships was, however, based solely on experience, which , in turn, was based on a procedure which could be called "trial -and-error method" where "errors" were sea disasters. Lessons from sea disasters materialised in rough recommendations on appropriate proportions and dimensions of ship's hull and its arrangement which would safeguard safety at sea and good seakeeping qualities. These recommendations were passed from generation to generation and guarded in extreme secrecy. Only in the second half of the nineteenth century first safety requirements were established by the authorities (e.g., British Merchant Shipping Act), but the scope of those requirements was limited initially only to the prevention of overloading of ships through the positioning of load line mark. In parallel, however, classification societies started to develop regulations related to ship scantlings.

It is worth mentioning that the shipping world was rather hesitant to introduce safety measures which obviously affect unfavourably economic results. This situation to some extent remained little changed up to this day. New methods and new approaches in the field of safety were developed in other fields of technology (nuclear, chemical industry, aviation) and then slowly being transferred to shipping but not yet fully implemented. One example of this attitude could be given. In 1866 the Head of the Marine Department Thomas Gray expressed the philosophy of legislators in the following terms (quoted after [1]): "there can be no question that government interference is not only necessary, but may really become vicious if it attempts to attain an end by official inspection and supervision that can be better attained by the development of free healthy competition and by self-interest and emulation of the trader, since it fetters the development of the trade, it stands in the way of the advancement of science, and it interferes to the prejudice of the liberty of the subject" The Board's Permanent Secretary at the same meeting said that: "they must look to self interest and not to governments regulations as the great element of safety of life on board ship" Shipowners agreed with them that

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"shipowner and ship master together are very much better judges of what ought to be done to a ship than anybody else can possibly be".

Recalling these opinions which resulted from the liberal ideas of the nineteenth century one must remember appalling conditions present onboard cargo and passenger ships, where sometimes one third of passengers died during the voyage and numerous casualties which occurred almost every day. Legislators and shipowners gave to only under great pressure of public agitated by high death toll at sea.

Such opinions are not expressed any more nowadays, but developments of new safety requirement still is often initiated under influence of public opinion moved by the sea disasters. It well known that the first SOLAS convention was drafted as the aftermath of the TITANIC casualty. But in more recent times we may recall AMOCO CADIZ disaster and subsequent work of IMO on new tanker regulations, HERALD OF FREE ENTERPRISE casualty and new requirements for passenger ro-ro vessels and finally the most recent tragedy, ESTONIA capsizing , and enormous activity towards developing new stability standards for ro-ro vessels. Those examples show that the method of development of safety standards is still the "trial and error" method and although this method could be accepted in certain areas of technology, it can not be accepted when loss of life is at stake. This is more so, because "rational" methods are known and are being applied in other fields of technology. The word "rational" in general has the meaning: "endowed with reason , derived from reasoning, sensible", but in this context we understand that rational method is a method based on scientific research. At present, however, safety requirements are result of a compromise which is achieved often under influence of various factors of the political and economic nature. In particular final figures in safety standards are settled often on the basis subjective judgement rather than on sound technical considerations.

Casualty statistics and analysis plays vital role in developing safety standards. But again, thorough analysis of particular casualties such as investigation programmes of GAUL [2], or HELLAND HANSEN [3] or, quite recently, ESTONIA disasters are rather rare events and majority of casualties are investigated by the Maritime Courts. But as underlined for example by Foy [4] those investigations do not, however provide a credible statistics. Maritime Courts often tend not to reveal true primary cause of casualty looking rather for person or persons who might be made responsible.

3 System approach to safety and safety assessment

From the previous considerations the conclusion could be drawn, that in order to promote safety at sea new approaches to the development of safety standards for ships are required. Even if overall statistics of fatalities is not bad for shipping (see Table 1), the majority of fatalities were in few great disasters which occur from time to time and which shock public opinion and force maritime authorities to do something about that. This is in particular the case, if the casualty happens in highly developed countries, such as ESTONIA disaster, whereas fire and capsizing of DONA PAZ in Philippines, the largest probably sea disaster where the total number of fatalities was more than 4000 was hardly noticed. The fact that majority of fatalities occur in few casualties is characteristic to shipping in contrary to the situation e.g. in road transport, where the total number of fatalities is split between thousands of casualties with few fatalities in each of them. This specific must have an impact on safety requirements and also shows that further work toward improvement of safety is needed. Although the risk is small, there is always the possibility that very serious casualty may happen destroying large areas of shoreline if e.g. a chemical tanker would be stranded in highly populated areas.

The solution of the problem might be application of system approach and safety assessment methods. System approach consists of looking at the problem as including several subproblems mutually interrelated. It is an approach where the process of achieving main aims are exactly defined and connected with the subprocesses in accordance with adopted scheme. The need to apply system approach to safety problems, in particularly to safety against capsizing, was advocated by the author several times [7,8].It was also supported by other authors [9]. It seems, that looking at the safety of ships in the chaotic way, where each particular aspect as for example stability, freeboard, subdivision, life saving appliances, fire protection measures, etc. is considered separately and independent of each other shall not be pursued further.

Safety assessment -SA-is defined as a broad range of approaches which could be applied to manage the safety of a vessel in a systematic manner (Spouge, [10]). SA is at present widely used in various branches of technology, first of all in nuclear industry, but in the last few years there have been great development of SA approaches in off-shore industry, particularly in post PIPER ALPHA disaster period (Fitzgerald &Grant, [6]). 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. Reliability approach and fault tree analysis are methods of risk assessment. Human factor must be included into the analysis.

Halebsky [11] reported on application of system safety engineering to safety of naval ships. Although the objective in this case was to incorporate safety into the ship during the design process, the classification and methodology proposed could be utilised in safety system which will include also ship operation. Achieving safety only by inbuilt stability is from practical as well as economical point of view unfeasible. Although inbuilt safety is very important, it is obvious that no ship can be built which can not be lost by negligence or incompetence.

The first step in SA is to identify possible hazardous situations and assess probabilities attached to them. Hazard is defined as a situation which can potentially result in disabling the system. Hazards could be identified on the

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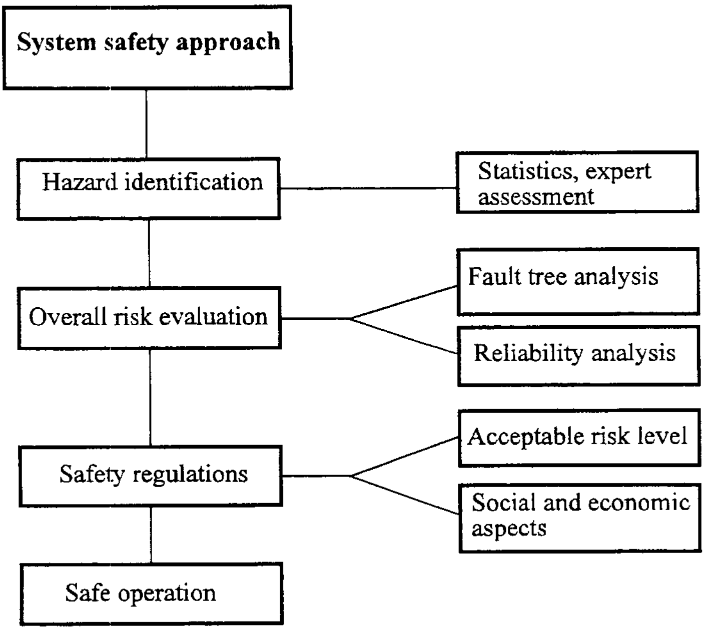
Table 1. Hourly mortality rates (FAR) for various activities
(Data for this table were taken from [5] and[6]}

Activity	FAR x 10^8
World fleet as a whole	11.8
Passenger aviation - crew members	14.0
Passenger aviation - passengers	1.4
Agriculture	10
Fishery	35
Coal mining	40
Car driving	70
Off-shore industry	76
Climbing	4000
30 years old men- all causes	15

Table 2. Methodology of System Safety Approach



basis of statistics or expert assessment. The next step in SA approach is risk evaluation which could be done using various methods, e.g. fault tree analysis or reliability analysis. Safety regulations could be developed on the basis of quantitative risk assessment (QRA) (Spouge,[10]), which is fully numerical approach based on an analysis of accident experience combined with available theoretical models. This paper is concentrating on QRA as applied to survivability aspects of ship safety.

The methodology of system safety approach is inductive, that it starts with the undesired result, e.g. capsizing and works backward to determine how it could occur. Reliability analysis on the contrary, is deductive, that it starts with the ship and determines how it could fail. Table 2 illustrates system safety approach schematically.

4 Quantitative risk assessment

Risk is defined as hazard probability times hazard severity (consequences), i.e.

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

In order to assess risk both quantities in the above equation should be evaluated. From the above definition of risk it is seen that even the most improbable event but having catastrophic consequences may be defined as having substantial risk. General classification of hazard probabilities is shown in Table 3, whether Table 4 shows classification of hazard severity (Halebsky [11],

Table 3. Classification of hazard probabilities

Level	Description	Frequency per ship	Frequency per fleet	Probability (hourly)
A	Frequent	Likely to occur frequently-one or more times per year	Continuously	Greater than 10^{-3} to 10^{-4}
B	Probable	Several times per ship's lifetime- once every few years	Once or more times in a year	10^{-4} to 10^{-5}
C	Occasional	Likely to occur once during the lifetime of the ship	Several times during fleet's lifetime-once every few years	10^{-5} to 10^{-7}
D	Remote	Unlikely, but possible during lifetime of the ship	Probable once during lifetime of the fleet	10^{-7} or less
E	Extremely improbable	So extremely remote that it does not to be considered as possible to occur		Substantially less than 10^{-7}

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Table 4. Classification of hazard severity

Category	Effect	Results
I	Catastrophic	Loss of vessel, fatalities
II	Critical hazardous effect	Dangerous degradation of handling, need for outside rescue operations
III	Marginal major effect	Significant degradation in handling, but not preventing to complete safe journey
IV	Negligible minor effect	Slight degradation in handling, need for slight modification of operating procedures

modified, and IMO [12]). Obviously, in order to use this classification in QRA numbers should be attached to categories specified as in Table 4. This could only be done by subjective judgement taking into account analysis of accidents and reaction of the public and governments to their consequences. On the other hand, hazard probabilities could be evaluated using reliability analysis.

Suppose there are k- situations, each situation consisting of loading condition, sea state, heading, speed in which a ship may find itself during specified time t. The probability of accident endangering the survivability during that time could be calculated by the formula:

$$PF_t = \sum_{k=1}^{k} C_k PF_k \qquad (1)$$

where: PF_k = probability of an accident in k-th situation

and $_k$ = probability of occurrence of this situation

Factors in each situation may be events such as shifting of cargo, crowding of passengers on one side, lashing of cargo defective, openings not secured, bow or stern visor fault etc. considered separately or in groups. Identification of all factors could be done using fault tree analysis. In this concept, all factors which may led to an accident are divided in two groups (Pin You Chang [13]).Those factors whose failure will cause failure of the whole system are called "components in series -CIS". Those whose failure will not lead to failure of the system unless all of them fail are called "components in parallel- CIP". With n - CIS factors and m - CIP factors the formula for calculating the probability of an accident in k-th situation is:

$$PF_k = 1 - \prod_{i=1}^{n} (1 - PF_{ki}) \cdot \left(1 - \prod_{i=n+1}^{m} PF_{ki} \right) \qquad (2)$$

where the symbol $\prod$ means multiplication of terms behind this symbol.

Evaluation of PF is substantially simple and it shows how PF of one circumstance affects the total probability of an accident. If for one circumstance of CIS category , say PF_{k1}=1, then PF_k =1 for this condition.. For example if it is certain that in extreme weather conditions, that is in k -th situation, the ship considered will capsize, then in the formula for PF_t ,for this situation PF_k should be taken as unity and then only probability of occurring this situation, C_k, has to be taken into account.

When using this concept it is necessary to identify all k -situations in which the ship may find itself during the specified time period t, and which include geographical region, weather conditions, heading loading condition and stability characteristics. Probability of occurrence of k-th situation, C_k, could be calculated by the formula:

$$_k = \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p}\sum_{l=1}^{r} p_i \cdot p_{ij} \cdot p_{ik} \cdot p_{il} \quad (3)$$

where: $p_i = T_i/T$ -probability that the ship will be in the i-th area

$_i$ -part of the time of the voyage in the i- th area total time of the voyage

p_{ij} -probability of meeting of j- th weather condition in the i- th area

p_{ik} -probability of k- th heading relative to wave direction in i- th area

p_{il} -probability of l- th stability characteristics in the i- th area

5 Development of stability requirements on the basis of risk evaluation

When considering utilisation of QRA as a supporting tool of stability regulations we must define first loss of stability accident. The concept of loss of stability accident was probably first proposed by Abicht [14], then it was formulated by Morrall[15]. In our understanding this concept covers all accidents where stability of a ship is endangered through flooding or shifting of cargo or other events, in such a way that ship capsizes or sinks or its angle of heel is exceeding the value at which further operation of the ship is impossible.

Assuming that the short term probability of loss of stability accident -PF_t- could be calculated using formula given above, the author in [16]proposed three principles on the basis of which the safety standards could be established.

Principle one is based on the reasoning, that extreme weather conditions which the ship considered can meet during its lifetime are the most dangerous and the ship should withstand such conditions. Therefore it would be necessary to calculate the probability of the loss of stability accident in these conditions, which should be specified on the basis of statistical data. If the stationary weather conditions are marked K_i, then the conditional probability of loss of stability accident is calculated by the formula:

$$PF/K_i = 1 - exp(-\lambda_0 t_i) \quad (4)$$

where λ_0 in the above formula is called risk function, i.e. probability of loss of stability accident in unit time divided by time of safe operation up to this time and t_i is time of operation in conditions K_i. PF is adopted then as a criterion for establishing standards.

The methodology when using principle two consists of discretisation of the route and it is assumed that the ship could find itself in k- different situations during the year or during its whole lifetime. The total probability of loss of stability accident could be then calculated by formula (1) where the time t is taken as a year or as the lifetime of the ship, whatever necessary. When using this principle additional factors (apart from sea state) should be taken into account and the formula (2) is used for calculation of probability of loss of stability accident in each situation.

The methodology of the third principle is similar to the one used in the second principle, but in this case full simulation of the sea voyage is performed. In this simulation human factor, i.e. tactics of the master could be included. According to the second principle, speed and heading of the ship are chosen independently on external conditions. This is in contradiction to good seamanship practice, where the master is adjusting heading and speed in order to avoid excessive rolling, slamming, deck wetness etc. Usually information on weather forecast could be utilised in order to change the route.

It is possible to include the tactics adopted by the master into the analysis. We assume conditional probability P(i/j), where i- is probability of meeting a situation without any attempt of avoiding it (tactics of a “fool”) and j- is probability of meeting this situation with the assumption that the master uses the best tactics to avoid it. With this assumption Markov matrix could be constructed. This method was proposed by Hutchinson [17] and applied by the author to stability problems [16]

In this concept risk is used as a criterion of safety. Risk has to be smaller than certain required safety index IS:

$$R \leq IS$$

Evaluation of the safety index requires separate consideration. This problem is not discussed in the paper. Some proposals how it could be done are included in the unpublished paper by the author . We may only mention that safety index could be evaluated on the basis of systematic calculations of risk for a population of ships and taking into account statistics of casualties. Possibly the safety index should be different for different types of ships taking account the need for greater protection for some types, such as passenger ships, chemical tankers etc.

The proposed procedure is in the opinion of the author fully feasible, although it requires further research effort. In order to check the practical applicability some test calculations of the probability of capsizing using about 10 000 situations and five additional factors of CIP type were analysed. Details of the calculation were reported in an Appendix to the paper [18]. In the test calculation the total probability of capsizing of ship considered was equal to 0.07×10^{-2}. It is known from statistics that rate of loss of ships due capsizing is of the order of 0.06 to $0.1x10^{-2}$, which shows that the result obtained is reasonable.

Calculations were also performed of the probability of capsizing (and also of the risk, because in all cases the same catastrophic event was considered) of three different ships each of them just satisfying existing stability standards. The result showed that the risk of capsizing for those ships was widely different from which conclusion could be drawn, that existing standards are not working very well.

References

[1] Cowley, A. Passenger Ship Legislation, Inst. of Marine Engineers, *International Conference IMAS'88,* London.

[2] Morrall, A. The GAUL Disaster: An Investigation into the Loss of a Large Stern Trawler, *RINA, Spring meetings 1980.*

[3] Dahle, E.A. & Kjaerland, O. The Capsizing of M/S HELLAND HANSEN, *RINA, Spring meetings 1979.*

[4] Foy, D.B. Marine Enquires and the Public Interest, *Trans.I.Mar.Eng.(C), Vol.95, 1982.*

[5] Caldwell, J.B. Prospects of a Rational Approach to Marine Safety, *The 4-th Intern. Shipbuilding and Ocean Engineering Conference,* Helsinki, 1986.

[6] Fitzgerald, B.P.& Grant McD.M. A practical Metodology for Risk Assessment of Offshore Installations, *Offshore Operations Post Piper Alpha Conference, I.Mar E/RINA, 1991.*

[7] Kobyliński, L. Safety of Sips Against Capsizing, *Third International Congress on Marine Technology,* Athens, 1984.

[8] Kobyliński, L. Contemporary Problems of Ship Hydrodynamics, *Advances of Mechanics,* Vol.9.No.3. Warsaw 1986.

[9] Kastner, S. Inclusion of Theoretical Achievements on Ship Stability in Ship Operation, *Proceedings of the IV STAB Conference,* Vol.II,Naples 1990.

[10] Spouge, J. Safety Assessment of Passenger/Ro-Ro Vessels, *RINA Intern. Conference on the Safety of Passengers in Ro-Ro Vessels,* London 1996.

[11] Halebsky, M. System Safety Engineering as Applied to Ship Design, *Marine Technology, Vol.26, No.3, 1989.*

[12] IMO, Code of Safety for Dynamically Supported Craft, *Resolution A.373(X), 1977.*

[13] Pin You Chang, A State-of-the-Art Review of the Reliability Approach and Methodology for the Design of Aerospace and Ocean Systems, *Marine Technology, Vol.27, No.5, 1990*

[14] Abicht, W. Die Sicherheit der Schiffe im nachlaufenden unregelmassigen Seegang, *Schiffbautechnik, Bd.19, 1972*

[15] Morrall, A. Philosophical Aspects of Assessing Ship Stability, *II-nd STAB Conference,* Tokyo, 1982

[16] Kobyliński, L. Stability Standards and Probability of Capsizing - Philosophical Aspects, *Intern. Symp. in Memory of Professor Sevastyanov,* Otryadnoye 1995.

[17] Hutchinson, B.L. Risk and Operability Analysis in the Marine Environment, *SNAME Transactions, Vol.89, 1981*

[18] Kobyliński, L. Possibility of Application of Safety Assessment to the Development of Stability Criteria. *Intern. Workshop on Physical and Mathematical Modelling of Vessel's Stability in a Seaway,* Otryadnoye 1993