# Rahola criterion and the development of the Intact Stability Code

Alberto Francescutto, *University of Trieste, Italy,* francesc@units.it

**ABSTRACT**

The Criterion for Intact Ship Stability proposed by Rahola in 1939 spread around different countries and after the war also, due to its simplicity, constituted the basis for the first international provision on intact stability in 1968 in the frame of the recently created International Maritime Organization. This Criterion, although heavily criticized since the beginning for its semi-empirical nature, was included in both the Intact Stability Code, Res. A. 749, and, with some modifications, got mandatory status in the International Intact Stability Code 2008. It is quite easy to foresee that it will survive in the near future too, at least until the Second Generation Intact Stability Criteria, if and when adopted, will undergo thorough testing and tuning.

**Keywords:** *ship stability, stability criteria, IMCO, IMO, Jaakko Rahola.*

## 1. INTRODUCTION

Considering the last two millennia, from Archimedes (Francescutto and Papanikolaou, 2011), or more realistically the last two hundred years, from Bouguer (1746), it is clear that Ship Stability is an extremely complex and at the same time controversial subject.

Historical summaries of the developments at scientific, practical and regulatory levels have been provided by several Authors (Rahola, 1939, Bird and Odabashi, 1975, Kuo and Welaya, 1981, Steel, 1956, Herd, 1979, Kobylinski and Kastner, 2003) and, more recently reviewed by Francescutto (2016) in the frame of the development of the Second Generation Intact Stability Criteria in progress at IMO. There is a clear progress in terms of comprehension of the dangerous phenomena; this, however for long time was not accompanied by a parallel progress at regulatory level. This is particularly true for what concerns Intact Stability, the issue discussed in this paper. The different role played by the different parties and the request to be "simple", indeed, delayed the practical application (Francescutto, 1993). If this was justified when calculations were made "by hand", it is becoming less and less justified now, especially if we think that the developed regulations should guarantee the safety of ships carrying the population of a small town or substances able to heavily contaminate the environment. The length of time required to pass from formulation of a stability problem to adoption of a measure to avoid it has been highlighted in (Francescutto 2016). To quote recent developments in progress, it is interesting the history of parametric rolling. The first scientific developments in this field, are typically connected with the names of Kerwin, Paulling, Grim and Wendel, all active on this phenomenon about 60 years ago. Bird and Odabashi (1975), however, remind us that parametric rolling was already mentioned in 1892 (Pollard and Dudebout, 1892), 20 years after Mathieu (1868), studying the vibrations of an elliptic membrane, introduced the well known equation suitable for its description. Partial stability failures have been reported attributable to this phenomenon, and yet in 2019 there is still some doubt concerning the adoption of criteria against parametric rolling!

As known, the development of provisions for Intact Stability at international level was started by IMCO, later IMO, triggered by the conclusions of SOLAS1960, and of SOLAS1974, this latter asking for explicit consideration of the effects of meteo-marine environment. After some post-processing this led to the Code of intact stability for all ships covered by IMO instruments (IMO, 1993).

In the following we will analyze the origins of this document, mainly consisting of two Stability Criteria, applicable to all ship types, which are based in two studies published in the 1930s of past century (Pierrottet, 1935, Rahola, 1939), i.e. around 80 years ago.

There is no doubt that the Code of Intact Stability, although issued as a "recommendation" improved substantially the safety of navigation and the protection of the environment. A number of critical points, however, were raised since the beginning to these Criteria, based on the statistical nature of the first one and on the many empirical data and formulas used in the second one.

Situation changed with the adoption at IMO of the Formal Safety Assessment (IMO, 2002) changing the point of view for the development of regulations from "what went wrong" to "what could go wrong", i.e. from a "reactive" approach to a "proactive" one.

The combination of criticism and FSA led, in recent times, to the revision of the Code of intact stability for all ships covered by IMO instruments, producing the new International Intact Stability Code 2008 (IMO, 2008) which to a large extent consists in a reorganization of the previous Code and is still in force, and to the studies aimed at the development of the Second Generation Intact Stability Criteria, which is still in progress.

In the following of this paper, we will consider in some detail the developments leading to the Code of intact stability for all ships covered by IMO instruments as contained in IMO Res. A.749 (IMO, 1993), to identify the reasons of the fortune of the approaches contained in the two above mentioned papers.

## 2. THE SITUATION OF INTACT STABILITY PROVISIONS AT THE BEGINNING OF THE 1960s AND THE SOLAS'60 CONFERENCE

The situation of Intact Stability provisions in the period between Great War and WW II, with few exceptions related to individual designers, shipyards or shipping companies, was often more dominated by comfort (Vincent, 1939), i.e. indications of maximum values of metacentric height, than by stability safety, i.e. by minimum values of metacentric height. These latter were quite generic, with some notable exceptions.

After WW II, perhaps along with the needs connected with the large scale reconstruction, requiring new fleets, and the slow restructuration of shipping lines due to the competition with the airplane, a new sensibility concerning stability safety spread-out.

At the beginning of the 1960s, several countries had adopted provisions:

- based on discriminatory analyses on the statical and dynamical elements of righting arm, conducted on databases of accidents of the type of that proposed by Rahola (1939),

and/or

- provisions based on physical modelling of the external forces acting on the ship, based on statical balance or on energy balance. Noteworthy of the first type, was the Russian standard (see IMO, 1988), developed on the basis of the proposal contained in (Blagoveschensky, 1932), while the Japanese standard (Yamagata et al., 1959), based on the proposal contained in (Pierrottet, 1935), is of the second type.

Consideration of the effects of wind was also part of the criteria developed by US Coast Guard and Germany.

The 1960 SOLAS Conference was held in London from 17th May 1960 to 17th June. The Conference was attended by delegates from 55 countries. It was the first Conference to be held by IMCO. During the Conference both Damage and Intact Stability were discussed in detail. Here a short summary of the discussion concerning the Intact Stability is reported following Spinelli (1961). In the meetings of the Subcommittee for the compartmentation and stability studies, the delegate of the URSS stressed the fact that the provisions of the SOLAS Convention relating to stability in the event of damage do not ensure sufficient intact stability of the ship, so it is essential to establish special rules on the intact stability of the ship to be applied to all types of ships, so that it is possible to count on sufficient safety of the ship during normal navigation. These rules should take into account the ability of the ship to resist external forces such as the actions of wind and sea and the agglomeration of passengers on one side of the ship.

Almost all the delegations agreed on the need to study norms regarding intact stability, rules that should be imposed especially for small ships, but at the same time it was pointed out that the problem was so important and so complex, that an in-depth study of it would have been impossible during the few days available for the work of the Conference. It was therefore unanimously decided to refer the matter to IMCO so that it could organize, with a matter of urgency, the study of intact stability provisions, which was the subject of recommendation n. 7 ("Intact Stability of Passenger Ships. Cargo Ships and Fishing Vessels") to the 1960 Convention (SOLAS, 1960):

"The Conference, having considered proposals made by certain Governments to adopt as part of the present Convention Regulations for intact stability, concluded that further study should be given to these proposals and to any other relevant material which may be submitted by interested Governments."

The Conference therefore recommended that "the Organization should, at a convenient opportunity initiate studies, on the basis of the information referred to above of:

a) intact stability of passenger ships,
b) intact stability of cargo ships,
c) intact stability of fishing vessels, and
d) standards of stability information,

taking into account the decisions of the present Conference on requirements for damage stability and the results of any further studies which may be carried out by the Organization on the subdivision and damage stability of cargo ships in pursuance of Recommendation 8 of the Conference, the object being the formulation of such international standards as may appear necessary."

The Conference further recommended that "in such studies the Organization should take into account studies already undertaken by the Food and Agriculture Organization of the United Nations on the stability of fishing vessels and should co-operate with that Organization on that aspect of the matter."

## 3. THE STATISTICAL APPROACH AND THE DEVELOPMENT OF THE GENERAL STABILITY CRITERION

As well reported in (Bird and Odabashi, 1975, Herd, 1979) several Authors developed Intact Stability provisions based on empirical formulas, with consideration of samples of ships, by discriminating some parameters, mostly consisting in the initial metacentric height and in characteristics of the statical righting arm. None of these had fortune, i.e. none became at least the basis for a national regulation.

Different consideration had the analysis done by Rahola (1939). While general details about this work are contained in the companion paper by Ruponen (2019), we consider here some strong points. It is a too important contribution to be summarized here, but it is important to consider at least the following couple of sentences from the Introduction: "The object of the present investigation is to find a procedure by means of which it may be possible to judge with adequate certainty the amount of the stability of a certain vessel which may come to navigate under the conditions prevailing on the lakes and the waters adjacent to our country, and to decide whether it is sufficient or not." … "With regard to stability circumstances we must clearly make a distinction between the determining and the judging of stability.". As reported by Kuo and Welaya (1981): "Rahola's thesis raised great interest throughout the world because it was the first comprehensive study of its kind and because the method is fairly simple to apply as it does not require any computations so long as the statical stability curve in still water is known. That is the reason why many national stability regulations or recommendations still rely on this approach in judging the stability of their fleets."

The situation regarding the current status of national stability requirement in various countries was analyzed in 1964 by the IMO Working Group on Intact Stability as a background for the development of international standards.

As reported by Kobylinski (in Kobylinski and Kastner 2003), commencing its work on intact stability criteria the STAB Sub-Committee stated that when developing international criteria, it is necessary to take into account the heeling moments from external forces at sea. It realized, however, that such an approach would not enable the development of stability criteria in a short time. Therefore, the SubCommittee decided to base future criteria, as a first step, on statistics of casualties, and in particular, analyzing stability parameters for ships which capsized and for those which were considered safe in operation. It decided also to analyze the contents of existing national stability requirements. As a result of this decision, the Intact Stability Working Group (IS) as well as the Panel of Experts on

Stability of Fishing Vessels (PFV) began to collect data on ships and fishing vessels that capsized and on ships that were considered safe in operation.

Rahola's work (1939), which at the time was already the base of several national regulations on Intact Stability, was considered the more systematic attempt to develop stability standards by applying an original method of analysis of stability parameters of ships that capsized and of ships considered safe in operation. This method, with modifications, was applied by IMO when developing the stability standards included in Resolutions A.l67 (IMO, 1968a) and A.l68 (IMO, 1968b), hence the nickname of "Rahola Criterion" often used to indicate these regulations.

Details on the development of IMO Res. A.167, regarding the extended sample of ships used in the statistics and the probability methods employed are contained in (Kobylinski and Kastner, 2003 and in Part C of International Intact Stability Code 2008). See also Nadeinski and Jens (1968) and Thompson and Tope (1970).

In their critical analysis, Bird and Odabashi (1975) discuss the cases of two ships in order to show the desirability of improved criteria with respect to Res. A.167 and A.168. Those ships more than fulfilled the minimum stability requirements of IMCO but yet capsized,

They concluded: "These examples show that IMCO recommendations, by themselves, are not sufficient to provide acceptable safety of ships, and as in both the cases the weather conditions were not too severe, we must look for some other basic reasons causing the capsize.". We note that this is presently under discussion at IMO.

## 4. THE ENERGY BALANCE AND THE DEVELOPMENT OF THE WEATHER CRITERION

Moseley (1850) introduced the concept of "dynamic stability" as the work done in inclining a ship and consequently stored as potential energy. The dynamic stability arm was used since long time to supplement the information contained in the initial metacentric height and in the statical stability arm. This allowed to obtain the series of semi-empirical stability criteria, progressively including analyses of accident at sea, culminating in the Rahola proposal in 1939. We had, however to arrive at 1935 (Pierrottet, 1935) to have the first complete formulation of an "energy balance" criterion. It is interesting to follow the debate following Pierrottet presentation at Royal Institution of Naval Architects; following the Chairman, "I do not wish in the least to detract from the good work that Professor Pierrottet has done. I think the Paper will be very useful to us, but I do hope it will be a long time before it is made the basis for new Board of Trade regulations by the Classification Societies. The number of losses from Capsizing is so exceedingly small, even more tiny than he says, that it would be a very stiff to impose these regulations."

We had to wait 15 years and the tragedy of Toya Maru to have a national regulation based on a weather criterion, and additional 35 years to have an international one.

The discussion above referred is cyclical in this field. The warnings of Reed became clear only after the painful sinking of the monitor Captain 150 years ago; unfortunately, it looks that this spirit was not completely absent in recent discussions at IMO.

As mentioned in § 2 above, at the beginning of the 60's, several countries had developed and adopted Criteria on Intact Stability based on physics, i.e. on the calculation of the heeling effect produced by external factors, like wind and waves, or internal factors, like passenger aggregation on side or manoeuvring. Two of them, although different as far as the "dynamic effects" were considered, i.e. if the maximum heeling was the result of a static balance or of the energy balance, were completely developed as Weather Criteria and applied since several years. In 1962 (Sarchin and Goldberg, 1962), laid the basis for what soon became the US Navy Weather Criterion.

It is interesting to note (as reported, for instance, in Spinelli, 1961) that during the Conference SOLAS'60, there was a wide discussion on Intact Stability, almost entirely based on a document submitted by the Russian delegation describing their intact stability criterion. The ensuing discussion was focused on the effect on stability of external forces. No conclusion could be reached, however, due to the important differences between the different criteria already existing, notably between the Russian and the Japanese criteria. Hence the above mentioned Recommendation n. 7. As we have seen in previous paragraph, the working group at IMO decided differently, converging on the modification of Rahola's work, which could guarantee an acceptable outcome in the short term available.

The following SOLAS Conference, while acknowledging the progress made, thus recommended that "steps be taken to formulate improved international standards on intact stability of ships taking into account, inter alia, external forces affecting ships in a seaway which may lead to capsizing or to unacceptable angles of heel." (SOLAS, 1974).

The result was the adoption of the "Weather Criterion" in 1985 (IMO, 1985) for passenger and cargo ships, and in 1991 for fishing vessels (IMO, 1991), mainly as effect of merging the Japanese Criterion (Yamagata, 1959) with elements of the Russian Criterion (Blagoveshchensky, 1932, see also IMO, 1988).

Actually, the first proposal of a criterion for "Severe Wind and Rolling" at an International level was done in Regulation 31 in the frame of the Torremolinos International Convention on Safety of Fishing Vessels (IMO, 1977). The original text of the Conference quoted: "Vessels shall be able to withstand, to the satisfaction of the Administration, the effect of severe wind and rolling in associated sea conditions taking account of the seasonal weather conditions, the sea states in which the vessel will operate, the type of vessel and its mode of operation". The Guidance on a Method of Calculation of the Effect of Severe Wind and Rolling in Associated Sea Conditions was contained in Recommendation I of Attachment 3 to the Final Act of the Conference. The Criterion contained in the Guidance was extremely close to what later on became the IMO Weather Criterion for passenger and cargo ships other than fishing vessels. The fast progress leading to this proposal was certainly due to the strict collaboration between IMO, FAO and ILO, in view of the extremely high risk for human life associated with this occupation. Unfortunately, the completion of the Weather Criterion for fishing vessels came only in 1991 (IMO, 1991) and all the matter never became mandatory (see Francescutto, 2013).

## 5. THE CODE OF INTACT STABILITY FOR ALL SHIPS COVERED BY IMO INSTRUMENTS, THE INTERNATIONAL INTACT STABILITY CODE 2008 AND BEYOND

The provisions contained in the mentioned IMO Resolutions (IMO, 1968a, 1968b, 1985), with the addition of all other provisions developed for other ship types, were finally included in the Resolution A.749 - Code of intact stability for all ships covered by IMO instruments (IMO, 1993). This Code was amended in several points by Res. MSC.75 (IMO, 1998).

In 2001 (IMO, 2001a), following a submission from Italian delegation (IMO, 2001b) criticizing the methodology adopted to calculate several parameters of Weather Criterion, the SLF Sub-Committee was tasked to start the revision of the Intact Stability Code as contained in Res. A.749. At the beginning the activity of the working group operating in the frame of the SLF Sub-Committee was concentrated on the development of "rational" intact stability criteria. Soon, however, priority was given to polishing and restructuring Res. A.749 to make Part A of the Code mandatory, under SOLAS and ILLC Conventions, as requested by German delegation who provided an FSA analysis supporting this decision (IMO, 2003). This part was completed in 2007 with adoption of the new International Intact Stability Code 2008 (IMO, 2008). This transformation, from "recommended" to "mandatory" of both the "General Criterion (ex Res. A.167) and the Weather Criterion (ex Res. A.562), made it necessary to provide alternative ways (IMO, 2006, Part C of ISC2008) to comply with Weather Criterion for ship typologies which previously could be managed at national level.

We note, in particular, that, in view of the difficulty for some ship typologies to fulfill the requirement regarding the position of the maximum of the righting arm curve the Res. A. 167 was modified by setting the angle to 25 deg and allowing to go down to 15 deg with a compensation in dynamic stability (see IMO, 2008, Part C). It is interesting to note that Rahola originally proposed 35 deg. This standard, in fact, was ambiguous since the very beginning, since the regulation stated: "The maximum righting arm should occur at an angle of heel *preferably exceeding* 30 deg *but not less than* 25 deg.".

The working group could at this point restarted the activity on development of "rational" intact stability criteria, finally changing the title in "Second Generation Intact Stability Criteria". The situation up to 2015 was summarized in (Francescutto, 2016); an updating of the progress of this item is contained in (IMO, 2019).

It is noteworthy that the two pillars of the Intact Stability Code, i.e.:

- Criteria regarding righting lever curve properties, present evolution of "Rahola Criterion";
- Severe wind and rolling criterion (weather criterion),

already survived 50 years, with reasonably small changes, and in addition reached the mandatory status. The statement "Criteria included in the Code are based on the best state-of-the-art concepts, available at the time they were developed, taking into account sound design and engineering principles and experience gained from operating ships." was reiterated in the Preamble to ISC 2008.

In this moment it is not completely clear which will be the status of the Second Generation Intact Stability Criteria, if and when finalized. One possibility is that they will supplement the existing Criteria as interim recommendations (possibly on voluntary basis) for the time needed to gain sufficient experience from their application.

## 6. CONCLUSIONS

The Criterion proposed by Rahola (Rahola, 1939) was the last before WW II; it included an extremely detailed critical analysis of all the research and regulations existing at the time and was the result of an innovative discriminatory analysis conducted on a sample of ships. After the war, it spread around in different countries and, also due to its simplicity, constituted the basis for the first international provision on intact stability in the frame of the recently created International Maritime Organization. This Criterion, although heavily criticized since the beginning for its semi-empirical nature, was included in both the Intact Stability Code, Res. A. 749, and, with some modifications, got mandatory status in the International Intact Stability Code 2008.

It is quite easy to foresee that it will survive in the near future too, at least until the Second Generation Intact Stability Criteria, if and when adopted, will undergo thorough testing and tuning.

## REFERENCES

Bird H., Odabasi A. Y., 1975, "State of Art: Past, Present and Future", *Proceedings International Conference on Stability of Ships and Ocean Vehicles*, Glasgow, pp. 312-317.

Blagoveshchensky S. N., 1932, "On a Method of Stability Standardisation", *Transactions of Scientific Research Institute of Shipbuilding USSR* 12.

Bouguer P., 1746, "Traité du Navire, de sa Construction et de ses Mouvements (Treatise of the Ship, its Construction and Movements)", Jombert, Paris.

Francescutto A., 1993, "Is it Really Impossible to Design Safe Ships?", *Transactions of the Royal Institution of Naval Architects* 135, pp. 163-173.

Francescutto A., Papanikolaou A. D., 2011, "Buoyancy, Stability and Subdivision: from Archimedes to SOLAS2009 and the Way Ahead", *International Journal of Engineering for the Maritime Environment (Proceedings of the Institution of Mechanical Engineers PartM)* 225, pp. 17–32.

Francescutto A., 2013, "The Evolution of the Regulatory Stability Regime for Fishing Vessels", Proceedings of the International Conference IDS2013, Iquitos, Perù, 17th – 19th July 2013, Iquitos, Peru, pp. 14.1-14.18.

Francescutto A., 2016, "Intact Stability Criteria of Ships – Past, Present and Future", *Ocean Engineering* 120, pp. 312-317.

Goldberg L. L., Sarchin T.H., 1962, "Stability and Buoyancy Criteria for U.S. Naval Surface Ships", *Transactions of the American Society of Naval Architects and Marine Engineers* 70, pp. 418–458.

Herd R. J. 1979, "Rahola Criterion – 40 Years On", *Royal Institution of Naval Architects*, Australian Branch, Sydney 17 August 1979.

IMO, 1968a, "Resolution A.167 - Recommendation on Intact Stability for Passenger and Cargo Ships Under 100 Metres in Length", 28 November.

IMO, 1968b, "Resolution A.168 - Recommendation on Intact Stability of Fishing Vessels", 28 November.

IMO, 1977, "International Conference on Safety of Fishing Vessels 1977 - Final Act of the Conference, with Attachments, including the Torremolinos International Convention for the Safety of Fishing Vessels, 1977".

IMO, 1985, "Resolution A.562 - Recommendation on a Severe Wind and Rolling Criterion (Weather Criterion) for the

Intact Stability of Passenger and Cargo Ships of 24 Metres in Length and over”, 20 November.

IMO, 1988, “SLF 33/INF.4 - Development of intact stability requirements for all types of ships covered by IMO instruments, Submitted by the USSR”, 6 May.

IMO, 1991, “Resolution A.685(17) - Weather Criterion for Fishing Vessels of 24 Metres in Length and Over”, 6 November.

IMO, 1993, “Resolution A.749 - Code of intact stability for all ships covered by IMO instruments”, 4 November.

IMO, 1998, “Resolution MSC.75(69) - Adoption of Amendments to the Code on Intact Stability for all Types of Ships Covered by IMO Instruments (Resolution A. 749(18))”, 14 May.

IMO, 2001a, “SLF 44/18 - Report to the Maritime Safety Committee”, 18 October.

IMO, 2001b, “SLF 44/INF.6 - Weather Criterion for Large Passenger Ships, Submitted by Italy”, 12 July.

IMO, 2002, “MSC/Circ.1023 - MEPC/Circ.392 - Guidelines for Formal Safety Assessment (FSA) for use in the IMO Rule-Making Process”, 5 April.

IMO, 2003, “MSC 78/24/1 - Revision of the Code on Intact Stability, Submitted by Germany”, 15 December.

IMO, 2006, “MSC.1/Circ.1200 - Interim Guidelines for Alternative Assessment of the Weather Criterion”, 24 May.

IMO, 2008, “International Code on Intact Stability”.

IMO, 2018, International Intact Stability Code 2008.

IMO, 2019, “SDC 6/WP.6 - Finalization of Second Generation Intact Stability Criteria - Report of the Experts' Group on Intact Stability”, 7 February.

Kobylinski, L. K., Kastner, S. 2003, “Stability and Safety of Ships – Volume 1: Regulation and Operation”, Elsevier.

Kuo C., Welaya Y., 1981, “A Review of Intact Ship Stability Research and Criteria”, *Ocean Engineering* 8, pp. 65-84.

Mathieu E., 1868, “Mémoire sur le Mouvement Vibratoire d'une Membrane de Forme Elliptique”, *Journal de Mathématiques Pures et Appliquées* (2) 13, pp. 137-203.

Moseley H., 1850, “On the Dynamical Stability and on the Oscillations of Floating Bodies”, *Philosophical Transactions of the Royal Society of London* 140, pp. 609-643.

Nadeinski V. P., Jens, J. E., 1968, “The Stability of Fishing Vessels”, *Transactions of the Royal Institution of Naval Architects* 110, pp. 1-27.

Pollard J., Dudebout A., 1892, “Théorie du Navire, Vol. III - Dynamique du Navire: Mouvement de Roulis sur Houle, Mouvement Rectiligne Horizontal Direct (Résistance des Carènes)”, Gauthier-Villars, Paris.

Pierrottet E., 1935, “Standards of Stability for Ships”, *Transactions of the Royal Institution of Naval Architects* 77, pp. 208–222.

Rahola J. 1939, “The Judging of the Stability of Ships and the Determination of the Minimum Amount of Stability – Especially Considering the Vessels Navigating Finnish Waters”, Doctoral Thesis, Helsinki, https://aaltodoc.aalto.fi/handle/123456789/15149

Ruponen P., 2019, “Rahola Criterion Revisited: An Overview of Jaakko Rahola’s Research and Career”, *Proceedings of the 17th International Ship Stability Workshop ISSW2019, Helsinki, Finland*, pp. 15-20.

SOLAS, 1960, “International Convention for the Safety of Life at Sea, 1960”, London.

SOLAS, 1974, “International Conference on Safety of Life at Sea 1974 - Final Act of the Conference, with attachments, including the International Convention for the Safety of Life at Sea, 1974”, London.

Spinelli F., 1961, “La Compartimentazione e la Stabilità delle Navi Mercantili dopo la Conferenza di Londra 1960 sulla Salvaguardia della Vita Umana in Mare (Compartmentation and Stability of Merchant Ships after London Conference of 1960 on Safety of Human Life at Sea)”, *Tecnica Italiana* 26, pp. 1-17.

Steel H. E., 1956, “The Practical Approach to Stability of Ships”, *Transactions of the Royal Institution of Naval Architects* 98, pp. 381-409.

Thompson G., Tope J. E., 1970, “International Consideration of Intact Stability Standards”, *Transactions of the Royal Institution of Naval Architects*, Vol. 112, pp. 43-67.

Vincent, S. A., 1939, “Transverse Stability”, Principles of Naval Architecture – Written by a Group of Authorities , Rossell, H. E. and Chapman,L. B.(Eds.), Vol. I.,SNAME, New York, pp. 99-137.

Yamagata M., 1959, “The Standard of Stability Adopted in Japan”, *Philosophical Transactions of the Royal Society of London* 101, pp. 417-443.