



Safety of Life at Sea, 1974 (SOLAS)

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Ship Design I

MSc in Naval Architecture and Marine Engineering



SOLAS - Historical Background

- Convention, 1974
- Protocol, 1978
 - Amendments, 1983
 - Amendments, 1988
- Protocol, 1988
 - Amendments, 1991
 - Amendments, 1992
 - Amendments, 1994
 - Amendments, 1995
 - Amendments, 1996
 - Amendments, 1997
 - Amendments, 1998
 - Amendments, 1999
 - Amendments, 2000
 - Amendments, 2001
 - Amendments, 2002
 - Amendments, 2003
 - Amendments, 2004
 - Amendments, 2005

International Convention for the Safety of Life at Sea

- The 1st Convention was approved in 1914 in the following of the TITANIC.
- The 2nd was in 1929
- The 3rd was in 1948
- The 4th was in 1960, and it was the first after the creation of IMO



Safety of Life at Sea (SOLAS)

Determines

Minimum standards for building, outfitting and operating ships, compatible to their safety.

Contents

Chapter I	General Provisions
Chapter II-1.	Construction - Subdivision and Stability, Machinery and Electrical Installations
Chapter II-2.	Fire Protection, Fire Detection and Fire Extinction
Part A.	General
Part B.	Passenger Ships
Part C.	Cargo Ships
Part D.	Tankers



Safety of Life at Sea (SOLAS)

Contents (cont.)

Chapter III.	Lifesaving Appliances and arrangements
Chapter IV.	Radio communications
Chapter V.	Safety in Navigation
Chapter VI.	Carriage of Cargoes
Chapter VII	Carriage of Dangerous Goods
Part A	Carriage of Dangerous Goods in Packaged Form
Part A-1	Carriage of Dangerous Goods in Solid Form in Bulk
Part B	Carriage de Liquid Chemicals in Bulk
Part C	Carriage of Liquefied Gases in Bulk
Part D	Carriage of Packaged Irradiated Nuclear Fuel or Radioactive Wastes
Chapter VIII	Nuclear Ships



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Contents (concl.)

Chapter IX	Management for the Safe Operation of Ships
Chapter X	Safety Measures for High-Speed Craft
Chapter XI-1	Special Measures to Enhance Maritime Safety
Chapter XI-2	Special Measures to Enhance Maritime Security
Chapter XII	Additional Safety Measures for Bulk Carriers

Chapt. IX, X, XI - Amendments of 1994



Safety of Life at Sea (SOLAS)

Application

- Ships engaged in international voyages

Exceptions

- War ships
- Cargo ships with $GT < 500$
- Ships not propelled by mechanical means
- Wooden ships of primitive build
- Pleasure yachts not engaged in trade
- Fishing vessels



Chapter II-1. Construction - Subdivision and Stability, Machinery and Electrical Installations



Some Definitions

- **Subdivision Length (L_s)** - is the greatest projected moulded length of that part of the ship at or below deck or decks limiting the vertical extent of flooding with the ship at the deepest subdivision draught
- **Breadth** - is the greatest moulded breadth of the ship at or below the deepest subdivision draught
- **Draught** - is the vertical distance from the keel line at mid-length to the waterline in question.
- **Deepest subdivision draught** - is the waterline which corresponds to the summer load line draught of the ship.
- **Bulkhead Deck**
 - In a passenger ship means the uppermost deck at any point in the subdivision length (L_s) to which the main bulkheads and the ship's shell are carried watertight and the lowermost deck from which passenger and crew evacuation will not be impeded by water in any stage of flooding for damage cases. The bulkhead deck may be a stepped deck.
 - In a cargo ship the freeboard deck may be taken as the bulkhead deck.



Peak Bulkheads (1)

Collision Bulkhead

- A collision bulkhead shall be fitted which shall be watertight up to the bulkhead deck.
- This bulkhead must be located at a distance d from the forward perpendicular so that:
$$\text{MIN}(0.05L, 10 \text{ m}) \leq d \leq \text{MAX}(0.08L, 0.05L+3)$$
- Where any part of the ship below the waterline extends forward of the forward perpendicular, e.g., a bulbous bow, the above distances shall be measured from a point either:
 - at the mid-length of such extension
 - at a distance $0.015L$ forward of the forward perpendicular
 - at a distance 3 m forward of the forward perpendicularwhichever is less
$$\text{MIN}(d_{\text{FWD}}, 0.015L, 3 \text{ m})$$



Peak Bulkheads (2)

Collision Bulkhead (cont.)

- The bulkhead may have steps or recesses provided they are within the limits prescribed previously.
- The collision bulkhead may be pierced below the bulkhead deck by not more than one pipe for dealing with fluid in the forepeak tank, provided that
 - It is fitted with a screw-down valve capable of being operated from above the bulkhead deck
 - The valve chest being secured inside the forepeak to the collision bulkhead
 - This valve can be fitted on the after side of the collision bulkhead provided that the valve is readily accessible under all service conditions and the space in which it is located is not a cargo space.
- No doors, manholes, access openings, ventilation ducts or any other openings shall be fitted in the collision bulkhead below the bulkhead deck



Machinery Spaces and Stern Tubes

Machinery Spaces

- Bulkheads shall be fitted separating the machinery space from cargo and accommodation spaces forward and aft and made watertight up to the bulkhead deck.
- In passenger ships an after peak bulkhead shall also be fitted and made watertight up to the bulkhead deck.
- The after peak bulkhead may, however, be stepped below the bulkhead deck, provided the degree of safety of the ship as regards subdivision is not thereby diminished..

Stern Tubes

- In all cases stern tubes shall be enclosed in watertight spaces of moderate volume.
- In passenger ships the stern gland shall be situated in a watertight shaft tunnel or other watertight space separate from the stern tube compartment and of such volume that, if flooded by leakage through the stern gland, the bulkhead deck will not be immersed.



Openings in the Shell Plating (1)

Below the bulkhead deck of passenger ships and the freeboard deck of cargo ships:

- The number of openings in the shell plating shall be reduced to the minimum
- No side scuttle shall be fitted in such a position that its sill is below a line drawn parallel to the bulkhead deck at side and having its lowest point at a distance $\text{MAX}(0.025 B, 500 \text{ mm})$ above the deepest subdivision draught.
- All side scuttles the sills of which are below
 - the bulkhead deck of passenger ships **and**
 - the freeboard deck of cargo ships,shall be of such construction as will effectively prevent any person opening them without the consent of the master of the ship



Openings in the Shell Plating (2)

- Efficient hinged inside deadlights so arranged that they can be easily and effectively closed and secured watertight, shall be fitted to all side scuttles
- Except that
 - abaft $1/8 L$ from the forward perpendicular **and**
 - above a line drawn parallel to the bulkhead deck at side **and**
 - having its lowest point at a height of $3.7 \text{ m} + 0.025 B$ above the deepest subdivision draught



Bilge System (1)

Passenger and Cargo Ships

- The ship must have a an efficient bilge system capable of draining **all the watertight compartments, other then tanks.**
- Sanitary, ballast and general service pumps can be accepted as bilge pumps if they are connected to the bilge system.



Bilge System (2)

Passenger Ships

- Minimum of 3 pumps connected to the bilge system.
- In ships with $L > 91.5$ m, one of the required pumps will be an emergency pump, of the submerged type, with a driver located above the bulkhead deck.
- Each pump working for the bilge system shall have the capacity to guarantee the water flow speed of 2 m/s in the piping.
- Bilge pumps located in machinery spaces shall take direct suction from those spaces, at least one at each side.
- The internal diameter shall be computed by the expression:

$$d = 25 + 1.68 \sqrt{L \cdot (B + D)}$$



Bilge System (3)

Cargo Ships

- Minimum of 2 pumps connected to the bilge system



Flooding Alarms in Passenger Ships

- Ships with more than 36 passengers
- Watertight compartments under the bulkhead deck shall be equipped with **flooding detection systems** if the volume is superior to the maximum of the following values:
 - Volume [m³] > TPC1 of the ship in the maximum subdivision draught, or
 - 30 m³
- The flooding detection systems is composed by:
 - Sensors - that activate a sign in the presence of water
 - Alarms - that produce an audible or visible sign
- Must be installed
 - Vertically, as low as possible
 - Longitudinally, in compartments forward of the mid-length, at the forward extremity; in compartments aft of midships, at the aft extremity;
 - Transversely, close to the mid plan of the compartment, or in alternative, in both sides PS/SB



Openings in Watertight Bulkheads in Cargo Ship

- The number of openings must be reduced to a minimum
- Doors, access doors or access opening are not allowed:
 - On the collision bulkhead, under the safety line
 - On the transverse watertight bulkheads which divide one cargo space from an adjacent cargo space
- The collision bulkhead, under the safety line can not be crossed by more than one pipe, for the service of the liquid contained in the fore peak tank, and the pipe must be provided by a valve driven from a point above the bulkheads deck. The valve body shall be fixed to the collision bulkhead in the inner side of the peak tank.
- The spaces that contain the main and auxiliary machinery shall not have more than one door in each main watertight transverse bulkhead
- The watertight doors shall be of the sliding type (*corrediça*), de charneira or of equivalent type



New Probabilistic Methods

- The damaged stability criteria from SOLAS are now based in probabilistic concepts rather than in the deterministic ones used previously
- These methods entry into force in January of 2009

Deterministic Standard	Probabilistic Standard
Specified a fixed standard damage	Global measure of the survivability
Damages that exceed the specified limits are not taken into consideration	All the damage cases can be examined; the probability of occurrence of the damage is based in statistical analysis of real accidents
Determines a minimum GM that must be satisfied in all criteria, for every critical damage; the ship must have a GM superior to the minimum specified	Cases of de damaged survivability contribute to an index that can be used as a global measure of the capacity of survival

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Subdivision and Damaged Stability in Cargo Ships (1)

Application

- All cargo ships with $L_S > 100$ m that are not covered by other dispositions of IMO, namely:
 - Annex I of MARPOL 73/78
 - International Code for the Carriage of Chemicals in Bulk
 - International Code for the Carriage of Gas
 - Resolution A.469 (XIII) - Guidelines for the Design and Build of supply-vessels for offshore
 - Resolution A.534 Code for the Safety of Special Ships
 - Damaged stability requirements from the Reg. 27 of International Load Line Convention, 1966

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Subdivision and Damaged Stability in Cargo Ships (2)

Definitions

- **Subdivision load line** is a waterline used in determining the subdivision of the ship.
- **Deepest subdivision load line** is the subdivision load line which corresponds to the summer draught to be assigned to the ship.
- **Partial load line** is the light ship draught plus 60% of the difference between the light ship draught and deepest subdivision load line.
- **Subdivision length of the ship (L_s)** is the greatest projected moulded length of that part of the ship at or below deck or decks limiting the vertical extent of flooding with the ship at the deepest subdivision load line.
- **Breadth (B)** is the greatest moulded breadth of the ship at or below the deepest subdivision load line.
- **Draught (d)** is the vertical distance from the moulded baseline at mid-length to the waterline in question.



Subdivision and Damaged Stability in Cargo Ships (3)

The subdivision index computed for the ship shall comply to the condition

$$A \geq R$$

Required Subdivision Index (R)

- The degree of subdivision to be provided shall be determined by the required subdivision index R , as follows:

$$R = (0.002 + 0.0009 \cdot L_s)^{1/3}$$



Subdivision and Damaged Stability in Cargo Ships (4)

Attained Subdivision Index (A)

- The subdivision index of the ship shall be computed by the expression:

$$A = \sum_i^n p_i \cdot s_i$$

where:

- i - represents each compartment or group of compartments under consideration
- p_i - accounts for the probability that only the compartment or group of compartments under consideration may be flooded, disregarding any horizontal subdivision
- s_i - accounts for the probability of survival after flooding the compartment or group of compartments under consideration, including the effects of any horizontal subdivision.



Subdivision and Damaged Stability in Cargo Ships (5)

Calculation of the factor p_i

- The factor P_i is determined for each single compartment:
- Where the compartment considered extends over the entire ship length L_s $p_i = 1$

- Where the aft limit of the compartment considered coincides with the aft terminal:

$$p_i = F + 0.5 \cdot a \cdot p + q$$

- Where the forward limit of the compartment considered coincides with the forward terminal:

$$p_i = 1 - F + 0.5 \cdot a \cdot p$$

- When both ends of the compartment considered are inside the aft and forward terminals of the ship length L_s

$$p_i = a \cdot p$$



Subdivision and Damaged Stability in Cargo Ships (6)

Notation

- For the purpose of these calculations, the following notation is applied:
 - x_1 - the distance from the aft terminal of L_s to the foremost portion of the aft end of the compartment being considered.
 - x_2 - the distance from the aft terminal of L_s to the aftermost portion of the forward end of the compartment being considered.

$$E_1 = \frac{x_1}{L_s} \quad E_2 = \frac{x_2}{L_s} \quad E = E_1 + E_2 - 1$$

$$J = E_2 - E_1$$

$$J' = J - E \quad p/E \geq 0$$

$$J' = J + E \quad p/E < 0$$

J_{\max} - The maximum nondimensional damage length

$$J_{\max} = \frac{48}{L_s} \quad (\text{max. } 0.24)$$



Subdivision and Damaged Stability in Cargo Ships (7)

a - The assumed distribution density of damage location along the ship's length

$$a = 1.2 + 0.8 \cdot E \quad (\text{max. } 1.2)$$

F - The assumed distribution function of damage location along the ship's length.

$$F = 0.4 + 0.25 \cdot E \cdot (1.2 + a)$$

$$p = F_1 \cdot J_{\max}$$

$$q = 0.4 \cdot F_2 \cdot (J_{\max})^2$$

$$F_2 = \frac{y^3}{3} - \frac{y^4}{12} \quad p/ y < 1$$

$$F_1 = y^2 - \frac{y^3}{3}$$

$$p/ y < 1$$

$$F_2 = \frac{y^2}{2} - \frac{y}{3} + \frac{1}{12} \quad p/ y \geq 1$$

$$F_1 = y - \frac{1}{3}$$

$$p/ y \geq 1$$



Subdivision and Damaged Stability in Cargo Ships (8)

Calculation of s_i

- For each compartment or group of compartments

$$s = C \cdot \sqrt{0.5 \cdot GZ_{\max}(range)}$$

where:

$$C = 1 \quad p / \theta_e \leq 25^\circ$$

$$= 0 \quad p / \theta_e > 30^\circ$$

$$= \sqrt{\frac{30 - \theta_e}{5}}$$

GZ_{\max} - maximum positive righting lever (metres) within the range as given below but not more than 0.1 m

$range$ - range of positive righting levers beyond the angle of equilibrium (degrees) but not more than 20°

θ_e - final equilibrium angle of heel (degrees)



Subdivision and Damaged Stability in Cargo Ships (9)

Permeability of Compartments

Type of Space	Permeability
Stores (paiois)	0.60
Accommodations	0.95
Machinery	0.85
Voids	0.95
Dry cargo	0.70
Reserved for liquids	0 or 0.95 *

* Whatever results into a more unfavorable case.

Permeability of a space - is the percentage of that space that can be occupied by water.



Steering Gear (1)

- Every ship shall be provided with a main steering gear and an auxiliary steering gear
- Arranged that the failure of one of them will not render the other one inoperative
- The **main steering gear** and the rudder stock shall:
 - Have adequate strength and be capable of steering the ship at the maximum service speed
 - Capable of moving the rudder from 35° at one side to 35° on the other side with the ship at its deepest seagoing draught and running ahead at maximum ahead service speed
 - On the same conditions, move the rudder from 35° at one side to 30° at the other side in less than 28 seconds



Steering Gear (2)

The **auxiliary steering gear** shall be designed to:

- Have adequate strength and be capable of steering the ship at a navigable speed and of being brought speedily into action in an emergency
- Capable of putting the rudder over from 15° on one side to 15° on the other side in not more than 60 s with the ship at its deepest seagoing draught and running ahead at one half of the maximum ahead service speed or 7 knots, whichever is the greater



Emergency Source of Electrical Power in Cargo Ships with $GT \geq 5000$

- A self-contained emergency source of electrical power shall be provided
- Located above the uppermost continuous deck and shall be readily accessible from the open deck
- Not to be located forward of the collision bulkhead
- The electrical power available shall be sufficient to supply all those services that are essential for safety in an emergency, such as:
 - Emergency lighting (for 18 h)
 - Fire detection and fire alarm systems
 - Navigation lights (for 18h)
- Energy supply for 6 hours
- The emergency source can be
 - Accumulator battery
 - Generator driven by a suitable prime mover with an independent supply of fuel



Emergency Source of Electrical Power in Cargo Ships with $GT < 5000$

- Must have an autonomous energy source located at satisfaction of the Administration
- Capable of lighting in the areas of stowage and launching of the lifeboats
- Energy supply for 3 hours

Stability of Ro/Ro Passenger Ships

Stability of RO/RO Passenger Ships

- The stability criteria applicable to Ro/Ro ferries has been under consideration since the accidents of the "Herald of Free Enterprise" (1987) and the "Estonia" (1994)
- SOLAS 90 (IMO SOLAS 1974 Convention as amended 1997)
- MSC Circ.574 (1991) defined the simplified method based on the evaluation of the Attained and Required subdivision index previously adopted in 1974 by the A.265 (VII)
- The latest IMO decisions after SOLAS 90 are contained in the resolutions:
 - MSC.14 (1995) - Regional agreement known as **Stockholm Agreement** (deterministic method)
 - Resolution MSC.216(82) - Describes the new probabilistic method applicable to passenger and cargo ships and replaces the MSC.47(66) that was only for cargo ships
 - Resolution MSC.194(80) known as SOLAS 2009
- The EU Directive 2003/25/CE adopted the Stockholm Agreement



Stockholm Agreement

- Agreement made in 1996 by 8 countries from North-Europe for damaged stability of **passenger Ro/Ro ships**
- Takes into consideration the effect of embarked water on the Ro/Ro deck for conditions with a significative wave height of 4 m (SOLAS 90 used 1.5 m)
- Applicable on the EU as follows
 - International voyages (SOLAS 90)
 - Domestic voyages (Directive 98/18 CE)
- The state member must determine and publish the significative wave heights in the regions crossed by Ro/Ro passenger ships operating on their port on a regular basis
- Its applicable to ALL the Ro/Ro passenger ships with regular service starting/ending in a port from a member state

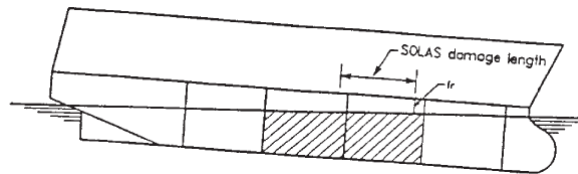


Some Definitions (1)

- **Significative Wave Height (H_s)** - mean value of the upper third of the wave heights measured during a determined time interval. These values are those which have a probability of being exceeded during a year $\leq 10\%$
 - State Members must determine and publish the wave heights of their maritime zones
 - In Portugal this information is not yet available (Information from IPTM on 200-06-26)
- **Residual Freeboard (F_R)** - minimum distance measured in the vertical between the damaged ro/ro deck and the final floating line, without taking into consideration the accumulated water on the damaged deck

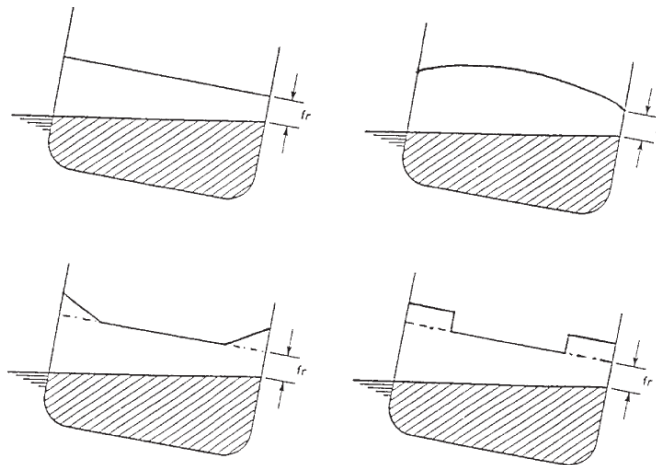
Some Definitions (2)

Damage Length



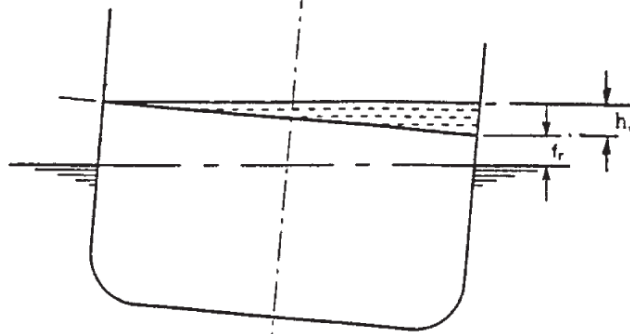
Some Definitions (3)

Measurement of Residual Freeboard



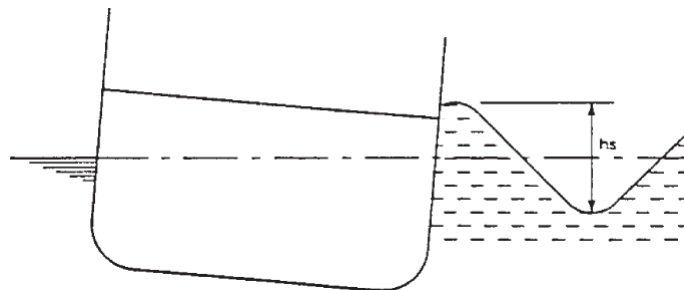
Height of Water on Deck

- Height of water on Ro/Ro deck:
 - $F_R \geq 2.0 \text{ m} \Rightarrow H_W = 0 \text{ m}$
 - $F_R \leq 0.3 \text{ m} \Rightarrow H_W = 0.5 \text{ m}$
 - $0.3 < F_R < 2.0 \text{ m} \Rightarrow H_W \text{ linearly interpolated}$



Height of Water on Deck

- $H_S < 1.5 \text{ m} \Rightarrow H_W = 0 \text{ m}$
- $H_S \geq 4.0 \text{ m} \Rightarrow H_W \text{ measured according to the figure}$



Tank Equalization (1)

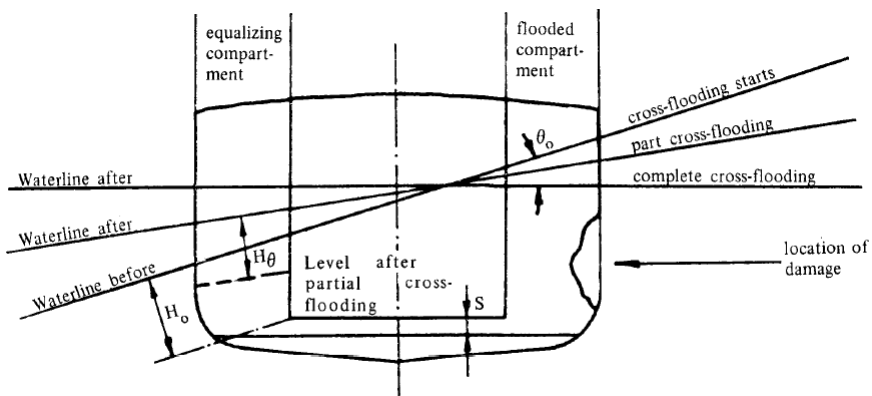
The time required for complete cross-flooding is defined on the Resolution A.265 (VIII)

$$T_o = \frac{2W}{SF} \cdot \frac{\left(1 - \sqrt{\frac{h_f}{H_o}}\right)}{\sqrt{2g \cdot H_o}} \cdot \frac{1}{\left(1 - \frac{h_f}{H_o}\right)}$$

The time required for bringing the ship from an angle of θ deg. (or the angle of margin line immersion) to an upright condition is

$$T_\theta = \frac{2W}{SF} \cdot \frac{\left(1 - \sqrt{\frac{h_f}{H_\theta}}\right)}{\sqrt{2g \cdot H_\theta}} \cdot \frac{1}{\left(1 - \frac{h_f}{H_\theta}\right)}$$

Tank Equalization (2)





SOLAS 2009

- Applicable to ships with keel laid after the 1st January 2009
- Updated the probabilistic method to evaluate the Required and Attained subdivision indexes, **now mandatory** for
 - Cargo ships
 - Passenger ships



References

- Papanikolaou, Apostolos and Vassalos, Dracos (2001), "Enhanced Safety Requirements for European Ro-Ro Passenger Ships - The Stockholm Agreement: Past, Present & Future", Proc. 2nd Int. Conf. on Safety of Maritime Transport, June 7-9, 2001, Chios, Greece.
- Directive 98/18 CE from the European Parliament and the Council, from 14 April 2003, relative to specific prescriptions for stability of Ro/Ro Passenger Ships
- A.265 (VIII) Regulations of Subdivision and Stability of Passenger Ships
- A.266 (VIII) Recommendation on a Standard Method for Establishing Compliance with the Requirements for Cross-Flooding Arrangements in Passenger Ships