Introduction to regulatory Framework for Damage Stability

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Overview

• In January 2009, the new harmonised probabilistic rules for damage stability became mandatory, initiating a new era of rule-making in the maritime industry.

• This constitutes the culmination of more than 50 years of work, one of the longest gestation periods of any other safety regulation.

✓ A step change in the way safety is being addressed and regulated, "taking our time" is well justified.

✓ The change from introducing the new probabilistic rules for damage stability is so fundamental that design implications are just beginning to register, driving home the realisation that "things" are no longer the way they used to be.
Titanic (1912) – 2½ hours

Sinking after collision with an iceberg
Andrea Doria (1956) – 11 hours

Capsized after collision with ’Stockholm’

Capsized after collision with ’Speedlink Vanguard’

http://www.bbc.co.uk/news/uk-england-suffolk-20784851
Herald of Free Enterprise (1987)–90s
MS Estonia (September 1994) - less than 15 min after flooding of RoRo deck
MS Express Samina (September 2000) - about 20-25 min after colliding with a reef
Costa Concordia, 13 Jan 2012
Background

- Ships may suffer a damage during their service
- Hull damages can be caused by collision, grounding or enemy action in case of warships
- The outcome such a damage would be change of draught, trim and heel
- If the vessel doesn’t have sufficient reserved buoyancy and stability, a damage may result to the loss of the ship
- In order a ship to survive the vessel has to be subdivided into a number of watertight compartments
- Flooding of a certain number of adjacent compartments should not lead to slow sinking, progressive flooding or rapid capsize of the ship
Background

- Watertight subdivision has a history of more than 1,000 years
- Chinese junks (ocean going ships) were using it since 12th century
- Isambard Kingdom Brunel’s Great Eastern built in 1858 had not only watertight subdivision but it was also double hull
- At the end of 19th century in Great Britain the Parliament chartered a “Bulkhead Committee” to investigate the impact of TBhds
- The first Merchant Shipping Act of 1854 is the first known legal requirement addressing safety at sea concerning watertight bulkheads

- In 1891 the committee proposed the installation of TBhds in order to make ships longer than 425 ft 2-compartment.
- As a motive for the industry, such ships would be able to carry less life boats
Background

• The tragic loss of the Titanic in April 1912 stressed the need for international regulations for the watertight subdivision of the hull

• 1st SOLAS 20/1/1914
• Should have been applied Jul 1915
• Stopped by WWI

• Next SOLAS Conference 1929 (1933)
• Technical developments led to SOLAS 1948

• The next step was SOLAS 1960

• Finally, the 1974 SOLAS Convention was held in London
Definitions

1. **Floatability**: the ability of the vessel to support a given weight \( W \), by means of the hydrostatic pressure acting on the underwater surfaces, giving rise to the buoyancy force, \( B \).

Furthermore, to achieve a condition of **upright** equilibrium, the weight and force vectors have to act along the same vertical line on the centre plane of the vessel.
2. **Hydrostatic stability**: the ability of the vessel to return to a state of equilibrium (preferably the upright) in still water when disturbed from it.

- A necessary condition for hydrostatic stability is that the metacentric height, GM, should be positive.
- Whilst positive GM is the necessary condition for stability at small angles of heel, it may not be so for larger angles.
- For this, they use a different measure of stability, the righting lever GZ, the variation of which with increasing heel provides a better indication of the hydrostatic stability characteristics of a vessel.

In relation to the above, regulators request that in addition to a positive GM, the GZ curve must satisfy certain criteria. These include maximum GZ and the angle at which it occurs, angle of vanishing stability and area under the GZ curve.
If a vessel is damaged so that part of her internal volume is flooded, she will sink, heel and trim until she reaches a condition in which reserve buoyancy (i.e. buoyancy above the initial waterline) has been brought into effect to offset the lost buoyancy until equilibrium is again restored, but with the vessel possibly taking a steady angle of heel.

For the most onerous cases GM is likely to decrease and the GZ curve characteristics are likely to diminish in all regards.

Capsize of the vessel occurs if GM became negative with the vessel upright and there were no positive righting levers in the residual GZ curve (GZ curve after damage).

On the basis of this reasoning, damage stability can be enhanced by ensuring that the residual GZ curve satisfied certain criteria.

The stability of ships is, in general, related to both intact and damage stability requirements.

For passenger vessels this is normally assessed by their stability in a damaged condition, i.e. by their residual stability.
GZ Cross Curves of Stability

Source: Ship stability for masters and mates
Evolution of damage stability standards for passenger ships in SOLAS

- SOLAS 1948
- SOLAS 1960
- SOLAS 1990
Definitions

- Watertight Bulkhead
- Bulkhead deck
- Margin line – 76mm below the deck at side
- Floodable length-the maximum length centred at a point that can be flooded without submerging the margin line
- Volume permeability-the ratio of a compartment’s volume that can be flooded
Watertight subdivision

- A ship might sink due to:
  - Carrying a weight larger than her displacement
  - Flooding due to:
    - Grounding
    - Collision
    - Enemy action
    - Operation of a system open to the sea

- For the case water finds its way in, the designer has to make sure that:
  - The loss of transverse stability is minimum
  - The damage to the cargo is minimum
  - The vessel has sufficient longitudinal stability
  - The loss of residual buoyancy is minimum

- Ideally, the ship should sustain more and more flooding without loss of stability until it sinks bodily by loss of its reserve of buoyancy (foundering).

- In order to achieve that, the ship is subdivided to a number of watertight compartments
Watertight subdivision

- The bulkheads must be watertight up to the bulkhead deck and able to withstand the water pressures they might be subject to after damage
- Ships over certain length should have a watertight inner bottom (double bottom) extending from the fwd collision bhd up to the afterpeak bhd
- Tankers, large warships and many Ropax have in addition longitudinal side bulkheads in order to minimize the transverse extent of flooding
Damaged condition

• To assess the ability of the ship to withstand the damage a number of different damage scenarios should be checked at design stage

• For every damage condition, the naval architect is checking:
  • The damaged waterline, heel and trim
  • The damaged stability according to standards laid down in the Rules
Damage Stability Calculations

• When a ship is damaged, creating a hole in the hull, water enters the ship. This results in:
  • Increase in draft
  • Change in trim
  • Change in heel

• The result of this flooding can be determined two ways:
  • Lost Buoyancy Method
  • Added Weight Method

• “Lost Buoyancy” approach is followed in all regulations
Example based on idea presented in Handbuch der Werften and later used by Watson

Starting point: Intact condition

Indices denote different conditions:

0 intact hull with original draft $T_0$

Associated with initial displacement volume: $V_0$

Associated with initial intact stability:  $GM_0 = KB_0 + BM_0 - KG_0$
Approach: “Lost Buoyancy”

After hull damage: ship loses displacement volume
draft increases because of buoyancy lost

loss of available volume $\kappa v_0$
Permeability $\mu$ considered

Flooded compartment does not fill completely with water.

Compartments contain:
- equipment
- furniture
- structural components
- cargo

Permeability = \[ \frac{\text{Available Volume}}{\text{Total Volume}} \]

Similarly we have the area permeability:

$\mu_f = \frac{\text{water area at waterline}}{\text{total compartment area at waterline}}$
Homogeneous permeability assumed

Empty room
\( \mu = \mu_v = 100\% \)

Reality
\( \mu = \mu_v = 95\% \)

Model
\( \mu = \mu_v = 95\% \)

Typical values:
- Watertight compartment (warship) 97%
- Watertight compartment (merchant) 95%
- Accommodation spaces 95%
- Machinery spaces 85%
- Dry cargo spaces 70%
- Bunkers, stores, cargo holds 60%

16/11/2015
Final damaged condition

Indices denote different conditions:

0 intact hull with original draft $T_0$

R residual hull at final draft $T=T_R$ (incl. trim)
Notation: Artificial intact-damaged condition

Indices denote different conditions:

0 intact hull with original draft $T_0$

R residual hull at final draft $T = T_R$ (incl. trim)

T intact hull at final draft $T = T_R$ (incl. trim)

Only used for mathematical derivations
No physical meaning
Masses remain fixed

Assumption: • cargo (or other objects) does not exit
• cargo (or other objects) do not float inside room

Then: • total mass of ship constant
• mass distribution (KG) constant

\[ V_R = V_0 \quad \text{and} \quad KG_R = KG_0 \]
Example: Pontoon with $\mu = 100\%$

1. Central compartment damaged
2. Loss of buoyancy
3. Loss of volume compensated by increased draft
Intact stability

Intact stability: \( V_0 = L \cdot B \cdot T_0 = 100 \cdot 20 \cdot 3 = 6000 \text{ m}^3 \)

\( KB_0 = T_0 / 2 = 3/2 = 1.50 \text{ m} \)

\[
BM_0 = \frac{I_0}{V_0} = \frac{L \cdot B^3/12}{L \cdot B \cdot T_0} = \frac{B^2}{12 \cdot T_0} = \frac{20^2}{12 \cdot 3} = 11.11 \text{ m}
\]

\( GM_0 = KB_0 + BM_0 - KG_0 = 1.50 + 11.11 - 8.00 = 4.61 \text{ m} \)

\( T_0 = 3 \text{ m} \)

\( B = 20 \text{ m} \)

\( KG_0 = 8 \text{ m} \)

\( \ell = 40 \text{ m} \)

\( L = 1000 \text{ m} \)
Floating position in damaged condition

Mass constant → Volume constant

\[ V_R = (L-\ell) \cdot B \cdot T_R \]
\[ V_R = V_0 \]

\[ T_R = \frac{V_0}{(L-\ell) \cdot B} = \frac{6000}{(100 - 40) \cdot 20} = 5.00 \text{ m} \]
Damage stability

Damage stability:

\[ KB_R = \frac{T_R}{2} = \frac{5}{2} = 2.50 \text{ m} \]

\[ BM_R = \frac{I_R}{V_0} = \frac{(L-\ell) \cdot B^3}{12 \cdot V_0} = \frac{(100-40) \cdot 20^3}{12 \cdot 6000} = 6.67 \text{ m} \]

\[ GM_R = KB_R + BM_R - KG_0 = 2.50 + 6.67 - 8.00 = 1.17 \text{ m} \]
### Intact vs. Damage

<table>
<thead>
<tr>
<th></th>
<th>Intact</th>
<th>Damaged</th>
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<tbody>
<tr>
<td>KB</td>
<td>1.50 m</td>
<td>2.50 m</td>
</tr>
<tr>
<td>BM</td>
<td>11.11 m</td>
<td>6.67 m</td>
</tr>
<tr>
<td>GM</td>
<td>4.61 m</td>
<td>1.17 m</td>
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</table>

The pontoon is still stable, but has lost $\Delta GM = 3.44$ m

Now consider an intermediate condition during flooding
Intermediate condition

- $BM_R$ now must consider correction for free surface
- on the other hand, waterline still intact

Net effect: $BM_R$ as in damaged condition: $BM_R = 6.67$ m

$$V_0 = V_R = L \cdot B \cdot T_R - \epsilon \cdot B \cdot h$$

$$T_R = \frac{V_0 + \epsilon \cdot B \cdot h}{L \cdot B} = \frac{6000 + 40 \cdot 20 \cdot 15}{100 \cdot 20} = 3.60 \text{ m}$$

$h = 1.50 \text{ m}$

$\epsilon = 40 \text{ m}$
KB computed for residual underwater body

<table>
<thead>
<tr>
<th></th>
<th>V</th>
<th>Z</th>
<th>V·Z</th>
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<tbody>
<tr>
<td>L</td>
<td>T</td>
<td>L·B·T_R²/2</td>
<td></td>
</tr>
<tr>
<td>-ε·B·h</td>
<td>h/2</td>
<td>-ε·B·h²/2</td>
<td></td>
</tr>
<tr>
<td>L·B·T_R -ε·B·h</td>
<td>KB</td>
<td>L·B·T_R²/2 -ε·B·h²/2</td>
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\[
\begin{align*}
V &= L \\
Z &= T \\
V\cdot Z &= L\cdot B\cdot T_R^2/2 \\
-\varepsilon\cdot B\cdot h &= h/2 \\
= L\cdot B\cdot T_R -\varepsilon\cdot B\cdot h &= KB \\
L\cdot B\cdot T_R^2/2 -\varepsilon\cdot B\cdot h²/2
\end{align*}
\]

\[
\begin{align*}
\varepsilon &= 40m \\
L &= 100m \\
h &= 1.50m \\
T_R &= 
\end{align*}
\]
GM computed for residual underwater body

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<th>Z</th>
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<tbody>
<tr>
<td></td>
<td>100·20·3.60</td>
<td>1.80</td>
<td>12960</td>
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<tr>
<td>-</td>
<td>-40·20·1.50</td>
<td>0.75</td>
<td>-900</td>
</tr>
<tr>
<td>=</td>
<td>6000</td>
<td>2.01</td>
<td>12060</td>
</tr>
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</table>

\[ GM_R = KB_R + BM_R - KG_0 = 2.01 + 6.67 - 8.00 = 0.68 \text{ m} \]
### Intact vs. Damage vs. Intermediate

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Pontoon still stable, but GM considerably lower than in final condition.

Intermediate conditions most critical, but...

…most regulations required stability proof only for final condition.
Non-symmetric damage of waterline

- change of draft
- change of trim
- change of heel

$S_T$ center of intact waterline at draft $T$

$F_T$ area of intact waterline

$f_T$ damaged waterline area at draft $T$
Center of waterline shifts

- center of residual waterline no longer on symmetry plane

\[ S_R \] center of residual waterline at draft T
Axes for moments of inertia change

- main axis of inertia (= axis with minimum moment of inertia) no longer on symmetry plane
“Floodable length” is simplified concept

- Useful for early estimate of damage stability (guiding arrangement of bulkheads)
  - easy to handle
  - no computer needed
    - assume constant permeability over cross section (often not true)
    - only approximation

- (Pre)historic approach
- Manual procedure described in PNA
- Diagrams still popular for communication
“Floodable length” definition

Consider a point situated at x (from the aftmost point of ship)

“Floodable length” (at x) =

Maximum length of the compartment having its center at x that will not submerge the margin line if symmetrically flooded.

‘Margin line’ = (often) 76 mm (3 inches) below deck at side

Position and longitudinal extent of damage.
Results usually displayed in diagrams

x-axis: position of center of room
y-axis: length of room (damage)

Possible space of solutions is triangle

FL computed exactly for several points
Spline interpolation

Permeability as parameter

FL = floodable length
Damaged Stability
Floodable length curves help placing bulkheads

- Isosceles triangle below curve = ship survives if room flooded
- Discontinuous limit curve due different permeabilities
- Shift bulkheads until all rooms (individually can be flooded)
- Two adjacent rooms can be considered by combining room lengths
Damage stability today analyzed by computer programs

Naval Architect specifies:
- hull geometry
- mass distribution (KG)
- compartments

Computer determines
- floating position
- residual GM and freeboard for all individual compartments and groups of compartments

Often applicable criteria included in code: automatic check

Source: NAPA
Deterministic vs. Probabilistic

- **Deterministic:**
  - Standard dimensions of damage extending anywhere along the ship’s length or between TBhds depending on the relevant requirements.
  - A number of standard damages involving single or multiple compartments is examined.
  - Each damage case is to be considered for each loading condition, and the applicable criteria are to be comply with.
Deterministic vs. Probabilistic

• **Probabilistic:**
  - The probability of survival after damage is the measure of ship safety in damage condition, refered to as the attained subdivision index A.
  - The philosophy behind the probabilistic concept is that two different ships with the same attained index are of equal safety and, therefore, there is no need for special treatment of specific parts of the ship, even if they are able to survive different damages.
  - The only areas which are given special attention in the Regulations are the forward and bottom regions, which are dealt with by special subdivision rules provided for cases of ramming and grounding.
New design paradigm (from prescriptive to goal-setting design)

• The probabilistic concept of ship subdivision affords new degrees of freedom in ship subdivision and layout but, in this process, designers are finding it rather difficult to move away from the prescription mind-set.

• Adapting design practice to the new freedom, offered by the new rules, requires new skills, which cannot be based on experience alone.

• The need to facilitate improved understanding of what this concept entails and of its limitations and range of applicability is now paramount.
New Naval Architecture (from hull focus to total ship focus)

• With the advent of the new probabilistic rules comes a major shift in the way the fabric of Naval Architecture, namely floatability and stability is being interpreted and used.

• The margin line disappears and Naval Architecture begins to delve into superstructure, seeking to identify and distribute watertight spaces so that floatability and stability are ensured in all the extreme damage scenarios covered by the probabilistic rules.

• Consideration of upper decks for stability needs, would lead to accounting all openings, escape routes, void spaces and layout; hence intruding into ship’s operation.

• Safety, performance and functionality must now be considered concurrently through routine utilisation of optimisation techniques in early design stages.
New rules of the game (mixing probabilistic and deterministic rules)

- Introducing the new probabilistic rules for damage stability during a period when existing deterministic instruments were still being enforced, namely SOLAS '90 (globally) and Stockholm Agreement (in Europe), and in particular the requirement for multi-instrument compliance in new building projects, raised questions and doubts for industry and regulators alike that hindered the already shaky process of implementing the new rules.

- These were fuelled by uncertainties concerning the derivation and applicability of SOLAS 2009.

- Explaining and demonstrating the relevance of each set of rules and the use of statistical damages in rule-making can go a long way in defusing a problem that, in principle, should not exist.
New problems in the new rules (lack of rationale in safety standards)

- The intention to provide a qualitative assessment of safety (a safety index) might have been enough at the time the probabilistic framework for damage stability was conceived.

- With the introduction of Design for Safety and of Risk-Based Design to the marine industry, quantification of safety is a prerequisite to treating safety as a design objective.

- The level of detail in the method used to quantify safety carries a much bigger weight.
New problems in the new rules

• With this in mind, calculating survival factors consistently and accurately is paramount.

• Unfortunately, a close scrutiny of the work that led to the current formulation of the s-factor raised concerns that it might be simply the result of a series of unjustified compromises, which inadvertently crept in during the rule-making process.

• In the SOLAS 2009 formulation, the s-factor derives from a regression analysis of only a filtered set of old cargo ships.

• What is of crucial significance is that there is little consistency between performance-based survivability (e.g. using model experiments or numerical simulation) and that postulated by the new rules.

• The EC-funded project GOALDS was launched in September 2009 to address this problem but the need remains of explaining the current pitfalls in the rules and of providing a way forward that will serve the industry well in the interim.
Summary

• Index-A reflects the average survivability of a vessel following collision damage and flooding in a seaway. As such, an accurate calculation of the survival probability in the probabilistic rules is of paramount importance.

• There is evidence indicating errors in the derivation of survival factors, demanding swift action by the profession.

• Such action requires industry-wide participation to ensure due process is followed in the revision of the rules and approval through IMO.

• In the meantime use of time-domain simulation tools or physical model tests must be fully exploited.
Summary

• Moreover, the new damage stability standard being statistical rather than performance-based may not cater for the higher level of safety expected for the mega-ships of today.

• Indeed, FSA studies performed by SAFEDOR have demonstrated the need to raise substantially the damage survivability standard of passenger ships.

• Equally important, recent innovative new-building projects have shown considerable potential for raising the damage survivability standard.
Introduction to probabilistic rules

• The first probabilistic damage stability rules for passenger vessels, deriving from the work of Kurt Wendel on "Subdivision of Ships", were introduced in the late sixties as an alternative to the deterministic requirements of SOLAS '60.

• Subsequently and at about the same time as the 1974 SOLAS Convention was introduced, the International Maritime Organisation (IMO), published Resolution A.265 (VIII).

• The next major step in the development of stability standards came in 1992 with the introduction of SOLAS part B-1 (Chapter II-1), containing a probabilistic standard for cargo vessels, using the same principles embodied in the 1974 regulations.

• The same principle was used in launching at IMO the regulatory development of "Harmonisation of Damage Stability Provisions" in SOLAS, based on the "Probabilistic Concept of Survival" in the belief that this represented a more rational approach to addressing damage stability.
Introduction to probabilistic rules

• Evidence, however, of "common sense" driving rule making is very scarce: with accidents providing the main motivation for rule making, emphasis has primarily been placed on reducing consequences, i.e., on cure rather than prevention.

• Against this background, it is widely believed that the prevailing situation could be drastically improved through understanding of the underlying mechanisms leading to vessel loss and to identification of governing design and operation parameters to target risk reduction cost-effectively.

• This, in turn, necessitates the development of appropriate methods, tools and techniques capable of meaningfully addressing the physical phenomena involved.
Introduction to probabilistic rules

• Having said this, it was not until the early 90's when dynamic stability pertaining to ships in a damage condition, was addressed by simplified numerical models, such as the numerical model of damaged Ro-Ro vessel dynamic stability and survivability.

• The subject of dynamic ship stability in waves with the hull breached received much attention following the tragic accident of Estonia, to the extent that led to a step change in the way damage stability is being addressed, namely by assessing the performance of a vessel in a given environment and loading condition on the basis of first principles.
In parallel, motivated by the compelling need to understand the impact of the then imminent introduction of probabilistic damage stability regulations on the design of cargo and passenger ships and the growing appreciation of deeply embedded problems in both the rules and the harmonisation process itself, an in-depth evaluation and re-engineering of the whole probabilistic framework was launched through the EC-funded project HARDER.

The overriding goal of the HARDER project was to develop a rational procedure for probabilistic damage stability assessment, **addressing from first principles all relevant aspects and underlying physical phenomena for all types of ships and damage scenarios.**
EC-funded project HARDER

- In this respect, HARDER became an IMO vehicle carrying a major load of the rule development process and fostering international collaboration at its best—a major factor contributing to the eventual success in achieving harmonisation and in proposing a workable framework for damage stability calculations in IMO SLF 47.

- Deriving from developments at fundamental and applied levels in project HARDER as well as other EU projects such as NEREUS, ROROPROB and SAFENVSHIP and other international collaborative efforts (e.g., work at the International Towing Tank Conference — ITTC), a clearer understanding of damage stability started to emerge together with a confidence in the available knowledge and tools to address the subject effectively, even at design concept level.
More importantly, the knowledge gained can be used to address critically all available regulatory instruments and to foster new and better methodologies to safeguard against known design deficiencies in the first instance, until safer designs evolved to reflect this knowledge.

At this point in time, it is known for example that damaged ships in waves may capsize in one of the following modes (the first three after the final equilibrium condition is reached post-damage):
High freeboard ships

Provided there is some minimal positive righting lever and range of stability the ship will not capsize in moderate waves.

Wave impacts on the side of the ship will induce some rolling in marginally stable cases, which could result in capsize at the larger sea states.

Often ships are more vulnerable with the damage to leeward, since the GZ levers are typically less in the damaged direction and the induced dynamic roll is typically somewhat greater leeward.
Low freeboard Ro-Ro ships

- This is the typical mechanism of capsize for Ro-Ro ships.
- The wave action gradually pumps water up onto the vehicle deck.
- The height of the water gradually increases until either a reasonably stable equilibrium level is reached where inflow is approximately equal to outflow for ships with sufficient reserve stability, or if stability is inadequate, the heeling moment of the water will cause a capsize to windward.
- In some rare cases Ro-Ro vessels may heel to leeward after the first few wave encounters with an insufficient freeboard on the weather side to prevent further water accumulation and the ship will continue to take water on the vehicle deck until a capsize results.
Low freeboard conventional ships

- This is the typical mechanism of capsize for non-Ro-Ro ships.
- The highest waves will form boarding seas and will pile-up on the windward side of the deck, inducing roll and capsize, usually to windward.
- The weather deck tends to drain quickly if there is no capsize, and there is no build-up or accumulation of water as seen with enclosed Ro-Ro decks.
- One or two high waves in close succession are often sufficient to cause capsize.
Multi-Free-Surface Effect

• This mechanism of capsize is relevant to ships with complex watertight subdivision such as cruise ships.

• As the hull is breached, water rushes through various compartments at different levels, substantially reducing stability even when the floodwater amount is relatively small.

• As a result the ship can heel to large angles, even for small damage openings, letting water into the upper decks that spreads rapidly through these spaces and may lead to rapid capsize at any stage of the flooding.
Available regulatory instruments

Understanding the aforementioned mechanisms of vessel capsize helps in judging how relevant or effective available regulatory instruments are, in being able to prevent or mitigate disasters, as indicated in the following for the instruments currently in use:

- **SOLAS '74**: 1-compartment standard (prevents ship from sinking capsizing if one compartment is breached; resistance to capsize in waves unknown).
- **SOLAS '90**: 2-compartment standard (prevents ship from sinking / capsizing if any two compartments are breached; resist capsize of 2-compartment worst damage in sea states with Hs approximately 3m - Ro-Ro vessels).
- **Stockholm Agreement (Ro-Ro Passenger ships)**: as in SOLAS '90 but with a pre-defined level of water on deck depending on freeboard and in operational sea states of up to 4m Hs, [4].
- **Harmonised SOLAS Chapter II-1**: SOLAS 2009 - equivalent to SOLAS '90.
Concerning the latter, a major revision to the subdivision and damage stability sections of SOLAS Chapter II-1, based on a probabilistic approach, entered into force for new vessels with keels laid on or after 1\textsuperscript{st} January 2009.

The new regulations represent a step change away from the current deterministic methods of assessing subdivision and damage stability.

Old concepts such as floodable length, criterion numeral, margin line, 1- and 2-compartment standards and the B/5 line have disappeared.

Whilst development of the probabilistic regulations included extensive calculations on existing ships, which had been designed to meet deterministic SOLAS regulations, little or no effort has been expended into designing new ships from scratch using the new probabilistic regulations.
Thank you for your attention!