High Speed Damage Stability Criteria: past & present for fast ferry design

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ABSTRACT: The recent HSC 2009 and HSC 2000 codes represent an evolution of the precedent HSC 94 code, this one derived from the Dynamically Supported Craft Code of IMO 1977. The HSC 2000 recognizes that an adequate level of safety, for high-speed marine vehicles, can be enhanced by the infrastructure associated with regular service on particular routes. An overview of the intact and damage stability criteria required for HSC Ro-ro passenger vessels has been carried out. The paper deals with an investigation on the monohull and multihulls fast ferry subdivision, compatible with the IMO HSC code. The study has been developed for typical high-speed ferries subdivisions; the results obtained have been discussed. Finally, three representative fast Ro-ro passenger ships have been developed and an extension of the Stockholm Agreement (SA) application has been pointed out. The main aim of the paper is to analyze the SA approach in order to ensure the survival and a meaningful evolution of Ro-ro fast vessels in the future.

1. INTRODUCTION

The main concern with the Ro-ro passenger ship design relates to safety. It is vital that a rational approach to safety is demonstrated, validated and adopted. This is the right way to ensure both the survival and a meaningful evolution of Ro-ro ships in the future.

In this paper an overview of the intact and damage stability criteria required for HSC Ro-ro passenger vessels has been carried out, in order to point out the development of the standard stability requirements in the different HSC codes. The recent HSC 2009 and HSC 2000 codes (RINA 2000 and RINA 2009) represent an evolution of the precedent HSC 94 code (RINA 1994), that replace the Dynamically Supported Craft Code of IMO 1977. Recent accidents have pointed out the importance of a careful consideration of the damage stability characteristics of such crafts before they are put in service. The safety levels requested by the passenger transportation demand an investigation on the actual damage stability standards and on possible rules developments.

For the conventional Ro-ro passenger ship enhanced requirements for damage survivability, known as the ‘Stockholm Agreement’ (SA) standard, were developed and several studies on the matter proposed (Vassalos et al. 2001, Papanikolaou et al. 2001, and Vassalos et al. 2003). The standards of SOLAS 90, for vessels operating in seas with significant wave height less than 1.5m, are equivalent to the HSC code. To take in account the effects of significant wave heights over than 1.5m the adoption of the SA has been proposed for the HSC vessels (MCA 2000). The work underline that in many cases the ship does not require variation of external geometry to pass SA additional stability criteria (as often happens in conventional Ro-ro ship (Vassalos et al. 2001), but only internal solution that doesn't invalidate the effectiveness of the vessel. Finally throw the analysis of damage stability on a typical catamaran this work underline that SA
criteria application on multi-hulls is not so irrelevant as mentioned in (MCA 2000), because of large car-decks.

In the next section a history of the development of the HSC codes, according to the intact and damage stability, is briefly presented, introducing also the SA criteria. In the following sections we will present three ships complying with the HSC 2000/09 codes in order to focus on the evolution of the damage stability requirements. We will also apply the SA, to probe the impact of this regulation on these high-speed vessels even on a catamaran. Finally the three models and the obtained results will be presented and discussed, leading to guidelines for SA applications to HSC vessels.

2. HSC CODE HISTORY AND DEVELOPMENT

Because of many new HSC built in the 1980's and 1990's, IMO decided to adopt new international regulations, dealing with the special needs of the stability of this type of vessels. In 1994, IMO adopted the International Code of Safety for High-Speed Craft (HSC Code resolution MSC.36). It was developed as a revision of Dynamically Supported Craft Code (resolution A.373).

As known, in 1994, IMO adopted a new SOLAS chapter X- Safety measures for high-speed crafts, which makes the HSC Code mandatory for vessels built on (or after) 1 January 1996.

The stability requirements of the HSC Code apply to high-speed crafts, engaged on international voyages. Passenger crafts, which do not proceed for more than four hours, at operational speed from a place of refuge, when fully laden, are included.

The 2000 HSC Code updates the 1994 HSC Code. It was applied to all HSC built after the first of July 2002 (the date of entry into force).

The safety level requested for passenger transportation, calls for an investigation on rules development. The HSC crafts have different layouts and dimensions, consequent to different service characteristics required to satisfy particular needs. Small and medium sizes fast ferries have been extensively studied at University of Naples “Federico II” - “Dipartimento di Ingegneria Navale”. In this scenario, it is very interesting to consider in detail the stability damage characteristics of monohull and catamaran, for the design procedure or also in the criteria applied to existing ships.

3. REGULATORY FRAMEWORK: A REVIEW OF THE INTACT AND DAMAGE STABILITY

3.1 Intact stability

As regard stability characteristics and criteria, HSC are separated according to the service (cargo or passenger ships). Passenger ships are divided in two categories (A and B) according to the number of passengers (more or less than 450 and to the max allowable rescue time of four hours).

The paragraphs, reported in the HSC Code 2009, explaining the relevant prescriptions and the stability criteria, relative to passenger ships, are mentioned in the following:

- Intact stability general prescriptions: Chapter 2, 2.3;
- Intact stability, additional prescriptions for passenger ships: Chapter 2, part B, 2.12

The crafts, should meet the intact stability criteria for monohull and multihull, respectively reported in the first paragraphs of the Annex 8 and Annex 7 of the code.

The requirements of annexes 7 and 8, according to the latest HSC rule, may be applied as indicated in the following table 2.3.4 of the code:

<table>
<thead>
<tr>
<th>GM1</th>
<th>Angle of maximum GZ</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>≤ 25°</td>
</tr>
<tr>
<td>≤ 3 m</td>
<td>annex 7 or annex 8</td>
</tr>
<tr>
<td>&gt; 3 m</td>
<td>annex 7</td>
</tr>
</tbody>
</table>

Table 2.3.4, from the HSC 2009 code

The HSC code 1994 required, in all permitted conditions of loading, to accomplish the IMO A. 562(14) Weather Criterion. The HSC 2000/2009 code, instead, requires different weather criteria for monohull and multihull, as well explained in the above mentioned Annexes.

3.2 Residual damage stability

In this section the evolution of the damage stability calculation, according to the HSC codes, will be presented.

The damage dimensions, imposed by the HSC 1994 code, descend from the DSC code prescriptions. The side and the bottom damage dimensions, according to the HSC 1994, are listed below:

- Side damage:
  \[ l = \min(0.1L, 3m+0.003L, 11m) \]
  \[ b = \min(0.2B, 5m, 0.05L) \]
  \[ h = \text{unlimited for the full vertical extent of the craft} \]
- Bottom damage
For passenger ships of Category B the bottom damage length from midship to forward, should be increase of 50%.

The HSC code 2000/2009 that has replaced the HSC code 1994, presents different formula for the calculation of the damage dimensions and a different approach to the bottom damage. The most recent code distinguishes between two bottom damage zones, as defined by the draft: vulnerable to raking damage and not vulnerable to raking damage.

The damage dimensions, according to the HSC code 2000/2009 should be evaluated as follows:

- **Side damage:**
  \[ l = \min\{0.1L, 3m + 0.003L, 11m\} \]
  \[ g = \min\{B, 7m\} \]
  \[ p = \min\{0.02B, 0.5m\} \]

- **Bottom damage in area vulnerable to raking damage:**
  \[ l_1 = 55\% L, \text{ measured from the most forward point} \]
  \[ l_2 = 35\% L \text{ if } L \geq 50 \text{ m; } (L/2 + 10)\% L \text{ otherwise} \]
  \[ g = 0.1V^{1/3} \]
  \[ p = \min\{0.04V^{1/3}, 0.5m\} \]

- **Bottom damage in area not vulnerable to raking damage:**
  \[ l = \min\{3 m + 0.225V^{1/3}, 0.75V^{1/3}, 11m\} \]
  \[ g = 0.2V^{1/3} \]
  \[ p = 0.02V^{1/3} \]

Particular care must be taken for passenger crafts of category B, for which is requested by the code an additional criteria after a damage involving the 100% of length of the ship. This damage on the whole length, applying to a catamaran, lead to one of the two hulls completely flooded.

The residual stability criteria, for the HSC codes, are referred to the below mentioned paragraphs:

- **HSC 1994 damage stability:** Chapter 2, 2.6.
- **HSC 2009 damage stability:** Chapter 2, 2.6; Annex 7 and Annex 8, as provided by Table 2.3.4.

### 3.3 Stockholm Agreement to the HSC vessels

The damage stability is crucial for the survival of Ro-ro passenger ships. The longer a ship remains afloat after a major loss, the more effective are the evacuation or search and rescue operations. The Estonia tragedy in 1994 prompted the authorities of the Nordic countries to try to improve the safety of navigation. Public pressure has required an answer soon. The result was the so-called "Stockholm Agreement", which takes into account the effect on the stability of the accumulation of water on the car deck. The corresponding legislation has caused a rift within the IMO and it resulted in a regional agreement signed by the countries of Northern Europe.

Studies clearly show (Rousseau et al. 1996) that the residual freeboard of the ship and the height of the waves exert a strong influence on the amount of water that may accumulate as a result of damage.

The rule presented below is based on the following considerations:

- 99% of all collisions recorded by the IMO have taken place in sea states with significant height up to 4.0 m;
- Compliance with SOLAS '90 standard is assumed to be equivalent to survival of the damaged ship in sea states of up to 1.5 m Significant Wave Height, that covers 89% of all collisions;
- The sea states with significant wave height between 1.5 and 4.0 m are taken into account;
- A study conducted by the SNAME indicates in 0.5 m$^3$/m$^2$ the reasonable level of water, that accumulates on the car deck, in a state of the sea with significant wave height of 4.0 m. The same study (and experimental tests conducted in Canada) indicates that the amount of water that accumulates on the deck becomes negligible when the ratio of residual freeboard and the significant wave height exceeds 0.5.

The standards of SOLAS 90 are equivalent to the HSC code. Therefore HSC vessels operating in seas with significant wave height less than 1.5m need only satisfy the requirements contained in the HSC code.

According to these considerations, the HSC damage stability requirements, for wave height over 1.5 m, should meet the Stockholm Agreement.

The calculation of the accumulation of water on the car deck is calculated according to the freeboard and significant wave height, following the standard practice (Vassalos et al. 2001).

The SA, applied to the HSC ships (MCA 2000), requires that the vessels, in addition to complying with the full requirements of the appropriate HSC Code, further complies only with that part of the HSC Code criteria contained in paragraphs 2.13 of the 2000 HSC Code and 2.3 of the 1994 HSC Code, with the defined amount of water on deck. The HSC vessels, as the conventional Ro-ro ships, do not need to comply with any requirements for the angles of equilibrium, for the SA calculation.

### 4. THE CONCEPTUAL AND PRELIMINARY STUDIES OF TYPICAL SUBDIVISIONS: APPLICATIONS
In the following sections we will introduce the example Ro-ro pax ships, complying with the HSC code 2000/2009. We will apply the SA according to the reference (MCA 2000) and we will present the obtained results.

4.1 Test cases

For the purpose of the applications, three example ships have been developed complying the main standard practices for the Ro-ro pax mono- and multi-hulls. The subdivision for each vessel has been designed in order to satisfy the HSC code 2000/2009 damage stability criteria.

The first ship named M1, whose main characteristics are listed in Table 1, represents a typical ferry operated in the “bay of Naples”. In Figure 1 and in Figure 2 the 3D view of layout and capacity plan of the M1 model are respectively represented.

The HSC 1994, the HSC 2000/09 codes and the SA applications, carried out on this representative ship, will be presented, envisaging a new subdivision in order to satisfy the damage stability criteria with added water height on the Ro-ro deck.

The CAT2 vessel has been designed to analyze the reasonableness in applying the SA criteria to the multihull. The main dimensions and the payload of this catamaran are presented in Table 2. In Figure 3 the general arrangement plans are showed.

Finally we introduce the M3 mono-hull (Figure 4 and Table 3) to evaluate the effect of a SA application on ships having the Ro-ro space arranged on different decks. We will give different interpretations to the problem, suggesting a more reliable approach.

| LOA  | 71.06 m |
| LWL  | 64.54 m |
| B    | 13.40 m |
| D    | 8.5 m   |
| Δ    | 650 t   |
| N° pax | 530 |
| N° ro-ro | 40 |
| Range | 350 NM |

Table 1. Main characteristics of the M1 mono-hull

| LOA  | 114.10 m |
| LWL  | 98.46 m |
| B    | 17.25 m |
| D    | 10.40 m |
| Δ    | 1825 t  |
| N° pax | 890 |
| N° ro-ro | 180 |
| Range | 450 NM |

Table 2. Main characteristics of the CAT2 catamaran

Table 3. Main characteristics of the M3 mono-hull
In the following subsections, for each defined ship, the standard damage dimensions, according to the reference codes, will be applied and the residual stability results discussed.

4.2 Damage stability on M1 ship: application of HSC code.

The damage stability investigation on the M1 vessels has been carried out according to “HSC” 1994 and 2000/2009 codes. The damage dimensions calculating with the semi-empirical formula given by the regulations are reported in Table 4.

The analysis of the side damage dimensions using the formulas from the different editions of HSC code leads to unappreciable results. The evolution of residual criteria, according to the more recent HSC code, seems to lead to less restrictive results: after damage, even ship with reduced area under the residual righting arm curve are retain stable providing an increase in the positive range of the residual righting arms.

The main turning point of the recent regulations, in order to increase the safety level, is the innovative approach to the bottom damage. The HSC code 2000/09 distinguishes two different raking damage zones, and imposes also the passing of the stability criteria with a raking damage on the whole ship bottom length.

All the damage scenery for the HSC code 2000/09 have been investigated, and compared with the HSC code 1994 damage conditions.

<table>
<thead>
<tr>
<th>a. Side damage dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>HSC 1994 code</td>
</tr>
<tr>
<td>( l ) (m)</td>
</tr>
<tr>
<td>4.94</td>
</tr>
<tr>
<td>HSC 2000/09 code</td>
</tr>
<tr>
<td>( l ) (m)</td>
</tr>
<tr>
<td>4.95</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>b. Bottom damage dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bottom damage according to the HSC 1994 code</td>
</tr>
<tr>
<td>( l_{aft} ) (m)</td>
</tr>
<tr>
<td>4.94</td>
</tr>
<tr>
<td>Areas vulnerable to raking damage HSC 2000/09</td>
</tr>
<tr>
<td>( l_{1} ) (55%L) (m)</td>
</tr>
<tr>
<td>35.48</td>
</tr>
<tr>
<td>Areas not vulnerable to raking damage HSC 2000/09</td>
</tr>
<tr>
<td>( l ) (m)</td>
</tr>
<tr>
<td>4.95</td>
</tr>
</tbody>
</table>

Table 4. Damage dimensions for the M1 ship
The residual righting arm curves, for all the damage scenery involving the side compartments, are showed in Figure 6: the comparison between the HSC 2000/09 and the HSC 1994 has been carried out on a representative damage case, involving the engine room (case 9 in Figure 5).

In Figure 7 are showed the results of 100% L raking damage.

4.2.1 SA application to M1 ship

The SA requirements for the Ro-ro passenger HSC vessel M1 have been verified applying the method explained in section 3.1. The SA for high-speed-craft requires the complying of the HSC codes damage standards with an additional amount of water on deck.

The application of the regulations has been carried out for all the damage cases for the design draft.

At first, the height of the added water on the Ro-ro deck have been calculated (Table 5) according to the residual freeboards of the ship (Figure 8), and assuming for the Tyrrhenian Sea $H_s = 2.5$ m, as stated by the (DL n. 65/2005). It is to be noticed that for the values of $H_s$ less than 4 m the interpolation law, showed in Figure 8, presents a sudden discontinuity around the values of 0.3 m of Fr.

The SA criteria, applied to the M1 vessel, are not complied by all the side damage cases of the ship. Both the damage Case 8 and 9 do not accomplish the regulation, showing also the higher value of $H_w$.

Note that, according to the experimental procedure suggested by SA, only case 8, showed in figure 3, should be analyzed, because of a minimum area under the residual righting arm curve. From analysis of all condition the case 9 results the worst case instead of case 8, because of a lower residual freeboard.

In Figure 9 are reported the case 8 and 9 results.

<table>
<thead>
<tr>
<th>Damage scenario</th>
<th>$H_s$ (m)</th>
<th>$2.5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 8</td>
<td>$0.382$</td>
<td>$0.190$</td>
</tr>
<tr>
<td>Case 9</td>
<td>$0.136$</td>
<td>$0.500$</td>
</tr>
<tr>
<td>Case 10</td>
<td>$0.670$</td>
<td>$0.156$</td>
</tr>
<tr>
<td>Case 11</td>
<td>$1.267$</td>
<td>$0.086$</td>
</tr>
<tr>
<td>Case 12</td>
<td>$0.944$</td>
<td>$0.124$</td>
</tr>
<tr>
<td>Case 13</td>
<td>$0.721$</td>
<td>$0.150$</td>
</tr>
<tr>
<td>Case 14</td>
<td>$0.589$</td>
<td>$0.166$</td>
</tr>
<tr>
<td>Case 15</td>
<td>$0.614$</td>
<td>$0.163$</td>
</tr>
<tr>
<td>Case 16</td>
<td>$1.185$</td>
<td>$0.096$</td>
</tr>
</tbody>
</table>

Table 5. Water height on Ro-ro deck for the M1 ship

The SA criteria, applied to the M1 vessel, are not complied by all the side damage cases of the ship. Both the damage Case 8 and 9 do not accomplish the regulation, showing also the higher value of $H_w$. Note that, according to the experimental procedure suggested by SA, only case 8, showed in figure 3, should be analyzed, because of a minimum area under the residual righting arm curve. From analysis of all condition the case 9 results the worst case instead of case 8, because of a lower residual freeboard. 
The SA calculation, according to the freeboard value, strictly depends on the final trim after damage. As first approach we try to modify the initial trim of the M1 vessel, loading the fore ballast tank, in order to change the Fr distribution along the ship. In this way we reduced the aft damage case \( H_w \) values, passing the SA criteria for the cases 8 and 9, but we worsened the fore damage cases that fail the residual stability requirements.

In order to comply with the SA standards for all the damage cases of the M1 vessels, we need to modify the Ro-ro deck subdivision, rearranging the cofferdam aster. The replaced side damage cases 8 and 9 that fail the SA, involving the local double-hull before the Ro-ro deck, do not require the SA calculation anymore (Figure 10).

4.3 HSC codes and SA application to a multihull craft.

The residual stability after damage for the catamaran CAT2 has been evaluated according to the annex 7 of the HSC code 2000/09. The calculated damage dimensions are reported in Table 6.

The applications of the SA to a multihull is not clearly required from the regulations (MCA 2000) as they assume, in the most cases, the large vessels residual freeboard upper than 2.0 m.

From the analysis of the residual freeboards after the side damage, the CAT2 denotes values of Fr even less than 0.3 m; this condition is due to an aft side damage that leads to a significant reduction of freeboard at the stern.

However, the large multi-hull present high volume of the Ro-ro deck with a wide water-plane area; that means, fixing \( H_w \), raising in volume of additional water on Ro-ro deck with heightened free surface moments.

In Figure 11 are showed the residual righting arm after damage compared to the righting arm obtained from the SA application. As could be noticed, the additional water height on Ro-ro deck significantly reduces the residual stability. The SA criteria for the catamaran CAT2 assuming 0.5 m of \( H_w \) are fulfilled with low margins.

In order to comply with the SA standards for all the damage cases of the M1 vessels, we need to modify the Ro-ro deck subdivision, rearranging the cofferdam aster. The replaced side damage cases 8 and 9 that fail the SA, involving the local double-

### Table 6. Damage dimensions for the CAT2 vessel

| Side Damage according to the HSC 2000/09 code |
|------------------|------------------|------------------|
| \( l \) (m) | \( b \) (m) | \( h \) |
| 6.00 | 2.67 | unlimited |

| Areas vulnerable to raking damage HSC 2000/09 |
|------------------|------------------|------------------|
| \( l \) (55%L) (m) | \( l_z \) (m) | \( p \) (m) | \( g \) (m) |
| 47.85 | 30.45 | 0.53 | 1.33 |

| Areas not vulnerable to raking damage HSC 2000/09 |
|------------------|------------------|------------------|
| \( l \) (m) | \( p \) (m) | \( g \) (m) |
| 6.000 | 0.267 | 2.667 |
4.4 An interpretation of the SA on a non-conventional monohull.

In order to investigate on the application of the SA criteria to a non-conventional Ro-ro deck arrangement, the M3 mono-hull has been designed. This Ro-ro pax ship complying with the HSC code 2000/09 is characterized by a non-continuum watertight Ro-ro deck, connected with the lower twin deck by non-watertight ramps (Figure 12 and Figure 13), localizing a huge garage compartment. The damage stability analysis has been carried out according to the HSC code 2000/09, to evaluate the residual freeboards for each damage scenario. It is to be taken in account that the freeboard value is defined as the minimum distance between the damaged Ro-ro deck and the waterline at the location of the damage.

The side damage dimensions, calculated according to the above mentioned code are reported in Table 7. From the damage stability analysis the worst scenery are the more astern cases that involve the engine room compartment, for which the freeboard are evaluated from the uppermost Ro-ro deck. The SA calculation for the above mentioned cases, at first assumed the whole Ro-ro compartment damaged, with the two Ro-ro decks connected.

\[
\begin{array}{lllll}
\text{Limit} & \text{Min/Max} & \text{Actual} & \text{Margin} & \text{Pass} \\
\hline
(1) \text{Absolute Angle at Equilibrium (HL3)} & <15.00\ deg & 7.60 & 7.80 & \text{Yes} \\
(2) \text{Area from Equilibrium to 15.00 deg or Flood (HL4)} & >0.0280\ m\cdot R & 0.631 & 0.603 & \text{Yes} \\
\end{array}
\]

For the side damage dimensions, calculated according to the above mentioned code, the worst scenery are the more astern cases that involve the engine room compartment, for which the freeboard are evaluated from the uppermost Ro-ro deck. The SA calculation for the above mentioned cases, at first assumed the whole Ro-ro compartment damaged, with the two Ro-ro decks connected.

\[
\begin{array}{llll}
\text{Limit} & \text{Min/Max} & \text{Actual} & \text{Margin} & \text{Pass} \\
\hline
(1) \text{Absolute Angle at Equilibrium (HL3)} & <15.00\ deg & 8.65 & 6.35 & \text{Yes} \\
(2) \text{Area from Equilibrium deg to Flood or 15.00 (HL4)} & >0.0280\ m\cdot R & 0.033 & 0.005 & \text{Yes} \\
\end{array}
\]

\[
\begin{array}{llll}
\text{Side Damage according to the HSC 2000/09 code} \\
\hline
l (m) & b (m) & h \\
5.51 & 2.23 & unlimited \\
\end{array}
\]

\[
\begin{array}{llll}
\text{Areas vulnerable to raking damage HSC 2000/09} \\
\hline
l_1 (55\%L) (m) & l_2 (m) & p (m) & g (m) \\
53.96 & 34.34 & 0.45 & 1.12 \\
\end{array}
\]

\[
\begin{array}{llll}
\text{Areas not vulnerable to raking damage HSC 2000/09} \\
\hline
l (m) & p (m) & g (m) \\
5.51 & 0.22 & 2.23 \\
\end{array}
\]

In this way the M3 ship seem to not satisfy the SA criteria, imposing the rearrangement of the astern cofferdam in order to avoid the Ro-ro space damage for the indicted cases.

A more in depth approach underlines that, according to the damage scenario, the added water loading is bounded astern.

The trim ensures that the water doesn’t flood the lower Ro-ro deck. According to this assumption we have re-modeled the Ro-ro space in two distinct compartments.

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**Figure 11. Results of SA application to a catamaran**

**Figure 12. M3 ship subdivision**

**Figure 13. M3 Ro-ro decks profile view**
compartments, taking into account the non-watertight ramps as internal flooding points.

We have noticed that the water from the uppermost damage Ro-ro deck does not reach the ramps points i.e. the lower twin deck that remains intact. The SA results are shown in Figure 14.

5. CONCLUSIONS
An investigation on the preliminary mono-hull and catamaran fast ferry subdivision, compatible with the new IMO HSC -High Speed Craft- codes has been developed.
A review on the intact and damage stability criteria required for a multihull passenger has been carried out. The successively intact and damage stability analyses show that the fast ferry vessel examined comply easily with the new IMO H.S.C -High Speed Craft- codes.
A Stockholm Agreement to the HSC vessels has been studied, extending the critical rules conditions normally considered for Ro-ro pax ships to the HSC Ro-ro passenger vessels.

6. ACKNOWLEDGEMENTS
This work has been supported by the Italian Ministry of University and University of Naples “Federico II”.

7. REFERENCES
RINA (1994) Rules for the Classification of HSC Craft, Effective from 1 January 1996
RINA (2009) Rules for the Classification of HSC Craft, Effective from 1 January 2009
DL n. 65 (2005) Attuazione della direttiva 2003/25/CE relativa ai requisiti specifici di stabilità per le navi Ro-ro da passeggeri, Effective from 12 may 2005

<table>
<thead>
<tr>
<th>HCS CODE 2000/09 DAMAGE STABILITY CRITERIA</th>
<th>Limit</th>
<th>Min/Max</th>
<th>Actual</th>
<th>Margin</th>
<th>Pass</th>
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<tr>
<td>(1) Angle from Equilibrium to RAzero or FM</td>
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<td>(2) Area from Equilibrium to FM or 27.00 deg</td>
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<td>(3) Absolute Angle at Equilibrium</td>
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<td>(4) Righting Arm at MaxRA</td>
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<td>(5) Distance from WPL to FM</td>
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<td>2.334</td>
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</tr>
</tbody>
</table>

SA with 0.112 m water height on deck

<table>
<thead>
<tr>
<th>Limit</th>
<th>Min/Max</th>
<th>Actual</th>
<th>Margin</th>
<th>Pass</th>
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<tbody>
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<td>(1) Angle from Equilibrium to RAzero or FM</td>
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<tr>
<td>(2) Area from Equilibrium to FM or 27.00 deg</td>
<td>&gt;0.0150 m²</td>
<td>0.139</td>
<td>0.120</td>
<td>Yes</td>
</tr>
<tr>
<td>(3) Righting Arm at MaxRA</td>
<td>&gt;0.341 m</td>
<td>0.979</td>
<td>0.676</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Figure 14 results for the M3 ship worst damage case