CASE STUDY ON STATIC EQUIVALENT METHOD (SEM)

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SUMMARY

Static Equivalent Method (SEM) developed by The Ship Stability Research Centre, University of Strathclyde, Glasgow, UK (SSRC) is explored through a calculation case on a modern Ro-Ro Passenger Ferry. Comparison of the results of SEM and IMO Circ.No.1891 (i.e. Stockholm Agreement) is carried out. The merits of the SEM are then considered on the designer's point of view.

INTRODUCTION

A modern Ro-Ro Passenger Ferry designed by Deltamarin Ltd is selected for this study.

Main dimensions of the ship are:

LPP	185.40 m
B	27.50 m
T	6.70 m
H	9.50 m

There are side casings on the trailer deck all the way from stern to bow. No centre casing or flood control doors are fitted on the trailer deck. The ship has an extensive B/5 lower hold. WT compartments of the ship are shown in Figure 1.

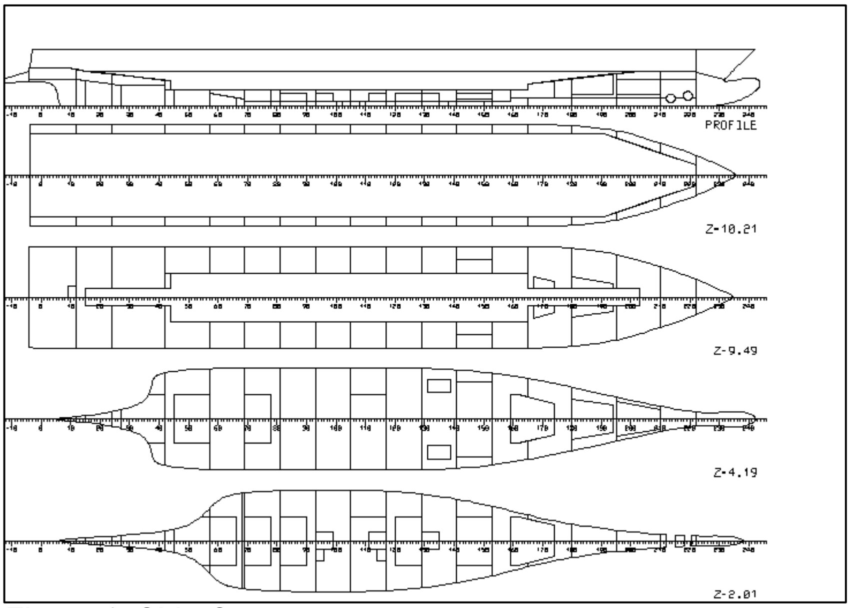

Figure 1: Ship Compartments

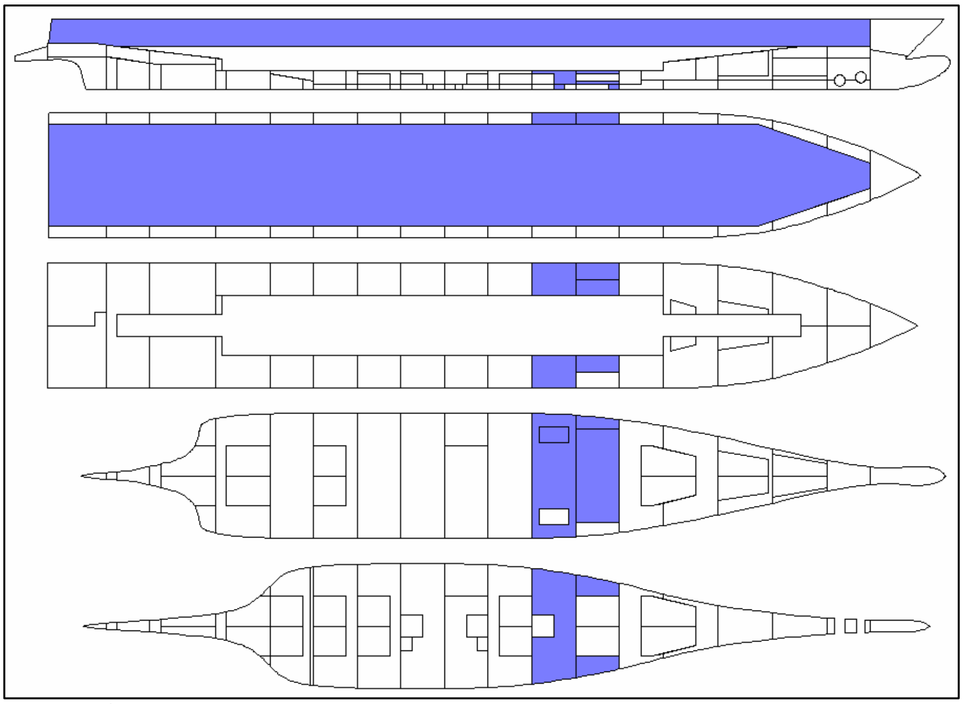

Figure 2: Most severe damage

All two-compartment damage cases according to the SOLAS 90 damage extents have been defined, that is 17 damages in total. Damages of lesser extent have been neglected in this study. The most severe damage is presented in figure 2. GM requirements taking into account the accumulated sea water on the deck according to the IMO Circ.No.1891 with Significant Wave Height of 4.0 m have been calculated. For each of these damages the SEM calculation has then been carried out with the intact condition having exactly the same GM that was found to be the requirement from Circ.No.1891. The resulting Critical Wave Heights from the Original SEM and the Alternative SEM have then been compared with the wave height used in Circ.No.1891 calculation. The merits of the SEM as a "ship designer's tool" have been considered.

REVIEW OF RESULTS

The Critical Wave Heights have been calculated with the formula given in the original SEM and also with formulae given in the alternative SEM developed to represent 0% and 100% capsize relative frequency. The SEM correlation between the Height of Accumulated Water **h** and the Critical Significant Wave Height $\mathbf{H_s}$ are shown in Table 1.

Original SEM	Alternative SEM	
$h = 0.085 \cdot H_S^{1.3}$	$h_{0\%C} = 0.250 \cdot H_S^{0.83}$	$h_{100\%C} = 0.215 \cdot H_S^{0.81}$

Note: $x\%C$ means $x\%$ *C*apsize probability

Table 1: Original SEM and Alternative SEM formulae

In Table 2 the most important results are gathered. The columns of the table are:

DAMAGE	Damage identification. Damages are numbered from the aft.
GMREQ	GM requirement calculated according to IMO Circ.No.1891 with Significant Wave Height of 4.0 m.
CRITERIA	The limiting damage stability requirement.
h	The Head of Water **h** calculated according to the SEM.
$H_{s\ original}$	Critical Wave Height calculated according to Original SEM
$H_{s0\%c}$	Wave Height corresponding to h0% Capsize Frequency
$H_{s100\%c}$	Wave Height corresponding to h100% Capsize Frequency
Tot V	Total volume of water on trailer deck
Add V	Volume of accumulated water above sea level

DAMAGE	GMREQ [m]	CRITERIA	h [m]	$H_{s\ original}$ [m]	$H_{s0\%c}$ [m]	$H_{s100\%c}$ [m]	Tot V [m^3]	Add V [m^3]
DDS0+W	1.493	MAXGZP	0.975	6.530	5.151	6.462	307	305
DDS1+W	1.584	MAXGZP	0.865	5.960	4.465	5.581	313	299
DDS2+W	2.324	MAXGZP	0.730	5.231	3.639	4.526	453	344
DDS3+W	2.471	RANGE	0.825	5.745	4.214	5.260	444	362
DDS4+W	2.063	RANGE	0.904	6.161	4.703	5.886	330	318
DDS5+W	1.842	RANGE	0.919	6.240	4.797	6.007	340	331
DDS6+W	1.685	RANGE	0.918	6.239	4.796	6.006	289	288
DDS7+W	1.650	RANGE	0.984	6.579	5.212	6.540	307	300
DDS8+W	2.372	RANGE	0.829	5.766	4.238	5.291	562	453
DDS9+W	2.459	RANGE	0.772	5.461	3.893	4.849	580	434
DDS10+W	2.148	RANGE	0.791	5.563	4.007	4.996	426	351
DDS11+W	2.473	MAXGZP	0.770	5.448	3.879	4.832	596	428
DDS12+W	2.430	MAXGZP	0.782	5.514	3.952	4.925	585	417
DDS13+W	2.386	MAXGZP	0.736	5.261	3.672	4.568	653	434
DDS14+W	2.401	MAXGZP	0.755	5.364	3.786	4.713	644	432
DDS15+W	2.205	MAXGZP	0.796	5.588	4.036	5.032	488	359
DDS16+W	1.662	MAXGZP	0.841	5.829	4.312	5.385	352	305
DDS17+W	1.330	MAXGZP	0.952	6.416	5.011	6.281	335	315

Table 2: Results of SEM calculation

Graphics of the calculation results are provided in Figures 2, 3, 4 and 5.

GM requirements calculated according to Circ.No.1891 vary between 1.330 m and 2.473 m. The highest requirement was caused by the damage into the compartments where the heeling tanks are located. The limiting criteria in the aft and forward part of the ship was the requirement of Maximum GZ taking into account the Passenger Crowding Heeling Moment. At the mid ship area the limiting criteria was the Range of 15 degrees.

The Head of Water **h** causing the angle of equilibrium θ_e that equals the angle θ_{max} derived without accumulated water was rather constant for all damages. Smallest value for **h** was 0.730 m and the maximum 0.975 m. (Note! The initial GM was always changed to correspond the Circ.No.1891 requirement)

The Volume of Water on the Deck calculated according to SEM showed peak values at the same damages that caused the biggest requirements in Circ.1891 calculation which seems quite logical.

At the present case study the SEM calculation showed 0% Capsize Frequency with Significant Wave Height varying between 3.639 m and 5.212 m, the average being 4.320 m, while the corresponding Circ.No.1891 calculation was carried out with H_s of 4.0 m. So the 0% capsize wave height gave in this particular case rather close results to the Circ.No.1891. The Critical Wave Height from Original SEM was clearly higher. The average $H_{s\ original}$ was 5.828 m.

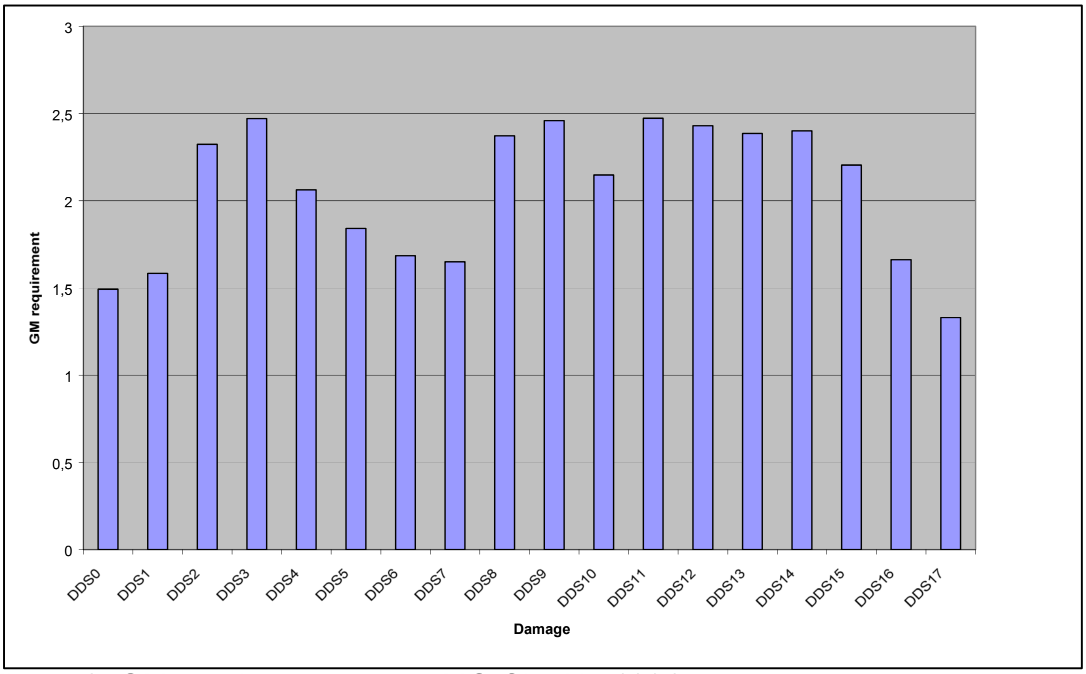

Figure 2: GM requirements acc. IMO Circ.No.1891

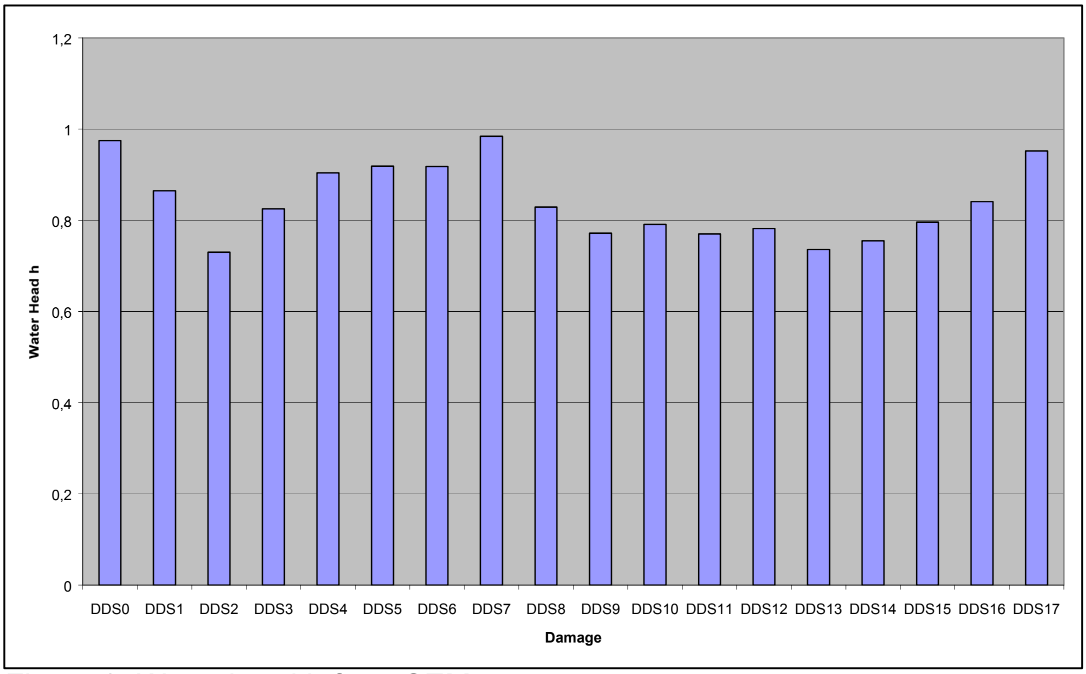

Figure 3: Water head h from SEM

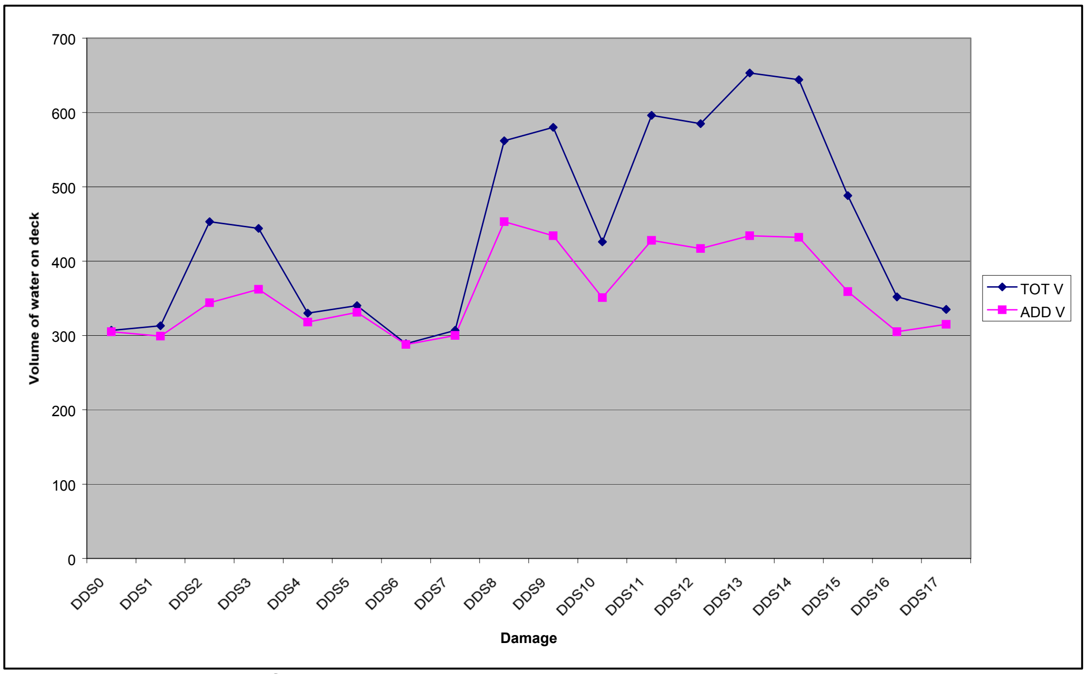

Figure 4: Volume of Water on Deck

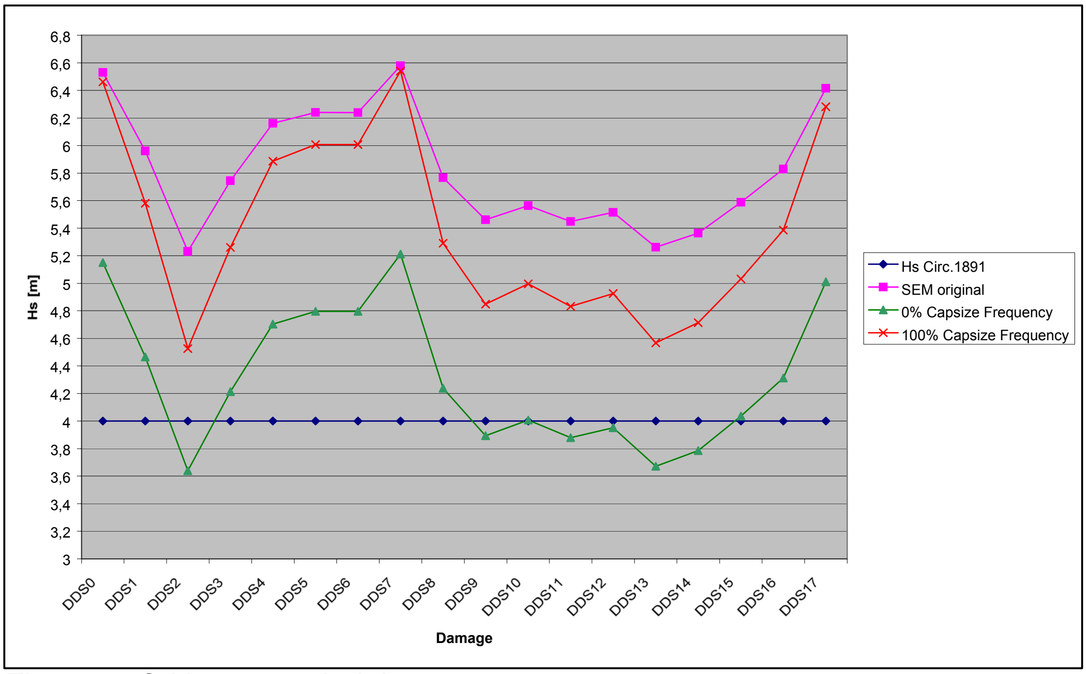

Figure 5: Critical wave heights

CONCLUSIONS

It is a well known fact from earlier experience that the Circ.No.1891 calculation and the alternative model test method can give differing results. The SEM has been tuned to give good correlation with model tests. This good correlation has been found in a lot of calculations, most of those carried out by the SSRC.

The SEM calculation is rather laborious if it is carried out “manually” using graphics of damaged GZ curves. At Deltamarin the first attempts to calculate SEM required several working days per ship. Luckily it is however possible to make most of the work automatic at least in case some modern Naval Architectural Software is used. Today by using Naval Architectural Package NAPA and a small macro program the calculation time for one ship configuration is about 2 – 3 hours.

SEM should be used with great care. Very small adjustments to calculation tolerances and calculation heeling angles seem to cause some tens of centimetres changes to the resulting Critical Wave Height. One reason for this is the normally rather flat form of the damaged GZ curve. The location of the maximum of the GZ curve need to be resolved very accurately.

The best merits of the SEM for a ship designer are that it makes it possible for small and medium sized design offices and small yards to perform analysis on dynamical water on deck performance of the ship without having expensive time domain simulation software and the necessary expertise to use that kind of software. Thus it is possible to calculate several compartment configurations in order to improve the safety of the final design for the ship.

The SEM can also reduce the amount of the water on deck model experiments needed especially in stability upgrade projects for existing ships with sailing routes on the sea area where The Stockholm Agreement is in force.

REFERENCES

SEM, Static Equivalent Method, Background and Application by
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