RESIDUAL STRENGTH OF DAMAGED SHIP HULLS

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ABSTRACT

The structural behaviour of several damaged hull girders of ships is predicted by a method that has already been tested in undamaged hulls with very good results. The method accounts for the elasto-plastic post-collapse behaviour of the panels, which are the main components of the structure and it can predict the effects of initial imperfections both in compression and tension. Different types of ships are analysed under different damaged situations. The study covers typical crude carriers and containerships and the degradation of the ultimate carrying capacity under longitudinal bending moments is evaluated.

1. INTRODUCTION

The method considers that the behaviour of the hull girder is a summation of the contributions of the individual stiffened plate elements of the hull (Gordo, Guedes Soares and Faulkner 1996). For this typical element of the structure one may estimate the corresponding load-shortening curve that characterises its behaviour. The curves are dependent on the plate and panel slenderness and they account for the presence of residual stresses in the plate, both in tension and compression (Gordo and Guedes Soares, 1993). The load-shedding pattern of the curves has already been tested in previous work with good results (Gordo and Guedes Soares, 1996). This is relevant because the accuracy of the prediction of the damaged hull strength depends very much from the prediction of the load shedding for high shortenings.

The general approach of calculating the moment curvature of the hull girder from the contribution of each element is similar to the ones adopted in Smith (1977), Adamchak (1984), Dow *et al.* (1981) and Rutherford and Caldwell (1990).

The analysis of damaged ship structures consider typical hazards both in their location as well in their extension. Examples of grounding, collision, and side damages are analysed.

2. SINGLE SKIN TANKER

The 'Energy Concentration' was an old ship that suffered hull collapse under still water conditions. Several studies of its ability to withstand bending moments have been done during the last decade due to the availability of its structural details published in sequence of the study conducted by Lloyds Register (Rutherford and Caldwell 1990). Thus, the behaviour of the intact ship under longitudinal bending is well established and the effect of a local damage may be determined. The particulars of the ship are 326.75m long, 48.20m of breadth and 26.00m in depth. The spacing between frames is 5.10m and the bottom and deck stiffeners are 1000mm apart. The ship is modelled with 241 stiffened plate elements for the 'as built' condition. The design is typical of the 70's, without double bottom, having two watertight longitudinal bulkheads and a large central keel 6.5m tall.

Four different conditions are considered for this single hull tanker, which correspond to four different major hazards: the 0 index represents the 'as built' condition, 1 refers to damage of the side below the first stringer and involving the bilge plating at one side of the ship, 2 denotes the damage of the bottom and stiffeners, and bottom girders at one side, and 3 refers to a central damage between the side girders of the bottom. The last three conditions may be understood as resulting from grounding and collision situations.

Figure 1 plots the geometry of the ship for all conditions of damage.

Table 1 summarises the most important information about the longitudinal strength of the ship under bending moment. The yield moment refers to the bending moment at which the first fibber yields in tension or compression if the material is considered to behave elastically and structural non-linearity due to imperfections and instability is ignored. This moment can be simply expressed by $M_y = \sigma_o \cdot Z$, where Z is the section modulus and σ_o is the yield stress. The plastic moment corresponds to the moment at which one of the points of beam forms a fully plastic hinge without considering non-linearities. It is the maximum theoretical moment that the cross section of the ship can sustain. The ultimate moment in sagging or hogging is the maximum moment that the ship's beam may withstand under the hypotheses described in Gordo et al. (1993), which account for material and structural non-linearities due to plasticity, residual stresses, panel buckling and initial imperfections.

A direct dependence between the net sectional area and the calculated moments is evident. The reductions on the ultimate strength are more marked for the hogging condition than for sagging because the damages are located in the bottom and in hogging the bottom is in compression, which induces a reduction on the ultimate strength of the panels as compared to their strength in tension.

Table 1 Longitudinal Strength of a Single Hull Tanker for as Built and Damaged Conditions.

Condition	Sectional Area (m2)	Yield Moment (GN.m)	Plastic Moment (GN.m)	Ultimate Moment (GN.m)			
				Sagging		Hogging	
				Vert.	Horiz.	Vert.	Horiz.
0	7.888	19.33	22.6	15.8	0.0	19.0	0.0
1	7.350	19.26	21.6	15.8	1.7	17.4	2.2
2	6.785	17.71	18.3	14.6	4.3	13.1	3.3
3	6.847	17.82	18.6	14.7	0.0	13.4	0.0

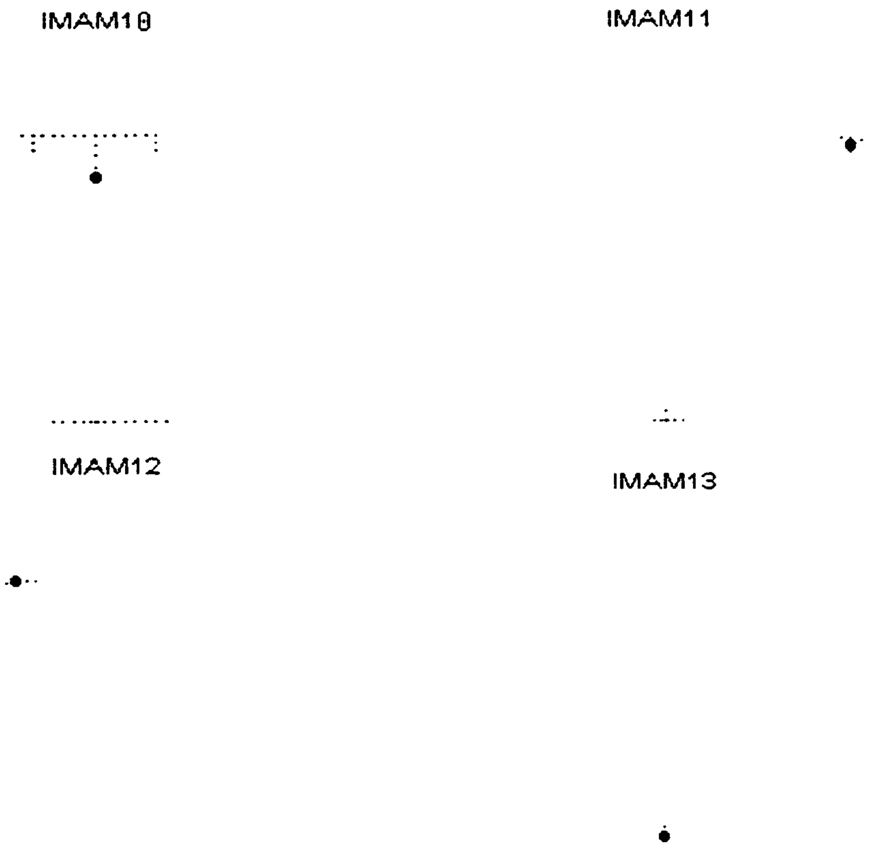

Figure 1 Models of Undamaged (IMAM10) and Damaged Cross Sections of a Single Hull Tanker (IMAM11, 12 and 13)

It is also noticeable that the degree of the damage, i.e., the reduction of the net sectional area, governs the reduction of ultimate vertical moment, in spite of the location of the damaged area. This location is only mandatory for the appearance of a horizontal component, which rises up to 29% of the vertical moment in sagging and 25% in hogging for condition 2.

This is due to the shift in the direction and location of the two principal axes of inertia, inducing horizontal bending even if the applied moment is kept perpendicular to the centre line of the ship. area of a Single Hull Tanker.

Figure 2 shows that the ultimate sagging moment is almost constant while, the ultimate hogging moment shows a large decrease with the reduction of the bottom net area.

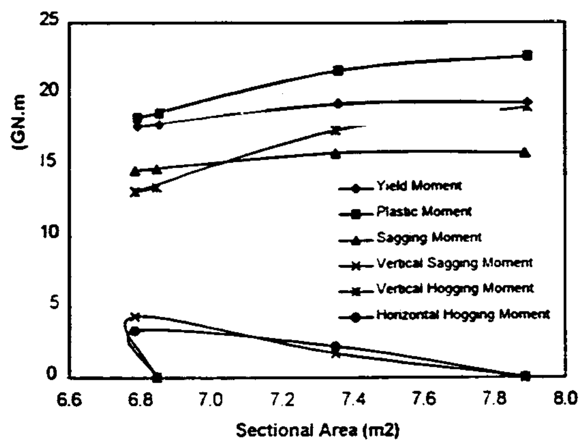

Figure 2 Dependence of the yield, plastic and ultimate moments on the net sectional

A decrease may be observed in the theoretical reserve of strength beyond the first yield, which is measured by the ratio between the plastic moment and the yield moment. One has a ratio of 1.17 that goes to a value of 1.03 on the worst case '2'. Note that the reserve of strength is not much affected by the damage of the side shell (case '1') having a ratio of 1.12.

3. DOUBLE SKIN TANKER

In tankers with double skin one may expect a better structural behaviour under damaged conditions. This statement results directly from the fact that double hull tankers have more steel in the bottom structures due to the presence of the inner bottom. So if the bottom is affected by grounding, the ship still has all the elements of the inner bottom to resist to bending and these plates and stiffeners are located very far away from the horizontal neutral axis allowing for a good resisting moment.

Figure 3 shows the models of the undamaged cross section of the tanker and three cases of damages in positions similar to those described for the single hull tanker. The tanker is 168.56m long, having a breadth of 28.00m and a depth of 15.60m. The intact ship was modelled with 197 stiffened elements, and the other cases respectively with 182, 181 and 181 stiffened elements. The spacing between frames is 3.925m and between longitudinal stiffeners is 800mm

Table 2 summarises the main results obtained for the longitudinal strength of the tanker. The worst case resulting from the reduction of area is Case 3 where the damage is located in the central area of the bottom and is affecting the integrity of the bottom girders. A reduction of 9.4% of the net sectional area of the tanker induces a reduction of 4.3% in the ultimate sagging moment and 14.1% on the ultimate hogging moment. These values confirm that the ultimate bending moment in hogging is much more affected by grounding than in sagging.

This is evident from Figure 4 by comparing the slope of the corresponding curves. But for this particular ship the hogging moment is kept above the sagging moment due to the existence of double bottom, which ensures the structural 'integrity' for all cases of damage.

A decrease in the reserve strength may be observed in Figure 4. One has a ratio of 1.09 for the intact condition '0', which is already a low value, reduced to 1.05 in damaged conditions '2' and '3'.

The low values for the reserve of strength observed in the tankers, result from the optimisation of cross section of the ships and the extensive use of two grades of steel.

Table 2 Longitudinal Strength of a Single Hull Tanker for as built and damaged conditions.

Condition	Sectional Area (m2)	Yield Moment (GN.m)	Plastic Moment (GN.m)	Ultimate Moment (GN.m)			
				Sagging		Hogging	
				Vert.	Horiz.	Vert.	Horiz.
0	2.76	3.76	4.10	2.58	0.00	3.33	0.00
1	2.54	3.70	3.93	2.55	0.32	3.02	0.42
2	2.52	3.59	3.77	2.48	0.47	2.88	0.33
3	2.50	3.57	3.74	2.47	0.00	2.86	0.00

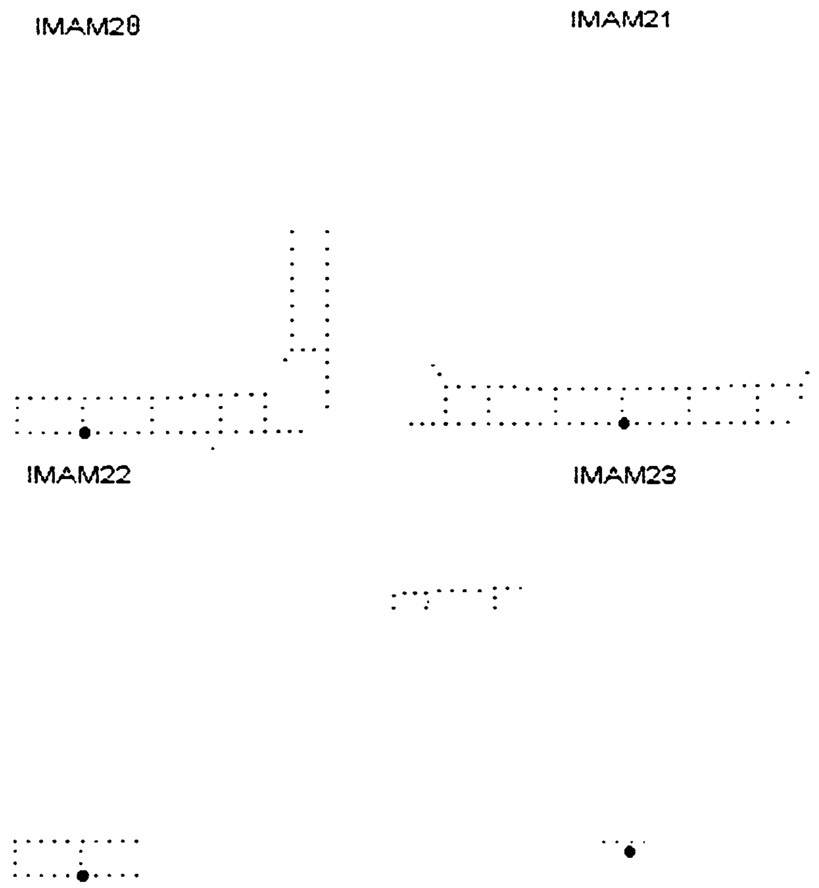

Figure 3 Models of Undamaged (IMAM20) and Damaged Cross Sections of a Double Skin Tanker (IMAM21, 22 and 23)

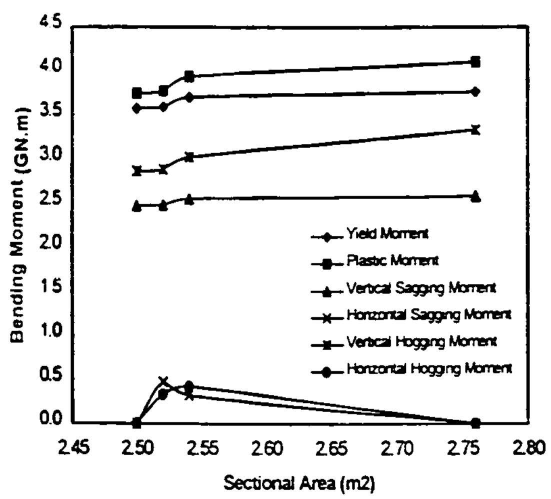

Figure 4 Dependence of the yield, plastic and ultimate moments with the net sectional area of a Double Skin Tanker

4. CONTAINER SHIP 1

The third example is a container ship with particulars of 193.25m long, 32.20m of breadth and 18.80m in depth. It was modelled using 198 elements representing the behaviour of representative reinforced plate panels for the undamaged condition.

The model for condition 1 has 18 damaged elements that are not included in the calculations, model 2 has 16 elements of the damaged bottom and model 3 has 33 elements damaged in the centre of the bottom and longitudinal girders. The spacing between frames is 860mm and the spacing between longitudinal stiffeners varies depending on the location.

The thickness of the plating also varies very much with the location due to the lacking of part of the deck, which forces the sheer strake to have a thickness of 21.5mm and the hatch coaming one of 24mm, while the bottom plating is typically 17.5mm thick (varies from 14.5mm to 20mm).

Figure 5 shows the imposed damages to the ship structure for the same conditions as previous. Condition 3 is most drastic in term of reduction of area, Table 3, and from the structural point of view all girders are affected leaving the inner bottom unsupported. The reserve of strength of the container ship is much higher than in the tankers due to the low vertical position of the neutral axis, which originates that the stress in the bottom of the ship are at low level. A small variation of the reserve of strength from 1.34 for the intact ship to 1.29 on case '3' is observed.

From the results of the ultimate moment one may conclude that the hogging moment is 25% than the sagging moment for the intact condition '0', but the difference reduces very much with the reduction of the net sectional area due to near bottom damage. The maximum reduction of the sagging moment is about 6.4% while the reduction on the ultimate hogging moment is 27.4% for the worst case, which corresponds to a reduction of 16.4% on the total sectional area.

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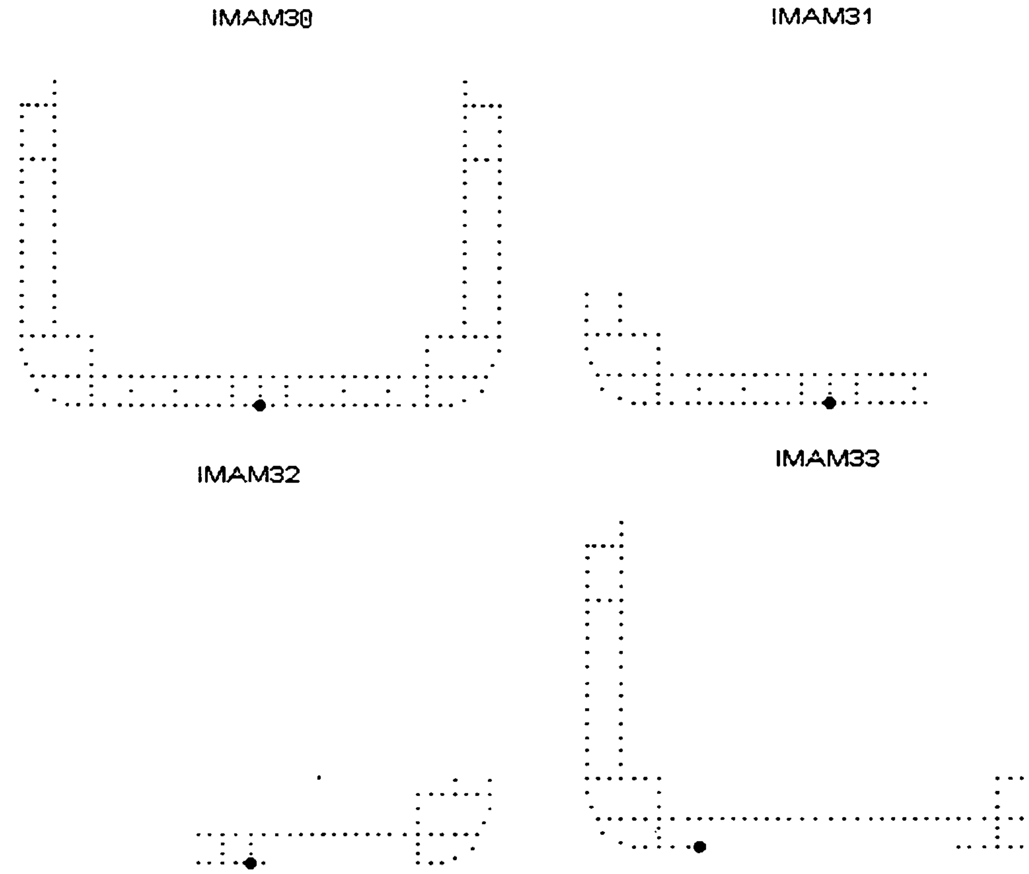

Figure 5 Models of Undamaged (IMAM30) and Damaged Cross Sections (IMAM31, 32 and 33) of a Container Ship 1

Table 3 Longitudinal Strength of a Container Ship for as built and damaged conditions.

Condition	Sectional Area (m2)	Yield Moment (GN.m)	Plastic Moment (GN.m)	Ultimate Moment (GN.m)			
				Sagging		Hogging	
				Vert.	Horiz.	Vert.	Horiz.
0	3.11	3.76	5.02	3.44	0.00	4.30	0.00
1	2.82	3.69	4.83	3.41	0.48	3.87	0.58
2	2.85	3.61	4.74	3.34	0.28	3.80	0.24
3	2.60	3.43	4.41	3.22	0.00	3.12	0.00

5. CONTAINER SHIP 2

The containership 2 is 166.96m long, 27.50m wide and has a depth of 14.30m. The spacing between frames is 780mm and between longitudinal of the bottom is 760 or 900mm depending on the location. The thickness of the bottom is 15mm at maximum and the short deck, sheer strake, is 25mm thick.

Four damaged conditions were analysed, being the last one, 'IMAM44', an extension of the model 'IMAM43' in order to have a term of comparison, see Figure 6.

This is the first ship of this study that has an ultimate hogging moment lower than the ultimate sagging moment. This is unusual and it results from the very different slenderness of the bottom and the torsion box at the deck. The first has a normal configuration, b/t=60, while the second is very stocky.

The design of the cross section seems to be unbalanced because the ultimate sagging moment is 21% higher than the ultimate hogging moment.

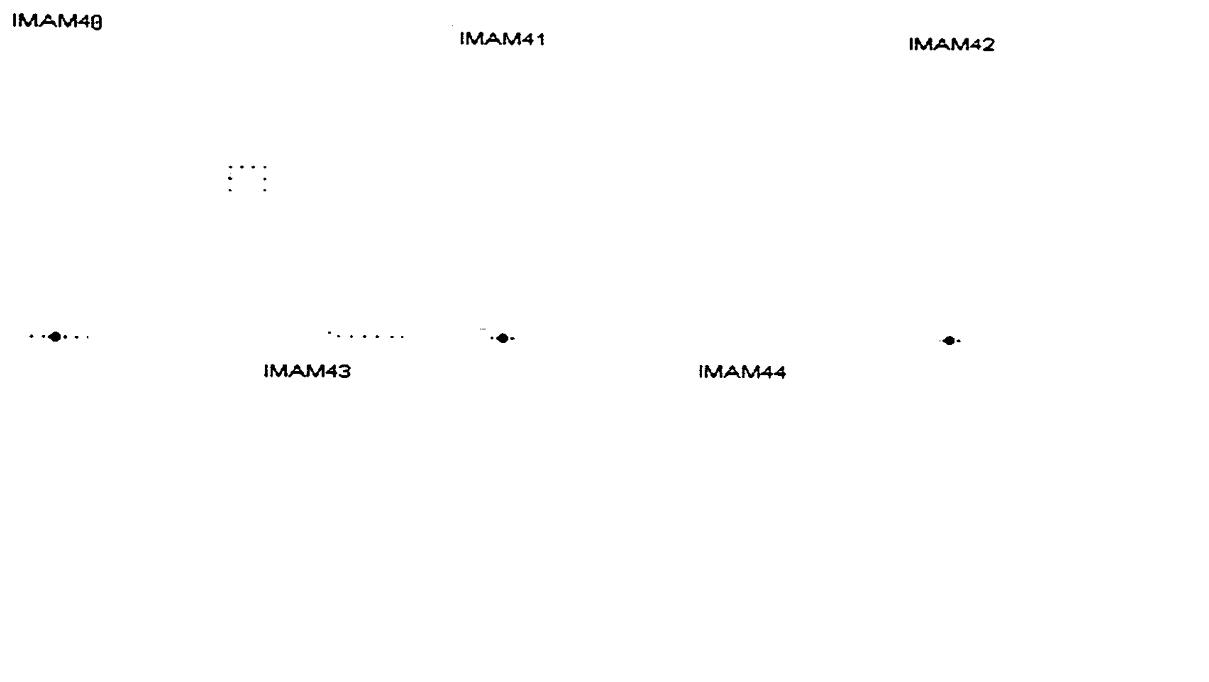

Figure 6 Models of Undamaged (IMAM40) and Damaged Cross Sections (IMAM41, 42 and 43) of Container Ship 2

Table 4 Longitudinal Strength of Container Ship 2 for as built and damaged conditions.

Condition	Sectional Area (m2)	Yield Moment (GN.m)	Plastic Moment (GN.m)	Ultimate Moment (GN.m)			
				Sagging		Hogging	
				Vert.	Horiz.	Vert.	Horiz.
0	2.268	2.578	3.273	2.525	0.000	2.081	0.000
1	2.150	2.558	3.181	2.519	0.203	1.949	0.188
2	2.088	2.463	3.028	2.440	0.291	1.813	0.148
3	2.118	2.484	3.074	2.462	0.000	1.781	0.000
4	2.011	2.402	2.907	2.385	0.000	1.634	0.000

The maximum sagging moment is almost insensitive to the reduction of area at bottom but the ultimate hogging moment goes to values very low, 21.5% lower than the intact case for damaged '4'. This is only 63% of the initial yield moment, which a reference for the classification societies, and therefore represents a serious case of damage.

6. Conclusion

Two different designs of tankers were studied in damaged conditions and one may conclude that the hogging moment is much more affected by bottom damage than the sagging moment. Thus, in case of grounding it is recommended to keep the ship in sagging because its ability to sustain bending moment remains almost intact.

The same conclusion may be applicable to the two containerships under study. In the case of very serious damage the ultimate hogging moment reduces very much and special attention must be paid to this reduction in the design of a container ship.

7. References

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