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IMPACT OF HIGH STRENGTH STEELS OVER LARGE SHIPS FORE PEAK STRUCTURE

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ABSTRACT

The fore area of the ships in extreme conditions is commonly subjected to external impact pressures such as bottom slamming and bow impact. The phenomenon combined with a poor design can lead to local structural damage (cracks, dents, buckling of plate panels) and malfunction to the installations on-board of the ship. In the present article, a comparison study between different steel material grades is performed for a VLCC fore peak structure subjected to external and internal dynamic pressures under the Harmonized Common Structural Rules for Bulk Carriers and Oil Tankers (H-CSR). Three steel grades generally used in the shipbuilding industry, one normal strength and two higher strength, are subjected for the assessment. The hull structure is built based on the benchmark crude oil carrier KVLCC2 surface developed by KRISO (Korea Research Institute for Ships and Ocean Engineering, and modelled with plate finite elements in FEMAP software. The study targets an optimization process to minimize the steel weight of the structural members by plate elements thickness reduction.

Keywords: KVLCC2, H-CSR, finite element analysis, steel grades.

1. INTRODUCTION

The slamming phenomenon in extreme conditions can lead to structural damage and malfunction to the installations on-board of the ship. However, there are few relevant studies and researches to simulate the slamming effects, which would help a safer ships design. There are many studies where the slamming phenomenon causes damages like cracks and buckling of plate panels. The slamming phenomenon can occur when the relative vertical motion between a hull section and the wave surface is equal to the draught in still water of the respective section, while the relative vertical speed is negative (when ship enters the water). The fore peak hull structure is based on the benchmark crude oil carrier developed by KRISO (Korea Research Institute for Ships and Ocean Engineering). The KVLCC2 (Fig. 1) is the second variant of the KRISO tanker with bulbous bow and U-shaped stern framelines. The main dimensions of the ship are presented in Table 1.

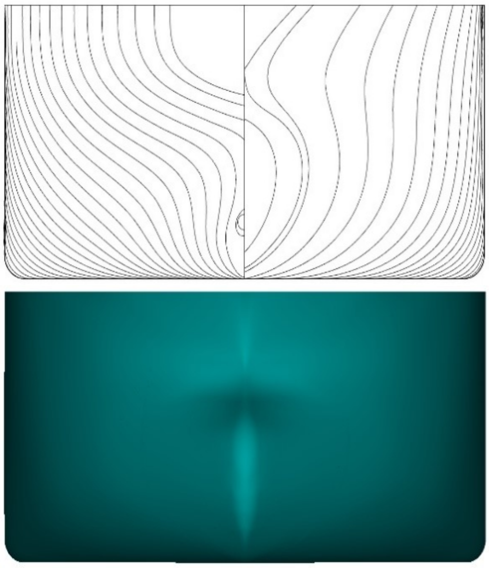


Fig. 1. KVLCC2 lines plan and hull surface

Table 1. KVLCC2 main particulars

Lpp (m)	320.0
Lwl (m)	325.5
Bwl (m)	58.0
D (m)	30.0
T (m)	20.8
Displacement (m^3)	312622
Cb	0.8098
Cm	0.9980
Cw	0.9077
LCB (%), fwd+	3.48
Design Speed (kn)	15.5

2. MINIMUM THICKNESSES

The minimum thicknesses scantling requirements for the hull structure plates, stiffeners and primary supporting members in way of the fore peak double bottom structure are based on net minimum thicknesses presented in Table 2, Table 3 and Table 4.

Table 2. Minimum net thickness for plating

Element	Location	Net Thickness
Shell	Keel	16.5 mm
	Bottom	15.5 mm
Inner bottom	-	14.5 mm
Bulkheads	Internal tank boundary	10.5 mm
Other members	Other plates in general	7.5 mm

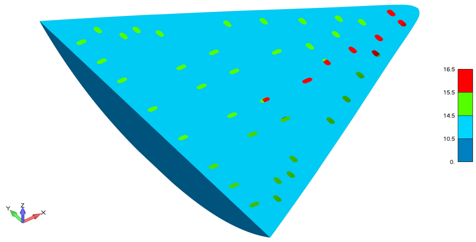


Table 3. Minimum net thickness for primary supporting members

Element	Net Thickness
Double bottom CL girder	13.0 mm
Other bottom girders	12.1 mm
Bottom floors	12.1 mm

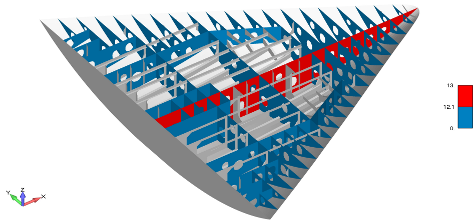
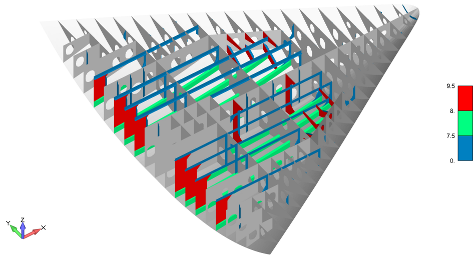


Table 4. Minimum net thicknesses for stiffeners and brackets

Element	Net Thickness
Stiffeners and attached end brackets (watertight boundary)	8.0 mm
Stiffeners and attached end brackets (other structure)	7.5 mm
Tripping Brackets	9.5 mm



3. CORROSION ADDITION

Corrosion is defined as a chemical or electrochemical reaction between a material, usually a metal and its environment that produces a deterioration of the material and its properties. The gross (as-built) thicknesses are obtained by applying the corresponding total corrosion addition, tc, in mm, for both sides of the structural member as presented in Table 2, by formula (1). Roundup0.5 (t) means that t is rounded to the upper half millimetre. The reserve thickness, tres, is considered 0.5 mm.

$$t_c = Roundup_{0.5}(t_{c1} + t_{c2}) + t_{res}$$

Table 5. Corrosion addition for one side of the structural members

Compartment type	Structural member	t_{c1} or t_{c2}
Ballast water tank	Face plate of PSM	1.5 mm
	Other Members	1.2 mm
Exposed to sea-water	Shell plating	1.0 mm

Fig. 2. Heavy corroded hull structure

4. ALLOWABLE STRESSES

The criteria for the structural assessment is based on the Working Stress Design (WSD) design method, also known as the permissible or allowable stress method. The reference stress is Von Mises stress, σvm, calculated based on the membrane normal and shear stresses of the plate element evaluated at the element centroid and at mid plane. The verification of the stress results against the acceptance criteria complies with the following formula:

$$\lambda_f \leq \lambda_{fperm}$$

where: λ_f is the fine mesh utilisation factor and λ_{fperm} is the permissible fine mesh utilisation factor.

$$\lambda_f = \frac{\sigma_{vm}}{R_y}$$

where: σ_{vm} is the calculated Von Mises stress and R_y is the nominal yield stress.

$$R_y = 235/k$$

where: k = 1, the material factor for A grade steel, k = 0.78, the material factor for HT32 grade steel, k = 0.72, the material factor for HT36 grade steel.

$$\lambda_{fperm} = 1.7 f_f$$

where: f_f = 1.0 in general, including free edge of base material.
The yield stresses for each material grade are defined as follows:
σ_{yield} (A) = 235 N/mm^2
σ_{yield} (HT32) = 315 N/mm^2
σ_{yield} (HT36) = 355 N/mm^2

Based on the formulae stated above, the allowable stresses for each steel grade are defined as follows:

σ_{vm_perm} (A) = 400 N/mm^2
σ_{vm_perm} (HT32) = 536 N/mm^2
σ_{vm_perm} (HT36) = 604 N/mm^2

5. BOTTOM SLAMMING PRESSURE

Classification societies categorize the bow and bottom slamming loads as impact loads applicable for the strength assessment of the fore part of the ships. The minimum requirement so that the bottom slamming loads to be taken into account is that the minimum draught forward should be less than 0.045L, where L is the rule length of the ship.

The CSR calculates the bottom slamming pressure for two load cases: an empty ballast tank or a void space in way of the bottom shell (Fig. 2) and a full ballast tank in way of the bottom shell (Fig. 3).

$$P_{SL} = 130\, g\, f_{SL}\, c_{SL\text{-}et}\, e^{c_1},\ for\ L \geq 170\ m$$

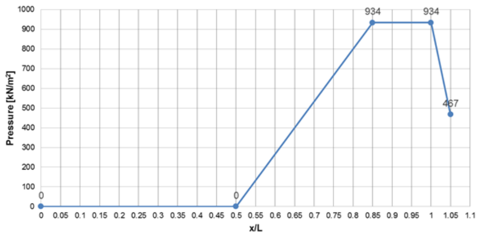


Fig. 3. Bottom slamming pressure – empty ballast tank scenario

$$P_{SL} = 130\, g\, f_{SL}\, c_{SL\text{-}ft}\, e^{c_1} - 1.25\, \rho\, g\, (z_{top} - z),\ L \geq 170\ m$$

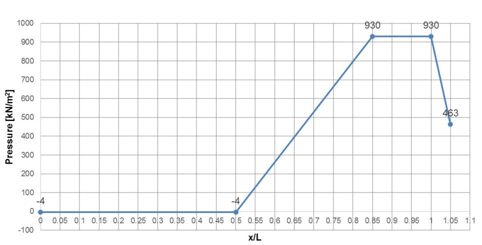


Fig. 4. Bottom slamming pressure – full ballast tank scenario

6. STRUCTURAL FE MODEL

The structural assessment is based on linear finite element analysis with 3-noded plate elements having in-plane stiffness and out-of-plane bending stiffness with constant properties. The FE model is extended sufficiently enough so that the calculated stresses are not significantly affected by the imposed boundary conditions. The mesh size is adopted ¼ of stiffener spacing (approx. 200 mm). In order to have accurate results, the aspect ratio of elements are kept close to 1 and not exceeding 3. The steels mechanical properties are: density (ρ = 7.85e-6 kg/mm^3, Young modulus (E = 206000 N/mm^2), Poisson ratio (ν = 0.3). The coordinate system is a right-hand system with X axis positive towards stem, Y axis positive towards portside and Z axis positive upwards.

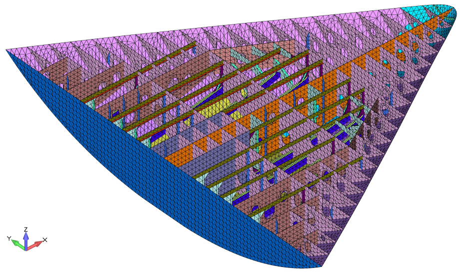


Fig. 5. Fore peak FE model

7. DESIGN OPTIMIZATION

The optimization flow is based on an objective function, design variables and constraints. The process uses design sensitivities to find the best search direction, a rate of change of analysis response with respect to changes in design variables and finding the local optimum. For the present study the design objective is the weight minimization of the hull structure by design variables, the plate thicknesses, being limited by design constraints, the plate von Mises stresses.

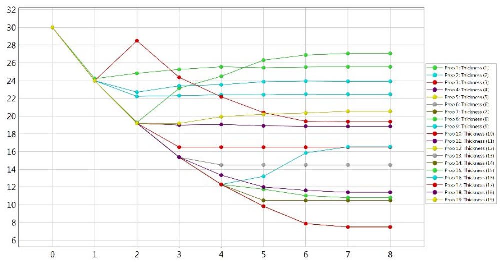


Fig. 6. Fore peak double bottom grade A steel optimization cycles

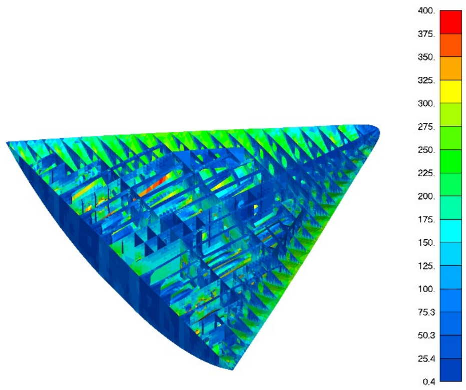


Fig. 7. Fore peak double bottom Von Mises stresses – A steel

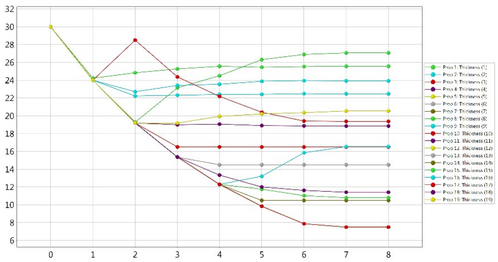


Fig. 8. Fore peak double bottom grade HT32 steel optimization cycles

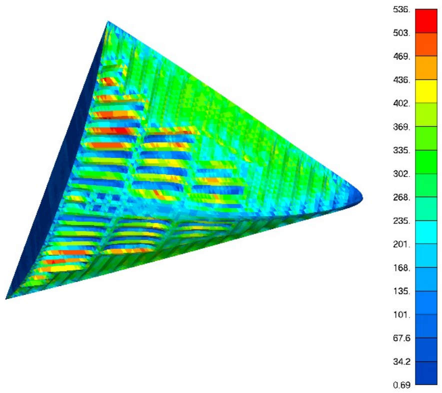


Fig. 9. Fore peak double bottom Von Mises stresses – HT32 steel

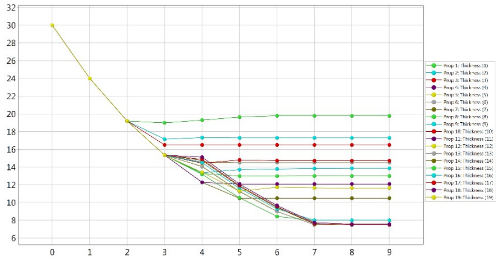


Fig. 10. Fore peak double bottom grade HT36 steel optimization cycles

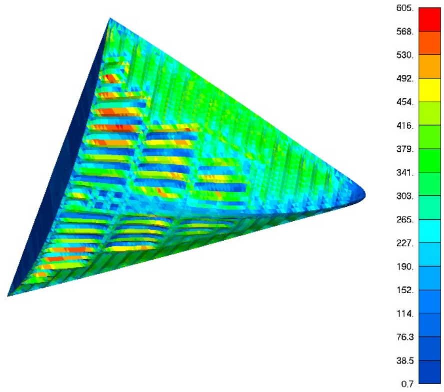


Fig. 11. Fore peak double bottom Von Mises stresses – HT36 steel

Table 5. Steel grades weight comparsion

Properties	A grade		HT32 grade		HT36 grade	
	Gross Thickness (mm)	Weight (kg)	Gross Thickness (mm)	Weight (kg)	Gross Thickness (mm)	Weight (kg)
1	*25.6*	*11928*	*21.3*	*11089*	*19.8*	*10391*
2	*22.5*	*27428*	*18.4*	*22930*	*17.3*	*21723*
3	*16.5*	*3084*	*16.5*	*3084*	*16.5*	*3084*
4	*14.5*	*18163*	*14.5*	*18163*	*14.5*	*18163*
5	*14.5*	*6126*	*14.5*	*6126*	*14.5*	*6126*
6	*14.5*	*1324*	*14.5*	*1324*	*14.5*	*1324*
7	*10.5*	*4835*	*10.5*	*4835*	*10.5*	*4835*
8	*27*	*8637*	*18.7*	*6247*	*13*	*4606*
9	*24*	*11062*	*16.7*	*8071*	*13.9*	*6924*
10	*19.4*	*4330*	*13.5*	*3190*	*14.7*	*3422*
11	*18.9*	*25254*	*13.1*	*18565*	*12.1*	*17412*
12	*7.5*	*1251*	*7.5*	*1251*	*7.5*	*1251*
13	*7.5*	*1289*	*7.5*	*1289*	*7.5*	*1289*
14	*7.5*	*579*	*7.5*	*579*	*7.5*	*579*
15	*10.8*	*3475*	*8*	*2770*	*8*	*2770*
16	*16.5*	*1595*	*11.5*	*1186*	*8*	*900*
17	*7.5*	*461*	*7.5*	*461*	*7.5*	*462*
18	*11.4*	*335*	*7.5*	*244*	*7.6*	*247*
19	*20.5*	*4515*	*14.3*	*3324*	*11.6*	*2805*
		135671		***114728***		***108313***

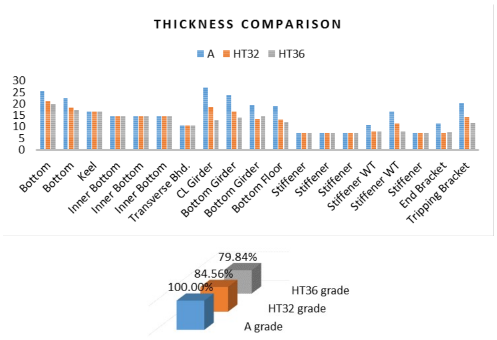


Fig. 12. Steel grades thickness comparison by functional elements

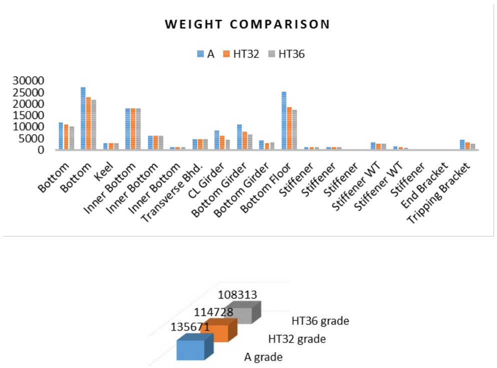


Fig. 13. Steel grades weight comparison by functional elements

8. CONCLUSIONS

During the optimization process a significant weight decrease is obtained with yielding stresses showing a convergence at an optimum cycle number. Buckling safety factors are significantly higher than the minimum required (η =1). Improvements to design optimization can be obtained by mesh finite element refinement to improve stress accuracy and by defining more design variables (properties) across the FE model.

9. BIBLIOGRAPHY

[1] **International Association of Classification Socities**, Common Structural Rules for Bulk Carriers and Oil Tankers, 1 Jan 2021.

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