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). The KVLCC2 (Fig. 1) is the second variant of the KRISO tanker with bulbous bow and U-shaped stern frame.

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 cause 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 frame.
lines. The main dimensions of the ship are presented in Table 1.

![Fig. 1. KVLCC2 lines plan and hull surface](image)

Table 1. KVLCC2 main particulars

| Element        | Location | Net Thickness |
|----------------|----------|---------------|
| Lpp (m)        |          | 320.0         |
| Lwl (m)        |          | 325.5         |
| Bwl (m)        |          | 58.0          |
| D (m)          |          | 30.0          |
| T (m)          |          | 20.8          |
| Displacement (m³) |        | 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](image)

| Element        | Location | Net Thickness |
|----------------|----------|---------------|
| Shell Keel     |          | 16.5 mm       |
| Shell 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](image)

| 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](image)

| 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, \( t_c \), 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, \( t_{res} \), is considered 0.5 mm.

\[
t_c = \text{Roundup}_{0.5}(t_{c1} + t_{c2}) + t_{res}
\]

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                      |
| Exposed to seawater | Other Members         | 1.2 mm                      |
|                  | Shell plating         | 1.0 mm                      |

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, \( \sigma_{vm} \), 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:

\[
\lambda_f \leq \lambda_{f\text{perm}}
\]

where: \( \lambda_f \) is the fine mesh utilisation factor and \( \lambda_{f\text{perm}} \) is the permissible fine mesh utilisation factor.

\[
\lambda_f = \frac{\sigma_{vm}}{R_y}
\]

where: \( \sigma_{vm} \) is the calculated Von Mises stress and \( R_y \) is the nominal yield stress.

\[
R_y = \frac{235}{k}
\]

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.

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

\[
\sigma_{vm\text{ perm}} (A) = 400 \text{ N/mm}^2
\]
\[
\sigma_{vm\text{ perm}} (HT32) = 536 \text{ N/mm}^2
\]
\[
\sigma_{vm\text{ perm}} (HT36) = 604 \text{ N/mm}^2
\]

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).

\[ P_{\text{SL}} = 130 g f_{\text{SL}} c_{\text{SL-er}} e^{a_1}, \text{for } L \geq 170 \text{ m} \]

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

\[ P_{\text{SL}} = 130 g f_{\text{SL}} c_{\text{SL-er}} e^{a_1} - 1.25 \rho g (c_{\text{top}} - z), L \geq 170 \text{ m} \]

**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 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 \((\rho = 7.85 \times 10^{-6} \text{ kg/mm}^3)\), Young modulus \((E = 206000 \text{ N/mm}^2)\), Poisson ratio \((\nu = 0.3)\). The coordinate system is a right-hand system with X axis positive towards stem, Y axis positive towards portside and Z axis positive upwards.

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. 5. Fore peak FE model**

**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

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 | 1 | 11320 | 7.1 | 2 | 1098 | 7.8 | 3 | 1059 | 7.8 |
| 4 | 2 | 1083 | 7.8 | 5 | 1083 | 7.8 | 6 | 1083 | 7.8 |
| 7 | 3 | 1083 | 7.8 | 8 | 1083 | 7.8 | 9 | 1083 | 7.8 |
| 10 | 4 | 1083 | 7.8 | 11 | 1083 | 7.8 | 13 | 1083 | 7.8 |
| 14 | 5 | 1083 | 7.8 | 16 | 1083 | 7.8 | 19 | 1083 | 7.8 |
| 20 | 6 | 1083 | 7.8 | 23 | 1083 | 7.8 | 26 | 1083 | 7.8 |
| 29 | 7 | 1083 | 7.8 | 32 | 1083 | 7.8 | 36 | 1083 | 7.8 |
| 40 | 8 | 1083 | 7.8 | 44 | 1083 | 7.8 | 52 | 1083 | 7.8 |
| 50 | 9 | 1083 | 7.8 | 61 | 1083 | 7.8 | 71 | 1083 | 7.8 |
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 ($\eta = 1$). 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
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