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Longitudinal Strength Analysis Considering the Cargo Load on Very Large Crude Carrier (VLCC)

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Abstract

Very Large Crude Carrier (VLCC) is one kind of Tanker Ship that has single hull. The single-hull is very sensitive since the ship is under longitudinal bending because of lack of the element construction to strengthen the longitudinal strength. Therefore, the longitudinal strength of Very Large Crude Carrier (VLCC) must be analysed. The objective of the present study is to analyse the longitudinal strength of the VLCC under hogging and sagging, considering one cargo hold. The Non-linear Finite Element Method is used to analyse the longitudinal strength of one cargo hold on VLCC. The Multi Point Constrained (MPC) is placed at the neutral axis position as a reference point. It is attached at one side of the cross-section, and the other is set to be constrained. The element shell is implemented to the VLCC one cargo hold model. The material properties are set to be homogenous. Other cracks, damage and failure, are not considered in the analysis. It is found that the longitudinal strengths obtained by the Finite Element Method in terms of vertical bending moments are 6.52 × 1012 and -5.5 × 1012 for hogging and sagging conditions, respectively. The longitudinal strength, including deformation and stress distributions, are also presented in this study..

1. Introduction

The process of designing a ship includes various aspects of both technical, economic and exploitation. The strength of the construction structure is one of the technical aspects that also affects the safety level of the ship when exploiting both calm and bumpy sea conditions. The benchmark that can guarantee the strength of the ship's structure is the stress experienced by the construction structure when operating in critical conditions must be smaller than the stress of the material used to form the construction component [1].

This is an indication that a ship, like any other structure, has an ultimate strength. Whether there is a periodic design purpose, damage investigation, or determining the impact of age-related to the deterioration of the ship's structure, procedures relating to strength accuracy are required [2]. One of the causes of ultimate strength failure in a ship structure is generally caused by some extremes or lack of structural resistance to material degradation. For example, continuously corrosion will reduce the dimensions of scantlings, so the supporting girders on the hull will be prone to buckling or cracking when subjected to extreme loads [3].

It is known that ultimate strength is very important in ship design. This strength must be assessed to protect the ship from damage. There are three types of forces: longitudinal, transverse, and local. Longitudinal strength is the most significant parameter that is always assessed to determine the bending moment capacity of the ship against the ship's external load when at sea [4].

Several studies have evaluated the strength of the ship's limit with the determination of the Nonlinear Finite Element Analysis method to analyze the strength of the ship. Marihutu analyzed the strength of the ship's structure due to the addition of length [1]. Paik focused on ultimate limit state analysis and design of the plated structure [2]. Pambudi analyzed the study of the peak strength of the FPSO mullet pedestal structure crane due to the interaction of the dynamic movement of cargo on the crane [3]. Progressive collapse analysis of the local elements and ultimate strength of a Ro-Ro ship by Muis Alie et al. [4]. Campanile et al. analyze the conditional reliability of bulk carriers damaged by ship collisions [5]. Hull girder ultimate strength assessment based on the experimental result and the dimensional theory by Garbatov et al. [6]. Muis Alie focuses a simplified approach on the ultimate hull girder strength of asymmetrically damaged ships [7]. Muis Alie focused residual strength analysis of asymmetrically damaged ship hull girder using beam finite element method [8]. Investigation of ship hull girder strength with grounding damage by Muis Alie et al. [9]. Parunov et al. focused on residual ultimate strength assessment of double hull oil tankers after the collision [10]. Bin Liu et al. focused review of experiments and calculation procedures for ship collision and grounding damage [11] and buckling of ship structure by Shama [12]. Comparative analysis among deterministic and stochastic collision damage models for oil tanker and bulk carrier reliability by Campanile et al. [13]. Campanile et al. focused the incidence of load combination methods on time-variant oil tanker reliability [14]. Estefen et al. concentrated the influence of geometric imperfections on the ultimate strength of the double bottom of a Suezmax tanker [15]. Probabilistic modelling of the hull girder target safety level of tankers by Guia et al. [16]. The influence of superstructure on the longitudinal ultimate strength RO-RO ships by Muis Alie et al. [17]. The assessment of the ultimate hull girder strength of Ro-Ro ship after damage by Muis Alie et al. [18]. Liu focused assessment of the strength of double hull tanker side structures in minor ship collisions [19]. Van et al. focused effect of uncertain factors on the hull girder ultimate vertical bending moment of bulk carriers [20]. Experimental and numerical investigation of the response of scaled tanker side double-hull structures laterally punched by conical and knife-edge indenters by Zhang [21].

According to the background, it is very urgent to analyze the longitudinal strength of VLCC under longitudinal bending in hogging and sagging conditions. One cargo hold is taken to be analyzed to know the behaviour of the cargo hold in terms of deformation and stress distribution. Those behaviours are also presented in the present study.

2. Methods

The longitudinal strength is analysed by using a numerical method by considering one cargo hold of the VLCC. The numerical methods are widely used and recommended by ship classification bureaus to calculate the strength of ship structures and other methods such as beam theory and stress distribution methods. Therefore, the calculation and analysis of the longitudinal strength either by using an analytical method or a simplified method are also welcome to be adopted. In the present study, the longitudinal strength of VLCC is analysed by considering one cargo hold to describe the behaviour of the VLCC under hogging and sagging conditions. The cross-section of one cargo hold is assumed to be remained plane during progressive failure and performing the Multiple Point Constrained (MPC) at the cross-section. The MPC at the neutral axis position as a reference point under zero axial force, as shown in Figure 1.

In addition, the cross-section of one cargo hold of VLCC and dimensions of the model in this study are shown in Figure 2. The full cross-section of one cargo hold is drawn in Figure 2 to better understand the VLCC behaviour under hogging and sagging conditions during the progressive collapse. The ship's dimensions are 241.5 m, 42 m, and 19.9 m for LOA, B, and D, respectively. The material properties such as type of material, modulus of elasticity, density, yield strength and Poisson's ratio are AH36, 210000 N/mm², 7850 N/mm³, 290 N/mm² and 0.33, respectively.

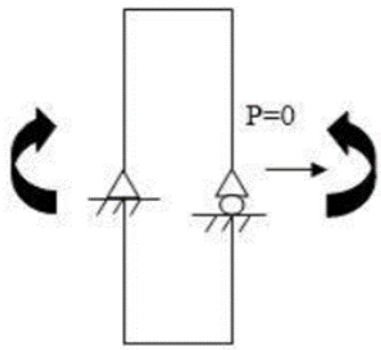


Figure 1. Boundary Conditions

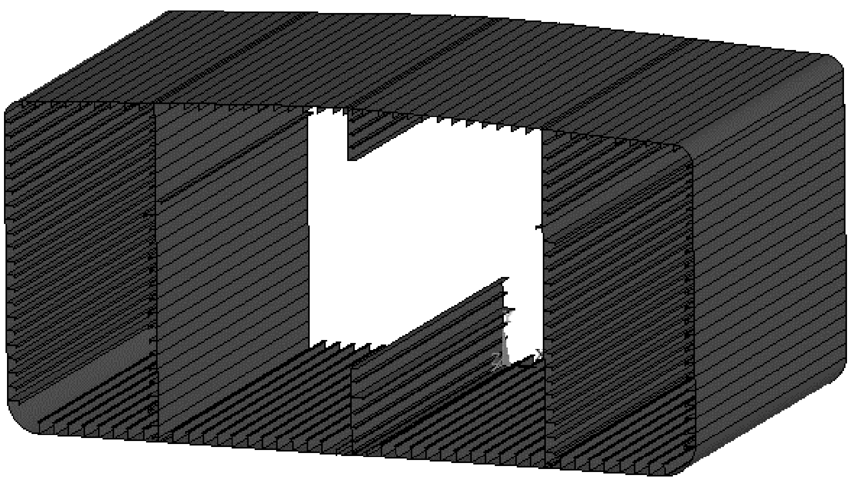


Figure 2. One cargo holds of VLCC

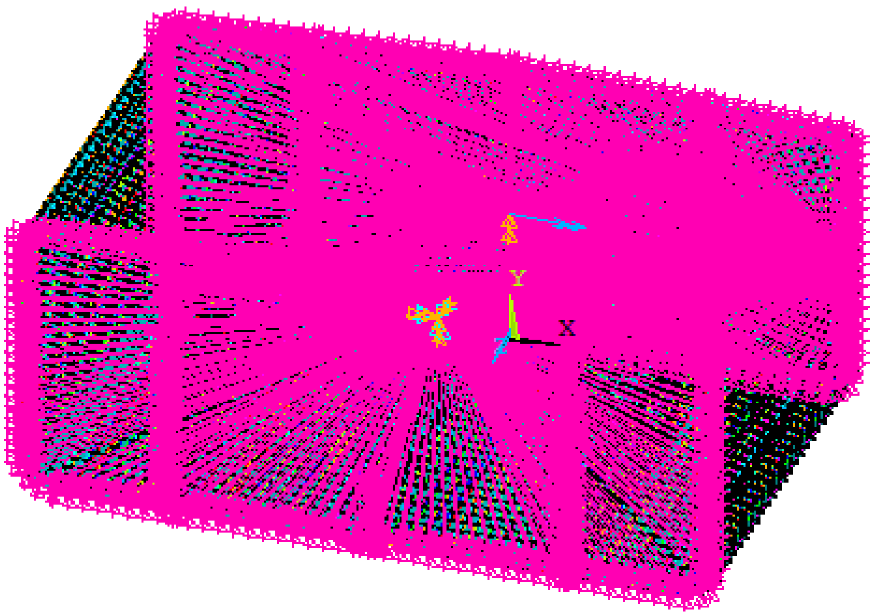


Figure 3. Boundary Conditions for NLFEA Method

The neutral axis position must be calculated in advance to determine the Multiple Point Constrained (MPC) locations. Then, the MPC is applied at one side of the VLCC cross-section and attached to the applied moment. This describes the stress distribution and deformation of the VLCC cargo hold during progressive collapse under longitudinal bending at hogging and sagging conditions, as illustrated in Figure 3. The shell 181 element type is used for the whole cargo hold model of VLCC. The material properties are set to be homogenous. The numerical method is adopted by implementing ANSYS Student Version to analyse one cargo hold model of the VLCC with the total meshing are 1000. The finite time step 500 substep and type of analysis is large displacement static. For simple calculations, strain, initial imperfections, residual weld stresses, and damage such as impact and cracking are not considered in the analysis.

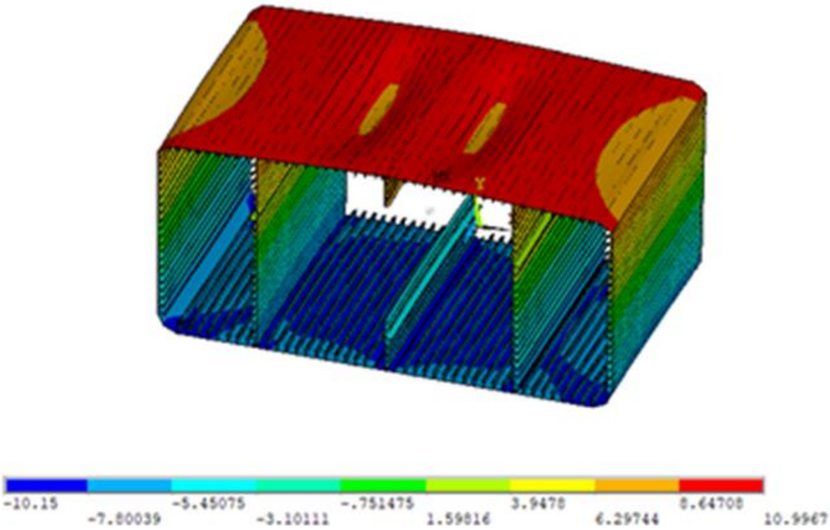
3. Results and Discussion

The longitudinal strength of the VLCC under hogging and sagging conditions are analysed using numerical methods. The analyses are performed on the model, including the behaviour during the progressive collapse. Figures 4 and Figures 5 show the VLCC deformation obtained by the numerical method under hogging and sagging conditions in elastic, ultimate strength and collapse conditions. It was found that the deformation takes place since the deck and the bottom part is under hogging and sagging conditions. The maximum deformation that occurs in the deck and bottom part are shown in Table 1.

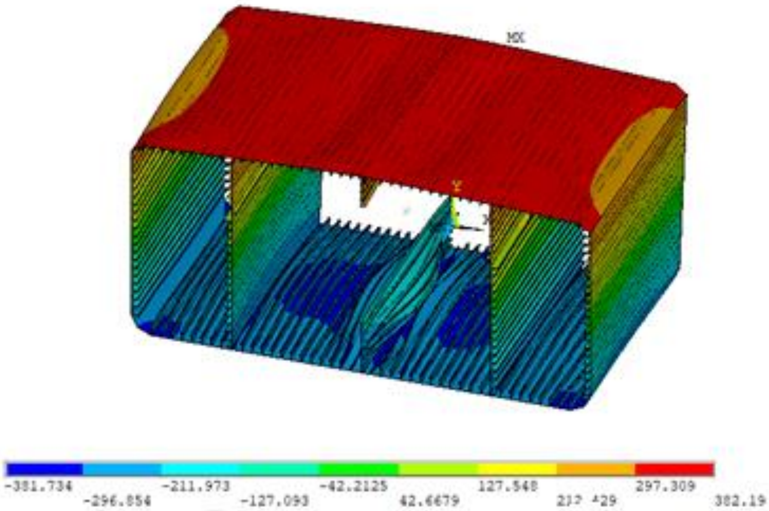
Table 1. Maximum Deformation

Dimension	**Deck (mm)**			**Bottom (mm)**		
	Elastic	**Ultimate Strength**	**Collapse**	**Elastic**	**Ultimate Strength**	**Collapse**
Hogging	44.6	48.9	54.9	39.2	46.2	51.9
Sagging	37.5	42.3	47.5	35.9	40.2	44.9

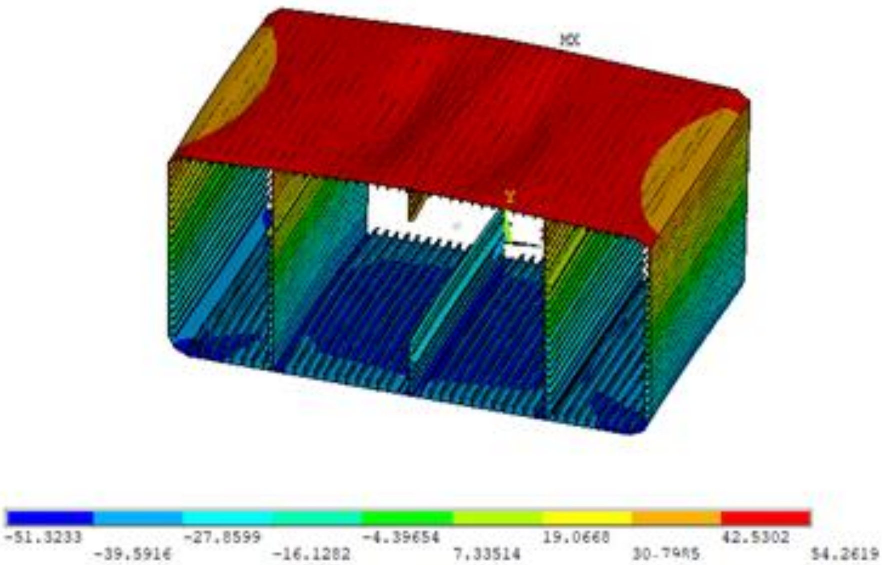
From the above analysis results, it is found that the bending moment capacity decreases after reaching its maximum value and deformation increases continuously during the progressive collapse. In accordance with the result, the hull girder is under tension, as illustrated in Figures 4 (a), 4(b) and 4(c), respectively.



(a) Elastic



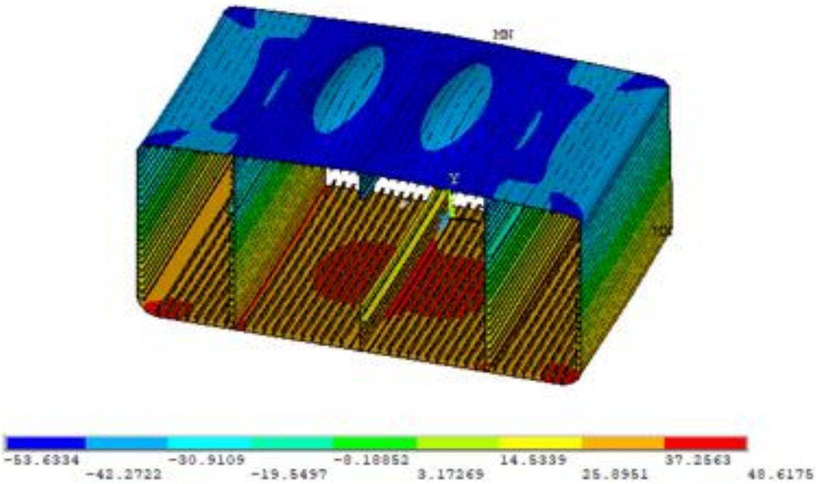
(b) Ultimate Strength



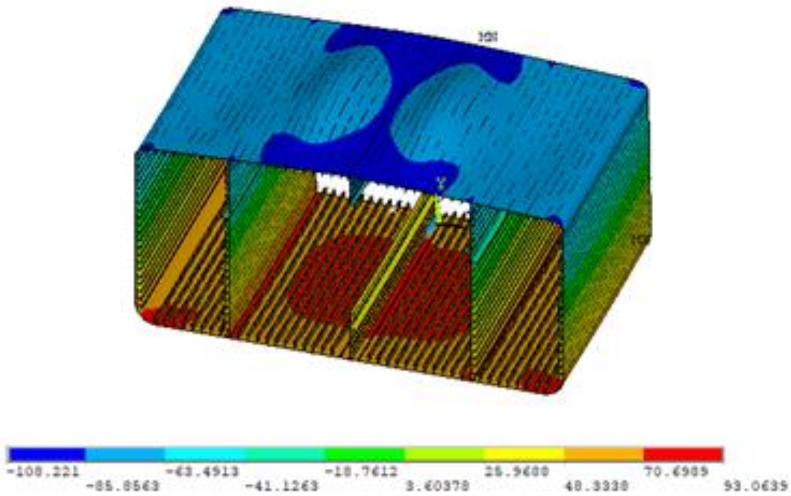
(c) Collapse

Figure 4. Deformation of Verry Large Crude Carrier (VLCC) Hogging Condition, (a) Elastic, (b) Ultimate Strength and (c) Collapse

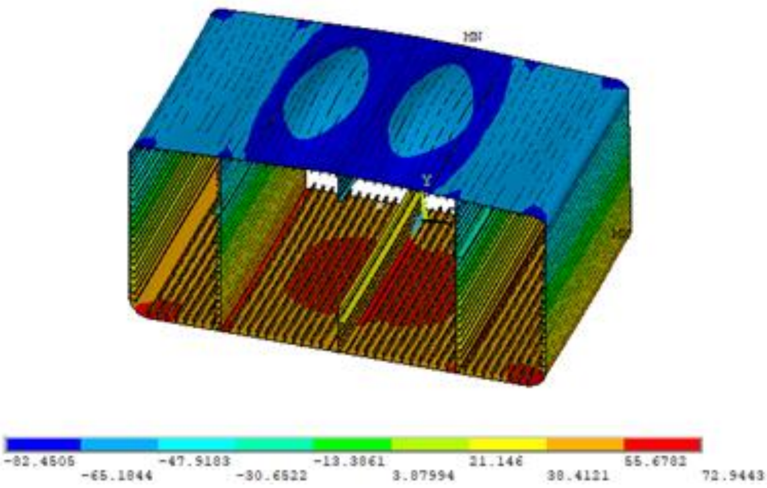
According to Figure 4 (a), the stress distribution occurs on the cargo hold model of VLCC in the elastic condition are -10.15 N/mm^2 and 10.99 N/mm^2 at the bottom and deck, respectively, since the hull girder is under tension in hogging states. In addition, Figure 4 (b) shows the stress distribution in the ultimate strength stage. In this regard, the values are -381.734 N/mm^2 and 382.19 N/mm^2 at the bottom and deck part, respectively. While in Figure 4 (c), the value of the stress distribution of the VLCC cargo hold model under hogging conditions since the hull girder under tension at collapse stage are -51.323 N/mm^2 and 54.26 N/mm^2 at the bottom and deck part, respectively. Figures 5 (a), 5(b), and 5(c) show the deformation under sagging conditions in elastic, ultimate strength and collapse regimes.



(a) Elastic



(b) Ultimate Strength



(c) Collapse

Figure 5. Deformation of Verry Large Crude Carrier (VLCC) Sagging Condition, (a) Elastic, (b) Ultimate Strength and (c) Collapse

In addition, according to Figures 5 (a), the stress distribution occurs on the cargo hold model of VLCC in the elastic condition are -53.63 N/mm² and 72.94 N/mm² at the bottom and deck, respectively, since the hull girder is under tension in hogging condition. In addition, Figures 5 (b) shows the stress distribution in the ultimate strength stage. In this regard, the values are -108.221 N/mm² and 93.063 N/mm² at the bottom and deck part, respectively. While in Figures 5 (c), the value of the stress distribution of the VLCC cargo hold model under hogging conditions since the hull girder under tension at collapse stage are -82.45 N/mm² and 72.94 N/mm² at the bottom and deck part, respectively.

The cross-sectional modulus, cross-sectional inertia and neutral axis are sensitive parameters, especially to analyse the longitudinal strength of the hull girder, including the progressive collapse behaviour such as stress distribution and deformation to the global structure of one cargo, hold VLCC. In addition, the cross-sectional modulus represents the bending strength of the hull girder in the ship structure. The plate and stiffened plates may buckle or yield since the hull girder is under tension or compression. Therefore, the behaviour of the one cargo hold VLCC must be analysed for the structural strength investigation.

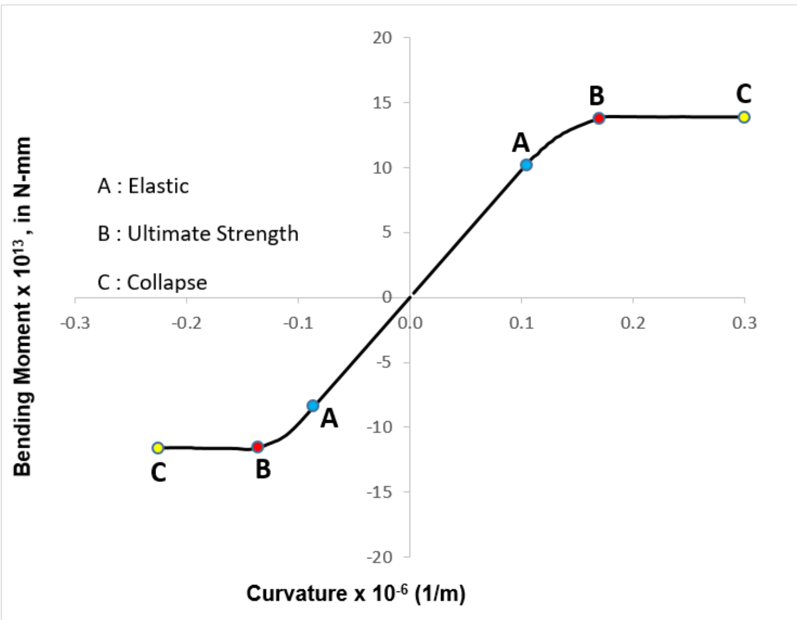


Figure 6. Moment of Curvature Verry Large Crude Carrier (VLCC)

Figure 6 shows the relationship of the moment of curvature obtained in the FEM analysis under hogging and sagging conditions. Point A describes the behaviour of the bending moment under the elastic regime, followed by point B for the ultimate strength and finally at point C for the collapse. The comparison of the longitudinal bending moment capacity ratio between hogging and sagging on the VLCC ship is 18.4%.

4. Conclusion

The analysis of the longitudinal strength of the VLCC is carried out using a numerical method under hogging and sagging conditions. The following conclusions are that those parameters, i.e. cross-sectional modulus, cross-sectional inertia, and the position of the neutral axis, significantly influence the global structure of one cargo hold VLCC model. This phenomenon is strengthened by the bending moment capacity ratio differences between hogging and sagging conditions.

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