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To cite this article: Tsumiratin Rizkiani *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **619** 012008

IOP Conf. Series: Materials Science and Engineering **619** (2019) 012008 doi:10.1088/1757-899X/619/1/012008

Progressive Collapse Behaviour of VLCC under Longitudinal Bending

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Abstract. The aim of this study is to analyse the ultimate strength of VLCC subjected to longitudinal bending moments under hogging and sagging conditions. One-frame space in the mid-ship section of VLCC is taken to be assessed. The Nonlinear Finite-Element Analysis method (NLFEA) is adopted in this study. The boundary and loading conditions are applied on both sides of the ship cross section. The Multi Point Constraint (MPC) is imposed to the cross section based on the neutral axis references. The element type is SHELL 181 is used on the model. The meshing size is 500 mm**,** and the arc length method is applied to solved the load and shortening curve. The initial imperfection, cracks and welding residual stress are ignored. The result obtained by NLFEA method for ultimate strength in hogging and sagging are $10,83 \times 10^{12}$ Nmm and $-10,34 \times 10^{12}$ Nmm, respectively. It is shown that the ultimate strength obtained by NLFEA is larger than Smith's method, and the ratios of the ultimate strength comparison are 7,71% and 11,27% for hogging and sagging conditions, respectively.

1. Introduction

Many tankers were operated using single hull on 1960-1990. In that year, there were many ship accidents results pollution and impact on the destruction of the marine environment. In this regard, due to structural degradation, the ship lost its stiffness because of damage then collapse occur. To avoid this accident, the ultimate strength of ship structure need to be investigated before and after damage takes place. Some tools of the calculation may be used to assess and/or evaluate the ultimate strength including their progressive collapse. One of them is The Non-Linear Finite Element Analysis (NLFEA) method that is very accurately and recommended by the classification and many researchers to calculate the ultimate strength of complex structures.

Many researches have been done regarding to the ultimate strength analysis of ships. Van Vu [8] performed finite element analysis to predict the ultimate longitudinal strength of intact ship using RISK method that was modified in ABAQUS software. The reliability of this approach was estimated on the comparison between results of experiment models and finite element models. Muis Alie, M.Z *et al* [4] assessed the ultimate hull girder strength of Ro-Ro ship after damage. The cross section of Ro-Ro ship was considered to be analyzed. Muis Alie, M.Z *et al* [3] analyzed the hull girder ultimate strength of asymmetrically damaged ships using Finite Element Method. The collision damage was modelled by removing the plate and stiffened plate elements. Muis Alie, M.Z *et al* [2] analyzed the residual strength of ship hull girder with bottom damage. The nonlinear finite element method was used and the fully cross section was considered in the calculation. Soares *et al* [7] evaluated the ability of structural analysis of simple method based on Smith's formulation to predict the power limit of hull girder in detriment.

The incremental-iterative approach in progressive collapse analysis of various hull girder structures, Andric, et.al [1], compares the hull girder bending moment values using 14 different methods to five different ship types, one of which is the single hull VLCC tanker. Based on the research conducted, the strength value of bending moment limit on hogging condition is greater than sagging.

The previous description has also been presented by Paik [5], for the double hull ship type. The boundary strength value is greater in the hogging condition because the bottom has a structural configuration that can massively withstand the compression force and tensile force better than the structure configuration on the deck. Configuration of double-hull and double-bottom structure cross-section models has greater border-strength than single hull and single bottom structures with the IACS design rules.

Paik et al [6], analyzed the accuracy of the ALPS / HULL calculations in the progressive collapse analysis of hull girder by comparing with the analysis method of element as well as nonlinear. The moment of inertia in the cross section and the limit strength of the girder hull is not the goal of optimization. The purpose of the optimization is on the weight of the structure and strength of the local boundary girder. This indicates that optimizing the local strength of the plate can increase the strength of the global boundary of the hull girder.

2. Method of Analysis

In the present study, the non linerar finite element analysis is used to investigate the progressive collapse behavior of VLCC under vertical bending moment in hogging-sagging condition. The breadth and depth of VLCC are 42 m and 20.3 m, respectively. The cross section of VLCC is shown in Figure 1 as follow.

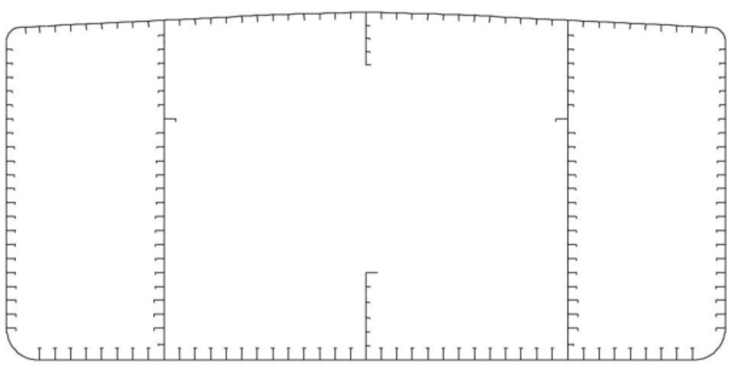


Figure 1. Cross section of VLCC.

The 3D of the finite element model is created by using shell element type 181 with configuration and material specifications for each element as shown in Table 1. The mesh size is 500 mm and it is applied for whole model. The material properties of VLCC using AH 27 as shown in Table 1.

In the present study, the ultimate strength is analysed under moment control process in order to know the progressive collapse of VLCC in intact condition. The Multi Point Constraint (MPC) is applied at both sides of the cross section as reference point. It should be noted that the MPC is placed where the neutral axis position is located. The verrtical bending moment 1.6 x 10^{13} N-mm is given on the MPC point. Then, all nodes at the fore-end are rigidly linked to the neutral axis reference point. The illustration of boundary condition and loading as shown in Figure 2.

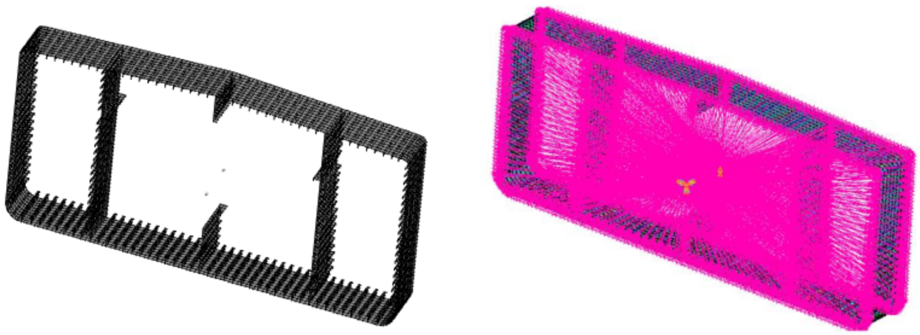


Figure 2. Modelling and boundary condition of VLCC by FE method

Table 1. Material Properties of VLCC

Density (kg/m^3)	7850
Modulus Young (N/mm^2)	210000
Poisson's Ratio	0,3
Yield Strength (N/mm^2)	290
Tangent Modulus (N/mm^2)	625

3. Results and Discussion

Table 2 shows result of the ultimate bending moment strength calculated at each percentage of intact condition in both sagging and hogging conditions using NLFEA. In intact condition, the ultimate strength of VLCC obtained as 10.83x10^{12} Nmm and -10.34x10^{12} Nmm under hogging and sagging conditions, respectively. Figure 3 shows the moment-curvature relationship of VLCC under hogging and sagging condition.

Table 2. The Ultimate Strength of VLCC (in Nmm).

Condition	NLFEA Method Nmm
$M_{u\ Hogging}$ x 10^{12}	10,83
$M_{u\ Sagging}$ x 10^{12}	-10,34

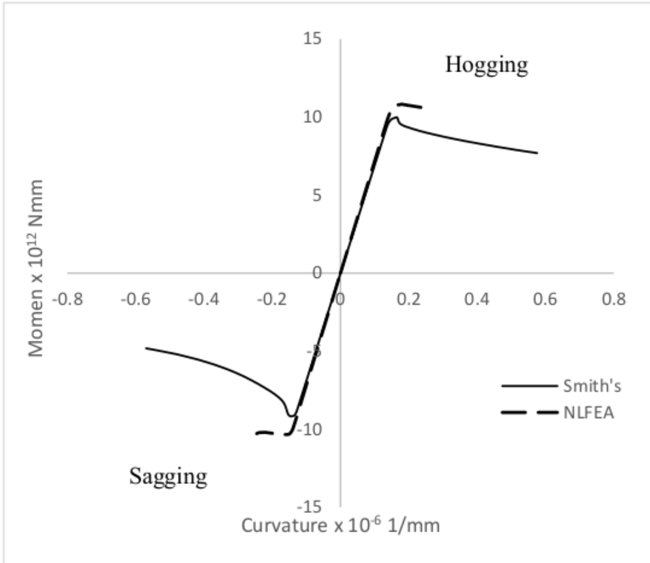
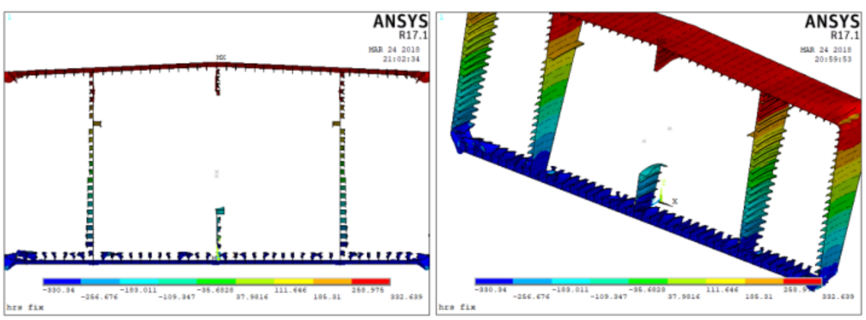


Figure 3. Moment-curvature relationship in intact condition.

Table 3. The Ultimate Strength of VLCC

Condition	Smith's Method x 10^{12} Nmm	NLFEA x 10^{12} Nmm	Ratio
$M_{u\ Hogging}$	9,986	10,82	1,084
$M_{u\ Sagging}$	-9,175	-10,34	1,127



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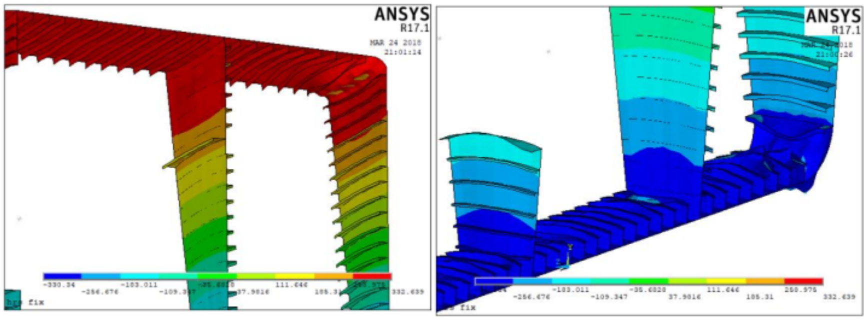

Figure 4. Stress distribution of VLCC at the ultimate strength in hogging condition.

Based on the result of the analysis using NLFEA method, the working stress on the VLCC tanker at hogging is -330.34 N/mm^2 at the bottom and 332,639 N/mm^2 on the deck as shown in Figure 4. At the hogging condition, the longitudinal section of the deck will experience the pull and the bottom will be pressed, so that the amount of stress value will vary. This is due to the process of control moment. The deformation that occurs in the bottom encounters a change in shape, where in the stiffeners and the plates on the side are bending.

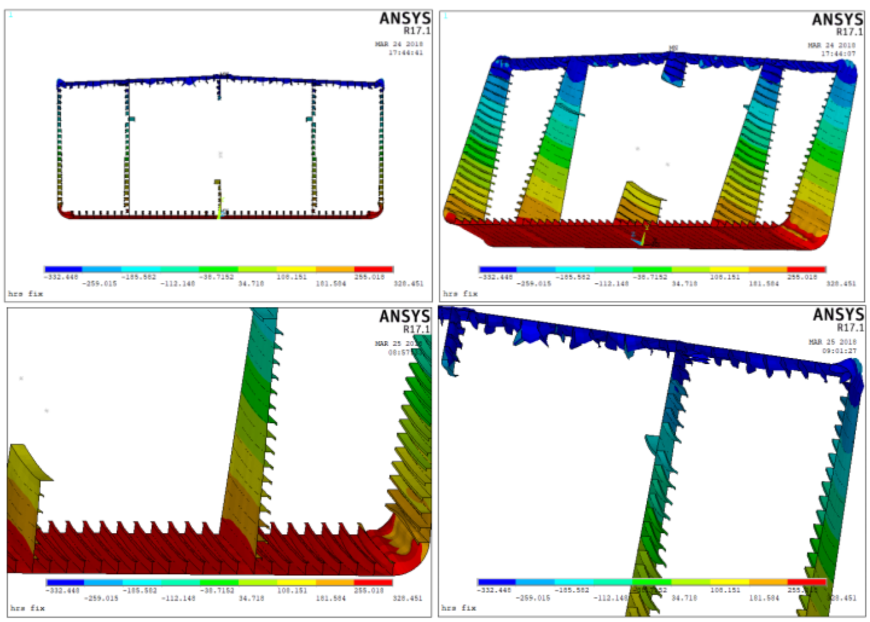

Figure 5. Stress distribution of of VLCC at the ultimate strength in sagging condition.

Based on the result of the analysis using NLFEA method, the working stress on the VLCC tanker at sagging is -332,448 N/m^2 on the deck and 328,451 N/mm^2 on the bottom as shown in Figure 5. At the sagging condition, longitudinal section of the bottom will experience the drag and the deck will be pressed. So that the amount of stress value will vary. This is due to the process of control moment. The deformation that occurs in the deck encounters a change in shape, wherein stiffeners and plate on the side are bending.

The use of the ANSYS application applying the method of NLFEA on this research has shown the ratio of the values resulted from the NLFEA method that is greater than the SMITH method. The NLFEA method can estimate the load redistribution and interaction between complex local and global failures that the accuracy of estimation of the NLFEA method is greater than the SMITH method.

4. Conclusions

The Nonlinear Finite Element Analysis (NLFEA) method to investigate the ultimate strength of VLCC under vertical bending moment in hogging and sagging condition may be summerized as follow; the comparison of the ultimate strength obtained by NLFEA is grather than Smith's method. The results obtained by the Smith method, for the hogging condition, the ultimate strength is 9,986 x 10^{12} Nmm, while in sagging condition, the ultimate strength is -9,175 x 10^{12} Nmm. The ultimate strength ratio between Smith's method and NLFEA in hogging and sagging conditions are 7.71% and 11.21%, respectively. This is because the NLFEA method can calculate the load redistribution of elements for local and global failures.

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