International Journal of Mechanical Engineering and Applications
2015; 3(1-3): 18-23
Published online January 21, 2015 (http://www.sciencepublishinggroup.com/j/ijmea)
doi: 10.11648/j.ijmea.s.2015030103.13
ISSN: 2330-023X (Print); ISSN: 2330-0248 (Online)

Prediction the ultimate longitudinal strength of intact ship by finite element method

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To cite this article:
Huynh Van-Vu. Prediction the Ultimate Longitudinal Strength of Intact Ship by Finite Element Method. *International Journal of Mechanical Engineering and Applications.* Special Issue: Transportation Engineering Technology. Vol. 3, No. 1-3, 2015, pp. 18-23.
doi: 10.11648/j.ijmea.s.2015030103.13

Abstract: This paper performed the approach to predict the ultimate longitudinal strength of intact ship by finite element method (FEM) on ABAQUS software. The reliability of this approach was estimated on the comparison between results of experiment models and finite element models. Thence, this approach will be applied on Double Hull VLCC(Very Large Crude Carrier)to predict the ultimate longitudinal strength in intact case.

Keywords: Ultimate Longitudinal Strength, Intact Ship, Double Hull VLCC

1. Introduction

In an intact condition, a ship hull will sustain applied loads smaller than the design load, and in normal seagoing and approved cargo loading conditions is will not cause any structural damage. However, the loads acting on the ship hull are uncertain due to the nature of rough seas and the possible unusual loading/unloading of cargo. In rare cases, imposed loads may exceed design loads and the ship hull may collapse locally and globally.

As imposed loads increase beyond the design loads, structural members of the ship hull will buckle in compression and yield intension. As loads continue to increase further, buckling and collapse of more structural members will occur progressively until the ultimate limit state is encountered for the hull girder as a whole.

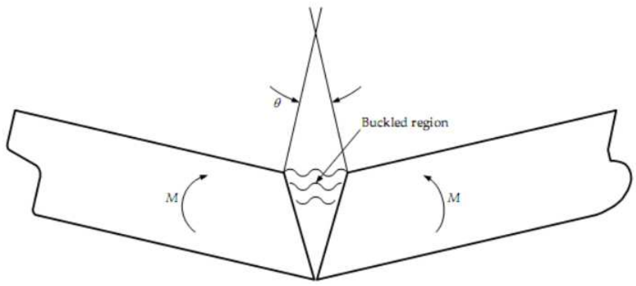

***Figure 1.** The ship model applied a vertical bending moment [1]*

There exist several approaches to carry out the progressive collapse analysis of ship hull girders. The FEM can be a powerful method to perform to this collapse analysis. Many authors published papers on calculating the ultimate or residual longitudinal strength of ship hull girders in intact or damaged condition by using the nonlinear FEM analysis.

In this present study, the ultimate longitudinal strength M_U of intact ship under vertical bending moment will be performed by the nonlinear FEM analysis which using three-dimensional model. This study has been analyzed on the ABAQUS software with the modified RIKS method [2] and it is applied on two modelsMST-3 and MSD of Nishihara experiments [3], the 1/3-scale Frigate model [4], and the Double Hull VLCC [5].

2. Procedure to obtain the Ultimate Longitudinal Strength of Intact Ship by FEM

2.1. The Finite Element Model

Many researchers proposed a kind of finite element model length, from 1+1/2 holds model [6], 1+1/4 holds model [7], 1/2+1/2 transverse frame spacing [8 – 10], 1/2+1+1/2 hold tanks [11], three cargo hold model [12, 13], 1+1+1 webframe spacing [14], or full-scale of ship [15] for different purposes. In this study, because the neutral axis shifting depend on the curvature of model during progressive collapse analysis, therefore it is necessary to eliminate the influence of the boundary condition on the analysis by extend the enough lengthen model.

The analysis shows that it is reasonable to at least extend the finite element model to the length of three web frames spacing (in Figure 2). The middle section of the finite element model is the valid section for the analysis. In the transverse and vertical direction, a full breadth and full depth model should be applied, respectively.

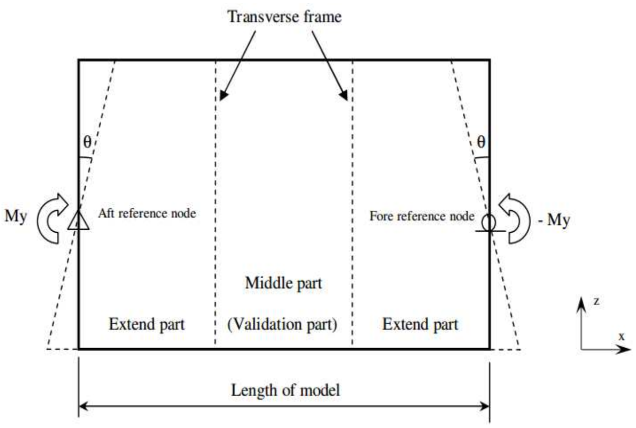

Figure 2. Fundamental of finite element model in this study

2.2. Boundary Conditions

The displacement at the two ends of the model (in Figure 2) can be simulated by means of multiple points constraints, it so called MPC. The independent point (reference point) is located at aft and fore end of model, there are the intersection between centerline and either centroid of the cross section[14] or an arbitrary height of a cross section of ship hull girder [8, 9]. The simply supported will be applied at two independent points as Table 1.

Table 1. Boundary conditions of the independent points

Location of independent point	Translational			Rotational		
	Dx	Dy	Dz	Rx	Ry	Rz
Aft end of model	fixed	fixed	fixed	fixed	-	fixed
Fore end of model	-	fixed	fixed	fixed	-	fixed

* Note.– is no constraint applied (free)

2.3. Load Application

A unit bending moment corresponding to the ultimate vertical bending moment of ship hull girder should be applied at the reference point (in Figure 2). In the modified RIKS method [2], the reference bending moment can be increased automatically by means of the load proportionality factor until the collapse of the ship hull girder.

2.4. Element Type

There are different kinds of shell elements available for modeling ship structures. The general purpose shell elements are integrated in most finite element codes provided accurate solutions in those circumstances and are used for most thick and thin shell problems. In this study, the small-strain shell elements S4R5 (4-node doubly curved thin shell, reduced integration, hourglass control, using five degrees of freedom per node) in ABAQUS[2] is used.

2.5. Initial Deflections

The initial shape deflections are assumed according to elastic buckling mode (see in Figure 3). It is given by equation (1).

$$w_i = A_o \sin\frac{m\pi x}{a}\sin\frac{\pi y}{b} \qquad (1)$$

Where: m is a number of half sinusoidal wave between the longitudinal stiffeners. A_0, B_0 and C_0 are the shape initial deflection amplitude of plate between stiffeners, stiffener sideways and stiffener lateral, respectively.

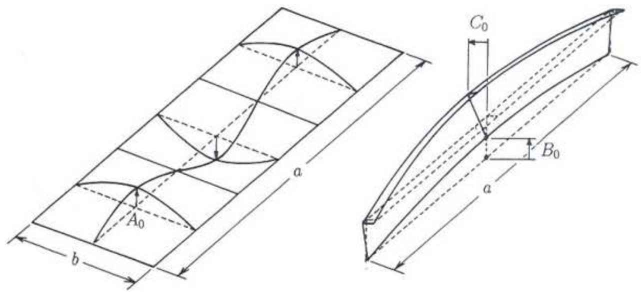

Figure 3. Assumed initial deflections in stiffened plates [5]

2.6. Residual Stress

In this study the residual stresses due to welding are estimated using equation (2) proposed by Hughes [16].

$$\sigma_r = \frac{2\eta}{s/t - 2\eta}\sigma_Y \qquad (2)$$

$$\eta = \frac{1}{t_p}\left[\frac{t_w}{2} + 0.26\frac{\Delta Q}{t_w + 2t_p}\right] \qquad (3)$$

where: t_w is the thickness of web, t_p is the thickness of plate, $\Delta Q = 78.8l^2$, $l = 0.7t_w$ when $0.7t_w < 7.0$ mm, $l = 0.7$ when $0.7t_w \geq 7.0$ mm.

3. Results and Discussions

3.1. Nishihara MST-3 Model

The length of MST-3 model is 540mm [3], therefore the overall length of finite element model is 3x540mm (show in Figure 5). The scantlings of cross section box girders show in Figure4.

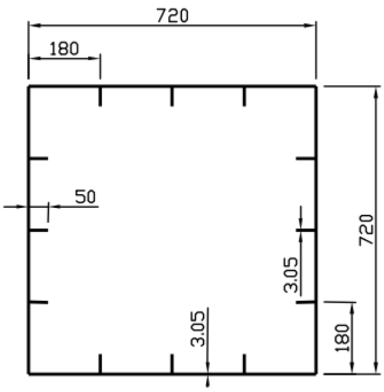

Figure 4. *The scantling of cross section in MST-3 model*

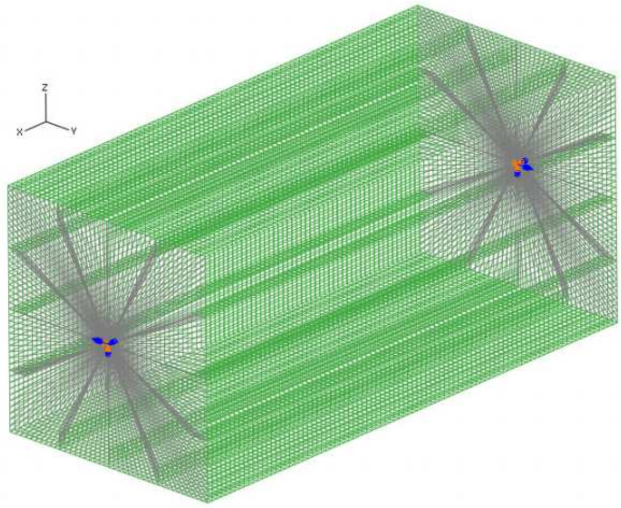

Figure 5. *The finite element model of MST-3*

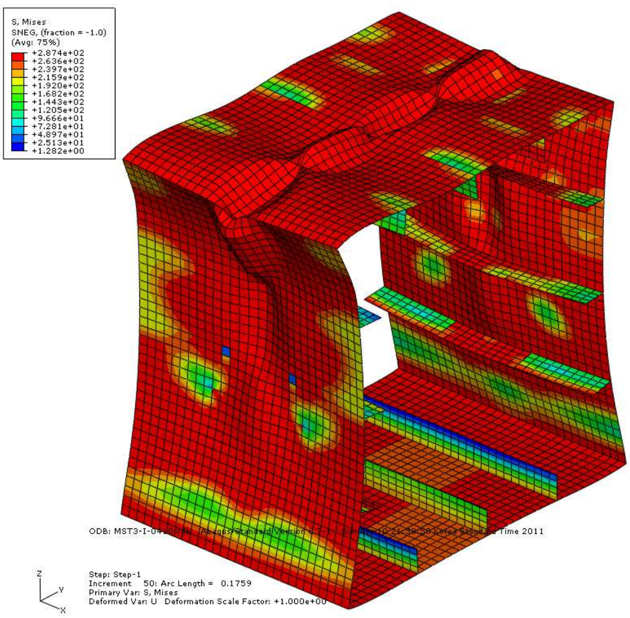

Figure 6. *Von-Mises stress plot of validation part in sagging condition*

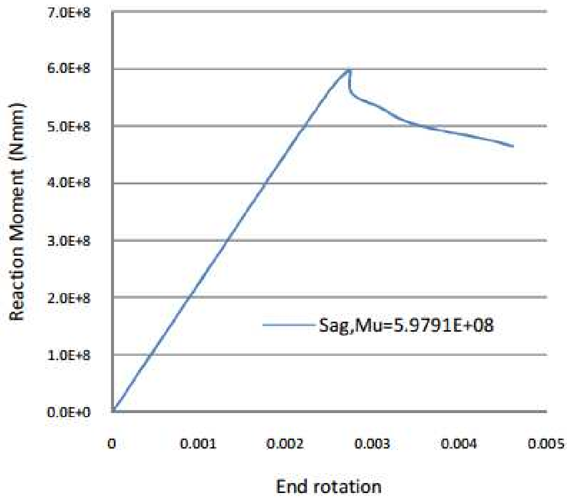

Figure 7. *The ultimate longitudinal strength M_U of MST model in sagging condition in case without residual stress*

Figures 6 and 7 show the result of ultimate longitudinal strength M_U of MST-3 model in sagging condition and Table 2 shows comparison of M_U between experiment and FEM. It can be observed that results of FEM are difference about 2% with experiment. That mean the prediction of ultimate longitudinal strength by FEM is true and accuracy.

Table 2. *The ultimate longitudinal strength for MST-3 model*

M_U (E+8 Nmm)	Experiment	FEM	
		Only initial deflection	Initial deflection and residual stress
Sagging	5.8840	5.9791	5.7611
Difference		1.6%	- 2.09%

3.2. Nishihara MSD Model

The length of MSD model is also 540mm [3], therefore the overall length of finite element model is 3x540mm. The scantlings of cross section box girders show in Figure 8.

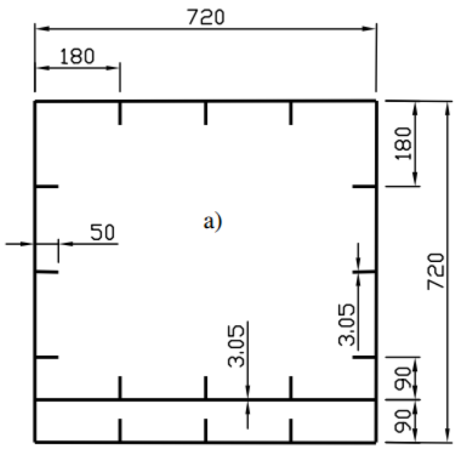

Figure 8. *The scantling of cross section in MSD model*

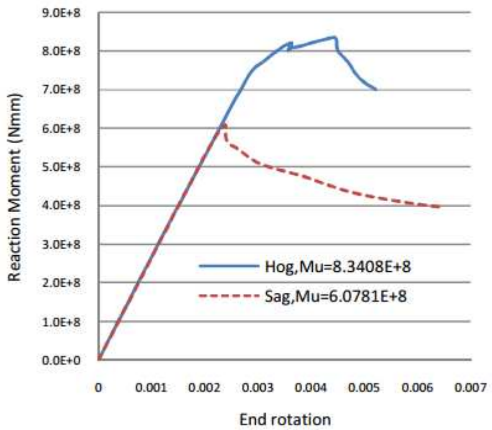

Figure 9. *The ultimate longitudinal strength M_U of MSD model in case without residual stress*

Table 3 shows the comparison of ultimate longitudinal strength between FEM and experiment results. It can be observed that results of FEM are good agreement with experiment. Difference results between without residual stress case and with residual stress case of FEM are about 3 % for sagging condition and about 1 % for hogging condition.

Table 3. *The ultimate longitudinal strength of MSD model*

	Sagging (E+8 Nmm)			Hogging (E+8 Nmm)		
		FEM			FEM	
	Experiment	Only initial deflection	Initial deflection and residual stress	Experiment	Only initial deflection	Initial deflection and residual stress
M_U	5.9330	6.0781	5.9028	8.3847	8.3408	8.3117
Difference		2.4 %	- 0.51 %		- 0.5 %	- 0.87 %

3.3. The 1/3-scale Frigate Model

The 1/3-scale Frigate model was conducted by Dow [4], the total dimensions are 18m length, 4.1m breadth and 2.8m depth. The scantling shows in Figure10. The validation part is one frame space, equal 457.2 mm. Therefore the length of a finite element model is 3x457.2mm.

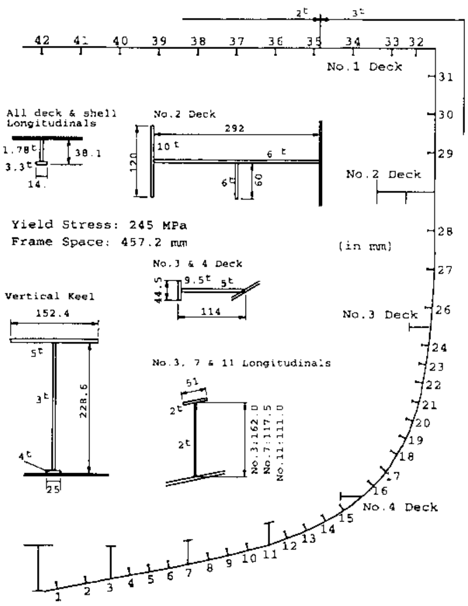

Figure 10. *The cross section of the 1/3-scale Frigate model [4]*

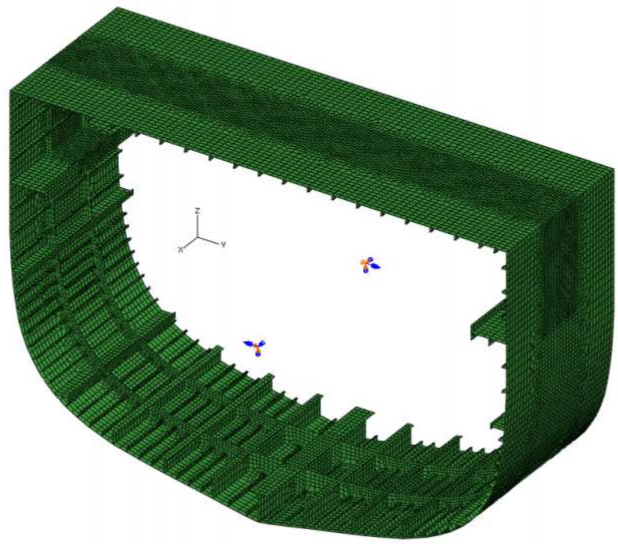

Figure 11. *The finite element model of 1/3-scale Frigate*

Table 4 shows the comparison of ultimate longitudinal strength M_U between experiment and FEM. It showed that the result of FEM is good agreement with experimental result.

Table 4. *The ultimate longitudinal strength for 1/3-scale Frigate*

	Experiment	FEM
M_U (E+9 Nmm)	9.78072	9.65688
Difference		- 1.27 %

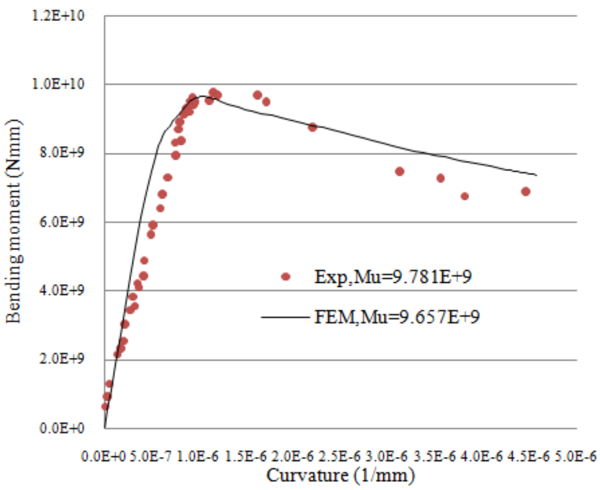

***Figure 12.** The ultimate longitudinal strength M_U in sagging condition for 1/3-scale Frigate*

The Figure 12 shows curves which performed the progressive bending moment by experimental results (red dot points) and FEM results (black line). Difference to other researchers, this study added the web frame in the finite element model (see in Figure 11), that is the reason why the FEM results are good agreement with experimental results within included in the post ultimate regime.

Through results between FEM and experiments are mentioned as above, from the laboratory model (Nishihara MST-3 for single bottom model, Nishihara MSD for double bottom model) to 1/3-scale Frigate model, it can be concluded that the FEM result is accuracy and reliability. Therefore, this FEM use to obtain the ultimate longitudinal strength for intact ship, in this paper is Double Hull VLCC given by ISSC 2000 [5].

3.4. Double Hull VLCC

The principal dimensions of Double Hull VLCC in ISSC 2000 [5] report are 315 m length, 58 m breadth and 30.3 m depth. The validation part is one frame space, equal 4980 mm. Therefore the length ofa finite element model is 3x4980 mm (see Figure 13).

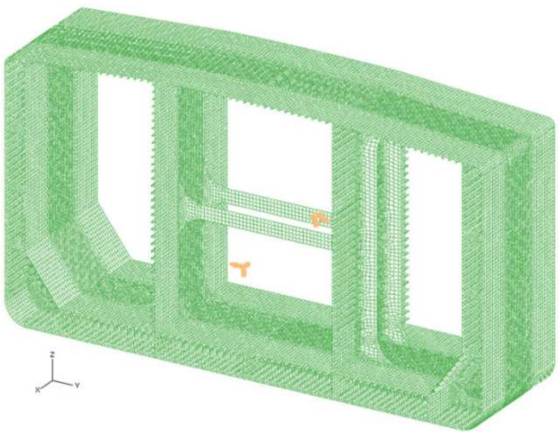

***Figure 13.** The finite element model of Double Hull VLCC*

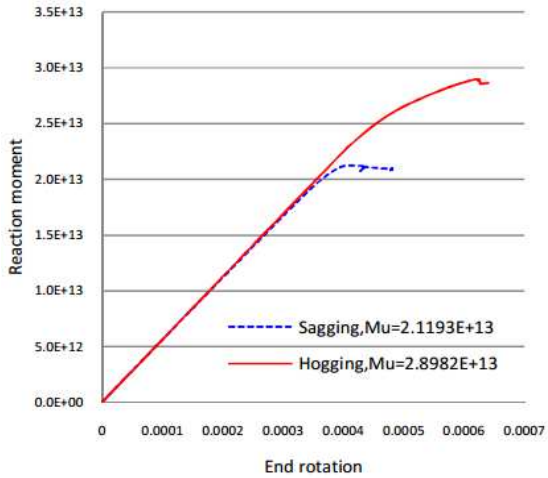

***Figure 14.** The ultimate longitudinal strength of Double Hull VLCC*

The curve in Figure 14 described relationship between reaction moment and end rotation of FEM analysis. The peak of curve is the value of ultimate longitudinal strength M_U of Double Hull VLCC in hogging (the red line) and sagging condition (the blue line).

4. Conclusions

In this research, by using the nonlinear FEM analysis through the modified RISK method in ABAQUS software, the ultimate longitudinal strength of intact ship under vertical bending moment was generated. Base on the result, these conclusions are obtained:

1. The three-dimesional finite element model has the length of three web frames spacing and the middle section of this model is the valid section for analysis.
2. The three-dimensional finite element model must to have the web frame.
3. The ultimate longitudinal strength of intact ship could be performed by nonlinear FEM analysis. This method was taken into account for two Nishihara models, 1/3-scale Frigate model and Double Hull VLCC. The result which was obtained by FEM analysis had good agreement with experimental results, the difference results between two method is about 2 %.

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Biography

Huynh Van-Vu (1975, Khanh Hoa, Viet Nam). From 2008, he has been worked as the Dean of Naval Architecture Department of Nha Trang University - Viet Nam, where he became a lecturer after graduation in 1998. He had a doctoral course in University of Ulsan – South Korea for three year (2008 - 2011) with the research on "Residual longitudinal strength and reliability analysis of damaged ships".

Dr Huynh is interested in the field of ship structures, especially the ultimate strength of steel-plated structures, safety structures, structural impact analysis, reliability analysis and so on