ECCOMAS Congress 2016
VII European Congress on Computational Methods in Applied Sciences and Engineering
M. Papadrakakis, V. Papadopoulos, G. Stefanou, V. Plevris (eds.)
Crete Island, Greece, 5–10 June 2016

ULTIMATE STRENGTH ANALYSIS OF STIFFENED PANELS OF SHIP STRUCTURES UNDER COMBINED LOAD

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Keywords: Stiffened panels, Ultimate strength, Combined load, Nonlinear.

Abstract. *Ultimate strength of stiffened panels of Ship Structures can evaluate the bearing capacity of stiffened plate structure more accurately, and it provides a way to evaluate the safety and reliability of the hull structure. A lot of studies on ultimate strength of the hull structure are basically focused on stiffened panels under uniaxial compression, without considering combined load acting on the hull structure.But in the voyage, the hull structure is subjected to combined effect involved with various type of external loads at the same time. These external loads will inevitably have some impact on the ultimate strength of the hull structure. So it is necessary to study the ultimate strength of the stiffened panels under combined load. The nonlinear finite element method was introduced based on the assessment requirements of buckling and ultimate strength of stiffened panels in IACS Common Structural Rules for Double Hull Oil Tankers. Some important factors of influence such as the structural dimensions, element size, boundary conditions, initial imperfections and loading types are studied. To check the accuracy of the analysis performed in this method.Numerical results were compared with data in the Background Document of buckling strength assessment in CSR and results calculated by empirical formulations performed by other researchers. This paper focuses on investigating the effect of combined load on the ultimate strength of stiffened plates by calculating the ultimate strength of stiffened plates under combined biaxial compression and lateral pressure loads, by means of the famous nonlinear finite element software Ansys. The different influence on the ultimate strength of the stiffened plates are analyzed.*

1 INTRODUCTION

The traditional checking method of ship structure strength checking based on linear elastic rationale. The impact of material nonlinearity and geometric nonlinearity caused by other factors not be considered,therefore it can not accurately assess the true strength reserve hull structure. "Common Structural Rules for Double Hull Oil Tankers" (herein after referred to as CSR-OT) introduced the concept of the ultimate strength of stiffened panels what can evaluate the bearing capacity of stiffened plate structure [1]. A lot of studies on ultimate strength of the hull structure are basically focused on stiffened panels under uniaxial compression, without considering combined load acting on the hull structure. But in the voyage, the hull structure is subjected to combined effect involved with various type of external loads at the same time. These external loads will inevitably have some impact on the ultimate strength of the hull structure. So it is necessary to study the ultimate strength of the stiffened panels under combined load. The nonlinear finite element method was introduced based on the assessment requirements of buckling and ultimate strength of stiffened panels in IACS Common Structural Rules for Double Hull Oil Tankers. This paper focuses on investigating the effect of combined load on the ultimate strength of stiffened plates by calculating the ultimate strength of stiffened plates under combined biaxial compression and lateral pressure loads.

2 NON-LINEAR FINITE ELEMENT ANALYSIS

Ultimate strength can be performed using the element analysis software ANSYS. The paper adopts ANSYS nonlinear finite element method for ultimate limit state assessment.

2.1 Geometric and Material Properties

For the current research a VLCC double hull oil tanker structure designed by CSR method is studied. The deck panel is chosen for the analysis purposes. Geometrical properties of the stiffened panel of the deck of the object ship are tabulated as follows:

The length of the panel is L=5640 mm. The longitudinal stiffener spacing is w=850 mm, because the number of longitudinal stiffeners with the type of Tee bar is 6. Therefore, the total breadth of the stiffened panel is W=5100mm.The plate thickness is t=21mm. The stiffener height (dw) is 393 mm and the stiffener webthickness (tw) is 13 mm. The stiffener flange breadth (df) is 172 mm and the stiffener flange thickness (tf) is 17mm. Young's modulus of the material is E=205.8 GPa, and Poisson's ratio is ν=0.3. The yield stress is σy =315 MPa for both plating and stiffeners. A plastic tangent modulus of 1000MPa is acceptable for higher strength steel.

2.2 Structural Modeling.

The extent of the model used in the ultimate strength assessment is to be sufficient to account for the structure that is surrounding the panel of interest, and to reduce the uncertainties introduced through the boundary conditions.

In general, the model is to include more than one stiffener span in the stiffener direction and the portion between two primary support members in the direction normal to the stiffeners [2].

The structural model and assessment method applicable for deck is to be taken as:

(a) parallel to the stiffener direction: at least two frame bays, in order to model imperfections between adjacent panels.

(b) normal to the stiffener direction: between primary support members, but maybe limited to six stiffener spacings.

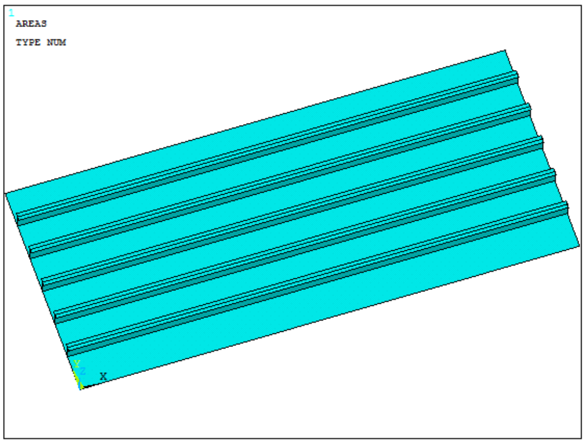


Figure 1: Stiffened plate geometry.

For the present nonlinear FEA, a half+one+half-bay model (1/2+1+1/2-bay model) in the length (x) direction is applied to accurately take into account the effect of rotational restraints along transverse floors, as described in Fig. 1. The meshing of the 3-D FE model of hull structure is to be carried out considering both calculation accuracy and computing time. The meshes are to be as square as possible.

The element type chosen for analysis is ‘Shell181’. This element is most suitable for ultimate strength analysis [3]. Stiffened plate plate and stiffener (including panels and web) are modeled with ‘Shell181’. The element size is to be small enough to describe the deflections accurately. A mesh size of 141 is chosen to mesh the area.

The coordinate system used within these Rules is shown in Figure 1. Motions and displacements are considered positive in the forward, up and to port direction. Angular motions are considered positive in the clockwise direction about the x, y or z axis.

2.3 Boundary Conditions

The boundary conditions are to represent the actual response of the stiffened panel. the simply supported boundary condition is often adopted in maritime industry . The edges of model may be taken as free to move in-plane, but forced to remain straight[4]. The panels can be taken as supported in the vertical direction at the primary support members. The stiffeners should be taken as horizontally supported at the crossing of primary support members. In this model, the transverse floor is not modeled. Instead appropriate boundary conditions are applied along the length of the transverse floor attached with plating and longitudinal stiffeners to account for the effects of the transverse floor [5]. The following are the boundary conditions of the nonlinear finite element model, namely

Longitudinal edges Y=0 and Y=W: UZ=0,ROTY=O,ROTZ=0.

At X=2L all nodes to have equal X-displacement.

At X=0 edge UX=0.

At Y=0 and Y=W: ROTY=0, ROTZ=0.

At Y=0 and Y=W all nodes to have equal y-displacement.

At transverse frame: All plate nodes UZ=0.

All stiffener web nodes all nodes to have equal Y displacement.

The boundary conditions for nonlinear analysis is shown in Figure 2.

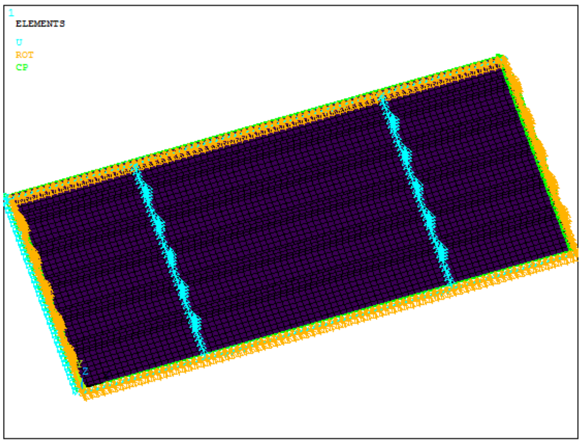


Figure 2: Boundary conditions of stiffened plate.

2.4 Initial Distortions

Initial distortions make significant impact on the result of the ultimate strength behavior of stiffened plate structures. Therefore, it is important to model the shape and magnitude of initial imperfections in a relevant way [6]. The imperfections may be divided into local imperfections (plate out-of-flatness and stiffener sideways out-of-straightness), and global imperfections of the stiffeners(stiffener lateral/vertical out-of-straightness). No residual stress is supposed to exist for this research study.

For performing a nonlinear finite element computations, the pattern of initial imperfections that are required to be generated for initiation of the buckling eigenvalue analysis is assumed to be the buckling mode of the structure that provides the minimum resistance against the actions.

2.5 Comparison of the Method.

To check the accuracy of the analysis performed in this method,Numerical results were compared with data in the Background Document of buckling strength assessment in CSR and results calculated by empirical formulations performed by other researchers.

In 2009, Shengming Zhang [7] calculated the ultimate strength of 132 Ship Common stiffened plate, and summed up the following empirical formula:

The following example is a single line equation:

$$\frac{\sigma_u}{\sigma_y} = \frac{1}{\beta^{0.28}} \frac{1}{\sqrt{1+\lambda^{3.2}}}, \text{take} \beta = 1, \text{if } \beta < 1 \tag{1}$$

The following example is a single line equation:

$$\beta = \frac{b}{t}\sqrt{\frac{\sigma_y}{E}} \tag{2}$$

The following example is a single line equation:

$$\lambda = \frac{a}{\pi r}\sqrt{\frac{\sigma_y}{E}} \tag{3}$$

Where B = (n + 1) b, n = the number of ribs, B = stiffened plate width, r = the radius of inertia ribs.

Background document lists the ultimate strength of stiffened plate[8], A quick comparison among the background document results, the non-linear FE results and empirical formula results for the six stiffened panels in Table 1 and 2 were carried out.

No.	L(mm)	w(mm)	t(mm)	d_w(mm)	t_w(mm)	d_f(mm)	t_f(mm)
T-1	6	850	15	613	10	200	13
T-2	4.5	850	25	613	10	200	13
T-3	6	850	20	613	10	200	13
T-4	4.5	850	20	613	10	200	13
T-5	5	850	19	462	9	150	12
T-6	3.5	850	19	462	9	150	12

Table 1: Basic characteristics of stiffened panels.

No.	background document results(Mpa)	empirical formula results(Mpa)	non-linear FE results(Mpa)
T-1	254	249.11	248.95
T-2	289	289.12	294.29
T-3	273	269.48	261.01
T-4	280	271.81	281.97
T-5	264	263.17	259.54
T-6	273	267.66	256.14

Table 2: Comparison of ultimate strength.

Contrast to results in this paper, the calculation method is right. The paper will analyze the ultimate strength of stiffened plates under combined loads using the above method.

3 ULTIMATE STRENGTH OF STIFFENED PANEL

3.1 Different Proportions of Axis Pressure

The ultimate strength of stiffened panels under different proportions of axis pressure is studied, include: σx: σy = 1.0: 0,0.79: 0.21,0.4: 0.6,0: 1.0, where σx: σy = 1.0: 0 the corresponding longitudinal uniaxial compression, σx: σy = 0: 1.0 corresponds to transverse uniaxial compression, the following table shows the strength of stiffened panels under different proportions of axis pressure.

σx:σy	σxu（MPa）	σyu（MPa）
1.0:0	246.38	-
0.79:0.21	236.37	62.83
0.4:0.6	63.31	94.96
0:1.0	-	96.89

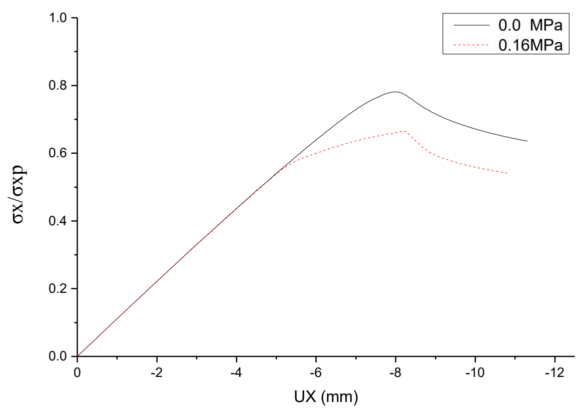
Table 3: Ultimate strength of stiffened panels under different proportions of axis pressure.

3.2 Combined Biaxial Compression and Lateral Pressure Loads

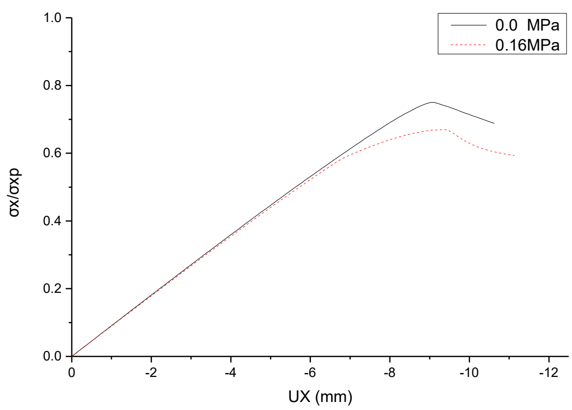
The ultimate strength of stiffened plates under combined biaxial compression and lateral pressure loads is studied.All calculations lateral pressure is added in 2.1, and remains constant lateral pressure, namely p = 0.16MPa throughout the calculation process [9]. Before the finite element calculation process, the lateral pressure is applied on the stiffened plates, and obtain the the ultimate strength of stiffened plates. The following table shows the ultimate strength of stiffened plates under combined biaxial compression and lateral pressure loads.

σx:σy	σxu（MPa）	σyu（MPa）
1.1:0	209.40	-
0.79:0.21	210.91	56.06
0.4:0.6	64.90	97.35
0:1.0	-	98.19

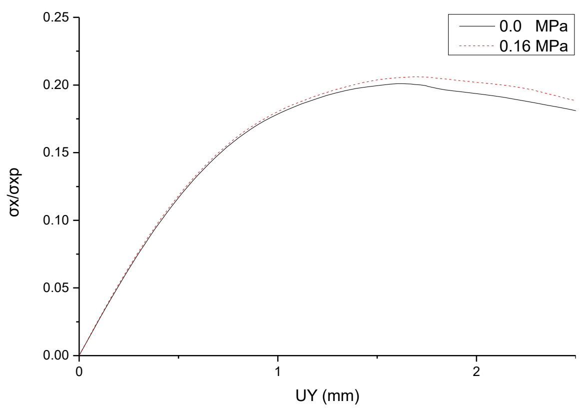
Table 4: Ultimate strength of stiffened plates under combined biaxial compression and lateral pressure loads.



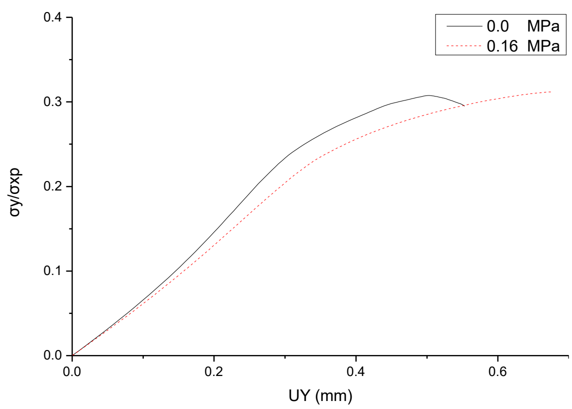
（a） σ x: σ y =1.0:0



（b） σ x: σ y =0.79:0.21



（c） σ x: σ y =0.4:0.6



（d） σ x: σ y =0:1.0\

Figure 3: stress-strain curves of stiffened plates under combined biaxial compression and lateral pressure loads.

4 CONCLUSIONS

- A FEA method of ultimate strength was put forward based on the analysis of the influence of different factors and the study on the CSR. Some important factors of influence such as the structural dimensions, element size, boundary conditions, initial imperfections and loading types are studied. A comparison among the background document results， the non-linear FE results and empirical formula results was provided to verify the method.
- By the calculation and analysis of stiffened plates under axial compression and lateral pressure, the results showed that lateral pressure make a negative impact on the ultimate strength of stiffened panels when t the proportion of Uni-axial compression in the direction of the stiffener is greater, and lateral pressure make a negligible impact on the ultimate strength of stiffened panels when the proportion of Uni-axial compression in the direction of the transverse is greater.

5 ACKNOWLEDGEMENTS

This paper is funded by the International Exchange Program of Harbin Engineering University for Innovation-oriented Talents Cultivation.

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