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Ultimate strength assessment of continuous stiffened panels under combined longitudinal compressive load and lateral pressure

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ABSTRACT

The collapse behaviour of stiffened panels under uniaxial compression load and lateral pressure are investigated in the FE analysis, in which two spans model with periodical boundary conditions are adopted. Fourier components including symmetric and asymmetric shapes are used to estimate the half-wave number of collapse for local plate by using nonlinear finite element analysis. The comparisons of the results between the FE analysis and analytical method are performed. The influences of half-wave number, direction and magnitude of initial deflection, lateral pressure as well as constraint conditions along longitudinal edges on the collapse behaviour and the ultimate strength of the stiffened panels are discussed. The ultimate strength and collapse deformation of stiffened panels are affected by not only the magnitude but also the half-wave number of initial imperfections. The lateral pressure caused by water head might increase the load carrying capacity of the stiffened panels, which depends on the collapse mode that relates with the configurations of stiffener and plate.

1. Introduction

The bottom plating and the lower parts of the side shells are mainly subjected to the uniaxial and biaxial compressive loads, and to the relatively high lateral pressure caused by water head. It is important to investigate the collapse behaviours of ship bottom under combined compressive load and water pressure, which had been investigated for many years, such as Crisfield (1975) and Paik et al. (2000). Using beam-column method, Wang and Moan (1996) studied the collapse behaviours of stiffened panels subjected to biaxial and normal loads for offshore and ships structures. Fujikubo et al. (2005a) proposed a formula to estimate the ultimate strength for steel stiffened panels subjected to combined transverse compression and lateral pressure, which can account for the interactions influence of adjacent plate and stiffener. Using analytical method, Paik et al. (2012) also developed a method that considers the influence of partially rotation-restrained edges in association with the torsional rigidity of the support members.

Kumar et al. (2009), Cho et al. (2013) and Choung et al. (2014) also proposed several formulations for predicting the ultimate strength of stiffened panels, which consider the different configurations of loads combinations including axial compression, transverse compression, shear force and lateral pressure. Zhang (2016) presented a review and study on ultimate strength analysis methods for steel plates and stiffened panels in axial compression, and then developed formula that was verified by the numerical and experimental results of 180 specimens. Khedmati et al. (2017) developed empirical expressions for predicting ultimate compressive strength of welded aluminium stiffened plates used under combined transverse in-plane compression and different levels of lateral pressure.

The consideration for the water pressure on the collapse behaviours of stiffened panels mostly focused on their magnitude. The lateral pressure on the plate could induce tensile stress, which influence the collapse behaviour and the load carrying capacity of the stiffened panels as well. There were few studies considering the effect of half-wave number of local plate and transverse tensile stress caused by the water head. This state of tensile stress distributions is still not well understood and is not accounted for in the design equation and interaction formulas for assessing the collapse strength of stiffened panel, such as CSR-H requirements (IACS, 2014). For plate elements, this effect of lateral pressure is usually considered by an additional term in the interaction equations, such as Davidson et al. (1992) and Guedes Soares and Gordo (1996). Teixeira and Guedes Soares (2001) also dealt with this problem for the square and rectangular plates under the combined effect of longitudinal compression and lateral

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Notations

β	plate slenderness;
s	width of plate;
t_p	thickness of plate;
h_w	web height of stiffener;
σ_y	yield stress of material;
m	buckling half-wave number;
w_{0pl}	initial deflection of local plate panel;
w_{0s}	side-way initial deflection of stiffeners;
A_s	stiffener area;
l	length of plate;
B	width of stiffened panel;
t_w,t_f	thickness of web and flange on stiffener;
b_f	flange width of stiffener;
E	Young's modulus of material;
q	lateral pressure;
w_{0c}	column-type initial deflection of stiffeners;
Φ_w	the effective width of the plate;
σ_u	ultimate strength in the longitudinal direction;
σ_{uu},σ_{ur}	ultimate strength with unrestrained and restrained conditions on the longitudinal edges;
σ_{ac},σ_{ab}, σ_T	average stress in the longitudinal direction for plate induced failure, beam-column failure and tripping failure of stiffeners;

pressure, and then the corresponding design curves were proposed. It was also found that the lateral pressure changes the collapse mode and then influence the load carrying capacity of stiffened panels (Xu et al., 2013). To identify how the tensile stress caused by the lateral pressure affects the ultimate strength of stiffened panels, more configurations of the stiffened panels for different influential factors will be conducted herein.

Moreover, the geometrical initial deflections caused by welding process also influence significantly the buckling strength of stiffened panels, which should be considered in FE analysis (Chen et al., 2014). The magnitude and distributions of these deflections are normally uncertain. Based on Monte Carlo simulation and ANOVA methodology, Garbatov et al. (2011) analyzed various uncertainties related with the prediction of the ultimate strength of stiffened panels including the shape of initial geometrical imperfections and other influential factors, whose smallest standard deviations were given. Khedmati et al. (2014) determined the effects of the geometrical imperfections on the ultimate strength and load-carrying capacity of aluminium stiffened plates under combined axial compression and lateral pressure. In the previous research, the consideration for initial imperfection on the collapse behaviours mostly focused on their magnitude. The effect of half-wave number on the ultimate strength of stiffened panels is also investigated herein.

2. Model for analysis

The flat, angle and tee-bar stiffeners are adopted to study the influence of geometry, whose cross-sectional geometries are shown in Fig. 1. Plate element with 850 mm width and different aspect ratios are often adopted for bulk carriers and VLCC (Very Large Crude Carrier) as show in Fig. 2 and Table 1. At TC8/SC8/WG3 in London on February 3/4, 2010, these dimensions of the stiffeners and plates have been choose to perform benchmark calculations for validation of ISO (International Organization for Standardization) formulas to estimate the load carrying capacity of hull girders, stiffened panels and plates, and were also adopted by Tanaka et al. (2014). The principal influential factors are given by Faulkner (1975):

Plate slenderness: $\beta = \frac{s}{t_p}\sqrt{\frac{\sigma_{yd}}{E}}$ (1)

Column slenderness: $\lambda = \frac{l}{\pi\rho}\sqrt{\frac{\sigma_{yd}}{E}}$ (2)

Radius of gyration: $\rho = \sqrt{\frac{I}{A}}$ (3)

3. Nonlinear finite element analysis

The region a-b-c-d between two transverse frames and two longitudinal girders is selected in Fig. 2. The FE software package "ANSYS" is adopted in the numerical simulation. The shell 181 element with four nodes is used to modelling the plates and stiffeners. The yield stress, Young's modulus and Poisson's ratio for elastic-perfectly plastic model are equal to 313.6 MPa, 205.8 GPa and 0.3, respectively. The element size of the FE model should be small enough to capture the collapse mode for obtaining reliable results. According to the benchmark of modelling techniques in 18th ISSC (2012) report, mesh size is set as less than 85 mm. Fig. 3 shows the geometry and finite element models of the stiffened panels.

The two spans/bays model (Fig. 2) with periodical boundary condition is used to consider influence of interaction between the adjacent stiffeners and plates (Xu et al., 2013). The displacement at transverse frames and longitudinal girders are constrained, which are assumed to be strong enough not to produce lateral deflection. The rotations are free at their locations. The boundary conditions of the stiffened panels are described as follows.

1. A_1-B_1: $\theta_x=\theta^*_x$, $\theta_y=\theta^*_y$, $\theta_z=0$, $u_x=0$, $u_y=u^*_y$, $u_z=u^*_z$;
2. A_2-B_2, A_3-B_3: $\theta_x=0$, $u_z=0$;
3. A_1-A_4: $\theta_x=0$, $\theta_z=0$, $u_y=0$;
4. B_1-B_4:
   1. For restrained boundary: $u_y=0$, $\theta_x=0$, $\theta_z=0$;
   2. For unrestrained boundary: $u_y= C_{dy}$, $\theta_x=0$, $\theta_z=0$;

1. A_4-B_4: $u_x= C_{dx}$, $u_y=u^*_y$, $u_z=u^*_z$, $\theta_x=\theta^*_x$, $\theta_y=\theta^*_y$, $\theta_z=0$;

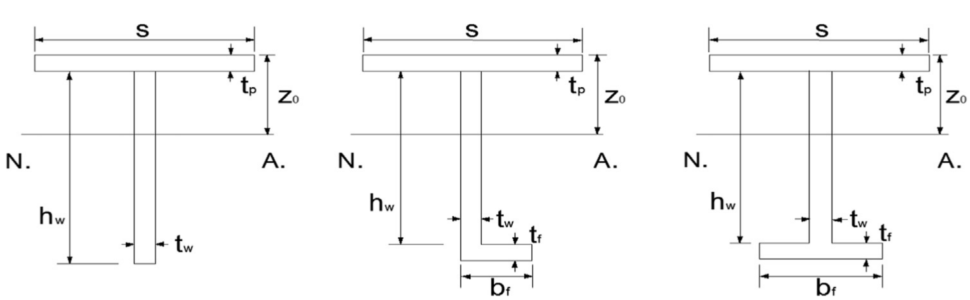

Fig. 1. Cross section of the stiffeners.