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Ultimate shear strength of intact and cracked stiffened panels

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ABSTRACT

The present paper focuses on the ultimate shear strength analysis of intact and cracked stiffened panels. Several potential parameters influencing the ultimate shear strength of intact panels are discussed, including the patterns and amplitudes of initial deflection, the slenderness and aspect ratios of the plates, and the boundary conditions defined by the torsional stiffness of support members. An empirical formula for the ultimate shear strength of intact stiffened panels is proposed based on parametric nonlinear finite element analyses in ANSYS. Furthermore, the ultimate shear strength characteristics of cracked stiffened panels are investigated in LS-DYNA with the implicit method. Three types of cracks are considered, namely vertical crack, horizontal crack and angular crack. A simplified method is put forward to calculate the equivalent crack length. And the formula for the ultimate shear strength of cracked stiffened panels is derived on the basis of the formula for intact stiffened panels.

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1. Introduction

Ship and offshore structures now tend to be designed based on the ultimate strength. Significant progress has been made on the ultimate strength characteristics of various types of structural components under typical load conditions as axial compression and edge shear [1]. Comparing to axial compression, less attention has been given to the shear loading [2,3]. Though several empirical formulae have been developed and applied in industry, most of them are based on the elastic buckling strength of the individual plate [e.g. 1,2]. In order to accurately assess the limit-state-based capacity of ship structures, systematic study on the ultimate shear strength of stiffened panels should be carried out further.

Moreover, failure due to shear loads will arise particularly for damaged structures [2]. Fatigue cracks are among the most typical damage or defect forms, which would be initiated in the concentration area of the structure. The importance on assessing residual ultimate strength of cracked ship structures under monotonically increasing extreme load has been highlighted [4,5]. Some studies have been paid on buckling characteristics of the cracked plates under shear [6], while the study on post-buckling or large-deflection regime is still not enough.

The aim of this paper is therefore to investigate the ultimate shear strength of intact and cracked stiffened panels. Since the deflection pattern of the plates under edge shear in the post-buckling or large deflection regime is quite complex, the analytical approach may not be straightforward to use [1]. In this case, nonlinear FEA softwares, ANSYS [7] and LS-DYNA-implicit [8] will be used for carrying out analyses on intact and cracked stiffened panels respectively, while cracked panel models used in LS-DYNA with initial deflection are preprocessed by ANSYS. Based on the computed FEA results, an empirical formula for estimating the ultimate shear strength of stiffened panels will be derived. And it will provide the basis for the residual shear strength assessment of cracked panels. Factors for shear strength reduction due to typical cracks will be put forward at the same time.

2. Ultimate shear strength of intact stiffened panels

The one-bay SPM (stiffened panels model) shown in Fig. 1 will be adopted for calculation in the present study. The plate dimension is $a \times b \times t_p$; the stiffener web dimension is $h_w \times t_w$; and the stiffer flange dimension is $b_f \times t_f$. The Young's modulus is E; the material yield stress is σ_Y; and the Poisson ratio is ν. The shear modulus can be expressed by $G = E/2(1+\nu)$; and the shear yield stress can be expressed by $\tau_Y = \sigma_Y/\sqrt{3}$. The plate slenderness ratio

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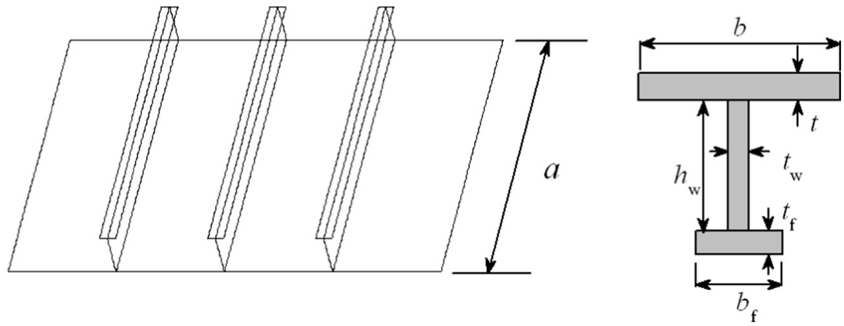

Fig. 1. One-bay SPM.

representing the degree of plate thickness is defined as $\beta=(b/t)\sqrt{\sigma_Y/E}$.

Uniform shear load will be applied on the edges of the SPM. The simply supported condition is assumed at the panel edges, and all edges will remain straight by proper displacement constraint equations during loading. Elastic perfectly plastic material model is adopted. Strain-hardening effect will not be included in numerical model. The ultimate shear strength of stiffened panels may be affected by the patterns and amplitudes of initial deflection, the slenderness and aspect ratios of the plates surrounded by longitudinal and transverse support members, and also the boundary conditions defined by the tortional stiffness of support members. Parametric studies will be conducted to investigate the effects of those potential influential factors.

2.1. Effect of initial deflection pattern

Initial deflections have to be considered for ultimate limit state assessment of stiffened panels. The geometric configuration of fabrication-related initial deflections in stiffened plate structures is quite complex [1]. For practical design purposes, the measurements of initial deflection for plate elements in steel-plated structures are usually idealized to a multi-wave shape predominant in the long direction and one half wave in the short direction. And the initial deflections into FE models are generally based on buckling mode under compression. More precisely, the initial deflections of stiffened panels can be divided into the local and global modes, which include the local buckling modes of plates and stiffeners, together with the vertical and horizontal components of global buckling mode. For more complicated structures such as cracked panels, it is more inconvenient to consider the real initial deflection patterns. In view of this, initial deflections are further simplified to the buckling mode by eigen analysis under the considered loading conditions. Generally speaking, the buckling mode under compression is more close to the real initial deflection pattern, while it is quite different from the buckling mode under edge shear. And the buckling mode of stiffened panels may also be varied if support members are included during eigen analysis. In this part, the effect of initial deflection patterns will be discussed first to provide the basis for further discussion. Four types of patterns will be considered, namely,

a) Compression-based initial deflection pattern considering local buckling modes of plates and stiffener webs respectively, and also the global failure modes of the stiffened panel;
b) Compression-based initial deflection pattern from eigen analysis;
c) Shear-based initial deflection pattern from eigen analysis with support members included in the model (but the support members will be removed during ultimate strength analysis in view of the same boundary conditions for comparison);
d) Shear-based initial deflection pattern from eigen analysis without support members included in the model.

The FE models of SPM are illustrated in Fig. 2 with four types of initial deflection patterns listed above. Initial deflection with the amplitude of $w_{opl}=b/200$ is assumed for the local mode of pattern (a) and the same amplitude is considered in other three patterns. A series of ANSYS ultimate strength analyses were undertaken with varying the initial deflection patterns and plate thickness. Fig. 3 shows the average shear stress (τ_{av}) versus strain (γ_{av}) curves of the SPM. It is noted that the initial deflection patterns will slightly change the modeling results. Relatively larger effect is found when plate thickness is 10mm and 8mm, but it can be ignored for thick plates and very thin plates. And the shear-based initial deflection patterns will induce relatively lower strength in FEA.

2.2. Effect of slenderness ratio

Based on the analysis above, the effect of plate slenderness ratio can be obtained at the same time. Fig. 4 gives the curves of normalized ultimate shear strength (τ_u/τ_Y) of SPM versus plate slenderness ratio with the four types of initial deflection patterns considered. A significant decreasing tendency can be observed with increasing slenderness ratio. Slight difference due to different initial deflection patterns can be further noticed, but the differences are within 6%.

2.3. Effect of initial deflection amplitude

Another potential parameter which may affect the ultimate shear strength of SPM is the initial deflection amplitude. Calculations are performed here on the SPM with$t_p=10$ mmconsidering two different initial deflection patterns. The initial deflection amplitude is changed from $0.01\beta^2t$ to $0.3\beta^2t$. The average shear stress versus strain curves are shown in Fig. 5 and the strength changing tendency can be further clarified by Fig. 6. Where, the value of $w_{opl}/(\beta^2t)$ is adopted to represent the level of initial deflection. It can be seen from the results that a proximate extent of 10% should be considered when the initial deflection amplitude changes from very small level to severe level.

2.4. Effect of aspect ratio

It has been pointed out that the ultimate shear strength depends weakly on the plate aspect ratio, especially for relatively thick plates [1]. However, for the completeness of the parametric study on SPM in the present paper, the effect of the aspect ratio combined with plate slenderness ratio will be further clarified here by a series of FE analysis results shown in Fig. 7. The aspect ratio will be changed from 1.0 to 5.0. From the results, it can be

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