Ocean Engineering 152 (2018) 6–16

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Ultimate strength characteristic and assessment of cracked stiffened panel under uniaxial compression

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ARTICLE INFO

Keywords:
Stiffened panel
Crack location
Residual ultimate strength
Empirical formula

ABSTRACT

In this paper the ultimate strength characteristics of stiffened panels with cracks under longitudinal compressive loading are investigated. The influences of various geometrical characteristics of cracks, especially the location of cracks, are studied by a numerical method. It is found out that the influence of crack location on the residual ultimate strength is very much depended on where the crack locates. Based on the numerical results, an empirical formula as a function of crack length, orientation angle and location, is proposed to predict the ultimate strength of cracked stiffened panels under longitudinal compressive loading.

1. Introduction

As the basic component of ships and offshore structures, a stiffened panel is extensively used due to simplicity in fabrication and excellent strength-to-weight ratio. Initial defects or cracks are unavoidable, and it may be initiated in the stress concentration areas under the action of repeated loading during the operation of a vessel. Even cracks do not represent necessarily an immediate danger to the structure, it is also well recognized as one of damages that can reduce the structural load-carrying capacity. On the other hand, the current ship rational design procedures require that structural ultimate strength is assessed and checked against specific criteria (IACS, 2006). In this regards, it is of crucial important to understand the effect of crack configurations, such as the length, location and orientation angle, on the residual ultimate strength characteristics. Additionally, axial compression is regularly taken as the typical load component for a stiffened panel, for instance, deck in sagging or bottom in hogging, hence it is of great importance to understand the ultimate strength characteristic and assess it reasonably.

A large number of studies on the fatigue fracture of cracked structure under cyclic loading (Sabelkin et al., 2006; Deng et al., 2016; Citarella et al., 2016; Albedah et al., 2016) and the influence of initial imperfection on the maximum load bearing capacity of stiffened panel (Paik et al., 2001; Lillemae et al., 2013; Xu and Guedes Soares, 2013; Yu et al., 2015) have been previously carried out and reported in the literature, but there are few investigated the ultimate strength behavior of a cracked structure. Until the recent decade, increasing efforts are made to the residual strength behavior of cracked structures under monotonic extreme load. Paik et al. (2005, Paik, 2008, Paik, 2009) and Cui et al. (2016) studied the ultimate strength of cracked plates under axial compression or tension experimentally and numerically. Furthermore, the investigation was extended to residual compressive ultimate strength of cracked stiffened plates (Margaritis and Toulios, 2012; Bayatfar et al., 2014; Xu et al., 2014), and ultimate shear strength analysis of cracked stiffened panel was carried out by Wang et al. (2015) as well. Regardless of any cracked structures, the length of cracks and especially its location can significantly affect the structural ultimate strength characteristics under axial compression. Longitudinal cracks, which are parallel to the axial loading direction, are investigated in Paik's research (Paik, 2008), the reduction of plate ultimate strength induced by cracks was demonstrated by comparing with intact plate ultimate strength, and the effect of crack location on ultimate strength reduction also was illustrated. Subsequently, the ultimate and collapse response of vertical cracked stiffened plate subjected to uniaxial compression was studied by Margaritis and Toulios (2012). In more recent studies, Xu et al. (2014) and Cui et al. (2016) considered the influence of not only longitudinal and vertical cracks but also inclined (angular) cracks for the ultimate compressive strength reduction. Although several of influence factors have been taken into account, there are few studies focusing on the reduction mechanism of crack on ultimate compressive strength, and comprehensive assessment of ultimate strength for cracked stiffened panel subjected to compression has not been fully carried out.

In this study, a series of nonlinear finite element analysis is carried out

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https://doi.org/10.1016/j.oceaneng.2018.01.015
Received 25 June 2017; Received in revised form 1 January 2018; Accepted 3 January 2018

Nomenclature

a,b	length and width of local plate panel
B	width of stiffened panel
h_w	height of stiffener web
b_f	width of stiffener flange
t_p,t_w,t_f	thickness of plate, stiffener web and flange, respectively
E	Young's modulus of the material
ν	Poisson's ratio
σ_y	yield stress of material
σ_u,σ_{uc}	ultimate strength of intact and cracked stiffened panel, respectively
β	plate slenderness ratio
w_{0pl}	initial deflection of local plate panel
w_{0s}	column-type initial deflection of stiffeners
v_{0s}	side-way initial deflection of stiffeners
c	length of the crack
θ	orientation angle of the crack
W	gap of the crack
s, h	the longitudinal and transverse distance from the crack center to the center of stiffened panel, respectively
e_c	relative length of the crack, $e_c = c/b$
e_h, e_s	the longitudinal and transverse relative distance from the crack center to the center of stiffened panel, respectively, $e_s = 2s/a$, $e_h = 2h/B$
e_x, e_y	the longitudinal and transverse relative distance from the crack center to the center of the buckling half wave, respectively, $e_x = 2s{\cdot}m/a$, $e_y = 2h/b$
m	the number of buckling half waves in the longitudinal direction

Table 1
Comparison of dimensionless ultimate strength between test and finite element method.

model	$(\sigma_u/\sigma_y)_{num}$	$(\sigma_u/\sigma_y)_{exp}$	Ratios of $(\sigma_u/\sigma_y)_{num}$ to $(\sigma_u/\sigma_y)_{exp}$
D0	1.001	0.931	0.930
D0A	0.965	0.843	0.874
D1	1.001	1.095	1.094
D2	0.826	0.900	1.090
D3	1.053	1.032	0.980
D4	0.907	0.990	1.092
D4A	1.094	0.875	0.800
D10	0.478	0.547	1.144
D11	0.603	0.527	0.874
D12	0.413	0.510	1.235

with varying the crack parameters such as length, location and orientation angle. Based on the results obtained, the mutual effects of different crack parameters are discussed, and the ultimate strength characteristics of a cracked stiffened panel are investigated by considering different structural failure modes. Finally, a rational assessment of ultimate strength for cracked stiffened panel under uniaxial compression is carried out.

2. Nonlinear finite element analysis

2.1. The feasibility verification of numerical method

The compressive experiment of stiffened panel with single crack is few as it is hard to acquire the cracks of what we expect. However, the numerical procedures are identical for cracked and intact stiffened panel, so it is feasible to verify the numerical method by comparing with the results of reference experiment.

Tanaka and Endo (1988) conducted a series of experiments to test the ultimate strength of stiffened panel. In this paper, the ultimate strength for ten of the experimental models is calculated by nonlinear finite element method. The comparison of dimensionless ultimate strength (σ_u/σ_y) obtained by experimental tests and numerical method are summarized in Table 1, where $(\sigma_u/\sigma_y)_{num}$ and $(\sigma_u/\sigma_y)_{exp}$ are numerical and experimental results respectively. The feasibility of numerical method is verified since the results are pretty close, and the mean and variance of the ratios of actual experimental to numerical predicted results are 1.011 and 1.968% respectively, which is permitted by the error in engineering.

2.2. Geometric and material properties of stiffened panel

The geometrical dimensions of a stiffened plate structure discussed in

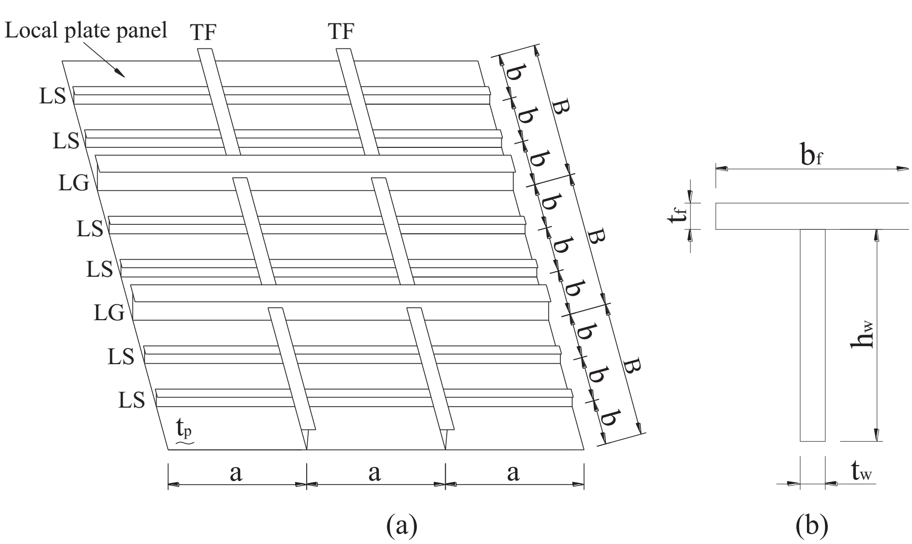

Fig. 1. Configuration of stiffened plate structure. (a) Stiffened plate structure. (b) Longitudinal tee-bar stiffener.
Note: LG, LS and TF are the abbreviations of longitudinal girder, longitudinal stiffener and transverse frame, respectively.