Marine Structures 56 (2017) 117–136

Contents lists available at ScienceDirect

Marine Structures

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

Ultimate strength of hull structural stiffened plate with pitting corrosion damage under unaxial compression

Yan Zhang [a], Yi Huang [b, *], Fanlei Meng [c]

[a] School of Naval Architecture and Ocean Engineering, Harbin Institute of Technology, Weihai 264209, PR China
[b] School of Naval Architecture Engineering, Dalian University of Technology, Dalian 116024, PR China
[c] CNOOC EnerTech-Safety & Environmental Protection Co., Tianjin 300457, PR China

A R T I C L E I N F O

Article history:
Received 6 December 2016
Received in revised form 26 May 2017
Accepted 17 July 2017

Keywords:
Ultimate strength
Corroded volume loss
Pitting corrosion
Stiffened plate
Hull structure

A B S T R A C T

Pitting corrosion can cause the ultimate strength degradation of hull structure. This research aims at the development of ultimate strength calculation formula of pitted stiffened plates under unaxial compression. Firstly, the relative parameters (such as sizes of stiffened plates, sizes and shape of pits, initial geometric imperfection and residual stresses of stiffened plates, boundary condition and type and size of finite element) of pitted stiffened plates in the finite element analysis were analyzed and assumed. Secondly, the effects of a few factors (such as distribution status, depth and position of pits, number of longitudinal stiffeners and sizes of stiffened plates) on the ultimate strength with respect to the corroded volume loss were discussed. Lastly, the ultimate strength reduction formulae of pitted stiffened plates based on corroded volume loss were obtained by the data analysis from lots of nonlinear finite element analyses.

1. Introduction

The corrosion in hull structure was inevitable during ship service and it would lead to the degradation of ultimate strength of hull structure. Uniform corrosion and pitting corrosion were the main corrosion in the hull structure. For uniform corrosion, only the thickness of hull structure was reduced, so the ultimate strength analysis of hull structure was easy. For pitting corrosion, complicated corrosion status on the surface of hull structure happened, so the ultimate strength analysis of hull structure was difficult.

[4] investigated the effect of localized corrosion on stiffened plates. They found that local corrosion reduced the ultimate strength and had a greater effect when the corrosion occurred near the midspan of stiffened plates. But in their research, the corrosion only existed in a little local position [13,14]. analyzed the effect of pitting corrosion on lateral-distortional buckling, local face buckling and web crippling behavior. They suggested that the average thickness was an appropriate parameter to evaluate the effect of pitting corrosion [1]. investigated the strength of pitted stiffened plates under biaxial compression loading by varying the degree of pit corrosion intensity (DOP), pit depth and the location of the densest pitted zone. They found that the ultimate strength of pitted stiffened plates was governed not only by the level of DOP, but also by the smallest sectional area and the location of densest pitted zone [11]. investigated the post-buckling behavior and ultimate strength of imperfect corroded stiffened plates suffering general corrosion wastage with random distribution and proposed a practical

* Corresponding author.
E-mail address: huangyi@dlut.edu.cn (Y. Huang).

http://dx.doi.org/10.1016/j.marstruc.2017.07.006

proposal to calculate the equivalent thickness of plate elements [9]. proposed an empirical formula based on Finite Element Analysis results to predict the ultimate capacity of pitted plates under in-plane compression in terms of the plate slenderness ratio and the volume loss due to corrosion. And [10] undertook a series of nonlinear finite element analysis to investigate the effect of pitting corrosion on the ultimate capacity of mild steel rectangular plates under biaxial compression. A closed form formula was conducted to predict the remaining strength of pitting corroded plates, where both volume loss and plate slenderness are taken into account [23]. generated 3575 corroded plate surface geometries by Monte Carlo simulation for different degrees of degradation, location and ages. They derived empirical formulae to predict the ultimate strength reduction of unstiffened rectangular steel plates subjected to uniaxial compressive load due to corrosion [21]. analyzed elastic tripping stress of corroded stiffeners with irregular surfaces and found that for different type stiffener, a few factors (corrosion loss, surface roughness and position of corrosion) had different effect on the reduction of tripping Euler stress. Then [22] found that the ultimate strength of stiffened plates with pitting corrosion was reduced by increasing pit depth to thickness ratio and for different thickness plates and different stiffeners, the effect of parameters (including plate thickness, type and size of stiffeners, pit depth and degree of pits) on ultimate strength reduction of stiffened plates with pitting corrosion was different [25]. investigated the effect of variables (included the extent of corrosion, slenderness ratio and aspect ratio) on the compressive strength capacity of stiffened plates. They found that structural element selection can strongly influence the accuracy of the estimated corrosion damage effect.

According to the existing researches, the effect of some factors on the ultimate strength of pitted stiffened plates had been studied. In the present paper, the aim of the research was to develop the ultimate strength assessment formula of pitted stiffened plates based on the corroded volume loss which had been applied in the analysis of ultimate strength of pitted plates [7].

2. Pitted stiffened plate models

2.1. Geometric model and basic properties

The stiffened plate models in the present paper are the stiffened plate with a T-stiffener and the stiffened plate with a L-stiffener. The geometric models are shown in Fig. 1, where a is the length of the stiffened plate, b is the breadth of the attached plate, h_w is the height of the web, t_w is the thickness of the web, b_f is the breadth of the flange and t_f is the thickness of the flange.

[27] investigated 12 double hull oil tankers and 10 bulk carriers with the length between 150 m and 400 m. They found that the plate aspect ratio (α) was 3.5–6.7 for the deck and the bottom in the middle of oil tankers, the plate aspect ratio was 4.6–6.3 for the deck and was 3.0–4.5 for the bottom in the middle of bulk carriers, the stiffened plate slenderness ratio (β) was 1.0–2.5 and the average value was 1.9 and the stiffener slenderness ratio (λ) was 0.25–0.95 and the average value was 0.47. The investigation about the sizes of hull stiffened plates [28] indicated that the parameters of the stiffened plates were in the range of $2 \le \alpha \le 6$,$1 \le \beta \le 4$ and $0.2 \le \lambda \le 1.2$. According to the above analyses, α was assumed as 3–7, β was assumed as 1.0–4.5 and λ was assumed as 0.15–0.95 in the present paper. The parameters (α, β and λ) were defined as Eq. (1)–(4).

$$\alpha = \mathrm{a}/\mathrm{b} \tag{1}$$

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

where t is the thickness of the stiffened plate, σ_y is Yield stress and is assumed as 315 MPa and E is Young's modulus and is assumed as 205.8 GPa.

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

where r is the radius of gyration of stiffener including the attached plate.

$$r = \sqrt{\frac{I}{A}} \tag{4}$$

where I is the area moments of inertia and A is the section area of the stiffened plate.

The thicknesses of the attached plate, the web and the flange of the stiffened plate were assumed referring to the hull structure and met the rules [8].

2.2. Corrosion pits

[12] observed the corrosion condition of two cargo holds of 14 year-old bulk carrier. The results indicated that the average diameter of pits was respectively 25 mm and 29 mm. The statistic analysis of the corrosion survey results for the actual ship