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Dynamic ultimate strength of outer bottom stiffened plates under in-plane compression and lateral pressure

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ABSTRACT

An investigation in conducted on the dynamic ultimate strength of ship bottom stiffened plates under uniaxial compression and lateral pressure. The nonlinear finite element method is adopted, considering both material and geometric non-linearities. The dynamic ultimate strength of a tested specimen is calculated based on the nonlinear finite element method, and the comparison with test results shows the applicability of the present numerical method. The static ultimate strength of stiffened plate structures obtained with the numerical method is compared with an empirical formulation and the error is within the allowable range. Then, the influence of modes and magnitudes of initial imperfections, boundary conditions, lateral pressure, strain rate and structural dimensions, on the dynamic ultimate strength are discussed.

1. Introduction

Over the past few decades, much research has been conducted on the ultimate strength of ship structures, and some useful methods have been developed. However, most methods of computing the ultimate strength were based on quasi-static approaches. They can be broadly classified into following categories: Caldwell method (Caldwell, 1965), nonlinear finite element method (Tekgoz et al., 2018), Idealized Structural Unit Method (Ueda and Rashed, 1984) and Smith method (Smith, 1977). A large number of experimental studies have been performed in order to investigate the ultimate strength characteristics of box girders (Gordo and Guedes Soares, 2009) (Gordo and Guedes Soares, 2014) (Saad-Eldeen and Garbatov, 2011) (Ao and Wang, 2016).

Hussein and Guedes Soares (Hussein and Guedes Soares, 2009) have studied the ultimate strength of double hull tankers designed according to IACS Common Structural Rules and developed also the respective reliability formulation. Shu and Moan (2012) investigated the ultimate strength of a Capesize bulk carrier hull girder under combined global and local loads in the hogging and alternate hold loading (AHL) condition systematically by using nonlinear FE analysis with ABAQUS software. Cui and Wang (Cui et al., 2017) studied the ultimate strength of container ship hull girder and local structures under pure bending (both hogging and sagging), pure torsion and combined bending and torsional moments including the effects of nonlinear corrosion. Cui et al. and Yang (Cui et al., 2016) presents the numerical results of ultimate strength of cracked plates under uniaxial compression.

The bottom plate of all ships is subjected to lateral pressure in addition to the in-plane loads. The behaviour of plates under compression and lateral loads was studied by Teixeira and Guedes Soares (Teixeira and Guedes Soares, 2001), while stiffened panels were considered by Guedes Soares and Gordo (Guedes Soares and Gordo, 1996). Paik and Seo (2009a) (Paik and Seo, 2009b)developed some useful insights on nonlinear finite element method application for ultimate limit state assessment of steel stiffened plate structures subject to combined biaxial compression and lateral pressure actions. Xu and Guedes Soares (Xu and Guedes Soares, 2012) studied the ultimate strength of five narrow stiffened panels with two stiffeners under axial compression based on finite element analysis, and the numerical results are in good agreement with experimental results. Xu and Guedes Soares (Xu and Guedes Soares, 2013) conducted a series of numerical calculations of the load-displacement behaviour of five specimens which compared well with the experimental results. Khedmati et al. (2009) investigated the post-buckling behaviour and ultimate strength characteristics of high-strength stiffened aluminium plates, of which material and geometric non-linearities were taken into account, subjected to combined in-plane compressive and lateral loads actions by using non-linear finite

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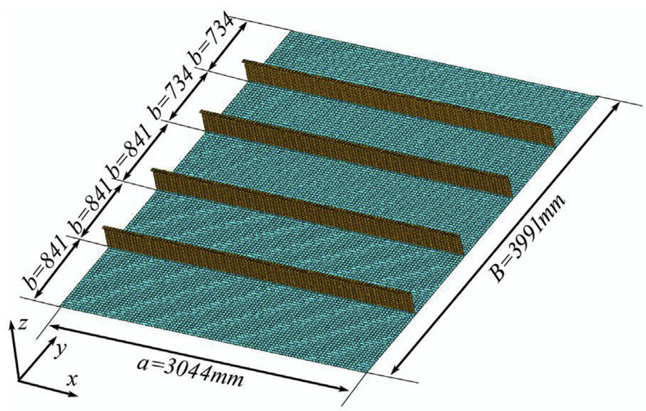

Fig. 1. Geometry properties of the outer bottom stiffened plate.

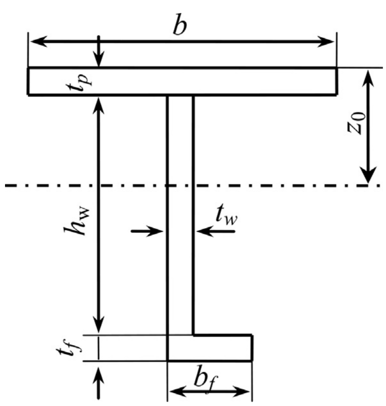

Fig. 2. Cross-section of stiffeners.

Table 1
Geometric properties of the stiffened plate.

Parameter	a	B	b	t_p	h_w	t_w	b_f	t_f
D1	3044	3991	734, 841	23	240	10	34	35
D2	3044	3991	734	23	240	10	34	35
D3	3044	3991	841	23	240	10	34	35

element method. It can be seen that various methods have been developed to study the ultimate strength of ship structures under all kinds of load types. The one common point for these loads is static so all these studies did not consider the dynamic effects.

However, external loading is usually dynamic with high amplitude when ships encounter with a large wave (Wang and Guedes Soares, 2013). Hull plate may buckle and collapse under compressive loading action if it exceeds the critical loads. With the increase of the size and design speed of a ship, the amplitude of the dynamic loads is larger and the dynamic duration is shorter, which often results in more apparent dynamic characteristics. Therefore, it is of importance to study the ultimate strength characteristics of ship plate structures under dynamic loads as well as quasi-static loads.

Wang et al. (2016) studied the dynamic structural response of ship bottom plates with forward speed under the transverse slamming impact and the compressive loading of hull bending. Yang and Wang (2017a) (Yang and Wang, 2016) studied the dynamic buckling of the ship plates with elastically restrained edges subjected to in-plane half sine impact load, a new simple dynamic buckling criterion was developed. Buckling of thin plates and stiffened plate with v-grooves under axial impact load by moving mass was studied by Chen and So (Chen et al., 2007) (So and Chen, 2007). The nonlinear dynamic buckling of rectangular plates considering initial imperfections subjected to various pulse functions with six different boundary conditions is investigated by Ramezannezhad et al. (2015). It can be noted that the dynamic response and buckling of ship plating under impact loading without considering the material non-linearities have been studied largely. Therefore, it is necessary to study the dynamic ultimate of the ship structures which include the effects of material non-linearities. The dynamic ultimate strength analysis of ship plates or hull girders is rarely found in published literature. Experimental and numerical methods are usually available methods to study the dynamic ultimate strength of stiffened plate under impact loading.

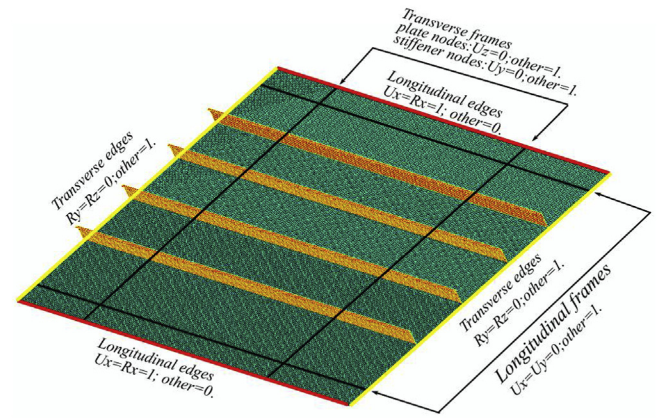

Fig. 3. Boundary conditions of the stiffened plate.

Cui et al. (1999) carried out a series water entry tests to investigate the dynamic post-buckling properties of the simply supported rectangular plate under intermediate velocity slamming loads. Cheong et al. (2000) experimentally studied the dynamic post-buckling behaviour and plastic collapse modes of rectangular plates subjected to fluid-solid slamming. A suitable critical dynamic plastic collapse criterion was presented to determine the load-bearing capacity of the plates. Numerical calculations are also performed, and numerical results compared well with the test results. Paik (Paik and Thayamballi, 2003a) conducted a series of dynamic ultimate compressive strength tests on ship plating under axial compressive loads by with different loading speeds. Liu et al. (2015) carried out the falling weight impact experiment of a stiffened plates and numerical calculation based on finite element method to study the dynamic collapse behaviour with considering the effect of strain rates. Similar falling weight tests and finite element calculations have been conducted by Liu et al. (2013) and Villavicencio and Guedes Soares (Villavicencio and Guedes Soares, 2013). Yang and Wang (2017b) studied the dynamic ultimate hull girder strength analysis on container ship subjected to impact bending moment based on 3-D nonlinear explicit finite element model.

In this paper, the ultimate strength of a stiffened plate under in-plane compression is important both because its ultimate strength can act as an indicator of the hull girder strength, and also because a stiffened plate can be considered as a structural "unit'' whose load-end-shortening response is directly used in the evaluation of the ultimate strength of the hull girder (Margaritis and Toulios, 2012). The present paper is focused on the dynamic ultimate limit states of stiffened plates which derived from 10,000TEU container ship surrounded by strong support members such as longitudinal girders and transverse frames. The dynamic ultimate strength of outer bottom stiffened plate of ships under combined in-plane compressive loads and lateral pressure is studied. The influences of the initial imperfections, boundary conditions, lateral pressure, strain rate and structural dimensions on the dynamic ultimate strength characteristics were discussed in detail.