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An Empirical Formula for Predicting the Dynamic Ultimate Strength of Stiffened Panels Under Longitudinal Impact

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An empirical formula for predicting the dynamic ultimate compressive strength of stiffened panels under longitudinal compressive load was proposed in this paper by curve fitting of massive nonlinear finite element (FE) analysis results. The formula was expressed in terms of the main geometrical properties of stiffened panels and loading speed. Three types of initial imperfections were considered in FE simulation. The applicability of the present FE procedure was verified by comparing it with existing formulae, published simulations, and test results. The influence of strain rate, initial imperfection, and the stiffener spacing was discussed. The fitting accuracy was proved by the comparison between the proposed formula and FE results of 1,058 stiffened panels. The formula was applied to the inner bottom plates of a container ship, an ore carrier, and an oil tanker, and the estimated results agree well with FE results.

INTRODUCTION

In the past few decades, extensive research has been conducted on the ultimate strength of ship structures. Some useful methods have been developed, including the nonlinear finite element method (Tekgoz et al., 2018), the Smith method (Smith, 1977), and the idealized structure unit method (Ueda and Rashed, 1984), for example. Most of them were based on quasistatic approaches.

Many researchers have studied the ultimate strength of ship structures through the experimental method. A large number of tests were conducted on plates and stiffened panels to investigate their compressive ultimate strength (Horne and Narayanan, 1976; Faulkner, 1977; Gordo and Guedes Soares, 2008, 2011, 2012). Xu and Guedes Soares (2013a, 2013b) conducted a series of experiments on narrow stiffened panels and wide stiffened panels to study the characteristics of the collapse behavior of stiffened plates. Also, many tests have been performed to evaluate the ultimate strength of box girders and ship models (Saad-Eldeen et al., 2011; Xu et al., 2012; Gordo and Guedes Soares, 2014; Ao and Wang, 2016).

The inner bottom plate is subjected to in-plane loads. Teixeira and Guedes Soares (2001) studied the ultimate strength of plates subjected to longitudinal compression and lateral pressure. Paik and Seo (2009a, 2009b) studied the numerical calculation procedure of plates and stiffened panels under combined biaxial compression and lateral pressure, from which some useful insights were built. Stiffened plates under longitudinal thrust were investigated by Tanaka et al. (2014). In addition, some formulae for predicting the ultimate strength were verified via comparing with finite element method (FEM) results. Paik et al. (2001) considered the stiffened panels as orthotropic plates and studied their ultimate strength under combined uniaxial compression and lateral pressure by the large deflection orthotropic plate approach. The results were verified by comparing them with finite element (FE) numerical solutions. Xu and Guedes Soares (2013c) simulated the load-displacement behavior of five wide stiffened panels using the FE method, and the results meet well with the experiment.

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According to the above studies, the ultimate strength of the ship structure under various kinds of load types was studied widely through experimental, analytical, and numerical ways, and many useful methods have been developed. The loads considered in the above research are generally static, and thus the dynamic effects were not considered. However, ships are generally subjected to dynamic loads with high amplitude during the voyage (Wang and Guedes Soares, 2013). When encountering freak waves and other extreme sea conditions, the period of the impact bending moment for the container ship subjected to slamming is usually in the order of a millisecond (Zhang and Zong, 2011; Liu, Suzuki, et al., 2014; Yang and Wang, 2018). The evolution of ship engineering leads to the increasing size and voyage speed of ships, which results in a higher loading amplitude and shorter duration of dynamic load. Given that, ship structures are more likely to be damaged and collapse under such dynamic loads because their amplitude can exceed the critical loads more easily. Therefore, it is of necessity and importance to study the dynamic ultimate strength of ship structures.

Many tests were conducted to investigate the dynamic ultimate strength of ship plates. Cheong et al. (2000) studied the dynamic postbuckling characteristics of rectangular plates subjected to in-plane fluid-solid slamming loads experimentally and a dynamic plastic collapse criterion was defined to estimate the load-bearing capacity of plates. The influence of boundary conditions and loading sequences were discussed. Paik and Thayamballi (2003) conducted a series of tests on the dynamic ultimate strength of squared plates under uniaxial in-plane compressive loads with different loading speeds. Numerous falling weight tests were conducted by Villavicencio and Guedes Soares (2013) to study the dynamic response of stiffened plates struck laterally by a mass. Furthermore, numerical simulations were also carried out and the strain rate effect was taken into account. Liu and Guedes Soares (2019) conducted several quasistatic and low-velocity impact tests to examine the plastic response and failure of clamped rectangular steel plates struck by hemispherical indenters. The effect of strain rate was studied, and a modified Cowper–Symonds model was proposed to characterize the material strain rate effect.

In addition to the experimental research, many numerical studies were also carried out to investigate the dynamic response of ship structures. Cui et al. (2001) investigated the dynamic buck-