Empirical formula of the dynamic ultimate strength of stiffened panels under in-plane impacts

Yufei Xiong, Deyu Wang
School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiao Tong University
State Key Laboratory of Ocean Engineering, Shanghai Jiao Tong University
Country Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration
Shanghai, China

ABSTRACT
An investigation on the dynamic ultimate strength of ship stiffened panels under longitudinal compression is conducted, the material and geometric non-linearities are taken into account. The dynamic compression is modeled as constant velocities of the loading edges. An average level of initial imperfection was applied in finite element modeling. The applicability of the present finite element analysis procedure was verified by comparing with existing formulae and test results. An empirical formula for predicting the dynamic ultimate compressive strength of stiffened panels under longitudinal compressive load was proposed based on massive numerical results. Then, the influences of strain rate and lateral pressure on the dynamic ultimate strength are discussed, indicates that the strain rate have strong impacts on the dynamic ultimate strength, while lateral pressure is of little importance.

KEY WORDS: dynamic compressive ultimate strength; dynamic compressive load; stiffened panel; strain rate; empirical formula

INTRODUCTION
The ultimate strength is an important index for evaluating the loading capacity of ship structures. Extensive researches have been conducted in the ultimate strength recently. Some useful methods have been developed, including non-linear finite element method (Tekgoz, Garbatov and Soares, 2018), Smith method (Smith, 1977), Idealized Structure Unit Method (Ueda and Rashed, 1984), etc. Most of them were based on quasi-static 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 in order to investigate their compressive ultimate strength (Horne, Narayanan and Merrison, 1976; Faulkner, 1977; Gordo and Soares, 2008; Gordo and Soares, 2011; Gordo and Soares, 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, Garbatov and Soares, 2011; Gordo and Soares, 2014; Xu, Iijima and Wada, 2012; Ao and Wang, 2016).

The inner bottom plates are 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, 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 FEM results. Xu and Guedes Soares (2013) simulated the load-displacement behavior of five wide stiffened panels using the FE method, and the results meet well with experiment.

The ultimate strength of the ship structure under various kinds of load types was studied widely through experimental, analytical and numerical ways according to above researches, and many useful methods have been developed. While the loads considered in the above researches are generally static, and thus the dynamic effects were not considered. However, ships are generally subjected to dynamic loads during voyage, and the dynamic loading amplitude can exceed several times of static load when ships encounter with large waves. The evolution of ship engineering leads to the increasing size and voyage speed of ships, which results in the higher wave encountering frequency and the larger amplitude of dynamic load. Given that, ship structures are more likely to be damaged and collapsed under such dynamic loads because its amplitude can exceed the critical loads more easily. Therefore, it is of necessity and importance to study the dynamic ultimate strength of ship structures.

Various experimental and numerical researches have been conducted to investigate the dynamic ultimate strength of ship plates. Cheong et al. (2000) studied the dynamic post-buckling 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 was 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. Cui et al. (2001) investigated the dynamic buckling of thin imperfect rectangular plates subjected to intermediate-velocity impact loads. The influence of boundary condition, initial imperfection, impact duration and material hardening ratio were studied. Yang and Wang (2016; 2017) investigated the dynamic buckling of rectangular plates with the elastically restrained edges subjected to in-plane impact loading. The influence of rotational restraint stiffness, initial imperfection, and