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Ultimate Strength of Container Ship Bilge Panels Subjected to Axial Compression Combined with Bending and Lateral Pressure

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Curved panels are widely used in fore and aft side shells and circular bilge parts of container ships, which are subjected to complicated load combinations including axial compression, bending, and lateral pressure, particularly in the most critical hull girder vertical bending conditions. In this paper, the nonlinear structural behaviors and ultimate strengths of bilge panels are investigated by performing a series of finite element analyses, and interactions between the above loads are also addressed. Meanwhile, variations in geometric parameters and structural scantlings are considered according to practical structural designs. Additionally, the effects of influencing factors such as initial deflections and geometric scantlings are investigated, and closed-form ultimate strength prediction formulae are proposed for curved stiffened plates. The results are representative and can be of reference values for structural evaluations and designs for similar structures.

INTRODUCTION

Container ships are widely used today, and about 90% of non-bulk cargo worldwide is transported by container ships; the largest modern container ships can carry over 21,000 twenty-foot equivalent units (TEU). Container ships now rival crude oil tankers and bulk carriers as the largest commercial seaborne vessels. The strength of container ships has been a concern of both industry and academia in the past few decades.

The hull girder bending ultimate strength of container ships is very important for structural evaluation, especially in the case of hogging. In hull girder hogging bending, the longitudinal members above the neutral axis are under tension, whereas those below are under compression (e.g., the double bottom structures are under longitudinal compression, which may fail as a result of buckling), so the associated ultimate strength problems are very important. Additionally, bottom plates are subjected to both longitudinal and transverse thrusts, especially with increased ship depth in ultra-large container ships; that is, biaxial compression exists in the bottom structures. The ultimate strength in this respect is a critical problem in practical structural designs, and many researchers have investigated these problems; for example, Fujikubo and Yao (1999) studied the elastic buckling strength by introducing torsional rigidity to simulate the interaction between stiffener and plate, and they also studied the influences of welding residual stress on the buckling strength. An extensive study was made on the ultimate strength of continuous plates and continuous stiffened panels under combined transverse thrust and lateral pressure (Fujikubo, Harada, et al., 2005; Fujikubo, Yao, et al., 2005); Tanaka et al. (2014) studied 720 cases with different numbers, types, and sizes of stiffeners by nonlinear finite element analysis (NFEA), and they compared the results with predictions by several existing methods, such as Common Structural Rules (CSR) method, Panel Ultimate Limit State (PULS) method by DNV, and Fujikubo/Yanagihara/Harada (FYH) method, and concluded that the PULS and FYH method can give good estimations.

Additionally, curved panels can be found in fore and aft side shells and circular bilge parts of ships, which are more complicated and different from flat stiffened plates due to introduction of curvature, etc. Compared with those of flat stiffened plates, investigations of curved plates/panels' ultimate strength are not numerous. Kwen et al. (2004) performed NFEAs of unstiffened curved plates, varying the aspect ratio, slenderness ratio, and curvature, and a simple formula was proposed to predict ultimate strength. Yumura et al. (2005) investigated the buckling and plastic collapse behavior of cylindrically curved plates under axial loading. Cho et al. (2007) performed both ultimate strength experiments and NFEAs on six stiffened curved plates under axial compression, and the numerical predictions were substantiated with the results, whereas curvature effects are quantified by numerical methods. Park et al. (2008) have studied the characteristics of buckling and ultimate strength and collapse behavior of cylindrically curved plates subjected to axial compression; the effects of the curvature, magnitude of initial imperfection, slenderness ratio, and aspect ratio on the characteristics of the buckling and post-buckling collapse behavior of cylindrically curved plates and circular cylinders under axial compression are discussed. Tran and colleagues have been dedicated to the development of semi-empirical formulae for the axial compressive ultimate strength of stiffened panels (Tran et al., 2012; Tran et al., 2014a, 2014b). Seo et al. (2016) have studied the nonlinear structural behavior and design formulae for calculating the ultimate strength of stiffened curved plates under axial compression, where influencing factors such as curvature and other geometric properties in the "double span and double bay" finite element method (FEM) model are included to derive the ultimate strength formulae.

As an extension to previous research (Cui and Wang, 2019), in this paper, the overall behavior and ultimate strength of bilge curved stiffened panels under axial compression have been investigated, where different types of initial deflections have been considered, and sensitivities of geometric scantlings have been studied. Additionally, considering the practical scenarios in hull girder bending, vertical bending and lateral pressure have also been introduced, and the interactions between them have been studied numerically. Meanwhile, considering different sizes of container

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KEY WORDS: Curved panel, ultimate strength, loads combination, prediction formulae, container ship.