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Numerical investigation on the buckling response of stiffened panel subjected to biaxial compression with non-linear equivalent single layer approach

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ABSTRACT

A ship experiences different loading conditions during service under which a structure composed of stiffened plates can buckle. Panel buckling can lead to an overall collapse of the ship hull girder that determines the hull girder ultimate strength. In the context of ultimate strength assessment, it is imperative to minimize the computational cost required for the analysis. Therefore, replacing the three-dimensional FEM stiffened panel model with a two-dimensional equivalent single layer (ESL) plate is a cost-efficient and attractive alternative. However, the premise in this switch from 3D to 2D is ESL accuracy in representing a stiffened panel's various buckling modes, which depend on the panel topology and the boundary condition. Therefore, we investigate the response of an equivalent single layer (ESL) plate representing a stiffened panel under different buckling modes. Because ESL is an asymmetric membrane, the modification of the geometry of the stiffened panel will change the buckling modes. The concern of buckling modes in this paper is (i) local buckling of the plate and web stiffener and (ii) local lateral torsional buckling of the stiffener. Results show that ESL can predict accurately the effect of local buckling for biaxial compression.

KEY WORDS: Equivalent single layer; stiffened panel; buckling analysis; biaxial compression.

INTRODUCTION

A stiffened panel, a structure composed of plate and attached longitudinal stiffeners, is extensively used as structural elements in marine, civil, and aerospace applications. The advantage of stiffener is significantly enhancing the bending stiffness by minimizing the use of extra materials. In the area of marine structures, a stiffened panel is designed with the aim of having sufficient strength and light weight. This work is done in the ship design process to ensure the panels can withstand the longitudinal bending moment due to sagging and hogging conditions. To calculate the ultimate strength of ship structures, finite element (FE) package software is a sophisticated tool for analyst where all structural elements are modeled in detail. However, the strength assessment by means of detailed FE modeling is costly and time-consuming when the entire structures are considered in calculation.

Buckling behaviors are important indicators that effect on the reduction of structure rigidity. Buckling mode is a phenomenon where an out-of-plane deformation of structures happens under compressive loads. Buckling behavior is dependent of the geometry of the structures and the boundary conditions applied (Ni et al., 2015). In the last decade, research on buckling of structures were conducted to investigate the load responses caused by local and global buckling behaviors (Paik and Seo, 2009; Wang and Abdalla, 2015; Deng et al., 2019). Simply supported and clamped boundary conditions were applied to result buckling behaviors on stiffened (Li et al., 2020) and sandwich panels (Goncalves et al., 2016). In term of geometry of structures, DNVGL provided a statement that the failure of slender structures is more dominant due to buckling effects (DNVGL, 2015).

In hull girder strength assessment, some methods have been developed for the simplification of FE simulation under a specific commercial product and have considered the loading conditions and failure mode shapes. The ALPS/HULL method is used to calculate the progressive collapse analysis of ship structures using the Idealized Structural Unit Method (ISUM) which stiffened panel is divided into structural units to obtain the load-end shortening curves from the analytical numerical formulation (Paik et al., 2010 and Ueda et al., 2003). This method was developed in the implementation of ultimate strength assessment of a container ship under pure bending, pure tension, and combined bending and torsion (Pei et al. 2015; Yao and Fujikubo, 2016). In addition, the progressive collapse (ProColl) method proposed the calculation of compartment level progressive collapse of ship structures by considering the effect of buckling behavior (Benson et al., 2013). This method was performed to analyze the ultimate strength of an intact and damaged box girder under bending load (Underwood et al., 2016). Another approach is the coupled beam (CB) method, which transforms stiffened panels in the 2D cross section area as beam elements (Naar et al., 2004). This method was applied to calculate the ultimate limit capacity of passenger ship that provides efficiency time consuming in the preliminary stage.

Equivalent single layer (ESL) approach can consider local and global buckling behaviors. The ESL method, two-dimensional single layer, is based on the homogenization technique where the stiffness matrix of ESL is equal to its three-dimensional structures. Global buckling