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Numerical investigation of three-dimensional hull girder ultimate strength envelope for an ultra large container ship

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ABSTRACT

Ultra large container ship (ULCS) structures feature large deck openings and low torsional rigidity. It is essential to accurately evaluate the maximum loading carrying capacity of ship structures. When the ship sails at an oblique heading in rough sea, the horizontal and torsional moments may approach or even exceed the magnitude of vertical bending moment. In such cases, hull girder ultimate strength assessment of container ships under load combinations comprising of vertical bending moment, horizontal bending moment and torsion is necessary in their structural design stage. In this paper, special attentions are thus paid to the hull girder ultimate strength of an ULCS (i.e., a typical 10,000 TEU container ship) subjected to combined three load components mentioned above, which is also a common load case in ships and ship-shaped offshore structures and it is assumed that the three kinds of main loads can be combined each other freely. A series of nonlinear finite element analyses (NFEA) is carried out. Effects of fabrication related initial imperfections are investigated in the present study. Based on the computed numerical results, the 3D hull girder ultimate strength envelope considering initial deformation and incorporating the interaction relationships among three kinds of load components mentioned above is established.

1. Introduction

The ULCS is regarded as one of the most representative high-tech products in the modern shipping industry for its particular characteristics, larger deck opening, larger hatch deformation, higher speed, higher stability requirement and high strength steel used more compared with normal container ships. HHI (Hyundai Heavy Industries) has developed an ULCS capable of carrying 13,000 TEU as described in Choi et al. (2006). Generally, the ultimate strength assessment for vessels is of importance, and the most essential strength measure is the ultimate strength under vertical bending moment which is usually referred to as the maximum hull girder loading capacity of the ship (Smith, 1977). However, in modern ship structural design, the maximum loading carrying capacity of ship hulls under combined loads is considered to be a necessary safety index especially for vessels such as ultra large container ships due to its characteristics. Therefore, it is of great importance to understand thoroughly the ultimate strength behaviors of ship hull girders under combined loads. Tracing the process of the progressive collapse and predicting a more complete and accurate ultimate strength envelope of hull girders are thus of great significance.

There have been a lot of efforts on the numerical analysis about ultimate strength behaviors of plates, stiffened panels and box beams under combined loads conducted in previous literature. A series of nonlinear finite element analysis to investigate the collapse behavior of plates having circular hole under combined biaxial compression and edge shear loads had been performed by Paik (2008). And later, Paik and Seo (2009a,b) has numerically conducted the ultimate strength behaviors study on steel unstiffened- and stiffened-plate structures subject to combined biaxial compression and lateral pressure actions, and developed some useful insights on nonlinear finite element method application. A comprehensive study including experimental and numerical study of finite element model of box beams under combined action of bending and torsion had been conducted by Kim and Chai (2008). For large scale ship structures, Paik et al. (2008a,b) numerically dealt with methods useful for the ultimate limit state assessment of ships and ship-shaped offshore structures. The buckling and post-buckling characteristics of hull girders under bending moment and combined loads have also been investigated to assess the hull girder strength (Paik and Kim, 2008; Benson et al., 2013; Saad-Eldeen et al., 2013). Furthermore, the safety margin of a 10,000 TEU container ship under two load combinations had

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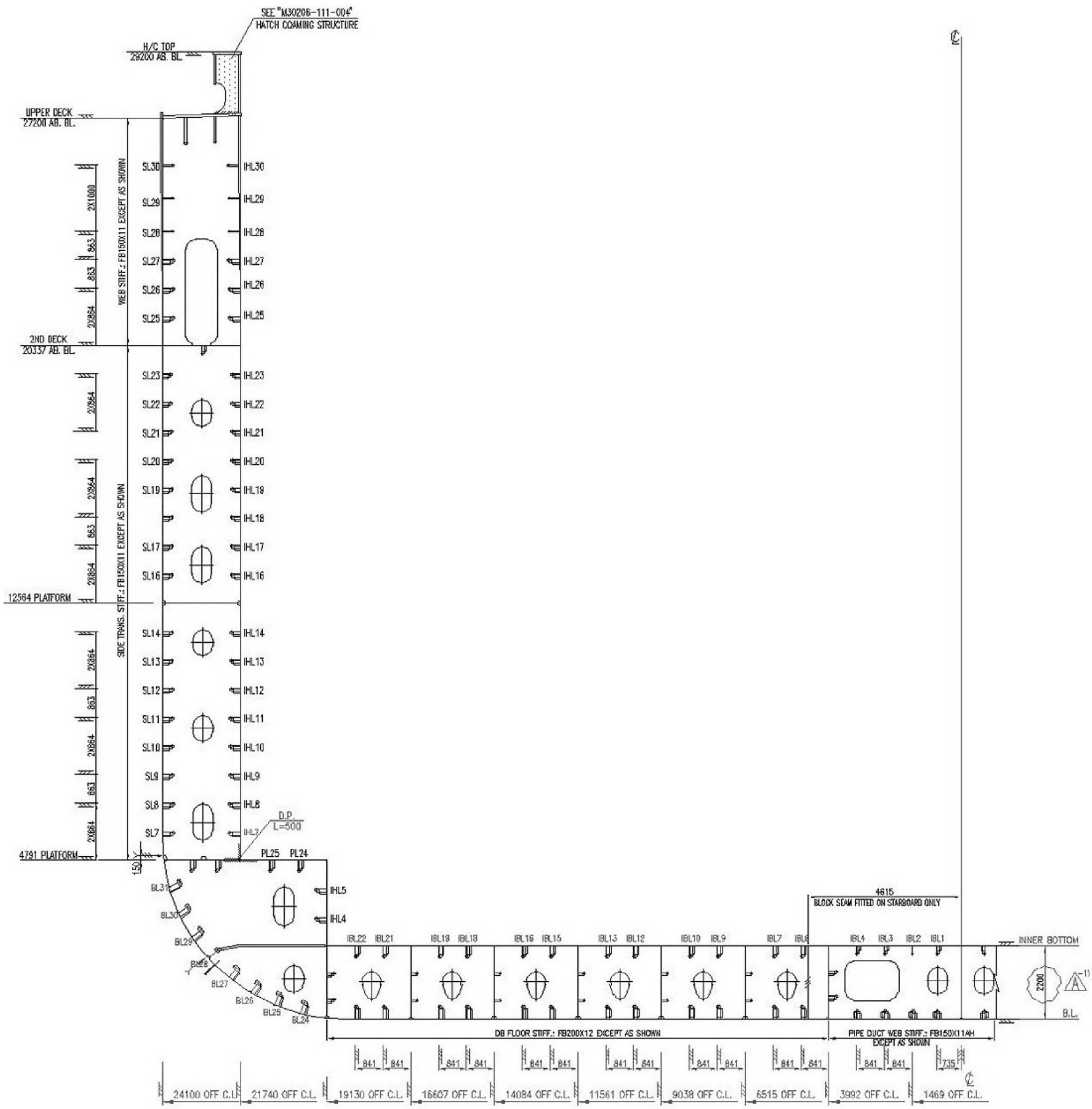

Fig. 1. The transverse mid ship section of the ULCS (all dimensions in mm).

been explored by Mohammed et al. (2016) more recently.

From all the aforementioned literature, it can see that most of studies assume the interaction relationships of hull girder structures' ultimate strength between two load components like biaxial compressive loads or combined bending moment and torsion have similar equation forms that may be generalized to the following form, namely

$$\left(\frac{\sigma_X}{\sigma_{XU}}\right)^{\alpha} + \left(\frac{\sigma_Y}{\sigma_{YU}}\right)^{\beta} = 1 \tag{1}$$

$$\left(\frac{M_V}{M_{VU}}\right)^{\alpha} + \left(\frac{M_T}{M_{TU}}\right)^{\beta} = 1 \tag{2}$$

where σ_X and σ_Y are applied longitudinal and transverse axial compression of a plate, respectively. σ_{XU} and σ_{YU} are the ultimate strength of a plate under longitudinal and transverse axial compression alone, respectively. M_V and M_T are applied bending and torsional moment, respectively. M_{VU} and M_{TU} are ultimate strength under individual bending moment and torsion, respectively. The exponents, α and β depend on the size and type of the plate or ship.

However, there are few investigations carried out for the maximum loading carrying capacity under combined three load components, such as vertical bending moment, horizontal bending moment and torsion. In this regard, this paper explores the progressive collapse of hull girder by applying NFEA using commercial FEA program Abaqus CAE and the ultimate strength interaction relationship of a typical 10,000 TEU ultra large container ship subjected to combined the three load components. One full hull compartment between two neighboring transverse