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Ultimate strength analysis of a SWATH ship subjected to transverse loads

Bin Liu[a,b,*], Weiguo Wu[a], C. Guedes Soares[c]

[a] Key Laboratory of High Performance Ship Technology of Ministry of Education, School of Transportation, Wuhan University of Technology, Wuhan 430063, China
[b] Collaborative Innovation Center for Advanced Ship and Deep-Sea Exploration (CISSE), Shanghai 200240, China
[c] Centre for Marine Technology and Ocean Engineering (CENTEC), Instituto Superior Técnico, Universidade de Lisboa, Lisboa 1049-001, Portugal

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ABSTRACT

When SWATH (Small Waterplane Area Twin Hull) ship hulls are exposed to horizontal extreme wave loads, the transverse ultimate strength is critical due to large stress concentrations in the narrow struts and haunches. In this paper, an experiment has been performed to examine the ultimate strength of a one-eighth scaled SWATH ship model subjected to transverse loads. The experimental results are compared with finite element simulations. The structural model, scaled from an actual SWATH ship, is designed with scaling laws and linear static analyses performed by the MSC.Nastran finite element solver. The procedure to design and manufacture the complex structural model is given. The actual ship and its scaled model are analysed numerically to achieve the consistency of the maximum stress and the stress distribution in their corresponding finite element models. The experimentally obtained force-displacement response and shape of the deformation show good agreement with the simulations performed by the implicit MSC.Marc nonlinear finite element solver. The maximum stresses are mainly concentrated around the hull haunches, and the stress distributions at the ship ultimate collapse are presented. The ultimate strength of the actual SWATH ship is evaluated according to scaling laws, and the ship safety margin is analysed. Moreover, the effects of hydrodynamic wave pressure distributions on the ship ultimate strength are investigated.

1. Introduction

SWATH (Small Waterplane Area Twin Hull) ships are twin-hull crafts characterised by demihulls and narrow struts connecting them to the haunches and deck structures (see Fig. 1). The hull structures are subjected to the side force acting at the submerged hulls, the lateral pressure acting on the outboard hull, the transverse bending moment due to the side force, the twin hull torsional connecting moment, and the vertical shear force at the cross-deck structure to mention the most important ones [1]. The side force acting at the submerged hulls is essential for estimating the transverse strength of twin-hull ships that is the most fundamental and important design criterion.

In the structural design of new ships, their ultimate strength should be evaluated in order to satisfy the high level of safety and low weight. The imposed environmental loads should be based on the extreme conditions, representing the maximum bending moment that the ship hull can withstand. Unlike conventional monohulls, it is lack of statistical database and practical experience for

* Corresponding author.Key Laboratory of High Performance Ship Technology of Ministry of Education, School of Transportation, Wuhan University of Technology, Wuhan 430063, China.
E-mail addresses: liubin8502@163.com, liubin8502@whut.edu.cn (B. Liu).

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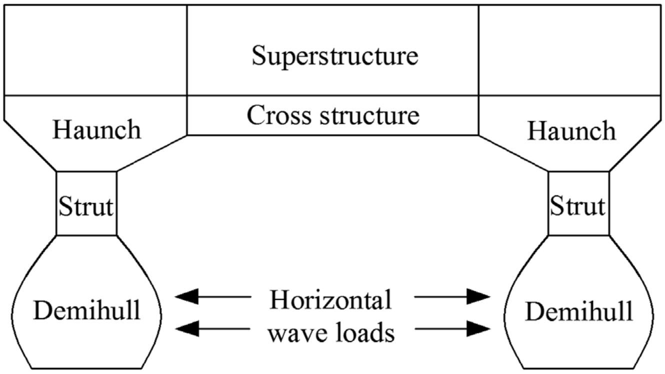

Fig. 1. Cross-section of SWATH ships exposed to horizontal wave loads.

designing multi-hull ships. The safety margin of these ships is difficult to be determined by the design of traditional ships on the basis of allowable stress assessment. Thus, it is of importance to evaluate the maximum capacity or the ultimate strength of the typical twin-hull ships, i.e. SWATH ships.

Experiments on large-scale ship models are extremely expensive and thus rarely conducted. Most of the studies on ultimate strength are relevant to common structural components in ship structures, such as stiffened panels [2–7] and box girders [8–10]. Quasi-static tests can record continuously the damage process, obtaining detailed information from each specimen. Generally, the stiffened panels under axial compression mainly fail by local buckling or tripping of longitudinal stiffeners, and the box girders under vertical bending moment mainly collapse at the compressive plate elements accounting for buckling and yielding.

Nowadays, the ultimate strength of conventional cargo ships under longitudinal bending is usually assessed by simplified methods, for example, IACS prescribed incremental-iterative method and direct assessment method. Nevertheless, these methods tend to be limited to relatively simple structural geometries, and cannot evaluate the strength of complex structures, for example, the transverse strength of twin-hull ships. In this perspective, the nonlinear finite element method is the preferred design tool for predicting the ultimate strength of multihull structures. However, the finite element results need to be validated against experimental tests before being implemented in the structural design. In this respect, it is necessary to perform experimental analysis of the ultimate strength of large-scale hull structures.

In general, ultimate longitudinal strength of conventional monohulls has been investigated extensively [8,11–16]. Nevertheless, the design of SWATH ships mainly depends on the transverse bending strength rather than the longitudinal strength due to their special sectional configuration, i.e. wide deck and small hull cross-section at the waterline. Hence, the transverse ultimate strength becomes critical. When the hull of SWATH ships is subjected to transverse loads, large stresses will be concentrated in the hull haunches and struts. Unfortunately, there is not much relevant investigation reported in the literature in this respect. Only some investigations have been carried out on the linear static analysis of the transverse strength of twin-hull ships. Stresses and deformations relevant for transverse strength analysis were calculated for a catamaran by a compartment model [17], in which similar structural configuration can provide a good understanding for the strength of SWATH ships. However, the collapse behaviour of SWATH ships is still not demonstrated experimentally.

Liu et al. [18] and Liu and Wu [19] presented initial results of the experimental programme. The present paper extends those papers by clarifying further the experimental details by giving scaling background for the experiments and by proving a comprehensive analyses of the experiments and performing systematic numerical simulations to study the ultimate transverse strength of the actual ship. It describes an experiment on one-eighth scaled model of a SWATH ship to examine its ultimate strength and collapse mode. The experimental results are compared with nonlinear finite element simulations. The structural model, scaled from an actual SWATH ship, is designed on the basis of scaling laws and linear static finite element analyses. The actual ship and its scale model are analysed numerically to achieve the consistency of the maximum stress and the stress distribution in their corresponding finite element models. Afterwards, the nonlinear finite element simulations are performed to compare with the experimentally obtained force-displacement response and shape of the deformation. The stress concentration and distribution at the collapse of hull structures are investigated. Finally, the ultimate strength of the actual SWATH ship is evaluated according to scaling laws, and the ship safety margin is analysed. More realistic loading distribution for hydrodynamic wave pressure at side inboard and outboard are taken into account for discussing their effects on the ship transverse strength.

2. Design and manufacture of scaled model

Structural tests are conducted on a scaled model in order to obtain the response characteristics of a geometrically similar full-scale prototype which is the actual system of interest. Here, a scaled structural model is manufactured to evaluate experimentally the ultimate strength of full-scale prototype. Thus, the procedure for designing the complex scaled model is illustrated in detail.