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A benchmark study of procedures for analysis of axial crushing of bulbous bows

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Abstract

Simplified methods to estimate mean axial crushing forces of plated structures are reviewed and applied to a series of experimental results for axial crushing of large-scale bulbous bow models. Methods based on intersection unit elements such as L-, T- and X-type elements as well as methods based on plate unit elements are employed in the analyses. The crushing forces and the total absorbed energy obtained by the simplified analyses are compared with those obtained from large-scale bulbous bow experiments. The accuracy and the applicability of these methods are discussed in detail.

Keywords: Ship collision; Simplified method; Axial crushing; Effective crushing distance; Bulbous bow; Buffer bow; Crashworthiness

1. Introduction

In order to reduce the risk of oil spill from struck oil tankers a buffer bow concept was proposed by the Association for Structural Improvement of Shipbuilding Industry (ASIS) [1] and its effectiveness was analytically and empirically investigated for several specific collision scenarios by Kitamura [2], and Endo and Yamada [3–6]. To apply the buffer bow concept, it is important to be able to estimate the crushing forces and energy absorption of

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buffer bow structures as well as of conventional bow structures. In general, the crashworthiness of ship structures against collision is one of the important matters relating to the safety of ships and crews on board. To evaluate the crashworthiness of ship structures, the finite element analysis (FEA) is a powerful numerical tool. To perform a large-scale FEA, however, is still time-consuming due to the effort required when creating the finite element model as well as the numerical calculation itself. Therefore, there is a need for simplified methods to calculate the crashworthiness of ships in the early stages of the design, in the rule making process as well as for risk and reliability analyses. A variety of simplified formulas have been proposed in order to estimate the mean crushing forces of plated structures such as ship bows. Although these formulas are based on the same rigid–plastic material modelling procedures they are in reality different due to different assumed folding mechanisms. The purpose of this paper is a review of existing simplified analysis methods and to find the most suitable and accurate formula for estimating the crushing behaviour of bulbous bows.

The International Ship and Offshore Structures Congress (ISSC) specialist panels on structural design against collision and grounding has continuously reviewed the most recent literature and its applicability for predicting the crushing and cutting damage of ships in collision and groundings [7].

Simplified formulas for estimating axial crushing forces of prismatic plated structures have been proposed by Wierzbicki [8,9], Amdahl [10], Yang and Caldwell [11], Ohtsubo and Suzuki [12], Abramowicz [13], Wang et al. [14,15], and Paik and Pedersen [16]. Lehman and Yu [17] derived analytical formulae for estimating the axial crushing strength of a conical shell modelling the outer part of bulbous bow structures. Later, Paik and Wierzbicki [18] performed a comprehensive benchmark study on the application of simplified methods to a series of quasi-static crushing tests using longitudinally, transversely or orthogonally stiffened square tubes. The analytical results by Amdahl [10], Wierzbicki and Abramowicz [9], Abramowicz et al. [12] and Paik and Pedersen [16] were compared with the experimental results. It was concluded in this study that the methods by Wierzbicki and Abramowicz [9] and Paik and Pedersen [16] give relatively good estimations as compared with other methods for axially compressed thin-walled prismatic structures with quite simple geometries. More recently, Zhang [19] and Endo and Yamada [3] developed a new set of simplified methods.

The above-mentioned theoretical procedures for estimation of the crushing behaviour of prismatic structures are based on experimental validation using thin lightly stiffened structures measuring 2–4 mm. However, these structures have much lower thicknesses and have much simpler geometries than found in practical bulbous bow structures on ships. It is anticipated that in more heavily stiffened structures the stiffeners and/or webs make earlier plate-to-plate contact and will prevent the deformation and folding of the outer shell. This can be expected to result in larger crushing resistance. Another source of concern is the assumption of prismatic structures. The configuration of practical bulbous bows differs from the exact prismatic shape.

In order to clarify the crushing mechanism of bulbous bow structures and to obtain realistic experimental data the first author has conducted a series of axial crushing tests using large-scale bulbous bow models, where the model is almost half-scale of actual very large crude oil carriers. These models are also representative for actual bulbous bows of ships of about 500 tons.