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Collapse Mechanism of the Buffer Bow Structure on Axial Crushing

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The purpose of this study is to obtain experimental data on the crushing of the buffer bulbous bow, especially to investigate the collapse mechanism of buffer bulbous bow structure. A series of experiments in quasi-static conditions was carried out on large-scale bulbous bow models of a conical shape and simplified cross-section. Two kinds of transversely stiffened models—a buffer bow and a longitudinally stiffened model as a conventional bow—were axially collapsed by a rigid board. The load-displacement curve, mean crushing strength as well as the total energy absorption capability were investigated. Finite Element Analysis (FEA) and simplified analysis were conducted to compare with the experimental results. As a result, the basic collapse mechanism of the buffer bulbous bow was clarified in comparison with the longitudinally stiffened one. Further, the accuracy of simplified analysis in estimating mean crushing force was validated by comparison with experimental results.

INTRODUCTION

The adoption of the double-hull system in the side hull of an oil tanker has been recognized as an effective countermeasure to prevent a disastrous oil spill from a stricken oil tanker. ASIS (1998), however, studied oil tankers' structural safety to prevent oil spills and concluded that safety has not yet been guaranteed to a satisfactory level in the case of a high-energy collision. In fact, in 2001, the double-hull tanker *Baltic*, struck by the bulk carrier *Tern* in the Baltic Sea, spilled about 2700 tons of oil, causing environmental disaster in the neighboring sea. Then it was recognized that a further countermeasure was necessary to reduce the oil spill risk from a stricken oil tanker. ASIS (1998) and Kitamura (2000) proposed the buffer bow concept that is adopting a transverse stiffening system instead of a longitudinal one as the effective countermeasure.

Based on the research contribution by ASIS, the Buffer Bow Project (BBP) was launched in 2001 by the National Maritime Research Institute (NMRI), which is sponsored by the Japanese Ministry of Land Infrastructure and Transport (MLIT). Project objective is to develop the practical design of the buffer bow, and also to investigate whether buffer bow design could be adopted as a regulation. This paper describes a part of the project results so far.

In the case of ship-to-ship collision, the bulbous bow and upper stem of the colliding ship is likely to make contact with the side structure. For a fully loaded oil tanker, a colliding ship in the ballast condition is considered the greatest menace, because the vertical location of the upper stem of the striking ship is expected to be above the deck of the ship being hit, and the bulbous bow is likely to penetrate the side hull's vertical center. Thus, in this study the main focus is on the bulbous bow of the striking ship as an objective of buffer bow structure for the beginning of the project.

In order to analyze ship-to-ship collision, FEA could be a strong tool (Kitamura, 2000, 2002). However, the simplified analysis method is strongly needed for various collision scenarios because FEA is time-consuming.

As for the simplified method, Minorsky (1959) proposed a method to estimate the absorbed energy by considering the structure's volume. Later many simplified methods to predict the mean crushing load for a circular/square tube or regular plate with/without stiffener were presented which considered consumed energy in rigid-plastic deformation (Alexander, 1959; Wierzbicki, 1992; and others). However, as far as the axial crushing of the bulbous bow structure, little research was conducted (Lee, 1983; Kierkegaard, 1993; Ohtsubo and Suzuki, 1994; Lehmann et al., 1995; and others).

Lehmann et al. (1995) developed the numerical model applicable to the crushing of the conical shell by applying the "two-folding model" proposed by Wierzbicki (1992). Ohtsubo and Suzuki (1994) developed the method with which to estimate the collapse strength of the bulbous bow by using the L-, T- and X-type super element. Endo and Yamada (2001) combined the methods by Lehmann et al. (1995) and by Ohtsubo and Suzuki (1994) to predict the mean crushing load for a bulbous bow with a transverse stiffening system.

In most of the simplified analysis mentioned above, the energy dissipation method using rigid-plastic analysis has been adopted on the assumption of the specific deformation mode. Thus, to grasp the deformation pattern and/or collapse mechanism is very important in order to develop simplified analysis for the buffer bulbous bow. This study intends to not only obtain experimental data on the crushing of the buffer bulbous bow, but also to investigate the collapse mechanism of the buffer bulbous bow structure. Those data are intended to improve the accuracy of simplified analysis in the future.

Authors have conducted a series of quasi-static crushing tests and numerical analysis using small-scale bow models by adopting the transverse stiffening system. Endo and Yamada (2001) adopted the models with the simplified transverse section (circle and cruciform). Further, Endo, Yamada et al. (2002) extended the transverse section of the model to the more actual section (ellipse and cruciform). Those studies investigated the basic characteristics of the buffer bow model. The accuracy of FEA was validated, and it is found that FEA could estimate the experimental result with reasonable accuracy, although small discrepancies are observed in the timing and fluctuation of peak load. Plus, it is found from those studies that using thin plate (<4 mm) may cause significant

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