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Experimental and analytical investigations on the response of stiffened plates subjected to lateral collisions

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A B S T R A C T

Rational structural design of ships or offshore platforms against collisions requires prediction of the extent of damage to stiffened plates generated by lateral impact. In predicting the extent of collision damage, most researchers employ numerical analysis methods using commercial software packages. Like other structural problems, any nonlinear dynamic analysis methods should be substantiated with relevant test data prior to being employed for design. Unfortunately, full-scale collision tests on marine structures are very rare. Still, results from collision tests on marine structural elements can help to substantiate theoretical methods for collision analyses. Lateral collision test data for unstiffened plates are available, but it is difficult to find results from tests on stiffened plates in the open literature. In this paper, the results of lateral collision tests on 33 stiffened plates are reported. A simplified analytical method is developed for the prediction of the extent of damage to stiffened plates due to lateral collisions and this method is substantiated with the test results. Also proposed is a simple criterion with which the occurrence of crack damage can be judged.

1. Introduction

The stiffened plate, a major structural element of ships and offshore structures, is prone to damage due to collision with other floating or fixed structures and falling objects. Rational design of stiffened plates against such kinds of mass impacts must incorporate predictions of the probability of the

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occurrence of accidents, the extents of damage and the residual strength of the damaged structure [3]. Many researchers have performed experimental and theoretical studies on the behaviour of stiffened and unstiffened plates subjected to lateral impulsive loadings. Nurick and Martin [9] and Nurick and Shave [10] reported on the deformation and tearing of thin plates subjected to impulsive pressure loads. Wierzbicki and Nurick [15] investigated the response of thin clamped plates to a localized impulsive load imparted over a central region experimentally and theoretically to determine the location of tearing failure and the critical impulse to failure. Lee and Wierzbicki [6,7] performed a comprehensive analysis of deformation and fracture of thin plates subjected to localized impulsive loading. They investigated many aspects of the problem including calibration for plasticity and fracture. Park and Cho [11] proposed simple design formulae to predict the extents of damage of unstiffened and stiffened plates under explosion loadings.

Samuelides [12], Zhu and Faulkner [16], and Cho et al. [1] reported results from experimental and theoretical studies on the structural behaviour of unstiffened plates subjected to lateral collisions. Wang [13] reviewed equations proposed to predict the plastic deformation of plates subjected to static punching loads. Lee et al. [8] investigated the response of thin clamped plates subjected to static punch indentation experimentally, analytically and numerically to determine the onset of fracture. Kaminski et al. [5] summarized research on ship structures under lateral collisions. Wang et al. [14] reviewed the publications on ship's side collision with wedge-type or bulbous bow.

Even though the stiffened plate is a basic structural element of marine structures, results from stiffened plate collision tests have not been reported in the open literature. Because ships and offshore structures consist of stiffened plates, their overall response to lateral collision loading cannot be considered without first studying the behaviour of stiffened plates subjected to lateral collisions. Commercial numerical packages, such as DYTRAN or ABAQUS, are appropriate for the analysis of stiffened plates subjected to collision, but their operation may be considered overly expensive and time consuming for design purpose. Therefore, it is essential that any simple, design oriented methods for stiffened plate collision analysis be developed.

The predictive capability of any commercial or in-house computer program or analytical method should be substantiated with relevant test data before performing nonlinear dynamic analyses. Reported in this paper are the results of lateral collision tests run on 33 stiffened plate models. Of the plate models, three were cracked and one was torn. A simplified analytical method is proposed for the prediction of the extents of damage to stiffened plates subjected to lateral collisions. In this method it is assumed that all kinetic energy of the striker is dissipated as plastic deformation of the struck stiffened plate. The plastic deformation consists of hinge rotation occurring at plate and stiffener flanges, the membrane tension of plates and stiffener flanges and the shear deformation of stiffener webs. The proposed method is substantiated with the test results. The mean ratios of predicted to actual lateral damage for 29 models without crack or tearing damage was 1.138 with a COV of 19.9%. Using the test data and the proposed analysis method, a criterion was developed to judge the occurrence of cracks.

2. Lateral collision tests on stiffened plates

2.1. Collision testing machine

Two kinds of collision testing machines were used in this study. Strikers lighter than 60 kg were accelerated by springs and were run on a frictionless roller conveyer [1]. Strikers heavier than 250 kg were accelerated using a pendulum type machine. The pendulum type collision testing machine is composed of a pendulum, a pendulum hanging frame and a pendulum height controller (see Fig. 1). The model support structure is made of $150 \times 150 \times 10/8$ H-beam, which has relatively much larger stiffness comparing with those of the models.

The mass of the striking pendulum can be increased up to 600 kg and the maximum collision speed is about 3.5 m/s. The colliding velocity of the pendulum was measured using a timer, which starts and stops using two different light sensors. The pendulum has a knife edge striker on its front face with a height of 165 mm. The cross-section plan of the striker header made of $75 \times 75 \times 10$ angle stiffened by a flat bar of 10 mm thickness is provided in Fig. 2. The striker was released from a desired height to produce an expected velocity.