Marine Structures 32 (2013) 84–112

Contents lists available at SciVerse ScienceDirect

Marine Structures

journal homepage: www.elsevier.com/locate/marstruc

Deformation process of web girders in small-scale tanker double hull structures subjected to lateral impact

R. Villavicencio [a], Y.-H. Kim [b], S.-R. Cho [b], C. Guedes Soares [a,*]

[a] Centre for Marine Technology and Engineering (CENTEC), Instituto Superior Técnico, Technical University of Lisbon, Av. Rovisco Pais, 1049-001 Lisboa, Portugal
[b] School of Naval Architecture and Ocean Engineering, University of Ulsan, Nam-Ulsan, P.O. Box 18, Ulsan, South Korea

A R T I C L E I N F O

Article history:
Received 6 May 2012
Received in revised form 30 January 2013
Accepted 22 February 2013

Keywords:
Double hull
Impact test
Numerical simulation
Material relation
Web girder
Local indentation
Fold

A B S T R A C T

Experimental drop weight impact tests are performed to examine the dynamic response of web girders in a one-tenth scaled tanker double hull structure struck laterally by a knife edge indenter. The small stiffeners of the full-scale prototype are smeared in the small-scale specimen by increasing the thicknesses of the corresponding plates. The plastic response is evaluated at two impact velocities and the impact location is chosen between two web frames to assure damage to the outer shell plating and the stringers. The laboratory results are compared with numerical simulations performed by the LS-DYNA finite element solver. In the simulations, the strain hardening of the material is defined using experimental data of quasi-static tension tests and the strain rate sensitivity is evaluated using standard coefficients of the Cowper–Symonds constitutive model. The experimental permanent deflection and shape of the deformation show a good agreement with the collision simulations. It is found that the crushing resistance of the specimens is determined by the deformation mechanism of the stringers. Thus, the deformation process is described and compared with theoretical deformation modes for web girders subjected to large in-plane quasi-static loads. Additionally, the influence of the stiffeners on the shape of the deformation of the stringers is illustrated through simulations of stiffened structural elements.

* Corresponding author.
E-mail address: guedess@mar.ist.utl.pt (C. Guedes Soares).

0951-8339/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.marstruc.2013.02.004

1. Introduction

Increased attention has being paid to reduce the risk of oil spill due to accidents involving large tanker vessels. According to the United Nations Environment Programme (UNEP), the maritime transport of crude oil is responsible for half of the global marine oil pollution. Since 1968, the UNEP has registered more than 7600 tanker incidents with over 10.6 millions tons of crude spillage. In 1979 was reported the largest amount of oil spill at sea estimated at about 1.5 million tons. These environmental disasters forced the United States Congress to approve the Oil Pollution Act of 1990 (OPA90), which mandates the use of double hull tanker designs to protect the ocean environment from potentially devastating oil pollution. This act is ratified by the International Maritime Organization (IMO) in 1992 [1]. Later in 1995, the IMO developed guidelines for approving alternative methods for design of oil tankers. These guidelines compare the oil outflow performance of alternative tanker designs with reference double hull designs that comply with the International Convention for the Prevention of Pollution for Ships (MARPOL, 13F). The major shortcoming of this methodology is that it only includes the oil outflow calculation and does not consider the effect of the structural design on the extent of damage [2].

The principal types of tanker accidents with consequences for the marine environment are: collision (25%), grounding (25%), internal structural failure (30%) and fire and explosion (20%) [1,3]. With respect to the volume of outflow, more than half are due to groundings affecting the bottom of the ships. Although all cases are characterized by a loss of structural integrity, the main causes for the tragic events are attributed to inadequate strategies and policies of security and prevention (50%), competence and motivation of the crew (20%), navigation conditions (10%) and concept of design and construction of the vessel (20%). In practice, all mentioned circumstances contribute to large collision or grounding accidents [1]. Therefore, the structural design of tankers requires further investigation in order to prevent the oil pollution during those accidents.

The analysis of ship collision is divided into two parts: external and internal mechanics [4,5]. Both are studied separately and linked together by the absorbed energy during the structural deformation. The external mechanics deals with the global motion of the ship under the action of the collision force and the hydrodynamic pressure exerted on the wetted surface [6]. On the other hand, the internal mechanics concentrates purely on the structural response, evaluating the structural crashworthiness of the ship during accidents [7,8]. In order to assess the internal mechanics of ship collision, empirical formulae, simplified analytical methods, finite element simulations and experiments are used.

In the case of a tanker collision, the penetration of the inner hull involves cargo spillage and, consequently, severe environmental damage. The absorbed energy by the struck ship at the moment of the inner hull rupture is named ‘critical deformation energy’, which can be maximized with a strengthened double hull structure [9]. Therefore, the design of tanker double hulls requires an accurate prediction of the extent of damage in the structural components subjected to lateral impact in order to minimize the volume of oil outflow during a ship-to-ship collision accident. Unfortunately, the influence of the structural details has received very little attention in the marine pollution prevention. The difficulties in predicting the behaviour of tanker structures under a variety of possible damage scenarios contribute to that circumstance. Thus, additional work is needed to investigate not only the worst case, but also other minor collision events that ships experience during service.

The finite element analysis is a useful tool to predict the extent of damage due to large in-plane and out-of-plane loading in the ship structural components. However, the results of the nonlinear dynamic analysis should be validated with experimental tests before being implemented in the structural design. Unfortunately, experiments using full-scale prototypes are extremely expensive and thus rarely performed. In this respect, prior to performing analyses of large-scale structures, it is necessary to validate the experimental–numerical models of the dynamic large deformation for small-scale structural elements. This provides the basis for the design of complex marine structures subjected to dynamic impact loads [10].

The available results for comparison between small-scale impact tests and finite element simulations of double hull structures are few. In most of the published works, the reported analyses are performed on structures that simulate the bottom or the side structures of the ship. In those cases, the experimental-numerical impact response is examined by penetrating the panels using quasi-static