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Experimental and numerical analysis of a tanker side panel laterally punched by a knife edge indenter

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A B S T R A C T

The paper presents finite element simulations of a small-scale stiffened plate specimen quasi-statically punched at the mid-span by a rigid indenter, in order to examine its energy absorbing mechanisms and fracture. The specimen, scaled from a tanker side panel, is limited by one span between the web frames and the stringers. The paper provides practical information to estimate the extent of structural damage within ship side panels during collision accidents. Moreover, the results of this investigation should have relevance to evaluate grounding scenarios in which the bottom sustains local penetration. This is possible since the structural arrangement of the double hull and the double bottom of tanker vessels is very similar. The experimentally obtained force–displacement response and shape of the deformation show good agreement with the simulations performed by the explicit LS-DYNA finite element solver. The numerical analysis includes aspects of particular relevance to the behaviour of ship structures subjected to accidental loads which could give rise to difficulties in interpreting finite element calculations. In particular, the paper comments on the material nonlinearities, the importance of specifying the precise boundary conditions and the joining details of the structure. The considerable practical importance of these aspects has been the focus of attention in previous publications of the authors which evaluate the experimental-numerical impact response of simple ship structural components, such as beams and plates. Therefore,

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this paper uses the definitions proposed in those references to evaluate its applicability in the scaled tanker side panel, as an example of a more complex ship structure.

1. Introduction

In the case of a tanker side 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 [1]. 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 side 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.

In order to assess the response of ship structures during accidental events, full-scale ship collision and grounding experiments have been performed [2–4]. Such experiments are extremely expensive and thus rarely conducted. Hence, model laboratory tests are the most practical means for investigating the crashworthiness of ship structures. The large-scale dynamic experiments require the use of expensive test facilities and equipment in order to capture the entire impact event. Therefore, in most of the studies of ship structures subjected to lateral collision, the experimental impact response is examined by penetrating the side or the bottom panels using quasi-static lateral loads. This information has been used to propose analytical expressions for the primary damage mechanics [5,6] or to perform numerical analyses that simulate similar quasi-static interactions [7–10]. The quasi-static tests have the advantage of continuous records of the damage process, obtaining detailed information from each specimen. However, the quasi-static test has the disadvantage of removing the dynamic effects produced by the high impact forces developed in the striker-structure contact during the collision process. It has been demonstrated that static and dynamic tests of the same ship structural arrangements show similar energy absorbing mechanism and fracture. However, the energy absorbed in a dynamic test is larger than that absorbed in the corresponding static test, a circumstance attributed to the phenomenon of material strain-rate sensitivity [11,12]. This characteristic was early demonstrated with the large scale impact experiments of ship structures [13] reviewed by Jones [11] in its discussion on the structural aspects of ship collisions, while recently dynamic and quasi-static collision simulations of an unstiffened double hull structural module provided similar conclusions [12].

Nowadays, the finite element method is the preferred design tool for predicting the controlled failure, the maximum deformation, or the largest loading which can be sustained by a structure. This class of problems is commonly encountered in the analysis of structural crashworthiness and energy-absorbing systems and in safety calculations, security studies and hazard assessments in many fields of the industrial engineering. Furthermore, the method finds application in structural optimization studies in order to achieve lightweight structures and prevention from environmental damage [14]. Therefore, complex finite element models of ship structures have been used to calculate the energy absorbed during collision and the extent of damage due to large in-plane and out-of-plane loadings in the hull structures [15,16]. However, as the numerical results should be validated with experimental tests before being implemented in the structural design, collision simulations of complex ship structures are performed only for comparative purposes. In this respect, prior to performing analyses of large-scale structures, it is necessary to verify the experimental-numerical models of the large deformation in small-scale structural components. This provides the basis for the design of complex ship structures subjected to dynamic impact loads [17].

In general, the collision analyses of tanker double hull structures aim at predicting the onset of fracture in the inner shell [1]. Before this damage, the shell plating and the main supporting members of the