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Finite element simulation of blank torpedo impact on submarine hulls

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ABSTRACT

The paper presents the development, evaluation and validation of a finite element model for the simulation of the impact of a blank torpedo against a submarine pressure hull. A parametric, shell finite element model was generated and analysed using ANSYS Finite Element Package to explore the effects of different loading conditions and analysis types in the accuracy of the results. Results were compared to a series of drop tests conducted by the Australian Defence, Science and Technology Organisation (DSTO). Geometric and material non-linear models were compared against varying methods of load applications. A numerical model subjected to a concentrated load was found to provide a poor representation of the drop tests. A clear improvement in the accuracy of the results was achieved by implementing a distributed impact load case; however, a full nonlinear analysis involving large deflection, plasticity and contact was found to offer the best agreement with the experimental test results.

1. Introduction

The Royal Australian Navy (RAN), as part of its training regime, takes part regularly in both domestic and multinational training exercises where its surface vessels and submarines are required to fire practice or 'blank' torpedoes (van der Schaaf, 2012). Blank torpedoes are conventional torpedos that have been stripped of their explosive warhead. These devices are normally fired to measure the readiness and reaction time of weapons crews and not with the intention of hitting another vessel or target. Nevertheless, if a blank torpedo was to accidentally hit a submarine, the concentrated load generated at the point of impact has the potential to cause significant and permanent deformations to the hull structure.

The pressure hull of a submarine can be idealised as a thin-walled cylinder under the action of an external pressure. The maximum pressure that such a structure can resist before imploding is inversely proportional to the degree of imperfection, i.e. out of roundness of its cross section (Burcher and Louis, 1994). Consequently, if the impact of a blank torpedo was to generate a significant permanent set in the pressure hull of a submarine, the structure would no longer be able to carry its design pressure forcing the submarine to operate at shallower depths or otherwise risk catastrophic stability failure of the pressure hull. This is a critical operational issue that puts both crew and vessel at risk as a submarine that is unable to reach its design dive depth is prone to be detected and attacked by enemy anti-submarine warfare vessels and/or aircraft (Armo, 2000). This potential safety risk has created the necessity of developing a simple and efficient analysis methodology capable of accurately predicting the magnitude and shape of the deformations generated by the impact of a blank torpedo against a submarine hull.

The detonation of a conventional torpedo is normally classified as an explosion/blast problem. In such problems, an extremely rapid chemical reaction converts the warhead explosive payload into gas, liberating a large amount of heat in the process. In turn, the resulting pressurised gases expand outward by generating a destructive pressure wave (Rajendran and Lee, 2009; Rajendran et al., 2006). Nevertheless, as already mentioned, a blank torpedo does not possess such an explosive warhead and hence a blank torpedo impact is better classified as a collision problem.

Since the late 1950s, collision research has been focused on the establishment of analytical and numerical models for the analysis of the motions and structural response of vessels involved in ship-to-ship collision and/or grounding (Samuelides et al., 2008). According to Paik (2007a), these analyses can be classified into external mechanics analyses, which deal with the rigid body motion of the ship during and after the collision, and internal mechanics analyses, which deal with the evaluation of the structural crashworthiness of the vessel during accident situations.

If we take into account that the mass of a conventional, modern torpedo is at least two orders of magnitude smaller than the mass of a modern diesel powered submarine it is easy to conclude that a blank torpedo impact will have a small effect on the motion of the struck submarine, especially if struck close to the longitudinal centre of buoyancy. In contrast, the calculation of the magnitude of the deformations generated by the impact is of great importance

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for analysts and structural designers and therefore the analysis of the internal mechanics of the blank torpedo collision becomes a necessity.

Numerous models have been developed to simulate the internal mechanics of ship-to-ship collisions and grounding (Ehlers et al., 2008; Ringsberg, 2009; Zhang and Suzuki, 2006; Zheng et al., 2007). However, the scenarios used for the collision assessment were developed for impacts were the kinetic energy of the impacting object exceeded 100 MJ (Klanac et al., 2009; Samuelides et al., 2008). Nevertheless these investigations are mostly concerned with collisions affecting large regions of the hull structure, and not with a concentrated impact zone as expected in the event of a of a blank torpedo impact.

The localised indentation generated by the impact of masses onto plates has been investigated by Shen (1995). His investigation presented an analytical model which examines the dynamic plastic response of thin circular plates struck transversely by a mass with a conical head and a solid and rigid spherical nose at the centre of the plates. A similar investigation was conducted by Simonsen and Lauridsen (2000). The authors used experiments, analytical theories and finite element simulations to predict failure (rupture) in a thin, ductile metal plate struck by a rigid sphere. Recently, Villavicencio et al. (2012) reported the experimental and numerical results of a series of drop impact tests examining the dynamic response of fully clamped aluminium circular plates struck laterally by a mass with a spherical, rigid indenter. It can be noticed that these investigations have concentrated in the study of the impact of a rigid object (sphere) against a flexible one (plate). However, in the case of a blank torpedo collision both the impacting body (i.e. the torpedo nose) and the struck object are flexible. Furthermore, these investigations have focused on localised impacts on flat plates and not curved panels as those present on a submarine hull.

The finite element method is currently the most powerful approach to simulate structural crashworthiness of ship collision, but the quality of this simulations is hindered by a lack of analysis guidelines especially in regards modelling techniques (Paik, 2007a, 2007b). The present investigation aims to develop a practical and efficient finite element simulation of the impact of a blank torpedo against a submarine hull. The results obtained in this investigation are validated against drop test experiments conducted by DSTO (van der Schaaf, 2012).

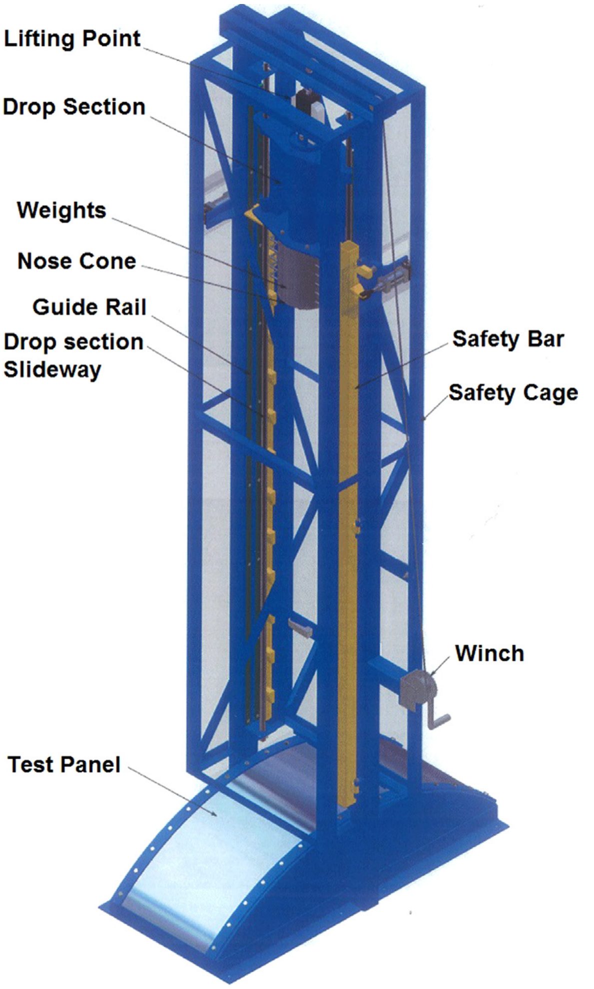

Fig. 1. General arrangement of the drop tower (van der Schaaf, 2012).

2. Experimental data

The tests conducted at DSTO consisted of dropping hemispherical shells onto curved panels using the testing rig shown in Fig. 1. The test rig allows the user to vary both drop heights and drop masses, ensuring that the impact data had sufficient levels of deformation within the test panels.

All tests maintained a constant impact mass of 140 kg, and varied the drop heights for three different types of panels: stiffened steel, unstiffened steel and unstiffened aluminium. Each panel was constructed out of a 500 mm wide, 1809 mm long and 3 mm thick plate, bent over an arc with a radius of 1265 mm. The panels were bolted into the test rig along their long edges, as shown in Fig. 2. This bolting arrangement was used to represent a fixed edge condition; the short edges of the panel were kept unsupported.

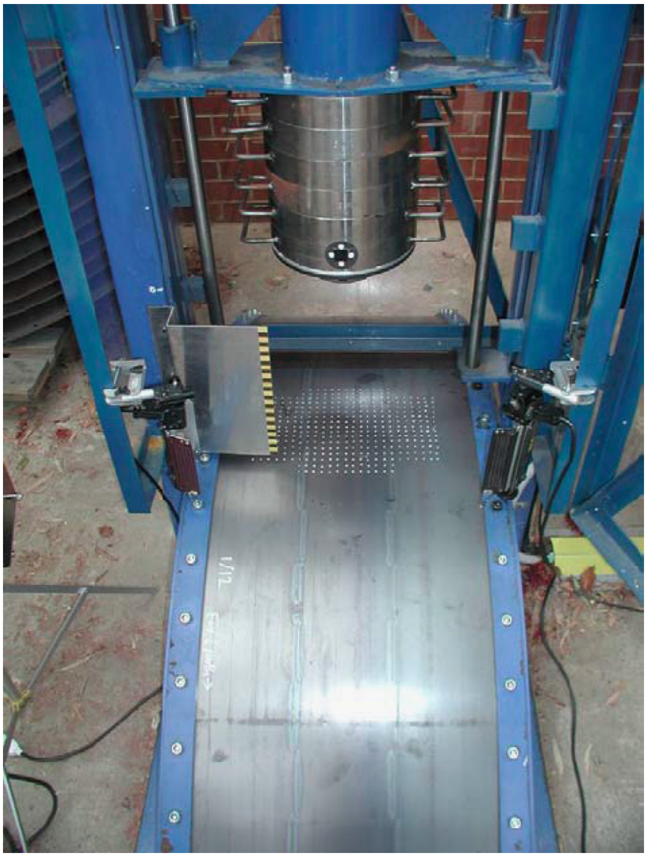

Fig. 2. Drop tower, showing the clamping arrangment for the curved hull panels (van der Schaaf, 2012).