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Experimental investigation of hydrodynamic loads and pressure distribution during a pyramid water entry

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ABSTRACT

In the maritime environment slamming is a phenomenon known as short duration impact of water on a floating or sailing structure. Slamming loads are local and could induce very high local stresses. This paper reports a series of impact test results and investigate the slamming loads and pressures acting on a square based pyramid. In this study the slamming tests have been conducted at constant velocity impact with a hydraulic high speed shock machine. This specific experimental equipment avoids the deceleration of the structure observed usually during water entry with drop tests. Three velocities of the rigid pyramid have been used (10, 13 and 15 m s^{-1}). Time-histories of local pressures, accelerations and slamming loads were successfully measured. The relationship between the pressure magnitude and the impact velocity is obtained and the spatial distribution of pressures on pyramid sides is characterized. The impact velocity was found to have a negligible influence in predicting the maximum pressure coefficient.

1. Introduction

The naval industry wishes clearly to increase operational speed of ship. It has become an important factor of competition in recent years. When the captain of a ship tries to maintain the highest speed whatever the sea state, is slamming phenomena cannot be avoided (Yousefi et al., 2013). Indeed, the ship bow can emerge from the water and then enter again in water at high speed. This generates high level pressure pulse locally on the hull and the whipping of the hull girder. Slamming events typically produce a short duration loading (Xu and Duan, 2009; Thomas et al., 2011; Van Nuffel et al., 2013).

The analytical and numerical solutions for the wedge entry into water widely influenced the study of slamming. Wagner has developed a two-dimensional theory and has calculated the local impact pressures. The solution of Wagner (1932) is relevant when two conditions are fulfilled: first the deadrise angle of the wedge must be small (lower than 20°), secondly air trapped between the wedge and the water surface must be negligible (deadrise angle superior to 3°, Okada and Sumi, 2000).

The water entry of rigid bodies has been studied for years, and many analytical solutions have been developed (Yettou et al., 2006, 2007; Mei et al., 1999; Iafrati and Korobkin, 2008). With these analytical models it is possible to properly evaluate the impact dynamics and the pressure at the fluid–structure interface. Xu and Duan (2009) present a full overview of the survey and assessment of the estimation techniques on hydrodynamic impact. In their paper, the description and definition of hydrodynamic impact are presented. The categorization of prediction techniques and the difficulties are discussed.

Battistin and Iafrati studied the water impact of two-dimensional and axisymmetric bodies. They focused their investigation on the resulting hydrodynamic loads. In their numerical approach, they developed a fully nonlinear boundary-element model

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taking into account the jet formation due to the local flow singularity at the intersection of the body contour and the free surface. Battistin and Iafrati (2003) completed their study by analysing and comparing the numerical approach with existing theoretical and experimental results for the water impact at constant velocity of a cone, a circular cylinder and a sphere.

Several studies have described the slamming phenomenon, which involves a localized pressure pulse travelling over a limited area of the hull (Forng et al., 2009). This can seriously damage structures, and it is usually taken into account in design as an equivalent pressure (Van Nuffel et al., 2013). Hermundstad and Moan (2005) proposed a fast and robust method for the prediction of slamming loads on a 20-knot 120-m car carrier. Calculation of the relative motions between ship and wave use a nonlinear strip theory. Slamming load on two panels in the upper part of the bow flare has been studied with a code based on a generalized two-dimensional Wagner formulation and a boundary element solver (2D BEM solver). They showed that the forward speed of the ship causes a pile-up of water around the bow. This pile-up increases significantly the slamming pressure on the panels in the upper part of the flare even for small waves. The flow around the bow flare is not two-dimensional, so the authors estimated that the results from the 2D slamming computations should be reduced by 30% to account for 3D effects. Results of Scolan and Korobkin (2001) indicate that 3D effects can reduce the 2D slamming pressures by around 30%. Hermundstad and Moan (2007) presented also a simplified method to obtain the instantaneous peak pressure on ship section in irregular waves. This method was used to identify the slamming events that should be analysed in a second step with their more refined 2D BEM solver. The two approaches were validated by comparison with slamming measurements on four panels in the bow flare region of a 290-m cruise ship scale model (ratio 36.2).

Battley et al. (2009) study the effects of panel stiffness on slamming responses of composite hull. In their study they observed that the slamming events produce high magnitude pressure pulse followed by a lower magnitude residual pressure. This pressure distribution travels across the width of the panel during its immersion. The authors showed that the pressure pulse magnitude and propagation speed strongly depend on the impact velocity and deadrise angle of the impacting body.

Silvia and Ravichandran (2012) carried out computational analysis of repeated hull slamming loading on foam core sandwich composite shells. They determined temperature and displacement when cyclic loading occurred. They found that the knowledge of pressure level after the peak is needed to obtain the delamination size between the foam core and the skins correctly.

Yoshimoto et al. (1997) study the slamming load on a large floating structure. Experiments were carried out using elastic models with different stiffness in regular waves. The results revealed that the slamming load, the pressure distribution and the deformation of the structure were strongly influenced by the stiffness of the model. Other studies of hydroelasticity effect during impact of wedge-shape hull show that deadrise angle, panel thickness and velocity are the most important parameters (Faltinsen, 1997, 2001; Bereznitski, 2001; Panciroli et al., 2012).

There are a few researches using high constant impact velocity. The major one has been limited to velocities lower than 7.5 m s^{-1} (Battley and Allen, 2012). All these studies show that the large and spiky local pressures, moving fast on the body surface during the slamming event, are very harmful for the strength of the structure. The purpose of this paper is to add new results in the experimental database concerning the slamming loads and pressures during the water entry of a pyramid. This kind of body shape has been study by Korobkin and Scolan (2006).

2. Model and experimental set-up

A 15° deadrise angle pyramidal rigid body has been made and tested with the high speed shock machine to determine the pressures and slamming loads applied during impacts (Fig. 1). The tests were conducted in calm water and the wind induced loading was neglected. The detailed description of the experimental equipments is given in El Malki Alaoui et al. (2012a, 2012b). However, a complementary instrumentation has been employed for this study. Four dynamic piezoelectric

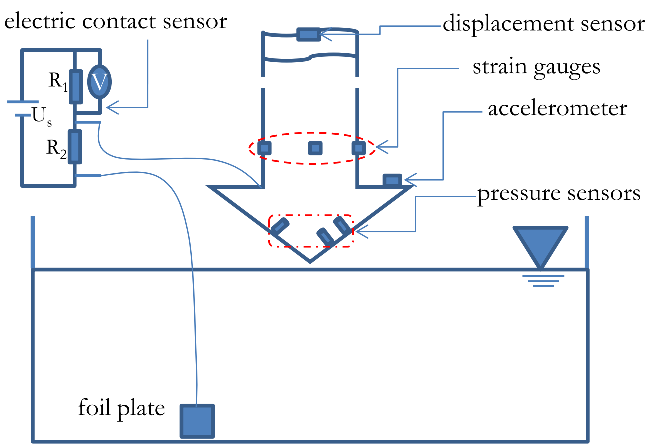

Fig. 1. Simple scheme of the experimental set-up.