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An experimental study on water entry of asymmetric wedges

Mojtaba Barjasteh, Hamid Zeraatgar*, Mohammad Javad Javaherian

Amirkabir Laboratory of Hydrodynamics (ALH), Faculty of Maritime Engineering, Amirkabir University of Technology, Tehran, 15875-4413, Iran

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ABSTRACT

The aim of the paper is to provide an experimental reference for investigation of asymmetric water entry of wedges. Parameters of the study include initial deadrise angle, inclination angle and impact speed. Initial deadrise angles of the wedges were 20° and 30° with inclination angles ranging from 0° to 15° in 5° increments. Wedges were freely fallen from three different heights. Time histories of impact pressure and body acceleration were recorded. Sampling rate of measurements were set to 25 KHz. Main configuration of each test including mass of the wedge and water level were kept unchanged during all experiments. Additionally, several calibration tests were conducted to assess the repeatability and accuracy of the recorded data. The experimental results are compared with different entry theories and other available experiments. The comparison shows a reasonable agreement and indicates that the inclination angle can dramatically affect the impact pressure experienced by the wedges. Finally, the results show that the traditional asymmetric theories are not appropriate for all inclination angles.

1. Introduction

Study of the asymmetric water entry has several applications in marine engineering. The most common one is to evaluate the hydrodynamics of marine vehicles. Maneuvering of vehicles or their motion in waves cause an asymmetric water entry as shown in Fig. 1. In such a circumstance, the hydrodynamic behavior of the impact is different from those predicted by the symmetric entry. The influence is highly dependent on the inclination angle of the vehicle. Investigation of this influence is the main motivation of the authors to study the present problem. The asymmetric entry is distinguished from the oblique entry by absence of horizontal component of the impact velocity as illustrated in Fig. 2. Therefore, the inclination angle, φ, and the oblique angle, α, do not affect the impact pressure in the same way.

The problem of water entry was firstly motivated in the design of seaplane structures. The survey was started by the pioneer theoretical models of Von Karman [1] and Wagner [2]. They established the contemporary theories of water entry. Their models predicted the impact pressure and its spatial distribution with different levels of accuracy. Most of latter analytical models were developed based on the Wagner theory to remove its drawbacks. These developed models are now employed to study spray and jet formation, air cushioning effect, oblique and asymmetric impacts, water compressibility and elastic wedge impacts.

Generally, the asymmetric problem is less investigated compared to the symmetric entry. The analytical investigation started with potential solution offered by Garabedian [3] and Borg [4]. Korobkin [5], Chekin [6], Miloh [7], Toyama [8], Hua et al. [9], Semenov and Iafrati [10], Algarin and Tascon [11] and Moore et al. [12] developed different asymmetric and oblique impact theories based on the Wagner model [2]. A distinctive analytical model is vortex distribution method proposed by Tulin [13] which was further developed by Vorus [14], Xu et al. [15] and Savander et al. [16]. All theories showed that even a small inclination angle may cause a large difference in hydrodynamic impact pressure. Additionally, forced flow separation and an induced sway force due to asymmetric impact are also predicted by these theories for large inclination angles. Chekin [6] showed that there is only one unique combination of asymmetric angle, φ, and inclination angle, α (see Fig. 2), for which no separation of flow from the apex would occur. For a given wedge and wedge orientation, any other impact angles would force separation. Hua et al. [9] evaluated the deflection and stress of a flat plate under asymmetric water entry and showed that asymmetry can highly increase the impact stress.

Numerical investigation of the asymmetric water entry was carried out using different methods. Iafrati [17], Xu et al. [18], Riccardi and Iafrati [19] and Rajavaheinthan [20] developed fully nonlinear numerical methods based on the potential flow for prediction of the free surface profile and the pressure distribution induced by pure vertical and oblique water entry of an asymmetric wedge. Algarin

* Corresponding author.
E-mail address: hamidz@aut.ac.ir (H. Zeraatgar).

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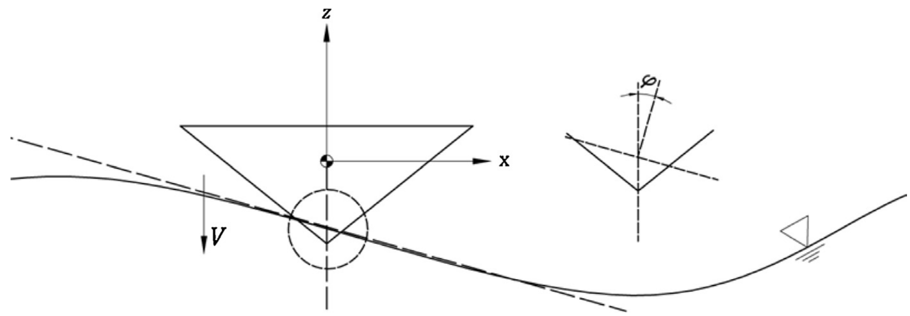

Fig. 1. Motion in wave analysis using analogy of asymmetric entry.

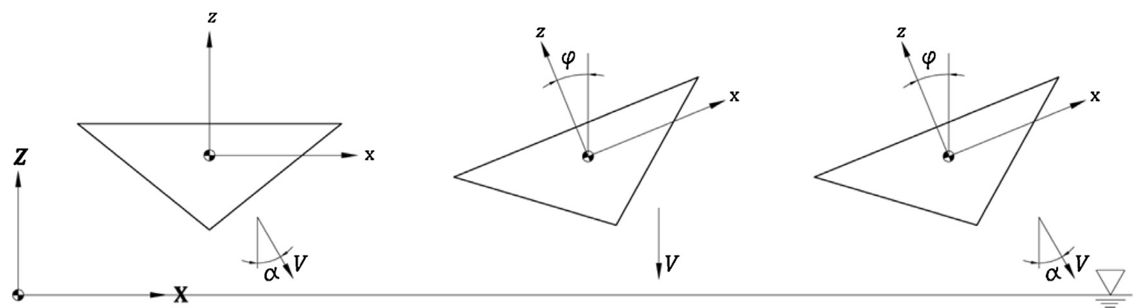

Fig. 2. Schematic of oblique entry (left), asymmetric entry (middle) and asymmetric oblique entry (right).

and Tascon [11], Ghazizadeh and Nikseresht [21] and Gu et al. [22] used different CFD techniques to simulate the problem. Oger et al. [23] and Farsi and Ghadimi [24] studied the problem using SPH method. All of the applied numerical methods showed reasonable accuracy in simulation of different aspects of the problem.

In spite of several experimental researches which were conducted for studying the symmetric entry, experimental investigations of the asymmetric entry are quite rare. Xu et al. [25] examined the accuracy of Xu et al. [15] method for prediction of the impact acceleration in asymmetric entry. Their test model included a wedge of 20° deadrise angle with a heel angle of 0° and 5°. The wedge was freely dropped from different heights and with different weights. Impact acceleration, instantaneous velocity, and instantaneous heel angle were reported whereas the impact pressure was not presented. The wedge was free to roll after the penetration. Therefore, the obtained results cannot be easily compared with other experiments mainly due to different mass moments of inertia in roll direction. Judge et al. [26] conducted a series of experimental research on the asymmetric-oblique water entry of a wedge. Visualization of initial separation of the flow from the apex was well investigated in their study. They also used a two-dimensional vortex distribution method with time dependent free vortex shedding to compare with experimental results. The comparison showed a good agreement. Sun and Faltinsen [27] also experimentally investigated the asymmetric entry of a bow flare ship section to validate their numerical results. The asymmetric angles varied from small to large angles. Acceleration, impact pressure and normal force were reported in their study. Comparison of the numerical and experimental results showed a reasonable agreement. However, the test section was a bow flare and the obtained results could not be compared with the wedge entry results.

Lack of comprehensive experiments on asymmetric impact is clearly seen. Thus, the present research concentrates on providing an experimental reference for other researchers. Tests were conducted in Amirkabir Laboratory of Hydrodynamics (ALH). The obtained results show that the impact pressure is highly affected by initial deadrise angle and inclination angle. Furthermore, it was revealed that the asymmetric impact theories deviate from experiments and cannot correctly predict the impact pressure particularly for small deadrise angles.

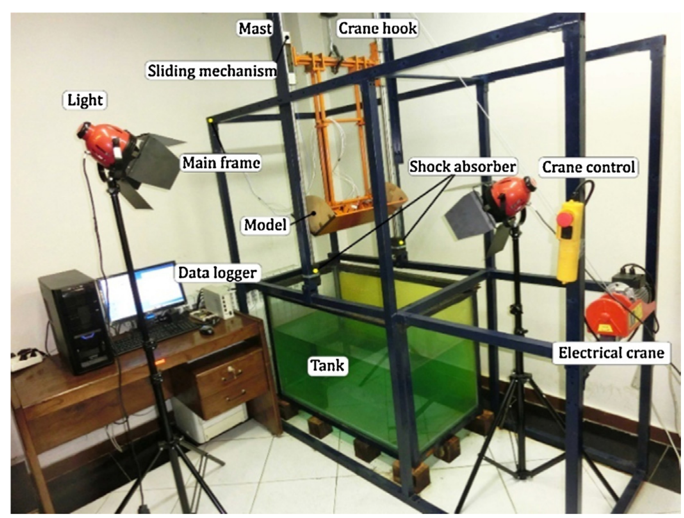

Fig. 3. The test frame.

2. Experiments

2.1. Experimental setup

The test setup is shown in Fig. 3. The model can freely fall into the water from different heights. The main frame is equipped with a high precision guiding rail to accurately constrain the motion of the model in vertical direction. The frame is fixed to the wall and the ground through some high strength dampers to supply maximum possible rigidity as well as minimum vibration amplitude. The wedge is dropped into a reinforced $1.122 \times 0.572 \times 0.681$ m transparent tank which is fixed to the main frame.

The impacting model includes an innovative wedge model with adjustable deadrise angle as shown in Fig. 4. This 44 kg wedge