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Experimental investigation of dynamic pressure loads during dam break

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ABSTRACT

The objective of this research work has been to conduct experimental measurements on a dam break flow over a horizontal dry bed in order to provide a detailed insight, with emphasis on the pressure loads, into the dynamics of the dam break wave impacting a vertical wall downstream the dam. The experimental setup is described in detail, comprising state of the art miniaturized pressure sensors, high sampling rate data acquisition systems and high frame-rate video camera. It is a 1:2 scale of the highly cited (Lee et al., 2002, Journal of Fluids Engineering, 124) article experimental apparatus. Kinematics has been analyzed focusing on the free surface and wave front evolution. Experimental observations regarding liquid height and wave front speed have found to be in agreement with existing literature. This agreement enables the authors, assuming a similar framework, to discuss the measured pressure loads as a consequence of the dam break wave front impacting on the downstream wall. These loads show a substantial variability which has been statistically characterized. The measured quantities have been compared with the scarce available data in the literature, whose consistency is discussed. Measurements have been conducted with two filling heights. Scaling effects for such heights are also analyzed. As a direct result of the present initiative, an extensive set of data for computational tools validation is provided as Supplementary Materials, including pressure signals, wave height measurements and experimental videos.

1. Introduction

The first studies analyzing dam break flows date back to the 19th century. In 1892, Ritter (1892) published a theoretical solution of the free-surface profile evolution for a collapsing rectangular column of fluid over a dry horizontal downstream bed based on Barré de Saint-Venant's (1871a,b) shallow water theory. In his approach, Ritter neglected turbulence effects and friction over the horizontal bed. The effect of friction over the bed was investigated by Dressler (1952). In general, Dressler's solution of the free-surface profile agrees well with Ritter's one except for the retarded initial downstream wave propagation and a non-zero wave front depth. These results were also confirmed by other independent theoretical studies (e.g. Pohle, 1950; Whitham, 1955). Dressler (1954) also published an experimental study confirming his theoretical solution.

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Martin and Moyce (1952) performed a series of tests and provided a complete set of data on kinematics of two-dimensional as well as three-dimensional dam break flow over an initially dry horizontal bed. The wave front velocity was found to be proportional to the root of the original column height. This was in agreement with Ritter's theoretical solution.

A rigorous experimental and theoretical study on dam break flows over both dry and wet horizontal beds was published by Stansby et al. (1998). They identified the mushroom-like jets that appear right after the dam release for wet downstream beds and provided data confirming that the experimental free-surface profiles for two different initial water depths scaled approximately according to Froude's criteria.

Although numerous experimental studies on dam break flow have been performed to date, there is a lack of data describing its dynamics. In 1999, Zhou et al. (1999) validated their numerical scheme using an experimental work performed at the Maritime Research Institute of the Netherlands (MARIN) that provided a description of dam break wave kinematics as well as the data of a wave impact on a solid vertical wall downstream from the dam. Measurements of impact pressure at several locations were performed by force transducers with large diameter circular impact panels. The details on the experimental setup and applied force transducers were published in the work of Buchner (2002). Zhou et al. (1999) published their experiments in a conference and Lee et al. (2002) published them in a journal. Due to easier accessibility, the journal reference is the one cited hereinafter.

The MARIN experimental setup was also used in the work of Wemmenhove et al. (2010) and Kleefsman et al. (2005). The former repeated and slightly altered the experiments of Lee et al. (2002) and the latter, Kleefsman et al. (2005), presented a fully three-dimensional dam break problem. From the presented figures in these publications, it can be deduced that the new pressure measurements in both studies were performed using pressure transducers of smaller diamante than the transducers used in Lee et al. (2002). Thus more localized data could be measured and the transducers could be located closer to the horizontal bed. However, the description of applied pressure transducers was missing in both studies (Kleefsman et al., 2005; Wemmenhove et al., 2010).

An elementary research on dam break flow dynamics was also conducted by Bukreev (2009) and Bukreev and Zykov (2008) who studied the overall forces exerted by the dam break wave on downstream vertical structures. A similar test case was studied by Gomez-Gesteira and (2004) and Greco et al. (2012a) in order to validate their computational model. Besides describing and predicting the flood events, understanding the dynamics of dam break flows is also useful when assessing certain types of impact flows, such as those found in slamming and green water events (Greco et al., 2004, 2012b).

Except for a few studies, such as Martin and Moyce (1952) or US Corps of Engineers (1960), that provide a complete set of kinematic data for a series of several tests, there is a lack of thorough discussion on repeatability of dam break experiments in the literature. However, such an analysis is crucial when assessing the fluid dynamics. The statistical analysis and the probability ranges of the measured nominal pressure values are missing and little information is provided on the setup and precision of the pressure measurements in the aforementioned dam break studies.

This paper aims at providing a detailed insight into the dynamics of the dam break flow over a dry horizontal bed under controlled laboratory conditions. In order to do so, an experimental tank setup similar to Lee et al. (2002) and Buchner (2002), widely used for validation purposes (e.g. Marrone et al., 2011; Asai et al., 2012), has been constructed and an extensive experimental campaign was performed.

In the present work, special attention is paid to the impact pressure measurements of the downstream wave on the flat vertical wall and the propagation of the pressure along this wall in the vertical direction. In order to address the repeatability of the experiments, a large set of measurements is performed under the same experimental conditions. As a result, a statistically relevant sample of data on the downstream wall is recorded and provided. The originality of this research resides in defining impact pressure confidence intervals and discussing the existing data from the literature applying this framework. This study may serve as a basis for CFD validations and to assist in such task, videos associated with all the flow images presented in the paper and figure curves, as ASCII tables and MATLAB figures, can be downloaded from http://canal.etsin.upm.es/papers/lobovskyetaljfs2014/.

This paper is organized as follows: experimental setup and data acquisition systems are first described. Test matrix and gate motion repeatability are then discussed. Analysis of the flow kinematics considering wave heights and front velocity is conducted next. The pressure loads measured in the downstream wall are then presented and statistically described. Finally, some conclusions and future work threads are summarized.

2. Experimental setup

2.1. General

The dam-break experimental setup was built and installed at the Technical University of Madrid (UPM) facilities where several experimental campaigns dealing with sloshing flows had been carried out in the past (see e.g. Souto-Iglesias et al., 2011) and have served well for CFD validation in a number of recent papers (e.g. Khayyer and Gotoh, 2009; Bulian et al., 2010; Idelsohn and Marti, 2008; Degroote et al., 2010). For the dam-break experiments presented herein, a dedicated tank setup was designed and assembled. It consists of a prismatic tank divided into two separate parts by a removable gate, a release system with a sliding mechanism, a weight inducing the gate motion and a damping system, as shown in Figs. 1 and 2. All parts of the experimental setup are further explained hereafter.