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Laboratory investigations on impulsive waves caused by underwater landslide

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ABSTRACT

Laboratory investigations have been performed on the submarine landslide generated waves by performing 120 laboratory tests. Both rigid and deforming-slide masses are considered. The effects of bed slope angle, initial submergence, slide geometry, shape and deformation on impulse wave characteristics have been inspected. Impulse wave amplitude, period, energy and nonlinearity are studied in this work. The effects of bed slope angle on energy conversion from slide into wave are also investigated. Laboratory-based prediction equations are presented for impulse wave amplitude and period in near and far-field and are successfully verified using the available data in previous laboratory and numerical works.

1. Introduction

Impulsive waves may be generated by underwater earthquakes, submarine landslides, rockslides or volcano explosions. Giant submerged landslides, normally in the form of debris avalanches, can produce impulsive waves and affect the entire coastline. Investigation on the impulse wave characteristics in near and far-field is of high importance in coastal engineering. The laboratory experiments can be considered as the most reliable and possible methods to investigate the impulse wave caused by underwater landslides. The conducted laboratory works can be classified in four categories based on the method that landslides were modeled: sub-aerial landslides considered as rigid sliding block, sub-aerial slide modeled as deformable sliding mass, underwater landslide modeled as solid block, and deformable submarine failure mass. An overview of the main experimental works in this regards are presented in Table 1.

As it can be seen in Table 1, although the sub-aerial landslide generated wave has been properly investigated using laboratory models, but there are basic distinctions between sub-aerial and underwater slide waves. The differences can be identified in wave feature as well as basic effective parameters. For sub-aerial landslides, some parameters such as slide impact velocity have an important influence on the characteristics of the impulse waves (Walder et al., 2003; Fritz et al., 2004; Panizzo et al., 2005; Ataie-Ashtiani and Malek-Mohammadi, 2007). However, other parameters such as initial submergence are important for underwater landslide generated waves. Regarding underwater landslide waves, some experimental investigations were performed by Heinrich (1992) and Rzadkiewicz et al. (1997) and Ataie-Ashtiani and Shobeyri (2008) used the data for verification of their numerical model. Watts (1998) presented some laboratory works on impulse waves caused by underwater slide. The experiments were performed only over 45° bed slope with triangular rigid slide. Enet et al. (2003), and Grilli and Watts (2005) carried out some experimental works in three-dimensional wave tank. The bed slope angle was fixed on 15° and slide was modeled as a fixed semi-elliptical rigid slide. They used the experimental data to verify their well-validated numerical model (BIEM). They also presented some numerical-based prediction equations only for impulse wave amplitude in near-field.

The main objectives of this work are to provide laboratory data covering some of the obscure and limitations of the previous works. A large number of laboratory tests are performed. The effects of bed slope angle on wave are investigated in a wide range as 15 to 60 . Impulse wave characteristics such as amplitude, period, energy and nonlinearity are considered and studied in this work. The effects of bed slope angle on energy conversion from slide into wave are also investigated. Also, the effect of slide deforming and shape on impulse wave characteristics is inspected. Finally, laboratory-based forecasting equations are presented for impulse wave amplitude and period in near and far-field and they are verified using available data from previous laboratory and numerical works.

2. Experimental set-up[1]

Experiments were set-up in a 2.5 m wide, 1.8 m deep and 25 m long wave tank at Sharif University of Technology, Iran. The experimental

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[1] Full information about experimental set-up including tabulated data, pictures and movies are presented on http://civil.sharif.edu/~ataie/ImpWave/SubmarinExp.

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Table 1
Literature review on landslide generated waves; comparison and categorization

References	Tank dimensions			Bed slope (degree)	Failure mass specifications	Model dimensions	Wave stage
	L (m)	*W* (m)	*H* (m)				
Category 1: sub-aerial landslides considered as rigid sliding block							
Johnson and Bermel (1949)	Shallow water tank			–	Steel plate	–	G
Wiegel (1955)	Shallow water tank			–	Steel plate	–	G
Prins (1958)	Shallow water tank			–	Steel plate	–	G
Kamphuis and Bowering (1972)	Shallow water tank			45	Steel box	–	G
Heinrich (1992)	4.0	0.3	2.0	45, 30	Triangle solid block (50×50 cm)	2VD	G
Walder et al. (2003)	3.0	0.285	1.0	10 20	Hollow rectangular nylon box	2VD	G
Panizzo et al. (2005)	11.5	6	0.8	16 36	Solid rectangular box	3D	G, P, R
Category 2: sub-aerial slide modeled as deformable sliding mass							
Fritz et al. (2004)	11	0.5	1.0	45	Failure soil mass caused by PLG	2VD	G, P
Category 3: underwater landslide modeled as solid block							
Watts (1998)	9.14	0.101	0.66	45	PVC triangle-section (86×86 mm)	2VD	G
Grilli and Watts (2005)	30	3.6	1.8	15	Semi-ellipse aluminum sheet	2VD	G, P
Enet et al. (2003)	30	3.6	1.8	15	Semi-ellipse aluminum sheet	3D	G, P
Category 4: deformable submarine failure mass							
Heinrich (1992)	4.0	0.3	2.0	30, 45	Gravel with identical diameter	2VD	G
Watts et al. (2003)	30	3.6	1.8	45	Glass beads, steel shots and lead shots	2VD	G

2VD: Two-vertical dimensional; G: Generation of impulse wave; 3D: Three dimensional; P: Propagation of impulse wave; PLG: Pneumatic landslide generator; R: Run-up of impulse wave.

set-up included two inclined planes with adjustable slope between 15 and 60 . One of the inclined beds was made for sliding down solid blocks and another one for observation of run-up of slide-generated waves. The sliding surface was smooth and was also lubricated in order to provide a frictionless slope. Therefore, the blocks could slide freely on the slope. A schematic of the wave tank and the adjustable slopes are shown in Fig. 1.

There were transparent windows at the tank wall for observation of the free water surface profile. Waves were generated by sliding down solid blocks along on the inclined bed. The blocks had different shape, volume and thickness and they had been made of steel plate with 2 mm thickness. All of the specifications of rigid blocks are given in Table 2. The total weight of block was determined based on the weight of steel plates and the filling water weight. It was considered that the block was full of water. Fig. 2 shows the schematics of rigid blocks. The water surface fluctuations were measured in eight points located at the central axis of the tank using Validyne DP15 differential pressure transducers (DPD-DP15). The locations of wave gauges ST1 to ST8 are shown on Fig. 1. All of the specifications of wave gauges are listed in Table 3.

Transducers used in hydraulic transient studies must have a fast response to the changes of pressure. Validyne variable reluctance sensors used here have only a single moving part, the sensing diaphragm. The diaphragm is free to move quickly as the pressure changes; there are no linkages or other mechanical connections to slow the sensor down. Additionally, variable reluctance sensors have extremely small displacement volumes. The DP15 series need just 6.0E–4 in.^{3} (9.8 mm^3) of fluid to go from 0 to full scale reading. The combination of small displacement volume and only a single moving part makes the variable reluctance sensor ideal for measuring rapidly changing pressures such as transient water surface fluctuations. The response time of DP15 differential pressure transducers series is 0.0033 (1/300) s. The sensors were calibrated before the commencement of experiments. Two digital cameras were also used simultaneously to capture the moving pattern of rigid sliding block. One of the cameras was used for side observation and another for photographing from top view. Both of the cameras were focused on the near zone of underwater sliding.

The experimental set-up data are listed in Table 4. As it can be seen, the experiment variable parameters can be listed as follow: slide

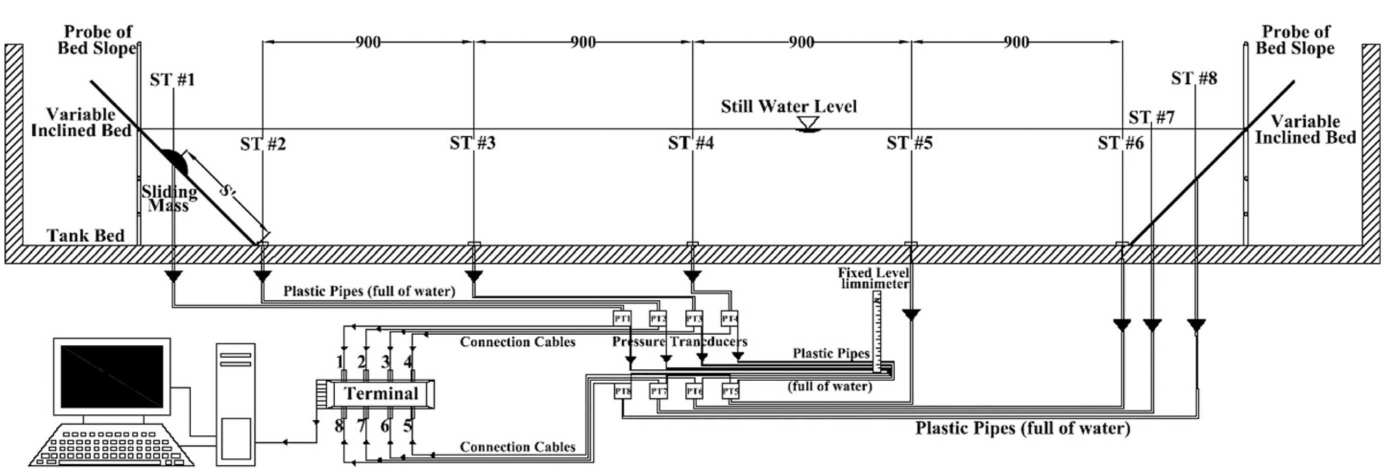

Fig. 1. Schematic of experimental set-up for underwater landslide generated waves, all dimensions are in millimeter.