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Procedia Engineering 00 (2015) 000–000

Procedia Engineering

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7th International Conference on Fluid Mechanics, ICFM7

Landslide-Generated Impulse Waves in Deep V Channel: Runup and Near Field Characteristics

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Abstract

Landslide induced impulse wave is a crucial risk for habitation and facility along mountain rivers. “Deep V” shape channels, which is characterized by their deep valleys and steep shores, are very common in mountain rivers. And due to the channels’ constraining on wave evolvement, landslide-generated-impulse-waves (LGIW) in “deep V” are very different from the well studied typical three dimensional and two dimensional situations. Focusing on this problem, a direct simulation based on N-S equation is carried out to study the evolving of LGIW in “deep V” channels. And then a series of numerical studies are carried out to investigate the mechanics in this problem. SPH (Smoothed Particle Hydrodynamics) method is used to simulate the whole process of fluid-solid interaction, including the processes of wave-generation, wave-propagation and wave-run-up. LGIW in a deep V channel are found having their special characteristics. They are always undeveloped before run-up at the opposite shore and their generation process and propagation are strongly influenced by both shores.

Peer-review under responsibility of The Chinese Society of Theoretical and Applied Mechanics (CSTAM).

Keywords: Landslide impulse waves; Deep V channel; SPH; Orthogonal arrays

1. Introduction

Landslide-induced impulse waves in reservoirs are classified as gravity waves. It can, in extreme cases, result in the overtopping of dams or run-up along the shoreline, with catastrophic consequences. Many laboratory experiments have been carried out in order to gain insight on the properties of the landslide generated waves. These laboratory tests can be classified as being proceeded either in a prismatic wave channel [1] (2D) or in a rectangular wave basin [2] (3D). Realistic reservoirs sometimes are more like a “deep V” shape channel rather than a rectangular wave basin. Especially

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in mountainous area, valleys are usually very deep and both sides are steep. Impulse waves generated in these deep V valleys are underdeveloped before run-up at the opposite shore and their generation and propagation are strongly influenced by both shores. So the impulse waves are different from waves in prismatic wave channels or in rectangular wave basins.

Nomenclature

h, g	still-water depth and gravitational acceleration; h=100m, g=9.81m/s^2
V_s, w, s	slide volume, width and thickness, respectively
V, W, S	dimensionless slide volume, width and thickness; $V=V_s/(Whh)$, $W=w/h$, $S=s/h$
v_s, Fr	slide impact velocity and Froude number; $F= v_s/(gh)^{1/2}$
ρ_w, ρ_s	water density and slide density; ρ_w=1000kg/m^3, ρ_s=1800kg/m^3

2. Methodology

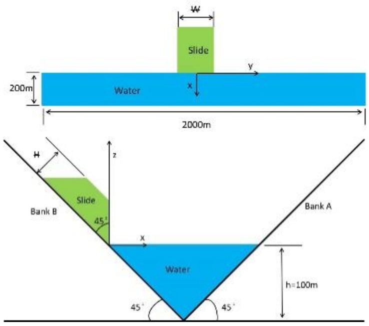

Fig. 1. Schematic diagram of deep V channel, slide block

Table 1. Values of the parameters.

CASE	V	W	S	Fr	CASE	V	W	S	Fr
Case1	1.8	2.0	0.3	0.6	Case9	3.6	2.0	0.9	2.4
Case2	1.8	2.5	0.6	1.2	Case10	3.6	2.5	1.2	1.8
Case3	1.8	3.0	0.9	1.8	Case11	3.6	3.0	0.3	1.2
Case4	1.8	3.5	1.2	2.4	Case12	3.6	3.5	0.6	0.6
Case5	2.7	2.0	0.6	1.8	Case13	4.5	2.0	1.2	1.2
Case6	2.7	2.5	0.3	2.4	Case14	4.5	2.5	0.9	0.6
Case7	2.7	3.0	1.2	0.6	Case15	4.5	3.0	0.6	2.4
Case8	2.7	3.5	0.9	1.2	Case16	4.5	3.5	0.3	1.8

Outline of the channel and slide block is shown in Fig.1. Landslide is reproduced by a rigid block in this paper, sliding along an inclined plane. The side face of the slide is isosceles trapezoid with basic angle 45°. Still water depth h is a constant value 100m. The length of channel is 20 times of h which is enough to research the near field characters of the impulse waves. Both shores (Bank A and Bank B) have a slope of 45°. Friction between the channel and slide is zero.

The interaction of landslide and water is a strong fluid solid coupling problem. SPH (Smoothed Particle Hydrodynamics), a Lagrangian numerical meshfree method, is used to simulate the complex interaction process. The governing equations of continuity and momentum equation in SPH can be expressed as:

$$\frac{D\rho_a}{Dt} = \sum_{b=1}^{N} m_b (v_a{}^{\alpha} - v_b{}^{\alpha}) \frac{\partial W_{ab}}{\partial x_a{}^{\alpha}} \tag{1}$$

$$\frac{Dv_a{}^{\alpha}}{Dt} = -\sum_{b=1}^{N} m_b \left(\frac{P_b}{\rho_b{}^2} + \frac{P_a}{\rho_a{}^2} + \prod_{ab}\right) \frac{\partial W_{ab}}{\partial x_a{}^{\beta}} + g^{\alpha} \tag{2}$$

The artificial viscosity term Π_{ab} is used to describe the diffusion terms of the momentum equation.

3. Results and Analysis

Using Taguchi's Orthogonal Arrays, four parameters of slide block, including slide thickness, width, length, impact velocity, are concerned and each parameter has four values (Table 1). So a total number of 16 cases are calculated and analyzed. Some common features are found of the impulse waves generated in the deep V channel in all cases. We have reasons to believe that these features can be representative. The whole process observed of all cases' simulation can be divided into three procedures: the landslide impacting the water and water running up the bank, water falling off the bank and rushing down to the channel, the leading wave developing to stable profile. And we mainly choose Case2 to help us understand the features in these three procedures.

3.1. Impact and Run-up

Water in front of the slide is initially expelled upwards and outward by the entry of the block forming a water crater (Fig. 2a, Fig. 3a, Fig. 6a). These water can elevate very high and rush onto Bank B. The water's shape is more like a cowboy hat than a water wave before the water contacts the bank. After contacting, water runs up along the inclined ramp, forming approximate semi-circle profile (Fig. 2b). Water near the flank of slide is also pushed away (Fig. 3b) and sometimes maybe turn-up at high impact velocities. Leading wave is formed when the pushed water move along the channel. Obvious crest and trough of the leading wave can be observation (Fig. 5a, b).

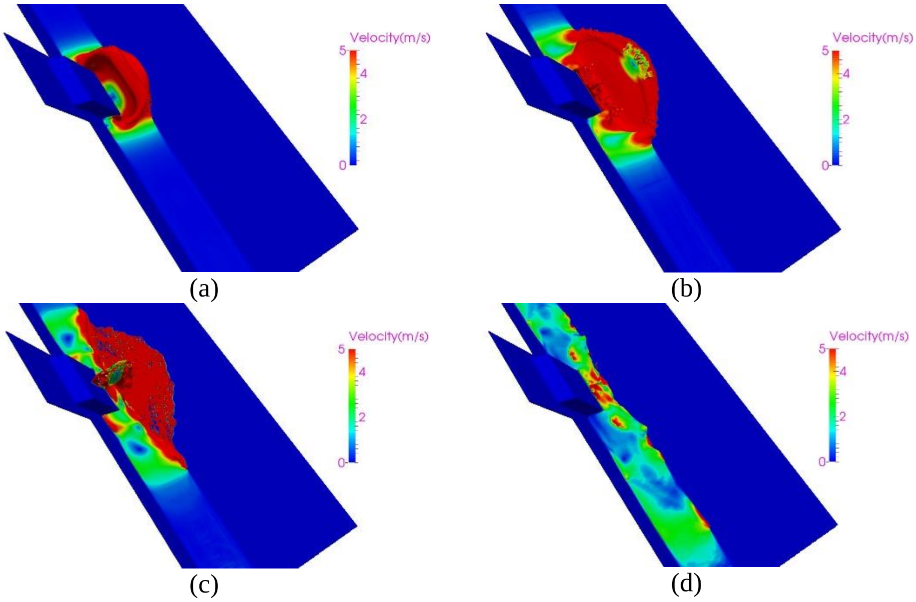

Fig. 2. Wave generation process: Case2 (a) t=6s (b) t=12s (c) t=16.8s (d) t=32s

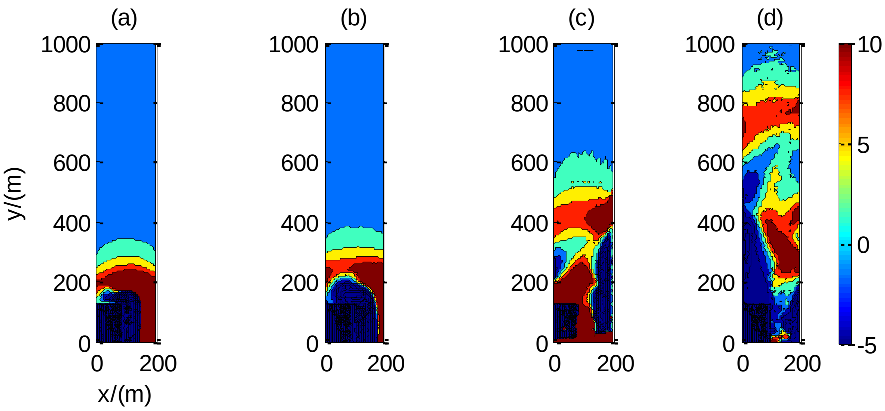

Fig. 3. Water's elevation: Case2 (a) t=6s (b) t=12s (c) t=16.8s (d) t=32s

3.2. Fall after Run-up

The run-up water begins to fall along Bank B with a considerable velocity before it reaches its maximum run-up height. In front of the slide, the rush-back water will crash onto the slide's front-surface and splash up, then it will run up along the upper surface (Fig. 2c). In the field near both sides of the slide, rush-back water will propagate almost vertical to y-direction to Bank A forming the first reflected wave. Then it will run up Bank A and fall down forming the second reflected wave. Simultaneously, at Bank B, water is still falling down after it reaches its maximum height. Falling water at both banks will collide, resulting in rapid rise-up. Collision like this can happen more than one time based on the volume and time of water falling at Bank B. All these reflected waves can be obviously observed in the near-field of impact zone due to the narrow deep V channel compared with situations like rectangular wave basins. The faster and bigger the slide is, the broader the near-field will be.

The crater collapse occurs in front of the slide after the water crater reached its maximum size. Water at both sides of the crater will rush inward under the influence of gravity resulting in a crash in plane y=0 (Fig. 6b, c) and water falling off Bank B will also join this crash. While the former develops to waves propagating along the channel and the later impacts the slide as described in section 3.1. The reflected waves between both banks of the relatively narrow channel and the waves along the channel will be superimposed generating complex wave profiles (Fig. 5a, b), which does not happen to the leading wave. In the near-field the second or the third wave crest sometimes exceed the leading wave crest in height because of the superimposition, which will not be found when the waves passed the field (Fig. 5a-d). The reflected waves are not obvious out of the near-field and so is the superimposition, making the leading wave crest still be the highest wave crest.

3.3. Leading Wave Development

The leading wave crest is issued by the crater rim and propagated outward during the crater collapse.It is always being influenced by the falling of first run-up water at Bank B. The outer part of the semi-circle falling water can always rush with high speed across the leading wave, causing the part of the leading wave near Bank B become instable (Fig. 3c). Velocity of this part wave also becomes larger (Fig. 2c). As the falling water rushing downwards, the first reflected wave forms and runs to Bank A with a bevelled front direction instead of vertical to y-axis. The first reflected wave can be divided into two components: one along the channel and the other vertical to the channel. The component along the channel and the leading wave will be superimposed, enlarging the height of the leading wave crest finally. We can see crest elevates somewhere when the leading wave propagating along the channel (Fig. 5c). The other component will run to Bank A vertical to y-axis. This component will delay quickly when it running across the instable leading wave, causing that the second reflected wave will not be observed obviously. After this process, the leading wave will develop to be approximately stable, which means the influence of reflected waves can be ignored (Fig. 2d, Fig. 3d, Fig. 6d).

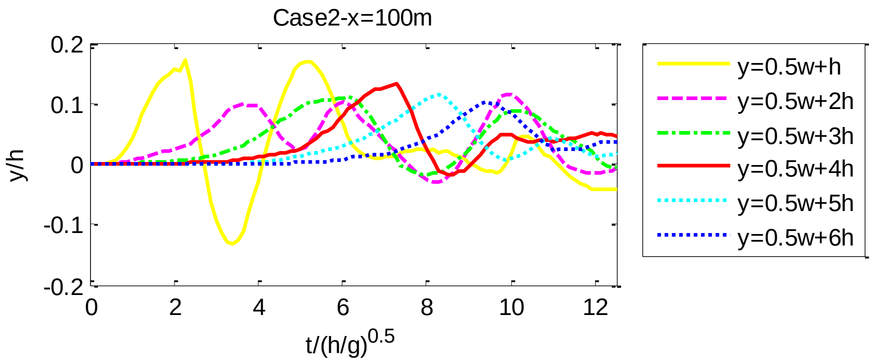

Fig. 4. Water surface displacement at different pints

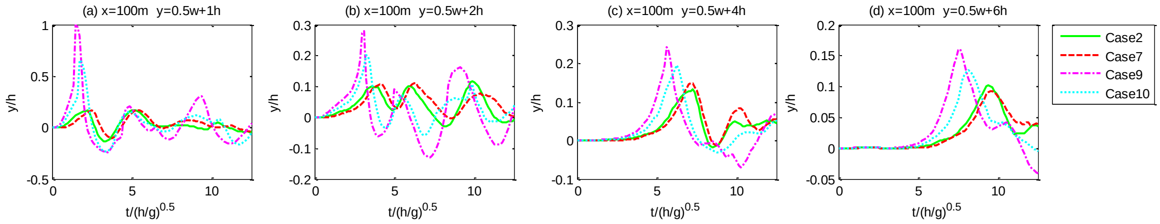

Fig. 5. Water surface displacement: cases of different Fr

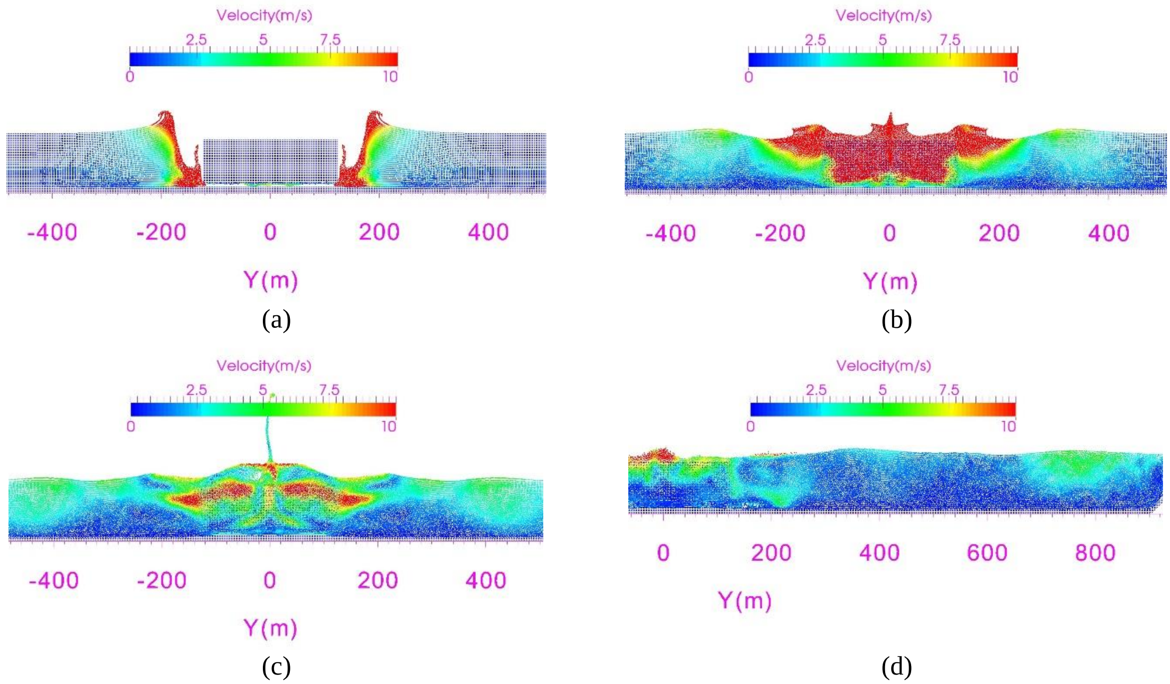

Fig. 6. Water generation process at x=100m: Case2 (a) t=6s (b) t=12s (c) t=16.8s (d) t=32s

4. Conclusions

The impulse waves in a deep V channel are different from waves in 2D or 3D situation. The process of waves' generation and evolution can be divided into 3 sections: landslide impacting the water and water running up the bank, water falling off the bank and rushing down to the channel, the leading wave developing to stable profile. All of these procedures are influenced obviously by both shores of the channel.

Acknowledgements

This work was financially supported by the Natural Science Foundation of China (No. 11372326, No.11432015) and the National Program on Key Basic Research Project of China (973 Program) (No.2014CB04680202).

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