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Slope Effect on Dam Break Flow over Movable Bed, Experimental Study

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A B S T R A C T

The failure of a major flood control structure may expose the surrounding population to serious risk. Such an event kind may involve rapid transients with strong interactions between flow and topography. So, to correctly simulate the consequences of a dam failure in a complex topography, this interaction should be accounted for in mathematical modeling, which should however rely on physical descriptions that are not yet completely established. Present study explores some configurations for plane movable bed with different percent of bed slope across the dam. Experiments were carried out in an ideal flume, and instrumentation of the tests performed by means of fast digital imaging through the flume. Results show that increasing in slope lead to increasing in flow velocity and therefore increasing in eroding force and volume of transported sediment. Important result is that increasing in slope lead to nonlinear variation rate of scouring and sedimentation parameters.

1. Introduction

Dam break waves have been responsible for numerous losses of life (e.g. Figure 1.). Figure 1. illustrates two tragic accidents [1]. Related situations include flash flood runoff in ephemeral streams, debris flow surges and tsunami run up on dry coastal plains. In all cases, the surge front is a sudden discontinuity characterized by extremely rapid variations of flow depth and velocity. Dam failures motivated basic studies on dam break wave, including the milestone contribution by Ritter (1892) following the South Fork (Johnstown) dam disaster (USA, 1889)[2]. Physical modeling of dam break wave is relatively limited despite a few basic experiments (Table 1) [1]. In retrospect, the experiments of Schoklitsch (1917) were well ahead of their time, and demonstrated that Armin von Schoklitsch (1888–1968) had a solid understanding of both physical modeling and dam break processes [3]. For the last 40 years, there have been substantial efforts in dam break research, in particular with the European programs CADAM and

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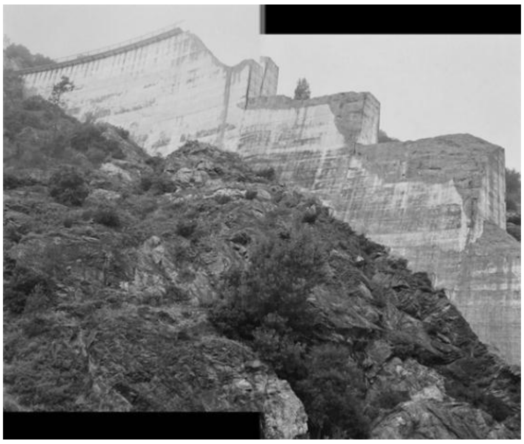
IMPACT, and some American programs. These efforts were associated with the development of numerous numerical models and a few physical model studies.

(A)



(B)

Fig.1. Photographs of dam break accidents (A) St Francis dam (USA) in March 1928 shortly after failure (Courtesy of Santa Clarita Valley Historical Society) - Looking downstream at the remnant piece (B) Malpasset dam (France) in 2004 looking at the right abutment (Courtesy of Sylvia Briechle) – Failure on 2 Dec. 1959 around9:10pm

Table 1. Experimental studies of dam break

Reference	Slope deg.	Experimental configuration
Turbulent flows		
Schoklitsch (1917)	0	D ≤ 0.25 m, W = 0.6 m D ≤ 1 m, W = 1.3 m
Dressler (1954)	0	D = 0.055 to 0.22 m, W = 0.225 m Smooth invert, Sand paper, Slats
Cavaillé (1965)	0	L = 18 m, W = 0.25 m D = 0.115 to 0.23 m, Smooth invert D = 0.23 m, Rough invert
Montuori (1965)	0.06	Casino I powerplant raceway L = 13.6 km, W = 1.95 m
Estrade (1967)	0	L = 13.65 m, W =0.50 m D = 0.2 & 0.4 m, Smooth & Mortar L = 0.70 m, W = 0.25 m D = 0.3 m, Smooth & Rough invert
Lauber (1997)	0	L < 3.6 m, W = 0.5 m, D < 0.6 m Smooth PVC invert
Laminar flows		
Debiane (2000)	0	L < 0.66 m, W = 0.3 m, D = 0.055 m Glucose syrups (12 ≤ μ ≤ 170 Pa.s)
Thixotropic flows		
Chanson et al. (2006)	15	L = 2 m, W = 0.34 m, D < 0.08 m Bentonite suspensions.

* D : initial reservoir height; L : channel length; W : channel width.

Earlier dam-break flow experiments were executed with clear-water on fixed bed in one dimensional configuration (e.g. Dressler 1954) or with two-dimensional features (e.g. Bell et al. 1992, Bellos et al. 1992, Aureli et al. 2004). Among the first laboratory studies concerning sand and gravel mobile bed, the investigation of Chen & Simons (1979) highlighted the effect of river sinuosity and deposited sediments after the failure of a dam [4]. Capart & Young (1998) used lightweight artificial pearls of uniform size as bed material in a horizontal flume [5]. The authors discovered that the dam-break wave, just after its release, excavates a growing scour hole and forms a hydraulic jump which propagates upstream with time. Leal et al. (2002) compared the propagation of dam-break waves on fixed, pumice and sand bed in a horizontal flume [6]. Spinewine & Zech (2007) realized dam-break experiments on sand and PVC bed featuring a level discontinuity at the location of the gate [4].This paper presents the results of a new modeling exercise, which investigates the influence of differing bed slope through the downstream of the dam. The experimental observations were obtained using digital imaging through the channel sidewall, and bulk measurements at the flume outlet. The paper is structured as follows: in section 2 we briefly recall the conditions of the test case. Section 3 is devoted to a general description of test cases. Finally formatted experimental profiles are presented in section 4.

2.Materials and Methods

2.1. Test case descriptions

Experiments were carried out in a flume at the laboratory of the Civil Engineering Department, University of Tehran, Tehran-Iran. The flume is 4.70 m long, 0.20 m wide and 0.4 m high, and is specifically designed for idealized dam-break experiments on movable beds (Figure 2.). Breaking of the dam is simulated by rapid upward movement of a gate at the 2 meter of upstream, moving up by releasing a weight attached by jigger. Each sidewall is made of steel frames fitted with transparent glass panels, and a height of 40 cm. The bottom of the channel is made of a plastic panel. After profiling a sediment bed on both sides of the gate, a dam- break wave is initiated by the sudden removal of the narrow vertical gate at the middle of the flume. The gate is made of a plastic structure, 10 mm thick, and is fitted on its circumference with a hollow PVC seal. Transparent silicon oil sprayed on the gate and sidewalls substantially reduced the friction. Water tightness at the bottom of the flume is achieved by compressing neoprene bands below the bottom panels, and covering them with lubricant oil to reduce friction during gate movement. In closed position, the top of the gate is maintained upright and chocked up against a steel stopper on top of the flume, hampering lateral movement and bending due to the upstream water pressure. A 30 kg weight provides the acceleration for the upward movement, guided by a system of roller bearings. Opening time in the order of 0.1 s is achieved over the full nominal height of 50 cm. According to Lauber and Hager (1998) the maximum time of gate removing is equal to $t_0 \max = (2h_u/g)^{1/2}$ in which hu is the upstream water level [7]. For all tests: $t_0 \max = 0.22s$

Instrumentation of the tests mainly involved digital imaging through the transparent side-wall, from 1 m upstream of the gate to the downstream end. Digital cameras are used for recording the process of dam break flow, three of them in right side of channel and one of them in left side. Also a black wall used in order to reduce light reflection and improve the extracted image quality. Figure 3. illustrates imaging process.

Fig.2. The flume used for the idealized dam-break experiments

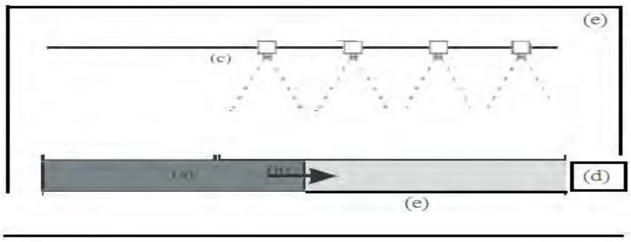


Fig.3. Side-view imaging process (a) flume, (b) gate, (c) digital camera, (d) settling tank, (e) black Wall

2.2. Test condition

2.2.1. Initial and boundary conditions

The downstream reach of the channel is filled with sediments at distinct levels. Horizontal beds of sediments are obtained by first pouring sediments in excess, compacting and profiling them at desirable heights. In test cases that need downstream sediment saturated, water is added cautiously, at a slow rate to ensure that the bed gets fully saturated and residual air pockets are not entrapped within the pores. Level regulation at the downstream end is achieved by inserting steel plates of various heights into a slot fitted with a watertight joint around the cross-section, depending on the desired level of water and sediments in the channel. Overflow is conveyed by a gully into a settling tank. Different initial conditions are investigated by adjusting the bed slope for 0.0, 0.01 and 0.02 percent respectively. Figure 4. illustrate the initial condition of model.

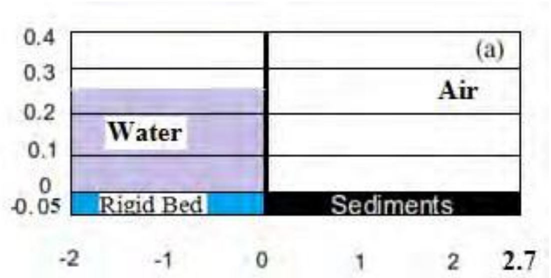


Fig.4. Initial dam-break configurations

2.2.2 Bed material properties

The mobile-bed material is composed of non-uniform coarse sand; with a median diameter of about 2.5 mm. "Figure 5." shows the grading curve of bed material. The sand also has the following properties: γs =1.82 g m-3, γd =1.65 g m-3 , an intrinsic density ρM =2683 kg m-3, a friction angle ϕ = 33◦ and negligible cohesion. Also for bed material: ωp = 10.2% and P=37.6%. The same sand was previously used for long-term morphodynamic equilibrium experiments by Capart et al (1998), from which the Manning roughness factor was estimated to be n = 0.0165 s m−1/3 [5]. During the experiments, the total amount of bed material transported by the wave is collected at the flume outlet. The sample is dried before being weighted, providing a rough idea of the intensity of geomorphic action within the channel.

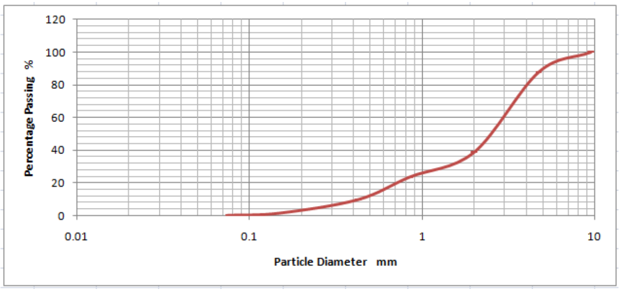


Fig.5. Bed material grading

3. Results and Discussions

First test is performed for plain bed condition i.e. in upstream the solid bed has 5cm height and in downstream the bed level adjusted to a level same as upstream. Figure 6. shows reconstructed flow mosaics at selected instants for this case. Globally, the downstream propagation of the dam break wave is seen to generate erosion by entraining substantial amounts of bed sediments in the flow. According to spinewine et al (2007) experiments and analysis of observed flow profiles, it is possible to distinguish four distinct stages of the wave development: a slumping phase, an inertial phase, an equilibrium transport phase and a viscous phase [4]. Similar stages were also identified for small-scale experiments of density and gravity currents (Hogg and Woods, 2001; Hogg and Pritchard, 2004; Huppert and Simpson, 1980) [8], [9], [10].

For second and third test, bed level was adjusted to 0.01 and 0.02 percent respectively. Table 2. presents the maximum height of bed scouring and its location, maximum height of deposition and its location and scoured sediment volume for all tests at end of the each test duration.

The celerity of the wavefront is depicted in Figure 7. Results are plotted for all three cases and for the reference solution of Ritter corresponding to the celerity of a dam-break wavefront over a fixed and frictionless bed. The effects of bed scour and friction both result in a notable deceleration of the wavefront as compared to the Ritter solution. Increase in bed slope result in increasing wavefront celerity and also scouring depth. The front celerity is nearly constant over a first time windowand then decreases slightly, revealing the gradual transition from the inertial and equilibrium phases to the viscous phase as bed friction further decelerates the wavefront. The dotted line features the theoretical characteristic of the wavefront for the Ritter solution, i.e. a dam-break propagating over a rigid and frictionless dry bed at speed u = 2 (gH)0.5 with H the initial water depth. Figure 8. presented simultaneously the all tests profiles at the same instant, further shows that the faster propagation of the wavefront for higher slopes is associated with lower flood levels all along the wave.

Fig.6. Flow patterns for first test case, for duration of 5s.

Table 2. all test case results

Test number	Bed slope (%)	Maximum scouring -dz (cm)	Distance of -dz From gate (cm)	Length of scouring reach L_1 (cm)	Maximum sedimentation +dz (cm)	Distance of +dz From gate (cm)	Length of sedimentation reach L_2 (cm)	Outlet sediment weight (Kg)
1	0	4.2	10	30	1.6	36	23	1.33
2	1	4.4	10	22	0.7	34	19	1.560
3	2	4.8	9	19	0.3	32	16	1.720

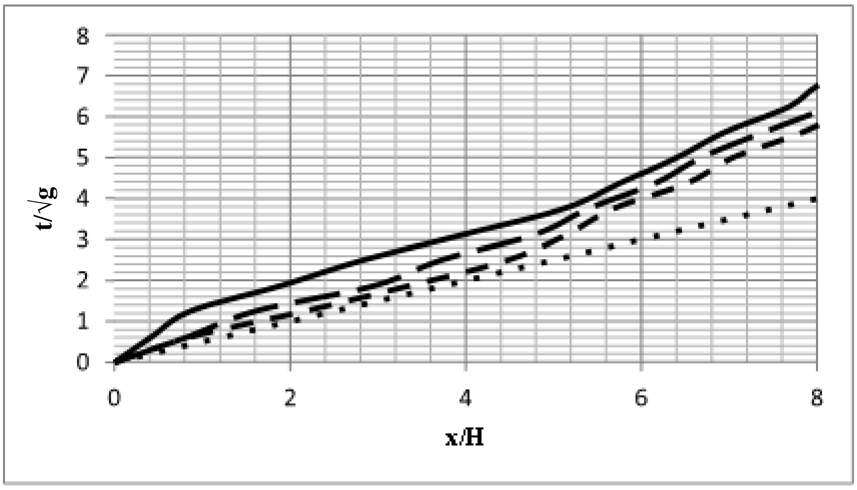


Fig.7. Dimensionless space-time characteristic path of the wavefront position. Plane bed case in solid line, planebed with 1 % bed slope in long dash line, plane bed with 2 % bed slope in long dash line and rigid frictionless bed case (Ritter) in dotted line.

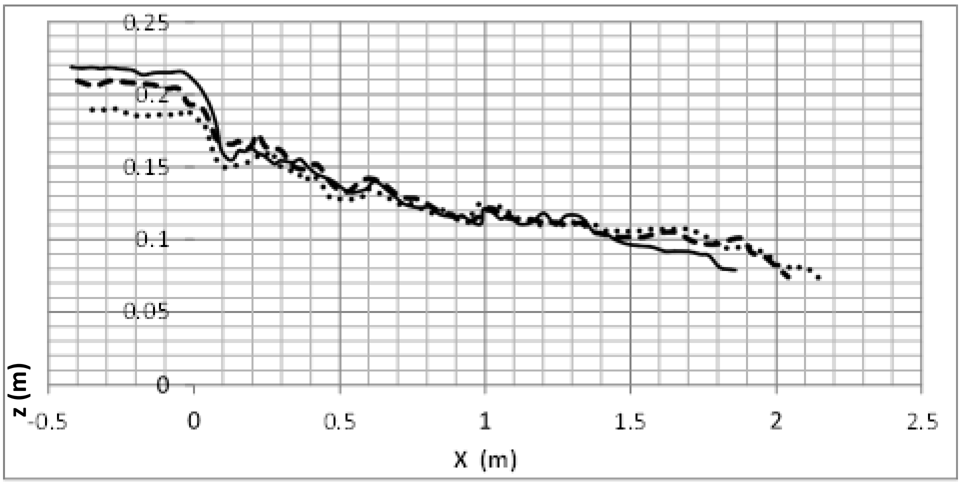


Fig.8. Comparison of all profiles: solid line for first test, dashed line for second test (1% bed slope), dotted line for third test (2% bed slope) at the same instant t = 1.0 s.

4. Conclusion

The problem with dam-break induced geomorphic flows is that they combine several difficulties. They involve such rapid changes and intense rates of sediment transport that the granular component plays an active role in the flow dynamics, and that inertia exchanges between the bed and the flow become important. Dam-break induced geomorphic flows cause dramatic and rapid evolution of the valley geometry. In return, this change in geometry strongly affects the wave behaviour and thus the arrival time and the maximum water level. An important experimental work has been achieved to get more insight into effect of slope on dam break flow. These data are then used to validate four different numerical. The present paper documented a series of small-scale laboratory dam-break waves propagating over loose granular beds, with grading bed materials and a range of initial bed slopes. The bed is mainly composed of saturated particles. Consequently, we can assume that the sedimentation is a gradual process and does not take certain travel time or distance to reach the transport capacity for a flow condition. The result shows the effect of slope on dam break flow. Important result from figures 7 and 8 is that for 2% bed slope wave celerity and wave progressing faster than 1% bed slope which is lead to following results: by increasing in slope for 1% and 2% bed slopes, scouring increased by 5% and 14%, reach of scouring decreased by 27% and 37%, outlet sediment weight increased by 17% and 29%, sedimentation decreased by 56% and 81% respectively. Obviously it could be concluded from results that increasing in slope doesn't has linear affect on eroding and sedimentation parameters, for 2% slope variation more sever that 1% slope. It is hoped that the present dataset may help model developers and permit testing a range of modeling approaches for sediment transport in intensively erosional and highly transient conditions.

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