Generation the hydraulic jumps by the dam-break flow over the movable beds

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Abstract
The paper aims to evaluate the dam-break characteristics over the movable beds. In this connection two different bed material including sand and pumice were considered as the bed material. Further, the effect of bed level-difference were scrutinized on the dam-break free surface fluctuations and the bed deformation across the downstream. In this connection the numerical study was carried out through Flow-3D CFD package. Accordingly, the volume of fluid method was used for tracking the dam-break free surface propagation along with the water-sediment interface evolution. The turbulence flow features stem from water-sediment interaction was predicted using kinematic energy-dissipation model. Moreover, the van Rijn bed load transport formula applied to evaluate the erosion and sediment entrainment throughout the downstream channel. Ultimately the re-sults indicated that first, the dam-break rapid unsteady flow evolution causes the formation of the sequential hydraulic jumps, local scouring and sedimentation across the downstream channel. Second, the dimensions of the first jump and scour hole are greater than the second ones, respectively. Third, the second hy-draulic jump is formed due to remaining dam-break flow power. The depths of the first and second scour holes are diminished through the increment of the downstream bed elevation.

Keywords
Dam-break, hydraulic jumps, scour holes, volume of fluid, kinematic energy-dissipation.

Introduction

Apart from the environmental effects stems from the dam construction such as salin-ity in soil and underground water, also the dam-break could be caused many life and property losses throughout the downstream region (Sallam et al. (2018)., Amini et al. (2017)). Sediment eroded from the drainage catchment is trapped in the dam reservoir. Whilst, during the dam-break the bed-load intensifies the property losses (Samad et al. (2016)., Heydari and Khoshkonesh (2016)). In this connection the effect of the bed material along with the elevation difference between the reservoir and the down-stream river on the dam-break flow characteristics has been studied rarely (Heydari and Khoshkonesh (2016)., Zhang et al. (2019)., Xu et al. (2015)., Hirt and Nichols (1981)., Nsom et al. (2007)., Nsom et al. 2019)., Khoshkonesh et al. (2019)). Therefore, in current study the effects of aforementioned factors are scrutinized in the flow fluctuations and scouring in the downstream channel using volume of fluid method in Flow-3D program.

Materials and Methods

In this study, the dam-break flow characteristics over the mobile bed are scrutinized as the following models: (i) tackling the equations of motion using finite volume method; (ii) tracking the free-surface using the standard VOF method; (iii) calculation of fluid pressure by the implicit method; (iv) simulating the turbulent flow through the k-ε model; (v) The flux equation of the sediments is fully coupled with the fluid mo-mentum equations.

Results

The mesh cells diameter dc and the turbulence models considered as sensitivity anal-ysis parameters (tables 1-3). Thus, the models accuracy in prediction the flow depth was evaluated using dam-break experiments (Fraccarollo and Toro (2012)., Leal et al. (2002)). The normal root mean squares error NRMSE represents the accuracy criteria of modeling.

Table (1). The NRMSE of the mesh cells mean diameter in the dam-break experiment [Fraccarollo and Toro (2012)]

	model A: 12.5-10			model B: 25-20			model C: 40-32		
Control points in flume	o	4a	8a	o	4a	8a	o	4a	8a
NRMSE values	0.15	0.11	0.08	0.16	0.09	0.08	0.22	0.09	0.09

Table (2). The NRMSE of the turbulence closure models in model B in the experiment [Fraccarollo and Toro (2012)]

Control points in flume	o	4a	8a
k-ε	0.138	0.093	0.072
k-w	0.19	0.104	0.081
RNG	0.19	0.104	0.079

Table (3). The NRMSE of the van Rijn formula in the case dc = 25-20 [Leal et al. (2002)]

	model D : sand bed		model E : pumice bed	
duration of the dam-break *t* (s)	1	2	1	2
Van Rijn formula NRMSE	0.036	0.043	0.064	0.048

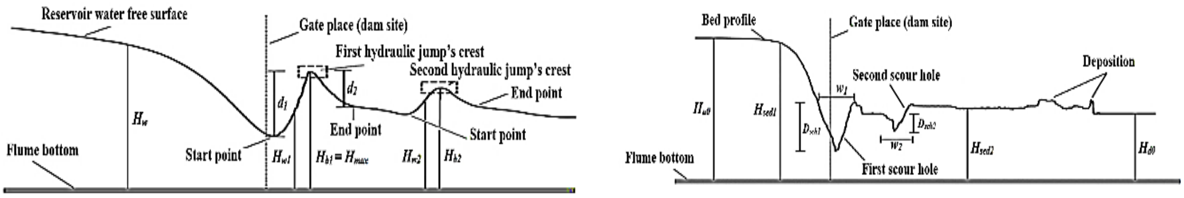

Figure (1). Geometric characteristics of the first and second jumps (left) and scour holes (right)

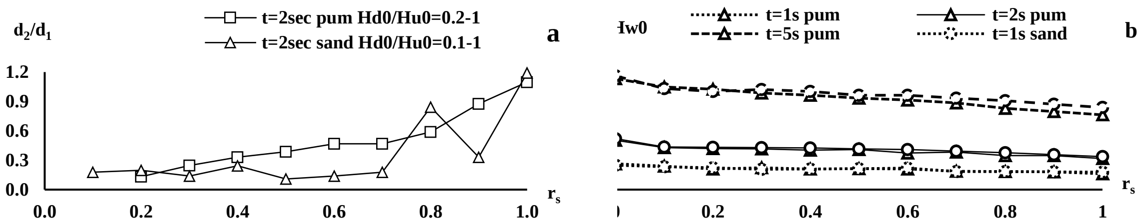

Figure (2). a: Ratio of the first jump depth to the upstream depth d2/d1, b: wave-front advancing distance in sand and pumice beds at t = 1s, 2s & 5s

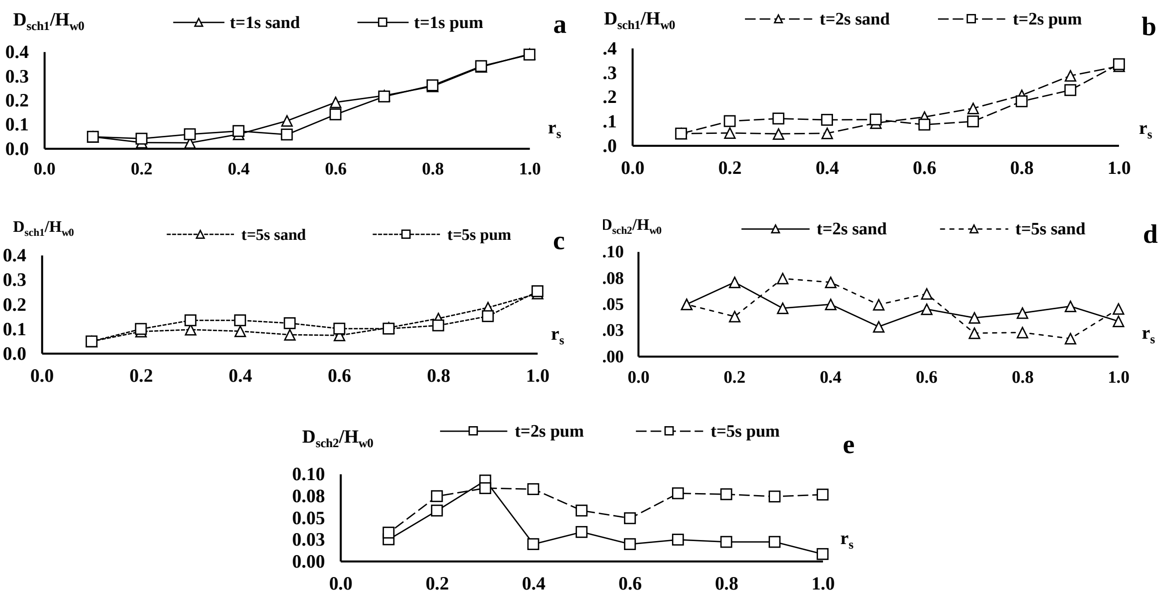

Figure (3). a-c: the first scour hole depth, d & e: the second scour hole depth at t= 1s, 2s & 5s in sand and pumice models

In tables 1-3, the model efficiency in predicting the flow depth is proper in d_c = 25mm and k-ε model. Further, van Rijn (1984) formula reveals high performance (table 3).

Discussion

In figs. 1&2, the difference between d_1 and d_2 values is vanished by rising r_s =H_{d0}/H_{u0}. In fig. 2a, d_2/d_1 shows an ascending trend by rising r_s at t = 2s, in the pumice bed. In fig. 2b, the wave-front advancing distance x_f values are plunged in both sand and pumice. Indeed, x_f increases with diminishing the sediment mobility. The greatest and least x_f values belong to the moments t = 5s and t = 1s in r_s = 0 and

r_s =1, respectively. The characteristics of hydraulic jumps induced by dam-break and its relation with the bed elevation have not scrutinized so far (Sallam et al. (2018)., Amini et al. (2017)., Samad et al. (2016)., Heydari and Khoshkonesh (2016)., Zhang et al. (2019)., Xu et al. (2015)). In this study, the reason for the formation of the first jump is a significant energy gradient between the dam-break flow and the downstream bed. It leads to local scouring, flow rotation, and formation of jumps. The result is consistent with (Leal et al. (2002)., Capart and Young (1998)). However, they illustrated the jump is formed over the fixed bed and not mobile bed. Afterward, the second jump is formed due to remaining flow power. The considerable flume length (L_d =16m) and 1D flow nature prevent the formation of the third jump. In fig. 3a, the first scour hole depth D_{sch1} is increased by increment r_s in both sand and pumice at t = 1s. Further, in figs 3b & 3c the pumice diagrams are sleep reverse S-shape. Indeed, an inflection point is observed in r_s = 0.5 and r_s = 0.7, respectively. While the D_{sch1} values in pumice are more than the sand in $r \leq 0.5$, there is a reverse trend in at $r \geq 0.6$. In fig 3c, D_{sch1} values are almost identical in both beds in r_s = 0.1, 0.7 and 1. Likewise, D_{sch1} values are considerably reduced during t =1-5s in both beds. In figs 3d & 3e, the diagrams of second hole depth D_{sch2} are irregular, unlike the figs 3a & 3c. In fig 3d, the $D_{sch2\text{-}max}$ are about from the order of 1/5 the $D_{sch1\text{-}max}$ values in fig. 3b. Besides, in fig. 3e, D_{sch2} values in the pumice bed are greater than the sand in fig. 3d (except the cases r = 0.1 & 0.6).

Conclusions

The height of both hydraulic jumps are dependent on the downstream bed elevation. Two scour holes appear under the first and second jumps. The dimensions of the first hole, which is formed in the near field, are bigger than the second one. The second jump is generated due to remaining dam-break flow power. The depths of the first and second scour holes are diminished through the increment of the downstream bed elevation.

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