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Numerical Simulation of Three-Dimensional Flow of Sudden Dam-Break over the Porous Bed

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ABSTRACT: Dam break is a very important problem due to its effects on the economy, security, human casualties and environmental consequences. In this study, 3D flow due to dam break over the porous substrate is numerically simulated and the effect of porosity, permeability and thickness of the porous bed and the water depth in the porous substrate are investigated. Classic models of dam break over a rigid bed and water infiltration through porous media were studied and results of the numerical simulations are compared with existing laboratory data. Validation of the results is performed by comparing the water surface profiles and wave front position with dam break on the rigid and porous bed. Results showed that, due to the effect of dynamic wave in the initial stage of dam break, a local peak occurs in the flood hydrograph. The presence of porous bed reduces the acceleration of the flood wave relative to the flow over the solid bed and it decreases with the increase of the permeability of the bed. By increasing the permeability of the bed, the slope of the ascending limb of the flood hydrograph and the peak discharge drops. Furthermore, if the depth and permeability of the bed are such that the intrusive flow reaches the rigid substrate under the porous bed, saturation of the porous bed, results in a sharp increase in the slope of the flood hydrograph. The maximum values of the peak discharge at the end of the channel with porous bed occurred in saturated porous bed conditions.

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1- Introduction

The sudden release of water stored in a reservoir due to the collapse of the dam can lead to serious environmental problems, the risk to human life and severe economic damages in the downstream valley. Therefore, dam break is a major concern in the field of hydraulics and environmental engineering [1]. Dressler (1952) examined the effects of roughness on flood wave propagation. He added the Chezy roughness formula to the non-linear equations of shallow water flow [2]. Lauber and Hager (1998) conducted some experiments on a rectangular prismatic channel with smooth, horizontal and sloped bed conditions to investigate the dam failure phenomenon. Based on preliminary experiments, it was found that the flow caused by the dam failure, subject to the initial flow depth of at least 300 mm, follows the Froude similarity law [3]. Castro-Orgaz, and Chanson (2017), by reviewing Ritter studies of dam break-induced flow on the dry bed, studied the positive and negative wave dynamics and investigated the effects of bed friction on the positive wave propagation [4].

Previous studies focused on the hydrodynamics of the dam break over the solid bed. In this study, 3D flow due to dam break over the porous substrate is numerically simulated and the effect of porosity, permeability and thickness of the porous bed and the water depth in the porous substrate are investigated on the hydrodynamics of the flood wave. Water surface profiles and discharge hydrographs of different cases are compared.

2- Methodology

In this study, three-dimensional simulation of dam break flow was performed using version 11 of Flow-3D software. Governing equations are continuity and momentum equations. A non-linear model is used to connect the pressure gradient and flow velocity through the porous medium. Computational fluid dynamics (CFD) analysis has been performed and RNG k-ε model is used as the turbulence closure for Reynolds averaged Navier Stokes (RANS) equations. The free-surface is determined by the volume of fluid (VOF) method. Also, the FAVOR method is used to define rigid volumes.

Verification of the numerical simulations is performed using the experimental data of Lauber, and Hager (1998) for sudden dam break over the rigid bed, experimental data of Ghimire (2009) for sudden flow through the permeable vertical porous column composed of spherical beads of 5 and 12mm in diameter, in two cases. Furthermore, the experimental data of Ghimire (2009) is used for sudden dam break flow over the porous bed.

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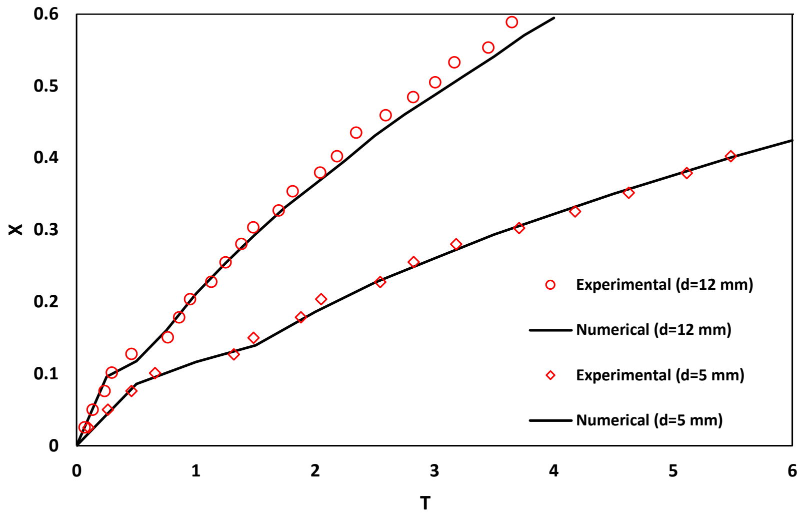

Fig. 1. Comparison of the wave front position between experimental (symbols) and numerical (line) results for flow inside of the vertical porous column of different grain sizes

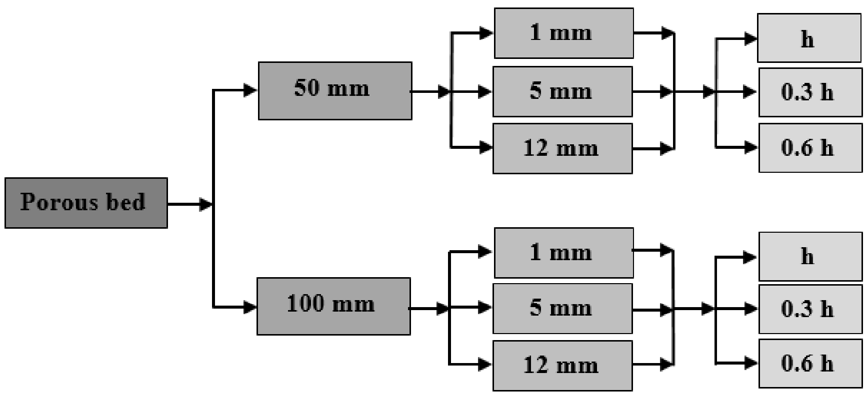

Fig. 2. Flowchart of numerical modeling steps performed on porous media in the present study

Figure 1 compares wave front position inside of the porous column between experimental and numerical results for two cases. Good consistency was obtained between the experimental and numerical results for both of the 5 and 12 mm grain size porous mediums.

Figure 2 shows the studied dam break models over porous beds at two depths of 50 and 100 mm with 1, 5 and 12 mm grain diameter. Also, for each of the granular diameters, water depths under h, 0.3h, and 0.6h were tested.

In Figure 3, the results of the numerical model for water surface profiles at t = 0.2s to t = 2s are compared with the experimental results over the porous substrate. The difference in the water surface profile over the porous substrate between the experimental and numerical results was 8.11%.

The temporal variations of the water surface profiles and the downstream flood wave locations, as well as the negative wave backflow into the reservoir in the numerical model, are well predicted.

3- Results and Discussion

Figure 4 shows the effect of the porous bed grain diameter and the depth of the porous bed on the progress of the wave front. By increasing the water depth in the porous bed, the wave front accelerates and at the submerged condition, it shows similar behavior to the dry bed. This is because, by increasing the water depth, the dam break wave interacts with the water inside of the porous bed and, the infiltration of the wave into the bed decreases.

By increasing the grain diameter in a saturated condition, the dam break wave moves faster than the solid bed.

Figure 5 shows the hydrographs of dam break wave at a station located in the middle of the porous bed. It is clear that in all of the porous bed conditions, the flood wave is less than the solid bed condition. Furthermore, the porous bed hydrographs for different water depths are almost similar until the flood wave reaches the water inside of the porous bed.

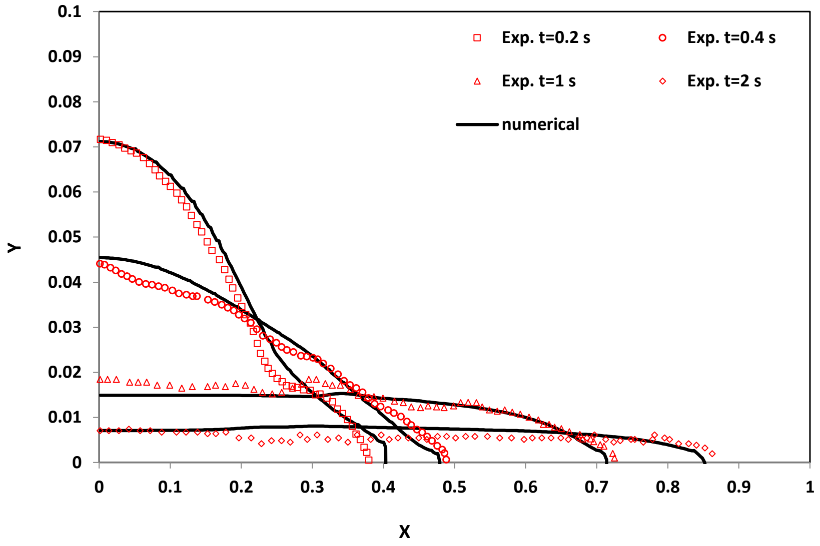

Fig. 3. Comparison of water surface profiles over porous media with 12 mm particle diameter in laboratory measurements (symbols) and numerical results (lines).

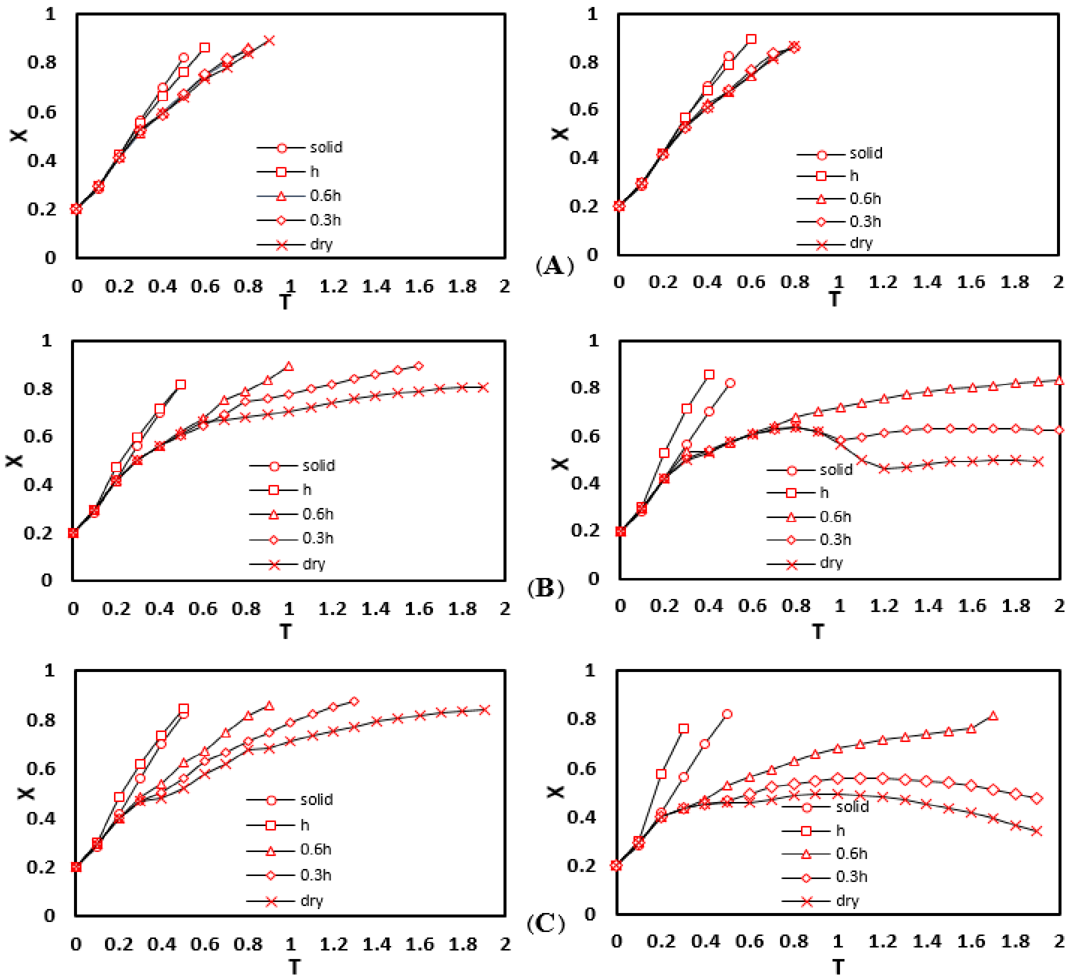

Fig. 4. Comparison of flood wave front (T in seconds and X in meters) on a 100 mm deep porous substrate (right diagrams), 50 mm depth (left diagrams) and a downstream solid bed and water of downstream 0.3h, 0.6h, h, dry substrate with particles in diameters of A) 1 mm B) 5 mm C) 12 mm

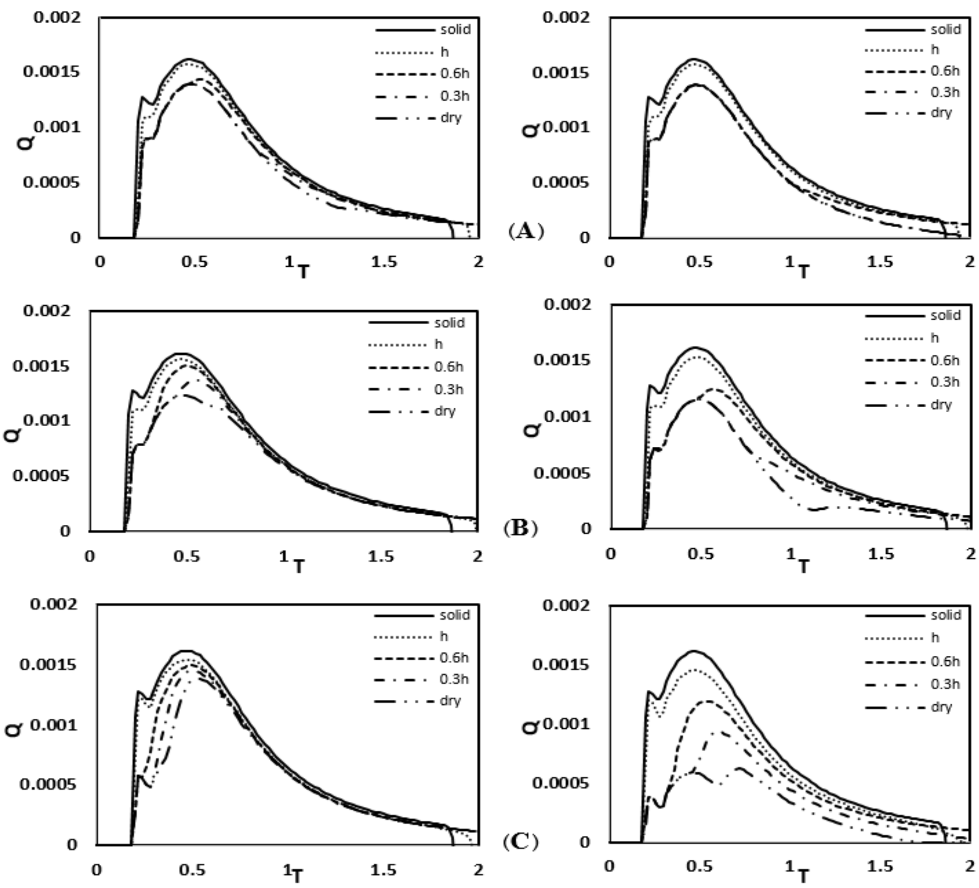

Fig. 5. Comparison of flood hydrographs (T in seconds and X in meters) on a 100 mm deep porous substrate (right diagrams), 50 mm depth (left diagrams) and a downstream solid bed and water of downstream 0.3h, 0.6h, h, dry substrate with particles in diameters of A) 1 mm B) 5 mm C) 12 mm

4- Conclusions

In this study, 3D flow due to dam break over the porous substrate is numerically simulated and the effect of porosity, permeability and thickness of the porous bed and the water depth in the porous substrate are investigated and the following results are obtained:

1. Due to the effect of dynamic wave in the initial stage of dam break, a local peak occurs in the flood hydrograph.
2. The presence of a porous bed reduces the acceleration of the flood wave relative to the flow over the solid bed and it decreases with the increase of the permeability of the bed.
3. By increasing the permeability of the bed, the slope of the ascending limb of the flood hydrograph and the peak discharge drops.
4. If the depth and permeability of the bed are such that the intrusive flow reaches the rigid substrate under the porous bed, saturation of the porous bed results in a sharp increase in the slope of the flood hydrograph.
5. The maximum values of the peak discharge at the end of the channel with porous bed occurred in saturated porous bed conditions.

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