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Investigation of the capability of a Numerical model to simulate a Mining Pit in River Bed

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ABSTRACT

Rivers are the most essential source of aggregates for civil works such as construction of roads, canals, concrete buildings and many other construction purposes. However, the improper mining of sand and gravel from bed rivers may cause significant damage to them in terms of mass bank failure, channel bed erosion. In this research, because of the widespread use of numerical models in different types of hydraulic problems, the variation of the packed bed river profile due to digging a trapezoidal pit in the bed river is analyzed by a leading numerical model. the simulation data is compared with the measured value and the result is discussed and the reason why the numerical model was almost unsuccessful to simulate this phenomenon is discussed. The objective of this research is to investigate limitation of a particular CFD model by comparison of its results with the experimental data. finally other related numerical models is introduced and.

KEYWORDS

Bed River, Numerical Simulation, Sediment Transport, Mining Pit

INTRODUCTION

Nowadays, usage of numerical models in hydraulic engineering due to simplicity and savings in time and money has come in a wide range of shapes (one, two or three dimensions, steady or unsteady flow conditions etc). All are based on derivations of the basic principles of fluid mechanics and make some numerical approximations to solve these principles. However, as situations become increasingly complex, the track of these essential principles is lost. Basic equations are replaced by empirical approximations, and mathematical calculations with numerical models. Numerical are based on derivations of the basic principles and all are required to make some form of numerical approximation to solve these principles which will cause some limitation in usage of them in some complex problems. Therefore, the ability of numerical models to simulate different hydraulic problems under different situations should be checked and the validity of the simulation results must be investigated [1]. As it mentioned above, one of the complex problems in hydraulic engineering is improper mining of sand and gravel from river beds. The objective of this research is to verify a computational fluid dynamics (CFD) model (Flow-3D) for sediment transport simulation by comparing their results with laboratory observations.

EXPERIMENTAL SETUP

To investigate improper removal of sand and gravel from river bed, a physical model was made at the laboratory of Soil Conservation and Watershed Management Research Institute (SCWMRI) Tehran, Iran.

The experiments were carried out in a rectangular flume and consisted of 12 m long, 0.6 wide and 0.8 m in depth. A sill with height of 27 cm was built for preventing sediment movement. The flow was uniform and a triangular sharp edge weir was installed at the end of the channel which was used to measure discharge. Experiments have been done for sub critical condition. The longitudinal slope of the sediment was set to 0.001. A rectangular control gate was used to adjust flow depth at the downstream of the flume. Figure 1 shows the experimental setup [2].

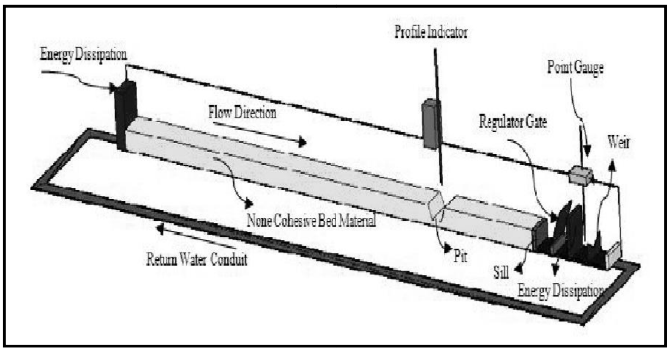

Fig 1. Experimental Setup

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NUMERICAL MODELING

In order to simulate the mining pit, Flow-3d v9.3 is used. FLOW-3D is a commercial package developed by Flow Science Inc at Los Alamos Scientific Lab. The software uses several special features for numerical solution of the Navier-Stokes equations for free surface flows (VOF-method) and meshing of complicated geometries (FAVOR method) [3,4]. The sediment scour model treats sediment as two concentration fields: the suspended sediment and the packed sediment. The suspended sediment advects and drifts with the fluid due to the influence of the local pressure gradient. Suspended sediment originates from inflow boundaries or from erosion of packed sediment. The packed sediment, which does not advect, represents sediment that is bound by neighboring sediment particles. From the physical point of view, the assumption of the two concentration fields seems to be valid to model fine sediment bed materials.

The geometry of the model consisted of a rectangular which is divided into a structural mesh block (Figure 2). The dimensions of this mesh block are shown in Table1. Two rectangular box with the length of 66 and 86 centimeters was placed at the upstream and downstream of the mesh block in order to place bed material between them.

Table 1: The dimensions of the numerical model and number of the grids used in the numerical model.

X(cm)	Y(cm)	Z(cm)	Ncellx	Ncelly	Ncellz	NTotal
60	1410	65	10	300	50	150000

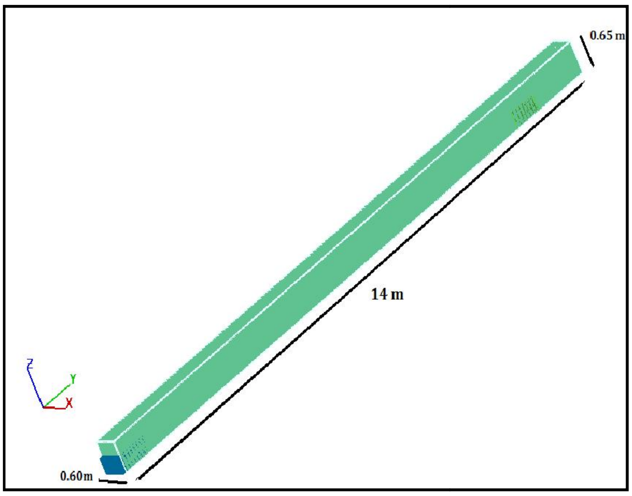

Fig 2. The Geometry of the numerical model

In order to define the mining pit, two fluid region have been labeled .The mining pit was located 3.6 meter from the downstream of the channel. The simulated mining pit had the depth of 15cm and the length of 30cm exactly same as experimental set up. Since the cohesive sediment fraction was set to zero and the angle of response of the material was almost 33 degree, the rectangular pit would convert to trapezoidal slowly.

The Renormalization-group (RNG) k-ε model was used to account for turbulence modeling and the volume of fluid (VOF) scheme was also used in the model in order to find free surface of flow

BOUNDARY CONDITIONS

The upstream boundary condition in x direction was defined as "specified Velocity". Specified pressure was set at the downstream of x direction. Boundary condition for the z direction was labeled as "symmetry" which implies that identical flows occur on the other side of the boundary and hence there is no drag. The "wall function" was applied in the y direction and the negative z direction. The acceleration of gravity was applied in the negative z-direction.

Simulation Results

Figure 3 to Figure 8 show the process of filing the pit during different times. Figure 9 and Figure 10 o show the bed profile variation during different times of simulation and experiments respectively.. By comparing simulated bed profile with the experimental bed profile, it can be concluded that they are different and their difference is found in the type of the pit being filled. As it is clear in Figure 9 As it the pit is fixed at its location and does not move toward the downstream of the channel. Conversely, the mining pit in Figure10 is filled as the pit moves toward the downstream of the channel. This reason is probable because of the lack of sediment transport equations in this CFD program. Another limitation that was seen in this research was very long computational time. As it was seen in the Figure 3, a very fine grid was needed for modeling the model. So computing long-term equilibrium scour required an exorbitant amount of computational time, much larger than that was required for running a physical model. However, Flow-3d is able to simulate sediment scour approximately well which is checked by different researches such as Vasquez and Walsh (2009). Vasquez and Walsh (2009) applied FLOW-3D to compute the initial stages of scour development in a complex pier made of a large pile cap and 10 cylindrical piles. The results were in qualitative agreement with experimental data [5].

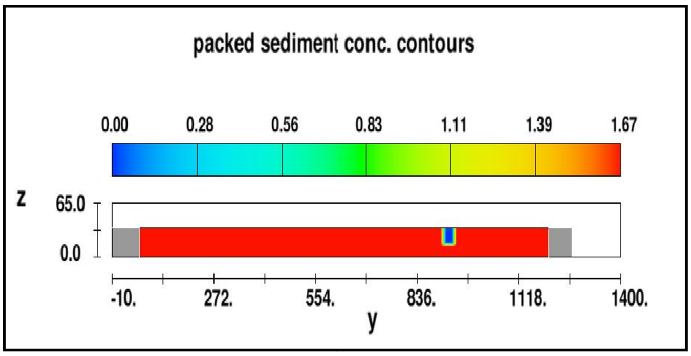

Fig 2. The definition of the bed material and the mining pit

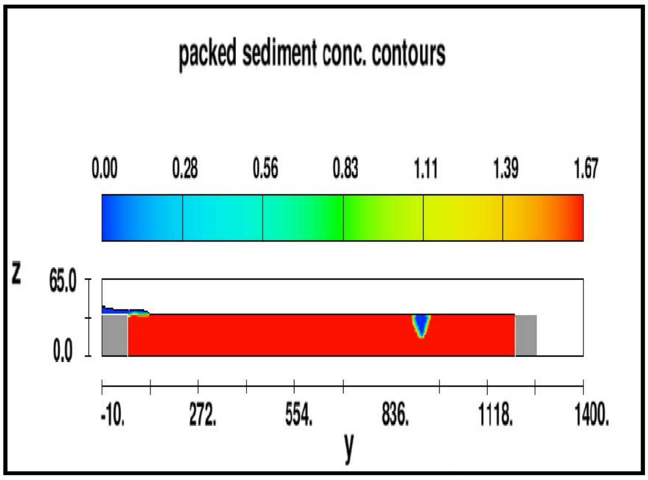

Fig 4. Transformation of the rectangular pit into trapezoidal and movement of flow

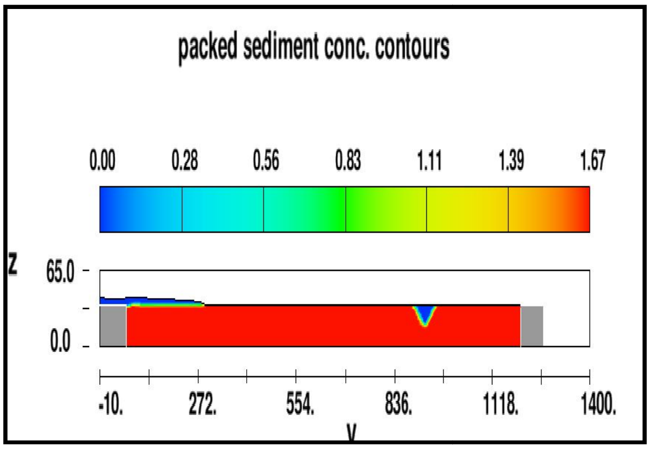

Fig 5: Transformation of the rectangular pit into trapezoidal and movement of flow

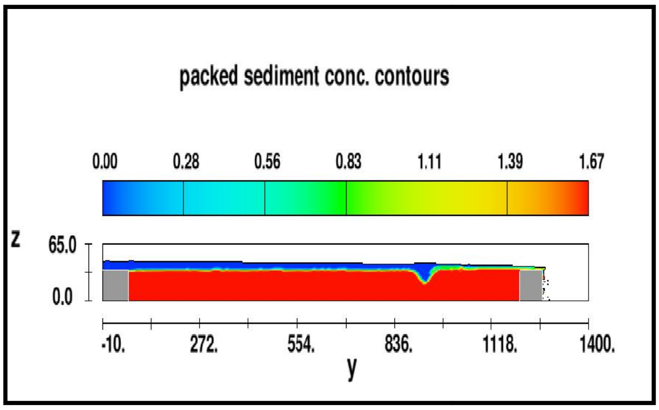

Fig 6: Movement of the bed material and the process of filling the mining pit

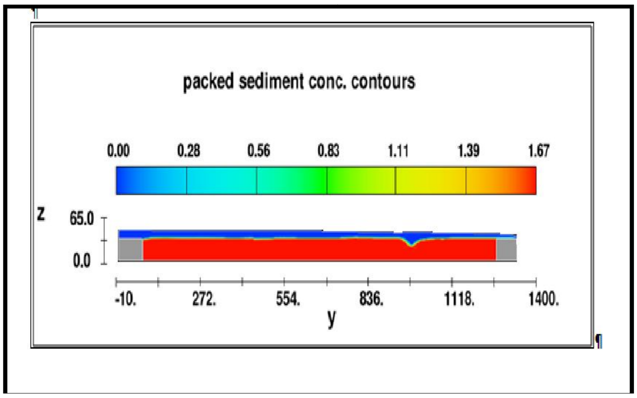

Fig 7. Movement of the bed material and the process of filling the mining pit

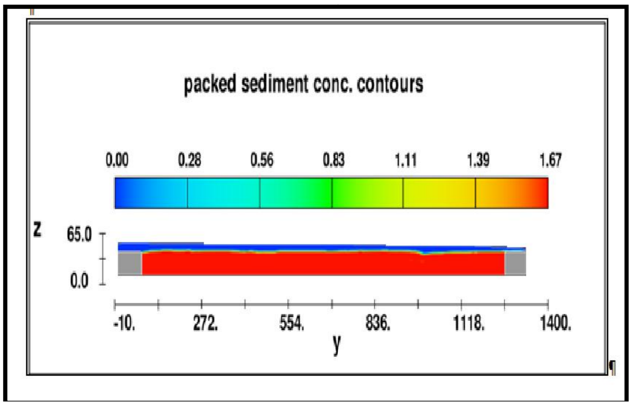

Fig 8: Movement of the bed material and the process of filling the mining pit

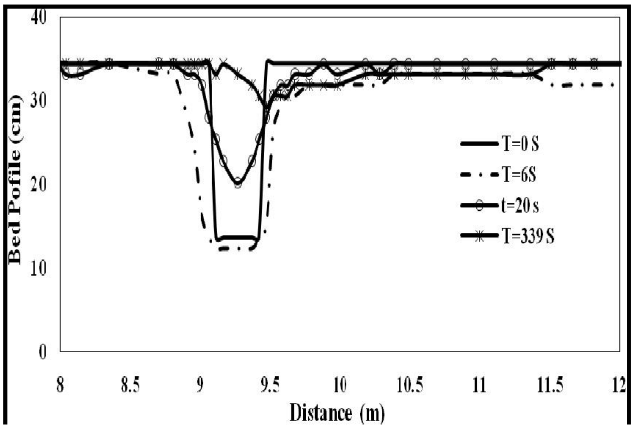

Fig 9: Simulated bed profile variation of the channel during different times of variation

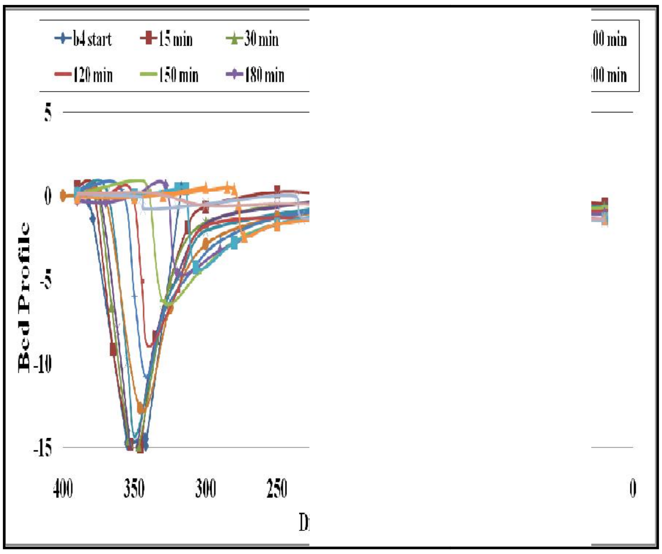

Fig 10: Experimental bed profile variation of the channel during different times of variation

CONCLUSION

In this paper,. Based on the experiential data, capability of a three dimensional CFD program in modeling the bed variation of the experimental model is checked. It is clear that the numerical model was helpless to simulate algorithm of filling the mining pit to a satisfactorily extend because of the lack of sediment transport equation.. It is also recommended that usage of other CFD programs which are able to simulate sediment transport condition such as MIKE 11 and MIKE be checked and their limitation in modeling the variation of the bed due to migration of the pit in more complex situation be verified.

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