

Scour downstream of a sluice gate using SedFoam and FLOW-3D

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Abstract: *Sediment scour caused by a confined water wall jet downstream of a sluice gate is an interesting hydro-morphological phenomenon. The aim of this research is to simulate effectively this phenomenon using two different numerical models, SedFoam, a two-phase flow RANS model that use consecutive laws to perform direct coupling between the solid and liquid phase, and FLOW-3D Hydro a CFD software for multi-phase flow that has a built-in scouring model which is unlike SedFoam, doesn't use direct coupling. A data of a study on a scour downstream of a sluice gate due to a confined water jet by Martino et al. (2019) will be used as the reference to study this phenomenon. This will show the advantages and defaults of both models as well as reproduce numerically this phenomenon.*

Keywords : Sediment transport, fluid mechanics, numerical simulation.

1 Introduction

Sediment bed erosion, near hydraulic structures, that is caused by the erosion due to water flow that interact with part of this structures is a natural phenomena called "scour". Scour has been an arising problem that can cause severe failure in fluvial and marine hydraulic structures. Calculating and forecasting the maximum depth that the scour can reach and the size and shape of this scour is interesting to predict points of failures and to protect against such failures in these hydraulic structures. Sediment scour due to a water wall jet downstream of a sluice gate in a channel with a high degree of confinement is not well documented, several experiments were made but to our knowledge, no numerical simulations were tested to describe the hydro-morphological phenomena of sediment erosion and deposition downstream of a sluice gate in a very confined channel. In 2019, Martino *et al.* tested for several flow rates, the sediment scour formation caused by a water jet downstream of a sluice gate in a very confined channel [1], where a sediment erosion and a dune formation were observed. Furthermore, the dune changed its shape from a triangle to a trapezoidal shape and for certain flow rates a phenomenon of cycles of erosion and filling of the scour was also observed, which is not observed in the literature for non-confined channels. The model was reproduced numerically using two different models, SedFOAM [2] and FLOW-3D [3], where the experimental results were compared to the numerical results and an explanation of the observed phenomena was deduced from the numerical results as well as the effect of the water jet on the erosion process and dune shape formation.

2 Numerical models

SedFOAM, is a two-phase flow RANS model for sediment transport based on the open-source toolbox, OpenFOAM, in which dynamical equations are applied on both the fluid and particles phases. This approach takes into consideration most of the physical processes. Two important closures are implemented, the flow turbulence and granular stress closures. For the turbulence closure there are two models, the $k - \varepsilon$ model [4] and the most recent $k - \omega$ model [5] similar to that of Amoudary (2014), the $k - \omega$ model was used. While for the granular stress models, the dense granular flow rheology initially proposed by GDRmidi (2004) [6] is used. On the other hand, FLOW-3D is a commercial CFD software that use a RANS-VOF method, which uses a three-dimensional sediment transport and scour model that is not considered as a coupled multi-phase flow model. In this model, the Flow is calculated using the Navier-Stokes equations with turbulence closure but without taken the solid phase into consideration. The RNG $k - \varepsilon$ model [7] is used and calibrated by the software to assure numerical stability. As for the sediment transport, a conventional equation of sediment transport like the Nielsen equation [8] as well as the Meyer-Peter and Muller equation [9] is implemented and used to calculate the transport of the sediments. The numerical results were validated using the experimental data by Martino *et al.* (2019).

3 Experimental setup

A hydro-sedimentary canal setup used by Martino *et al.* (2019) is reproduced numerically. It consists of a 140 cm long confined channel of a 2 cm width and lateral glass walls confinements. A pump is installed that can control the flow rate Q . Several flow rates were used to test the scour formation as a function of the flow rate. A 60 cm long sediment bed composed of 1.1 mm diameter granular glass beads and a density of 2.65 g/cm^3 was laid directly downstream of the sluice gate with a 10 cm depth. A 13 cm water depth is used. The used aperture of the sluice gate is 1 cm.

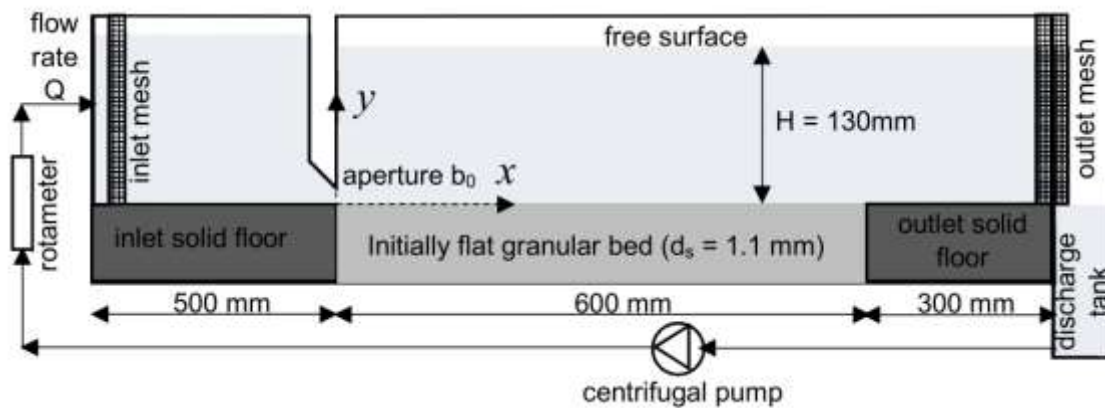


Figure 1: Experimental setup sketch by Martino *et al.* (2019).

4 Results

Numerical simulations were performed using several flow rates Q , for a sluice gate aperture of 1 cm. The numerical results were then compared with the experimental data from the study of Martino *et al.* (2019). A comparison of the form of the dune and change of shape of the dune from triangle to trapezoidal shape was compared at first between the experimental data and the numerical results on both models, SedFoam and FLOW-3D (Figure 2). The three-dimensional numerical simulations were

able to reproduce the form of the dune as well as the shape of both the scour and dune since the dune submitted a change in form, from a triangular shape to a trapezoidal shape on both numerical models. These numerical results showed the capability of these models to perform scour simulations with a high degree of physical accuracy.

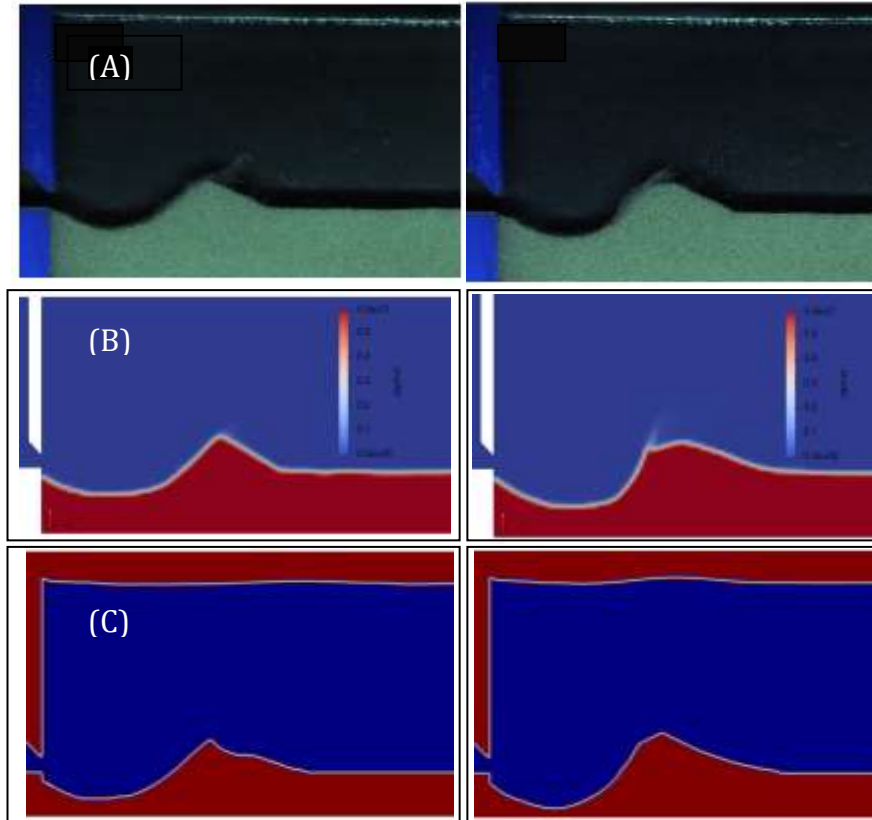


Figure 2: Dune formation, Experimental (A), SedFoam (B) and FLOW-3D (C).

This shape shifting was only observed in a very confined channel. The numerical results were only able to reproduce this phenomenon using three-dimensional numerical simulations which indicate the importance of walls on giving accurate numerical results as well as their impact on the dune size and shape. More numerical results are to be analyzed during this research where the scour maximum depth of both models will be compared with the experimental data. The evolution of the maximum scour depth through time will also be studied and analyzed based on the experimental data to check for the accuracy of these models in reproducing every aspect of the confined scour phenomena. Moreover, the numerical results of the water velocity will be validated through the experimental data to assure a good agreement of the velocity profiles between the experimental and the numerical results. This will also allow us to check if the numerical models are capable of reproducing the velocity decay phenomena through a confined channel. This phenomenon occurs for wall jets where the maximum velocity of the jet decreases the more it gets far from the sluice gate aperture in the stream wise direction.

6 Conclusion

Two different numerical models, SedFoam and FLOW-3D Hydro, were used to study a particular phenomenon of scouring downstream of a sluice gate in a confined channel. The main objective of this

study is to reproduce the scour phenomena observed in the experimental research done by Martino *et al.* (2019) which will show the capability of both models as well their advantages and defaults in such complex conditions. Moreover, the numerical results will be validated using the experimental data, especially the dune shape shifting as well as the maximum scour depth. This validation can serve as a numerical data base that can help complete the experimental data, where measurements were not made as well as a tool to explain the scouring phenomena observed in the experimental procedure which will help later on in predicting maximum scour depth and changes in the scour and dune characteristics.

References

- [1] R.G. Martino, F.G. Ciani, A. Paterson, M.F. Piva, Experimental study on the scour due to a water jet subjected to lateral confinement, *European Journal of Mechanics / B Fluids*, 75 (2019) 219–227.
- [2] J. Chauchat, Z. Cheng, T. Nagel, C. Bonamy, T.J. Hsu, Sedfoam-2.0: a 3-D two phase flow numerical model for sediment transport, *Geosci. Model Dev*, 10 (2017) 4367–4392
- [3] FLOW-3D Version 12.0 User's Manual (2018). FLOW-3D [Computer software]. Santa Fe, NM: Flow Science, Inc. <https://www.flow3d.com>
- [4] R. Bakhtyar, A. Yeganeh-Bakhtiary, D. Barry, A. Ghaheer, Two-phase hydrodynamic and sediment transport modeling of wave-generated sheet flow,, *Adv. Water Resour.*, 32 (2009) 1267–1283.
- [5] Amoudry, L. O., *Adv. Water Resour.*, Extension of turbulence closure to twophase sediment transport modelling: Application to oscillatory sheet flows, *Adv. Water Resour.*, 72 (2014) 110–121.
- [6] GDRmidi, On dense granular flows, *Eur. Phys. J. E*, 14 (2004) 341–365.
- [7] Yakhot, V. and Smith, L.M., 1992, The renormalization group, the e-expansion and derivation of turbulence models, *Journal of Scientific Computing* (7), 35-61.
- [8] Nielsen, P., 1992, Coastal bottom boundary layers and sediment transport (Vol. 4). World scientific.
- [9] Meyer-Peter, E. and Muller, R., 1948, Formulas for bed-load transport, *Proceedings of the 2nd Meeting of the International Association for Hydraulic Structures Research*. pp. 39–64.