# Comparison of the SWE and 3D models in simulation of the dam-break flow over the mobile bed

**Alireza Khoshkonesh**
Ph.D. in water structures, department of water engineering, Bu-Ali Sina University, Hamedan 65178, Islamic Republic of Iran.

**Blaise Nsom**
Université de Bretagne Occidentale. IRDL/UBO UMR CNRS 6027. Rue de Kergoat, 29285 Brest, France

**Fariba Ahmadi Dehrashid**
Ph.D. Student of water structures, Department of Water Science and Engineering, Faculty of Agriculture

**Payam Heidarian**
MSc in water and hydraulic structures engineering, Department of hydraulic structures, Faculty of civil and environment engineering, Tarbiat Modares University

**Khuram Riaz**
The University of Lahore, Faculty of Civil Engineering and Technology, Department of Technology, Lahore, Pakistan

## Abstract

The purpose of this study is to specify the capability of SWE and 3D models in reconstructing the instantaneous dam-break phenomenon. The numerical simulations implemented by a CFD software. The results showed that SWE model had lower accuracy, in reproducing the wave evolution and bed deformation, compared to the 3D model. Furthermore, the kinematic and dynamic properties of the dam-break wave affected by the initial conditions and bed characteristics.

**Keywords:** dam-break, numerical models, CFD, SWE, 3D models

## Introduction

The catastrophic floods generated by instantaneous dam failure leads to many life and property losses downstream the dams. Capart and Young (1998) studied the dam-break on the granular bed problem. The shallow water theory was applied for elucidating of the free surface evolution. In other research, Nsom et al. (2000) and Nsom (2002) studied the influence of the bed slope variation and fluid viscosity on the dam-break flow characteristics. For this purpose, the Navier-Stokes equations were solved with the approximation of the Kinematic wave model. Pritchard and Hogg (2002) studied the sediment transport processes influenced by the dam-break flow on dry and wet beds. They indicated that the formation of sheet-flow, bed load displacement and sediment concentration are thoroughly different in dry and wet beds. Kelly and Dodd (2009) evaluated the dam-break flow in ne-dimennsional case of characteristic method on fixed and mobile beds. They concluded that the numerical and analytical methods have various performances in a simulation of the flow evolution on various beds. Banejad et al. (2015), Heydari and Khoshkonesh (2016), Nsom et al. (2019), Bahmanpouri et al. (2020), Khoshkonesh et al. (2016-2021) simulated the dam-break free surface evolution in 3D case by VOF technique using a CFD package and the Lagrangian methods. Results showed that the 3D Navier-Stokes models and Lagrangian models have high accuracy in predicting the dam-break wave evolution and bed deformations during the dam-break events.
A concise review of literatures asserts that the performance of the SWE and 3D Navier-Stokes models in modeling the dam-break flow have been compared rarely. Therefore, the current study focused on comparing the efficiency of those models in reproducing the dam-break over mobile bed phenomenon using a CFD package.

## Governing Equations

The volume of fluid (VOF) method is a numerical technique for tracking of the free surface of the flow based on donor-acceptor cell concept. In fact, this technique is an advection scheme that applied for specification of the spatiotemporal variation on the free surface. While, function of F represents the regions contains the fluid that updated with the free surface evolution (Flow Science, 2012). The gradient form of equation of motion in this technique, as follows:

$$\partial F/\partial t + \nabla .(uF) = 0 \tag{1}$$

$F$ is a step-function that filled with fluid:

$$F = \begin{cases} 0 & , A_i, V_i = 0 \\ 1 & , A_i, V_i = (A, V) \\ (0,1) & , A_i, V_i = (A, V)/n \end{cases} \qquad (2)$$

F: Step function represent a fraction occupied by fluid and A, V: area/volume of cell that full of fluid, n: real number between zero and unit.

## Results and Discussion

The processor used in all simulations was Intel Core i3 M330 2.13 GHz with four threads. The numerical results compared with the experimental results provided in previous experimental works of Spinewine (2005) according to tables 1 and 2.

**Table1. NRMSE error values of modeling results**

| Variables | SWE | LES | RNG | k-w |
|---|---|---|---|---|
| $H$ | 0.1266 | 0.0373 | 0.0388 | 0.0397 |
| $H^*_{sed} = H_{sed}/H_{0sed}$ | --- | 0.4028 | 0.4083 | 0.4297 |
| $X_f{}^* = x_f/H_0$ | 0.3476 | 0.4321 | 0.4708 | 0.4772 |
| $X_f{}^* = x_f/H_0$ | --- | 0.2960 | 0.2697 | 0.2778 |

Based on NRMSE analysis, the SWE model had a least accuracy in simulation of the free surface profile. In fact, this model indicated considerable rupture in a free surface curve. Likewise, the SWE presumptions were not valid when the free surface had a sharp gradient near the dam site. As well, the LES model had most accuracy in simulation of the free surface profile, among all the 3D models. The results of 3D-models were also analogous. Besides, the wave-front tip region has a convex shape in experimental and the numerical profiles. Indeed, this shape modified by the combined effects of bed roughness, bed resistance, mixing of the bed material on flow and boundary layer developments in this region. It should be noted that the morphological variation of bed, had a remarkable effect on free surface evolution.

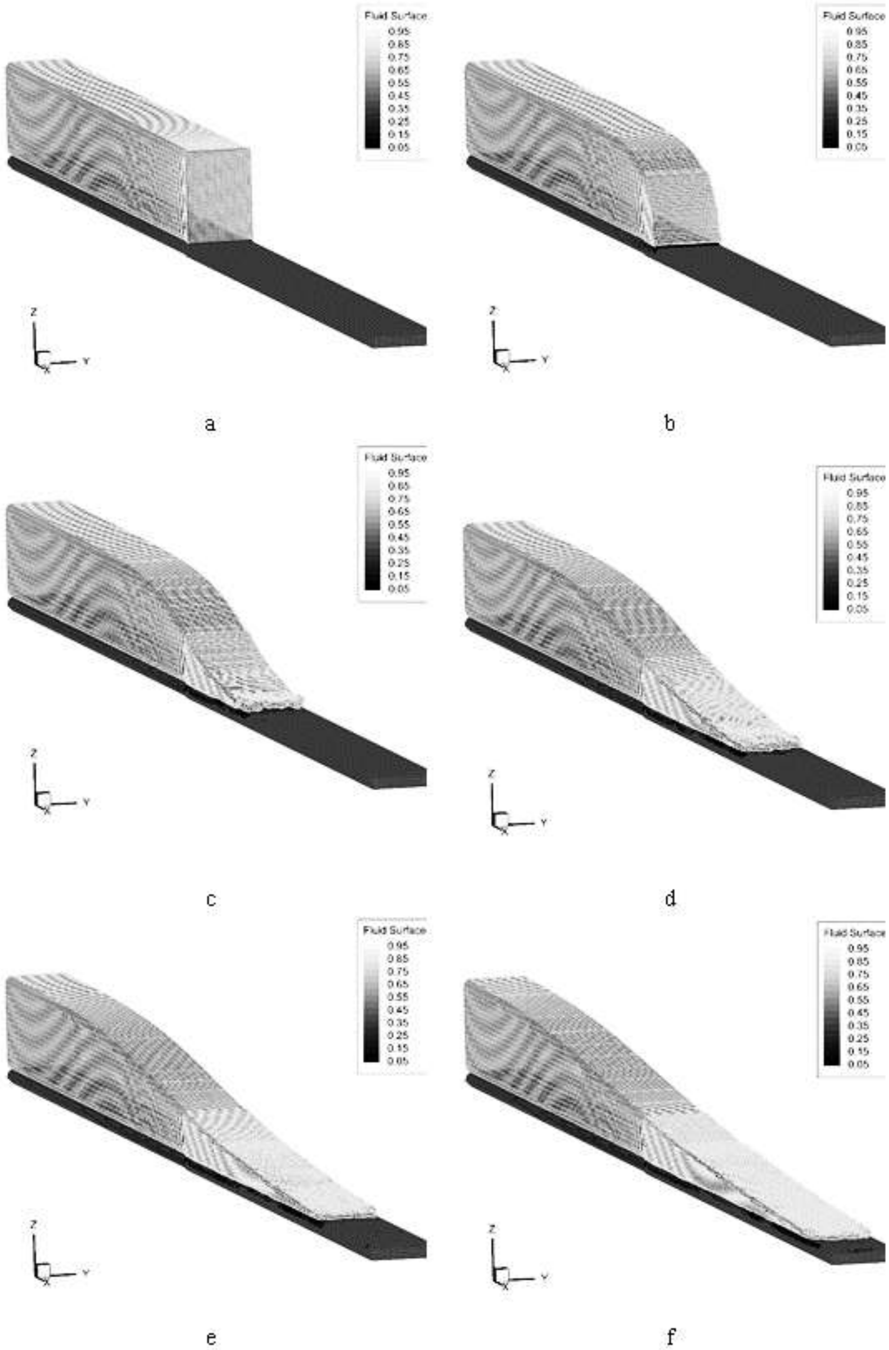


**Figure 1. The free surface evolution in *k-e* model**

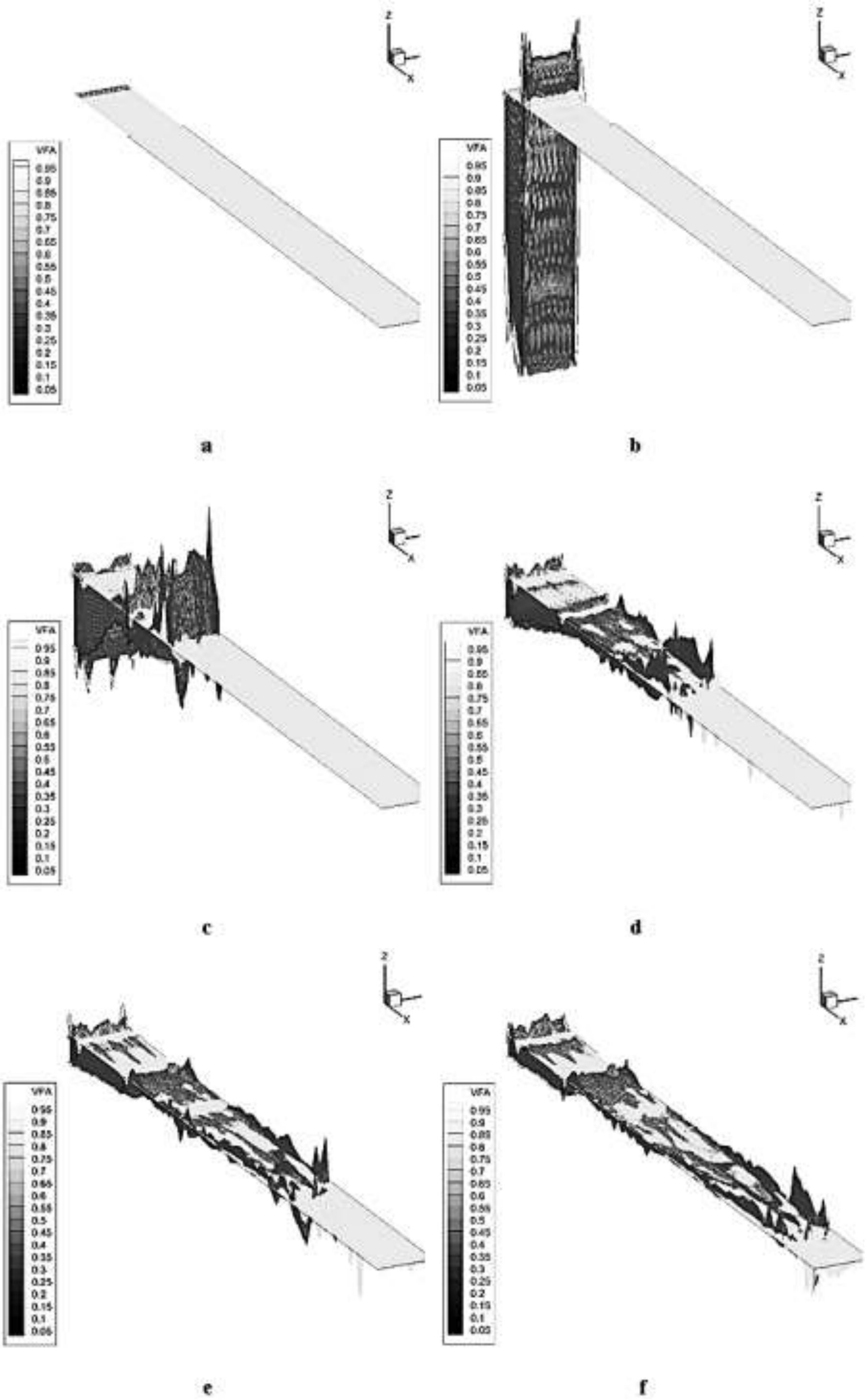
VFA
a
b
c
d
e
f

**Figure 2. Spatiotemporal variations of the z-component of the dam-break flow velocity in k-e model**

The dam-break free surface evolution was reproduced by both the RANS and LES 3D models. In contrast, the fluctuations of free surface were significantly high in SWE model during the wave propagation. Furthermore, the accurate results in SWE model acquired in higher mesh resolution than the 3D models. The dam-break wave was smoothly propagated over the downstream in 3D models. The free surface advancing distance was different in 3D and SWE models (Figure 1). The dam-break flow velocity increased significantly by wave evolution over the downstream. However, the highest vertical velocity values observed in the near field at the early stages. The flow was three-dimensional locally across the downstream channel (Figure 2). The LES model had the highest precision amongst the other 3D models.
The bed deformation, sediment transport and the severe scouring observed in the near field at the early stages. However, the maximum scouring depth and sediment transport rate were dependent on the bed-load transport models and selecting the turbulence models. It worth noting that the model performance in predicting the sediment transport rate was significantly lower than its performance in reproducing the free surface evolution.

## Conclusion

The dam-break wave evolution over the erodible bed was simulated using a CFD package. In this direction the performance of the two-dimensional SWE model and the 3D Navier Stokes models were compared in reproducing the free surface height and distance and the bed deformation. Overall, the 3D models, and LES amongst them, had highest accuracy in reproducing the free surface evolution and bed deformations compared to the SWE model. Furthermore, the 3D models need lower computational efforts in reproducing this phenomenon.

## References

Bahmanpouri, F., Daliri, M., Khoshkonesh, A., Montazeri Namin, M., Buccino, M. (2020). Bed compaction effect on dam break flow over erodible bed; experimental and numerical modeling. Journal of Hydrology, 594: 125645.

Banejad, H., Heydari, M. and Khoshkonesh, A. (2015). The comparison of the performance of single-equation models of turbulence kinetic energy and two ke equation models in hydraulic simulation of dam failure on the mobile, 15 December 2015, Kuala-Lumpur, Malaysia. http://civilica.com/doc/435910/.

Capart, H and Young, D. (1998) Formation of a jump by the dam-break wave over a granular bed. Journal of Fluid Mechanics. 372:165-187.

Flow Science (2012). FLOW-3D Documentation.

Heydari, M., Khoshkonesh, A. (2016). The Comparison of the Performance of Prandtl| Mixing Length, Turbulence Kinetic Energy, K-e, RNG and LES Turbulence Models in Simulation of the Positive Wave Motion Caused by Dam Break on the Erodible Bed. Indian Journal of Science and Technology, 9(7). 1-33.

Kelly Dodd N (2009) Floating grid characteristics method for unsteady flow over a mobile bed. Comput Fluids 38:899-909.

Khoshkonesh, A., Gohari, S. and Banejad, H. (2019). Numerical Study of the Effect of Floodplain Obstacles on the Flow Induced by Dam Break using MPS method. Journal of Water and Soil Conservation. 26(6): 119-138.

Khoshkonesh, A., Heydari, M., Ahmadi Dehrashid, F. (2021). Numerical study of the effect of mobile bed elevation on dam-break flood evolution. 19th Iranian Hydraulic Conference. 14 February 2021, Ferdowsi University of Mashhad, Mashhad, Iran. https://civilica.com/doc/1168051/

Khoshkonesh, A., Nsom, B., Bahmanpouri, F., Ahmadi Dehrashid, F., Adeli, A (2021). Numerical study the dynamic and structure of partial dam-break flow using VOF method. Water Resource Management, Springer, https://doi.org/10.1007/s11269-021-02799-2.

Khoshkonesh, A., Nsom, B., Gohari, S. and Banejad, H. (2019). A comprehensive study on dam break flow over dry and wet beds. Ocean Engineering (Elsevier), 188:106279. https://doi.org/10.1016/j.oceaneng.2019.106279.

Khoshkonesh, A., Heydari, M., Ahmadi Dehrashid, F. (2021). 3-D Numerical study of the air entrapment in dam-break over the mobile beds. 11th National Conference on Civil Engineering, Architecture and Urban Development. 12 March 2021, Mazandaran, Iran. https://civilica.com/doc/1133660/

Khoshkonesh, A., Banejad, H., Gohari, S., Ahmadi Dehrashid, F. (2020). Numerical study of two-dimensional Dam-break Flow over the dry and wet fixed bed using moving particles simulation (MPS) method The 10th National Conference on Environment, Energy and Sustainable Natural Resources, March 5th 2020, Tehran, Iran. http://civilica.com/doc/1040133/.

Khoshkonesh, A., Banejad, H., Gohari, S., Ahmadi Dehrashid, F. (2020). Comparison the performance of VOF, MPS and SPH methods on modeling the dam-break wave. The 10th National Conference on Environment, Energy and Sustainable Natural Resources, March 5th 2020, Tehran, Iran. http://civilica.com/doc/1040131/.

Khoshkonesh, A., Gohari, S., Banejad, H., Ahmadi Dehrashid, F. (2020). Comparison of the efficiency of MPS, MPS-DEM and VOF methods in simulation the dam-break flow over the fixed and mobile beds. The 10th National Conference on Environment, Energy and Sustainable Natural Resources, March 5th 2020, Tehran, Iran. http://civilica.com/doc/1040130/.

Khoshkonesh, A., Gohari, S., Banejad, H., Ahmadi Dehrashid, F. (2020). Evaluate the bed-resistance effect on dam-break flood. The 10th National Conference on Environment, Energy and Sustainable Natural Resources, March 5th 2020, Tehran, Iran. http://civilica.com/doc/1040129/.

Khoshkonesh, A., Gohari, S., Banejad, H., Ahmadi Dehrashid, F. (2020). Numerical study of the dam-break waves by two-dimensional weakly compressible smoothed particles hydrodynamic (WCSPH) method. The 10th National Conference on Environment, Energy and Sustainable Natural Resources, March 5th 2020, Tehran, Iran. http://civilica.com/doc/1040132/.

Khoshkonesh, A., Ahmadi Dehrashid, F., Gohari, S., bajelvand, S. (2020). Numerical modeling of dam-break on erodible bed by volume of fluid method. The First National Conference on Mathematical Modeling and Computational Methods in Science and Engineering, University of Eyvanekey, Semnan, Iran. http://civilica.com/doc/1012707/.

Khoshkonesh, A. and Banejad, H. (2017). Froudian analysis of dam-break unsteady flow over the dry fixed bed. Proceedings of 2nd national conference on new findings of research and educational developments, Iranian urban and environmental architecture, Tehran, Iran. http://civilica.com/doc/689850/.

Khoshkonesh, A. and Banejad, H. (2017). The sensitivity analysis of Theoretical relationships in calculation the unsteady rapid flow energy loss. Proceedings of 2nd national conference on new findings of research and educational developments, Iranian urban and environmental architecture, Tehran, Iran. http://civilica.com/doc/689849/.

Khoshkonesh, A. and Banejad, H. (2017). The Simulation of the positive wave induced by dam-break over the dry fixed bed. Proceedings of 2nd national conference on new findings of research and educational developments, Iranian urban and environmental architecture, Tehran, Iran. http://civilica.com/doc/689852/.

Khoshkonesh, A., Banejad, H. and Heydari, M. (2015). Simulation of dam-break flow over the mobile bed using RANS equations. International conference on science and engineering, 1st December 2015, Dubai, UAE. http://civilica.com/doc/425017/.

Khoshkonesh, A. and Banejad, H. (2015). Comparison of the performance of turbulence models of Prandtl mixing length and turbulence kinetic energy in simulating dam break over the movable bederodible bed. 10th international River Engineering conference 19-21 Jan 2016, Shahid Chamran university, Ahwaz, Iran. http://civilica.com/doc/677051/.

Nsom B, Debiane K, Piau J (2000) Bed slope effect on the dam break problem. Journal of Hydraulic Research. 38:459-464.

Nsom B (2002) Horizontal Viscous Dam—Break Flow: Experiments and Theory. Journal of Hydraulic Engineering- ASCE, 128:543-546.

Nsom B, Jenny M, Askoura Y, Peron F (2007) Numerical Solution to Horizontal Zero-inertia, Viscous Dam-Break Problem. Innov Adv Tech Comput Inf Sci Eng 123-128.

Nsom, B., Latrache, N., Ramifidisoa, L. and Khoshkonesh, A. (2019). Analytical Solution to the Stability of Gravity-driven Stratified Flow of Two Liquids over an Inclined Plane. 24ème Congrès Français de Mécanique, Brest, 26 au 30 Août 2019. Pritchard, D. and Hogg, A.(2002) On sediment transport under dam-break flow. Journal of Fluid Mechanics.

Pritchard D, Hogg A (2002) On sediment transport under dam-break flow. Journal of Fluid Mechanics.

Spinewine B (2005) Two-layer flow behaviour and the effects of granular dilatancy in dam-break induced. Dissertation. University of Luvain, Belgium