# LOCAL SCOUR ANALYSIS AROUND SINGLE PIER AND GROUP OF PIERS IN TANDEM ARRANGEMENT USING FLOW 3D

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## ABSTRACT

Along with collisions and overloading, scouring near the bridge piers is thought to be amajor reason for the bridge collapse. It leads to a large number of deaths and economic losses.To predict the scour depth, Flow-3D was used in this study. Using Flow-3D, simulation ofclear-water local scour around a cylindrical-shaped single pier has been done. Simulation for a group of piers (3 piers) in tandem arrangements has also been done.Flow-3D is a CFD (Computational Fluid Dynamic) software. The purpose of the study is to compare the numerical simulation findingsto the previous laboratory experiment. In this study, two different pier diameters 5.08 cm and 3 cm were selected during the simulation for single and tandem pier arrangements, respectively. During numerical simulation of the single pier, sediment density, median grain size, and angle of repose were selected as 2650kg/m$^3$, 0.385mm, and 32$^0$, respectively. In the tandem arrangement, sediment density, and median grain size were selected as 2640kg/m$^3$, and 0.70mm respectively. The tandem pier arrangements were constructed in a way where the upstream pier was placed at the center of the channel. The simulations were carried out using a pier spacing of 3d (d= diameter of the pier). A Uniform mesh size of 10mm was chosen for the single pier simulation, whereas, for the tandem arrangements, a total of 150,000 cells were used. Velocity and depth of flow were selected as 0.25m/s and 0.15m respectively for the single pier simulation, whereas, for the tandem arrangement flow rate and depth of flow were selected as 6.0 l/s and 0.12m respectively. The simulations were conducted following the experimental runs duration and the results of the simulation were compared to those of the experiment. Finally, the overall performance of the simulation results in determining the pier scour depth was analyzed using the Flow-3D model.

***Keywords:****Single pier, Tandem pier, Scour, Flow-3D*

## 1. INTRODUCTION

Scouring can be defined as the removal and erosion of bed material from near bridge piers and abutments due to the action of flowing water (Breusers et al., 1977). Different variables that influence this process are the flow, pier, and sediment characteristics. Scour can be divided into three major forms named general scour, contraction scours, and local scour.General scour occurs in the river bed naturally by aggregation and degradation. The construction of water structures reduces the cross-sectional area of the channel. This reduction causes a contraction to scour. Local scour occurs around bridge piers and abutments.

Among these, local scour is considered the most important phenomenon as it plays the most important part associated with the pier scour. Along with collisions and overloading, scouring is thought to be one of the main reasons the bridge collapsed, resulting in a large number of deaths and significant economic losses (Shepherd & Frost, 1995). On average, erosion of the bridge foundations causes at least one severe bridge failure each year. So proper analysis of pier scour is of utmost importance for the safety of the bridge (Melville & Coleman, 2000).

To estimate the scour depth at the base of piers, several studies have been conducted. Those investigations were carried out mostly through laboratory flume experiments. In those studies, dimensionless equations have been used. That eventually lead to certain semi-empirical formulae for maximum scour depth (Ataie-Ashtiani & Aslani-Kordkandi, 2012). The majority of these studies are focused on the single pier. Pile groups and complex piers have become popular in bridge design for geotechnical and economic reasons (Coleman, 2005). To apply the results derived from the single pier, in the case of a group of piers is problematic (Landers & Mueller, 1996).

Besides the laboratory flume experiments, the three-dimensional simulation method of scouring has grown in popularity as computer and software capabilities have increased, allowing for greater use of computational fluid dynamics (Jalal & Hassan, 2020). Users can use Flow-3D to a wide range of fluid flows and heat transfer phenomena due to the combination of physical and numerical options, and to solve various hydraulic problems (*FLOW-3D User Manual*, n.d.). For example, FLow-3D was used by (Richardson & Panchang, 1998) to simulate the flow that occurs within a scour hole at the base of a circular bridge pier. Besides, (Vasquez & Walsh, 2009) simulated local scouring in complicated bridge piers under tidal flow using a numerical model. The use of CFD (Computational Fluid Dynamics) software is similar to setting up an experiment, but it has more advantages as it replaces the design and construction of physical models. Numerical simulations can easily be used instead of complicated physical models which are difficult to set up in the laboratory. Flow-3D is a CFD software that solves fluid motion equations numerically to obtain transient, three-dimensional solutions to multi-scale, multi-physics flow problems. In this study, Flow-3D will also be used to simulate local scour around a single pier and group of piers in tandem arrangement.

## 2. METHODOLOGY

To develop the pier scour model in Flow-3D, in the model setup tab necessary information regarding the model has been provided. That information includes finish time, necessary physics, information related to the fluid in concern, the geometry of the model, meshing parameter, and selection of desired output. Then the model has been simulated. After the simulation of the model, necessary output regarding the local scours around the pier has been obtained. Those outputs are then analyzed with the laboratory experiment of previous works. Figure 1 represents the schematic diagram of the overall procedure.

### 2.1 Single Pier

For single pier arrangement, in this study, Melville experimental data has been used (Melville, 1975). The pier diameter was 5.08 cm. The total length of the channel has been selected as 1.16m where the initial 0.16 m isan inlet (solid component) and the rest of the 1 m is a packed sediment bed. The width of the channel has been selected as 45.6 cm. Packed sediment bed is composed of sediment with a mean diameter of 0.385 mm and sediment density of 2650 kg/m3. The depth of the packed sediment bed is 12.7 cm. Other information related to the packed sediment bed has been kept as default, where critical shield number is 0.05, entrainment coefficient is 0.018, bedload coefficient is 13, and angle of repose is 320.

The mesh size for the model has been selected as 10mm. Finer mesh would produce a better result but due to computational limitations finer mesh below 10mm couldn't be used. The boundary condition at upstream was specified velocity (velocity= 0.25 m/s & fluid elevation= 0.15 m). At downstream the boundary condition was outflow, at the bottom boundary condition was the wall. In the other 3 side boundary condition has been selected as symmetry. The developed model has been simulated for 30 min (1800 sec) using two initial flow conditions (with initial water level 0.15m & without initial water level). Figure 2 represents the developed model in Flow-3D for a single pier.

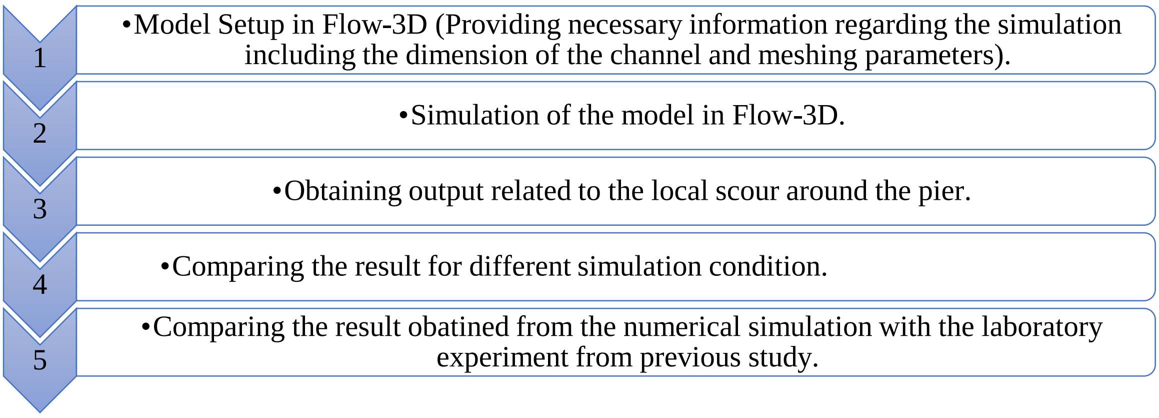


Figure 1: Schematic diagram of the overall procedures.

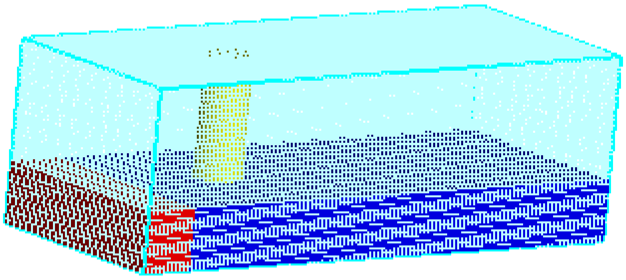

Figure 2: Developed model in flow-3d for single pier.

## 2.2 Group of Piers in Tandem Arrangement

For the group of piers in a tandem arrangement, in this study,Wang's experimental data has been used (Wang et al., 2016). Three piers of diameter 3.0 cm have been used. The spacing between the piers has been selected as 3d (d= pier diameter). The total length of the channel has been selected as 7 m where the initial 1 m is an inlet (solid component) and the rest of the 7 m is a packed sediment bed. Packed sediment bed is composed of sediment with a mean diameter of 0.7 mm and sediment density of 2640 kg/m3. The depth of the packed sediment bed is 15 cm.Other information related to the packed sediment bed has been kept as default, where critical shield number is 0.05, entrainment coefficient is 0.018, bedload coefficient is 12, and angle of repose is 320.

In this model, instead of cell size, cell counting has been chosen due to computational limitations. A total of 200,000 cells has been selected for meshing. Finer mesh would produce a better result but due to computational limitations finer mesh couldn't be utilized. In vertical directions, the total number of layers was 19. The boundary condition at upstream was specified velocity (velocity= 0.135 m/s & fluid elevation= 0.12 m). At downstream the boundary condition was outflow, at the bottom boundary condition was the wall. In the other 3 side boundary condition has been selected as symmetry. The developed model has been simulated for 40 min (2400 sec) using noinitial flow condition. Figure 3represents the developed model in Flow-3D for a single pier. Table 1 represents the values of different parameters used to develop the model and for simulating the model.

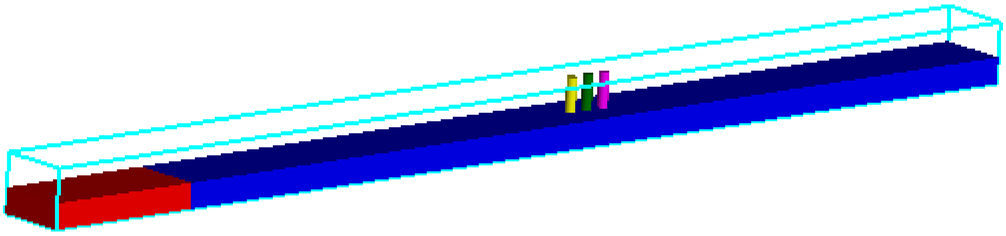

Figure 3: Developed model in flow-3d for group of piers in tandem arrangement.

Table 1: Values of Different Parameters Used for Model Development & Simulation

| Parameter Name | Single Pier | Group of Piers |
|---|---|---|
| Finish Time | 1800 seconds | 2400 seconds |
| Sediment Diameter | 0.385 mm | 0.7mm |
| Sediment Density | 2650 kg/m$^3$ | 2640 kg/m$^3$ |
| Pier Diameter | 5.08 cm | 3.0 cm |
| Packed Sediment Depth | 12.7 cm | 15 cm |
| Channel Length (Including Inlet) | 1.16 m | 7.00 m |
| Flow Velocity | 0.25 m/s | 0.135 m/s |
| Flow Depth | 0.15 m | 0.12 m |
| Cell Size/Cell Count | 10 mm | 200k |

## 3. ANALYSIS & RESULTS

### 3.1 Single Pier

#### 3.1.1 With Initial Flow Depth of 0.15 m

For a single pier arrangement, the maximum depth of scouring after 1800 sec around the cylindrical pier has been obtained as 2.1 cm in Flow-3D, which has been shown in Figure 4. Temporal variation of scour depth has also been obtained in Flow-3D for an initial water depth of 0.15 m, which has been shown in Figure 5.

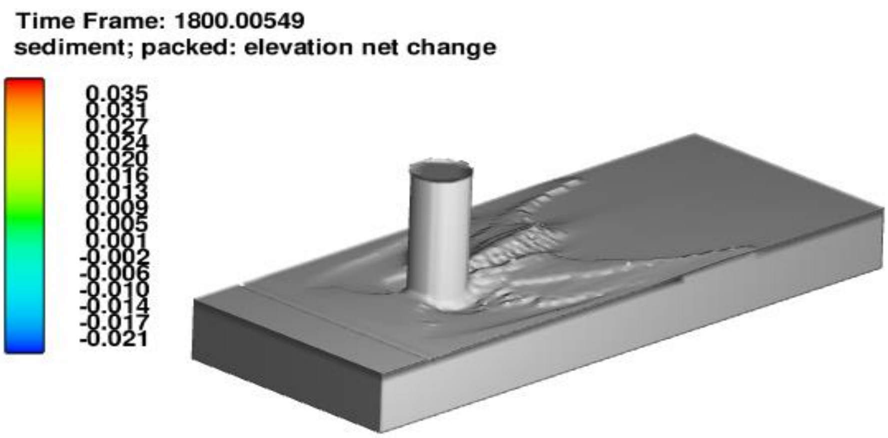


Figure 4: 3D Image of maximum sour around single pier

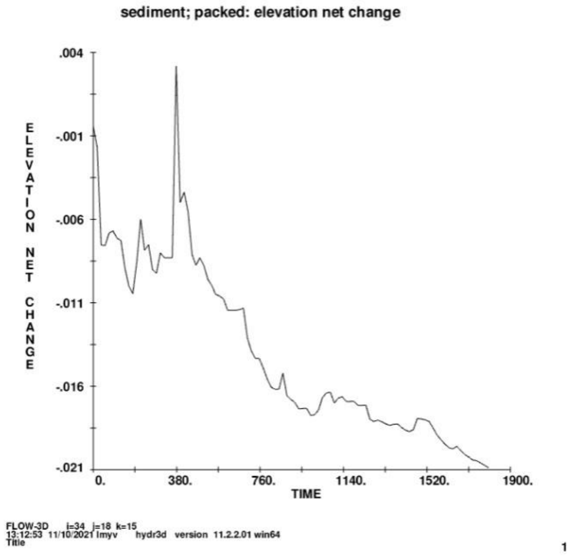


Figure 5: Elevation net change with time.

A contour map of scouring around the pier has been prepared using ArcMap 10.3 which has been shown in Figure 6.

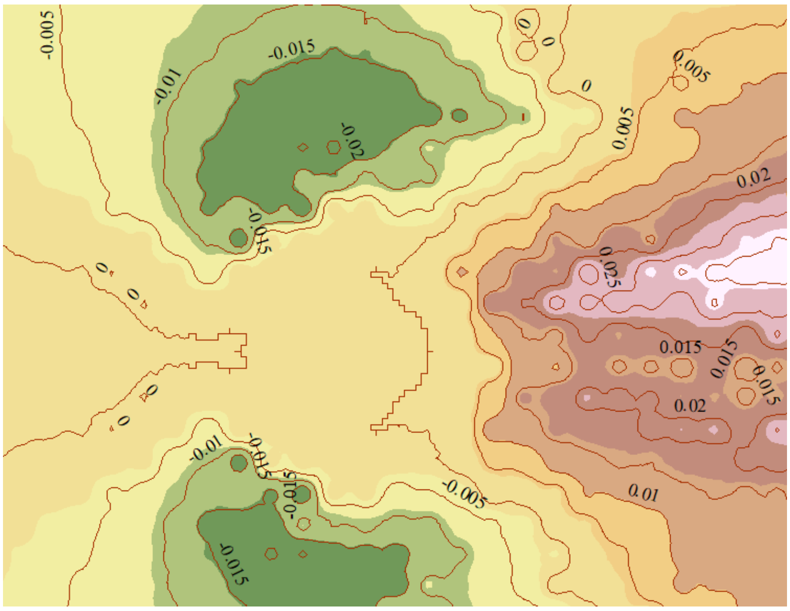


Figure 6: Contour map of scouring around the pier (unit in m)

Figure 7 represents the variation of depth along the X-Z plane around the pier. From which, it has been clearly visible that, near the upstream of the pier the depth has increased up-to 19.11 cm and in the downstream the depth has been decreased to 14.90 cm. Where the depth of flow at the beginning of the simulation was 15 cm. Figure 8 represents the velocity vector around the single pier in X-Y plane.

### 3.1.2 No Initial Flow

When there is no initial flow in the channel, the value of maximum scours depth is expected to increase compared to the initial flow condition, as the initiation of water flow will cause the bed load transport at a higher rate. Figure 9 represents the 3-D image of the packed sediment bed after 1800 seconds of simulation without initial flow condition. The maximum depth of scouring is 5.5 cm. Temporal variation of scour depth has also been obtained in Flow-3D for no initial flow condition. Figure 10 represents the temporal variation of scour depth.

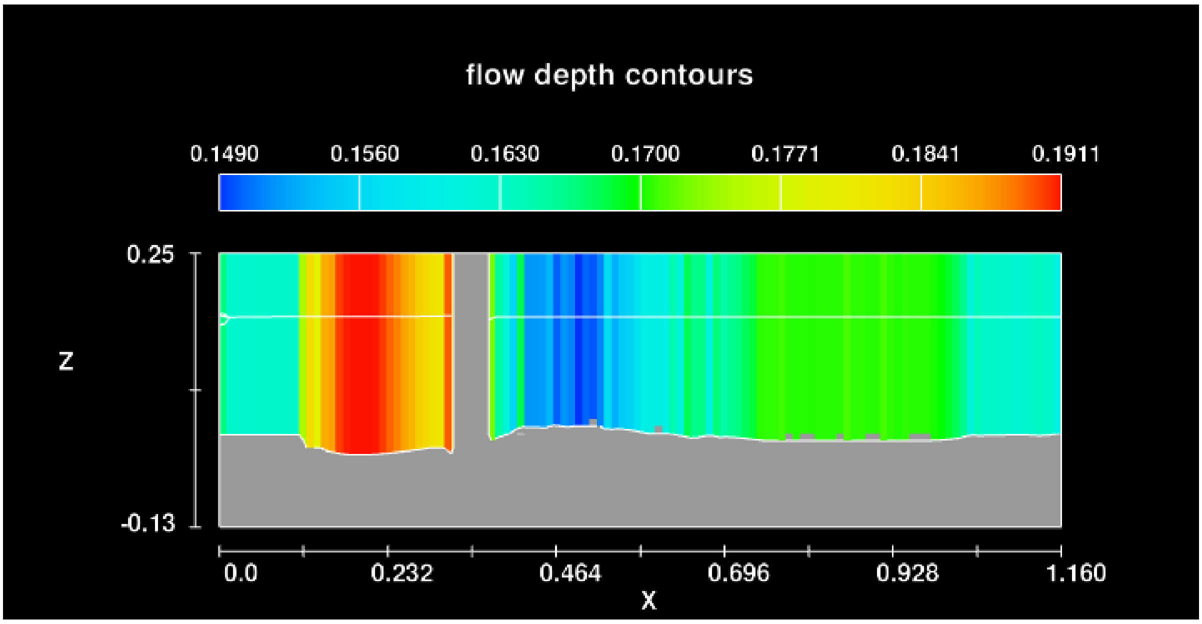


Figure 7: Variation of depth of flow around the pier (X-Z plane)

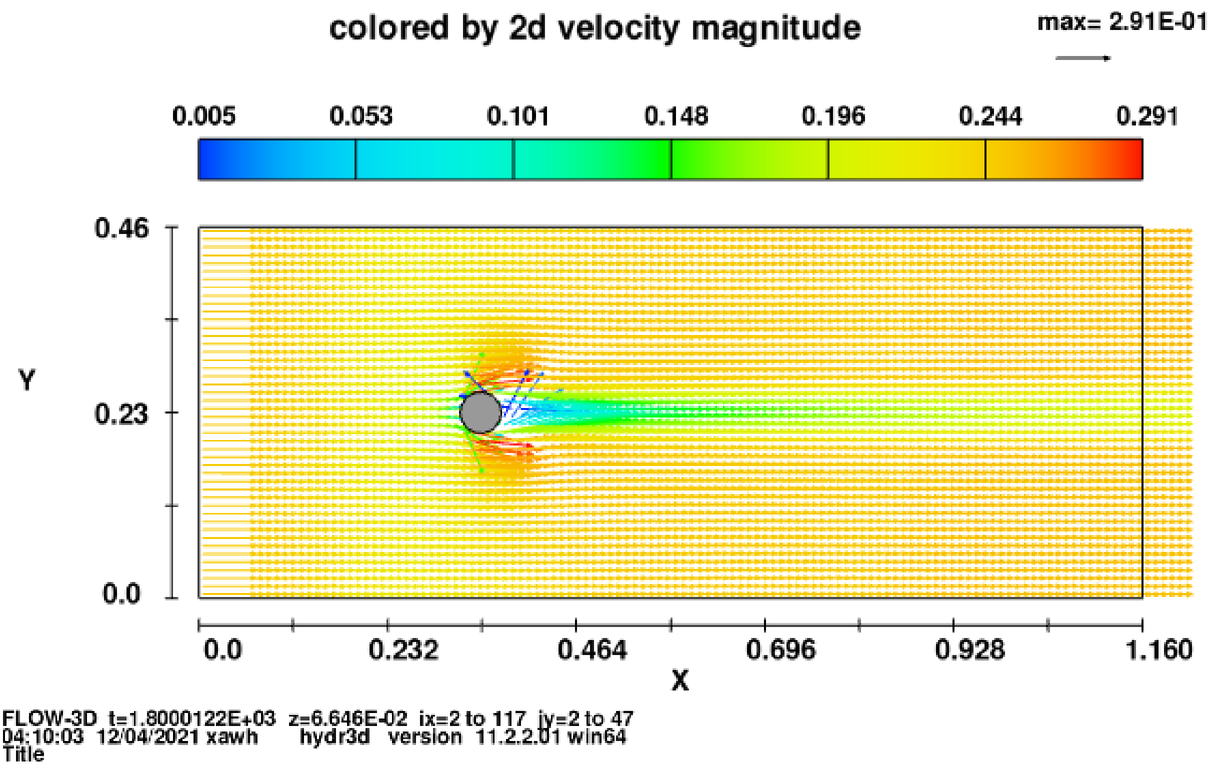


Figure 8: Velocity vector around single pier in X-Y plane.

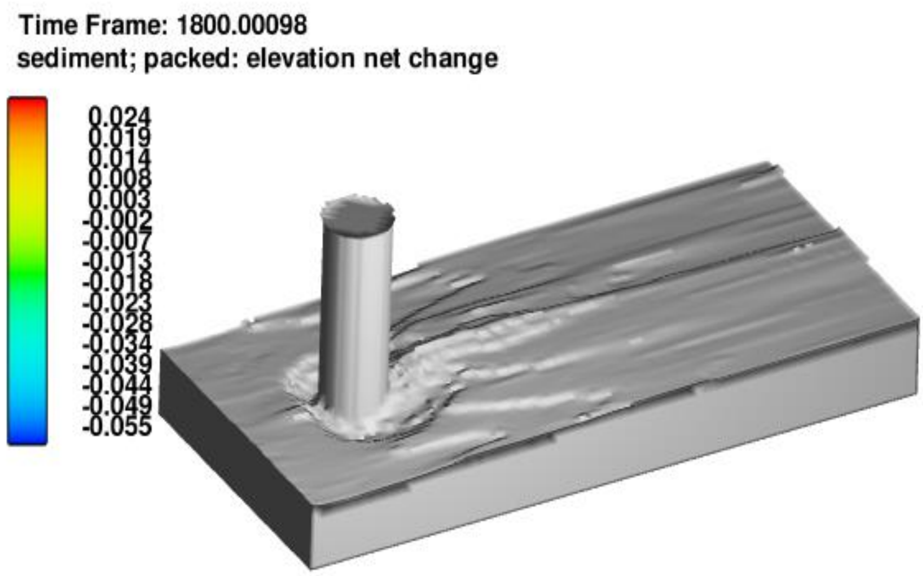


Figure 9: 3D maximum sour around single pier (no initial flow)

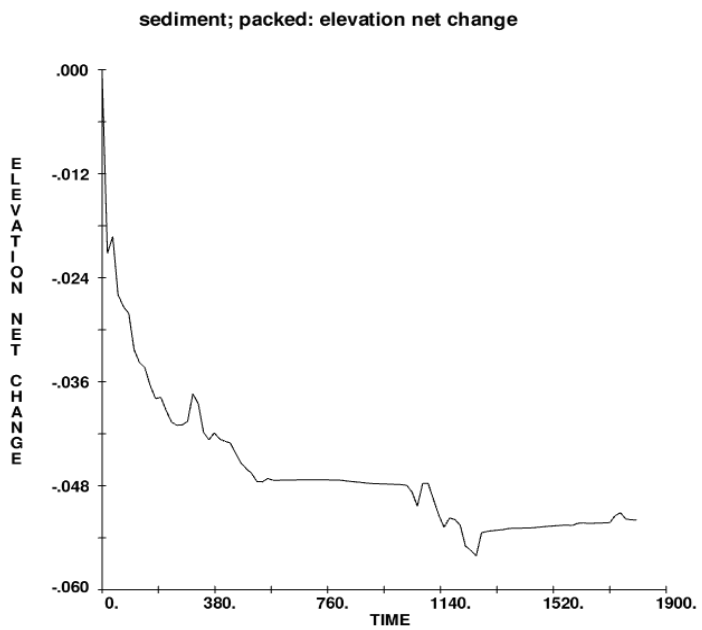


Figure 10: Elevation net change with time.

### 3.1.3 Comparison With Melville Laboratory Experiment

From the Melville laboratory experiment it has been found that, after 1800 sec, for the same single pier configuration, the value of maximum scour depth is about 4.0 cm (Melville, 1975). Whereas, in Flow-3D simulation, the value is obtained as 2.1 cm. Due to computational limitations, in this study finer mesh size (less than 10mm) can't be used, so the deviation between the simulation and laboratory experiment is higher. Besides, some sediment parameter has been kept default which also contributes to this deviation.

In Table 2, a comparison of maximum scours depth between initial flow (flow depth=0.15m) and no initial flow condition has been shown

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Table 2: Comparison of maximum scour for single pier

| Maximum Scour Depth | Initial Flow Depth of 0.15 m | No Initial Flow | Increase of Scour Depth in No Initial Flow Condition | Melville Experiment |
|---|---|---|---|---|
| | 2.1 cm | 5.5 cm | 61.8% | 4.0 cm |

### 3.2 Group of Piers in Tandem Arrangement

In this study, three piers of tandem arrangement with pier spacing 3d (d=diameter of pier) have been simulated for scour analysis in Flow-3D. The maximum scour depth in equilibrium condition has been obtained as 0.01m (1cm). Which agrees with the Wang (Wang et al., 2016) laboratory experiment for the same configuration. Figure 9 represents the 3D image of the scouring around group of piers obtained from the Flow-3D simulation. Figure 10 represents the velocity vector in X-Y plan around the tandem piers arrangement.

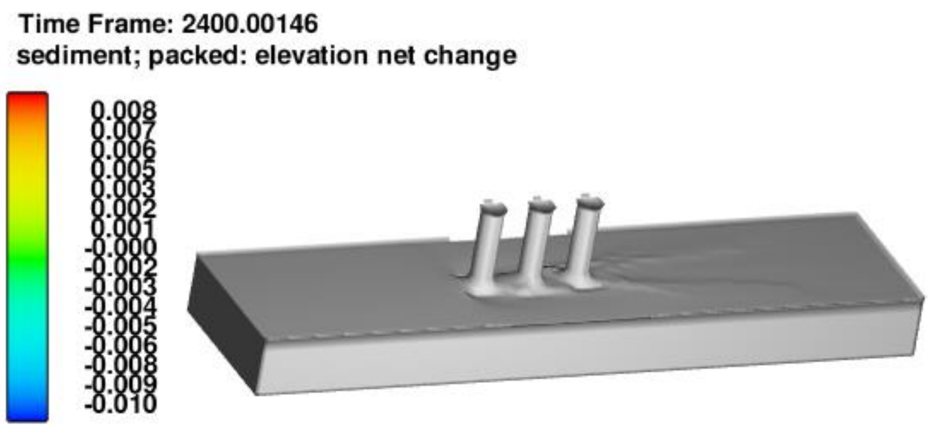


Figure 9: 3D image of maximum sour around group of piers (no initial flow)

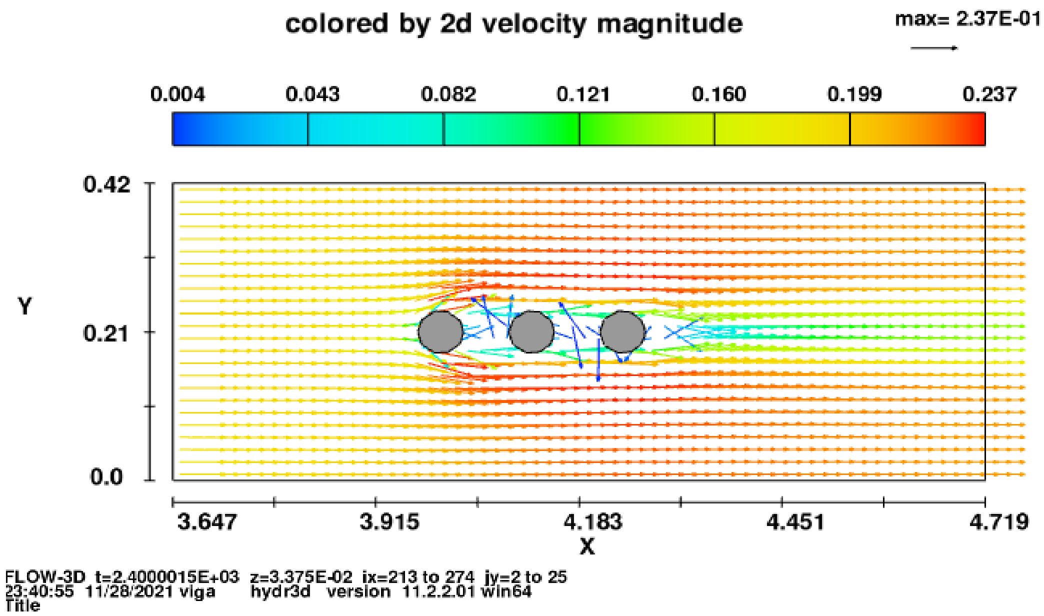


Figure 10: Velocity vector in x-y plane around group of piers in tandem arrangement

## 4. CONCLUSIONS

In this study, local scour around piers has been simulated in Flow-3D. This simulation has been conducted both for a single pier and a group of piers. For single piers, two flow conditions have been considered during local scour simulation. With an initial flow depth of 0.15m, the maximum scours depth after 1800 sec has been obtained as 2.1 cm. And in case of no initial flow, the maximum scour depth has been obtained as 5.5 cm. During no initial flow, condition scours depth has been increased due to the higher bed material transfer rate at the beginning of the flow. Both of the simulations for a single pier have shown deviation from the laboratory experiment result of Melville. Limited computational capabilities may be one of the major contributors to this deviation, as in this study, finer mesh size can't be used. For the group of piers in tandem arrangement maximum depth of scour around the piers has been obtained as 0.01m (1cm), which agrees to the result obtained from Wang's laboratory experiment.

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