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# Prediction of Local Scour Rate around Bridge Piers Using SSIIM Model

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## Abstract

Scouring around bridge piers phenomena are studied by several researchers. They proved that SSIIM (Sediment Simulation In Intakes with Multi-block option) model is a powerful tool in predicting local scour around rectangular piers for clear water scour. The main objective of this paper is to verify SSIIM model in predicting the local scour for live bed and clear water scour around bridge piers. Also, it covered prediction of scour for circular and rectangular piers with different sizes. In addition the predicted scour rate was compared with the scour rate obtained from experimental results by Sharafaddin A.A.S. (2003). All results were represented in curves. These curves showed good agreement between the predicted values by SSIIM and the experimental results. Moreover, the final scour values were in a good agreement with the values calculated by the most famous scour equation

***Keywords:*** *Local Scour; Scour Rate; SSIIM; Numerical model; k–ε Turbulence model; CFD.*

## 1. INTRODUCTION

Prediction of local scour has been extensively studied by river engineers since last century. Most of the provided researches were concentrated on the experimental studies and field measurements. Numerical studies used in prediction of scour around bridge piers and at abutments have been studied by researchers in the last decade due to the rapid increase in computers speeds and capacities. The advantage of predicting the scour around bridge piers using numerical models is that it will not be affected by the scale effect as the prototype can be studied directly as done by [2] where a numerical model for scouring around bridge piers crosses the Tanana river have been studied.

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A pioneer study have been done by [3] and [4], where steady and unsteady Navier-Stokes equations have been coupled with sediment transport calculations to predict the scour around circular pier for clear water condition.

SSIIM numerical model have been used by [5], [6] and [7] to predict the local scour around bridge pier for different pier shapes, the study proves that the scour depths are agree to some extent with the flume results. [8] proved that roughness coefficient is inversely proportional to the discharge when fixing the bed material and water level. In the current paper the ability of SSIIM to predict local scour depths for clear and live bed scours will be investigated and verified with the experimental results and equations.

## 2. SSIIM MODEL

### 2.1. Model Theoretical Bases

In this section the theoretical bases of the used numerical model are presented, SSIIM is a noncommercial program developed by Professor Nils B Olsen at NRNU; for research activities. SSIIM solves the Navier-Stokes equations with the k-ε model for a rectangular grid in the three-dimensional. The main advantage of SSIIM is its ability of modelling sediment transport with movable bed in a complex geometry. One of the disadvantages of the model is that it hasn't a technical support and it does not have an input graphical user interface. More details about the methods and equations used in the program can be found in the program manual prepared by [3].

### 2.2. Numerical Model Geometry and Properties

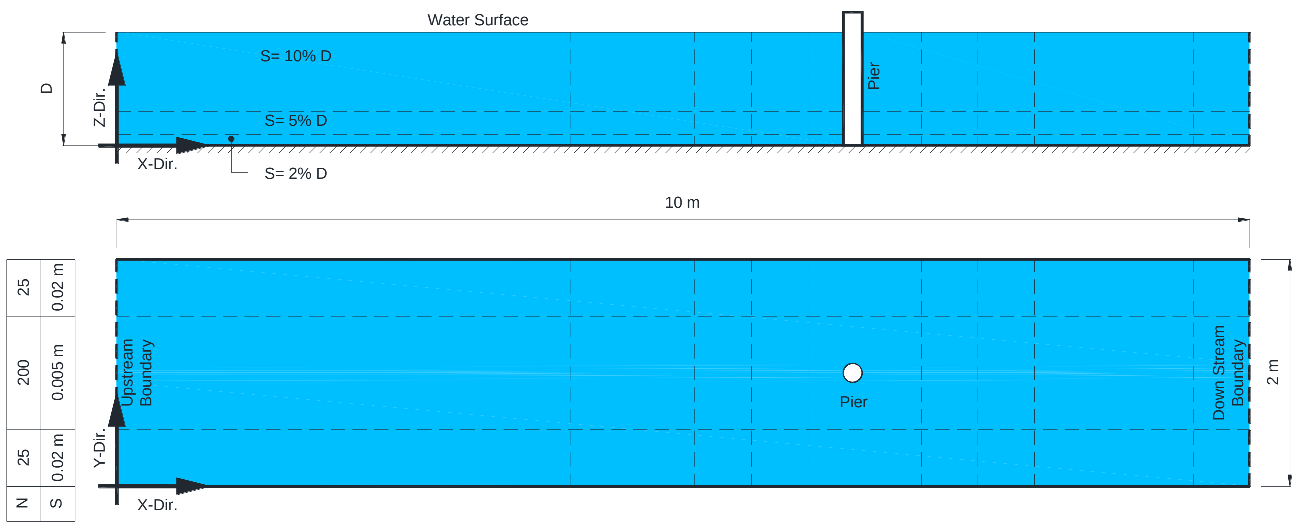
The Numerical model in the current paper was verified with the experimental results conducted by [1] at Hydraulic Laboratory of Cairo University, Giza, Egypt. A large scale rectangular type flume with dimension of 21.0m long, 2.0m width and 0.9m depth was used in the experimental work. This flume was built from red bricks blocks with a plain concrete bed and six glass widows of 10 mm thick glass installed through the side walls at the test area. The numerical model was done only for 10.0m which represents the test area.

In order to keep the number of grid in an acceptable range, and irregular distribution of grids as shown in Figure (1) was preferred where a finer grid were adopted in the vicinity of piers while a coarser grids were used outside the study area. The structured three dimensional grids used in the Numerical Model are as follows:

**X-direction:** The total numbers of 350 cells represent a total length of 10.0m; the grids were distributed from upstream of the model to the downstream as 4 cells with size of a 1 m, 11 cells with a 0. 1m size, 10 cells with a 0.05m size, 50 cells with a 0.01m size, 200 cells with a 0.005m size, 50 cells with a 0.01m size, 10 cells with a 0.05m size, 14 cells with a 0. 1m and 1 cell with a 0.5 m consequently.

**Y-direction:** The total numbers of 250 cells represent a total length of 2.0m; the grids were distributed as 25 cells with size of 0.02 m, 200 cells with a 0.005m size and 25 cells with a 0.02m size consequently.

**Z-direction:** In this direction the finer grids was used near the flume bed and coarser towards the water surface. The cells were distributed as a percentage from the total depth as 5 cells with 2% height of the water depth, 4 cells with 5% of the water depth, and 7 cells with 10% of the water depth.




| Number of Grids (N) | 4 | 11 | 10 | 50 | 200 | 50 | 10 | 14 | 1 |
|---|---|---|---|---|---|---|---|---|---|
| Cell Size (S) | 1.00 m | 0.10 m | 0.05 m | 0.01 m | 0.005 m | 0.01 m | 0.05 m | 0.10 m | 0.50 m |

Figure (1) Numerical model grids layout

### 2.3. SSIIM Model Inputs

In the main input file (control file) of SSIIM, the user should prepare the different data blocks before commencing of calculations. The main data blocks are related to geometry, sediment sizes, calculation parameters and boundary conditions. In the boundary conditions, initial water level at upstream boundary should be defined in addition to the discharge. One of the most important boundary conditions is making a zero gradient at the downstream to prevent instabilities in model. Time step and roughness should be calibrated in order to get results closer to the experimental results.

### 2.4. Models Program

The mathematical model used in the current study has been validated by [9], where rectangular piers under a clear water scour condition were used. The current study will be validated for clear water scour and live bed scour, in addition rectangular and circular pier shapes will be used.

In order to calibrate the numerical model, three different flow conditions were used, as described in Table (1), the data presented are extracted from the experimental work of [1], circular pier of diameter 100mm was used in calibration process. Water depth of 200mm have been considered for all cases

**Table (1):** Flow Conditions Used In Calibration

| | Pile Shape | Pile d or b (cm) | Discharge Q (m3/s) | Fr | Time (Hrs.) | Scour Type |
|---|---|---|---|---|---|---|
| Run 5 | Circular | 10 | 0.12 | 0.21 | 45[Note 1] | Clear Water |
| Run 6 | Circular | 10 | 0.16 | 0.28 | 12 | Live Bed |
| Run 7 | Circular | 10 | 0.18 | 0.32 | 12 | Live Bed |

**Note 1:** only 12 hours have been modeled to reduce the total computational time.

### A. Time Step Calibration

A fixed time step of 20 seconds have been used in all models used in calibration and verification of model, this time step have been selected after many trials, the main criteria used in selection of time step are the compatibility of model results with the experimental results and the total computation time.

### B. Roughness Calibration

In order to get the optimum roughness value for different flow conditions fifteen trial runs have been computed using many values of roughness. For clear water scour condition, three different values of roughness have been used in validation process 0.0072, 0.0099 and 0.0157. While for live bed conditions, six different values have been tested, the values were ranging from $0.8d_{50}$ to $3d_{50}$, the used values are 0.0042, 0.0052, 0.0062, 0.0072, 0.099 and 0.0157 respectively.

Computer with Intelcore I5, 2.4 MHz and 8 GB RAM have been used in analysis of the data presented in this paper, the computation time was ranging from 8 to 11 hours. It was noted that the time of computation increases by decreasing the time step and increasing the number of sediment groups.

## 3. RESULTS AND DISCUSSION

### 3.1. SSIIM Calibration

The scour rate is an important parameter in the model verification, the scour depth progress have been recorded at each time step until the end of the total experiment time. A comparison between the predicted and recorded values has been plotted tighter as indicated in Figures (2-4).

Figures (2-4) represent the time rate of scour for different roughness values. It can be concluded from these figures that the optimum roughness values are 0.0157, 0.0062 and 0.0042 for Froude numbers of 0.21, 0.28 and 0.32 respectively. The estimated bed roughness is inversely proportional to the discharge as previously approved by M.M. Ibrahim, et al. (2014). The difference between the experimental work and the predicted scour values by SSIIM are 5.16%, 0.10% and 4.44% respectively which is a very good agreement with the experimental results.

It is clear from Figure (2) that the time rate of scour at the beginning of scouring process are almost the same as the experimental readings which is a very good indication that the used time step as long as the selected roughness are optimum. Whereas Figure (3) and Figure (4) shows that for live bed scour cases, the scour rate are not similar to the experimental readings in the beginning of process. This can be adjusted by reducing the time step, however in the study the time step will be fixed value as the concern is to have an agreement with the final scour value, and in addition this will help in reducing the computation time.

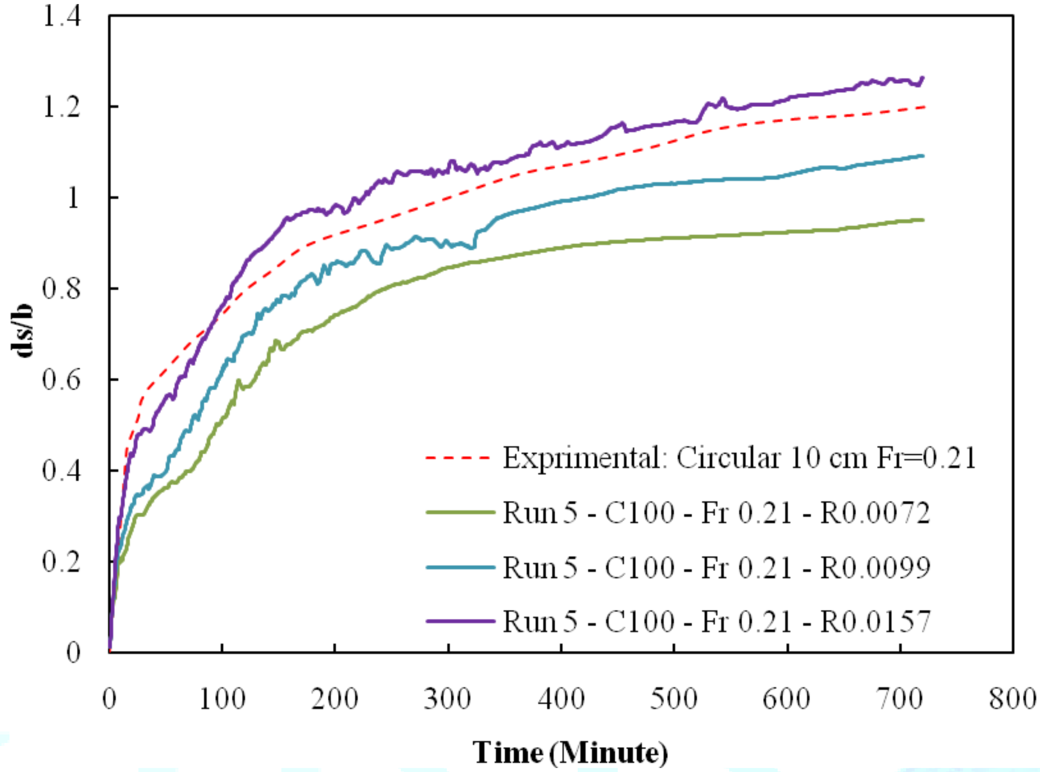



Figure (2) Time Rate for Run No. 5

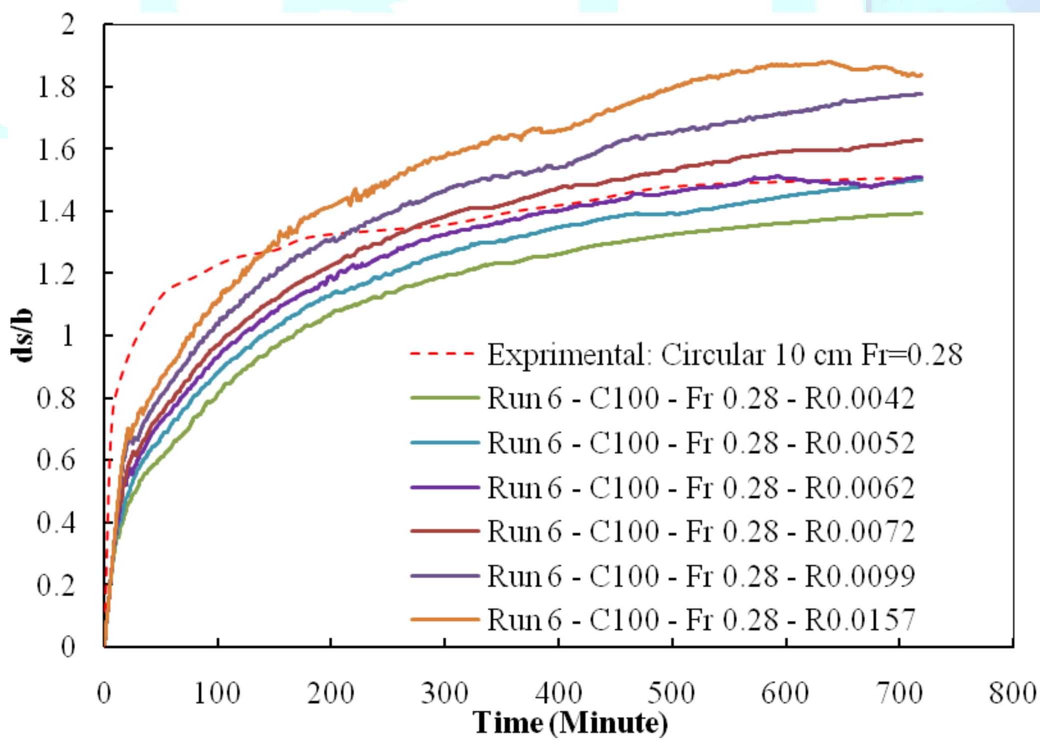


Figure (3) Time Rate for Run No. 6

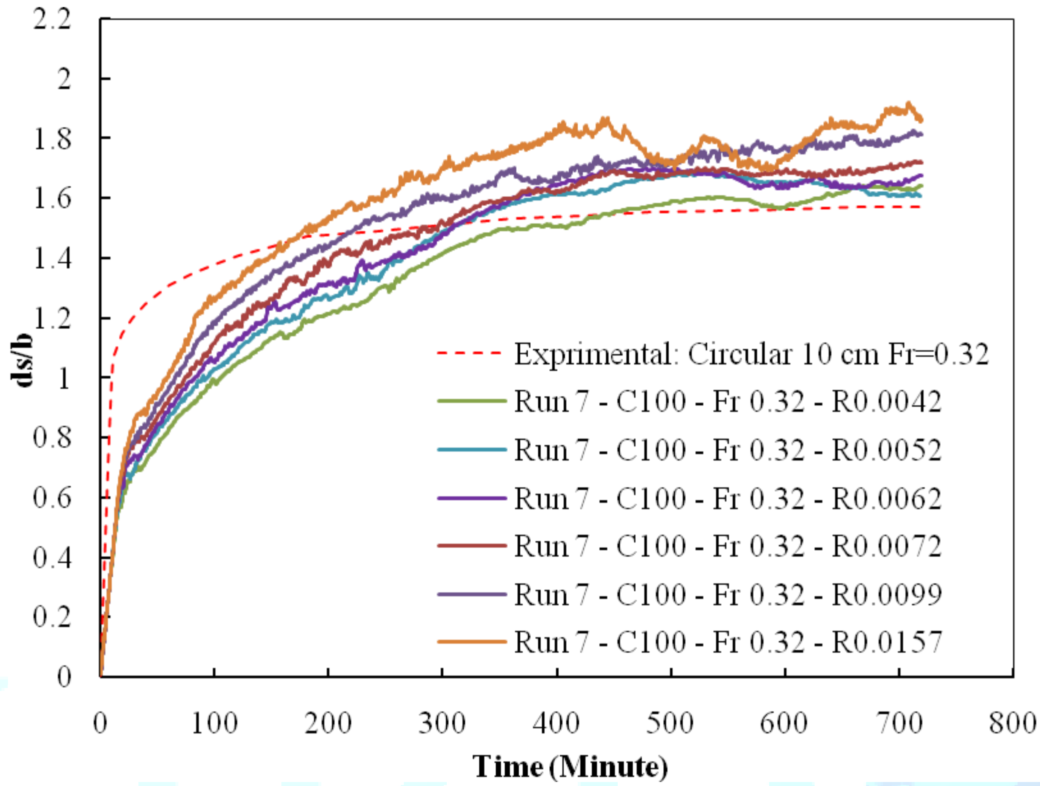



Figure (4) Time Rate for Run No. 7

The three Figures reports that the scour rate is higher due to the strong effect of horse shoe vortex at the initial stage, while in later stages when the scour hole become deeper the horse shoe vortex become weaker and the rate of scour is reduced. Consequently, the shear stress at the beginning was high and it is reduced gradually until the equilibrium scour condition was reached.

### 3.2. SSIIM Model Verification

In this step the calibrated model will be checked whether it is able to predict the maximum scour for different pier sizes and shapes. The scour of 15 experiments will be verified in order to check the sensitivity of calibrated model. Circular and rectangular shapes have been tested with the same flow condition described above. A comparison between scour values predicted by SSIIM and the physical model by [1] are also presented in Table (2) and Figure (5). It can be concluded that the scour depth increases as the pile size increases. The scour depths for the square piles are larger than the circular piles. The same results have been obtained from both numerical and physical models. The SSIIM model generally predicts the maximum scour within accepted limits where most of the predicted scour values are within ±10%.

**Table (2)**: Summary of Experimental results and the predicted values by SSIIM

| Test No. | Pile Shape | Pile d or b (mm) | Discharge Q (m3/s) | Fr | Time (Hrs.) | [1] | | SSIIM | | Scour Type |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | ds (mm) | ds/b | ds (mm) | ds/b | |
| Run 1 | Circular | 50 | 0.12 | 0.21 | 10 | 74 | 1.48 | 72.4 | 1.449 | Clear Water |
| Run 2 | Circular | 50 | 0.16 | 0.28 | 10 | 79.5 | 1.59 | 90.6 | 1.812 | Live Bed |
| Run 3 | Circular | 50 | 0.18 | 0.32 | 10 | 86 | 1.72 | 94.73 | 1.895 | Live Bed |
| Run 5 | Circular | 100 | 0.12 | 0.21 | 45 Note 1 | 120 | 1.2 | 126.2 | 1.262 | Clear Water |
| Run 6 | Circular | 100 | 0.16 | 0.28 | 12 | 151 | 1.51 | 151.1 | 1.511 | Live Bed |
| Run 7 | Circular | 100 | 0.18 | 0.32 | 12 | 157 | 1.57 | 164 | 1.64 | Live Bed |
| Run 9 | Circular | 150 | 0.12 | 0.21 | 47 Note 1 | 137.2 | 0.91 | 159.7 | 1.065 | Clear Water |
| Run 10 | Circular | 150 | 0.16 | 0.28 | 12 | 192 | 1.28 | 202 | 1.347 | Live Bed |
| Run 11 | Circular | 150 | 0.18 | 0.32 | 12 | 202 | 1.35 | 224.3 | 1.496 | Live Bed |
| Run 13 | Square | 50 | 0.12 | 0.21 | 10 | 90.3 | 1.81 | 77.65 | 1.553 | Clear Water |
| Run 14 | Square | 50 | 0.16 | 0.28 | 10 | 106.1 | 2.12 | 107.55 | 2.151 | Live Bed |
| Run 15 | Square | 50 | 0.18 | 0.32 | 10 | 115.1 | 2.3 | 123.66 | 2.473 | Live Bed |
| Run 17 | Square | 100 | 0.12 | 0.21 | 35 Note 1 | 157 | 1.57 | 140.4 | 1.404 | Clear Water |
| Run 18 | Square | 100 | 0.16 | 0.28 | 12 | 173 | 1.73 | 186.2 | 1.862 | Live Bed |
| Run 19 | Square | 100 | 0.18 | 0.32 | 12 | 194 | 1.94 | 208.1 | 2.081 | Live Bed |
| Run 21 | Square | 150 | 0.12 | 0.21 | 37 Note 1 | 168.6 | 1.12 | 182.4 | 1.217 | Clear Water |
| Run 22 | Square | 150 | 0.16 | 0.28 | 12 | 219 | 1.46 | 241 | 1.607 | Live Bed |
| Run 23 | Square | 150 | 0.18 | 0.32 | 12 | 225 | 1.5 | 274.9 | 1.83 | Live Bed |

1: only 12 hours have been modeled to reduce the total computational time. The values from experimental results have been interpolated from scour rate curves.

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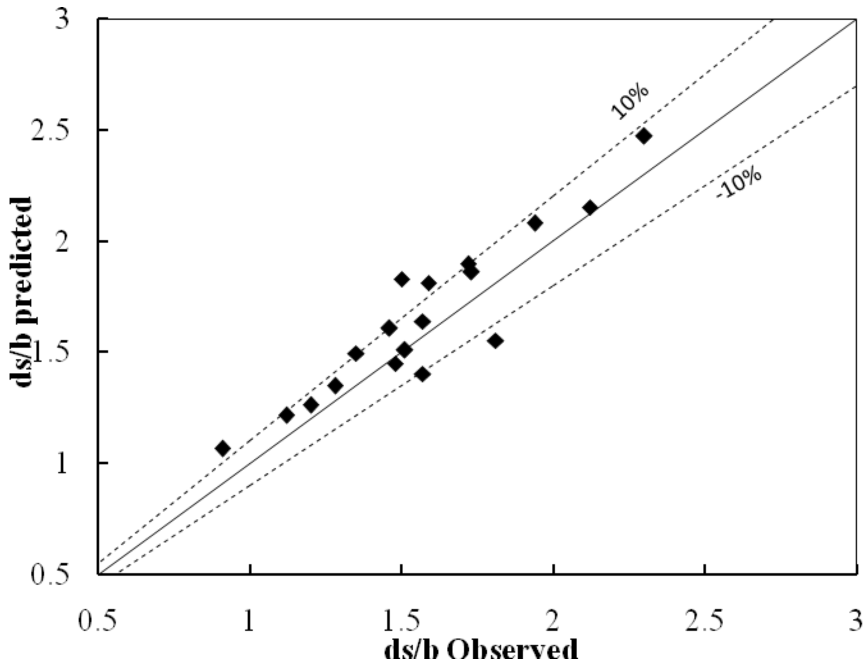


Figure (5) Comparisons between predicted and observed relative scour

Based on this it can be concluded that the SSIIM Model results have a good agreement with the experimental work. The Model can be used to predict the maximum local scour for different flow conditions, pier sizes and shapes. Figure (6-9) show the predicted scour rate by SSIIM program for different pile shapes and flow conditions. The same conclusion obtained from Figures (2-4) is valid here.

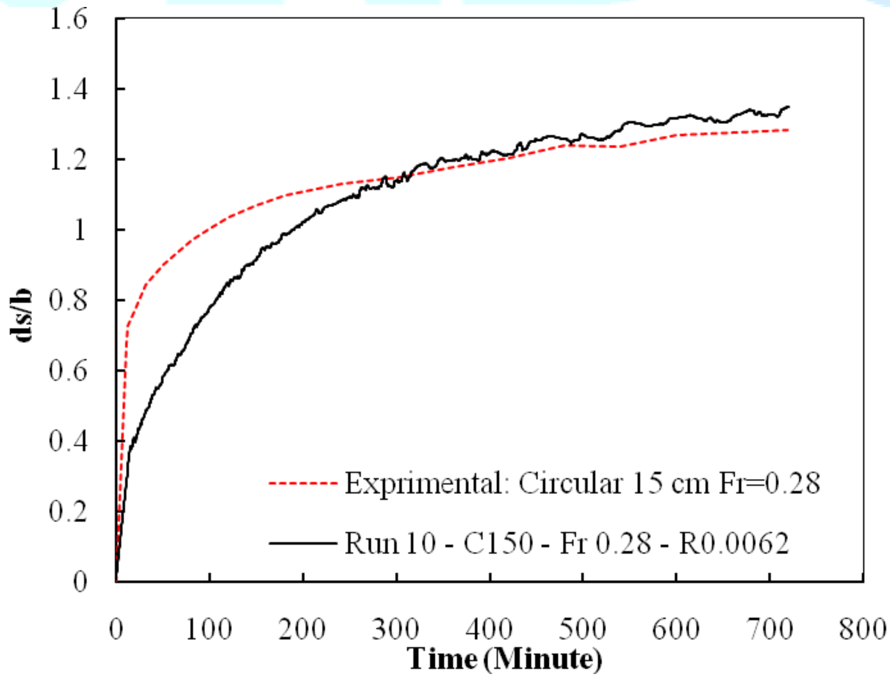


Figure (6) Scour Rate for Circular Pile of Size 150mm at Fr = 0.28

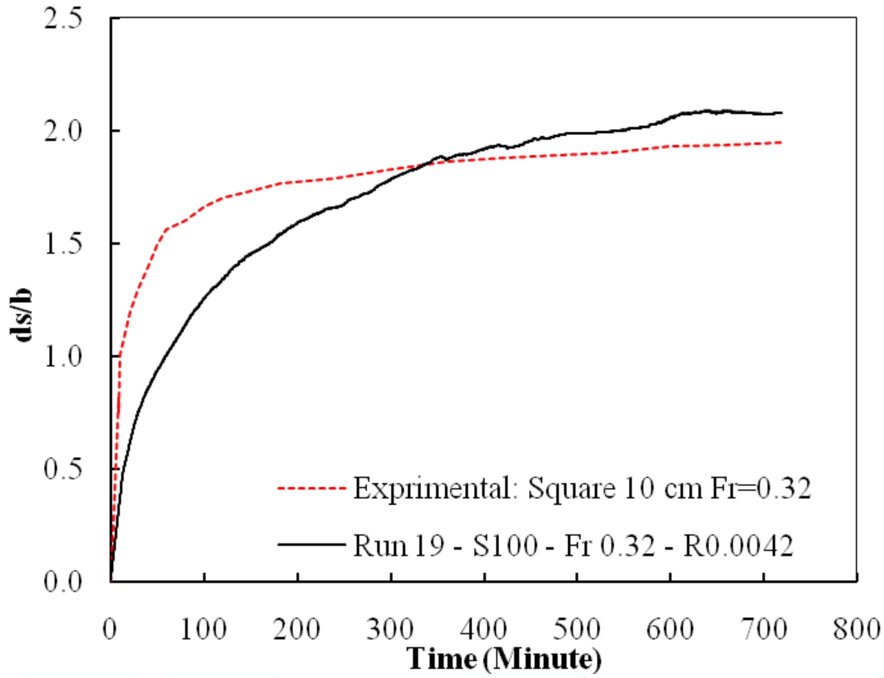


Figure (7) Scour Rate for Square Pile of Size 100mm at Fr = 0.32

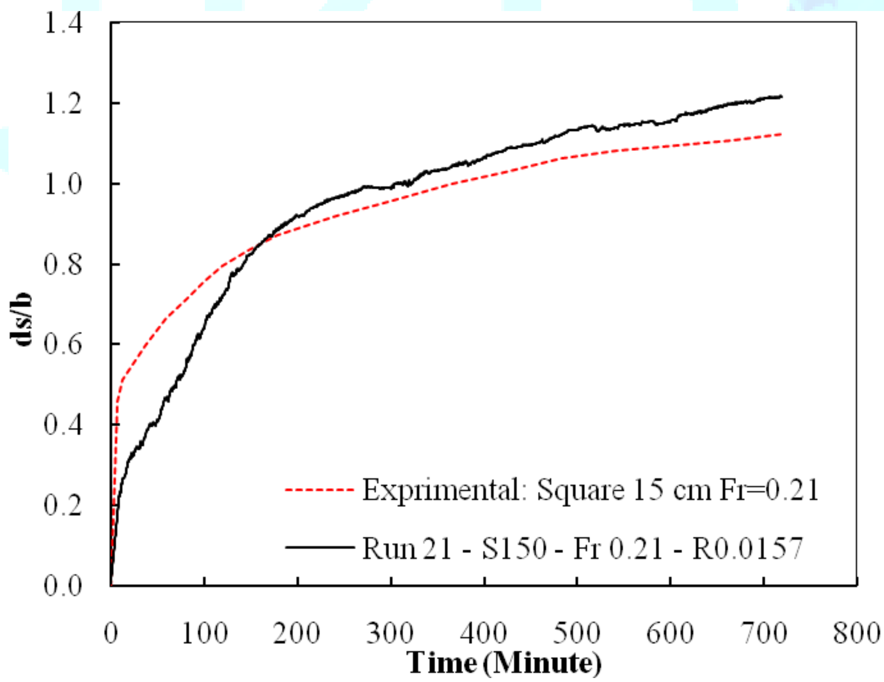


Figure (8) Scour Rate for Square Pile of Size 150mm at Fr = 0.21

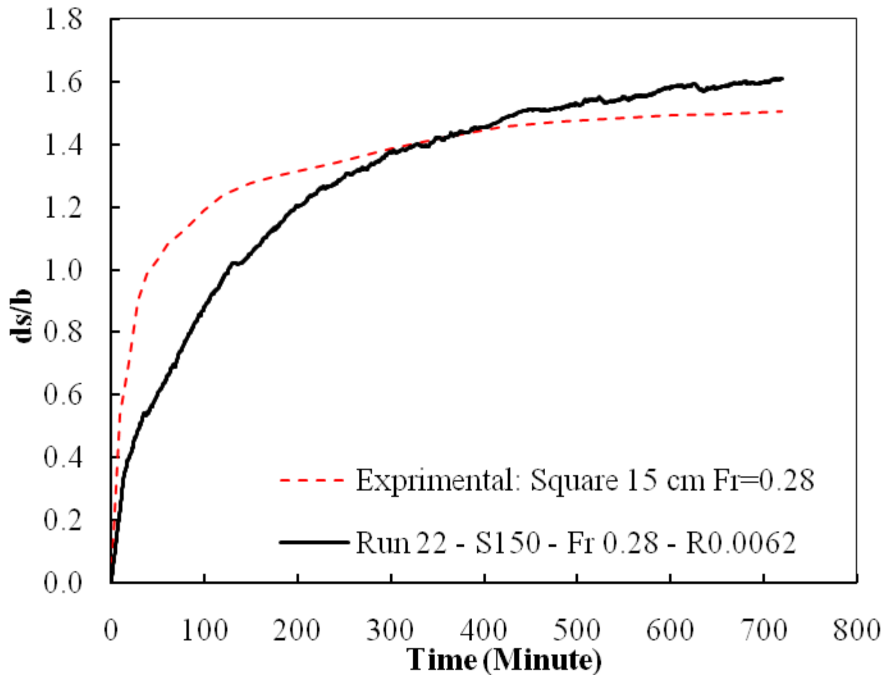


Figure (9) Scour Rate for Square Pile of Size 150mm at Fr = 0.28

### 3.3. SSIIM Model Validation with The Most Famous Scour Equations

Figure (10) and Figure (11) represent a comparison between the predicted scour values by SSIIM Model and the values calculated by the famous equations. It can be concluded from these Figures that the equations developed by [10] and [11] overestimates the scour values while the equations developed by [12] and [13] underestimate the scour values. The comparison also shows that the predicted values have a good agreement with the values predicted by HEC-18 equation. Also, [14], [15] and [16] equations agree with the predicted values.

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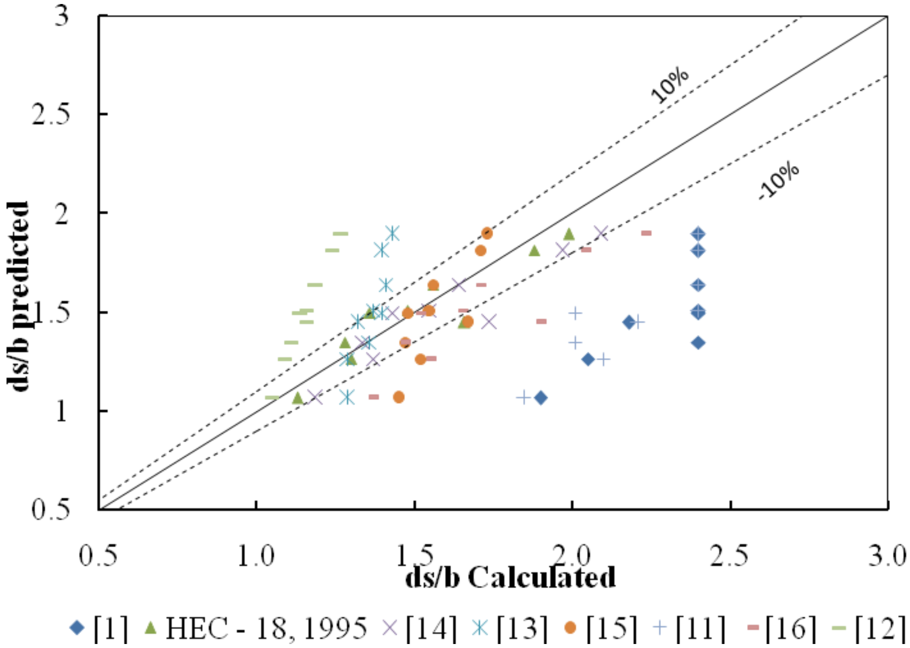


Figure (10) Comparisons between predicted and calculated values for circular piles

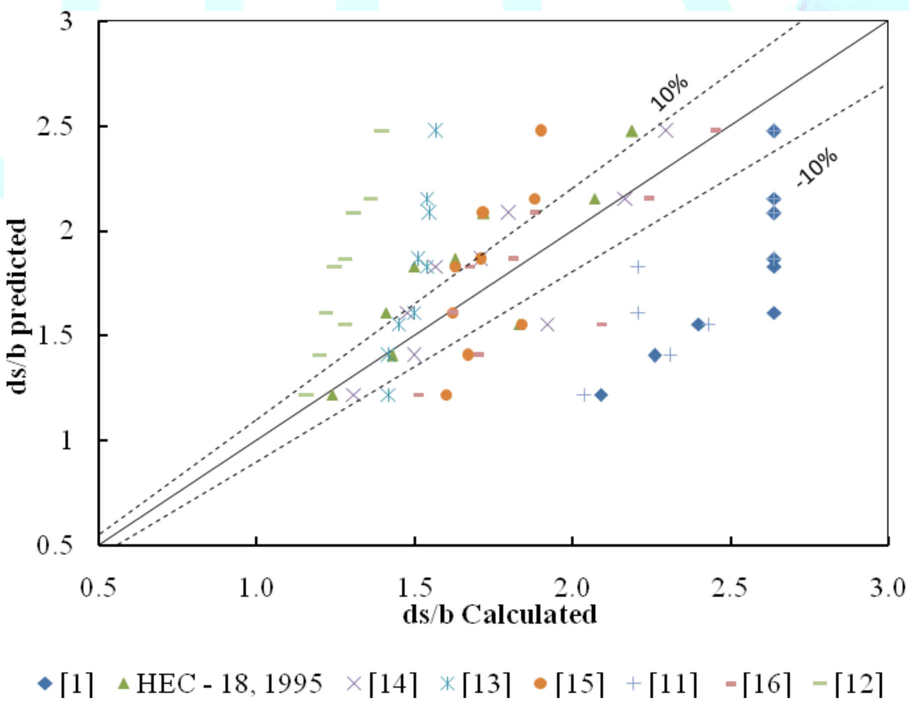


Figure (11) Comparisons between predicted and calculated values for Square piles

## 4. CONCLUSIONS

From the above discussion, the following conclusions can be drawn:

1. The predicted scour values agree with the experimental results.
2. Famous scour equations are used for verifying SSIIM model.
3. SSIIM numerical model is a powerful tool in prediction of scour hole depth for clear water and live bed scour.
4. Scour rate for different scour types and pile shapes can be predicted by SSIIM numerical model.
5. The predicted values are in a good agreement with the values calculated by the most famous scour equations.

## 5. REFERENCES

1. Sharafaddin A.A.S. (2003). "Local Scour around Exposed Bridge Pile Foundations in Sandy Soil Channel", Ph.D. Thesis, Cairo University at Cairo, Egypt.
2. T. Esmaeili, A. A. Dehghani, A. R. Zahiri and K. Suzuki (2009). "3D Numerical Simulation of Scouring around Bridge Piers (Case Study: Bridge 524 crosses the Tanana River)", World Academy of Science, Engineering and Technology (58), pp. 1028-103.
3. Olsen N.R.B. and Melaaen M.C. (1993). "Three-Dimensional Calculation of Scour around Cylinders", Journal of Hydraulic Engineering (119), pp. 1048–1054.
4. Olsen N.R.B. and Kjellesvig H.M. (1998). "Three-Dimensional Numerical Flow Modelling for Estimation of Maximum Local Scour", Journal of Hydraulic Engineering (36), pp. 579–590.
5. G. H. Elsaeed (2011). "Validating SSIIM 3-D Numerical Model to Calculate Local Scour around Bridge Piers", International Journal of Academic Research, 3 (3), pp. 501-505.
6. Abouzeid G., Mohamed H. I. and AliS. M. (2007). "3-D Numerical Simulation of Flow and Clear Water Scour by Interaction between Bridge Piers", Journal of Engineering Sciences, Assiut University, Egypt, 35(4), pp. 891-907.
7. Ebrahim Jafari, H. Hassunizadeh, Ehsan Zaredehdasht and Maryam Kiuani (2011). "Estimating Scour Depth around Bridge Piles Using Ssiim Software and Comparing its Results with Physical Model Results", Australian Journal of Basic and Applied Sciences, 5 (7), pp. 167-173.
8. M.M. Ibrahim and Neveen B. Abdel-Mageed (2014). "Effect of Bed Roughness on Flow Characteristics", International Journal of Academic Research Part (A), 6 (5), pp. 169-178.

9. A.A. Ghareeb (2011). "Effect of Pile Group and Its Arrangement on Local Scour around Bridge Piers", M.Sc. Thesis, Faculty of Engineering, Shobra, Banha University, Egypt.
10. Melville B. W. (1997). "Pier and Abutment Scour-Integral Approach", Journal of Hydraulic Engineering, ASCE, 123 (2), pp. 125-136.
11. Melville. B.W., and Sutherland, A. J. (1988). "Design Method for Local Scour at Bridge Piers" Journal of Hydraulic Engineering, ASCE, 114 (10), pp. 1210-1226.
12. Coleman N. L. (1971). "Analyzing Laboratory Measurements of Scour at Cylindrical Piers in Sand Beds", Proceeding 14th IAHR Congress, Vol. (3), Paris, pp. 307–313.
13. Johnson P. (1992). "Reliability-Based Pier Scour Engineering", Journal of Hydraulic Engineering, 118 (10), pp. 1344–1358.
14. Richardson J.R. and Richardson E. R. (1993). "Proceedings of the 1994 Conference", Hydraulics Division of the American Society Civil Engineers
15. Froelich D.C., (1987). "Local Scour at Bridge Piers Based on Field Measurement", U.S. Geological Survey, Water Resources Division.
16. Jain S. C. and Fischer E. E. (1979). "Scour around Circular Bridge Piers at High Froude Numbers", Report FHWA-RD-79-104, Federal Highway Administration, Washington.