SCOUR AROUND THE COMPOUND PIER FOUNDED IN NON- UNIFORM SEDIMENT

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ABSTRACT: - Constriction of the width of streamflow at a bridge site waterway decreases. As a result velocity of flow in river increases, this causes erosion or removal of sediment occurs near to bridge elements. This is known as bridge scour which may cause the failure of the bridge. Therefore, before constructing bridges in the alluvial channel. It is of great importance to estimate accurate scour depth around the bridge elements for safe and economical design. This study presents the scour around the circular compound pier founded in non-uniform sediment. Two types of sediment procured having a mean diameter equal to 2.5 mm and 1.3 mm for the preparation of hydraulic flume bed.

In all a total of 27 runs were conducted with three series (1) 70% by weight of median size 2.5 mm mixed with 30% by weight of median size 1.3 mm, (2) 60% by weight of median size 2.5 mm mixed with 40% by weight of median size 1.3 mm and (3) 30% off by the weight median size 2.7 mm mixed with 70% by weight of median size 1.3 mm. In each series total, nine experiments carried out at the different position of the well diameter of footing. The mathematical model proposed by Kumar and Kothiyari (2012) has been used to predict temporal variation and maximum scour depth around the circular compound bridge pier in such sediments. The temporal variation of scour depth is observed and is compared with the mathematical model proposed by Kumar and Kothyari (2012).

Keywords: Scour, Alluvial channel, Circular compound pier, Scour depth, Non-uniform sediment.

1. INTRODUCTION

Local scour at the bridge pier is the main reason for the collapse of bridge pier founded in alluvial sediments (Melville and Coleman 2000). This process involves two complexities, the three-dimensional flow pattern and the sediment transport. The determination of the scour characteristic is the main topic of interest for the hydraulic engineers. By underestimation of scour depth, it will result in the exposure of foundation and ultimately lead to endangering the safety of the structure. By overestimation of scour depth, it will lead to uneconomical design.

Numerous studies have been conducted and relationships were developed for estimation of scour depth around the non-uniformly shaped compound pier. The methods available for estimation of scour depth around non-uniformly shaped piers include those by Kumar and Kothiyari (2012), Melvillel and Raudkiviz (1996), Beheshti et al. (2010), Kothyari et al. (2007), Umeda1 et al. (2010)

Kumar and Kothyari (2012) proposed a new mathematical model for computation of temporal variation of scour depth which has the capability to compute the temporal variation of scour depth around circular compound piers for all possible cases of footing position with respect to general bed level channel. **Melvillel and Raudkiviz (1996)** measure local scour around a non-uniform cylindrical pier. He carried out the number of experiments for different position of foundation with respect to channel bed level. **Beheshti et al. (2010)** calculate local scour around complex piers under the steady clear-water condition for a variety of parameter, including different sizes and shapes of complex piers. **Kothyari et al. (2007)** experiment conducted on scour entrainment at piers, at rectangular and sloping abutments, as well as singular and multiple spur dikes. The new relationship of Froude's similitude equations develops by considering the effect of the element shape for the temporal scour evaluation.**Umeda1 et al. (2010)** conducted laboratory experiments on the time development of clear water scour around a non-uniform cylindrical pier in a steady flow to investigate the effects of foundation depth on the scour process and concluded that the scour depth increases with foundation level when the foundation protrudes above the initial bed level.

The main aim of the present study is observed the temporal variation of scour depth around circular compound piers with the top surface of the footing placed at three different positions with respect to the general level of the channel bed. The top surface of footing placed above the bed level and also at the bed level and below the level of the channel bed. The observed experimental data are then compared with the calculated data from the mathematical model proposed by **Kumar and Khothiyari (2012)**.

2. EXPERIMENTAL SETUP

Experiments were conducted in a recirculating hydraulic flume of 6.0-m-length, 0.30-m-wide and 1.0-m-deep (see figure: 1) located in hydraulic laboratory of Shantilal Shah Government Engineering College, Bhavnagar, Gujarat, India. Scouring tests were carried out in a sediment recess section situated at 3.5 m from the inlet. Two uniformly graded sediments are procured having to mean size of d_{50}=2.5 mm and d_{50}=1.3 mm used for the preparation of non-uniform channel bed. Sediments are laid in the central 4.0 m portion in 0.10 m uniform depth for conducting the experiment.

The bed is prepared by mixing both materials in a varying proportion of 70-30%, 60-40%, 30-70% by increasing percentage of finer sediment and decreasing proportion of coarser sediment. Pier of the diameter of 26 mm with 205 mm height and well diameter is equal to 50.8 mm with 95 mm height is used in the experiment and is fixed at 3.5 m from the inlet at the center to its width. Scouring tests were performed under a clear water scouring condition. Three series of experiments are carried for the slope of 0.0008333. The main varying parameters in the experiments are position of the well diameter of the footing with respect to general bed level of the channel, depth of flow, velocity and discharge of flow and sediment size. The velocity was measured using the current meter. The scour depth was measured using point gauge with the flat bottom. The water depth was measured using point gauge. The uniform flow was set by tailgate positioning. The temporal variation of scour is recorded at the nose and wake of the pier.

Figure 1 Experimental Flume (Hydraulic laboratory of SSEC, Gujarat, India)

3. PREPARATION OF NON-UNIFORM SEDIMENT BED

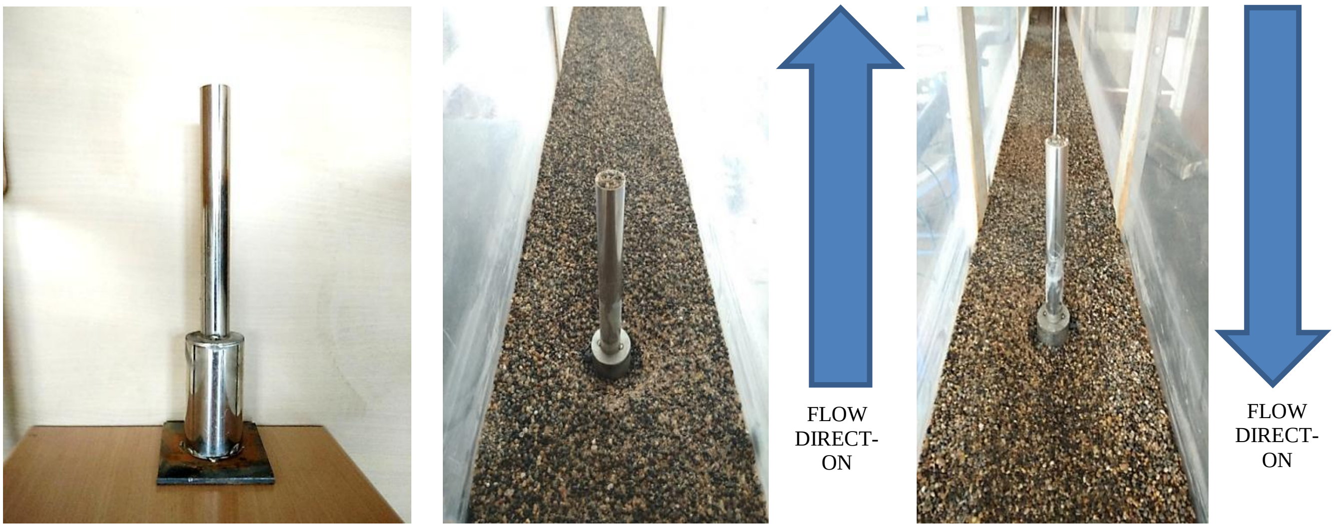
To carry out the experiment and for analysis on the effect of scour hole due to the varying proportion of a non-uniform sediment, two different size of sediments are procured one is having mean grain size of sediment d_{50}=2.5 mm and another is having mean grain size of sediment d_{50}=1.3 mm. Two uniform sediments are mixed in required proportion by weight to have non-uniform bed of 100 mm thick of that proportion. For the experimental work, three different proportions of sediment are used and nine runs are carried out for each series for required time till the scouring almost cease.

For the series-1 experiment, sediment having d_{50}=2.5 mm is taken as 70% and d_{50}=1.3 mm is taken as 30% by weight and properly mixed. For the series-2 experiment, sediment having d_{50}=2.5 mm is taken as 60% and sediment having d_{50}=1.3 mm is taken as 40% by weight and properly mixed. For the third experiment, both materials are taken as 50% by weight and properly mixed. After mixing sediments in required proportion it is laid in 100 mm thick layer in the flume.

4. EXPERIM7ENT PROCEDURE

The Slope of the hydraulic flume was set using mechanical arrangement. 100 mm thick bed was prepared by mixing sand in the required proportion. Circular compound Pier of the diameter of 26 mm with 205 mm height and well diameter is equal to 50.8 mm with 95 mm height was fixed in the middle of the flume. The surface of the pier is made stainless steel. The Required flow was set and for uniform flow establishment the tail gate positioning is carried out.

Initially reading taken after 1 minute and after for 30 minutes, readings will be taken for each 5 minute interval then after per 30 minutes readings will be taken till scour ceases. Velocity was checked using venturimeter. The discharge was calculated using the continuity equation. The experiment was continued till scour ceases. Here figure-2(a) below shows the model of circular compound pier used in the experiments and figure-2(b) shows the photograph of bridge pier scour at nose and wake after the experiment was stopped.



(a) Scour at nose of pier Scour at wake of pier

(b)

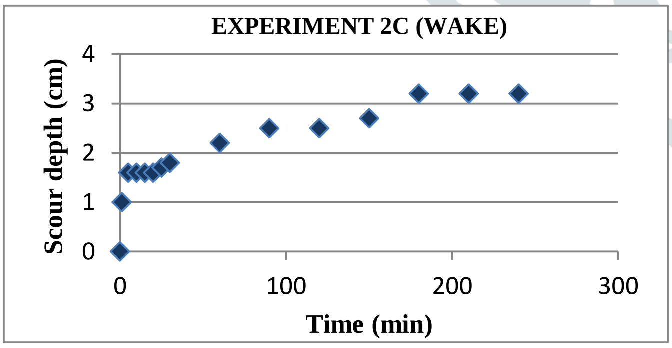
Figur 2 (a) Circular compound pier (b) Photographs of scour around bridge pier at nose and wake side of pier (Hydraulic laboratory of SSEC, Gujarat, India)

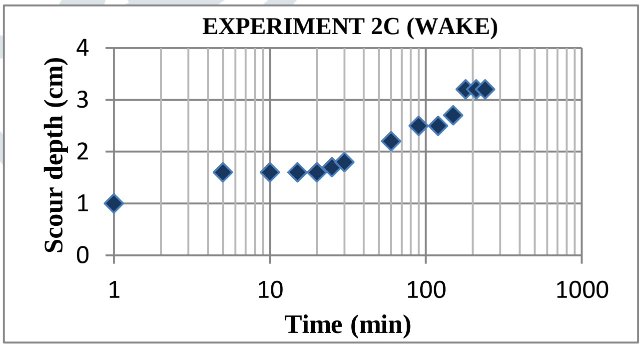
5. EXPERIMENTAL RESULT

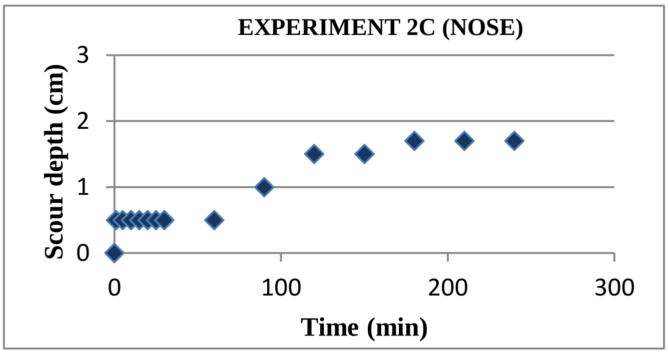
As mentioned above, three series of experiments are carried out each of having nine runs. The effect of the scouring process was noticed immediately after starting the test at the nose and wake of the circular compound pier of 26 mm with 205 mm height and well diameter is equal to 50.8 mm with 95 mm height 48 mm diameter. The varying parameters in these experiments are the position of the well diameter of the footing with respect to general bed level of the channel, depth of flow, velocity and discharge of flow and sediment size. As the results show, the maximum scour depth increases with time. The test was stopped when the rate of scour was same for about an hour.

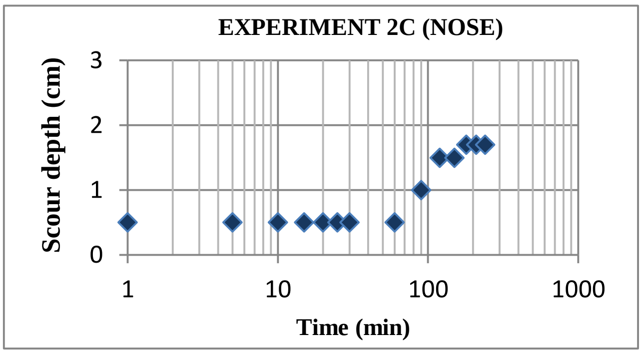
Results for three experiments are shown below in figure-3 and 4 by plotting arithmetic scale, log-log scale and scour rate curve at nose and wake of the circular compound pier for different position of footing from general bed level of channel. Figure-3(a) shows the graph of temporal variation of scour versus time on arithmetic scale for observed data. Figure-3(b) shows the graph of same on Log-Log scale to show that the equilibrium scour is not approached as the slope of line is continuously increasing. Figure-4 shows the graph of scour rate with time to show that scour decreases with time and at the end of run scour rate will be almost slow as compared to starting of run.

When the top of the footing place below the general bed level of channel

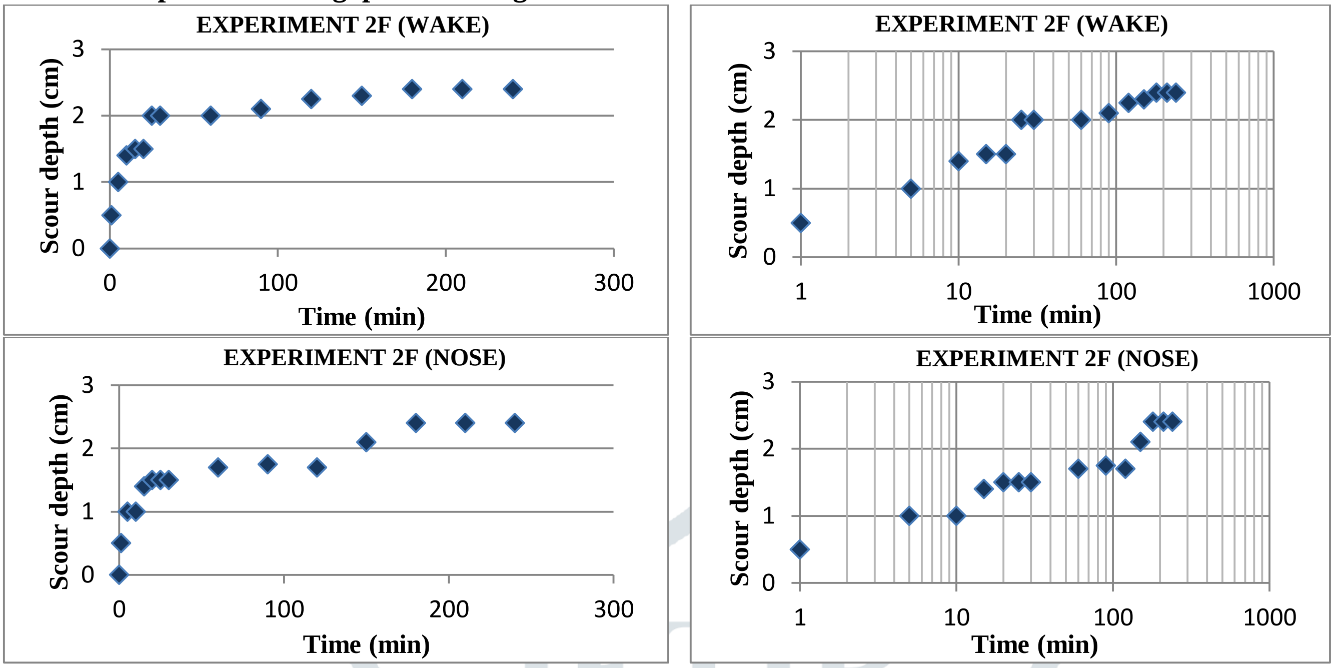




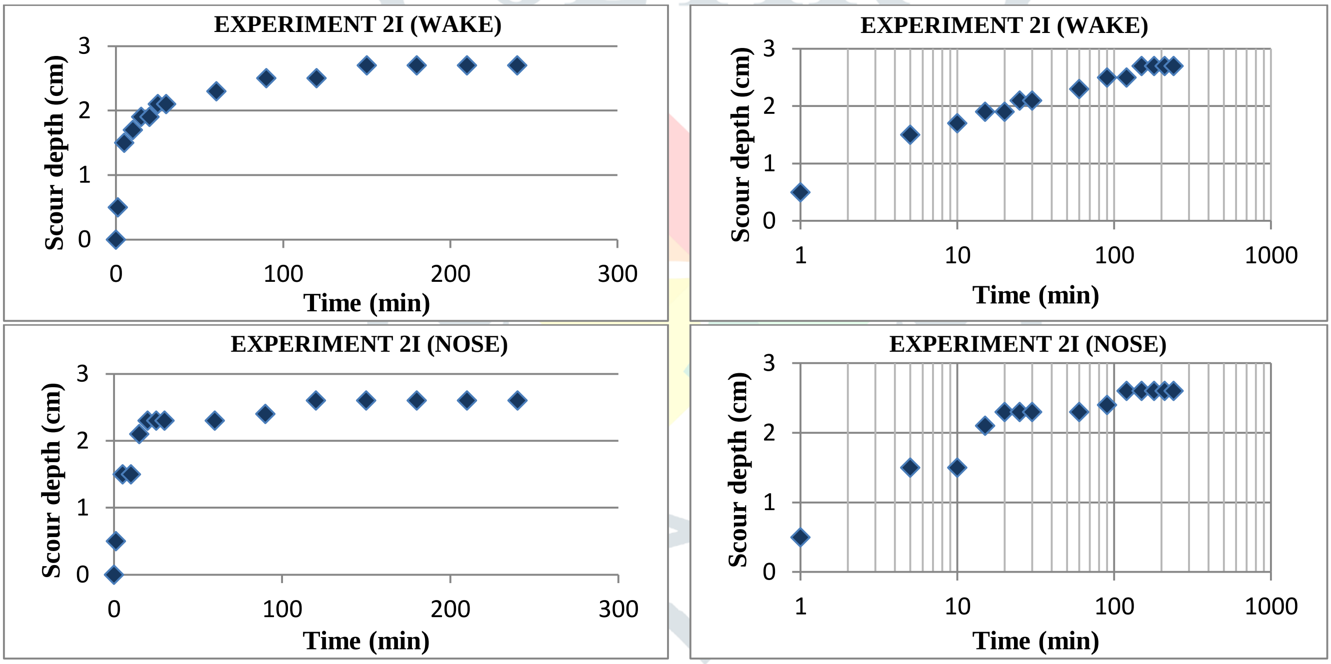




When the top of the footing place at the general bed level of channel



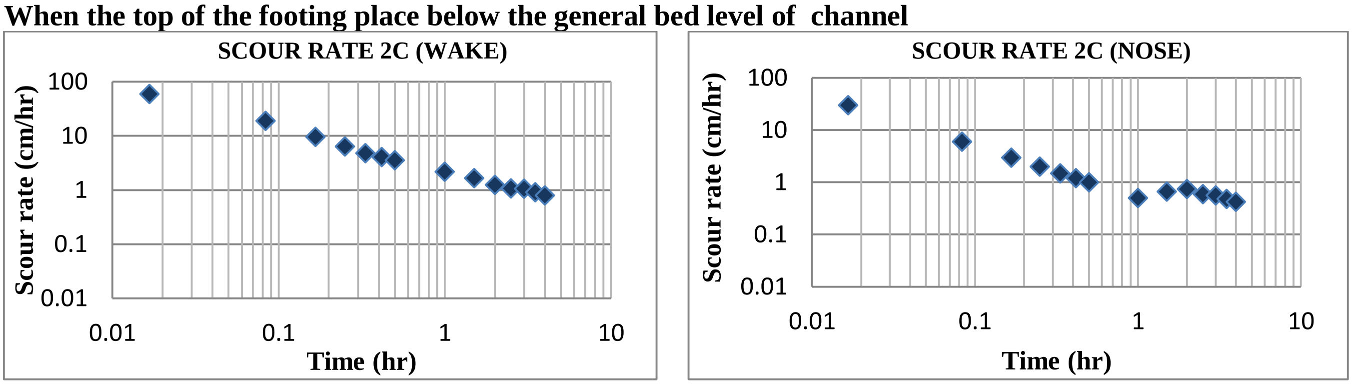
When the top of the footing place above the general bed level of channel



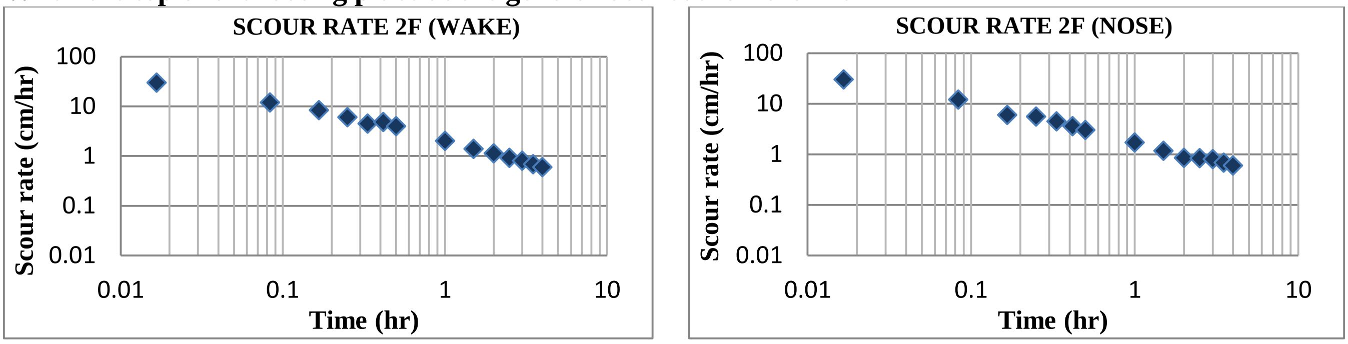
(a) (b)

Figure 3 Series 2 temporal development of scour depth:
(a) Arithmetic scale (b) Log-Log scale

When the top of the footing place below the general bed level of channel



When the top of the footing place at the general bed level of channel



When the top of the footing place above the general bed level of channel

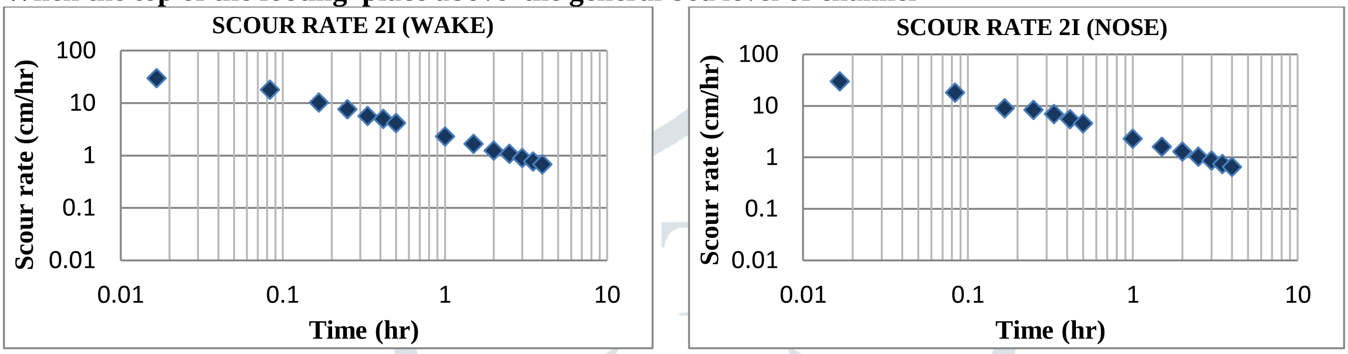


Figure 4 Series 2 scour rate with time Log-Log scale

6. METHODOLOGY

Kumar and Kothyari (2012) proposed a new mathematical model for computation of temporal variation of scour depth which has the capability to compute the temporal variation of scour depth around circular compound piers.

The effective diameter of a circular compound pier is computed as (Melville and Raudkivi 1996).

$$b_e = b\left(\frac{h+Y}{h+d_{st}}\right) + b^*\left(\frac{d_{st}-Y}{d_{st}+Y}\right) \quad (1)$$

The diameter of principle vortex of the horseshoe vortex (D_v) is calculated from equation (Kothyari et al. 1992b).

$$\frac{D_v}{h} = .28\left(\frac{b}{h}\right)^{.85} \quad (2)$$

The area of principle vortex of the horseshoe vortex system (A_t) at any time t is calculated from equation (Kothyari et al. 1992b). The initial area of principle vortex is $\frac{\pi}{4}{D_v}^2$.

$$A_t = A_0 + A_s \text{ or } A_t = A_0 + {d_{st}}^2\big/2\,\tan\phi \quad (3)$$

The bed shear stress within the scour hole at the nose of the compound pier after time t from the start of the scour process is computed from equation (Kothyari et al. 1992b).

$$\tau_{pt} = 4\tau_u\left(\frac{A_0}{A_t}\right)^{.57} \quad (4)$$

Nominal shear stress or dimensionless shear stress at the pier nose at time t,

$$\tau_{*pt} = \tau_{pt}\big/\Delta_{\gamma_s} d_{50} \quad (5)$$

The time required for removal of a single particle is computed from equation (Paintal 1971; Kothyari et al. 1992b).

$$t_* = \frac{cd_{50}}{P_{0t}u_{*t}} \quad (6)$$

$$u_{*t} = \sqrt{\frac{\tau_{pt}}{\rho_f}} \quad (7)$$

The average probability of movement of the particle at time t (P_{0t}) is calculated using the following formula.

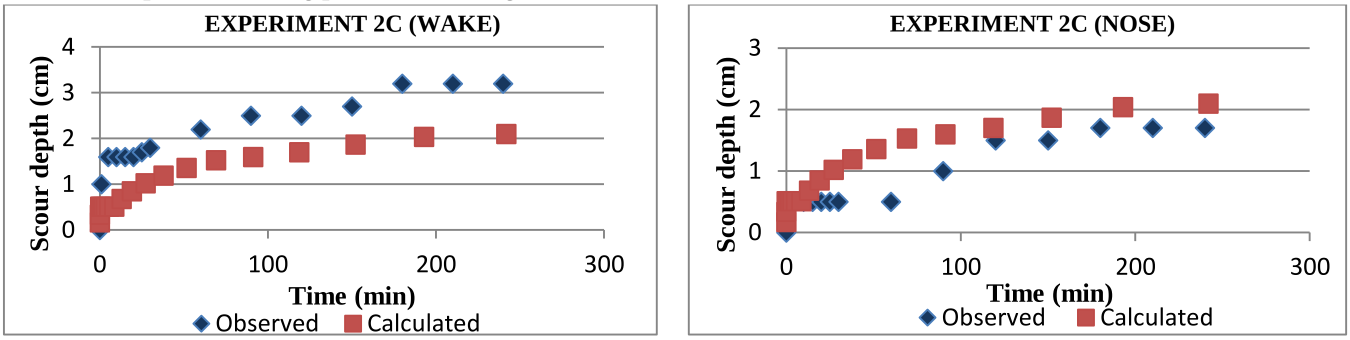
$$P_{0t} = .8{\tau_{*pt}}^{4.2}, \quad \text{for } \tau_{*pt} \leq 0.5 \quad (8)$$

$$P_{0t} = .18\ln\tau_{*pt} + .17P_{0t}, \quad \text{for } \tau_{*pt} > 0.5 \quad (9)$$

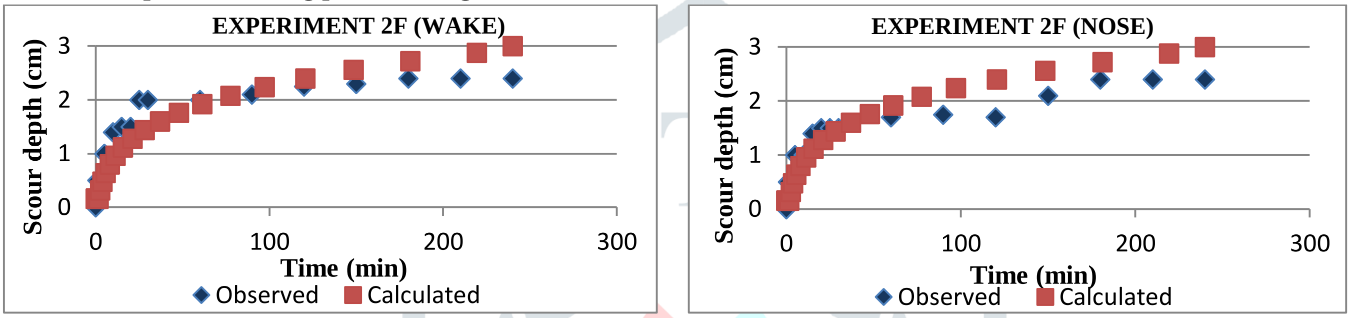
7. COMPARISON OF OBSERVED AND CALCULATED DATA

By using the above methodology with the same flow conditions that prevailed while performing an experiment, the results were obtained for calculated data. Figure-5 shows the comparison of few observed data with that of calculated data in which almost the same scour depth is observed. From the figure-4 it can be seen that the model presented by Kumar and a Kothyari (2012) predicts the scour depth in non-uniform sediment satisfactorily.

When the top of the footing place below the general bed level of channel



When the top of the footing place at the general bed level of channel



When the top of the footing place above the general bed level of channel

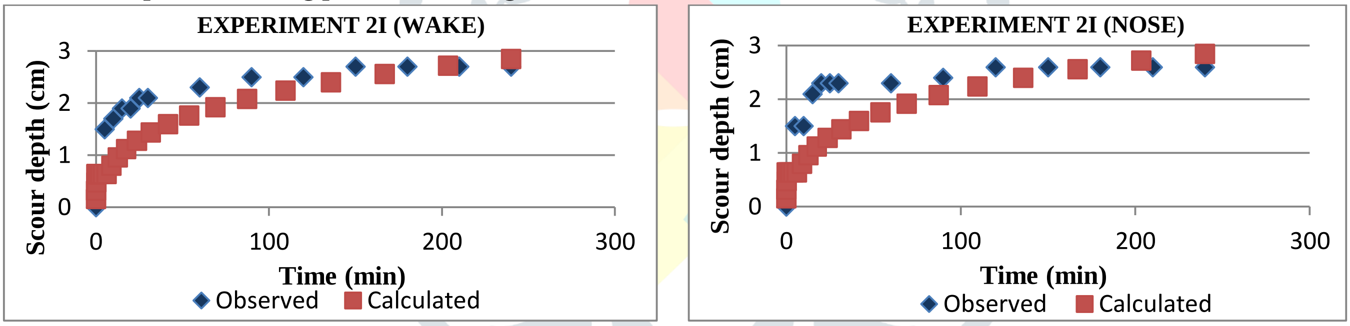


Figure 5 Series 2 comparison of observed and computed scour depth

8. CONCLUSION

In this work, the temporal development of scour at the circular compound bridge pier was experimentally studied using a recirculating hydraulic flume. The study was performed under clear-water conditions using a non-uniform cohesionless bed material and the circular compound bridge pier. The principal objective of this study is to carry out an experiment and to determine the maximum depth of clear-water scour around circular compound bridge pier and to propose a procedure to predict scour depth using the mathematical model proposed by Kumar and a Kothyari (2012).

The following conclusions are derived based on the experiments of maximum depth of scour around the circular bridge pier with non-uniform sediment bed of varying proportions:

- Temporal variation of the scour is time dependence phenomenal, scour depth changes with time and also analyzed rate of the scour is decreasing continuously with time and tends to be zero as the rate of scour in its equilibrium state.
- Scour depth depends on the position of well diameter of footing with respect to the general channel bed level. If the footing is placed below the channel bed level there is no measurable scour at the nose and if it is placed above the bed level there is measurable scour.
- Scouring depth is also depends on kinematics parameter of fluid such as velocity and discharge, due to the increase in velocity and discharge the scour depth is increasing.
- The proposed method may be used to estimate the evolution of scour depth in non-uniform sediment at a certain time, which can appropriately reduce the design depth and construction cost of a bridge foundation according to design flow and peak flow duration.

- These experimental results can be useful for the understanding of scouring mechanism as well as calibration of the mathematical modeling. The agreement between observed scour depth and computed values by the mathematical model is satisfactory.

NOTATIONS

The following symbols are used in the paper:

A_S = area of scour hole at time t;
A_t = area of the principal vortex;
A_0 = area of primary vortex;
B = flume width;
b = diameter or width of bridge pier;
b_e = effective pier diameter for circular compound pier;
b_*= diameter or width of the foundation;
c = parameter
c_1= coefficient
D_V = diameter of the principal vortex of the horseshoe vortex system;
D_* = dimensionless sediment size;
d_s = depth of scour after time t;
d_{st} = depth of scour below the initial bed level at time t;
D_{50} = median sediment grain diameter;
;
τ_{*pt}= dimensionless shear stress at the pier nose at time t;
ν = kinematic viscosity of fluid; and
ϕ = angle of repose of sediment
ρ_f = mass density of fluid;
ρ_s = mass density of sediment;nt;
τ_u = shear stress of the approach flow;
τ_{pt} = shear stress at the pier nose at time t;
γ_f = specific weight of fluid;
γ_s = specific weight of sediment;
$\Delta\gamma_s = \gamma_s - \gamma_f$;
P = rate at which principal vortex expands over the top of the foundation;
P_{ot} = average probability of movement of the particle at time t;
Q = discharge;
R = hydraulic radius;
R_2 = coefficient of determination;
S = energy slope;
s = specific gravity of sediment;
t = time after beginning of scour when scour depth is d_{st};
t_* = time required for single sediment particle to get scoured;
U_∞ = velocity of approach flow;
u, w = longitudinal and downward velocity component;
u_* = bed shear velocity of approach flow;
u_{*c} = critical bed shear velocity for D_{50} size, defined by Shields' function;
u_{*t} = shear velocity at time t;
Y = depth of the top of the foundation below the initial bed level;

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