EFFECT OF STREAM-WISE SPACING OF BRIDGE PIER ON LOCAL SCOUR DEPTH OF CIRCULAR PIERS
A PROJECT

Submitted in partial fulfillment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

IN

***STRUCTURAL* ENGINEERING**

Under the supervision of

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May, 2015

CERTIFICATE

This is to certify that the work which is being presented in the project title **“*EFFECT OF STREAM-WISE SPACING OF BRIDGE PIER ON LOCAL SCOUR DEPTH OF CIRCULAR PIERS*”** in partial fulfillment of the requirements for the award of the degree of Master of Technology in Structural Engineering and submitted in Civil Engineering Department, Jaypee University of Information Technology, Waknaghat is an authentic record of work carried out by Parveen Kumar during a period from August 2014 to May 2015 under the supervision of “**Dr. Ashish Kumar”** Associate Professor, Civil Engineering Department, Jaypee University of Information Technology, Waknaghat.

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled effect of stream wise spacing around circular bridge pier in partial fulfillment of the requirement for the award of the degree of M.Tech structural engineering submitted in the department of civil engineering Jaypee University of information technology.

Here is an authentic record of my own work carried out for a period from august 2014 to May 2015.under the supervision of **'Dr Ashish Kumar'** Associate professor, department of civil engineering

I have not submitted the matter embodied in this dissertation for the award of any other degree.

Dated: May 24, 2015 (Parveen Kumar)

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(PARVEEN KUMAR)

ABSTRACT

One of the main causes of the bridge failures scour around its piers and abutment. Requirement of new bridge in the close vicinity of existing one is increased day by day due to rapid urbanization and increased traffic volume the structures of the flow significantly altered due to the presences of an obstruction for example a pier n the flow.

The situation even more complex when a bridge is constructed in the close vicinity of existing one. The proposed new bridge interfaces the flow geometry. This interference also depend upon the stream wise spacing between the bridge .The main objective of the present work is to find the optimum distance between the two bridge so that new bridge constructed in the vicinity of old bridge or vice versa by studying the mechanism of scour ad scour depth at bridge pier.Keeping the objective in mind, Present work is carried out through the set of laboratory experiment conducted in the hydraulic laboratory of civil engineering department JUIT waknaghat. The present investigation will be an add to design the new bridge in proximity of old one.

LIST OF SYMBOLS

d_{50}=median grain size

V= kinematic viscosity

S= relative density

τ_0=bed shear stress

Υ=unit weight

R =hydraulic mean radius

S=slope of river bed

τ_c=bed shear stress at initiation of bed sediment

τ^*c=From graph of modified form of yalin karahan curve

A =cross section area of flow

Q=discharge

u =velocity

h=flow depth

n=manning coefficient

u_c^*=shear velocity at intuition of sediment motion

ds(f)=scour depth of front pier

ds(r)=scour depth of rear pier

X= centre-to-centre spacing between piers
d = B= pier diameter
dse =equilibrium scour depth below river-bed level
D =flow depth
F= Lacey's silt factor
K =constant
P= perimeter of the channel
q =design flood discharge intensity
Q= design flood discharge

α =opening ratio

σg= geometric standard deviation.

b= pier diameter

x/b=entre-to-centre spacing between piers

D= median size of bed material

dse =equilibrium scour depth below river-bed level

f =Lacey’s silt factor

K =constant

P= perimeter of the channel

q =design flood discharge intensity

Q =design flood discharge

α =opening ratio

σg= geometric standard deviation.

γ =specific weight of water [N/m3]

τ c =critical shear stress [N/m2]

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CHAPTER 1

INTRODUTION

1 GENERAL

A **bridge** is a structures built to span physical obstacles such as a body of water, valley, or road, for the purpose of providing passage over the obstacle. There are many different designs that all serve unique purposes and apply to different situations. Designs of bridges vary depending on the function of the bridge, the nature of the terrain where the bridge is constructed and anchored, the material used to make it, and the funds available to build it

Bridges can be categorized in several different ways. Common categories include the type of structural elements used, by what they carry, whether they are fixed or movable, and by the materials used.

There are many different way which causing the failure of bridge structures

1. **Earthquake:** Cause damage to all structures, including bridges. Major earthquakes can bring about the collapse of dozens of buildings, but collapsed bridges are often the most visible signs of the havoc an earthquake can wreak.

2. **Fire:** might be the rarest cause of bridge collapses, but fire has brought a few bridges down in the past. In fact, it used to happen much more often, when bridges were made out of wood.

3. **Bomb attack:** Many bridges cross rivers and other bodies of water. Boats passing under a bridge are usually moving pretty slow (compared to trains), but boats have incredible mass. This means that even a barge, which typically creeps along at very slow speeds, can impart tremendous force if it collides with bridge pilings or piers. That force is sufficient to knock down the bridge in some cases

4. **Flood:** Cause Bridge collapses in a few different ways. Severe floods can cause rivers and creeks to overflow, picking up debris like trees, cars and parts of houses. When the river passes under a bridge, the high water level smashes the debris into the bridge. If the impact doesn't destroy the bridge immediately, the weight of the piled up combined with the force of the flowing water pushing on it can bring the bridge down.

5. **Bridge scour :** Bridge scour is the removal of sediment such as sand and rocks from around bridge abutments or piers. Scour, caused by swiftly moving water, can scoop out scour holes, compromising the integrity of a structure. It is the one of the major cause of the bride failure.

Scouring is the main cause of bridge failure .This project is all about scouring phenomena.

1.2 SCOURING

Pier on which the superstructures of this bridge rest play an important role in their stability safety and failure of bridge due to scoring of pier at their support is not an uncommon occurrence .the scour is the local lowering of the stream bed elevation which takes place in the vicinity or around a structure constructed in the flowing water. The scour around the pier is a result of the development of high shear stress due to the three dimensional separation of the boundary layer which result in a high level of turbulence and vorticity around the pier. The estimation of thecorrect depth of scour below the stream bed is very important since that determines the depth of the foundation.

Most existing relationship for determines of local scour depth at bridge pier apply to pier with a constant cross sectional dimensional over the full length of the pier. Therefore most existing scour depth equations are expressed in term of a single pier dimension usually the projected pier width normal to the approach flow.

1.3 MECHANISM OF SCOUR

When the water flow in river is deflected by obstructions like bridge piers, scouring would occur arising from the formation of vortexes. The mechanism of formation of vortices is as follows: the flow hits the bridge piers and tends to move downwards. When the flow reaches the seabed, it would move in a direction opposite to its original flow direction before hitting the bridge piers. Hence, this movement of flow before the bridge piers results in the formation of a vortex. Owing to the formation of this vertical vortex, seabed material is continuously removed so that holes are formed at the seabed and this result in local scour at bridge piers. As the shape of vortices looks like horseshoes, it is sometimes called “horseshoe vortex

1.4 CLASSIFICATION OF SCOUR

The scour in the vicinity of a bridge pier and a footing may be classified under the following categories.

1.4.1 CLASSIFICATION BASED ON THE CHARACTERSTICS OF FLOW

THREE TYPES OF SCOUR AFFECT BRIDGES:

1. **Local scour:**

Local scour is the removal of sediment from around bridge piers or abutments. (Piers are the pillars supporting a bridge. Abutments are the supports at each end of a bridge.) Water flowing past a pier or abutment may scoop out holes in the sediment; these holes are known as scour holes.

2. **Contraction scour :**

Contraction scour is the removal of sediment from the bottom and sides of the river. Contraction scour is caused by an increase in speed of the water as it moves through a bridge opening that is narrower than the natural river channel.

3. General scour:

General scour occur in a river or stream as a result of natural process irrespective of whether a structure is there or not

1.4.2 CLASSIFICATION BASED ON TRANSPORT SEDIMENT

1. Clear water scour

If the bed material in the natural flow upstream of the scour area is at rest. The shear stresses on the bed some distance away from the sub structure are thus not greater than the critical or threshold shear stress or the initiation of particle movement

2. Live bed scour

A scour with bed materials sediment transport occur when the flow induces a general movement of the bed material. That is the shear stress is greater than the critical one. equilibrium scour depth are reached when the amount of material removed from the scour hole by the flow equals the amount of materials supplied to the scour hole from upstream.

1.5 BRIEF REVIEW

The phenomenon of scour around bridge pier has been studied extensively by a large number of investigators. We have done study related to the following:

1. Study related to local scour around circular bridge pier.

2. Study related to effect of stream-wise spacing of bridge pier on local scour.

3. Study related to effect of stream-wise spacing of bridge piers on temporal variation of scour depth

1.6 NEED FOR THE PRESENT STUDY

Requirement of new bridge in the close vicinity of existing one is increasing day by day due to rapid urbanization and increased traffic volume. The flow field around a bridge pier presents the picture of a complex phenomenon. The structure of the flow is significantly altered due to the presence of an obstruction, for example a pier in the flow. This situation becomes even more complex when a new bridge is constructed in the close vicinity of existing one. The proposed new bridge interfere the flow geometry .This interference depends upon the stream-wise spacing between the bridges.

1.7 PROJECT OBJECTIVE:

1. To Study related to local scour around circular bridge pier.

2. To study the effect of stream wise spacing of bridge pier on scour depth

3. To Study related to effect of stream-wise spacing of bridge piers on temporal variation of scour depth

1.8 LIMITATION OF THE STUDY

The following are the main limitation of the present study:

1. Uniform cohesion less sediment size 0.5 mm with relative density of 2.58 was used.

2. The experiment is restricted to the case of local scour steady flow.

3. Study is confined only to circular piers.

CHAPTER II

LITERATURE REVIEW

2.1 GENERAL

Long roadway approach sections and narrow bridge openings force floodplain waters to re-enter the main channel at the bridge, causing a severe contraction in flow area that results in both contraction and local scour. This severe contraction in flow area produces a mixed flow pattern under the bridge, with increased velocities, shear stresses, and turbulence around the bridge pier. As a result, it is difficult to separate contraction scour and local scour processes. However, current scour practice assumes that contraction and local scour processes are independent and thus are determined separately and summed for total scour depth (Richardson and Davis, 2001). Furthermore, existing contraction scour prediction equations are based on theories of flow continuity and sediment transport in an idealized long contraction, while existing local scour prediction equations are based primarily on laboratory data, making many of the existing contraction and local scour prediction equations unsuitable with respect to field conditions.

Scour around the bridge failure is one of the major causes of structural failure and has consequently received a large amount of research.

2.2 STUDY RELATED ON BRIDGE SCOUR

A large number of investigations have been carried out over past five decades, mostly focused on the development of the relationships for computation of equilibrium or maximum scour depth around the circular bridge piers. But a little or no work has been done on effect of stream-wise spacing of uniform piers on local scour depth. Review of literature therefore has been categorized here in into following sections:

2.2.1 Study related to Local Scour around Circular Bridge Piers.

2.2.2 Study related to Effect of Stream-Wise Spacing of Bridge Piers on Local Scour.

2.2.3 Study related to Effect of Stream-Wise Spacing of Bridge Piers on Temporal variation of Scour Depth

2.2.1 Study related to Local Scour around Isolated Circular Bridge Piers.

The local scour at isolated circular bridge piers has to be added to general scour and constriction scour to obtain the maximum scour depth for use in the design of bridge pier. In an analysis of local scour one must differentiate between clear water scour because both the development of the scour hole with time and the relationship between scour depth and approach flow velocity depend upon which type of scouring occurring .

There are few researchers who studied about local scour around single isolated circular bridge pier. These are listed below:

Ettema et al.(1998) According to his research he concluded that the scale effect is the important factor in studies involving lab flume experiment on bridge scour.

The scale effect evidently overlooked in studies involving lab flume experiment on bridge scour .scale effect mean for the hydraulic modeling the cohesion less materials used are geometrically scaled means same size .

The constraint requires most lab-flume experiments to use coarser sediment relative to pier width than that typically prevails at bridge sites.

It leads to a significant scale effect in simulating the local scour at a pier. Flume experiments, consequently, may produce larger values of maximum scour depth relative to pier width than that would likely occur at actual bridge piers. According to Ettema analysis they find out that similitude of flow field at a circular cylindrical pier require constants of U_∞/U_C, U_∞^2/gb, h/b and b/d.

Here,

b is the diameter or width of bridge pier.

d size of uniform sediment.

h is the depth of flow.

U_∞ is the velocity of flow approach.

U_C is the velocity of approach flow corresponding to incipient motion of sediment.

g gravitational acceleration

Sheppard et. (2004)

Local clear-water scour tests were performed with three different diameter circular piles (0.114, 0.305, and 0.914m), three different uniform cohesion less sediment diameters (0.22, 0.80, and 2.90mm) and a range of water depths and flow velocities. The tests were performed in the 6.1m wide, 6.4m deep, and 38.4m long flume. He performed 14 experiments. These tests extend local scour data obtained in controlled experiments to prototype size piles and ratios of pile diameter to sediment diameter to 4,155.

They presented the clear-water scour prediction equations which are an update version of those published by Sheppard *et al*. (1995):

$$\frac{d_{se}}{b} = 2.5 f_1\left(\frac{h}{b}\right) f_2\left(\frac{U_\infty}{U_c}\right) f_3\left(\frac{b}{d_{50}}\right) \tag{1}$$

Here,

$$f_1\left(\frac{h}{b}\right) = \tanh\left[\left(\frac{h}{b}\right)^{0.4}\right] \tag{2a}$$

$$f_2\left(\frac{U_\infty}{U_c}\right) = 1 - 1.75\left[ln\frac{U_\infty}{U_c}\right]^2 \tag{2b}$$

$$f_3\left(\frac{b}{d_{50}}\right) = \frac{b/d_{50}}{0.4(b/d_{50})^{1.2} + 10.6(b/d_{50})^{-0.13}} \tag{2c}$$

According to his experimental data he concluded:

1. The reduction in dependence of d_{se}/b on b/d_{50} with increase in value of b/d_{50}.
2. The equilibrium scour depth is also affected although not affected by the presence of suspended fine sediment in the flow.

Bruce W. Melville1

The relationship between scour depth at cylindrical isolated bridge piers founded in cohesion less sediments, and mean approach flow velocity is defined for flows above the threshold of particle motion. Experimental data are collected in which pier size; sediment size and mean approach flow velocity are systematically varied.

These data show that the relationship between scour depth and flow velocity differs, depending on whether the bed sediment is ripple forming or non-ripple forming, and separate functions are identified for each case. Both functions exhibit two scour peaks. These occur at the threshold and transition flatbed conditions. Contrary to previous findings, the maximum scour depth is found to occur at the transition flat bed condition in the case of ripple forming sands. For no ripple forming sediments, however, the maximum scour depth occurs at threshold condition

Sheppard and Willaim (2006) conducted the clear-water and live-bed scour experiments around the circular uniform pier of diameter 0.15 m with uniform cohesion-less sediment of 0.27 mm and 0.84 mm sizes respectively. The tests were performed in a 1.5 m wide, 1.2 m deep and 45 m long tilting flume. These tests were conducted with the velocity ratio (U_∞/U_c) values as high as 6.

The scour relationships of Sheppard (Sheppard, 2003 a, b), *HEC*-18 (Richardson and Davis, 2001), Melville (Melville, 1997) and Breusers (Breusers *et al.*, 1977) were used to predict the normalized equilibrium scour depth. It was concluded that all the four equations used over predicted the experimental values for most of the experimental runs. Sheppard's equations yielded better results in the live-bed scour range covered in the experiments

Dey and Raikar (2007) conducted the clear-water scour experiments at circular and square piers in sand beds with an armor layer of gravels and some experiments with out an armor layer. The armor thickness was kept two times of the size of the gravels. Depending on the pier width, flow depth, armor gravel, and bed sand sizes, they identified the three cases of scour holes in armored beds.

On the basis of analysis of the experimental data they concluded that in Case 1, the scour hole at a pier develops through the armor layer, and the equilibrium of the scour hole reaches when it is fully covered up by the secondary armor layer and the scour depth in armored beds is less than that in unlayered beds, as the scour hole is shielded by the secondary armor gravels. In Case 2, the scour hole at a pier forms through the armor layer having a relatively longer extension toward the upstream. The equilibrium scour hole is partially covered up by the secondary armor layer. The original armor layer disintegrates over a short distance downstream, but it remains intact around the upstream perimeter of the scour hole. In Case 3, the scour hole at a pier develops, collapsing the armor layer over a considerable distance upstream and , the scour depth in armored beds is greater than that in unlayered beds, since the secondary armor gravels are scattered within the scour hole. They also proposed the equations of maximum equilibrium scour depths for cases 2 and 3.

Chreties *et al.* (2008) proposed a new methodology to determine the equilibrium scour depth at bridge piers under clear-water conditions. According to The hypothesis given by them is that the shape of the scour hole is essentially related to the scour depth and sediment properties, but not to flow conditions. Thus

$$\frac{l}{b} = f\left(\frac{d_{se}}{b}, \frac{\rho_s}{\rho}, \frac{d_{50}}{b}, \frac{b}{B}\right) \tag{4}$$

Here, l is the characteristic length of the scour hole and**,** B is flume width or section width. So following this they proposed a experimental methodology to determine the flow conditions for a given equilibrium scour instead of determining the equilibrium scour for given flow conditions. So

$$\frac{h}{b} = f\left(\frac{q}{b\sqrt{gb}}, \frac{d_{se}}{b}, \frac{\rho_s}{\rho_f}, \frac{d_{50}}{b}, \frac{b}{B}, \frac{gd_{50}^{3}}{\nu^{2}}\right) \tag{5}$$

Where q is flow rate per unit width, ρ_f is mass density of fluid, ρ_s is mass density of sediment and ν is kinematic viscosity of fluid. They conducted two sets of experiments on circular pier under clear-water conditions to validate and verify the proposed methodology.

Lee and Strum, (2009) conducted the pier scour experiments on rectangular and circular bridge pier models of three different prototype bridge piers with three different sediment sizes using flat-bed models of individual bridge pier, as well as full hydraulic river models of the river bathymetry, bridge piers, and abutments at different geometric scales. To investigate the effect of relative sediment size on pier scour depth.

They used the experimental data of present study, three field site measurement monitored by the *USGS* and laboratory data from literature, to investigate the effect of sediment size on scour depth. From analysis of data they found that the relative scour depth is a unique function of the ratio of pier width to sediment size, b/d_{50}, if attention is restricted to data for which the approach flow Froude number is less than 0.4.

Based on regression analysis to all the laboratory data plus three field data points from this study, they developed two equations for pier scour depth

$$\frac{d_{se}}{b} = 5.0\log\left(\frac{b}{d_{50}}\right) - 4.0, \qquad 6 \le {}^{b}\!/_{d_{50}} \le 25 \qquad (6a)$$

$$\frac{d_{se}}{b} = \frac{1.8}{\left(0.02\,b/d_{50} - 0.2\right)^2 + 1} + 1.3, \qquad 25 \le {}^{b}\!/_{d_{50}} \le 1X10^4 \qquad (6b)$$

They narrated that the choice of sediment size in the laboratory model distorts the value of b/d_{50} in comparison with the prototype that causes larger values of scour depth in the laboratory than in the field. They explained this model distortion due to sediment size behavior by the scaling, or distortion, of the large-scale unsteadiness of the horseshoe vortex which is directly related to the distortion in b/d_{50}. It was suggested that the quasi periodic oscillation of the horseshoe vortex is related to transport of sediment particles during the scouring process. Two distinct types of sediment motion were observed for two different sediment sizes that ultimately affect the equilibrium scour depth in front of the pier. They further advised for research on the coherent structure of the horseshoe vortex at very large scales.

2.2.2 Study related to effect of stream-wise spacing of bridge Piers on scour depth.

A lot of investigations have been conducted around the circular bridge piers but only a few investigations are available on the effects of stream-wise spacing of group of bridge piers on scour depth (Hannah, 1978; Elliot and Baker, 1985; Breusers & Raudkivi, 1991; Sidek & Ismail, 2002 *etc*). However little or no information is available on the flow structure around the group of piers, when these piers are placed in a line parallel to the direction of flow.

Elliot and Baker (1985) conducted the experimental study on the effect of pier spacing on scour around bridge piers. They used the wooden pier models having rectangular shape with semi circular nose having width of pier 46 mm and length as 150 mm. They placed the pier models parallel to the direction of the flow and varied the spacing between the pier from 1.6 -3.2 times the pier diameter. They introduced multiplying factors in scour depth equation of Breusers et al., 1977 stating that these multiplying factors have been derived for clear-water scour, for one set of pier geometries, one value of water depth and one sediment type only and use in other condition should be done with caution.

Breusers and Raudkivi (1991) have summed up that in general the scour hole for a group of two piers could be considered as the coincidental positioning of separate scour holes of the individual piers. They proposed the correction factors for computation of equilibrium scour depth for a group of two piers when piers are placed in tandem, two piers side by side and two piers at a variable angle. According to them when two piers are in a line parallel to the flow direction; the maximum scour depth around the front pier will increase by a maximum of 15% if the pier spacing is 2 to 3 times the pier diameter. The influence of the second pier on the front pier disappear as pier spacing is greater than 15 times the pier diameter. The maximum scour depth of the rear pier is reduced by 10-20%. This reduction is almost independent of pier spacing.

Choi and Ahn (2001) have examined experimentally the local scour depth variation due to interaction between stream-wise placed bridge piers. They varied the stream-wise spacing from 5*b* to 25*b* and the cross-section of the piers was elliptical. They have collected extensive data on the variation of the scour depth for different sizes of the piers, stream-wise and transverse spacing, and Froude numbers. They concluded that the local scour depths are severely affected when the interaction between adjacent stream-wise spaced bridge piers exists. The maximum scour depth increment (compared to single pier) observed was of about 60%, when the interaction between bridge piers exists.

Sidek and Ismail (2002) conducted laboratory experiments concerning scour development around a group of two cylindrical piers. Experiments were conducted with sediment size 0.3 mm under clear-water condition using two similar steel pipes having diameter

32 mm, 42 mm and 60 mm. Spacing of the pier were varied from 1b, 1.5*b*, 2*b*, 3*b*, 4b, 5*b*. The flow depth were varied from 160 mm to 230 mm and flow velocities as 175 mm/s, 206mm/s and 232 mm/s. In all total of 42 experiments were conducted. An Acoustic Doppler Velocimeter (*ADV*) was used to measure the three dimensional velocities around the pier in equilibrium scour hole after 3-4 hrs of duration of running. They showed that when piers were arranged in a group of two, factor such as spacing, sheltering, reinforcing and horseshoe vortex greatly influenced the potential formation of the equilibrium scour hole depth. The following empirical relationships to predict maximum scour depth in case where two piers placed in tandem were developed.

$$d_{sg}/b_e = 211(h/b_e)^{0.63}\left(U_\infty/\sqrt{gh}\right)^{0.85} \quad \text{for } S/b \le 1.5 \tag{7a}$$

$$d_{sf}/b = 3.61(h/b)^{0.52}\left(U_\infty/\sqrt{gh}\right)^{0.95}(S/b)^{-0.09} \quad \text{for } S/b > 1.5 \tag{7 b}$$

$$d_{sr}/b = 1.85(h/b)^{063}\left(U_\infty/\sqrt{gh}\right)^{1.16}(S/b)^{0.15} \quad \text{for } S/b > 1.5 \tag{7 c}$$

Here, d_{sg} equilibrium scour depth around pier group, d_{sf} & d_{sr} is equilibrium scour depth at front pier and rear pier respectively, *S* is the pier spacing and b_e is the effective diameter.

Mandal (2003): performed experiments on effect of stream-wise spacing of cylindrical piers on equilibrium scour depth. Three different iron pipes having diameter as 27mm, 33.5 mm and 42 mm were used as uniform cylindrical piers. Piers were arranged for two types of arrangements, viz., in-line and staggered. In the first case, the pipes were placed one behind other to represent piers of two bridges in a line. In the second case piers were placed with a staggered arrangement. On the basis of experimental study **Mandal (2003)** concluded that

(a) The equilibrium scour depth for the upstream piers is more than that of the downstream pier in case of in-line arrangement of piers.
(b) The equilibrium scour depth for the downstream piers is more than that of the upstream piers in case of staggered arrangement.
(c) As the diameter of the cylindrical piers increases the stream-wise spacing for the non-interference effect also increases. The non-interference effect of downstream piers have been noticed for pier diameter 27 mm, 33.5 mm and 42 mm as at stream-wise distance 30 *b*, 38 *b* and 44 *b* respectively.

2.2.3 Study Related To effect of stream-wise spacing of bridge piers on temporal variation of scour depth.

As already mentioned the circular bridge piers are mostly used in India for the road and railway bridges. Whereas various studies are conducted in the past for study of the scouring process and flow structure around circular bridge piers, the effect of stream wise spacing of bridge piers on the process of scour and flow structure around the circular bridge piers is not yet studied as yet in detail.

A little effort has been made to study the temporal variation of scour around the bridge piers, when these are placed in a line parallel to the direction of the flow. The significance of the temporal scour evolution rather than the equilibrium scour depth has been recently emphasized (Cardoso and Bettess, 1999; Ahmed and Rajaratnam, 2000; Melville and Coleman, 2000; Kothyari and Ranga Raju, 2001; Oliveto and Hager, 2002 and 2005; Mia and Nago, 2003; Chang et al., 2004 and Sheppard et al., 2004). Kothyari et al. (1992 a, b) were among the first to demonstrate that the temporal development of scour rather than the equilibrium scour of a peak flood constitutes the relevant design basis. The modern trend in scour investigations is therefore to study the temporal variation of scour rather than the equilibrium scour because the equilibrium scour occurs after a very long period of time. However, the flood discharge of the river is not expected to last very long.

Due to the above stated reasons there is an urgent need for investigations regarding the effect of effect of stream wise spacing on the flow pattern and temporal variation of scour depth around the circular bridge piers.

CHAPTER 3

EXPERIMENTAL SET UP AND PROCEDURE

3.1 GENERAL

Extensive data are available in literature on scour around bridge .But not much data are available for effect of stream wise spacing around the bridge pier. It is intend to study the equilibrium scour depth with temporal variation of scour depth. Keeping this in view experiment were planned and conducted in in the hydraulics laboratory of the Jaypee University. This chapter contains the description of the experimental set-up and procedure used.

3.2 DETAIL OF EXPERIMENT SET UP

3.2.1: Flume

The experiments will be conducted in a 10.0 m long, 0.75 m wide, and 0.60 m deep flume under carefully controlled conditions in the Hydraulics Laboratory of Civil Engineering, Department of Jaypee University of Information Technology Waknaghat. A working section in the flume is 3.0 m long, 0.75 m wide and 0.3 m deep, which is located 4.0 m downstream of the flume entrance. The working section will be filled with the desired sediment to the level of the flume bed. The channel view shown in fig. The water circulates in a closed loop with the help of sump pump. It follows the hydraulic circuit (3), and enters to the flume by passing through the channel inlet-basin. After the inlet basin, a type of honeycomb is provided at the upstream end of the flume to minimize the disturbance in the flow entering the flume. To make the flow parallel to the flume walls, flow straighteners are provided just downstream of the grid at the upstream end of the flume. Boulders are filled from flume entrance to 0.5 m length towards downstream to minimize the disturbance in the flow entering the flume.

An adjustable steel plate gate is provided at the downstream end of the flume to make adjustment of the depth of the flow in flume. An adjustable wooden gate is provided at the downstream end of the flume to enable adjustment of the depth of the flow in the flume. Adjustable rails and trolleys are mounted on the two walls of the flume to carry the pointer gauge and other equipment used for measurements of flow pattern, water surface and bed level.

3.2.2: Sediment

River sediment retained and passed between two successive sieves will be used in all the experiments as the sediment. Generally river bed is composed of fine sediment. The sand had a d_{50} size of 0.50mm as the sediment having relative density of 2.58.

3.2.3: Sieve analysis graph

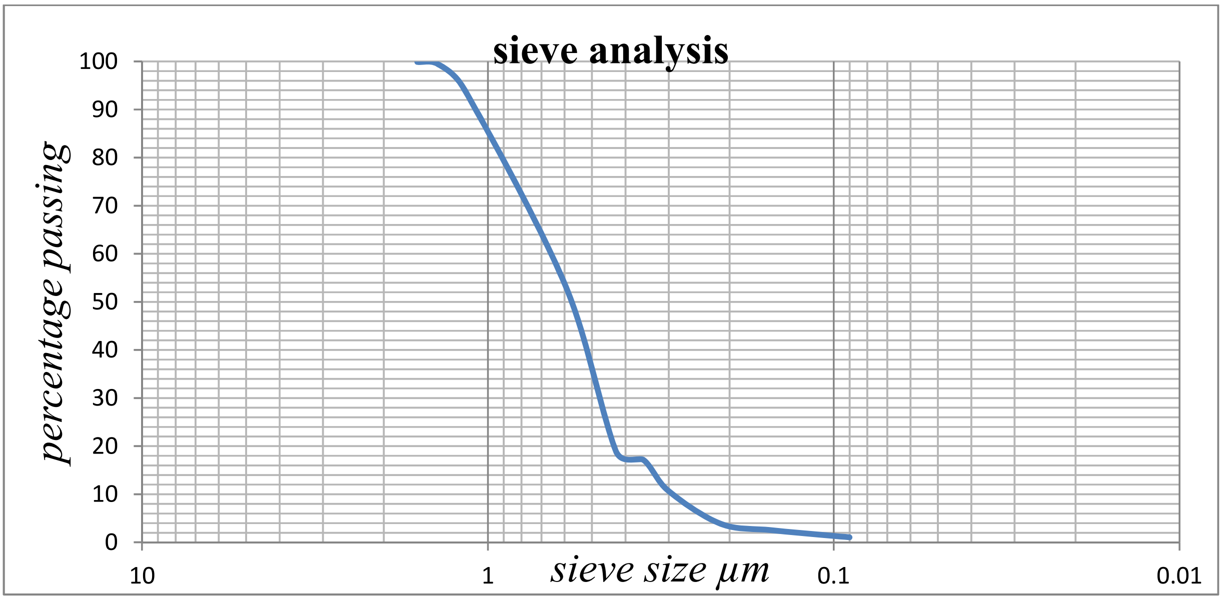

Fig 3.1 size distribution curves for the sediment used in experiment

3.2.4: Piers

The models of piers will be prepared using concrete. Large ratio of channel width (B) to pier diameter (b) ensures that flow around the pier is only due to interaction between approach flow and pier. A circular pier have diameter 11.5 cm was used as a pier model.

3.3 MEASURING INSTRUMENTS

(a) Discharge measurement

The discharge in the flume was measured with the help of orifice fitted in the inlet pipe of the flume only one value of flow discharge (Q) was used here in. Q =0.0273 m3/s.

(b) Scour depth measurement

The temporal variation of scour depth at the nose of the pier was measured using a pointer gauge with least count of 0.1mm. a digital watch used to measure the time elapsed since the beginning of the scour .The initial and final bed level were also measured with help of a pointer gauge.the experiment run time is 6 hour.

Fig 3.2 pointer gauge used for measuring scour depth

3.4 EXPERIMENTAL PROCEDURE

(a) Experimental details

The study of the temporal variation of scour depth around circular pier alone and when two pier was placed at specified spacing was conduct. In the first series of experiments, the study of the temporal variation of scour depth around circular pier will be conducted. As previously mentioned, three circular piers of uniform section having diameters 11.5 cm will be used as pier models. The sediment having particle size $d_{50} = 0.50$ mm ,flow depth 13 cm and specific gravity 2.58 will be used as sediment in all the experimental runs of this series. Clear - water scour conditions $\frac{u*}{u_c^*} = 0.97$ will be prevailed during the experiments. The two circular pier models arrangements will be inserted in the sediment bed of d_{50} = 0.50 mm respectively with specified stream –wise spacing along he direction of flow.

In the experiments, longitudinal spacing between the piers will be varied and effect of the spacing of piers on the scour depth and on flow structure will be observed. One experiment was conducted at the circular pier alone. Then two pier were placed in the working section and pier spacing between them (x/b) were varied from 3,4,5,6,9,12,14. In each experiment time variation of scour depth and scour pattern after the scour process with the help of contouring.

In all a total of 8 experiments were conducted in the present study.

Measurement of scour depth

Before the start of each run for the temporal variation of scour, the working section was filled with desired sediment and the piers will be inserted in it vertically and centrally with specified stream-wise spacing. The area around the model will be leveled, and then covered with 3 mm thick Perspex sheet.

The predetermined discharge will be allowed into the flume and when the desired flow conditions were established using tailgate and the inlet valve, the Perspex sheet will be removed carefully so that no scouring occurred around the model due to this operation. As the perplex sheets are removed the process of scour start around the piers. Theoretically, scour depth develops asymptotically with time. It is well known that scour development is rapid initially and becomes slow after a few hours. Temporal variation of scour depth at upstream nose of the pier will be measured using a pointer gauge. The geometry of scour hole will also be measured at the end of each run

CHAPTER 4

RESULT AND DISCUSSIONS

4. OBJECTIVE:

To study the effect of stream wise spacing around the circular bridge piers. To study the effect of stream wise spacing of bridge pier on scour depth and to Study related to effect of stream-wise spacing of bridge piers on temporal variation of scour depth A series of laboratory experiments were conducted in the hydraulics lab of department of civil engineering at Jaypee University of information technology .The details of which have been given in chapter are listed below. Analysis of the data collected on temporal variation of scour depth around the circular uniform pier alone and on the piers (upstream pier and down pier) when spacing between them was varied is presented in this chapter.

4.1 Scour around isolated bridge pier

In order to check the effect of stream wise spacing on the scour depth at upstream pier and down-stream pier one experiment was performed on a single bridge pier .The pier of size 11.5 cm was placed on the text section and predetermined flow condition was establish as explained in the previous chapter. The time variation of scour depth was monitored at the nose of the pier at regular time interval. The experiment was run for a period of 6 hour fig show the geometry of the scour hole for single pier .It has been observed during the past as well as in the present study that for the case of circular pier, the deepest scour hole occurred in the pier front and side while wake scour was much smaller in depth. The deepest scour depth was measure at the nose and it was equal to 9.9 cm.

4.2 Effect of stream wise spacing on scour depth:

In order to check the effect of stream wise spacing on the scour depth at upstream pier and down-stream pier the variation of the center to center distance between the pier change. The distance changed to multiply the diameter of size of pier to spacing(x/d). The spacing varies 3d, 4d, 5d .6d.9d.12d.14d. The changing the distance between front pier and rear pier changed the scour depth of two piers which is placed in tandem. The effect of rear pier is maximum when the spacing between the piers is 3d.

The main objective of the recent work to study the effect of stream wise spacing of the bridge pier on scour depth so in order to determine the effect of pier spacing between the two pier were changed systematically in the direction of flow .Stream wise spacing between piers was varied 3,4,5,6,9,12,14 the pier diameter.

4.3 The temporal variation of the scour depth was studied around the bridge pier models.

The temporal variation of scour depth is the measurement of scouring occur during the flow of discharge and take reading both piers after certain time interval i.e. 2 m ,5 m,10 m,15 m,30 m.24 m,60 m,90 m,120 m,150 m,180 m,210 m,240 m,270 m,300 m,330 m,360 total 6 hour run time of discharge in each experiment. The graph show the temporal variation of scour depth around the bridge pier model.

Table 4.1: show the variation between pier spacing and scour depth

Experiment no	Spacing (x/b)	scour front pier ds (mm)	scour rear pier ds (mm)	scour depth at front pier /scour depth at single pier	scour depth at rear pier /scour depth at single pier
1		9.9		-	-
2	3d	11.2	5.9	0.948	0.556
3	4d	10.9	5.9	1.043	0.391
4	5d	10.9	5	1.093	0.458
5	6d	10.8	4.8	1.028	0.457
6	9d	10.7	3.8	1.046	0.546
7	12d	10.7	3.5	0.946	0.566
8	14d	9.8	3.1	0.850	0.364

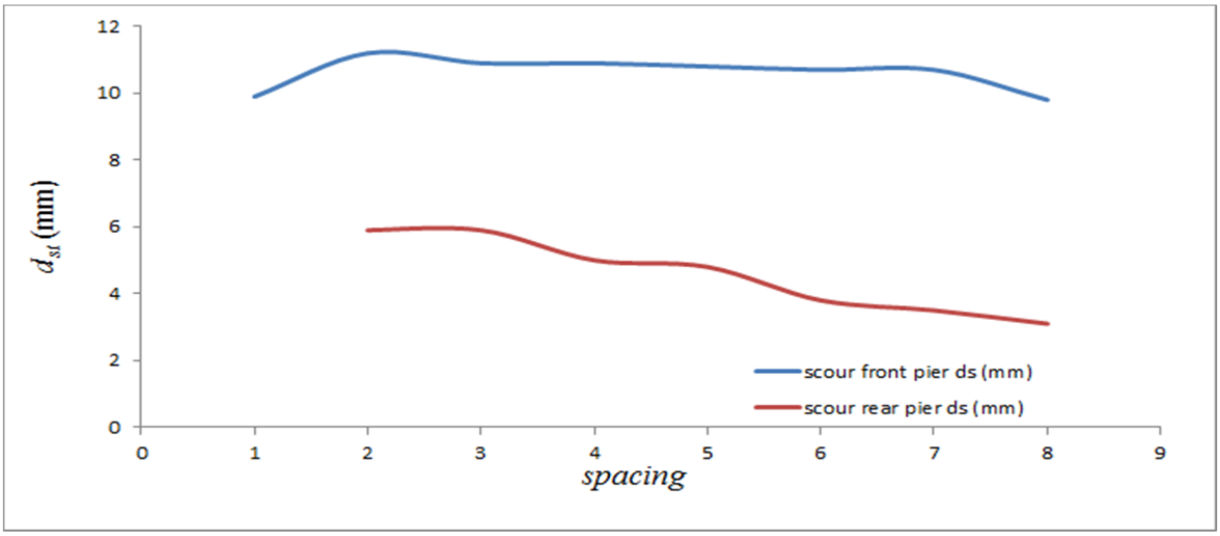

Fig 4.2: scour depth for two plies in line as function of pile spacing.Figure show the temporal variation of scour depth at both the pier for X/b=3,4,5,6,9,12,14.in all the experiment run the scour depth at the rear pier was observed less than that is was observed .more over scour depth observed at rear pier was less than that is was observed at front pier .from the fig 4.6 it is observed that for X/b≤3d .

CONCLUSIONS

Scour around bridge pier is one of the main causes of the bridge failure. In the present work effect of stream wise spacing of circular pier on scour mechanism and scour depth has been studied through laboratory experiment

The temporal variation of scour depth around the upstream and downstream circular piers were noticed by varying the stream wise spacing among the bridge pier from 3,4,5,6,9,12and 14 times the pier diameter.

It is observed that while value X/b ≤3 the influence of the rear pier on the front pier was observed.it is noticed that the scour depth at the front pier is increased by 13 % than that was noticed at isolated bridge pier from ,4,5,6,9,12,14.the effect of rear pier diminish as per spacing between the pier increase above 12

The geometry of scour hole for both the pier at *X/b*=9 reveals that both the piers have independent scour hole and thus there is no mutual interference of piers beyond the pier spacing of 9.

Maximum scour depth at front pier was increased by 13 % if pier spacing is 3 to 9 times the pier diameter. The maximum scour depth of the rear pier is reduced to around 20% for all spacing.

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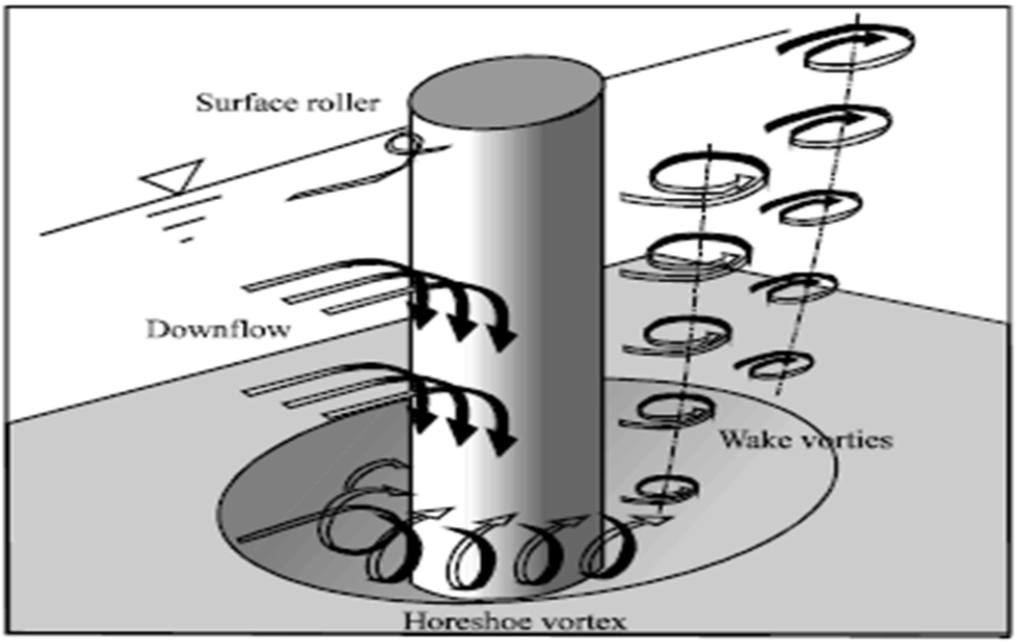

Fig 1.1: Mechanism of scour (Raudkivi,1990)

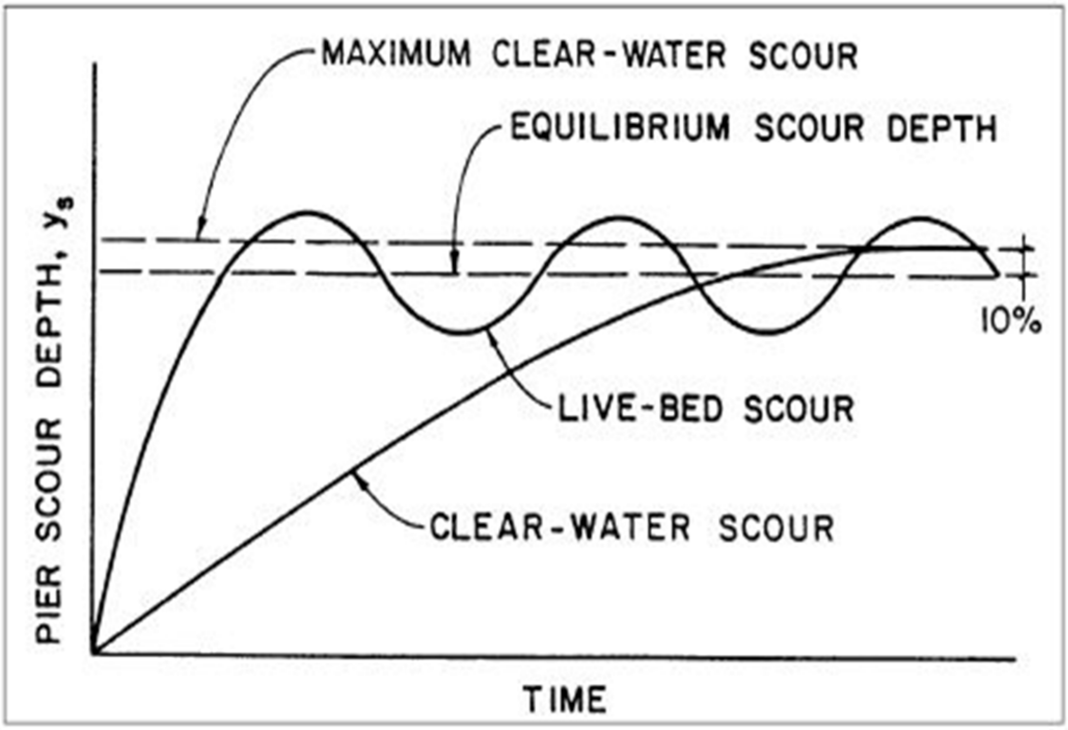

Fig 1.2: Typical variation of scour depth with time for two case (Shen,1971)

Table 3.1: Sieve analysis

Sr. no	**Sieve size**	**Retained weight (g)**	**Retained %**	**Cumulative weight (g)**	**Cumulative %**	**Pass %**
1	1.6	1	0.1	1	0.1	99.9
2	1.4	3.5	0.35	4.5	0.45	99.5
3	1.18	49	4.9	53.5	5.35	94.65
4	0.6	409	40.9	462.5	46.25	53.75
5	0.425	350.5	35.05	813	81.25	18.75
6	0.355	16.5	1.6	829.5	82.25	17.15
7	0.3	65.5	6.5	895	89.35	10.65
8	0.212	68	6.8	963	96.15	3.85
9	0.15	14	1.4	977	97.5	2.5
10	0.09	11.5	1.4	988.5	98.95	1.05
11	sum		1.15	989.65	100.1	0

Table 3.2 (a) Scour depth estimation parameter and their calculated value

time (hour)	**ds(f) m**	**ds(r) m**	**Q(m3/s)**	**h(m)**	**d50(mm)**	**u***
6	0.099		0.0273	0.13	0.00055	0.0165
6	0.112	0.059	0.0273	0.13	0.00055	0.0165
6	0.112	0.054	0.0273	0.13	0.00055	0.0165
6	0.109	0.05	0.0273	0.13	0.00055	0.0165
6	0.108	0.042	0.0273	0.13	0.00055	0.0165
6	0.107	0.038	0.0273	0.13	0.00055	0.0165
6	0.105	0.035	0.0273	0.13	0.00055	0.0165
6	0.097	0.031	0.0273	0.13	0.00055	0.0165

Table 3.2(b)

u*/u*c	**b (m)**	**slope**	**spacing(x/d)**	**u m/s**	**Uc**	**Froude number**
0.972	0.113	0.000214	0	0.28	0.2781	0.248
0.972	0.113	0.000214	0.349	0.28	0.2781	0.248
0.972	0.113	0.000214	0.46	0.28	0.2781	0.248
0.972	0.113	0.000214	0.575	0.28	0.2781	0.248
0.972	0.113	0.000214	0.69	0.28	0.2781	0.248
0.972	0.113	0.000214	1.035	0.28	0.2781	0.248
0.972	0.113	0.000214	1.38	0.28	0.2781	0.248
0.972	0.113	0.000214	1.61	0.28	0.2781	0.248

Table 3.2(c)

ds/b (f)	**h/b**	**b/h**	**d50/h**	**x/b**	**d***	**ds/b(r)**
0.876	1.150	0.869	0.0042	0	29.54	0
0.991	1.150	0.869	0.0042	3.088	29.54	0.522
0.991	1.150	0.869	0.0042	4.070	29.54	0.477
0.964	1.150	0.869	0.0042	5.088	29.54	0.442
0.955	1.150	0.869	0.0042	6.106	29.54	0.371
0.946	1.150	0.869	0.0042	9.159	29.54	0.336
0.929	1.150	0.869	0.0042	12.212	29.54	0.309
0.858	1.150	0.869	0.0042	14.247	29.54	0.274

Table 3.3: Temporal variation data for experiment isolated pier

Time (m)	**Bed level (cm)**	**Reading isolated pier (cm)**	**Scouring (cm)**
0	86.5	86.5	0
2	86.5	85.3	0.2
5	86.5	83.7	2.8
10	86.5	82.5	4
15	86.5	81.9	4.6
30	86.5	80.3	6.2
45	86.5	80.1	6.4
60	86.5	79.2	7.3
90	86.5	78.1	8.4
120	86.5	77.4	9.1
150	86.5	77.1	9.4
180	86.5	76.9	9.6
210	86.5	76.9	9.6
240	86.5	76.8	9.7
270	86.5	76.6	9.8
300	86.5	76.5	9.9

Table 3.4: Temporal variation data for 3d spacing

Time (m)	**Bed level (cm)**	**Reading front pier (cm)**	**Scouring (cm)**	**Reading rear pier (cm)**	**Scouring (cm)**
0	85.7	85.7	0	85.7	0
2	85.7	83.4	2.3	84.2	1.5
5	85.7	82.1	3.6	85.3	1.4
10	85.7	81	4.7	84.6	1.1
15	85.7	80.1	5.6	84.7	1
30	85.7	79.5	6.2	83.8	1.9
45	85.7	79.2	6.5	83.9	1.8
60	85.7	78.7	7	83.8	1.9
90	85.7	78.3	7.4	83.4	2.3
120	85.7	77.8	7.9	82.9	2.8
150	85.7	77.2	8.5	82.2	3.5
180	85.7	76.7	9	81.6	4.1
210	85.7	76.2	9.5	81.2	4.5
240	85.7	75.7	10	80.8	4.9
270	85.7	75.3	10.4	80.5	5.2
300	85.7	74.9	10.8	80.2	5.5
330	85.7	74.7	11	80	5.7
360	85.7	74.5	11.2	79.8	5.9

Table 3.5: Temporal variation data for 4d spacing

Time (m)	**Bed level (cm)**	**Reading front pier (cm)**	**Scouring (cm)**	**Reading rear pier (cm)**	**Scouring (cm)**
0	85.7	85.7	0	85.7	0
2	85.7	83.4	2.3	85.1	0.6
5	85.7	82.4	3.3	84.5	1.2
10	85.7	82	3.7	83.6	2.1
15	85.7	81.7	4	83.3	2.4
30	85.7	80.3	5.4	83	2.7
45	85.7	79.2	6.5	82.8	2.9
60	85.7	78.8	6.9	82.5	3.2
90	85.7	77.9	7.8	82.7	3
120	85.7	77.4	8.3	81.9	3.8
150	85.7	77	8.7	81.8	3.9
180	85.7	76.6	9.1	81.5	4.2
210	85.7	76.2	9.5	81.2	4.5
240	85.7	75.8	9.9	80.8	4.9
270	85.7	75.4	10.3	80.5	5.2
300	85.7	75.3	10.4	80.2	5.5
330	85.7	75	10.7	80	5.7
360	85.7	74.8	10.9	79.8	5.9

Table 3.6: Temporal variation data for 5d spacing

Time (m)	**Bed level (cm)**	**Reading front pier (cm)**	**Scouring (cm)**	**Reading rear pier (cm)**	**Scouring (cm)**
0	85.7	85.7	0	85.7	0
2	85.7	82.4	3.3	84.3	1.4
5	85.7	81.4	4.3	83.7	2
10	85.7	80.9	4.8	83.2	2.5
15	85.7	80.8	4.9	83	2.7
30	85.7	79.5	6.2	82	3.7
45	85.7	78.8	6.9	81.4	4.3
60	85.7	78	7.7	82.3	3.4
90	85.7	77.5	8.2	82.2	3.5

120	85.7	77.2	8.5	81.9	3.8
150	85.7	76.5	9.2	80.7	5
180	85.7	75.9	9.8	80.8	4.9
210	85.7	75.4	10.3	81.5	4.2
240	85.7	75.3	10.4	81.2	4.5
270	85.7	75.1	10.6	81.1	4.6
300	85.7	75.2	10.5	80.9	4.8
330	85.7	75	10.7	80.8	4.9
360	85.7	74.8	10.9	80.7	5

Table 3.7: Temporal variation data for 6d spacing

Time (m)	**Bed level (cm)**	**Reading front pier (cm)**	**Scouring (cm)**	**Reading rear pier (cm)**	**Scouring (cm)**	
0	85.7	85.7	0	85.7	0	
2	85.7	82.6	3.1	83.4	2.3	
5	85.7	81.4	4.3	83.3	2.4	
10	85.7	80.9	4.8	83.8	1.9	
15	85.7	80.6	5.1	82.5	3.2	
30	85.7	79.6	6.1	82.2	3.5	
45	85.7	79.1	6.6	82	3.7	
60	85.7	78.3	7.4	81.8	3.9	
90	85.7	78.1	7.6	82	3.7	
120	85.7	77.5	8.2	82	3.7	
150	85.7	76.9	8.8	81.7	4	
180	85.7	75.6	10.1	81	4.7	
210	85.7	75.4	10.3	80.7	5	
240	85.7	75.2	10.5	80.5	5.2	
270	85.7	75	10.7	81.3	4.4	

300	85.7	74.9	10.8	81.1	4.6	
330	85.7	74.9	10.8	80.9	4.8	
360	85.7	75.2	10.5	81.3	4.4	

Table 3.8: Temporal variation data for 9d spacing

Time (m)	**Bed level (cm)**	**Reading front pier (cm)**	**Scouring (cm)**	**Reading rear pier (cm)**	**Scouring (cm)**	
0	85.7	85.7	0	85.7	0	
2	85.7	82.1	3.6	84.2	1.5	
5	85.7	81.4	4.3	83.7	2	
10	85.7	80.1	5.6	82.6	3.1	
15	85.7	79.3	6.4	80.6	5.1	
30	85.7	78.8	7.6	80.9	4.8	
45	85.7	78.1	7.9	80.6	5.1	
60	85.7	77.8	8.2	80.9	4.8	
90	85.7	77.5	8.8	81.3	4.4	
120	85.7	76.9	9.1	81.2	4.5	
150	85.7	76.6	9.5	81.5	4.2	
180	85.7	76.2	9.9	81.6	4.1	
210	85.7	75.8	10.2	81.8	3.9	
240	85.7	75.5	10.4	81.7	4	
270	85.7	75.3	10.6	81.6	4.1	
300	85.7	75.1	10.6	81.7	4	

330	85.7	75.1	10.7	81.8	3.9	
360	85.7	75	10.7	81.9	3.8	

Table 3.9: Temporal variation data for 12d spacing

Time (m)	**Bed level (cm)**	**Reading front pier (cm)**	**Scouring (cm)**	**Reading rear pier (cm)**	**Scouring (cm)**	
0	85.7	85.7	0	85.7	0	
2	85.7	83.1	2.6	84.3	1.4	
5	85.7	81.2	4.5	82.6	3.1	
10	85.7	80.5	5.2	82.4	3.3	
15	85.7	79.4	6.3	82	3.7	
30	85.7	78.9	6.8	81.5	4.2	
45	85.7	78.2	7.5	81	4.7	
60	85.7	77.8	7.9	80.3	5.4	
90	85.7	76.6	9.1	80.5	5.2	
120	85.7	76.1	9.6	79.9	5.8	
150	85.7	75.6	10.1	80.2	5.5	
180	85.7	75.5	10.2	80.6	5.1	
210	85.7	75.5	10.2	80.9	4.8	
240	85.7	75.3	10.4	81.3	4.4	
270	85.7	75.2	10.5	81.7	4	
300	85.7	75	10.7	81.9	3.8	

330	85.7	75	10.7	82	3.7	
360	85.7	75	10.7	82.2	3.5	
			11.3	79.8	5.9	

Table 3.10: Temporal variation data for 14d spacing

Time (m)	**Bed level (cm)**	**Reading front pier (cm)**	**Scouring (cm)**	**Reading rear pier (cm)**	**Scouring (cm)**	
0	85.7	85.7	0	85.7	0	
2	85.7	82	3.7	83.3	2.4	
5	85.7	81.5	4.2	83.1	2.6	
10	85.7	80.2	5.5	82.6	3.1	
15	85.7	80.1	5.6	82.5	3.2	
30	85.7	79.4	6.3	82.9	2.8	
45	85.7	78.8	6.9	83.3	2.4	
60	85.7	78.2	7.5	81.9	3.8	
90	85.7	78.1	7.6	82	3.7	
120	85.7	77.4	8.3	82.4	3.3	
150	85.7	77.1	8.6	82.1	3.6	
180	85.7	76.9	8.8	82.2	3.5	
210	85.7	76.9	8.8	82.3	3.4	
240	85.7	76.8	8.9	82.3	3.4	
270	85.7	76.6	9.1	82.3	3.4	
300	85.7	76.3	9.4	82.2	3.5	
330	85.7	76.1	9.6	82.5	3.2	
360	85.7	75.9	9.8	82.6	3.1	

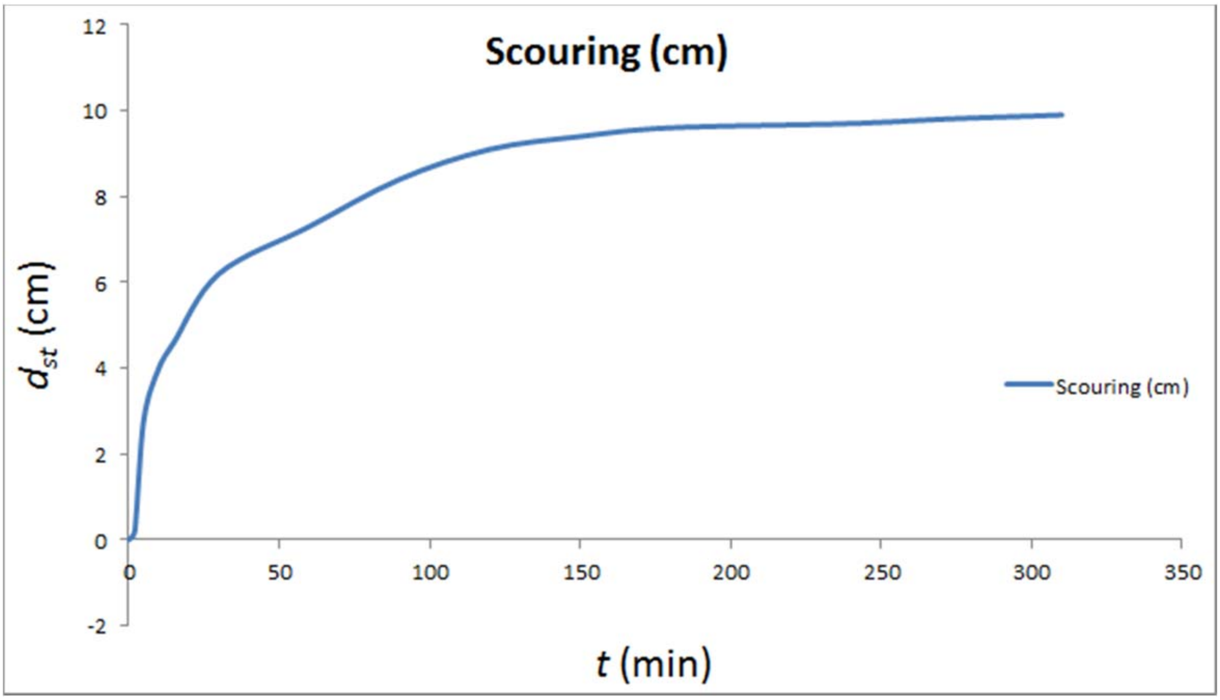

Fig.4.1 Temporal variation for isolated circular bridge pier

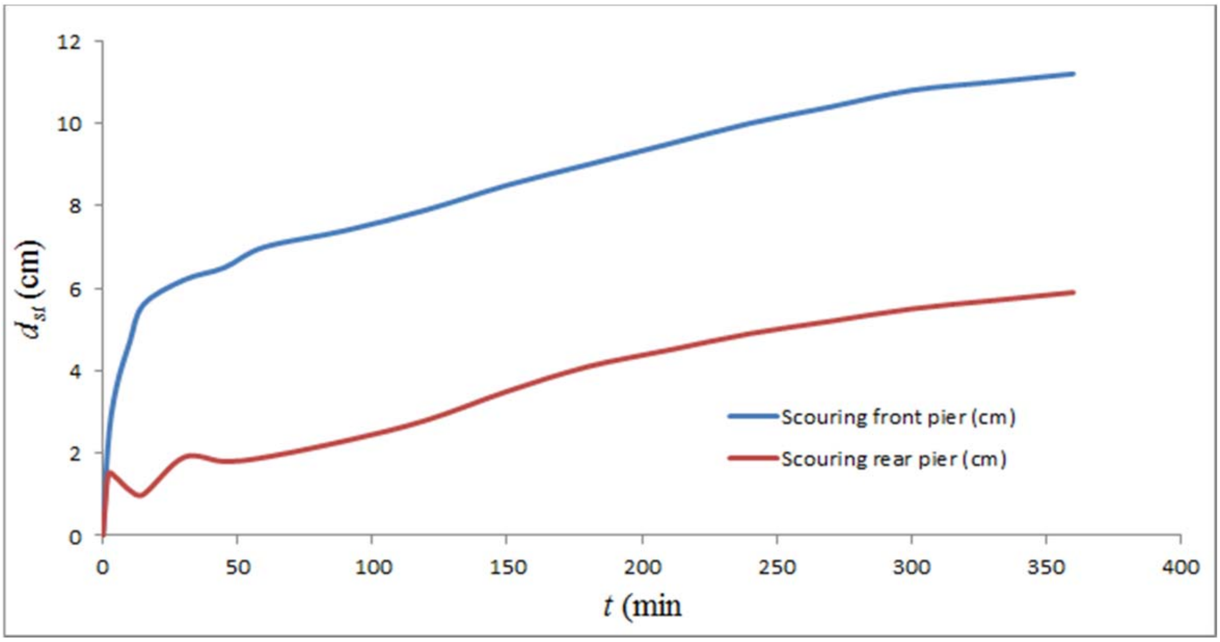

Fig no 4.2: Temporal variation for experiment x/b=3

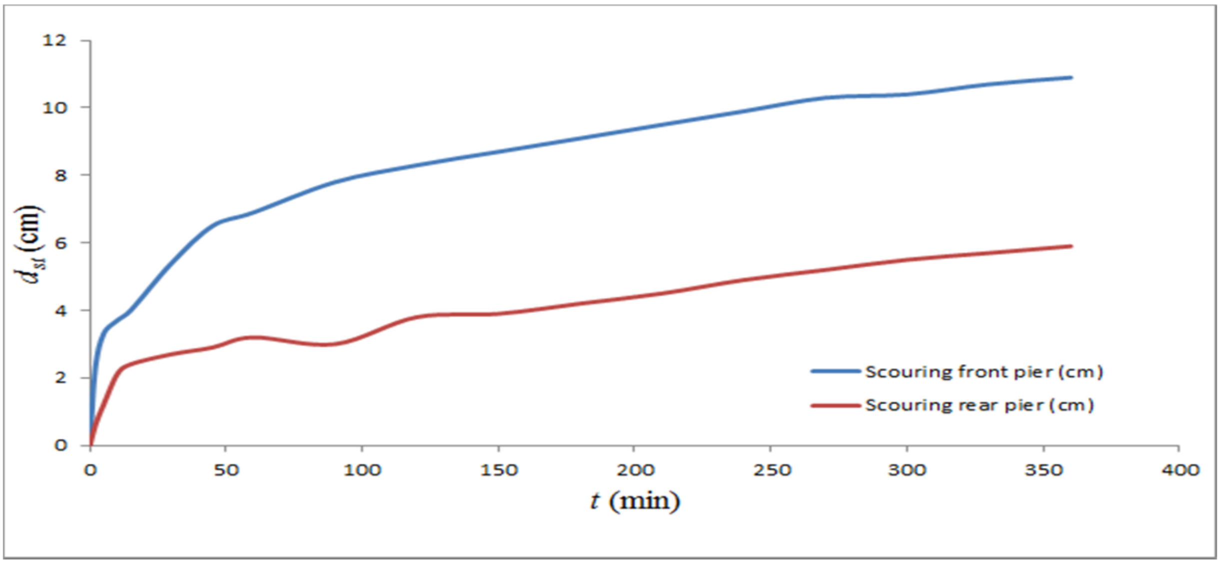

Fig no 4.3: Temporal variation for experiment x/b=4

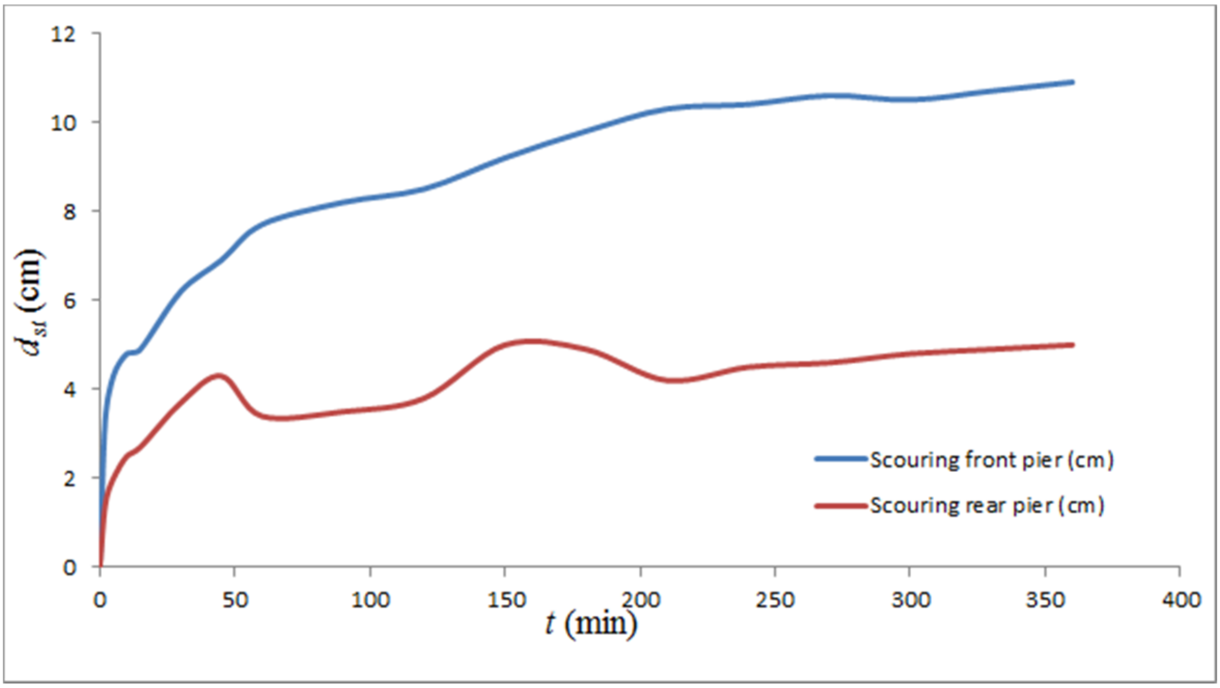

Fig no 4.4: Temporal variation for experiment x/b=5

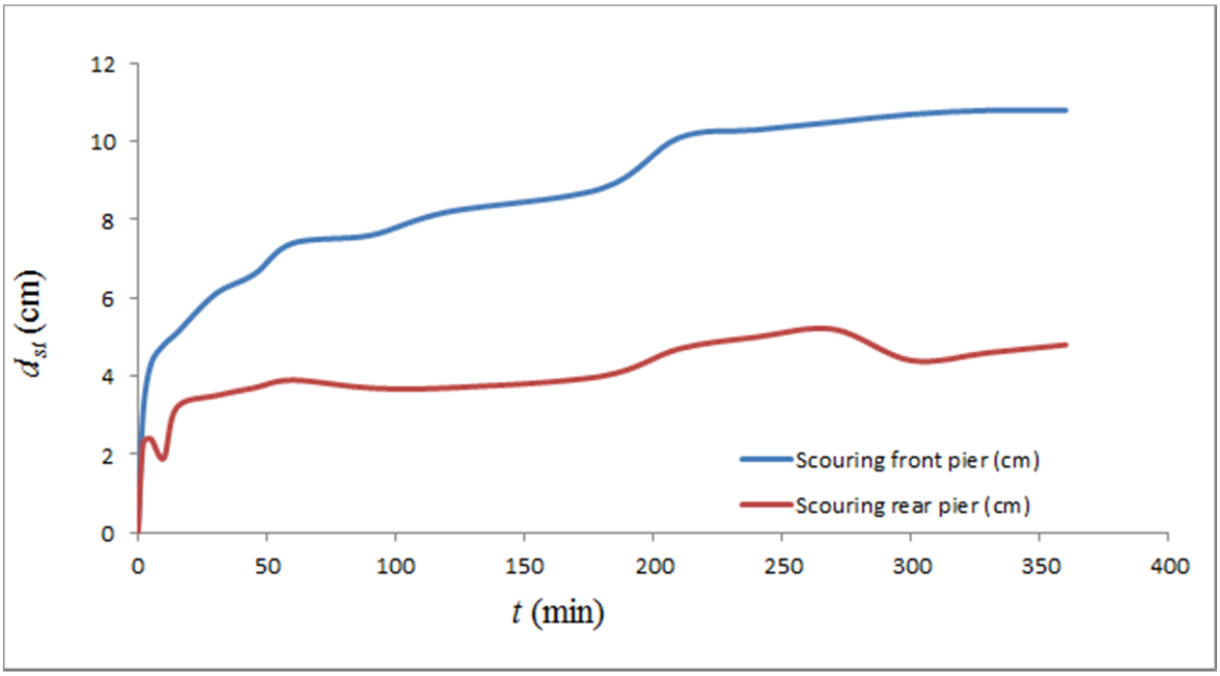

Fig no 4.5: Temporal variation for experiment x/b=6

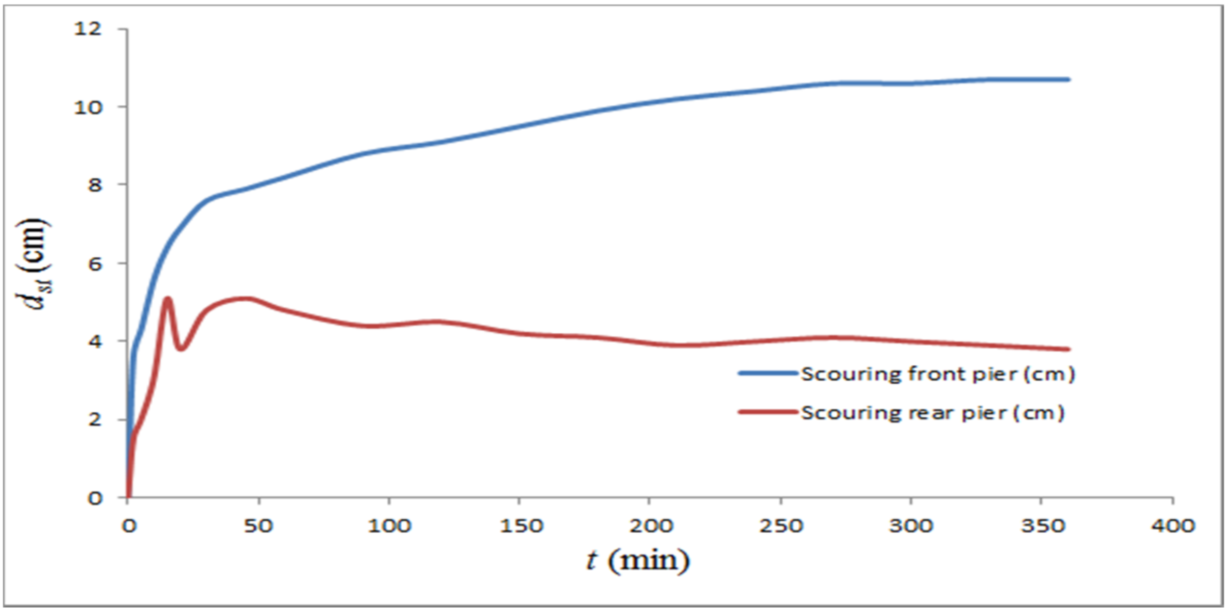

Fig no 4.6: Temporal variation for experiment x/b=9

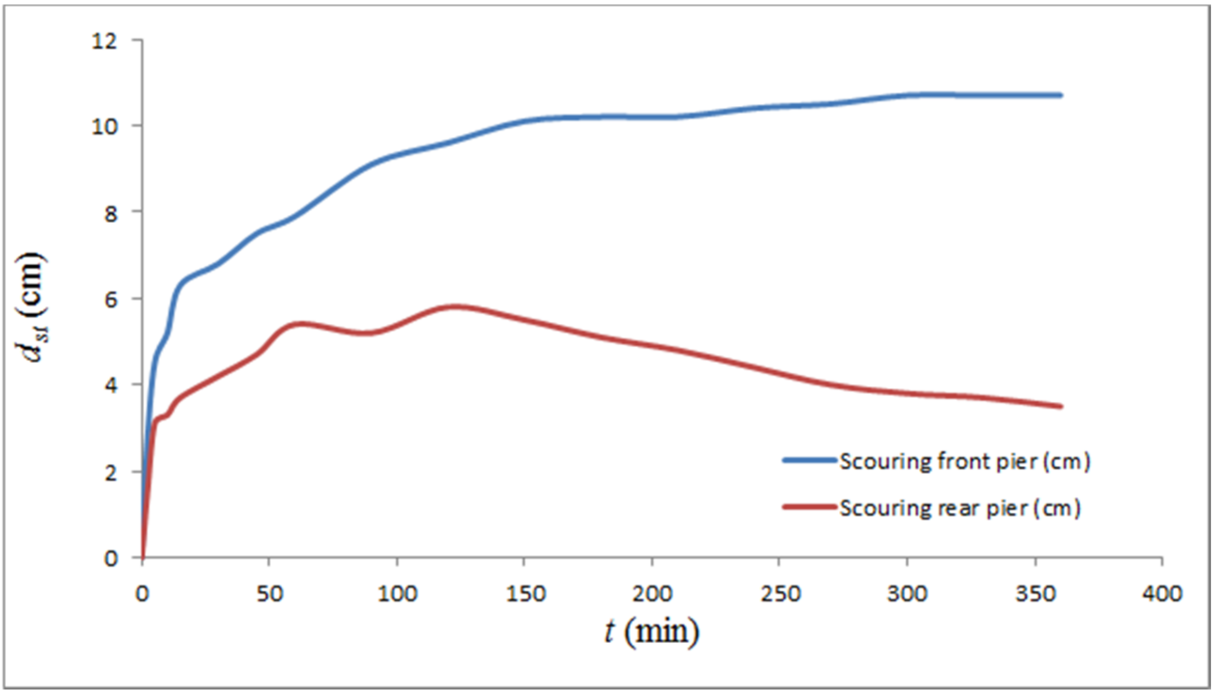

Fig no 4.7: Temporal variation for experiment x/b=12

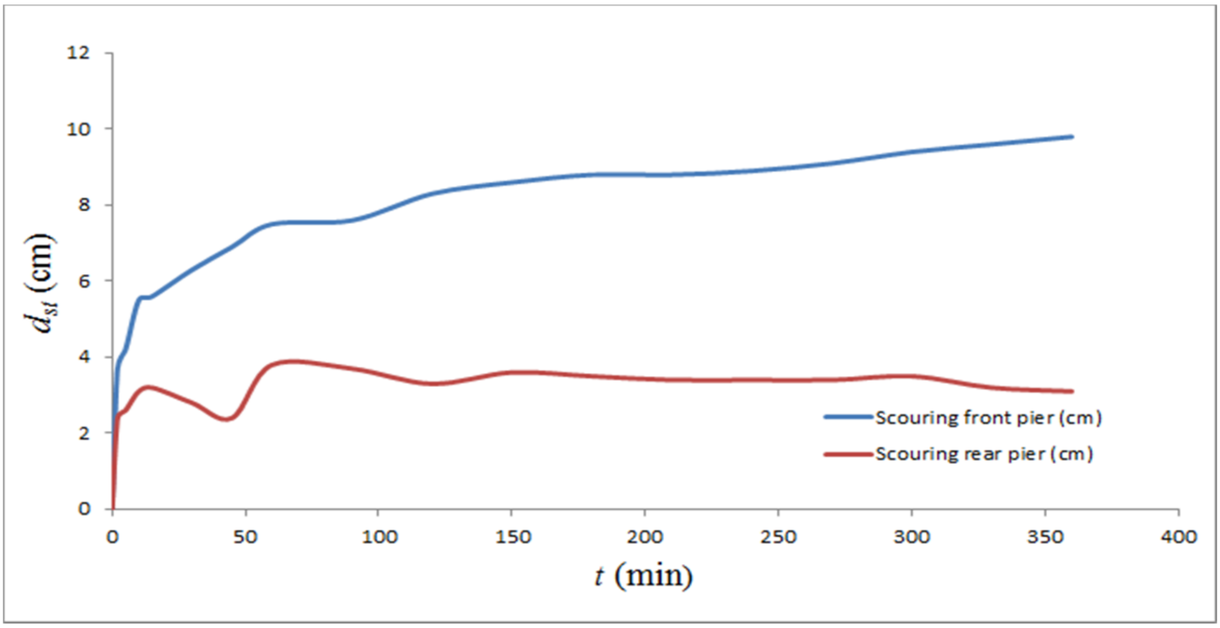

Fig no 4.8: Temporal variation for experiment x/b=14

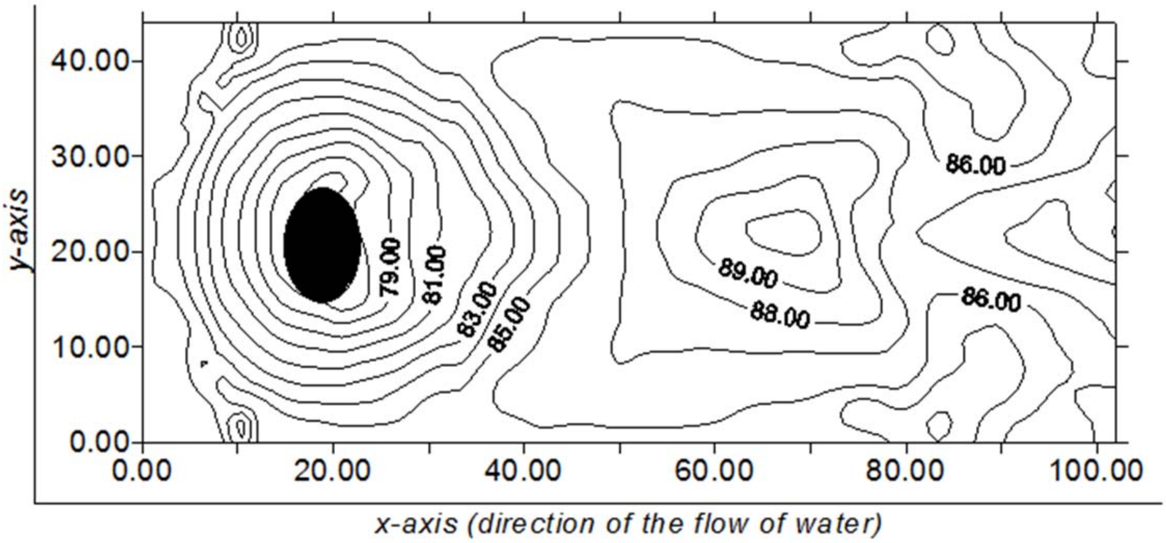

Fig no 4.9: Contour map of scour depth for isolated pier

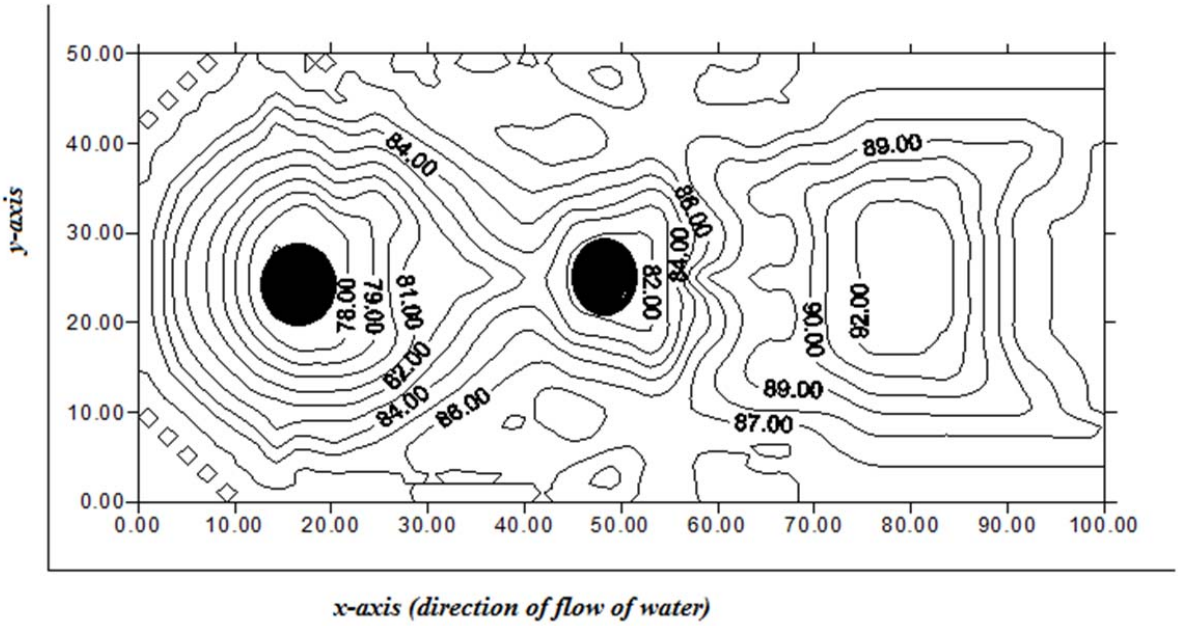

Fig 4.10: Contour map of scour depth for both piers (upstream and downstream) at a spacing of 3 times the pier diameter

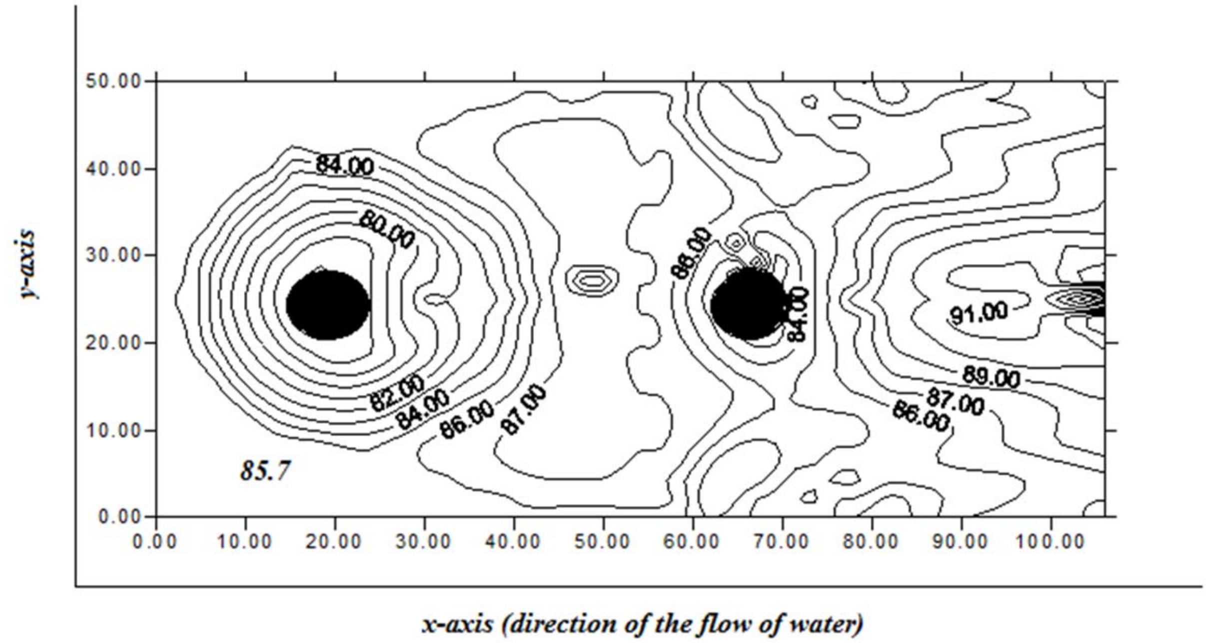

Fig no 4.11: Contour map of scour depth for both piers (upstream and downstream) at a spacing of 4 times the pier diameter

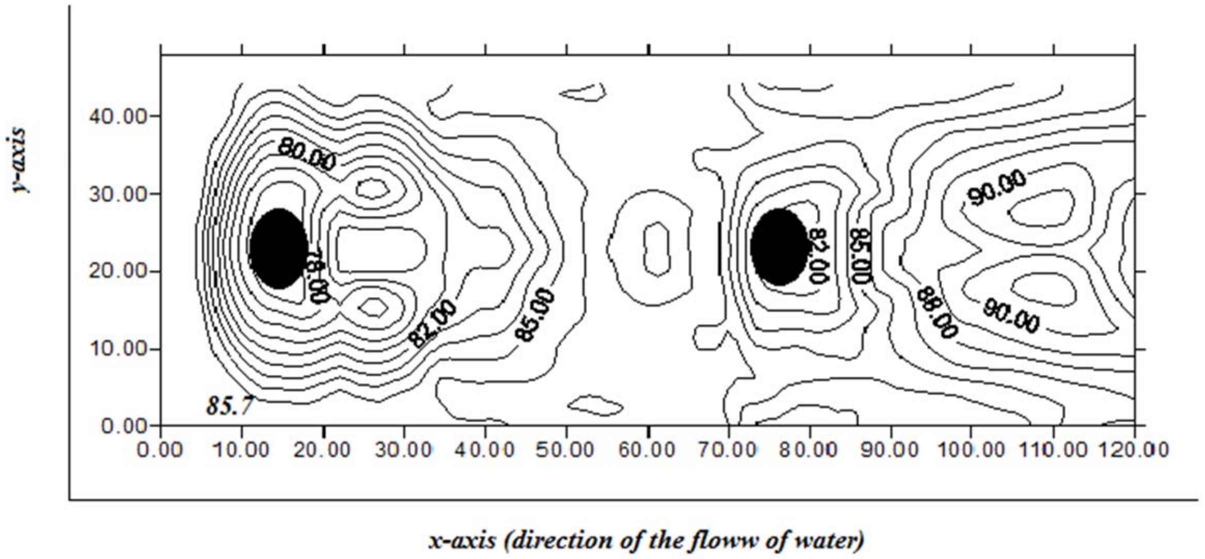

Fig 4.12: Contour map of scour depth for both piers (upstream and downstream) at a spacing of

5 times the pier diameter

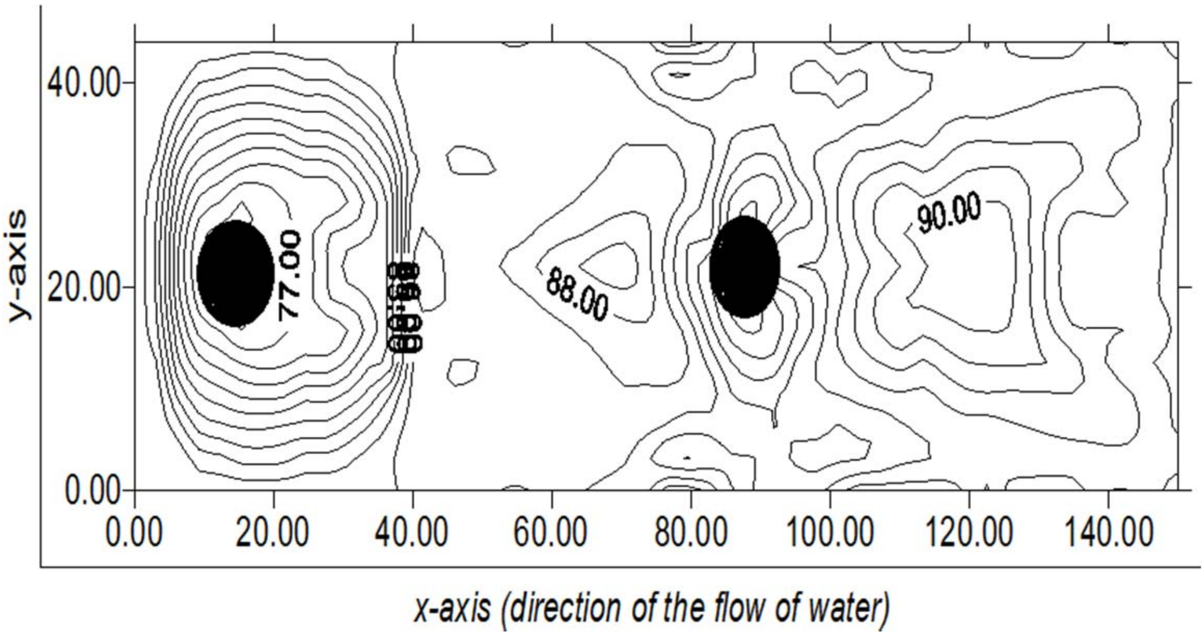

Fig 4.13: Contour map of scour depth for both piers (upstream and downstream) at a spacing of 6 times the pier diameter

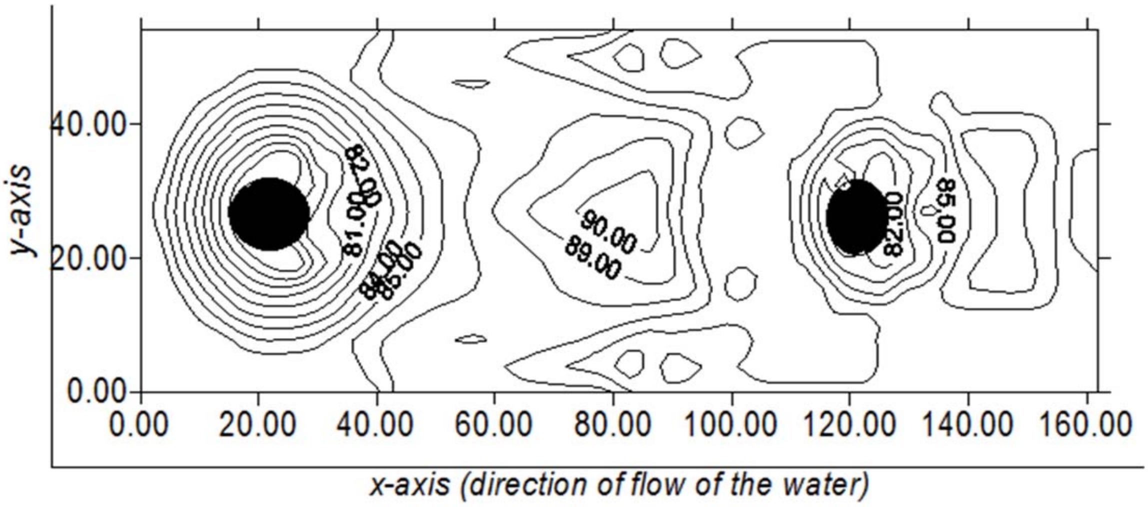

Fig 4.14: Contour map of scour depth for both piers (upstream and downstream) at a spacing of 9 times the pier diameter

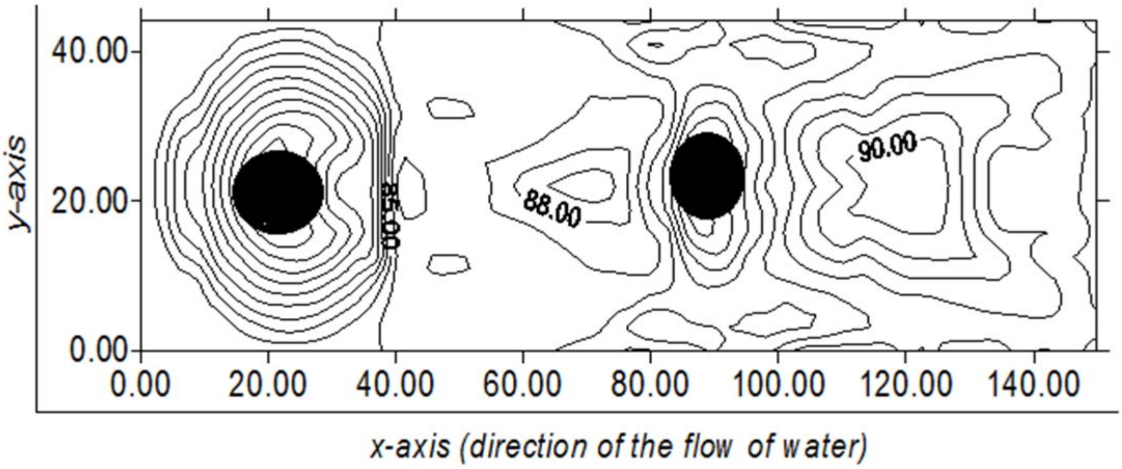

Fig 4.15: Contour map of scour depth for both piers (upstream and downstream) at a spacing 12 times the pier diameter

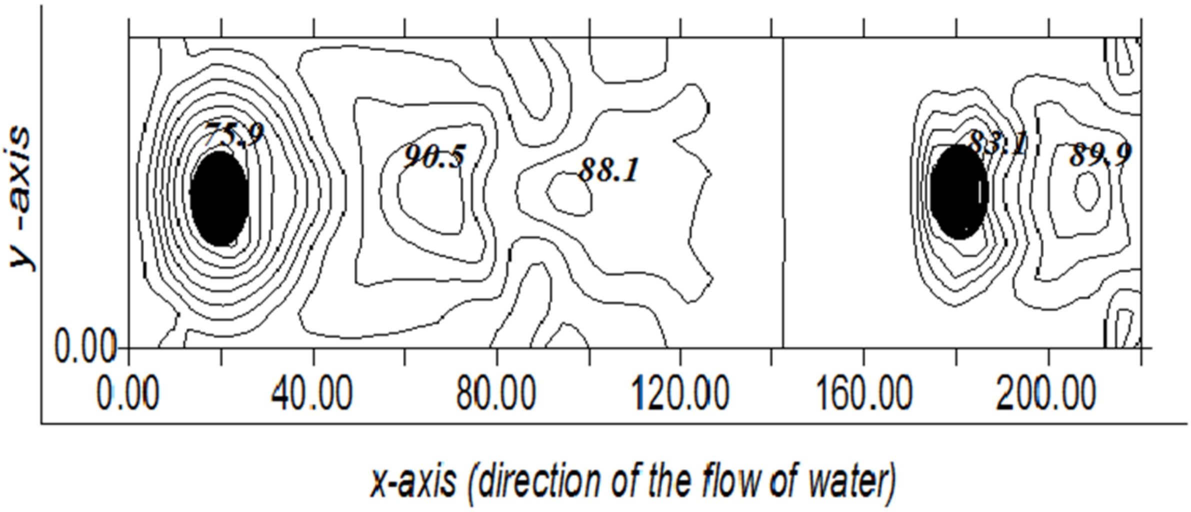

Fig 4.16: Contour map of scour depth for both piers (upstream and downstream) at a spacing of 14 times the pier diameter

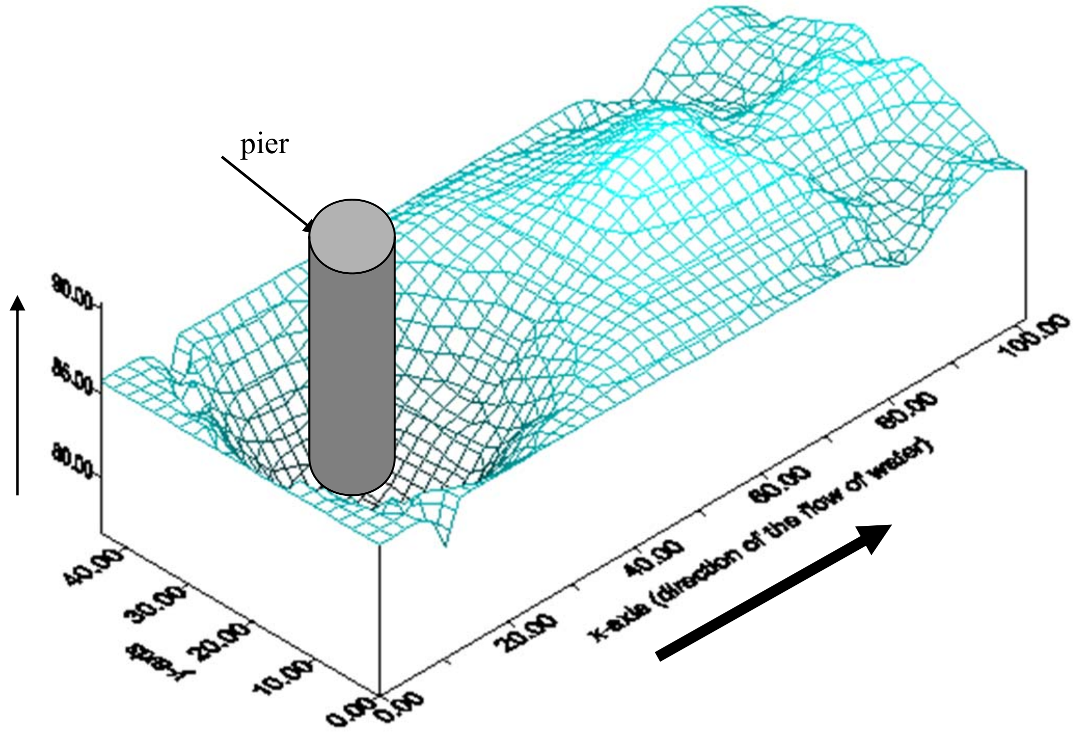

Fig 4.17: 3d map of scour depth for isolated pier

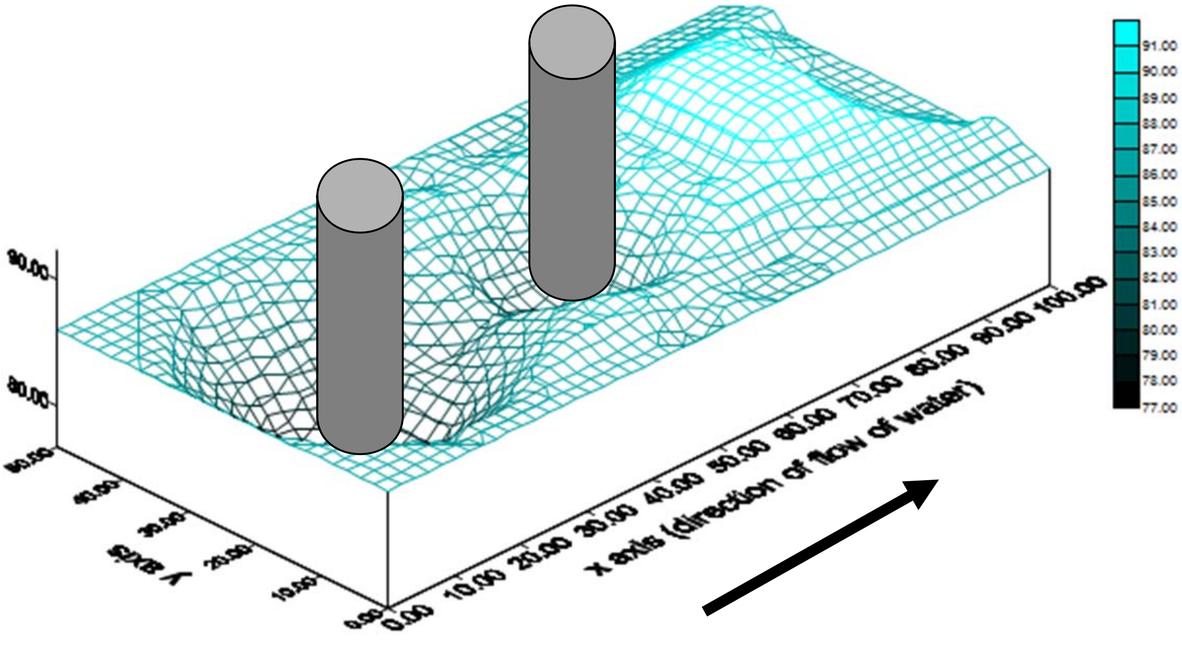

Fig 4.18: 3d map of scour depth for both piers (upstream and downstream) at a spacing of 3 times the pier diameter

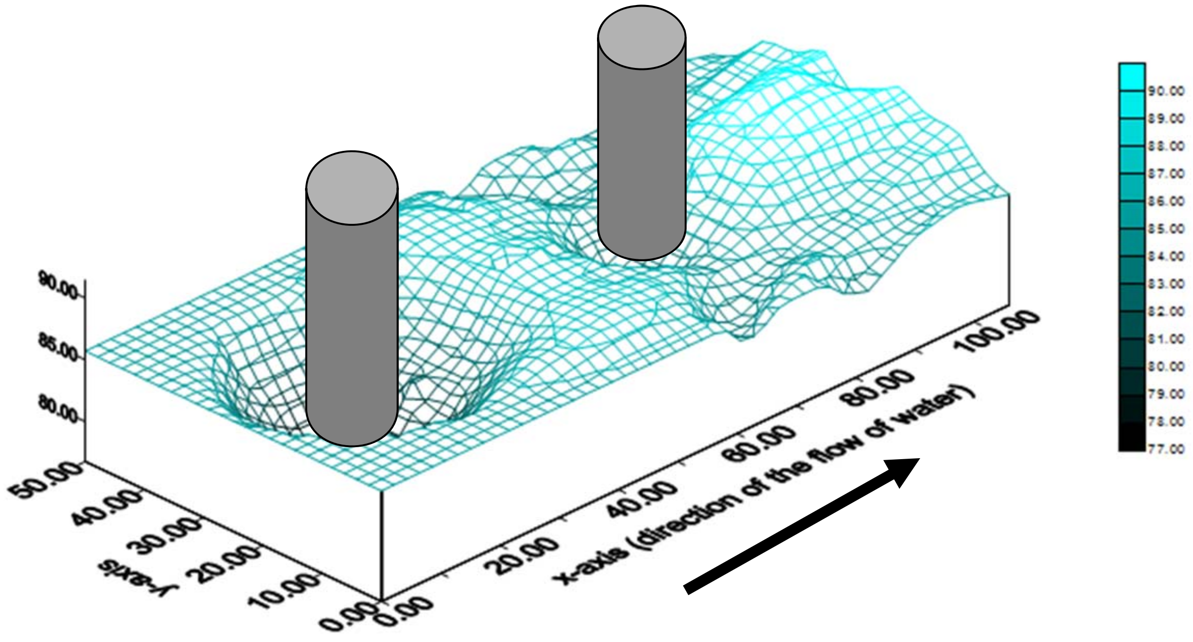

Fig 4.19: 3d map of scour depth for both piers (upstream and downstream) at a spacing of 4 times the pier diameter

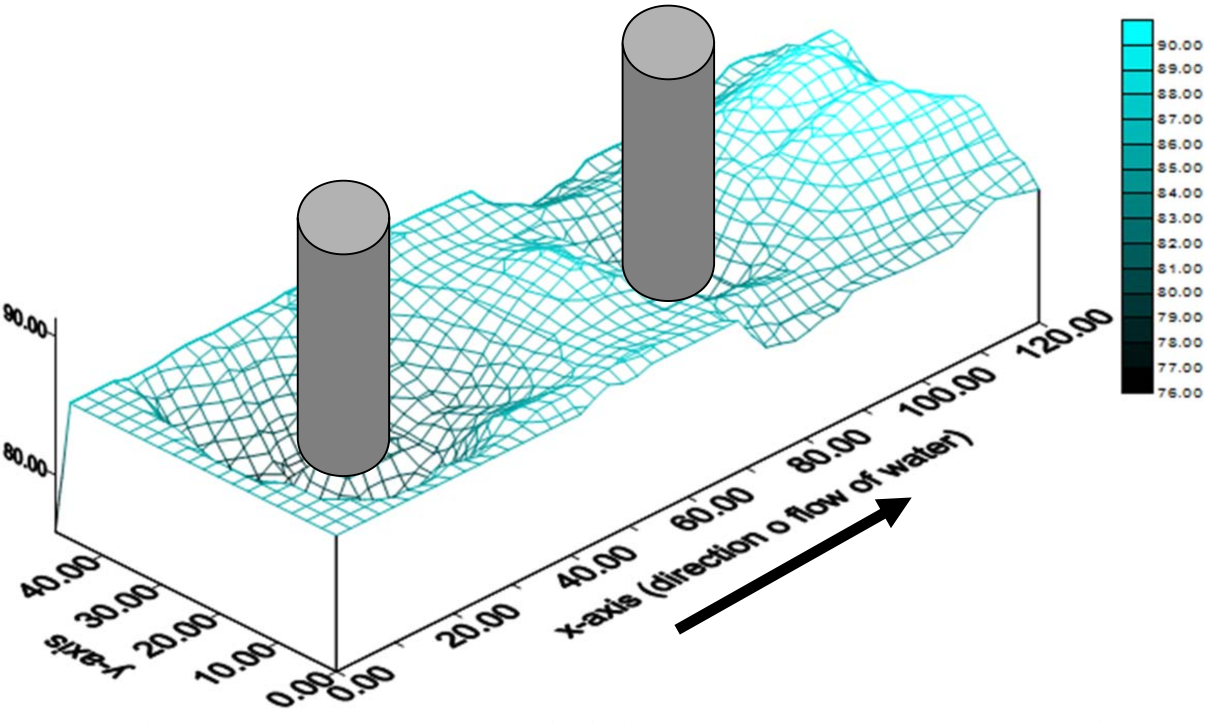

Fig 4.20: 3d surface map of scour depth for both piers (at a spacing of 5 times the pier diameter

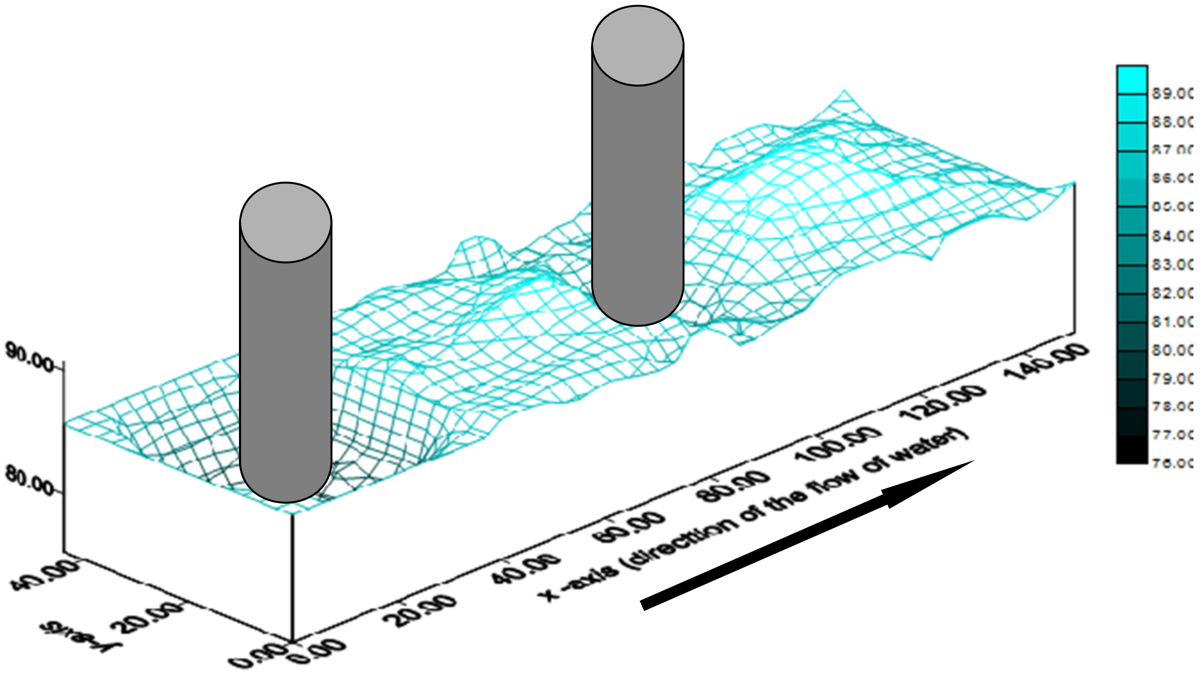

Fig 4.21: 3d surface map of scour depth for both piers (upstream and downstream) at a spacing of 6 times the pier diameter

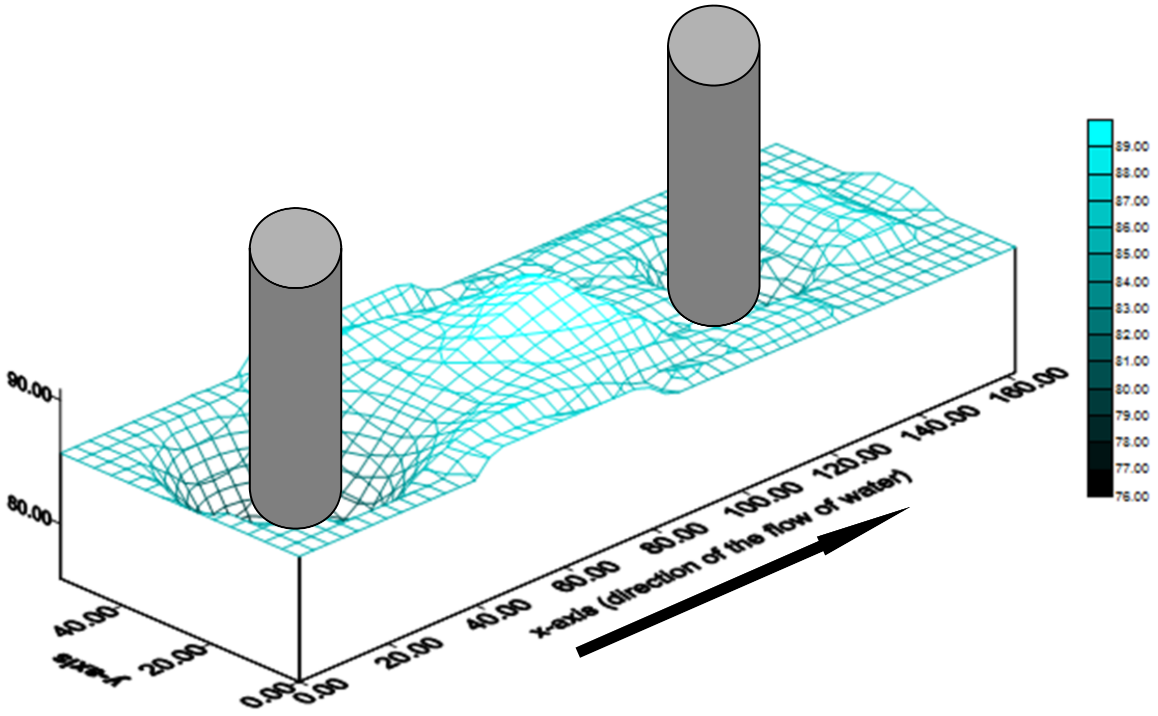

Fig 4.22: 3d map of scour depth for both piers (upstream and downstream) at a spacing of 9 times the pier diameter

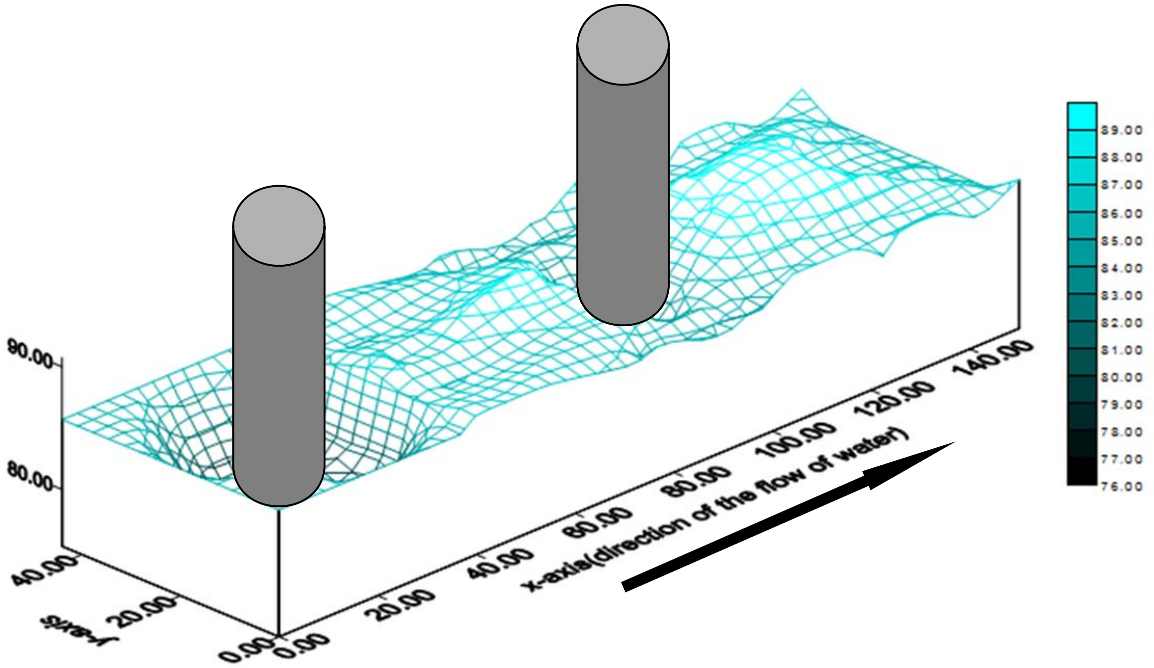

Fig 4.23: 3d map of scour depth for both piers (upstream and downstream) at a spacing of 12 times the pier diameter

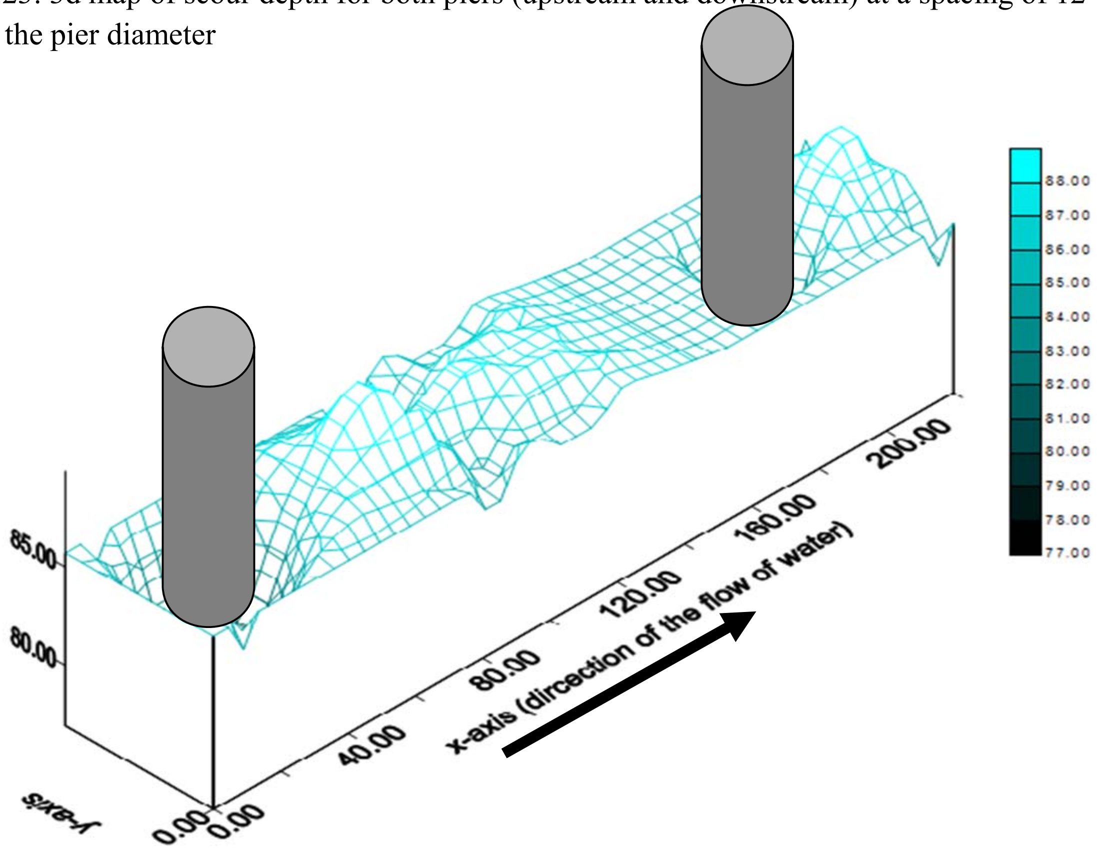

Fig no 4.24: 3d map of scour depth for both piers at a spacing of 14 times the pier diameter

LIST OF PHOTOGRAPH:

Fig 4.25 Snap of the Scour hole for isolated circular bridge

Fig 4.26: Snap shot of scour depth for both piers (upstream and downstream) at a spacing of 3 times the pier diameter

Fig no: 4.27 Snap shot of the scour hole for both the pier at x/b=5

Fig no 4.28: Snap shot of the scour hole for both the pier at x/b=6

Fig 4.29: Snap shot of the scour hole for both the pier at x/b=12

Fig 4.30: Snap shot of the scour hole for both the pier at x/b=9

Fig 4.31: Snap shot of the scour hole for both the pier at x/b=12

Fig 4.32:Snap shot of the scour hole for both the pier at x/b=14