“SCOUR AROUND DIFFERENT SHAPES OF PIERS AT DIFFERENT ORIENTATION WITH FLOW”

Submitted in partial fulfillment of the requirements of the degree of

Master of Technology

In Hydraulics and Flood Engineering

by

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Department of Civil Engineering

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(Formerly Delhi College of Engineering)

CERTIFICATE

This is to certify that the major project report entitled "**SCOUR AROUND DIFFERENT SHAPES OF PIERS AT DIFFERENT ORIENTATION WITH FLOW**" being submitted by me is a bonafide record of my own work carried by me under the guidance of Prof. RAKESH KUMAR ARYA in the partial fulfillment of the requirement for the award of the degree of Master of Technology in Civil Engineering with specialization in HYDRAULICS AND FLOOD ENGINEERING, DELHI TECHNOLOGICAL UNIVERSITY, DELHI-110042.

The matter embodied in this project has not been submitted for the award of any other degree.

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This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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DECLARATION

I certify that

a) The work contained I the dissertation is original and has been done by myself under the general supervision of my supervisors.

b) The work has not been submitted to any other Institute for any degree or diploma.

c) I have followed the guidelines provided by the Institute in writing the report.

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Name of the Student: ADITYA ARYA

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Signature

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Summary

Scour is the process of local lowering of stream bed elevation which takes place in the vicinity or around a structure constructed in flowing water. Scour takes place around bridge piers, abutments, around spurs, jetties and breakwaters due to modification of flow pattern in such a way as to cause increase in local shear stress. Due to improper knowledge of scour around bridge pier, there were lots of bridges failure cases faces by our country which leads to economic loss and life loss. To understand the phenomenon of local scour around piers an attempt is done by experiment on different shape of bridge piers at different angle of attack of flow.

A series of experiments were performed to study the phenomenon of local scour that takes place beside a bridge pier of different shape on straight channel at different angle of attack, and to investigate the relation between the dimensions of the scour hole and between non-dimensional parameters describing the flow ratio, and angle of flow attack. All tests were held under clear-water condition, using a horizontal bed consisted of non-uniform sandy soil.

The experiments were conducted under different condition of flow parameters which helps to better understanding of local scour around different shapes of piers, and piers along the channel flow, across the channel flow and inclined to channel flow. The shape of scour hole, depth of scour, length of scour hole upstream and length of scour hole downstream helps in understanding geometry of scour hole and rate of scour in different cases of piers shape and orientation.

Under the different condition of flow, its helps to understanding the scour depth variation with time, with parts run of flow and with continuous flow run in a certain time. The others parameters like length of scour hole upstream and downstream to study the variation of geometry of scour hole.

With the different shape of piers, the pier having minimum scour is best for the design consideration for scour point of view, it also helps in designing of foundation as the increasing depth of foundation increase the cost of project with proper knowledge about scour phenomenon helps in designing cost effective piers.

List of symbols

g = gravitational acceleration.
ρ, = fluid density.
ν = fluid kinematics viscosity.
H= depth of approach flow upstream(flow depth).
V = mean flow velocity.
Vc= critical flow velocity.
B= channel width.
b= pier width.
θ= angle of attack.
S= shape factor.
L_{up}= distance of scour hole from upstream side.
L_{down} = distance of scour hole from downstream side .
L_r = distance of scour hole from right-side.
L_l = distance of scour hole from left-side.
Fr = Froude number.
d_s = depth of scour hole.
θ_{up} = angle of scour from upstream side.
θ_{down} = angle of scour from downstream side.
U_a = armour velocity.
d_{50} = mean size particle.
Q = discharge(m^3/s).
T= time
e= contraction ratio.

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CHAPTER 1

INTRODUCTION

1.1. Scour

Scour is a natural phenomenon caused by cumulative erosive action of the flowing water on the bed and banks of alluvial channels. Scour also even occurs at the coastal regions due to result of the passage of waves. The construction of the bridges in a alluvial channels will always cause a contraction in the waterway at the bridge site over a river. The contraction in the waterway will cause significant scour at that site. Many bridges failed around the countries because of extreme scour around piers, abutments due to local scouring.

As total scour at the bridge site is comprised of 3 components, namely as degradation and aggradation and, contraction scouring, and the local scouring. Aggradation involves the deposition of sediments eroded from other area sections of a stream channel, whereas degradation involves the lowering or scouring of river bed level of a stream. This scour component is a natural and has long-term effect on stream-bed elevation changes. The contraction scour certainly results from a reduction of flow area at bridge sites due to large obstructions into the flood plain or in main channel by the piers, abutments and approaching embankments.

Local scour involves the removal of sediments from bed of channels around piers, spurs and abutments. It is caused by an acceleration of channel flow and that results into large vortices produced by the flow obstructions. Local scour occurred at the bridge piers are caused mainly by the interference or obstructions of the piers with flowing water. This interference will results in a considerable increase in average velocity of flowing water in river channel. Scouring vortex will be always formed when the fast moving flow near the water surface (at the location of maximum velocity in a channel section) strikes the nose of the pier and deflected towards the bed downwards where the flow velocity is quite low. Portion of the deflected surface flow will go downwards towards the bed and then outwards. This will act like a vacuum cleaner and remove the soil particles at pier site and results in a considerable increase in the scour depth at that location. Local scour phenomenon can occur as either clear-water scour or live-bed scour. In clear-water scour, bed sediments are generally removed from the scour hole, but not refilled by approach flow while in a live-bed scour, the scour hole will continuously supplied with sediment by approach flow and till an equilibrium is attained, when over a time period, the average amount of sediment materials transported into a scour hole by approach flow is equal to average amount of sediment removed from the scour hole. Under this conditions, the local scour depth changes time to time about a average value. The occurrence between the flow near a bridge pier and the erosive sediment bed level surrounding it is a very complex process.

The boundary layer in a channel flow around the bridge elements undergoes a 3-D separation of flow. The layer of separated shear force moves up along the hindrance caused duo bridge element to form a strong vortex system in upstream side of the bridge pier which is then flows to downstream side with river flow. From the top view of the bridge element, the shape of vortex system is just like a horseshoe that's why it is known as a horseshoe vortex as shown in figure 1.1. The formation of these horseshoe vortex and the down-flow associated around the bridge pier which results in shear stress increase and hence which leads to local increase in rate of sediment transport of the flow and which leads to formation of a scour depth (deep hole) around the bridge pier, that changes the flow pattern which causes a reduction in the shear stress by the flow and results in lowering of its rate of sediment transport. The temporal variation of scour depth hole and the maximum scour depth at bridge pier mainly depends upon the characteristics of flow, piers and riverbed sediment. The formation of the horseshoe vortex and the associated down-flow causes scouring at different elements of a bridge such as pier, spur dike and abutments

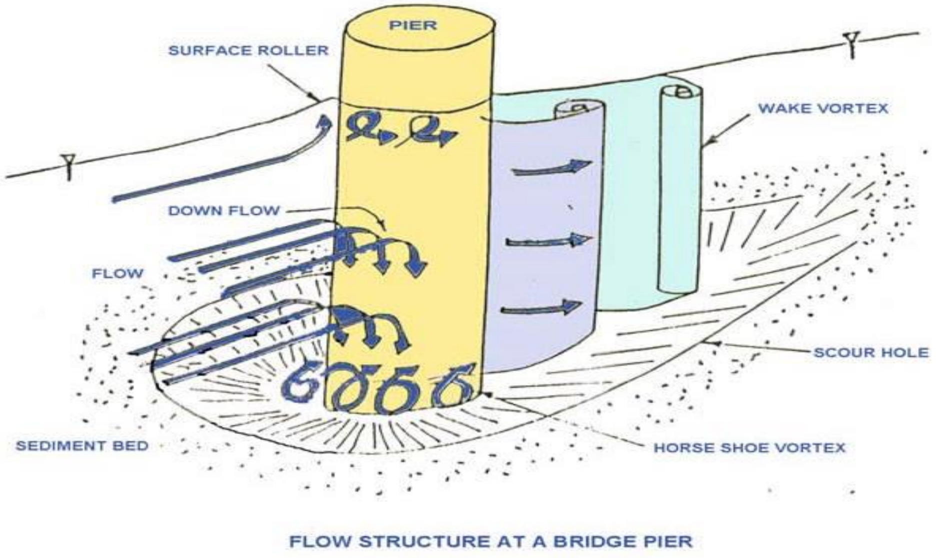

Figure 1.1 Flow pattern around bridge piers.

1.2. Motivation

As the flow occurs around piers which leads to generation of turbulence due to obstruction of pier to form the strong vortex flow system near the base of pier, this process is called as scouring, which is complex in nature which involves three-dimensional separation of flow around the bridge elements like piers and abutment. The scouring around piers and abutments depends upon lots of factors such time, depth of flow, flow discharge etc. The estimation of correct scour depth around the pier is very important because it helps to determines the foundation depth. In USA, around 600 bridges failed because of scouring around the piers of the bridge which results into exposing of foundation or removal of sediment material around foundation.

As a proper knowledge about scour around piers not only helps in better understanding about the scour phenomenon but also helps in cost effective designing for bridge piers. The shapes of piers also depends on the on the scour condition around the bridge piers, as the shape of piers changes totally the rate of sediment transportation changes and also changes shape of scour hole. The scour with different shapes of bridge piers helps in better understanding of local scour around piers and also helps in choosing the shape of piers from the point of minimum scour around the pier.

1.3 Purpose

In this thesis work, an attempt is made to understand the phenomenon of scour around different shapes of piers with different orientation with flow on sandy channel bed. As the scour depends upon shape of piers, that’s why an experiment is conducted under different conditions. The different shapes of piers used in experiment are cylindrical pier, sharp-nose pier, round-nose piers and rectangular piers along the channel flow, across the channel flow and at certain angles of channel flow. The geometry of scour hole under different condition is analysis along with slope of scour hole and also at which angle and which pier having analysis minimum scour in sandy channel helps in cost effective designing for bridge piers.

1.4 Overview

Chapter 2 summarizes some of the literature work that describes about different aspects of scour around a piers under different condition of flow.

Chapter 3 deals with theoretical background that includes different parameters related to scouring around a pier in a channel. The total scour at a bridges cross-section is comprised of as

Long-term aggradation and degradation , general scour at the bridge and local scour at the piers or abutments. The proper phenomenon of local scour around piers and factors affecting them.

Chapter 4 explains the experimental work done for measuring the scour around different shapes of piers under different conditions. It explains the procedure to perform the experiment for measuring the scouring around different angle of attack on different shapes of piers.

Chapter 5 deals with experimental results which comprises of tables and figure of different shapes of piers scour which helps in getting some of the results.

Chapter 6 deals with analysis and discussion of the experimental work. It explains the results and discussion of some concepts of scouring which helps in better understanding of the phenomenon of scouring around different shapes of piers at different angle of attack to piers.

Chapter 7 deals with conclusion of the work. It also includes future scope related to this work in brief.

CHAPTER 2

LITERATURE REVIEW

This thesis mainly focused on better understanding the phenomenon of local scour around a bridge pier under different condition. Generally, cylindrical piers is used by many researchers in the past for the understanding the phenomenon of local scour around pier under different conditions of flow. But still some researchers also used different shapes for their experiment to investigates the local scour around different shapes of pier.

Some of the researchers have investigated the scour around piers and some of them are elaborate below:

Shen(1969) performed a study of scour around a single circular pier in which pier diameter and sediment size were taken as constant and at the same time the hydraulic conditions of the flow were varied, he concluded an empirical equation for scour depth was derived in which the scour depth is a function of time as it depends upon depth mean velocity, upstream water depth and pier diameter.

Cunha(1975) found that the Shen study was likely to be unsuitable as it excluded sediment size factor and deals with very narrow ranges of conditions, he also investigates at the relationship between Reynolds number and vortex strength at the front tip of the pier and gave another scour depth relationship.

Raudkivi and Ettema (1983) concluded that the ratio of flow depth(H) to pier width (b) increased, d_{se} /H increased as well but it became independent or have no effect of the flow depth for the ratio H/b greater than 3. For a constant velocity of the channel flow, when depth is increased then the flow rate will also increases which leads in a greater scour depth, as the scour depths does not change with increases in flow depth(H)/discharge(Q).

Chiew (1984) studied the changes for rippling and non-rippling sediments scour using his experiments pier scour data and concluded that scour depths reduce for very high velocities on the far side of transition flat bed level condition where flow will become supercritical.

Dongal (1994) conducted a experiment and found the scour depth generally increases with flow velocity in a linear trend until the velocity reaches to critical velocity condition. After that, he studied the live bed condition in which the scour depth variation depends upon bed regime on flow bed. He divided the study of scour around pier in rippling and non-rippling sediments. For rippling sediment (d_{50} < 7mm), the scour depth at critical condition is less than at the 2nd maximum because of the formation of ripple at lesser velocity than critical velocity causes a steady supply of sediment material into scour hole through which less scour occurs. For non-rippling sediments (d_{50} > 7mm) the equilibrium condition of scour depth first decreases with flow velocity beyond the critical velocity condition then it reaches to minimum value of scour depth, hence it again increases towards 2nd maximum with increase in flow velocity. The changes in scour depth occurs only due to non-uniform rate of sediment transport in the scour hole, thus at the 2nd maximum, the scour depth is lesser than the critical condition.

Melville and Chiew (1999) concluded from their experiment in which just 10% of the equilibrium time (time which takes to reach the equilibrium scour depth) about 50% to 80% of scour depth takes place and the rate of scouring under constant flow conditions was results to be highest in initial phase of scouring then it decreases in a logarithmic manner till then the vortices induced from deflection of flow were not strong to remove sediment material from the scour hole**.**

Totapally (1999) also investigate the development of local scour around piers with time under steady(constant) flow and raises questions on the existence of an equilibrium state under scouring process and then he concluded that a power equation which is used to represent variation of scour depth should be replaced by logarithmic equation because scour will always increases with time, anyways it will increase at a greatly decreasing rate.

Graf(2001) examined the flow patterns at upstream and at downstream of a cylindrical pier and concluded that there was alot of turbulent kinetic energy infront and behind the circular pier and that there is reduced shear stress within the scour hole as it compared to the approaching flow depth.

Richardson(2002) concluded in his study that bridge foundations should be designed in such a way so that the effects of scour without failing the structure for the worst conditions resulting from floods equal to the 100-year flood, or a flood condition smaller than 100-year flood if it will cause scour depth more deeper than the 100-year flood. The bridge foundations should also be investigated to ensure that the foundations would not fail due to scour resulting from the occurrence of super flood (about 500-year flood).

Patrick D.A.(2005) performed a experiment to reduce the effects of scour depth around bridge pier using collars with time variation. The concept of using collars is give a sufficient protection around bridge pier so that the bed shear stress reduces around the pier which leads to less formation of vortices so that the rate of scouring can be reduced to a certain level and the temporal development of scour hole is studied by using collar and without of it.

Oscar(2006) investigates that on a non-uniform sand material, how the 3-D scour-hole geometry changes on time variation at a circular pier. The time-dependent of geometry scour-hole results provide the information about different scour phases, as initial development of scour hole, stabilization and equilibrium phase.

Thamer (2007) conducted a research that the flow velocity and flow depth have effects on the rate of scouring around piers and found that if the flow depth is increased twice than the scour depth can increase change more than 200 %.

Sabita and Maiti(2012) conducted an experimental study of local scour around a cylindrical pier in a straight channel with an erodible bed material. They concluded that the flow fields around a circular pier is highly unsteady complex in nature which produces scour mainly due to the presence of strong vortices and the horse-shoe vortex is a part of main mechanism that drives the formation of scour hole around the bridge pier.

CHAPTER 3

THEORETICAL BACKGROUND

3.1 Scour:General

Scour is a natural phenomenon caused by cumulative erosive action of the flowing water on the bed and banks of alluvial channels. Scour also even occurs at the coastal regions due to result of the passage of waves. The construction of the bridges in a alluvial channels will always cause a contraction in the waterway at the bridge site over a river. The contraction in the waterway will cause significant scour at that site. Many bridges failed around the countries because of extreme scour around piers, abutments due to local scouring.

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3.2 Total Scour

Total scour is of three types as:

1. Long-term degradation and aggradation of the channel bed.

2. General scour at a bridge section
   a. Contraction scour
   b. Other general scour

3. Local scour at the piers, abutments section

3.2.1 Aggradation and Degradation

Aggradation is a process in which deposition of sediments materials that eroded from the bed of river channel or upstream side of the bridge section.

Degradation is a process in which lowering of bed or removing of sediments of the channel-bed due to a reduction in rate of sediment supply from upstream side of channel.

3.2.2 General Scour

General scour is a process lowering of streambed across the stream section at the bridge location.. The general scour may also result from contraction of channel flow, which results in removal of sediments from the bed across the channel width, also from other general scour conditions like flow around a bend or mender where the scour may be more concentrated near the outside of a bend.

3.2.3 Local Scour

Local scour is a process in which removal of sediments from around piers, spurs, and abutments which is caused by an acceleration of channel flow and that results into vortices produced by obstructions to the channel flow. Local scour can be divided into 2 parts as clear-water or live-bed scour.

3.3 Clear-Water And Live-bed Scour

As there are two conditions for contraction and local scour: firstly clear-water and secondly live-bed scour. Clear-water scour occurs only when there is no movement of bed sediments in flow upstream side of crossing or the bed sediments being transported in upstream side is transported in suspension from scour hole an abutment or pier at less than flow capacity. At the pier or abutment, the acceleration of channel flow and vortices created by blockage causes the bed sediments around them. Live-bed scour condition occurs when there is transport of bed sediments from the upstream side into crossing. Live-bed local scour condition is a cyclic in nature; i.e., the scour hole which develops during the rising level of a flood wave filled up again or refills during the falling stage.

Typical clear-water scour conditions include as:

- Streams having coarse-bed material,
- At low flow or discharge having flat gradient streams ,
- larger bed materials are deposit that are larger than the sediments being transported by the flow,
- armored streambeds where the tractive forces are sufficient to penetrate the armor layer,
- overbank areas or vegetated channels.

Clear-water scour condition reaches its maximum value over a longer time period than live-bed scour (Figure 3.1). This is because in clear-water scour condition occurs mainly in coarse-bed sediments streams. At piers, maximum local clear-water scour is about 10 percent greater than the equilibrium condition local live-bed pier scour.

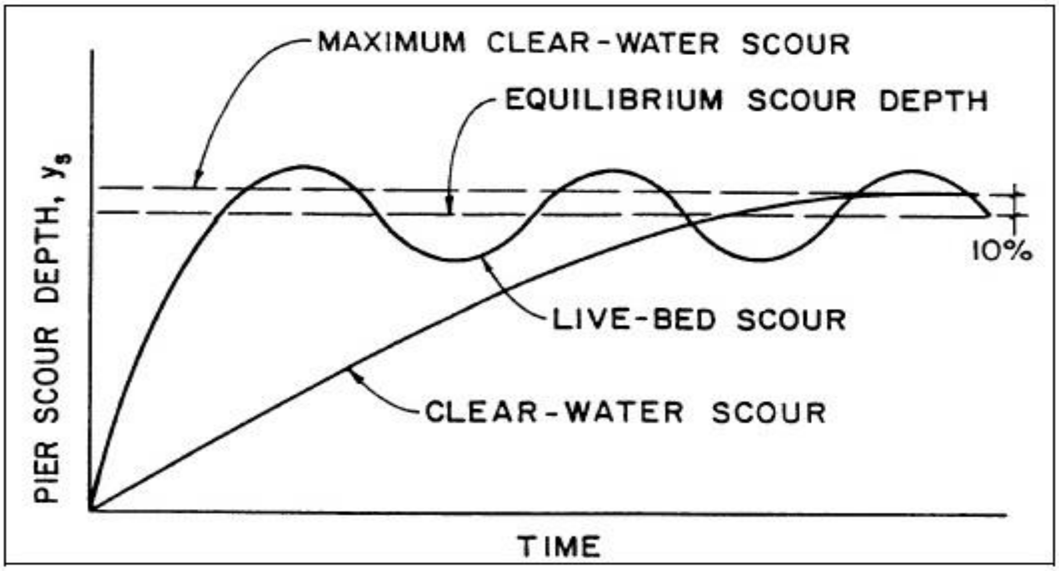

Figure: 3.1 Pier scour depth in a sand-bed stream as a function of time.

Live-bed pier scour in sand-bed streams with a dune bed configuration fluctuates about the equilibrium scour depth (Figure 3.1). This is due to the variability of the bed material sediment transport in the approach flow when the bed configuration of the stream is dunes. In this case (dune bed configuration in the channel upstream and through the bridge), maximum depth of pier scour is about 30 percent larger than equilibrium depth of scour. However, with the exception of crossings over large rivers, the bed configuration in sand-bed streams will plane out during flood flows due to the increase in velocity and shear stress. For general practice, the maximum depth of pier scour is approximately 10 percent greater than equilibrium scour.

3.4 General Scour

3.4.1 Contraction Scour

Contraction scour occurs when the flow area of a stream at flood stage is reduced, either by a natural contraction of the stream channel or by a bridge. It also occurs when overbank flow is forced back to the channel by roadway embankments at the approaches to a bridge. From continuity, a decrease in flow area results in an increase in average velocity and bed shear stress through the contraction.

Other factors that can cause contraction scour are :

- natural stream constrictions,
- pressure flow
- long highway approach to bridge over a large floodplain,
- natural berms along the banks of channel due to sediment deposits,
- ice formations or jams,
- vegetative growth in the channel or floodplain,

3.5 Local Scour

The basic mechanism causing local scour at piers or abutments is the formation of vortices (known as the horseshoe vortex) at their base (Figure 3.2). The horseshoe vortex results from the pileup of water on the upstream surface of the obstruction and subsequent acceleration of the flow around the nose of the pier or abutment. The action of the vortex removes bed material from around the base of the obstruction. The transport rate of sediment away from the base region is greater than the transport rate into the region, and, consequently, a scour hole develops. As the depth of scour increases, the strength of the horseshoe vortex is reduced, thereby reducing the transport rate from the base region.

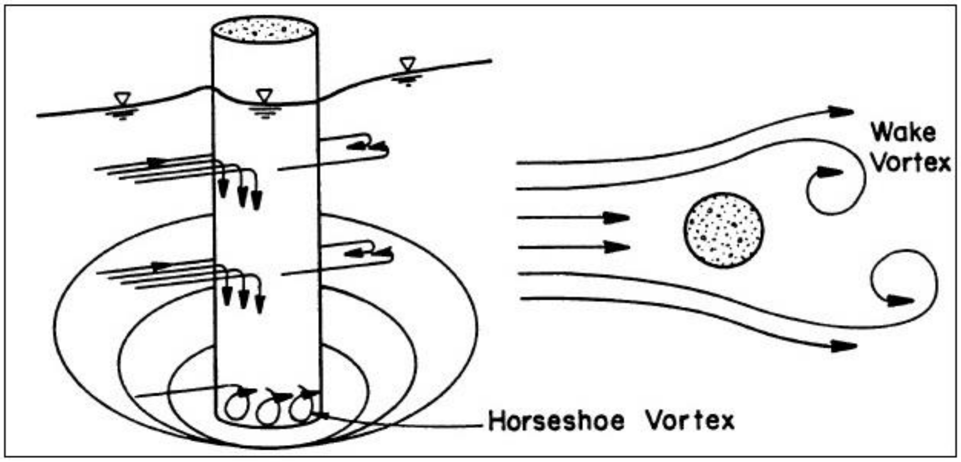

Figure 3.2 Schematic representation of scour at a cylindrical pier.

Eventually, for live-bed local scour, equilibrium is reestablished between bed material inflow and outflow and scouring ceases. For clear-water scour, scouring ceases when the shear stress caused by the horseshoe vortex equals the critical shear stress of the sediment particles at the bottom of the scour hole.

In addition to the horseshoe vortex around the base of a pier, there are vertical vortices downstream of the pier called the wake vortex (Figure 3.2). Both the horseshoe and wake vortices remove material from the pier base region. However, the intensity of wake vortices diminishes rapidly as the distance downstream of the pier increases. Therefore, immediately downstream of a long pier there is often deposition of material.

Factors which affect the magnitude of local scour depth at piers and abutments are

- Approaching velocity of the flow,
- Flow depth,
- pier width,
- discharge disturbed by abutment and that returned to the main channel
- length of pier if skewed to channel flow,
- size and gradation of bed sediment material,
- angle of attack of approaching flow to pier or to abutment,
- shape of a pier or abutment,
- bed configuration,

CHAPTER 4

EXPERIMENTAL SETUP AND PROCEDURES

Experiments were conducted at the Hydraulics Laboratory, Department of Civil Engineering at Delhi Technological University, New Delhi. Details of the equipment and instruments used, the experimental setup, experiments performed, and procedure are outlined in this section.

Experimental Setup

The experimental program was performed in the re-circulating hydraulic tilting flume of dimensions 6m long, 30cm wide and 6cm deep was used. A horizontal scale was fixed for measurement of horizontal distance along the flume with accuracy of 1.0 mm. A point gauge with a venire scale, was installed along the flume to measure the bed elevation, the flow depth and the geometry of scour hole. The sand (non-uniform) was used as bed sediment material with depth of bed equals to 15cm. The hydraulic flume is having a centrifugal pump to re-circulate the water from water distribution tank to need the required discharge of flow in the flume. Figure (4.1) shows the detail scheme of experimental setup of the flume.

The objectives of our experiments are that four different shapes of piers models were differentiate in four different groups. The 1st group was setup parallel (along the flow) to the flow, the 2nd, the 3rd groups were setup with an angle 60° and 30° respectively and the 4th groups were perpendicular (across the flow) to the channel flow and study of scour and flow parameter is done around all shapes of pier model with the different shape of scour hole.

The flow in a channel was controlled by the discharge varying valve that fitted in delivery pipe. The discharge was measured through the meter reading tip of venture-meter. The flow depth was measured with the help of a point gauge which connects to the flume and the scour depth was measured by the bed-elevation scale provided in the flume.

A model of pier is placed at the middle of a test area that we provided in the channel section of the tilting flume (figure 4.2). The circular pier of bridge is quite similar to cylindrical model of pier. A layer of non-uniform sand (sediment) of 15 cm thick is made flatter with the help of leveler and 1.8m as a test area is used along the length of hydraulic flume along the channel length. The sand is compacted and then leveled with the help of leveler after every flow run in the flume. The upstream side of channel flume section should be designed in such a way so it helps to maintain the flow uniformity at transition zone(i.e. turbulence generation is minimum), so coarser sediment is used in sloping way so that it provide excess friction which reduces the turbulence of flow to zero percent, therefore now the study of different condition of flow around the piers at upstream of the channel.

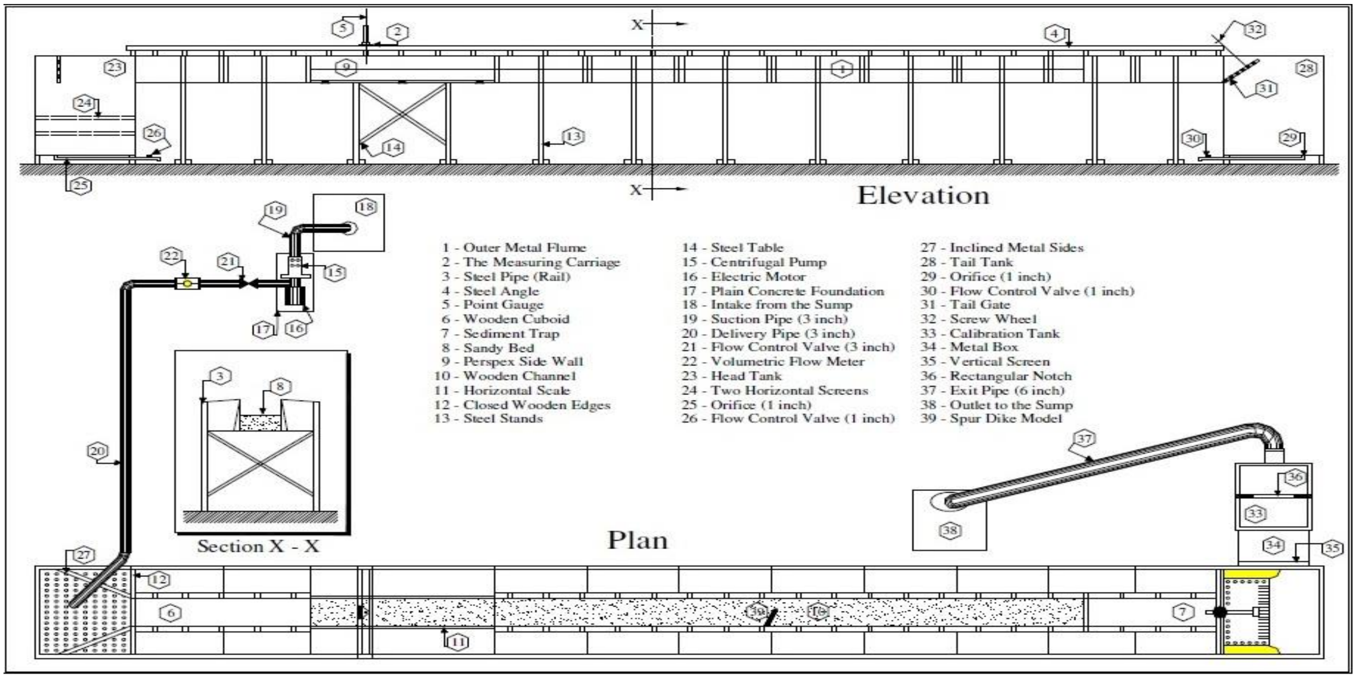

Figure 4.1: A detail scheme of experimental setup of flume.

Figure: 4.2 A hydraulic tilting flume on which all experiments were performed in laboratory.

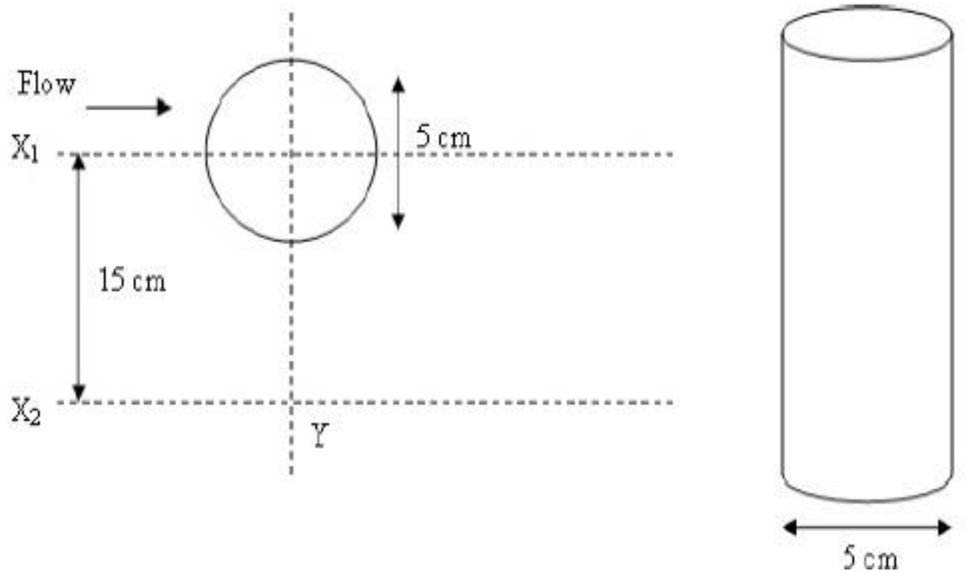

Figure: 4.3 Circular bridge pier

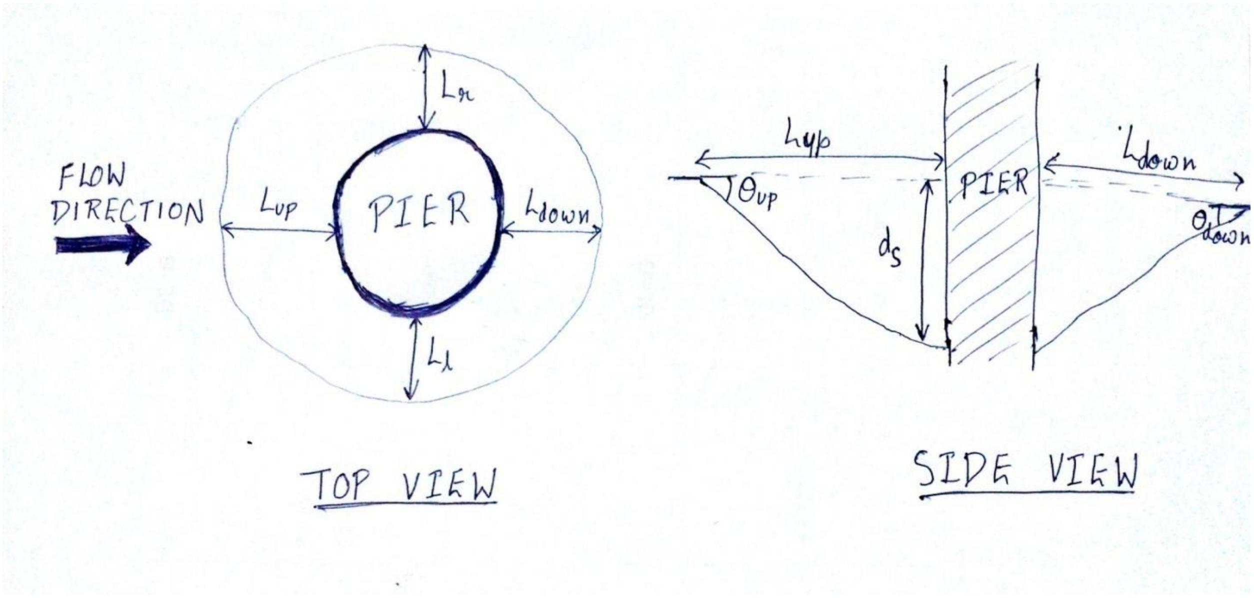

Figure: 4.4 Systematic top view and side view of scouring around a pier

Figure 4.5: A model of cylindrical pier (b=5cm) installed in a flume in laboratory.

Figure 4.6: A model of round-nose pier (l=10cm and b=5cm) installed in a flume in laboratory

Figure 4.7: A model of sharp-nose pier (l=10cm and b=5cm) installed in a flume in laboratory

Figure 4.8: A model of rectangular pier (l=10cm and b=5cm) installed in a flume in laboratory

TEST PROCEDURE

As the all four models of piers were tested in the hydraulic flume under different condition of flow at different angle of attack of flow. A cylindrical pier were tested under three different condition as keeping discharge constant with varying flow depth, keeping flow depth constant with varying discharge, keeping discharge and flow depth constant with varying time.

All other three remaining models of pier (round-nose pier, sharp-nose pier and rectangular pier) were tested under condition of keeping discharge constant with varying flow depth at different angle of attack of channel flow (along the channel flow, across the channel flow, at 30^0 and 60^0 angle with flow).

The following procedure was followed to conduct each test:

1. The pier model was placed in the test area of our study reach and the pier is fixed well to prevent any lateral movement.

2. The bed material was leveled properly with the help of leveler to insure that the bed have flatter surface with the same elevation at every point of test area.

3. First, the discharge at very rate is filled in the flume so that any disturbance of bed material takes place due to the turbulence or the condition should be steady and uniform for the experiment and a tail gate was kept closed in the starting of run then it can be adjusted upto the condition requirement.

4. The required condition of discharge was allowed to run gradually until constant value of required condition of discharge reaches.

5. The tail gate was lowered gently until the required water depth condition reaches.

6. The time is recorded properly for every run of required flow condition.

7. After the flow run in flume for a specific time period, the flow discharge is stopped then the water is dried gently so that there is no movement of sand particles and then the measurement of scour hole is done properly.

8. Repeat above seven steps for different shapes of piers at different orientation.

CHAPTER 5

EXPERIMENTAL RESULTS

As all the four models of piers were tested in the hydraulic flume under different condition of flow at different angle of attack of channel flow. A cylindrical pier were tested under three different condition as keeping discharge constant with varying flow depth, keeping flow depth constant with varying discharge, keeping discharge and flow depth constant with varying time.

All other three remaining models of pier (round-nose pier, sharp-nose pier and rectangular pier) were tested under condition of keeping discharge constant with varying flow depth at different angle of attack of channel flow (along the channel flow, across the channel flow, at 30^0 and 60^0 angle with flow).

The experiments were conducted in a range of flow parameter discharges changed $4.08*10^{-3}$ to $5.40*10^{-3}$ m^3/s keeping flow depth(5.9cm) constant to study the variation of scour depth around cylindrical pier. Some experiments were conducted around different shapes of piers keeping discharge and flow depth both constant variation of scour depth different shape and orientation with flow.

The results from all the models are elaborate below in a tabular form separately under different conditions as:

Cylindrical Pier

The readings of cylindrical pier were tested under different condition of flow observed as:

Keeping flow depth constant with increasing discharge for time = 35 minutes for each run.

Table no. 5.1: values of different flow and scour parameters around cylindrical pier varying discharge with constant flow depth.

Cylindrical Pier									
Keeping flow Depth (H) constant H=5.9									**t=35min**
Sr No.	**e(%)**	**Q(10^{-3} m^3 /s)**	**Fr**	**d_s (cm)**	**L_{up} (cm)**	**L_{down} (cm)**	**L_l (cm)**	**L_r (cm)**	**Θ_{up}**
1	16.67	4.08	0.303	3.400	5.3	3.5	4.7	4.9	32.69
2	16.67	4.56	0.339	3.700	5.8	3.8	5.1	5.2	32.54
3	16.67	5.00	0.370	4.100	6.3	4.3	5.5	5.6	33.06
4	16.67	5.40	0.400	4.400	6.9	4.7	5.9	5.8	32.54

Keeping discharge and flow depth constant with the varying time period of each run.

Table no. 5.2: values of different flow and scour parameters around cylindrical pier varying time

Cylindrical Pier							
Keeping Discharge & Flow Depth constant							time vary
Sr No.	Time (min)	d_s (cm)	L_{up} (cm)	L_{down} (cm)	L_l (cm)	L_r (cm)	Θ_{up}
1	35	3.40	5.300	3.500	4.7	4.9	32.69
2	+30	3.60	5.400	3.600	4.8	5.0	32.9
3	+25	3.70	5.500	3.800	4.8	5.1	33.18
4	+30	3.80	5.700	3.900	4.9	5.1	32.95
5	120	3.90	5.700	4.000	4.9	5.2	33.21

(for. constant flow depth and discharge.)

Keeping discharge constant with varying flow depth of flow for time = 35 minutes for each run.

Table no. 5.3: values of different flow and scour parameters around cylindrical pier varying flow depth with constant discharge.

Cylindrical Pier										
Keeping Discharge constant $Q_1=4.08X10^{-3}$ m^3/s										T=35min
Sr. No.	e(%)	H (cm)	Fr	d_s (cm)	L_{up} (cm)	L_{down} (cm)	L_l (cm)	L_r (cm)	Θ_{up}	Θ_{down}
1	16.67	1.7	1.96	2.4	6.2	4.4	5.4	5.1	21.16	16.23
2	16.67	2.6	1.035	2.7	6.5	4.8	5.9	5.5	22.56	16.67
3	16.67	3.9	0.564	3.6	6	4.3	5.2	5.3	30.97	18.54
4	16.67	5.9	0.303	3.4	5.3	3.5	4.7	4.9	32.69	18.64
5	16.67	6.5	0.261	3.3	4.7	3.1	4.6	4.7	35.08	19.23
6	16.67	7.3	0.219	3.1	4.3	2.8	4.5	4.7	35.79	19.23

Round-Nose Pier

Keeping discharge and flow depth constant for time = 35 minutes for each run.

Table no. 5.4 values of scour and flow parameters around round-nose pier keeping discharge and flow depth constant.

Round-nose Pier								
Keeping discharge($4.08*10^{-3}m^3/s$) and flow depth(5.9 cm) constant								Time=35min
Sr no.	Ɵ	e(%)	d_s	L_{up}	L_{down}	L_r	L_l	$Ɵ_{up}$
1	0^0	16.67	3.3	5.1	0.0	4.5	4.6	32.91
2	30^0	31.1	3.4	5.7	0.0	4.6	5.2	30.82
3	60^0	37.2	3.6	5.6	4.6	4.8	5.1	31.25
4	90^0	33.34	3.7	5.9	0.0	5.7	5.6	30.68

Keeping discharge constant with varying flow depth of flow for time = 35 minutes for each run.

Table no. 5.5: values of different flow and scour parameters around round-nose pier varying flow depth with constant discharge.

Round-Nose Pier (For Constant Discharge)										
Sr No.	Ɵ	H (cm)	V (m/s)	Fr	d_s (cm)	L_{up} (cm)	L_{down} (cm)	L_l (cm)	L_r (cm)	$Ɵ_{up}$
1	0	3.70	0.367	0.610	3.3	5.1	0.0	4.5	4.6	32.91
		5.30	0.256	0.355	2.7	5.4	0.0	4.2	4.1	26.57
		6.80	0.200	0.245	2.7	5.2	0.0	3.9	3.9	27.44
2	30	4.00	0.340	0.543	3.4	5.7	0.0	4.6	5.2	30.82
		5.90	0.230	0.303	2.9	5.4	0.0	4.3	4.9	28.24
		7.10	0.192	0.231	2.7	5.1	0.0	3.9	4.1	27.9
3	60	4.60	0.300	0.446	2.6	5.7	5.4	4.7	6.3	24.52
		5.90	0.230	0.303	2.2	5.3	4.9	4.5	5.9	22.55
		7.30	0.186	0.219	2	4.9	4.8	4.2	5.6	22.21
4	90	4.60	0.300	0.446	3.5	5.9	0.0	5.7	5.6	30.68
		5.90	0.230	0.303	3.1	5.7	0.0	5.4	5.6	28.54
		7.30	0.186	0.219	2.9	5.4	0.0	5.1	5.1	28.24

Sharp-Nose Pier

Keeping discharge and flow depth constant for time = 35 minutes for each run.

Table no. 5.6 values of scour and flow parameters around sharp-nose pier keeping discharge and flow depth constant.

Sharp-nose Pier								
Keeping discharge($4.08*10^{-3}m^3/s$) and flow depth(5.9 cm) constant								Time=35min
Sr no.	**Ɵ**	**e(%)**	**d_s**	**L_{up}**	**L_{down}**	**L_r**	**L_l**	**$Ɵ_{up}$**
1	0^0	16.67	2.8	5.1	0.0	5.3	5.4	28.17
2	30^0	31.1	3.1	5.1	0.0	5.5	5.5	31.29
3	60^0	37.2	3.4	5.3	4.8	5.6	5.6	32.68
4	90^0	33.34	3.8	5.5	0.0	5.7	5.4	34.65

Keeping discharge constant with varying flow depth of flow for time = 35 minutes for each run.

Table no. 5.7: values of different flow and scour parameters around sharp-nose pier varying flow depth with constant discharge.

Sharp - Nose Pier (For Constant Discharge)										
Sr No.	**Ɵ**	**H (cm)**	**V (m/s)**	**Fr**	**d_s (cm)**	**L_{up} (cm)**	**L_{down} (cm)**	**L_l (cm)**	**L_r (cm)**	**$Ɵ_{up}$**
1	0	5.60	0.242	0.326	2.8	5.1	0.0	5.3	5.4	28.17
		8.00	0.170	0.192	2.5	4.1	0.0	4.8	4.7	31.38
		6.80	0.200	0.245	2.6	4.5	0.0	5.2	4.9	30.02
2	30	5.50	0.247	0.336	2.9	5.2	0.0	4.2	4.1	29.15
		8.50	0.160	0.175	2.6	4.3	0.0	3.1	3.3	31.16
		7.20	0.188	0.223	2.8	4.8	0.0	3.7	3.6	31.16
3	60	3.90	0.348	0.563	3.4	5.9	4.8	0	4.7	29.96
		6.30	0.215	0.273	3	4.8	4.2	0	4.1	32.01
		5.20	0.261	0.365	3.5	5.5	4.6	0	4.4	32.48
4	90	3.90	0.348	0.563	3.6	5.8	0.0	6.1	5.9	31.83
		5.30	0.256	0.355	3.8	5.5	0.0	5.7	5.4	34.65
		6.60	0.206	0.255	3.3	4.9	0.0	5.3	5.1	33.96

Rectangular Pier

Keeping discharge and flow depth constant for time = 35 minutes for each run.

Table no. 5.8 values of scour and flow parameters around rectangular pier keeping discharge and flow depth constant.

Rectangular Pier								
Keeping discharge($4.08*10^{-3} m^3/s$) and flow depth(5.9 cm) constant								Time=35min
Sr no.	Θ	e(%)	d_s	L_{up}	L_{down}	L_r	L_l	$Θ_{up}$
1	0^0	16.67	3	5.7	0.0	0	0	27.76
2	30^0	31.1	3.2	4.8	5.1	0	5.7	32.01
3	60^0	37.2	3.5	5.1	5.3	0	5.8	29.75
4	90^0	33.34	3.8	5.5	0.0	5.7	5.4	34.65

Keeping discharge constant with varying flow depth of flow for time = 35 minutes for each run.

Table no. 5.9: values of different flow and scour parameters around rectangular pier varying flow depth with constant discharge.

Rectangular Pier (For constant Discharge)										
Sr No.	Θ	H (cm)	V (m/s)	Fr	d_s (cm)	L_{up} (cm)	L_{down} (cm)	L_l (cm)	L_r (cm)	$Θ_{up}$
1	0	4.60	0.296	0.441	3.4	5.9	0.0	0	0	29.96
		5.90	0.231	0.303	3	5.7	0.0	0	0	27.76
		7.20	0.188	0.223	2.9	5.4	0.0	0	0	28.24
2	30	4.60	0.296	0.441	3.3	5.3	5.5	0	6.2	31.91
		5.90	0.231	0.303	3	4.8	5.1	0	5.7	32.01
		7.20	0.188	0.223	2.8	4.6	5.2	0	5.4	31.33
3	60	4.60	0.296	0.441	3.1	5.2	6.7	0	6.1	30.81
		5.90	0.231	0.303	2.8	4.9	5.3	0	5.8	29.75
		7.20	0.188	0.223	2.6	4.6	5.6	0	5.6	29.48
4	90	4.60	0.296	0.441	3.6	7.4	0.0	5.4	5.5	25.95
		5.90	0.231	0.303	3.8	5.5	0.0	5.7	5.4	34.65
		7.20	0.188	0.223	2.8	6.8	0.0	5	4.9	22.39

NOTE: In all the figures of different shapes scour hole below, arrow indicates direction of flow.

Figure: 5.1 Scour around cylindrical pier

Figure: 5.2 A picture of reading of flow depth a point gauge with a sharp edged end

Figure: 5.3 Scour around cylindrical pier at up-stream side of flow.

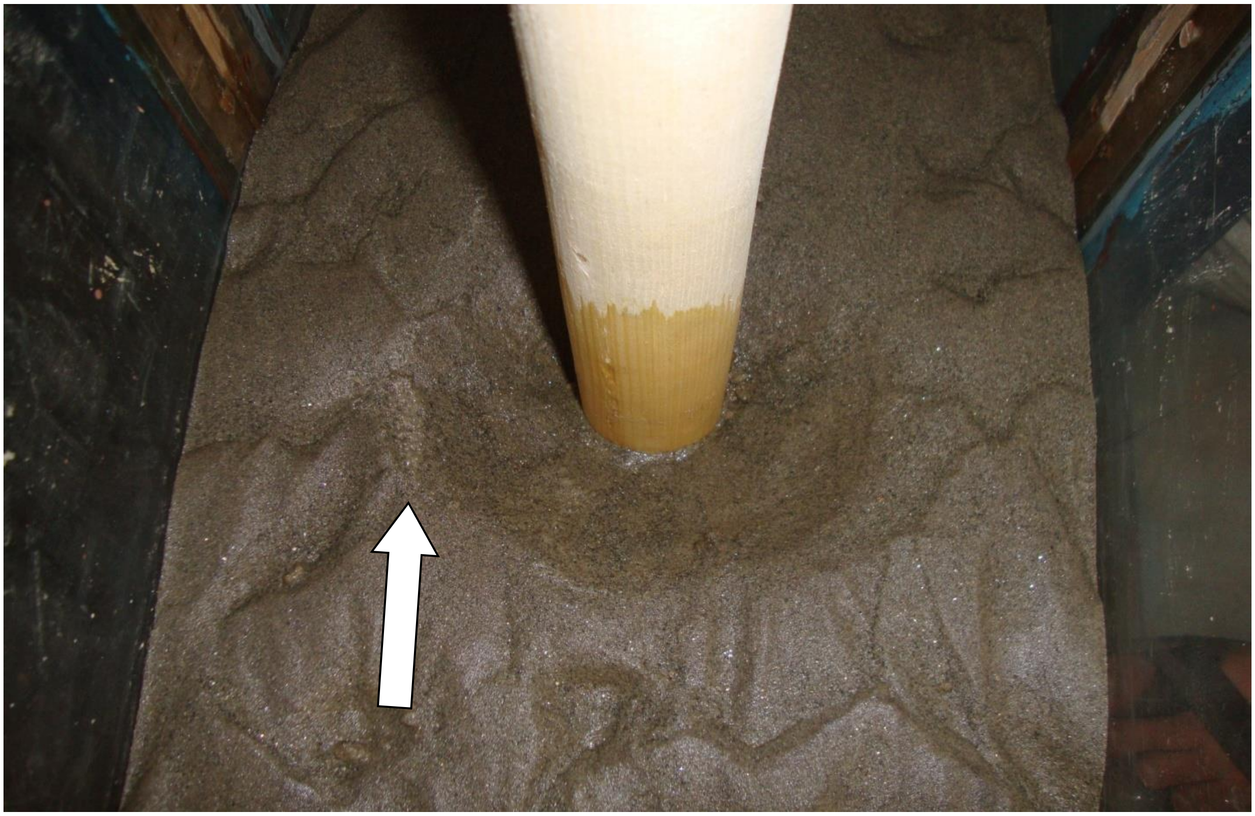

Figure: 5.4 A close look of scour around cylindrical pier at flow depth = 5.9cm

Figure: 5.5 Scour around cylindrical pier at discharge (Q)=$4.08*10^{-3}$ m^3/s

Figure: 5.6 Scour around cylindrical pier at downstream side

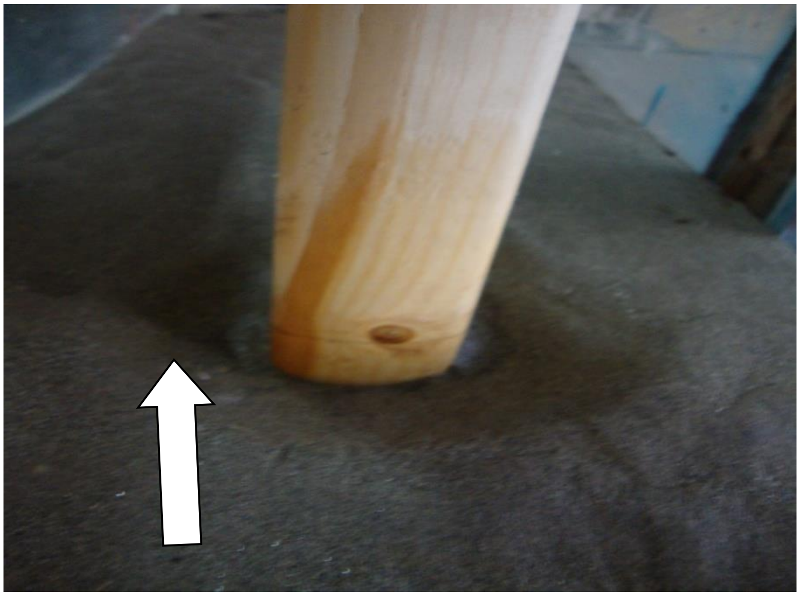

Figure: 5.7 Scour around round-nose pier at upstream side along the channel flow($\Theta=0^0$)

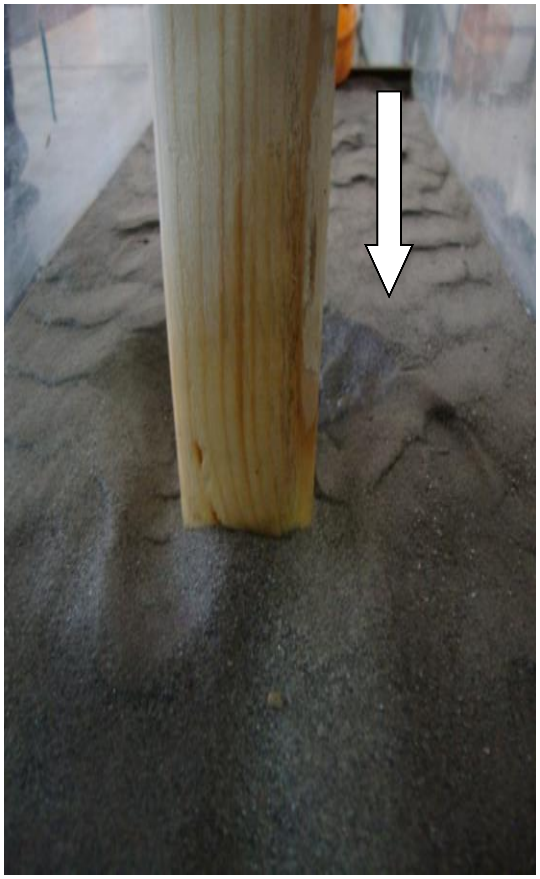

Figure: 5.8 Scour around round-nose pier at downstream side along the channel flow($\Theta=0^0$)

Figure: 5.9 Scour around round-nose pier at upstream side (ϴ=30^0)

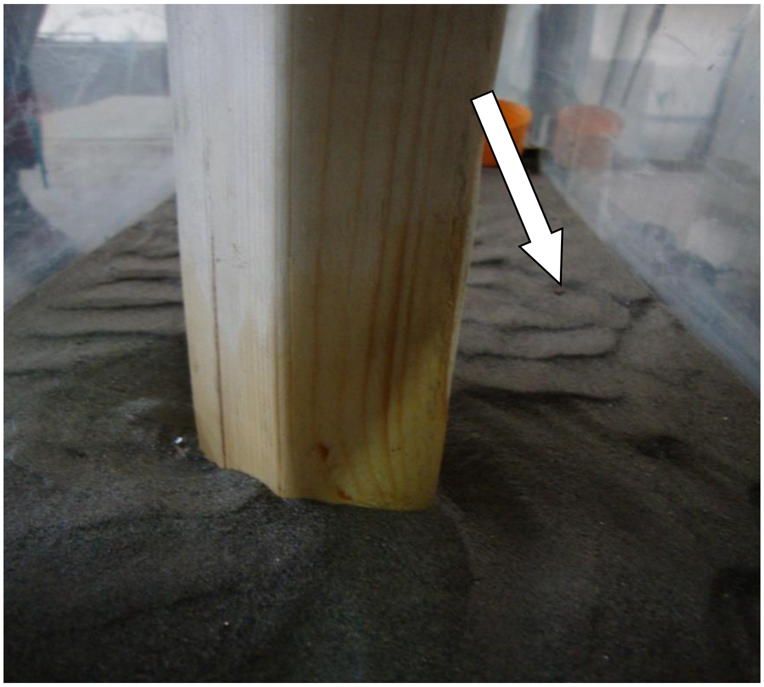

Figure: 5.10 Scour around round-nose pier at downstream side (ϴ=30^0)

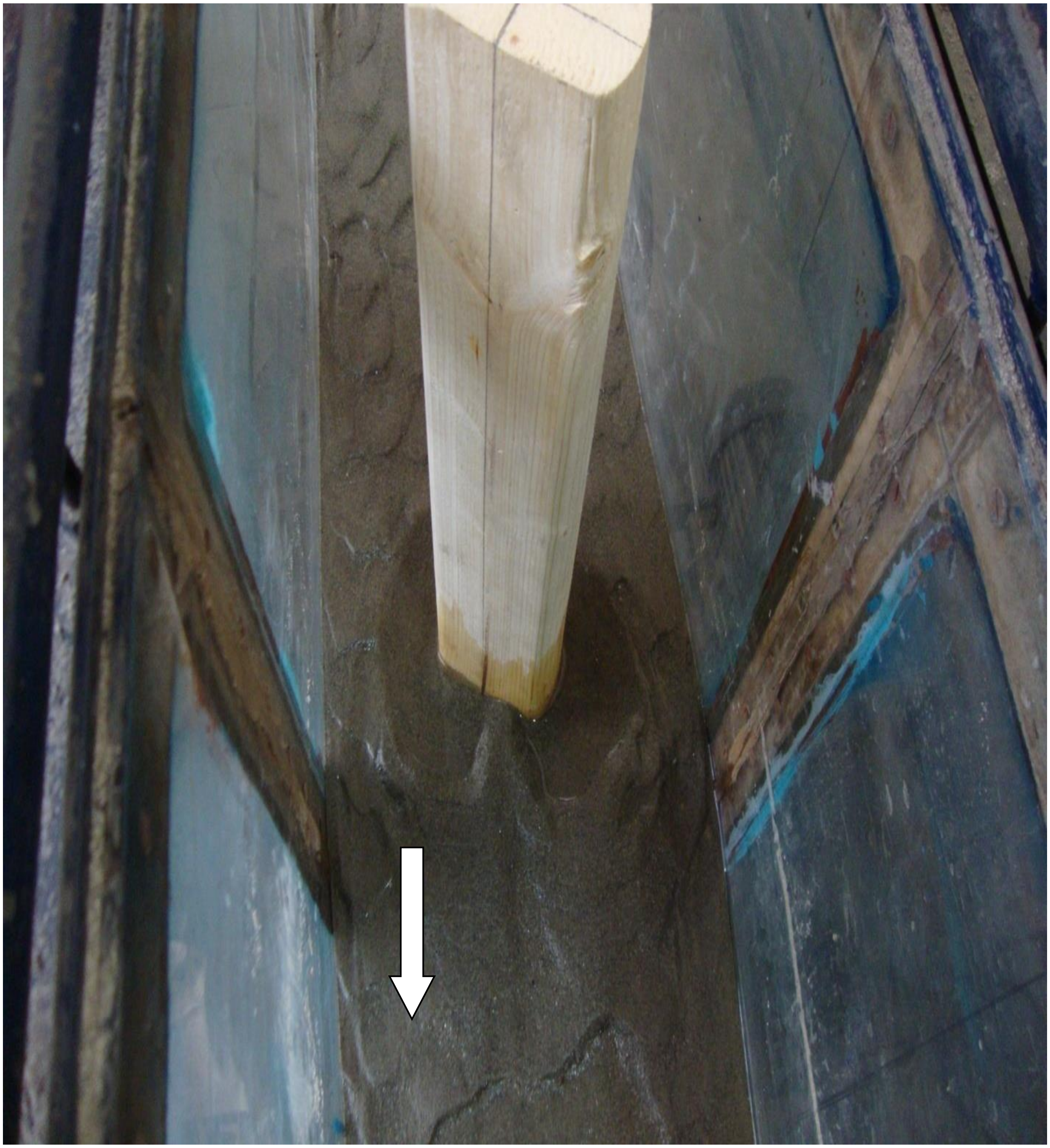

Figure: 5.11 Scour around round-nose pier at downstream side ($\Theta=60^0$)

Figure: 5.12 Scour around round-nose pier at upstream side ($\Theta=60^0$)

Figure: 5.13 Scour around round-nose pier at upstream side across the flow (ϴ=90^0)

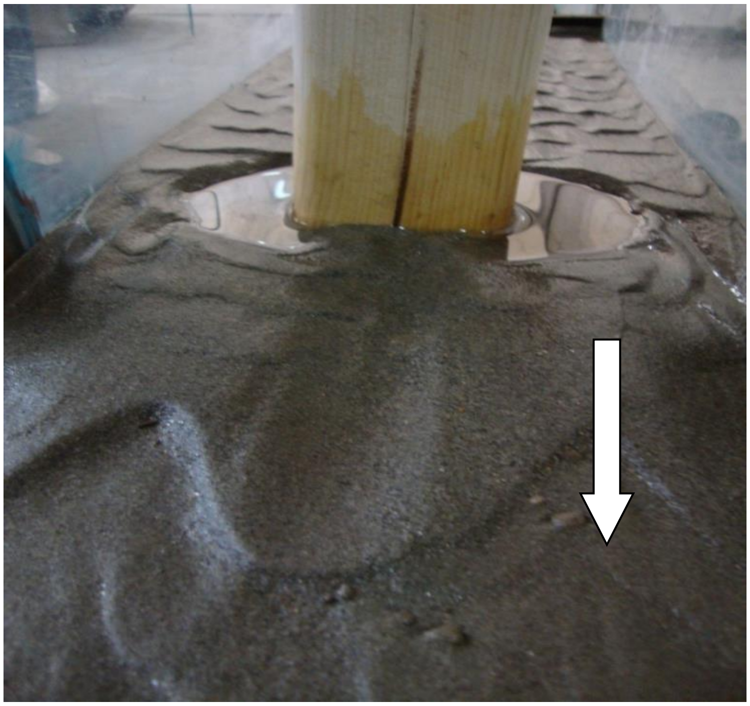

Figure: 5.14 Scour around round-nose pier at downstream side across the flow($\Theta=90^0$)

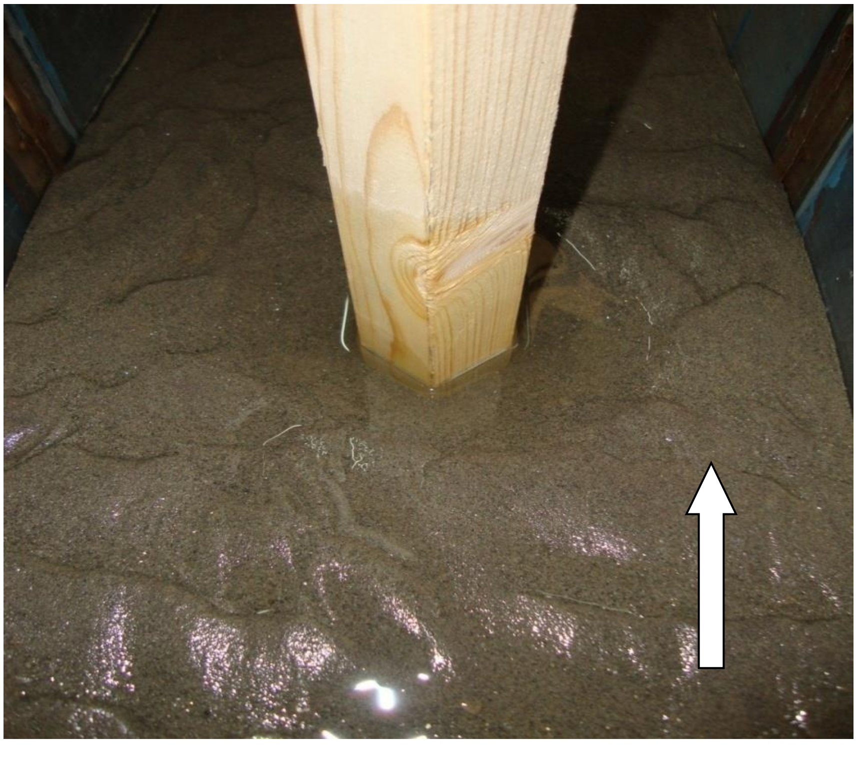

Figure: 5.15 Scour around sharp-nose pier at upstream side along the flow ($\Theta=0^0$)

Figure: 5.16 Scour around sharp-nose pier at downstream side along the flow(ϴ=0^0)

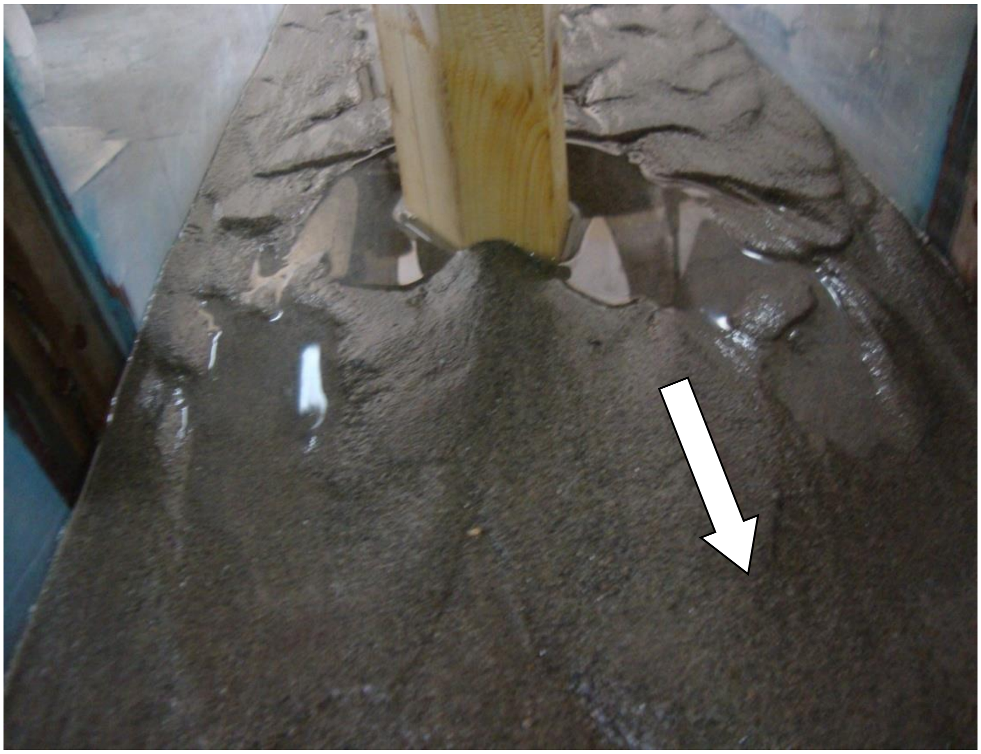

Figure: 5.17 Scour around sharp-nose pier at downstream side (ϴ=30^0)

Figure: 5.18 Scour around sharp-nose pier at downstream side (ϴ=60^0)

Figure: 5.19 Scour around sharp-nose pier at downstream side (ϴ=60^0) after water drained

Figure: 5.20 Scour around sharp-nose pier at upstream side (ϴ=60^0)

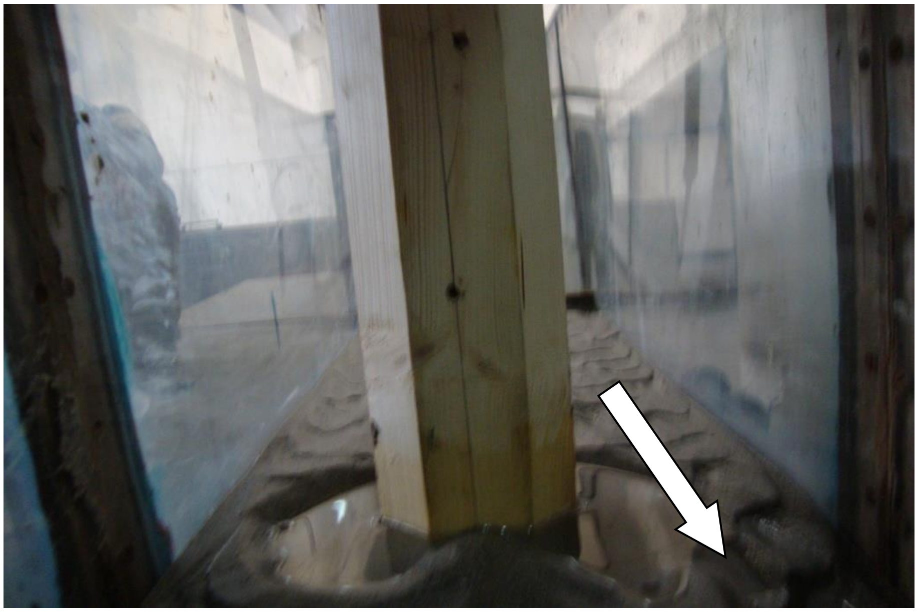

Figure: 5.21 Scour around sharp-nose pier at downstream side across the flow (ϴ=90^0)

Figure: 5.22 Scour around sharp-nose pier at upstream side across the flow ($\Theta=90^0$)

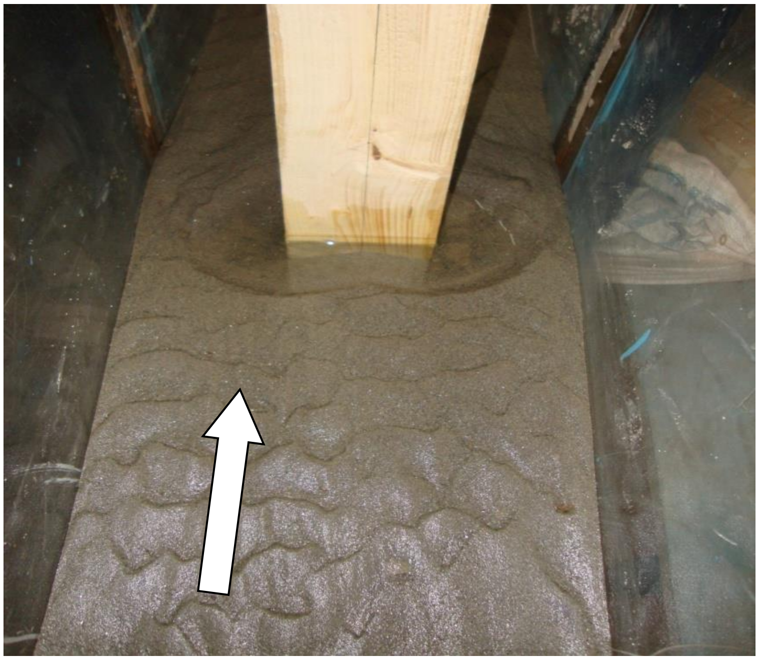

Figure: 5.23 Scour around rectangular pier at upstream side across the flow ($\Theta=90^0$)

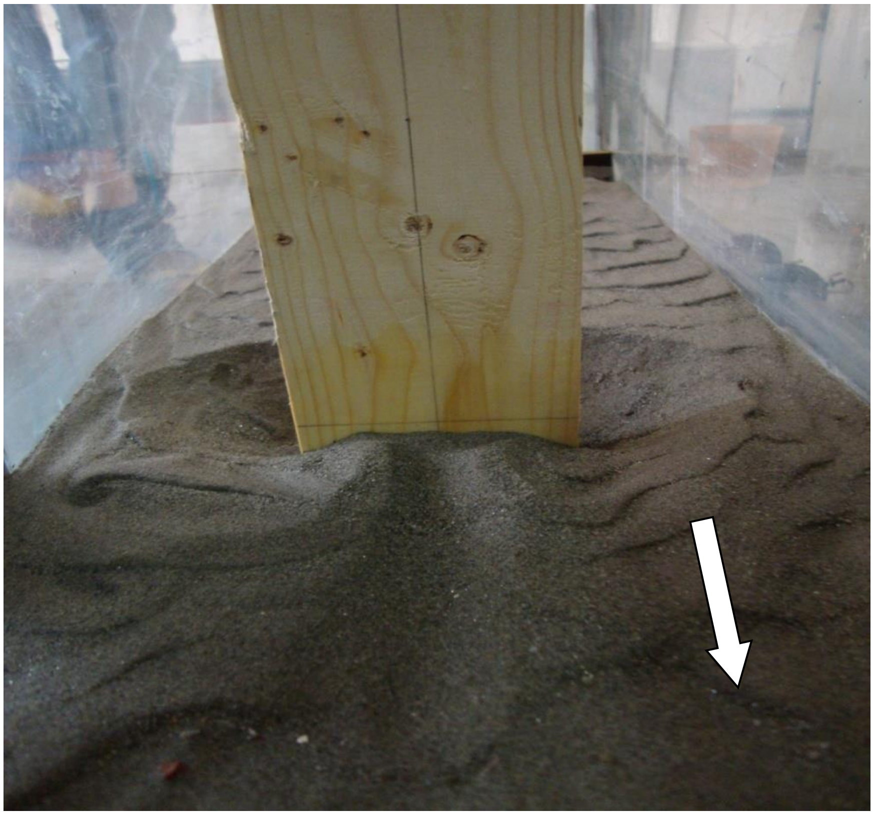

Figure: 5.24 Scour around rectangular pier at downstream side across the flow ($\Theta=90^0$)

Figure: 5.25 Scour around rectangular pier ($\Theta=60^0$)

From Figures 5.1 to 5.25 and tables 5.1 to 5.9, which show the picture of different shapes of scour holes of different piers, it can be concluded that geometry of scour hole has following characteristics:

- As under different condition of flow, scour depth slope is quite larger in amount at upstream side of the cylindrical pier, but at downstream side of scour hole has smaller value of slope then upstream of the channel flow. This difference in slopes is due to strong formation of vortices(higher flow energy) at the upstream side of the scour hole than the downstream side.

- The scour hole has the layout or geometry like an inverted frustum cone and the maximum scour depth occurs at the near of the pier tip.

- The scour hole side slope in upstream is nearly equivalent to cylindrical pier in all other cases of piers.

- The scour hole side slope in upstream is nearly equivalent or similar to cylindrical pier in all other cases of piers, as in all others cases there is not a severe effect of scouring on the downstream side of the channel.

- The shape of scour hole in case of cylindrical pier is nearly a circular shape circular around a pier, in case of round-nose and sharp-nose pier, the shape of scour hole is about U-shaped around a pier from the upstream side and in case of rectangular pier, the shape of hole is circular but only upstream side (when the latter three cases piers were installed along the flow).

- When all three cases piers were installed across the channel flow, the maximum scour takes in case of rectangular pier than the round-nose and sharp-nose pier, because in round-nose and sharp-nose, as they have smooth ends which helps to reduced the bed shear stress.

- The slope of upstream side of scour hole is nearly equal to angle of repose(wet) of bed sediment, while the downstream side average slope is almost about 50% of the value of the upstream. The results of these side slopes angles for sand used in bed sediments, are about 33° at upstream side of scour hole and the downstream side of scour hole is about 17°.

- From table no. 5.4, 5.6. 5.8, the flow depth and discharge is kept constant, values of scour depth around different shapes of pier and orientation. In all the shapes of piers, the scour increases with the increase in angle of attack of flow or orientation of pier with flow i.e. when the pier were placed with flow that means $\Theta= 0^0$ the scour depth is minimum in all cases but at $\Theta= 90^0$, the scour depth is maximum. The reason behind this aerodynamic flow at piers not contraction ratio, at $\Theta=60^0$ the contraction ratio is maximum still has greater scour depth value. At $\Theta=60^0$, the pier is still aerodynamic so that it does effect the flow too much but at 90^0 the scour depth is higher than at any other angle. So, it be concluded that scour depth is not a function a contraction ratio but depends upon the shape and orientation of flow.

- In case of all models except cylindrical pier, the downstream length of scour hole is zero as the piers were installed along the channel flow or across the channel flow (i.e. $\Theta= 0^0$ or 90^0).

- Under the condition of constant discharge and flow depth, the depth of scour increases with time, when the flow is run in parts runs the scour depth will be always less then continuous runs, therefore it was found that the scouring rate of increasing hole was decreasing over a longer time interval. The rate of flow (i.e. increasing discharge) does affect the scour depth of scour hole; scour depth was always more at higher flow rate.

- In all above cases of experiment, the maximum scour depth was generally observed to occur at upstream side of the pier. The maximum scour depth is a function of both time as well as flow rate, as it was observed that maximum scour depth was in increasing trend with increase of flow rate and time.

- As in case of cylindrical pier, when the flow depth is varied and keeping discharge constant, the scour depth increases with flow depth then at a certain depth of flow the depth of scour hole is decreased again when the Froude number tends towards zero. This will occurs because of back-water effect, as the water at the downstream side will helps to counter the turbulence or vortices which are induced due to deflection of flow by bridge elements.

- When the channel flow strikes the inclined pier towards upstream side, the effective pier width will be more than in case of pier along with flow, then at the upstream face of pier to flow direction creates a high pressure zone because of high value of blockage ratio and at the downstream face creates a low pressure zone. At high pressure zone, the rate and depth of scour hole is quite high than the face having low pressure zone.

- As in case of 0^0 and 90^0 with the flow direction, the geometry of scour hole is symmetric but in case of 30 and 60 the geometry of scour is asymmetric, and scouring at high pressure zone face will be high as comparison to low pressure zone face.

- **Slope and dimensional depth and distance of the scour hole**

Table no. 5.10: Dimensional values of different flow and scour parameters around cylindrical pier varying discharge with constant flow depth.

Cylindrical Pier									
Keeping flow Depth (H) constant H=5.9									t=35min
Sr No.	e(%)	Q(*10^{-3} m^3 /s)	Fr	d_s/b	L_{up}/b	L_{down}/b	L_l/b	L_r/b	Θ_{up}
1	16.67	4.08	0.303	0.68	1.06	0.70	0.94	0.98	32.69
2	16.67	4.56	0.339	0.74	1.16	0.76	1.02	1.04	32.54
3	16.67	5.00	0.370	0.82	1.26	0.86	1.10	1.12	33.06
4	16.67	5.40	0.400	0.88	1.28	0.94	1.18	1.16	32.54

Table no. 5.11: Dimensional values of different flow and scour parameters around cylindrical pier varying flow depth with constant discharge.

Cylindrical Pier										
Keeping Discharge constant Q_1=4.08X10^{-3} m^3/s										T=35min
Sr. No.	e(%)	H (cm)	Fr	d_s/H	L_{up}/H	L_{down}/H	L_l/H	L_r/H	Θ_{up}	Θ_{down}
1	16.67	1.7	1.96	0.48	1.24	0.88	1.08	1.12	21.16	16.23
2	16.67	2.6	1.035	0.54	1.3	0.96	1.18	1.1	22.56	16.67
3	16.67	3.9	0.564	0.72	1.2	0.86	1.04	1.06	30.97	18.54
4	16.67	5.9	0.303	0.68	1.06	0.7	0.94	0.98	32.69	18.64
5	16.67	6.5	0.261	0.66	0.94	0.62	0.92	0.96	35.08	19.23
6	16.67	7.3	0.219	0.62	0.86	0.56	0.9	0.96	35.79	19.23

Table no. 5.12 Dimensional values of different flow and scour parameters around round-nose pier varying flow depth with constant discharge.

Round-Nose Pier (For Constant Discharge)										
Sr No.	Ө	H (cm)	V (m/s)	Fr	d_s/H	L_{up}/H	L_{down}/H	L_l/H	L_r/H	$Ө_{up}$
1	0	3.70	0.367	0.610	0.891	1.378	0.000	1.216	1.243	32.91
		5.30	0.256	0.355	0.509	1.018	0.000	0.792	0.773	26.57
		6.80	0.200	0.245	0.397	0.764	0.000	0.573	0.573	27.44
2	30	4.00	0.340	0.543	0.850	1.425	0.000	1.150	1.300	30.82
		5.90	0.230	0.303	0.491	0.915	0.000	0.728	0.830	28.24
		7.10	0.192	0.231	0.380	0.718	0.000	0.549	0.577	27.9
3	60	4.60	0.300	0.446	0.565	1.239	1.173	1.021	1.369	24.52
		5.90	0.230	0.303	0.372	0.898	0.830	0.762	1.000	22.55
		7.30	0.186	0.219	0.273	0.671	0.657	0.575	0.767	22.21
4	90	4.60	0.300	0.446	0.760	1.282	0.000	1.239	1.217	30.68
		5.90	0.230	0.303	0.525	0.966	0.000	0.915	0.898	28.54
		7.30	0.186	0.219	0.397	0.739	0.000	0.698	0.698	28.24

Table no. 5.13 Dimensional values of different flow and scour parameters around sharp-nose pier varying flow depth with constant discharge.

Sharp - Nose Pier (For Constant Dishcharge)										
Sr No.	Ө	H (cm)	V (m/s)	Fr	d_s/H	L_{up}/H	L_{down}/H	L_l/H	L_r/H	$Ө_{up}$
1	0	5.60	0.242	0.326	0.500	0.910	0.000	0.946	0.964	28.17
		8.00	0.170	0.192	0.312	0.512	0.000	0.600	0.587	31.38
		6.80	0.200	0.245	0.382	0.661	0.000	0.763	0.720	30.02
2	30	5.50	0.247	0.336	0.527	0.945	0.000	0.763	0.745	29.15
		8.50	0.160	0.175	0.305	0.505	0.000	0.364	0.388	31.16
		7.20	0.188	0.223	0.388	0.667	0.000	0.513	0.500	31.16
3	60	3.90	0.348	0.563	0.871	1.512	1.230	0.000	1.205	29.96
		6.30	0.215	0.273	0.476	0.761	1.667	0.000	0.650	32.01
		5.20	0.261	0.365	0.673	1.057	0.884	0.000	0.846	32.48
4	90	3.90	0.348	0.563	0.923	1.487	0.000	1.564	1.512	31.83
		5.30	0.256	0.355	0.500	0.742	0.000	0.803	0.772	34.65
		6.60	0.206	0.255	0.716	1.037	0.000	1.075	1.018	33.96

Table no. 5.14 Dimensional values of different flow and scour parameters around rectangular pier varying flow depth with constant discharge.

Rectangular Pier (For constant Dishcharge)										
Sr No.	**θ**	**H (cm)**	**V (m/s)**	**Fr**	**d_s/H**	**L_{up}/H**	**L_{down}/H**	**L_l/H**	**L_r/H**	**θ_{up}**
1	0	4.60	0.296	0.441	0.739	1.282	0.000	0.000	0.000	29.96
		5.90	0.231	0.303	0.508	0.966	0.000	0.000	0.000	27.76
		7.20	0.188	0.223	0.402	0.750	0.000	0.000	0.000	28.24
2	30	4.60	0.296	0.441	0.717	1.152	1.195	0.000	1.347	31.91
		5.90	0.231	0.303	0.508	0.813	0.864	0.000	0.966	32.01
		7.20	0.188	0.223	0.388	0.638	0.722	0.000	0.750	31.33
3	60	4.60	0.296	0.441	0.673	1.130	1.239	0.000	1.326	30.81
		5.90	0.231	0.303	0.474	0.830	0.898	0.000	0.983	29.75
		7.20	0.188	0.223	0.361	0.638	0.777	0.000	0.777	29.48
4	90	4.60	0.296	0.441	0.782	1.608	0.000	1.173	1.195	25.95
		5.90	0.231	0.303	0.525	1.200	0.000	0.881	0.898	23.69
		7.20	0.188	0.223	0.381	0.944	0.000	0.694	0.680	22.39

CHAPTER 6

ANALYSIS AND DISCUSSION

For cylindrical pier (keeping flow depth constant)

As cylindrical pier was installed in flume and tested under the condition of constant flow depth and time with a varying discharge. As we can see from graphs, with the increase in discharge the parameters d_s (scour depth), L_{up} increases.

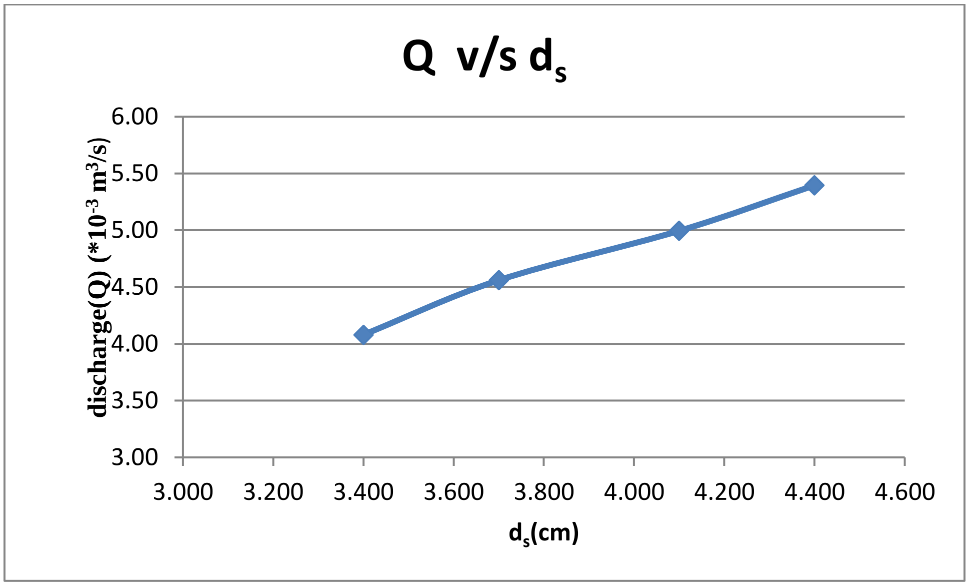

Figure: 6.1 A graph between discharge and scour depth (d_s) keeping flow depth constant

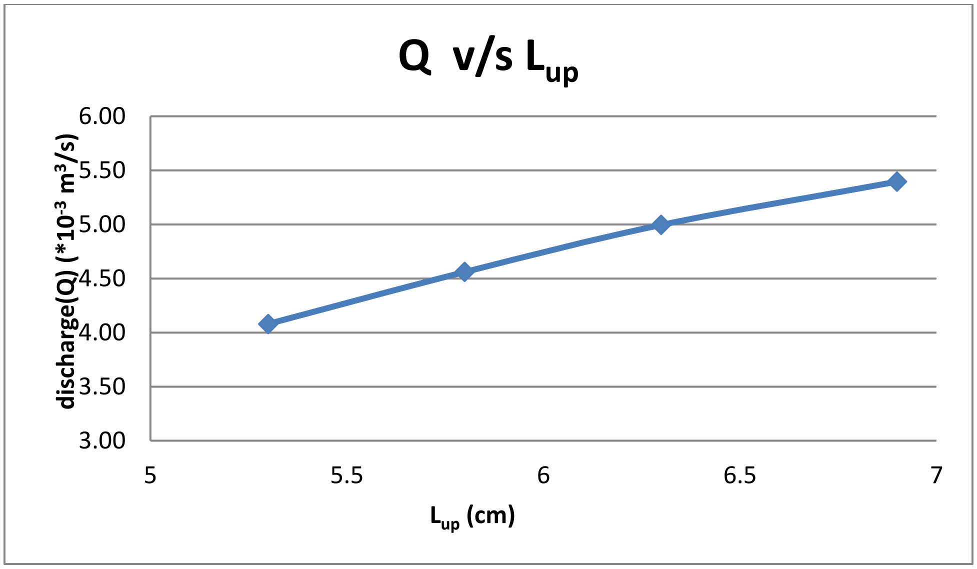

Figure: 6.2 A graph between discharge and upstream length (L_{up}) keeping flow depth constant

As the discharge increases, the scour depth and length of scour hole on upstream side increases about linearly. It simply means that the scouring rate will increases with increase in discharge.

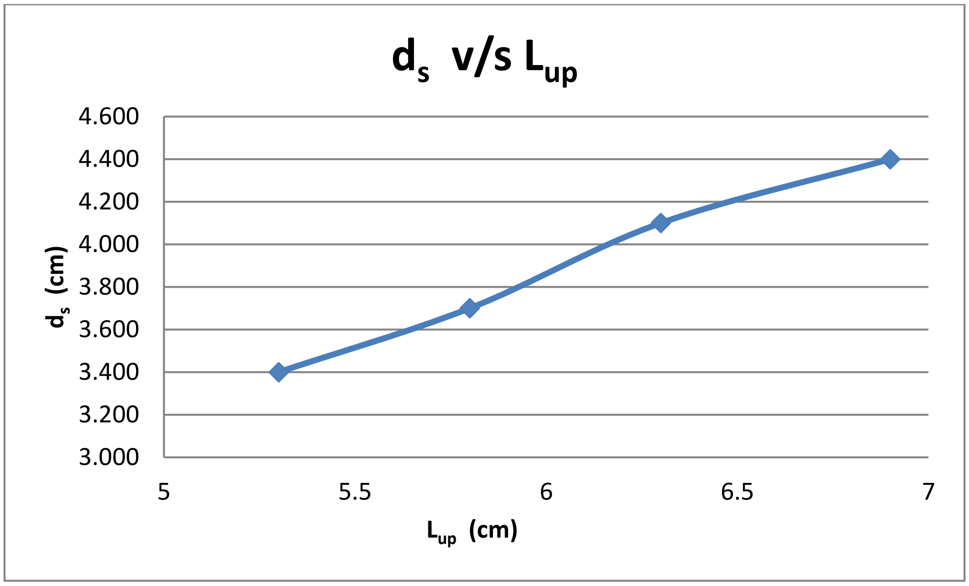

Figure: 6.3 A graph between scour depth(d_s) and upstream length(L_{up}) keeping flow depth constant

As the discharge increases, keeping flow depth increases that simply means increase in flow velocity, which will increases the value of Froude number and the scour depth will increases with the increases of discharge and Froude number.

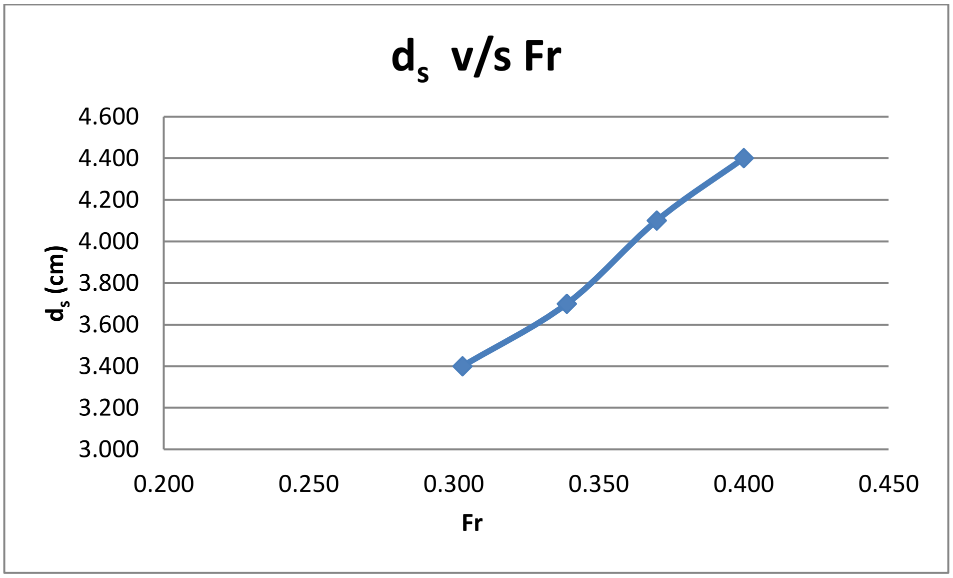

Figure: 6.4 A graph between scour depth(d_s) and Froude no.(Fr) keeping flow depth constant.

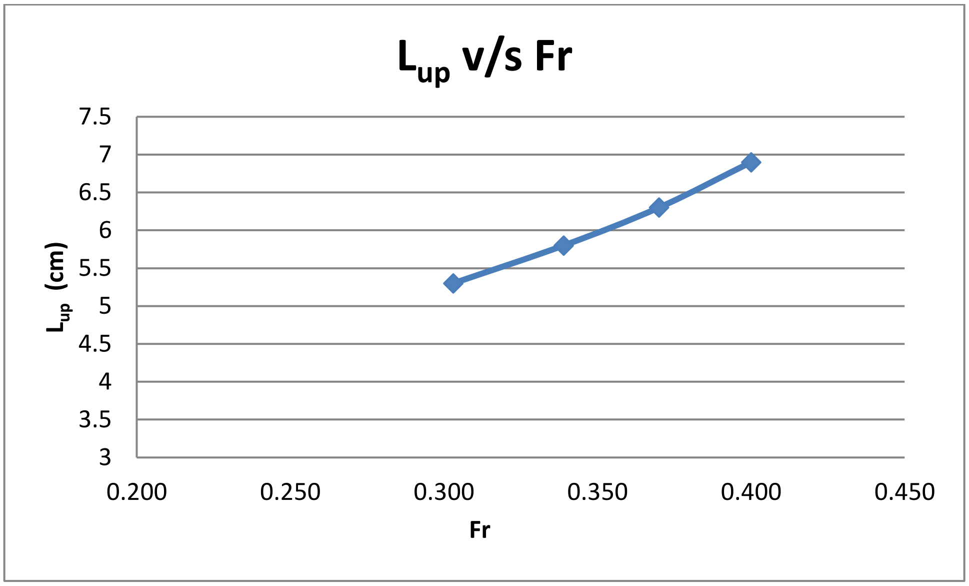

Figure: 6.5 A graph between upstream length (L_{up}) and Froude no.(Fr) keeping flow depth constant.

The variation of scour depth with discharge is presented in the graph below figure (6.6) and observed that with the increase of discharge, the scour depth also increase linearly. The scour depth around pier will be greater if the discharge is greater. At lower values of discharge, the scour depth variation is in a linear trend but at the higher value of discharge there become a non-linear relation between scour depth and discharge this is because of local scouring depends upon strong vortex formation due to obstruction occurs around the pier. As the vales of discharge increases the strength of vortices formed near the bridge pier also increases which results into scouring at higher value so the scour hole is quite deeper at higher value of discharge.

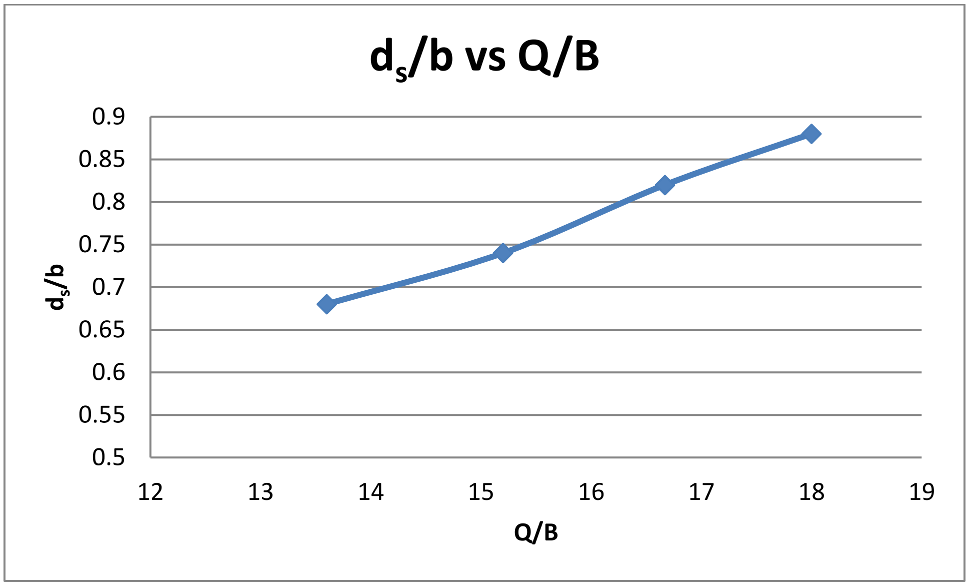

Figure: 6.6 Equilibrium scour depth variation with discharge

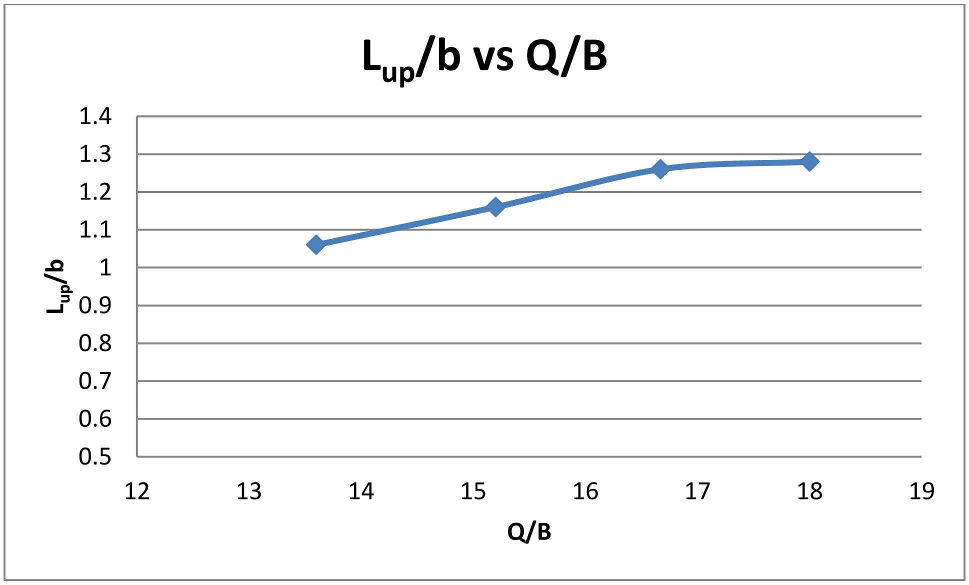

Figure: 6.7 Equilibrium scour upstream length (L_{up}) variation with discharge

For cylindrical pier (keeping discharge constant)

In case of keeping discharge constant, flow depth is varied it's a clear case of bridge pier condition on river or channel just falling into sea. As the cylindrical pier was installed in a flume under condition of keeping discharge constant and the flow depth is varied. The graph below is giving a result when the flow depth increases, the scour depth also increases but after a certain flow depth then the scour depth will decreases with increase in flow depth.

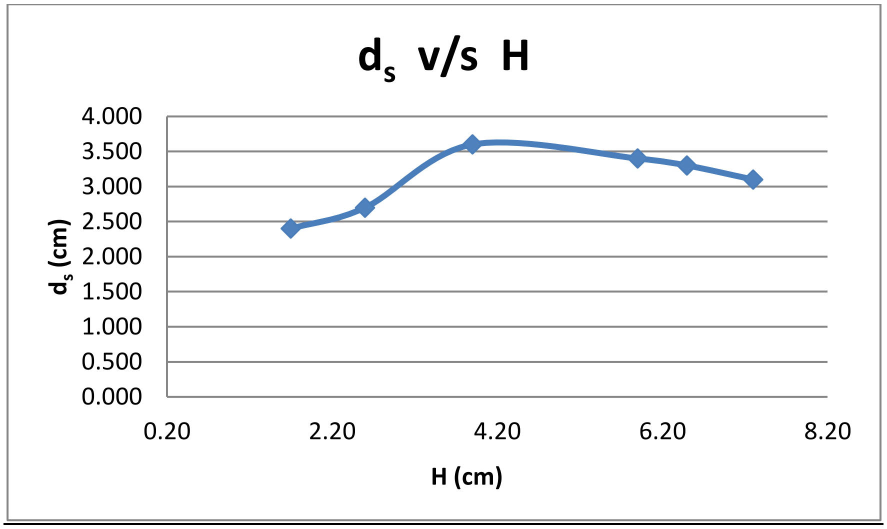

Figure: 6.8 A graph between scour depth(d_s) and flow depth(H) keeping discharge constant.

As the decrease in Froude number, the scour depth increases up to a point then it will again decrease when Froude number tends to zero.

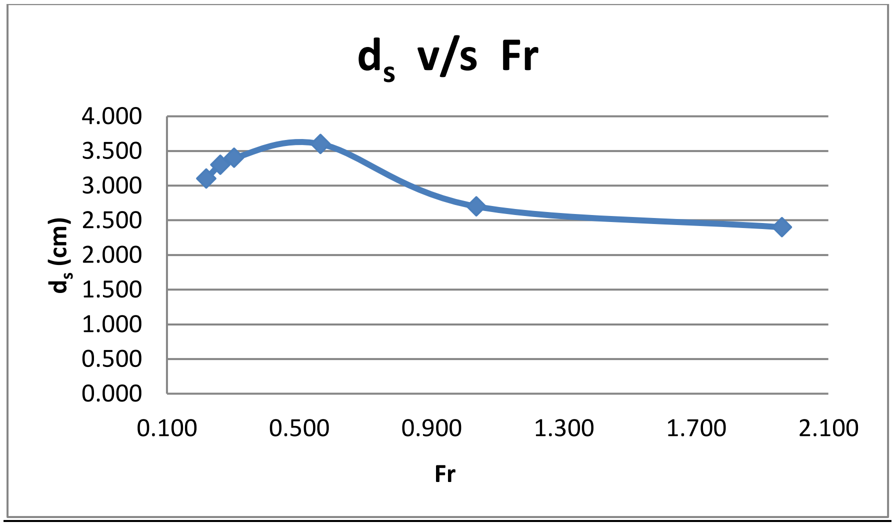

Figure: 6.9 A graph between scour depth(d_s) and Froude no.(Fr) keeping discharge constant.

In the above two figures (6.8) and (6.9), the graphs show the results which are not match with the literature of scour around pier, as the literature says the scour depth (d) will increases with increase in flow depth that is because of generation of strong vortices by separation of flow by piers which are mainly responsible of scouring around pier, but in the above case keeping the discharge constant and flow depth of channel flow is varied, that means it could be bridge pier near the sea or big check dam, the river hydraulics changes. As the discharge is constant, at lower flow depth the velocity is high, as the flow depth increases the flow velocity decreases. Now the till a certain flow depth, the vortices are strong enough that are mainly responsible for scouring. Then after a certain depth, the back water on the downstream plays it role as the depth of flow increases, the vortices are not enough strong as it is earlier because of counter attack of back water which results into decrease in scour depth after a certain flow depth.

For cylindrical pier (keeping discharge and flow depth constant)

As the cylindrical pier was installed under condition of discharge and flow depth constant, time varies. The flow was run in four individual runs like a seasonal river and a run was made for continuous time. The difference between them when flow run in parts the scour depth will less than the if the run was made continuously.

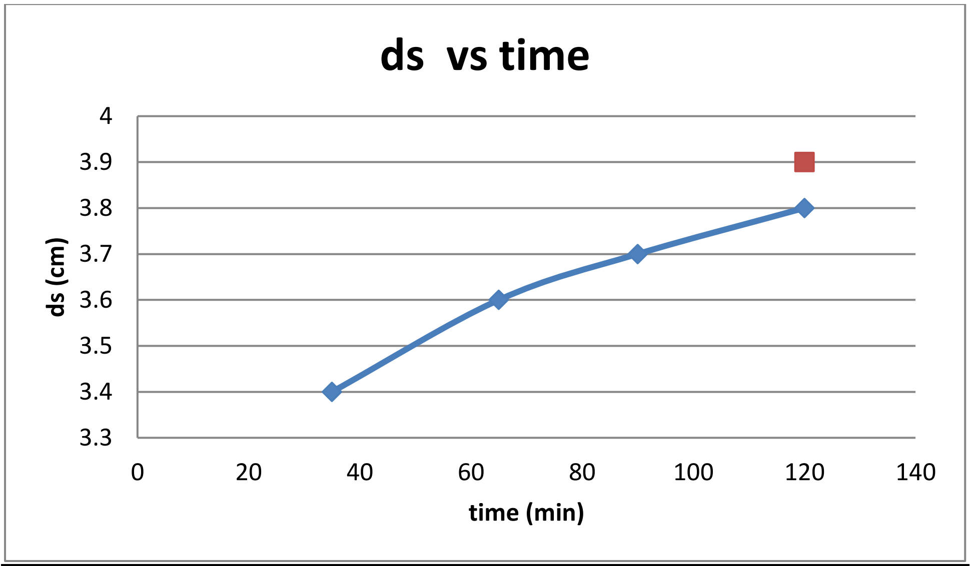

Figure: 6.10 A graph between scour depth (d_s) and time keeping flow depth and discharge constant.

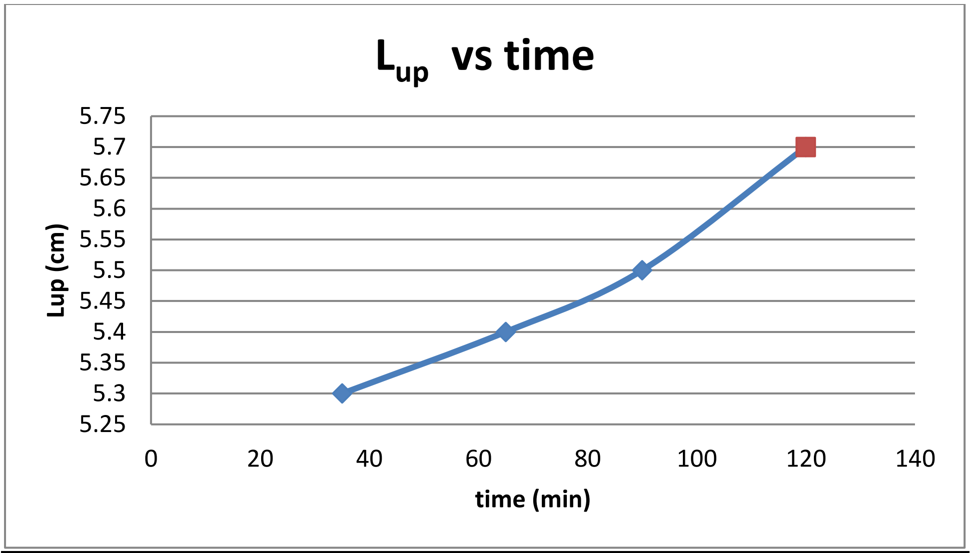

Figure: 6.11 A graph between upstream length(L_{up}) and time keeping flow depth and discharge constant.

All the parameters like d_s, L_{up} and L_{down} are less in the condition of parts run than the continuous run. With the increase of time of flow run, all the parameters increases. But in case of parts run of flow, the parameters like ds are less or equal to continuous run but not more than that. The flow in part run means the flow takes place for few minutes then stops and flow run again, like a typical seasonal drains which generally flow during rainy seasons.

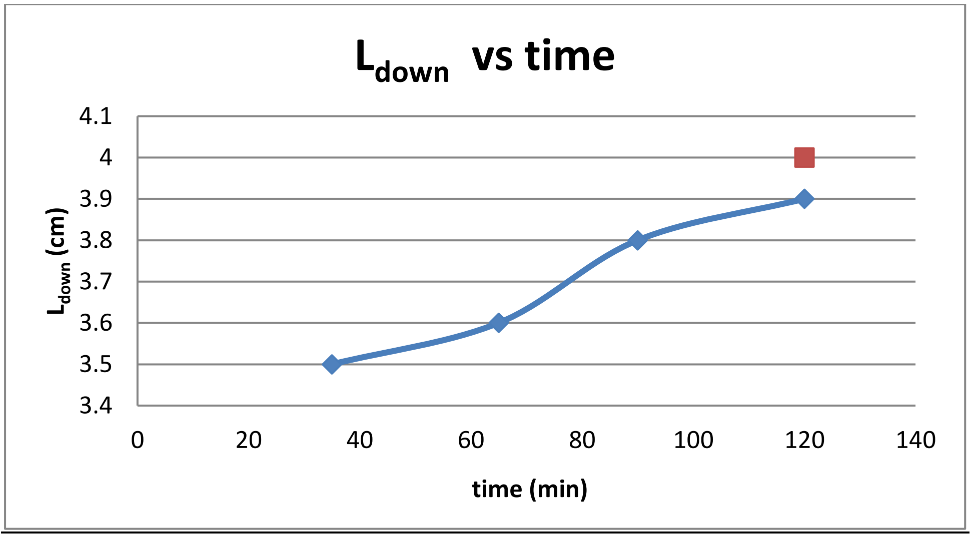

Figure: 6.12 A graph between downstream length(L_{down}) and time keeping flow depth and discharge constant.

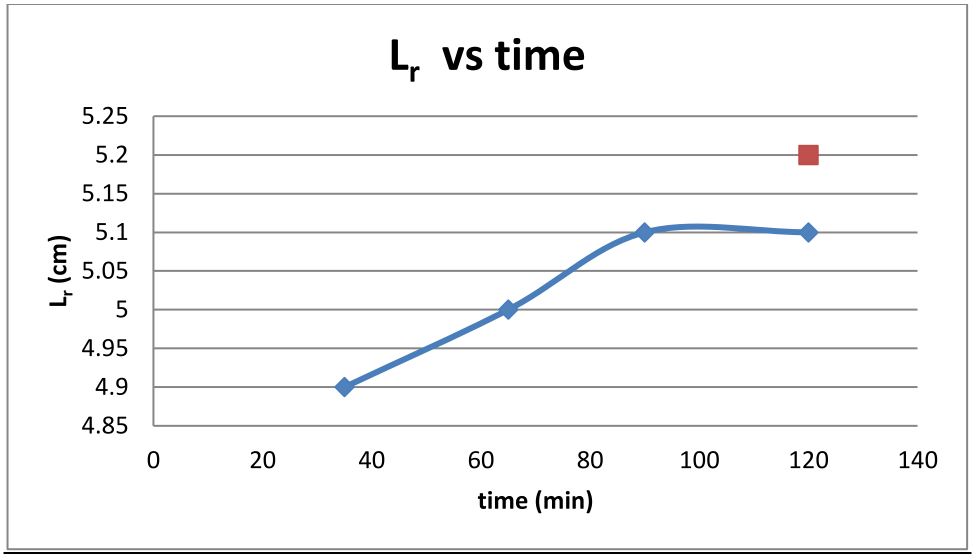

Figure: 6.13 A graph between right-side length of scour hole(L_r) and time keeping flow depth and discharge constant.

Effect of the Flow Conditions on Scour Hole Characteristics

As the pier was placed in the flume, the obstruction results into generation of strong vortex, due to which the velocity profile changes in the contracted area. So the Froude number and flow velocity are very important parameters which help in analyzing the characteristics of scour hole around different of pier at different orientation. As the flow velocity increases that simply means the Froude number should also increase. For these reasons different flow conditions, namely with F_r = 0.2 to 0.7, were applied to each model, to investigate the influence of flow condition on scour hole depth and width. As a consequence of increasing the value of Froude number, the ratio V/V_c increases, in such a manner that the maximum value of this ratio was not exceed the unity, because all experiments were held under clear water conditions as stated before.

From graphs below, it is obvious that for different models of piers and angels of orientation, all of the scour parameters increased as Froude number increased. On the other hand, the rate of increase of relative scour depth and length decreases as the pier width decreases, because with less pier width the effect of pier on flow velocity get smaller.

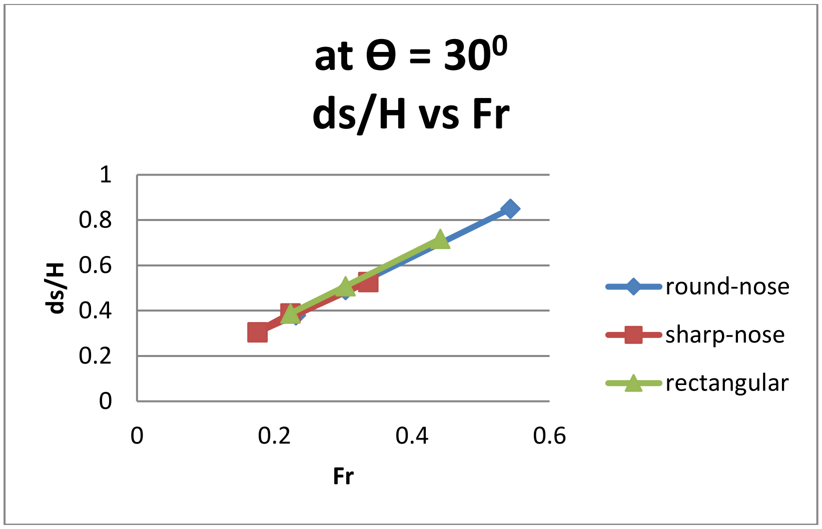

Figure: 6.14 scour depth vs Froude number of different piers at (ϴ=30º)

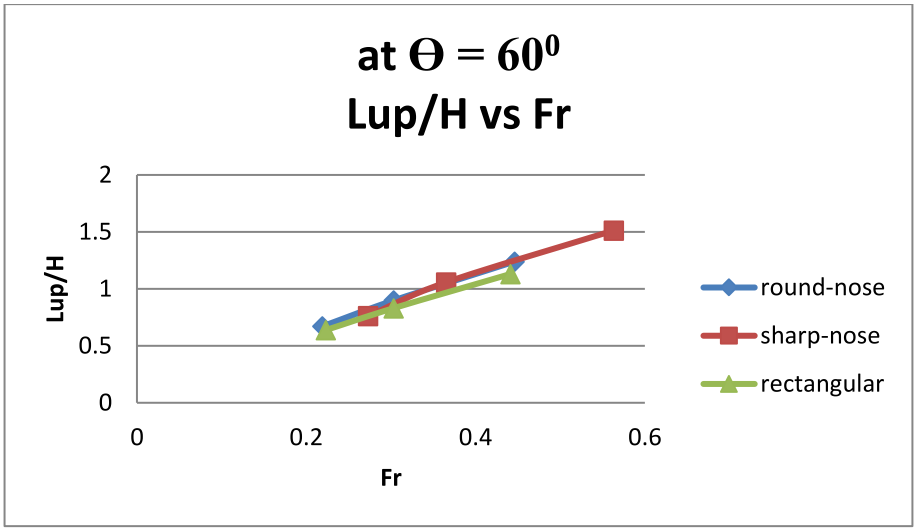

Figure: 6.15 relative scour depth vs Froude number of different piers (ϴ=60º)

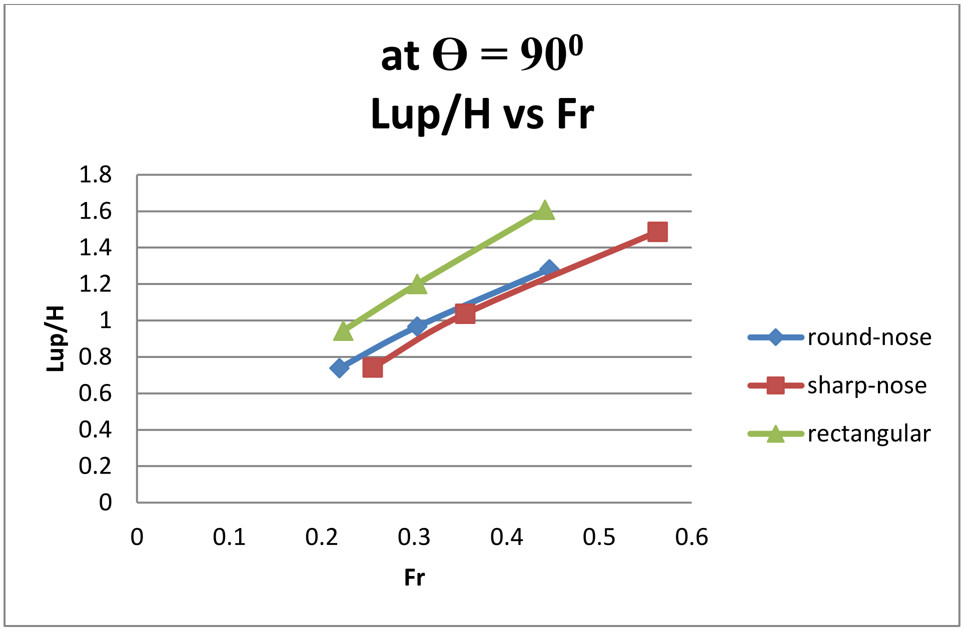

Figure: 6.16 relative scour depth vs Froude number of different piers at ϴ=90º

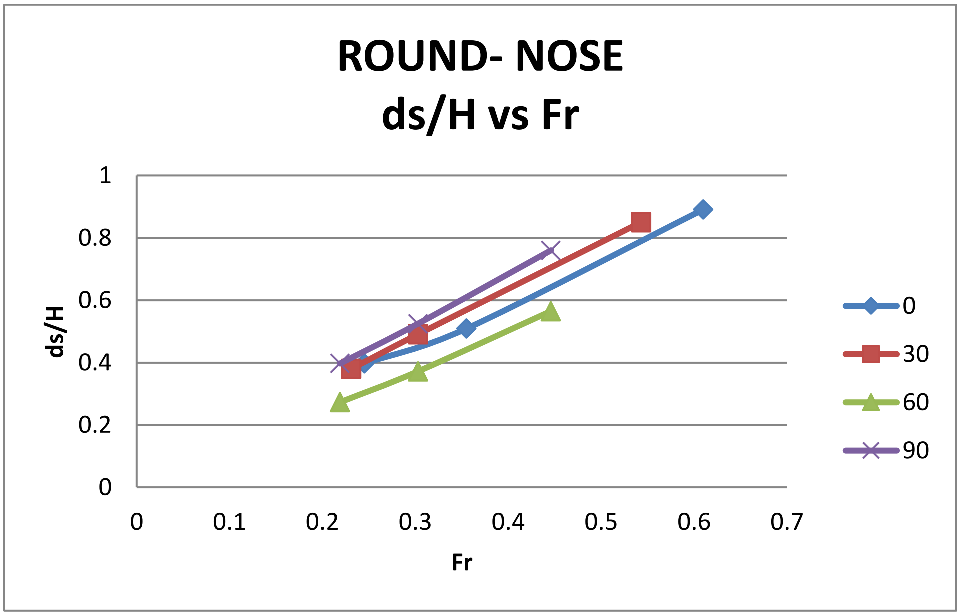

Figure: 6.17 relative scour depth vs Froude number at round-nose pier

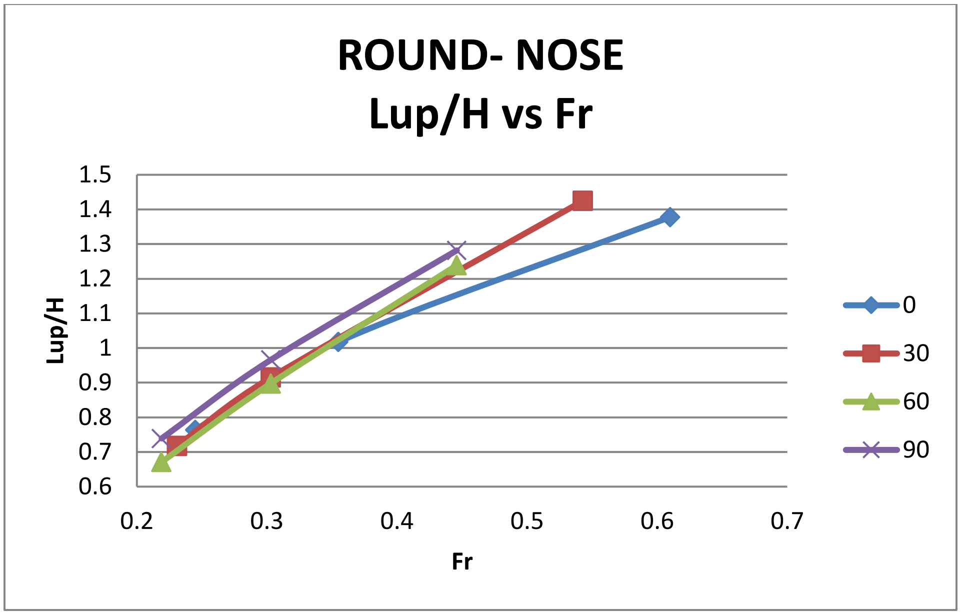

Figure: 6.18 relative scour depth vs Froude number at round-nose pier

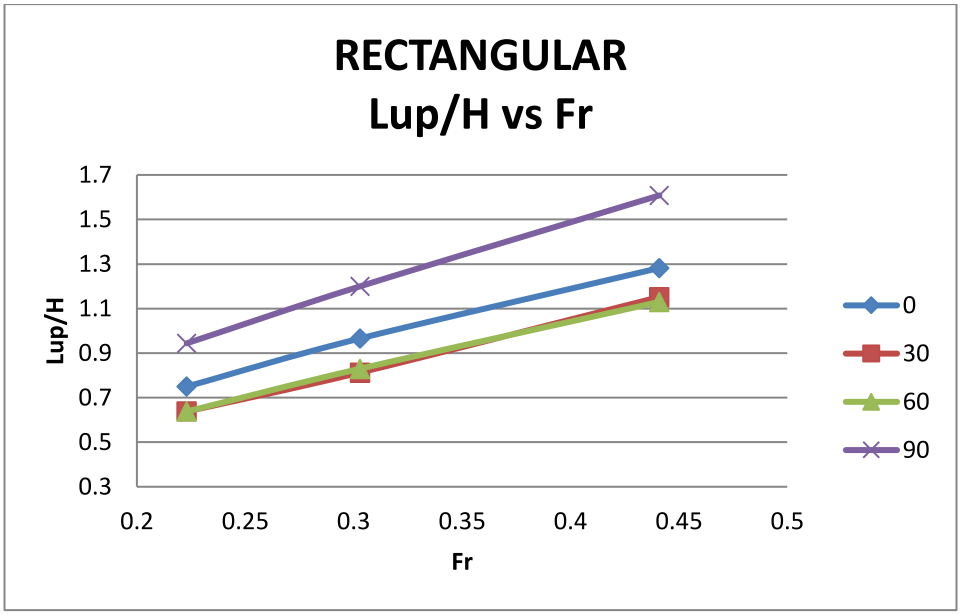

Figure: 6.19 relative scour depth vs Froude number at rectangular pier

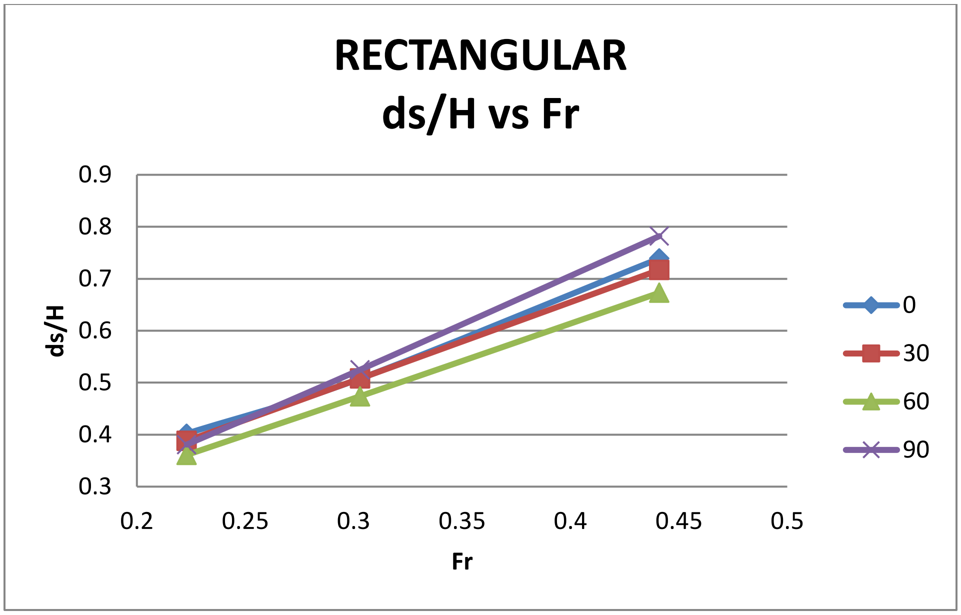

Figure: 6.20 relative scour depth vs Froude number at rectangular pier

<u>Pier alignment, α</u>

The scour pattern of inclined piers is quite different from the piers which is position along (parallel) and across (perpendicular) the channel. As there become two pressure area as first low pressure area and second one is high pressure area in inclined piers that low pressure zone is part of piers that does not exposed in direct way of channel and high pressure zone is part of piers which contact directly with flow (Figure: 6.21). When the angle of piers kept along the channel that is zero, the scouring starts from the vertical sides of piers and then after sometime it comes to the front of pier (see Figure 6.21 a). when the alignment of attacking angle increases up to 45 degree, that is 0<α< 45 scouring will occurs on two vertical sides of piers by keeping in mind that the scouring rate is less in low pressure zone side of piers, than the high pressure sides and the scour hole will extended to front side of pier (see Figure. 6.21 b). Where 45<α<90, there is no observations of scour on high pressure vertical sides of pier, scouring starts from the low pressure zone sides of pier (see Figure 6.21 c). In alignment of attack 90^0 that pier is across the channel scouring starts from the sides of pier with two symmetrical arc and thereafter sometime, scour hole extends from the vertical sides of pier to front face pier (see Figure 6.21 d)

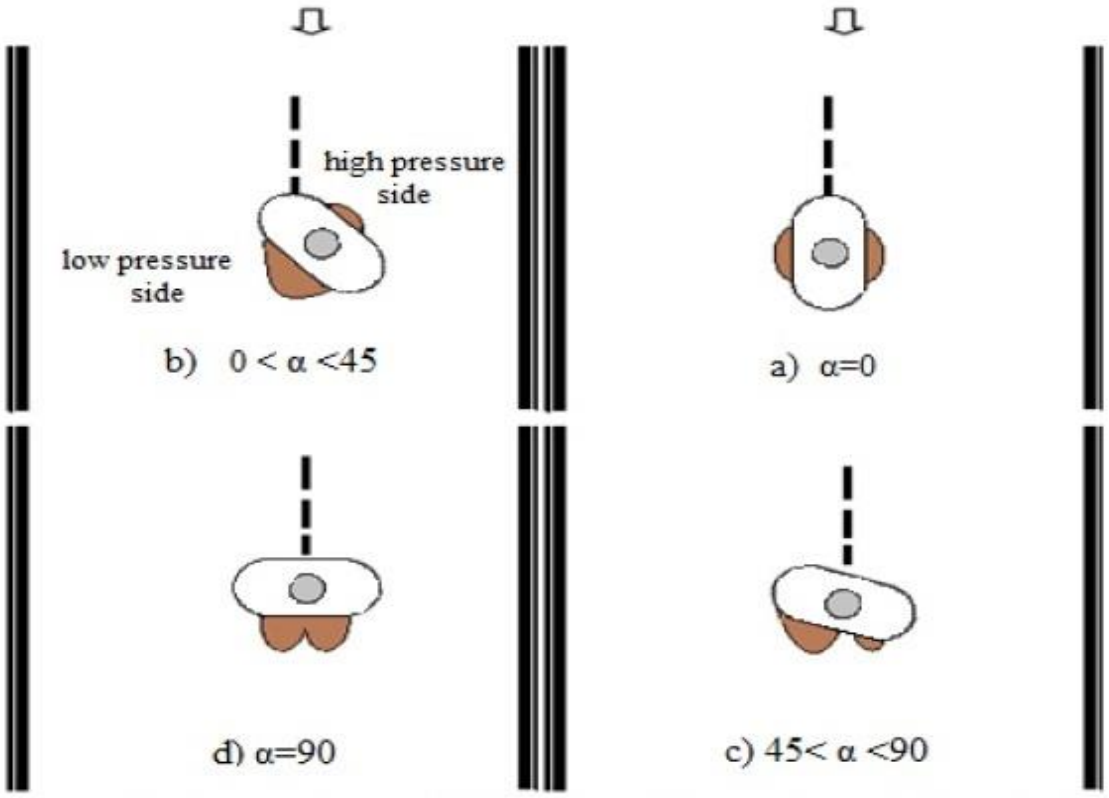

Figure: 6.21 Scour pattern at pier with aerodynamic shape

By increasing angle of attack of pier with channel flow the effective width of pier is increased then the turbulence or vortices around the pier increased and scouring around the piers also increased. In Figure 6.22 shows the flow pattern around a round-nose bridge pier at inclined position and at 90^0 position (i.e. across the channel flow). As the angle of attack increases with channel flow, at high pressure zone the scouring rate will be more than transverse side of pier(i.e. low pressure side) and the bigger particles will find in the scour hole towards the downstream side of channel flow.

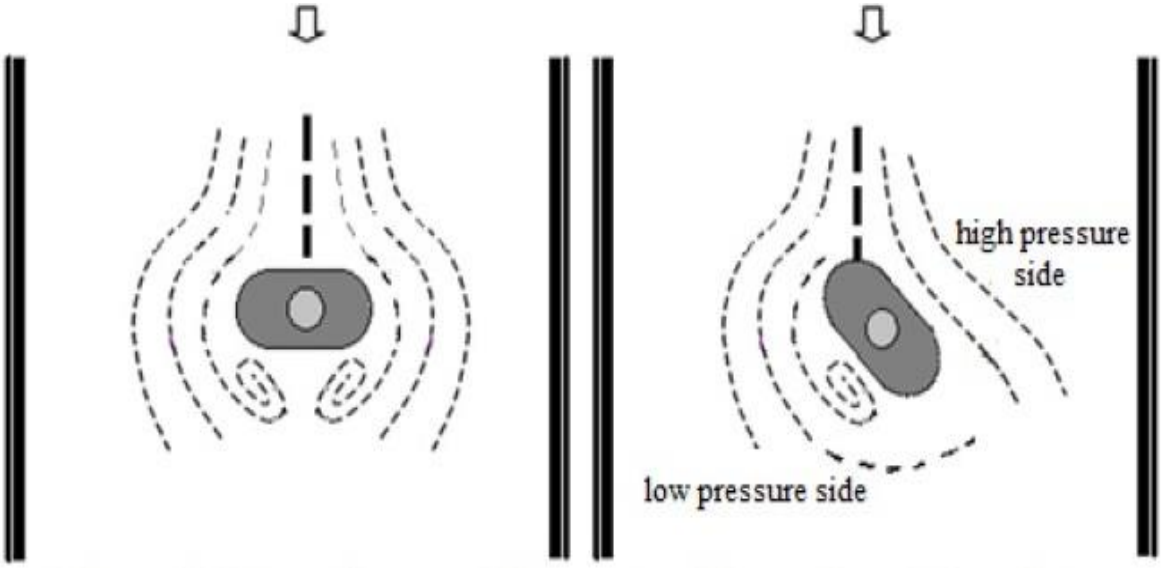

Figure: 6.22 Flow paths around pier with aerodynamic shape

As shown in above figure, increasing an angle of pier with the channel flow scour rate around the pier increased. The depth of scour in low pressure side increases due to the strong vortex strength and the sediments or materials moved from the sides of pier and starts gathering on the back side of pier. The sediments gathering rate is low in the high pressure side and this causes the sediments level will be higher than the original bed level. This phenomena is mainly responsible for the geometry of the scour hole in inclined pier is asymmetric, but when the pier is at zero or 90^0 the scours hole geometry is symmetric.

As when pier long the channel flow there will be minimum scouring takes place due to aerodynamic shape of pier which obstract minimum amount of water and across the channel flow scouring will be maximum, because of the width of pier will increase across the channel and obstract the more volume of water which will create a hugh amount of pressure on upstream side of pier. But the shape of scour hole will symmetric in above cases we discusses, in case of inclined pier to flow, the shape of scour hole is asymmetric.

CHAPTER 7

CONCLUSIONS

The experiments were conducted under different condition of flow(i.e. keeping discharge constant in one and keeping flow depth constant in other) with different shapes of piers at different orientation with flow. The geometry of scour hole is quite different as the shape of pier changes as well as condition of flow, so there some conclusions after performing and deeply analysis of results from the experiment are:

- The scour hole side slope is larger at upstream side of the cylindrical pier which is around to the angle of repose of sand, but the downstream side of scour hole having lesser than the upstream side of scour hole. This difference in slopes is due to strong formation of vortices(higher flow energy) at the upstream side of the scour hole than the downstream side.

- The scour hole has the layout or geometry like an inverted frustum cone and the maximum scour depth occurs at the near of the pier tip.

- The scour hole side slope in upstream is nearly equivalent to cylindrical pier in all other cases of piers.

- All of the scour parameters like scour depth (d_s), upstream scour length(L_{up}) increases with the increase of Froude number in a linear trend. But, Froude number has no great effect on the general geometry of scour hole.

- The shape of scour hole in case of cylindrical pier is nearly a circular shape circular around a pier, in case of round-nose and sharp-nose pier, the shape of scour hole is about U-shaped around a pier from the upstream side and in case of rectangular pier, the shape of hole is circular but only upstream side (when the latter three cases piers were installed along the flow).

- As in case of cylindrical pier, when the flow depth is varied and keeping discharge constant, the scour depth increases with flow depth then at a certain flow depth of scour depth hole is decreased again when the Froude number tends towards zero.

- The best pier shape which leads to minimum scour around it, was round-nose pier aerodynamic shape along the channel, round-nose pier aerodynamic across the channel and cylindrical shape, respectively.

- The maximum scour occurs in case of cylindrical pier and minimum scour occurs in case of round-nose pier aerodynamic shape along the channel, then sharp–nose piers, rectangular pier as on.

- Inclined pier creates two low pressure and high pressure area around the foundation. The accumulation of sediments in high pressure area and washing the sediment in low pressure is high so scour hole around the non-uniform pier is asymmetric.

- By increasing the angle of flow to pier increasing the effective width of pier which allows increasing the depth of scour. In 90 degree angle, the maximum of scour depth in relation to inclined position is less, because in this position water rejection is more and approaching speed in company with the other position is less so its scour is low.

- The scour depth of hole around cylindrical pier depends on pier size, soil properties of bed, and the flows Froude number. The rate of scouring depends upon the vortices formation around the piers and their nature.

- The scour depth is a not a function of contraction ratio, because the scour depth depends on shape and orientation of flow.

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