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STUDY OF SCOUR REDUCTION AROUND THE CIRCULAR PIER USING COLLAR AND SLOT

Submitted in partial fulfillment of the requirements of the degree of

Master of Technology in

Hydraulics and Water Resource Engineering

SUBMITTED BY

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CERTIFICATE

This is to certify that thesis report entitled "**STUDY OF SCOUR REDUCTION AROUND THE CIRCULAR PIER USING COLLAR AND SLOT**" being submitted by me is a bonafide record of my own work carried by me under the guidance of Dr. MUNENDRA KUMAR 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 Water Resource 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 the work contained in the dissertation is original and has been done by myself under the general supervision of my supervisor. The work has not been submitted to any other institute for any degree or diploma. I have followed the guidelines provided by the institute in writing the report. I have conformed to the norms and guidelines given in the Ethical Code of Conduct of the institute. Whenever, I have used materials (data, theoretical analysis and text) from other sources, I have given due credit to them by citing them in the text of the dissertation and giving their details in the references. Whenever, I have quoted written material from other sources, I have put them under quotation marks and given due credit to the sources by citing them and giving required details in the references.

Signature of the Student:

Name of the Student: SIDDHARTH PANJATHIA

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INTRODUCTION

The erosion of the bed material surrounding any substructure or obstruction is known as scouring. The extent of erosion of the soil bed around the structure due to the score is called scour depth. When bed particles washed away from the bed near the obstruction resulting in the formation of depression in the bed, this depression is called scour hole. Removal of the soil particles from the adjacent area of the bridge supporting structure called pier or abutment is called the local scour. It is due to the meeting obstruction of supporting structure or abutment to the flow. Due to this interference of the of the obstruction to the flow, results in acceleration of the flow, which forms vortex flow around the supporting structure that washes away the bed particle from the adjacent area of the pier or abutment. Scouring process depends on the factors, which include shape of the pier, type of the flow, type of fluid, bed characteristics. If flow forms the vortices around the substructure than it results in scouring. If the fluid posses the characteristics like erosive capacity, then it will lead the washing away of the bed particles from the area surrounding the pier or abutment, shape of the pier also affects scouring. Various shapes have different extent of the scouring, and if the bed material have non cohesion material, then there is more possibility of the individual particle of being getting washed, when the stabling force of the particle is overcome by the force of the approaching flow.

On the other hand, if the bed material has cohesion material like clay it requires large force to move the individual particle. If the flow which is coming towards the pier or abutment, carries any soil particle from the past then it is called live bed scour, and if it does not contain any soil particle from the past then it is called clear water scour. When the flow comes with a certain velocity then there is stagnation of the flow at front face of the pier, when this flow comes in contact with the soil bed, it results in the formation of depression at the front of the pier. Due to this, vortices are created in the area near the piers.

This vortices goes downstream of the pier and then passes through the sides of pier. This type of vortex flow is called the horseshoe vortex because it resembles with horseshoe. Due to this type of the vortex flow, hole which was formed earlier will go on increasing depth wise, till the shear stress on the soil bed particles becomes less than the critical shear stress. This vortex flow results in the formation of the two slots in the bed, which results in the movement of the sediment particle which are removed from the soil bed. This phenomenon causes the formation of the scour depression at the front face of the supporting

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substructure. Now, there is a separation of the flow from the sides of the piers which results in the formation of whirlpool which removes the soil particle from the bed. These vortices are not stable at all. These vortices results in the formation of the scour hole of itself on d/s of the substructure. Now, we have been already discussed the live scour. Now, when the velocity of the flow is more than the velocity of the particles transported by the flow then there is occurrence of live scour. And when the flow velocity is 0.3 times the velocity of the flowing sediments then the clear water scour takes place. There are various other factor like pipe geometry, angle of attack etc which also affects the scouring.

As we all know that the bridges are the important parts of the transportation in any country and failure of the bridges are not only caused by the faulty structure but also due to the process of scouring around the supporting substructures called piers. The scouring has the tendency to affect the structural capacity of the bridge supporting structures called piers, which results in the failure of the supporting structure of the bridge due to the undermining action of the water around the foundation of bridge supporting structure called piers. This failure results in the loss human lives, loss of economical values and loss of money, time. A series of failure of bridge due to scouring is presented by various researchers i.e BARBHUIA (2004), Hoffman and VERHEIJ (1997). Floods results in large scouring, as it was experienced in the Malaysia, which causing large surface run off. Scouring also decreases the capacity of the reservoir d/s of the flow as it contains the large number of the sediment transport.

So, it is of utmost importance for safety of the structure like bridges and also the safety of the humans that various countermeasure are required to control or to check scouring. For the prevention of the scouring, various researchers have developed various methods. There are generally, two methods for checking against scouring which includes strengthen the soil bed in the adjacent area of piers to control the shear stresses which are occurring during floods or high velocity flow. One of the methods for doing is application of riprap and other method like grout filled bags etc. And the second method is, controlling the flow alignment to breath the vortex flow which reduces the velocity of the water in the neighborhood area of the pier, this can be done by the use of sacrificial piles, collars etc. Now, the strengthening device includes riprap when the riprap is applied it increases the resistance of the bed particles around the piers and flow dividing devices include collars, which reduces the velocity of flow around the pier.

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1. Scouring process

1a Scouring

The erosion of the bed material resulting in the formation of the depression around the structure or obstruction resulting in washing of the sediment particles is called scouring. It depends on various factors like, type of the flow, type of the fluid, shape of the pier, bed characteristics. It is very serious problem which can lead to many failures which results in the loss of human lives, and economical values. So, it should be checked or prevented by suitable measures.

1b Types of scouring

1b.1 Natural scour

This type of scour includes:

- Channel degradation
- Migration of the channel laterally
- Bend scour
- Confluence scour

This type of scour depends upon the behavior of the catchment and form of river instead of the bridge location or type of hydraulic structure examined.

1b.1.1 Migration of the channel

This can occur naturally or due to human interference or due to the degradation of channel. This includes the meandering process or the deep water channel movement towards the bank of the channel. It may be sudden due to the flood event or it may be gradual. Maximum natural scour is related to d/s of bar, if island is present in the channel.

1b.1.2 Bend scour

This is associated with meandering but it relates the addition scouring because of the curvature of the flow.

It generally depends on the:

1. Curvature of bend

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2. Ratio of width/depth
3. Eroding capacity of the bank
4. Material bed and strata it contains

1b.1.3 Confluence scour

This is described by MELVILE and CALEMAN (2000), the flow streams of two channels converging towards the centerline of the confluence, get penetrated to the channel bed and then come back to the water surface around sides of the confluence.

1b.2 Contraction scour

The narrowing of the width of the river channel results in the contraction scour. The majority of this scour is because of the approaching embankment towards a bridge which results in the joining of flood plain to the main channel and passing through the bridge. It also results in removal of d/s, due to the increasing discharge. It results in the velocity increment and shear stress which results in scraping the material from the most of river bed.

1b.3 Local scour

It is related with structure which deviate the flow like bridge pier or abutment. These structure results in the increment of the flow velocity and turbulence according to their shape. This also includes the formation of the vortices around the structure due to formation of the vortex flow there is a formation of the whirlpool, which scraps soil particle from the area near the piers, results in the formation of the scour hole at the u/s face of the pier.

This related to the following features:

1. Bridge pier
2. Abutment of the bridge
3. River training work
4. Weir
5. Diversion work etc.

1b.4 Total scour

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Total scour is related to particular structure and the combination any of following scours;

- Natural scour
- Concentration scour
- Local scour

1b.5 Marine scour

In general, marine scour is affected by same factor that contributes to the natural scour, local scour, and contraction scour. Various other contributed to the marine scour are, tidal flow, lateral flow, the exposure to the wave action etc.

1b.6 Boat scour

Navigation also increases the scouring, as follows:

- It can increase the velocity of the flow by displacement effect of the boat.
- The current which are produced by propeller of the boat.
- The waves formed by the movement of the boat.

1b.7 High headed scour

Scouring of the rock bed is generally occurred due to situation of the high head of the water which can result in scouring of even hard rocks like igneous rock. The present of joint in strata is generally responsible for this.

2. Types of sediment and its behavior

Generally it is assumed, that scour can estimated by assuming that the bed material contain deposits of alluvial or other material which can easily be eroded. It may be cohesive or non-cohesive. Scour process which is related with interference of bed material and flow condition. Hence, from the above discussion we came to know that, material present in the bed is more important for knowing the scouring process.

2a Non-cohesive material

These material are compose of the granular structure, with the possibility of individual particle get washed away when its stabling force is overcame by the

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flow, flowing with certain velocity. The capability of the individual to get washed away depends upon its shape, density and its packing on the bed. In natural condition the non-cohesive particles are not uniform and are of non-uniform shape therefore, it can be easily eroded and randomly when its stabling force is overcame by the flow of the water.

2b Cohesive material

These particles generally consist of the clay. These materials require large velocity of flowing water to overcome the stabling force of individual particle but when it is achieved, it can be easily transported by flowing water once it is removed from its packing.

2c Soil strata

If the strata consists a stratified layers, then it is necessary to predict scouring tendency of each layer going downwards. The conservative thinking is required with less resistance is beneath more resistant layer.

2d Armouring

The processing of preserving a large particle and let the washing away of the small particle in well graded channel is called Armouring. This controls the scouring up to some extent. This included the laying of elongated shape material on the bed. Armouring consists of studying the layer and particles which are easily erodible and which can stay, it also including the addition of the non-erodible material. If there is tendency of Armouring to get washed away, which result in large scouring.

3. Effect of time in scouring

3a Clear water scour and live bed scour

When the approach velocity of the flow carries a sediment transport, the scour is called live bed scour, and when the approach flow carries no sediments then it is called clear water scour. Clear water scour does not mean that the water is crystal clear because it contains the particle which is in suspension and does not affect the scouring.

Local scouring can also come into play when the transition from the clear water scour to live bed scour takes place because of the addition of the particles

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from u/s. Sometimes, there is max scour depth when there is reduction in the scour depth because of addition of the particle from the u/s.

3b Effect of tides in the scouring

When there is tide, scouring can also be developed due to tidal flows. This case is generally occurs in case of fluvial flood flows.

Tidal flows effects all types of scour. For the proper determination of tidal scour location following factor should be considered:

- Tidal amplitude range
- The highest tidal velocity
- The combined effect of series tides
- The location of scour because of different direction of the flow
- The highest velocity

4. Scour failure

Many river beds consist of material which can be transported easily by the flowing water which results in failure of the bed level. Scouring around the structure can be occurred by any of the combined effect of contraction, local, or navigation. When the spread footing is used for the construction of the structure it can fail due to scour, when the water level reaches base of the footing of bridge. However, there is scouring when it is subjected to the water pressure only. When the pile foundation is used skin friction loss and loss of the load bearing capacity scouring can occur.

Undermining around the foundation and tilting of structure can cause by the local scour at a bridge pier, which is very dangerous situation. Higher floods, high, run off, high precipitation also results in failure of the structure due to scouring.

5. Mechenism of scour

Various researchers have already study the mechanism of sour in the past. Which describe that the velocity of the water approaching the pier gets stagnated at the front face of the pier results of which there is generation of down flow which is parallel to the face of substructure, when this down flow comes in contact with river bed, the hole is got dig at the d/s of the pier and starts rolling up. Result of which there is formation of a vortex flow around the substructure. This flow go down to pier and passes from its sides. This type of vortex flow is also

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known as horseshoe vortex because it gives resemblance to the horseshoe. The vortex flow digs more particle from the hole which is already been dig in the past at u/s of the pier till the shear stresses on the river bed material will be less than the material. The flow which passes the sides of the pier results in the formation slots in river bed, which enable the carriage of the particle from hole to u/s of the substructure.

On the sides of structure, flow separates which gives the formation of whirlpool, which results in digging of more soil particles from the hole. These vortices are not stable. These types of vortices have their own scour hole. As we discussed above, at the front face of the pier velocity becomes zero. This will result in pressure increment. Because of this the water level on u/s face increases. Dynamic pressure at structure face also decreases d/s due to the decrease of velocity from water surface to the river bed. This downward flow of water will result in formation of hole at u/s of pier. This phenomenon forms a complex vortex system. This vortex system is also called as horseshoe vortex. There various countermeasure like armouring devices and flow altering devices.

6. Factor affecting scour

- Type of flow
- Type of fluid
- Shapes of the substructure
- River bed characteristics

6a Types of the flow

Type of the flow is responsible for the scouring as we discussed above, if the flow form vortices then there will be more scouring around the pier. And if the flow is turbulent it also leads to scouring as the velocity of the flow is high. High flood flows also causes scouring.

6b Type of the fluid

Type of the fluid is also another factor on which the scouring depends. The fluid may considered as erosive fluid or non-erosive fluid. The erosive fluid velocity is more if it contains any debris or any other material on the other hand, the non-erosive fluid does not erode the particle and hence scouring does not take place.

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6c Shape of substructure

This is also an important factor on which the scouring depends. Shape of substructure may be circular, square, etc. And extent of scouring is different for different shape.

6d River bed material

Extent of scouring also depends on the material which is present in the river bed. The river bed may contain non-cohesive or cohesive material. If the river bed contain the non-cohesive material there is capability of individual particle to get washed away if the stabling force of the individual particle is overcame by the force of approaching water. The capability of individual particle depends upon its shape and its packing density. On the other hand, if river bed contains cohesive material like clay then, the capability of individual particle getting washed away is less because of the large force requirement or high velocity water to overcome the stabling force of the individual particle for being washed away. But when there is sufficient force to overcome the stabling force of the individual particle, it flow easily. And if the river bed is stratified then proper approach is required to study the effect.

7. Measure to protect the scouring around the bridge pier

There are two categories of scour protection 1. Rigid system 2. Flexible system. Flexible systems are those which do not losses its armouring and also adjust to any settlement because of its flexible nature. It fails because it is not properly designed or erosion of the material from its sides. On the other hand, rigid systems are those which loses their armouring capability because it cannot adjust to changes. The main causes of the failure of rigid system are undermining and uplift pressure.

Choice of the material:

- It should be economically during construction.
- It should be capable of underwater and dry construction.
- The material thus chosen should be locally available.
- It should be chosen according to the suitability of the channel.
- It should be eco-friendly.

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In summation flexible system are more preferred over the rigid system because it can adjust according to the suitability of the channel. On the other hand, if there is requirement of system which is more resilient to surface erosion, which can provide good protection against scouring during flood event, which includes high velocity than the rigid system are preferred.

7a Riprap

For the protection against scouring, loose bed of well graded stones are known as riprap. It is easy to use, it falls under the category of the flexible system, and it does not fails even it loses some of its stone. It is found useful in protecting the bank of the channel and slope of channel upto 1:1.5. If it is properly designed it can be used for high turbulence and high velocity flow. Riprap is easy to use and install. It can be easily place with the help of machine and it also does not require compaction. It can also use underwater. The filter or any granular particles are required for laying the riprap.

The main reason of the failure of the riprap:

- There may be individual stone in the riprap which is of not proper shape for particular flow condition which results in the scouring of the riprap and loses its thickness.
- Due to the erosion of bed by riprap voids.
- This can also fails, if the stone from the edge falls in the scour hole in natural bed.
- Due to the undermining because of bed movement.

7b Gabion mattress

When the stone are filled in wire mesh, then it is called Gabion mattress. It falls under the category of the flexible system. The flexibility of the wire allows it to change according to the ground movement and also helps in holding the stone in proper position. In the gabion mattress, the steel wire is commonly used. It may be welded or woven. If there is deformation then woven wire is suitable for it because of its flexible nature and, if there is requirement of the earth retaining in addition to the scouring protection then, wire welded wire mesh is used because of its rigidity. If there is salinity in the water, then it can cause corrosion, but it can be prevented by the use PVC coated wire etc. And if there is more abrasion expected than large diameter wire are preferred.

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The failure of the Gabion mattress can be occurred because of the following reason:

- The wire mesh may fail due to erosion or abrasion.
- If thickness of the gabion is not properly designed then there can be erosion on the underlying bed.
- Edge of failure, due to falling of the stone in the scour hole formed on natural river bed.
- High movement of stone within the mesh.

7c Articulated concrete block

When the precast concrete blocks are laid on the filter then it is known as articulated concrete block. They are cellular, and have 20% of the area open. They act as individual block. The cables are made up of the galvanized steel concrete mat of size 6×2 m. If the mats are cable tie then it is placed with the help of machine at suitable depth. And the block which are used of interlocking, is placed by hand. The block which are above the water surface, they are filled with the soil. Cable tied blocks are preferred over the interlocking blocks. This type of protecting measure is suitable for the fluvial flood situation. If there are any gap between the block it should properly filled.

The reason of the failure of the articulated blocks may be are follows:

- If there are gap between the blocks its leads to it movement.
- Edge failure as discussed in the failure reason for above countermeasures.
- It also fails due to movement of blocks which results in undermining.
- Due to the lifting from the edges.
- Due to improper locking, blocks can plucked out

7d Rigid grout-filled mattress and bag

Bridge filled with concrete or cement also used as a protective measure as it can reduce the cost of the protective measure. Dry mixtures or prepared mixture can be filled in the bag. The bags are made up of polyester or polypropylene and it will behave as shutter to maintain the shape and prevent the movement of the bag. In case of the wall it may be laid on side of the walls or for retaining it can be laid on the stable slopes. It is mostly used of underwater protection mattress can be constructed by joining by bag with the help of tie and straps.

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For designing following points should be considered:

- The mattress edge should properly fixed in the bed
- There should be no gaps
- The anchors should be used to prevent its movement

7e Reduction of the scour using slots

Scour reduction also accomplished by the use of slot in the substructure from which most of flow passes. This is due to the good gradient of pressure and which results less scouring. This helps diverting the down flow which form the scour hole at u/s face slot should be properly designed. Though, slot can be chocked by debris which reduces the strength of structure.

7f Reduction of scour with the help of collar

With the installing of the collar and on the pier, it will reduce the scour depth and also the rate by preventing direct contact of down flow with river bed. This type of production is very useful in reducing the scour, when there is flood of short duration.

7g Sacrificial piles

If the groups of piles are installed on u/s face of pier, it will reduce the velocity of flow and also reduce the effect of horseshoe vortex, which results in less scouring.

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Chapter 2

8. Literature Review

As we all know that the bridges are the important parts of the transportation in any country and failure of the bridges are not only caused by the faulty structure but also due to the process of scouring around the supporting substructures called piers. The scouring has the tendency to affect the structural capacity of the bridge supporting structures called piers, which results in the failure of the supporting structure of the bridge due to the undermining action of the water around the foundation of bridge supporting structure called piers. This failure results in the loss human lives, loss of economical values and loss of money, time. A series of failure of bridge due to scouring is presented by various researcher i.e Barbhuia (2004), Hoffman and Verheij (1997). Floods results large scouring, as it was experienced in the Malaysia, which causing large surface run off. Scouring also decreases the capacity of the reservoir d/s of the flow as it contains the large number of the sediment transport.

So, it is of utmost importance for safety of the structure like bridges and also the safety of the humans that various countermeasure are required to control or to check scouring. For the prevention of the scouring various researchers have developed various methods. There are generally two, method for checking against scouring which includes strengthen the soil bed in the adjacent area of piers to control the shear stresses which are occurring during floods or high velocity flow. One of the methods for doing is application of riprap and other method like grout filled bags etc. And the second method is controlling the flow alignment to breath the vortex flow which reduces the velocity of the water in the neighborhood area of the pier, this can be done by the use of sacrificial piles, collars etc. Now, the strengthening device includes riprap when the riprap is applied it increases the resistance of the bed particles around the piers and flow dividing devices include collars, which reduces the velocity of flow around the pier.

The scouring around the per has already been done by the various researched such as Chabert and Engeldinger (1956), Lawson and Toch (1956), Liu et al (1961), Shetet (1969), Milvile and Raudkiv (1977), Hijoth (1975), Kotyari et al (1993), Garde et al (1995), Kumar (1996), Dey (1997), Ahmed and Rajuratnam (1998), Graf and Istiaro (2002), Sheepared(2004), Jain (1981), Kotyari (1989), Mubeen beg and salman beg.

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We also know that the scouring leads to the failure of the bridges, various researchers studied the failure of bridges due to the scouring, such as Tafarnajozli ali et al (2010), Barbhuiya (2004), Wardhana and Hadipriono (2003). Hoffman and Verheij (1997), and various other researchers.

As we already discussed above the there are various measure to protect scouring and various researchers study different method of preventing scour and to provide protection against scour.

Various works of the various researchers are described below:

- Chiew (1992) and Kumar et al (1999). These researchers used vertical slot in pier for the reduction of scour. They found that horizontal slot reduces the strength of the pier. Function of the pier is to allow the passage of the water through them and reduces the pressure gradient.
- Zarrati et al (2006), Zarrati et al (2004), Kumar at el (1999), Chiew (1992), Yano and Tanaka, Ettema, Schenieble and various other researchers uses the collar around the bridge pier to reduce the scouring. They Collars prevent direct contact of down flow with the bed .Vittal et al, Chabert (1996), Engeldinger (1956), Melvile and Hadfield (1999), uses the group of piles for scour reduction. They found, by placing group of piles at u/s of the pier reduce the velocity of the flow and also reduce strength of the vortex flow.
- Chabert and Engeldinger (1956), Shen and Schenieder (1969), used the foundation cassion to reduce the scouring around the bridge pier.
- Gangadharia and Gupta (1992), uses a delta wings, a passive device to control the scouring. They found that with this device attached to the leading edge of the pier junction, it modifies the rotating direction of horseshoe vortex.
- Parker el at (1995) used the submerged vanes as scouring controlling device.
- Parker el at (1998) used artificial riprap for controlling scouring.

And there are many other researchers, studied the scouring around the pier such as:

Johnson and Dock (1996), Lagase el at (1995), Lim and Chiew (1996), Worman (1989), Yoon et al (1995), Parala (1993), Croad (1993), Brice et al (1978), Tanaka

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and Yana (1967), Odgard and Wana (1987), Meleville and Coleman (2000), Surkar and Ratha (2014), Akunetal (2014a), Jahangiziaden et al (2014b).

9. Objective of the Work

As we already discussed that scouring around the bridge pier affected the stability of substructure and structure and it also leads to the failure of the structure which affects the human lives, economical values, and also the wastage of time and labour for reconstructing the structure and also for maintenance. Also we have discussed that there are various prevention measures for scouring around the pier, which includes application of collar, riprap, sacrificial piles, passive device, gabion mattress, bituminous material, concrete apron, slots.

The main objective of this work is to study the effect of collars and slot on the scouring around the pier and to provide safety against scouring which results preventing damage to the structure and resulting lesser loss of the human live, money, time labour.

10. Overview of the Work

In this work discussion is made, how to prevent scouring by the application of collar and slot both using separately and also as combination and the observations are carried out, which is more useful in preventing scouring around the bridge pier. Further in this work, two types collars are used i.e square and circular around the circular pier and also as combination with slot and observation are carried out by allowing three different discharge (or Froude no).

In this work we use circular pier model of diameter 5cm which is placed in flume which represents the channel. In the flume sand is laid upto 1 m length laterally and vertical height of the sand bed is 15 cm above the flume bed level which represents the river bed. In this research we use the length of the pier model of about 60 cm. Circular collars of dimension's 1.5D, 2.0D, 2.5D, 3.0D and square collar of area 1.5Dx1.5D, 2.0Dx2.0D, 2.5Dx2.5D, 3.0Dx3.0D where D is diameter of circular pier and slot of dimension 5cmx1cm and study is carried out at three different Froude No's i.e 0.285, 0.297, 0.313.

In this work first of all we studied the scouring simple circular pier and then by applying square collar and circular collar and slot and then we use combination of both square and circular collar of increasing dimension at the Froude no 0.285.

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Then we repeat the same process for the Froude no 0.297 and 0.313 and observations are carried out to know which is more effective in reducing scouring.

11. Experimental setup

The experimental setup includes:

- Flume of 6m length having hump
- The circular pier of diameter 5cm
- Circular collar of dimension 1.5D, 2..0D, 2.5D, 3.0D.
- Square collar of are 1.5Dx1.5D, 2.0Dx2.0D,2.5Dx2.5D, 3.0x3.0D
- And circular pier with vertical slot of dimension 5cm×1cm.

Experimental setup consists of a circular pier model of diameter 5cm and length of 60 cm. For performing the scouring process, we take flume of 6m. The flume is cleaned by allowing free discharge through it. Then we laid sand representing the bed material 1m and it is laid laterally and 15 cm above the flume bed level. Then we fix the circular pier of diameter 5cm at a distance of 50cm from the sides of the flume. After fixing the circular pier of diameter of 5cm, the three different dischargesis allowed to the flume for 15 min. After 15 min water is allowed to drain out from the flume. And then observations are made for the scour hole so formed around the bridge pier model. We, continue the same process by applying circular collar of diameter 1.5D, 2.0D, 2.5D, 3.0D and square collar of area 1.5D×1.5D, 2.0D×2.0D, 2.5D×2.5D, 3.0D×3.0D, where D is the diameter of the pier (5cm). Same process is carried for the pier having vertical slot of dimension 1cm width and 5cm length and also for the combination of slot and circular and square collar.

12. Observations.

Observation for the following caseswere carried out for three different FroudeNo's.

- Case 1, Scouring around simple circular pier of 5cm diameter.
- Case 2, Scouring around the circular pier with circular collar of diameter 1.5D.
- Case 3, Scouring around the circular pier with circular collar of diameter 2.0D.
- Case 4, Scouring around the circular pier with circular collar of diameter 2.5D.

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- Case 5, Scouring around the circular pier with circular collar of diameter 3.0D.
- Case 6, scouring around the circular pier with square collar of dimension 1.5D×1.5D.
- Case7, Scouring around the circular pier with square collar of dimension 2.0D×2.0D.
- Case 8, Scouring around the circular pier with square collar of dimension 2.5D×2.5D.
- Case 9, Scouring around the circular pier with square collar of dimension 3.0D×3.0D.
- Case 10, scouring around the circular pier having vertical slot of dimension 5cm×1cm.
- Case 11, Scouring around circular pier with slot circular collar of diameter 1.5D.
- Case 12, Scouring around circular pier with slot circular collar of diameter 2.0D.
- Case 13, Scouring around circular pier with slot circular collar of diameter 2.5D.
- Case 14, Scouring around circular pier with slot and circular collar of diameter.
- Case15, Scouring around circular pier with slot and square collar of 1.5Dx1.5D.
- Case16, Scouring around circular pier with slot and square collar of 2.0Dx2.0D.
- Case 17, Scouring around circular pier with slot and square collar of 2.5Dx2.5D.
- Case 18, Scouring around circular pier with slot and square collar of 3.0Dx3.0D.

.

A. For Froude no = 0.285

Case 1. Scouring around the simple circular pier having diameter of 5cm

Figure 1

Circular pier of diameter 5 cm

.

Figure 2
Scouring around the circular pier of diameter 5 cm

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	3.7	7.7	5.6	14	15

.

Case 2. Scouring around the circular pier with circular collar of diameter 1.5D (D is the diameter of circular pier)

Figure 3
Flow around the circular pier with circular collar of diameter 1.5D (D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	3	5.3	4.9	10.8	15

.

Case 3. Scouring around the circular pier with circular collar of diameter 2.0D (D is diameter circular pier)

Figure 4

Scouring around circular pier with circular collar of diameter 2.0D

(D is diameter of circular pier)

.

Figure 5
Scouring around the circular pier with circular collar of diameter 2.0D (D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	2.4	4.3	3.3	9.4	15

.

Case 4. Scouring around the circular pier with circular collar of diameter 2.5D (D is diameter of circular pier)

Figure6
Circular pier with circular collar of diameter 2.5D
(D is the diameter of the circular pier)

.

Figure 7
Scouring around the circular pier with circular collar of diameter2.5D (D is diameter of the circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	1.7	4.1	2.8	7.2	15

.

Case5. Scouring around the circular pier with circular collar of diameter 3.0D (D is diameter of the circular pier)

Figure-8

Circular pier with circular collar of diameter 3.0D

(D is diameter of the circular pier)

.

Figure 9

Scouring around the circular pier with circular collar of diameter 3.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	1.1	2.1	1.6	4.5	15

.

Case 6. Scouring around the simple circular pier with square collar of dimension 1.5D×1.5D (D is diameter of circular pier)

Figure 10

Circular pier with square collar of dimension 1.5D×1.5D

(D is diameter of circular pier)

.

Figure 11

Scouring around the circular pier with square collar of dimension 1.5D×1.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	3.2	7.3	5.1	13	15

.

Case7. Scouring around the circular pier with square collar of dimension 2.0D×2.0D (D is diameter of circular pier)

Figure 12

Circular pier with square collar of dimension 2.0D×2.0D

(D is diameter of the circular pier)

.

Figure 13

Scouring around the circular pier with square collar of dimension 2.0D×2.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	2.7	6.0	4.9	10	15

.

Case 8. Scouring around the circular pier with square collar of dimension 2.5D×2.5D (D is diameter of circular pier)

Figure 14

Circular pier with square collar of dimension 2.5D×2.5D

(D is diameter of circular pier)

.

Figure 15

Scouring around the circular pier with square collar of dimension 2.5D×2.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	2.3	3.5	4.8	7.8	15

.

Case 9. Scouring around the circular pier with square collar of dimension of 3.0D×3.0D (D is diameter of circular pier)

Figure 16

Circular pier with square collar of dimension 3.0x3.0D

(D is diameter of circular pier)

.

Figure 17

Scouring around circular pier with square collar of dimension 3.0D×3.0D (D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	1.6	2.2	1.7	5.6	15

.

Case 10. Scouring around circular pier with vertical slot of dimension 5cm×1cm

Figure 18

Circular pier with vertical slot of dimension of 5cm×1 cm

.

Figure 19

Scouring around the circular pier with vertical slot of dimension 5cm×1cm

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	2.4	4.1	3.6	11.2	15

.

Case11. Scouring around circular pier with slot and circular collar of diameter 1.5D (D is diameter of circular pier)

Figure 20

Circular pier with slot and circular collar of diameter 1.5D

(D is diameter of circular pier)

.

Figure 21

Scouring around circular pier with slot and circular collar of diameter 1.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	1.9	3.7	3.0	10.2	15

.

Case 12. Scouring around circular pier with slot and circular collar of diameter 2.0D (D is diameter of circular pier)

Figure 22

Circular pier with slot and circular collar of diameter 2.0D

(D is diameter of circular pier)

.

Figure 23

Scouring around circular pier with slot and circular collar of diameter 2.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	1.5	3.4	3.1	7.1	15

.

Case 13. Scouring around the circular pier with slot and circular collar of diameter 2.5D (D is diameter of circular pier)

Figure 24

Circular pier of with slot and circular collar of diameter 2.5D

(D is the diameter of circular pier)

.

Figure 25

Scouring around circular pier with slot and circular collar of diameter 2.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	1	2.7	2.1	6.1	15

.

Case 14. Scouring around circular pier with slot and circular collar of diameter3.0D (D is diameter of circular pier)

Figure 26

Circular pier with slot and circular collar of diameter 3.0D

(D is diameter of circular pier)

.

Figure 27

Scouring around circular pier with slot and circular collar of diameter 3.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	0.6	1.7	1.2	4.3	15

.

Case15. Scouring around circular pier with slot and square collar of dimension1.5Dx1.5D (D is diameter of circular pier)

Figure 28

Circular pier with slot and square collar of dimension 1.5Dx1.5D

(D is diameter of circular pier)

.

Figure 29

Scouring around circular pier with slot and square collar of dimension 1.5Dx1.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	2.3	3.8	3.2	10.7	15

.

Case16. Scouring around circular pier with slot and square collar of dimension of 2.0Dx2.0D (D is diameter of circular pier)

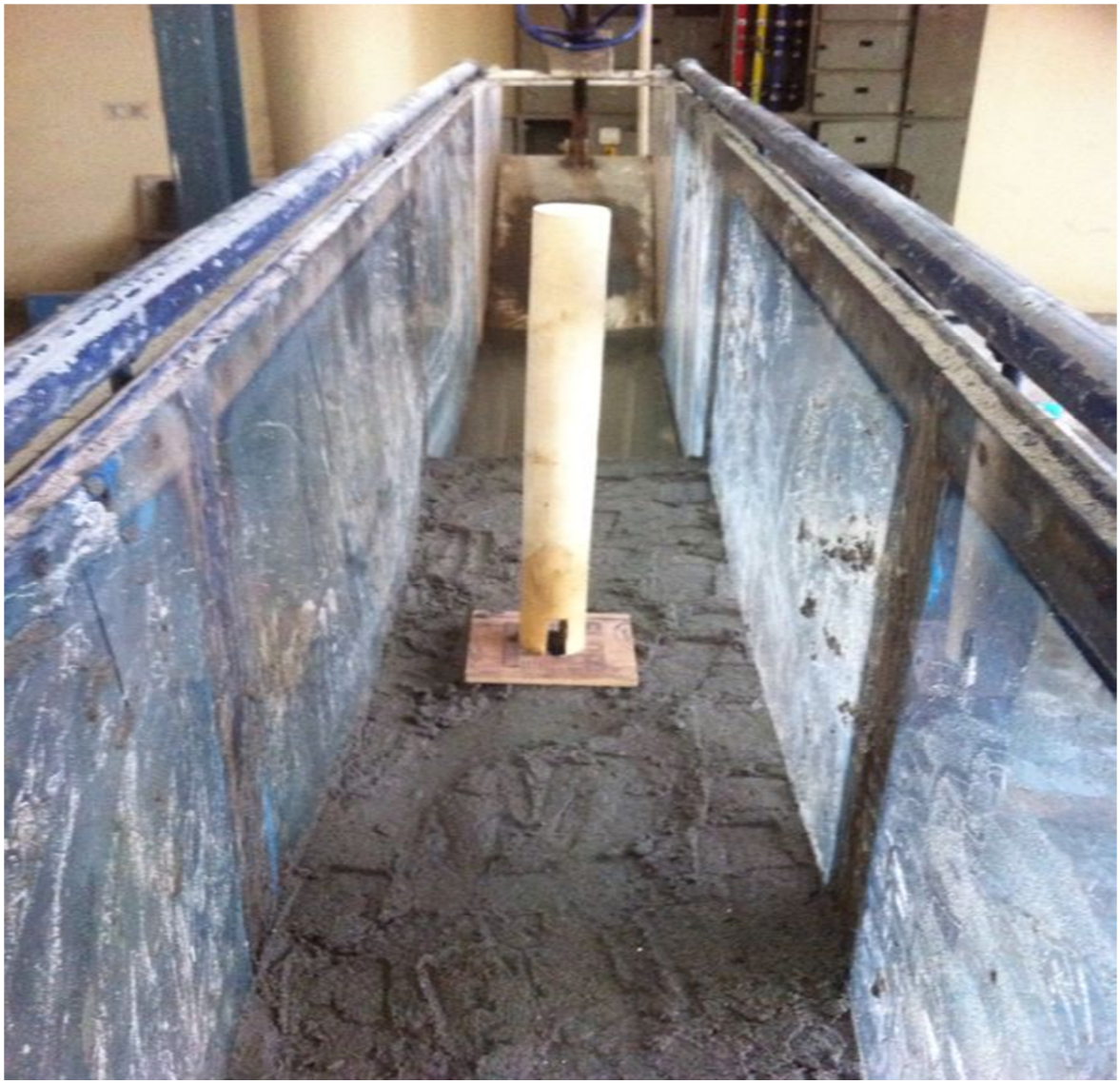

Figure 30

Circular pier with slot and square collar of dimension 2.0Dx2.0D

(D is diameter of circular pier)

.

Figure 31

Scouring around circular pier with slot and square collar of dimension 2.0Dx2.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	1.7	3.6	3.2	7.8	15

.

Case 17. Scouring around circular pier with slot and square collar of dimension2.5Dx2.5D (D isdiameter of circular pier)

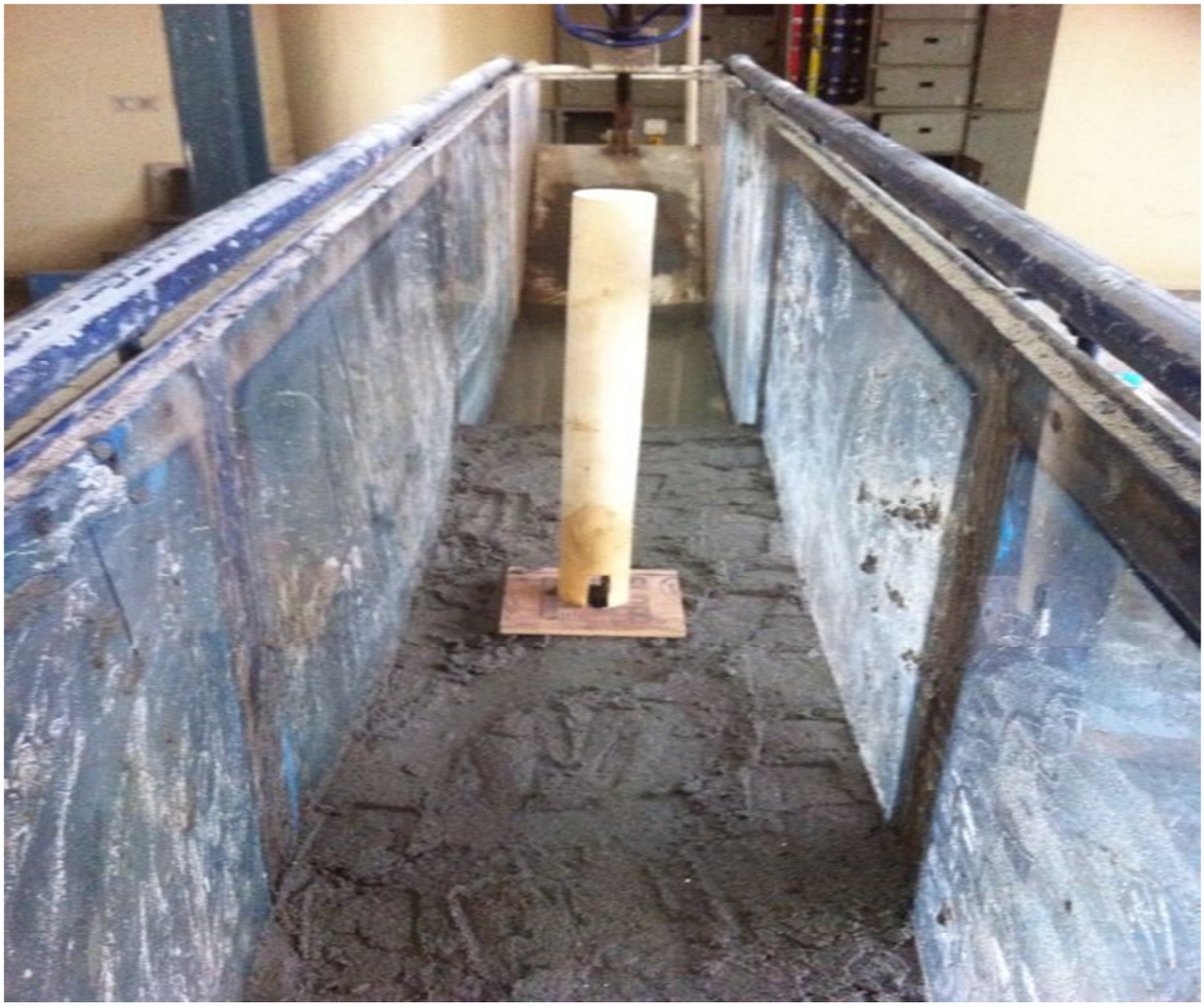

Figure 32

Circular pier with slot and square collar of dimension 2.5Dx2.5D

(D is diameter of circular pier)

.

Figure 33

Scouring around circular pier with slot and square collar of dimension 2.5Dx2.5D

(D is diameter of Circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	1.3	3	2.4	6.3	15

.

Case 18. Scouring around the circular pier with slot and square collar of dimension 3.0Dx3.0D (D is diameter of circular pier)

Figure 35

Circular pier with slot and square collar of dimension of 3.0Dx3.0D

(D is the diameter of circular pier)

.

Figure 36

Scouring around the circular pier with slot and square collar of dimension 3.0Dx3.0D (D is diameter Circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.285	0.8	2	2	5	15

.

B. For Froude No =0.297

Case1. Scouring around simple circular pier

Figure37

Simple circular pier of diameter 5 cm

.

Figure 38

Scouring around simple circular pier

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	4	7.9	6	14.3	15

.

Case2. Scouring around circular pier with circular collar of diameter 1.5D (D is diameter of circular pier)

Figure 39

Circular pier with circular collar of diameter 1.5D

(D is diameter of Circular pier)

.

Figure 40

Scouring around circular pier with circular collar of diameter 1.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	3.2	5.5	5.1	11	15

.

Case3. Scouring around circular pier with circular collar of diameter 2.0D (D is diameter of circular pier)

Figure 41

Circular pier with circular collar of diameter 2.0D

(D is diameter of circular pier)

.

Figure 42

Scouring around circular pier with circular collar of diameter 2.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	2.6	5.7	3.9	9.7	15

.

Case4. Scouring around circular pier with circular collar of diameter 2.5D (D is diameter of circular pier)

Figure 43

Circular pier with circular collar of diameter 2.5D

(D is diameter of circular pier)

.

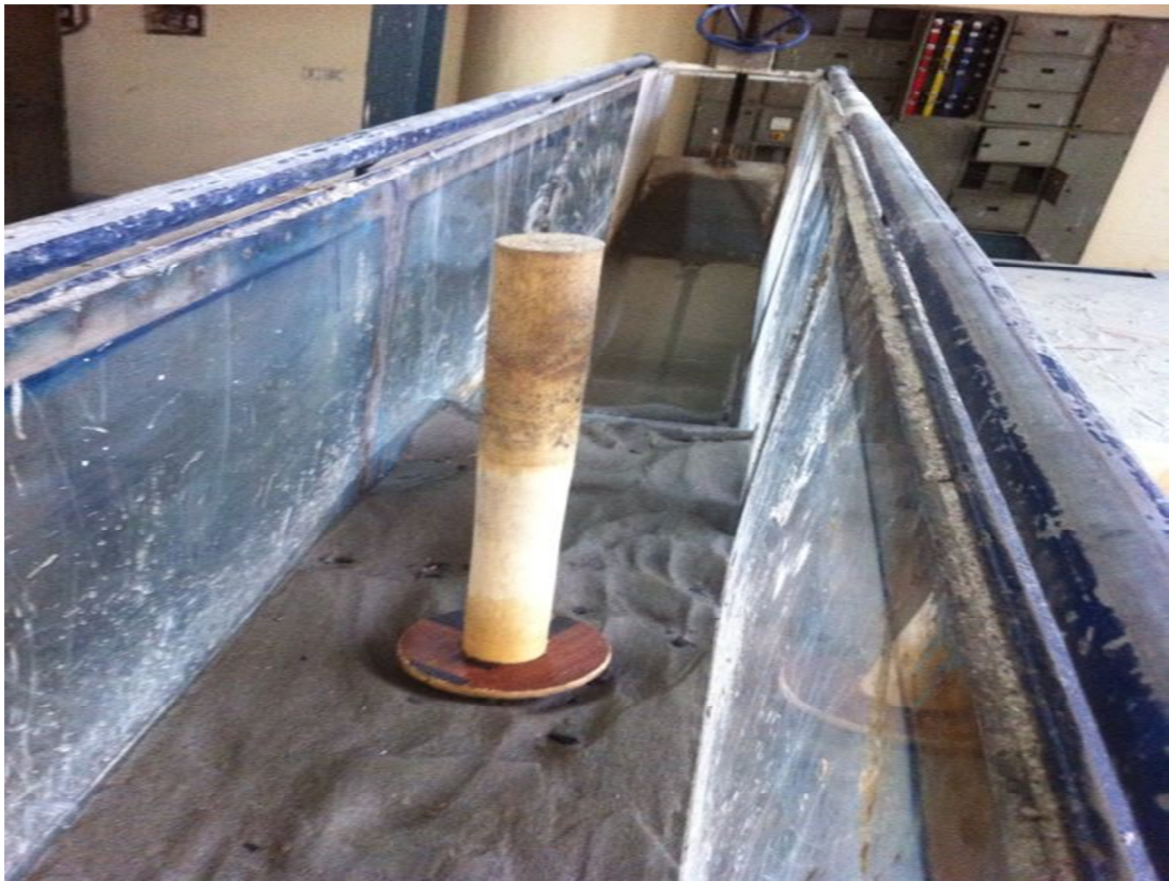

Figure 44

Scouring around circular pier with circular collar of diameter 2.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	1.9	4.3	3.1	7.5	15

.

Case5. Scouring around circular pier with circular collar of diameter 3.0D (D is diameter of circular pier)

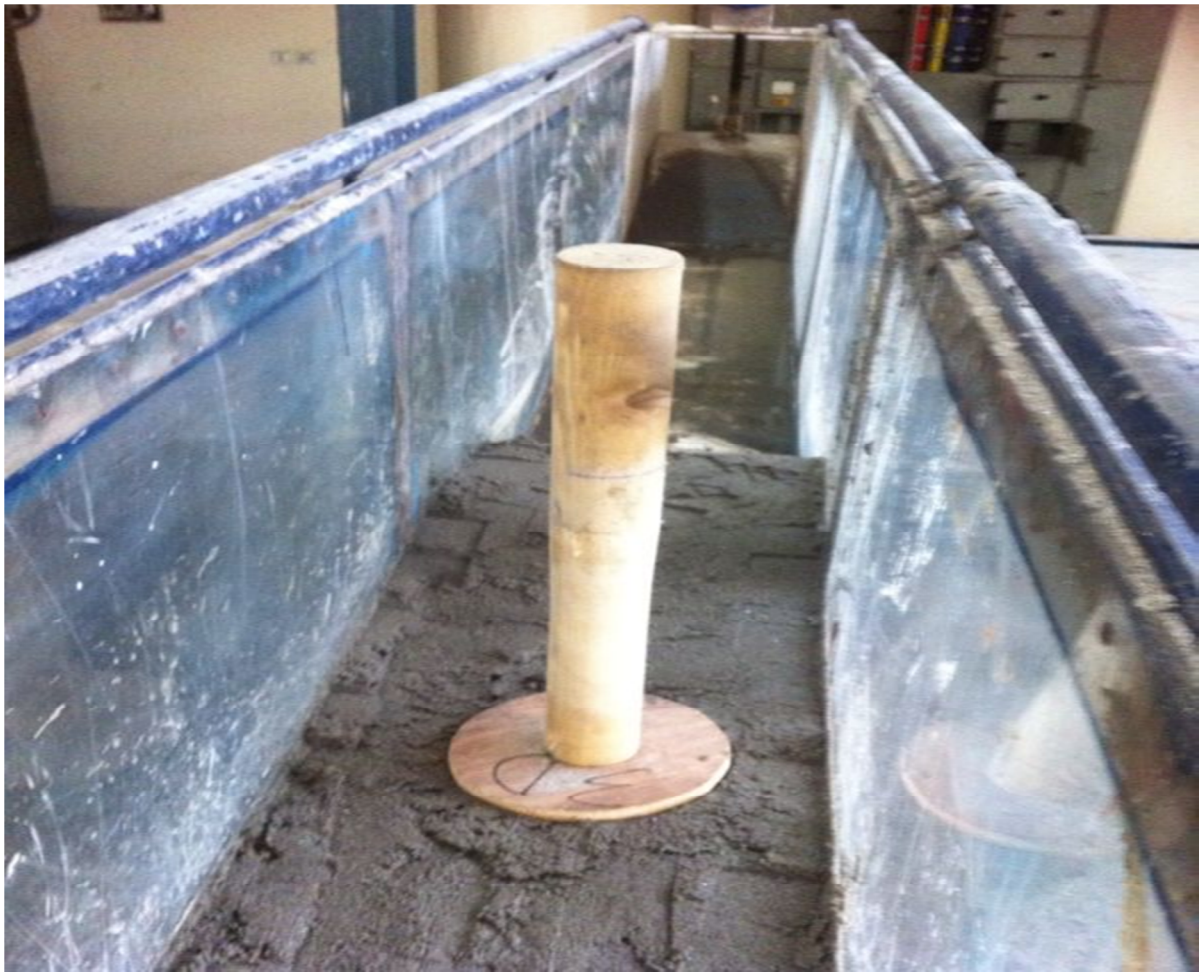

Figure 45

Circular pier with circular collar of diameter 3.0D

(D is diameter of circular pier)

.

Figure 46

Scouring around circular pier with circular collar of diameter 3.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	1.2	2.4	2	5	15

.

Case6. Scouring around circular pier with square collar of 1.5Dx1.5D (D is diameter of circular pier)

Figure 47

Circular pier with square collar of 1.5Dx1.5D

(D is diameter of circular pier)

.

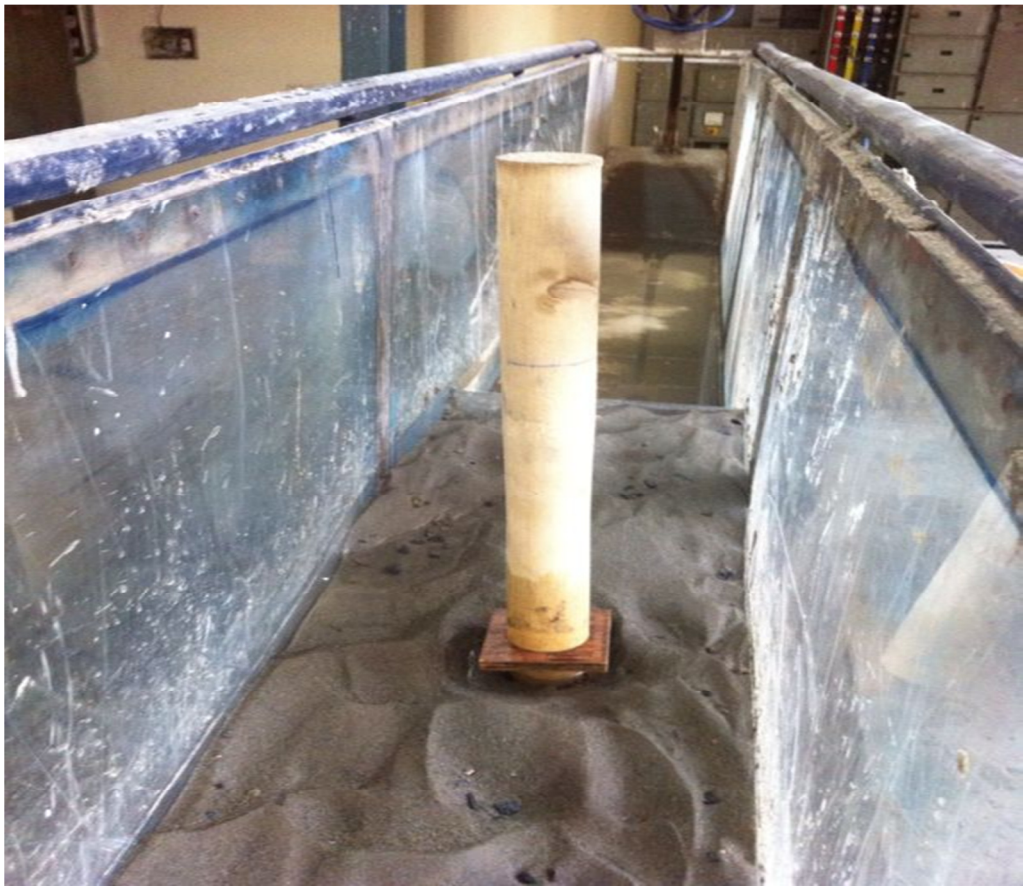

Figure 48

Scouring around circular pier with square collar of 1.5Dx1.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	3.6	7.6	5.6	13.2	15

.

Case7. Scouring around circular pier with square collar of 2.0Dx2.0D (D is diameter of circular pier)

Figure 49

Circular pier with square collar of 2.0Dx2.0D

(D is diameter of circular pier)

.

Figure 50

Scouring around circular pier with square collar of 2.0Dx2.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	3	6.2	5.2	10.8	15

.

Case8. Scouring around circular pier with square collar of 2.5Dx2.5D (D is diameter of circular pier)

Figure 51

Circular pier with square collar of 2.5Dx2.5D

(D is diameterof circular pier)

.

Figure 52

Scouring around circular pier with square collar of 2.5Dx2.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	2.4	4.2	5.1	8.4	15

.

Case9. Scouring around circular pier with square collar of 3.0Dx3.0D (D is diameter of circular pier)

Figure 53

Circular pier with square collar of diameter 3.0Dx3.0D

(D is diameter of circular pier)

.

Figure 54

Scouring around circular pier with square collar of 3.0Dx3.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	1.9	2.7	2.3	6.1	15

.

Case10. Scouring around circular pier with vertical slot of dimension 5cmx1cm

Figure 55

Circular pier with vertical slot of dimension 5cmx1cm

.

Figure 56

Scouring around circular pier with vertical slot

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	2.8	4.5	3.9	11.6	15

.

Case11. Scouring around circular pier with slot and circular collar of diameter 1.5D (D is diameter of circular pier)

Figure 57

Circular pier with slot and circular collar of diameter 1.5D

(D is diameter of circular pier)

.

Figure 58

Scouring around circular pier with slot and circular collar of diameter 1.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	2.3	4.3	3.5	10.7	15

.

Case12. Scouring around circular pier with slot and circular collar of diameter 2.0D (D is diameter of circular pier)

Figure 59

Circular pier with slot and circular collar of diameter 2.0D

(D is diameter of circular pier)

.

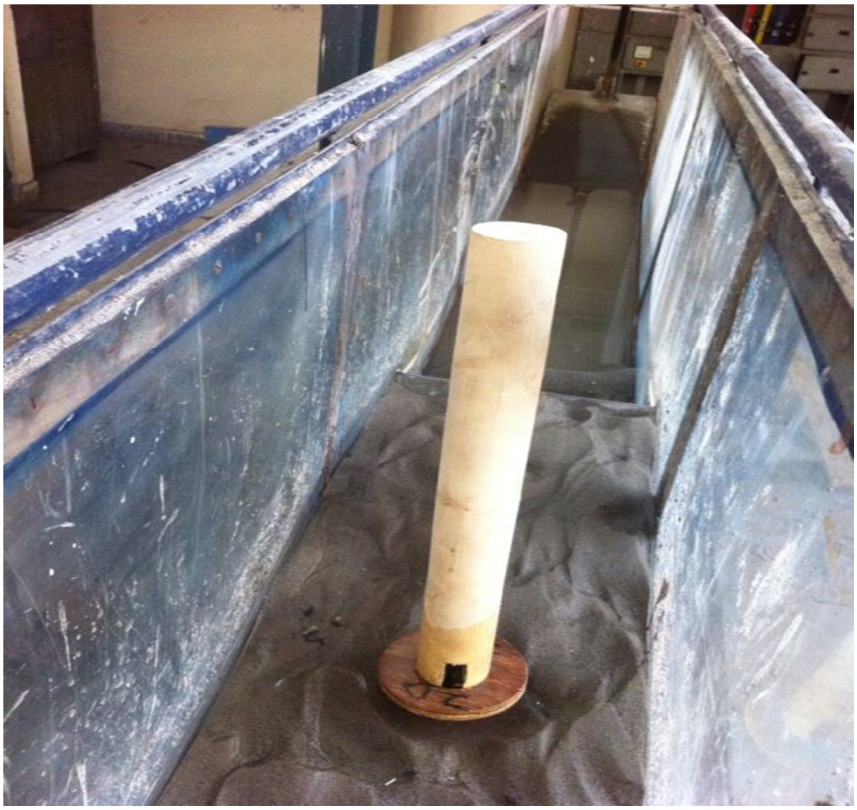

Figure 60

Scouring around circular pier with slot and circular collar of diameter 2.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	1.8	3.8	3.4	7.8	15

.

Case13. Scouring around circular pier with slot and circular collar of diameter 2.5D (D is diameter of circular pier)

Figure 61

Circular pier with slot and circular collar of diameter 2.5D

(D is diameter of circular pier)

.

Figure 62

Scouring around circular pier with slot and circular collar of diameter 2.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	1.3	3.2	2.5	6.5	15

.

Case14. Scouring around circular pier with slot and circular collar of diameter3.0D (D is diameter of circular pier)

Figure 63

Circular pier with slot and circular collar of diameter3.0D

(D is diameter of circular pier)

.

Figure 64

Scouring around circular pier with slot and circular collar of diameter 3.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	0.8	2.0	1.6	4.7	15

.

Case15. Scouring around circular pier with slot and square collar of 1.5Dx1.5D (D is diameter of circular pier)

Figure 65

Circular pier with slot and square collar of 1.5Dx1.5D

(D is diameter of circular pier)

.

Figure 66

Scouring around circular pier with slot and square collar of 1.5Dx1.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	2.6	4.4	3.7	11.1	15

.

Case16. Scouring around circular pier with slot and square collar of 2.0Dx2.0D (D is diameter of circular pier)

Figure 67

Circular pier with slot and square collar of2.0Dx2.0D

(D is diameter of circular pier)

.

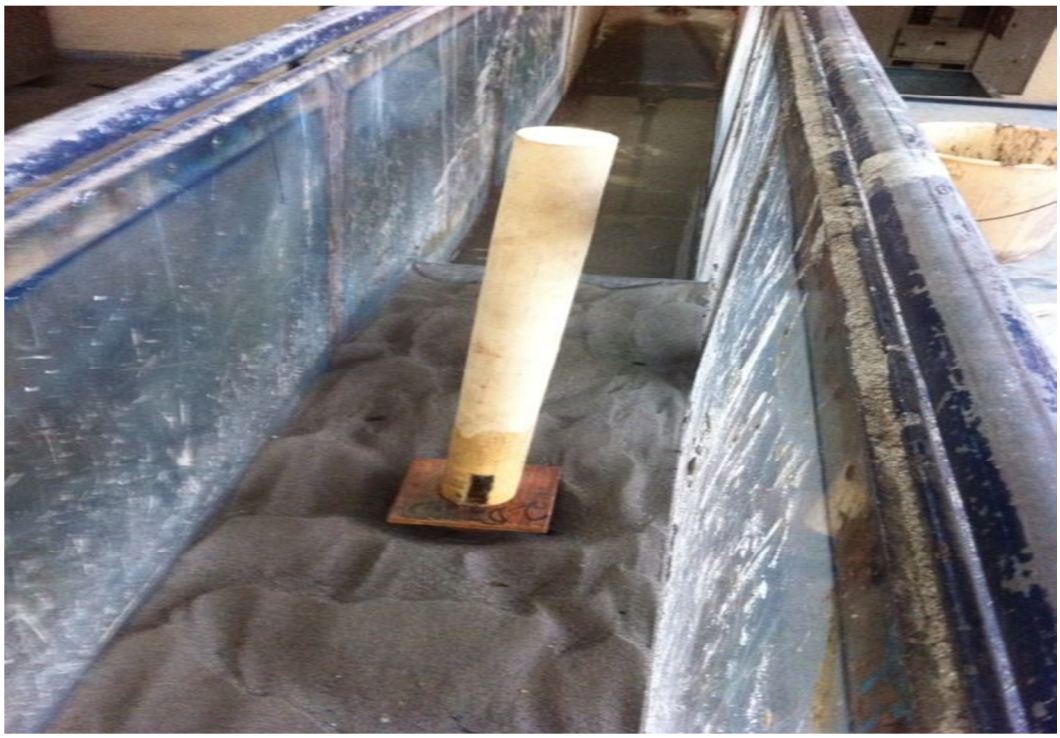

Figure 68

Scouring around circular pier with slot and square collar of 2.0Dx2.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	2.1	4	3.5	8.5	15

.

Case17. Scouring around circular pier with slot and square collar of 2.5Dx2.5D (D is diameter of circular pier)

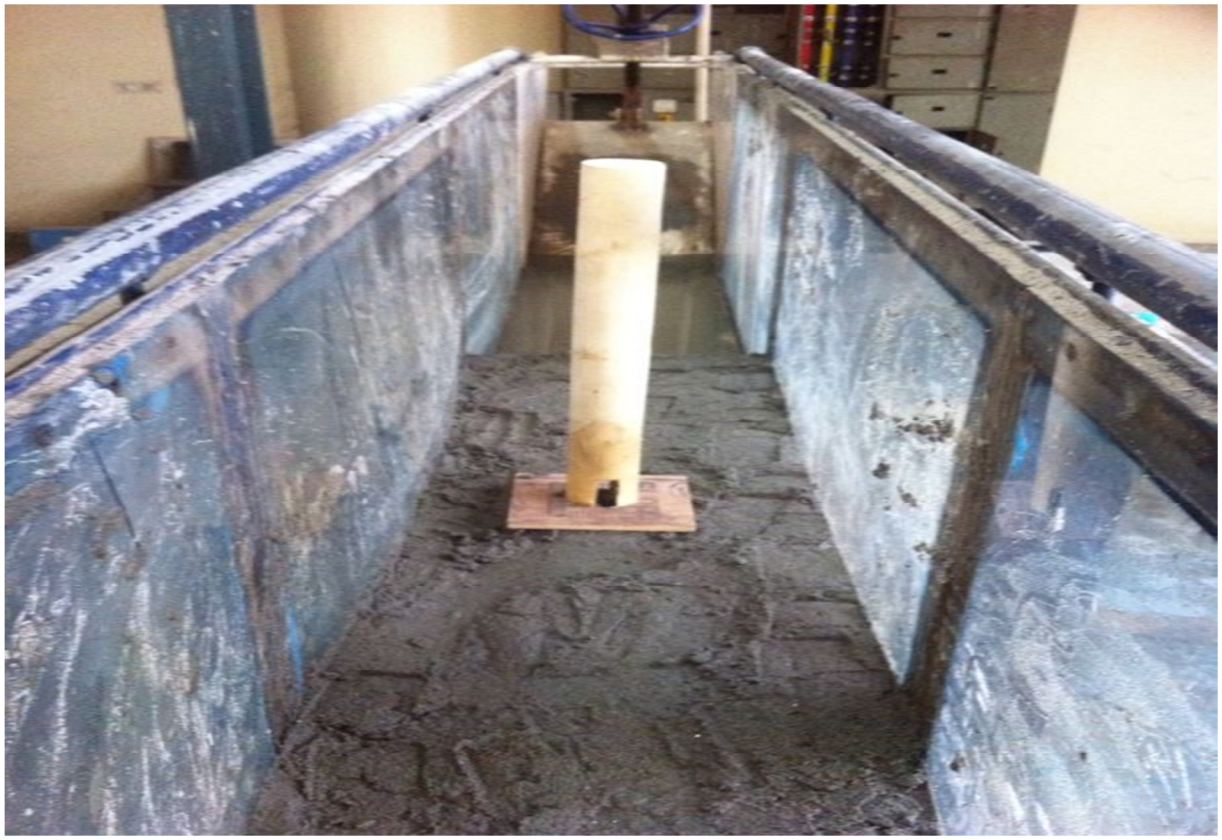

Figure 69

Circular pier with slot and square collar of 2.5Dx2.5D

(D is diameter of circular pier)

.

Figure 70

Scouring around circular pier with slot and square collar of 2.5Dx2.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	1.6	3.4	2.8	6.7	15

.

Case18. Scouring around circular pier with slot and square collar of 3.0Dx3.0D (D is diameter of circular pier)

Figure 71

Circular pier with slot and square collar of 3.0Dx3.0D

(D is diameter of circular pier)

.

Figure 72

Scouring around circular pier with slot and square collar of 3.0Dx3.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.297	1	2.3	2.2	5.2	15

.

C. For Froude no = 0.313

Case1. Scouring around the circular pier

Figure 73

Circular pier of diameter 5cm

.

Figure 74

Scouring around circular pier

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	5	8.1	7.2	15	15

.

Case2. Scouring around circular pier with circular collar of diameter 1.5D (D is diameter of circular pier)

Figure 75

Circular pier with circular collar of diameter 1.5D

(D is diameter of circular pier)

.

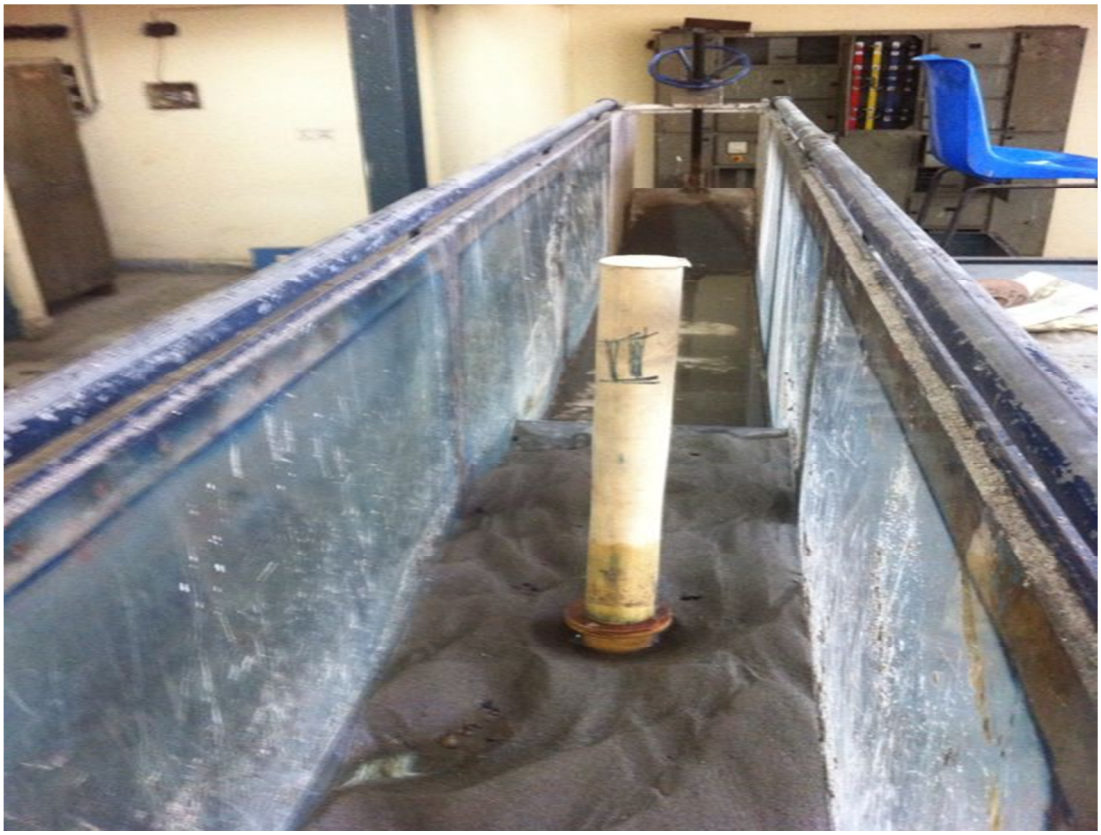

Figure 76

Scouring around circular pier with circular collar of diameter 1.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	3.8	7	5.6	12.2	15

.

Case3. Scouring around circular pier with circular collar of diameter2.0D (D is diameter of circular pier)

Figure 77

Circular pier with circular collar of diameter 2.0D

(D is diameter of circular pier)

.

Figure 78

Scouring around circular pier with circular collar of diameter 2.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	3.3	6	4.7	11.7	15

.

Case4. Scouring around circular pier with circular collar of diameter 2.5D (D is diameter of circular pier)

Figure 79

Circular pier with circular collar of diameter 2.5D

(D is diameter of circular pier)

.

Figure 80

Scouring around circular pier with circular collar of diameter 2.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	2.1	4.8	4.2	8	15

.

Case5. Scouring around circular pier with circular collar of diameter 3.0D (D is diameter of circular pier)

Figure 81

Circular pier with circular collar of diameter3.0D

(D is diameter of circular pier)

.

Figure 82

Scouring around circular pier with circular collar of diameter 3.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	1.3	3.8	3	6.8	15

.

Case6. Scouring around circular pier with square collar of 1.5Dx1.5D (D is diameter of circular pier)

Figure 83

Circular pier with square collar of 1.5Dx1.5D

(D is diameter of circular pier)

.

Figure 84

Scouring around circular pier with square collar of 1.5Dx 1.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	4.1	7.8	7	13.4	15

.

Case7. Scouring around circular pier with square collar of 2.0Dx2.0D (D is diameter of circular pier)

Figure 85

Circular pier with square collar of 2.0Dx2.0D

(D is diameter of circular pier)

.

Figure 86

Scouring around circular pier with square collar of 2.0Dx2.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	3.7	6.4	5.7	12.1	15

.

Case8. Scouring around circular pier with square collar of 2.5Dx2.5D (D is diameter of circular pier)

Figure 87

Circular pier with square collar of 2.5Dx2.5D

(D is diameter of circular pier)

.

Figure 88

Scouring around circular pier with square collar of 2.5Dx2.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	2.6	5.4	5.3	9.3	15

.

Case9. Scouring around circular pier with square collar of 3.0Dx3.0D (D is diameter of circular pier)

Figure 89

Circular pier with square collar of 3.0Dx3.0D

(D is diameter of circular pier)

.

Figure 90

Scouring around circular pier with square collar of 3.0Dx3.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	2.1	3.9	3.3	7	15

.

Case10. Scouring around circular pier with slot of dimension 5cmx1cm

Figure 91

Circular pier with slot of dimension 5cmx1cm

.

Figure 92

Scouring around circular pier with slot of dimension 5cmx1cm

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	3.5	4.9	4.6	12	15

.

Case11. Scouring around circular pier with slot and circular collar of diameter 1.5D (D is diameter of circular pier)

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Figure 93

Circular pier with slot and circular collar of 1.5D

(D is diameter of circular pier)

.

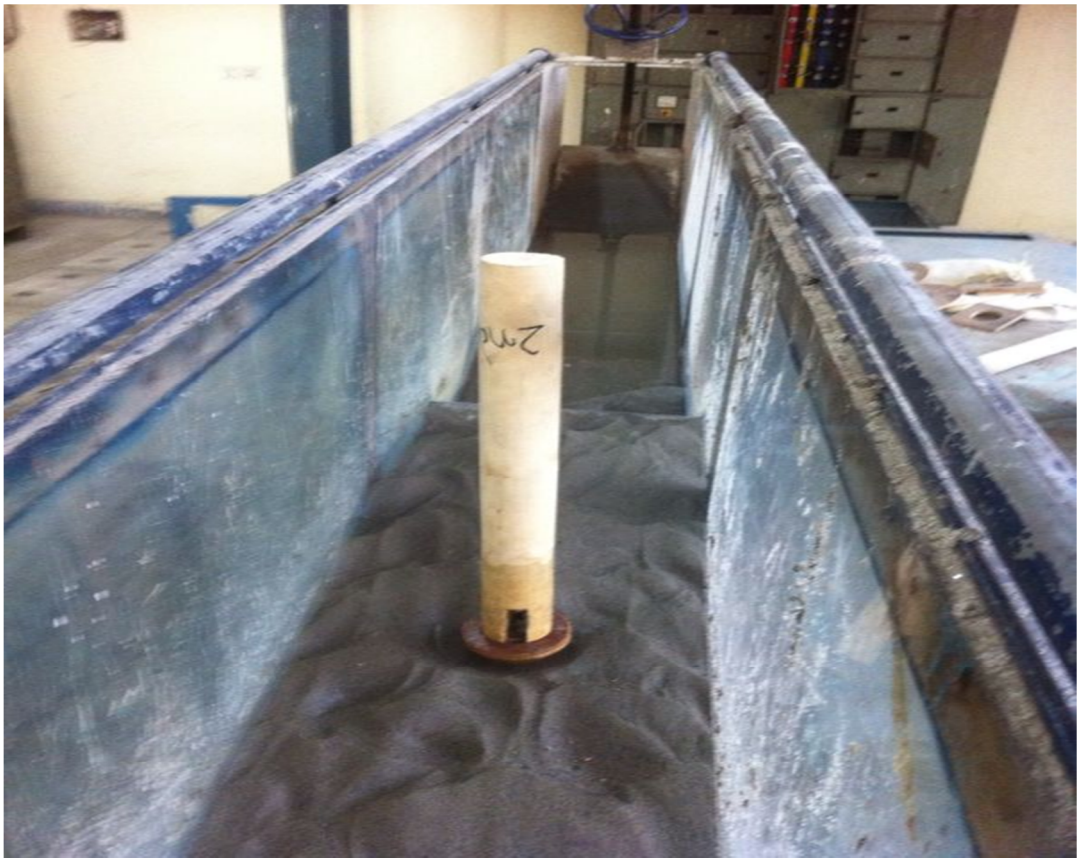

Figure 94

Scouring around circular pier with slot and circular collar of diameter 1.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	2.7	5.2	4.3	11.3	15

.

Case12. Scouring around circular pier with slot and circular collar of diameter2.0D (D is diameter of circular pier)

Figure 95

Circular pier with slot and circular collar of diameter2.0D

(D is diameter of circular pier)

.

Figure 96

Scouring around circular pier and circular collar of diameter 2.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	2.2	4.3	3.9	9	15

.

Case13. Scouring around circular pier with slot and circular collar of diameter 2.5D (D is diameter of circular pier)

Figure 97

Circular pier with circular collar of diameter 2.5D

(D is diameter of circular pier)

.

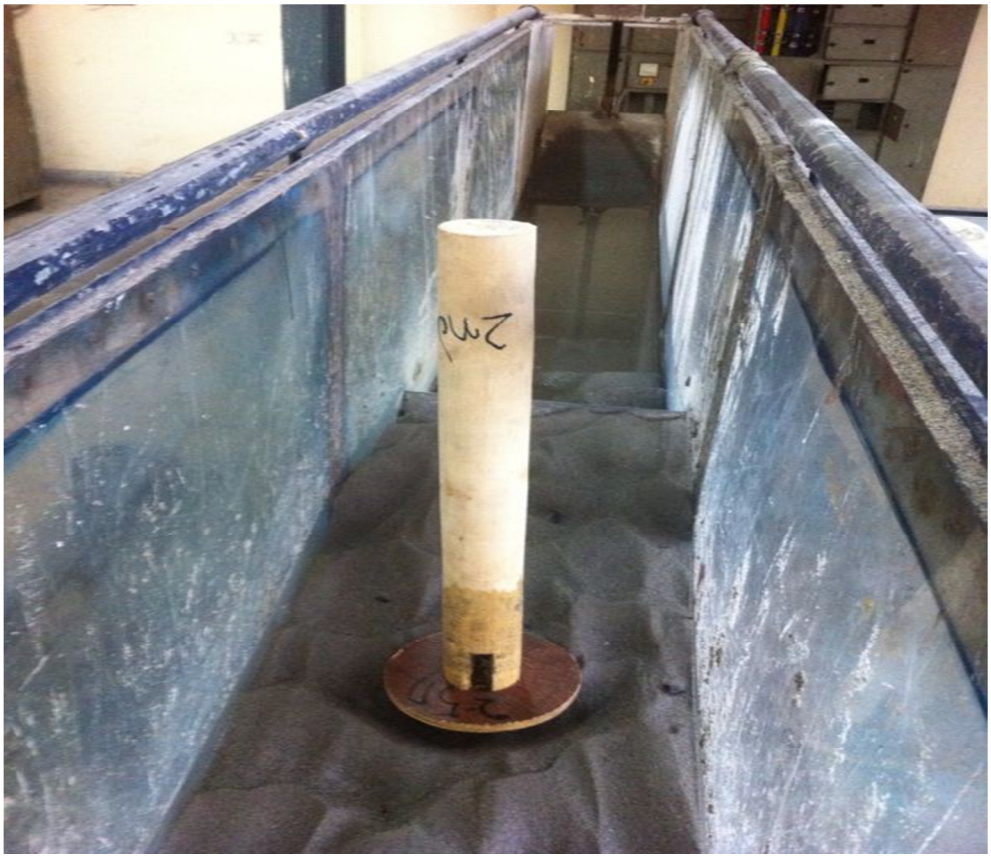

Figure 98

Scouring around circular pier with slot and circular collar of diameter 2.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	1.7	3.7	3	6.9	15

.

Caes14. Scouring around circular pier with slot and circular collar of diameter 3.0D (D is diameter of circular pier)

Figure 99

Circular pier with slot and circular collar of diameter3.0D

(D is diameter of circular pier)

.

Figure 100

Scouring around circular pier with slot and circular collar of diameter 3.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	1	2.4	2	5.1	15

.

Case15. Scouring around circular pier with slot and square collar of 1.5Dx1.5D (D is diameter of circular pier)

Figure 101

Circular pier with slot and square collar of 1.5Dx1.5D

(D is diameter of circular pier)

.

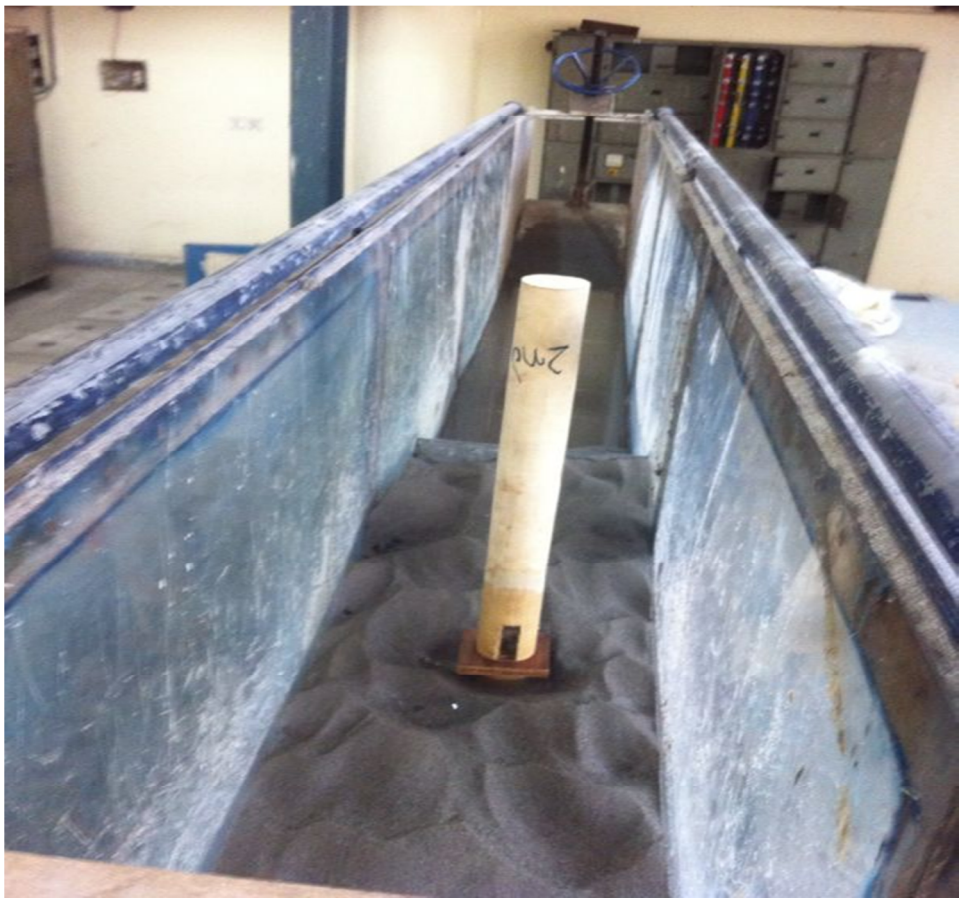

Figure 102

Scouring around circular pier with slot and square collar of 1.5Dx1.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	3	8.4	4.4	11.5	15

.

Case16. Scouring around circular pier with slot and square collar of 2.0Dx2.0D (D is diameter of circular pier)

Figure 103

Circular pier with slot and square collar of 2.0Dx2.0D

(D is diameter of circular pier)

.

Figure 104

Scouring around circular pier with slot and square collar of 2.0Dx2.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	2.6	4.6	4.0	9.6	15

.

Case17. Scouring around circular pier with slot and square collar of 2.5Dx2.5D (D is diameter of circular pier)

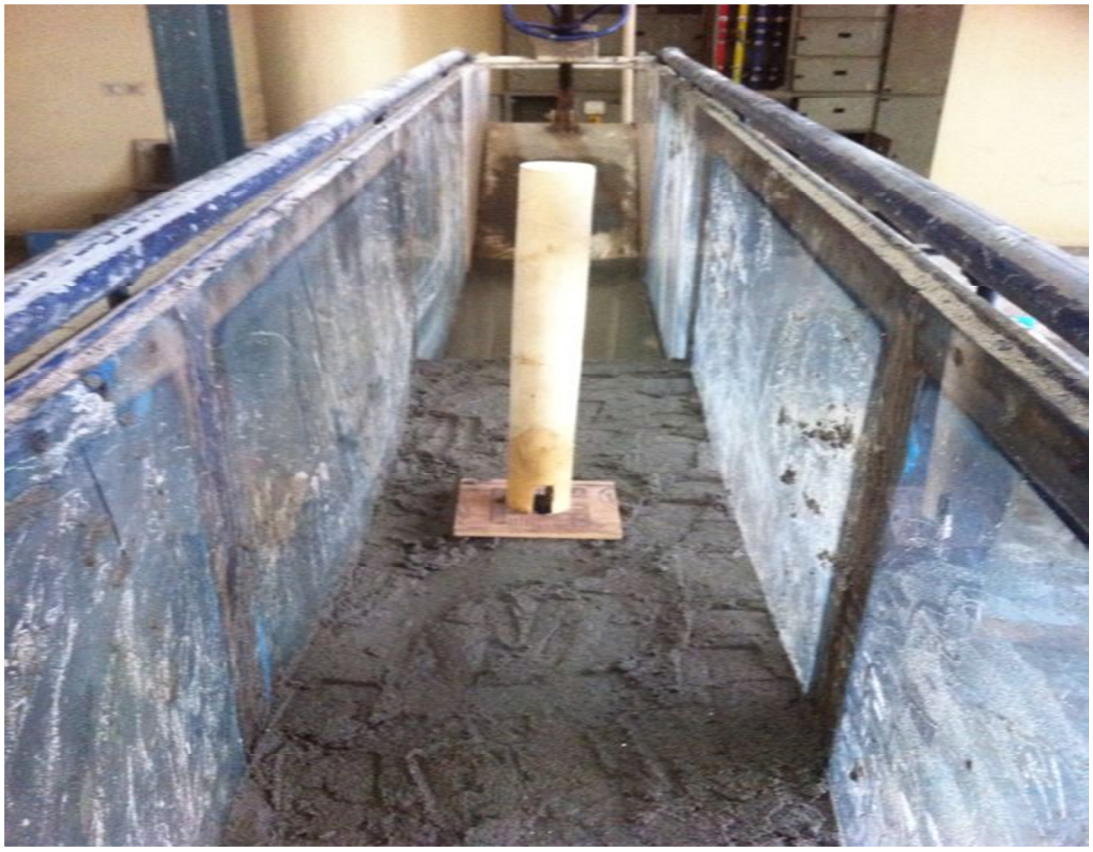

Figure 105

Circular pier with slot and square collar of 2.5Dx2.5D

(D is diameter of circular pier)

.

Figure 106

Scouring around circular pier with slot and square collar 0f 2.5Dx2.5D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	2.0	3.9	3.2	7.1	15

.

Case18. Scouring around circular pier with slot and square collar of 3.0Dx3.0D (D is diameter of circular pier)

Figure 107

Circular pier with slot and square collar of 3.0Dx3.0D

(D is diameter of circular pier)

.

Figure 108

Scouring around circular pier with slot and square collar of 3.0Dx3.0D

(D is diameter of circular pier)

Froude no (Fr)	Scouring depth(d_s) (in cm)	L u/s (in cm)	L d/s (in cm)	Width of scour hole (in cm)	Bed level (in cm)
0.313	1.2	2.7	2.2	5.5	15

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13. Results and discussion

In this research, we perform different cases for observing the reduction of the scouring process around the circular pier. For this we choose two measures. 1st, use of the collar on circular pier and 2nd, use of slot on the circular pier and we also took the combinations of collar and slot on circular pier. In this work, we took two shapes of collar, circular and square. Then we choose the different dimension of the circular and square collar which is described as follows.

- Circular collar of diameter1.5D
- Circular collar of diameter 2.0D
- Circular collar of diameter 2,5D
- Circular collar of diameter 3.0D
- Square collar of dimension of 1.5Dx15D
- Square collar of dimension of 2.0Dx2.0D
- Square collar of dimension of 2.5Dx2.5D
- Square collar of dimension of 3.0Dx3.0D
- Slot of dimension 5cmx1cm

In this work we also took the combination of the following:

- Slot of dimension 5cmx1cm and circular collar of diameter 1.5D
- Slot of dimension 5cmx1cm and circular collar of diameter 2.0D
- Slot of dimension 5cmx1cm and circular collar of diameter 2.5D
- Slot of dimension 5cmx1cm and circular collar of diameter 3.0D
- Slot of dimension 5cmx1cm and square collar of dimension 1.5Dx1.5D
- Slot of dimension 5cmx1cm and square collar of dimension 2.0Dx2.0D
- Slot of dimension 5cmx1cm and square collar of dimension 2.5Dx2.5D
- Slot of dimension 5cmx1cm and square collar of dimension 3.0Dx3.0D

And following results were obtained.

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1. For Froude no =0.285

Cases	Froude no (Fr)	Scouring depth(d_s) (cm)	L u/s (cm)	L d/s (cm)	Width of the scour hole (cm)	Bed level (cm)
Scouring around the simple circular pier	0.285	3.7	7.7	5.6	14	15
Scouring around the circular pier having circular collar of diameter1.5D	0.285	3.0	5.3	4.9	10.8	15
Scouring around the circular pier having circular collar of diameter2.0D	0.285	2.4	4.3	3.3	9.4	15
Scouring around the circular pier having circular collar of diameter2.5D	0.285	1.7	4.1	2.8	7.2	15
Scouring around circular pier having circular collar of diameter3.0D	0.285	1.1	2.1	1.6	4.5	15

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Scouring around circular pier having square collar of area $1.5D^2$	0.285	3.2	7.3	5.1	13	15
Scouring around circular pier having square collar of area$2D^2$	0.285	2.7	6.0	4.9	10	15
Scouring around circular pier having square collar of area$2.5D^2$	0.285	2.3	3.5	4.8	7.8	15
Scouring around circular pier having square collar of area$3D^2$	0.285	1.6	2.2	1.7	5.6	15
Scouring around circular pier having slot of dimension 5cmx1cm	0.285	2.4	4.1	3.6	11.2	15
Scouring around circular pier having slot and circular collar of dia1.5D	0.285	1.9	3.7	3.0	10.2	15

.

Scouring around circular pier having slot and circular collar of diameter 2.0D	0.285	1.5	3.4	3.1	7.1	15
Scouring around circular pier having slot and circular collar of diameter 2.5D	0.285	1	2.7	2.1	6.1	15
Scouring around circular pier having slot and circular pier of diameter3.0D	0.285	0.6	1.7	1.2	4.3	15
Scouring around circular pier having slot and square collar of area $1.5D^2$	0.285	2.3	3.8	3.2	10.7	15

.

Scouring around circular pier having slot and square collar of area $2D^2$	0.285	1.7	3.6	3.2	7.8	15
Scouring around circular pier having circular pier having slot and square collar of area $2.5D^2$	0.285	1.3	3.0	2.4	6.3	15
Scouring around the circular pier having slot and square collar of area $3D^2$	0.285	0.8	2	2	5	15

.

2. For Froude no = 0.297

Cases	Froude no (Fr)	Scouring depth(d_s) (cm)	L u/s (cm)	L d/s (cm)	Width of the scour hole (cm)	Bed level (cm)
Scouring around the simple circular pier	0.297	4	7.9	6	14.3	15
Scouring around the circular pier having circular collar of diameter1.5D	0.297	3.2	5.5	5.1	11	15
Scouring around the circular pier having circular collar of diameter2.0D	0.297	2.6	4.7	3.9	9.7	15
Scouring around the circular pier having circular collar of diameter2.5D	0.297	1.9	4.3	3.1	7.5	15
Scouring around circular pier having circular collar of diameter3.0D	0.297	1.2	2.4	2	5	15

.

Scouring around circular pier having square collar of area $1.5D^2$	0.297	3.6	7.6	5.6	13.2	15
Scouring around circular pier having square collar of area$2D^2$	0.297	3	6.2	5.2	10.8	15
Scouring around circular pier having square collar of area$2.5D^2$	0.297	2.4	4.2	5.1	8.4	15
Scouring around circular pier having square collar of area$3D^2$	0.297	1.9	2.7	2.3	6.1	15
Scouring around circular pier having slot of dimension 5cmx1cm	0.297	2.8	4.5	3.9	11.6	15
Scouring around circular pier having slot and circular collar of dia1.5D	0.297	2.3	4.3	3.5	10.7	15

.

Scouring around circular pier having slot and circular collar of diameter 2.0D	0.297	1.8	3.8	3.4	7.8	15
Scouring around circular pier having slot and circular collar of diameter 2.5D	0.297	1.3	3.2	2.5	6.5	15
Scouring around circular pier having slot and circular pier of diameter3.0D	0.297	0.8	2	1.6	4.7	15
Scouring around circular pier having slot and square collar of area $1.5D^2$	0.297	2.6	4.4	3.7	11.1	15

.

Scouring around circular pier having slot and square collar of area $2D^2$	0.297	2.1	4	3.5	8.5	15
Scouring around circular pier having circular pier having slot and square collar of area $2.5D^2$	0.297	1.6	3.4	2.8	6.7	15
Scouring around the circular pier having slot and square collar of area $3D^2$	0.297	1	2.3	2.1	5.2	15

.

3. For Froude no = 0.313

Cases	Froude no (Fr)	Scouring depth(d_s) (cm)	L u/s (cm)	L d/s (cm)	Width of the scour hole (cm)	Bed level (cm)
Scouring around the simple circular pier	0.313	5	8.1	7.2	15	15
Scouring around the circular pier having circular collar of diameter1.5D	0.313	3.8	7	5.6	12.2	15
Scouring around the circular pier having circular collar of diameter2.0D	0.313	3.3	6	4.7	11.7	15
Scouring around the circular pier having circular collar of diameter2.5D	0.313	2.1	4.8	4.2	8	15
Scouring around circular pier having circular collar of diameter3.0D	0.313	1.3	3.8	3	6.8	15

.

Scouring around circular pier having square collar of area $1.5D^2$	0.313	4.1	7.8	6	13.4	15
Scouring around circular pier having square collar of area$2D^2$	0.313	3.7	6.4	5.7	12.1	15
Scouring around circular pier having square collar of area$2.5D^2$	0.313	2.6	5.4	5.3	9.3	15
Scouring around circular pier having square collar of area$3D^2$	0.313	2.1	3.9	3.3	7	15
Scouring around circular pier having slot of dimension 5cmx1cm	0.313	3.5	4.9	4.6	12	15
Scouring around circular pier having slot and circular collar of dia1.5D	0.313	2.7	5.2	4.3	11.3	15

.

Scouring around circular pier having slot and circular collar of diameter 2.0D	0.313	2.2	4.3	3.9	9	15
Scouring around circular pier having slot and circular collar of diameter 2.5D	0.313	1.7	3.7	3	6.9	15
Scouring around circular pier having slot and circular pier of diameter3.0D	0.313	1	2.4	2	5.1	15
Scouring around circular pier having slot and square collar of area $1.5D^2$	0.313	3	5.4	4.4	11.5	15

.

Scouring around circular pier having slot and square collar of area $2D^2$	0.313	2.6	4.6	4.0	9.6	15
Scouring around circular pier having circular pier having slot and square collar of area $2.5D^2$	0.313	2.0	3.9	3.2	7.1	15
Scouring around the circular pier having slot and square collar of area $3D^2$	0.313	1.2	2.7	2.2	5.5	15

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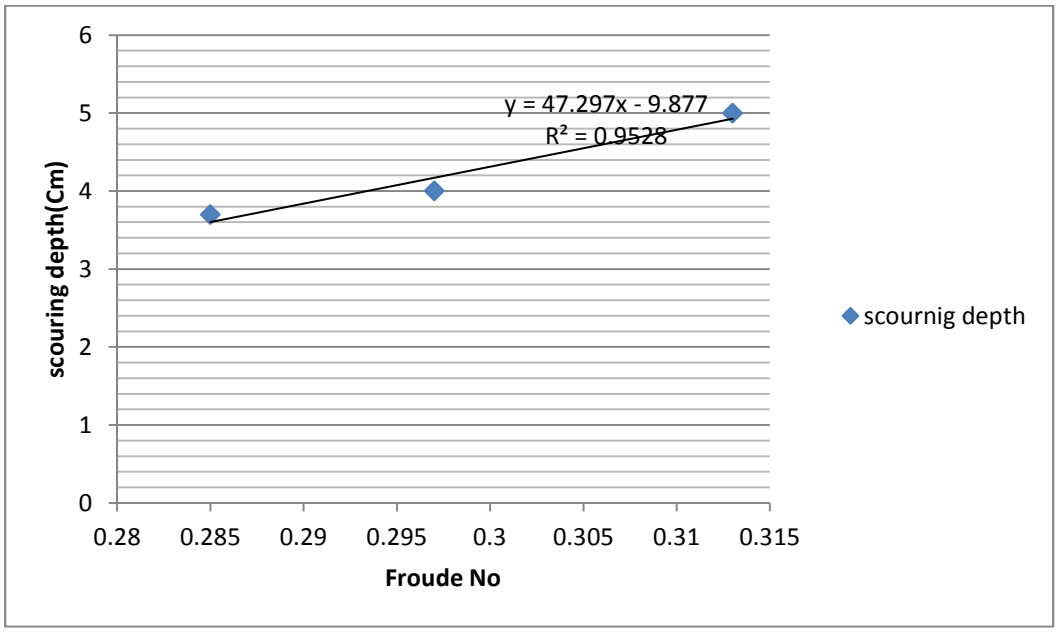
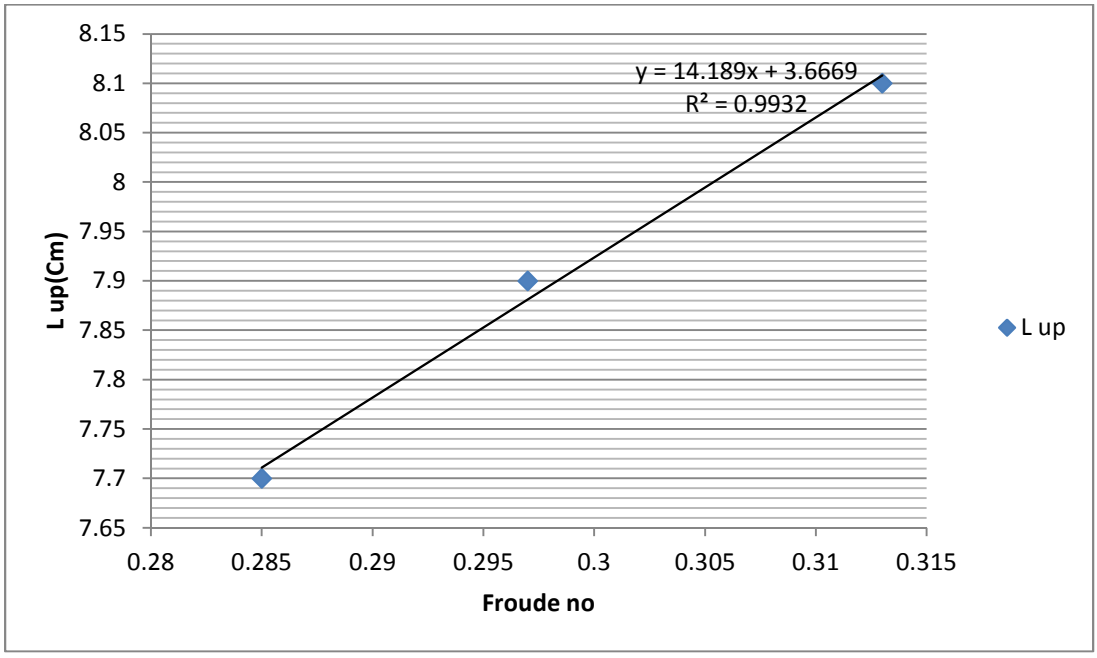
14. Graphs

Case 1. Scouring around simple circular pier:



Equation: y=47.297x-9.877



Equation: y = 14.189x + 3.6669

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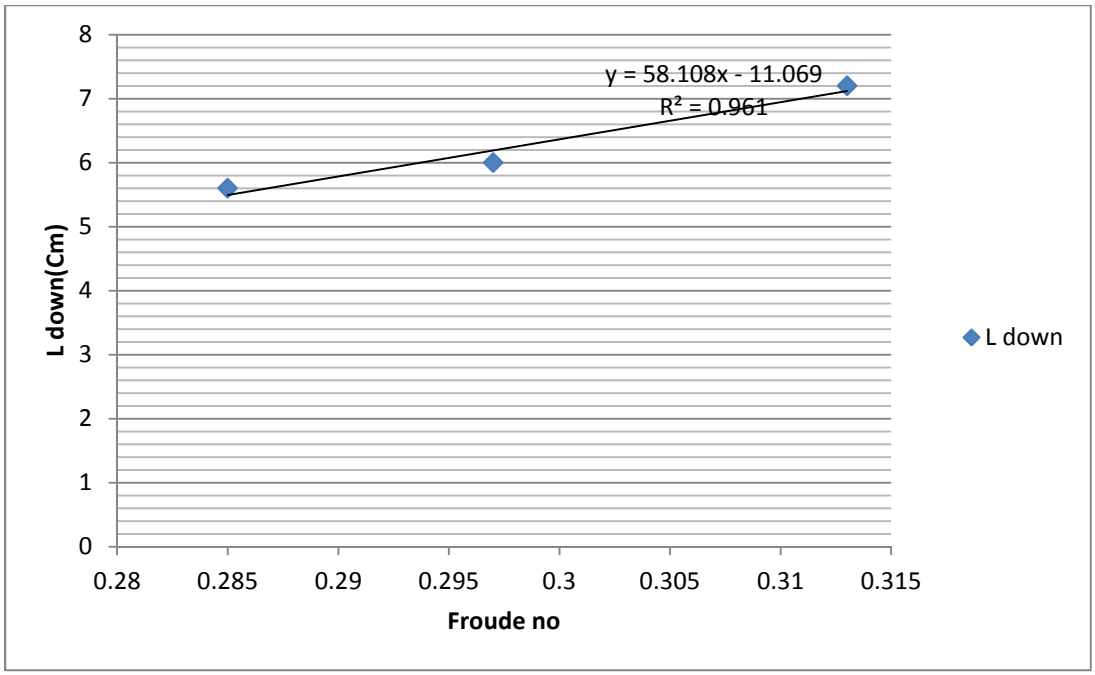
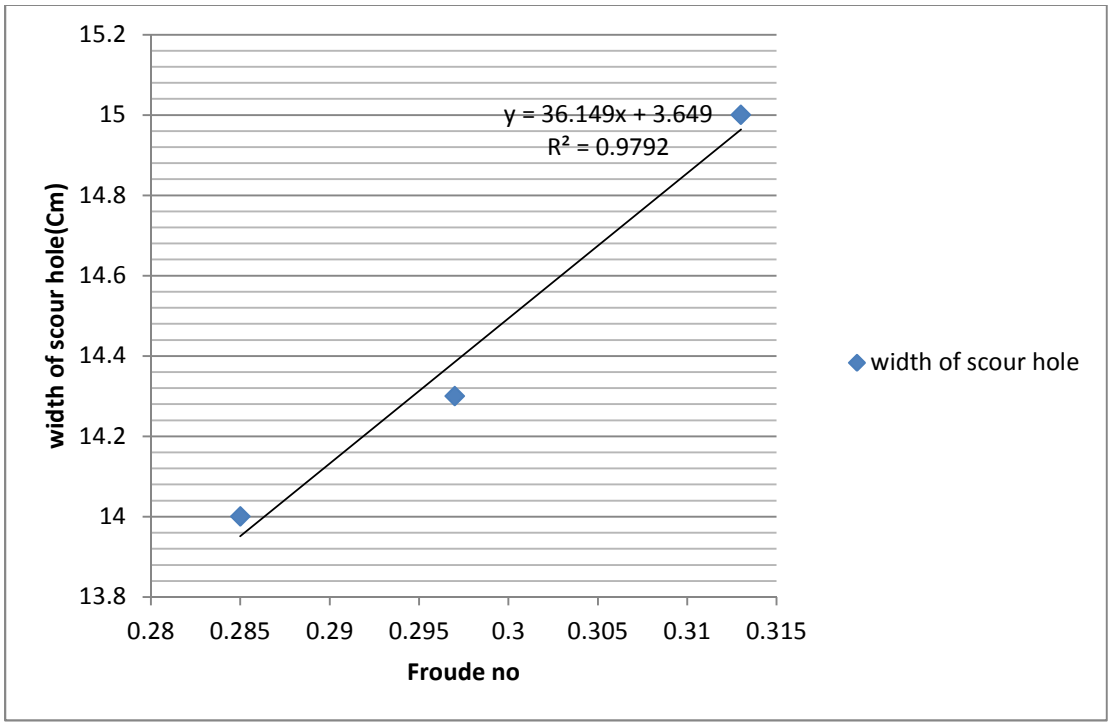


Equation: y = 58.108x - 11.069



Equation: y = 36.149x + 3.649

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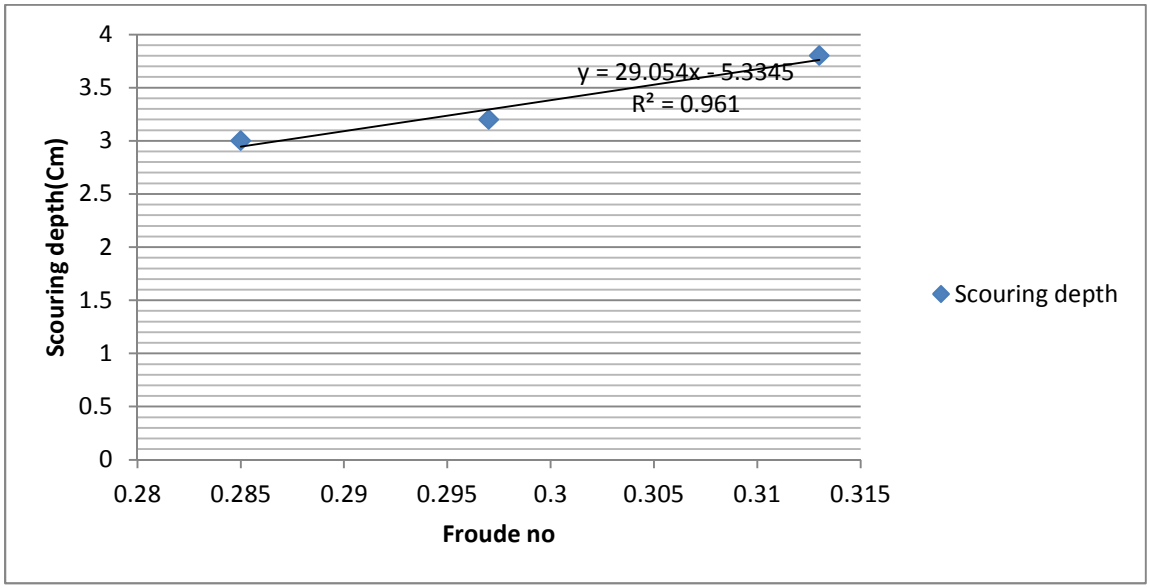
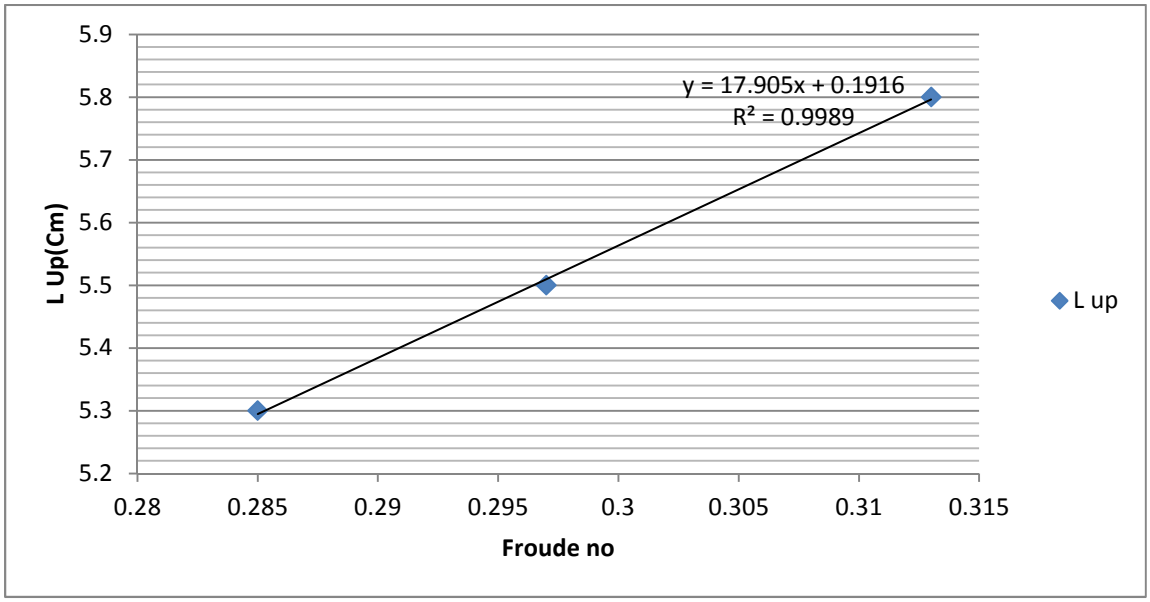
Case 2. Scouring around circular pier with circular collar of diameter 1.5D (D is diameter of circular pier)



Equation: y = 29.054x - 5.3345



Equation: y = 17.905x + 0.1916

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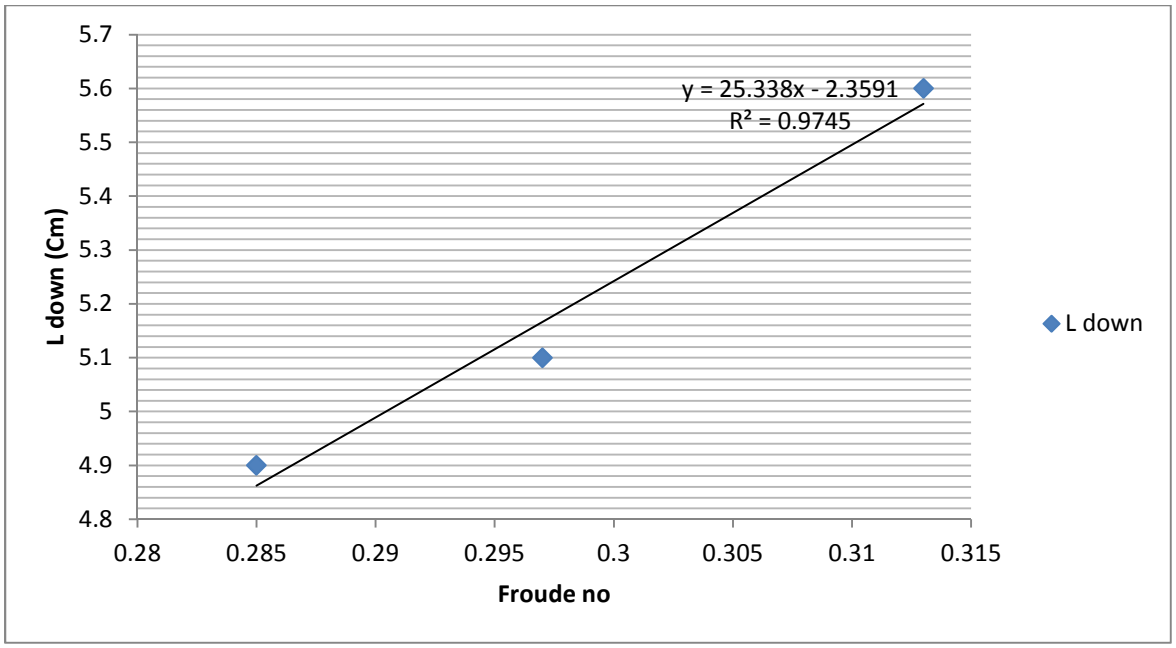
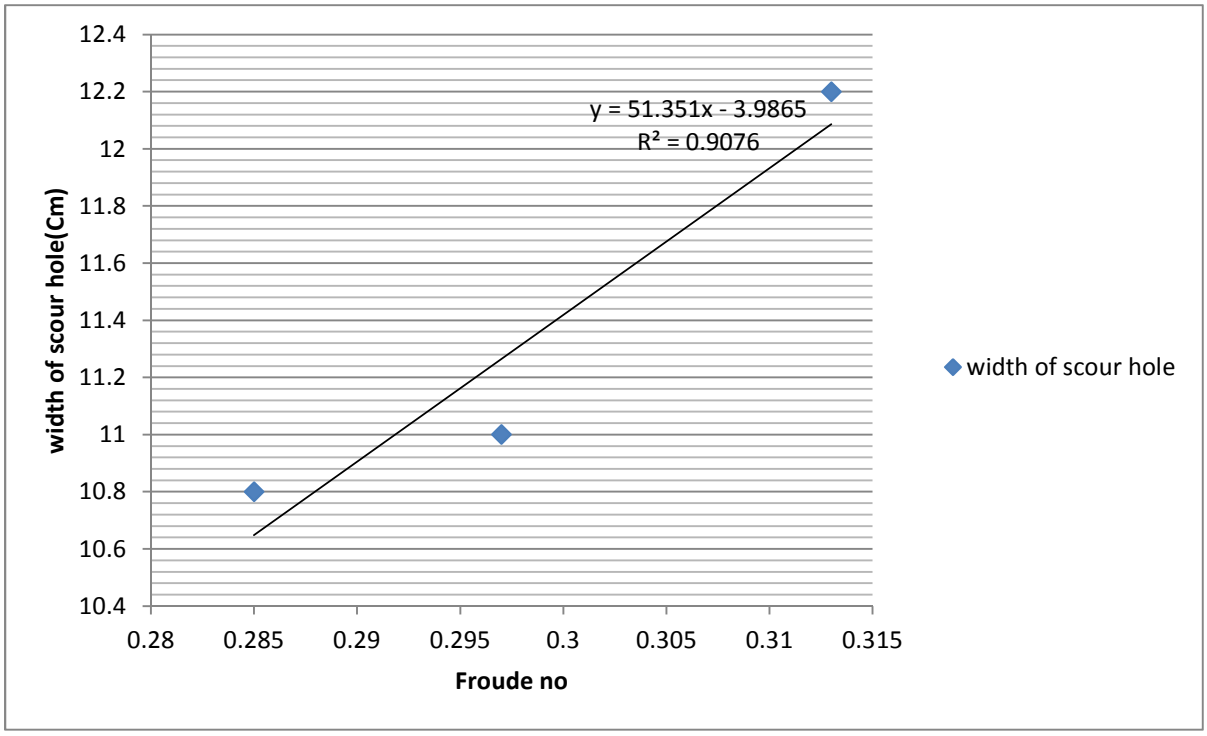


Equation: y = 25.338x - 2.3591



Equation: y = 51.351x - 3.9865

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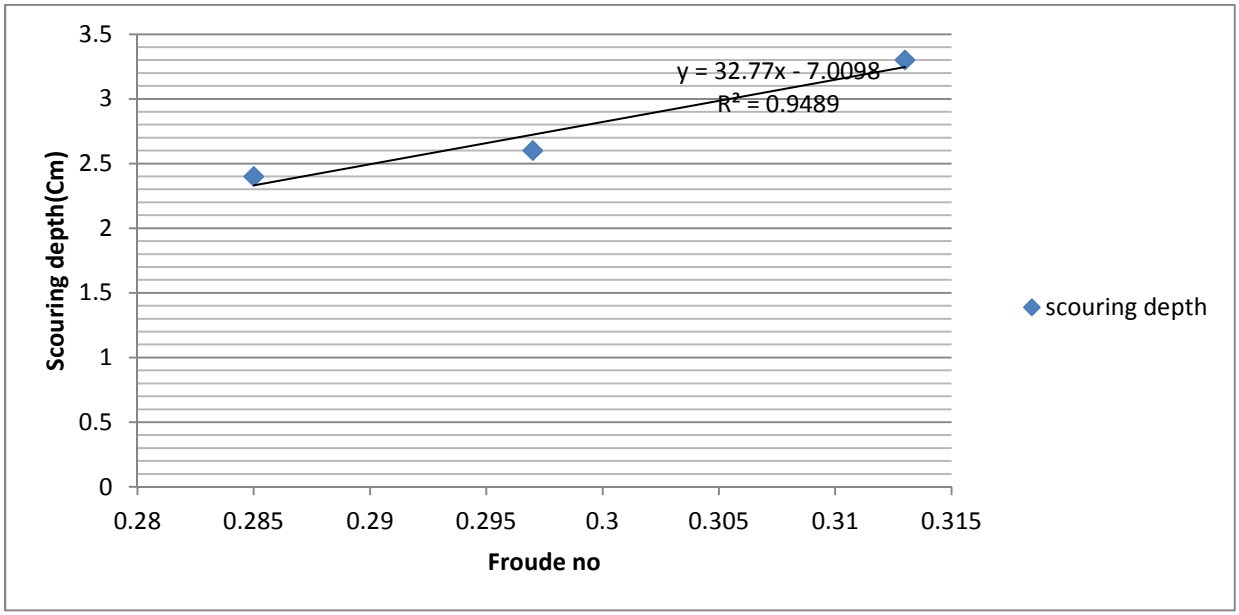
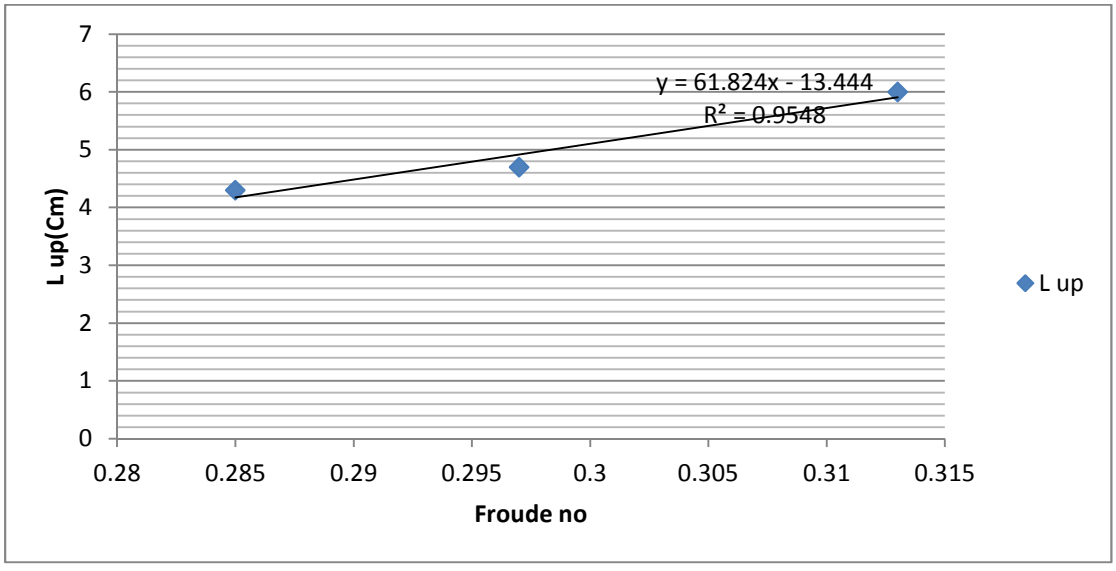
Case 3. Scouring around the circular pier with circular collar of diameter 2.0D (D is diameter of circular pier)



Equation: y = 32.77x - 7.0098



Equation: y = 61.824x - 13.444

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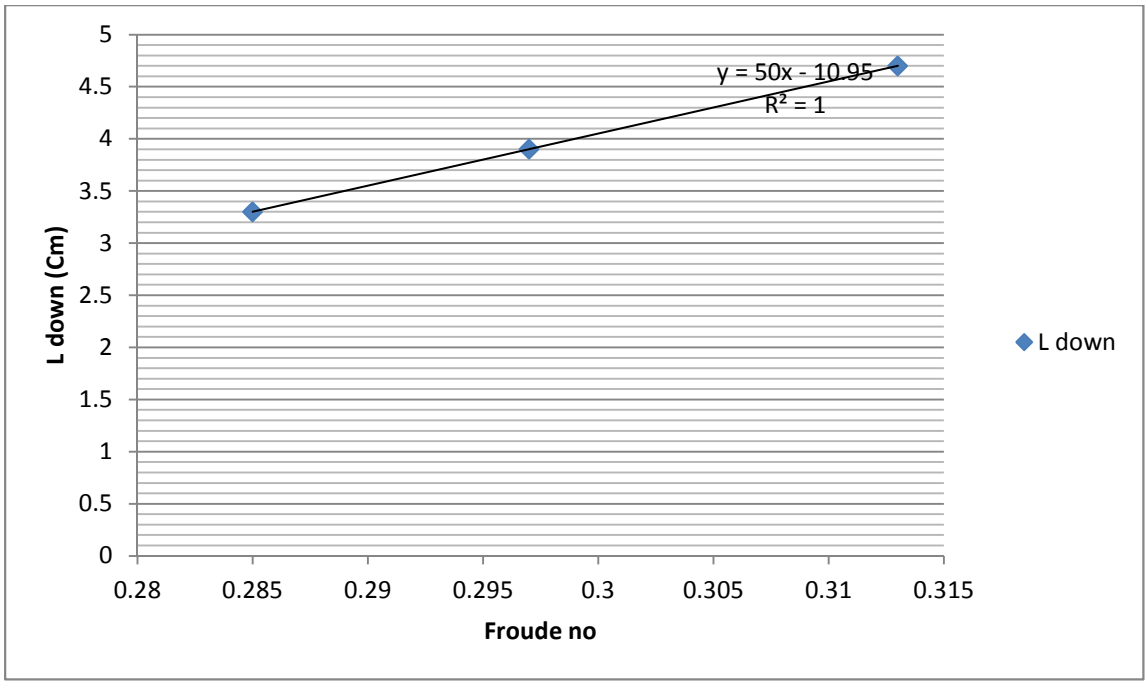
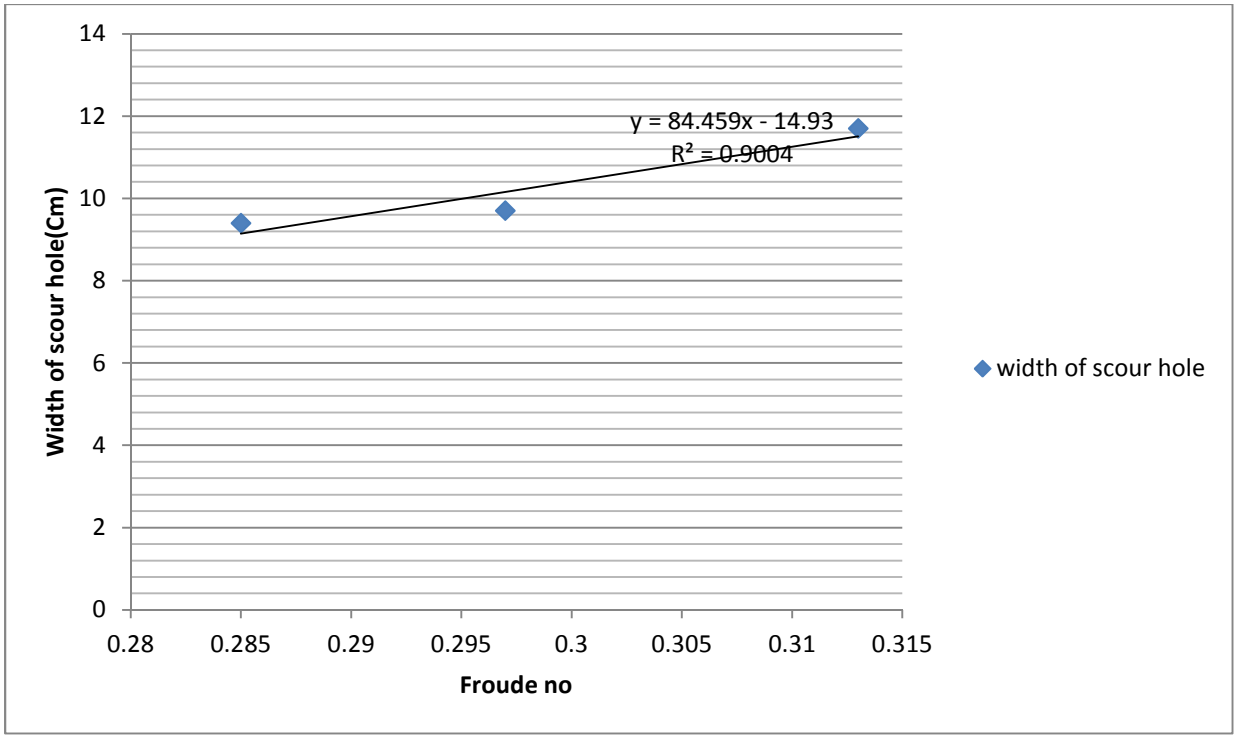


Equation: y = 50x - 10.95



Equation: y = 84.459x - 14.93

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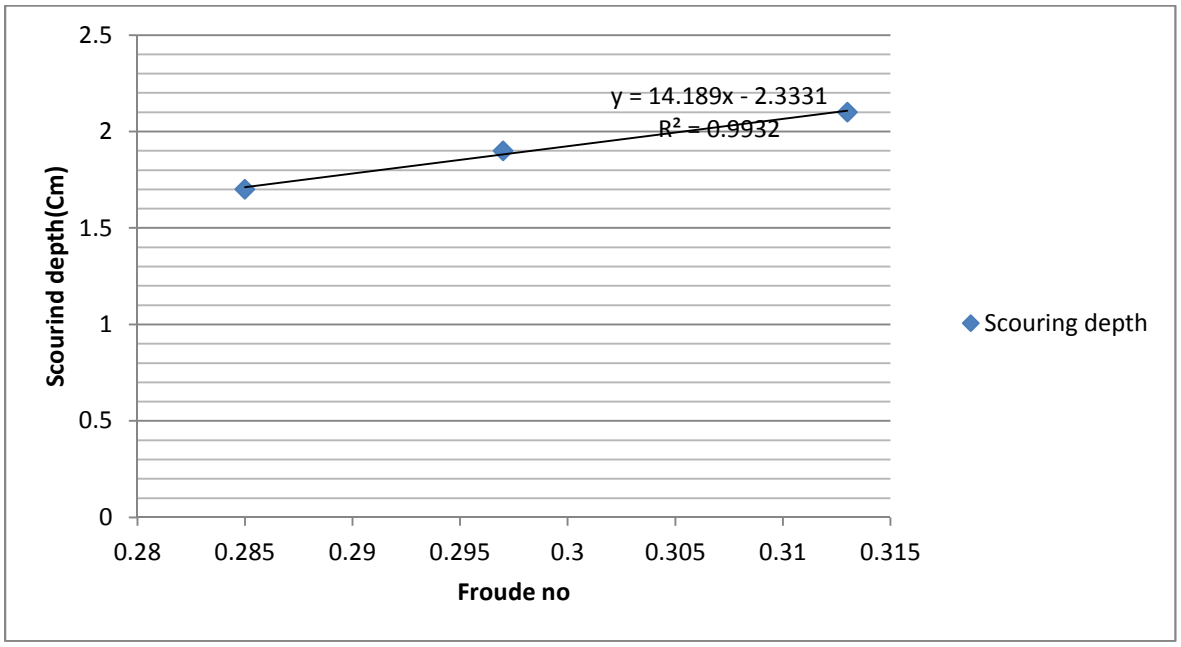
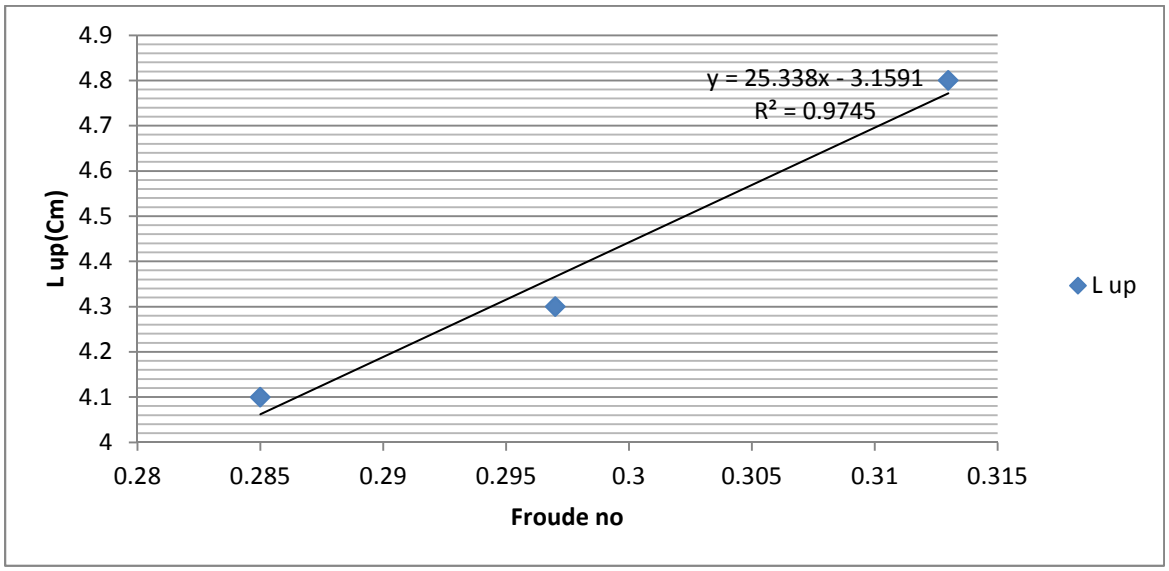
Case 4. Scouring around the circular pier with collar of diameter 2.5D (D is diameter of circular pier)



Equation: y = 14.189x - 2.3331



Equation: y = 25.338x - 3.1591

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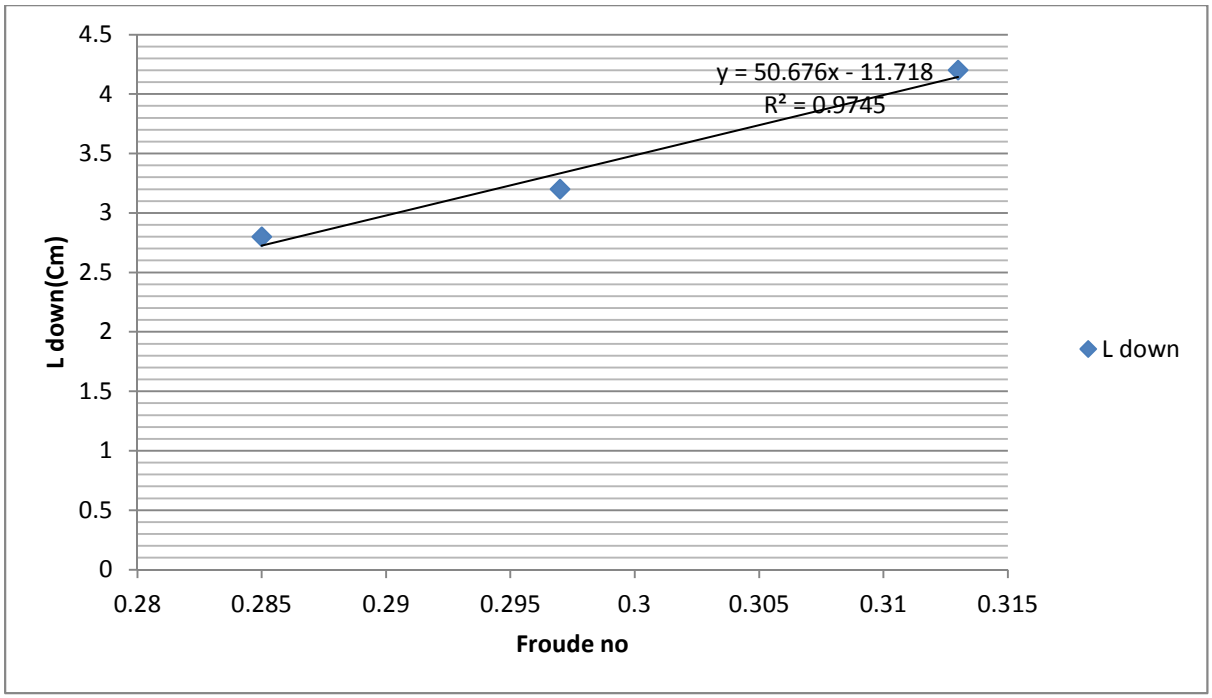
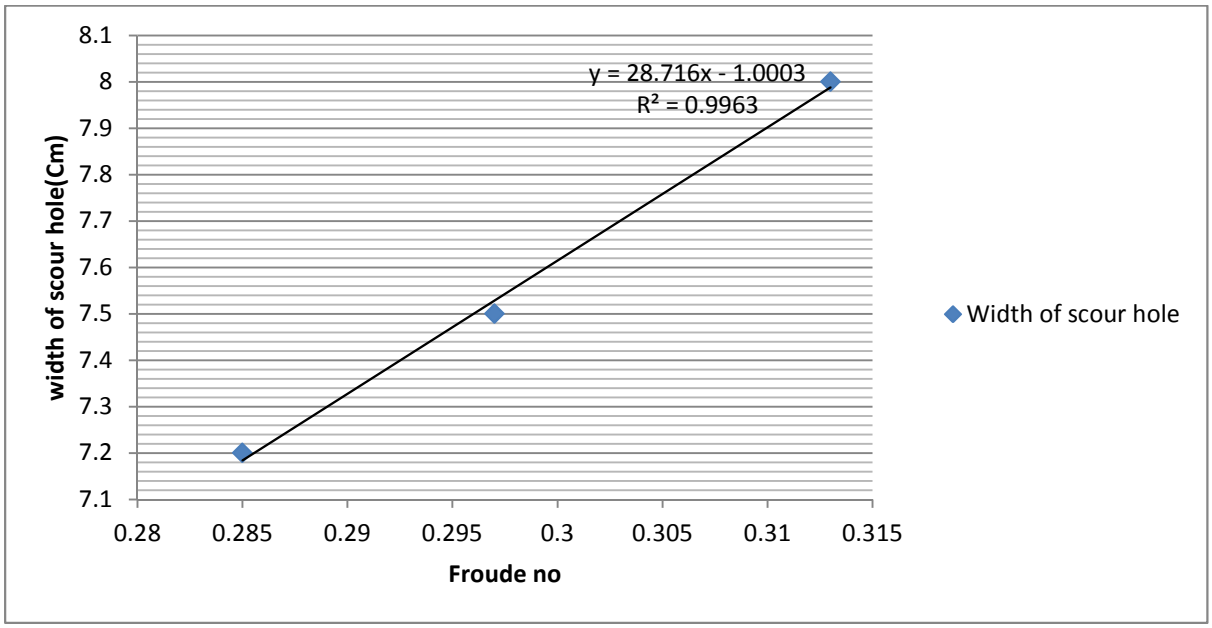


Equation: y = 50.676x - 11.718



Equation: y = 28.716x - 1.0003

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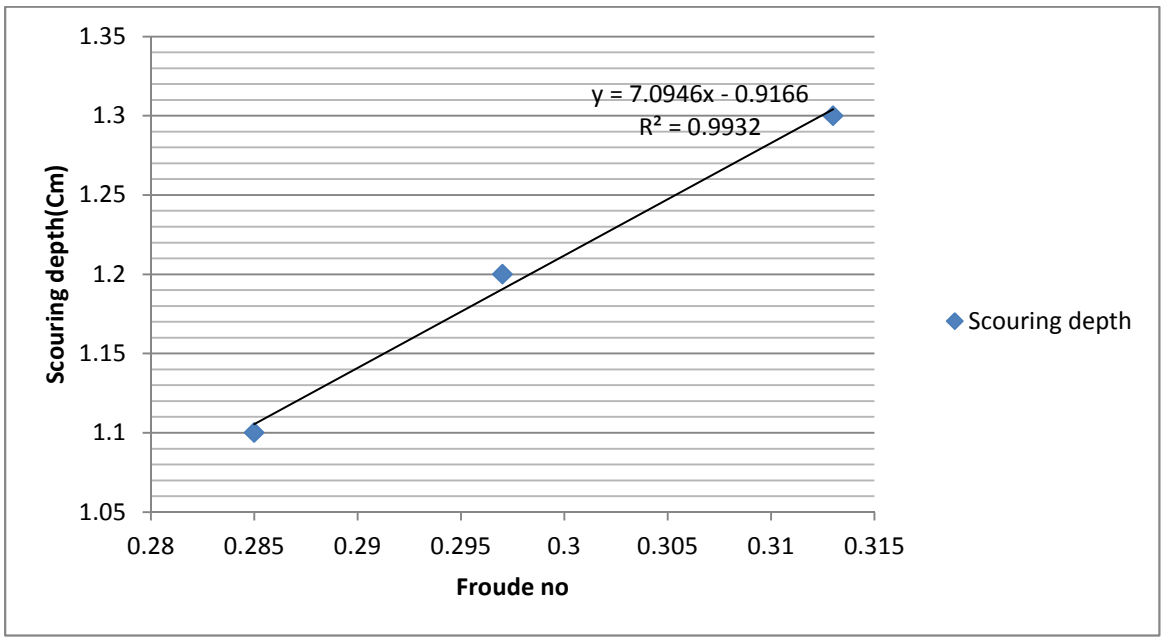
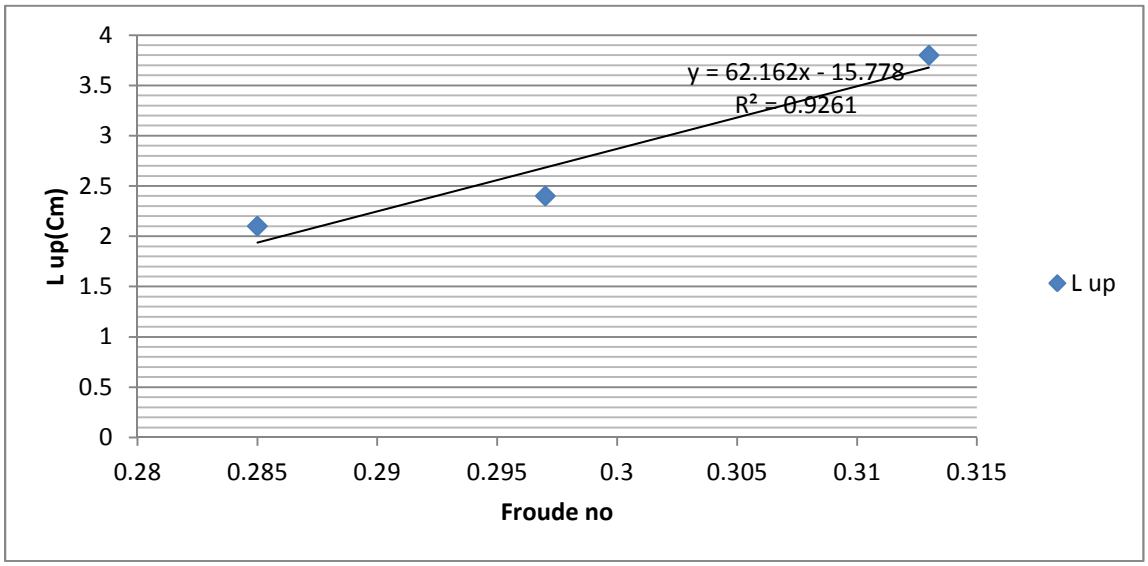
Case 5. Scouring around circular pier with circular collar of diameter 3.0D (D is diameter of circular pier)



Equation: y = 7.0946x - 0.9166



Equation: y = 62.162x - 15.778

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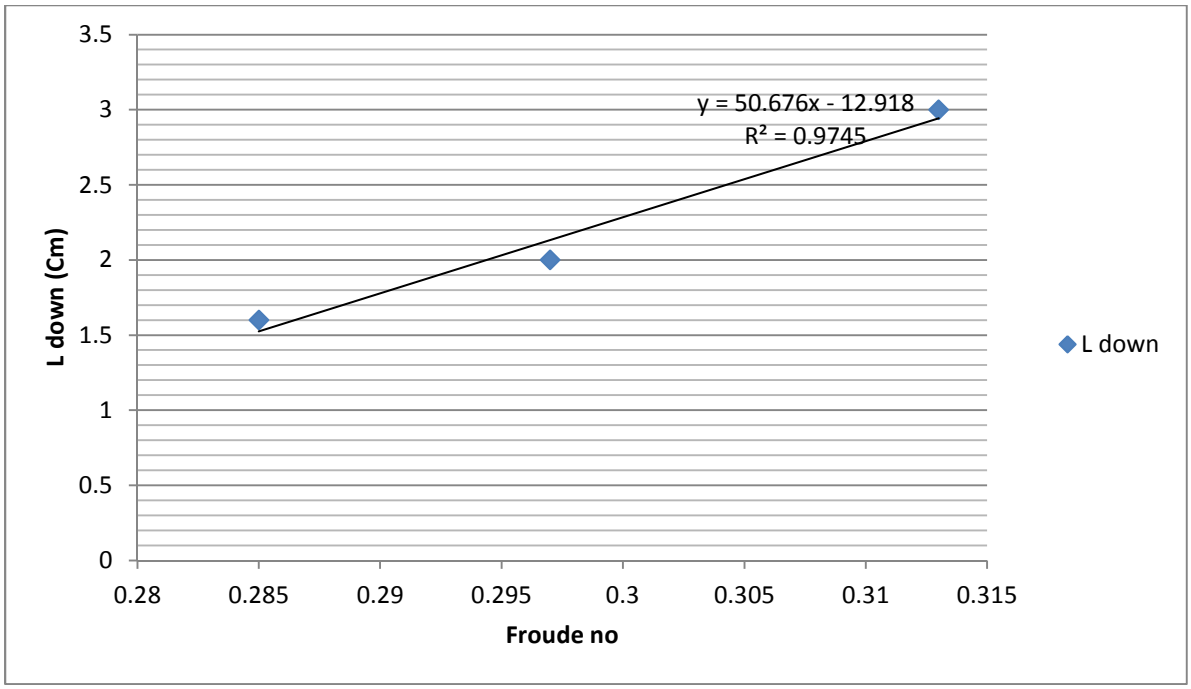
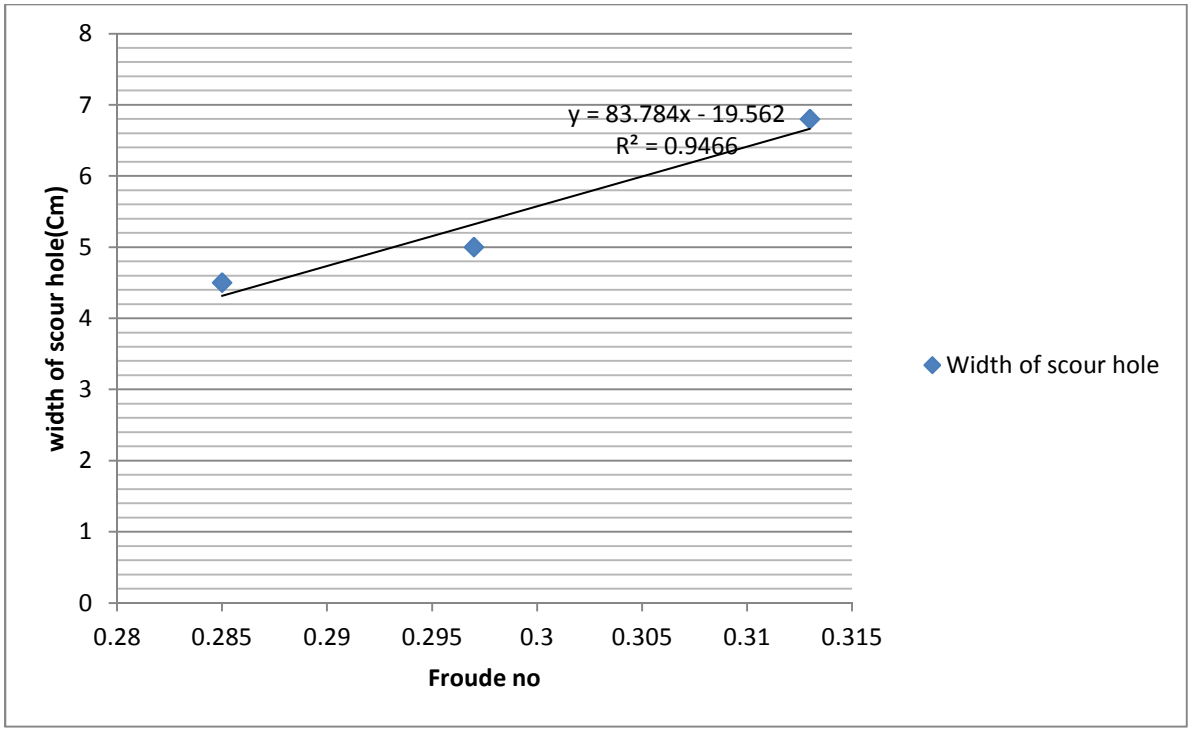


Equation: y = 50.676x - 12.918



Equation: y = 83.784x - 19.562

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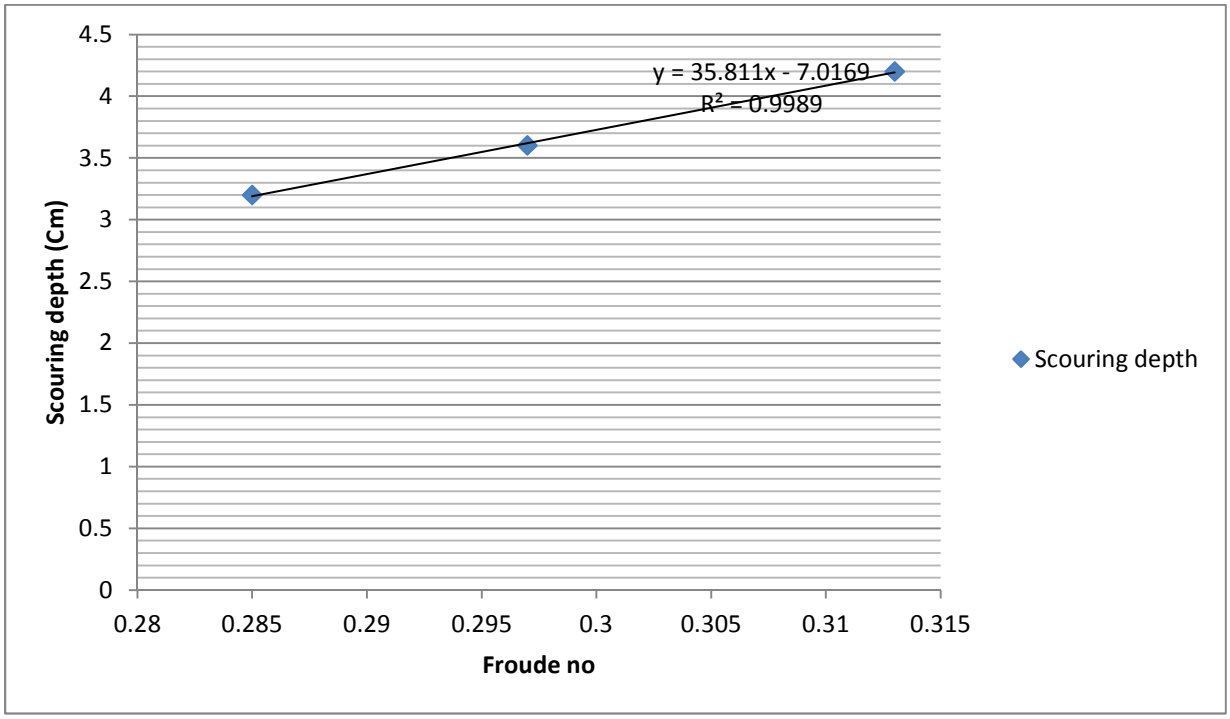
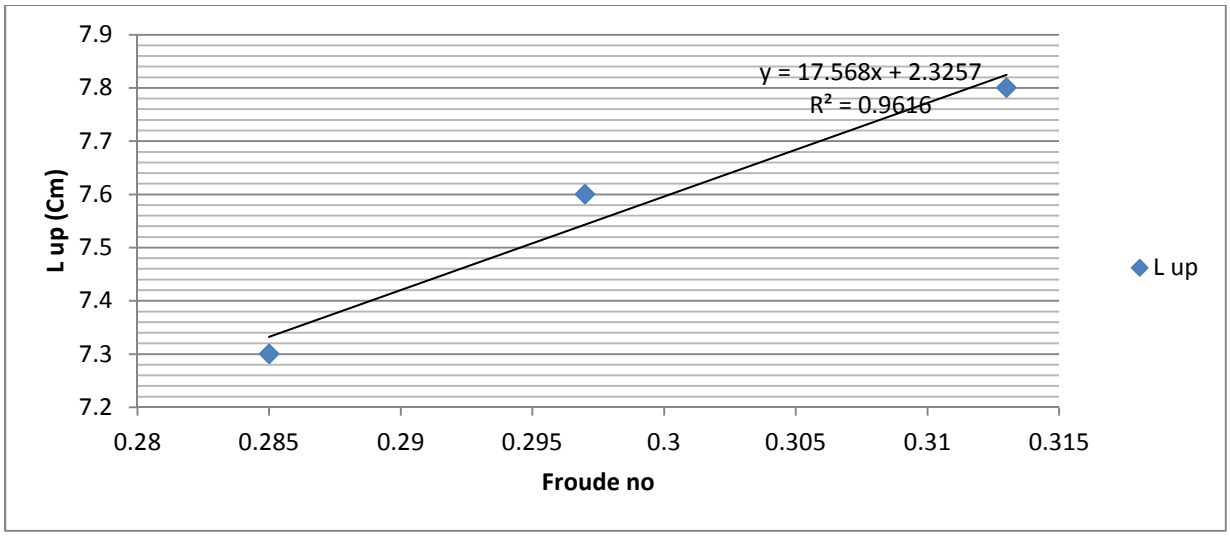
Case 6. Scouring around circular pier with Square collar of area 1.5Dx1.5D (D is diameter of circular pier)



Equation: y = 35.811x - 7.0169



Equation: y = 17.568x + 2.3257

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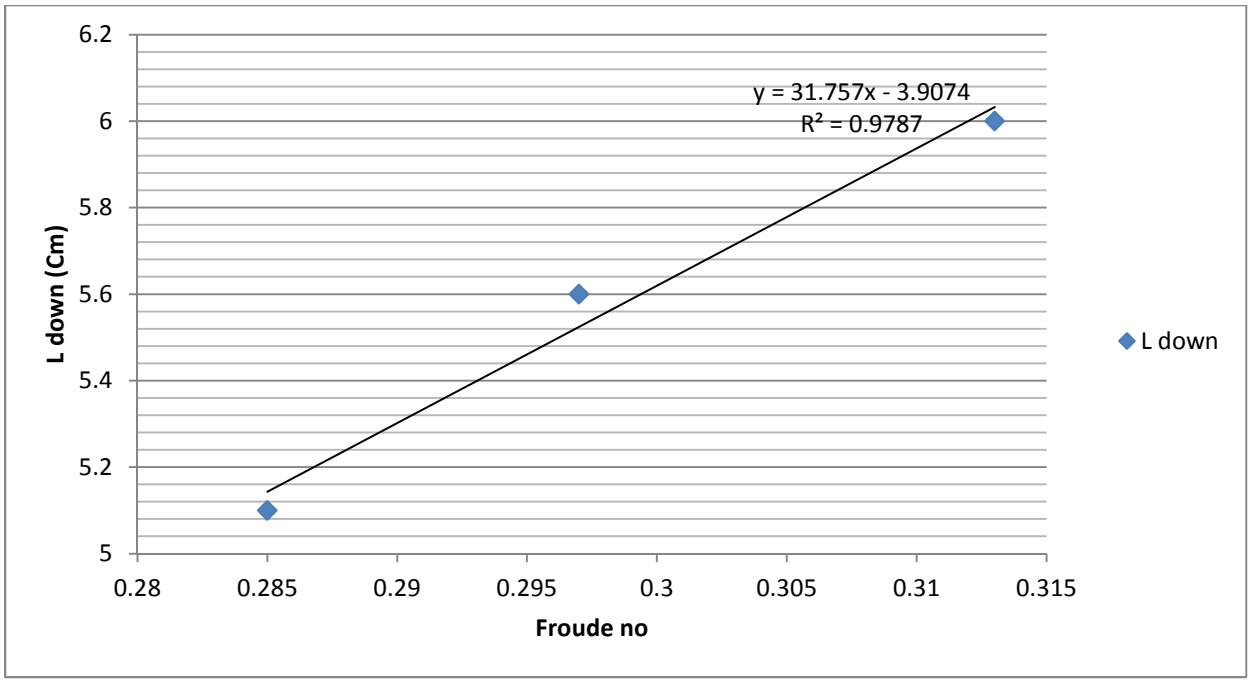
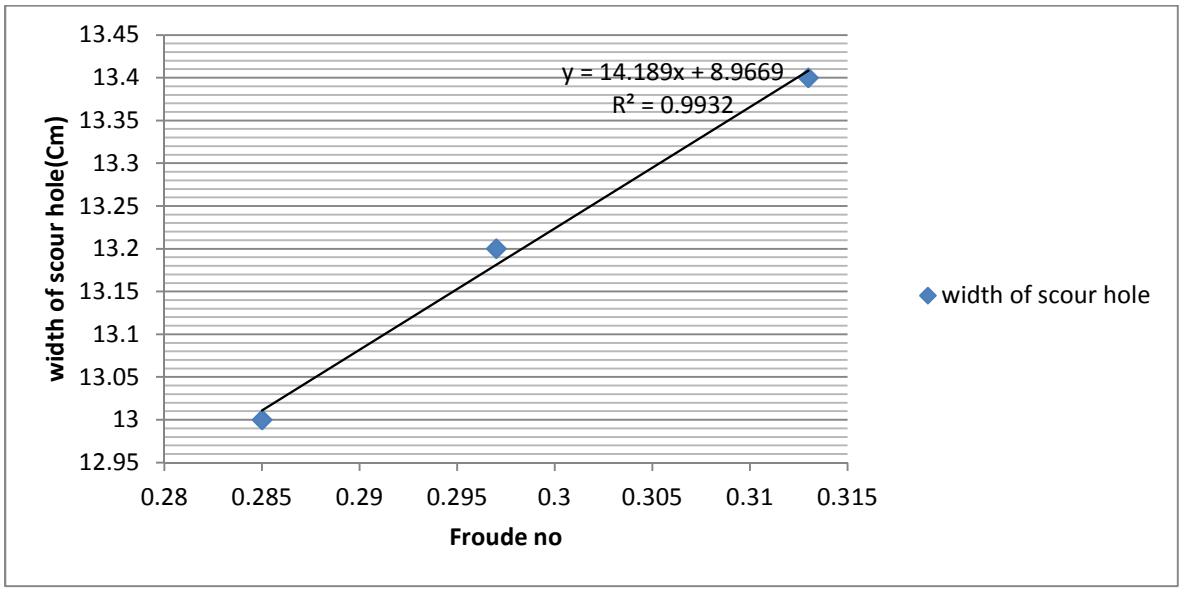


Equation: y = 31.757x - 3.9074



Equation: y = 14.189x + 8.9669

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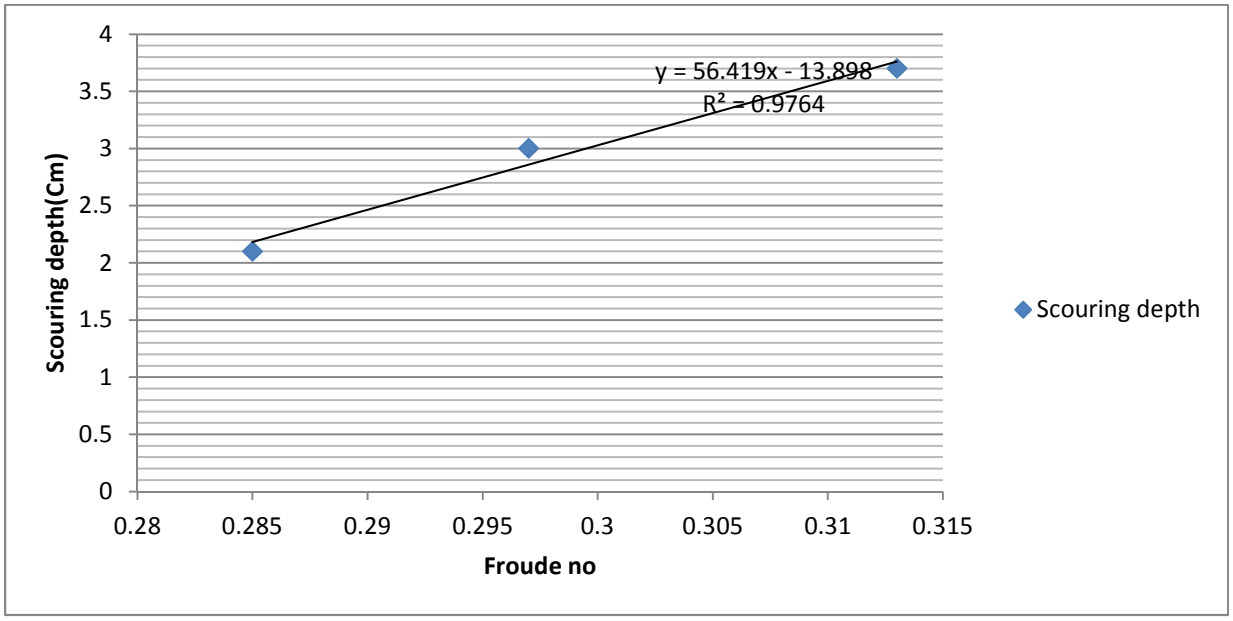
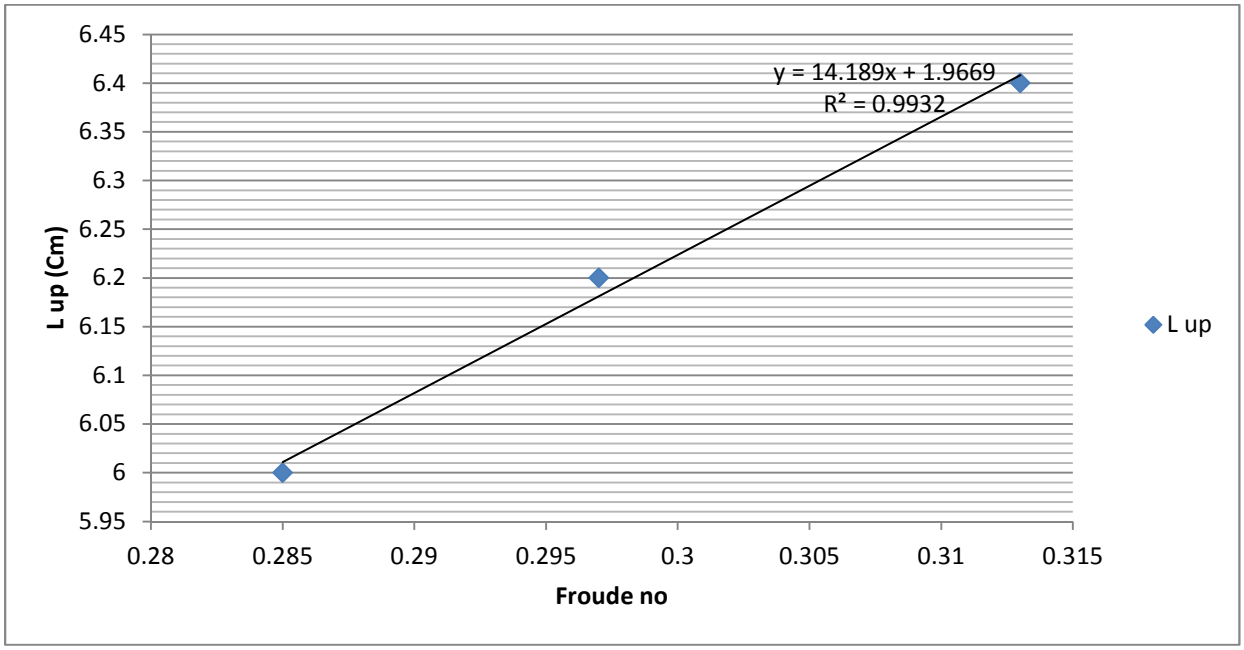
Case 7. Scouring around circular pier with Square collar of area 2.0Dx2.0D (D is diameter of circular pier)



Equation: y = 56.419x - 13.898



Equation: y = 14.189x + 1.9669

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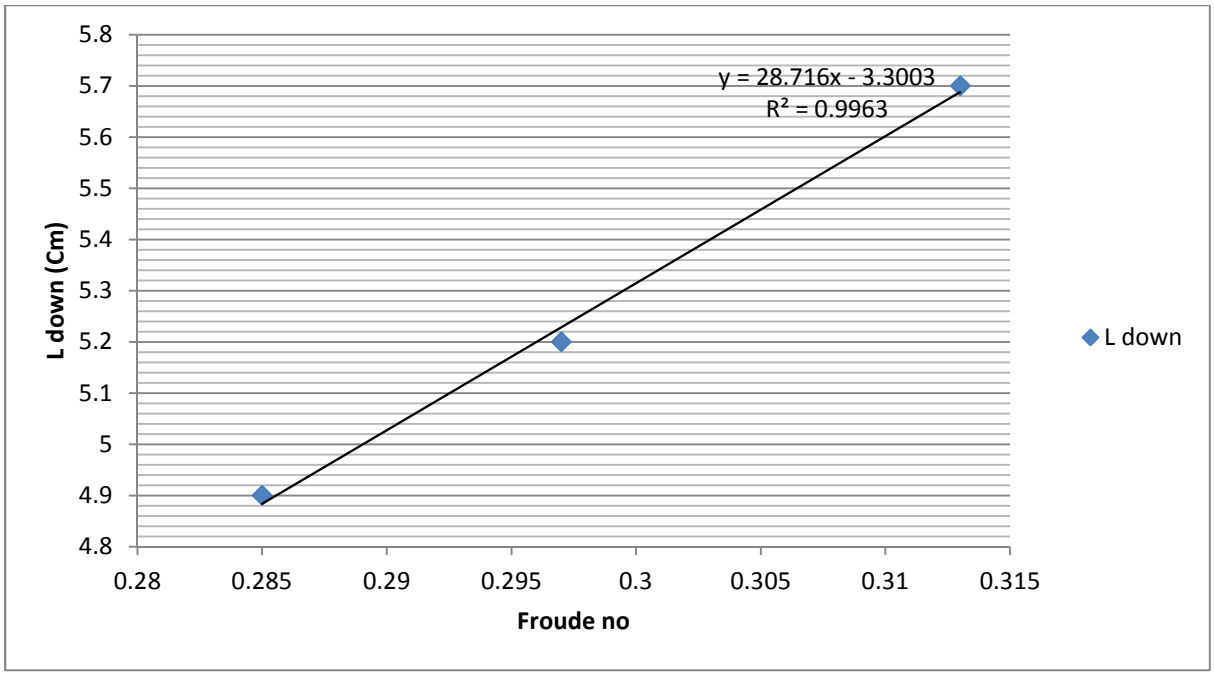
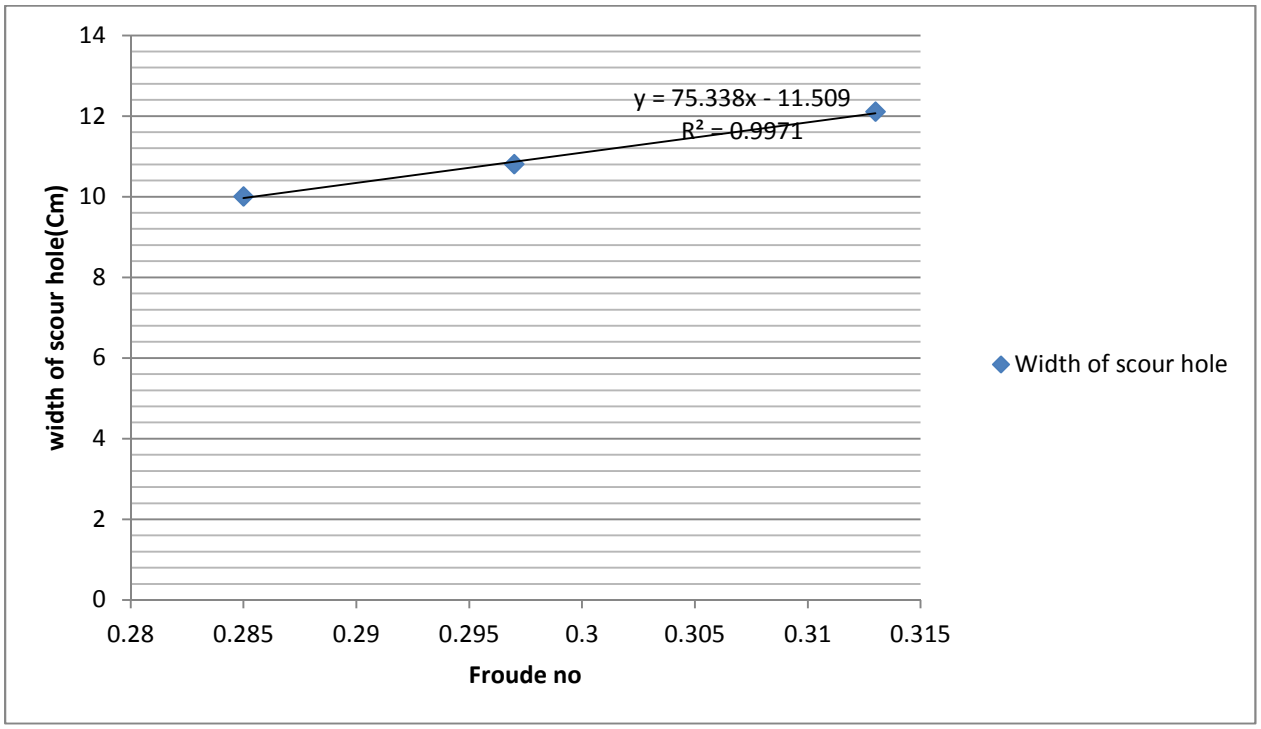


Equation: y = 28.716x - 3.3003



Equation: y = 75.338x - 11.509

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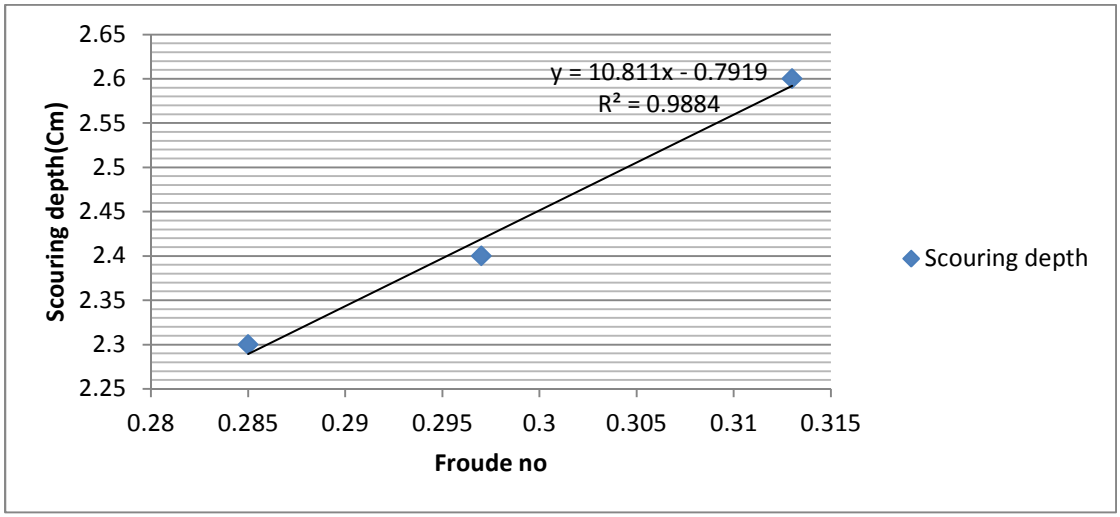
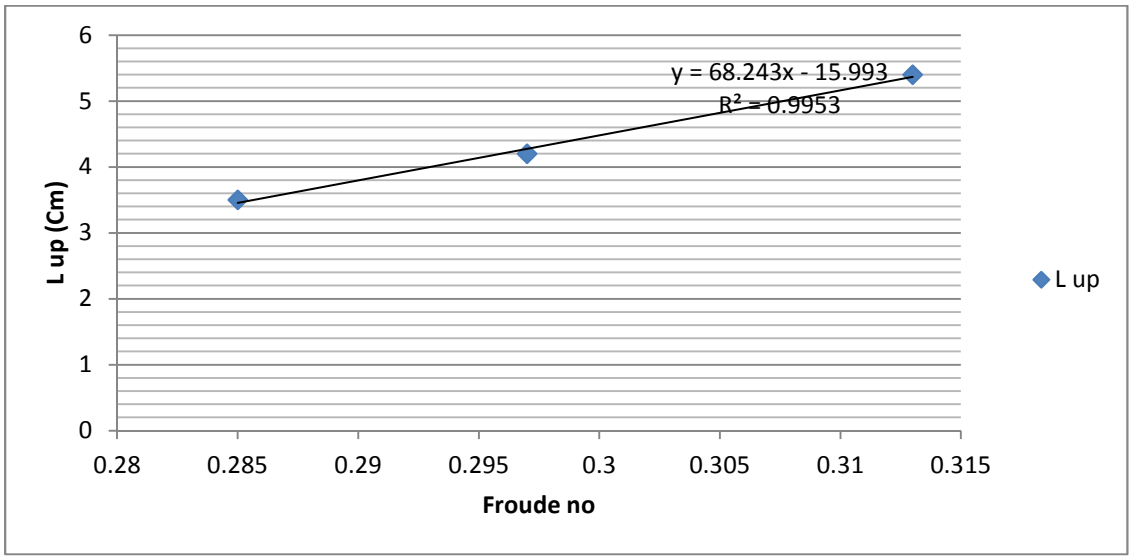
Case 8. Scouring around circular pier with Square collar of area 2.5Dx2.5D (D is diameter of circular pier)



Equation: y = 10.811x - 0.7919



Equation: y = 68.243x - 15.993

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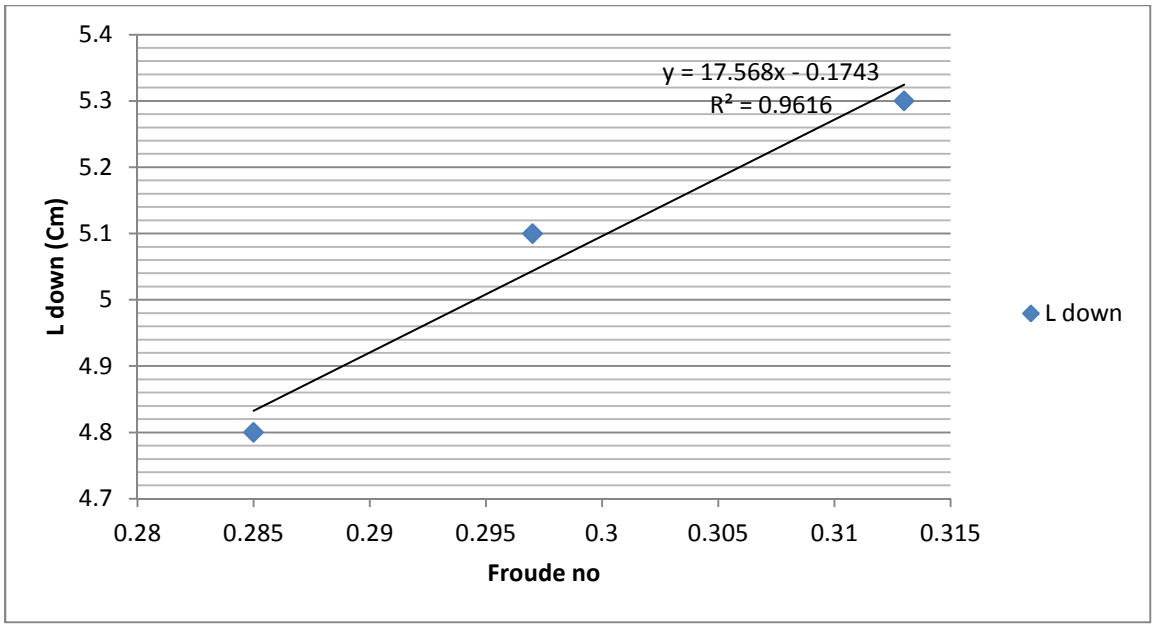
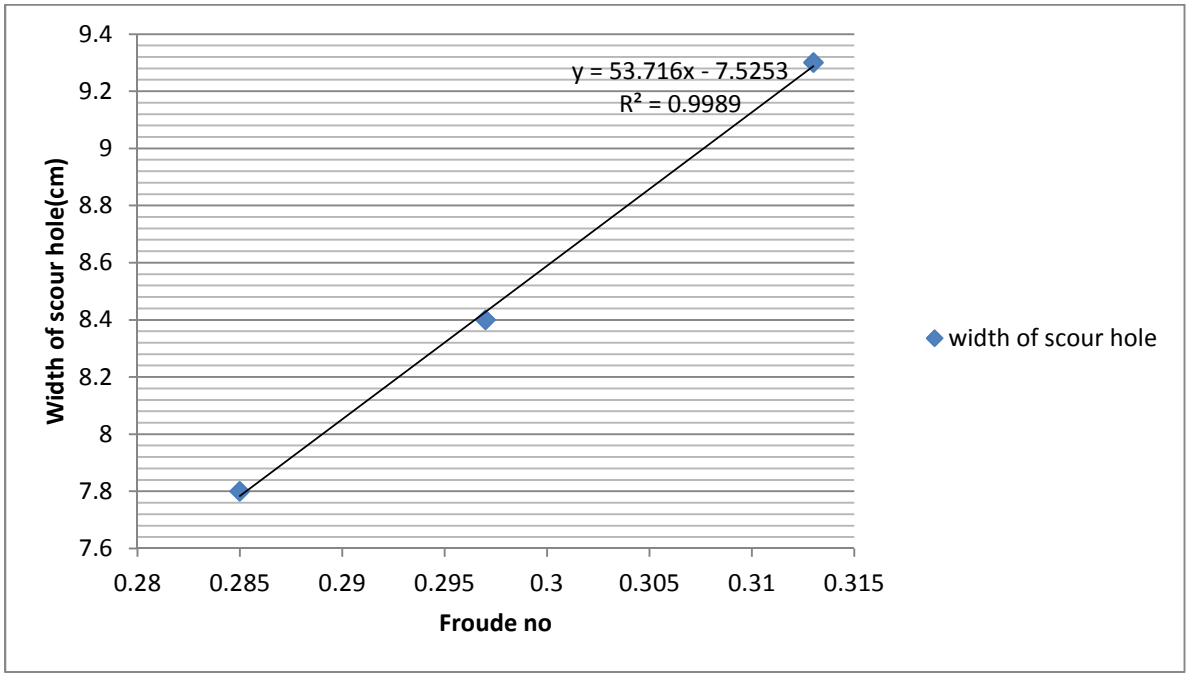


Equation: y = 17.568x - 0.1743



Equation: y = 53.716x - 7.5253

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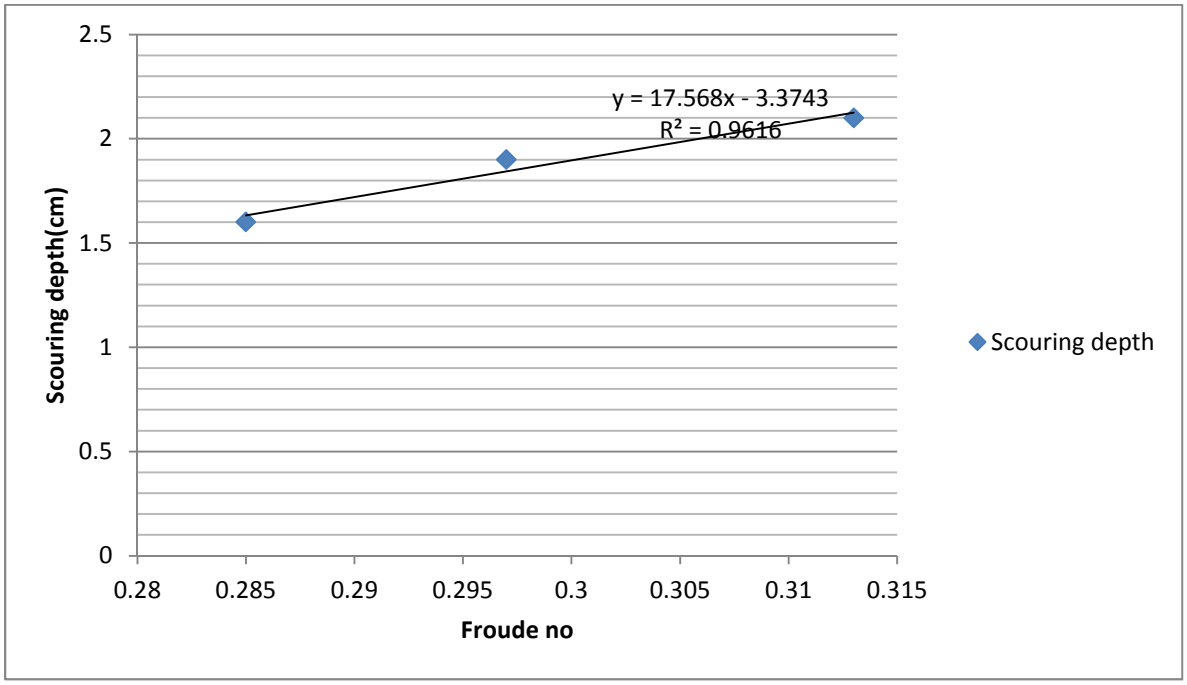
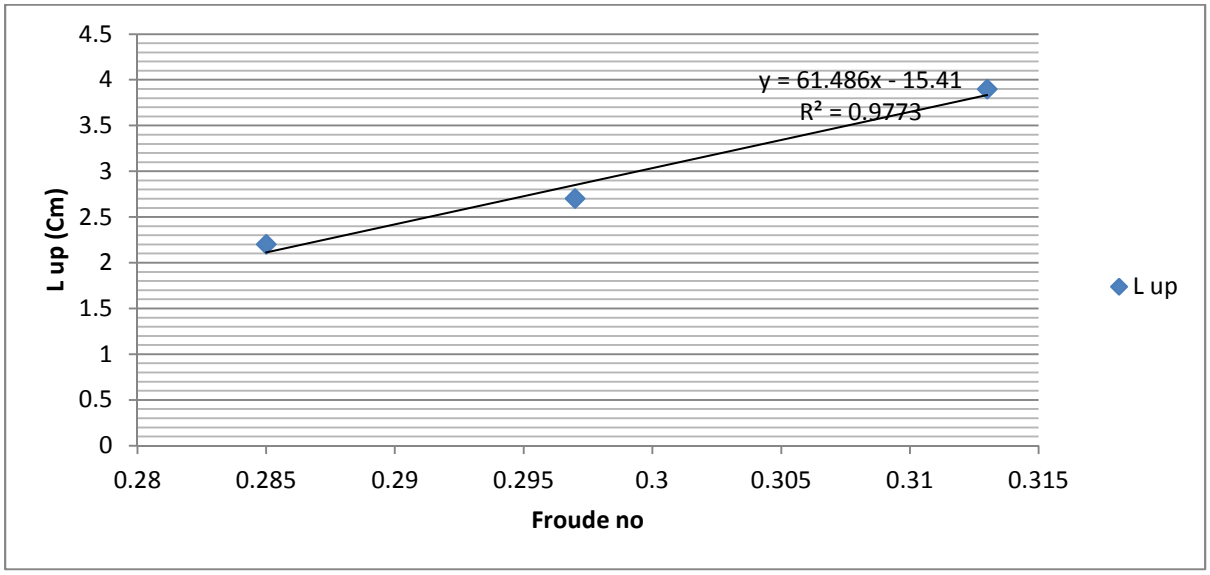
Case 9. Scouring around circular pier with Square collar of area 3.0Dx3.0D (D is diameter of circular pier)



Equation: y = 17.568x - 3.3743



Equation: y = 61.486x - 15.41

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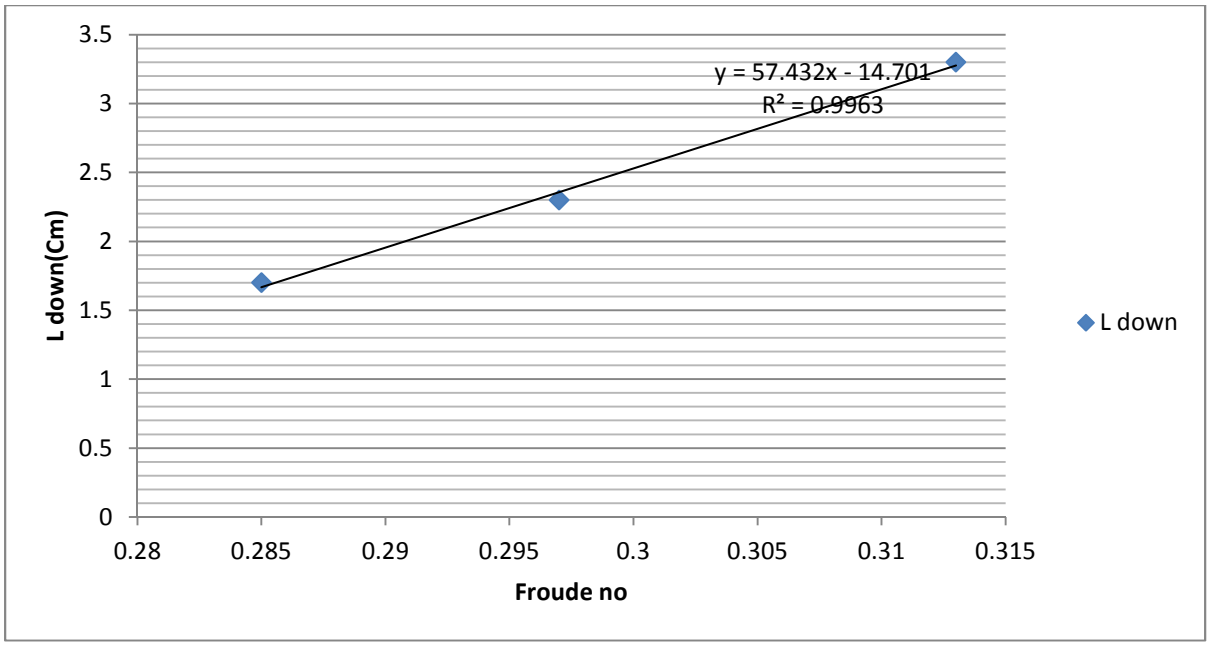
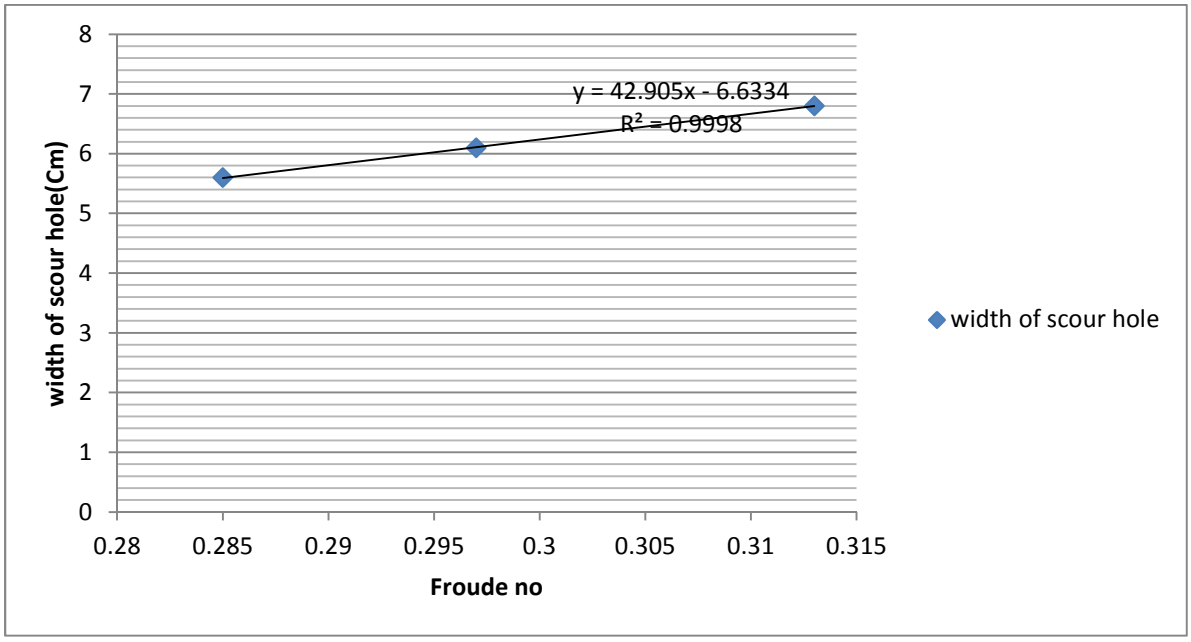


Equation: y = 57.432x - 14.701



Equation: y = 42.905x - 6.6334

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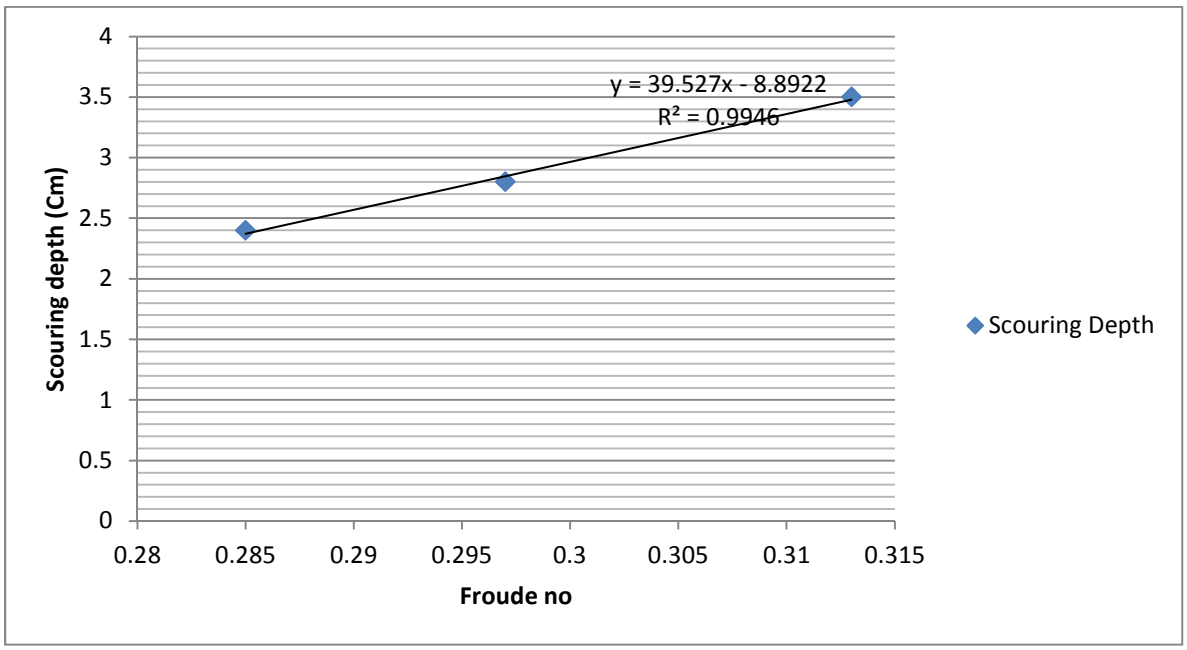
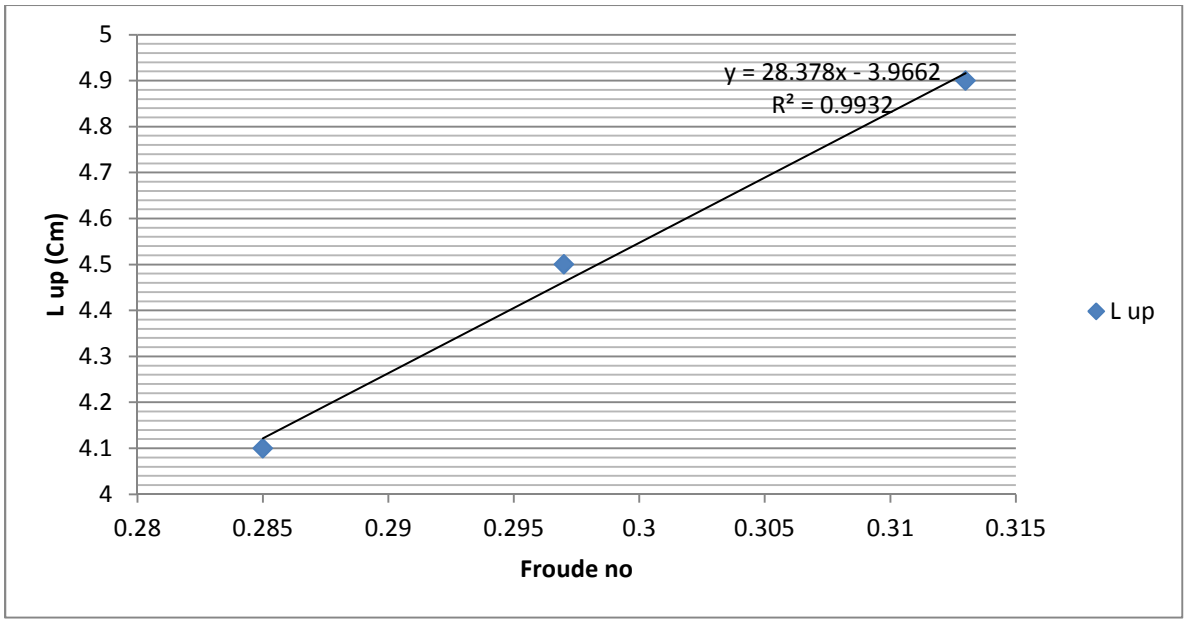
Case 10. Scouring around circular pier with vertical slot of dimension 5cmx1cm



Equation: y = 39.527x - 8.8922



Equation: y = 28.378x - 3.9662

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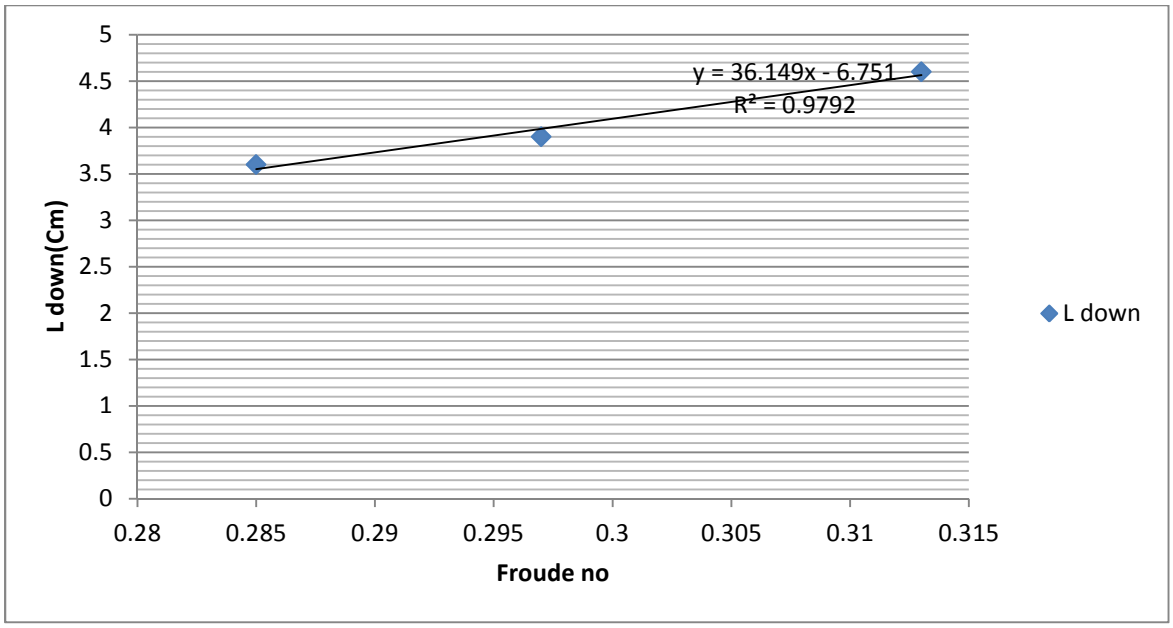
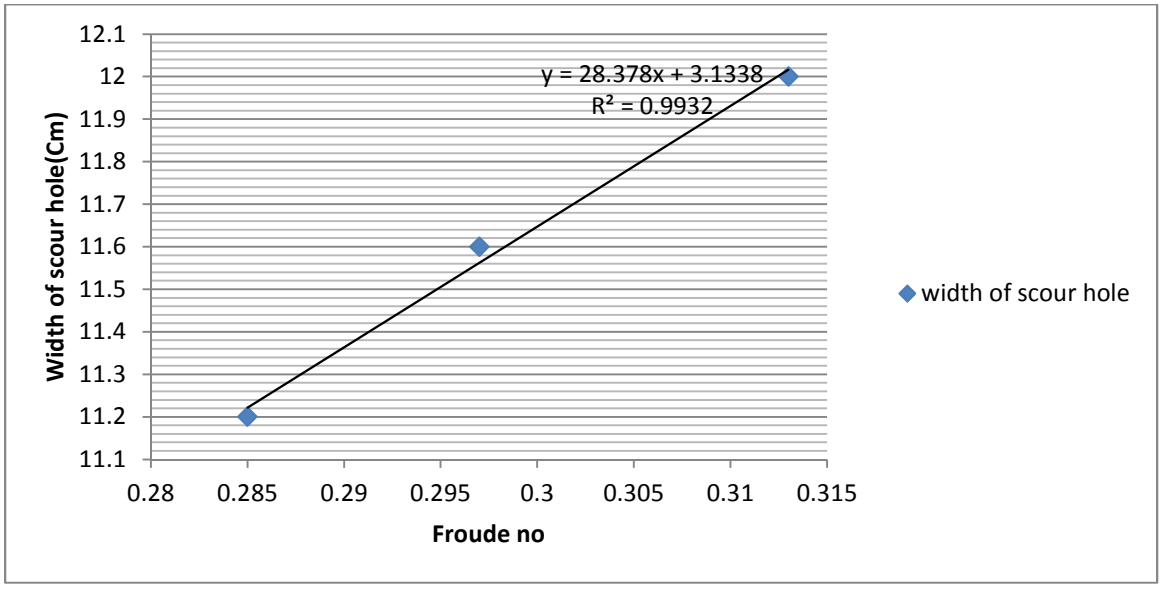


Equation: y = 36.149x - 6.751



Equation: y = 28.378x + 3.1338

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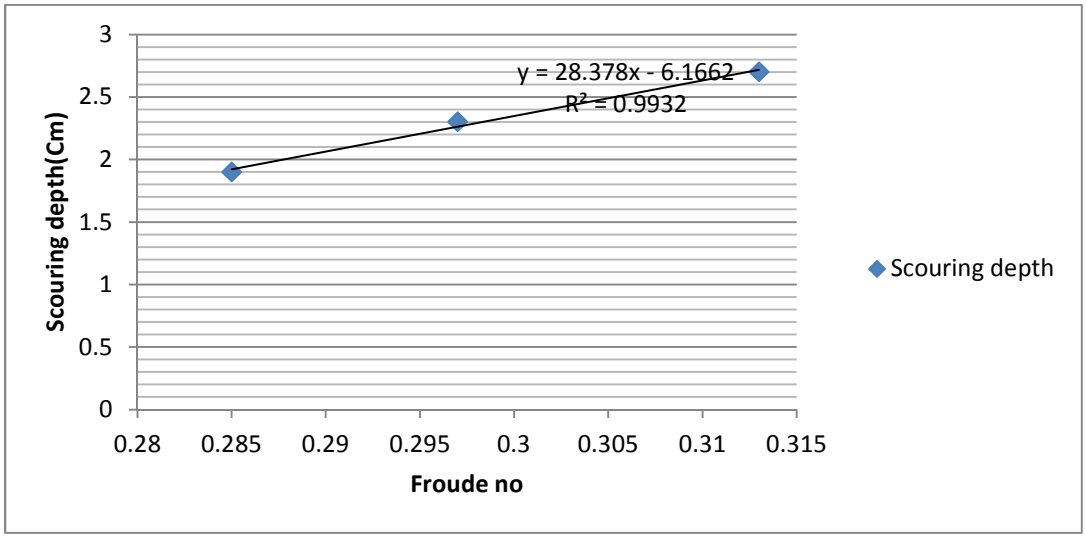
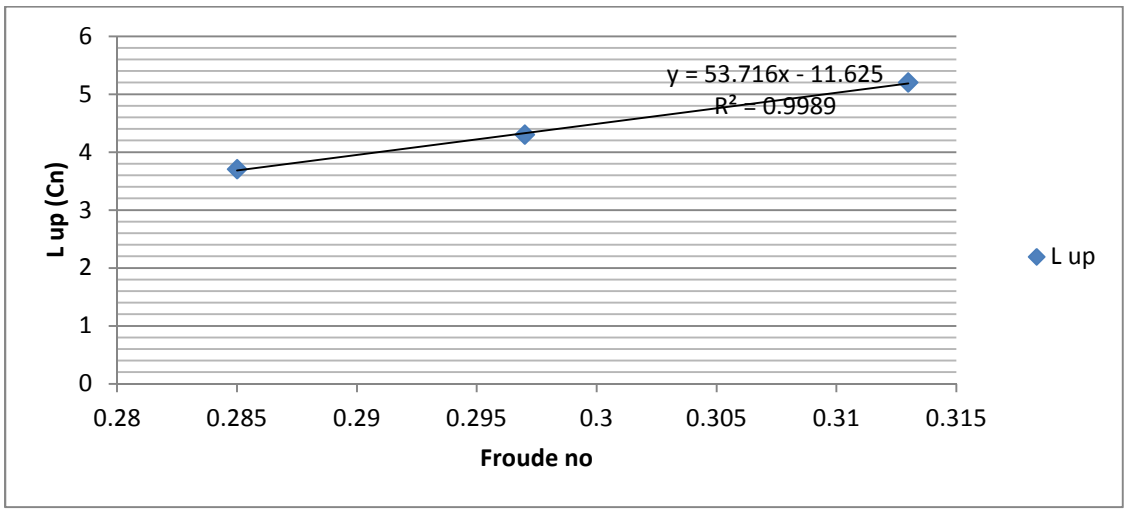
Case 11. Scouring around circular pier with vertical slot and circular collar of diameter 1.5D (D is diameter of circular pier)



Equation: y = 28.378x - 6.1662



Equation: y = 53.716x - 11.625

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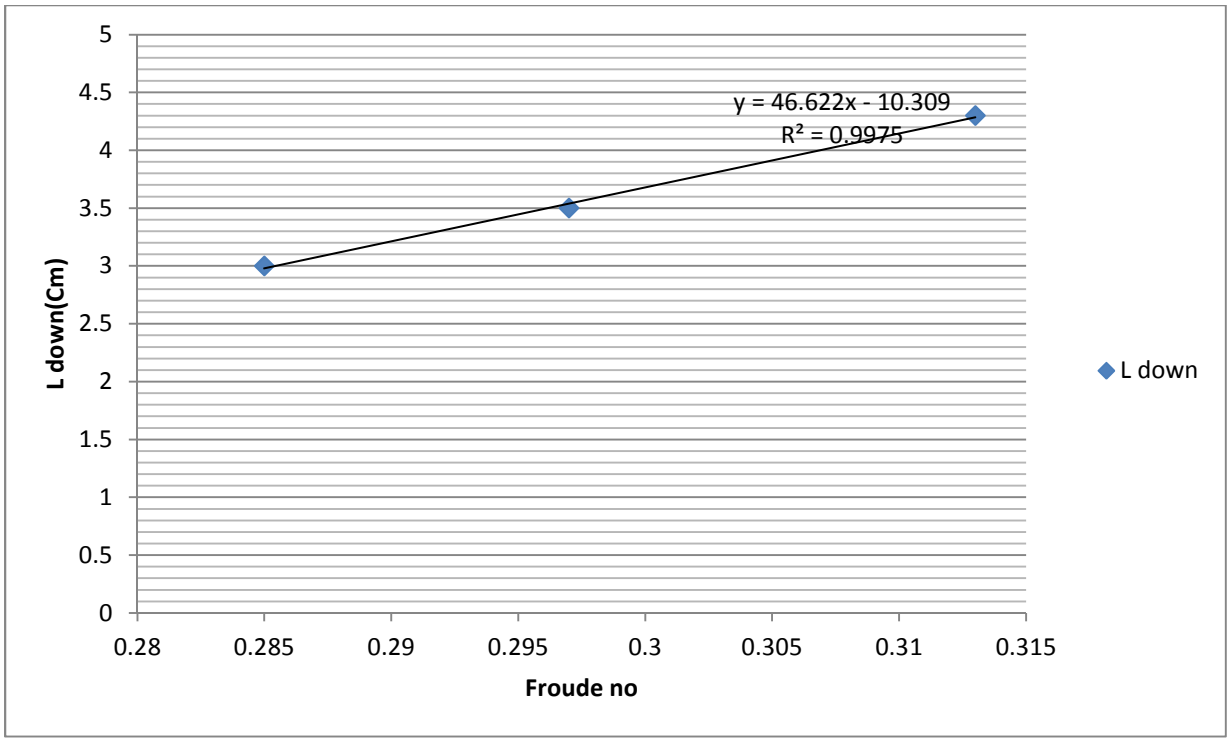
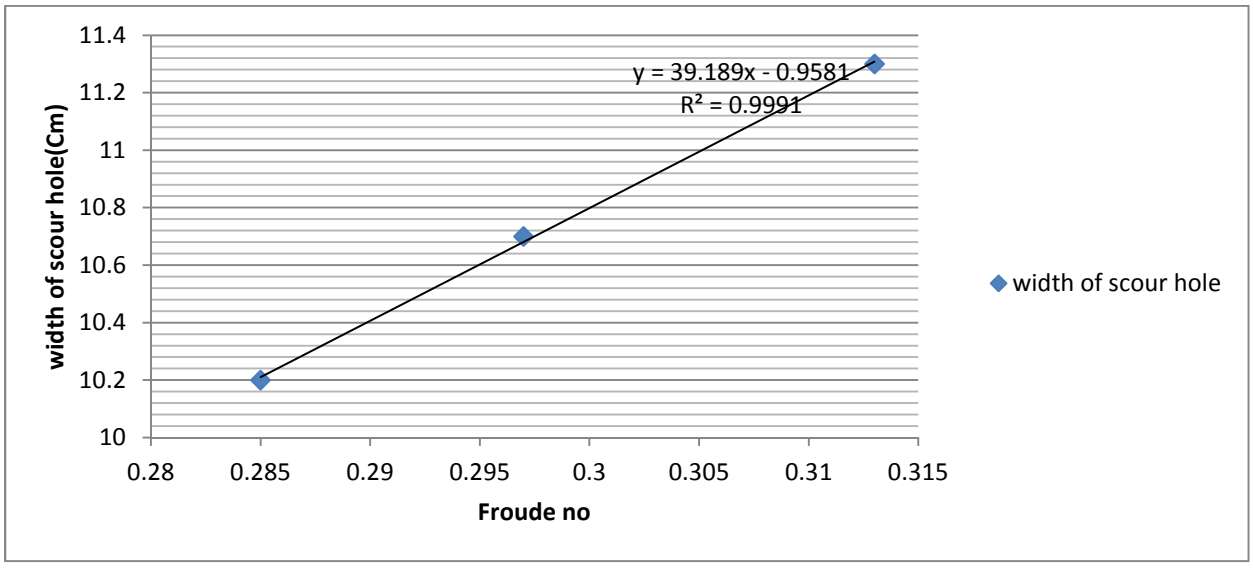


Equation: y = 46.622x - 10.309



Equation: y = 39.189x - 0.9581

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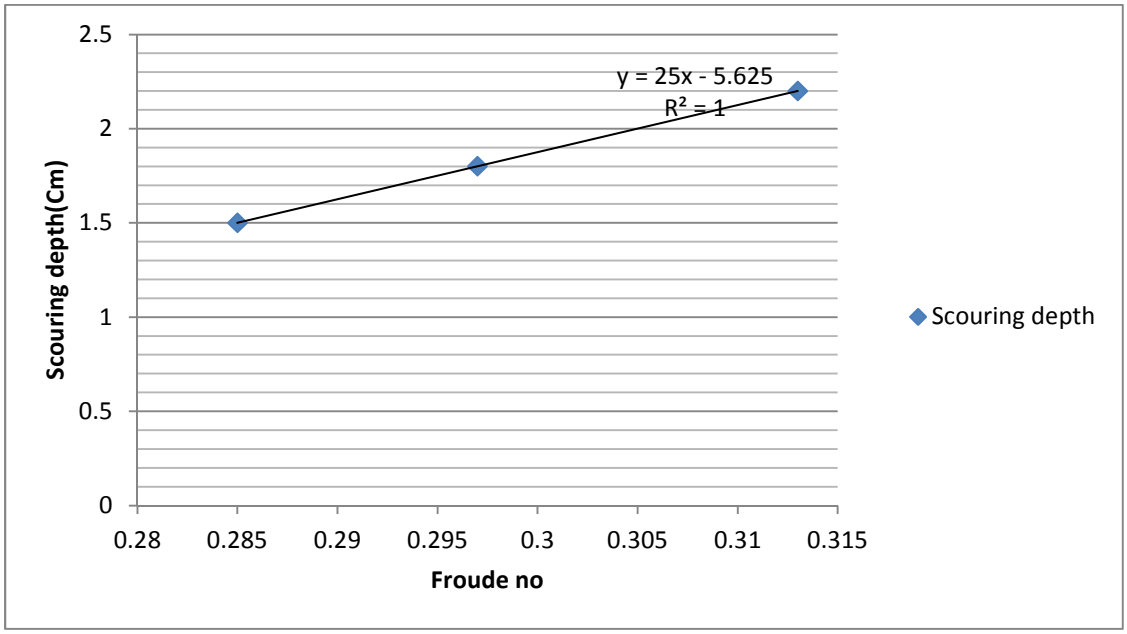
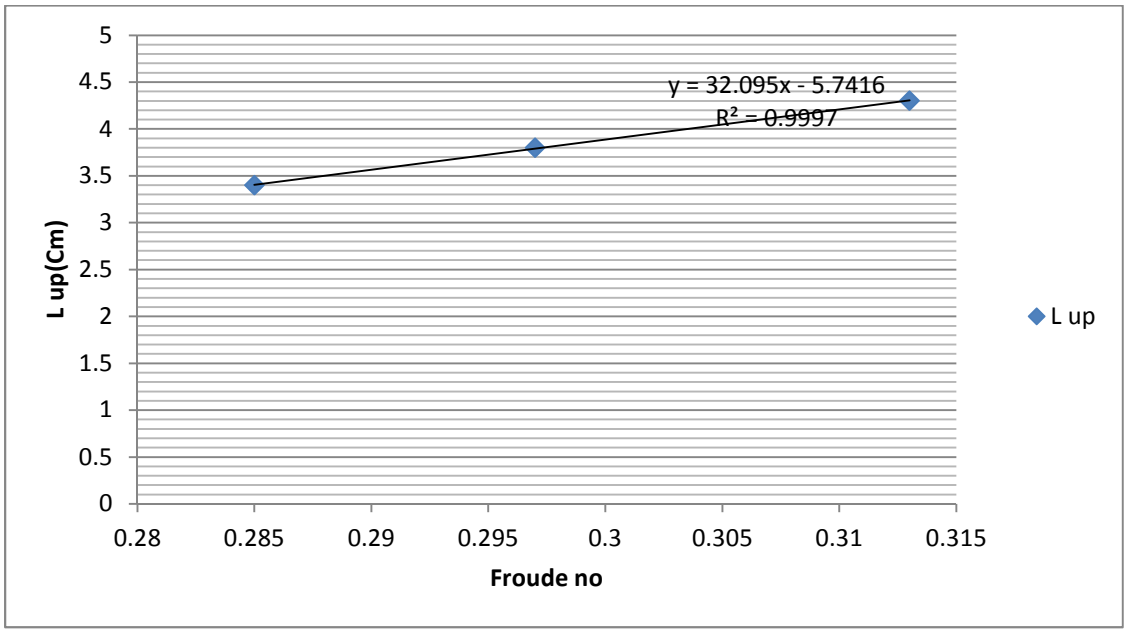
Case 12. Scouring around circular pier with vertical slot and circular collar of diameter 2.0D (D is diameter of circular pier)



Equation: y = 25x - 5.625



Equation: y = 32.095x - 5.7416

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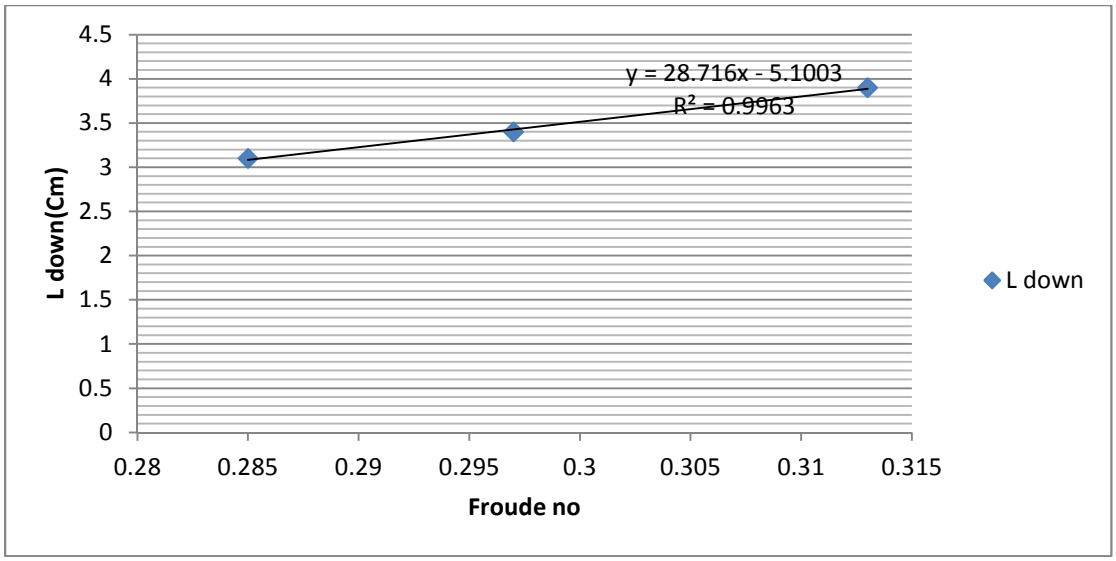
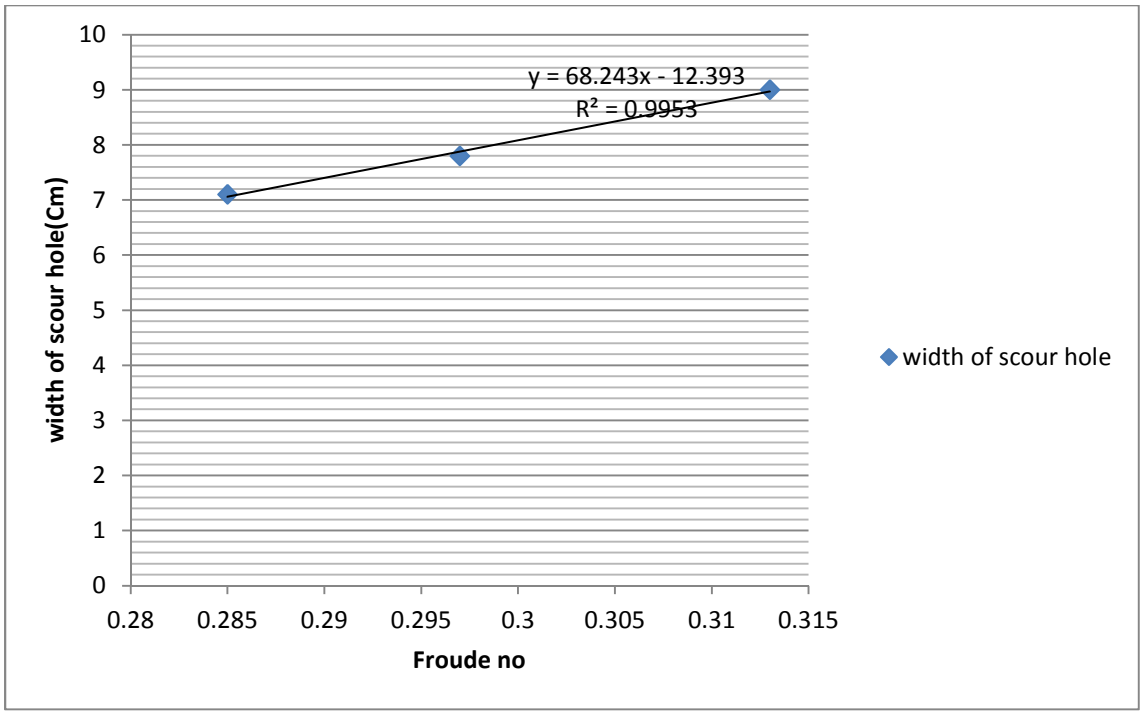


Equation: y = 28.716x - 5.1003



Equation: y = 68.243x - 12.393

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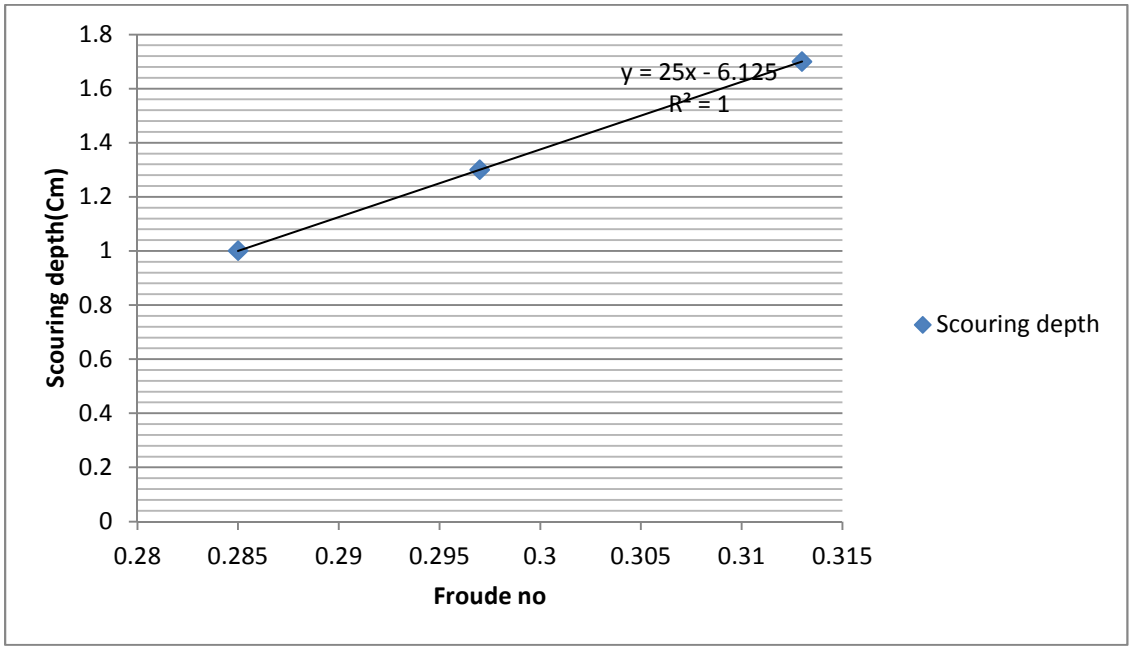
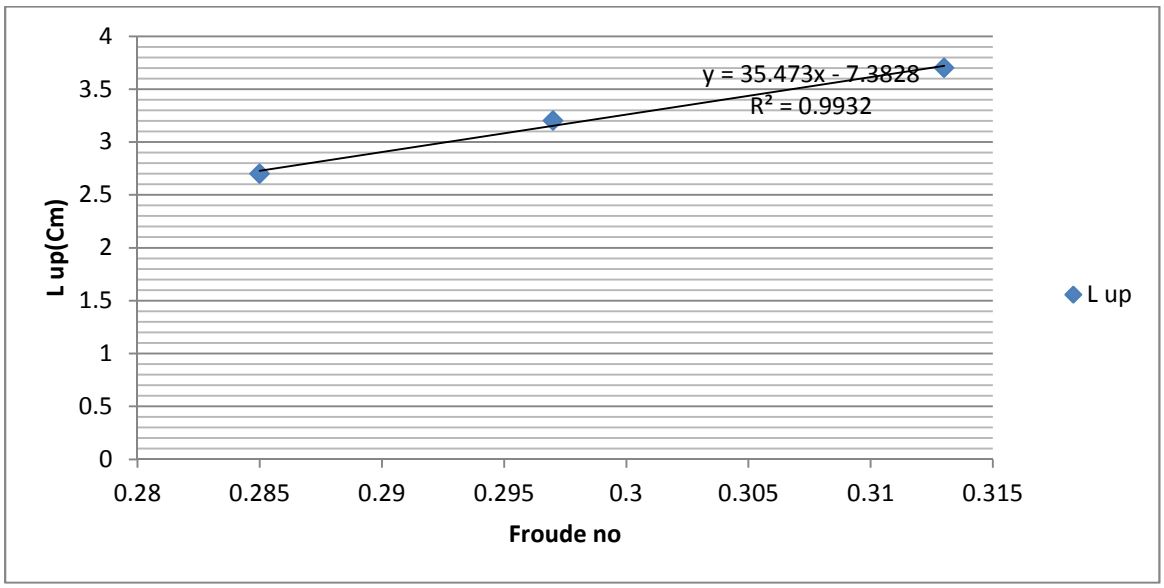
Case 13. Scouring around circular pier with vertical slot and circular pier of diameter 2.5D (D is diameter of circular pier)



Equation: y = 25x - 6.125



Equation: y = 35.473x - 7.3828

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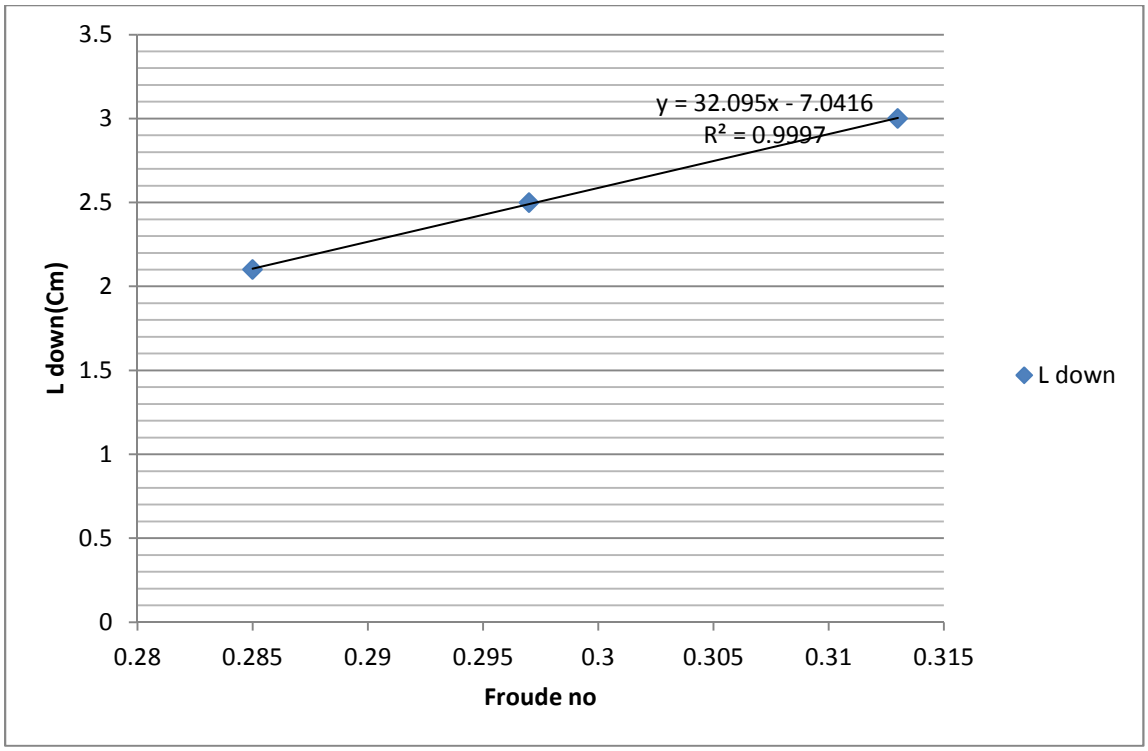
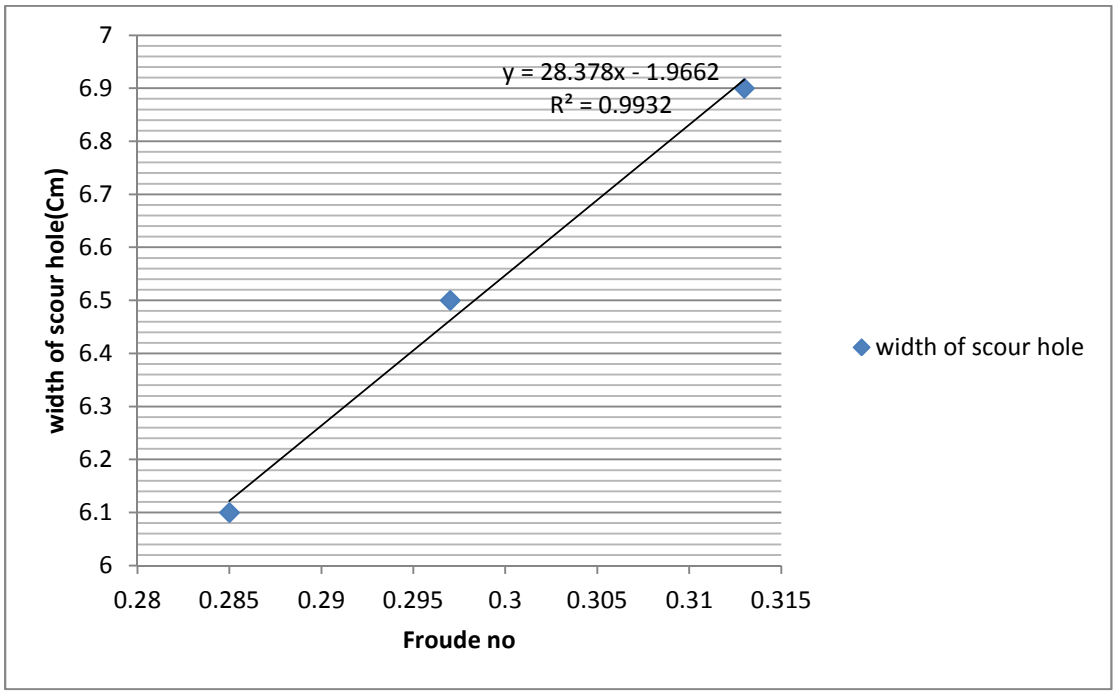


Equation: y = 32.095x - 7.0416



Equation: y = 28.378x - 1.9662

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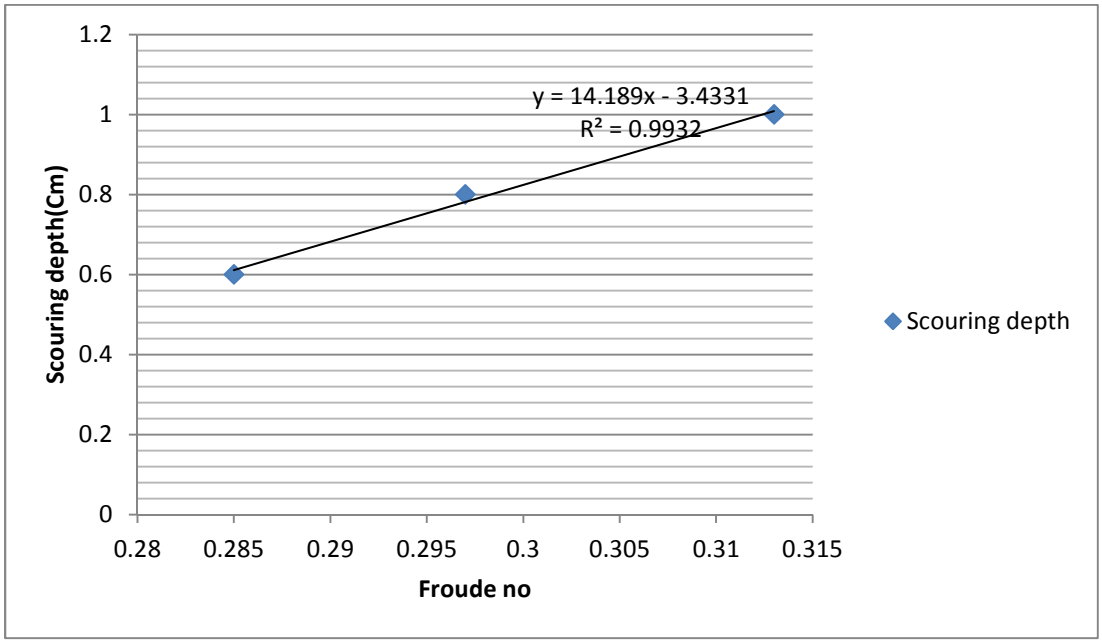
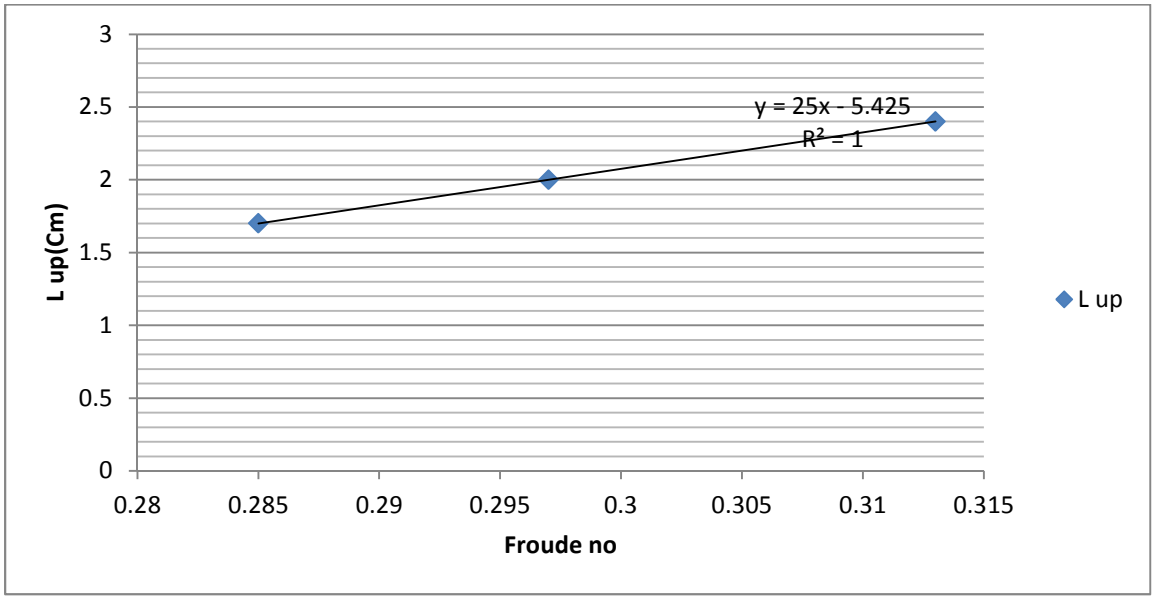
Case 14. Scouring around circular pier with vertical slot and circular collar of diameter 3.0D (D is diameter of circular pier)



Equation: y = 14.189x - 3.4331



Equation: y = 25x - 5.425

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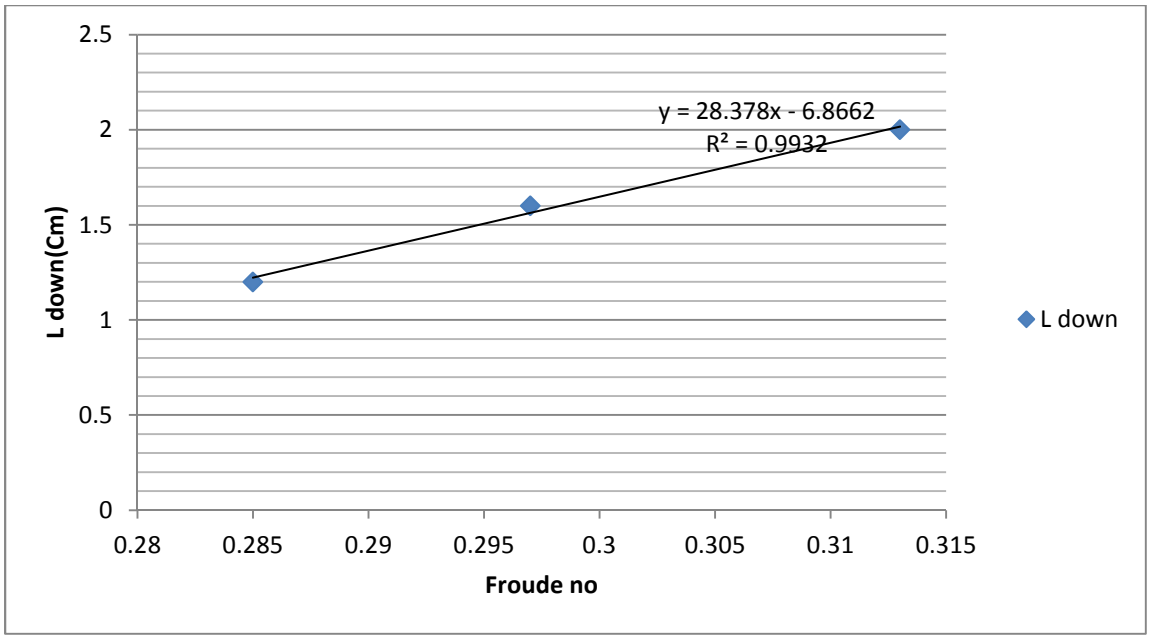
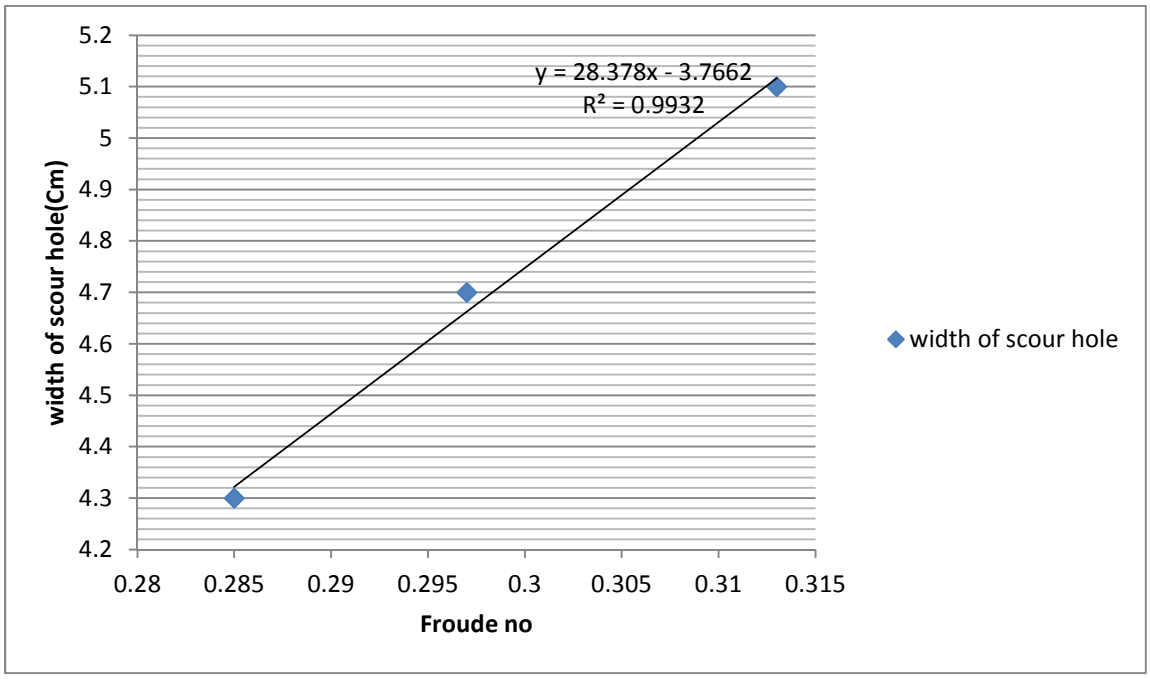


Equation: y = 28.378x - 6.8662



Equation: y = 28.378x - 3.7662

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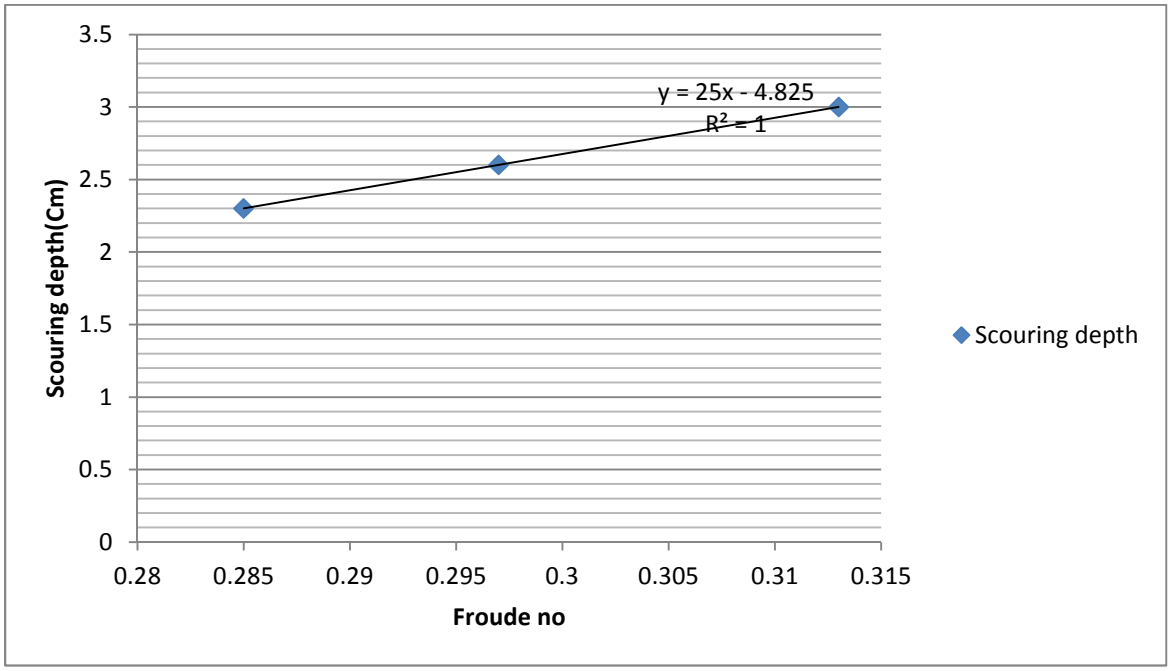
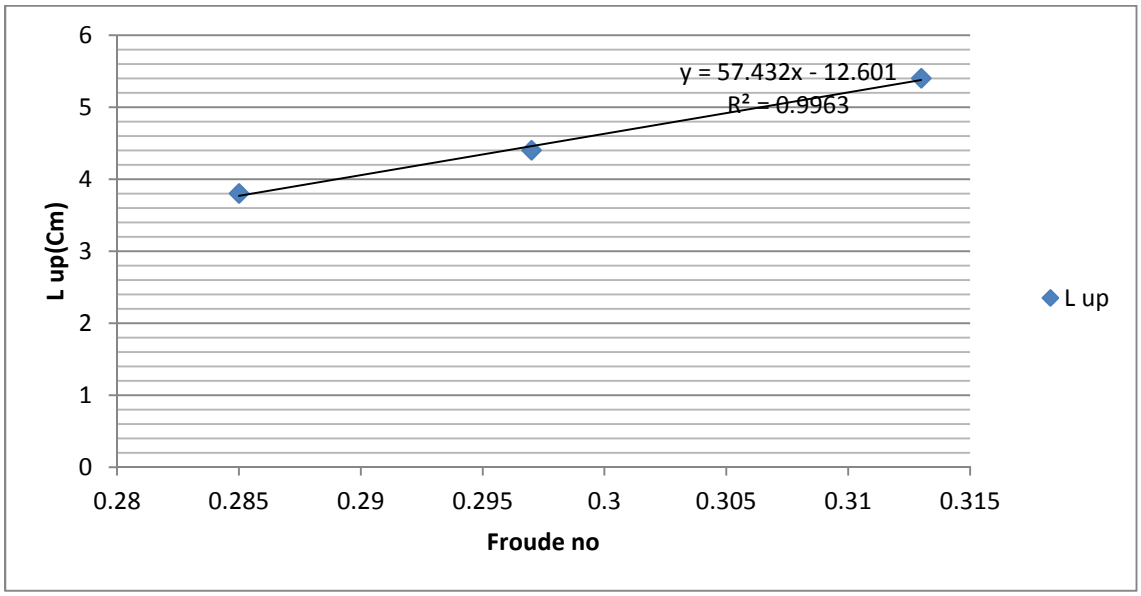
Case 15. Scouring around circular pier with vertical slot and Square collar of area 1.5Dx1.5D (D is diameter of circular pier)



Equation: y = 25x - 4.825



Equation: y = 57.432x - 12.601

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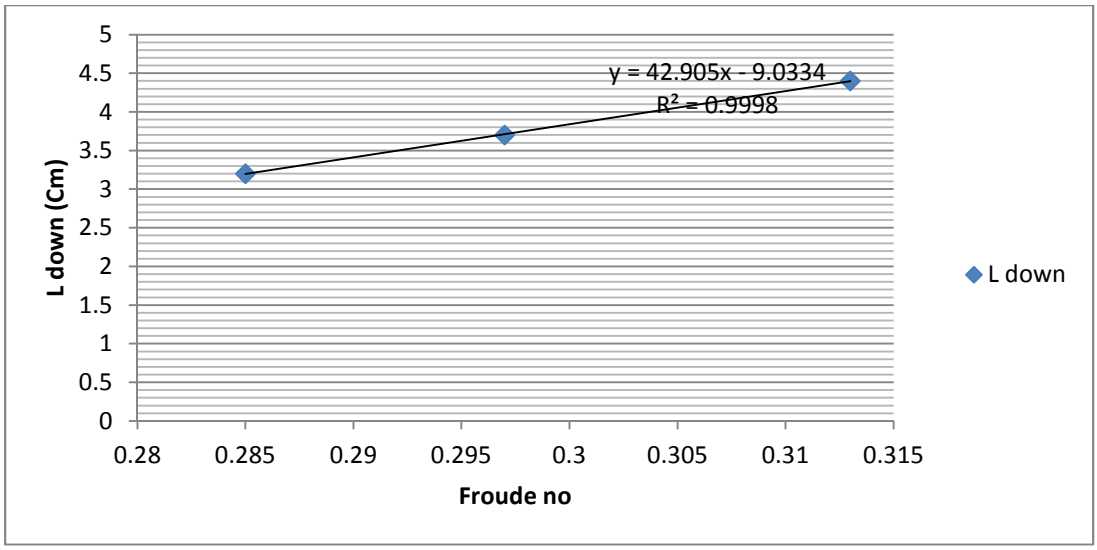
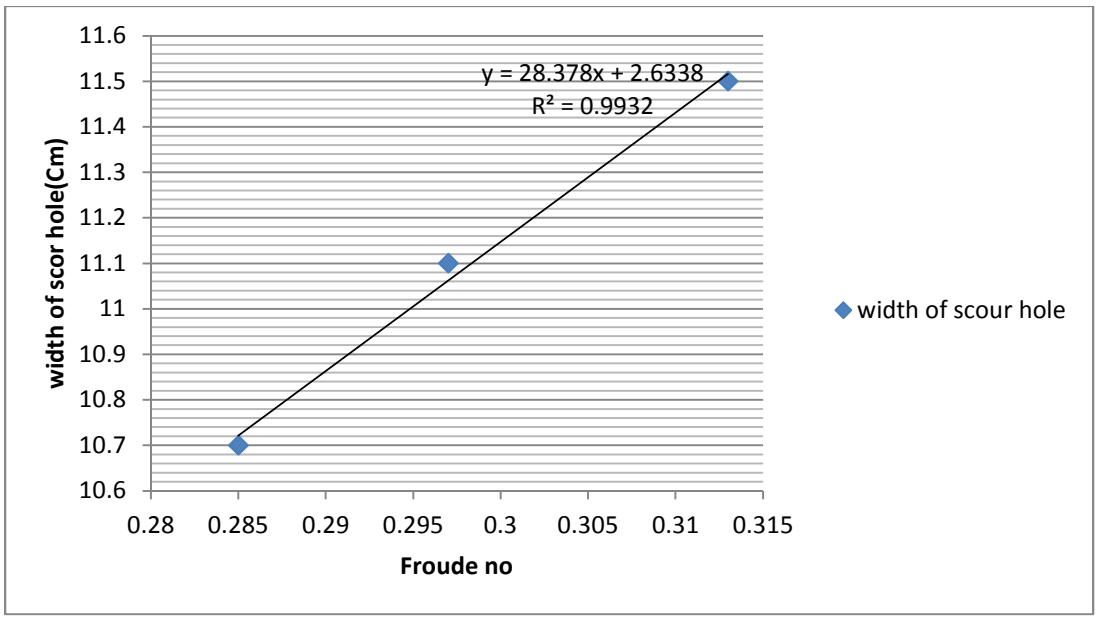


Equation: y = 42.905x - 9.0334



Equation: y = 28.378x + 2.6338

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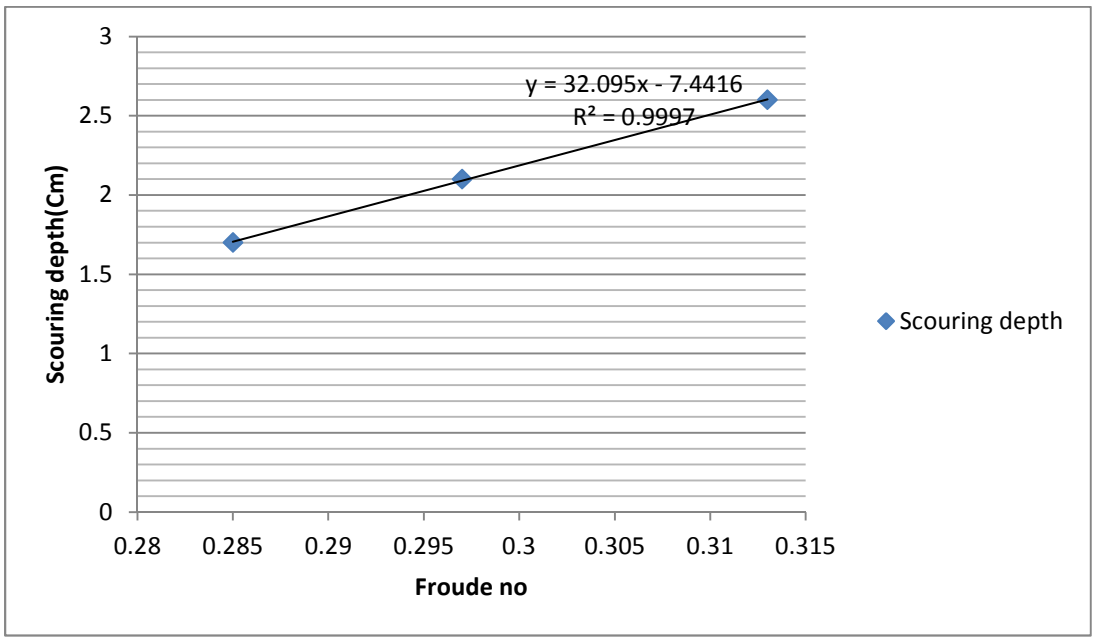
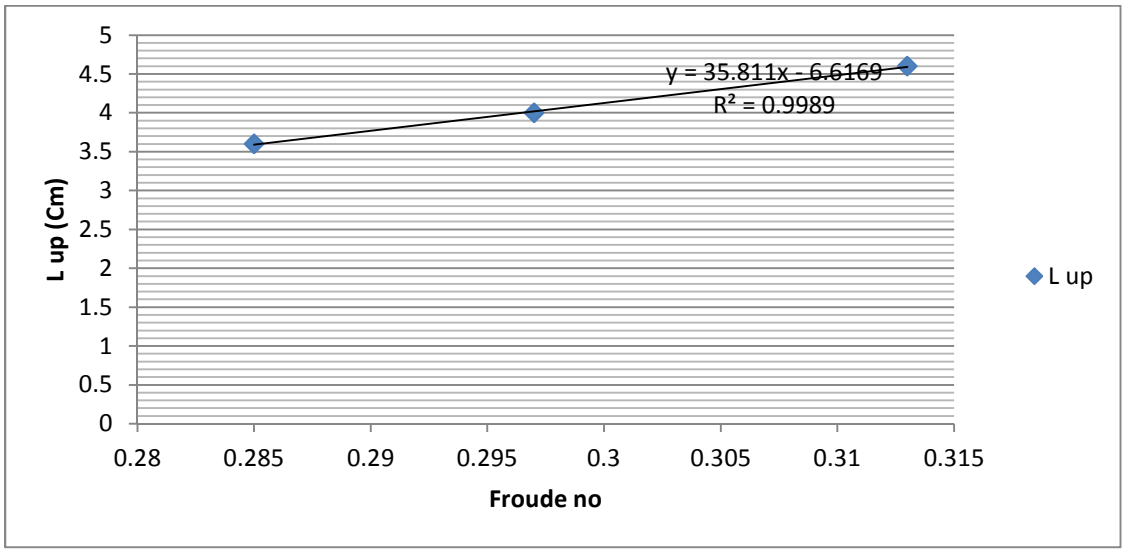
Case 16. Scouring around the circular pier with vertical slot and Square collar of area 2.0Dx2.0D (D is diameter of circular pier)



Equation: y = 32.095x - 7.4416



Equation: y = 35.811x - 6.6169

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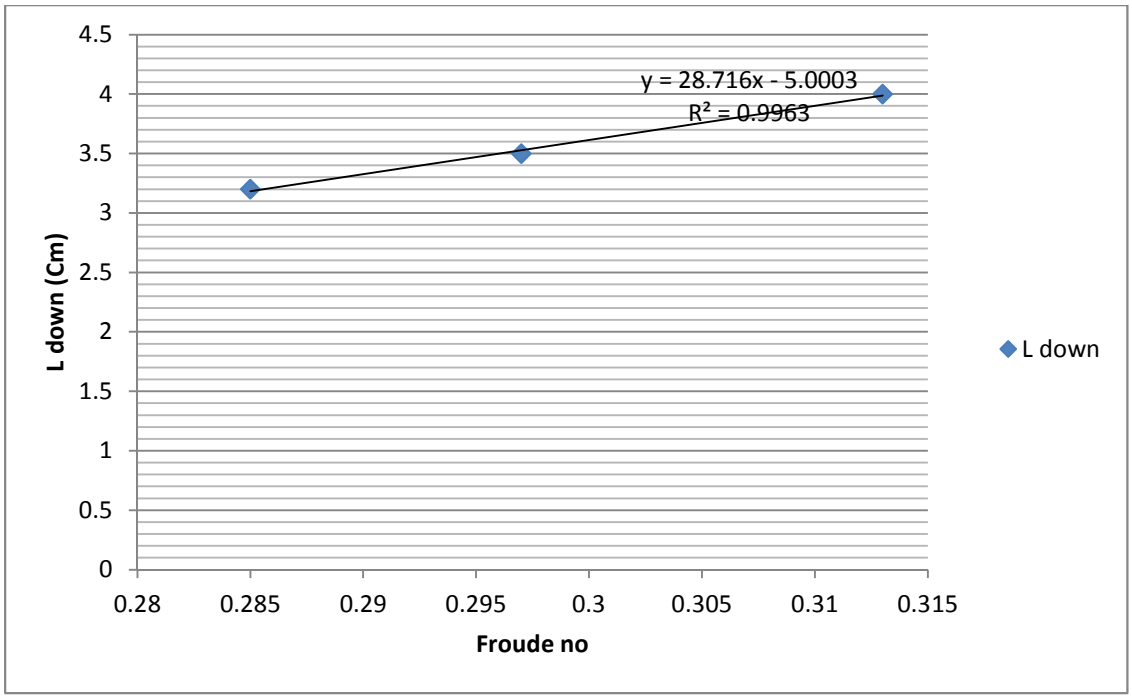
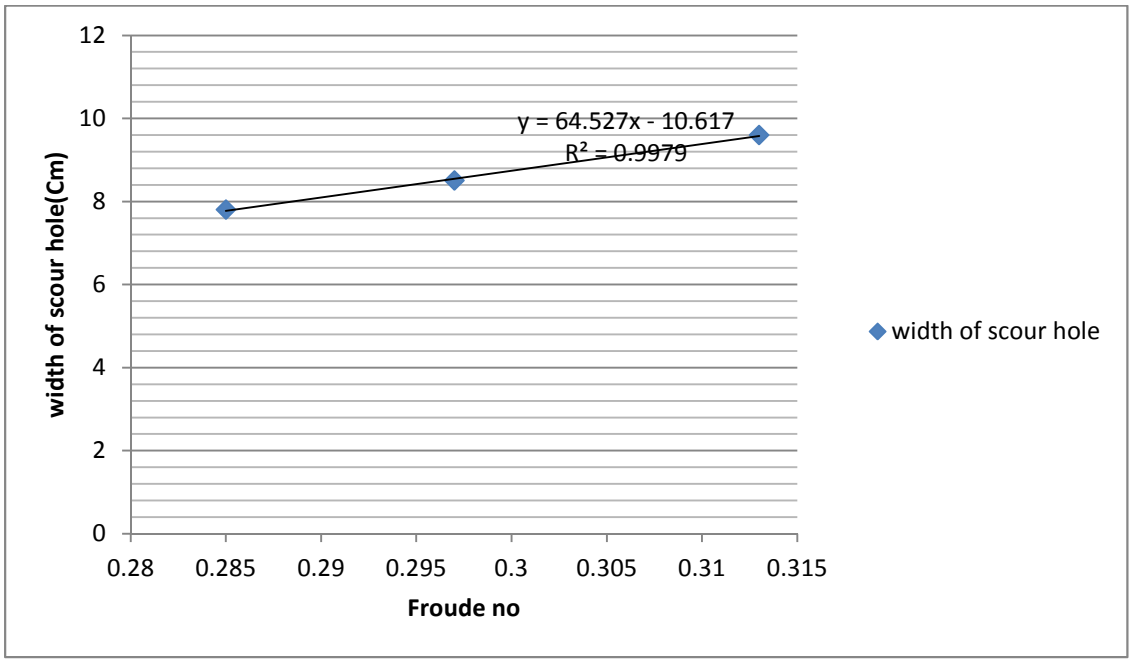


Equation: y = 28.716x - 5.0003



Equation: y = 64.527x - 10.617

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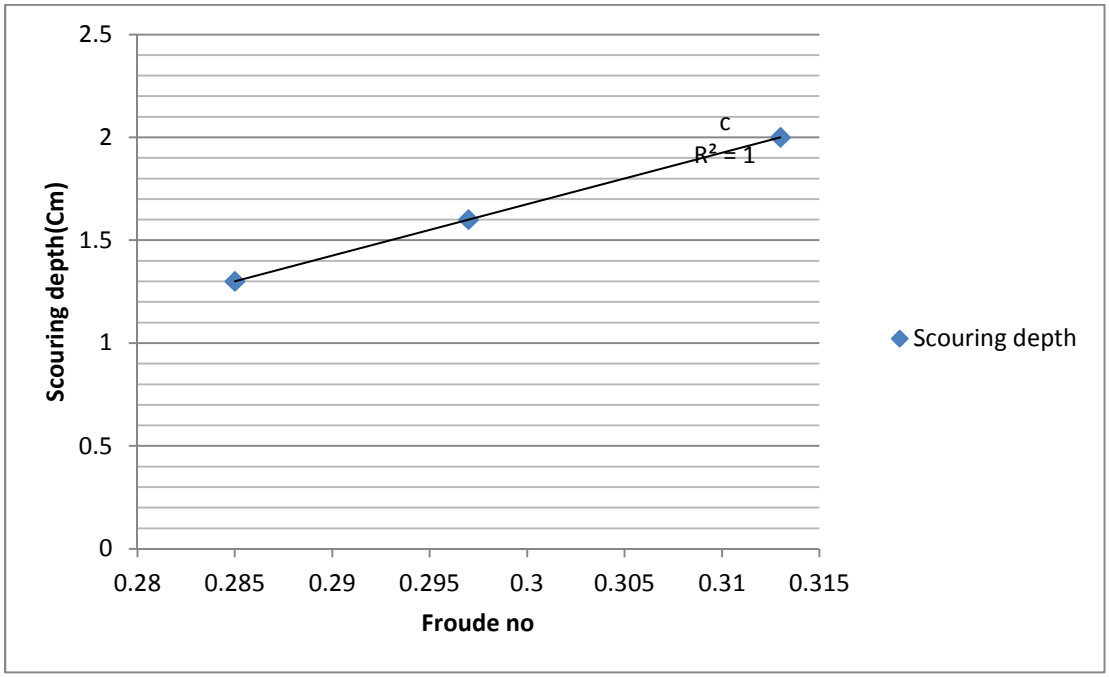
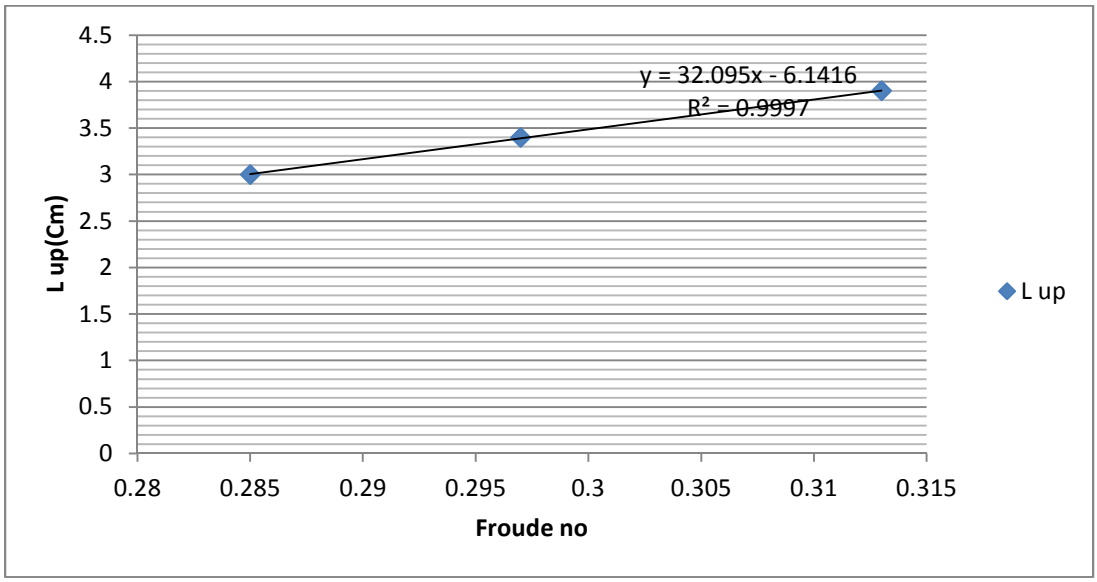
Case 17. Scouring around the circular pier with vertical slot and Square collar of area 2.5Dx2.5D (D is diameter of circular pier)



Equation: y = 64.527x - 10.617



Equation: y = 32.095x - 6.1416

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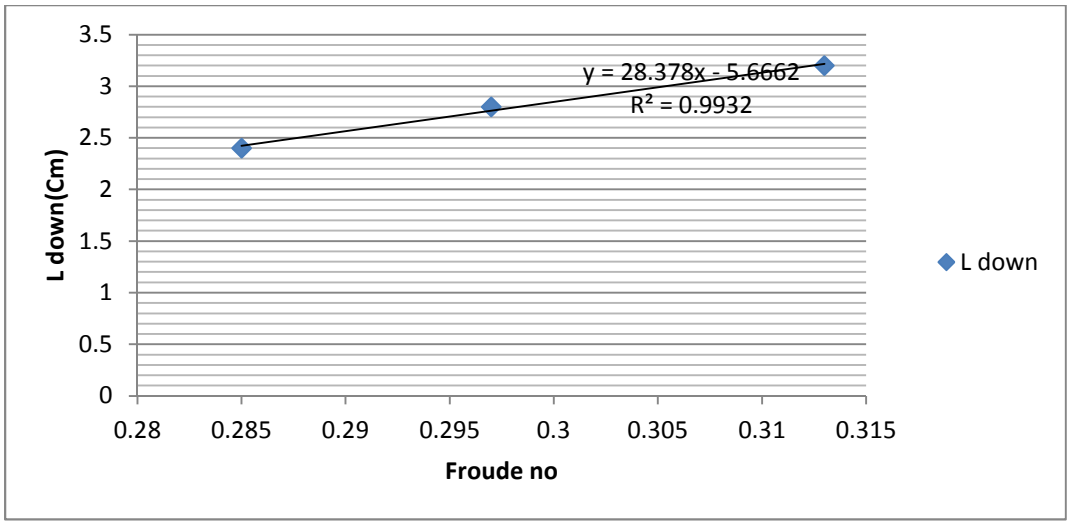
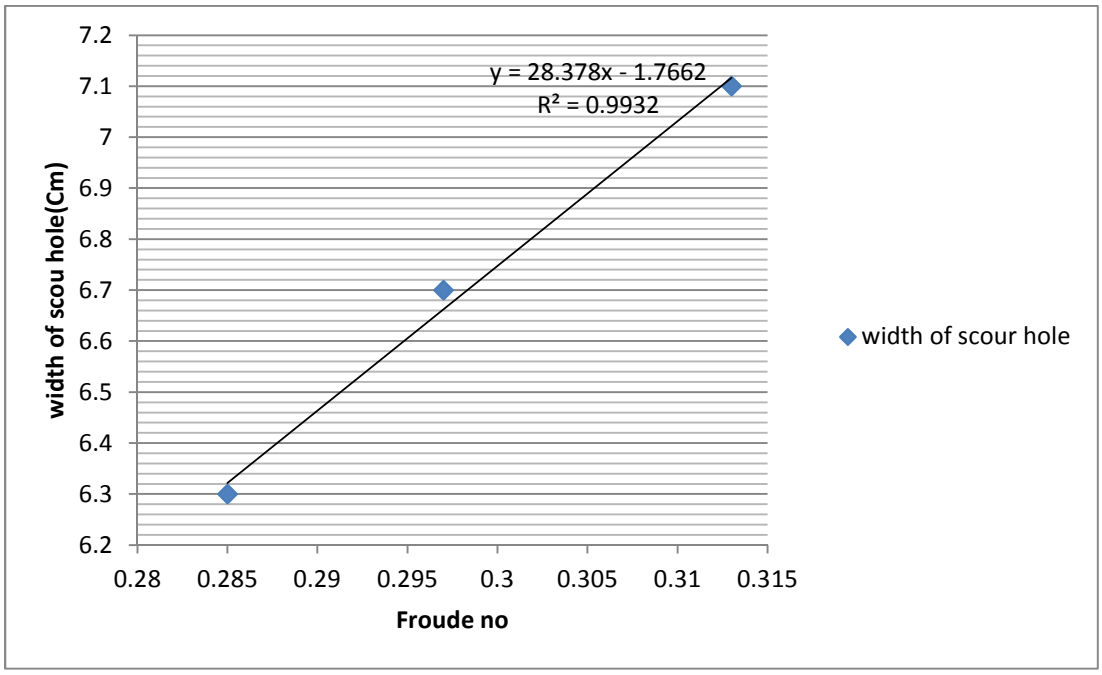


Equation: y = 28.378x - 5.6662



Equation: y = 28.378x - 1.7662

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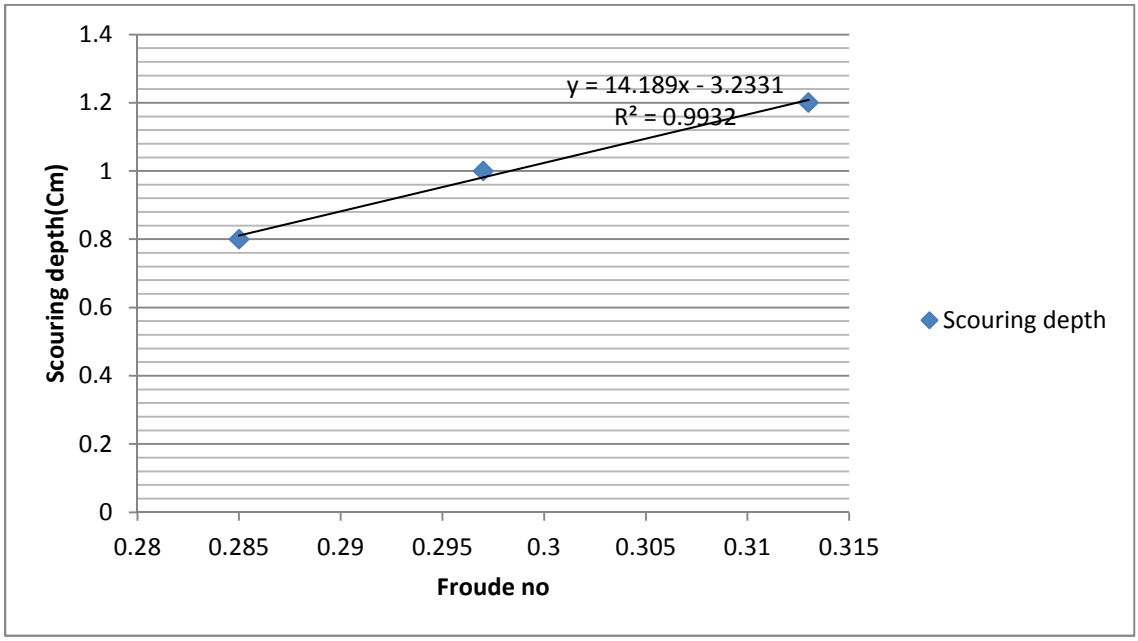
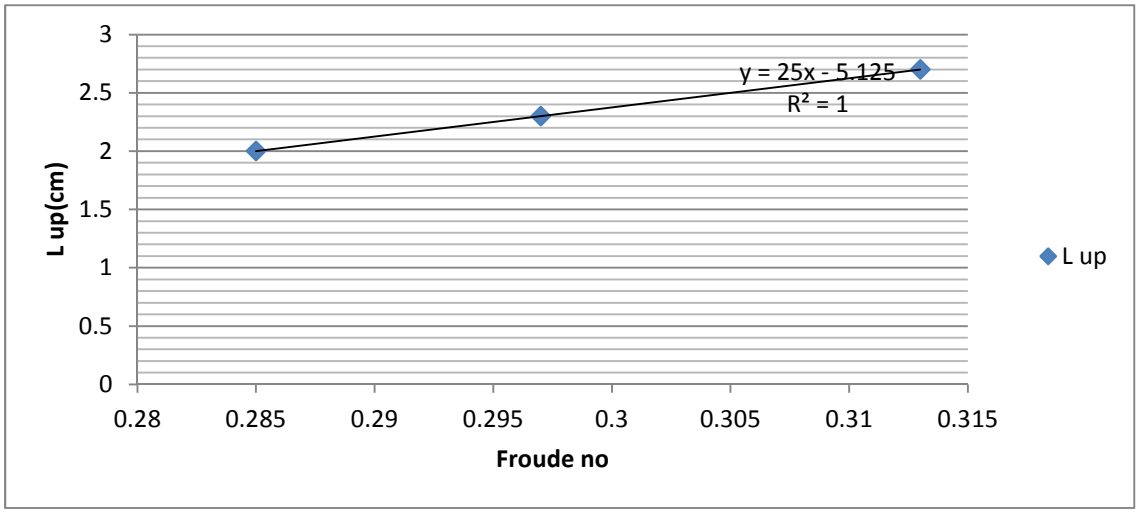
Case 18. Scouring around the circular pier with vertical slot and Square collar of area 3.0Dx3.0D (D is diameter of circular pier)



Equation: y = 14.189x - 3.2331



Equation: y = 25x - 5.125

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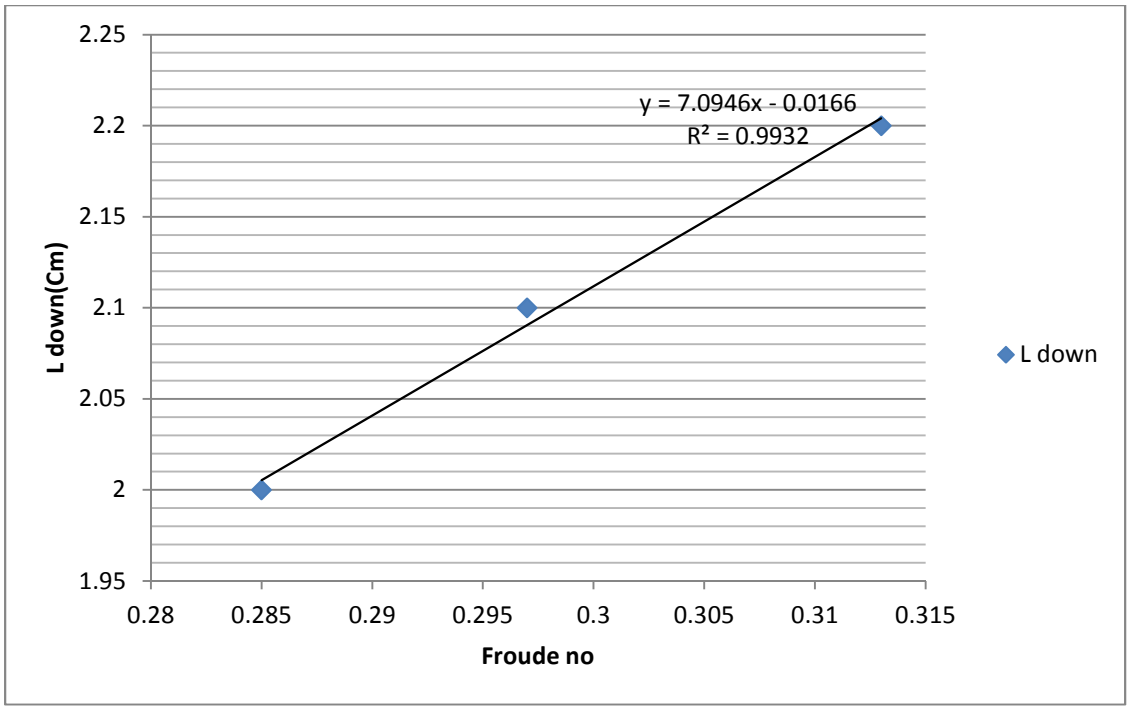
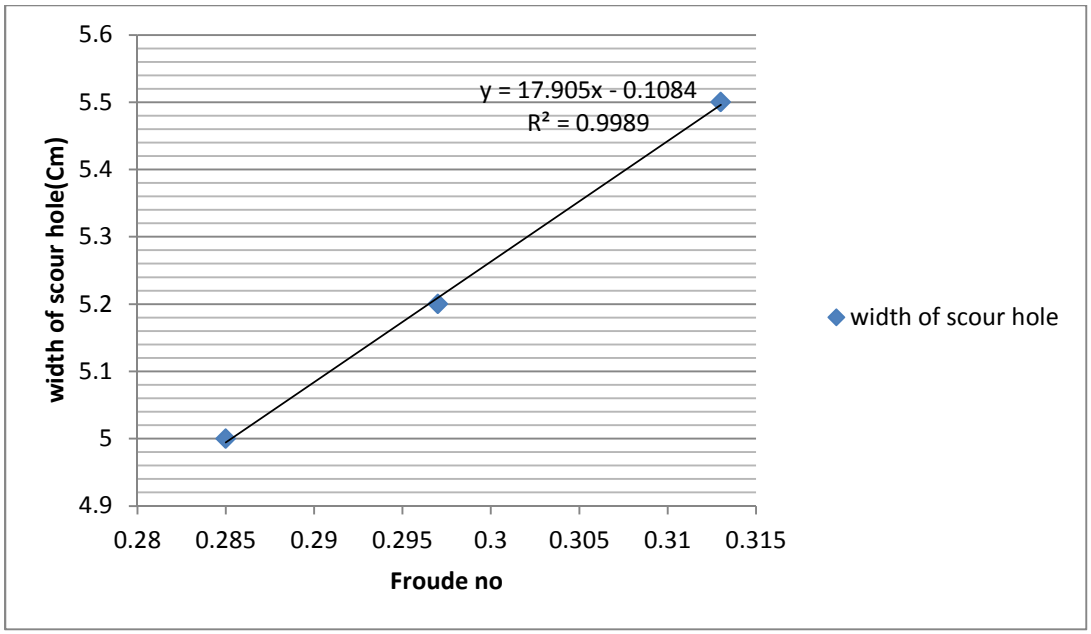


Equation: y = 7.0946x - 0.0166



Equation: y = 17.905x - 0.1084

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15. Conclusion.

In this work, we found that scouring is reduced around the bridge pier by the use of collar and slot on the pier. On the basis of the results obtained, we came to know that the circular collar is, more effective in reducing the scouring process around the pier than the square collar. We also found that effectiveness of the collar in reducing scour is directly proportional to its dimension, for example greater the diameter of the circular collar, greater its effectiveness in reducing scour. In this work we found that circular collar of 3.0D is more effective than vertical slot and square collar of same dimension in preventing scour. Circular collar is also more effective in reducing scouring around pier when it is used as combination with the slot then the slot and square collar of same dimension.

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