TO STUDY THE EFFECTS OF INCLINATION OF A BRIDGE PIER ON LOCAL SCOURING AROUND THE BRIDGE PIER

Submitted in partial fulfillment of the requirements of the degree of

Master of Technology in

Hydraulics and Water Resources Engineering

Submitted by:

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CANDIDATE'S 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 have given due credit to the sources by citing them and giving required details in the references.

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CERTIFICATE

This is to certify that thesis report entitled "**TO STUDY THE EFFECTS OF INCLINATION OF A BRIDGE PIER ON LOCAL SCOURING AROUND THE BRIDGE PIER**" 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 Resources Engineering, Delhi Technological University, Delhi-110042. The matter embodied in this project has not been submitted for the award of any other degree in any other college.

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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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ACKNOWLEDGEMENTS

I would like to give my heart-felt thanks first to my supervisor, Dr. Munendra Kumar, whose profound knowledge of water resources engineering helped me from the first day of my research to the eventual completion of my project. His invaluable guidance, warm encouragement and continuous constructive criticism has made this research easier. I know very well that without his enthusiastic supervision and hard work, it would have been impossible to finish this study on time.

I would like to extend my heartiest thanks to all the professors of Civil Engineering Department for the kind co-operation and necessary advice they have provided whenever required.

I would also like to thank all my family members especially my mother (Late) Mrs. Nayab Akhtar Quraishi for her immense love, patience and continuous support, without whom I could not have completed this work.

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ABSTRACT

In this experimental work, we used three pier of same dimensions but different shapes i.e., circular, octagonal and square. The octagonal shaped pier was purposely used so as to make it a transitional shape from smooth circular pier to sharp edged square pier. Each pier was founded in a test section inside the hydraulic flume and inclined to desired angle by using a pier inclining model. The experimental runs were carried out on three different discharge values in the hydraulic flume. Water was allowed to flow in the flume for 4 hours and after 4 hours, readings were taken for the scour hole so developed.

The experimental study revealed that the average scouring got reduced by upto 15% for the circular shaped pier, 22% for the octagonal shaped pier and 21% for the square shaped pier by inclining the pier towards the downstream direction.

Thus we can conclude that the maximum reduction in scour depth occurs in octagonal shaped pier.

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INTRODUCTION

The erosion of the bed material around any substructure or obstruction is known as scouring. The vertical extent of erosion of the soil bed around the structure is called scour depth. When the bed particles get washed away from the bed near the obstruction resulting in the formation of depression in the bed, this depression is called scour hole. The phenomenon of removal of bed particles from just adjacent to the pier is called local scouring. It occurs due to the obstruction caused by the pier to the direction of flow. This interference of the obstruction to the flow, results in the acceleration of the flow, which results in the formation of vortex flow around the supporting structure that washes away the bed particles from the pier surrounding area. If flow forms the vortices around the substructure then it results in scouring.

Scouring process depends on the factors, which includes shape of the pier, type of the flow, type of fluid and bed characteristics. If the fluid possesses enough erosive capacity, then it will lead to washing away of the bed particles from the area surrounding the pier or abutment. Various shapes have different extent of the scouring, and if the bed material has non cohesive material, then there is more possibility of the individual particle of being getting washed, when the stabilising force of the particle is overcome by the force of the approaching flow.

On the other hand, if the bed material has cohesive 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.

These vortices go downstream the pier and then passes along the sides of pier. This type of vortex flow is called the horseshoe vortex because it resembles with horseshoe. Due to this, the 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.

As we all know that the bridges are an important part of the transportation industry in any country and the 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 piers, which results in the failure of the bridge due to the undermining action of the water around the foundation of bridge piers. This failure results in the loss human lives, loss of economical values and loss of money & time.

So, the safety of structures, like bridge are a matter of utmost importance. For reducing the scouring, various researchers have developed various methods. There are generally two ways for checking against scouring , one way is to strengthen the soil around the pier and the other way is to regulate the flow of water around the pier. For strengthening the soil, we can do application of riprap ,grout filled bags etc . And for regulating the flow, we can control the flow alignment to breath the vortex flow which reduces the velocity of the water in the adjoining area of the pier, this can be achieved by the use of sacrificial piles, collars, submerged vanes, slot, threading, inclining the pier towards d/s side etc .

1.Types of scouring

1.1 Natural scour

This type of scour includes:

• Channel degradation

• Migration of the channel laterally

• Bend scour

• Confluence scour

1.1.1. Channel degradation

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.

1.1.2 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.

1.1.3 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
2. Ratio of width/depth
3. Eroding capacity of the bank
4. Material bed and strata it contains

1.1.4 Confluence scour

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.

1.2 Contraction scour

The narrowing of the width of the river channel results in the contraction scour. It causes the increase in velocity of flow which results in scraping the material from the most of the river bed.

1.3 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, resulting in the formation of the scour hole at the u/s face of the pier.

1.4 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.

1.5 High headed scour

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

2. Types of sediments and their behaviour

Generally the material present in the bed is more important for knowing the scouring process.

2a Non-cohesive material

These material are composed of the granular structure, with the possibility of individual particle getting washed away when its stabilising force is overcome by the force of approach flow. The capability of the individual to get washed away depends upon its shape, density and its packing on the bed.

2b Cohesive material

These particles generally consists of clay. These materials require large velocity of flowing water to overcome the stabilising force of individual particle but when it is achieved, it can be easily transported by flowing water.

2c Armoring

The process of preserving a large particle and let the washing away of the small particle in well graded channel is called Armoring. This controls the scouring up to some extent. This includes the laying of elongated shape materials on the bed.

3. 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 do contains the particles which are in suspension and does not affect the scouring.

4. Factors affecting scour

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

4a Type of the flow

Type of flow is responsible for the scouring. If the flow forms 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.

4b Type of the fluid

Type of the fluid is also another factor on which the scouring depends. The fluid may be considered as erosive fluid or non-erosive fluid. In 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.

4c 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 shapes.

4d 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 contains non-cohesive material then there is a possibility of individual particle getting washed away if the stabilising force of the particle is overcome by the force of approaching water. On the other hand, if river bed contains cohesive material like clay then the possibility of individual particle getting washed away is less because of the large force requirement or high velocity water to overcome the stabilising force of the individual particle.

LITERATURE REVIEW

The bridges play a very important role in the transportation sector of any country and it is said that a country's development can be judged by the advancements in the roads of that country. So the failure of any bridge causes huge loss of economy, human lives, money and time. Now after collision and overloading, the third main reason for the failure of a bridge is the scouring around a bridge pier. The scouring affects the structural capacity of a bridge pier by initiating the undermining action of water around the foundation of bridge piers.

So, the safety of structures, like bridge are a matter of utmost importance. For reducing the scouring, various researchers have developed various methods. There are generally two ways for checking against scouring , one way is to strengthen the soil around the pier and the other way is to regulate the flow of water around the pier. For strengthening the soil, we can have application of riprap ,grout filled bags, gabion mattress etc . And for regulating the flow, we can control the flow alignment to breath the vortex flow which reduces the velocity of the water in the adjoining area of the pier, this can be achieved by the use of sacrificial piles, collars, submerged vanes, slot, threading, inclining the pier towards d/s side etc .

A lot of research has already been done by many researchers such as Peggy A. Johnson[1][1991], Mohammad B. Mashahir[2] et al[2010], Nandana vittal[3] et al[1994], Yee-Meng Chiew[4][1992], Carmelo Grimaldi[5] et al[2009], Roberto Gaudio[6] et al[2009], M. Karimaee Tabarestani[7] et al[2013], Peggy A. Johnson[8] et al[1992], Zafer Bozkus[9] et al[2004], Mohammad Vaghefi[10] et al[2015], Ali Tafarojnoruz[11] et al[2012], A.R. Zarrati[12] et al[2006] etc.

Some research work on the protection of bridge pier and prevention of scouring is briefly described below:

- Peggy A. Johnson[1991]. Earlier the equations and models that were used to predict the pier scour provided a single maximum value of scour depth rather than scour depth as a function of time. Therefore the number of number of years in which the that scour depth will be reached cannot be estimated. So in this research , a time dependent model and subsequent risk of failure analysis has been used and this has enabled the design engineer to base a bridge pier design on an estimated probability of failure rather than on the basis of experience , thus proving it to be a method of safer design of bridges.

- Mohammad B. Mashahir et al[2010]. They used an application of riprap alone and a combination of riprap and collar to control the scour around rectangular bridge piers. A collar three times wider than the pier's width was installed around the pier at the streambed level. The results of the experiments showed that with increase in both the skew angle and the aspect ratio of the piers, the stable riprap size and extent also got increased.
- Nandana vital et al[1994]. In their research, they have replaced the solid pier by a group of three smaller piers. The extent of pier scouring in the pier group in its best orientation is compared with that due to a solid pier of diameter equal to the circumscribing circle diameter of the pier group. The results showed that scour reduction is about 40% in the pier group.
- Yee-Meng Chiew[1992]. He used a slot alone and a combination of slot and collar as devices for controlling the depth of scour. The results showed that scour got reduced by as much as 20% on using a slot alone. The combination of slot and collar further reduced the scour hole.
- Carmelo Grimaldi et al[2009]. They have used a bedsill located at downstream side of the circular pier as a scour reduction device. The effectiveness with the distance between the pier and sill was evaluated. The results showed that a bedsill placed at a small distance downstream of the pier reduces the scour depth upto a great extent.
- Roberto Gaudio et al[2009]. They have used a slot alone and a combination of slot and bedsill as a countermeasure against local scouring at a smooth circular bridge pier. The effectiveness of the slot was evaluated by changing its sinking depth into a sand bed. The results showed that maximum scour depth reduction was about 30% in the best configurations. And the scour

reduction when using the combined system of slot and bedsill was about 45% on average.

- Zafer Bozkus et al[2004]. In this research, the effects of inclination of a bridge pier on local scour depths around bridge pier was investigated experimentally. Single circular pier inclined towards the downstream direction was founded in a unform bed material. The results showed that the scour depth decreased as they increased the inclination angle of the pier.
- Ali Tafarojnoruz et al[2012]. They have used six different types of flow altering countermeasures i.e., submerged vanes, bedsill, transverse sacrificial piles, collar, threading and pier slot and the effectiveness of each of them in controlling scouring has been separately investigated. Laboratory tests were performed in clear water conditions with flow intensity slightly below the threshold of sediment motion. The test results showed that the efficiency of bedsill, submerged vanes and threading came out to be less than 20% whereas collar, slot and sacrificial piles reduced the scouring upto 35% approximately.
- Mohammad Vaghefi et al[2015]. In their scour around circular shaped bridge piers with two different diameters and different inclination angles towards downstream side has been investigated experimentally under clear water condition and different discharges. The results showed that an increase in the inclination angle leads to a significant decrease in the scour depth.
- A.R. Zarrati et al[2006]. They have used independent and continuous pier collars in combination with riprap for reducing local scour around bridge pier groups. The effectiveness of collars was evaluated experimentally. The results showed thatin the case of two piers in line, combination of continuous collarsand riprap results in the most significant scour reduction of about 50 and 60 % for the front and rear piers respectively.

OBJECTIVE OF THE WORK

After collision and overloading, the third main cause for bridge failure is scouring around a bridge pier. It is estimated that nearly two-third of bridge failure occurs due to scouring and other flow related causes. Scouring around a bridge pier is a phenomenon that can never be totally ended to zero but can surely be reduced upto a great extent. So, the objective of this work is to study the effects of inclination of a bridge pier on local scouring around a bridge pier.

OVERVIEW OF THE WORK

In this experimental work , scouring is reduced by inclining the bridge pier towards the downstream direction. Further in this work, we used three pier of different shapes i.e., circular, octagonal and square. The octagonal pier is purposely used so as to have a transitional shape pier from smooth circular to sharp edged square pier. The experimental runs are carried out by allowing different discharges in the hydraulic flume.

In this work, a circular pier of diameter 4 cm and length 50 cm is placed inside the tilting hydraulic flume using a pier inclining model. The hydraulic flume represents a channel. A test section is made in the flume of length 1.1m and height 14cm. The test section is filled with sand and flattened with the help of trowel. Water is allowed to flow in the flume for 4 hours and after 4 hours readings are taken for the scour hole so developed.

The same procedure is repeated for the other shapes of pier by inclining them at different values of angles in the downstream direction.

EXPERIMENTAL SETUP

The experimental setup consists of :-

- Tilting hydraulic flume of length 6m
- Pier inclining model
- Circular pier
- Octagonal pier
- Square pier
- Trowel

For performing the experimental runs we take three different shapes of the pier i.e., circular, octagonal and square. The experimental runs are first performed for circular shaped pier of diameter 4cm and length 50cm. The flume is first cleaned off dust by allowing free discharge through it. After this a test section of 1.1m length and 14 cm height is set inside the flume. The circular pier is then placed in the test section and inclined at an angle of 0^0 with respect to vertical axis with the help of pier inclining model. Sand is then laid in the test section and flattened perfectly with the help of a trowel. Water is allowed to flow in the flume for 4 hours. After 4 hours water is allowed to drain out of the flume and readings are taken for the scour hole so formed.

The same procedure is then again repeated for circular pier after changing the inclination angle to 5^o,10^o,15^o and 20^o .

And similarly the same procedure is then repeated for the other shapes of pier.

OBSERVATIONS AND CALCULATIONS:

The following experimental runs were carried out for three different discharge values :-

Case 1: Flow around circular pier inclined at 0^0 with vertical axis towards the downstream direction

Case 2: Flow around circular pier inclined at 5^0 with vertical axis towards the downstream direction

Case 3: Flow around circular pier inclined at 10^0 with vertical axis towards the downstream direction

Case 4: Flow around circular pier inclined at 15^0 with vertical axis towards the downstream direction

Case 5: Flow around circular pier inclined at 20^0 with vertical axis towards the downstream direction

Case 6: Flow around octagonal pier Inclined at 0^0 with vertical axis towards the downstream direction

Case 7: Flow around octagonal pier inclined at 5^0 with vertical axis towards the downstream direction

Case 8: Flow around octagonal pier inclined at 10^0 with vertical axis towards the downstream direction

Case 9: Flow around octagonal pier inclined at 15^0 with vertical axis towards the downstream direction

Case 10: Flow around octagonal pier inclined at 20^0 with vertical axis towards the downstream direction

Case 11: Flow around square pier inclined at 0^0 with vertical axis towards the downstream direction

Case 12: Flow around square pier inclined at 5^0 with vertical axis towards the downstream direction

Case 13: Flow around square pier inclined at 10^0 with vertical axis towards the downstream direction

Case 14: Flow around square pier inclined at 15^0 with vertical axis towards the downstream direction

Case 15: Flow around square pier inclined at 20^0 with vertical axis towards the downstream direction

FROUDE'S NO. = 0.281

Case 1 : circular pier inclined at 0^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.0	9.5	2.5	2.0

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 2 : circular pier inclined at 5^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	1.8	9.0	2.5	1.6

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 3 : circular pier inclined at 10^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	1.7	8.8	2.5	2.0

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 4 : circular pier inclined at 15^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	1.6	8.7	2.0	1.8

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 5 : circular pier inclined at 20^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	1.5	8.6	1.5	1.3

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 6 : Octagonal pier inclined at 0^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.0	12.0	3.8	3.0

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 7 : Octagonal pier inclined at 5^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.7	11	3.3	2.8

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 8 : Octagonal pier inclined at 10^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.3	10.5	3.0	2.3

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 9 : Octagonal pier inclined at 15^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.1	10.0	3.0	2.1

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 10 : Octagonal pier inclined at 20^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.9	9.0	3.0	1.8

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 11 : Square pier inclined at 0^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.1	15.0	6.0	8.5

Figure : initial picture at t=0

Figure : final picture at t=4

Case 12 : Square pier inclined at 5^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.9	13.5	5.2	6.0

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 13 : Square pier inclined at 10^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.5	12.0	4.5	4.0

Figure : initial picture at t=0

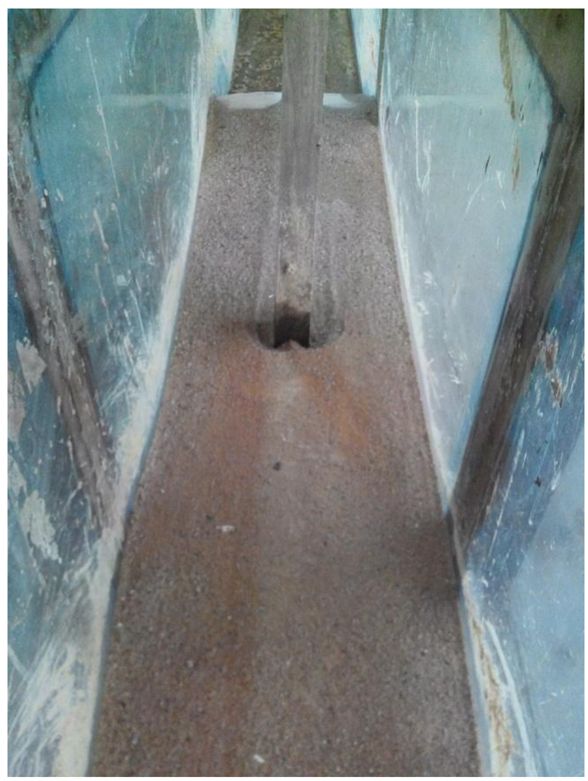


Figure : final picture at t=4h

Case 14 : Square pier inclined at 15^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.2	11.5	3.5	2.5

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 15 : Square pier inclined at 20^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.0	11.3	3.3	2.0

Figure : initial picture at t=0

Figure : final picture at t=4h

FROUDE'S NO. = 0.300

Case 16 : Circular pier inclined at 0^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.8	11.5	4.0	2.5

Figure : initial picture at t=0

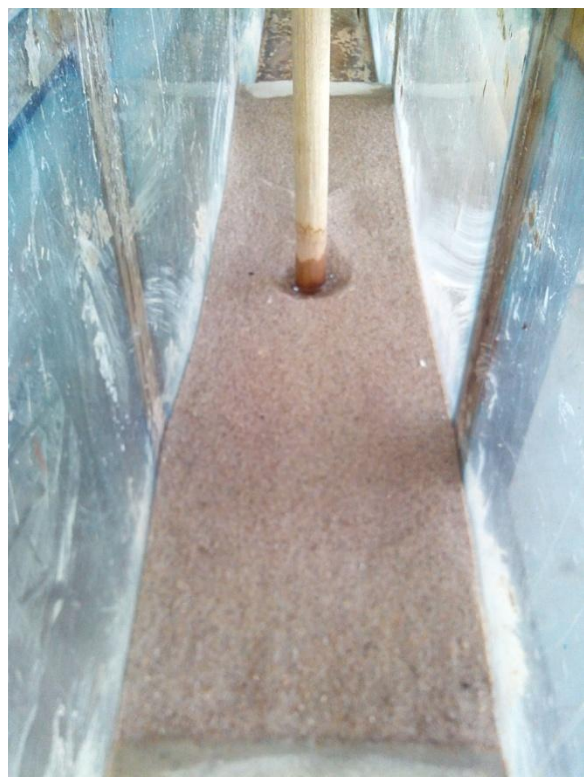


Figure : final picture at t=4h

Case 17 : Circular pier inclined at 5^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.6	11.3	4.0	3.0

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 18 : Circular pier inclined at 10^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.5	11.0	4.0	3.0

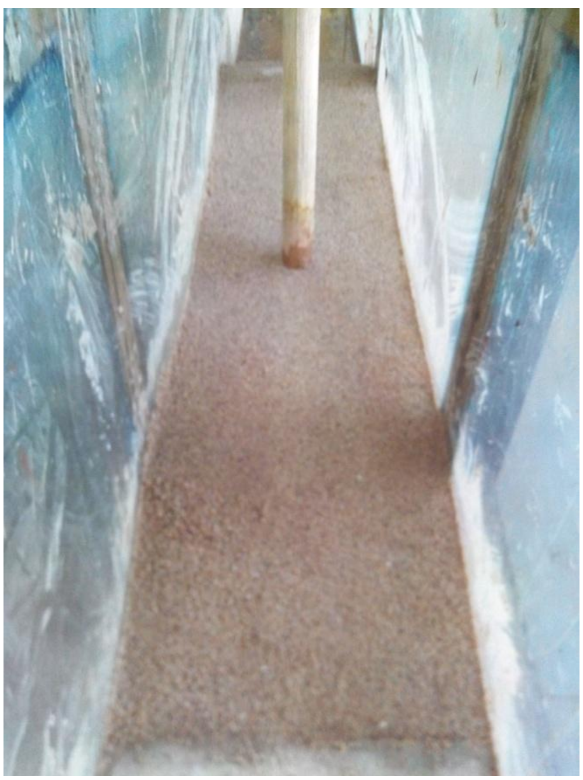


Figure : initial picture at t=0

Figure : final picture at t=4h

Case 19 : Circular pier inclined at 15^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.4	10.7	3.6	2.8

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 20 : Circular pier inclined at 20^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.3	10.5	3.3	2.5

Figure : initial picture at t=0

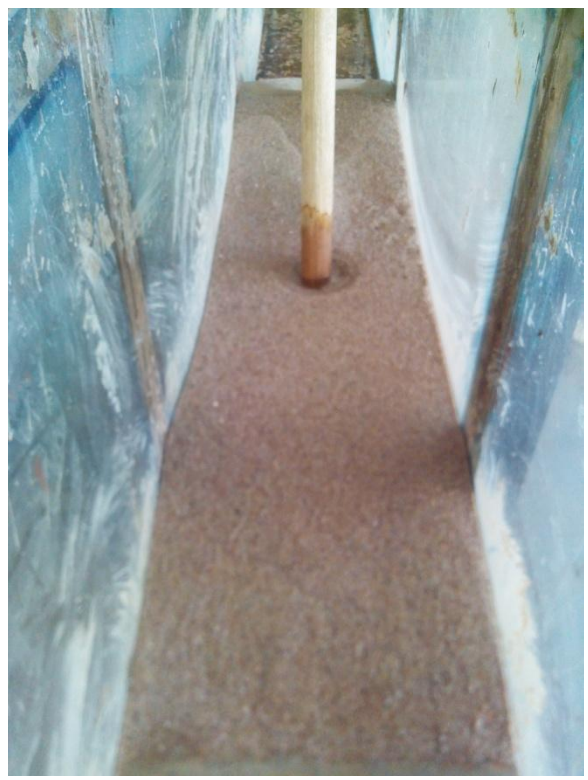


Figure : final picture at t=4h

Case 21 : Octagonal pier inclined at 0^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.2	12.5	4.1	3.2

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 22 : Octagonal pier inclined at 5^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.9	12.2	4.0	3.1

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 23 : Octagonal pier inclined at 10^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.8	12.0	4.0	3.0

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 24 : Octagonal pier inclined at 15^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.6	11.0	3.8	2.8

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 25 : Octagonal pier inclined at 20^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.5	11.8	3.8	2.7

Figure : initial picture at t=0

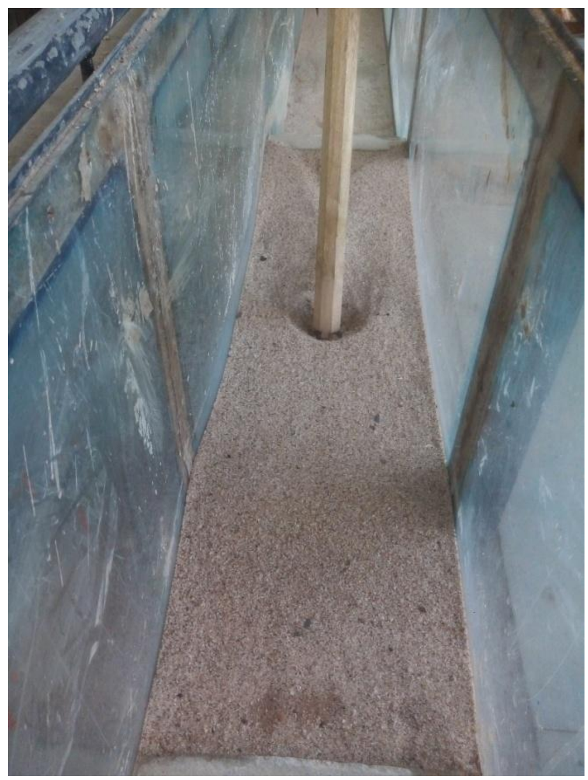


Figure : final picture at t=4h

Case 26 : Square pier inclined at 0^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.3	14.0	5.0	2.6

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 27 : Square pier inclined at 5^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.1	13.5	4.8	2.5

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 28 : Square pier inclined at 10^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.0	13.0	4.8	2.5

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 29 : Square pier inclined at 15^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.0	12.8	4.8	2.5

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 30 : Square pier inclined at 20^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.9	12.7	4.5	2.3

Figure : initial picture at t=0

Figure : final picture at t=4h

FROUDE'S NO. = 0.311

Case 31 : Circular pier inclined at 0^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.5	16.0	5.5	10.5

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 32 : Circular pier inclined at 5^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.4	15.5	5.5	10.0

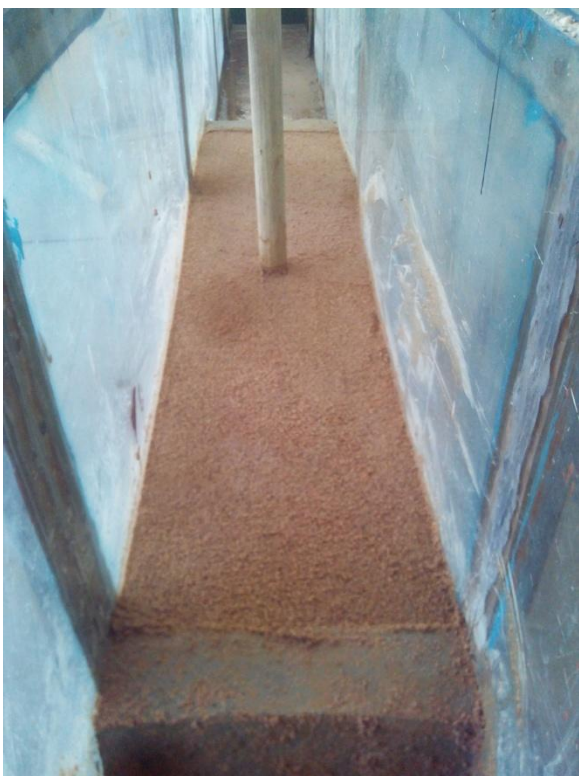


Figure : initial picture at t=0

Figure : final picture at t=4h

Case 33 : Circular pier inclined at 10^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.2	15.0	5.0	9.0

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 34 : Circular pier inclined at 15^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.9	13.5	5.0	9.3

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 35 : Circular pier inclined at 20^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.5	11.8	5.0	9.5

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 36 : Octagonal pier inclined at 0^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.8	16.5	5.0	11.0

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 37 : Octagonal pier inclined at 5^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.6	16.0	5.0	9.0

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 38 : Octagonal pier inclined at 10^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.4	15.5	5.0	8.2

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 39 : Octagonal pier inclined at 15^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.0	14.2	5.2	7.7

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 40 : Octagonal pier inclined at 20^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	2.8	12.2	3.7	7.0

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 41 : Square pier inclined at 0^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	4.3	18.0	7.0	8.3

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 42 : Square pier inclined at 5^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	4.0	17.3	7.0	8.1

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 43 : Square pier inclined at 10^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.6	16.2	7.0	8.0

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 44 : Square pier inclined at 15^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.4	14.8	5.5	7.8

Figure : initial picture at t=0

Figure : final picture at t=4h

Case 45 : Square pier inclined at 20^0 with the vertical axis

S.No	Depth of scouring (cm)	Width of scouring (cm)	Length of scouring u/s (cm)	Length of scouring d/s (cm)
1.	3.3	13.0	4.8	7.5

Figure : initial picture at t=0

Figure : final picture at t=4h

RESULTS AND DISCUSSIONS

In this research work, we have taken 45 different experimental runs to observe the trend of scouring. Three different shapes of the pier were used. Five different inclination angles were set for each of the pier i.e., 0^o, 5^o, 10^o, 15^o and 20^o. And the experimental runs were taken on three different discharge values i.e., Froude no. for first discharge condition was 0.281, Froude no. for second discharge condition was 0.300 and Froude no. for third discharge condition was 0.311.

The results that were obtained are tabulated as follows:-

FOR FROUDE NUMBER = 0.281

CIRCULAR PIER

CASE	FROUDE NO. (Fr)	DEPTH OF SCOURING (CM)	WIDTH OF SCOURING (CM)	LENGTH OF SCOUR HOLE AT U/S (CM)	LENGTH OF SCOUR HOLE AT D/S (CM)
Circular pier inclined at 0^o with respect to vertical axis towards d/s direction	0.281	2	9.5	2.5	2.0
Circular pier inclined at 5^o with respect to vertical axis towards d/s direction	0.281	1.8	9.0	2.5	1.6

Circular pier inclined at 10^o with respect to vertical axis towards d/s direction	0.281	1.7	8.8	2.5	2.0
Circular pier inclined at 15^o with respect to vertical axis towards d/s direction	0.281	1.6	8.7	2.0	1.8
Circular pier inclined at 20^o with respect to vertical axis towards d/s direction	0.281	1.5	8.6	1.5	1.3

OCTAGONAL PIER

CASE	FROUDE NO. (Fr)	DEPTH OF SCOURING (CM)	WIDTH OF SCOURING (CM)	LENGTH OF SCOUR HOLE AT U/S (CM)	LENGTH OF SCOUR HOLE AT D/S (CM)
Octagonal pier inclined at 0^o with respect to vertical axis towards d/s direction	0.281	3	12	3.8	3.0
Octagonal pier inclined at 5^o with respect to vertical axis towards d/s direction	0.281	2.7	11	3.3	2.8
Octagonal pier inclined at 10^o with respect to vertical axis towards d/s direction	0.281	2.3	10.5	3.0	2.3
Octagonal pier inclined at 15^o w.r.t. vertical axis towards d/s direction	0.281	2.1	10.0	3.0	2.1

Octagonal pier inclined at 20^o with respect to vertical axis towards d/s direction	0.281	1.9	9.0	3	1.8

SQUARE PIER

CASE	FROUDE NO. (Fr)	DEPTH OF SCOURING (CM)	WIDTH OF SCOURING (CM)	LENGTH OF SCOUR HOLE AT U/S (CM)	LENGTH OF SCOUR HOLE AT D/S (CM)
Square pier inclined at 0^o with respect to vertical axis towards d/s direction	0.281	3.1	15	6	8.5
Square pier inclined at 5^o with respect to vertical axis towards d/s direction	0.281	2.9	13.5	5.2	6.0
Square pier inclined at 10^o with respect to vertical axis towards d/s direction	0.281	2.5	12.0	4.5	4.0

Square pier inclined at 15^o with respect to vertical axis towards d/s direction	0.281	2.2	11.5	3.5	2.5
Square pier inclined at 20^o with respect to vertical axis towards d/s direction	0.281	2.0	11.3	3.3	2.0

<u>FOR FROUDE NUMBER = 0.300</u>

CIRCULAR PIER

CASE	FROUDE NO. (Fr)	DEPTH OF SCOURING (CM)	WIDTH OF SCOURING (CM)	LENGTH OF SCOUR HOLE AT U/S (CM)	LENGTH OF SCOUR HOLE AT D/S (CM)
Circular pier inclined at 0^o with respect to vertical axis towards d/s direction	0.300	2.8	11.5	4.0	2.5

Circular pier inclined at 5^o with respect to vertical axis towards d/s direction	0.300	2.6	11.3	4.0	3.0
Circular pier inclined at 10^o with respect to vertical axis towards d/s direction	0.300	2.5	11.0	4.0	3.0
Circular pier inclined at 15^o with respect to vertical axis towards d/s direction	0.300	2.4	10.7	3.6	2.8
Circular pier inclined at 20^o with respect to vertical axis towards d/s direction	0.300	2.3	10.5	3.3	2.5

OCTAGONAL PIER

CASE	FROUDE NO. (Fr)	DEPTH OF SCOURING (CM)	WIDTH OF SCOURING (CM)	LENGTH OF SCOUR HOLE AT U/S (CM)	LENGTH OF SCOUR HOLE AT D/S (CM)
Octagonal pier inclined at 0^o with respect to vertical axis towards d/s direction	0.300	3.2	12.5	4.1	3.2
Octagonal pier inclined at 5^o with respect to vertical axis towards d/s direction	0.300	2.9	12.2	4	3.1
Octagonal pier inclined at 10^o with respect to vertical axis towards d/s direction	0.300	2.8	12.0	4.0	3.0
Octagonal pier inclined at 15^o w.r.t. vertical axis towards d/s direction	0.300	2.6	11.0	3.8	2.8

Octagonal pier inclined at 20^{o} with respect to vertical axis towards d/s direction	0.300	2.5	10.5	3.8	2.7

SQUARE PIER

CASE	FROUDE NO. (Fr)	DEPTH OF SCOURING (CM)	WIDTH OF SCOURING (CM)	LENGTH OF SCOUR HOLE AT U/S (CM)	LENGTH OF SCOUR HOLE AT D/S (CM)
Square pier inclined at 0^{o} with respect to vertical axis towards d/s direction	0.300	3.3	14	5	2.6
Square pier inclined at 5^{o} with respect to vertical axis towards d/s direction	0.300	3.1	13.5	4.8	2.5
Square pier inclined at 10^{o} with respect to vertical axis towards d/s direction	0.300	3.0	13.0	4.8	2.5

Square pier inclined at 15^o with respect to vertical axis towards d/s direction	0.300	3.0	12.8	4.8	2.5
Square pier inclined at 20^o with respect to vertical axis towards d/s direction	0.300	2.9	12.7	4.5	2.3

<u>FOR FROUDE NUMBER = 0.311</u>

CIRCULAR PIER

CASE	FROUDE NO. (Fr)	DEPTH OF SCOURING (CM)	WIDTH OF SCOURING (CM)	LENGTH OF SCOUR HOLE AT U/S (CM)	LENGTH OF SCOUR HOLE AT D/S (CM)
Circular pier inclined at 0^o with respect to vertical axis towards d/s direction	0.311	3.5	16.0	5.5	10.5

Circular pier inclined at 5^o with respect to vertical axis towards d/s direction	0.311	3.4	15.5	5.5	10.0
Circular pier inclined at 10^o with respect to vertical axis towards d/s direction	0.311	3.2	15.0	5.0	9.0
Circular pier inclined at 15^o with respect to vertical axis towards d/s direction	0.311	2.9	13.5	5.0	9.3
Circular pier inclined at 20^o with respect to vertical axis towards d/s direction	0.311	2.5	11.8	5.0	9.5

OCTAGONAL PIER

CASE	FROUDE NO. (Fr)	DEPTH OF SCOURING (CM)	WIDTH OF SCOURING (CM)	LENGTH OF SCOUR HOLE AT U/S (CM)	LENGTH OF SCOUR HOLE AT D/S (CM)
Octagonal pier inclined at 0^o with respect to vertical axis towards d/s direction	0.311	3.8	16.5	5.0	11.0
Octagonal pier inclined at 5^o with respect to vertical axis towards d/s direction	0.311	3.6	16.0	5.0	9.0
Octagonal pier inclined at 10^o with respect to vertical axis towards d/s direction	0.311	3.4	15.5	5.0	8.2
Octagonal pier inclined at 15^o w.r.t. vertical axis towards d/s direction	0.311	3.0	14.2	5.2	7.7

Octagonal pier inclined at 20^o with respect to vertical axis towards d/s direction	0.311	2.8	12.2	3.7	7.0

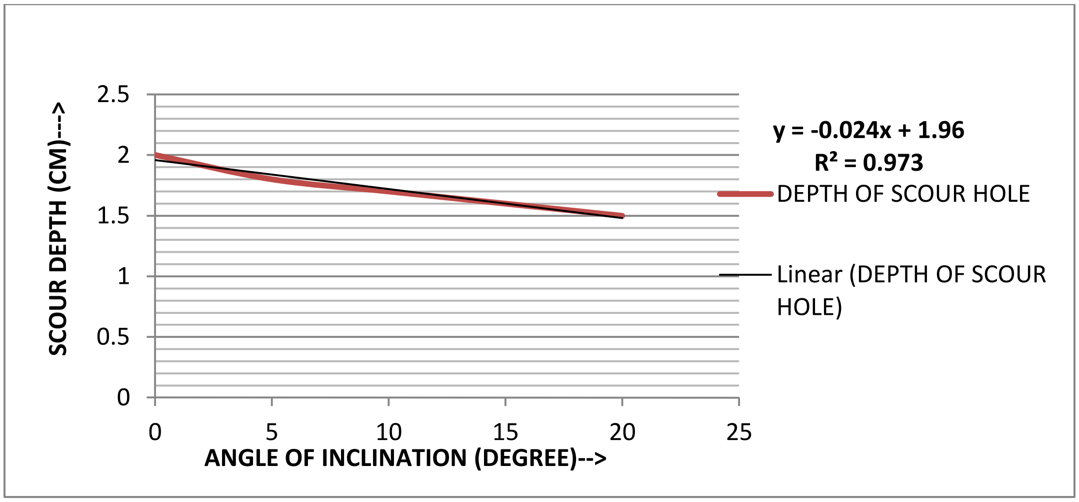
SQUARE PIER

CASE	FROUDE NO. (Fr)	DEPTH OF SCOURING (CM)	WIDTH OF SCOURING (CM)	LENGTH OF SCOUR HOLE AT U/S (CM)	LENGTH OF SCOUR HOLE AT D/S (CM)
Square pier inclined at 0^o with respect to vertical axis towards d/s direction	0.311	4.3	18.0	7.0	8.3
Square pier inclined at 5^o with respect to vertical axis towards d/s direction	0.311	4.0	17.3	7.0	8.1
Square pier inclined at 10^o with respect to vertical axis towards d/s direction	0.311	3.6	16.2	7.0	8.0

Square pier inclined at 15^o with respect to vertical axis towards d/s direction	0.311	3.4	14.8	5.5	7.8
Square pier inclined at 20^o with respect to vertical axis towards d/s direction	0.311	3.3	13.0	4.8	7.5

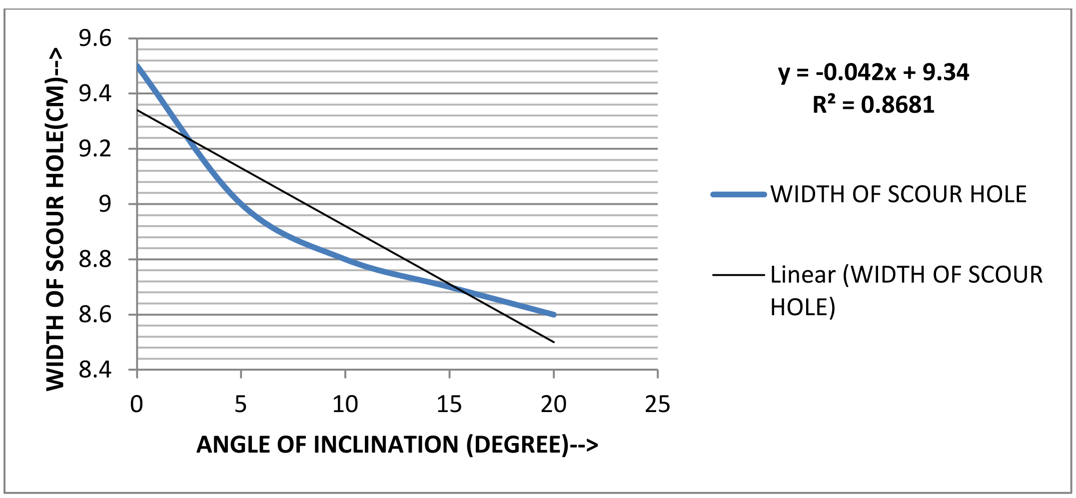
GRAPHS

CIRCULAR PIER (FROUDE NUMBER = 0.281)



GRAPH 1: DEPTH OF SCOUR HOLE Vs INCLINATION ANGLE

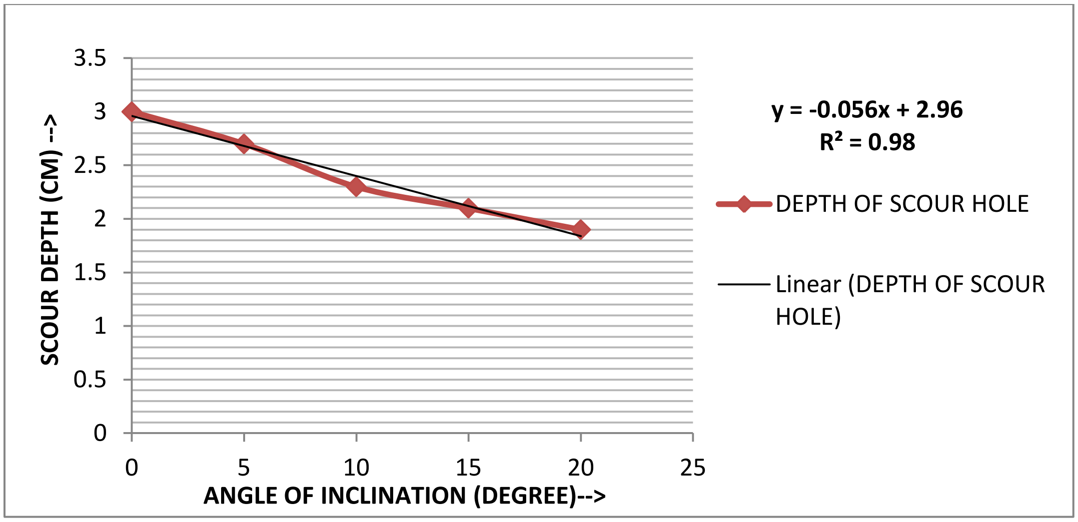
Discussion: In the above graph we can see as the angle of inclination increases, the scour depth decreases respectively.



GRAPH 2: WIDTH OF SCOUR HOLE Vs INCLINATION ANGLE

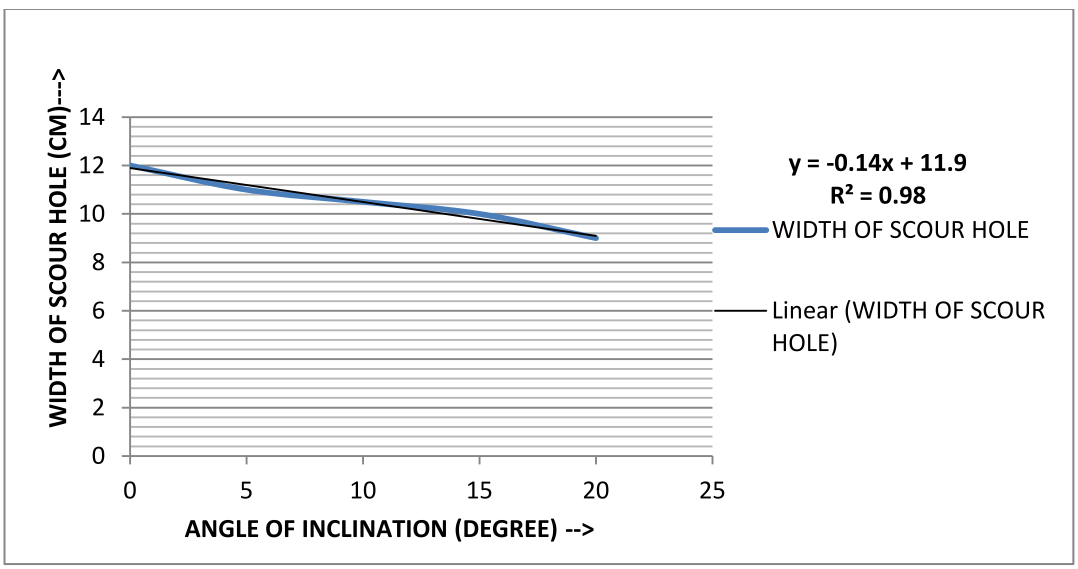
Discussion: In the above graph we can see as the angle of inclination increases, the width of scour hole decreases respectively.

OCTAGONAL PIER (FROUDE NUMBER = 0.281)



GRAPH 3: DEPTH OF SCOUR HOLE Vs INCLINATION ANGLE

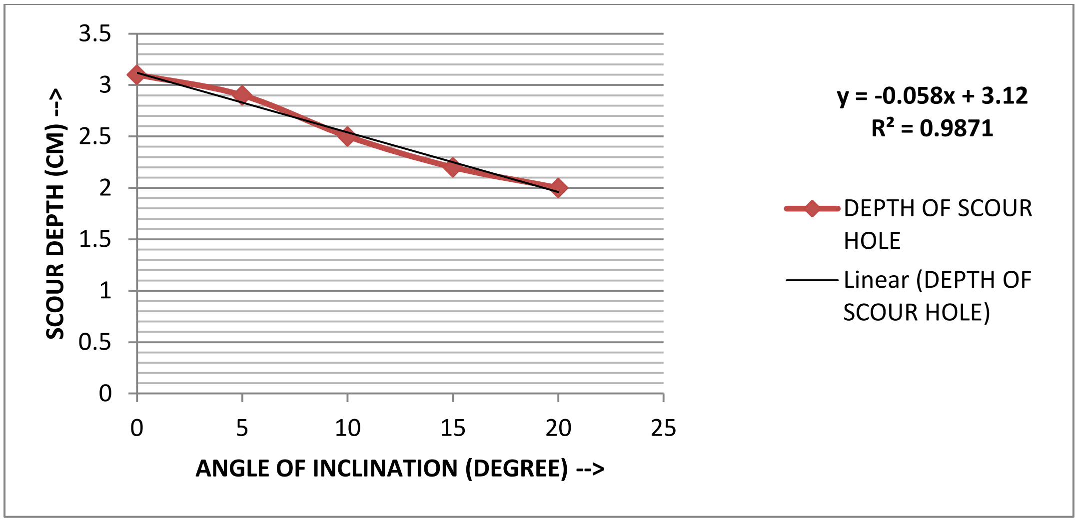
Discussion: In the above graph we can see as the angle of inclination increases, the scour depth decreases respectively.



GRAPH 4: WIDTH OF SCOUR HOLE Vs INCLINATION ANGLE

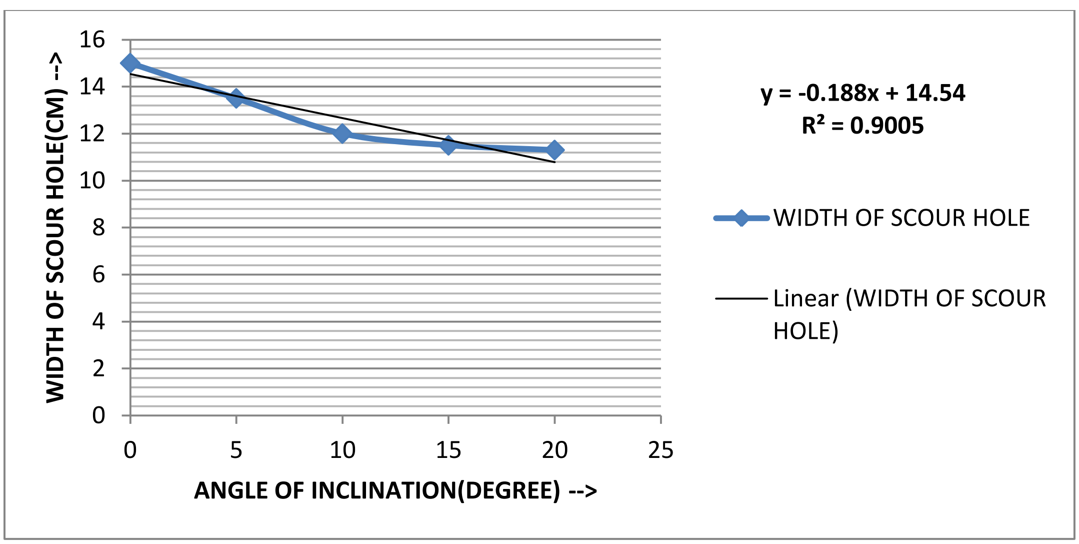
Discussion: In the above graph we can see as the angle of inclination increases, the width of scour hole decreases respectively.

SQUARE PIER (FROUDE NUMBER = 0.281)



GRAPH 5: DEPTH OF SCOUR HOLE Vs INCLINATION ANGLE

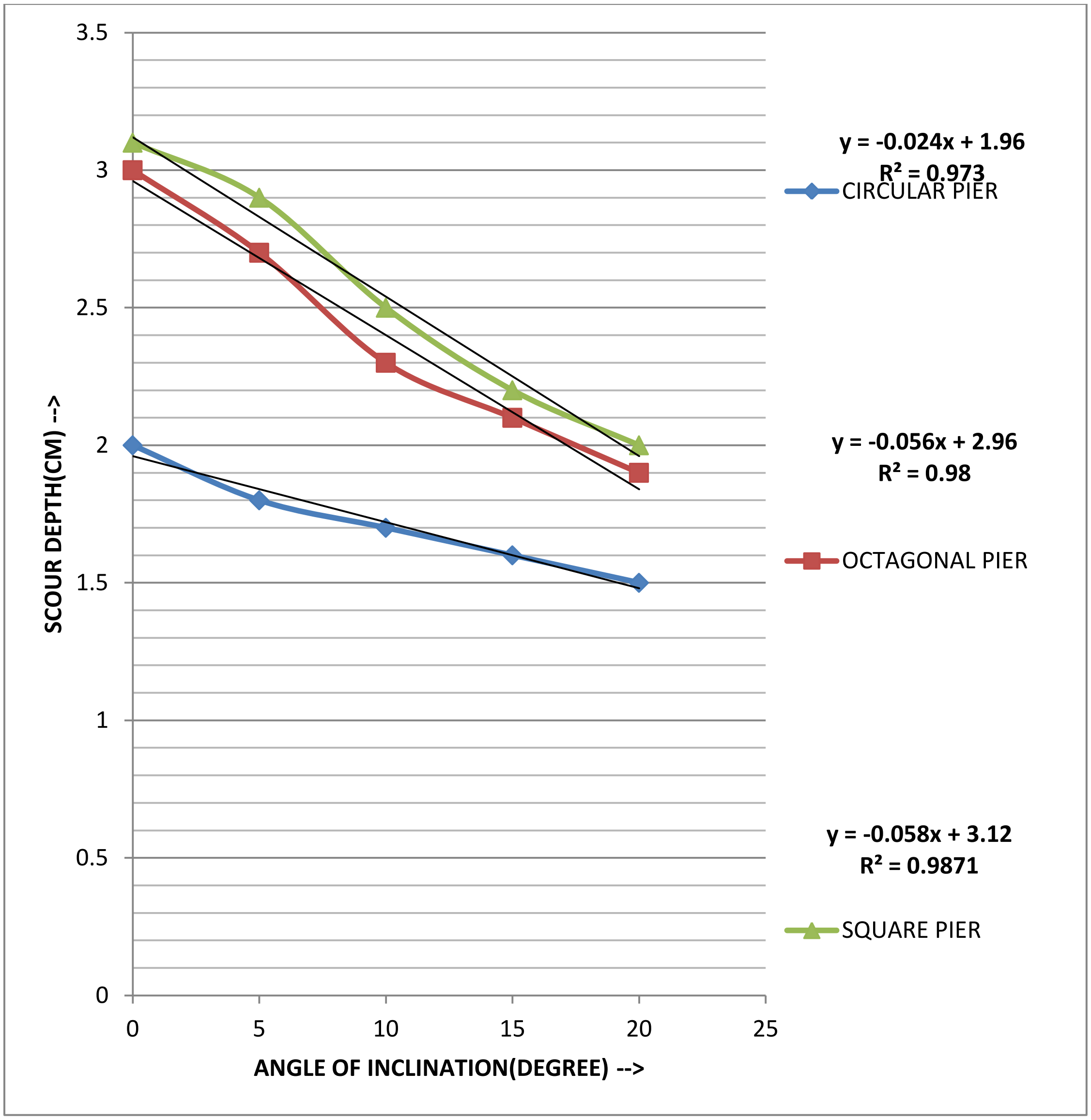
Discussion: In the above graph we can see as the angle of inclination increases, the scour depth decreases respectively.



GRAPH 6: WIDTH OF SCOUR HOLE Vs INCLINATION ANGLE

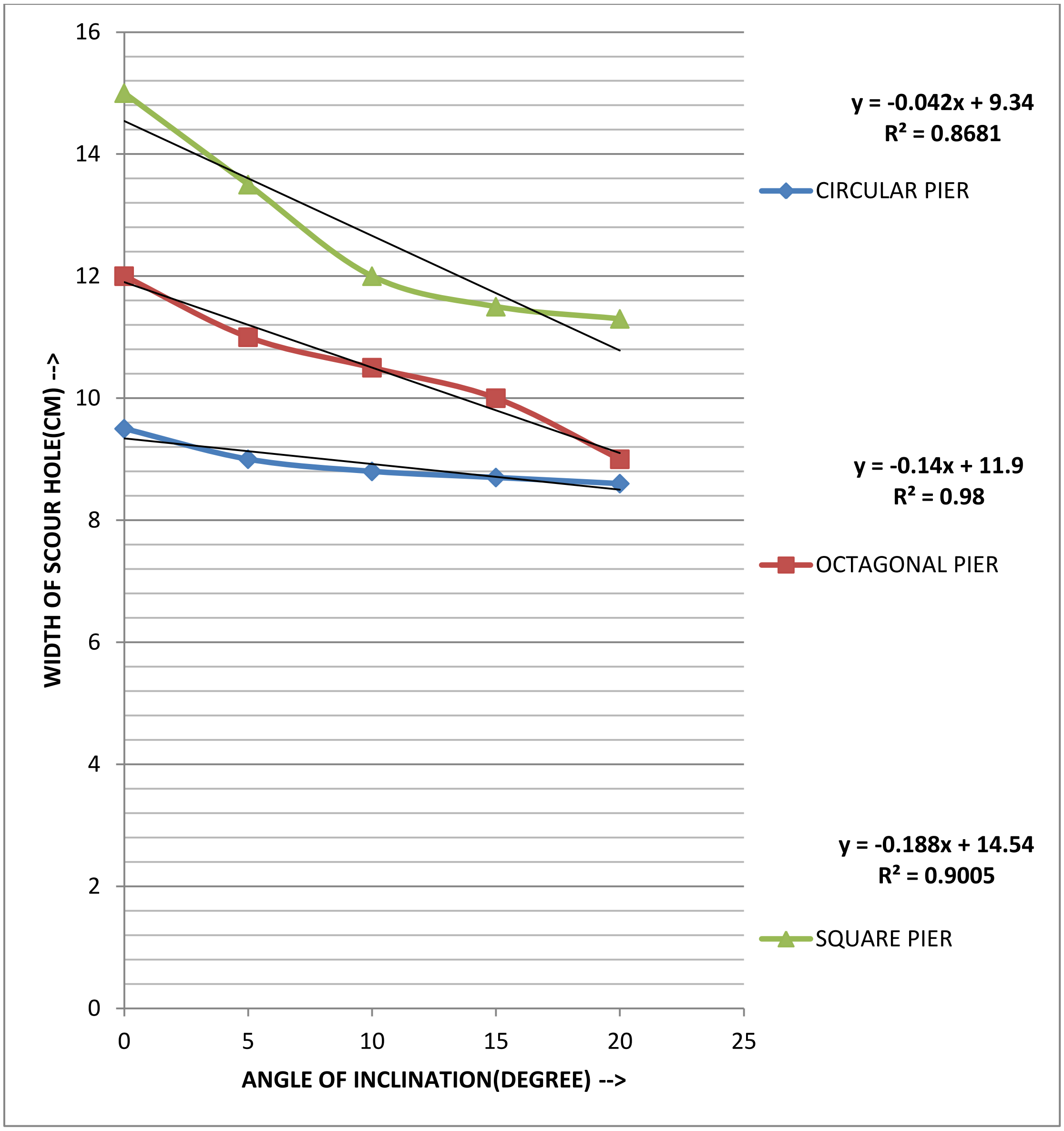
Discussion: In the above graph we can see as the angle of inclination increases, the width of scour hole decreases respectively.

CIRCULAR Vs OCTAGONAL Vs SQUARE (FOR FROUDE NUMBER = 0.281)



GRAPH 7: COMBINED GRAPH SHOWING DEPTH OF SCOURING Vs ANGLE OF INCLINATION

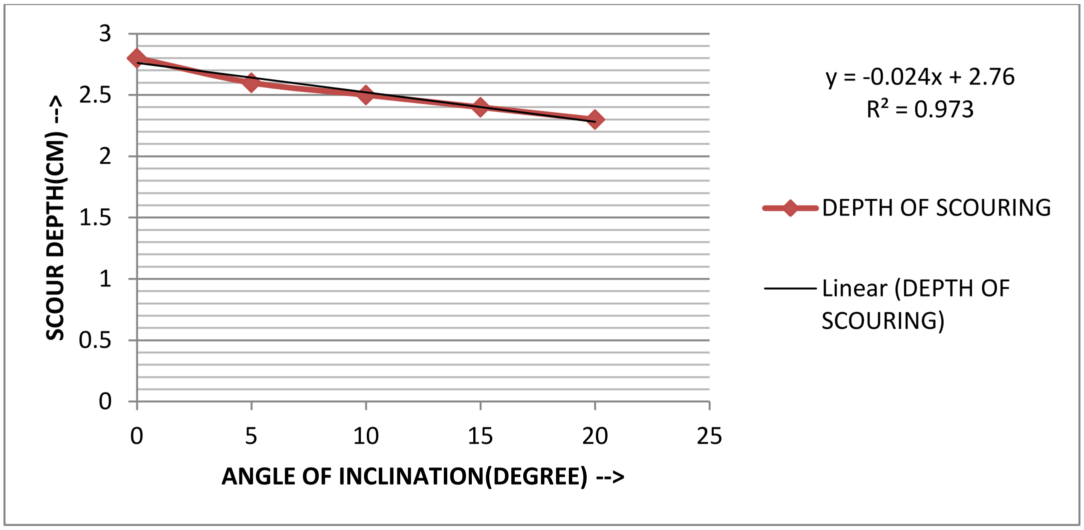
Discussion: In the above graph it can be clearly seen that as we increased the angle of inclination towards the downstream side, the scour depth got reduced in all the three shapes of pier i.e., circular, octagonal and square. However, the maximum reduction in scour depth takes place in the square shaped pier.



GRAPH 8: COMBINED GRAPH SHOWING WIDTH OF SCOURING Vs ANGLE OF INCLINATION

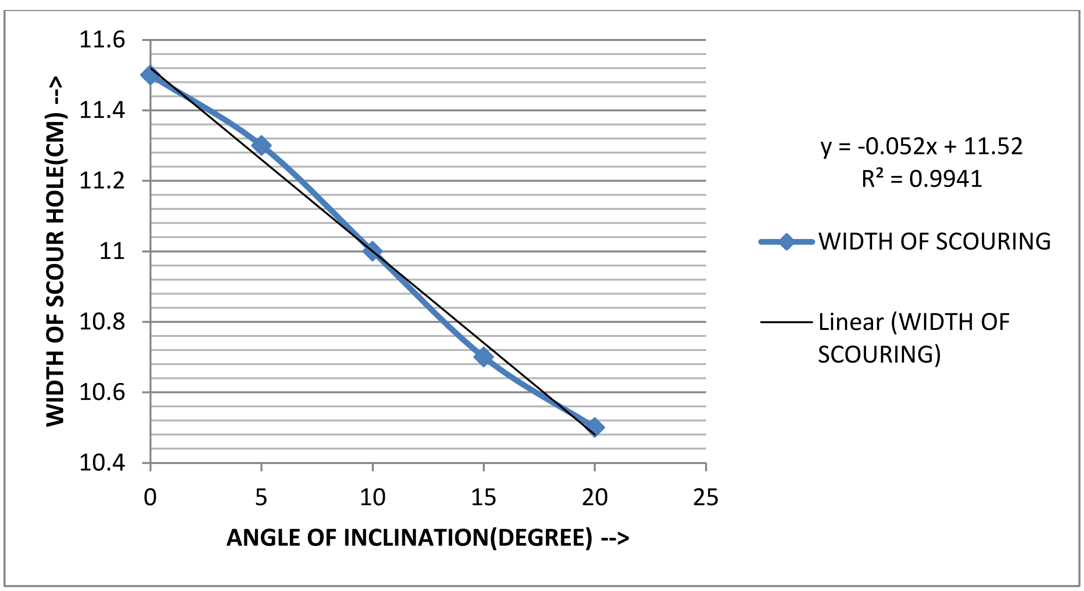
Discussion: In the above graph it can be clearly seen that as we increased the angle of inclination towards the downstream side, the width of scour hole got reduced in all the three shapes of pier i.e., circular, octagonal and square. However, the maximum reduction in the width of scour hole takes place in the square shaped pier.

CIRCULAR PIER (FOR FROUDE NUMBER = 0.300)



GRAPH 9: DEPTH OF SCOUR HOLE Vs INCLINATION ANGLE

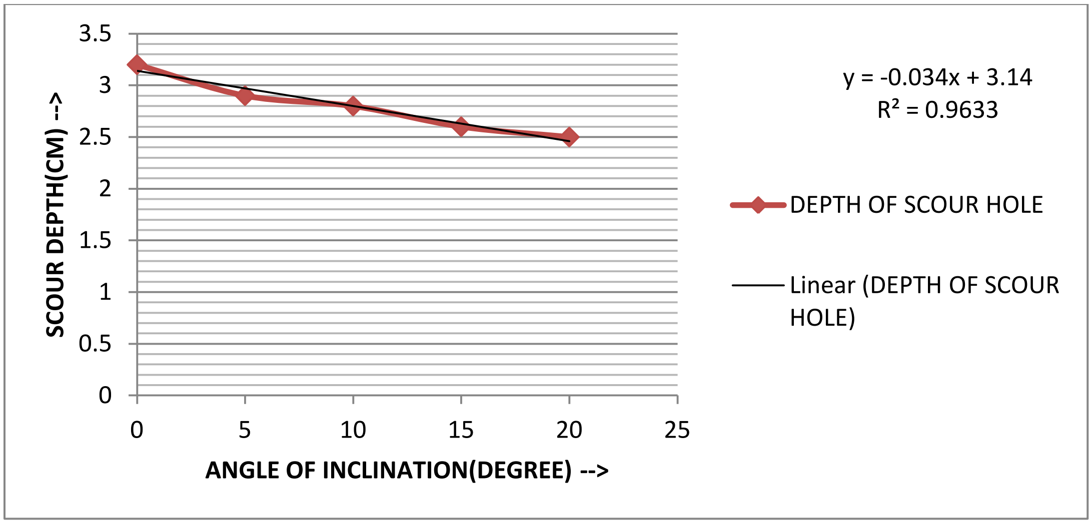
Discussion: In the above graph we can see as the angle of inclination increases, the scour depth decreases respectively.



GRAPH 10: WIDTH OF SCOUR HOLE Vs INCLINATION ANGLE

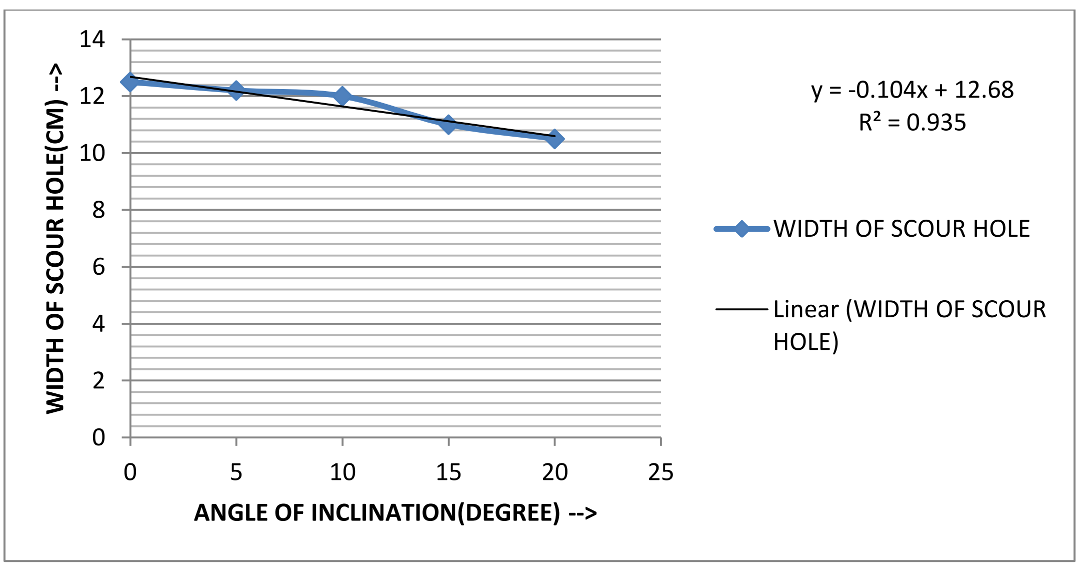
Discussion: In the above graph we can see as the angle of inclination increases, the width of scour hole decreases respectively.

OCTAGONAL PIER (FOR FROUDE NUMBER = 0.300)



GRAPH 11: DEPTH OF SCOUR HOLE Vs INCLINATION ANGLE

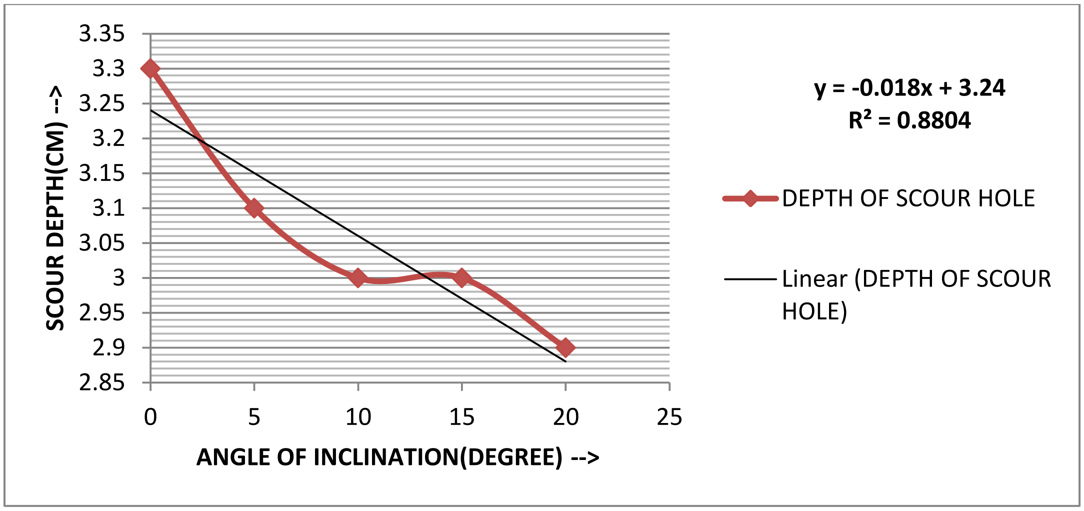
Discussion: In the above graph we can see as the angle of inclination increases, the scour depth decreases respectively.



GRAPH 12: WIDTH OF SCOUR HOLE Vs INCLINATION ANGLE

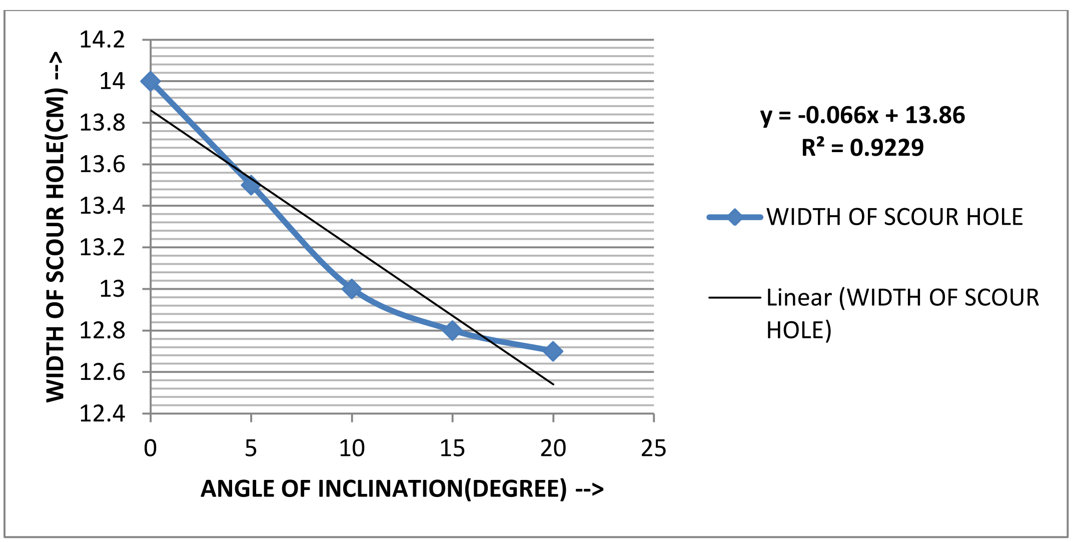
Discussion: In the above graph we can see as the angle of inclination increases, the width of scour hole decreases respectively.

SQUARE PIER (FOR FROUDE NUMBER = 0.300)



GRAPH 13: DEPTH OF SCOUR HOLE Vs INCLINATION ANGLE

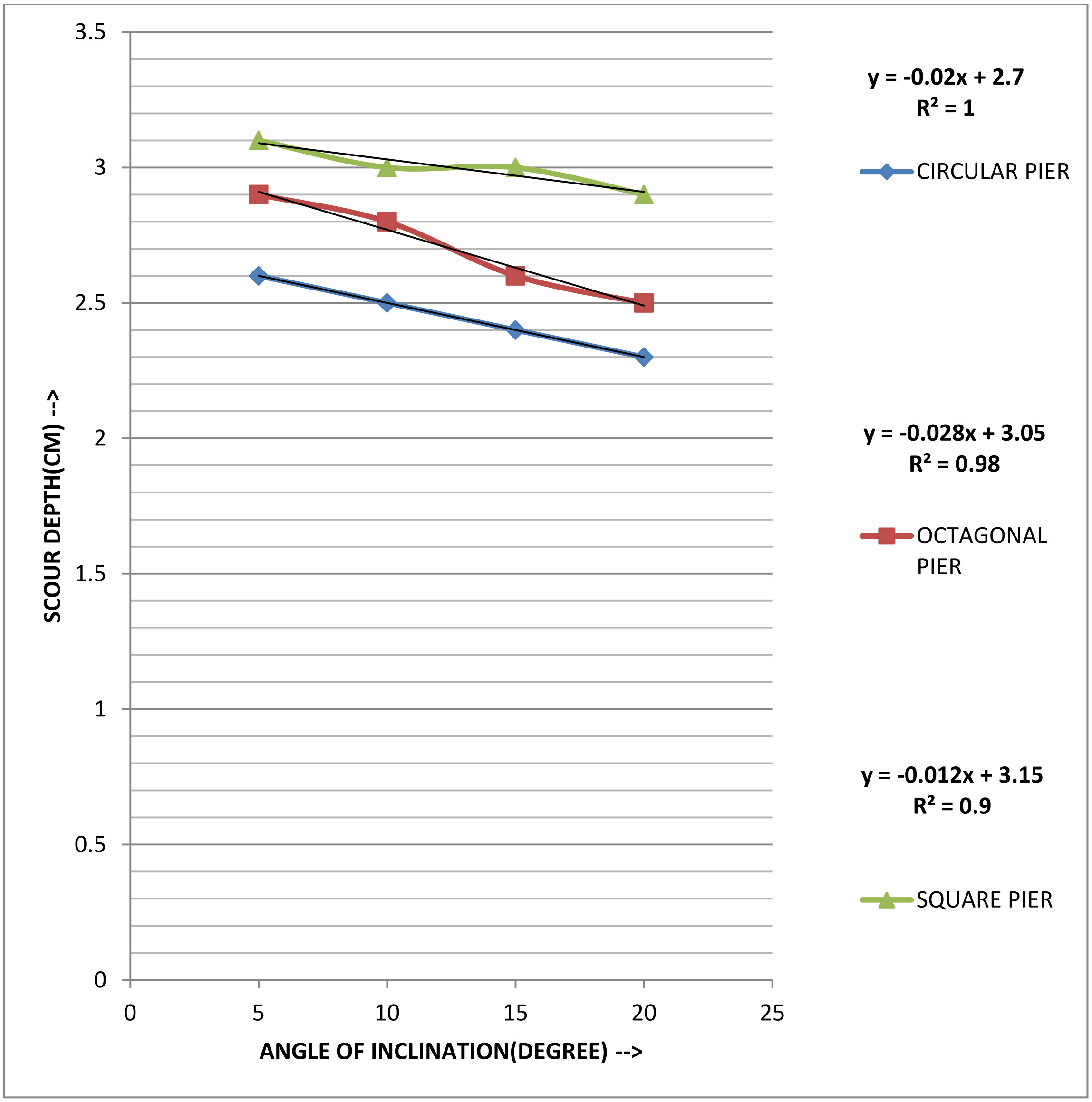
Discussion: In the above graph we can see as the angle of inclination increases, the scour depth decreases respectively.



GRAPH 14: WIDTH OF SCOUR HOLE Vs INCLINATION ANGLE

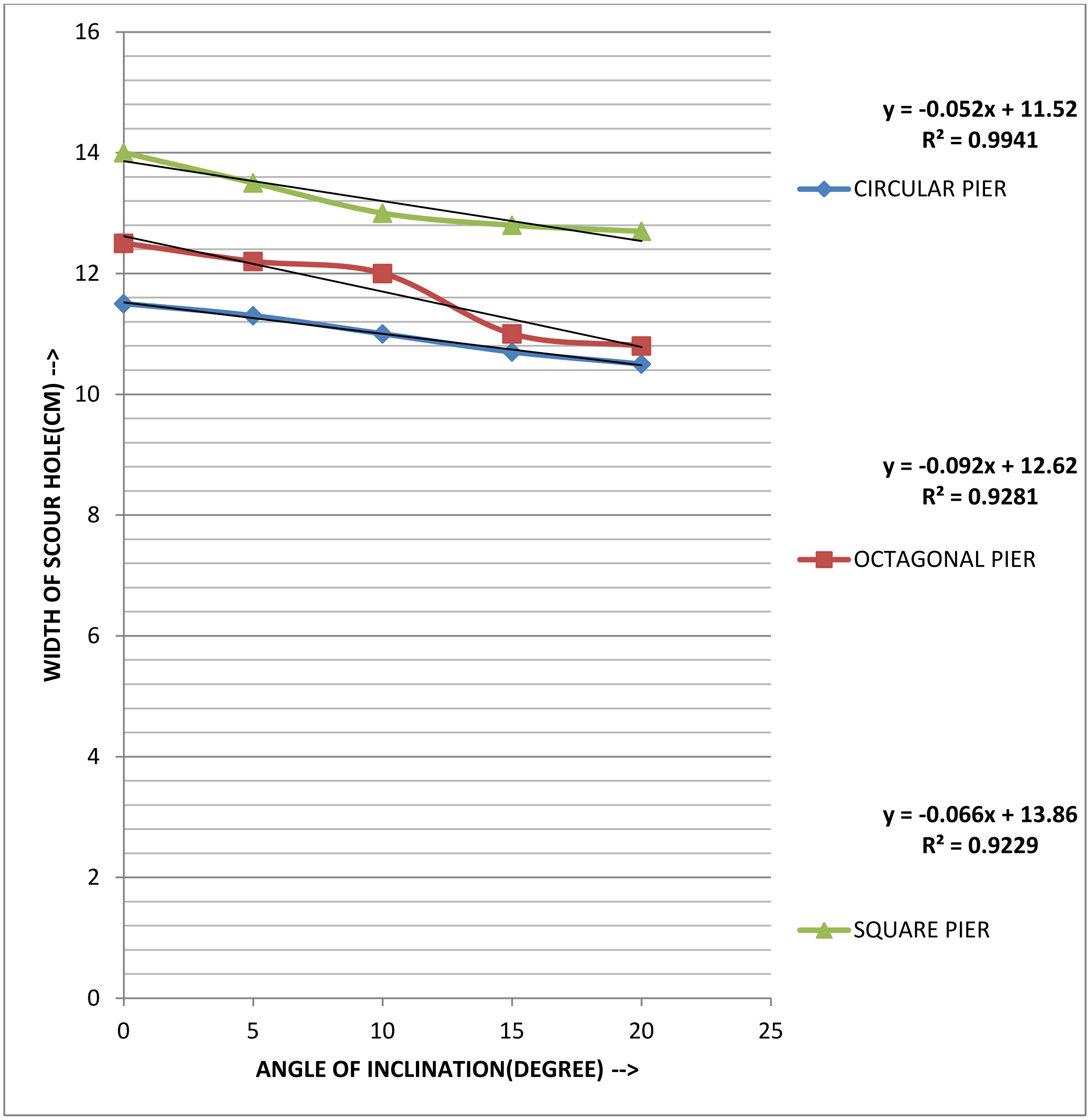
Discussion: In the above graph we can see as the angle of inclination increases, the width of scour hole decreases respectively.

CIRCULAR Vs OCTAGONAL Vs SQUARE (FOR FROUDE NUMBER = 0.300)



GRAPH 15: COMBINED GRAPH SHOWING DEPTH OF SCOURING Vs ANGLE OF INCLINATION

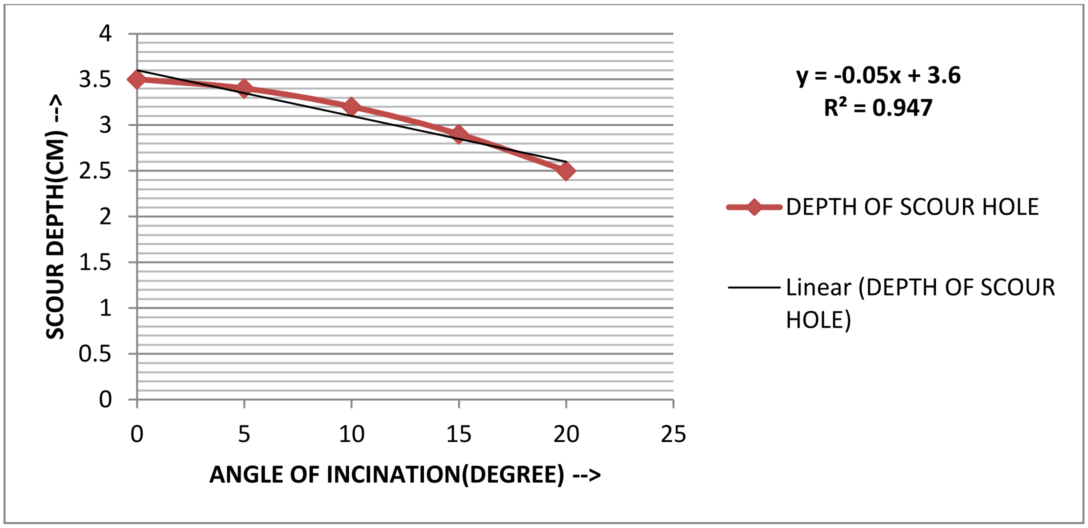
Discussion: In the above graph it can be clearly seen that as we increased the angle of inclination towards the downstream side, the scour depth got reduced in all the three shapes of pier i.e., circular, octagonal and square. However, the maximum reduction in scour depth takes place in the octagonal shaped pier.



GRAPH 16: COMBINED GRAPH SHOWING WIDTH OF SCOURING Vs ANGLE OF INCLINATION

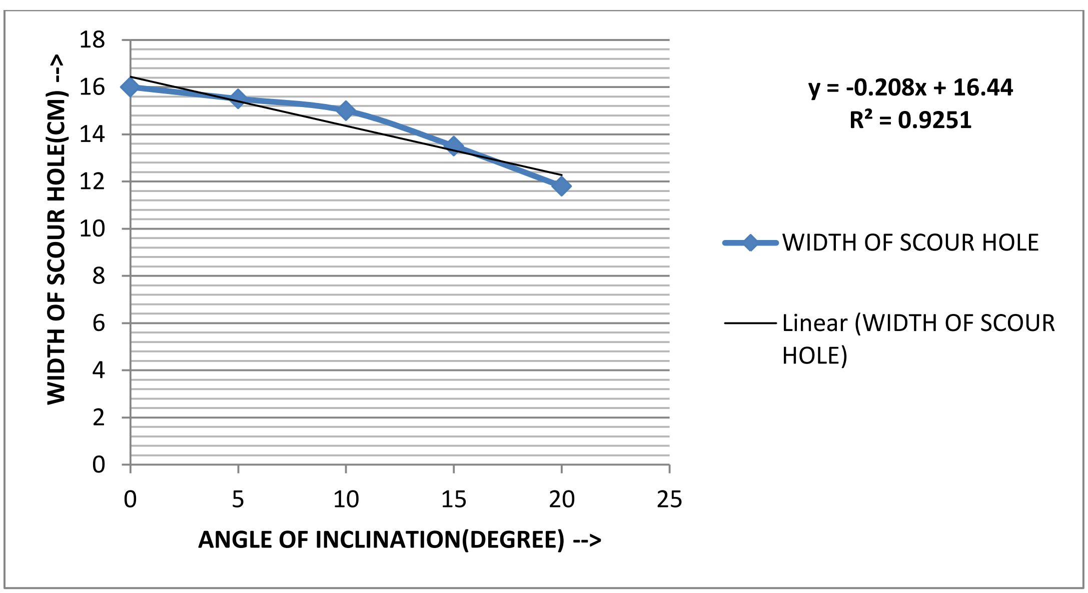
Discussion: In the above graph it can be clearly seen that as we increased the angle of inclination towards the downstream side, the width of scour hole got reduced in all the three shapes of pier i.e., circular, octagonal and square. However, the maximum reduction in the width of scour hole takes place in the octagonal shaped pier.

CIRCULAR PIER (FOR FROUDE NUMBER = 0.311)



GRAPH 17: DEPTH OF SCOUR HOLE Vs INCLINATION ANGLE

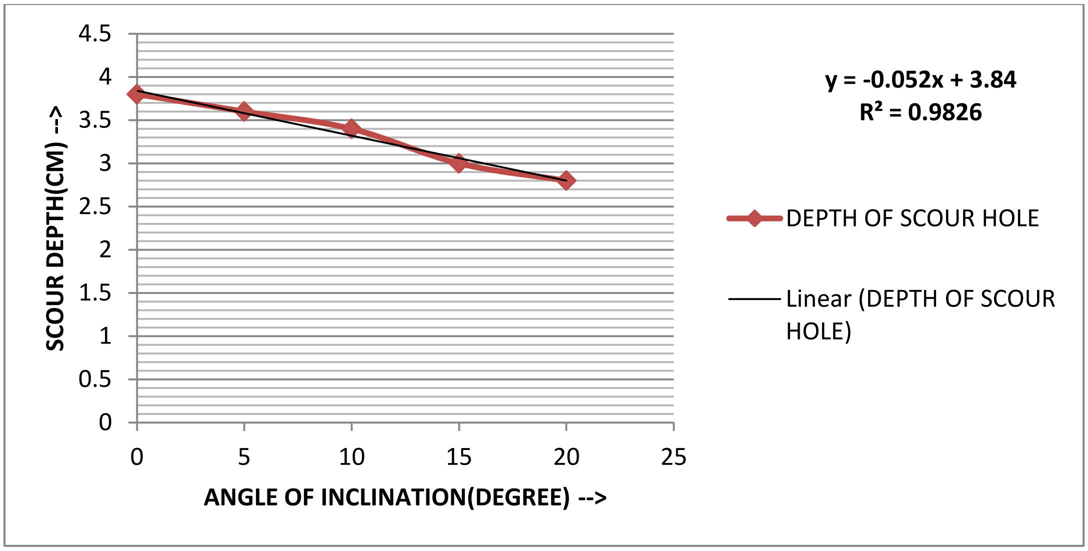
Discussion: In the above graph we can see as the angle of inclination increases, the scour depth decreases respectively.



GRAPH 18: WIDTH OF SCOUR HOLE Vs INCLINATION ANGLE

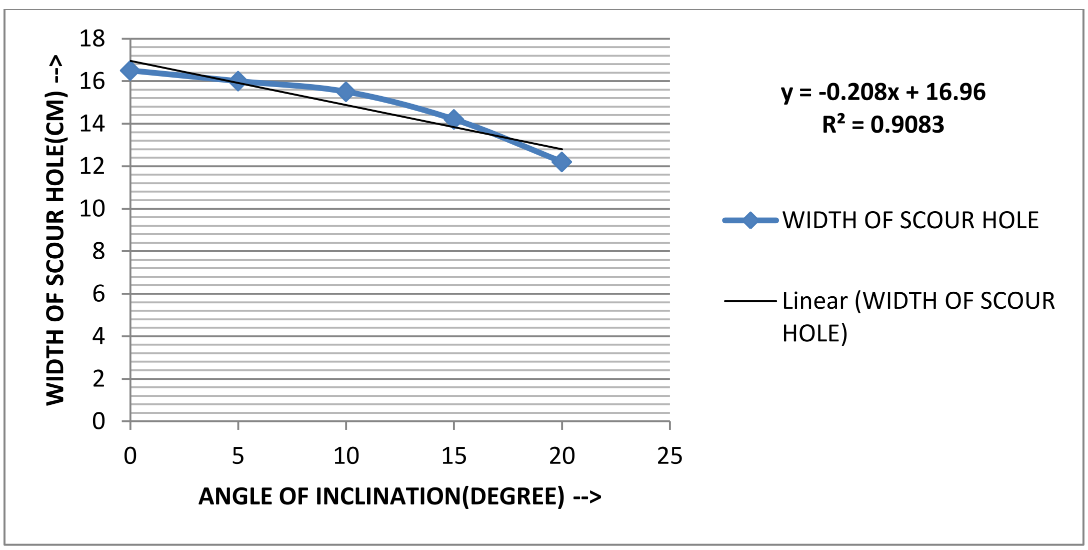
Discussion: In the above graph we can see as the angle of inclination increases, the width of scour hole decreases respectively.

OCTAGONAL PIER (FOR FROUDE NUMBER = 0.311)



GRAPH 19: DEPTH OF SCOUR HOLE Vs INCLINATION ANGLE

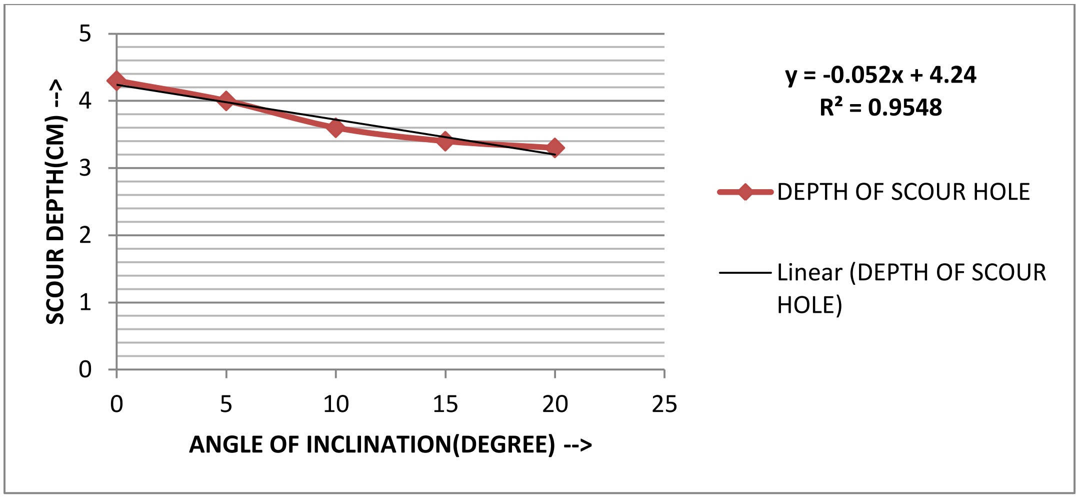
Discussion: In the above graph we can see as the angle of inclination increases, the scour depth decreases respectively.



GRAPH 20: WIDTH OF SCOUR HOLE Vs INCLINATION ANGLE

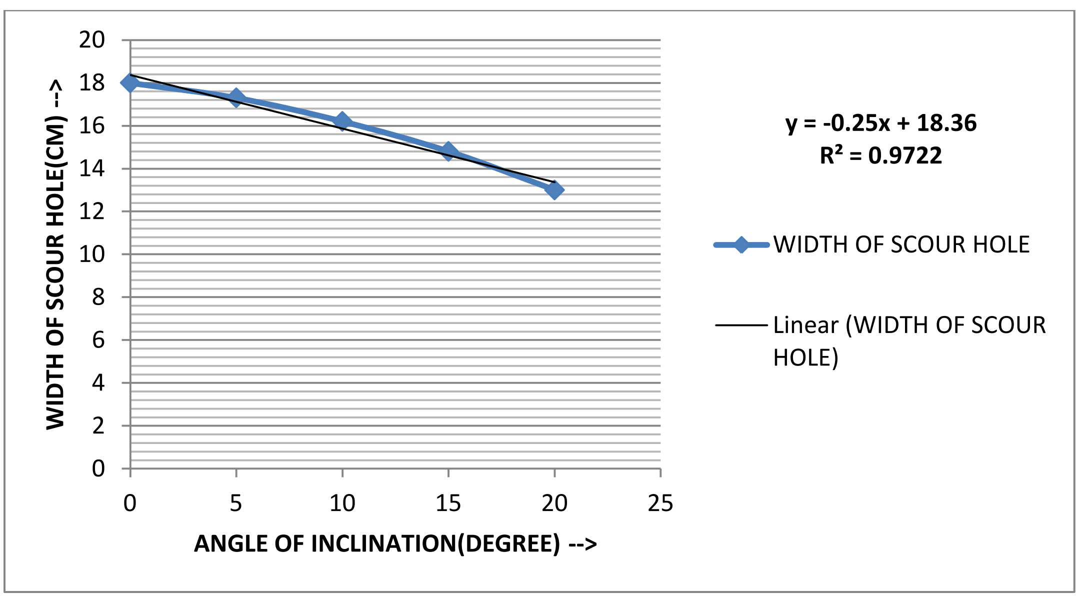
Discussion: In the above graph we can see as the angle of inclination increases, the width of scour hole decreases respectively.

SQUARE PIER (FOR FROUDE NUMBER = 0.311)



GRAPH 21: DEPTH OF SCOUR HOLE Vs INCLINATION ANGLE

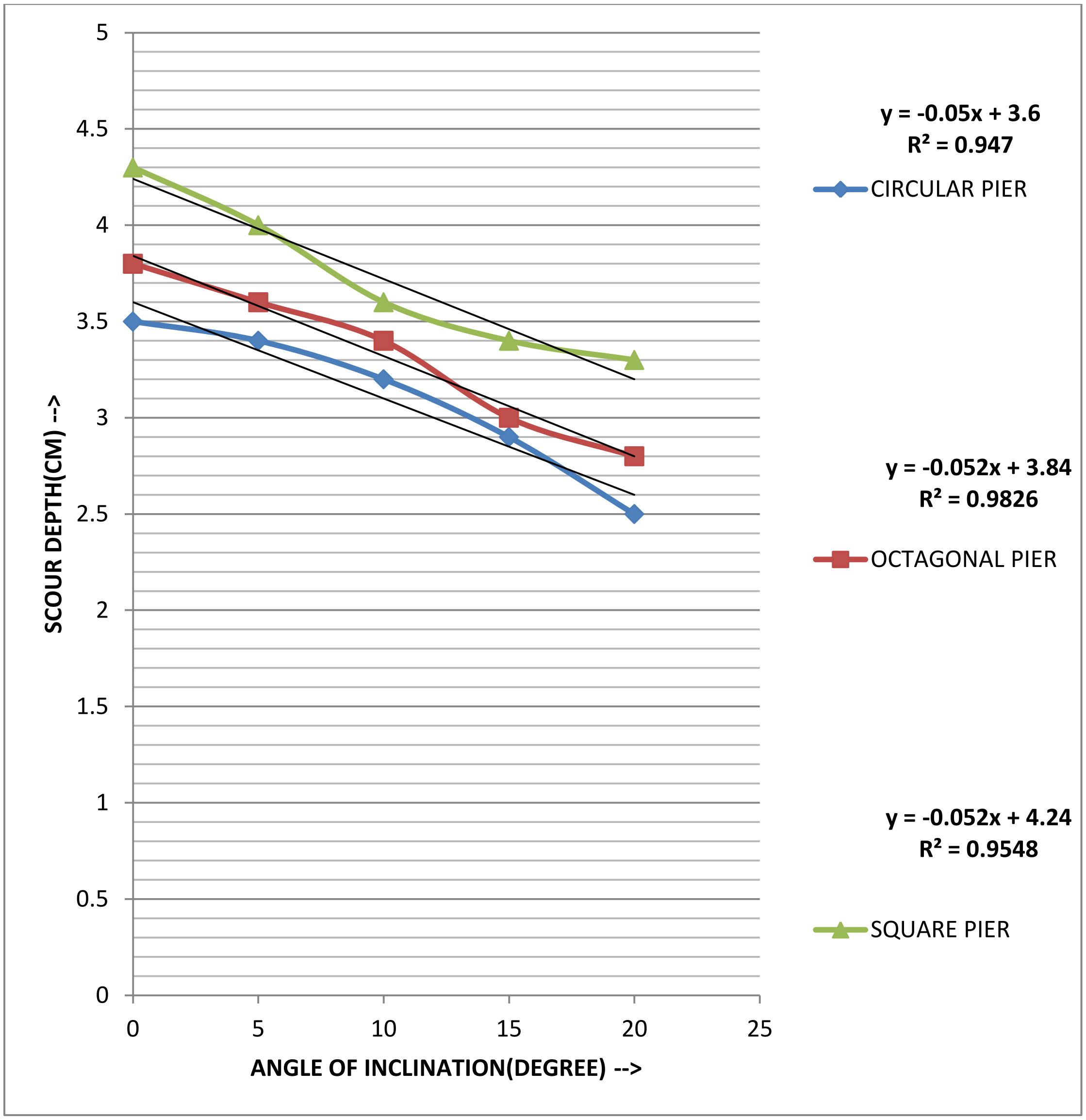
Discussion: In the above graph we can see as the angle of inclination increases, the scour depth decreases respectively.



GRAPH 22: WIDTH OF SCOUR HOLE Vs INCLINATION ANGLE

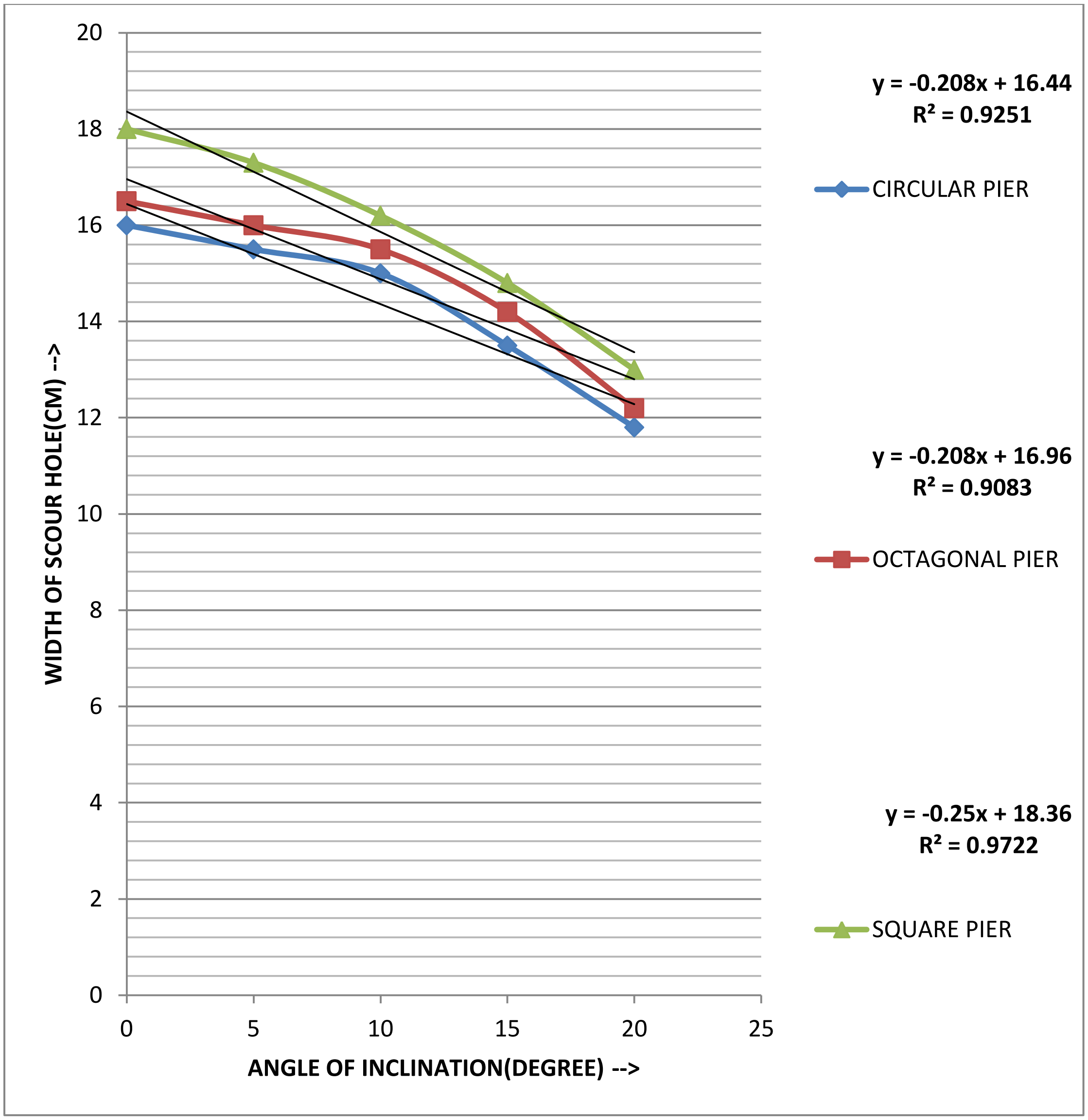
Discussion: In the above graph we can see as the angle of inclination increases, the width of scour hole decreases respectively.

CIRCULAR Vs OCTAGONAL Vs SQUARE (FOR FROUDE NUMBER = 0.311)



GRAPH 23: COMBINED GRAPH SHOWING DEPTH OF SCOURING Vs ANGLE OF INCLINATION

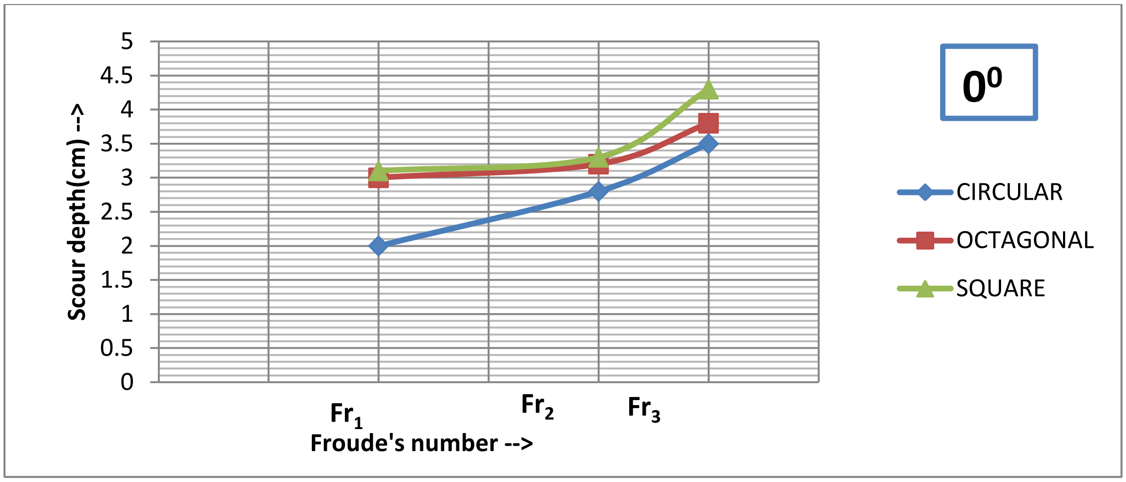
Discussion: In the above graph it can be clearly seen that as we increased the angle of inclination towards the downstream side, the scour depth got reduced in all the three shapes of pier i.e., circular, octagonal and square. However, the maximum reduction in scour depth takes place in the octagonal shaped pier.



GRAPH 24: COMBINED GRAPH SHOWING WIDTH OF SCOURING Vs ANGLE OF INCLINATION

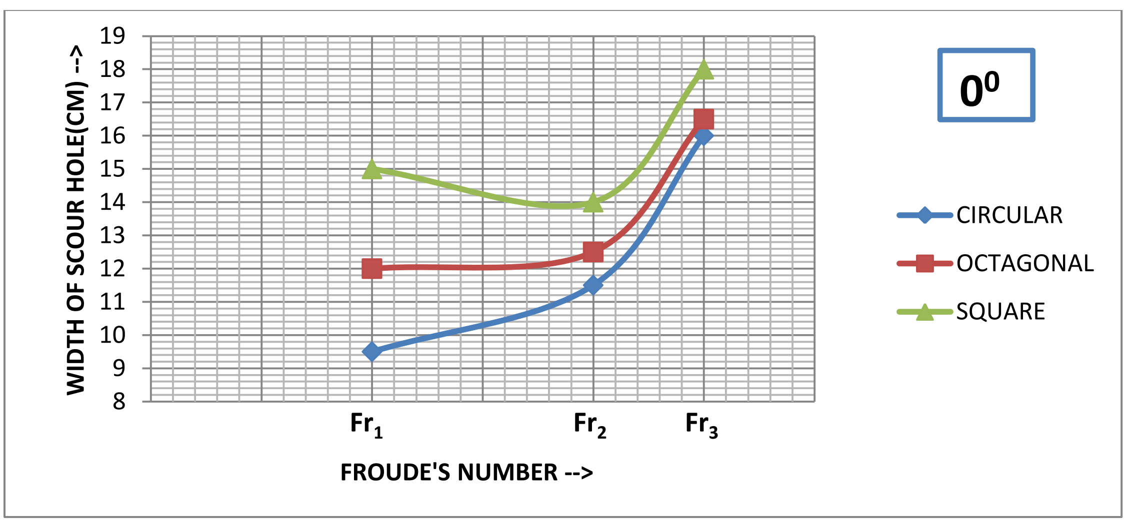
Discussion: In the above graph it can be clearly seen that as we increased the angle of inclination towards the downstream side, the width of scour hole got reduced in all the three shapes of pier i.e., circular, octagonal and square. However, the maximum reduction in the width of scour hole takes place in the square shaped pier.

SOME MORE GRAPHS:-



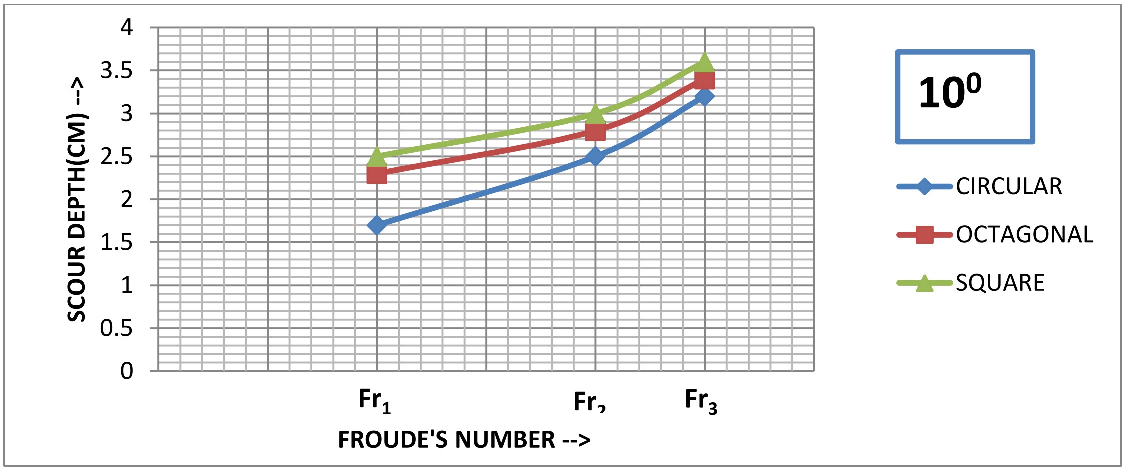
GRAPH 25: COMBINED GRAPH SHOWING VARIATION OF SCOUR DEPTH W.R.T. FROUDE'S NUMBER

Discussion: In the above graph it can be clearly seen that as we increased the Froude number, the scour depth increases for all the three shapes of pier.



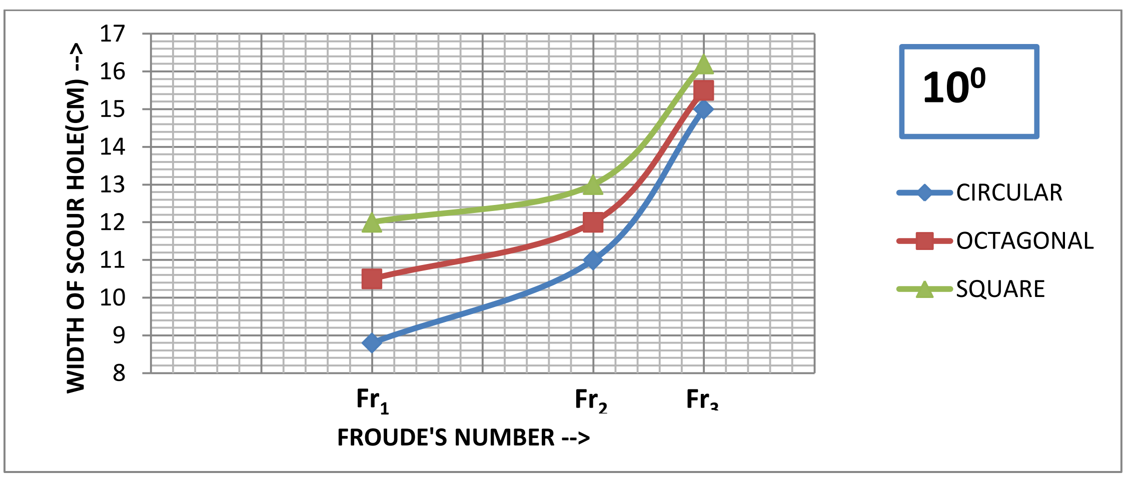
GRAPH 26: COMBINED GRAPH SHOWING VARIATION OF WIDTH OF SCOUR HOLE W.R.T. FROUDE'S NUMBER

Discussion: In the above graph it can be clearly seen that as we increased the Froude number, the width of scour hole increases for all the three shapes of pier.



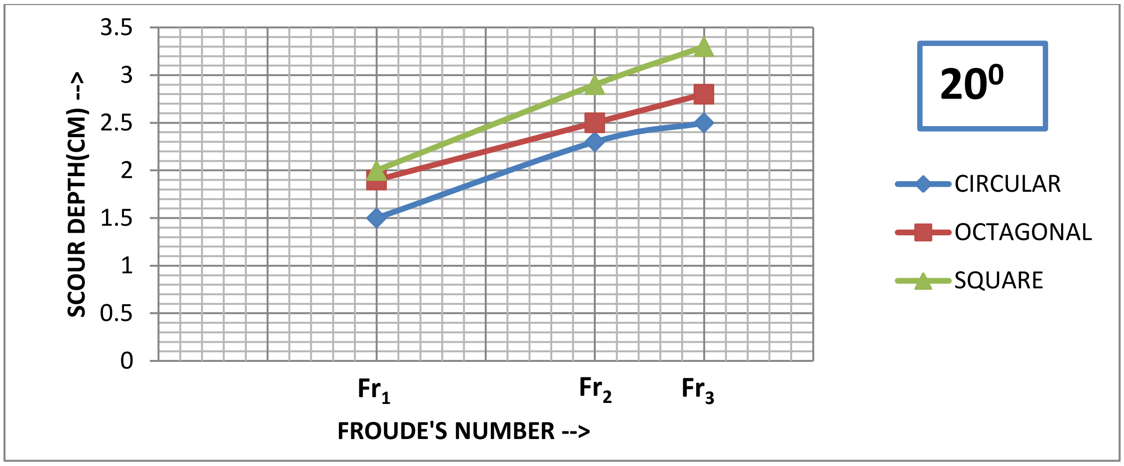
GRAPH 27: COMBINED GRAPH SHOWING VARIATION OF SCOUR DEPTH W.R.T. FROUDE'S NUMBER

Discussion: In the above graph it can be clearly seen that as we increased the Froude number, the scour depth increases for all the three shapes of pier.



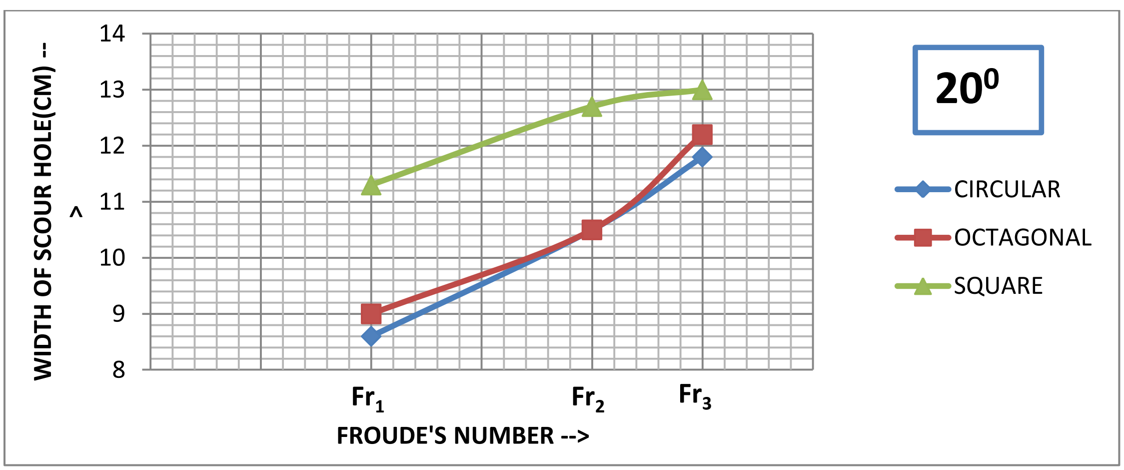
GRAPH 28: COMBINED GRAPH SHOWING VARIATION OF WIDTH OF SCOUR HOLE W.R.T. FROUDE'S NUMBER

Discussion: In the above graph it can be clearly seen that as we increased the Froude number, the width of scour hole increases for all the three shapes of pier.



GRAPH 29: COMBINED GRAPH SHOWING VARIATION OF SCOUR DEPTH W.R.T. FROUDE'S NUMBER

Discussion: In the above graph it can be clearly seen that as we increased the Froude number, the scour depth increases for all the three shapes of pier.



GRAPH 30: COMBINED GRAPH SHOWING VARIATION OF WIDTH OF SCOUR HOLE W.R.T. FROUDE'S NUMBER

Discussion: In the above graph it can be clearly seen that as we increased the Froude number, the width of scour hole increases for all the three shapes of pier.

CONCLUSIONS

In our experimental study, we found that the effects inclination of a bridge pier on local scouring around a bridge pier. The results revealed as follows:

- As we increased the angle of inclination of a bridge pier towards the downstream direction from 0^o to 20^o w.r.t the vertical axis, the local scouring around a bridge pier got reduced accordingly.
- The scouring depends on the shape of a bridge pier i.e., scouring is minimum for a circular pier , intermediate for an octagonal pier and maximum for a square pier of same dimensions.
- Dimension of a pier is also a function of scouring. Greater the obstruction to the flow, greater is the scouring around it.
- The scouring also depends on the Froude number i.e., as we increased the Froude number , the scouring also got increased.

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