EXPERIMENTAL STUDY FOR THE REDUCTION OF SCOUR AROUND CIRCULAR PIER

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Submitted By

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CANDIDATE'S DECLARATION

I, Sangeeta, ROll NO. 2K17/HFE/06 of M.Tech. Hydraulics and Water Resources engineering, hereby declare that the project Dissertation titled "**Experimental study for the reduction of scour around circular pier**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma , Fellowship, or other similar title or recognition.

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ABSTRACT

The flow pattern around a bridge pier is complex to understand, and the complexity increases with the development of a scour hole. As a result of scouring in piers, collapse of piers in bridges can easily occur so it is very important to understand the variation of flow in and around the piers to take some factor of safety in constructing piers .It is an important task that design engineers in practice predict the local scour around bridge piers as accurately as possible because excessive local scour around bridge piers unbalance and demolish the bridges. Many equations have been proposed previously by various researchers, based on their experimental findings, but no general method has been developed so far due to the complexity of the topic.

In this study our aim is to simulate the flow around pier and providing the protection devices around the piers. Collar plates of circular and square shapes by varying the diameter of the collar plates and two piers in line by varying the distance between them were used for the reduction in the scour depth. The size of collars considered for the study was 2D,3D,4D and 5D.For two piers setup distance between the piers was varied i.e. 2D,3D,4D and 5D,where D is the diameter of pier.

Results of the present study shows circular collar with 5 D size was found to be most effective about 97.78 % reduction in scour was noted in comparison to single pier without collar, in case of square collar 5D size collar give best reduction about 77.11%. and in case of Two piers the tread of scour depth was decreasing up to 4D distance and started increasing for 5D so, 4D distance was best suited for two piers.

Key words: Scour, Collar Plates, Square and Circular Plates, Two Piers

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Chapter -1

INTRODUCTION

The topics such as river flow and their concerned problems like deformation of river, sediment transportation, scouring and flooding are the major issues in the field of ‘Hydraulic Engineering’. Out of these issues, scouring has resulted into the major failures at bridge sites. Bridge, being an important massive and expensive civil engineering structure, its design should be carried out with extensive care. Scouring especially near the pier of the bridge is featured as one of the major cause of bridge failure. According to the previous records, it was observed that at least one out of every three major bridge failure was attributed alone by the scouring around bridge pier or by scoured bridge foundation. To ensure proper working of hydraulic structure, their causes of failure and deep understanding of flow structures is necessary and so this research is carried out to serve a novel approach in this regard.

Not only hydrological but also there observed change in morphological characteristics of rivers due to construction of bridges over these rivers. The existence of bridge piers and supports across a river would deplete water flow cross section, cause the flow to afflict the piers, and redirect stream lines towards river bed floor, thus creating horse-shoe, swirling, and rising vortices, a leading engender of local scouring at bridge piers. During the flooding season every year, many bridges are demolished due to scouring and slippage at bridge piers, thus cutting off the very communication lifelines to the flooded areas and interrupting relief operations. For these reasons, studying bridge pier scouring is important.

Scour is due to the erosive action of flowing water, which gouge and carries away bed and bank materials of streams, and from around bridge piers and abutments and is also one of the leading causes of bridge failure. The scour removes the bed materials around the foundation of the bridge which results in submission of the foundation and imperil the stability of the bridge. The scour is accountable for about 60% of bridge failures (Lagasse et al., 1997) resulting in loss of lives and huge economic losses. The cost of reconstruction, the cost of maintenance and monitoring of the existing structure and disturbance in traffic movements all precise to a huge economic loss due to scour.

Scour occurrence is liable and more frequent when there is high discharge. High discharge implies that the stream velocity is much more higher than the limiting bearing discharge velocity of river bed materials. It takes place in the domain of a structure when the flow gets amend due to the presence of the structure in such a way that there is an increase in the bed shear stress. The shear stress around the structure eventually gets reduced by enlargement of the flow cross-section due to scour. Underestimation of the scour depth and its areal extent results in design of too shallow a foundation which may consequently cause exposure of foundations endangering the safety of the bridge, over-rated of the scour depth results in uneconomical design of the piers.

The complex process of scour development is poorly understood as evident from the literature survey. To improve our understanding, a more detailed description of the flow field must be obtained..Although there has been significant studies in the past regarding the problem of scouring flow but it is still very tough job to study the flow for the given conditions .The flow around a bridge has various scales of length and time so it is very complex and difficult to predict correctly. The flow characteristics are highly variable due to different types of piers and channel bed geometry.

This experimental research considers the bridge hydraulics problem where the flow amends when it interacts a obstruction like bridge pier and creates scour hole around it and may lead to bridge failure. The understanding of flow field around a pier is one of the most important aspects of bridge hydraulics. Flow approaching a bridge pier has tendency to move downward towards the channel bed which has implication in removing sediments from the channel bed. Excessive sediment removal or scouring is alarming for the safety of the bridge pier, which can eventually lead to uprooting of pier from the channel bed and yield bridge failure. The purpose of the study is to experimentally predict the flow around circular bridge pier and change in scour after using square and circular collar of different sizes and changes in scour for two pier arrangement at different center to center distances.

1.1 Types of scour

Scour is the process of removal of bed materials due to erosive action of flowing water in an erodible channel .The amount of drop in the streambed level below the normal river bed level of the river earlier to the initiation of scour is denoted as the scour depth. A scour hole is defined as depression left behind when sediment is washed away from the riverbed in the locale of the structure. The scour can be broadly classified into three types based on the location and major cause of the scour i.e. (i) local scour, (ii) contraction scour and (iii) aggradations and degradation which is also known as general scour. Total scour at a abutment or bridge pier consist of three components:

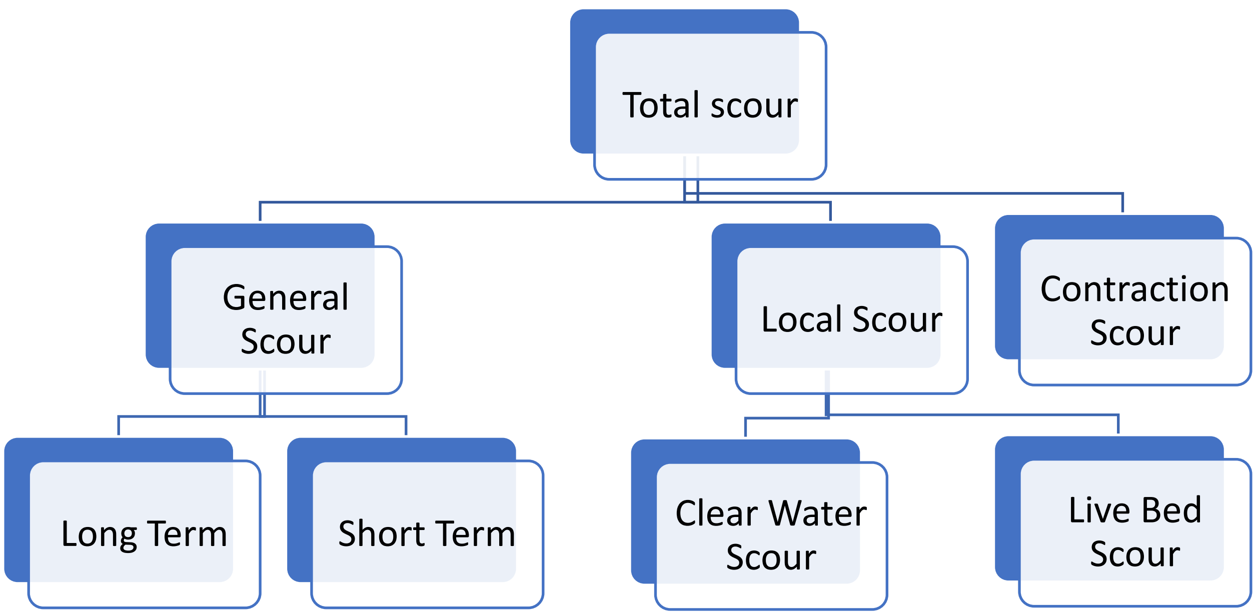


Figure 1 Representation of classification of scour (Melville, et al., 2000)

1. Prolonged degradation or aggradation of bed of the river

2. General scour at the bridge

    a. Contraction scour

b. General scour

3. Local scour at the piers or abutments.

1.1.1 Aggradation and Degradation

Aggradation and degradation are long-term streambed elevation changes due to natural or man-induced causes which can influence the reach of the river on which the bridge is located. In laymen's language Aggradation is the process in which eroded material from either upstream of watershed or channel upstream gets deposited or somewhere, whereas degradation is simply defined as erosion or scouring of bed of the river, due to a deficit in sediment supply from stream. Degradation scour is caused either by natural phenomena such as channel straightening, climate changes, and land activities (landslides, mudflows) or by human activities such as land-use changes, dam and reservoir construction, river bed material mining, and channel alterations (Brandimarte et al. 2012)

1.1.2 Contraction Scour

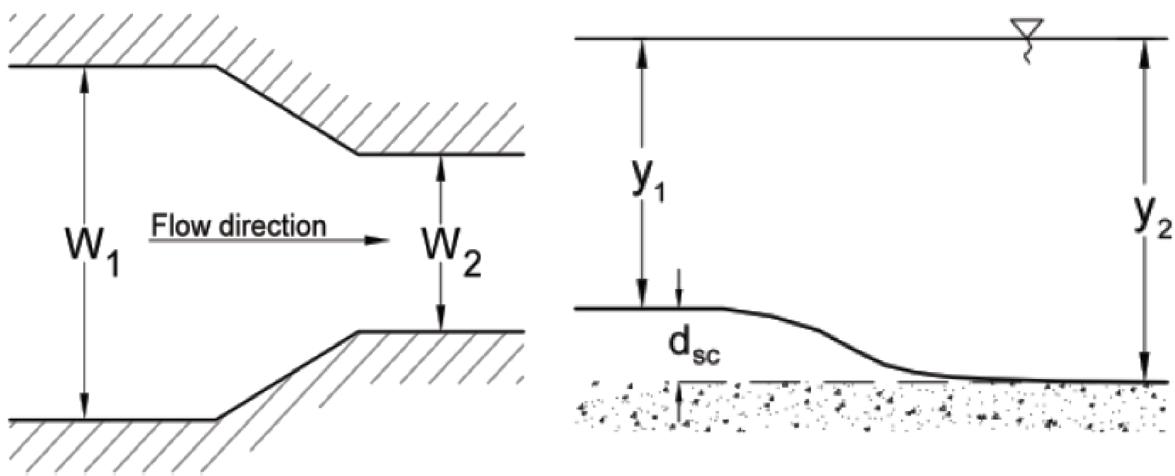
Contraction scour of a river involves the removal of material from the bed across all or most of the channel width in the bridge reaches due to the increased velocities and shear stress on the bed. Contraction scour often occurs when the bridge embankments encroach on the floodplain or into the main channel. Contraction scour to be considered is of two types.

a) Live bed scour-It occurs when there is transport of bed material in the upstream reach into the bridge cross section. With live-bed contraction scour the area of the contracted section increases until, the transport of sediment out of the contracted section equals the sediment transported in.

b)Clear water scour-It occurs mainly when shear stress exceeds the limit of critical shear stress. There is no net motion of materials of river bed is noticed in clear water scour only sediments get transported. So in Clear water scour bed material is not moved from either upstream or downstream section whereas the sediments which are in suspension are transported mainly from upstream to downstream.

1.1.3 General Scour

General scour is commonly defined as the process of lowering the level of the streambed across either the stream or waterway bed near the bridge. This drop may be uniform across the bed or non-uniform, that is, the depth of scour may be more in some parts of the cross section. General scour may result from contraction of the flow, which results in removal of material from the bed across all or most of the channel width, or from other general scour conditions, such as, flow around bends where the scour may be concentrated near the outside of the bend. General scour is different from long-term degradation, in that general scour may be cyclic or related to the passing of the flood.



(a) (b)

Figure 2 Contraction scour (a) Plan view (b) Profile view (Yanmaz, 2002)

1.1.4 Local Scour

The vortex formation at the base is the general mechanism responsible for local scour around piers of the bridge and the abutments. The vortex or the whirlpool initiates from the base of the river and cut the material of river bed. As rate of transportation of the incoming sediments which is much more lesser than the outgoing sediment transport rate, which increases as the scour hole advances. Also the strength of vortices is reduced with increase in the scour hole depth, the strength of the vortices is reduced. In 2001, Federal Highway administration gave an empirical result through which depth of scouring in local as well as general contraction scour are related to each other as per factors of ten. Wake vortices are moreover a sort of vertical vertices which are formed at downstream of the bridge structure. Local pier scour initiates with increase in flow velocity when it overpower the safe stagnation.

1.2 Local scour mechanism around bridge piers

Local scour the erosive action of accelerated flow due to the presence of an obstacle (pier) in rivers and streams. As the flow passes the pier, mean flow velocity increases and vortices are formed at piers face. Many researchers (Melvile 1975); (Melville and Coleman 2000);(E.V.Richardson and Davis 2001); and (Y.-M. Chiew September, 1992) in the past have believed that the basic mechanism of local scour is the formation of vortices around the bridge piers. The figure below is showing the different components which contribute to scouring around piers.

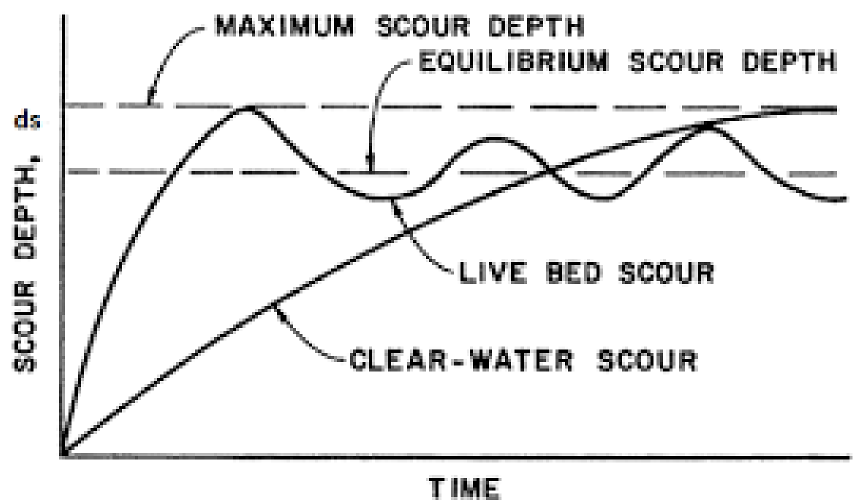


Figure 3 Local scour around bridge piers as a function of time (E.V.Richardson, et al., 2001)

1.2.1Flow Pattern Around Cylindrical Piers

The flow pattern around cylindrical pier is a very complex problem. To understand this problem several investigators have made detailed studies on flow patterns. Depending on these studies which were carried out by (Melvile 1975); (R. Ettema 1976); (Qadar 1981); (Y. Chiew

1984);(Melville and Coleman 2000); (E.V.Richardson and Davis 2001) the results of the flow patterns are divided into four components:

a) Down flow in front of pier

b) Horseshoe vortex

c) Wake vortices

d) Bow wave

As reported by (Melville and Coleman 2000), the principal features of the flow field at a bridge pier are down-flow at upstream side of the pier, the horseshoe vortex at the base of the pier, the surface roller at upstream side of the pier and wake vortices at downstream of the pier.

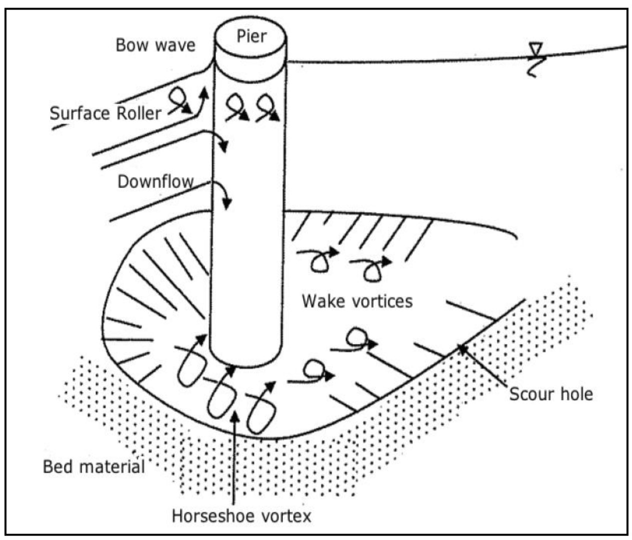


Figure 4 Representation of scour mechanism (Ettema, et al., 2011)

1.2.1.1 Down flow in front of pier

When the water is flowing in the river or stream it comes in contact with the face of pier, depth of the flow increases and the formation of stagnation place took place at the face. Thus this formation results in the pressure difference between upstream and stagnation point. According to (A. Melih Yanmaz and Altinbilek 1991), the increase in flow depth depends on approach flow velocity and pier shape. Since velocity decreases gradually from water surface to the bed level, stagnation pressure also decreases downwards as it depends on approach velocity. That means there exists a high pressure at the water surface and downward pressure gradient to the bed. In the presence of a scour hole, the strength of Down flow at the face of the pier gets through to its utmost value just beneath the bed level.

According to (A.J.Raudkivi and Breusers 1991) the ultimate velocity of the down flow presents itself at a distance of 0.05 to 0.02 pier diameters upstream of it at any level, being closer to the pier taken down. Furthermore, down flow reaches its maximum velocity value in the scour hole approximately one-pier diameter (D) below the bed level and can reach up to 80% of the mean approach velocity.

1.2.1.2 Horseshoe vortex

The interaction of approach flow and down flow results in the formation of vortices at the upstream side of the pier. These vortices are termed as horseshoe vortex because of the shape they generate at the scour hole. Horseshoe vortex is formed after the development of scour hole around a bridge pier. As it formed as a consequence of scour, horseshoe vortex plays an important role in transportation of bed material away from scour hole. Horseshoe vortex loses its strength and becomes a part of general turbulence after extending downwards for a few pier diameters (A.J.Raudkivi and Breusers 1991). The intensity of the horseshoe vortex directly depends on the degree of the turbulent flow and pier geometry (Yanmaz 2002). As it is out of the question to change the flow conditions, appropriate pier geometry should be chosen to reduce the effects of horseshoe vortex.

1.2.1.3 Wake vortices

Due to the shear stress gradients at the upstream side of the pier, the wake vortices originate from flow separation at the sides of the pier. With the effect of down flow, wake vortices are transferred downstream by the approach flow and behave like vacuum cleaners picking up and carrying the sediment entrained by the down flow and horseshoe vortex(Melville and Coleman 2000). The strength of wake vortices decreases very quickly as the distance downstream of the pier increases. When compared to horseshoe vortex, the intensity of wake vortices is weaker. Thus, maximum scour depth occurs at the upstream face of the pier.

1.2.1.4 Bow wave

Waves which rotates in the counter direction of the horseshoe at the upstream side of the piers on the water surface are termed as bow waves. The formation of bow waves results in the increase of water depth as the flow approaches the pier. Bow wave has an influence on horseshoe vortex. As long as depth of flow decreases, bow wave affects the horseshoe vortex to become weaker, so local scour depth is reduced for shallow flow (E.V.Richardson and Davis 2001).

1.3 Sediment Transport

1.3.1 Basics of Sediment Transport

The fragmental material formed by the physical and chemical disintegration of rocks is known as sediment. The size of the sediment varies from the large boulder to colloidal size of fragments with a variety of shapes. Once the sediment particles are detached from their original source, they may either be transported by gravity, wind or water. Usually the sediments can be transported in three different modes of particle motion namely: rolling or sliding particle motion; saltation or hopping particle motion; and suspended particle motion.

When the value of shear velocity at the bed just exceeds the critical value, the bed material will start rolling or sliding in continuous contact with the bed. Further increasing the value of bed shear velocity, the particle will move along the bed by more or less regular jumps, which are called sediment transport by saltation. The transport of sediment particles by rolling and saltation is called bed load transport. As the bed shear velocity exceeds the fall velocity of the particles, there is lifting of sediment particles; as a result the particles may go into suspension. The transport of sediment particles in this way is called suspended load transport.

1.3.2 Threshold of Sediment Motion

(Melvile 1975), presented the definition of threshold of motion or critical condition as given in Sedimentation Manual published in 1966. It states that "when the hydrodynamic force acting on a grain of sediment has reached a value that, if increased even slightly will put the grain into motion, critical or threshold conditions are said to have been reached."(Chaudhary 2007). The drag force exerted on sediment particles on the riverbed is the main factor for initiating the sediment motion. For the initiation of sediment motion the applied drag force must exceed a threshold value. The resistance to motion is due to cohesion in the case of clay-rich sediment and from the Coulomb friction in the case of non-cohesive sediment. As shown in Figure 6, a simplified case of sediment motion, for a small bed slope, such that S<<1.

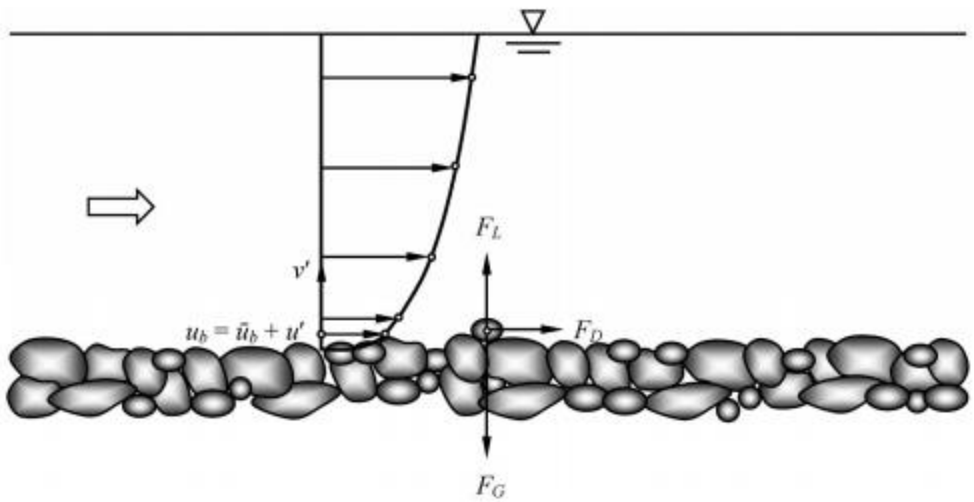


Figure 5 Threshold condition for the sediment entrainment (Bose, et al., October, 2013)

1.4 Causes of scour

- Stream channel instability results in river erosion and change in angle-of-attack can be responsible for bridge scour.
- Debris can have a substantial affect on bridge scour in different ways. Aggradation of material under a bridge can reduce the size of the waterway and lead to contraction scour . A build-up of debris near the abutment can increase the obstruction area and increase local scour. Debris can deflect the water flow, changing the angle of attack, increasing local scour. Debris might also shift the entire channel around the bridge causing increased water flow and scour in another location.
- Loose alluvial bed material can be easily eroded. However, it should not be assumed that total scour in cohesive or cementious soils will not be same as in non-cohesive soils, the scour takes more time to develop.
- Urbanization is one of the cause of increasing flood magnitudes and causes earlier peak hydrographs , yields in large stream velocities and higher degradation.

- Scour can get affected by channel upgradation or the extraction of gravel (above or below the site) can chnage water levels, flow velocities, bed slopes and sediment transport properties . For example, if an alluvial channel is straightened, widened or changed in a way that results in increased flow-energy condition, the channel will divert towards a lower energy state by degrading upstream, widening and aggrading downstream.
- The potential for scour is more for small opening ratio as it leads to large waterway velocity and hence large scour.
- Scour depth may also get affected by the lateral stability of a river channel , as movement of the channel may result in unalignment or incorrect position of the bridge with respect to the approach flow.
- Under initial clear-water conditions maximum scour depth may occur , not necessarily at peak flood levels and when live-bed scour is underway.
- When the flow is within the banks relatively high velocities can be experienced as compared to flow spread over the floodplains at the peak discharge and hence leads to high scour.
- Live-bed scour takes place where the upstream shear stress is more than the critical value and the bed material upstream of the crossing are moving.
- The maximum local scour depth is attained when the size of the scour hole reduces the local shear stress to the critical value such that the flow is no longer able to remove bed material from the scoured area.

Conditions favouring clear water scour are:

- Coarse bed material that is difficult to be transported
- artificial reinforced channels or vegetative channels where velocities are high only due to local scour, or
- Flat bed slopes during short flows.

1.5 Factors affecting scour

The factors affecting the scour depend upon the type of scour.

For contraction scour, the main affecting factor is magnitude of constriction by which the waterway became narrower and also the type of vegetation in the catchment area as the floating woody debris from the plantation also narrow the waterway by clogging(Kamil et. al,2016).

The main factors affecting in case of local scour are geometry of the bridge, the type, shape and size of the pier and the orientation of the pier in the normal flow of water etc. The armor phenomenon also affects the local scour. When the finer bed materials are eroded an armor layer is formed by the coarser materials; but deeper scour holes are expected when the flow exceeds the mobility threshold for the coarser materials.

In case of general scour, the main factor involved are natural and human activities factors. The natural factors involved are geomorphology of the catchment area, river bed characteristics and natural disasters such as earthquake induced riverbed uplift and human activities involves construction of hydraulic structures and riverbed mining etc.

The local scour developed around the bridge pier depends upon a number of factors, the most important ones being

1. Approach Flow Factors: Average flow velocity and its initiation with the pier axis, depth of flow, Sediment transport rate, flow depth, unsteadiness of approach flow and obliquity of flow are approach flow. Stream flow characteristics such as velocity and flow depth significantly increases scour depth. As the velocity and flow depth on upstream increase, it results into increase in the rate of erosion and scour depth on the downstream .Along with velocity and scour depth, the direction of flow with respect to alignment of pier should be well studied because as the angle of incidence increases, exposed width increases which results into increase in scour depth (Jain and Modi et al., 1986) . (Melville and Sutherland2) confirmed that when (depth of flow/pier width) ratio is greater than 2.6, scour depth is irrespective of the depth of flow but when the ratio is less than 2.6,the scour depth depends on the depth of flow.

2. Fluid Characteristics: Mass density , Specific weight of fluid and Dynamic viscosity of the fluid.

3. Bed Material And Its Characteristics: Median size , geometric standard deviation, specific weight of the sediment , and stratification. Maximum depth of clear water scour is also a function of standard deviation of the grain size distribution of the bed material (ag). The ability of graded bed material mixture to form armor layer in scour hole distinguishes scour development in uniform and non-uniform sediment. For given flow conditions, each fraction in given mixture of bed material has different mobility depending on its size relative to the arithmetic mean size da. This is responsible for selective transport and cause armoring of bed material in the scour hole. As the standard deviation of the grain size distribution of the bed material increases, larger sand particles accumulate on the surface and form an armor layer in the scour hole resulting reduction in the scour depth. As mentioned by Kothyari et al. (1992), Ettema (1980) and Kothyari (1992) that stratification in which relatively thin coarse top layer covers a thick bottom layer is the critical condition. Once the top coarse layer portion is scoured away, scour depth will rapidly increase. (Placeholder1)

4. Pier Characteristics - Scour depth is also affected by pier characteristics such as shape, diameter of bridge pier (Peggy A. Johnson,1991). The bridge shape affects the strength of horse-shoe vortex as well as separation of the flow around a bridge pier with a resulting effect on maximum scour depth. The length of the pier has a negligible effect unless the pier is not aligned with the flow. Greater the angle of attack of flow over the pier, greater will be effective pier width and scour depth. Scour depth will vary to some extend depending on shape of bridge pier(Richardson, 1988). Scouring is maximum in case of rectangular pier, 90% for circular pier whereas it is least, about 80% for sharp-nosed pier(Chang, 1988)..

1.6 Cases of bridge failure

Failure of the Schoharie Creek Bridge: In 1987 due to excessive scouring of foundation soils of Schoharie Creek Bridge, the I-90 New York State Thruway over it near Fort Hunter and the Mohawk River collapsed and resulted in ten fatalities (Lichtenstein, 1993). On 5th April, 1987 due to record rainfall the scouring exceeds the permissible and caused the bridge failure.

Tangiwai Disaster: On 24th December 1953, when the clock struck 22:21 the Whangaehu River bridge collapsed in the central North Island of New Zealand at Tangiwai, during the voyage of Wellington-to-Auckland express passenger train No. 626. The accident was so fatal that the locomotive along with first six carriages derailed into the river and there noticed death of 151 people. The main reason behind the accident was the collapse of the Tephra dam which in turn resulted in flooding in the Whangaehu River, this flood scoured one of the piers of bridge at Tangiwai only minutes before the train get to the bridge.

Hintze Ribeiro disaster: The inauspicious night of 4 March 2001 witnessed the Hintze Ribeiro disaster when the bridge made of steel and concrete (Hintze Ribeiro), collapsed in Entre-os-Rios, Castelo de Paiva, Portugal. The incident was very fatal resulted in the death of 59 people. It was more than 100 years old bridge which was collapsed due to uncontrolled sand extraction.

Glanrhyd Bridge collapse : In the morning of 19th October,1987 at about 05:27 the Glanrhyd Bridge collapsed due to excessive scouring, leaving the train on the Central Wales Line be derailed near near Llandeilo, Carmarthenshire, Wales. There revealed the death of four people.

Custer Creek train wreck: It was the worst rail disaster in history of Montana. On 19th June 1938 after the foundation being completely washed away by a flash flood, the bridge collapsed beneath near Saugus, Montana, south-west of Terry killing at least 47 people.

Objective

This study is carried out to fulfill following objectives:

I. To experimentally predict the flow around circular pier in uniform sand under clear water conditions.

II. To experimentally predict the flow around square and circular collar of different sizes and analyze the results for maximum scour reduction.

III. To experimentally study the effect of a other pier in front of main pier at varying distances for scour reduction under clear water conditions .

CHAPTER 2

LITERATURE REVIEW

2.1 Literature review for scour

(Youbiao Wang; Xiaofeng Liu, Changrong Yao; Yadong Li; Saizhi Liu; and Xun Zhang , 2018) carried experiments to study impact pressure and force of debris flows on round and square piers under three distinctive flow regimes i.e. Types A, B, and C .The grain Reynolds number and the modified Savage number, were used in combination for the classification of the three regimes. The critical grain Reynolds number value for separating Type A from Types B and C is 1.0 and the critical modified Savage number value for separating Type B from Type C is 0.002.It can be concluded that at large Froude number , the impact pressure coefficient attains a constant value of approximately 0.75 and 1.5 for Type A and Type B, respectively. Drag coefficient depends on pier shape and flow regimes. For Type A debris flow, the value is 1.23 for square piers and 0.58 for round piers .For Type B, the values for square and round piers are comparable ð≈0.9Þ. For Type C, the hydraulic model is not suitable because debris flow is not fluid like.

(Keshavarzi , 2018) carried out experimental investigation, over two bridge pier aligned in the direction of flow, in their research work to determine the effect of pier spacing on their maximum scour depth under clear water scour conditions. There were found variations in scour depth with change in spacing between two piers. They inferred from their research that scour depth at upstream of the front pier was recorded to its maximum when the spacing between the two piers was 2.5 times the diameter of pier. They developed two semi empirical equations for the prediction of maximum scour depth. These equations were viable for the calculation of scour depth at upstream of both front and rear piers. The scour depth, thus calculated from these equations, was a function of the pier spacing. For validation of newly developed equations, the scour depth calculated from these new equations were compared with the scour depth calculated from conventional method, and inferred that both are in good agreement with each other. The S/M equation showed the best performance as compared to the various equations tested and was highly recommended for its use in calculation of the equilibrium scour depth. Their findings are of huge importance when scouring is a major design criteria, these are used to fix the position of piers in the design of bridge.

(E.A. Elnikhely , 2017) experimentally studied the effect of cylinder blocks fixed on the back slope of the spillway on the scour hole dimensions downstream of spillway using different diameters, lengths, and arrangements of cylinder blocks with different discharges. The best dimensions of cylinder blocks obtained are L/B = 0.133, D/B = 0.1. It reduced the values of scour parameters by approximately 26% and reduced the deposition parameters dd/yup and Ld/yup by 28% and 22.2% respectively. The overall reduction of the scour and deposition parameters is about 25.55%. Case of staggered cylinder blocks over sloped spillway gives the smallest values of scour and deposition parameters. Statistical equations developed to predict scour parameters give a good agreement with the experimental data.

(Alireza Keshavarzi , Chij Kumar Shrestha , Bruce Melville , Hadi Khabbaz , Mohsen Ranjbar-Zahedani , James Ball ,2017) carried laboratory experiments to analyze the effect of the spacing between two circular piers aligned in the flow direction on the maximum scour depth at equilibrium. Different spacing are L = 1D, 2D, 2.5D, 3D, 4D, 5D, 6D, 8D, 10D and 12D.Results show that largest maximum scour depths for two in-line piers occurred at spacing of L/D equals to 2.5 and it was 22% higher than that of the single pier case. For L/D>2.5, the maximum scour depths at upstream pier decreased and became equal to that at a single pier at L/D approximately equal to 10. At L/D = 1, the maximum scour depth at upstream pier was equal to that for the single pier. For 1<L/D<2.5, the maximum scour depth at upstream pier increases rapidly as the spacing between the two in-line piers increase. Experiment results were used to analyze different scour depth equations and found that the equation proposed by Sheppard/Melville predicts the maximum asymptotic scour depth best within an error of ± 12%.

(Junhong Li and Junliang Tao , 2017) conducted experimental tests to investigate the effect of pier streamlining on bridge local scour under clear-water conditions using four different cases. Results showed that the pier with streamlined horizontal cross-section ,sloped nose and vertically straight sidewalls gave lowest value of both maximum scour depth and scoured volume at equilibrium. The scour rate was decreased around streamlined piers. Results verified previous studies and showed that pier streamlining can help reduce the local scour at piers and can serve as a effective counter-measure

(Wang , 2016) carried laboratory experimentations for the investigation of local scouring in open-channel flows. The research was carried out specifically around twin cylindrical piers in open-channel flows. They inferred from results of their experimentations that the scour hole formed due to clear water scouring around the upstream pier at varying pier spacing is approximately equal to that around an isolated pier. Though, the local scour depth around the upstream pier was more than that around the downstream pier. To develop a relationship between pier spacing and radical deviation region, they divided the local scour depth around the downstream pier into four different regions namely: a no-scour region, synchronous-scouring region, transition region, and a radical-deviation region.

(Y. Abdallah Mohamed , G. Mohamed Abdel-Aal , T. Hemdan Nasr-Allah ,Awad A . Shawky , 2016) carried experimental and numerical studies to investigate the effect of different contraction ratios and entrance angles of bridge abutment on local scour depth. A 3-D numerical model to simulate the scour and the k-e turbulence model to solve the Reynolds-stress term. Three contraction ratios(e= 2b/B = 0.37, 0.25, and 0.17) were used and it was found that , as the contraction ratio increases the local scour depth increases and vice versa.Also, the relative scour depth increases as the tail Froude number increases. The velocities created around bridge abutment increases in both vertical and horizontal direction as the contraction ratios increases. The entrance angle which maximum reduces the scour depth is 10 0 by 92%.The simulation results showed that the numerical model can be used to simulate local scouring at bridge abutments with high accuracy.

(Abdul-Hassan K. Al-Shukur , Zaid Hadi Obeid , 2016) carried experiments using three different velocities to investigate the upshot of the bridge pier's shape on local scour to infer the optimal shape that gives minimum depth of scour under clear water condition. They used ten different shapes of pier ten different shapes, Circular, Rectangular, Octagonal, Chamfered, Hexagonal, Elliptical, Sharp, Joukowsky, Oblong, streamline with constant length to width ratio of 4.Results inferred that equilibrium depth of scour and initial scour rate depends on pier shape. Rectangular pier has a maximum scour depth (7.6) cm while the scour depth for streamline geometry was minimum(3cm) . The scour depth increases as the flow intensity increases and vice versa. The streamline shape is considered the best shape of piers that reduces the maximum scour depth by 60% as compared with rectangular shape. Measured scour depth of pier models in this study agreed well with the calculated scour depth from theoretical equations (Colorado state university and Breusers et al, 1977).

(Muzzammil, Alama and Danish , 2015) revealed in their research work that the water erosion i.e. Scouring occurs around the bridge foundation is the main cause of bridge failure. Scouring increases with increase in velocity of flow, when there is a high flow the flowing water erodes and transposes the material from the bed and banks of streams and the piers and abutments of bridges. The intensity of scouring is not constant. Scour depth is the term to inculcate the extent of scouring. Scouring not only depends on velocity of flow but also depends on bed material. Higher scour rate is observed when bed is made up of coarser material. This is the main cause because of which cementious cohesive soils or finally packed beds are less prone to scouring as compared to the granular coarsely packed beds. But the ultimate scour depth is more in case of cemented cohesive soils beds, however, the time to attain ultimate scour depth is much more than the coarse sand gravel bed. The sand gravel bed can be easily scoured to ultimate scour depth within few hours whereas cemented cohesive soil take days or years to reach the maximum value of scour depth. They listed different bed materials under two category heads viz. Slow Ultimate Scouring Materials and Quick Ultimate Scouring Material. Limestone and dense granite are the examples of former while latter consists of glacial till, sandstones, and shale. As scouring is moreover a cyclic process and its intensity varies abruptly with different locations and type of obstructions in the flow direction for example, scouring differs in intensity at pier nose and abutments. These are the reasons which make exact calculations of intensity of scour an impossible task. Therefore, to cater this problem of scour estimation there are developed many location specific instantaneous scour estimation models and techniques.

(Umesh C. Kothyari ; Ajay Kumar ; and Rajesh K. Jain , 2014) carried experiments to investigate the effect of the presence of cohesive material such as clay on the process of scour around the piers founded in uniform and non-uniform sediments consisting of gravel and mixture of sand and gravel. They varied the proportion of clay from 20% to 60% by weight. From experiment results it can be concluded that maximum scour took place in the wake zone of piers and no sediment deposition in cohesive sediments in comparison to cohesionless sediments. The scoured zone in some cases extended on the downstream side of the pier in the form of a narrow but long strip. Variables that affects most the depth of scour in cohesive sediments are fraction of clay and unconfined compressive strength of the sediments. The depth of scour decreased with the increase in clay fraction, and it also decreased with an increase in the value of unconfined compressive strength.

(Ibrahim H. Elsebaie , 2013) carried laboratory experiments to evaluate the time development of the local scour at cylindrical pier in addition to the evaluation of the effectiveness of a pier shape and different flow rates on the depth of local scour. From results it can be concluded that time and flow rate both affects the depth of scour and it increases with increase of flow rate. Maximum scour depth was observed to occur at the upstream of the pier and increases with increase of flow and time as well. The coarse portion of the sediment is deposited at downstream zone of the pier and scour hole dimensions in the transverse direction was found to be almost same.

(Beg , 2010) carried out a research for which he had performed a controlled widespread experimental study for the prediction of local scour. For his research he used two bridge piers in steady uniform flow each of them were placed in the direction transverse to the flow. The spacing between these piers was varied for different readings. The value of flow intensity was maintained to 0.95 and clear water scour was predicted. The main motive behind his research was to find out the agreement of bridge piers spacing with the local scour. The major inference of his research was the presentation of significant characteristics such as temporal scour depth, the areal extent of scour and sediment deposition around the piers and scour hole characteristics in the form of data. This data was of huge importance for a bridge engineer. The main conclusion drawn from his research was that the transverse piers at close proximity were the major cause behind any sort of bridge failure.

(Deng and Cai , 2010) highlighted through their research work that scour is one of the key sources responsible for bridge failures. On a rough estimate about 60% of total bridge failures in the United States were an outcome of scouring. Scour failures are the most difficult failures to be monitored or catered during floods, because these failures occur without prior intimation or warning. In their research paper they summed up broader reviews on latest works, techniques and instrument developed for countering scour at bridge piers as well as abutments. They also explained Numerical and laboratory models for the prediction of scouring at bridge site and carried out important laboratory experimentations and field tests for reviewing real-time scour.

Different techniques and instruments for countering bridge scour are summarized with their advantages, disadvantages, and relative cost in a table. At the end a discussion was made regarding various mitigation countermeasures advanced for bridge scour.

(Abdelazim M. Negm , Gamal M. Moustafa , Yasser M. Abdalla and Amira A. Fathy, 2009) studied different shapes of collar around bridge pier to minimize the maximum local scour under similar subcritical flow conditions with tail Froude number ranging from 0.2 to 0.55.It can be concluded from results that rectangular collar is most efficient of all and gives best results for width 5 times the pier width, triangular is the worst, trapezoidal and circular shows almost same results. The relative scour depth increases as the tail Froude number increases and the relative scour depth decreases as relative width of collar increases and vice versa.

(Hannah , 1978) worked carefully over the laterally placed bridge pier to predict the cause of scouring and emerged victorious with the inference that compressed horseshoe vortices are the main source for enhancement of scouring. Individual horseshoe vortex were observed in the vicinity to each distantly spaced transverse piers. With decrease in pier/pile spacing there observed a compression in the inner arms of the horseshoe vortices. This was the main cause of consequent increase in scour depth with higher velocities in the inner arms of horseshoe vortices.

2.2 Literature review for protection devices :

Till date a lot of computational models have been developed for the determination of both general as well as localized scour. There is a series of commendable works in this direction by Laursen (1956), Shen (1969), Breussers (1977), Raudkivi (1983), Melville (1984) Richardson and Davis(1995), from abroad and Jain (1981), Gangadharaiah (1985), Kothyari (1992, 1993), Garde (1996), and others. Their works were mainly concerned about the development of scientific scour estimation method. The only loophole in these works was that most of them developed their models using the data from laboratory flume data, this data is not proved or validated from any realtime field measurement of scour in prototype piers. As per the recommendations of IRC Codes {IRC-5(1998), IRC:SP-13(2004) and IRC:78(1980)} Lacey's (1930) equation is highly recommended for estimation of scour depth irrespective of its limitations. So, this method of estimation of scour is neither relevant nor precise for the correct estimation as it overlooks many parameters which impact the scour or are very important for governing the scour around the bridge piers.

(Mehdi Osroush , Seyed Abbas Hosseini , Amir Abbas Kamanbedast , Amir Khosrojerdi , 2019) studied the effects of height and vertical position of slots on the reduction of scouring on rectangular abutments under varying flow conditions. It was concluded that the depth and dimensions of the erosion hole around the abutment increased with an increase in the Froude number. The effects of the slot on the scour reduction increased with a decrease in the Froude number. The closer the slot to the bed or beneath the bed, the more effective the performance. The slots with heights equal to the flow depth plus the equilibrium depth of the scour in the no-slot model exhibited the best results. The insertion of slots in abutments was more effective in reducing the scour than bridge pier.

(Mehdi Osroush, Seyed Abbas Hosseini , Amir Abbas Kamanbedast , Amir Khosrojerdi , 2019) studied the effects of height and vertical position of slots on the reduction of scouring on rectangular abutments under varying flow conditions. It was concluded that the depth and dimensions of the erosion hole around the abutment increased with an increase in the Froude number. The effects of the slot on the scour reduction increased with a decrease in the Froude number. The closer the slot to the bed or beneath the bed, the more effective the performance. The slots with heights equal to the flow depth plus the equilibrium depth of the scour in the no-slot model exhibited the best results. The insertion of slots in abutments was more effective in reducing the scour depth as compared to bridge piers.

(Su-Chin Chen , Samkele Tfwala , Tsung-Yuan Wu , Hsun-Chuan Chan and Hsien-Ter Chou , 2018) carried experimental and numerical studies to evaluate the performance of the hooked-collar of width 1.25b and a height of 0.25b and to find optimum position for maximum reduction in scour depth under clear water conditions. It can be concluded from results maximal down-flow is highly reduced along with a corresponding decrease in horseshoe vortex strength. The hooked-collar positioned 0.25b above the bed reduced the scour hole by 24% and collar at the bed greatly improved collar performance, and no scour was observed at the front and sides of the pier. A single hooked-collar placed at the bed level, the final scour depth was reduced by 42%, while a double collar, at the bed and 0.25b above the channel bed had the largest scour rate reduction of 50%.Simulation results using FLOW-3D was slightly above measured scour depths, and the maximum time-dependent scour depth was similar to observed flume experiments.

(H. Hamidifar , M. Nasrabadi , M.H. Omid ,2018) carried study to explore the efficiency of reduction in scour by a single bed sill countermeasure at downstream of the apron , and to assess its effectiveness at various distances from the end of the apron. Results show that bed sill placed downstream of a rigid apron, not too far from it, reduces local scouring. Two distinct scour holes develop behind and in front of the sill.Sill reduced the maximum scour depth in front of the sill up to 95%.Completely buried sill showed no reduction for scour depth either behind or in front of the sill. Different scour profiles were obtained for sills at different locations and heights.

(Payam Khosravinia , Amir Malekpour , Ali Hosseinzadehdalir , Davod Farsadizadeh , 2018) in their study used collars of different width to reduce the flow strength and consequently to mitigate the scour development around a wing-wall abutment. It is concluded that an increased collar width leads to a better performance for shorter abutments and for a given abutment length, the increased collar width delays the start of scour development. The scour reduction rate varied from 37% to 9% when L/B varies from .75 to 5.

(E.A. Elnikhely , 2018) studied the effects of perforated piles with holes with different orientations, a sacrificial pile and perforated sacrificial pile at the upstream in minimization of scour depth around bridge pile. He found that a perforated pile leads to reduce the local scour depth by 80% for Ø=45 degree and a reduction of 47% for Ø=90,imperforated sacrificial pile upstream of bridge perforated pile reduces the local scour depth by 76% for Ø= 45, a perforated sacrificial pile minimize and control the scour depth around the bridge pile by about 84% for the case of α= 45 and Ø= 45, the relative scour depth reached its minimum value in case of d/D= 0.43 and it reduces the relative scour depth ds/D by about 89%.

(E.A. Elnikhely , 2017) experimentally studied the effect of cylinder blocks on the back slope of the spillway, on scour hole dimensions downstream of the spillway using various diameters, lengths, and arrangements of cylinder blocks with distinct discharges. The best dimensions of cylinder blocks obtained are L/B = 0.133, D/B = 0.1. It reduced the values of scour parameters by approximately 26% and reduced the deposition parameters dd/yup and Ld/yup by 28% and 22.2% respectively. The overall reduction of the scour and deposition parameters is about 25.55%. Case of staggered cylinder blocks over sloped spillway gives the smallest values of scour and deposition parameters. Statistical equations developed to predict scour parameters give a good agreement with the experimental data.

(F. Tang , 2016) used a smart rock in their study, which is actually nothing else but a magnet embedded in a concrete ball. This smart rock will monitor the bridge scour depth. In their study with the help of the theory of magnetic field they developed the magnet-induced magnetic field (MMF) distribution. An algorithm was also developed for fixing the position of the smart rock and field tests were carried at a bridge pier site at three different times. A magnetometer was used to measure the intensities of the ambient magnetic field (AMF) as well as the total magnetic field (TMF). The inference drawn by them was that variation in AMF alters the effective monitoring range. The maximum monitoring depth ranged from 11.5 to 8.5 m with the standard deviation of the AMF increased from 32.3 to 80.75.

(Yasser A. Mohammed ,Yasser K. Saleh , Abdel-Azim M. Ali , 2015) carried study to control and reduce the local scour around multi-vents bridge piers using collar, current deflectors that fixed over collar and mobile bed, and sacrificial pile upstream piers. They found that using collar the local scour depth can be reduced by 65%,the current deflectors over the mobile bed and collar reduce the local scour depth by additional 10% and sacrificial pile upstream of bridge pier, collar and current deflectors reduce the local scour depth at bridge piers by more than 90%.

(Ali Tafarojnoruz , Roberto Gaudio , Francesco Calomino , 2012) studied six different types of flow-altering countermeasures that are submerged vanes, bed sill, transverse sacrificial piles, collar, threading, and pier slot against pier scour in clear-water conditions. Tests were sketched on the basis of the best configurations recommended in previous studies to acquire the maximum reduction in scour depth. It can be concluded that single flow-altering countermeasure may results in an inadequate protection. The efficiencies of downstream bed sill, double submerged vanes, and threading are less than 20%.The efficiency of a 3b-wide collar flush with the bed is less than 30% at equilibrium. Slot length and location for the best configuration cannot be suggested on the basis of the approach flow depth only.

(Jueyi , 2010) studied clear-water scour around abutments of semi-elliptical shape with armored beds. Experimental study has been carried out under a clear-water scour condition to explore the local scour around semi-elliptical model bridge abutments with armor-layer bed, compared with the local scour process around semi-circular abutment. The researcher inferred that for both semi-elliptical and semi-circular abutments, the equilibrium scour depth of the scour hole will increase with increase in flow velocity for all runs.

(M. Heidarnejad , M. Shafai Bajestan , and A. Masjedi,2010) investigates the application of slots in the reduction of pier scouring using four slotted models of bridge piers and a model of non-slotted bridge pier in the position of 60-degree of the mild 180-degree bend. The average reduction in slotted pier scouring depth was 23.89% (0-2b) for slotted pier type 1, 17.53% (b/2-3b/2) for slotted pier type 2, 22.05% (0-b) for slotted pier type 3 and 12% (b-2b) for slotted pier type 4. Scouring depth is a function of average flow velocity ratio to threshold velocity of bed sediments so that the effects of slots on scouring reduction improve when this ratio decreases..

(Abdelazim M. Negm , Gamal M. Moustafa , Yasser M. Abdalla and Amira A. Fathy , 2009) studied different shapes of collar around bridge pier to minimize the maximum local scour under similar subcritical flow conditions with tail Froude number ranging from 0.2 to 0.55.It can be concluded from results that rectangular collar is most efficient of all and gives best results for width 5 times the pier width, triangular is the worst, trapezoidal and circular shows almost same results. The relative scour depth increases as the tail Froude number increases and the relative scour depth decreases as relative width of collar increases and vice versa .

(Mohammad B. Mashahir , 2006) carried out a successful study over the application of riprap alone and a combination of riprap and collar in scour protection about the rectangular bridge piers. The position of pier was not skewed to an angle ranging from 5, 10, and 20° to the flow. These are aligned along the flow. Reading for various experimentations were taken at three different aspect ratios of 1:3, 1:5, and 1:7 of the pier and the experiments were conducted at the threshold of motion of the bed material. They calculated the size as well as extent of stable riprap which served best for prevention of scouring around the piers..

(Deepika Bhulla and Rajendra Magar , 2006) studied scouring around bridge pier with the help of various Laboratory experiments. Substantial amount of data was collected from these experiments and this data was further used for dimensional analysis as well as for the derivation of empirical equation. The overlooked the effect of the varying flow characteristics over the empirical equations.

Chapter 3

METHODOLOGY

3.1 Experimental setup

The experiment was conducted in a masonry flume of 12 m length, 1.04 m width, and 0.8 m height in the Hydraulic Laboratory of the Department of civil engineering at Delhi Technological University, New Delhi. Glass side walls has been provided along both the sides of the working section to facilitate visual observations. Working section is located at 6 m downstream from the inlet of flume section. A steady flow was effected by the use of a re-circulating pump installed beneath the flume. In order to smoothen the flow, a false floor with a ramp was placed at the upstream end of the flume while an adjustable tail gate at the downstream end was used to control the water depth . Uniform sand was placed in the sediment recess to form the sand bed. A hollow and transparent circular pier of diameter D 5 cm was installed vertically at the center of the recess. Different counter-measures that is square and circular collar of varying sizes that are 2D,3D,4D,5D used to study scour reduction .Two pier arrangement with varying center to center distance from 2D,3D,4D,5D for studying affect of second pier on first for scour reduction was also done. The scour depth was determined by means of a point guage. The discharge was measured with the help of v-notch.

Figure 6 Masonry Flume in Hydraulic laboratory DTU, Delhi

Figure 7 Types of square and circular collar used in experiment

3.2 Experimental procedure

Followings steps were performed in the laboratory for the study:

1. Sand bed was leveled and leveling was also checked through point gauge.

2. Water was passed through the bed to remove air bubbles and to prevent disturbances .

3. Pier model was placed in the middle of the sand bed.

4. After pumping, the tail gate was adjusted to get the desired depth and to make the flow stable.

5. Scour near the pier and its surroundings was noticed and measured with the point guage under varying discharge. Readings were taken at interval of 10 min. for 2hours and then at interval of 30 minutes in total a run of 4 hours was given.

6.Experiments for scour protection devices were carried. Different shapes of collar that is circular and square of different sizes were used for study under clear water conditions. After each run the bed was leveled and checked through point gauge.

7. An experimental study for two piers on the uniform sand bed was carried out to observe the change in the behaviour of sand by varying the distance between the piers in the direction of flow. Two piers of same size were placed in alignment and varying there center to center distance.

8. Analysis of results obtained for square collar, circular collar and two pier arrangement were carried out and best size for each case was obtained.

9.comparison of results of all the three cases was done and the best case which gives maximum reduction in scour depth was concluded.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

The experimental study is carried out to predict the flow around pier with and without collar. It also include experiments to study the effect of a pier in front of the main pier. In this study total 16 experiments were carried out. Initially ,4 experiments were carried out for single pier under varying discharge from 3.04 m^3/s to 3.45 m^3/s. It was found that maximum scouring takes place for discharge 3.45. Scour depth obtained at upstream was 4.5cm and scour depth at downstream was 2.5cm.

Experiments were then carried out for pier with square collar , circular collar and two piers. The size of collars were considered from 2D , 3D , 4D and 5D. For two pier experiments the distance between the piers was varied as 2D , 3D , 4D and 5D, where D is the diameter of pier. While varying discharge the experiments were carried out for a run of 4-hours and for experiments with protection devices it was run for 1-hour.

4.1.1 Results for square collar

(a)

(b)

(c)

(d)

(e)

(f)

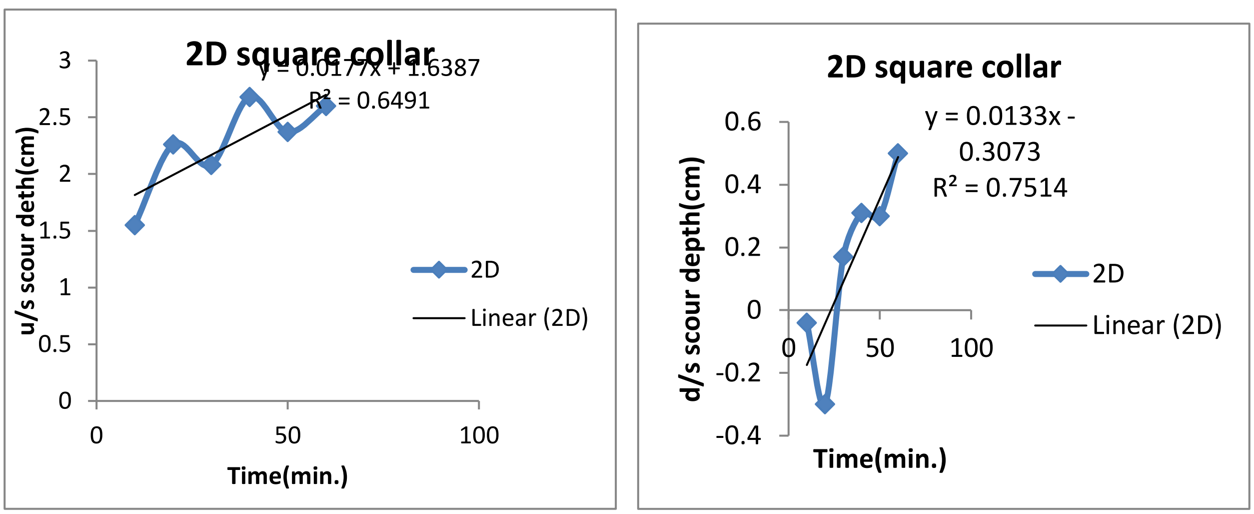
Figure 8 Different size of square collars and their surface profile after experiment

(a) 2D square collar

The scour depth obtained at upstream after ten minutes and sixty minutes is 1.55 cm and 2.6 cm whereas scour depth obtained at downstream is -0.4 and 0.5 respectively. The percentage reduction in scour depth at upstream and downstream comes out to be 42.22% and 80% respectively as compared to no collar case. Variation of scour depth at upstream and downstream with time is shown in figure .

(b) 3D square collar

Initially scour depth obtained at upstream and downstream is 0.5 cm and -1.9 cm respectively. As the time advances scour depth at upstream increases and reach to 1.4 cm after 1 hour run. The change in downstream scour depth with time was negligible. The percentage reduction in scour depth at upstream is 68.89%.

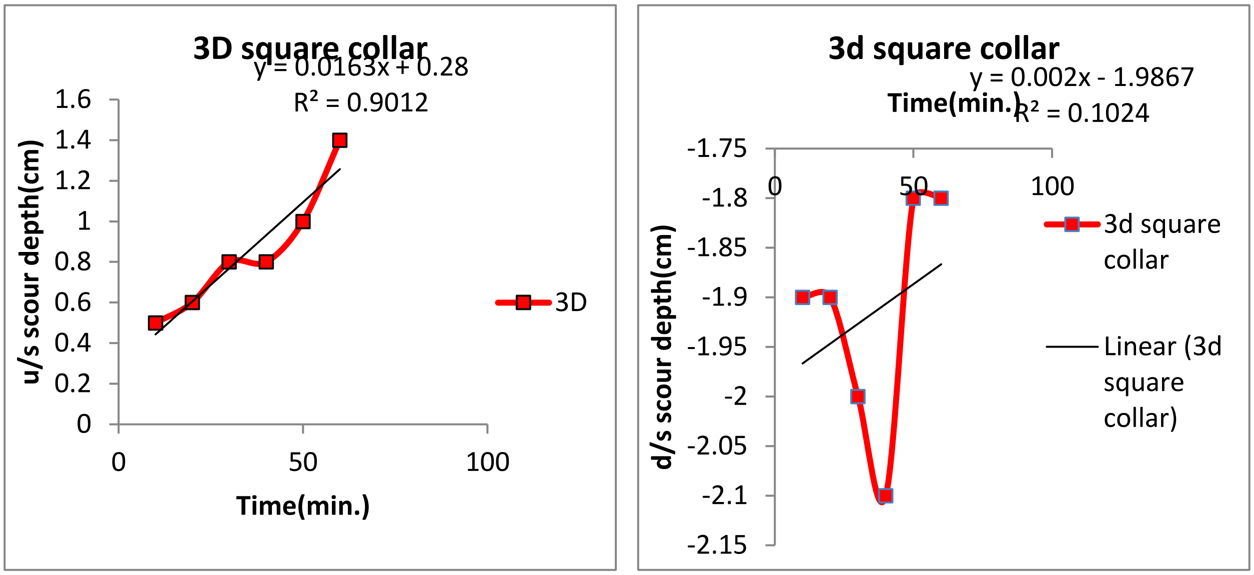


(a) (b)

Figure 9 representation of scour depth in square collar of size 2D (a) upstream (b) downstream

(c) 4D square collar

The scour depth obtained initially at upstream and downstream is 0.58 cm and -0.17 cm respectively. The scour depth at upstream increases to 1.14 cm and scour depth at downstream increases to -0.08 cm. As the values obtained at downstream are negative , which shows aggradation. The percentage reduction in scour depth at upstream is 74.67% in comparison to no protection



(a) (b)

Figure 10 representation of scour depth in square collar of size 3D (a) upstream (b) downstream

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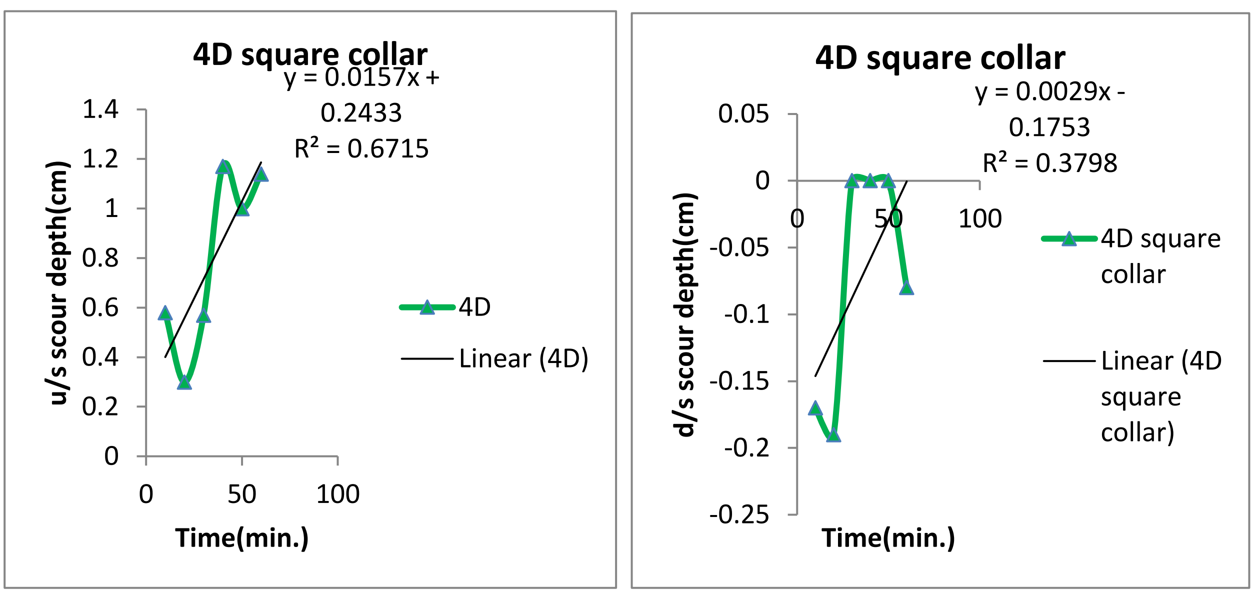
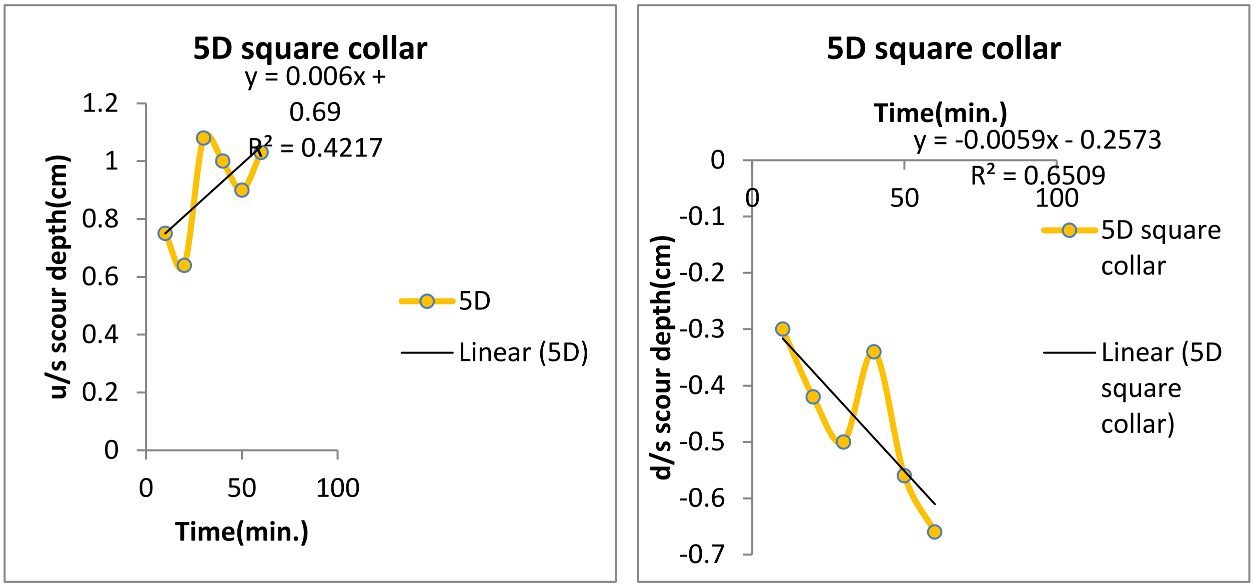


(a) (b)

Figure 11 representation of scour depth in square collar of size 4D (a) upstream (b) downstream



(a) (b)

Figure 12 representation of scour depth in square collar of size 5D (a) upstream (b) downstream

(d) 5D square collar

Initially the scour depth noted at upstream and downstream is 0.75 cm and -0.3 cm. The scour depth at upstream increases with time whereas scour depth at downstream decreases. After 1 hour run, scour depth obtained at upstream and downstream is 1.03 cm and -0.66 cm respectively. The percentage reduction in scour depth at upstream is 77.11%. Variation of scour depth at upstream and downstream is shown in figure

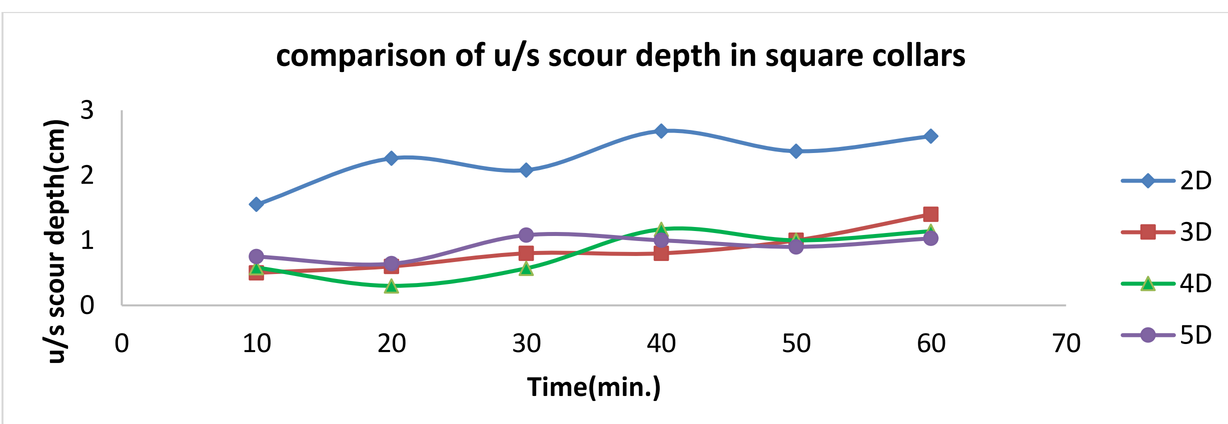


Figure 13 graph for scour depth at upstream for different size of square collar

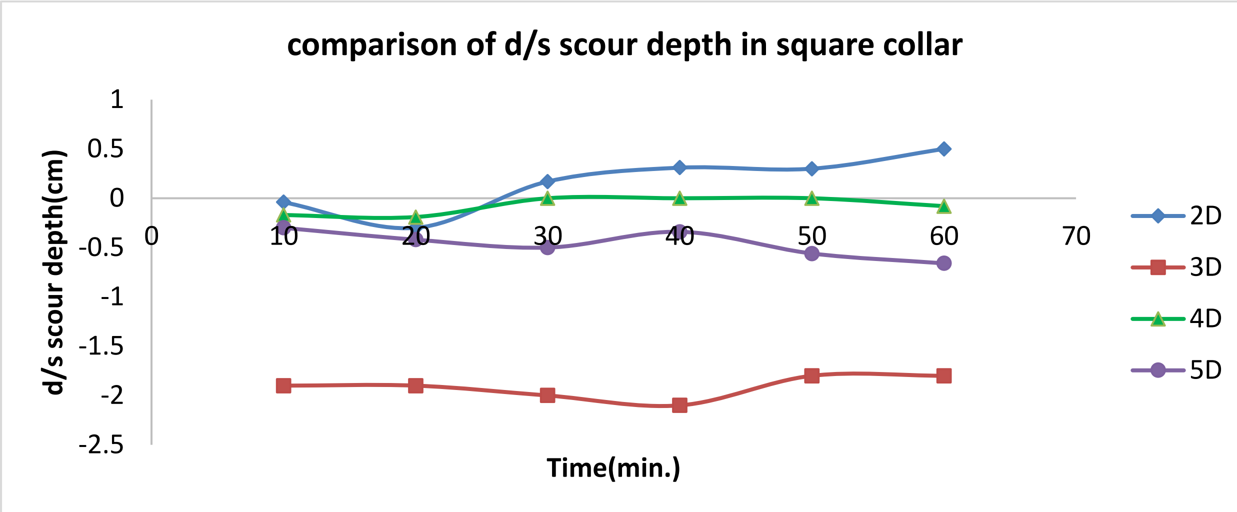


Figure 14 scour depth at downstream for different size of square collar

4.1.2 Results of circular collar

(a) 2D circular collar

Scour depth obtained initially at upstream and downstream is 3.2 cm and 0.35 cm respectively. scour depth at upstream and downstream after an hour run reach to 3.12 cm and 0.7 cm. The percentage reduction in scour depth at upstream is 30.66 % and scour depth reduction at downstream is 70%. Variation of scour depth with time at upstream and downstream is shown in figure .

(b) 3D circular collar

Initially scour depth at upstream and downstream is 1 cm and -0.43 cm respectively. Scour depth increases with time at upstream and downstream. Scour depth at upstream and downstream after an hour reaches to 1.84 cm and 0 cm. The percentage reduction in scour depth at upstream is 59.11%. after an hour run. Variation of scour depth at upstream and downstream is shown in figure

Figure 15 Types of circular collar and surface profile after experiment

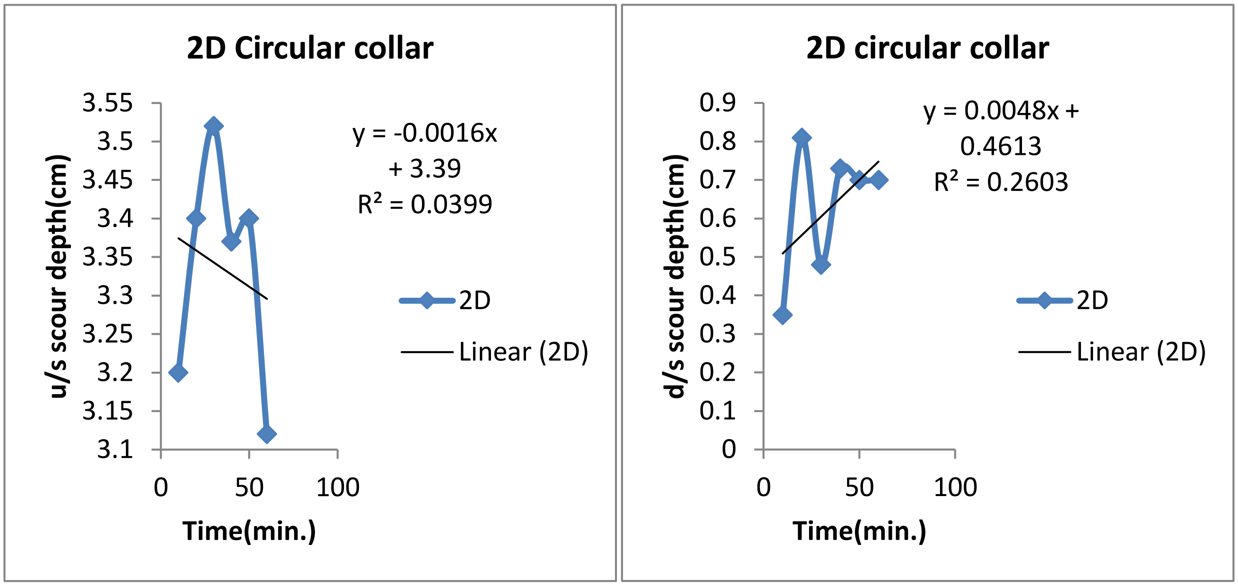
(c) 4D circular collar

Initially scour depth of 0.7 cm and -0.36 cm obtained at upstream and downstream respectively**.** After completion of experiment scour depth noted at upstream and downstream is 1.4 cm and -0.3 cm.It can be noticed from results that scour depth is doubled after an hour run and negligible change at downstream scour depth. Percentage reduction in scour depth at upstream is 68.88%.Variation of scour depth at upstream and downstream is shown in figure

(d) 5D circular collar

Scour depth initially noted at upstream and downstream is 0.05 cm and -2 cm respectively.

Scour depth at the end of experiment is found to be 0.1 cm and -1.91 cm at upstream and downstream respectively. percentage reduction in scour depth in comparison to no protection is 97.78% at upstream. no scour was noted at downstream.Variation in scour depth with time at upstream and downstream is shown in figure .



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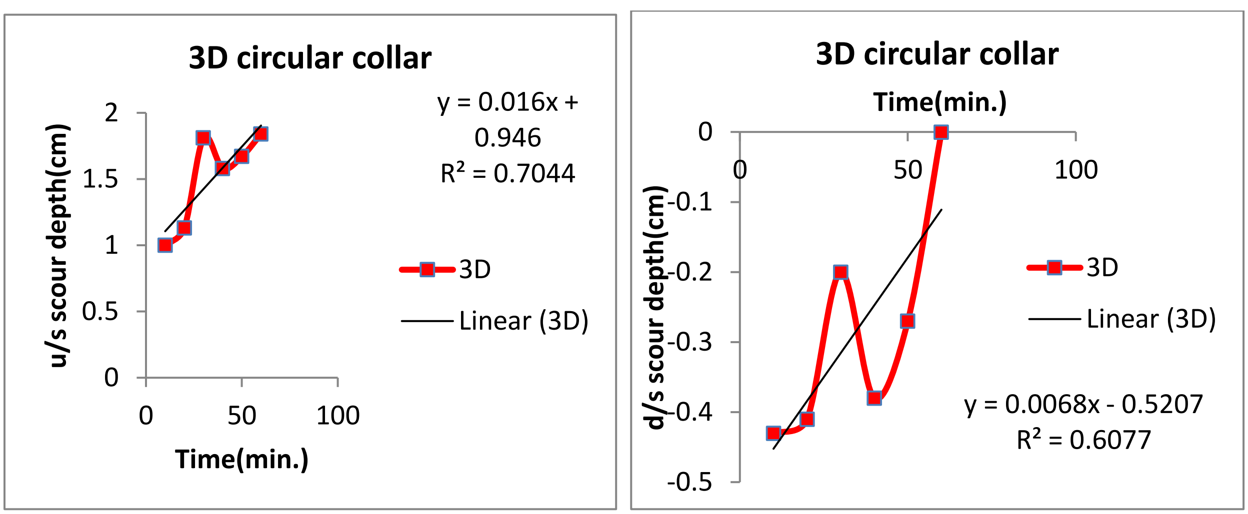
(a) (b

Figure 16 represents scour depth in circular collar of size 2D (a) upstream (b) downstream



(a) (b)

Figure 17 representation of scour depth in circular collar of size 3D (a) upstream (b) downstream

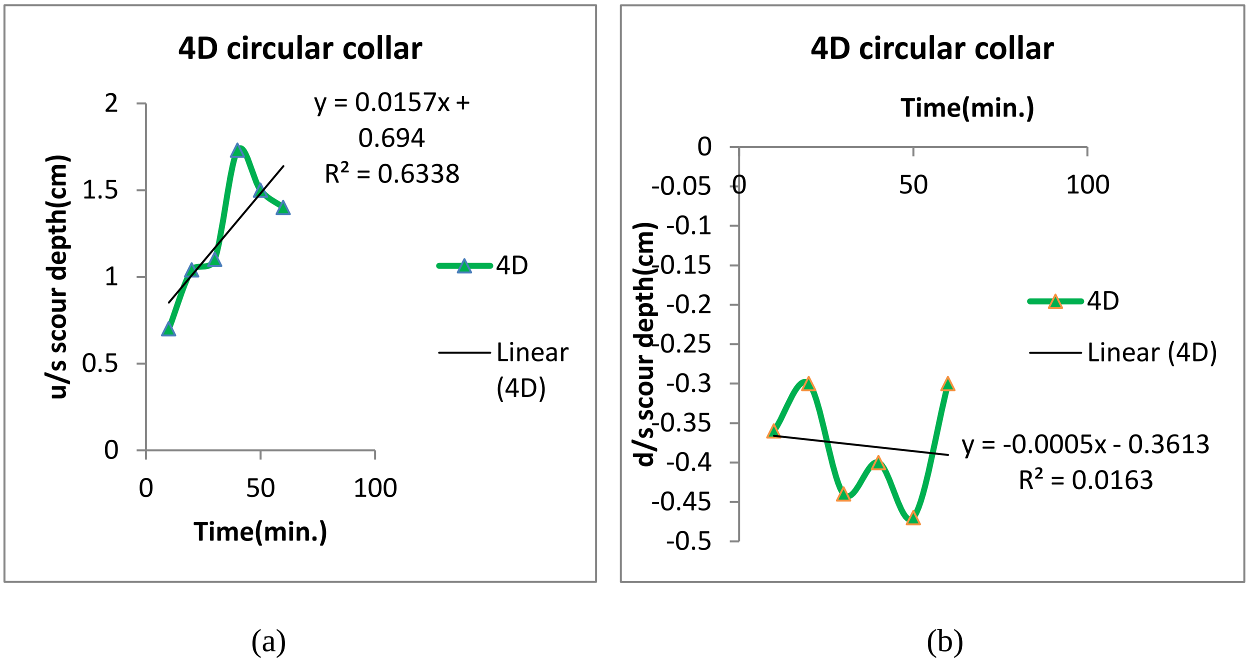


Figure 18 represents scour depth in circular collar of size 4D (a) upstream (b) downstream

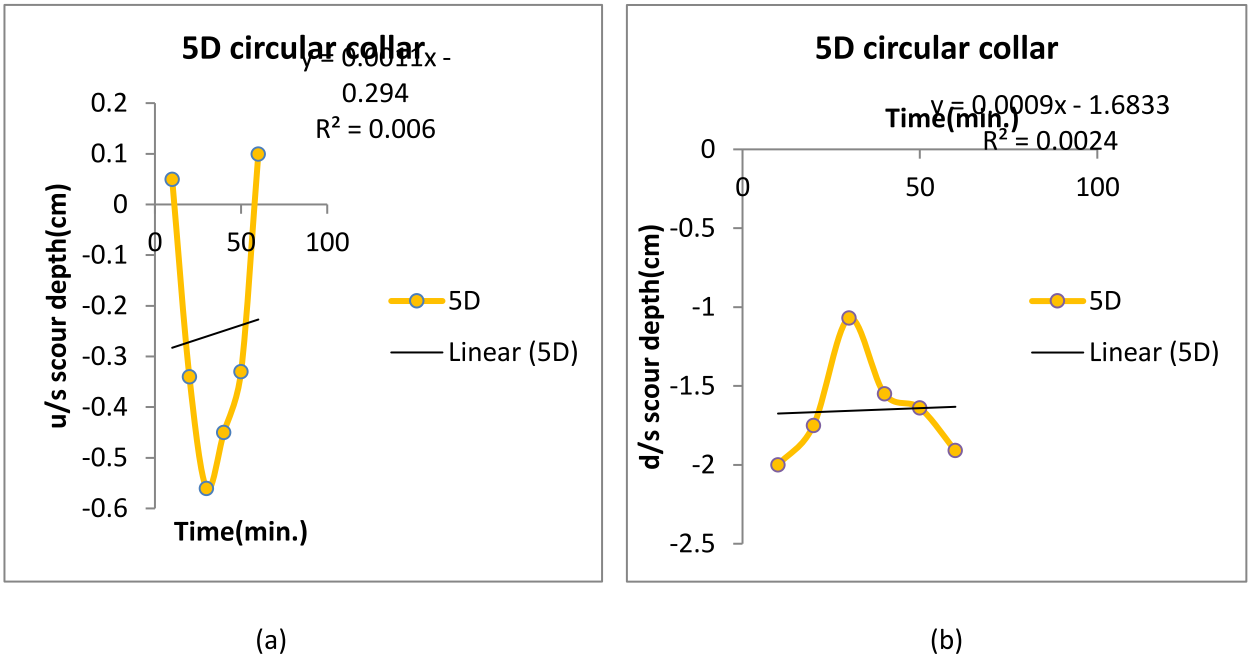


Figure 19 represents scour depth variation in circular collar of size 5D (a) upstream (b) downstream

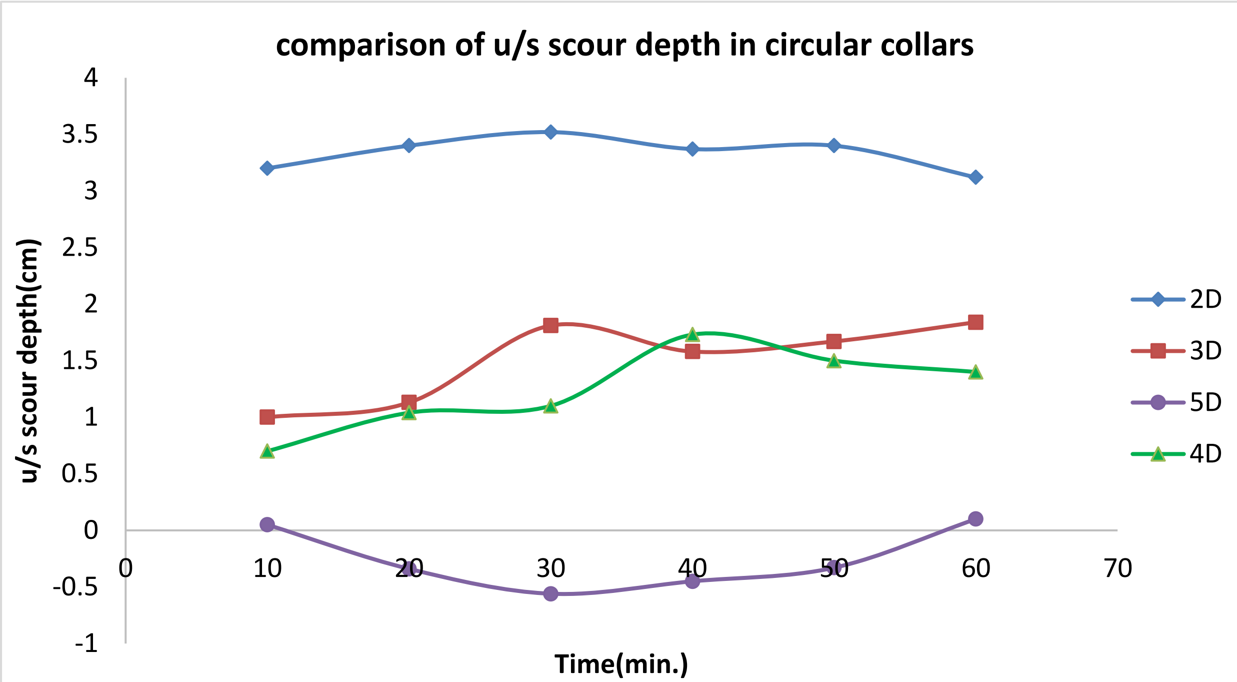


Figure 20 graph showing variation of scour depth at upstream in various circular collar

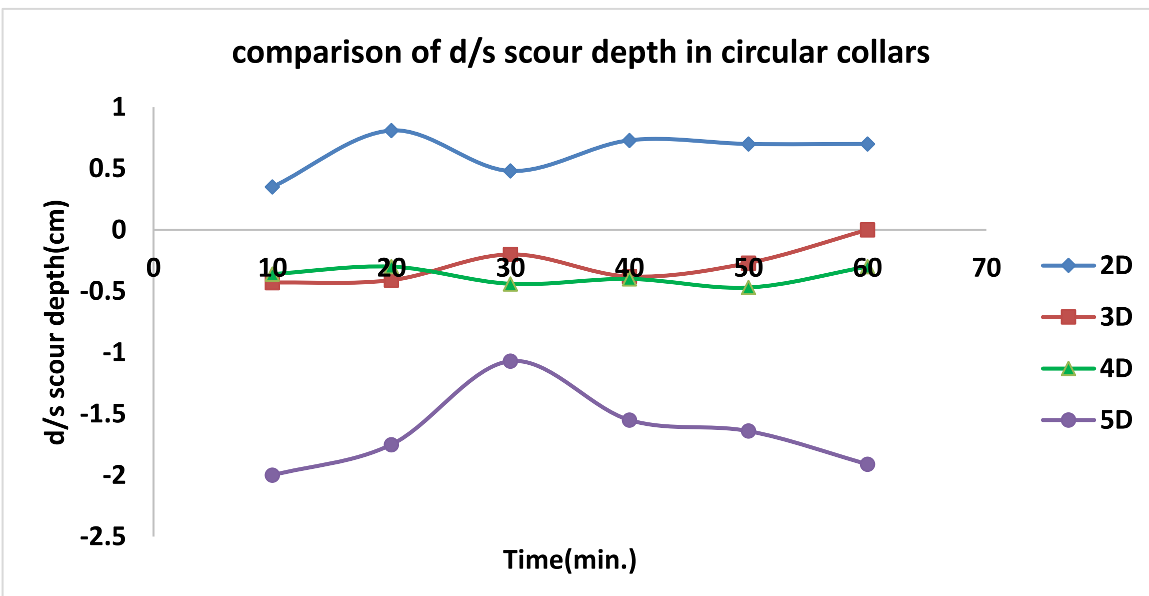


Figure 21 graph representing scour depth variation at downstream in different circular collars

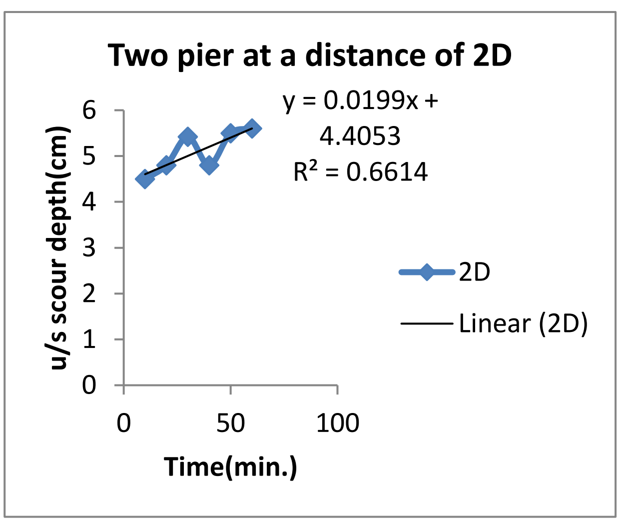
(e) Comparison of scour depth in circular collar

In case of 5D collar the scour depth at upstream comes out to be only 0.1 which is very less as compared to pier without collar. Reduction in scour depth for 2D , 3D , 4D , 5D is 30.66% , 59.11% , 68.88% , 97.78% respectively. It can be concluded that circular collar 5 times the pier diameter is most efficient and 2D was the least efficient .At downstream of pier the best results were obtained from 5D and bad from 2D. Scour depth reduction using 2D at downstream comes out to be 72% and for 5D there was no scour. Aggradation was seen on downstream side in case of 5D

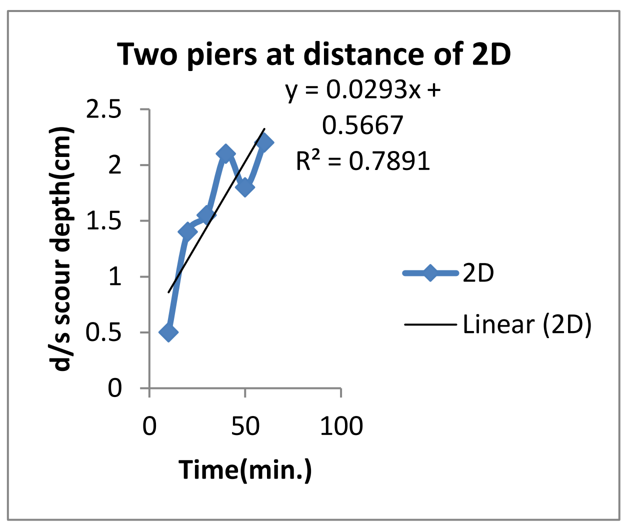
4.1.3 Results for two piers

(a) Two pier at a distance of 2D

Initially scour depth at upstream and downstream noted is 4.6 cm and 0.5 cm. Scour depth initially obtained at upstream is more than single pier scour depth. Scour depth at upstream and downstream increases with time and reach to 5.6 cm and 2.2 cm respectively at the end of experiment. Percentage increase in scour depth at upstream is 24.44% and percentage decrease in scour depth at downstream is 12%. It can be inferred from results that pier in-front of main pier increases scour depth at upstream of main pier.



(a)

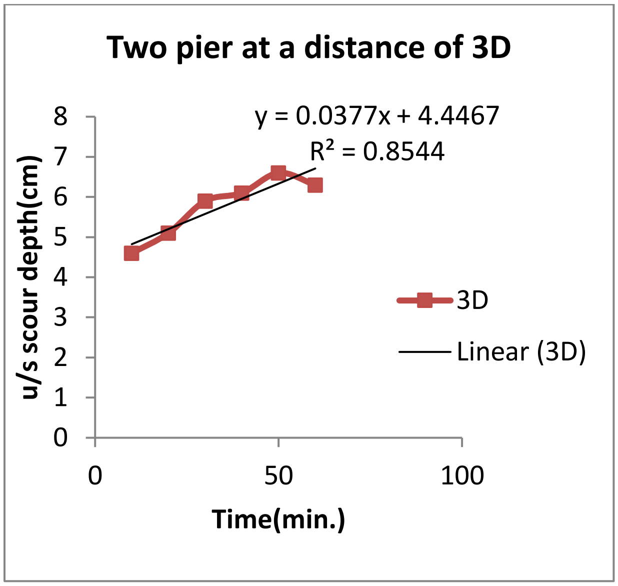


(b)

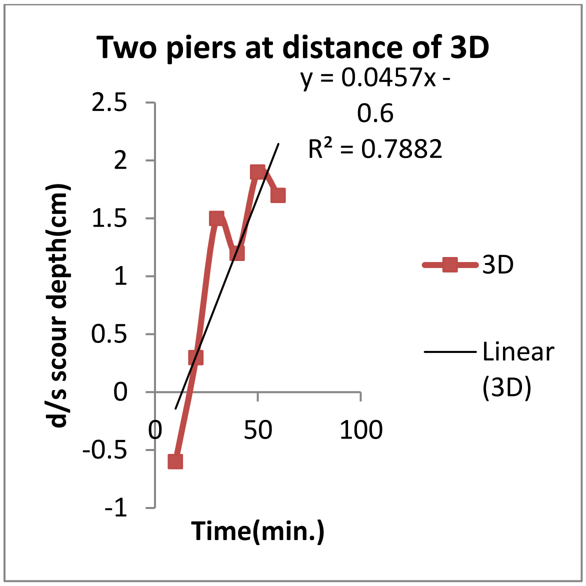
Figure 22 variation of scour depth for two pier at distance of 2D

(b) Two piers at a distance of 3D

When experiment was performed for two piers at distance of 3D ,initial scour depth noted is 4.6 cm and -0.6 cm at upstream and downstream respectively. As the time advances the scour depth increases to 6.3 cm and 1.7 cm at upstream and downstream respectively after an hour run. Scour depth at upstream increases by 40% and scour depth at downstream reduces by 32% . Variation of scour depth with time is shown in figure



(a)



(b)

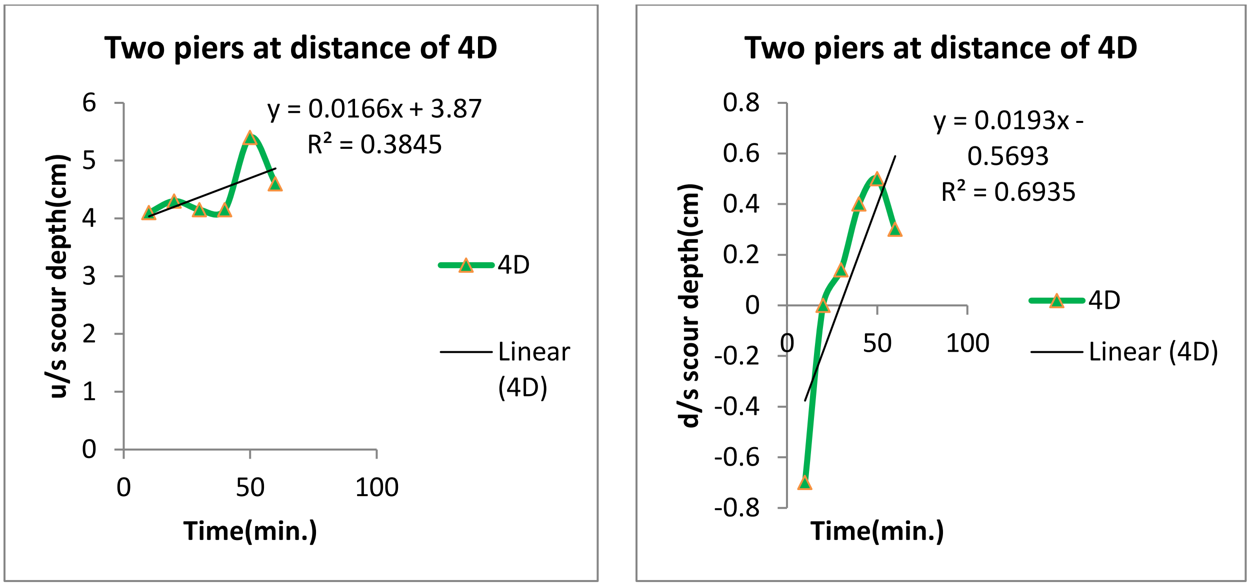
Figure 23 variation of scour depth in two pier at distance of 3D (a) upstream (b) downstream

(c) Two piers at a distance of 4D

In starting the scour depth of 4.1 cm and -0.7 cm was obtained at upstream and downstream respectively. As the experiment advances scour depth increases at upstream and downstream and reaches to 4.6 cm and 0.3 cm.percentage increase in scour depth at upstream is 2.22% and percentage decrease in scour depth at downstream is 80%.Variation of scour depth with time is shown in figure .

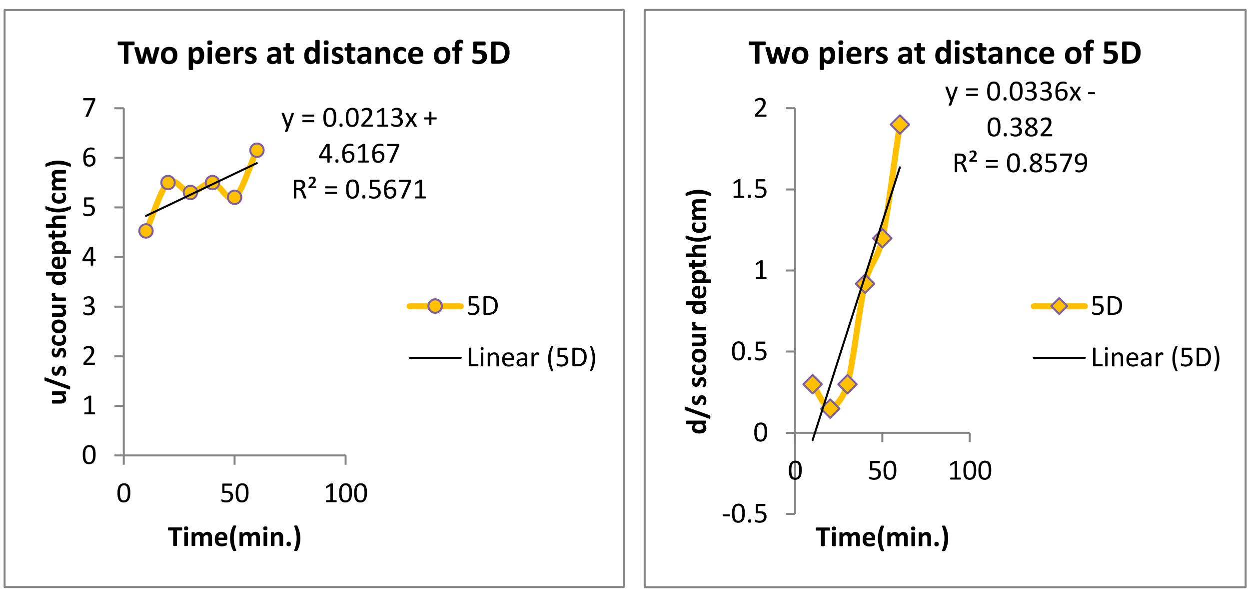
(d) Two piers at a distance of 5D

Results of experiment show that scour depth increases at downstream and upstream with time. Scour depth at upstream increases from 4.56 cm to 6.15 cm and scour depth at downstream increases from 0.3 cm to 1.9 cm.Percentage increase in scour depth at upstream is 36.67% and percentage decrease in scour depth at downstream is 24%. Variation of scour depth at upstream and downstream is shown in figure .



(a) (b)

Figure 24 scour depth variation for two piers at distance of 4D (a) upstream (b) downstream



(a) (b)

Figure 25 variation of scour depth in two piers at a distance of 5D (a) upstream (b) downstream

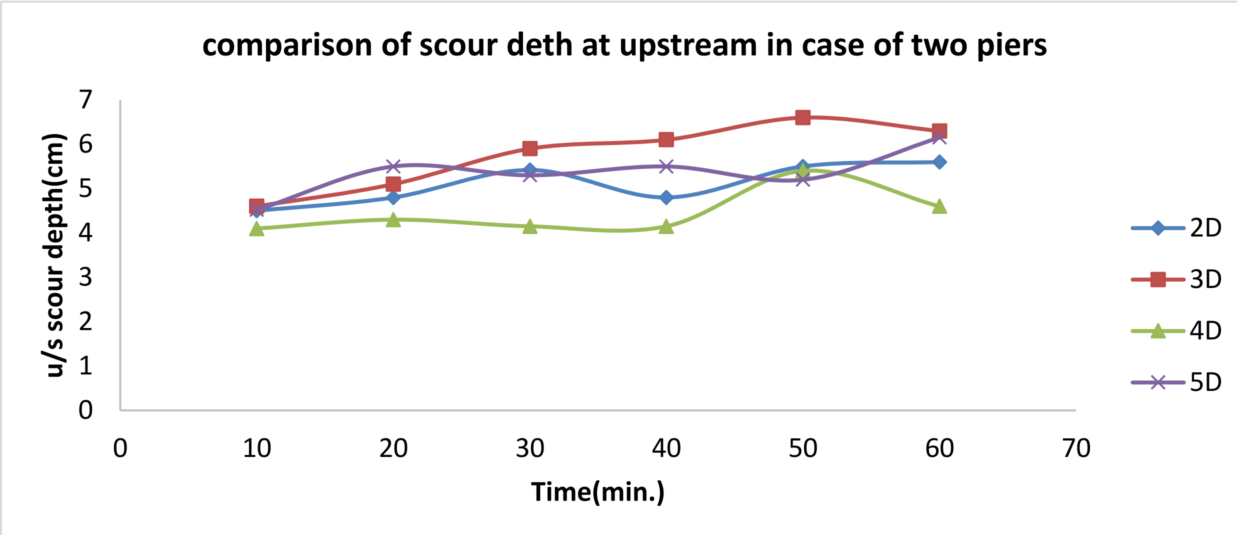


Figure 26 comparison of scour depth variation at upstream in case of two piers at different distances

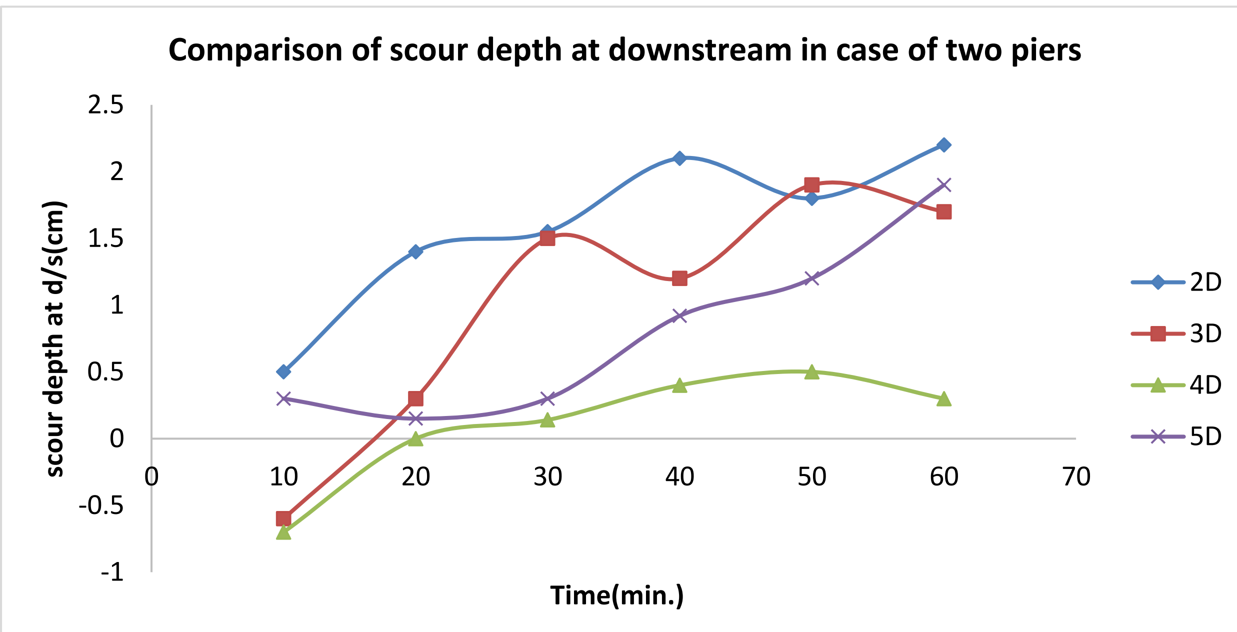


Figure 27 comparison of scour depth variation at downstream for two piers at various distances

In case of two piers, the scouring at front pier affects the rear pier in direction of flow. Two different scour holes are observed as the distance between the two is increased. The best results were obtained when the distance between the two is four times the pier diameter . Scour depth obtained for discharge 3.45 in case of 2D , 3D . 4D and 5D is 5.6 , 6.3 , 4.6 , 6.15 cm respectively at upstream. At downstream scour depth obtained in case of 4D is 0.3 that means 88% scour reduction in comparison to pier without collar.

4.1.4 Comparison of results

I. For size 2D

When we consider the results obtained from 2D collar, it can concluded that minimum scour depth was obtained in case of square collar. Scour depth obtained at upstream is 2.6cm and at downstream is 0.5 cm .Percent reduction at upstream is 42.22% and at downstream is 80%.In case of 2D square collar is more efficient than other cases.

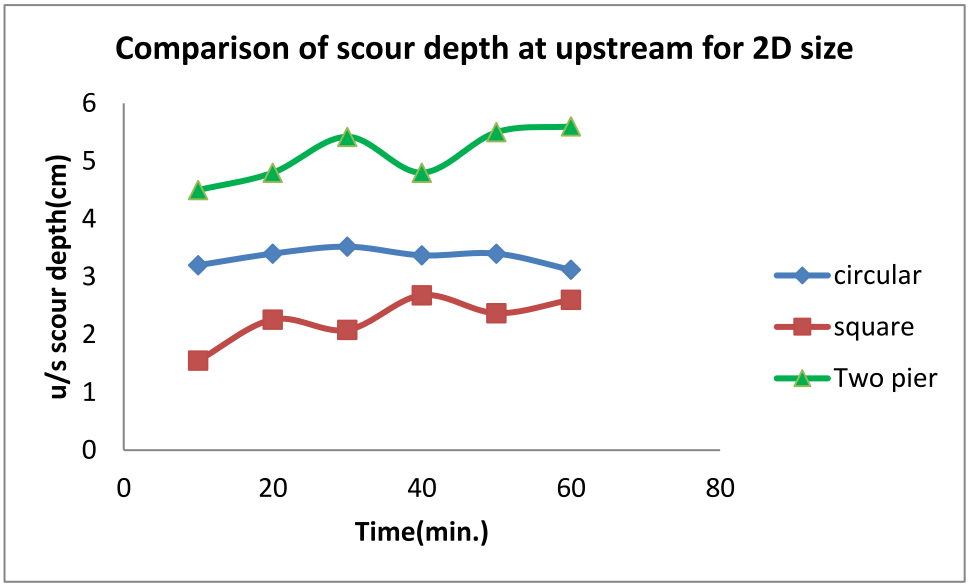


Figure 28 scour depth at upstream in different arrangements of size 2D

II. For size 3D

The results obtained are shown in below table and graph. The minimum scour depth obtained is 1.4 at upstream in case of a square collar and maximum scour depth is obtained in case of two pier that is 6.3.It can be inferred through results that square collar is more efficient.

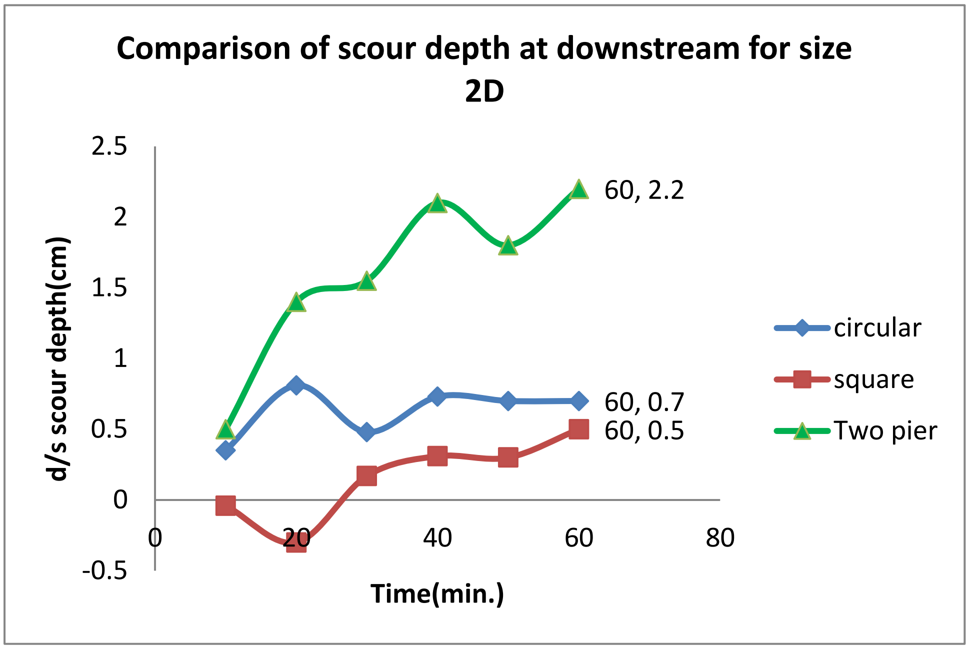


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Figure 29 scour depth at downstream in different 2D arrangements.

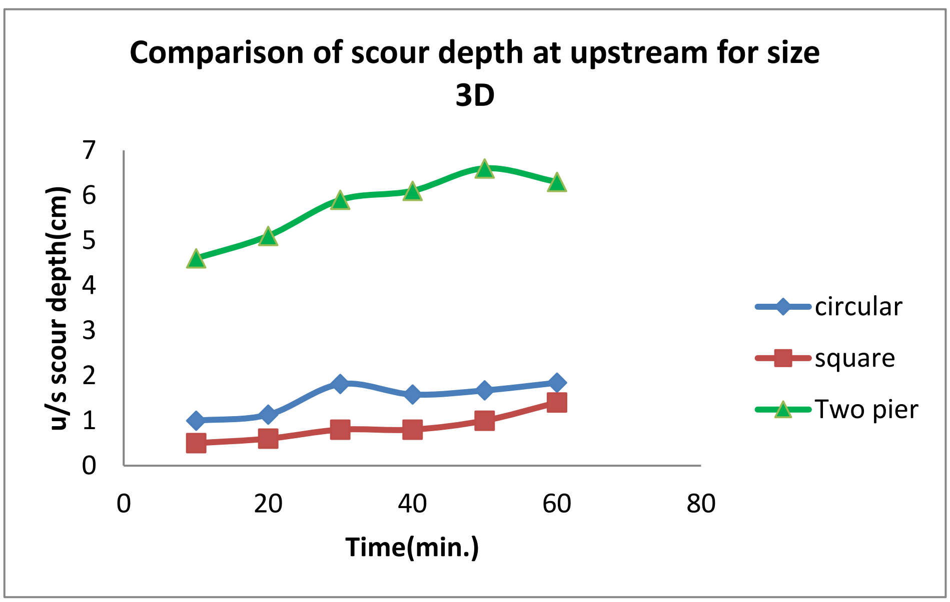

Figure 30 comparison of scour depth for size 3D in different cases

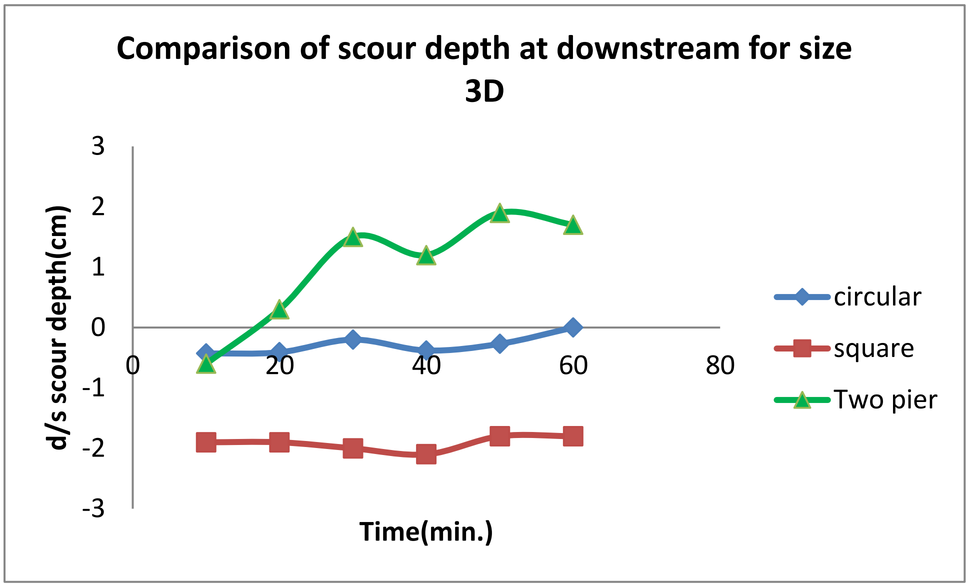

Figure 31 comparison of scour depth at downstream for 3D in different cases

III. For size 4D

The value of scour depth at upstream in circular collar, square collar and two pier are 1.4,1.14,4.6 cm respectively. Hence, minimum scour occurs in square collar. The percent reduction in scour depth at upstream is 74.67% in square collar .At downstream circular collar provide better results than other two.

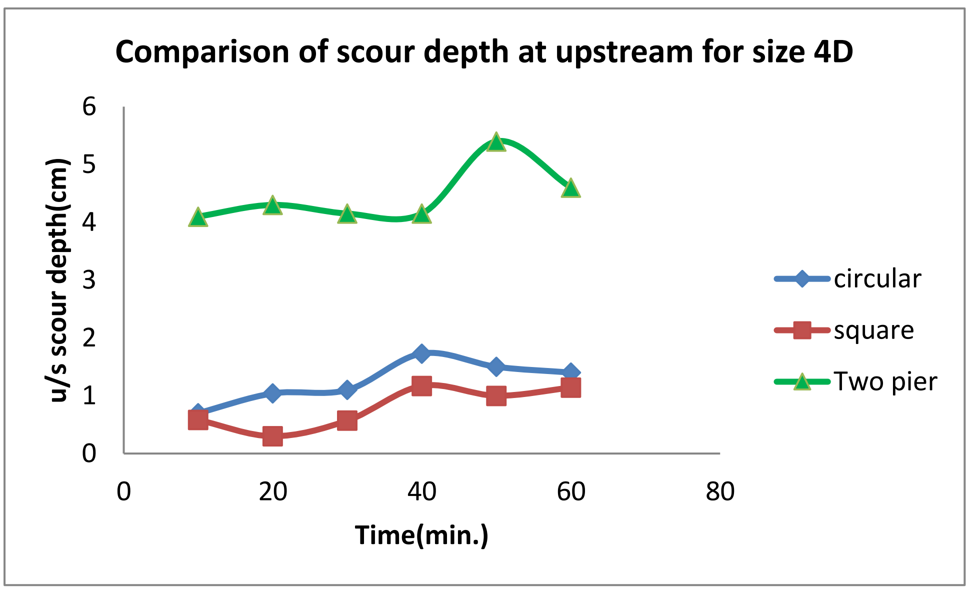

Figure 32 scour depth at upstream in different 4D cases

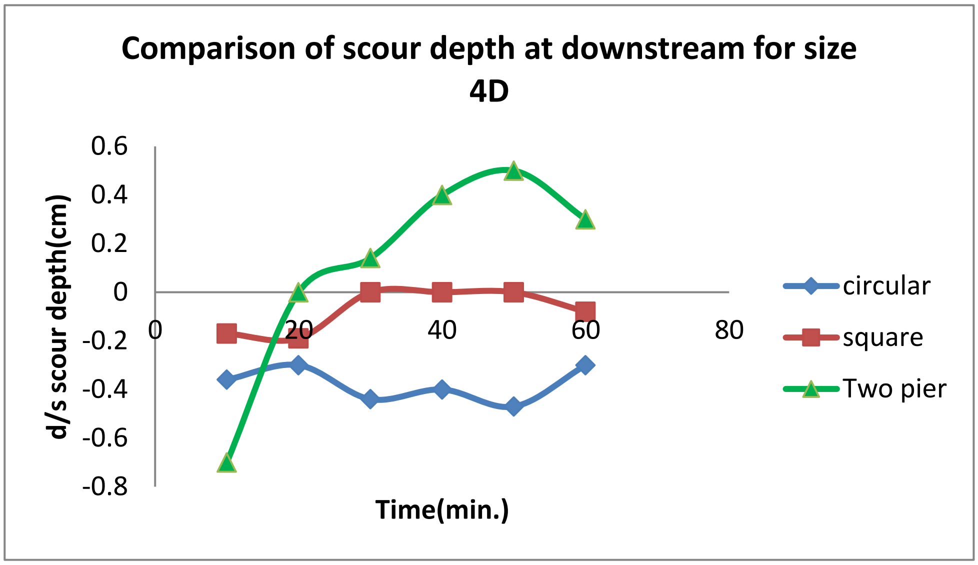

Figure 33 scour depth comparison at downstream in different 4D cases

IV. For size 5D

In case of 5D circular collar gives best results both at upstream and downstream .Scour depth obtained after one hour run in circular collar ,square collar and two pier is 0.1,1.03 and 6.15 respectively. Maximum reduction occurs in case of circular collar that is 97.77%.Graph shows the scouring results of 5D.

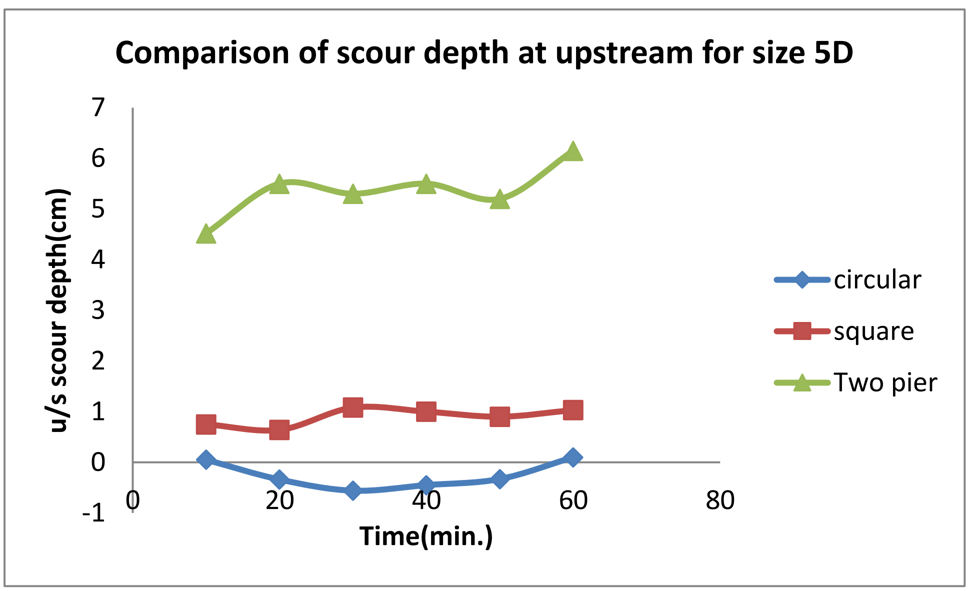

Figure 34 comparison of scour depth at upstream in different 5D cases

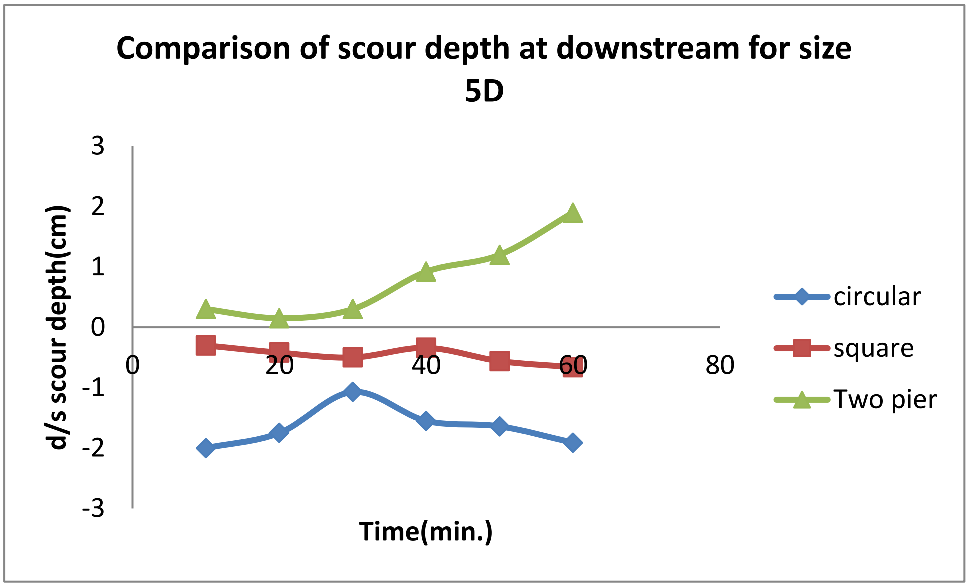

Figure 35 comparison of scour depth at downstream in different 5D cases

5.2 Conclusion

The experiments were carried out in a flume with uniform sand and under clear water conditions to predict the scour around a pier without any protection device and with protection devices for discharge of 3.45 The following conclusions are made on the experimental work on the scour development process around a bridge pier with varying the protection device and its size.

- Scour depth was calculated for a pier without protection device under four discharges and it is found that maximum scour occur at discharge of 3.45 m^3/s. Scour depth at upstream is 4.5 cm and scour depth at downstream is 2.5 cm.
- Scour depth in case of square collar reduces maximum in the case of 5D. The reduction in scour depth at upstream in 5D is 77.11%. Minimum reduction is found in case of 2D that is 42.22%.
- In case of circular collar, maximum reduction in scour depth takes place in case of 5D and maximum reduction is 97.88%. In case of 2D minimum reduction takes place that is 30.66% in comparison to no protection for pier.

- In two pier case ,best results are obtained when center to center distance between two pier is 4D.As we increase the distance two separate holes are formed and affect of front pier on rear pier decreases. Scour depth at upstream is 4.6 cm and at downstream scour depth is 0.3 cm.
- When we compare the results from all 3 approaches it is concluded that best results are obtained from a circular collar of size 5D(means five times the pier diameter).It gives maximum reduction of 97.88% at upstream which is not obtained in any other case.

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