EFFECT OF SCOURING AROUND BRIDGE PIERS

A Thesis Submitted

By

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ABSTRACT

A series of relatively recent bridge failures due to pier scour, as reported in literature, has rekindled interest in furthering our understanding of the scour process and for developing improved ways of protecting bridges against scour. Moreover, increased attention is being given to the state of Bangladeshi infrastructure, a major aspect of which is the transportation network. In part, there is concern about both the impact of a failure on the handling of traffic flow while the failure is being remedied and on the cost of replacing the failed system component. As such, attention is being given to the scour design of new bridges and to the inspection, maintenance and management of existing bridge structures. The two major countermeasure techniques employed for preventing or minimizing local scour at bridge piers are increased scour resistance and flow alteration. In the former case, the objective is to combat the erosive action of the scour-inducing mechanisms using hard engineering materials or physical barriers such as rock riprap. In the latter case, the objective is to either inhibit the formation of the scour-inducing mechanisms or to cause the scour to be shifted away from the immediate vicinity of the pier. This research focuses on a particular application of the latter technique together with the view to improving bridge performances against scouring.

In this study, the use of collars for reducing the effects of local scour at a bridge pier is presented together with the time aspect of the scour development. The adoption of a collar is based on the concept that its existence will sufficiently inhibit and/or deflect the local scour mechanisms so as to reduce the local scour immediately adjacent to the pier.

The overall objective of the research is to study the temporal development of the scour for a pier fitted with a collar and a pier without a collar. More specifically, the objectives are: i) to study the causes of scouring around bridge piers, their types and threats it imposes on bridges and overall structures; ii) to identify pier shape that responses best in order to minimize scouring effect; iii) to find out the relationship of scouring depth with flow velocity, discharge, depth of flow; iv) to find out parameters on which scouring depth depends and develop a relationship with scour depth for changes in the parameters; v)to find out an alternative measure which might reduce suction around bridge piers, which are primarily responsible for scouring.

Keywords: scouring, pier shape, local scour, horseshoe vortex, scour depth

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1 INTRODUCTION

1.1 Background

Scour is a natural phenomenon caused by erosive action of flowing water on the bed and banks of alluvial channels. In other words, Scour is defined as the erosion of streambed sediment around an obstruction in a flow field (Chang, 1988). That is, it is the local lowering of stream bed elevation which takes place around a structure constructed in flowing water, for example, a river. Scouring mechanism has the potential to threaten the structural integrity of hydraulic structures and bridges. This may lead to ultimate failure when the foundation of the structures is undermined. A series of relatively recent bridge failures due to pier scour has rekindled interest in furthering the understanding of the pier scour process and for developing improved ways of protecting bridges against the ravages of scour. The construction of bridges in alluvial channels causes a contraction in the waterway at the bridge site. The contraction in the waterway might cause significant scour at that site. Hoffmans and Verheij (1997) have noted that local scour around bridge piers and foundations, as a result of flood flows, is considered to be the major cause of bridge failure. Bangladesh experienced an unprecedented flood in 1998 and the existing infrastructures underwent a great havoc leading to damage of about 400 nos. of small and medium size culverts and bridges in the country. The 67 m long Turag-Bhakurta Bridge with a width of 3.70 m near Dhaka, the capital city, was constructed under the jurisdiction of Local Government and Engineering Department (LGED) of Bangladesh in 1994. The bridge came under flood attack even before 1998 flood in the year 1995. During 1995 flood the first piers of the bridge from Dhaka-Aricha National Highway side settled down by about 1.61 m. After recession of flood, the affected piers were rehabilitated with additional 30 m long piers but during 1998 flood it was washed away except the rehabilitated piers. The Meghna Bridge has 12 foundations and 15 metres of scouring is found at pier 8, which is considered very risky. Bridge failures cost millions of dollars each year in direct expenditure for replacement and restoration in addition to the indirect expenditure related to the disruption of transportation facilities. The potential losses accruable from bridge failures and the need to guard against same have prompted for better understanding of the scour process and for better scour prediction methods and equations.

Under-prediction of pier scour depth can lead to bridge failure while over-prediction leads to excess expenditure of resources in terms of construction costs (Ting et al. 2001).

Total scour at the bridge site is comprised of three components, namely the aggradations and degradations, contraction scour, and the local scour. Aggradations involve the deposition of materials eroded from other sections of a stream reach, whereas degradations involve the lowering or scouring of the bed of a stream. This scour component is natural and has a long-term effect on streambed elevation changes. The contraction scour results from a reduction of the flow area at the bridge site due to the encroachment into the flood plain or the main channel by the piers, abutments and approach embankments. Local scour involves the removal of material from around piers, abutments, spurs, and embankments. It is caused by an acceleration of the flow and resulting vortices induced by the flow obstructions. Local scour occurred at bridge piers are caused by the interference of the piers with flowing water. This interference will result in a considerable increase in the mean velocity of the flowing water in the channel section. Scouring vortex will be developed when the fast moving flow near the water surface (at the location of the maximum velocity in the channel section) strikes the blunt nose of the pier and deflected towards the bed where the flow velocity is low. Portion of the deflected surface flow will dive downwards and outwards. This will act as a vacuum cleaner and suck the soil particles at the pier site and result in a considerable increase in the scouring depth at this location. Local scour can occur as either ‘clear-water scour’ or ‘live-bed scour’. In clear-water scour, bed materials are removed from the scour hole, but not replenished by the approach flow while in live-bed scour the scour hole is continually supplied with sediment by the approach flow and an equilibrium is attained when, over a period of time, the average amount of sediment transport into the scour hole by the approach flow is equal to the average amount of sediment removed from the scour hole. Under these conditions, the local scour depth fluctuates periodically about a mean value. The interaction between the flow around a bridge pier and the erodible sediment bed surrounding it is very complex [1]. In fact, the phenomenon is so involved that only very limited success has been achieved by the attempts to model scour computationally, and physical model remains the principal tool employed for estimating the expected depths of scour. In this paper, a physical model was used to investigate the effect of the variables affecting the clear-water local scour around piers.

Numerous experimental and numerical studies have been carried out by researchers in an attempt to quantify the equilibrium depth of scour in various types of soil material. Moreover, while a lot of work has been done to develop equations for predicting the depth of scour, researchers have also worked extensively to understand the mechanism of scour. Raudkivi and Ettema (1983), Ahmed and Rajaratnam (1998), Chiew and Melville (1987) and Breusers et al. (1977), among others, are some of the researchers that have worked on pier scour. Local scour around bridge piers was studied by Shen and Schneider (1969) while Breusers et al. (1977) gave a “state of the art” review on local scour around circular piers. Posey (1974) provided guidance on how bridge piers in erodible material can be protected from under-scour by means of an inverted filter extending out a distance of 1.5 to 2.5 pier diameters in all directions from the face of the pier. The potential losses accruable from bridge failures and the need to guard against same have prompted for better understanding of the scour process and for better scour prediction methods and equations. Under-prediction of pier scour depth can lead to bridge failure while over-prediction leads to excess expenditure of resources in terms of construction costs (Ting et al. 2001). Numerous experimental and numerical studies have been carried out by researchers in an attempt to quantify the equilibrium depth of scour in various types of soil material. Moreover, while a lot of work has been done to develop equations for predicting the depth of scour, researchers have also worked extensively to understand the mechanism of scour. Raudkivi and Ettema (1983), Ahmed and Rajaratnam (1998), Chiew and Melville (1987) and Breusers et al. (1977), among others, are some of the researchers that have worked on pier scour. Local scour around bridge piers was studied by Shen and Schneider (1969) while Breusers et al. (1977) gave a ìstate of the artî review on local scour around circular piers. Posey (1974) provided guidance on how bridge piers in erodible material can be protected from under-scour by means of an inverted filter extending out a distance of 1.5 to 2.5 pier diameters in all directions from the face of the pier. Current research areas include understanding the scour processes, temporal development of scour, predicting scour in cohesive soils, parametric studies of local scour, and prediction of scour depth at various types of hydraulic structures. For example, Ansari et al. (2002) studied the influence of cohesion on scour around bridge piers. Ahmed and Rajaratnam (1998) investigated the flow around bridge piers in their laboratory study on flow past cylindrical piers placed on smooth, rough and mobile beds. Jia et al. (2002) reported the findings of a numerical modeling study for simulating the time-dependent scour hole development around a cylindrical pier founded on a loose bed in an open channel. Lim and

Chiew (2001) presented a parametric study on riprap protection and failure around a cylindrical bridge pier with uniform bed sediments. Link and Zanke (2004) studied the time-dependent scour-hole volume evolution at a circular pier in uniform coarse sand and developed a mathematical correlation between the scour volume and the maximum scour depth for water depth to pier diameter ratios between one and two.

However, just as the scour depth is important in scour studies, the time taken to reach a particular scour depth is also very significant as scour holes take some time to form. For this reason, it becomes necessary to understand the development of the local scour hole with time. Also, in clear-water scour conditions, the depth of a scour hole approaches an equilibrium condition asymptotically with time (Breusser 1977). Consequently, time is an important factor in undertaking scour studies. The temporal development of scour has been studied by many researchers (e.g. Melville and Chiew 1999; Yanmaz and Altinbilek 1991). Moreover, the rate of local scour around a bridge pier is a significant factor in scheduling scour mitigation measures and is also essential in understanding scour under time-varying flows (Gosselin and Sheppard 1995). For adequate representation of the temporal development of scour and also the efficacy of using a collar as a countermeasure in a bridge pier in model studies, the definition of time to equilibrium adopted is very vital as this determines the test duration.

1.2 Objectives

- To run CFD simulation of scouring around bridge piers
- To identify pier shape that responses best in order to minimize scouring effect.
- To find out the relationship of scouring depth with flow velocity
- To compare the results with the physical experiment

1.3 Title Page

The study reported herein is based on model designed in ANSYS and run the simulation in CFX-PRE and finally processed in CFX-POST.

1.4 Synopsis of thesis

In Chapter 2, the background and current state of knowledge of scour, temporal development of scour and literature related to it are covered. Chapter 3 gives a description of the models and procedures. Results and discussion of results are presented in Chapter 4. Finally, the principal conclusions drawn from the results of the study and recommendations for future studies are presented in Chapter 5.

2. LITERATURE REVIEW

2.1 Introduction:

A large amount of published literature is available on the local scour of cohesionless bed sediment around a bridge pier. This chapter attempts to summarise the present state of understanding of local scour in cohesionless soil, the temporal development of scour as well as mitigation strategies for minimising the local scour at a bridge pier. The chapter is included to familiarise the reader with terminologies germane to local scour at a bridge pier as well as to facilitate the understanding of scour.

2.1.1 What is scour?

Cheremisinoff et al. (1987) defined scour as the lowering of the level of the river bed by water erosion such that there is a tendency to expose the foundations of structures such as bridges. Breusers et al. (1977) defined scour as a natural phenomenon caused by the flow of water in rivers and streams. It is the consequence of the erosive action of flowing water, which removes and erodes material from the bed and banks of streams and also from the vicinity of bridge piers and abutments. As noted by the authors, scour can either be caused by the normal flow or flood events. Normal flow can lower the channel bed but scouring is most assisted during a peak flow in which the flow velocity is higher. In other words, scour can occur under any flow condition that makes the bed mobile within the vicinity of the obstruction but the rate of scouring is much higher with larger flow events. The amount of the reduction below an assumed natural level (generally the level of the river bed prior to the commencement of the scour) is termed the scour depth. A scour hole is defined as the void or depression left behind when sediment is washed away from a stream or river bed.

2.1.2 Types of Scour

The total scour at a river crossing consists of three components that, in general, can be added together (Richardson and Davies 1995). They include general scour, contraction scour, and local scour. Cheremisinoff et al. (1987) on the other hand divided scour into two major types, namely general scour and localised scour. Some other sub-divisions of scour are as shown in Figure 2.1.

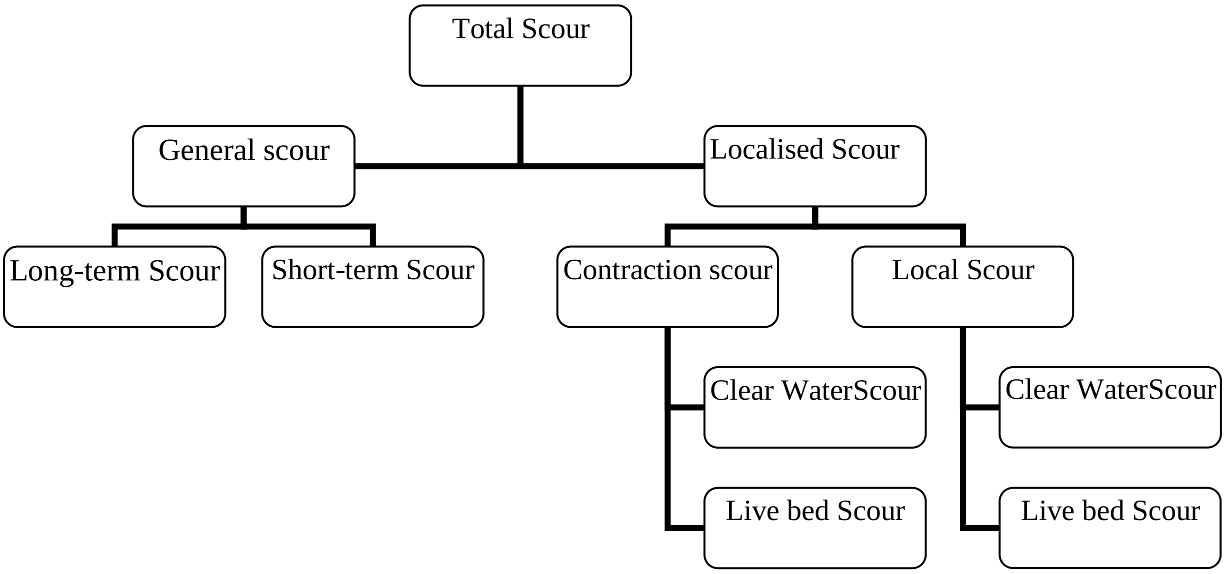

Figure 2.1 Organogram showing various types of scour (Modified from Cheremisinoff et al. 1987)

General scour: This type of scour deals with the changes in river bed elevation due to natural/human-induced causes with the effect of causing an overall lowering of the longitudinal profile of the river channel. It occurs through a change in the river regime resulting in general degradation of the bed level. General scour develops irrespective of the existence of a bridge. General scour can further be divided into long-term and short-term scour, with the two types being differentiated by the temporal development of the scour (Cheremisinoff et al. 1987). Short-term general scour occurs in response to a single or several closely spaced floods whereas long-term general scour develops over a significantly longer time period, usually of the order of several years, and includes progressive degradation and lateral bank erosion.

Localised scour: In contrast to general scour, localised scour is directly attributable to the existence of a bridge or other riverine structures. Localised scour can further be divided into contraction and local scour.

Contraction scour: This type of scour occurs as a result of the contraction of a channel or waterway, either due to a natural means or human alteration of the floodplain. The effect of such a constriction is a decrease in the flow area and an increase in the average flow velocity, which consequently causes an increase in the erosive forces exerted on the channel bed. The overall effect of this phenomenon is the lowering of the channel bed. A bridge with approaches or abutments encroaching onto the floodplain of a river is a common example of contraction scour.

Local scour: This type of scour refers to the removal of sediment from the immediate vicinity of bridge piers or abutments. It occurs as a result of the interference with the flow by piers or abutments, which result in an acceleration of the flow, creating vortices that remove the sediment material in the surroundings of the bridge piers or abutments. Scour occurring as a result of spur dykes and other river training works is also an example of local scour.

2.2 Local Scour Mechanism

It has long been established that the basic mechanism causing local scour at piers is the down-flow at the upstream face of the pier and formation of vortices at the base (Heidarpour et al. 2003; Muzzammil et al. 2004). The flow decelerates as it approaches the pier coming to rest at the face of the pier. The approach flow velocity, therefore, at the stagnation point on the upstream side of the pier is reduced to zero, which results in a pressure increase at the pier face. The associated stagnation pressures are highest near the surface, where the deceleration is greatest, and decrease downwards (Melville and Raudkivi 1977). In other words, as the velocity is decreasing from the surface to the bed, the stagnation pressure on the face of the pier also decreases accordingly i.e. a downward pressure gradient. The pressure gradient arising from the decreased pressure forces the flow down the face of the pier, resembling that of a vertical jet. The resulting down-flow impinges on the streambed and creates a hole in the vicinity of the pier base. The strength of the down-flow reaches a maximum just below the bed level. The down-flow impinging on the bed is the main scouring agent (Melville and Raudkivi 1977).

Figure 2.3 shows the flow and scour pattern at a circular pier. As illustrated in the figure, the strong vortex motion caused by the existence of the pier entrains bed sediments within the vicinity of the pier base (Lauchlan and Melville 2001). The down-flow rolls up as it continues to create a hole and, through interaction with the oncoming flow, develops into a complex vortex system. The vortex then extends downstream along the sides of the pier. This vortex is often referred to as horseshoe vortex because of its great similarity to a horseshoe (Breusers et al. 1977). Thus the horseshoe vortex developed as a result of separation of flow at the upstream face of the scour hole excavated by the down-flow. The horseshoe vortex itself is a lee eddy similar to the eddy or ground roller downstream of a dune crest (Breusers and Raudkivi 1991). The horseshow vortex is very effective at transporting the dislodged particles away past the pier. The horseshoe vortex is as a result of scour but is not the cause of scour (Breusers and Raudkivi 1991). As the scour depth increases, the horseshoe vortex strength diminishes, which automatically leads to a reduction in the sediment transport rate from the base of the pier (Lagasse et al. 2001). As shown in Figure 2.3, besides the horseshoe vortex in the vicinity of the pier base, there are also the vertical vortices downstream of the pier referred to as wake vortices (Dargahi 1990). The separation of the flow at the sides of the pier produces the so-called wake vortices. These wake vortices are not stable and shed alternately from one side of the pier and then the other. It should be noted, however, that both the horseshoe and wake vortices erode material from the base region of the pier. The intensity of the wake vortices is drastically reduced with distance downstream, such that sediment deposition is common immediately downstream of the pier (Richardson and Davies 1995).

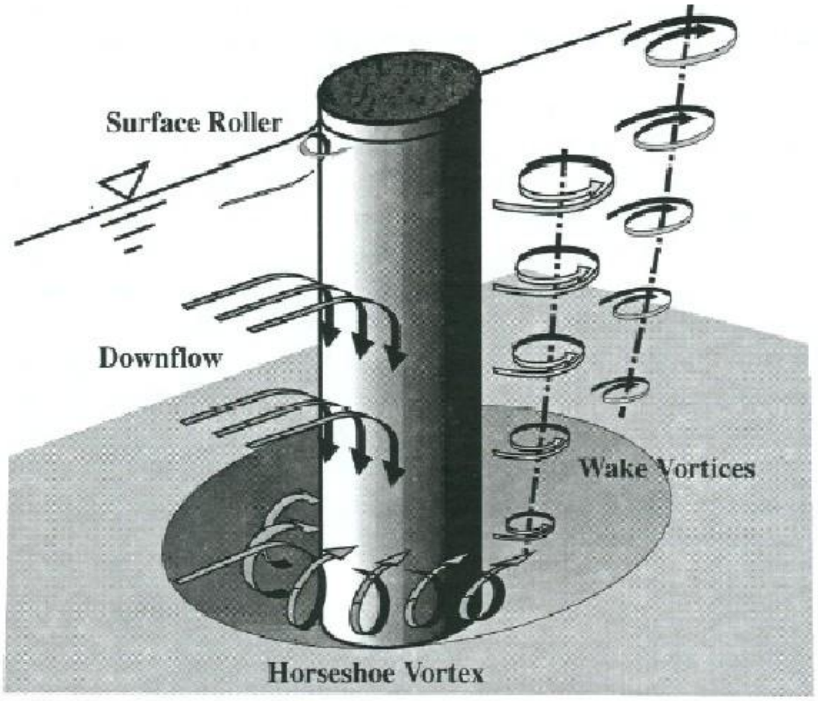

Figure 2.2 Illustration of the flow and scour pattern at a circular pier (Melville & Coleman2000)

2.3 Classification of local scour

Chabert and Engeldinger (1956) identified two main classifications of local scour at piers based on the mode of sediment transport by the approaching stream, namely clear-water scour and live bed scour. These classifications depend on the ability of the flow approaching the bridge to transport bed material (Chiew and Melville 1987). Clear-water scour is defined as the case where the bed sediment is not moved by the approach flow, or rather where sediment material is removed from the scour hole but not refilled by the approach flow (Melville 1984). Similarly, Raudkivi and Ettema (1983) defined clear-water scour as occurring when the bed material at the upstream side of the pier is not in motion. Live-bed scour, on the other hand, occurs when there is general transportation of the bed material by the flow. Live-bed scour occurs when the scour hole is continually replenished with sediment by the approach flow (Dey 1999). In clear-water scour, the maximum scour depth is reached when the flow can no longer remove particles from the scour hole (Breusers et al. 1977). In live-bed scour, an equilibrium scour depth is reached when, over a period of time, the quantity of material eroded from the scour hole by the flow equals the quantity of material supplied to the scour hole from upstream (Melville 1984). The temporal development of the maximum scour depth under clear-water and live-bed scour conditions is illustrated in Figure 2.3.

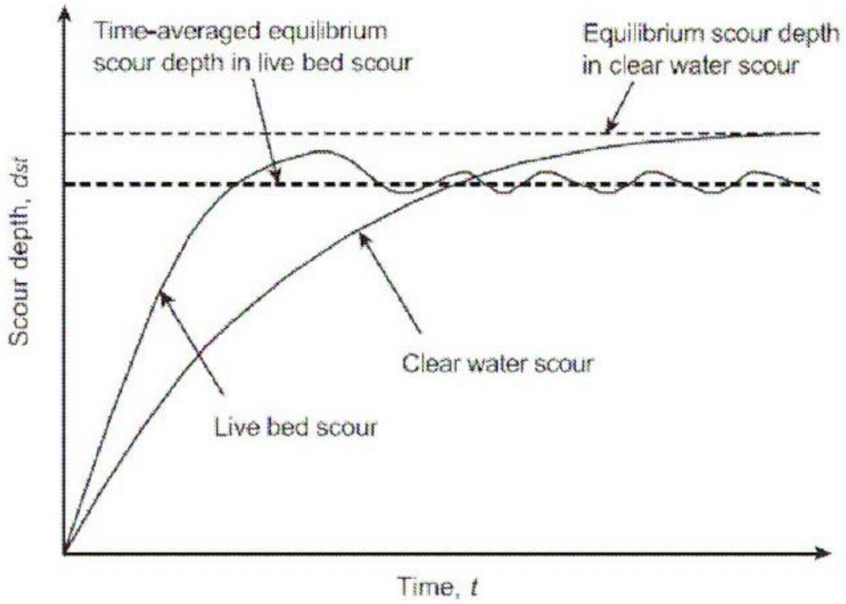

Figure 2.3 Clear-water and live-bed scour conditions (Raudkivi and Ettema 1983)

2.4 Scour Parameters

Factors which affect the magnitude of the local scour depth at piers as given by Richardson and Davies (1995), Raudkivi and Ettema (1983) and Lagasse et al. (2001) are (1) approach flow velocity, (2) flow depth, (3) pier width, (4) gravitational acceleration, (5) pier length if skewed to the main flow direction, (6) size and gradation of the bed material, (7) angle of attack of the approach flow to the pier, (8) pier shape, (9) bed configuration, and (10) ice or debris jams.

According to Breusers et al. (1977) and Ansari et al. (2002) the parameters listed above can be grouped into four major headings, viz.

- Approaching stream flow parameters: Flow intensity, flow depth, shear velocity, mean velocity, velocity distribution and bed roughness.

- Pier parameters: Size, geometry, spacing, number and orientation of the pier with respect to the main flow direction (i.e., angle of attack).
- Bed sediment parameters: Grain size distribution, mass density, particle shape, angle of repose and cohesiveness of the soil.
- Fluid parameters: Mass density, acceleration due to gravity and kinematic viscosity.

2.4.1 Flow Depth

The influence of flow depth on the scour depth has been discussed by many authors (e.g. Chabert and Engeldinger 1956; Laursen and Toch 1956; Dey 1977; Breusers et al. 1977; Breusers and Raudkivi 1991; Hoffmans and Verheij 1997; Ettema 1980; Melville and Coleman 2000). The presence of the pier in the channel causes a surface roller around the pier and a horseshoe vortex at the base of the pier. Flow depth affects local scour depth when the horseshoe vortex is affected by the formation of the surface roller (or bow wave) that forms at the leading edge of the pier. The two rollers, (i.e., the bow wave and the horseshoe vortex) rotate in opposite directions. In principle, as long as there is no interference between the two rollers, the local scour depth does not depend on the flow depth but depends only on the pier diameter. In such an instance, often called deep flow, the local scour is said to occur at narrow piers. As the flow depth decreases, the surface roller becomes relatively more dominant and causes the horseshoe vortex to be less capable of entraining sediment. Therefore, for shallower flows, the local scour depth is reduced. Subsequently, in a very shallow flow, the local scour is dependent on the flow depth and the local scour is said to occur at a wide pier. Melville and Chiew (1999) claimed that these trends are evident in the laboratory data of many researchers, including Chabert and Engeldinger (1956), Laursen and Toch (1956), Breusers et al. (1977) and Ettema (1980).

The flow shallowness, D/ yo, (where D and yo are the pier diameter and flow depth, respectively) can be used to classify the influence of the flow depth in relation to the width of the pier (Melville and Coleman 2000). Table 2.1, as adapted from Melville and Coleman, shows a classification of local scour processes at bridge pier foundations.

Table 2.1 Classification of local scour processes at bridge pier foundations

Class	**D/y_0**	**Local Scour Dependence**
Narrow	$D/y_0 < 0.7$	$y_s \alpha D$
Intermediate Width	$0.7 < D/y_0 < 5$	$y_s \alpha (Dy_0)^{0.5}$
Wide	$D/y_0 > 5$	$y_s \alpha y_0$

In summary, observations showed that at shallow flow depths the local scour at piers increases with flow depth, but for larger water depth (i.e., deep flow), the scour depth becomes independent of flow depth but depends on the pier diameter.

2.4.2 Pier Size

Experiments have clearly shown that it is possible to relate the scour depth to the size of the pier (Breusers et al. 1977). This observation, can be explained physically by the fact that scouring is due to the horseshoe vortex system whose dimension is a function of the 19 diameter of the pier. It has also been observed by Shen et al. (1969) that, the horseshoe vortex, being one of the main scouring agents, is proportional to the pier Reynolds number (R_b), ($R_b = uD/ \upsilon$), which in turn is a function of the pier diameter. For the same value of mean approach flow velocity, therefore, the scour depth is proportional to the pier width. The influence of pier size on the local scour depth is of interest when data from the laboratory are interpreted for field use (Breusers and Raudkivi 1991). Under clear-water conditions, pier size influences the time taken to reach the ultimate scour depth but not its relative magnitude ys/D, if the influence of relative depth, yo/D, and relative grain size D/d50 on the local scour depth are excluded (Breusers and Raudkivi 1991). They also concluded that the volume of the local scour hole formed around the upstream half of the perimeter of the pier is proportional to the cube of the pier diameter (or the projected width of the pier). The larger the pier the larger the scour hole volume and also the longer is the time taken for the development of the scour hole for a given shear stress ratio.

2.4.3 Pier Shape

Bridge piers are constructed of various shapes. The most common shapes used are circular, diamond shaped and elliptical. Figure 2.4.3 shows a schematic illustration of some pier shapes. The effect of pier shape has been reported by many researchers (e.g. Laursen and Toch 1956, Dey 1997, Breusers 1977, Breusers and Raudkivi 1991, Melville and Coleman 2000). The blunter the pier, the deeper the local scour has been the general conclusion. The shape of the downstream end of the pier is concluded to be of little significance on the maximum scour depth. The pier shape is often accounted for by using a shape factor. Melville and Chiew (2000) cited the work of Mostafa (1994) in which shape factors for uniform piers, that is piers having constant section throughout their depth, was proposed. Mostafa measured the local scour depths for variety of different pier shapes all having the same projected width (140 mm). From his results, a circular pier produced the least scour while a rectangular pier having blunt ends produced the most scour. In practice, shape factors are only significant if axial flow can be maintained 20 because even a small angle of attack will eliminate any benefit from a streamlined shape (Melville and Chiew 2000). Non-uniform piers include piers with piled foundations, caissons, slab footings and tapered piers. For piers tapered on the upstream and downstream faces, the slope, in elevation, of the leading edge of the pier affects the local scour depth. Downward-tapered piers induce deeper scour than does a circular pier of the same width.

Figure 2.4.3 Schematic illustration of some pier shapes.

3. COMPUTATIONAL FLUID DYNAMICS (CFD)

Computational fluid dynamics, usually abbreviated as **CFD**, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by boundary conditions. With high-speed supercomputers, better solutions can be achieved. Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows. Initial validation of such software is performed using a wind tunnel with the final validation coming in full-scale testing, e.g. flight tests.

CFD is part of computational mechanics, which in turn is part of simulation techniques. Simulation is used by engineers and physicists to forecast or reconstruct the behaviour of an engineering product or physical situation under assumed or measured boundary conditions (geometry, initial states, loads, etc.). A variety of reasons can be cited for the increased importance simulation techniques have achieved in recent years:

- Need to forecast performance
- Cost and/or impossibility of experiments
- The desire for increased insight
- Advances in computer speed and memory (1:10 every 5 years)
- Advances in solution algorithms

The simulation of flows is accomplished by:

- Solving numerically partial differential equations (PDEs),
- Following the interaction of a large numbers of particles, or
- A combination of both.

CFD, by its very nature, encompasses a variety of disciplines, which may be enumerated in the following order of importance:

- Engineering
- Physics
- Mathematics (classic and numerical analysis, discrete mathematics)
- Computer Science (algorithms, coding, software)
- Visualization Techniques
- User Community (benchmarking, documentation, teaching)

4. EXPERIMENTAL SETUP AND METHODOLOGY

4.1 Introduction

In this chapter, the software used for simulation, design parameters of the model data acquisition system and variables measured in the model study are described.

4.2 Software

ANSYS, Inc. is an engineering simulation software (computer-aided engineering, or CAE) developer that is headquartered south of Pittsburgh in Canonsburg, Pennsylvania, United States.

ANSYS was listed on the NASDAQ stock exchange in 1996. In late 2011, Investor's Business Daily ranked ANSYS as one of only six technology businesses worldwide to receive the highest possible score on its Smart Select Composite Ratings. ANSYS has been recognized as a strong performer by a number of other sources as well. The organization reinvests 15 percent of its revenues each year into research to continually refine the software.

ANSYS CFX software is a high-performance, general purpose fluid dynamics program that has been applied to solve wide-ranging fluid flow problems for over 20 years. At the heart of ANSYS CFX is its advanced solver technology, the key to achieving reliable and accurate solutions quickly and robustly. The modern, highly parallelized solver is the foundation for an abundant choice of physical models to capture virtually any type of phenomena related to fluid flow. The solver and its many physical models are wrapped in a modern, intuitive, and flexible GUI and user environment, with extensive capabilities for customization and automation using session files, scripting and a powerful expression language.

But ANSYS CFX is more than just a powerful CFD code. Integration into theANSYS Workbench platform, provides superior bi-directional connections to all major CAD systems, powerful geometry modification and creation tools withANSYS DesignModeler, advanced meshing technologies in ANSYS Meshing, and easy drag-and-drop transfer of data and results to share between applications. For example, a fluid flow solution can be used in the definition of a boundary load of a subsequent structural mechanics simulation. A native two-way connection to ANSYS structural mechanics products allows capture of even the most complex fluid–structure interaction (FSI) problems in the same easy-to-use environment, saving the need to purchase, administer or run third-party coupling software

4.3 Flow Channel

The experimental model reported herein was 10 m long, 0.3 m wide and 0.6 m deep. The channel has a working section in the form of a recess that is filled with sediment to a uniform thickness of 0.10 m. The working section of the flume is made up of concrete.

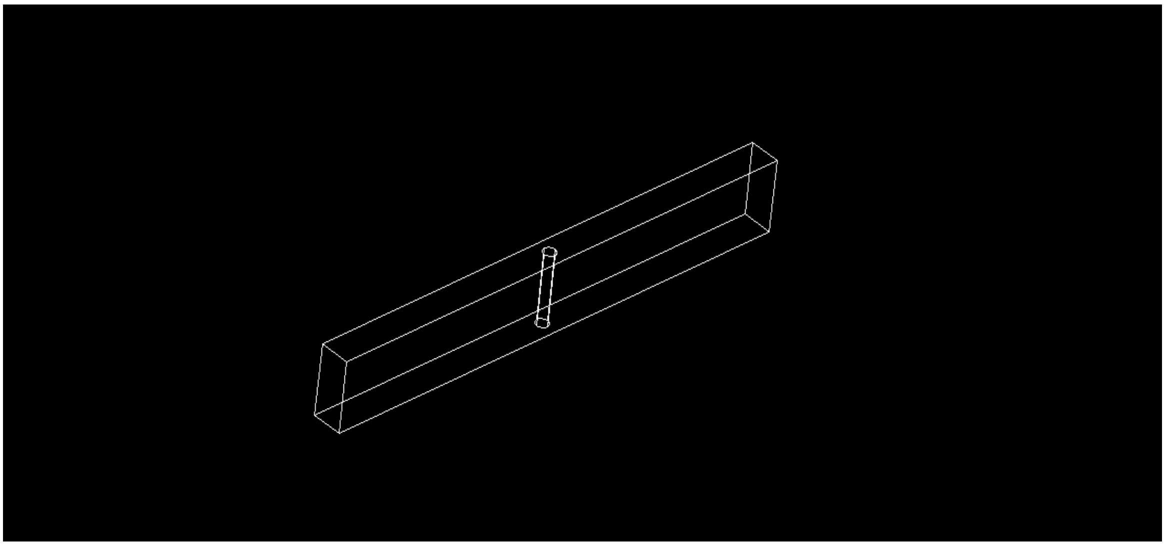

Figure 4.3(a) Schematic illustration of the experimental model

4.4 Pier Models

The pier model was one circular model pier of diameter 25 mm having a vertical scale of 600 mm marked onto their sides were used for the study. The pier was placed on the centreline of the flume at the same longitudinal location. For all of the tests, the piers were positioned at the bed level in accordance with the recommendations of earlier researches. The pier diameter was carefully chosen so that there was negligible effect of flume width on the depth of scour.

4.5 Meshing

The partial differential equations that govern fluid flow and heat transfer are not usually amenable to analytical solutions, except for very simple cases. Therefore, in order to analyze fluid flows, flow domains are split into smaller subdomains (made up of geometric primitives like hexahedra and tetrahedra in 3D and quadrilaterals and triangles in 2D). The governing equations are then discretized and solved inside each of these subdomains. Typically, one of three methods is used to solve the approximate version of the system of equations: finite volumes, finite elements, or finite differences. Care must be taken to ensure proper continuity of solution across the common interfaces between two subdomains, so that the approximate solutions inside various portions can be put together to give a complete picture of fluid flow in the entire domain. The subdomains are often called elements or cells, and the collection of all elements or cells is called a mesh or grid. The origin of the term mesh (or grid) goes back to early days of CFD when most analyses were 2D in nature. For 2D analyses, a domain split into elements resembles a wire mesh, hence the name.

Before defining the boundary conditions we had to do the meshing of the model. The picture of the meshed model is shown below.

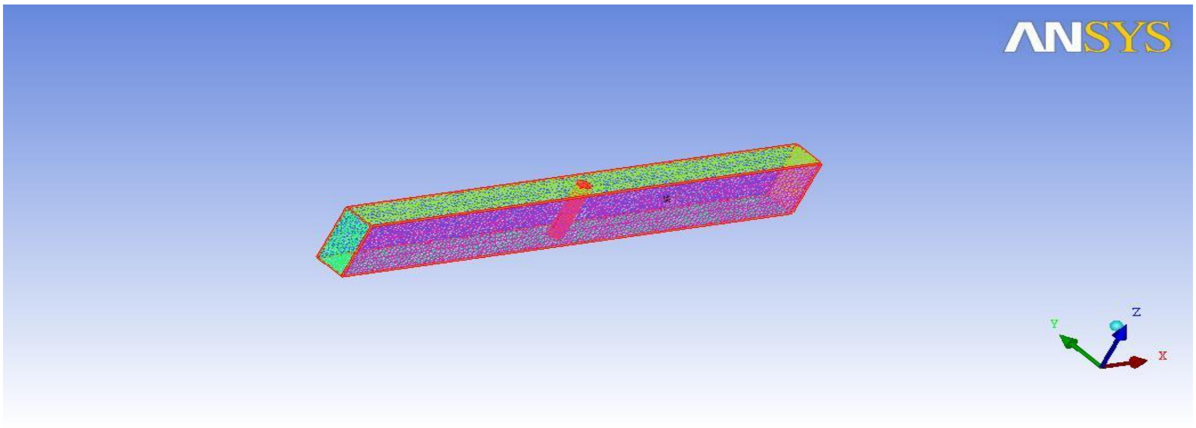

Figure 4.5 Schematic illustration of the meshed experimental model

4.6 Defining Boundary Conditions

At this stage we had to define the boundaries and declare the inlet, outlet, free surface and wall. We have run the simulation for two different boundary conditions.

1. Condition: 1
   - Inlet velocity: 2 m/s
   - Outlet velocity: 2 m/s
   - Pressure on the free surface: 1 atm
   - Walls: non slipping walls
2. Condition: 2
   - Inlet velocity: 5 m/s
   - Outlet velocity: 2 m/s
   - Pressure on the free surface: 1 atm
   - Walls: non slipping walls

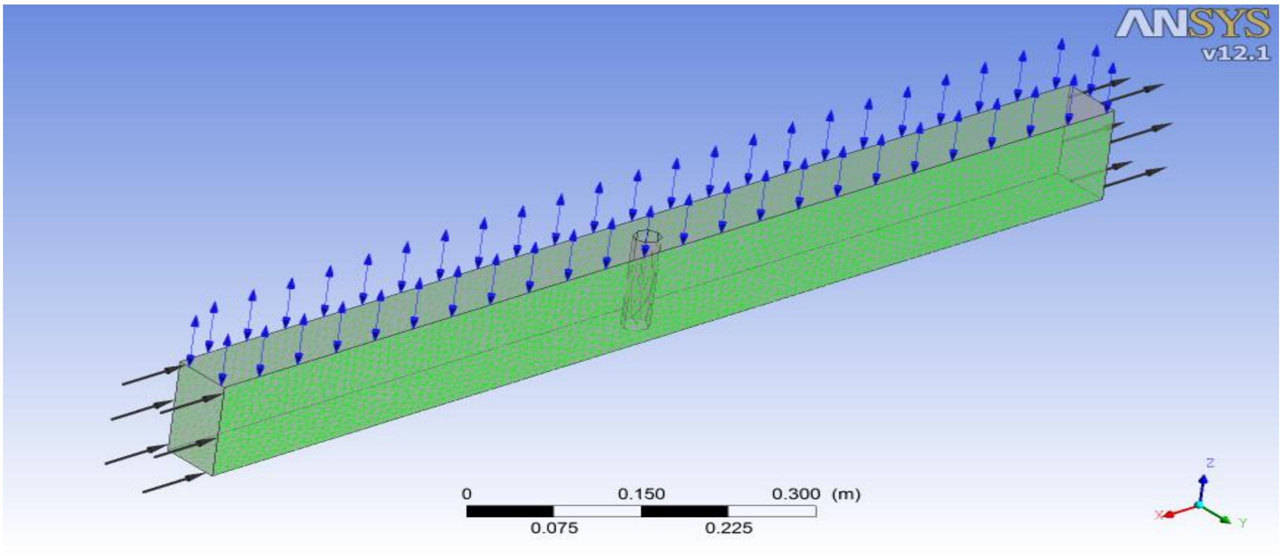

Figure 4.5(a) Defined boundaries of the model

4.7 Theoretical Approach

The dimensional analysis technique using Buckingham π-theorem was applied to obtain dimensionless groups from the variables governing the local scour depth in a mobile bed resulting from constricting the flow by the bridge piers. These variables are as follows:

- The flow characteristics in the open channels represented by the average velocity, V and the water depth, y.
- Characteristics of the flowing fluid represented by the mass density, ρ and the dynamic viscosity, μ .
- Geometrical characteristics of the pier which include pier length, L, pier width, b, angle of attack, θ, and the spacing between piers, x.
- Characteristics of the bed material for the open channel represented by the particle size, d, the local scour depth, d_s, and finally the acceleration due to gravity g.

$$\varphi_1(V, y, \rho, \mu, L, b, \theta, x, d, d_s, g) = 0 \tag{3.5}$$

5. DATA ANALYSIS

5.1 Introduction

The primary objective of this study program was to simulate the scouring effect with the help of ANSYS at a bridge pier. Assessment of the occurrence of an equilibrium scour condition, if achieved, or of the implications of not achieving such a condition in respect of interpreting the results obtained from a physical hydraulic model study was to be carried out. In this chapter, the results obtained from all of the experiments are presented.

5.2.1 Condition 1

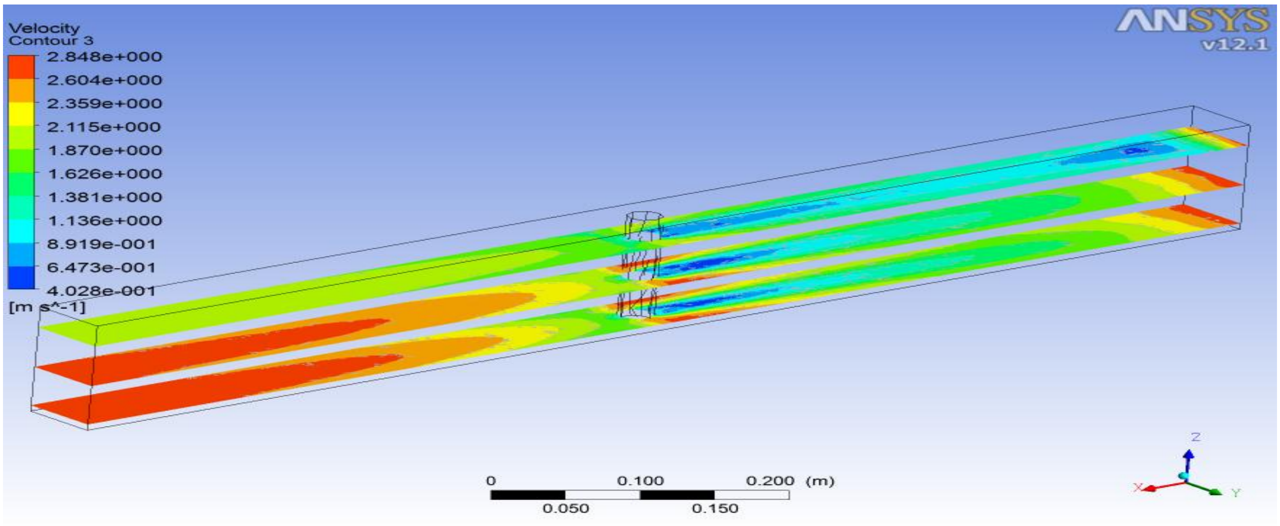

Figure 5.2.1(a) Velocity profile in XY plane

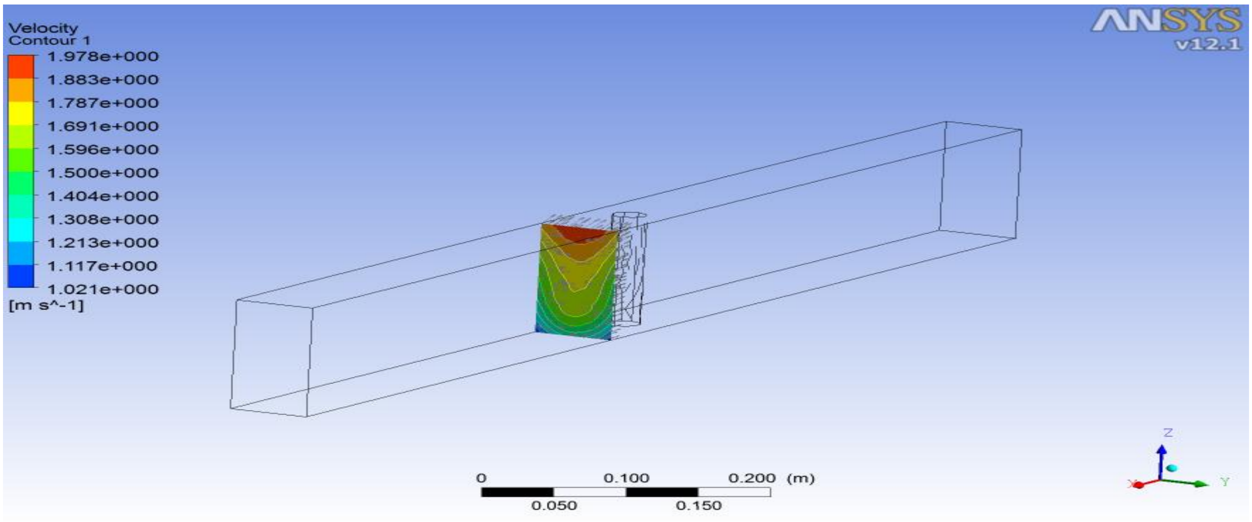

Figure 5.2.1 (b) Velocity profile in YZ plane

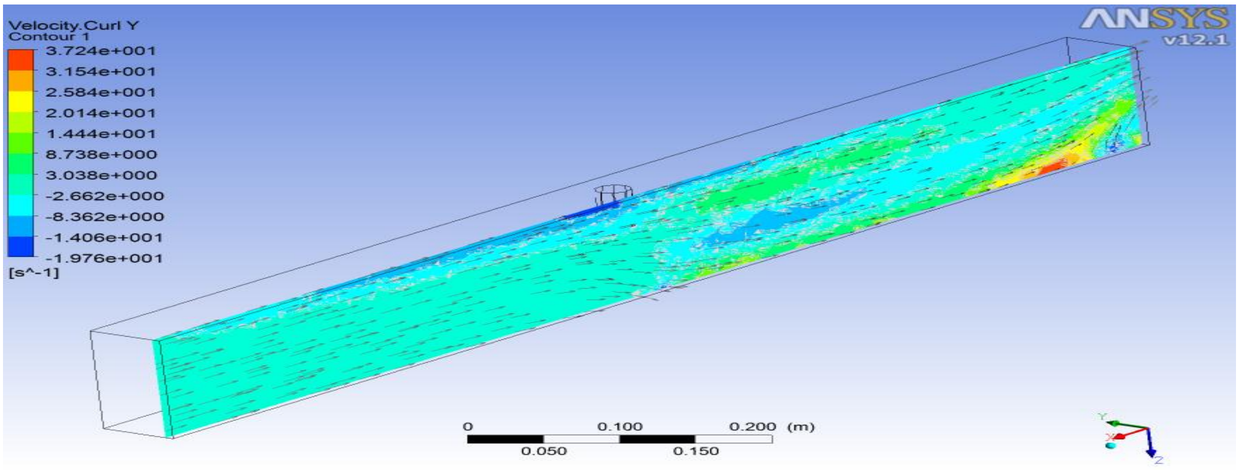

Figure 4.2.1 (c.1) Velocity profiles in ZX plane

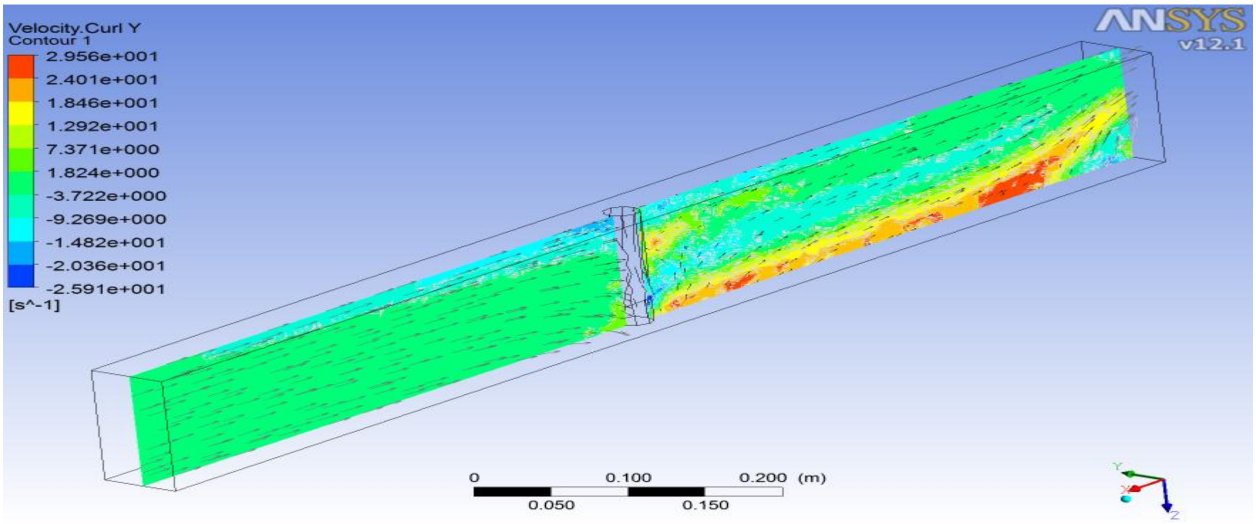

Figure 5.2.1 (c.2) Velocity profiles in ZX plane

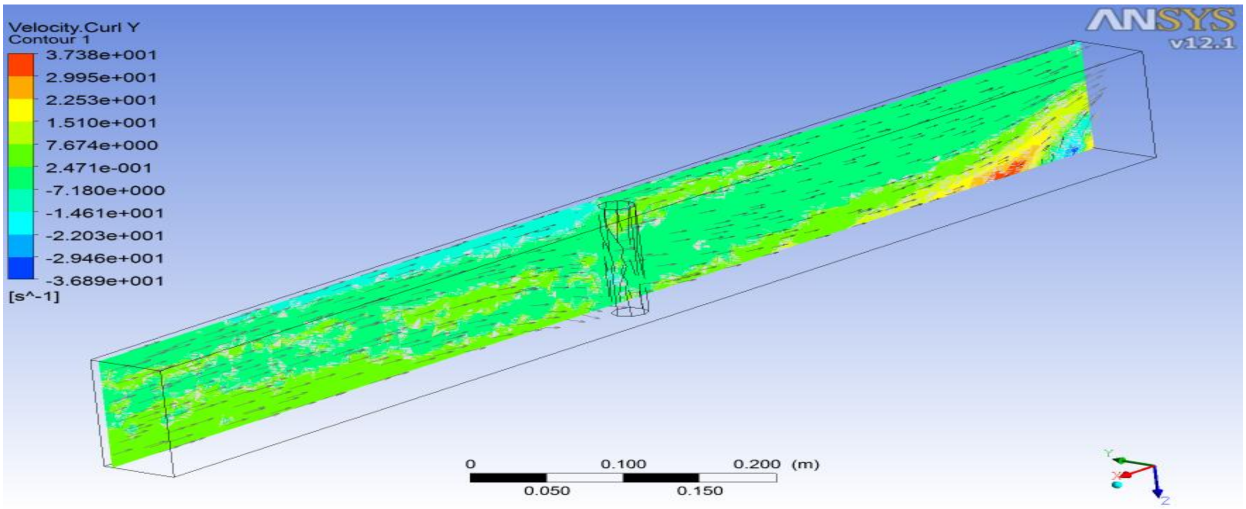

Figure 5.2.1 (c.3) Velocity profiles in ZX plane

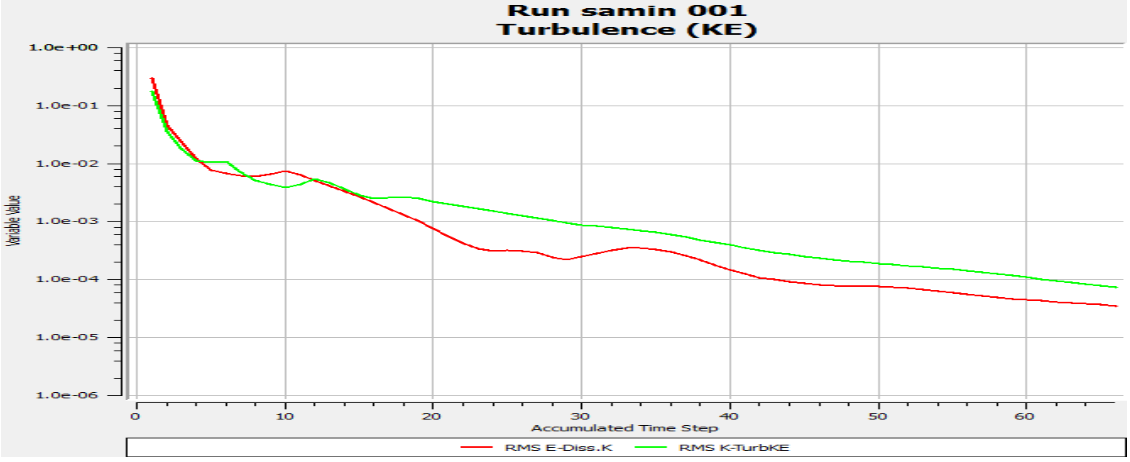

Figure 5.2.1 (d) Variation in turbulence with time

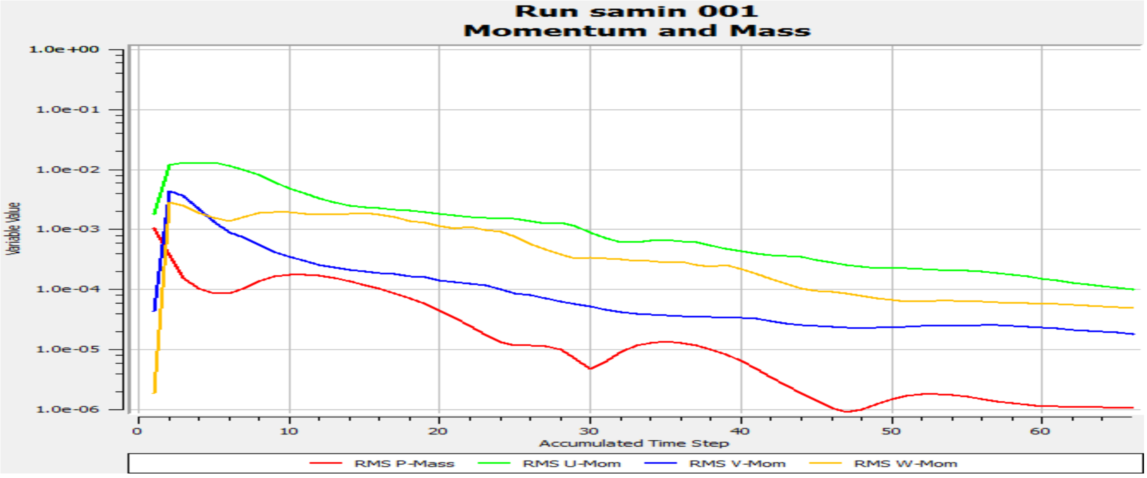

Figure 5.2.1(d) Variation in momentum and mass with time

5.2.2 Condition 2

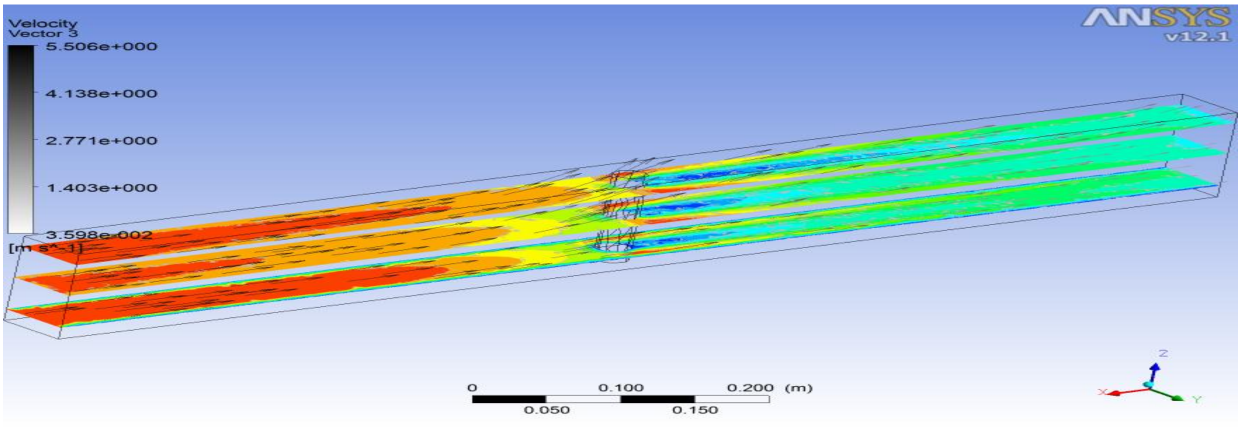

Figure 5.2.2(a) Velocity profile in XY plane

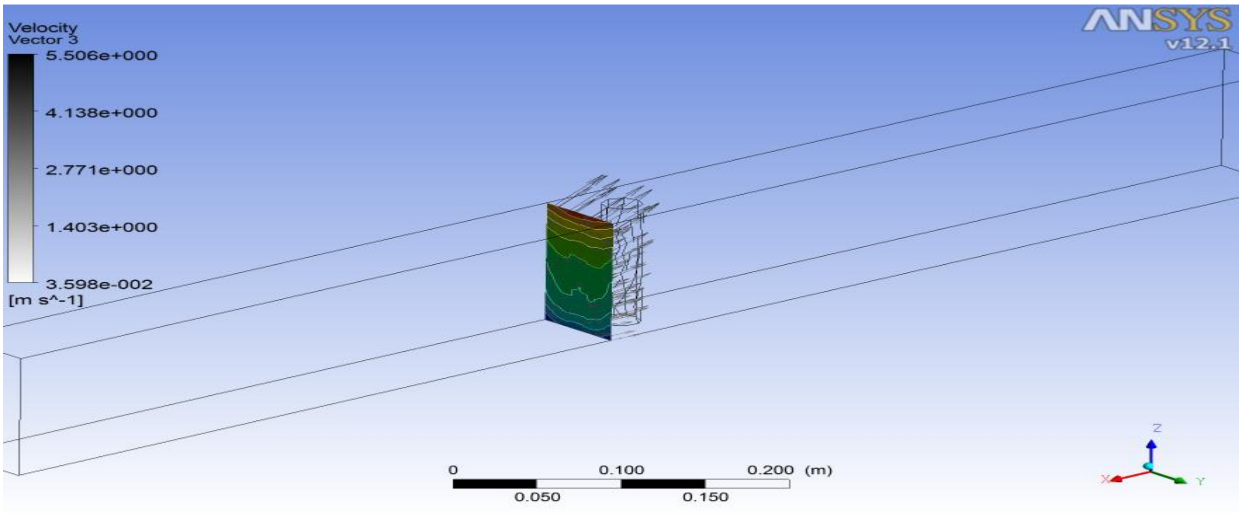

Figure 5.2.2 (b) Velocity profile in YZ plane

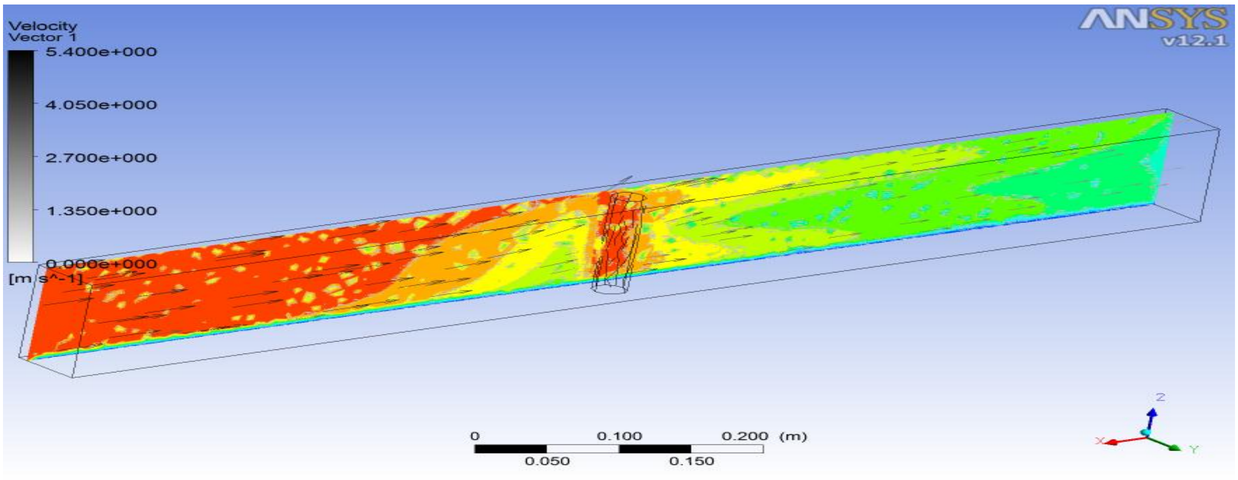

Figure 5.2.2 (c.1) Velocity profiles in ZX plane

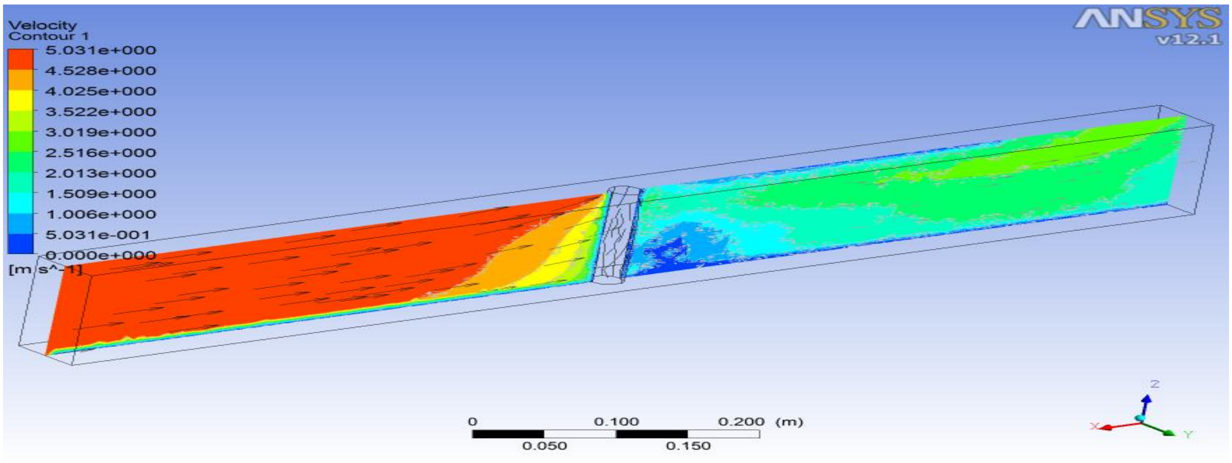

Figure 5.2.2 (c.2) Velocity profiles in ZX plane

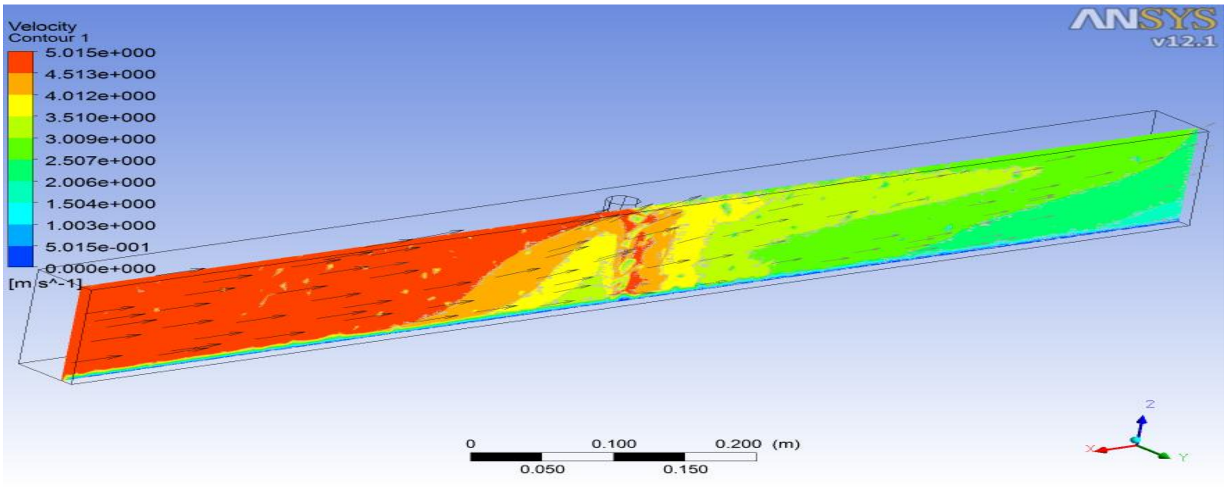

Figure 5.2.2 (c.3) Velocity profiles in ZX plane

Figure 5.2.2(d) Variation in momentum and mass with time

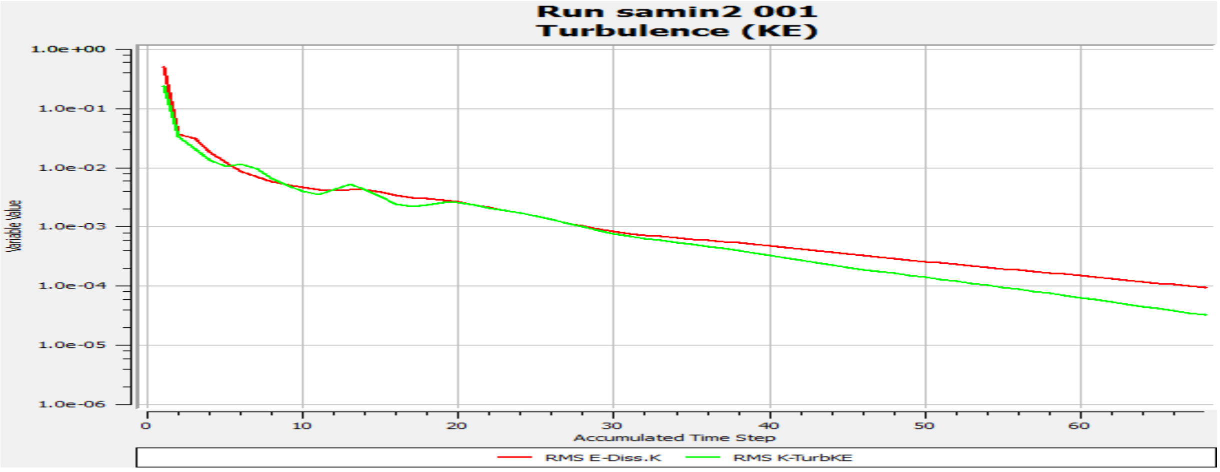

Figure 5.2.1(e) Variation in turbulence with time

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Local scour around bridge pier located in an alluvial channel is a complex problem and only very limited success has been made to model the local scour computationally. For that reason physical model remains the most effective way to be employed to estimate local scour depth. The data collected from the physical model showed that flow and pier geometry have an appreciable effect on local scour at the bridge site. The selection of the pier width and shape can help in the reduction of the local scour depth. A reduction of about 15% in local scour depth can be obtained by using an elliptical pier instead of using a diamond pier and about 10% in local scour depth can be obtained by using a elliptical pier instead of using a circular pier. The alignment of the bridge piers bridge with the flow also affects the local scours depth, which was not considered in our study. The flow depth has an appreciable effect on the local scour and the Data from physical model showed that the unit rise in flow depth resulted in local scour depth increase by almost 50%. Unit increase in velocity resulted in 400% of local scour depth. It is necessary to involve the hydraulic engineers in the design stage for bridges to take care of hydraulic effects of the flow on these bridges. Many methods were proposed for estimating the local scour around piers at the bridge site, but these methods were based mainly on the data collected from physical models and field data need to be collected to verify these methods.

6.2 Recommendations

Recommendations regarding possible future work in relation to the current research project are as follows:

- Since a river usually carries debris and sediments in excess during flood conditions, a study of the effect of debris and sediments on scour depth should be emphasized. It might be established that sediments from flow could settle around bridge piers reducing scour depth. But that should not be concurred upon without factual data and proofs.

- What is common in the literature is the description of flow mechanism causing local scour at a plain pier. Some new techniques in designing of bridge pier should be adopted that could reduce turbulence and resulting scouring effect. River bed around pier foundation could be stabilized by using physical, chemical or mechanical means. A precise research in this context should be carried on to evaluate results for adopting counter-measures to reduce scouring effect.

- This study on local scour at a bridge pier has been confined to cohesion-less material and clear-water flow conditions. Since local scour other than under a clear-water scour condition is possible at a bridge pier, it could be useful if a live-bed scour condition was studied. Also, since a bridge pier can be located on a soil other than cohesion-less soil, studying the performance of a collar as well as the temporal development of scour in a cohesive soil will give valuable clues to the behaviour of a collar under this circumstance.

- Run the same simulation for different shapes of piers for instance square, elliptical, hexagonal, slotted bar and compare the outcomes with the results of the experiment carried out with a physical model. The comparative study will lead to the conclusion for selecting the appropriate bridge pier which will tend to reduce the scouring effect around the pier.

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