CRITICAL SHEAR STRESS NEAR BRIDGE PIER FOR NON-UNIFORM SEDIMENTS

Abhishek Chougule
Bharati Vidyapeeth's college of Engineering Lavale, Department of Civil Engineering
Savitribai Phule Pune Universitiy, Pune-412115
abhishekchougule8055@gmail.com

Sachin Chavan
Bharati Vidyapeeth's college of Engineering Lavale, Department of Civil Engineering
Savitribai Phule Pune Universitiy, Pune-412115
chavansachin5365@gmail.com

Girish Pawar
Bharati Vidyapeeth's college of Engineering Lavale, Department of Civil Engineering
Savitribai Phule Pune Universitiy, Pune-412115
girishpawar9636@gmail.com

Venkatesh Rao
Bharati Vidyapeeth's college of Engineering Lavale, Department of Civil Engineering
Savitribai Phule Pune Universitiy, Pune-412115
venkyrao9697@gmail.com

Prof. U.S. Patil Sir
Head of Department of Civil Engineering
udayshubhu@gmail.com

Abstract: This paper describes the main reason of local scour are generally classified into flow condition, structure, and riverbed material used in it and to obtain the simple critical shear stress for the non-uniform sediments. Scouring is significant factor which affects on the safety of bridges. Scouring develops around the pier on the bed channel with non-uniform sediments achieve the great on scour depth prediction. In this a flume experiment has been conducted to predict the relative parameters of shear stress for various size of pier diameter and scour depth using the non-uniform sediments. From the analysis a relationship between shear stress and it's scour depth may be developed.

Keywords— Critical shear stress, scour, non – uniform sediments, pier, scour prevention, structure, scour depth.

INTRODUCTION

Since 1980 over 500 in USA fails due to scouring around bridge pier such scour around pier and pile supported structures and abutments can result in structural collapse and loss of life and property. An estimate of the maximum possible scour around a bridge pier is necessary for its secure design. Numerous investigations have been done since the late 1950s to understand the flow and the erosion mechanisms around bridge piers and to estimate the scour depth and critical shear stress. Scouring is local lowering of bed stream elevation which takes place around structure in flowing water. Hence for safe and economical design, scour around the bridge piers is required to be controlled The present work is concerned with the flow as it is slowed and little deflected around the bridge pier, the bed shear stress distribution, and the effects of roughness and the scour hole.

Many scientists have conducted various experiments to determine the maximum depth and diameter of scour hole. An attempt has been made to review few previous studies related to scour .Scour has been the major concern for safety of marine and hydraulic structures. A large numerous of hydraulic structures failed as the local scour progresses determined the foundations. Recent study by Guney showed that the Local scours around bridge piers affected their stabilities and play a main role in bridge failures. In his study local scours around bridge piers is from unsteady flow has been measured. It was concluded that the main mechanism that drives the formation and evolution of the scour hole around bridge pier is horse shoe vortex motion. Failure of bridges due to local scour has encouraged many investigators to explore the causes of scouring and to predict maximum scour depth.

An estimate of the maximum possible scour around a bridge pier is necessary for its safe design. Numerous researchers have been performed since the late 1950s to understand the flow and the erosion mechanisms around bridge piers and to estimate the scour depth. However, the convolution of the three-dimensional (3D) separated flow, its interacted with the transport of sediment and the changing mobile boundary. Therefore the early researchers mostly concentrated on scour estimation based on dimensional analysis and data correlation of small-scale laboratory experiments (Breusers et al. 1977; Raudkivi 1991) and the scour prediction methods developed do not always produce determinable results for field conditions or even for laboratory conditions (Melville 1975; Dargahi1982;

Jones 1984). A lack of understanding of the structure of the flow and erosion mechanism seems to be at least partly responsible for this state.

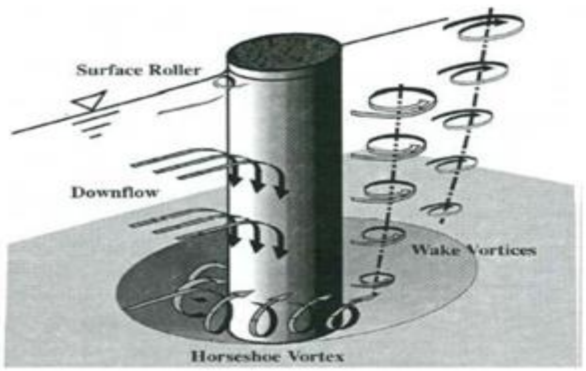

Figure 1. Flow and scour pattern at a circular pier

- **Factors Affecting Scour Depth:**

Various papers have been published from 1940 on scour depth around bridge piers. Experimental work and theoretical analysis is found that the factors affecting on the scour at bridge pier.

a) Incoming Flow is Clear Water Flow or Carries Sediments
b) Effect of Change in Depth of Flow
c) Effect of Shape of Pier Nose
d) Effect of Angle of Inclination on Scour Depth
e) Effect of Opening Ratio on Scour Depth
f) Effect of Bed Material Characteristics
g) Stratification on Bed Slope
h) Effect of Flow Parameters
This factor plays vital role in scour depth formation. And due to this the critical shear stress formation occurs.

Aim & Objectives:

Aim of this experimental work is to determine stresses developed around the bridge pier due to scouring and determine relation between various flow parameters.

- To determine the critical shear stress around bridge pier.
- To determine the scouring depth around pier.
- To establish a relation between velocity of flow and scouring at bridge pier.
- To provide bed scour data.
- To estimate the maximum scour depth.
- To find out conditions for this maximum scour depth.

Future Scope:

- This analysis is useful to establish sufficient depth of foundation for bridge pier.
- Estimation of maximum scouring is required to avoid possibility of undermining.

Related Terms:

- Critical shear stress - The shear stress acting on the bed at which sediments just starts to move is called as Critical shear stress.
- Scouring - Scouring is local lowering of stream bed elevation which takes place around pier, abutment in flowing water.
- Incipient motion - The water exert tractive force on bed material in the direction of flow, this results in to particle lift from the bed and just start to moving in the direction of flow this condition is called as incipient motion.

LITERATURE REVIEW:

1. **Flow around bridge piers:**

Ferdous Amed and Nallamuthu Rajaratnam, Fellow, ASCE.

In this paper researcher conclude that the results of a laboratory study on flow past cylindrical piers placed on smooth, rough, and movable beds. Experimental results are analyzed on the flow in the plane of symmetry, including the frontal down flow and the effects of bed roughness and the scour hole on it. The Clauser-type defect scheme describes the velocity profiles better than the log-law and defect law. Frontal down flows as large as 95% of the approach flows were seen. Experimental results are also analyzed on the deflection of flow and bed shear stress field. Bed roughness increased the magnitude of bed shear stress and the area over which the shear amplification was felt and also resisted.

2. **Shear stress at base of bridge pier**

Peggy a. Johnson and j. Sterling Jones

In this paper the experiment on shear stress and scour depth analyzed that the magnitude of the vertical velocity in the diving current is a maximum near the surface of the scour hole. They found that the maximum vertical velocity is same to the approach flow velocity and that the shear stress at the bottom of the scour hole is approximately equal to the shear stress of the approach flow at maximum scour condition. A method of determining the approach velocity at which riprap around a bridge pier will fail was developed by Parola (4). In his experiment, Parola set a 4-in. model bridge pier in sand, scoured a hole to a predetermined depth, stabilized both the scour hole and bed surface, and then lined the hole with Y4-in. gravel. He then introduced a flow to the flume, gradually lowered the tailgate, and watched for failure (i.e., movement) of the gravel within the hole. He repeated the experiment for various scour depths and two pier configurations. Parola found that the effective velocity at the pier was approximately 1.5 times the approach velocity required to cause failure of the riprap for a circular pier and 1.7 times the approach velocity for a rectangular pier. Shear stress is a function of velocity squared; hence the effective shear stress at the pier is on the order of 2.25 to 2. 90 times the shear stress of the approach flow. This indirect approach to "measuring" velocity and shear stress at a pier was the basis for the design of the experiment in this study.

3. Design method for local scour at bridge piers
B. W. Melville1 and A. J. Sutherland2

A design method for the determination of equilibrium depths of local scour at bridge piers is presented. The method is based upon curves drawn to experimental data derived mostly from laboratory experiments. The laboratory data include wide variations inflow velocity and depth, particle size and gradation, and pier size, shape, and alignment. Local scour depth estimation is based upon the largest possible scour depth that can occur at a cylindrical pier, which is 2.4D, where D = the pier diameter. According to the method, this depth is reduced using multiplying factors where clear-water scour conditions exist, the flow depth is relatively shallow, and the sediment size is relatively coarse. In the case of nonrectangular piers, additional multiplying factors to account for pier shape and alignment are applied.

4. Bridge pier scour model with non-uniform sediments
By Shaghayegh Pournazeri, Fariborz Haghighat

Pier scour is a core problem affecting the safety of bridges. For given hydraulic and geometric conditions, perfect determination of scour with non-uniform sediments is important, but this need has not been fulfilled. The purpose of this research was to develop a three-dimensional model for scour prediction and to verify the model using laboratory measurements. The model allows for selective transport of non-uniform sediments, particle hiding and bed-level change in response to scour and deposition. The development of scouring around a circular pier on a mobile channel bed with non-uniform sediments was successfully predicted and scours depth prediction agreed well with the measurements. It was found that scour patterns emerge from the lateral sides of the pier and migrate towards its upstream nose. Upstream of the pier, strong down flow and vortex motions develop and effectively remove sediments from the foot of the pier; at equilibrium, the bed-surface slope almost reaches the angle of repose of sediments.

5. Indian practice on estimation of scour around bridge pier
By Umesh Kothari

Well-base foundation is mostly provided in road and Railway Bridge in India over large and medium size river. The age old Lacey-Inglis method is used for estimation of design of scour depth around bridge element such as pier, abutment, and guide bank. Codal provisions are seen to produce large scour depth around a bridge element resulting in bridge substructure that lead to increase in construction cost. New railway and Road Bridge are required to build in large number in near future across several rivers to strengthen such infrastructure in country. It is strongly felt that provision in the existing code of practice for determination of design scour depth required immediate review. The present paper provide critical note on the practice followed in India for estimating the design scour depth.

METHODOLOGY:

- **Data collection**
- **Materials and testing:**
  - a) Concrete
  - b) Sediments
    - i. Sieve analysis
    - ii. Specific gravity
    - iii. Density of sediments

- **Casting:**

Pier was casted well before conductance of experiment.

- **Experimental arrangement:**

The experiment was conducted in tilting flume of dimensions 10m length, 0.6m wide and 0.4m in depth. The flume is provided with baffle walls at inlet and outlet chambers. The circular shape pier was made of M20 grade concrete, having length 300 mm, diameter 70 mm. The pier was placed at center of section and then bed material (sieved sand) was placed around it. The flume was kept horizontal while doing the experiment and flume was provided with gate to control discharge of flow and maintain the uniformity. The depth of scour was measured with point gauge. Also velocity is measured by taking numerous readings (runs).

- **Parameters:**

Shape of Pier - Circular pier

Velocity of Flow

1) V_1
2) V_2
3) V_3

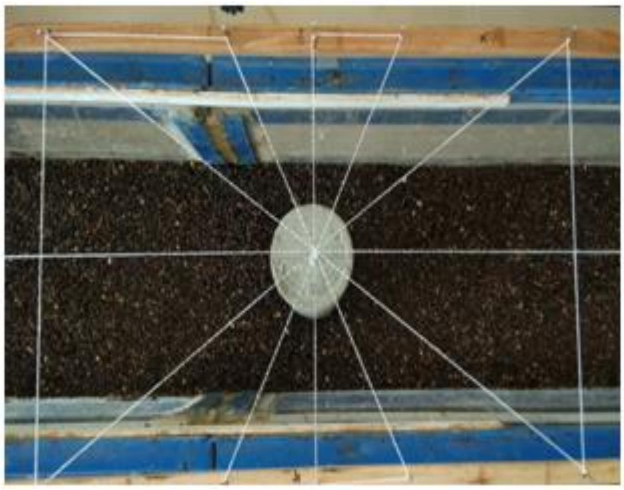

Figure 2. Arrangement of flume

EXPERIMENTAL WORK DONE BY RESEARCHERS:

- **Introduction:**

The aim of the experiment is to study Critical shear stresses and measure scour depth around circular bridge pier for non-uniform sediments. The experiment was performed in clear water condition and at standard temperature and pressure condition.

- **Experimental setup**

The experiment was performed in tilting flume of dimensions 10m length, 0.6m wide and 0.4m in depth. The flume is provided with baffle walls at inlet and outlet chamber which were used to keep flow of water steady and calm. A section of 2.5m length and 150mm depth was prepared by using acrylic sheet. The pier was fixed at center of section and then bed material (sieved sand) was placed around it.

The flume was kept horizontal while performing the experiment and flume was provided with gate to handle discharge of flow and maintain the uniformity. The depth of scour was measured with point gauge.

- **Description of bed material**

The bed slope material of non-uniform sediments was used for the experiment. Having specific gravity 2.7 and size which ranges from 150 microns to 4.75 mm. Bed materials was washed thoroughly with clean water to remove silt and organic material. After that the sieve analysis is done for the specific sample of sand and we get following curve (graph).

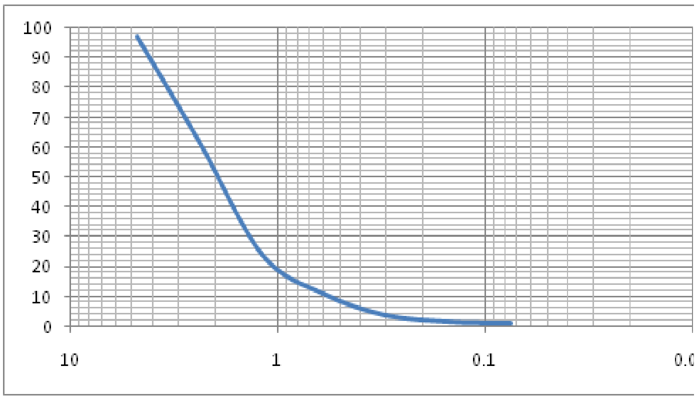

Fig 3. Sieve analysis

- **Experimental procedure**

1. Preliminary runs were carried out to calculate the discharge of water through flume by volumetric method.
2. Then velocity of the flow was measured by analytical method and it was compared with theoretical velocity.
3. Section was prepared and bed material (sieved sand) was placed around pier.
4. Bed material was compacted and was leveled.
5. Then the flume section was filled with water slowly, so that entrapped air was removed.
6. After that the frame is prepared with thread arrangement on it. This arrangement is used to take reading at various angles and at different positions.
7. This frame was placed over top of the flume to take angular readings of scouring.
8. Valve was fixed at position to keep steady flow condition for a run.
9. Steady flow was maintained for few minutes and velocity was measured.
10. Scouring effect occurs and the scour hole depth was measured using point gauge.
11. Same procedure was repeated for numerous runs for an interval of few time for a single set keeping the same velocity.
12. Four sets of four different velocities were taken to measure scouring at different velocities.
13. Same procedure was adopted to carry out numerous runs.
14. Readings were noted down and analyzed for developing relation between velocities, scour depth, pier dimensions.

- **Analogy**

To determine shear stresses we used formula given by Peggy A. Johnson and J. Sterling Jones. [2]

$$\tau = \frac{\rho V^2}{[5.75 \log(12.27\frac{d}{Ks})]^2}$$

Where,
τ = Shear stress around pier
V = Velocity of flow
d = Depth of flow
Ks = Mean diameter of sediment

- **Time scour study**

Then it was observed that primarily scouring depth rises considerably. For this time period rate of particle moved out was more. As the time goes on this rate get decreased and finally maximum scour depth is obtained. The total runs performed were numerous and data and results were collected. The extend of scour hole is not depend on velocity and depth of flow. The extend and depth of scour hole is not related to any of these parameters.

CONCLUSION:

The results of an experimental study of the flow and bed shear stress by various researchers in the field around circular cylinders said that the different types of bed conditions are emerged. The down flow velocity in front of the pier goes as much as 95% of the approach velocity inside the scour hole before diminishing. The relative magnitudes of shear stress at the base of a bridge pier as a function of pier diameter and scour depth. The results also conclude that the shear stress at the base of the pier decreases as scour depth increases. As the scour depth continues to increase, the shear stress approaches the bed shear stress upstream of the scour hole. The model has successfully been applied to predict the flow around a circular pier and the development of a scour hole. The determined scour depth at equilibrium agrees well with measurements reported by Chang et al. (2004). For reliable determination of pier scour with a sediment mixture, it is appropriate to consider selective transport and relative exposure of sediment particles. The results of this study were based on an experimental method in which the shear stress at the base of the scour hole was measured indirectly. There are advantages and disadvantage in using such a method. One important advantage is that no instrumentation was required in the scour hole; hence there was no interruption of the flow pattern around the pier or within the scour hole. On the basis of these results, it can be concluded that the shear stress at the base of a pier increases with increasing bridge pier diameter; however, the increase is not a linear one. The shear stress increases nonlinearly with increasing pier diameter, as does the depth of scour. Once a relationship between the shear stress ratio and the equilibrium depth of scour is determined, then the indirect shear stress measurements could become a laboratory expedient for conducting pier scour experiments

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