EXPERIMENTAL STUDY OF LOCAL SCOUR AROUND CIRCULAR COMPOUND BRIDGE PIER

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ABSTRACT

Local scour around the circular bridge pier in alluvial channel is main factor for failure of hydraulics structures such as bridge pier, abutment etc. It is a complex phenomenon. Local scour around bridge pier is depends upon the depth of flow, Discharge, Geometry of Pier, Types of sediment particles. Many researchers have studies on scour around uniform cross section of pier without considering the effect of footing of bridge pier. But the study on scour under steady condition for compound bridge piers is limited. In present study, the experimental work was carried out on different geometry of compound bridge pier under clear water scour condition with uniform and non uniform sediments. The compound bridge pier was placed at a various location with respect to initial bed level. i.e. the top level of foundation at bed level, top level of foundation below bed level and top level of foundation above bed level. It is observed that the maximum scour occurs when the foundation top above initial bed level and it is reduce at bed level and below bed level. It is also observed that there is reduction scour in non uniform sediment as compare uniform sediment.

KEYWORDS: - Bridge pier, Sediment, Scour, Compound pier, Foundation etc.

1. INTRODUCTION

The process around the bridge pier in which reduces elevation of initial bed level of stream due to degradation of bed soil due to flowing water. It is main factor for failure of hydraulics structures i.e. bridge pier, abutment etc. Local scour is a three dimensional process caused by various agents like changes the flow condition of channel due to construction of bridge pier, flood , human interferences etc. Out of 500 bridges collapsing in the united state since 1951, it was reported that 60% of bridge collapsing due to bridge pier scour. Therefore the study of phenomenon of local scour around the bridge pier has become the important topic in hydraulic engineering.

To determine the maximum depth of scour around bridge pier is important from point of view by design of bridge pier foundation. Local scour is complicated phenomenon due to three dimensional flow separation on upstream side of bridge pier and sediment load transport. Lots of research work has been done on this topic for basically to deriving the relationship for maximum depth of scour, to understanding the mechanism of local scour and its control. Therefore the large amount of research work is available on the topic of bridge scour and its protection. However, only a few studies are available so far on the flow field around the bridge elements. The flow pattern within the scour hole around circular uniform bridge piers have been studied through laboratory experimentation by following investigator by Melvilleand Raudkivi(1977), Deyetal.(1995), Ahmedand Rajaratnam (1998), Grafand Istiarto (2002),Muzzammil and Gangadhariah (2003) and Deyand Raikar (2007). These investigations have mainly study on scour around such piers which have uniform cross section(geometry) along their height but without considering the effect of footing of bridge pier. But actual site (in field work) bridge piers are constructed in different types of shape and sizes and many of them can have varying uniform cross sections along their heights, then such types of pier are known as compound piers (ornon-uniform piers). Kumar and Kothari (2012) conducted experimental work on the flow pattern and turbulence characteristics around the circular uniform and non uniform piers in the presence of scour hole using an ADV. Lu et al (2011) have recently proposed a semi empirical model to estimate the temporal variation of local scour around compound bridge pier without exposed foundation.

The local scour around the bridge pier is time dependent process. It is always show in the graphical form by plotting the maximum scour depth versus the time. It is very difficult to calculate the correct maximum scour depth in the given time due to the complex three dimensional phenomenon. Therefore many methods have been used to developing the relationship between maximum equilibrium scour depth and time. Many attempt to describe phenomenon of the temporal variation of local scour around bridge pier have been made by many authors in the last 50 years. And they show that the temporal variation around the bridge pier is dependent on the flow condition, types of sediment, shape of bridge pier etc.

The circular compound bridge pier defined as the circular bridge pier is placed on the bigger diameter of circular foundation and such geometry piers foundation are mostly used in bridge sub structures in India.

2. EXPERIMENTAL SETUP

The experimental work were carried in a glass both sides rectangular titling flume having 10m long, and cross section of 0.30m in width and 0.50m depth in the hydraulics laboratory at the department of civil
engineering, Bharati Vidyapeeth Deemed University Pune, Maharashtra, India. The tilting flume is consists of two controlling gates, one gate upstream side of flume is known as inlet gate and other gate at downstream of flume is known as outlet gate. Water supplied into tilting flume from a underground water tank constructed below the floor of the hydraulics laboratory by using centrifugal pump. For calculating discharge sharp crested weir was fitted at downstream of re-circulating channel. The rehbock weir equation was used to determine the discharge for the experimental work. The flow rate is adjusted by inlet valve. The required water depth is adjusted by using the outlet gate. The depth of water level, initial bed level and depth of scour is measured by using pointgauge. The working section 0.70m long, 0.3m in width and 0.1m in thickness located from 4.5m from the upstream side of tilting flume. The working section filled with sediment particles. The compound piers of different sizes were used in this experimental work. The compound pier were placed at the vertically at the middle portion of the working section of the tilting flume (Sediment area). The bed was levelled before the starting of flow of the tilting flume. The initial level of bed was measured by using the point a gauge. The clear water scour condition was maintained during the experiment i.e. \( \frac{V}{V_c} \) ratio is less than one,where V= approach flow velocity and \( V_c \) = Critical velocity calculated by using the \( d_{50} \) and shields method (Garde and Ranga Raju 2006).

2.1 PIER MODEL

The two different types compound piers was made up of PVC pipes, are given below,

3. RESULT AND DISCUSSION

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Pier diameter b* mm</th>
<th>Foundation Diameter b mm</th>
<th>Footing elevation w.r.t. Bed level Y mm</th>
<th>Flow depth D in mm</th>
<th>Approach velocity of flow V m/s</th>
<th>Critical velocity of sediment motion ( V_c ) m/s</th>
<th>Median grain size ( d_{50} ) mm</th>
<th>Geometric standard deviation ( \sigma_g )</th>
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<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>60</td>
<td>-10</td>
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In this V is the approach velocity of flow calculated from the know discharge and depth of flow for a single discharge value. During the experimental work discharge is adjusted by inlet valve and outlet gate. The discharge can be calculated from the Rehbock equation. Depth of flow is measured in the titling flume for particular discharge values and the approach velocity of flow is calculated by using the continuity equation.

Using Shields chart for threshold condition of uniform sediments in water (Melville and Sutherland 1988) the shear velocity \( u_c \) corresponding to \( d_{50} \) is obtained .The shear velocity \( u_c \) is converted to mean shear velocity \( V_c \) by the logarithmic form of velocity profile given in equation 1

\[
\frac{V_c}{u_c} = 5.75 \log \left( \frac{D}{d_{50}} \right)
\]  

Similarly required data is obtained for non uniform sediments and given below in table 2

1. The diameter of pier was taken as 3cm and diameter of foundation was taken as 6cm
2. The diameter of pier was taken as3cm and diameter of foundation was taken as 7.40cm

The top level of foundation of compound bridge pier was placed at different location Y with respect to initial bed level. In this work, the following three cases are considered,

Case:-A Top level of foundation is taken as 1cm above the initial bed level.

Case:-B Top of foundation is taken at initial bed level.

Case:- C Top of foundation is taken as 1cm below initial bed level.

2.2 TYPES OF SEDIMENT MATERIALS USED

The bed material was a mixture of river sand with different particle sizes varying range from the sediment filled in the working section up to thickness of 10cm. Mechanical sieve analysis was used to determine the relative proportion of different particle size in a given sediment sample. Three samples of sediments are prepared as given below,

Sample No: 1 \( d_{50} = 1 \) mm and standard deviation =1.14

Sample no: 2 \( d_{50} = 1 \) mm and standard deviation = 1.68

Sample no: 3 \( d_{50} =1 \) mm and standard deviation =2
Table 2 Experimental Data for Non Uniform sediments.

| Sr.No. | Pier diameter b mm | Footing diameter b* mm | Footing elevation w.r.t. Bed level Y mm | Flow depth D mm | Velocity of approach flow V m/s | Critical velocity for sediment motion Va m/s | Median grain size d₅₀ mm | Geometric standard deviation σᵣ
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The method to determine $V_a$ is given in Melville (1997). Thus $V_a = 0.8 \times V_{ca}$

$$V_{ca} = 5.75 \log \left( \frac{D}{d_{50a}} \right)$$

In this $u_{ca}$ is critical shear velocity for $d_{50a}$ size and $d_{50a}$ is median armour size. Shear velocity is determined from Shields diagram for respective sizes.

The particle size $d_{50a}$ is found using the Expression as given by Chin (1985)

$$d_{50a} = \frac{d_{max}}{1.8}$$

$d_{max}$ is the maximum particle size determined from particle size distribution.

The experimental results are shown in graphical form to observed scour depth versus time as given below,

Case: I Pier Diameter =3cm and footing diameter =6cm with uniform sediment ($d_{50}=1$ and $\sigma_g = 1.16$

Figure 1: Temporal variation of scour depth in uniform sediments
Case: II Pier Diameter =3cm and footing diameter =6cm with uniform sediment ($d_{50}=1\text{mm}$ and $\sigma_g = 1.68$

Figure 2: Temporal variation of scour depth in Non uniform sediments

Case: III Pier Diameter =3cm and footing diameter =6cm with uniform sediment ($d_{50}=1\text{mm}$ and $\sigma_g = 2$
4. CONCLUSION

The following conclusions are based on the experimental work on the scour development process around the compound bridge pier with varying the foundation depth with respect to initial bed level of channel.

1. In the uniform sediment particles the top level of foundation was placed above the initial bed level the maximum scour depth occurs due to more area of foundation was exposed to the flowing water.
2. When the top level of foundation was placed at the at initial bed level with uniform sediment, then scour depth reduces as compare to above condition.
3. When the top level of foundation placed below the initial bed level further reduction was observed in the scour depth.
4. Same pattern of scour was observed in non uniform sediment for the three cases as mentioned above only overall reduction of scour depth was observed as compared to uniform sediment as there is armouring action in non uniform sediment.
5. When the standard geometric deviations increases, then scour depth decreases and for higher value armouring effect occurs on the upstream side of bridge pier.

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