EXPERIMENTAL ANALYSIS OF SCOUR DEPTH REDUCTION BY USING GEOTEXTILE RIPRAPPING AROUND BRIDGE PIER

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ABSTRACT

Flood currents are considered threatening factors by creating local scour around bridge piers, so there is a need to control and minimize the local scour depth. Engineers are presently estimating the scour conditions at existing bridges and also thinking to design and build new bridges that should be safe from the problem of scour. Many researchers have focused in recent years on the phenomenon of scour and providing different methods to control this phenomenon. The study of local scour in the region of bridge piers is very essential for safe design of piers or abutments and other hydraulic structures. In this study, experiments should be conducted using laboratory flume, operated under the clear water condition using sand as a bed material. One method used for declining local scour is to strengthen the bed against imposed tensions in which to put riprap alongside bridge piers and to employ geotextile around them. Geotextiles is a large assembly of geosynthetic products produced from polypropylene and polyester fibers, and are used in separation, strengthening and reinforcing, filtration, and drainage. In the present study, the effect of geotextile layer in decreasing local scour around different shapes of bridge piers should be investigated and the best coverage pattern with the most effect would be obtained so that layers with circular and oval shapes were put around the pier relative to its diameter, and the performance of each would be compared with the unprotected pier. Test results showed that, by using geotextile with an appropriate cover, the scour location is transferred to downstream and the scour depth is decreased. These obtained benefits can reduce the risk of pier failure when the duration of flood is short. The test results would also indicates that, the scour reduction increases as the layer area increase and find out the better cover shape which gives good efficiency in between oval and circular one.

Key words: Non-Uniform Sediment, Shapes of Bridge pier, Geotextile coverage pattern.
1. INTRODUCTION

Scour is a natural phenomenon that is created because of river flows or flood waters, the result of which is erosion by water flow leading to transferring and grinding the materials from the floor, coasts and around the bridge piers and abutments. The depth caused by the bed erosion relative to the initial bed is called scour depth. Scour is a natural incident caused due to erosion or removal of stream bed or bank material from bridge foundations because of flowing water. This phenomenon occurs when the shear stress due to the flow around the structures is exceeded the critical shear stress related to initiation of motion. The scour around Bridge pier is a dynamic incident that changes with different factors for example flow angle, water depth, strength, pier and abutment shape and width, properties of the sediment material, and so on. In general, collision and separation of the stream from the bridge piers are the two main factors in the development of scour around the piers. The stream collision to the piers forms a horseshoe vortex, and flow separation from the base creates the wake vortex. The horseshoe vortex is the main cause of erosion of the river bed around the pier, especially in its front (Fig. 1). Horseshoe and wake vortices contribute to scour holes around bridge piers [11]. The basic mechanism causing local scour at piers is the down flow at the upstream face of the pier and formation of the horseshoe vortex at the base of the pier. The horseshoe vortex hence formed due to the flow separation at the edge of the scour hole rolls upstream to create a helical flow, which is alike to the ground roller downstream of a dune crest. The flow departure from the pier creates wake vortices behind the pier.

1.1. BRIDGE PIER PROTECTION MEASURES:

Numerous studies in the past years by various researchers have been made with the purpose of study the mechanisms of development and forecast the scour hole downstream of sluice gates with rigid apron as well as methods for reducing and controlling its effects. Following are the measures by which the bridge piers can be protected:

1) Using Ripraps 2) using Slots 3) using Collar 4) Foundation Caissons 5) Delta wings like Passive Device 6) Submerged Vanes and 7) Tetra pots as artificial Riprap.
The Literature was reviewed in the field of scour around piers of bridges. Many articles, papers and reports were collected, investigated and comprehended. Based on this review, it was apparent that many researchers investigated scour, as follows: reported that investigated bridges’ failure around the world is due to scouring. Therefore, there is an extensive research on bridge scour ranging from laboratory experiments In terms of the importance of protecting bridges against failure, this research was started. It aims to minimize scouring around bridge pier using geotextile rip rapping under clear-water conditions. The research also aims to investigate the better cover shape which gives good efficiency in minimizing scour.

The reduction of maximum depth of scouring is highly dependent on shape of pier, sediment sample (uniform and non-uniform) and flow depth, elliptical shape pier has least scour depth than diamond and circular shapes for all operating conditions of experimentation [1]. A method is proposed for the design of rip rap layer to control scour around circular bridge piers [10]. The maximum scour found around circular pier relatively than round-nose rectangular pier in both type of non-uniform sediment. The reduction of scour can be observed when the layer of riprap is placed around the scour depth around bridge piers [2]. The most excellent coverage pattern with the largely effect was obtained so that layers with circular and oval shapes were situated around the pier relative to its diameter and the performance of each was compared with the unprotected pier. Test outcomes showed that, with using geotextile with an appropriate suitable cover, the scour location is transferred to downstream and the scour depth is decreased [6].

In experimental study of bridge pier shape to minimize local scour, in that the rectangular pier gives the maximum scour depth (7.6) cm, while the streamline shape gives the lowest scour depth (3) cm [10]. The up-to-date work on scour reduction around bridge piers is obtainable including every possible aspect, such as parameters affecting scour depth, flow field, scouring process, time-variation of scour [4].

2. MATERIALS AND EXPERIMENTAL SETUP
The experiments in this study are conducted in deep tilting flume in P.G Hydraulic Laboratory of BVDU College of Engineering, Pune. The tilting flume consists of a rectangular section of with 10 m long, 0.30 m wide and 0.45 m deep flume. There is non-uniform sediment with the mean particle sizes of 1.18 mm with geometric standard deviations of particles are equal to \( \sigma_g = 1.6 \) filled a recess in which piers located. While geometric standard deviation of sediment particles is lower than 1.3, the effect of non-uniformity sediment on the depth of scour hole becomes insignificant in accordance by Chiew and Melville [9]. And also in accordance with Chiew and Melville, the diameter of pier should not be more than 10 % of width of channel in order that the effect of sidewalls of flume on the depth of scour hole becomes negligible. Since the diameter of pier to mean particle size (\( D/d_{50} \)) was more than 20–25 (\( D/d_{50} = 18.75 \)), the effect of sediment particle size on the depth of scour hole becomes negligible. To achieve flow transition in smooth condition in the flume, ramps with a 1:20 (vertical: horizontal) slope were constructed at opposite ends of the mobile bed. Photo no.2 shows the experimental set up of flume. The geotextile layer was installed around pier and seamed to soil by a wireframe under the layer. The velocity of the approaching flow is set to 0.480 m/s in all experiments. The clear-water condition, i.e., \( U/U_{cr} = 1 \), was satisfied in all experiments to reach the maximum scour depth. Clear-water condition is where the flow velocity is too low for general sediment transport to occur. For discharge measurement the V-notch will be used at downstream end of the tilting flume for measuring discharge. The velocity of flow was checked and measured by mini-water velocity meter. The three different types of piers (Circular, Elliptical and Diamond) having 3cm dia. or width were made up of acrylic fibre are shown in Photo No.1. The diameter of pier was taken as 3cm and set exactly centre of the working section. For each pier, experiments were conducted by keeping all experimental parameters same i.e. flow depth, bed slope and sediment.
The scour depth was measured at different intervals of time from a scale attached to the pier. Each run was of 6 hours.

3. AIM & OBJECTIVES

AIM: Control of the local scouring around the different shapes of bridge pier using armed soil by geotextile.

OBJECTIVES:

- To find out magnitude of scour depths in non-uniform sediment bed around different pier shapes (circular, elliptical and diamond) and discover a pier shape which gives minimum scour depth than the other and illustrate through chart.
- To find out pier shape that responses best in order to minimize scouring effect.
- To determine if geotextile has an acceptable effect on scour-reduction in bridge pier.
- To investigate in selecting the best dimensions of cover in order to minimize the scour phenomenon.

4. METHODOLOGY

It consists of two parts:

- Scour Depth Measurement: - In this step of the scour depth measurement use three different shapes of bridge piers (circular, elliptical and diamond) and find out magnitude of scour depths in non-uniform sediment bed with sediment sample having standard deviation was $\sigma_g = 1.6$ around the pier shapes and find out a pier shape which gives minimum scour depth than the other and illustrate through chart.
- Scour Reduction: - I) In this step scour depth reduction should be done by using different shapes of geotextile materials which are presented by (Bonasounda’s, Gale’s and Neil’s pattern) and find out scour depth reduction.
- By analyzing their result gives the best dimensions of cover in order to minimize the scour phenomenon.

III) Investigated the most appropriate cover shape by analyzing the results of other covers.

5. SEDIMENT ANALYSIS & EXPERIMENTAL SETUP

Geometric standard deviation used for classifying sediment as uniform or non-uniform. The standard deviation was calculated for one sediment in this thesis (table No.1). The Geometric standard deviation value of 1.6 was used to classify sediment used in this thesis as non-uniform.

Chart No.1 Illustration of sediment sample $d_{50} = 1.18$ mm & $\sigma_g = 1.6$
5.1. TEST WITHOUT GEOTEXTILE LAYER

In the investigation without geotextile layer, the pier was situating in the current route without installing the cover and the proposed discharge and depth easily occurred in the flume. It was observed that by forming a horseshoe vortex, the materials in front of the pier are washed forming a pile of both sides of it which gradually moves downstream. Ahead reaching the piles to the end of the pier, the protruded vortex is accelerated causing the deepening of the scour hole, and as a result, the collapse of its walls. Hence, the scour formation speed is high in the beginning of the test but gradually reduced. Ghorbani and Kells [7] deduced that more than 70% of scour occurs in the first 7 h of the test. In this case more than 80% of the scour occurs in the first 5 h.

Table No. 2 Scour Depth Calculation

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Type of pier</th>
<th>Discharge (Q) m³/s</th>
<th>Depth of flow (cm)</th>
<th>Velocity (V) m/s</th>
<th>Scour depth (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Circular</td>
<td>0.030</td>
<td>21</td>
<td>0.480</td>
<td>4.80</td>
</tr>
<tr>
<td>2</td>
<td>Elliptical</td>
<td>0.030</td>
<td>21</td>
<td>0.480</td>
<td>3.80</td>
</tr>
<tr>
<td>3</td>
<td>Diamond</td>
<td>0.030</td>
<td>21</td>
<td>0.480</td>
<td>5.40</td>
</tr>
</tbody>
</table>

Chart 2 Scour Depth Calculation   Chart 3 Development of scour w.r.t. time with geotextile layer
For experimental analysis work, there are three different shapes of geotextile material used which are presented by Bonasounda’s, Gale’s and Neil’s for riprap covers are shown below. The geotextile layer was installed around pier.

5.2. BONASOUNDA’S COVER PATTERN:

As the first treatment of geotextile layer to the size presented by Bonasounda’s for the riprap cover (Fig. 2). The pier surrounding was laid on the soil surface so that 2 mm of soil covered its surface. After 6 h at the lowermost of the layer, the hole depth at its deepest point reached 2.4 cm for circular pier, 2.1 cm for elliptical pier and 3.0 cm for diamond pier respectively and the amount of scour in the area where the layer has been laid on the surface equals zero. Figure 3 shows the hole dug and chart 4 shows time developments for circular, elliptical and diamond shaped piers.

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Shape of cover</th>
<th>Type of pier</th>
<th>Flow Depth (cm)</th>
<th>Discharge m³/s</th>
<th>Velocity m/s</th>
<th>Max. Scour depth (cm)</th>
<th>Scour depth (L*B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bonasounda’s</td>
<td>Circular</td>
<td>21</td>
<td>0.030</td>
<td>0.480</td>
<td>2.4</td>
<td>9*8</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Elliptical</td>
<td>21</td>
<td>0.030</td>
<td>0.480</td>
<td>2.1</td>
<td>8*8</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Diamond</td>
<td>21</td>
<td>0.030</td>
<td>0.480</td>
<td>3.0</td>
<td>12*10</td>
</tr>
</tbody>
</table>

**Table 3** Scour Depth Reduction using Bonasounda’s Suggested Pattern
5.3. GALES SUGGESTED PATTERN

As the second treatment of geotextile layer to the size presented by Gale’s, the layer shape was inclined from oval to circular and was laid on the soil surface, the layer on the soil surface was covered with 2 mm of soil. After 2 h, the first signs of layer leaching appeared. It was progressing upstream longitudinally and towards the pier width wise at a very low speed so that at the end of the test (6 h) the amount of scour under the layer was merely 3.0 cm for circular pier, 2.4 cm for elliptical pier and 3.1 cm for diamond pier respectively. At the lowermost part of the layer, a hole was formed which was larger than the oval cover state (Bonasounda’s) from all aspects. Figure 4 shows the layer and formed hole and time development of scouring in this state in chart No.5 respectively.
Experimental Analysis of Scour Depth Reduction by Using Geotextile Riprapping Around Bridge Pier

**Photo 4** Gale’s Suggested Pattern for circular, elliptical and diamond pier shape

**Table 4** Scour Depth Reduction using Gale’s Suggested Pattern

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Shape of cover</th>
<th>Type of pier</th>
<th>Flow Depth (cm)</th>
<th>Discharge m³/s</th>
<th>Velocity m/s</th>
<th>Scour depth (cm)</th>
<th>Scour depth (L*B)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Gale’s</td>
<td>Circular</td>
<td>21</td>
<td>0.030</td>
<td>0.480</td>
<td>3.0</td>
<td>8*10</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Elliptical</td>
<td>21</td>
<td>0.030</td>
<td>0.480</td>
<td>2.4</td>
<td>11*9</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>Diamond</td>
<td>21</td>
<td>0.030</td>
<td>0.480</td>
<td>3.1</td>
<td>11*12</td>
</tr>
</tbody>
</table>

**Figure No.4** Dimensions of hole dug in the pattern suggested by Gale’s
5.4. NEIL’S SUGGESTED PATTERN

The third treatment of geotextile layer to the size presented by Neil’s under the previous conditions. It was noticed that two grooves were progressively developed at the downstream rim of the layer. After 2 hrs the grooves gradually developed and extended upstream and ultimately reached at upstream edge of the cover. The edges of the geotextile layer are bent downwards and the digging speed of the hole is decreased. Figure 5 shows a comparative state of scour between this state and the evidence test. At the end of the test (6 h) the amount of scour under the layer was merely 3.2 cm for circular pier, 2.8 cm for elliptical pier and 3.4 cm for diamond pier respectively. At the lowermost part of the layer, a hole was formed which was larger than the oval cover state (Bonasounda’s) and Gale’s from all aspects. Figure No.5 shows the layer and formed hole and time development of scouring in this state in chart No.6 respectively.

Photo No.5 Neil’s Suggested Pattern for circular, elliptical and diamond pier shape
Table No.5 Scour Depth Reduction using Neil’s Suggested Pattern

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Shape of cover</th>
<th>Type of pier</th>
<th>Flow Depth (cm)</th>
<th>Discharge $m^3/s$</th>
<th>Velocity m/s</th>
<th>Max. Scour depth (cm)</th>
<th>Scour depth (L*B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Neil’s</td>
<td>Circular</td>
<td>21</td>
<td>0.030</td>
<td>0.480</td>
<td>3.2</td>
<td>13*11</td>
</tr>
<tr>
<td>2</td>
<td>Neil’s</td>
<td>Elliptical</td>
<td>21</td>
<td>0.030</td>
<td>0.480</td>
<td>2.8</td>
<td>12*13</td>
</tr>
<tr>
<td>3</td>
<td>Neil’s</td>
<td>Diamond</td>
<td>21</td>
<td>0.030</td>
<td>0.480</td>
<td>3.4</td>
<td>10*12</td>
</tr>
</tbody>
</table>

Figure No.5 Dimensions of hole dug in the pattern suggested by Neil’s

Chart No.6 Development of scour w.r.t. time for a layer with Neil’s pattern

5.5. MOST APPROPRIATE COVERAGE PATTERN

With regard to the scour process in the above patterns, the cover behind the pier should be increased similar to the shape to an oval as far as possible. Hence, a cover was presented to Fig. 6. By putting a layer with these dimensions shown in fig. after 2 h, the first signs of scour were noticed down the layer developing at a very low speed. Only a hole was formed at the downstream edges of the layer which was smaller than Bonasounda’s, Gale’s and Neil’s from all aspects. At the end of the test (6 h) the amount of scour under the layer was merely 2.0 cm for circular pier, 1.6 cm for elliptical pier and 2.4 cm for diamond pier respectively. At the
lowermost part of the layer, a hole was formed all during the test no scour occurred in the front and at the sides of the pier. The layer shape, final dimensions of the hole and time development of scouring can be seen in Fig.No. 6 and chart No.7.

Photo No. 6 Appropriate Suggested cover Pattern for circular, elliptical and diamond pier shapes

Table 6 Scour Depth Reduction using appropriate dimensions of geotextile layer

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Shape of cover</th>
<th>Type of pier</th>
<th>Flow Depth (cm)</th>
<th>Discharge m³/s</th>
<th>Velocity m/s</th>
<th>Max. Scour depth (cm)</th>
<th>Scour depth (L*B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Appropriate cover pattern</td>
<td>Circular</td>
<td>21</td>
<td>0.030</td>
<td>0.480</td>
<td>2.0</td>
<td>3*4.5</td>
</tr>
<tr>
<td>2</td>
<td>Appropriate cover pattern</td>
<td>Elliptical</td>
<td>21</td>
<td>0.030</td>
<td>0.480</td>
<td>1.6</td>
<td>3*4</td>
</tr>
<tr>
<td>3</td>
<td>Appropriate cover pattern</td>
<td>Diamond</td>
<td>21</td>
<td>0.030</td>
<td>0.480</td>
<td>2.4</td>
<td>3*5</td>
</tr>
</tbody>
</table>

Figure No. 6 Most appropriate geotextile layer and final amount of scour

Chart No.7 Development of scour w. r. t. time for a most appropriate geotextile pattern
6. CONCLUSION

In this study, an investigation of the reduction of scour around different shapes of bridge piers (Circular, Elliptical and Diamond) using geotextile has been carried out for the case of clear-water flow over non-uniform sediment.

- The elliptical pier has lower scour depth as compare to other shapes of pier. Since elliptical pier is best pier shape against local scour instead of other conventional shapes like circular and diamond.
- Twelve long-lasting experiments have been used to assess appropriate cover. The most appropriate pattern that be seen in Figure No.6 is suggested as the best pattern in geotextile installation.
- By using geotextile with the appropriate cover, the scour location is transferred to downstream and the scour depth is decreased.
- Geotextile has a dual performance in decreasing scour; that is, in both strengthens the bed against the current and changes the flow pattern. Because of the intensity of the protruding vortexes which are formed behind the pier, the circular pattern is not suitable for the coverage. Since the cover pattern as similar to oval is the best appropriate cover.
- As far as economy and method of application are concerned, the larger layer; and as far as the scour is concerned, the smaller layer would be problematic.
- In order to decrease the depth and dimensions of the hole, provide less cover area in the sides and the front of the pier than its cover area behind the pier. Means put large cover area behind the pier.

REFERENCES


