Effect of Abutment Shape on Bed Changes by the Means of Physical Model

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ABSTRACT

Scour is a natural phenomenon which is caused by the water flow of rivers or floods; and it leads to erosion by the means of water flow. It erodes and transfers particles from the bed, banks and around the bridge piers. In many cases, it leads to failure of bridges and hydraulic structures. In this paper, we investigated effect of abutment shape on bed changes in the laboratory using uniform sediments with the diameter of 0.08 mm which were exposed to flow of 20 lit/s in the three heights of water flow (H=11, H=12, H=13) under condition of clear water. The results showed that semicircular abutment showed better performance in comparison with trapezoidal and triangular abutments.

KEYWORD

experimental model, scour, effect of abutment shape, scour hole, clear water

INTRODUCTION

Every year, accompanied by appearances of floods, numbers of bridges and hydraulic structures are destroyed. Based on presented statistics by different countries, it can be declared that majority of bridge failures are caused by the scour phenomenon around the abutments and they are not related to structural weakness. Scour is a natural phenomenon which is caused by the water flow of rivers or floods; and it leads to erosion by the means of water flow (Breusers et al., 1977). Depth caused by bed erosion in comparison with initial bed is called scour depth. Furthermore, the created hollow space caused by removing sediments from the bed of the river is called scour hole. Melville & Coleman (2000) have studied the scour. Studying their researches, it can be said that scour has been evaluated from two general aspects (Khazim Nejad, 2012): scour in terms of cause of appearance, scour in terms of condition of transferring bed particles. Types of scour are divided into three groups.

1- General scour: general scour is caused by the changes of river flow regardless of existence of bridge in the flow rout.
2- Contraction scour: building any structure in the natural rout of the river that makes the width of the river narrower. This increases the flow velocity and shear stress of the bed in these areas, as a result capacity of carrying sediments is increased and bed particles of the river are transferred from contraction areas to the downstream parts of the river.

Local scour: locating an obstacle like the bridge in front of the flow changes flow pattern in the vicinity of these structures and creates spinning turbulent flows and vortex around them which leads to erosion beneath these structures. This erosion just happens around the mentioned structure, thus it is named local scour. Aggregating these three scours, total scour is obtained. Chabert and Engeldinger (1956) divided scour into two states regarding condition of transferring sediments and based on amount of sediments which enters or exits scour hole (Khazime Nejad, 2012): scour of clear water and scour of dynamic bed. Scour of clear water happens when transferring sediments from upstream of the river doesn’t exist. Scour of dynamic bed happens when upstream flow contains sediment; so it can be said that flow velocity is higher than critical velocity (motion threshold) of sediments (U>Uc). scour depth under condition of clear water is 10% larger than condition of dynamic bed, thus maximum scour depth happens under the condition of motion threshold of sediments (the moment particles start to move is called motion threshold)(i.e. U/Uc=1) (Graf & Barbhuiya & Dey, 2004).

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FLOW PATTERN AND MECHANISM OF SCOUR IN THE VICINITY OF ABUTMENT

Bridge abutments are piers which are attached to the banks of the river. If an abutment is located vertically in the bed of the river, water flow around it becomes turbulent and a series of vortex flows appears. These vortex systems are considered as the main mechanism of scour. In fact factors involving in scour around the bridge abutment could be divided into down flow, bow flow, horseshoe vortex (main vortex), secondary vortex and wake vortex.

In the upper surface of the structure, where water flow hits the head of bridge abutment, velocity of approaching flow becomes almost zero; this part of the structure is called static point (Kothyari et al, 1992). At this point whole velocity converts to load. Regarding non-uniform distribution of velocity in different depth of the river, created load distribution is also non-uniform and follows profile pattern of velocity. Since velocity decrease from surface to the bed, dynamic pressure on pier also decreases from up to down and as a result created pressure gradient causes a stream towards the bed. Downward flow hits the bed and scatters in different directions and digs the floor partially. Velocity reduction in the upper part of flow velocity profile causes an upside pressure gradient over the pier; it changes the flow direction towards the surface and bow flow vortex appears. Some Parts of down flow which returns to upside deals with general flow and moves in the same direction and hits the pier. This flow circle and its return is the basic of formation of horseshoe vortex. Spin of this vortex continues in the downstream and forms a shape of horseshoe in the plan, thus it is named horseshoe vortex. When the flow passes the end of abutment, it is drawn to the behind of abutment which is because of low pressure at the back of abutment. This appeared vortex is called wake vortex.

EFFECTIVE PARAMETERS ON ABUTMENT SCOUR

In order to neglect effect of channel wall on scour, Laursen & Toch (1956) and Chiew and Melville (1987) suggest that the ratio of channel width to the width of bridge pier is equal or larger than 10 (B/L>10).

Chiew (1984) performed some experiments under the condition of dynamic bed and realized that the suggested ratio (B/L=8) by the Shen et al (1966) decreases effect of channel wall significantly.

Melville (1992) performed some experiments with different width and length of abutment in the long term. He finally could recognize areas related to scour equilibrium depth (ds). He divided abutment into three short (h/l≤1), long (h/l≥25) and medium (1<h/l<25) abutment.

MATERIALS AND METHODS

The experiments were performed in the laboratory of hydraulic structures of technical and engineering faculty of Islamic Azad University of South Tehran. Material of the applied flume was Galvanized sheets which was 4.2 meter long and 50 cm wide and 55 cm high. Regarding this issue that changes of bed slop is not considered and it belongs to constant parameters, the bed is created with the zero slope and water is pumped from the main reservoir to the channel (Fig4).

In order to prevent transferring surface wave of reservoir to the flume, a series of perforated plates (stabilizer) were used at the beginning of the flume (Fig5). Distance between these plates is 40 cm and it is long enough for the flow to reach development state. Compound abutment which is Made of Plexiglas (rectangular- semicircular, rectangular-trapezoidal, rectangular-triangular) is installed in the distance of 1.60 cm from the beginning of the flume in the glass part. Each of three Lengths of compound abutment (rectangular- semicircular, rectangular-trapezoidal, rectangular-triangular) is 9 cm, it is 12 cm wide and 42 cm high. Size of bed particles and their way of gradation are also effective on scour amount. Increasing size of bed particles decreases dimensions of scour hole. The more gradation of particles is uniform, scour dimensions will be larger. In the sediments with non-uniform gradation, scour depth is usually less than what exists in the uniform materials (guide of calculative methods of local scour, 2011). Material of bed particles is silica with the average diameter of 0.08 mm (d50=0.08mm) and density of 2.65. All stages of the experiment are performed with the flow of 20 liter per second and height of water changes to 11 cm, 12 cm, and 13 cm by the means of the gate. Furthermore, a rectangular overflow is used to adjust the flow. Experiments without collar (control tests) were performed and evaluated. The motion threshold condition is considered for all particles. In order to reach motion threshold of particles, a metal rectangular gate at the end of Flume is used.
**PROCEDURE OF PERFORMING EXPERIMENTS**

Firstly, before the beginning of each experiment, surface of sediments is flattened, and then accompanied by closing gate of the channel, we turn the pump on and open the valve so that water with low Debbie enters the channel and water level becomes high enough to prevent replacement of sediment before adjusting Debbie. After adjusting Debbie by the means of valve, we lower the gate till the particles reach motion threshold and as a result height of the gate is adjusted. The time which is considered as the time that particles reach equilibrium (time of each experiment) is two hours. After this time, we turn the pump off and the channel is fully discharged; after fully drainage of the channel, at the end of each experiment, a profile is picked up by the means of laser meter. At the end of each experiment, depth and place of erosion hole is investigated and its amounts are compared with control test (without collar). In addition to depth and place of erosion hole, bed profile and effect of adding collars on its uniformity are evaluated.

**RESULTS AND DISCUSSION**

In this part, obtained results of scour experiments of compound abutments of the bridge (rectangular-semicircular, rectangular-trapezoidal, rectangular-triangular) without collar and over each compound abutment are presented and evaluated. In some experiments, sediments remain in the front of abutment without change and in some other experiments sediments are eroded and transferred gradually to the downstream. Accompanied by lowering height of water flow inside the channel by the means of adjusting gate to considered heights (11cm, 12cm, 13cm), velocity of water flow inside the channel and velocity of wake vortex around the experimented abutments increase. Accompanied by deepening scour hole, created hole expands to different sides. Pace of scour hole deepening is high in the initial moments of the experiment and it gradually decreases. 90% of maximum scour depth is created in the first two hours. After four hours, we survey the area in order to analyze the results and draw bed topography in the vicinity of the abutment. For instance, three dimensional form of bed topography for compound abutment with the constant Debbie of 20 liter per second for all experiments has been shown in the Fig(3). The results of the experiments show that semicircular abutment shows better performance in comparison with triangular and trapezoidal abutments.
EVALUATING CHANGES OF MAXIMUM SCOUR DEPTH OF THREE ABUTMENTS (TRIANGULAR, SEMICIRCULAR, TRAPEZOIDAL) REGARDING TWO FACTORS (WITHOUT COLLAR AND CHANGE OF WATER FLOW DEPTH)

Tab.1. (triangular abutment) maximum scour depth regarding change of water flow depth and without collar

<table>
<thead>
<tr>
<th>$d_{\text{max}}$</th>
<th>H</th>
<th>Number of collar</th>
<th>Debbie</th>
<th>pe of abutment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9444</td>
<td>0.22</td>
<td>Without collar</td>
<td>20</td>
<td>triangular</td>
</tr>
<tr>
<td>0.7911</td>
<td>0.24</td>
<td>Without collar</td>
<td>20</td>
<td>triangular</td>
</tr>
<tr>
<td>0.6911</td>
<td>0.26</td>
<td>Without collar</td>
<td>20</td>
<td>triangular</td>
</tr>
</tbody>
</table>
Fig. 17. Diagram (triangular abutment) of maximum scour depth regarding change of water flow depth and without collar

Tab. 2. (Semicircular abutment) maximum scour depth regarding change of water flow and without collar

<table>
<thead>
<tr>
<th>( \frac{d_{\text{max}}}{L_a} )</th>
<th>( \frac{H}{B} )</th>
<th>Number of collar</th>
<th>Debbie ( \text{Lit/sQ} )</th>
<th>Type of abutment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8777</td>
<td>0.22</td>
<td>Without collar</td>
<td>20</td>
<td>Semicircular</td>
</tr>
<tr>
<td>0.665</td>
<td>0.24</td>
<td>Without collar</td>
<td>20</td>
<td>Semicircular</td>
</tr>
<tr>
<td>0.532</td>
<td>0.26</td>
<td>Without collar</td>
<td>20</td>
<td>Semicircular</td>
</tr>
</tbody>
</table>

Fig. 18. Diagram (Semicircular abutment) of maximum scour depth regarding change of water flow depth and without collar

Tab. 3. (Trapezoidal abutment) maximum scour depth regarding change of water flow depth and without collar

<table>
<thead>
<tr>
<th>( \frac{d_{\text{max}}}{L_a} )</th>
<th>( \frac{H}{B} )</th>
<th>Number of collar</th>
<th>Debbie ( \text{Lit/sQ} )</th>
<th>Type of abutment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.9311</td>
<td>0.22</td>
<td>Without collar</td>
<td>20</td>
<td>Trapezoidal</td>
</tr>
<tr>
<td>0.7677</td>
<td>0.24</td>
<td>Without collar</td>
<td>20</td>
<td>Trapezoidal</td>
</tr>
<tr>
<td>0.6722</td>
<td>0.26</td>
<td>Without collar</td>
<td>20</td>
<td>Trapezoidal</td>
</tr>
</tbody>
</table>

Fig. 19. Diagram (Trapezoidal abutment) of maximum scour depth regarding change of water flow depth and without collar
Tab. 4. comparing maximum scour depth of three abutments with each other regarding being without collar and height of water surface inside the channel

<table>
<thead>
<tr>
<th>Height of water surface inside the channel</th>
<th>Height of water surface inside the channel</th>
<th>Height of water surface inside the channel</th>
<th>Number of collar</th>
<th>Experiment of semicircular abutment, triangular abutment, trapezoidal abutment</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{h}{b} = 0.26 )</td>
<td>( \frac{h}{b} = 0.24 )</td>
<td>( \frac{h}{b} = 0.22 )</td>
<td>( n = 0 )</td>
<td>Without collar (n=0) Semicircular abutment</td>
</tr>
<tr>
<td>( d_{max}/La )</td>
<td>( d_{max}/La )</td>
<td>( d_{max}/La )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.532</td>
<td>0.665</td>
<td>0.8777</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6911</td>
<td>0.7911</td>
<td>0.9444</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.6722</td>
<td>0.7677</td>
<td>0.9311</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Without collar (n=0) Triangular abutment</td>
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<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Without collar (n=0) Trapezoidal abutment</td>
<td></td>
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</tbody>
</table>

Fig. 20. diagram of comparing maximum scour depth of three abutments with each other regarding being without collar and height of water surface inside the channel

CONCLUSION

Regarding experimental data, following results have been obtained:

1. Performing experiments over different abutments (trapezoidal, triangular, semicircular), the measured scour for semicircular abutment was 69.15%, it was 80.88% for triangular abutment and 79.03% for trapezoidal abutment.

2. According to the experimental data, concentration of created vortex around the triangular and trapezoidal abutments is higher, thus their destructive power is more intensified and depth of scour hole created around them is larger than semicircular abutment.

3. Performed experiments show that increasing length of abutment increases maximum depth and width of scour linearly and larger Froude number leads to higher slope of this line.

4. Scour in the head of abutment reaches its supreme amount sooner than other points and the more we go away from the head of abutment, the elapsed time for the point to reach its supreme depth is longer.

REFERENCES


