Journal of Ferdowsi Civil Engineering, Vol.33, No.4, 2020.

Bed Stabilization around Abutment using Combination of Six-Legged Concrete Elements and Pebbles

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1. Introduction

The failure of many bridges is caused by the scour around their abutments and piers during floods. This reveals the need for studies on scour prediction and bridge protection methods. There are two methods to protect bridges against scour, namely flow altering and bed armoring countermeasures. In armoring countermeasures, which are the main focus of this study, a rigid barrier, made of heavy pieces that could not be easily transported by the flow, is installed against the abutment or pier, such as placing large sizes of well graded rocks (WGR), gabion, rectangular concrete blocks (RBC) and geo-bags, the effects of which have been extensively studied by various researchers. The results of such experiments are generally based on determining the geometric properties such as size of the pieces, armoring coverage, and thickness. In bridges located on plain area with high capacity rivers, both rocks and RCB are subjected to local shear stress, which requires large sizes of materials for their stability. Therefore, engineers are interested in applying new materials that are both stable and economical, especially when rocks of appropriate size are not available near the construction site. One of the concrete blocks which has been used in marine structures in recent years is the Six Legged Concrete (SLC) elements. SLC elements can be placed in different densities and provide interlocking and self-stabilizing which can be considered as a superiority for scour countermeasure purposes. A few studies have been conducted on the SLC elements. These elements are recommended to control the erosion of riverbank toe. Another study on the effect of SLC elements placement density on abutment scour was also conducted by in 2016. The main objectives of this study are: defining the effect of SLC element and pebbles placement on scour reduction, individually and in combination with each other, around wing-wall and vertical-wall abutment. SLC element failure at bridge abutment is also discussed.

2. Materials and Methods

In order to assess the performance of the SLC elements as a bridge abutment scour countermeasure, and pebbles, some experiments in a glassed wall flume of 9 m length, 1 m width, 0.6 m depth and a 0.0003 floor slope were done. Uniform sand materials with D_{50}=0.65 mm (where D_{50} is the median size) were leveled in a sedimentary box. The flow depth within the flume was kept constant equal to 12 cm in all tests. Four different flow conditions were produced with four different Froude numbers. All experiments were carried out under clear water conditions. The critical velocity was measured in initial tests before installation of the abutment. Experimental results were also compared with some available relations in the literature.

Two types of vertical-wall and wing-wall abutments were examined. In the absence of SLC elements, 12-hours duration experiments were carried out in four selected Froude numbers. During the experiment, the scour depths at specific time intervals were recorded. A constant value for the scour depth was reached after about 100 minutes. To be on a safe side, we resolved to run experiments for 4 hours (240 minutes).

3. Results and Discussion

Baseline experiments were carried out by installing abutment in absence of SLC elements and pebbles. The experiments completed, the bed topography data were measured in 3×3 cm mesh by a laser distance meter. On the basis of topography variations, the mesh was selected denser in desired locations, for example at the abutment toe. Results showed that the scour depth at the upstream of the abutment nose is deeper than that in other locations. Therefore, the scour depth at the abutment nose was considered as a basepoint to be compared between different alternatives.

Three categories of assuagement experiment were designed to investigate the effect of placement depth and density of the SLC elements and pebble installation on scour reduction around the abutments. In the 1st, 2nd and 3rd classes, installation of riprap (with D_{50}=2.3 mm), SLC elements (with 1/12 scale of the prototype), and a combination of them were considered respectively. Two densities, namely open and dense were used to assess the influence of the SLC elements density on controlling scour around the abutments. The denser the elements, the higher the stability, and the greater the area they could cover. Likewise, the number of elements needed for the unit of area increased as well. At the end of each experiment, in order to record the topography data, in places where the elements were placed on the bed, they were gently removed from the bed surface, so that the bed formation was not disassembled nor changed. In arrangements where elements were placed under the bed or buried under the sediments, they were kept intact in order to prevent disassembly of the topography of the bed. The pebbles were also kept intact to record the topography.

Table 1 presents the results of base line experiments. The table shows that the scour depths, located at the vertical-wall abutment nose is deeper compared to the wing-wall abutment.

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Table 1. Results of base line experiments

Abutment shape	Fr_1	Fr_2	Fr_3	Fr_4
Vertical-wall	3.1	4.6	5.4	7.9
Wing-wall	2.0	2.9	4.2	6.5

Different arrangements decrease the base point scour variously as compared with the baseline tests in three categories of assessment experiment. However, edge failure occurred in the 2nd series of the experiments. Generally, the average percent of maximum scour reduction in the 1st, 2nd and 3rd class of assessment experiment were 51.3%, 57.3%, and 87.5%, respectively, demonstrating that combination of SLC elements and riprap can reduce the maximum scour depth more noticeably. Besides edge failure was controlled in the latter category.

4. Conclusion

Based on the experimental analysis the fallowing conclusions are drawn:

The average of maximum scour depth at vertical-wall abutment is 28% deeper than that of wing-wall abutment.

1. Placement of riprap reduced the abutment nose scour up to 60% and 70% at wing-wall and vertical-wall abutments, respectively.
2. Installation of SLC elements decreased the abutment nose scour up to 86% and 100% at vertical-wall and wing-wall abutments, respectively. Edge failure was, however, witnessed in this category of the experiments.
3. The best results were obtained when the combination of SLC elements and pebbles were installed. In this case, the maximum scour depth decreased up to 97% and 100% in vertical-wall and wing-wall abutments, respectively. Besides, edge failure was also controlled.