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Effect of Concurrent Use of the Six-Legged Element and Rip-Rap for Scour Control with Economic Considerations

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ABSTRACT: The scour control downstream of the ski-jump spillways is one of the most important issues encountered by hydraulic engineers. In this paper, an experimental investigation was performed to evaluate the reduction in the maximum volume of the scour hole due to the concurrent use of the six-legged concrete elements (A-Jacks) and rip-rap materials in different hydraulic conditions. These elements were placed in the downstream of the ski-jump spillway. The experiments included a single size of concrete element and two sizes of rip-rap with five flow discharges and three tail-water depths. The change in tail-water depth resulted in the spillway having free, semi-submerged and submerged conditions. The results were showed that as scour depth increased, the scouring rate is significantly reduced. By simultaneous usage of concrete elements and rip-rap materials, the maximum scour volume decreased up to 100% in different hydraulic conditions as compared to the control tests. In addition, the results showed that the use of a rip-rap layer is about 80% cheaper than the coating with six-legged elements, which this difference is reduced by increasing the thickness of rip-rap layer.

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1. INTRODUCTION

Scour is considered as a complex hydraulic phenomenon and it is one of the most important problems leading to such major structural hazards as the failure of the main structure [1]. One of the important parts where the scouring control is crucial is the downstream of ski-jump spillways. Over the mid-1930s, the ski-jump spillways were introduced in the Dordogne Hydraulic Project in France as a successful hydraulic project [2]. The ski-jump energy dissipaters is one of the energy-dissipating systems of the flow. In this system, the high energy of the flow at the downstream of the spillway or flood drainage of the dams is dissipated at various stages. Because the air entertainment into the flow may reduce the energy per unit area of the flow, it will result in high energy dissipations.

In the ski-jump spillways, the inflow water is dispersed in the air as a high energy free jet and impacts the bed surface far away the dam and causes to scouring. Although some part of the supercritical flow energy is dissipated in the air, the jet still has the ability to destruct the downstream bed. The most common method for dissipating the kinetic energy and reducing the scour hole dimensions is to create a plunge pool at the jet impact area with the river bed. This requires the accurate estimation of the scour hole dimensions [3].

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the use of rip-rap has many problems such as instability of stones against high flow velocity (due to action of single stones), lack of access to suitable materials with large diameter, and consequently economic problems caused by carrying it to the site of the projects. By choosing improper rip-rap size or incorrect length of the rip-rap layer, there is a possibility of instability and failure in rip-rap layer at the presence of the turbulent flows; therefore, the rip-rap will practically lose its effectiveness and protection role. Due to these problems, it is necessary to cover this structure with a protective layer on it to improve its performance. Some researchers have studied a type of materials, including the use of Tetra Hadron by Wang et al. [4]. In this study, the new six-legged concrete elements (SLCE) (A-Jacks) were used to control the scouring at the downstream of vertical jets, particularly, the ski-jumps to evaluate their performance.

In the present study, the rip-rap and SLCE was simultaneously used for the bed protection. The reason is that the rip-rap is one of the materials that are available in smaller dimensions. On the other hand, the SLCE are more stable with a high roughness factor has the ability to eliminate the weaknesses of rip-rap. In addition, the simultaneous use of the SLCE and the rip-rap can reduce the size of the stones.

2. MATERIALS AND METHODS

In the laboratory, these elements were designed by

Table 1. Number of experiments conducted in this study

Type of experiment	Number of experiments
Control (unprotected bed)	15
SLE and 9 mm rip-rap	15
SLE and 20 mm rip-rap	15

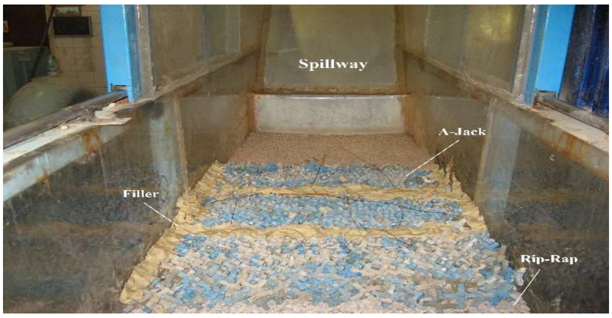

Fig 1.The protected bed with SLC and rip-rap materials

Table 2. Cost of the Rip-Rap and SLCE in an area of 100 m2

Type of Cover	Price (Rial)
Rip-Rap	35484372
SLCE Layer	36831605

AutoCAD software, with a scale of 1:12 made of concrete. In order to evaluate the effect of concurrent use of rip-rap and six-legged elements in the scouring phenomenon downstream of ski-jump spillways, the experiments were carried out as Table 1.

The control experiments were first performed in an unprotected bed conditions. Then, for the main experiments, the rip-rap and the six-legged elements were placed in the downstream of the spillway so that a layer of rip-rap was poured over the bed with a length of the maximum scour length obtained from the control experiments; then, the six-legged elements with a density of 100%, were locked together and placed on a screen mesh(Fig 1.)Results and Discussion During the scour tests, first, due to the impact of ski-jump on the surface of the sediments, considerable scouring occurs. After collision of the vortices due to jet impact to the bed, the sediments slide back and forth and the sediment move in such a way that at high tail-water depths, the effect of impact of a ski-jump is reduced, the roller waves may create a considerable scouring, and by applying the SLCE and rip-rap, the jet impact caused by ski-jump and scouring can be significantly reduced.

Economic comparison

As previously mentioned, the use of new materials is recommended for projects where the access to large-size stone materials is not possible or it is necessary to provide from a long distance. Therefore, an economic comparison is provided for a project in the downstream of the Bahmanshir River (Khuzestan province, Iran). Although this study was merely to introduce a new type of material under different flow conditions (flow discharges and tail-water depths), as well as various rip-rap materials, and the results were extracted as dimensionless parameters. Therefore, it could be a suitable model for economic comparison for various materials.

In order to estimate the cost of protecting the bed with two methods of rip-rap and six-legged element, first, according to the dimensions of the laboratory element, the area and the volume of the element were calculated by AutoCAD software. Then, in order to calculate the volume of the element on an actual scale, the calculated volume was 12 times. Considering the specific gravity of the concrete (2400 kg/m3), the weight of actual element was calculated. This weight equals the weight of a piece of stones. The equivalent diameter of the stone was calculated according to the specific gravity of the stone (2650 kg/m3). To ensure, the diameter of the stone was increased by 20% and the weight of the stone was re-calculated. According to the calculations and obtained dimensions, the number of six-legged elements needed to cover the area of 100 m2 (10 * 10 m) and the number of stones needed to cover this area were calculated. Since the average distance for carrying the stone in the projects is about 400 km and the distance from the nearest site to the construction of concrete materials is about 100 km, the calculations in each structure for bed protection are conducted. In addition, all calculations are made for an area of 100 m^2(10 * 10 m). Due to the number of concrete elements and rip-raps, the cost of bed cover with two structures of the six-legged elements and rip-rap is as follows (Table 2)

3. CONCLUSIONS

In the present study, the effect of concurrent use of SLCE and rip-rap was experimentally studied in five flow discharges of 5, 10, 15, 20 and 25 lit/s and three tail-water depths of 10, 20 and 30 cm on the reduction in the scouring downstream of the ski-jump spillway. The results indicated that by increasing the flow discharges, the scouring downstream of the spillway is increased; instead, increasing tail-water depths the scouring is reduced. In addition, with increasing Froude number, the maximum scour hole depth increases. The use of a protective layer as combination of two coating methods of SLCE and rip-rap on the bed has the ability to control scouring completely or to a large extent, which is of higher importance in high flow discharges and low tail-water depths. For example, in a flow discharge of 20 lit/s and a tail-water depth of 10 cm, the maximum scour volume was reduced by 89 percent for the 9 mm rip-rap and SLCE and by 99 percent for the 9 mm rip-rap and SLCE. The results of economic comparison between the use of rip-rap and SLCE, due to the existence of limitations for the construction of SLCE and their step-by-step construction, assuming that 10% of the elements are formatted daily, the cost of bed cover with a rip-rap layer is the same as the cost of covering with SLCE. However, the technical advantages of

SLCE and its main feature, i.e. locking and grid performance, can be considered in the desired options for hydraulic engineers. In addition, if the thickness of stones is increased, the use of SLCE will be more cost-effective as a grid with a single layer. Obviously, before implementation, further research is needed, especially regarding the weight and dimensions of these elements.

4. REFERENCES

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