Analysis of Hydraulic Failure Mechanism of River Bank Protection and Reinforcement Treatment Practice

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Abstract. Based on the reinforcement engineering of the revetment retaining walls at the lower reaches of a reservoir, this study analyzes the fracturing mechanism and proposed technically-advanced, economical and feasible reinforcement measures, which provide important reference for similar engineering work.

1. Introduction

River bank revetments are structures that reinforce and protect river banks from hydraulic fracturing. Concrete revetments are the most common revetment structure currently. Natural river banks are susceptible to scouring of floods, so the bank revetments usually are damaged or even collapse, endangering those protected by the revetments. Therefore, it is of practical value to understand the fracturing mechanism of revetments and propose advanced, economical and feasible revetment reinforcement measures. Based on the reinforcement schemes of the revetment at the lower reaches of a reservoir, this study analyses the hydraulic fracturing mechanism of the revetment and proposed reinforcement measures.

The reservoir studied herein has undergone a flood that lasted 22 hours in September 2018. When the reservoir was discharging the flood, the flood destructed the galvanized gabions on the surface of the lower-reach river bed of the flood discharging architecture, the bottom part of the bank revetment was emptied due to flood scouring, part of the retaining wall were deformed and sloped towards the water-facing side, the expansion joint between the blocks of the retaining wall extended or compressed, the concrete on the top surface of the retaining wall was scaled off.

When the flood occurred, reinforcement measures were taken. Galvanized gabions were filled to the foundation of the retaining wall that had been damaged from the emptied bottom part to the river bed; for the base pits on the back side of the retaining wall where the sludge and loose media were scoured away, self-compacting concrete was used to fill the base pits (figure 1).
2. Fracturing mechanism analysis

Natural river banks, under hydraulic actions, are susceptible to scour-and-fill effects. When the force of scouring is larger than the resistance of rocks, the river bed will be scoured and corroded. The following two equations are used to calculate the scouring depth.

A. The scouring depths of different media on the river bed rocks can be obtained using Equation (1). Calculation of river bed scouring depth is shown in table 1.

\[
    d_m = 0.8 \frac{q_m}{[v_0]} - h_m
\]

Where \(d_m\) is the scouring depth of the head end of the revetment bottom on the upper reaches, (m^3/s); \(q_m\) represents the unit discharge of the river bed head end of the revetment bottom on the upper reach (m^3/s); \([v_0]\) represents the allowable non-scouring velocity of the soil along the river bed (m/s); and \(h_m\) indicates the lower-reach river depth (m).

| Rock-soil media in river bed | Drainage flow \(Q\) (m^3/s) | Single width flow \(q_m\) (m^3/s) | Allowable unwashed flow velocity \([v_0]\) (m/s) | Downstream water depth \(h_m\) (m) | Scouring depth \(d_m\) (M) |
|-----------------------------|-------------------------------|-----------------------------------|--------------------------------|-------------------------------|------------------|
| Gravel                      | 350                           | 9                                 | 1.0                          | 2.54                          | 4.8               |
| Conglomerate                | 350                           | 9                                 | 2.5                          | 2.54                          | 0.3               |

B. The scouring depth on the surface of the riverbed can be obtained by using Equation (2). Calculation of river bed scouring depth is shown in table 2.

\[
    h_d = \frac{0.66q\sqrt{2a_0 - z/h}}{\sqrt{(\frac{v}{g} - 1)gd \left(\frac{h}{d}\right)^{1.6}}} - h_i
\]

where \(q\) is the unit discharge at the end of the protection apron (m^3/s); \(h\) is the depth of water at the end of the protection apron (m); \(z\) is the altitude of highest flowing velocity in the flowing velocity distribution chart at the end of the apron (m); \(a_0\) refers to the correction factor of the momentum of flow velocity distribution at the end of the apron; \(h_i\) is the water depth of the lower
reach (m); \(d\) is the grain diameter of the river bed sand (\(d_{50}\)) (m); and \(\rho_s\) and \(\rho\) is the unit weight of the river water and bed materials (KN/m³).

| Riverbed geotechnical media | Drainage flow \(Q\) (m³/s) | Single width flow \(q_m\) (m³/s) | Water depth at the end of the apron \(H\) (m) | Sand particle size \(d_{50}\) (mm) | Bed sand volume \(\rho_s\) (KN/ m³) | Erosion depth \(h_e\) (m) |
|-----------------------------|-----------------------------|----------------------------------|--------------------------------------------|-------------------------------|----------------------------------|---------------------|
| Gravel                      | 350                         | 9                                | 2.54                                       | 0.015                         | 18                               | 7                   |

Given all calculation results, the maximum of the scouring depth 7.0 m of the river bed is obtained. Based on the feedback on the on-site drilling materials after damages, the foundation of the retaining wall was made of sand gravels, and no rocks are used. The sand gravels on the foundation of the retaining wall is 5.2m-thick, which do not meet the requirements to resist scouring. As a result, the river bed was corroded, the foundation gravels were emptied and the wall deformed and toppled.

3. Reinforcement measures

3.1. Reinforcement principles

To demolish and reconstruct the retaining wall completely will incur substantial engineering workloads and high investments. It is advisable to demolish part of the retaining wall considering the scouring conditions, the storage conditions by emergency reinforcement schemes and the damaging degrees.

3.2. Reinforcement measures

The damaged retaining wall is 90 m long, so permanent reinforcement should be performed on 110 m of the wall on the water-facing side. Slope-protection concrete should be used to reinforce the front part of the wall and to avoid scouring by water. Structure of permanent revetment reinforcement is shown in figure 2 and the detailed measures are as follows.

1) Digging up the surface sand gravels of the river bed at the front of the retaining wall foundation, and the digging depth should reach the surface of the conglomerate layer. The digging depth should be 3 -5 m, and the width should be 3 m.

2) Sorting the galvanized gabions that were thrown into the revetment pits during rescue and improve the side slope. The gabion is 3 m wide on the top, and the side slope should be 1:1.5.

3) A dredge should be dug at the bottom of rocks that protrude above the surface, and the size is 1×1 m. when the dredge is created, steel gabions of a size of 0.75×0.75×1.5 m are put into the dredge.

4) Φ25 joint bars should be installed onto the slope of the bulk rockfill, the length is 1 m, the spacing is 1 m, and the bar is 0.1 m above the surface. Self-compacting concrete should be injected into the bulk rockfill slope and the steel gabions. The injection spacing is 1 m, and the depth should be above 1.0 m.

5) Φ8 steel grids are installed on the slope, with a 200×200 mm spacing. The grids are welded with θ25 joint bars. 0.2m-thick slope-protection concrete is injected to create a toe protection structure that integrates the concrete protection backplate and steel gabions.

6) After the concrete protection plate is injected and maintained for 14 days, large rocks of a diameter bigger than 300 mm are filled for 2 m above the bottom, and the top is covered by the materials that have been dug up.
4. Conclusions
The reinforcement measures described above should be conducted under the premise that the original retaining wall is not demolished. These measures include setting toe protection structures below the scouring depth of the retaining wall to stabilize the original structure. The practice proves that the measures are reasonable and feasible.
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