Physical Model of Head-Cut Mitigation Alternative on the Rio Coca

Jeremy Sharp, Hydraulic Engineer, USACE-ERDC, Jeremy.A.Sharp@usace.army.mil
Stanford A. Gibson, Hydraulic Engineer, USACE-HEC
Yamiretsy Pagan-Albelo, Hydraulic Engineer, USACE-ERDC
Efrain Ramos-Santiago, Hydraulic Engineer, USACE-ERDC
Dana Moses, Hydraulic Engineer, USACE

Introduction

An active head cut from a waterfall collapse has eroded about 200 million tons of sediment over 14 kilometers on the Rio Coca in Ecuador. Stakeholders evaluate mitigating measures to limit its impact and protect the nation's largest-producing hydro-power plant. The U.S. Army Engineering Research and Development Center, Coastal and Hydraulics Laboratory, developed a section model of this system. The model evaluates the effectiveness of head-cut countermeasures. The model is a 1:50 Froude scaled model where the in-situ prototype sediment uses the critical shear stress. The model tests a "permeable dam" structure, which used tetrapods like those found in coastal breakwaters - as a porous structure across a narrow point of the river. As the head-cut approached, the tetrapods would adjust. Stakeholders would actively manage the system by placing additional tetrapods from a bridge with a crane.

Methods

The permeable dam physical section model is a Froude-scaled 1:50 undistorted movable bed model. This model represented only 38.4% of the bridge prototype's total length (i.e., 45.7 m out of 119 m), reducing to a 2D analysis. The scale provides a fully turbulent flow with no surface tension influences for the selected flows. This model study's initial permeable dam configuration is the original design (Tecnosuelos Cia. Ltda. 2021). It consists of a bridge structure with an additional upstream set of piles and a tetrapod mat. The model bridge piers and upstream piles are acrylic, and the tetrapods are 3D printed.

The model intends to replicate the permeable dam design's local and regional scour potential and the impacts of the modifications. As scour is the primary driver, the initiation of motion is how the bed material is scaled (Shields scaling). The prototype material is a lacustrine deposit with an alluvial layer on top. A superficial alluvial layer (around 5 m in thickness) composed of rocks with d50 =0.48 m. For the model, the alluvial layer is geometrically scaled with 10 mm wash rock. The lacustrine layer underneath the alluvial layer is composed mainly of silt and clay and is very susceptible to hydraulic erosion. The critical shear stress for this in-situ material is 21 Pa (as validated in CELEC CERC's numerical modeling effort). Thus, applying the scaling relationship of L_r, the model's required critical shear stress is 0.42 Pa, equating to course sand.

For head-cut replication, a bed invert gate controls the elevation of the channel. During testing, the gate is systematically lowered to simulate the progression of a head-cut.

Results

Modeling of a frequent flow event (5-year, 2800 cms) showed rapid removal of the tetrapods. After the tetrapods mobilized in the model, designers switched to a robust locally sourced rip-rap gradation. In all, six different designs were evaluated. Additionally, piers helped hold the rip-rap in place by providing a fixed structure where material could bridge between adjacent piers. By adding a cut-off, the designer can maintain the channel invert at the bridge and prevent the head-cut from propagating upstream. The design, with rip-rap and cut-off wall, can accommodate up to 15 meters of channel degradation

Conclusions

The six alternatives included two variations of the tetrapod-based design (alternatives 1 and 2) and four runs that replaced tetrapods with rock (alternatives 3 to 6). Model alternatives 4, 5, and 6 evaluated the structural modifications with the large rock. Then in alternative 6, designers added a rigid cut-off wall. All model alternatives included two rows of piers with 1.25 m diameter at 7 m (prototype) spacing on the center integrated with a bridge deck for access and maintenance. Model alternative #6, however, outperformed the other models by successfully preventing the head-cut migration with the sheet pile. This model alternative attained low damage and promoted the formation of an armored scour hole downstream and a stable downstream bed slope. Fundamentally, the invert must be held to prevent the head-cut migration. An additional model study that focuses on the design may be beneficial to improving its efficiency.

References

Tecnosuelos Cia. Ltda. 2021. “RCO y Diseño de Obra de Control de La Erosión Del Río Coca Tipo Presa Permeable, Aguas Abajo Del Frente de Erosión.” Reporte Tecnico.