International Conference on Case Histories in Geotechnical Engineering

(1984) - First International Conference on Case Histories in Geotechnical Engineering

08 May 1984, 8:00 am - 10:00 am

Braced Cofferdam to Improve Spillway Stability During Rehabilitation

Rodney M. Wong
Harza Engineering Company

James T. Passage
Harza Engineering Company

Sami S. Naami
Harza Engineering Company

Braced Cofferdam to Improve Spillway Stability During Rehabilitation

Rodney M. Wong, P.E.
Senior Geotechnical Engineer, Harza Engineering Company

James T. Passage, P.E.
Associate and Head, Special Projects, Harza Engineering Company

Sami S. Naami
Senior Structural Engineer, Harza Engineering Company

SYNOPSIS. Dewatering of scour pools at the toe of existing spillways can significantly increase forces on such structures and reduce their overall stability below acceptable levels. Such dewatering may be required however to undertake needed repairs or to construct a stilling basin. Use of a braced cofferdam permits the necessary dewatering while at the same time temporarily improving the stability of the spillway. This is accomplished by mobilizing earth pressures and tailwater pressures through the braces to restrain the spillway against sliding.

INTRODUCTION

The Panama Canal Commission retained Harza Engineering Company in 1978 to design a temporary cofferdam and new stilling basin for the Miraflores Spillway of the Panama Canal. Construction was performed between 1980-82. Supervision of construction was performed by the Panama Canal Commission. The braced cofferdam which is the subject of this paper was constructed as designed and performed as expected.

GEOLOGIC CONDITIONS

Years of operation at Miraflores spillway had scoured the bedrock of the spillway to a depth of 10 feet along the toe, and as much as 15 feet maximum depth in the middle of the plunge pool. Dewatering of the scour pool would increase the hydrostatic force on the spillway by 31 kips per linear foot. Figure 1 shows a section through the spillway.

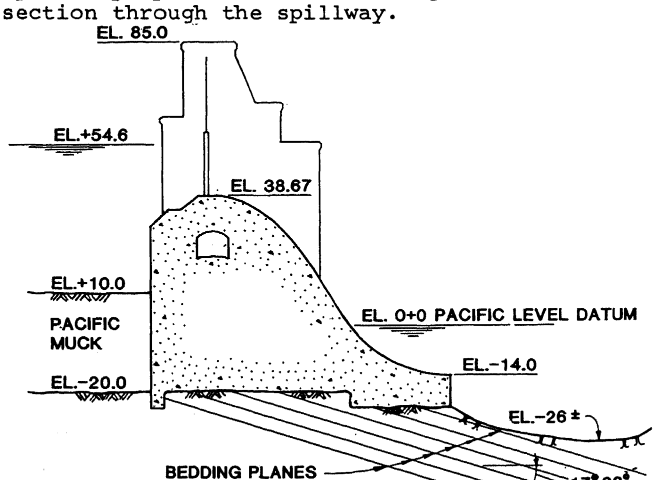

Fig. 1. Spillway Section

In addition, the interbedded sandstone and claystone layers of the LaBoca Formation dipped in the downstream direction approximately 17 to 26 degrees. Continued scour would progressively undermine the structure and deepen the scour hole, increasing the number of bedding planes which "daylighted" in the scour hole.

Previous investigation reports prepared by others had indicated the possible presence of continuous shear zones with fault gouge and weathered rock within open bedding planes.

Aside from the increase in horizontal load on the spillway the presence of open bedding joints also led to concern by the Commission that scour pool dewatering could initiate a process of piping that would progressively remove the upstream sediment blanket and lead to increased uplift beneath the spillway. This would contribute to the decrease in sliding stability of the spillway. Partial or complete failure of the spillway would have unacceptable consequences to the operation of the Panama Canal.

The sediment in the reservoir is known as Pacific Muck and is a black, fine grained sediment high in organic content. To test the theory that the sediments could pipe several cased boreholes into the rock were installed. Slurries consisting of several concentrations of the Muck were prepared and the boreholes were water pressure tested. The test results indicated a noticeable reduction in water take as the fine materials in the slurry progressively choked off the open seams in the rock in the vicinity of the boreholes.

TEMPORARY STABILIZATION ALTERNATIVES

Previous studies by others had also included a recommendation to install post-tensioned cable anchors through the spillway to provide temporary stabilization prior to the construction of the stilling basin. The anchors would necessarily have had to be installed diagonally from a high scaffold across the downstream face of the spillway to best utilize the horizontal component of the anchor force to resist sliding. Approximately 9,600 linear feet of anchors, each having 600 kips of capacity, would have been needed. The estimated cost of installing post-tensioned anchors was nearly equal to the construction cost of the stilling basin.

As an alternative to the costly post-tensioned anchors, Harza recommended that consideration be given to designing the cofferdam using the master pile concept, with steel pipe bracing to transfer to the spillway structure tailwater and earthfill pressures against the cofferdam. The braced cofferdam thus served a double purpose, namely improving the sliding stability of the spillway while permitting the scour pool to be dewatered. Neither a cellular sheet pile cofferdam or an earthfill cofferdam would have served both purposes.

Stability analyses indicated that construction of the braced cofferdam would enable all post-tensioned anchors to be eliminated while providing an acceptable factor of safety against sliding.

COFFERDAM DESIGN AND ERECTION

The cofferdam was designed to be built in two stages. This approach enabled one-half the spillway capacity to be available in the event of a major flood.

Tailwater levels are affected by the tidal fluctuations of the Pacific Ocean and could result in a depth of water of about 28 feet on the toe of the spillway and 36 feet along the alignment of the cofferdam. The depth of water along the cofferdam alignment ruled out use of a conventional steel sheet piling bulkhead with wales and bracing.

A master-pile sheet pile wall system was adopted based on ease of construction, economics and ease of removal, since it was intended to reuse much of the materials in the second stage.

Designing a master-pile system includes analyses common to designing a conventional soldier pile and lagging system. The sheet pile arcs are designed according to the principles used in cellular sheet pile cofferdams.

A plan of the 1st Stage cofferdam is shown in Figure 2. An earthen ramp was constructed from the right (looking downstream) abutment to provide for truck and crane access to the top of the cofferdam.

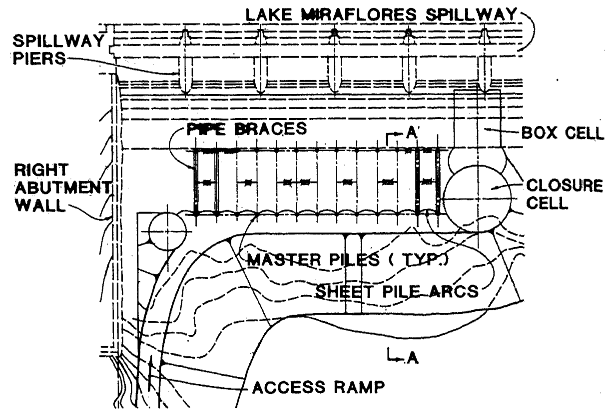

Fig. 2. Plan of Cofferdam - 1st Stage

The cofferdam was located at a distance of fifty (50) feet from the toe of the dam to accommodate construction of the stilling bas

The terminal ends of the cofferdam were designed as gravity circular cells. The cel in the middle of the spillway was designed a an integral part of the special steel sheet pile closure cell, fitted to the geometry of the spillway ogee.

A typical section through the cofferdam is shown in Figure 3. The outer shell consiste of pervious fill with dumped rockfill to act wave protection. Pervious fill was selected that maximum active earth pressures would develop on the sheet pile arcs enabling the greatest stabilizing forces possible to be transferred to the spillway through the pipe braces.

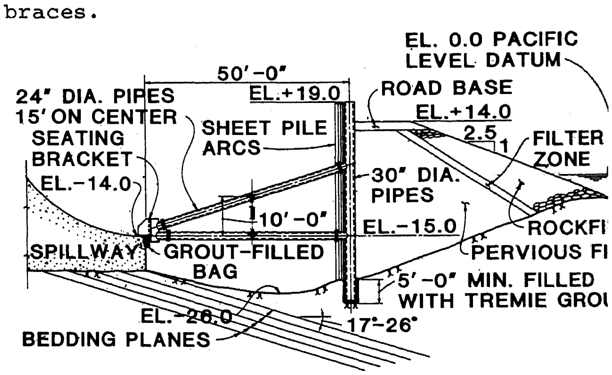

Fig. 3. Cofferdam Section

The master-pile system used at Miraflores w designed for a dewatering depth of 31 feet to retain a backfill height of 41 feet. Th inch diameter pipe braces consisted of two tiers, one diagonal and one horizontal whic meet in an L-shaped steel bracket seated ov the edge of the spillway toe.

Both the master pile wall and the steel pip bracing were designed to be able to transfe maximum horizontal load of 55 kips per foot based on near "at rest" earth pressures (cc ficient of 0.5) and full hydrostatic water depth of 31 feet.

For analyzing the stability of the spillway, however, it was assumed only the "active" load from earth pressure would be available, as well as the hydrostatic force from normal tailwater. This active load was expected to be approximately 36 kips per linear foot. Provisions were made in the pipe braces to achieve this load by jacking if it did not develop due to small deflections of the wall. The design horizontal loads in the upper (diagonal) and lower struts were 330 kips and 495 kips respectively, based on the 15 foot span between soldier piles.

Along the alignment of the sheet pile wall the height of the cofferdam averaged 45 feet. The 30 inch diameter vertical master piles were spaced at intervals of 15 feet and interconnected by arc segments of PS-28 steel sheet piles driven to the top of rock. The computed interlock tension and the maximum allowable interlock tension at the master pile connection was 4.2 kips per inch and 8.2 kips per inch respectively. The master piles were installed in rock sockets cored a minimum of 5 feet into the rock. Tremie concrete was placed in the annular space around the pipes.

Following installation of the master piles and sheet pile arcs, the pre-assembled bracing frame was lowered onto the edge of the spillway and bolted by divers to the master piles.

In order to ensure a uniform seating of the L-bracket, fabric "pillows" were positioned between the bracket and the concrete of the spillway. These were then pumped full of grout. This approach ensured that whatever loads were transmitted into the braces from the backfill and tailwater would be applied to the spillway structure.

The cofferdam earthfill had been partially placed to provide access for construction. Following installation of the braces the remaining backfill was placed and compacted.

Fig. 4 shows the dewatered cofferdam area with portions of the stilling basin completed, under construction, and in preparation for construction.

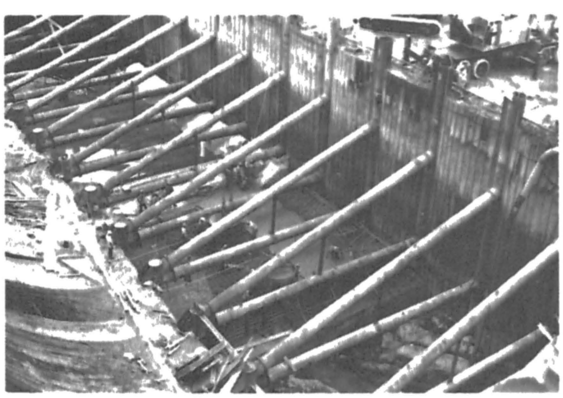

Fig. 4. Completed Cofferdam

CONSTRUCTION MONITORING

Survey measurements were made on monuments located on the cofferdam as well as the spillway. Electrical strain gages were installed on the pipe braces to monitor possible overload of the braces. Piezometers installed through the spillway structure were intended to give an early warning of increasing uplift beneath the structure. Measurements prior to dewatering indicated uplift pressures were more responsive to tailwater levels than headwater levels.

Dewatering of the scour pool did not result in any detectable movement of the spillway structure, or adverse deflection of the cofferdam structure. The rock foundation beneath the spillway drained without initiating a process of accelerating seepage, piping of sediments, or increasing uplift pressures. Strain gage readings indicated acceptable loads.

CONCLUSIONS

Use of a master pile system at Miraflores spillway demonstrated the advantages of a braced cofferdam where the sliding stability of a structure would be reduced to unacceptable levels by dewatering for repairs.

Advantages of braced, master pile type cofferdams are as follows:

- Soil and water loads are transferred to the master piles by interlock tension in the sheet pile arcs. This permits elimination of wales.
- Mobilization of interlock tension in a wall of sheet piles reduces seepage through the wall.
- Elimination of wales enables sheet piles to be driven to additional depths, if needed, an advantage where the top of rock is not well defined. Where a particularly dense soil condition is encountered, the sheeting can be progressively driven as the excavation is performed.
- Sheet piling of the master pile system can be easily salvaged.
- The vertical spacing of braces in the master pile system allows more headroom flexibility. The desired headroom can be provided by designing the proper bending capacity in the master piles. The vertical spacing of tie-backs is interchangeable during construction; with a conventional sheet pile and wale system, wales are restricted to the design location.