REMR TECHNICAL NOTE CS-MR-8.5

CASE HISTORY OF IMPROVING STRUCTURAL STABILITY OF CONCRETE STRUCTURES ON ROCK: INSTALLATION OF ROCK ANCHORS TO IMPROVE STABILITY AGAINST OVERTURNING, LOCK NO. 3, MONONGAHELA RIVER*

PURPOSE: To present a case history of improving stability of a structure against overturning.

PROJECT PROBLEMS: Lock No. 3, Monongahela River, is located 24 river miles from Pittsburgh, Pennsylvania. Traffic at the lock is extremely heavy averaging one lockage per hour around the clock. Rock anchors were installed at Lock 3 at two separate times. The first contract was let to rectify recognized critical items, one of which being the stability of the filling flume retaining walls. These walls were dependent on the stability of the top filling flume slab and beams to transfer the load to the landwall proper. The slabs and beams were badly deteriorated. The second contract was the major rehabilitation of the locks, and rock anchors were used to bring the stability of the lock walls closer to that required by present-day criteria. The critical items contract was awarded in April 1977 for $210,000 and completed in October 1977 for a total contract price of $242,000 including change orders. The major rehabilitation contractor work was begun in July 1978 at a contract price of $11,314,000, and work was completed in November 1980 at a total price of $12,452,000. The government estimated the cost of the rock anchors to be around $1,000,000 and the lowest contractor's bid was around $430,000. Other bids for the rock anchors were in the $700,000 to $800,000 range.

In the filling flume contract, the original design called for 72, 1-3/8-in.-diam Dywidag bars; however, the 1-3/8-in. bars were found to be foreign so the contract drawings were changed to show 97, 1-1/4-in. Dywidag bars which were domestically made. The contractor proposed using 1-3/8-in.-diam Stressbond bars that were smooth except within the anchorage length in rock. The approval resulted in returning the number of anchors to 72 and a savings to the government of $28,000. The spacing of the anchors was approximately 8 ft with a working load per anchor of 147.8 kips at 60 percent of the ultimate strength of the bar. Since these types of anchors were unfamiliar to the Corps of Engineers and since watertightness tests, as such, were waived, the Design Branch required the test anchor loads to be taken to 80 percent of the ultimate strength to ensure a reliable anchor. This load is a little higher than normally required for test anchors. The 1-3/8-in.-diam Dywidag bars are now domestically made.

Installation of the filling flume anchors was especially difficult because the anchor heads downstream of the operations building are located 5 ft below the

* This technical note is taken from "Experience and Problems in the Pittsburgh District Installing Rock Anchors at Lock 3, Monongahela River," by Anton Krysa, US Army Corps of Engineers, Pittsburgh District, In: Concrete Structures Repair and Rehabilitation, Vol C-82-1, Sep 1982, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

top of the filling flume slab (Figure 1). Another difficulty was that high

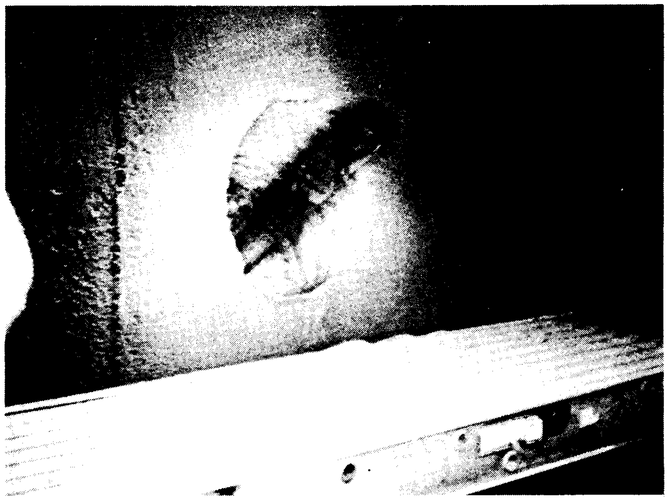

Figure 1. Installation of filling flume anchors

water is fairly common at Lock 3 and the contractor had to install scaffolding or work platforms inside the flume that could be easily raised. The contractor had to break an opening in the slab and drill at a 1V to 1.5H slope through the concrete retaining wall and the overburden material while advancing a 4-in.-diam casing and, finally, into the rock for a depth of at least 20 ft. The casing was required for corrosion protection and to keep the hole from collapsing while drilling. The hole diameter in rock was 3-1/2 in. for the first stage grouting.

The slope and vertical location of the anchors were optimized by many trials using various slopes and locations. The controlling criterion for the design of the anchors was to keep the resisting-to-overturning moment ratio around 1.3. This value is not usually computed for new structures. When investigating stability for existing structures undergoing rehabilitation, the Pittsburgh District found that this ratio gives a better perspective of possible overturning failure, more so than just the percent active base criteria.

DRILLING EQUIPMENT: The drilling equipment used by the contractor consisted of a crawler-mounted hydraulic drill rig specially designed and built for anchor installation (Figure 2). The contractor was restricted in possibly overloading the slab with his drilling equipment and, therefore, was required to place planking across the beams spanning the deteriorated slab. The beams were not as deteriorated and were found to take a load of 500 psf. The biggest problem the contractor had in installing the anchors was in drilling a hole through abandoned sheet piling in the overburden behind the retaining wall. After some difficulties, the hole was finally drilled to the required depth and the anchor installed.

CRITICAL AREAS: The anchors for the rehabilitation work required special attention in two critical areas. The first area was the middle wall in the vicinity of the cofferdam where the closure of the steel sheet pile circular cofferdam was formed by the lower monoliths of the middle wall. The second area was the reach of river wall exposed to upper pool. Here it was known that a coal seam was near the foundation line and caused special concern for sliding stability. All areas of the other walls were also unstable and required rock anchors; however, they did not cause any unusual problems.

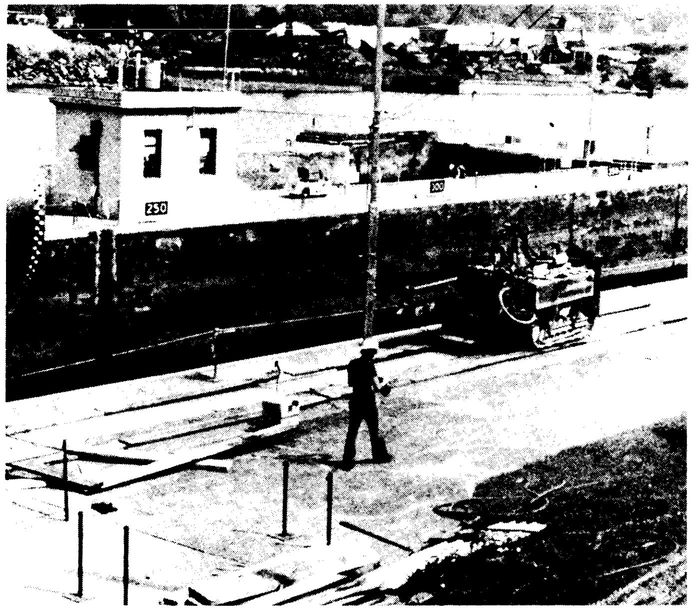

Figure 2. Crawler-mounted hydraulic drill rig used by contractor

The first critical area near the cofferdam was first stabilized with just vertical rock anchors until the cofferdam was dewatered (Figure 3). It was discovered

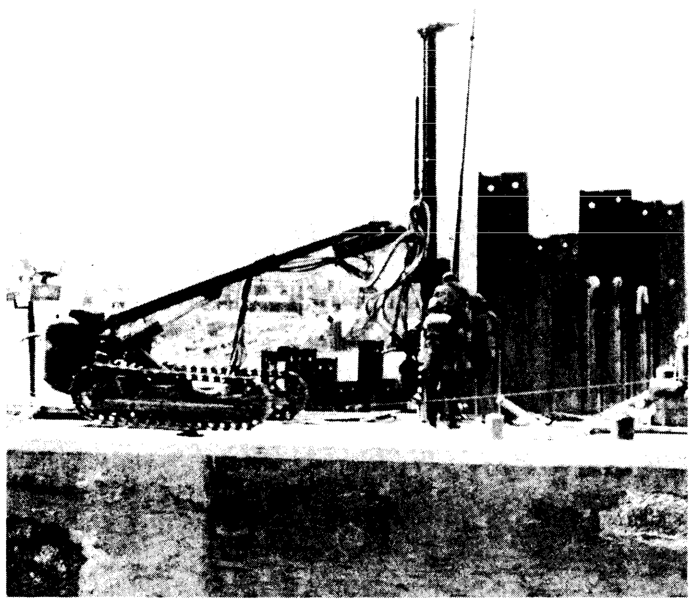

Figure 3. Stabilizing and dewatering cofferdam

that these monoliths were formed in the wet without the benefit of today's technology used in placing tremie concrete. As a result, the concrete was segregated and it was apparent that the foundation was not prepared very well when concrete was placed. There was concern that sliding could be a problem and, as a result, nine inclined anchors were installed from within the cofferdam to prevent this type of failure.

The second critical area in the upper end of the river wall was resolved by the placement of a large number of inclined anchors spaced as close as 3 ft 4 in. from each other. Another problem was the number of voids within these monoliths. It was very difficult to locate an anchor line without getting close to voids. Three conditions contributed to the anchors being installed through the filling culvert. First, the culvert was not constructed to the elevations and dimensions indicated on the original contract drawings; secondly, construction personnel allowed the contractor to relocate the anchor line slightly for his convenience and the support for the drilling rigs was not rigid enough to accurately drill the anchor holes. Drill rigs were supported on a barge within the chamber because the top of river wall was too narrow and slight fluctuations in the pool within the chamber affected the drilling line.

RESIN-GROUTED ANCHORS: Plans and specifications called for cement-grouted anchors grouted in two stages. As an option, the contract allowed the use of resin-grouted anchors (Figure 4). The contractor proposed a hybrid system using

Figure 4. Resin-grouted anchors

resin within the anchorage length in rock and cement grout within the concrete of the lock wall. This resulted in two hole sizes, a 2-1/4-in. hole in rock to allow proper mixing of the resin and a 4-1/2-in. hole in the concrete to allow passage of the coupling of the long anchors and to provide adequate corrosion protection of the stressed bar. The contractor had difficulty extracting the cuttings from the hole supposedly because air velocity was reduced at the transition to the larger hole. The government directed the contractor to temporarily reduce the size of the larger hole by inserting a casing. After the contractor did this, he had much better success in extracting the cuttings.

The Corps eliminated the pregrouting requirement of the holes once it was known that the contractor was going to use resin instead of cement grout. Apparently the resin system did not require pregrouting of the anchor hole because it could be mixed in the presence of water and is not eroded by any flowing water within rock, as cement grout possibly could be. The subcontractor installing the anchors protested the deletion on the grounds that the hole diameter would not be true enough in rock unless the hole was grouted then redrilled. It is believed that the real reason for the protest was that his bid was unbalanced and relied heavily on overruns in grout-take in the anchor holes.

SUMMARY OF ANCHOR INSTALLATION: Summary of the rock anchor installation is as follows:

- There were 76 river wall anchors; 41 resin and 35 cement grouted. Twenty-three anchors failed (30 percent) with 14 having to be replaced and 9 accepted at lower loads.
- On the middle wall, there were 127 anchors; 117 resin and 10 cement grouted. Twelve anchors failed with 2 having to be replaced and 10 accepted at lower loads.
- Within the land wall, 23 cement grouted anchors were installed with just one failing, but it was accepted at a lower load.
- The 173 rock anchors in the upper and lower guide walls were eliminated because the contractor was having a lot of difficulty. Difficulties experienced by the contractor were in extracting cuttings from the hole; encountering obstructions such as wood, tramp steel, and form tie steel; encountering voids; uncoupling of the spliced bars; pad failures; getting the drill steel stuck; difficulty in performing the second stage grouting supposedly because of poor rock/concrete contact zone; and direct contact with riverflow. Because of these difficulties, the anchor hole had to be abandoned and the anchor hole offset 67 times.

REASONS FOR FAILURE: A failed anchor was removed from the middle wall and closely examined for any possible explanation for the failure of the anchor. It was found that the resin between the deformation of the bar was still soft and pliable. In other reaches of the bar, the resin was not soft, and it was harder to remove from the bar. The contractor claimed that improper mixing occurred because the hole was enlarged due to the caving of the hole in the poor rock which would not have happened had he been allowed to pregrout each hole. To investigate the actual hole size, he was directed to core drill the hole where the failed anchor was pulled out. A reddish grout was allowed to set in the hole and the core drilling was successful in retrieving core within the rock and anchor hole (Figure 5). The diameter of the anchor hole was consistently

Figure 5. Core samples retrieved for testing

found to be 2-1/4 in. as the contractor intended. In the interest of finding the exact cause of failure, several boxes of resin cartridges with short lengths of anchor bars were sent to the Waterways Experiment Station in Vicksburg for testing. Their conclusion was that the size of hole chosen was borderline on being too large, and the semihardened condition of the hardening agent required a greater amount of mixing than specified by the resin manufacturer's literature. A review of the shop drawing submittals indicated that the contractor may have inadvertently chosen the wrong hole size for the cartridge he was using.

NEW STABILITY CALCULATIONS: Because of the number of failed anchors and the reduced loads that they could hold, new stability calculations were necessary to evaluate possible failure modes. In addition, since the reliability of the anchors passing through voids was uncertain, the reduced criteria were further lowered to accept the river-wall stability without depending on the ten anchors in the river-wall filling culvert. For this reach of wall, the percent active base criteria had to be reduced from 70 percent active base to 60 percent; however, the resisting moment to overturning moment ratio would still be above 1.3.

AVOIDING PROBLEMS: The best solution to avoid problems in installing rock anchors is to have an experienced contractor perform the work. A good contractor can overcome many difficulties that may arise that were not anticipated by the engineer and keep any possible claims down to a minimum. Another factor that led to problems at Lock 3 was that the contractor submitted an unbalanced bid. The specifications also were not clear enough in that they did not disallow pregrouting when using resin-grouted anchors.