REMR TECHNICAL NOTE CS-MR-8.4

CASE HISTORY OF IMPROVING STRUCTURAL STABILITY OF CONCRETE STRUCTURES ON ROCK: INSTALLATION OF ROCK ANCHORS TO IMPROVE STABILITY AGAINST SLIDING, ALUM CREEK DAM*

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

PROJECT: Alum Creek Dam which was constructed between 1970 and 1974 is located on Alum Creek, a tributary of Big Walnut Creek, which drains into the Scioto River. The site is located in Delaware County just north of Columbus, Ohio. It is a multipurpose reservoir operated by the Corps of Engineers' Huntington District and provides flood control, water supply, and recreation benefits.

The dam is a rolled earth-fill embankment 10,000 ft in length with a maximum height of 93 ft. The spillway is located high on the right abutment with the raceway dropping off in front of it to the stilling basin below. Control is provided by three 34- by 25-ft tainter gates supported by 8-ft-wide concrete piers resting on concrete ogee sections. The ogee sections have a crest elevation of 878 and are founded at elevation 839.

GEOLOGY: The rock at the Alum Creek Dam site is Ohio Black Shale which is largely a hard, massive silt shale. It is highly fractured below the base of weathering. Within this shale are several light gray, silty to clayey shale seams up to 1 ft thick. The core logs indicate that occasionally contacts between the seam and the black shale are clayey coated. The information obtained from these logs was used in the design.

DESIGN: The spillway monoliths were designed to resist overturning, failure of the rock in bearing, and sliding on the foundation or any seam in the foundation (deep-seated sliding). Overturning and bearing were not problems; however, there was considerable concern within the District regarding sliding safety of the spillway monoliths "perched" high on the abutment. It was decided that the clayey seams mentioned above were not continuous and did not constitute a problem; therefore, sliding on the foundation was the controlling mode of failure.

INSPECTION OF PROJECT: On 24 April 1975 during a periodic inspection of the completed project, concern was again expressed about the safety of the spillway monoliths and that further investigation was warranted. It was decided to drill 6-in.-diameter core holes in the raceway to obtain samples of the weak foundation seams. Special care would be taken when penetrating the clayey shale horizons and all losses would be redrilled. If the clayey seams were present in a high percentage of the holes, specimens would be tested in the

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laboratory and foundation shear strength parameters derived. A deep-seated sliding analysis would be made using the latest analytical criteria and the derived laboratory shear strengths.

DRILLING AND TESTING OF ROCK: Twelve 6-in.-diameter core holes were drilled in the raceway directly in front of the ogee weirs. At least six of these cores exhibited a clayey seam about elevation 830. All specimens containing the clayey seams were wrapped in plastic and sealed with wax to maintain as nearly as possible their natural moisture condition. This limited number of specimens was sent to the Corps' Ohio River Division Laboratory in Cincinnati, Ohio, for testing. Test results and a subsequent deep-seated sliding analysis indicated that the spillway monolith should be anchored by the use of high-capacity rock anchors.

DESIGN OF ANCHORS: The loading conditions and assumptions used in the deep-seated sliding analysis were also used in design of the anchors. A minimum shear friction factor of safety of 1.5 was considered necessary to ensure the safety of the structure. After several trials, it was decided that seven 1300-kip anchors per monolith acting at 45 degrees would satisfy the design criteria. Following is a chart for the various loading conditions showing shear friction factors of safety (Ssf) with and without anchors:

Loading Condition	Ssf With Anchors	Ssf Without Anchors
2	1.74	0.48
4	1.56	0.23
6	1.41	0.39
7	2.94	1.00

The Ssf of 1.41 obtained for loading condition 6 does not satisfy the 1.5 criteria; however, since this is a seismic condition it was considered satisfactory.

It was decided that 53 seven-wire, high-strength (fy = 270 ksi) strands, with a total area of 8.11 sq in. (53 times 0.153), would satisfy the 1300-kip load with a working stress of 160 ksi. The 160-ksi stress is less than 0.6 fy (162 ksi) which is required in prestress design.

All anchors would be stressed initially to 1532.6 kips (0.7 fy) plus seating losses. A test lift-off would be performed at 1 hour and at 14 days after stressing in order to evaluate the losses in the anchor. A minimum load of 1400 kips would be required at 14 days. It was anticipated that additional losses beyond the 14-day period would lower the load to the design value of 1300 kips.

It was decided that all anchors should be anchored below the bottom of the stilling basin slab (elevation 813). This would ensure that the anchorage zone was beneath all possible weak seams daylighting in the raceway (Figure 1). The bottom of the anchor holes would be staggered to avoid stress concentrations in the rock. The "Post-tensioning Manual" of the Post-tensioning Institute recommends a 9-in. drill hole for anchors of this size. It was decided to use three bell anchors in the anchorage zone to ensure positive resistance for the anchors. An allowable bearing value of 500 psi for the bell against rock and an allowable grout to rock shear value of 90 psi were used in determining an anchorage length of 31.2 ft.

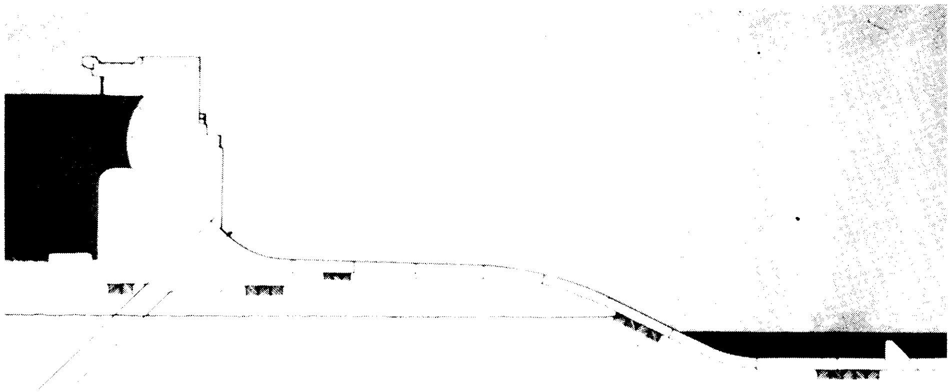

Figure 1. Profile of the centerline spillway

A 3.0-ft-diameter hole 3.0 ft deep would be drilled in the face of the spillway at the top of the 9-in.-diameter holes. The upper portion of the 3.0-ft-diameter hole would accommodate the anchor head and strand extensions and be filled with concrete upon completion of the stressing. The lower portion of the 3.0-ft-diameter hole would provide for a high-strength concrete (f'_c = 5000 psi) area under the bearing plate. The high-strength concrete area was designed in accordance with prestressed concrete codes for end regions considering the spalling and bursting zones.

INSTALLATION OF ANCHORS: Bids for installing the anchors were opened on 2 March 1977. Four contractors took part in the bidding. VSL Corporation was awarded the contract at a price of $254,777.50.

The contractor designed a work platform which could be towed transversely across the raceway (Figure 2). The drilling for the anchors began on 15 June 1977. The contractor was given permission to change the anchor hole size from 9 in. to 14 in. to facilitate his drilling. The bell diameter was changed from 21 in. to 24 in. to offset the loss in bearing area. Auger bits were used in the drilling of both the 14- and 36-in.-diameter holes. All holes were drilled, grouted, and redrilled to ensure that all voids and cavities were filled. Drilling was completed on 24 August 1977.

Figure 2. Work platform designed by the contractor

The high-strength concrete under the bearing plate was placed for all 14 anchors on 23 and 26 August 1977. Results of individual compressive strength tests were as follows:

	Strength, psi	
	Placed 23 Aug 1977	Placed 26 Aug 1977
7-day	4810-4880-4660	4130-4060-4060
28-day	6110-6130-6080	5480-5550-5580

The contract specifications required that the high-strength concrete have a compressive strength of not less than 4000 psi prior to stressing of the anchors and a 28-day strength of not less than 5000 psi. The first anchor was stressed on 21 September 1977; therefore, the above testing satisfied the contract specifications.

The anchor strands were cut to the desired lengths and tied together in 52 unit anchors (Figure 3). The contractor was allowed to use 52 strands per anchor with a minimum yield strength of 275 ksi in lieu of 53 strands with a minimum yield strength of 270 ksi. An 0.6 fy at a working load of 1300 kips was not exceeded by this change. The anchor assemblies with a maximum weight of 3400 lb each were installed in the anchor holes by use of a helicopter. Only about 5 hours was required on 6 September 1977 to install all 14 of the anchors by use of the helicopter (Figure 4).

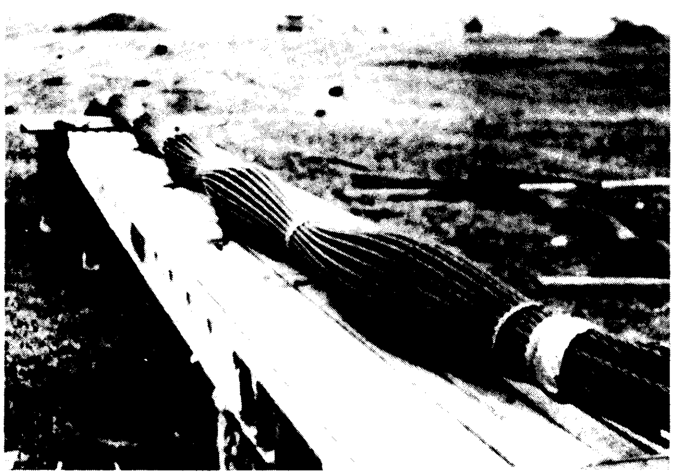

Figure 3. Anchor strands were cut and tied together in units

The first stage grouting was accomplished on 7-9 September. The grout mix consisted of 5 gal of water per bag of cement with 1 percent (by weight of cement) of Intraplast-N manufactured by the Sika Chemical Corporation. Four 2-in. cubes were taken for testing. One of the cubes was broken at 7 days and yielded a compressive strength of 4220 psi. The other three cubes were broken at 21 days and yielded an average compressive strength of 6200 psi. These breaks satisfied the contract specification requirements of 4000 psi.

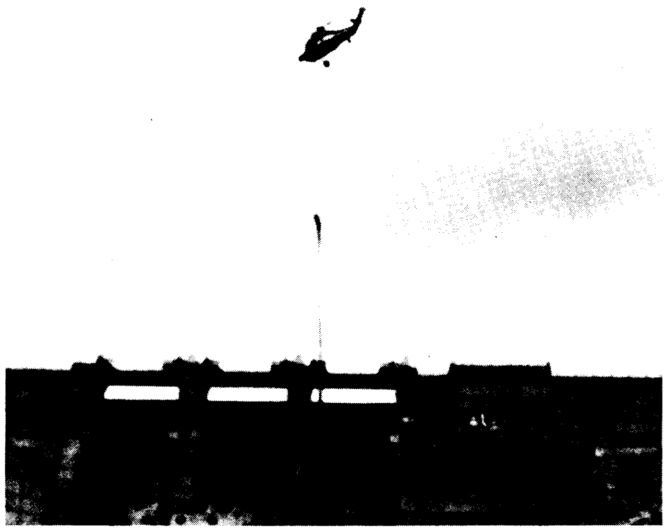

Figure 4. Helicopter was used to install anchors

After the first stage (grouting reached a compressive strength of 4000 psi), the anchors were stressed. Each of the 52 strands was individually pulled to 3 kips each, to take the slack out of the system, prior to simultaneous stressing to 29.4 kips per strand or 1528.8 kips per anchor. The load of 1528.8 kips was applied by a 1000-ton centerhole jack (Figure 5). The loads were determined by a pressure gage on the jack reading to the nearest 100 psi.

Figure 5. Reading pressure gage on centerhole jack

Each anchor was pulled to 20, 40, 60, 80, and 100 percent of 1528.8 kips, plus seating losses, and secured. An initial lift-off was made to determine the load still in the anchor. The load was then released from the jack and after a minimum time of 1 hour the jack was reloaded and a second lift-off made. All anchors were again tested at 14 days prior to second-stage grouting. A final lock-off load of 1400 kips was required in the contract specifications. All 14 of the anchors had in excess of 1400 kips except for anchor M7-4 which had 1398 kips. It is assumed that all of the anchors will continue to lose some stress; however, a final load of 1300 kips per anchor should be guaranteed.

In stressing anchor M7-3 on 28 September 1977, the high-strength concrete below the bearing plate failed. Air voids formed in placing of the concrete were found to be the source of trouble. The plate and some of the concrete were removed, new concrete added, the plate reset, and the anchor restressed. On all anchors stressed after 28 September 1977, the bearing plate was drilled and the area below the plate grouted to ensure against the above failure. No more problems were experienced.

The contractor varied the allowance for seating losses from 1/4 to 3/4 in. It became apparent after stressing the 14 anchors on this project that this allowance should be 1/4 to 3/8 in.

After the anchors were locked-off at 14 days, the second-stage grouting was accomplished to ensure positive corrosion control.

The exposed edges of the concrete spalled when drilling the 36-in.-diameter holes. A rectangular area about 1-1/2 in. deep was sawed out around the 36-in.-diameter holes in an effort to match the existing concrete. A mat of wire mesh was installed in the rectangular area, and all concrete surfaces were coated with epoxy bonding compound prior to placing the concrete to complete the project.

CONCLUSIONS: Anchoring of the spillway monoliths at Alum Creek demonstrates that high-capacity rock anchors can be installed in a short time at a relatively low cost if properly designed and installed. The success of this installation should suggest to other engineers the possibility of using this technique for upgrading old or inadequate structures of various types.

ENVIRONMENTAL CONSIDERATIONS: Consideration should be given to proper disposal of debris from repairs such as this to prevent degradation of water quality.