REMR TECHNICAL NOTE CS-MR-8.3

# CASE HISTORY OF IMPROVING STRUCTURAL STABILITY OF CONCRETE STRUCTURES ON ROCK: GROUTING, CRACK REPAIR, AND INSTALLATION OF ROCK ANCHORS AT JOHN DAY LOCK AND DAM*

PURPOSE: To present a case history of repair of structural cracking in lock monoliths.

PROJECT: John Day Lock and Dam is located on the Columbia River between Oregon and Washington, 215.6 miles above the river mouth, about 110 miles upstream from Portland, Oregon, and 23 miles upstream from The Dalles, Oregon. John Day Navigation Lock began operating in 1968. The lock is 675 ft long, 86 ft wide, and provides a maximum lift of 113 ft, making it one of the highest single-lift locks in the world. Figures 1 and 2 show aerial views of the project and the position of the navigation lock with respect to the dam.

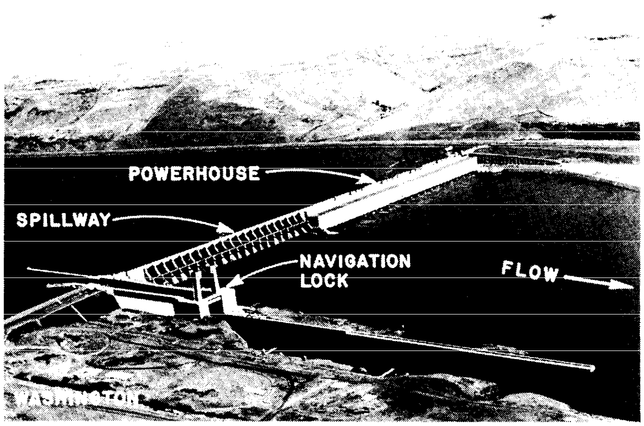


Figure 1. Overall view of lock and dam

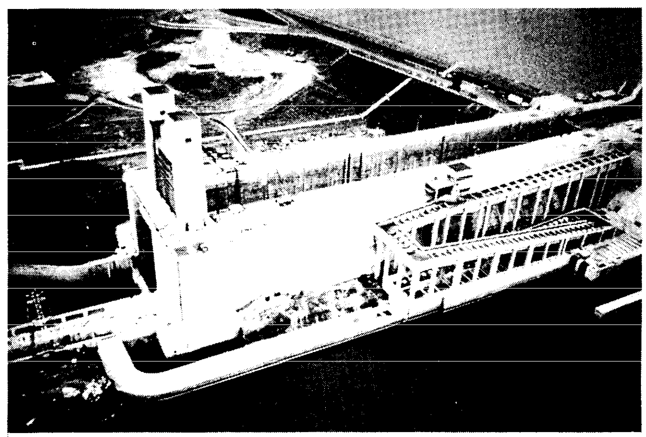

Figure 2. Side view of navigation lock

PROBLEM: During an inspection in 1975, significant structural cracking and associated spalling were discovered in lock monoliths 17 and 19. By 1979, cracking and spalling had been detected in monoliths 13, 15, 17, 19, 21, and 23 (Figures 3 and 4). The structural distress in the monoliths consisted of a crack that originated at and propagated from the upper inside corner of the

* This technical note is taken from "John Day Lock Repair," by Ken J. Neugerger, US Army Corps of Engineers, Portland District, In: Concrete Structures Repair and Rehabilitation, Vol C-82-1, Sep 1982, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

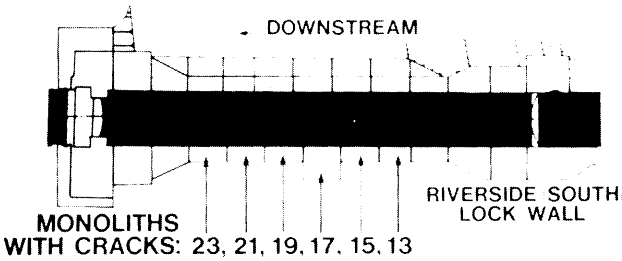


Figure 3. Position of lock monoliths with cracking and spalling

Figure 4. Wall of locks showing structural deterioration

filling and emptying culvert and terminated at the surface of the wall in the lock chamber (Figure 5). Because of the continued progression of the cracking and spalling, a remedial repair was devised to halt and correct the ongoing structural deterioration.

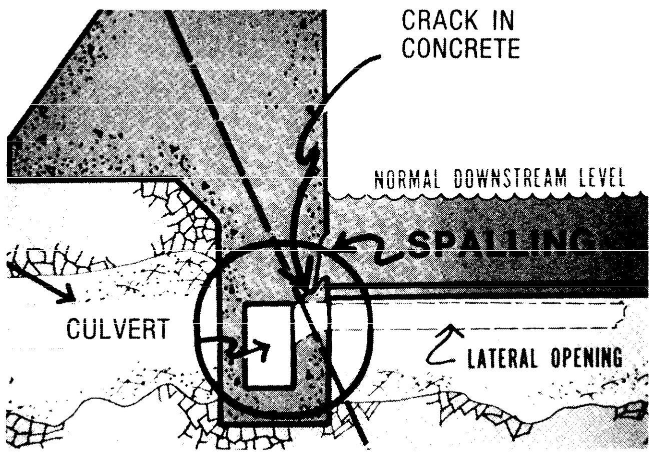


Figure 5. Schematic of cracking and spalling in the culvert

REMEDIAL REPAIR: The philosophy behind the remedial repair was to restore the existing cracked structure to its near original uncracked condition. This goal was to be accomplished by a three-phase repair. The repair consisted of: (a) grouting the foundation rock, (2) installing rock anchors through the cracks after injecting structural epoxy adhesive into the cracks, and (3) repairing the surface of the wall in the lock chamber. The foundation grouting (Phase I) was performed to reduce the excessive foundation deformations. The structural repair (Phase II) was performed to return the cracked areas to a monolithic state and subsequently to maintain this state. The proposed surface repairs (Phase III) will be performed to replace any drummy concrete, to return the walls to their original neat concrete lines, and to add extra protection to the structural repair elements. The Phase I and II repairs were designed with the intent of keeping to a minimum any disruptions to normal lock service.

DESIGN: The riverside cracked monoliths were initially designed as gravity retaining wall type structures with base elevations varying between 170.0 and 180.0. The 12-ft-wide by 20-ft-high filling and emptying culvert, with an invert elevation of 114.0 and attached to a 26-ft-wide wall segment below the gravity sections, was designed as a rigid frame. The frame was considered fixed at the bottom of the 26-ft-wide wall (Figure 6), and was designed for bursting and collapsing pressures. Forces due to excessive foundation rock deformations and vertical dead load from the structure above were inappropriately omitted.

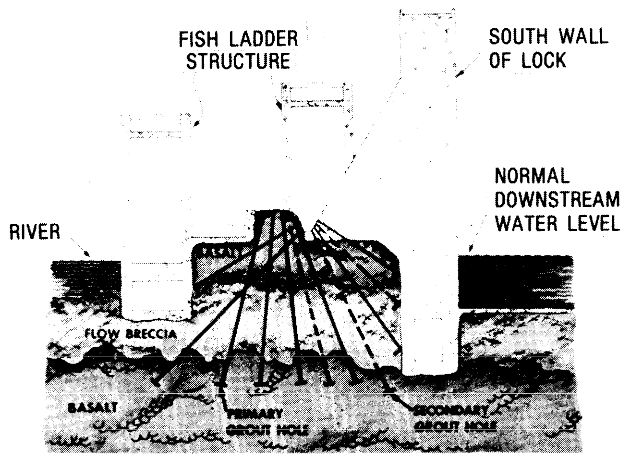


Figure 6. Cross section shows orientation of grout holes. View is looking downstream

CRACKING: Stress analysis using finite element models revealed two probable causes for the cracking. One cause was due to the original filling procedure that, before it was changed, produced high hydraulic surge pressures in the culvert. The other cause was due to the normal lock-full condition that produced excessive foundation deformations because of a layer of weak-flow breccia rock (Figure 6). Both causes produced high tensile stresses in the concrete and, because of inadequate reinforcing steel in the cracked area to distribute these stresses, lead to the ensuing cracking and associated spalling. Prior to the Phase I and II repairs, the cyclic loading of the lock walls, due to the filling and emptying of the lock, contributed to the continued propagation of the cracking and spalling.

Stability analyses showed, for the lock-empty condition and the loss of the inside culvert supporting wall, the monoliths were unstable for overturning into the lock. This was unacceptable and, through the corrective action taken by implementing the Phase II repair, overturning will be prevented.

FOUNDATION GROUTING: Consolidation grouting using cement grout was performed in 1980 as the first phase of the remedial repair. A contract was awarded to Continental Drilling - U.S., a Division of R. F. Thies, Inc., and R. O. Thies, an individual, as joint venturers on 22 January 1980 to perform the Phase I work. The purpose of the grouting was to fill any void spaces or open joints in the supporting rock mass. The supporting rock mass consists of a weak layer of flow breccia sandwiched between two layers of basalt. The soft, weak, highly fractured flow breccia layer was the primary target of the consolidation grouting (Figure 6). Finite element modeling during the repair design showed that increasing the rigidity of the confining and supporting rock mass would significantly reduce the monolith deflections and related tensile stresses around the culvert. Postconsolidation grouting deflection measurements at the crest of the monoliths revealed that the deflections were reduced approximately 50 to 60 percent from the pregrout condition.

STRUCTURAL REPAIR: In March 1981, a contract was awarded to Western Pacific Drilling Co., a division of Riedel International, to perform the Phase II repair work. This phase of the repair included the installation of 73 rock anchors and the injection of structural epoxy adhesive into the cracks. Finite element analyses showed that the induced rock anchor forces substantially reduced the tensile stresses in the crack area at the top of the culvert.

Without interrupting lock service, 10-in.-diam rock anchor holes, up to 172 ft in length, were drilled from the outside of the monoliths and into the basalt rock below. The holes were drilled at either 55- or 66-deg angles from the horizontal. The allowable deviation to avoid drilling into either the filling and emptying culvert or the lock chamber was 1 ft in 100 ft. The contractor accomplished this challenging requirement without any major difficulties (Figure 7).

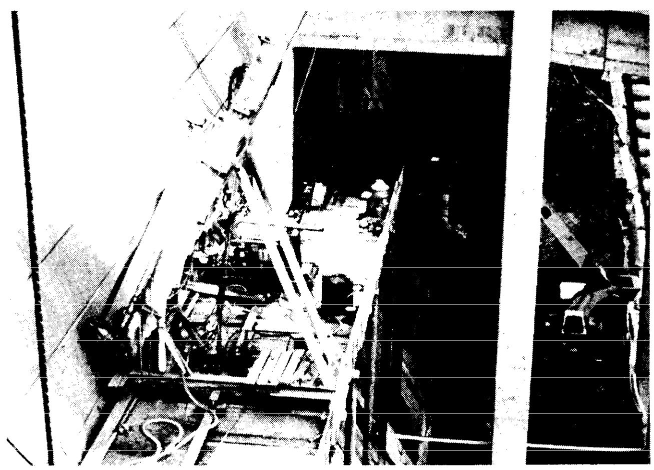

Figure 7. Contractor's equipment used in drilling

The 73 rock anchors consisting of 37 separate seven-wire strands, 0.6 in. in diameter, were installed in monoliths 11, 13, 15, 17, 19, 21, and 23. The length of the rock anchors varied from 138 to 172 ft. The rock anchors were composed of four major elements. These elements were the 30-ft anchor ends, the inflatable grouting packers above the anchor ends, the greased and polyethylene sheathed strands above the packers, and the stressing end assemblies. Packers were used to ensure a good grouting job in the crucial anchor end area. Greased and sheathed tendons were used to have the capability to retension or detension the rock anchors. The rock anchors were inserted into the drilled holes, generally spaced at 4 ft, without any disruption to lock service. The 30-ft anchor (bonded) ends of the anchors were grouted during slack times in lock usage.

During the July 1981 lock outage, the cracks were pressure cleaned with a cleaning solution, rinsed with water, then dried. Epoxy was then injected under pressure into the cracks. Following the injection of epoxy into the cracks, the rock anchors were stressed. No major complications developed during the rock anchor stressing. Fourteen load cells were installed to monitor rock anchor performance (Figure 8). To date all cells show a force remaining in the anchors above the 1300-kip design working force. The second phase of the repair program was completed in September 1981.

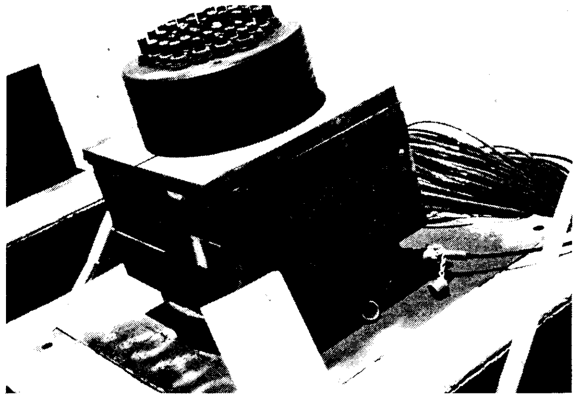

Figure 8. Load cells installed to monitor rock anchor performance

LEAKAGE: During the initial rewatering of the lock, a number of rock anchor assemblies were leaking water from their stressing ends. The leaking occurred when the lock was being filled and at lock full. The normal lock-full elevation is 50 to 65 ft above the stressing end elevations. Because of the leaking water problem, Portland District has taken the following steps: initiated a strand corrosion potential test program with North Pacific Division Laboratory, taken water samples periodically from the rock anchor stressing ends, and installed heat tapes around the stressing end assemblies to prevent any freeze damage. The water samples have shown pH values greater than 11, which is not conducive to corrosion.

INSPECTION: On 17 March 1982, the dewatered navigation lock was inspected by Portland District and North Pacific Division personnel. The purpose of the inspection was to evaluate the effectiveness of the Phase II remedial repair. This was the first opportunity to inspect the repaired area since the completion of the structural repair in September 1981. The filling and emptying culvert was inspected initially. A hairline crack was discovered in the epoxy patch at the culvert north wall-ceiling interface (Figure 9). The hairline

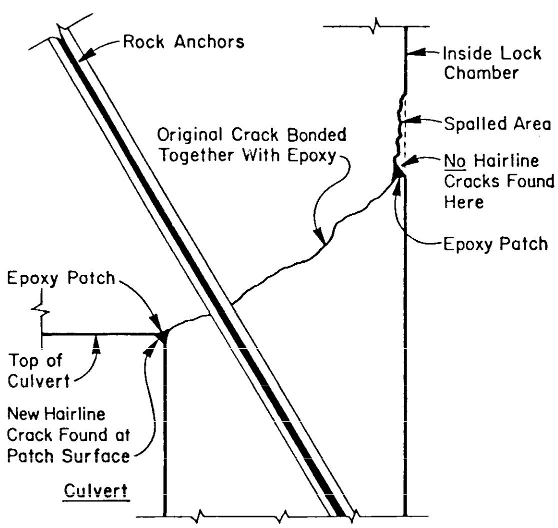


Figure 9. Existing culvert wall section, March 1982

crack was most evident in monoliths 21 and 23 where it was continuous throughout the length of the monoliths. Traces of the hairline crack were also seen in the other repaired monoliths (11, 13, 15, 17, and 19), but they did not appear to be continuous and were evident only in short lengths. Because of no spalling or chipping at its edges, the hairline crack showed no signs of working or being progressive in nature. After inspecting the culvert, the lock chamber wall was then inspected. Evidences of recracking of the injected epoxy were found only in a monolith 15 ladder well. The crack was hairline in size and did not appear to be progressive. No evidence of recracking was found at any other areas and no traces of the crack were seen at the epoxy patch areas where the previous cracking had surfaced (Figure 9). Areas of previously drummy surface concrete were found to be solid, indicating that the injected epoxy was bonding the cracked surfaces together.

SUMMARY: In summary, considering the magnitude and complexity of the original problem, the uniqueness of the repair design, and the restraints imposed on the design and the contractors (desiring to minimize the lock outage periods), the repair should be considered an extraordinary success. Even though there are evidences in the culvert of some hairline cracking of the injected epoxy, the hairline cracking has not propagated through the culvert wall and out to the lock chamber wall surface. In addition, the nonworking of the newly discovered hairline crack edges demonstrates that the 73 installed rock anchors are keeping the crack restricted and preventing any new large-scale cracking and spalling. After 8 months of lock use following the completion of the structural repair, the repaired monoliths are in a stabilized condition and show no signs of future continued cracking and spalling. The repair, therefore, will prolong the life of the structure and prove to be a worthwhile solution to a difficult problem.

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