The Repair of Large Concrete Structures by Epoxy Resin Bonding

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Cracking of any concrete structure is usually a matter of concern. When the structure in question is a major dam, the problem may be especially troublesome and sensitive.

The extent of the cracking is usually difficult to discern and often incompletely understood. For example, the dam foundation or abutment may perform differently than anticipated, or the dam itself may behave in a nonmonolithic manner. There may be cyclic processes at work generated by temperature or hydrostatic fluctuations. There may also have been intrinsic flaws in the concreting practices and materials, affecting over time the structural integrity and fundamental quality of the dam. It may even be the case that unforeseen problems arise from the adoption of new construction techniques and practices in dams of novel concept.

It has long been standard practice to attempt to fill major cracks by injecting cement-based grouts, and smaller aperture fissues with "chemical grouts," including silicates, phenols, and acrylates. Most recently, use has been made of various polyurethane grouts. These attempts have met with mixed results and have often needed repeating at frequent intervals because the brittle nature of the grout has not been compatible with the tendency of the structure to continue straining.

The state of practice in the control of cracking in concrete structures has been summarized by Darwin (1980), and in 1984 he reviewed further the causes, evaluation, and repair methods. He wrote that the method selected for repair should clearly be based on that aspect of the structure that needs remediation — strength or stiffness or water tightness or appearance or protection from aggressive solutions in the environment. Darwin also recorded that cracks as narrow as 0.002 in (0.05 mm) could be sealed and bonded by injection of epoxy resin.

There are difficulties in conducting such sealing and rebonding operations when conditions prevent substantial drawdown of reservoir level. These difficulties include:

- Inflow of cold water at high velocity and pressure
- Segregation, dilution, and displacement of grouts
- Matching grout properties to the often very irregular fissure geometry
- The need to avoid using high injection pressures with grouts of long setting times.

Such repair attempts are in a sense irreversible, as an inefficient repair attempt with the wrong material will greatly reduce the success potential of any subsequent attempt at treatment, no matter how conscientiously executed.

There are three basic elements in ensuring effective treatment:

- One must first make every effort to understand the cause of the problem. This understanding* involves a detailed review of all the geological, constructional, and behavioral data available. Often this research forms the basis for executing a new phase of exploration (by coring) and monitoring.
- Once the probable cause for the cracking has been determined, the repair material can be selected. The repair material must be a true Binghamian fluid, not a suspension of particles. It must harden as soon as practical after injection to deliberately limit and control flow distances. It must have a reasonably constant and controllable viscosity until hardening; this viscosity must reflect the anticipated crack width. It must have minimal shrinkage on hardening.

  It must be durable, and it is usually required to bond efficiently to wet surfaces, under high hydrostatic or dynamic heads, often in low temperatures and so must have high tensile and shear strengths. It is usually advantageous to have modulus of elasticity significantly less than that of the concrete. It must have low surface tension in order to ease penetration into fine fissures. It must be easily and safely handled, with minimal environmental problems.

* A good understanding of the role of restraint, volume change, and reinforcement on the cracking of massive concrete is given by Cannon (1973). A general summary of knowledge of mass concrete is given by Mass (1987).

- The performance of the grouting and of the structure should be continuously monitored during the repair. In this way, the grouting parameters can be varied as needed to optimize the procedure.

CASE HISTORIES

Epoxy resin grouting has been used to seal cracks in many major, high dams (Muzas, Campos, and Yges 1985). Particular case histories include Atazar (Eschevarria and Gomez 1982), Zeuzier (Berchten 1985), and Cabril (Portuguese National Commission Working Group 1985).

A recent application has been to repair an old concrete dam in the Eastern United States (Figure 1). The repair was highly successful. However, since such repairs are usually as delicate politically as they are technically, the owner in this case wishes to retain the anonymity of the project pending further seasons of acceptable performance.

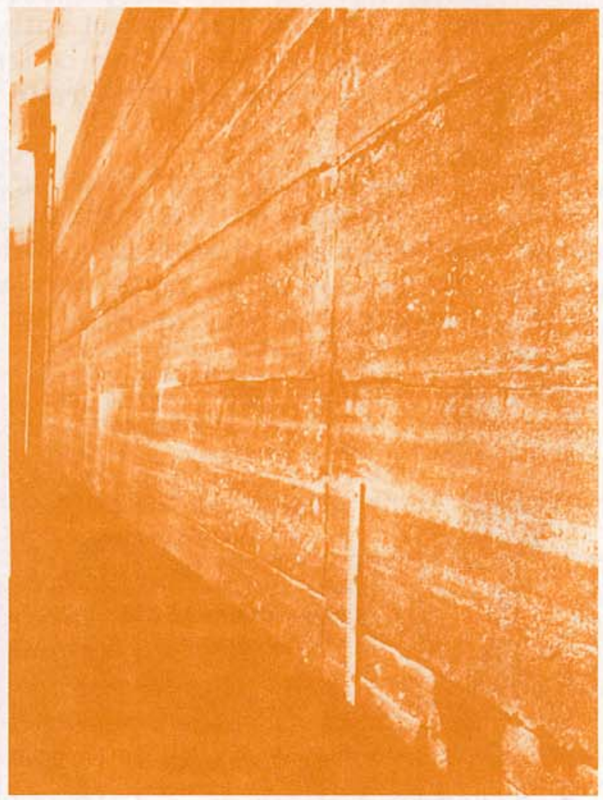

Figure 1. Upstream face of dam showing horizontal lift joints and vertical construction joints between blocks

This project involved a 60-year-old, 320-m-long, 65-m-high concrete arch, with gravity abutments and two spillways. Substantial leakage has been experienced from the first impoundment. Despite major structural modifications to the dam and repeated phases of cement grouting in the horizontal lift joints, the situation continued to deteriorate. By mid-1987, leakage in the left side alone had reached over 4,000 L/min and was entering the lower drainage gallery at higher pressures and over larger areas than before. Seepages on the downstream side of the gallery were also noted. Following the structured analytical approach as outlined above, treatment was concentrated on a 23-m-long section in the most critical area and was conducted from within the 2.4- by 2.2-m lower gallery, running about 3 m above the foundation and 4.5 m back from the upstream face (Figure 2). Fans of primary holes, up to 6 m long, were cored at regular intervals upstream from the gallery to investigate the suspect joints. These holes confirmed that the water flows were travelling through the joints: the concrete itself was materially sound. Many holes intercepted flows of up to 400 L/min at full hydrostatic head.

After all the primary holes had been drilled (Figures 3 and 4) and the data carefully considered, the systematic epoxy resin grouting program was commenced through special packers fixed in each hole. Resin, injected through one packer, would be observed to travel and connect with the next hole, to which injection would then be transferred. In this way, the continuity of the resin filling could be promoted.

A secondary phase of drilling and grouting was then conducted to demonstrate this continuity and to permit "tightening up" of especially difficult areas. Resin thicknesses of up to 10 mm were found, illustrating the in situ aperture of the joints, while later tertiary check holes — all totally dry — confirmed the penetration of the secondary grout into microfissures.

By the conclusion of the work in the fall of 1988, the total flow into the section grouted was about 120 L/min — virtually all of which was entering the gallery through vertical roof drains, intersecting fissures well above the levels grouted. The concrete of the upstream gallery wall had begun to dry, and flows from secondary, longitudinal roof fissures and from the downstream gallery wall were also stopped completely. This performance has persisted to date, even during the maximum reservoir levels recently experienced for the first time in several years. A fuller description of this work was given by Bruce and De Porcellinis (1989).

FINAL POINT

Grouting techniques have long been used to seal leaks in concrete dams. Advances in drilling, grouting and material technologies have been made during the last decade to the extent that the reliable remediation of major high dams can be conducted. It is highly significant that such treatments, usually carried out under extremely adverse conditions, can be used not only to seal off leakages but to bond the structure together again. This is a major breakthrough in the concept and horizons of dam repair.

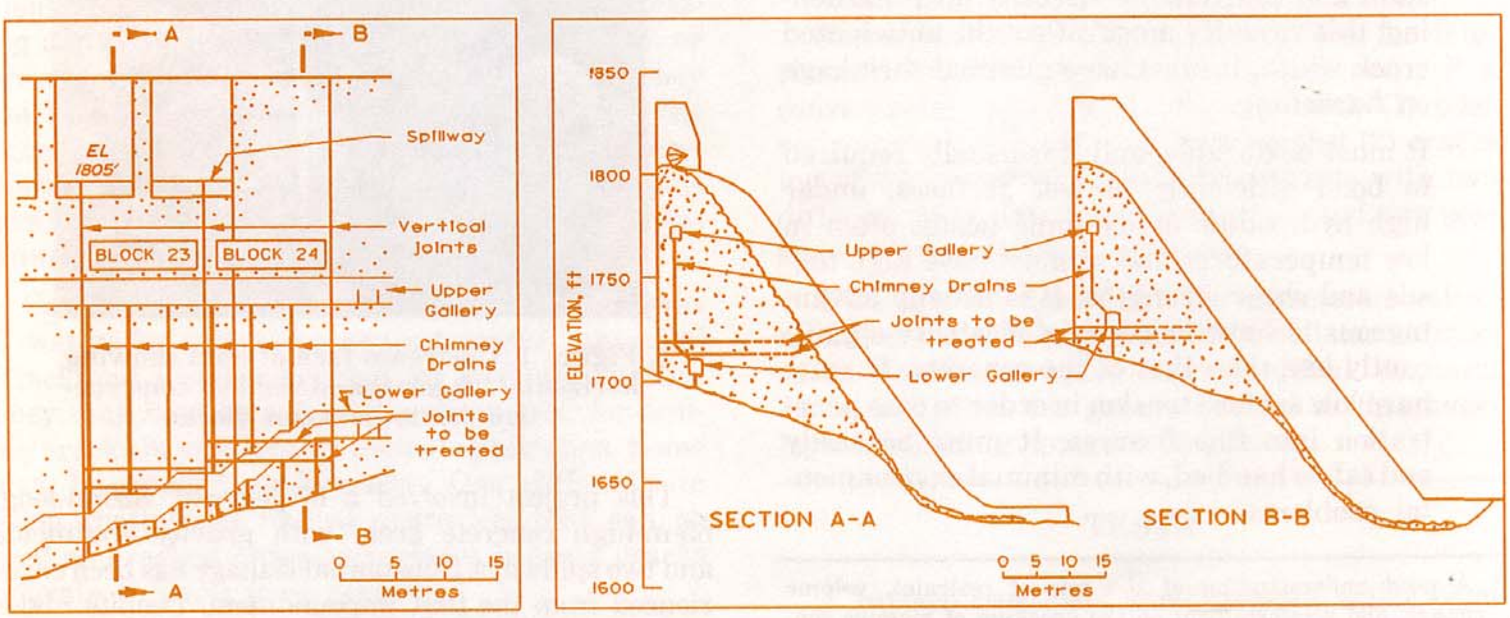

Figure 2. Horizontal joints investigated and treated in Blocks 23 and 24

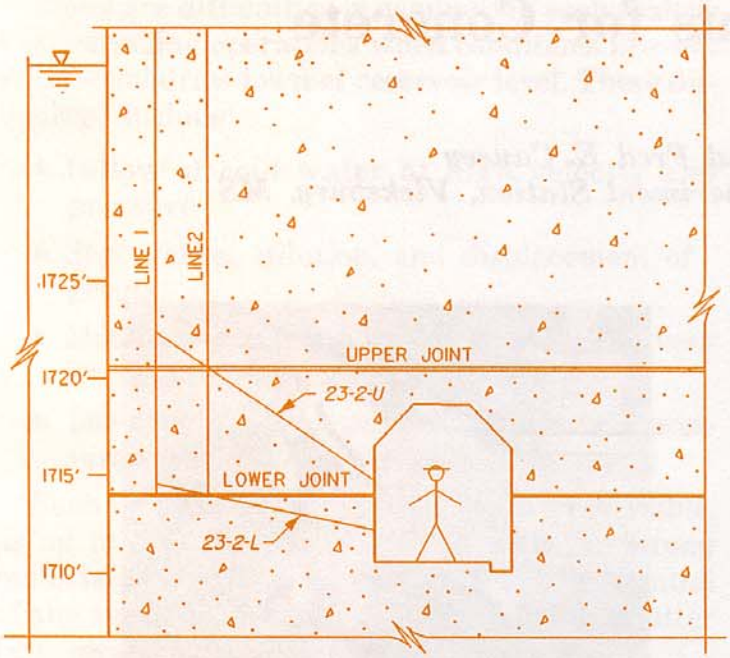

Figure 3. Typical section showing intended joint interception at one station

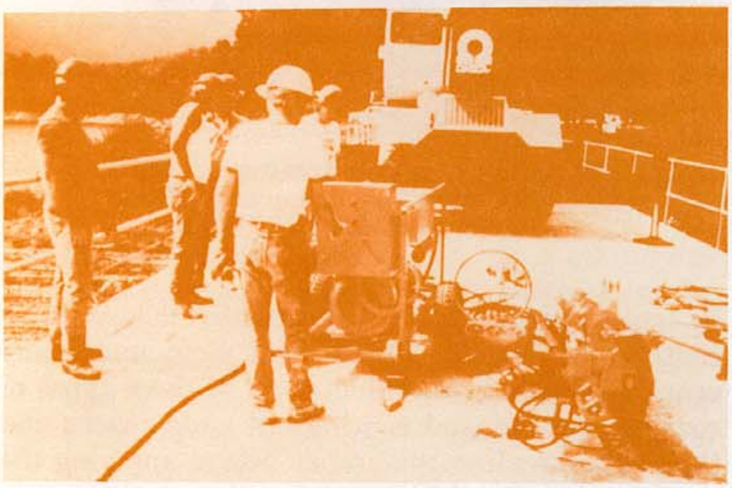

Figure 4. Components of the electrohydraulic coring rig (from right, mast w/head, controls, power pack)

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