Structural Repair Of Major Concrete

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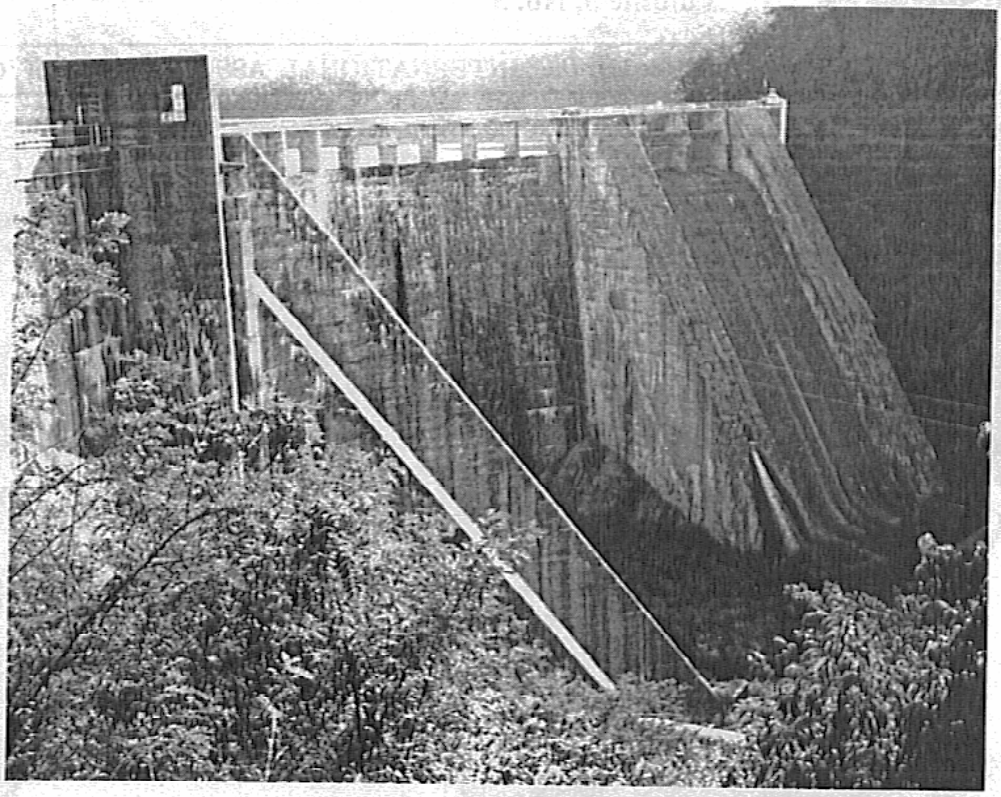

The structural fissuring of any concrete construction is always a matter of great concern. When the structure in question is a major dam regulating drinking water or irrigation flows, or permitting electricity generation, the problem is especially troublesome and highly sensitive.

The cause of the cracking is usually difficult to discern and often incompletely understood. For example, foundation or abutment performance may be different from that anticipated, or the dam itself may behave in a non-monolithic manner. There may be cyclic processes at work generated by temperature or hydrostatic fluctuations. Equally, there may have been intrinsic flaws in the concreting practices and materials, affecting in 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 concepts and practices in dams of novel concept.

It has long been standard practice to attempt to fill major fissures by injecting cement based grouts, and smaller aperture fissures 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 due to the brittle nature of the grout being incompatible with the tendency of the structure to continue straining.

There are also major practical difficulties in conducting such sealing operations, where conditions prevent substantial drawdown of reservoir level.

- inflow of 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.

In addition, it must be borne in mind that such repair attempts are often irreversible: 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.

Against this background, a group of structural, chemical and geotechnical engineers from Rodio, of Madrid, Spain, developed a system called RODUR℠. To date this system has been used with spectacular success on major dams, old and new, in Europe, Asia and most recently, in the United States in conjunction with specialty contractor, Nicholson Construction. The system has been used for both leak sealing and structural bonding in a wide variety of dam types. (Reference 1)

RODUR℠ PROCESS

The process has three key elements:

● Analytical Philosophy: Every effort is first made to understand the cause of the problem. This involves a detailed review of all the geological, constructional and behavioral data available. Often this forms the basis for executing a new phase of exploration (by coring) and monitoring. This element is typically conducted in liaison with the owner and consultant, as an engineering joint venture.

● Materials Philosophy: Given the practical problems of grouting, referred to above, the following properties are required of the grout:

- it must be a true Binghamian liquid, and 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 reasonable constant and controllable viscosity till hardening. This viscosity must reflect the anticipated fissure width.
- it must have minimal shrinkage.
- it must be durable.
- it is usually required to bond efficiently to wet surfaces, under high hydrostatic or dynamic heads often in low temperatures and so have high tensile and shear strengths.
- it is usually advantageous to have an elastic modulus significantly less than concrete.
- it must have as low a surface tension as possible in order to ease penetration into fine fissures.
- it must be easily and safely handled, with minimal environmental problems.

RODUR℠ is based on the use of various types of synthetic epoxy resins. Depending on their formulation, such resins can be provided with a wide range of

Dams Through Epoxy Resin Bonding

initial viscosities, and preset polymerization times. Table 1 summarizes properties from two resins used recently in the United States.

● Control Philosophy: the performance of the grouting and of the structure are continuously monitored during treatment. In this way the grouting parameters - preset initially after the analytical phase - can be varied responsively and continuously to optimize the procedure.

CASE HISTORIES

There have been several cases where Rodur℠ has been used in the repair of concrete structures for nuclear generation and dam appurtenances such as spillways and penstocks. Three of these dams have already been described in Zeuzier (Reference 3), and Cabril (Reference 4). The most recent application has been to repair an old concrete dam in the Eastern United States. As will become evident below, the repair has proved exceptionally successful. However, such dam repairs are usually as delicate politically as they are technically, and in this case the owner currently wishes to retain the anonymity of the project until the current excellent performance over several yearly cycles has been confirmed.

U.S. APPLICATION

From first impounding over 60 years ago, the 320m (1050 ft.) long, 65m (213 ft.) high concrete arch, with gravity abutments and two spillways, experienced substantial leakage. Despite major structural modifications to the dam, and repeated phases of cement grouting in the problematic horizontal lift joints, the position continues to deteriorate. By mid-1987, these flows in the worrisome left side alone had reached over 4000 liters/min. (1060 gal./min.) and were entering the lower drainage gallery at higher pressures and over larger areas than ever before. Seepages on the downstream side of the Gallery were also noted.

Bids were solicited for appropriate remedial action and the contract was awarded to Nicholson Construction, in association with Rodio.

The treatment was concentrated on a 23m (75 ft.) long section in the most critical area, and was conducted from within the 2.4m x 2.2m (7'-10" x 7'-3") Lower Gallery, running about 3m (10 ft.) above the foundation and 4.5m (14'-9") back from the upstream face. Fans of Primary holes, up to 6m (20 ft.) long, were cored at regular intervals upstream from the Gallery to investigate the suspect horizontal joints about 1.5m (5 ft.) apart. 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 liters/min. (106 gal./min.) at full hydrostatic head.

After all the primary holes were drilled and the data carefully reviewed, the systematic epoxy resin program was commenced, through special packers fixed in each 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 of the joint was promoted.

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	RODUR 1	RODUR 2
Description	Liquid epoxy resin compound with amine hardener composition, free of solvents, free of solvents, two components	Liquid epoxy resin compound with amine hardener composition, free of solvents, pigmented, two components
General	Free of solvents and mineral aggregates, low viscosity allows use in very fine cracks, and in the presence of water at low temps.	Hardened material has very low creep under compression. Liquid resin has excellent resistance to wash out by flowing water.
Fluid Properties		
Viscosity at 20° (Brookfield Visc.)	2000/3000 MPa. S.	6500/7500 MPa. S.
Mean Surface Tension (liquid)	50 dyn/cm	50 dyn/cm
Pot life	Approx. 50 min. At 20°C	Approx. 90 min at 20° C
Lowest hardening temp	4°C (39°F)	4°C (39°F)
Water absorption of hardresin @ 23°C (73°F)	1.98%	1.8%
Specific gravity @ 20°C (68°F): liquid	1.10 g/cm³	1.93 g/cm³
solid	1.19 g/cm³	1.99 g/cm³
Mechanical Properties (Values depending on Test Conditions)		
Compressive Strength	95 Mpa (13,800 psi)	110 Mpa (15,950 psi)
Flexural Strength	40 Mpa (5,800 psi)	35-40 Mpa (5,075-5,800 psi)
Tensile Strength	28 Mpa (4,060 psi)	20 Mpa (2,900 psi)
Elongation at failure (Tensile)	3%	2%
Adhesion Tests (Cylindrical concrete specimens bonded with resin in different conditions, at 20°C. Simple tensile test.)		
Dry Concrete	100% break in concrete	100% break in concrete
Damp Concrete	80% "	80% "
Submerged Concrete	65% "	60% "

Table 1. General properties of RODUR Series resins used in U.S. application.

Epoxy Bonding of Major Concrete Dams

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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 10mm (3/8") 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, the total flow into the section grouted was about 120 liters/min. (32 gal./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 out, and flow 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 can be found in Reference 5.

Special packers placed into boreholes intersecting two horizontal lift joints, showing flows prior to resin grouting. The fissures in this section were completely sealed.

FINAL COMMENT

For ten years, major high dams in Europe and Asia have been successfully repaired against major structural defects using the RODUR℠ system. Now an equally impressive reference in America can be cited. Given the current national trends towards remediation and upgrading of such structures, the technique may well have considerable potential for bonding and sealing conventional and rolled concrete dams, regardless of vintage, in this country in the years to come. ❑

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