RECLAMATION
Managing Water in the West

Leaking Crack Repair Using Chemical Grouts

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Mission Statements

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to Indian Tribes and our commitments to island communities.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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1.0 Executive Summary

The intent of this program was to evaluate several types of grouts to seal small leaking cracks in a real-world setting. We selected several areas of leaking cracks in gate chambers and galleries of Pueblo Dam. Water from the leaking cracks was dripping onto equipment and conduits in several locations throughout the dam. Because of the alkaline nature of the water, it is very corrosive and was damaging equipment and conduits.

Originally, polyurethane resin, epoxy resin, polyurea resin, and ultrafine cement grout were proposed for testing. Later, two other materials, an expanding acrylate resin and a vinyl ester resin were proposed for evaluation. However, funding levels allowed for evaluation of polyurethane resins only.

This program examined several polyurethane (PU) materials designed to seal small, leaking cracks in concrete. PU materials are nonparticulate (solution) grouts based on chemical reactions and are generally called chemical grouts. These are true polymer materials, since the reaction of the monomer forms a three dimensional system of chemical bonds. While PU technology is not new, there have been continual advances in material formulation, so that materials available now offer new possibilities for sealing these types of leaks. Eight different types of PU were evaluated for the study. Of those 8, 3 were selected for evaluation at Pueblo Dam.

In addition to evaluating materials, we examined different application methods, including low pressure injection and high pressure injection. Also, we sponsored a training class so that interested personnel could learn about the different resin systems and potential uses.

Leaking cracks in the Fish Hatchery Outlet Works Gate Chambers, small cracks in the galleries in buttresses 8, 9,11, and 13, buttress 17 Entry Audit, the buttress 10, 15, and 17 inspection and equipment galleries, and buttress 16 equipment gallery were identified as areas with troublesome leaks.

The plan was to inject grout so that a 1 to 3 foot zone of the crack was filled with grout to divert water from dripping onto conduits and equipment. Injection pressures were closely monitored to ensure that pressures were kept within reasonable limits. In addition, approval from the Dam Safety Office was obtained before commencing work.

The program was a combined effort of staff and funds from Pueblo Dam, staff from the Materials Engineering and Research Laboratory (MERL), and funds from the Science and Technology program. The training and information gathered from this program will be useful throughout Reclamation. By combining work efforts and funding, we had an excellent opportunity to evaluate new materials for sealing leaking cracks.

2.0 Introduction

In the early 2000's, staff from the Materials Engineering and Research Laboratory (MERL) were asked to provide guidance on methods to repair leaking cracks and joints in concrete at Pueblo Dam (Figure 1). In addition to losing water through the leaks, up to 2 gallons/minute in some locations, the leaks identified for repair were leaking onto equipment and electrical conduits at several locations throughout the dam. The subsequent corrosion of the metal was an ongoing, expensive maintenance and repair activity requiring continual re-coating of fixtures and conduit repair and replacement.

Figure 1. - Pueblo Dam, located west of Pueblo, Colorado.

One of the main goals of the Science and Technology Program is to increase water supply and reduce costs as a result of research funding. Saving water that leaks through cracks, and preventing that water from damaging equipment meets those goals.

We provided the area office with some guidance for methods to repair the leaking cracks. We also suggested that this might be an opportunity to evaluate new crack repair materials by partnering S&T research funds and area office funds.

After some discussion with both offices, proposal development, and further discussions, funds from both offices were approved for this study.

As originally planned, the grout injection would start in late winter or early spring of 2003, and would have supporting help from facility and area office personnel. However, some emergency project related concrete repair work that MERL was involved with interfered with that schedule. Consequently, the start was delayed until early June of 2003.

Due to the nature of the cracks and water flows through the crack, the injection work was of limited success. As the concrete warmed up, the cracks became smaller, water flows diminished, and injecting the cracks was more difficult. Due to these reasons, the program was cancelled for the year, and was rescheduled to start the following spring of 2004.

The injection work started again in March of 2004. In addition to the planned injection work, a training class was added to the program to help transfer available information to area office staff and others to help them in their efforts to seal similar leaks. Also, for this stage of the work, a recognized expert from outside Reclamation was brought in to assist with the training and grouting operations. This was done to ensure that the latest and most appropriate technologies and methods were being included in the study. However, due to other work commitments, assistance from facility and area office staff was largely unavailable at this time, so the extent of repairs was smaller than originally planned.

3.0 Background

3.1 Test Materials

Originally, polyurethane resin, epoxy resin, polyurea resin, and ultrafine cement grout was proposed for testing. Later, two other materials, an expanding acrylate resin and a vinyl ester resin were proposed for evaluation. However, funding levels allowed for only evaluating polyurethane resins.

This program examined several polyurethane (PU) materials designed to seal small, leaking cracks in concrete. Eight different types of PU were evaluated for the study. Of those 8, 3 were selected for evaluation at Pueblo Dam. The three selected covered a range of materials available. Table 1 below shows the names and some propertied for the grouts used.

PU's are formed by reacting a polyisocyanate with water, polyol or other similar chemical containing an active hydrogen group. During the reaction, carbon dioxide can be released, forming bubbles and a foaming action. Catalysts can be used to control the reaction rate and other ingredients can be used to control the bubble size. Many times, the chemicals can be pre-mixed, forming a prepolymer. With a prepolymer, only one or two other ingredients are needed to initiate the reaction, which makes mixing and injecting much easier.

Table 1. – Grouts used and some typical physical properties						
Product	**Type**	**Viscosity (centipoise, cps)**	**Gel Time**	**Tensile Strength**	**Elongation**	**Shrinkage**
Statathane ST-504	Hydrophilic	700 cps @25 C	100 sec at 20C	250 psi	700%	< 11%
De Neef Hydro Active Combi Grout	Hydrophobic	700cps @77° F	6 min @65 ° F	89 psi	60%	< 4%
Prime Resins Prime Flex 900 XLV	Hydrophilic	550 cps @77° F	2 to 3 min	310 psi	280%	<2%

Generally, PU’s can be divided into 3 types based on the final reaction product – foams, gels, and solids. Solids are usually 2 part systems and are non-foaming. Foams and gels are good for crack sealing for cracks as small as about .03 in. and larger, and having damp to heavy water flows. Solids can be injected into cracks .03 in. and larger, with damp to light water seepage.

The prepolymerized PUs are frequently referred to as single component, water activated resins. The addition of water starts the reaction. They are useful for sealing cracks, but are not useful for structural repairs. They form foams and gels, with very low to high viscosity (1 to over 500 centipoise, cps). The foams can be soft to hard, are expansive, and can have medium to high elongation. The gels are soft, expansive, and have medium to very high elongation, and can contain large amounts of water.

Two component systems, which react with each other, are frequently referred to as plural component systems. These systems can be used for structural repairs, and are best used in dry to damp cracks. With more water, they will be less effective. These systems typically form solids and have medium to high viscosity (50 to over 500 cps). The solids can be rubbery to hard, can be expansive or not, and have medium to high elongation.

Polyurethanes can be formulated with widely varying properties. They can be formulated to have a low viscosity while being pumped and then gain strength in a short period. Typical PU grouts are not as effective in cracks less than 0.03 inch, unless high injection pressures are used, or they are specially formulated to have very low viscosities.

Frequently, PU’s used for concrete crack sealing are single component, water activated resins and are referred to as either hydrophilic, which can react with large amounts of water, and hydrophobic, which react with much less water. Even though this distinction is made, the basic chemistry of the two systems is very similar. Typically, hydrophilic resins use more water in the reaction, and are softer, and hydrophobic use less water and are more rigid.

One of the main advantages of hydrophilic resins is that they are more economical to use. Since the base costs for hydrophilic and hydrophobic resins are about the same, the higher water requirement for hydrophilic resins makes them more economical to use. However, the moisture content of hydrophilic PU’s can change as the moisture in the surrounding environment changes, so they can dry out and shrink (allowing leaking) if they are not kept moist.

One of the difficulties associated with using PU resins in this type of application is that there are no consensus standards for their use and properties. There are standards for their use in certain pipe joint repair applications, but that is of limited use for selecting material for injecting into small cracks in mass concrete.

Another issue is that these materials can have vastly different properties, depending on the amount of water or other catalyst that is used to polymerization the resin or complete the reaction. For instance, water activated hydrophilic resins can form a very hard, dense foam when mixed with equal amounts of water and injected into tight cracks, or can be soft gelatinous materials if mixed with large amounts of water.

Finally, service exposure conditions can have an impact on material selection. Freezing temperatures can damage some grouts, as well as sunlight exposure. Wetting and drying can cause some grouts to shrink.

Figure 2. - Hand held, caulk gun injection system.

3.2 Equipment and Methods

Several different approaches were used for injecting the grout. Low pressure, hand-held plural component caulking type guns were tested (Figure 2) , higher

Figure 3. - Modified paint sprayer for chemical grout injection.

pressure single component modified paint sprayer was evaluated (Figure 3), and a multi-component, variable ratio, high pressure, high volume rocker pump was used (Figure 4). The rocker pump requires supplied air to operate the air motor. For the single component system, the products were premixed, and then added to the pail for injection.

Figure 4. - Multi component, variable ratio, rocker pump.

In addition, several different types of packers were evaluated. The simplest was a plastic tapered fitting that could be hammered (bang-in, Figure 5) into an injection port. Grout would then be injected through a screw-in zirc fitting. Several types of small mechanical packers were also evaluated (Figure 6 and 7). The mechanical packers were inserted into the injection ports and then nuts were turned that compressed rubber sleeves so that the sleeves swelled and locked onto the sides of the injection port holes. Depending on size and configuration, mechanical packers can withstand very high pressures without becoming dislodged.

Figure 3. - Example of a bang-in packer with the zirc fitting removed.

Figure 6. - Examples of mechanical packers. Typically, a nut near the top of the packer is tightened, compressing and expanding the rubber sleave(s), locking the packer into the hole. Grout can be injected through the zirc fitting.

Figure 7. - A mechanical packer with a longer tube, useful for insertion into deeper holes. Note water dripping from end, indicating water bearing crack has been intercepted.

The first step involved cleaning the exposed opening of the crack to be injected (Figure 8). Many of the cracks had extensive deposits of calcium carbonate that made it difficult to see exactly where the crack was. This step required grinding and chipping to expose the crack, and was fairly labor intensive. Several methods were tested to determine the best way to remove the surface deposits. The best method was to use a surface grinder with a stiff metal brush.

Figure 8. - Grinding surface deposits from face of crack.

Figure 9. - Drilling holes for mechanical packers.

After the crack opening was exposed, injection ports were drilled into the concrete. For the bang-in ports, 3/8-inch diameter holes were drilled into the concrete. For the mechanical packers, 5/8-inch diameter ports were drilled into the concrete (Figure 9). Figure 10 shows a combination of bang-in and mechanical ports. All the ports we evaluated used either 3/8 or 5/8-inch port sizes. We determined these sizes were appropriate since all the cracks we were injecting were small. Larger cracks requiring higher flows of grouts would need larger ports. There are many different sizes of packers and ports that can be used.

A major concern when injecting grouts into a dam is plugging of drains that can relieve uplift pressure. That concern played a role in how injection ports were laid out and how grout was injected. Ports were laid out to reduce the possibility of extensive grout travel. In addition, grout flows and pressures were monitored

Figure 10. - In several locations, combinations of bang-in and mechanical packers were used to assist with grout injection.

to prevent unduly high pressures or large grout flows. Exact pressures depended on the viscosity of the grout injected. Higher viscosity grouts required higher pressures and lower viscosity grouts could be injected with lower pressures.

For the most part, the ports were drilled either above or below the crack, and angled to intercept the crack a few inches from its face. Because we didn't want the chemical grout to flow very far, we spaced the ports fairly close together. In a few cases, we tested installing the ports directly into the cracks.

Once ports were installed, water testing could start. Water testing was performed to ensure that grout could be injected into the crack by attempting to inject water into the crack first. Several methods were tried for this. In one method, used for larger cracks, house water at about 80 lbs/in^2 was attached to the port. For another method, a pressure washer was attached to the port (Figure 11) for the water test. Finally, when the rocker pump was used, the water line from that could be attached to the port for water testing.

Figure 11. - Pressure washer used to water test cracks.

If no water could be injected, then either the crack was too tight, or the port missed the crack. If it was determined that it was likely the crack had been missed, then the packer would be removed and the port would be re-drilled, the packer re-installed, and the port water tested again.

After all the ports were water tested, and re-drilled/re-installed as necessary, grouting was started. Grouting would generally start at one end of the crack to be injected, and proceed from port to port to the terminating end. When higher pressure injection equipment was used, an assembly as shown in Figure 12 would be used to attach to the grout port and inject the grout. With 2 incoming lines, reacting components can be kept separate until just before the point of injection.

After the components combine, a small chain or mixer in the small tube can be used to mix the components. The crack face would be monitored for grout leakage as an indication of grout flow. If grout appeared quickly at a crack face, the crack face would be closed up by hitting with a hammer, or pounding in jute (Figure 13), wood, or cloth. For this program, since we did not want the grout to travel far, the crack faces were generally not sealed unless a large amount of water or grout was leaking from them.

Figure 12. - Assembly used to connect grout lines to injection ports for higher pressure injection. Note provision for 2 material lines, which allows for keeping reacting materials separate until close to the point of injection. A small chain or mixer in the small tube provides for mixing just prior to injection.

Figure 13. – Jute used to seal crack faces. The jute can be soaked with resin, or resin and water depending on the system, then pounded into the crack opening.

3.3 Areas Repaired

Table 2 shows all the areas identified for repairs, the length of cracks to be repaired and other information about the injection program. Appendix 1 shows photographs of areas with leaking cracks originally identified for repairs. Due to funding limits, not all areas were repaired. In addition, follow-up inspections to determine effectiveness of repairs were not funded.

Table 2 – Results of Injection						
Location of Crack	**Length of Crack Injected (feet, ft.)**	**Port Location (over/ adjacent)**	**Type of Port (bang-in/ mechanical**	**Product Used**	**Amount Injected (gallons, gal)**	**Notes**
Fish Hatchery Outlet Works Gate Chambers	100	ADJ/Over	Bang-in .	900 SLV	1.5 gal	Cracks repaired June 2003 900 SLV injected with hand units. Over ports – not effective Mechanical ports more effective.
Fish Hatchery Outlet Works Gate Chambers	100	ADJ	Mech.	ST504	7.5gal	Cracks repaired March 2004 Power (Rocker pump) units more effective.
Buttress 8 Equipment Gallery	30	ADJ	Bang-in/mech.	ST 504 Combi	3.25 1.75	Mechanical ports more effective. Only power injection units tested – both effective. Modified paint sprayer effective for Combi grout.

Buttress 9 Gate Chamber (150 ft.), Buttress 11 Gate Chamber (150 ft), Buttress 13 Chamber (150 ft), Buttress 17 Entry Adit (35 ft). Buttress 10 Inspection and Equipment Gallery (30 ft), Buttress 15 Inspection and Equipment Gallery (50 ft), Buttress 16 Gate and Equipment gallery (40 ft) were initially included as possible repair areas, but were not repaired as part of this program. However, staff at this facility planned to use the knowledge gained from this program to continue to perform crack repairs on their own.

Appendix 1 shows photographs of areas with leaking cracks originally identified for repairs.

4.0 Conclusions

1) The chemical grouts evaluated were effective for sealing leaking cracks. All were effective, but their selection on other jobs would need to be based on actual site conditions. For cracks with moist to flowing conditions, then a single component water activated polyurethane may be appropriate. For dry to moist cracks where some crack rebonding is desirable, a plural component polyurethane may be appropriate.

2) The rocker pump worked best in most situations, had the most flexibility for various chemical grouts and greatest control of pressure. However, due to its size and operating requirements, it is much harder to transport and set-up (Figure 14).

3) The modified paint sprayer was only effective for the resin system with relatively long set times, and/or for situations where injection times were fast, since the materials had to be premixed and poured into a pail prior to injection. If operators were not careful, the grout would start to set in the pail, in the injection gun, or would set prematurely in the crack, which would limit effective crack sealing.

4) The hand operated caulk gun type injectors were only effective on relatively large, shallow cracks that required little pressure to inject. With narrower, deeper cracks, the units were not able to create enough pressure to inject resin, and frequently malfunctioned. With longer cracks, operators had trouble operating the gun for sufficient time to seal the cracks.

5) Using a surface grinder with a stiff metal brush effectively removed surface deposit of calcium carbonate to expose crack openings.

Figure 14. - Lowering the rocker pump into a gallery.

6) The bang-in packers were very easy to install, but were only effective for small, localized crack repairs that utilized lower pressures. With higher pressures, and depending on the quality of the concrete, grout would begin to leak around the ports, or the ports would be dislodged.

7) Mechanical packers worked best in most situations, but required more work to install.

8) For cracks that will likely dry out for periods of time, hydrophobic grouts are a good choice.

9) For cracks that will stay moist, hydrophilic grouts are a possible choice. Since they are typically mixed with water at a 1:1 ratio, they will likely be more economical to use.

10) Even though chemical grout materials can be more expensive than cementitious grouts, overall repair costs using chemical grouts may be less. Mobilization costs can be significantly less, since chemical grout equipment is generally smaller and lighter than cementitious grouting equipment, the materials are lighter, and in many cases swell to fill cracks and voids.

11) Additional funding would have allowed for examination of more grouts and follow-up inspections to track longer term performance of installed grouts.

Appendix 1

Photographs of Leaking Areas

Figure 4. - Fish hatchery outlet works gate chambers water leaks.

Figure 5. - Buttress 8 equipment area water leaks.

Figure 6. - Buttress 9 gate chamber water leaks along joint in wall.

Figure 7. -Buttress 11 gate chamber water leaks through joints.

Figure 8. - Buttress 13 gate chamber leak and water deflection sheeting across roof.

Figure 6. - Buttress 17 entry adit water leaks.

Figure 7. -Buttress 10 inspection and equipment gallery area water leaks.

Figure 8. Buttress 15 inspection and equipment gallery area water leaks.

Figure 9. - Buttress 16 gate and equipment gallery water leaks.