RECLAMATION

Managing Water in the West

Report DSO-07-10

Underwater Crack Repair

Dam Safety Technology Development Program

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

September 2007

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)* 9-2007	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
4. TITLE AND SUBTITLE Underwater Crack Repair	**5a. CONTRACT NUMBER**	
	5b. GRANT NUMBER	
	5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Dolen, Timothy, Katie Bartojay, and Kurt Mitchell	**5d. PROJECT NUMBER**	
	5e. TASK NUMBER	
	5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Bureau of Reclamation Technical Service Center Materials Engineering and Research Laboratory Denver, Colorado	**8. PERFORMING ORGANIZATION REPORT NUMBER** DSO-07-10	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Bureau of Reclamation Denver, Colorado	**10. SPONSOR/MONITOR'S ACRONYM(S)**	
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) DSO-07-10	

12. DISTRIBUTION/AVAILABILITY STATEMENT
National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**a. THIS PAGE**	SAR		**19b. TELEPHONE NUMBER** *(Include area code)*
UL	UL	UL			

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

BUREAU OF RECLAMATION
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Underwater Crack Repair

Dam Safety Technology Development Program
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2/25/08
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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.

Acknowledgments

This research was sponsored by the Dam Safety Technology Development Program of the Bureau of Reclamation.

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Introduction

Leakage through cracks in concrete dams and seepage through voids in embankments have both operational and dam safety concerns. Most corrective actions require draining the reservoir to inject various chemical and/or cement base grouts on a pattern of drill holes or placement of protective membranes. This is expensive due to the loss of water and the time to perform repair operations. Three attempts have been made to eliminate the leakage through several thermal cracks at Upper Stillwater Dam, Utah. The cracks were caused by thermal gradients in mass roller-compacted concrete (RCC) during the winter months after placement in 1986 and 1987. The RCC dam was designed without formed contraction joints, allowing transverse cracking instead, with the intent to grout cracks after they formed. However, filling the cracks with a durable material has proved to be very difficult in practice. Two attempts to grout the cracks with chemical grouts were temporarily effective. But the chemical grouts deteriorated over time due to continued thermal movement essentially grinding the seal. A third repair involving a combination of chemical grouts and embedded steel barriers is under way at an estimated final cost of about $6 million (Reclamation, 2002).

In 1987, divers temporarily repaired thermal cracks at Galesville Dam by placing a relatively low technology material (a quick-setting, cement patching material) over the cracks. "Cement balls" with a consistency of putty were mixed at the water surface and delivered directly in front of the cracks by divers. Hemp rope, followed by the freshly mixed cement were sucked into the cracks, and the cement was sufficiently cohesive to remain in place until fully hydrated, significantly reducing crack leakage (Dolen, 1987). These cracks were grouted about 10 years after the initial sealing using conventional grouting techniques and proprietary repair materials. Although the initial sealing was temporary, the repair demonstrated a technique of using the water pressure itself to move a filling material into the crack, rather than drilling and high-pressure injection methods in the dry.

Reclamation has developed methods to place concrete underwater for tremie placements and for underwater canal lining placements using a combination of fluidifiers and "anti-washout" admixtures, or AWA's (Kepler, 1980). More recently, viscosity-modifying admixtures (VMAs) are used in concrete to place a fluid mixture with little or no vibration, as in "self-leveling" concrete. These admixtures are essentially the same as AWAs for placing the concrete underwater through tremies or free-flowing for direct placement. The AWA/VMAs have the ability to significantly decrease washout of the cement paste by water as was demonstrated by Reclamation's Underwater Canal Lining Demonstration Project in 1980 (Kepler, 1980). A self-leveling, underwater concrete was recently used to place a concrete slab in spillway stilling basin repairs at Canyon Ferry Dam, Montana (Heyder, 2005).

These AWA/VMAs show promise for placing grout and mortar mixtures underwater as a repair method. If an AWA/VMA grout or mortar could be delivered directly in front of and fill the crack without divers, the cost of crack repairs could be substantially reduced. Furthermore, the penetration of the material into the crack could be more successful if the viscosity of the material could be adjusted for hydraulic head and crack width, allowing it to penetrate deeper. If successful, this method has the advantage of being mobilized from the top of the dam and would not require divers for application (or allow divers to stay underwater to direct the flow rather than coming up for more materials) and could be placed without draining the reservoir. A remote underwater vehicle might be used for the observing the placement of the repair material and might eliminate the need for divers entirely.

Alternate delivery methods to direct pumping for filling cracks could include wrapping freshly mixed grouts/mortars in semi-permeable membranes to resist washout. The material could be placed in front of the cracks with or without the use of divers. Repeated diving and resurfacing is not desirable for both productivity and safety reasons, particularly for remote locations, cold reservoirs, and high altitudes. The cementitious “ropes or noodles” could be lowered into the water without washing out and fit into the crack itself. An advantage with this material is that it would harden and not readily deteriorate.

Where cracks in a dam cross foundation drain holes, leakage is substantial and the original purpose of the foundation drain is compromised. The volume of crack leakage far outweighs that from normal foundation drainage, and any increase in foundation seepage is not likely to be detected. Grouting through a crack and intercepting a drain can plug the drains, rendering them ineffective for their intended purpose. A repair method for introducing underwater grouts also needs to be able to prevent plugging the drains. Appendix A documents various methods of isolating drains to identify those that will be both technically feasible and cost effective if cracks are grouted.

Direct, underwater placement of AWA/VMA mortars or grouts could potentially be used to fill sinkholes. Sinkholes in dams and foundations present a serious threat from seepage-induced piping failure through internal erosion of the foundation or embankment core material. This could lead to rapid failure with catastrophic consequences. A grout directed in front of underwater sinkholes without washing out has the potential to quickly stop seepage. This material would have the advantage of permanently setting up to a hardened matrix within hours.

Conclusions

Several concepts were evaluated for filling cracks underwater, resulting in the following conclusions:

- Cement-based mortars were developed for underwater placement to repair cracks in concrete structures. The mixtures combined high-range, water-reducing admixtures (HRWRA) to increase fluidity with AWA/VMAs to change the adhesive/viscosity properties of the paste in water.

- The proposed crack-filling mortar has promise for underwater crack-filling applications or as an underwater patching material for vertical faces of concrete structures.

- At high dosages, the washout of mortar is virtually eliminated, and the mortar can be extruded directly in front of a vertical crack. The mortar enters about 25 mm (1 in) or more into the crack under 3 m (10 ft) of hydraulic head. This is the most promising formulation for underwater crack repairs.

- At moderate dosages, the mortar can enter cracks about 3mm (⅛ in) wide. Flow reduction is primarily by surface plugging the crack by sand and fibers as the paste washes out of the crack. Some mortar fills up the cracks by displacement.

- Low dosages of AWA allow placement of fluid mortars that resist washout underwater. This application is recommended whereever the mortar displaces water near the port of entry and blocks off the flow.

- The increased dosage of HRWRAs caused delays in mortar setting time, which, for these applications, is undesirable. Additional testing is needed to accelerate the setting time or to investigate different HRWRAs.

- The increased dosage of AWAs greatly affected the adhesive nature of the mortars as demonstrated by the drop table flow test. Increasing the dosage of AWA reduced the flow from about 75 to about 25 percent of the original diameter.

- A laboratory test or a field trial is recommended to test anti-washout mortars at higher head applications of 10 m (30 ft), or higher. Further materials research using the low-head apparatus would include tests filling fine (less than 3-mm [⅛-in]) cracks underwater using AWAs with cement-based grouts and no sand.

- Two methods were identified for filling cracks without plugging drain holes. Standard drill stem is readily available and can effectively block plugging drains if inserted into the full length of the drain holes. This is recommended where the drain hole intercepts the crack at multiple points. This system can also be used with a centering device or geonet wrap to allow mortar to flow around the perimeter of vertical contraction joint drains and still fill the crack. Mechanical or inflatable packers can also be used to block flow at the point where cracks cross drain holes at single points or over a short distance.

Research Objective

The objective of this research to investigate the use of advanced chemical admixtures for modifying the fluidity and viscosity properties of cement-based grouts or mortars so they can be placed in water flowing into cracks or open voids. Specifically, the materials must be able to withstand washout when placed directly in front of cracks in concrete dams or voids in embankments. A simplified method of delivery is desirable to either eliminate the need for, or reduce the time for divers repairing crack. This method involved modifying the viscosity of the grout/mortar depending on the head of the water level and allowing the water pressure alone to pull it into the structure. The strength of the materials should be similar to the strength of the concrete to withstand the stresses of thermal movement. If sufficient filler is introduced into the crack, it might completely fill the crack or allow sufficient reduction in leakage so that other, more permanent methods of sealing can be used without draining the reservoir. Experience at Upper Stillwater Dam, Utah have shown that introducing hydrophilic, polyurethane grouts in flowing water was only temporarily effective, and at great cost.

Research program DSO-CRACK provided funding in 2005 for the development and testing of underwater, cement-based grouts and mortars for crack sealing or filling applications. Research tasks include:

- Design and construction of underwater crack standpipe
- Development of underwater mortars/grouts
- Test underwater crack repairs with 3 m (10 ft) of water head
- Identify methods of preventing plugging of drain holes in concrete dams by the underwater mortar
- Complete Final Report
- Peer review / Dam Safety Advisory Team (DSAT)

The focus of this research program will be on mortars containing both cementitious paste and sand. The materials used in this research were classified as anti-washout or "AWA" mortars. Cement-based grouts without sand may also be used, if desirable for narrower crack widths. This initial research program is focused on low head (3 m [10 ft] of hydraulic head) application due to the high cost of a large scale application. These mortars required more fluidity than expected for higher hydraulic head applications. However, the principals learned from this research are expected to apply to higher head applications as well. However, the fluidity and viscosity of the mortars needed to fill a crack under higher water pressures differ from those of low head applications. The ultimate goal of this research is to be able to develop a mixture suitable for a high head application.

Underwater Crack Test Standpipe

In order to effectively demonstrate the performance of the underwater mortar/grouts, a test standpipe was designed to introduce them in front of a flowing crack. The underwater standpipe is shown in figures 1 through 5. The 150-mm (6-in) inside diameter polyvinyl chloride (PVC) vertical pipe has a 90-degree elbow to a short, horizontal section where a precracked concrete test sample is inserted. Water is introduced in the standpipe from hoses until a constant flow is obtained under the 3 meters (10 ft) of hydraulic head. Concrete

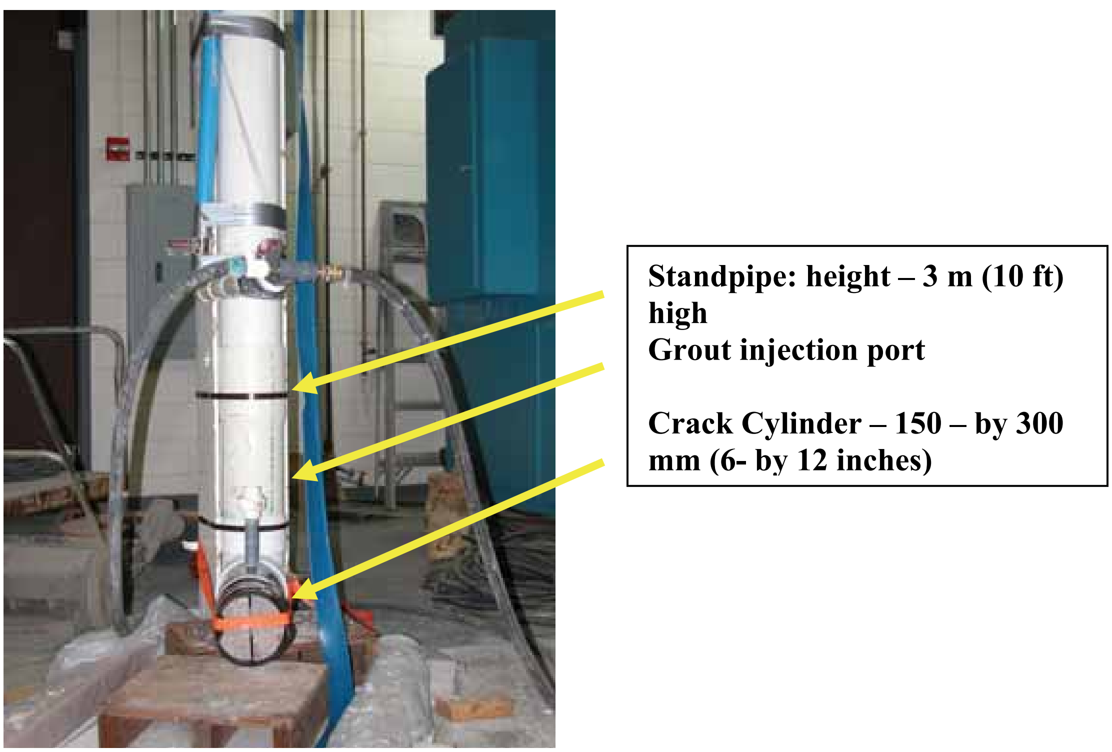

Figure 1.—Underwater crack test standpipe assembly with cracked concrete cylinder.

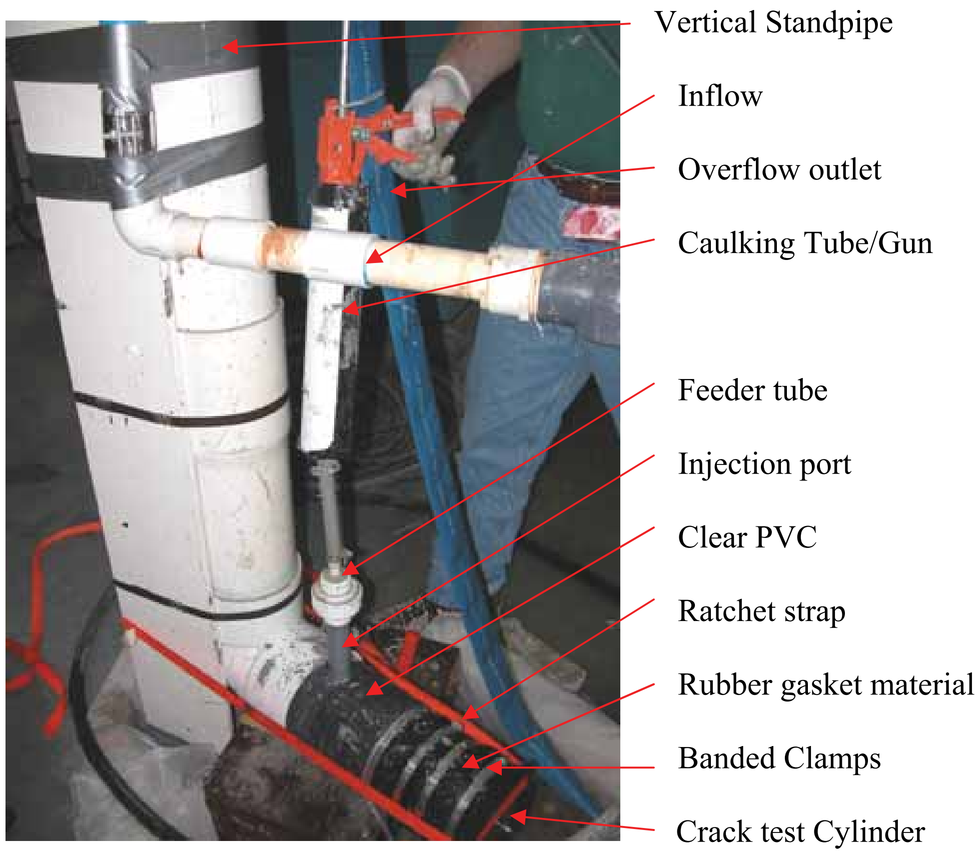

Figure 2.—Laboratory crack filling standpipe with test specimen ready for mortar injection. Filling procedures are described in appendix B.

Figure 3.—End view of water flow through a cracked concrete test specimen under 3 m (10 ft) of hydraulic head before mortar injection. Flow is about 40 L/min (10 gal/min).

Figure 4.—Side view of a high flow of water through a cracked concrete test specimen under 3 m (10 ft) of hydraulic head before mortar injection. Flow is about 100 L/min (25 gal/min).

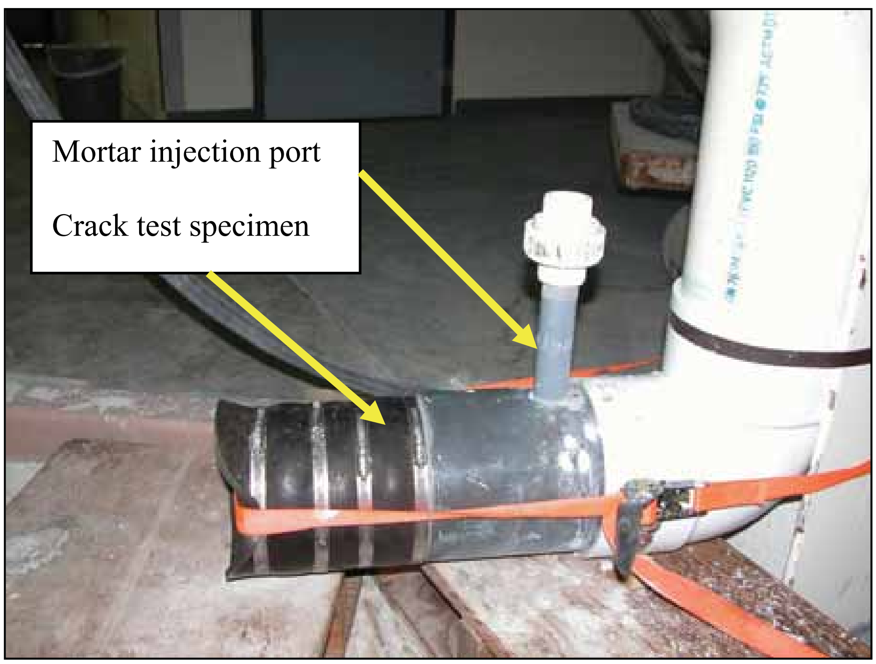

Figure 5.—Underwater crack repair standpipe setup. Crack test specimen with injection port.

test cylinders were either saw-cut or cracked lengthwise with the splitting tension test procedure to create a defined crack. The 150- by 300-mm (6- by 12-in) concrete cylinders were wrapped with a neoprene rubber membrane to direct the flow of water entirely through the crack. The flow ranged from about 20 to 100 L/min (5 to 25 gal/min) depending on the surface smoothness (saw-cut or split-tensile cracked) and crack width (about 1/16 inch to ¼ inch) as shown in figures 3 and 4.

A 12-mm (½-in) inside diameter, vertical injection port is located immediately in front of the face of the test specimen as shown in figure 5. The injection port allows a steady stream of mortar to be injected through a clear plastic feeder tube using a conventional caulking gun. The mortar has sufficient fluidity to be extruded by the caulking gun, but has an extremely sticky or adhesive-like consistency. The mortar initially has the consistency of thick honey during mixing and in about 15 to 30 minutes thickens similarly to construction caulk or adhesive.

Crack Test Specimen Preparation

Two methods were used to prepare a cracked concrete test specimen, shown in figure 6. Concrete test cylinders (150 by 300 mm [6 by 12 in]) were either saw-cut lengthwise through the center or cracked lengthwise using the ASTM C 496 "splitting tensile" test (ASTM, 2004). The crack width was initially formed to a fixed width using steel washers glued to the surface or by gluing coarse sand particles inside the crack. The maximum particle size was purposely selected to be just smaller than the crack opening. For example, a mortar with a 2.36-mm (No. 8) maximum grain size had the front crack opening created with 4.5-mm (No. 4) sand grains glued to the inside surface with epoxy. After the crack width was defined, the two pieces of the concrete cylinder were realigned and banded together. The cylinder was sealed along the outer crack openings using either silicon caulk or a fitted "backer rod." The backer rod proved more successful filling the outside edge of the crack. A thin neoprene rubber gasket was then wrapped around the cylinder, followed by a 6-mm (¼-in) flexible neoprene membrane. The wrapped test specimen was banded with pipe clamps and inserted in the end of the standpipe. A ratchet strap held the test specimen in the fixture under pressure with the face of the concrete fixed about 25 mm (1 in) in front of the injection port. The injection port is closed to prevent leakage of water until just prior to filling. Two rubber hoses supplied the water necessary to maintain the head in the 3-meter (10-ft) high standpipe which ranged from about 40 to 100 L/min (10 to 25 gal/min), depending on the width of the crack opening. The standpipe was equipped with an overflow hose at the top to help regulate the 3-meter head; as the crack fills, the overflow increases.

Figure 6.—Saw-cut and splitting tension 150-mm (6-in) diameter crack test specimens.

Underwater "Anti-Washout" Mortar

Materials

The materials used for mortars are summarized in table 1. Three cementitious materials were used in the mixtures, including Portland cement, ASTM C 618 Class F pozzolan, and a condensed silica fume pozzolan (ASTM, 2004). The combinations of cementitious materials were used to make the mortar gluelike or "sticky" even before adding the AWA. Two Portland cements were evaluated, a standard Type II, low-alkali cement, and proprietary manufactured microfine cement purposely ground fine for use in traditional cement grouting applications. The microfine cement was used in the final formulations. The Class F pozzolan is used as cementitious filler between the coarser grained cement particles. The silica fume is added as ultrafine cementitious filler and to make the mortar sticky. A highly cementitious materials volume is desirable to reduce the potential for separation of water from the paste under injection pressures in water. Fine aggregate consisted of ASTM C 33 concrete sand, lab standard fine aggregate M-8196. The sand was screened at either 4.5-mm (No. 4), 2.36-mm (No. 8), or 1.18-mm (No. 16) sizes to remove oversize particles that might plug the front of the crack. The objective of varying the maximum sand grain size was to have the maximum particle size just smaller than the crack opening. An ASTM C 494, Class F high-range, water-reducing admixture was added to fluidify the mortar and reduce the water content before adding the anti-washout admixture. Polypropylene fibers were also added as additional "clogging" filler in the cracks and also to hold the mortar together.

Table 1.—Underwater crack repair—materials for underwater mortars

Material	ASTM designation	Comments
Portland cement	C 150, Type II, low alkali	Cementitious material
Microfine Portland cement	C 150	Cementitious material, increase “adhesive” properties of fresh paste
Pozzolan	C 618, Class F	Cementitious filler
Silica fume		Cementitious filler, increase “adhesive” properties of fresh paste
Water	C 94	Hydration of paste
High-range, water-reducing admixture	C 494	Fluidify mortar for flowing properties
Anti-washout / viscosity modifying admixture	U.S. Army CRD-C61	Resist washout by flowing water, viscosity-modifying properties

A commercial AWA or VMA was used to inhibit washout of the paste by flowing water and the viscosity of the mortar changing. The AWAs were first introduced for their ability to greatly reduce washout of paste for underwater applications in the 1980s. However, they also have more recently served a dual role as a VMA for self-leveling concrete. The VMA is used to eliminate bleeding of water from paste in flowing concrete that would ordinarily separate. The resulting AWA/VMA mortar has a thick, caulk like consistency as shown in figure 7. AWAs and VMAs are more or less the same and for the purposes of this report, will be referred to as AWAs. The mortar has enough adhesive or “gluelike” properties to stick to a dry pan turned upside down like construction glue or caulk or be placed underwater without washing out as shown in figures 7 and 12. The mortar can be readily extruded from a caulking gun and because of the fibers, can be suspended in water as a continuous bead.

Mixture Proportions

The proportions of materials for underwater mortar mixtures are summarized in table 2. The sand to cementitious materials ratio was initially 2 to 1 by mass, with a pozzolan content of 20 percent by mass—15 percent Class F pozzolan and 5 percent silica fume. The sand to cementitious materials ratio was decreased to 1.33 to 1 to reduce injection pressure so the mortar could be extruded with a caulking gun. The water to cementitious materials ratio ranged from about 0.37 to 0.42. The standard composition of mortars is a 2.75 sand to cement ratio and a water to cement ratio of 0.46 to 0.49 by mass, respectively. The fiber content was about 6.2 lb/yd^3. The dosage of HRWRA was doubled from recommended to about 2,600 mL per 100 kg (40 oz per 100 lb) of cementitious materials to increase the fluidity of the mortar before adding the AWA. However, this delayed the setting time of the mortar and was changed back to the maximum recommended dosage, 1,300 mL per 100 kg (20 oz per 100 lb) cementitious

Figure 7.—Underwater crack filling mortar extruded through a caulking gun.

Table 2.—Underwater crack repair—mortar mixture proportions and preliminary physical properties testing

Mix ID	Cement (g)	Fly ash (g)	Silica fume (g)	Fibers (g)	Sand (g)	Glenium 3030 (mL)	Rheomac UW 450 (tsp)	w/c	Flow	Compressive Strength (psi) 1-Day	7-Day	28-day avg	90-day avg	Notes
CRK-1	796	150	50	0.6	2000	26	2	0.40	82	370	5580	8350		1
CRK-2	796	150	50	1.2	2000	26	2	0.37	76	270	5720	9205		1
CRK-1	796	149	50	0.6	2000	26	2	0.40	85	60	4110	7555	7560	2, 3
CR2	597.1	112	37.3	1.2	1500	20	3	0.42	71	200		7015		2
CR2	597.1	112	37.3	1.2	1500	20	3	0.42	71	200	-	7015	-	2
CR2-A	597.1	112	37.3	1.2	1500	20	4	0.42	53	115	-	7195	-	2
CR2-B	597.1	112	37.3	1.2	1500	15	3	0.42	71	370	-	7035	-	2

[1] 2- by 2- by 2-in cubes
[2] 3- by 6-in cylinders
[3] 1 yr—9065 lb/in^2

materials. The AWA was added at about 780 mL per 100 kg (12 oz per 100 lb) cementitious materials. The amount of fibers and AWA later doubled to increase the viscosity or adhesive properties of the freshly mixed mortar and keep the mortar together in a continuous extruded bead.

The desired fresh properties are more descriptive in nature and cannot be readily measured by standard tests. The mortar must be sufficiently fluid to flow into cracks. But, it also needs to be cohesive or even adhesive in the fresh state. If it has the consistency of thick glue, it should enter cracks as narrow as about 3 mm (⅛ in). If the mortar has a puttylike consistency, it will function more like an adhesive caulk or a surface patching compound and may enter cracks of about 6 mm (¼ in) or wider. The dosage of the AWA strongly influences these properties. Throughout the program, attempts were made to balance these two desired parameters. The best indicator of the consistency is the standard mortar flow test, ASTM C 109.

Consistency of Freshly Mixed Mortar

The consistency of the mortar was determined with a mortar flow test in accordance with ASTM C 109. The sample is placed in a 50-mm (2-in) high cone-shaped mold with an average diameter of about 86 mm (3.4 in). After withdrawing the mold, the sample is dropped 12.5 mm (½ in) 25 times on the flow table. The flow is determined by measuring the increase in diameter of the sample. A standard mortar sample has a flow increase of about 110 percent of the original diameter. The flow for the underwater mortars ranged from about 25 to 75 percent increase of the original sample as shown in figure 8.

Compressive Strength of Hardened Mortar

The compressive strength development of the mortars is shown in table 2. The overdosage of HRWRA significantly delayed the early compressive strength. The 1-day compressive strength of the mortar was only 400 KPa (60 lb/in^2), even though the 7- and 28-day compressive strengths were about 31 and 42 MPa (4,500 and 6,100 lb/in^2), respectively. The hardened mortar has extremely high ultimate strength, which is desirable as cementitious filler in cracks subject to movement.

Crack Filling Trials

Several trials were conducted to test the underwater standpipe apparatus and evaluate various mixture formulations and methods for filling the cracks underwater. The standpipe apparatus and test procedures were refined for the different conditions encountered in the program. A mortar mixer and hand pump were initially used to mix the mortar and inject it into the standpipe. This type of equipment is anticipated for large scale, high-head applications. However, this was not successful for a small scale application in the laboratory. Lumps of unmixed mortar and fibers clogged the pump valves and injection hose. It is also extremely difficult to clean this equipment when using the AWA mortars. Large scale tests will also need to consider a means of cleaning the equipment and delivery pipe/hose.

The best results were obtained mixing the mortar in a standard laboratory Hobart mixer and injecting the mortar with a construction caulking gun. The injection

Figure 8.—Mortar flow consistency test: flow is 25 after 25 drops on the flow table indicating a 25-percent increase in diameter.

port was fitted with a 12-mm (½-in) clear, flexible tube that can slide up and down in front of the crack. The mortar can either be "tremied" from the bottom by burying the end of the tube, allowed to free-fall in the water, or slowly extruded over the crack itself by raising or lowering the plastic feeder tube. The low-head test apparatus presents some difficulties as the mass of the mortar causes it to sink and stick to the bottom of the standpipe where it is not readily sucked into the crack. Possible ways to counteract this problem without changing the mortar properties include increasing the head on the pipe or pressurizing the test apparatus. For the initial work, the mortar flow ranged from 75 to 50 to allow it to flow into the crack under the 3-meter (10-ft) hydraulic pressure. The last two trials were conducted with a mortar flow of about 25 and extruded directly onto the vertical crack itself by manipulating the feeder tube. The extruded mortar had little or no washout and would stick to the face of the test specimen until it was physically dislodged. Using this process, the mortar flowed about 1 inch into a 6-mm (¼-in) wide crack without washing out, sealing off the flow over about one half of the face of the test specimen. A second trial closed off most of the remainder of the flow. The penetration into the crack is ultimately limited by the head pressure of the test apparatus.

Results of Underwater Crack Filling Trials

The results of the underwater crack filling trials are summarized in table 3. The main focus of these trials is to investigate the effect of the underwater admixture consistency relative to the crack width and different crack configurations. The consistency of the mortar is estimated by the mortar flow in accordance with ASTM C 109. Flows greater then 70 will enter the fine cracks where the primary flow reduction comes from blocking flow with the fine aggregate particles and fibers as the paste is washed out as shown in figures 9 and 10. A secondary problem encountered is when the mortar falls to the bottom, in front of the test specimen. It stops all flow by blocking off the entry point. This may be suitable for filling a sink hole but not the intended purpose of filling vertical cracks. This problem was reduced by carefully directing the flow of the mortar directly in front of the crack without letting it settle. At flows of about 50, the mortar enters the finer crack and reduces about 90 percent of the flow by a combination of plugging the flow with sand and fibers and some filling with mortar.

Table 3.—Underwater crack repair. Results of underwater crack filling trials. Mixes prepared and tested in crack test apparatus

Mix ID	Fibers (g)	Sand (g)	Glenium 3030 (mL)	Rheomac UW 450 (tsp)	Flow	notes from testing
CR2-C	1.2	1500	15	4	-	Material settled in front of crack
CR2-D	1.2	1500	15	2	-	Material settled in front of crack
CR2-D1	1.2	1500	15	0.75	-	Material washed out
CR2-D2	1.2	1500*	15	0.75	-	*150 g of total sand replaced with silica sand, material washed out
CR2-E	1.2	1500	15	2.5	-	Switch to minus No. 8 sand, materials settling in front of crack
CR2-F	2.5	1000	15	2.5	-	Material settled in front of crack
CR3	2.5	1000	10	2.5	-	Slowed application, material settled in front of crack
CR4-A	2.5	1000	10	3	-	Materials washed out
CR4-B	2.5	1000	10	4	-	Material stays together longer, eventually washed out
CR4-C	2.5	1000	10	5	-	Thick bead of materials, stayed on crack surface longer and was more controllable
CR4-D	2.5	1000	10	5	-	Switched back to sand meeting C-33
CR4-E	2.5	1000	10	6	25	Thick bead of material, stayed on crack surface and penetrated into crack in places

Figure 9.—3-mm (⅛-in) crack filled by sand and mortar surface plugging.

Figure 10.—Sand grains embedded in crack after injection; paste has washed out at reduced dosage of anti-washout admixture.

In the final trial with a mortar flow of about 25, the mortar can be extruded over the crack and remain against the vertical crack without washing out as shown in figure 11. The mortar entered a 6-mm (¼-in) wide crack to a depth of about 25 mm (1 in). The mortar flow of 25 is the anticipated consistency for a wider crack and at higher heads. At a mortar flow of about 25, the mortar can be

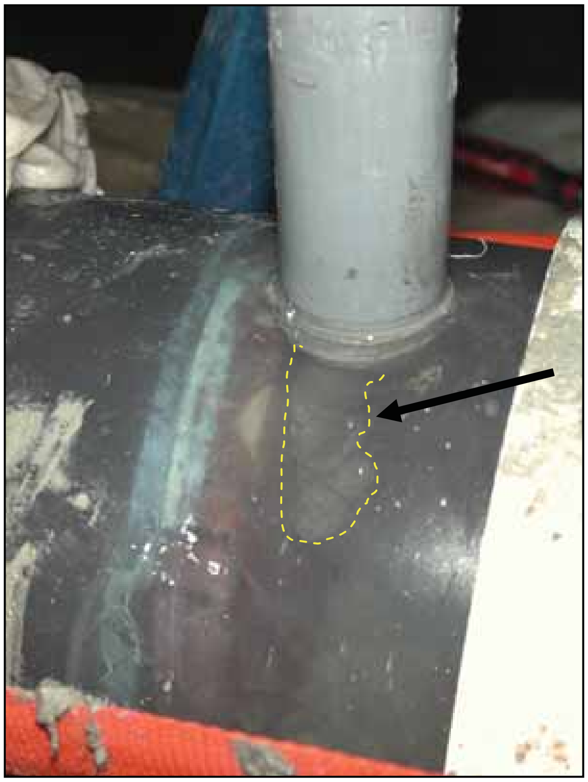

Figure 11.—Extruded bead of mortar placed on the vertical face of a 6-mm (¼-in) wide vertical crack flowing about 100 L/min (25 gal/min).

dropped into standing water and retain a stiff consistency, as shown in figure 12. During the test, a 125-mm (5-in) long, 12.5-mm (½-in) diameter extruded mortar bead was suspended in water. Mortar entered the crack to a depth of about 25 mm (1 in), and some mortar flowed along the entire length of the test specimen to a depth of about 12 to 25 mm (½ to 1 in), as shown in figures 13 through 15. Examination of the test specimen showed the mortar is also well bonded to a smooth, saw-cut vertical surface, shown in figure 14.

Overall, the crack-filling trials were effective in demonstrating the ability of the AWA mortar to resist washout by water flowing through cracks. The 3-meter (10-ft) tall standpipe was sufficient to demonstrate how the fluidity and AWA affect the consistency of the mortar and how it fills into cracks. The 3-meter (10-ft) head is insufficient to demonstrate how AWA mortar with stiff, puttylike consistency will behave as crack filler. The fluidity required for 3-meter (10-ft) head is considerably higher than what is expected to be used in a high head application. Further research with a high head standpipe about 15 to 20 meters (45 to 60 ft) tall would be useful to evaluate stiffer mortar, or a test site may also be suitable. One candidate site is the leaking contraction joints at Pueblo Dam where the leakage is temporarily stopped by introducing sawdust in front of the cracks. The sawdust must be periodically reintroduced.

Figure 12.—Sample of mortar with a flow of 25 placed in standing water.

Figure 13.—First trial of underwater mortar with flow of 25 L/min filling about 25 mm (1 in) into the vertical crack face without washout. The face of the crack was filled with a second application of mortar.

Figure 14.—End view of 6-mm (¼-in) wide crack test specimen after test filling with 100-L/min (25-gal/min) crack flow.

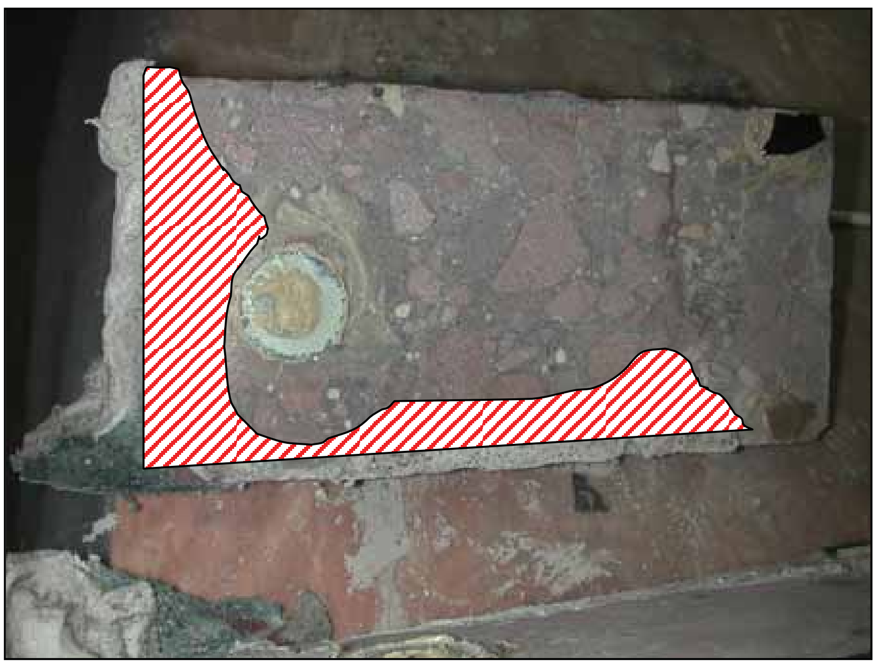

Figure 15.—View of 6-mm (¼-in) wide crack test sample after filling with underwater mortar. Mortar is bonded to the vertical face of the specimen (left) and filled the crack to the limits shown.

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Appendix A—Evaluation of Drains Intercepted by Cracks

Drains Intercepted by Cracks

Underwater Crack Repair—Crossing Drain Holes

A major concern for grouting repairs is the potential for grout to migrate through the crack and into existing foundation and contraction joint drain holes, rendering them ineffective. If this condition were to happen, the drains would have to be redrilled. Ideally, a crack-filling scheme that does not plug the drains is most desirable to avoid the added cost of redrilling the holes. A temporary means of isolating only the drain where intercepted by cracks would make a foundation drain ineffective in that location. But, it risks the possibility of being plugged if the temporary plug fails. If maintaining flow through a drain is desired during grouting, the system would have to extend the length of the entire drain from the bottom up. Both schemes were considered. Several ideas were evaluated to prevent plugging drains during filling, including packer systems, inflatable balloons, inserted pipes, pipe spacers, and geosynthetic wraps or "socks." These various ideas were divided into two options:

Option A—Cracks crossing foundation drains—isolating the drain intercepted by a crack

If cracks cross the foundation drains, the method to fill the cracks needs to prevent the drains from being plugged. In some cases, the drain crosses the crack at a defined location that can be located and isolated. Other times, a long section or intermittent sections of the drains are crossed by the crack. Various methods were evaluated to isolate these sections of the drains.

Equipment suitable for isolating drains includes the following methods:

- PVC pipe
- Steel pipe
- Insituform balloon
- Mechanical packer
- Inflatable packer

Transverse thermal cracks may cross foundation drains at relatively steep angles and require a significant length of the drain to be isolated. Isolating the entire drain below the grouted area is accomplished by inserting pipe or packers. This prevents the mortar from filling the drain hole below the intersection with the crack. A disadvantage of pipe options is they would have to be a slightly smaller diameter to be inserted into the drain hole. If grout leaks into the void around the pipe and hardens, the diameter of the drain would be reduced. The pipes would be lubricated to inhibit bond with the grout. Pipes might have to be drilled out if they become stuck or are grouted in. Mechanical or inflatable packers would be more suitable if the distance that the crack intercepts the drain is limited and can be located accurately. Packers would have to be long enough to cross the entire crack to prevent leakage of mortar. Packers would be much more difficult to install if the crack crosses at multiple locations.

Option B—Contraction joint drains—maintain water/mortar flow through cracks around the drain during filling

For vertical contraction joint drains behind waterstop, filling the crack cannot be accomplished with the proposed methods if the drain is completely filled. Since the object of the crack filling repair is to allow flowing water to bring in the AWA mortar into the crack, drains can also become filled. A protection system is needed to prevent the AWA mortar from entering the drain, but allow it to flow around the perimeter, if needed. The water would still need to flow through the crack in order to pull the mortar in.

Equipment that may be used as a temporary seal in drains includes:

- Pipe centered with spacers
- Balloon form wrapped with spacers
- Sheet drain tubes
- Geonet and geotextiles

Steel or PVC pipe were previously discussed. For this application, the pipes will need to be centered to allow the AWA mortar to flow in the void around the perimeter of the pipe. The use of sheet drain or geonet is likely to be combined with other positive means, such as pipe or balloon forms. Or, the material can be wrapped into a tube that acts like a pipe itself to maintain the drain, but still fill the crack. The purpose is to provide a path for water and mortar to flow into the crack and around the drain perimeter and continue past until it no longer can penetrate. If left in place, the drain would have a reduced cross section. But, it may be possible to leave it in place and still function properly. The prefabricated tube might be easier to drill out, then install steel or PVC pipe if it becomes embedded and stops flow. There is a possible advantage that the material may be premanufactured and shipped in rolls. Thus, it might be possible to insert continuously, rather than in sections. A potential disadvantage is that if the material is not stiff enough, it might get caught in offsets in the drain holes or at the crack.

Evaluation of proposed options

A1. PVC Pipe.—Insert PVC pipe into the drain, 12 to 25 mm (½ to 1 inch) undersize. Use 1.5- to 3-m (5- to10-ft) lengths if working inside the gallery. Joints will be flush thread to allow disassembly and removal after grouting. Pipe will not be centered in the drain, and some crack water can still flow into the gap between the pipe and perimeter of the drain. After filling the crack, the pipe will be pulled out of the drain hole (grease pipe for removal), and disassembled (flush threads). If grouted into place, there may be a need to auger out the PVC pipe. If centering of pipe is desired for contraction joint drains, use a geonet or sheet drain wrap (see Insituform option below). Mechanical spacers attached to the pipe could also be used for centering, but may prevent removal of the pipe if it's grouted in.

A2. Steel Pipe.—Insert steel pipe into the drain 12 to 25 mm (½ to 1 inch) undersize. Drill stem pipe should work well, and the drill crews have this on hand in various lengths. Use 1.5-m (5-ft) lengths if working inside the gallery. Joints are flush thread to allow disassembly and removal after grouting. Pipe will not be centered in the drain, but water can still flow into the drain, around the pipe and out the far crack. Even if pipe presses against the crack, it won't seal off flow completely. After grouting, the pipe will be pulled out of the drain hole (lubricate pipe for removal) in sections. Steel pipe is stronger than PVC and can be twisted to help break free of grout for removal. Also, steel pipe can be jacked out.
If centering of pipe is desired, use a geonet or sheet drain wrap (see Insituform option below). Mechanical spacers attached to the pipe could also be used for centering but may prevent removal of the pipe after grouting.

A3. Insituform Balloon.—Insituform is normally supplied with thin polyethylene liner (visqueen) and resin-impregnated fabric wrap. For this application, we want only the polyethylene liner (balloon). The balloon would be installed by inverting into place with water pressure, inserted to bottom of drain, or perhaps just into the foundation. The balloon will seal tightly against drain walls sealing cracks and would not allow flow through contraction joint drains. Therefore, this method may not work without additional drainage element to maintain perimeter flows during crack filling.

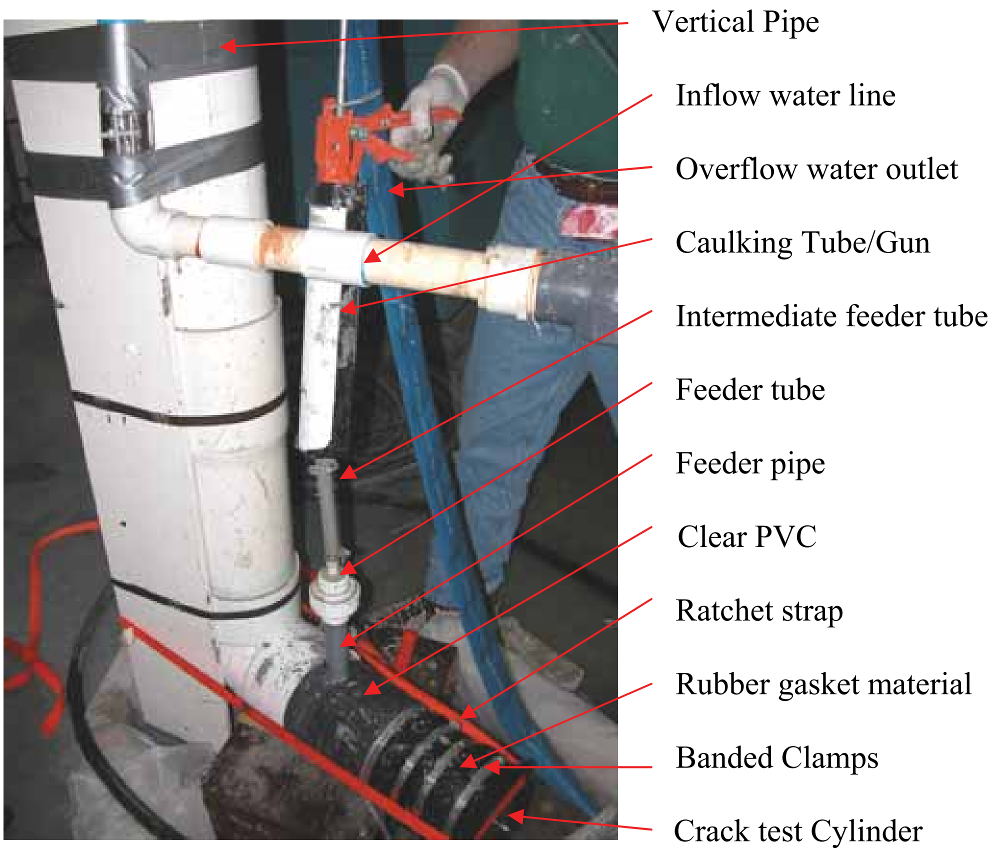
A4/A5. Packers.—Mechanical or inflatable packers could be used to isolate portions of the drain, especially when the location of cracks is known. Packers are inflatable or mechanical rubber tubes of varying length that can be inserted or inflated (or mechanically "squeezed" to expand) to close a void, and later deflated and withdrawn. Packers conform to the sidewalls of voids to prevent leakage. Packers could be used in combination with steel pipe to extend their length or could be inserted from the bottom of the drain, working up in stages as the crack is filled. The lower packer would have to deflate to a diameter smaller than the pipe diameter for removal after filling. Even then, removal of the lower packer after grouting may be problematic. Insituform balloon might be used as the lower packer. This could probably be removed or drilled out if it were to become stuck.

B1 – B3. Maintain flow around perimeter of drains with Geonet or sheet drain wrap.—Use 6-mm (¼-inch) geonet (or sheet drain) as drainage layer around Insituform balloon. The geonet (or sheet drain) would be inserted into the drain first and pressed against the sides of the drain by water pressure from the balloon. These materials may also be used as centering devices, perhaps by wrapping them around a pipe. Insituform balloon would then be inserted into the drain by inversion. After filling the crack, the balloon would be removed by a rope attached to far end of balloon. Geonet (or sheet drain) is grouted into place and left inside the drain.

Based on evaluating the options to avoid plugging drains with grout, we feel that inserting drill rod is the preferred method for initial experimentation, especially for contraction joint crack repairs. The drill rod comes in various diameters, and it may be possible to use old pieces that are no longer useable for other work. The regional drill crews have this equipment readily available in different lengths, and they already have the experience using their equipment. The equipment for suspending and/or lifting the drill rod is also on hand. We recommend testing this equipment on a smaller scale test block to evaluate the feasibility. Both pipe and packer systems are feasible for foundation drains crossed at known locations by cracks.

Appendix B – Crack Standpipe filling Procedures

STANDPIPE TESTING APPARATUS



The procedures used to introduce the mortar into the cracked test specimen are:

1. Wrap the test cylinder in neoprene rubber.
2. Wrap crack test cylinder in rubber gasket material and inserted into 160-mm (6½-in) diameter clear PVC pipe in the end of the elbow section of the test standpipe.
3. Insert foam backer-rod at interface of rubber gasket material and clear PVC.
4. Place and tighten four equally spaced banded clamps around rubber, ending with one centered over backer-rod.

5. Tighten ratchet strap around front of crack test cylinder and back of testing apparatus to hold cylinder tight during testing.
6. Place clear, flexible tube into injection port.
7. Temporarily plug feeder tube to prevent water from discharging at this point.
8. Adjust water flow until the standpipe fills and a minimal amount of water is discharging into overflow outlet.
9. Cut tip off the caulking tube.
10. Punch hole in the caulking tube foil bottom—bend down on inside.
11. Mix mortar.
12. Fill caulking tube.
13. Place rear cap in caulk tube—reinforce cap to prevent bending due to back pressure.
14. Cinch (bend over) feeder tube and remove plug.
15. Fasten to caulking tube tip with small banded clamp.
16. Begin applying mortar raising and lowering the cinched feeder tube slowly during application to regulate the mortar flow.
17. If tubes get clogged during application:
    a. Cinch feeder tube.
    b. Loosen banded strap and remove caulking gun.
    c. Used threaded rod to dislodge blockage from the tube and cinch feeder tube immediately upon clearing blockage.
    d. Reattach caulking gun and repeat steps 15 to 16.
18. After filling the crack, cinch feeder tube and remove caulking tube.