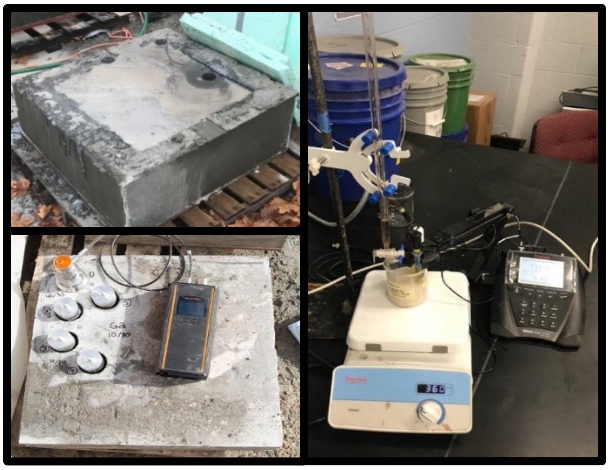
Durability of Anchorage Pour-backs and Improvements



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Pour-back materials are integral to the corrosion protection of post-tensioning anchorages, where all prestressing force is delivered. Two common grout materials and surface preparation techniques were investigated to assess the quality of the bond between the pour-back and the primary concrete member with regards to susceptibility to chloride intrusion and shrinkage effects. Recommendations for pour-back best practices are given based on these findings.		
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PROBLEM STATEMENT

Protecting post-tensioning (PT) anchorages from corrosion is critical to the durability and integrity of PT structures. PT anchorages -- often cast iron or machined steel components -- are embedded in a structural member at the termination of prestressing tendons. The anchorage region is critical because it is the location where all of the prestressing force is applied to the structural member. Degradation of the anchorage from corrosion can lead to prestress and capacity losses, with potential for catastrophic failure of the structure (1). Anchorages are typically encased in a secondary material -usually concrete or grout – after PT operations are completed. This secondary material is referred to as an anchorage pour-back and protects the anchorage from exposure to corrosive agents (Figure 1). Investigation and implementation of best practices related to pour-back details have been limited, with limited guidance provided by most state DOTs (2,3). This has led to inconsistencies in pour-back material usage and bond quality between the pour-back and concrete substrate. Instances of severe anchorage corrosion have been attributed to compromised pour-back regions (4,5).

This research investigates the impact of materials and surface preparation techniques on the quality of the bond between the pour-back and the primary concrete member. This project investigates common practices in PT anchorage pour-backs and the susceptibility of these practices to chloride intrusion and shrinkage effects. Recommendations for pour-back best practices are given based on these findings.

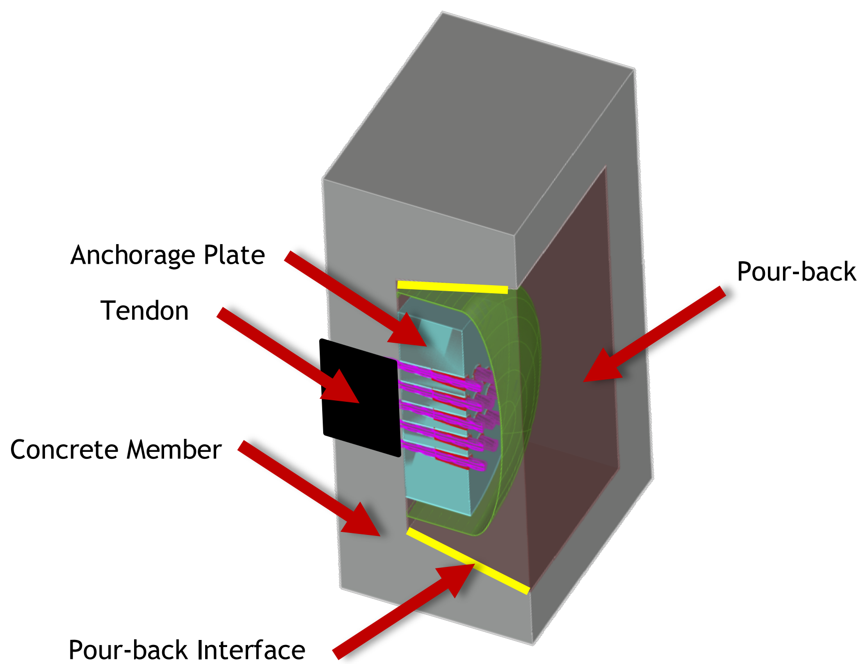


Figure 1. PT Anchorage Pour-back Cross-Section

RESEARCH BACKGROUND

Research Objectives

The goal of this research was to examine three aspects of pour-back performance –- bond strength, chloride permeability, and shrinkage potential –- utilizing commonly specified surface preparations and pour-back materials and to suggest improved practices for anchorage pour-back construction. The first task of this project was to investigate common practices related to pour-back construction. Second, the project evaluated these methods for bond strength, chloride permeability, and shrinkage potential at the benchtop lab scale and with full-scale anchorage mock-ups.

Current PT Pour-back Specifications

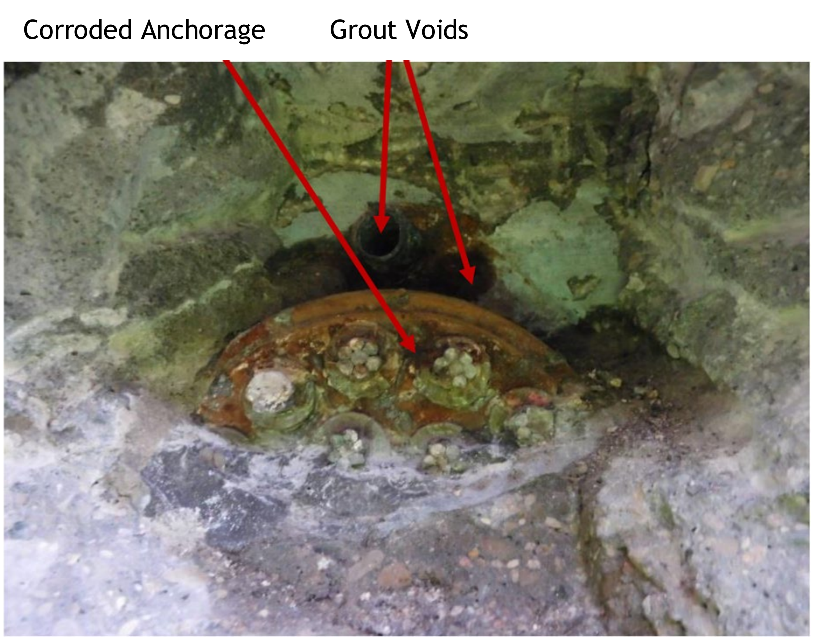
DOT specifications regarding surface preparation and pour-back materials are varied across states. Table 1 shows the anchorage pour-back specifications from three state Departments of Transportation (DOTs) and the Post-Tensioning Institute (PTI). The California and Florida DOTs are provided as an example as these states have a large inventory of PT structures, and their specifications are often used as a reference for nearby states (3). The PTI specifications are referenced by many states in their PT specifications (2).

In general, pour-back details include a non-shrink pour-back material and surface preparation to develop a 175 psi pull-off strength. These materials and procedures are provided to form a dimensionally stable pour-back with a reduced risk of moisture intrusion from pour-back shrinkage. A measurable quantity assumed to be related to performance, specifications often include a minimum developed bond strength.

Recent research has demonstrated that surface preparation techniques can significantly impact the strength of the bond between materials (6,7), but the degree to which these practices affect other aspects of bond performance, including bond ion permeability, is not well understood. This has led to a wide range of practices for PT anchorage protection.

Table 1. Current Anchorage Pour-back Specifications

Agency	Specification	Last Updated	Pour-back Material	Surface Preparation
California DOT	Standard Plan B8-5 Standard Specification 50-1.03B(2)(c)	01/29/2018	Same concrete as structure	None specified
Florida DOT	Standard Plan 462-002 Standard Specification 462-7.3.3.2	11/01/2018	Epoxy grout Magnesium ammonium phosphate or Reinforced concrete in atypical situations	Grit or water blasting with minimum pull-off of 175 psi, no nozzle pressure specified
Ohio DOT	Supplemental Specification 855.17	04/20/2018	Epoxy grout	Grit or water blasting at 10,000 psi nozzle pressure with a minimum pull off of 175 psi
PTI	M50.3-12 Section 14.2	08/2019	Concrete or Epoxy Grout	Grit or water blasting at 3,000 psi nozzle pressure with minimum pull-off of 175 psi



From: Montgomery (2018), Slide 28

Figure 2. Corroded anchorage assembly from moisture intrusion through concrete pour-back shrinkage cracks

Anchorage Pour-back Degradation

Current PT anchorage details typically have at least three layers of protection from corrosion: a permanent grout layer from the filler injection of the tendon, a plastic grout cap, and the pour-back. This redundancy helps to reduce the possibility of moisture and chloride intrusion from voids in tendon grouting and/or damage to the pour-back. A damaged pour-back can permit moisture and corrosive agents to penetrate to the anchorage. For the purposes of this study, a compromised pour-back is one that has cracked or one that allows the diffusion of sufficient chloride ions to initiate corrosion during the service life of the structure. Pour-back degradation, in some cases, has led to severe anchorage corrosion (Figure 2)(4,5).

Perhaps the most prominent form of pour-back compromise occurs due to differential volume change during pour-back curing that results in cracking. These cracks can allow moisture and corrosive agents to penetrate the anchorage. Differential volume change can be caused by shrinkage of the pour-back material during curing or by differential thermal expansion. Shrinkage in cementitious materials refers to the volume change of unloaded concrete as a result of environmental, thermal, and chemical strains (8,9).

All cementitious materials experience some shrinkage, be it drying shrinkage, thermal shrinkage or autogenous shrinkage, which could all lead to the formation of cracks, particularly along the pour-back interface, which could compromise the pour-back (10). Drying, thermal, and autogenous shrinkage are inter-related volume changes that result from concrete curing and cement hydration; these phenomena are often described as simply “shrinkage”. Concrete pour-back shrinkage has been documented in both bridge and building construction (4,5). Damage from thermal strains can also occur in non-cementitious pour-back materials like epoxy grout. Differential thermal expansion during curing of the epoxy may cause cracking, especially when the pour-back is irregularly shaped (11).

Chloride ion intrusion, facilitated by cracking of the pour-back and moisture intrusion, can initiate corrosion by eroding the passive layer of protection surrounding steel embedded in concrete (8,12). Pour-backs in PT concrete are particularly vulnerable to chloride-ion intrusion (13). Chlorides may be present in the constitutive components of the pour-back due to chloride contamination before casting, or they may diffuse through the material after exposure from a marine environment or deicing salts.

Diffusion is accelerated in areas of increased porosity (14). The interface between the concrete substrate and the pour-back may have localized increased porosity, similar to the interfacial transition zone (ITZ) between cement paste and coarse aggregates in concrete (15). When a threshold level of chloride ions is present in the material surrounding the embedded steel, corrosion will initiate (16). Using a plastic grout cap cover serves as a physical barrier to prevent diffusion of chlorides to the anchorage. Understanding how chlorides will diffuse through the pour-back will provide a better estimate of the service life of the pour-back itself.

RESEARCH APPROACH

Methods

This project evaluated the effects of surface preparation on the chloride permeability and shrinkage potential of PT anchorage pour-backs with benchtop and full-size testing. Benchtop testing included chloride profiling and pull-off testing. Mock-ups of the pour-back area for full-scale PT anchorages dimensioned to accommodate a typical 19-strand anchorage were constructed to evaluate the performance of materials at a realistic scale. Figure 3 summarizes the experimental approach.

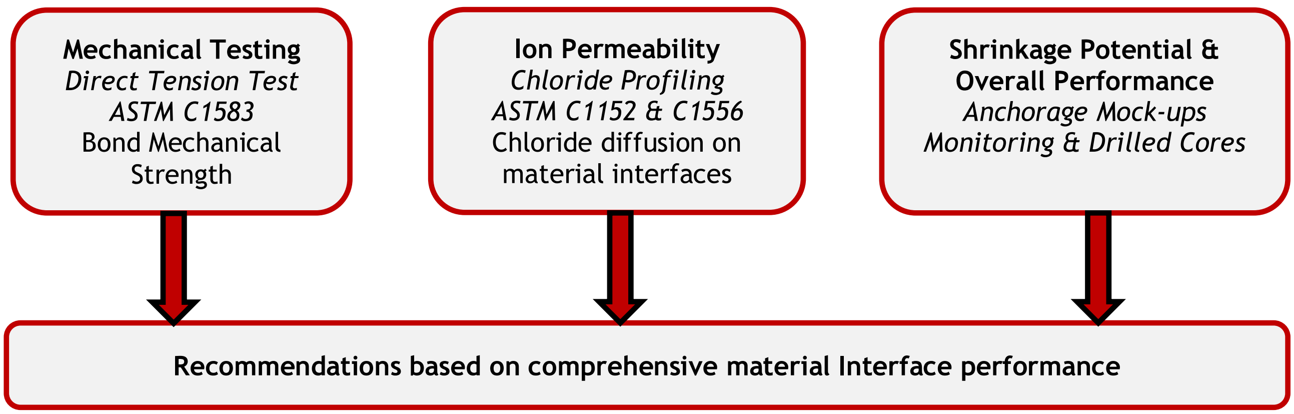


Figure 3. Experimental approach

Experimental Groups

Experimental groups are shown in Table 2. The pour-back materials and surface preparation techniques were determined by a review of PT specifications for state departments of transportation (DOTs). Two common surface preparation techniques were identified: water blasting at 3,000 psi and wet sand blasting at 3,000 psi nozzle pressure. Water blasting at 10,000 psi nozzle pressure is a common technique in older specifications; because it has been removed from many specifications, it was not evaluated in this effort.

Two classes of material were evaluated as pour-backs: common (cementitious) grout and epoxy grout. More recent DOT anchorage details specify epoxy grout for the pour-back material. Common grout – typically a cementitious, pre-bagged proprietary mix – was specified in older anchorage details and is still currently specified in other regions of the PT system (i.e., vent pour-backs and grout caps). Thus, it was important to evaluate the performance of both materials. At the time the experiments were planned, there were no products were listed on the Ohio DOT Qualified Products' List (QPL) for this detail due to the relatively few quantity of post-tensioned structures in their inventory. The specific products utilized in this investigation were taken from the Florida DOT approved products lists (APL), conform to the properties specified in Supplementary Specification 855, and have been approved for use as PT pour-backs in the past.

Each experimental group was evaluated with an ordinary Portland cement (OPC) concrete substrate. The mix design is presented in

Table 3. Concrete was batched and cast in accordance with ASTM C192-19 (17).

Table 2. Experimental Groups

Pour-back Material	Surface Preparation Technique	
	Water Blasting at 3,000 psi	Wet Sand Blasting at 3,000 psi
Common Grout	**GW**	**GS**
Epoxy Grout	**EGW**	**EGS**

Table 3. OPC Concrete Mix Design

Material	Portland Cement [lb]	Class F Fly-Ash [lb]	Water [gal]	#57 Coarse Aggregate [lb]	#8 Coarse Aggregate [lb]	Fine Aggregate [lb]	Type A Water Reducer [fl oz]	Air Entraining Admixture [fl oz]
Amount per cubic yard	700	100	41.77	1211	306	1075	20	4.8

Surface Preparation Techniques

Surface preparation was performed utilizing a commercially available pressure washer rated for a maximum pressure of 3,300 psi. For water blasting, a 15° spray nozzle was utilized. For wet sand blasting, a ceramic sand blasting nozzle and feeder hose were attached to the pressure washer and dry play sand was used as the media.

Water blasting was performed at a distance of 3-4 inches from the concrete such that the water jet striking the concrete was approximately ¾” wide (Figure 4a). An overlapping s-pattern was followed to roughen the whole surface area. Three passes were conducted to uniformly expose the coarse aggregate.

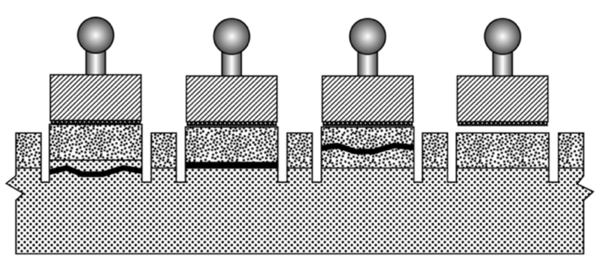
Wet sand blasting was performed at a distance of 3-4 inches from the concrete such that the water jet striking the concrete was approximately 1” wide (Figure 4b). An overlapping s-pattern was performed on each specimen. One pass was required to uniformly expose the coarse aggregate.

(a) (b)

Figure 4. Surface preparation methods for ion testing samples: (a) water blasting and (b) wet sand blasting

Mechanical Testing

The most direct method to evaluate the mechanical strength between a concrete substrate and an overlay is ASTM C1583, the Direct Tension Test (18). This standardized test involves coring a section through both the overlay and substrate, gluing a metal test dolly to the test site, and using a hydraulic tester to apply tension to the test dolly until a tensile failure occurs. Failure can occur in the concrete substrate (concrete tensile failure, Figure 5a), in the grout overlay (grout tensile failure, Figure 5c), along the interface between the materials (bond failure, Figure 5b), or in the glue holding the test dolly to the test site (glue adhesion failure, Figure 5d). A failure at the interface characterizes the bond, defining the performance of the interface of the concrete substrate and the overlay material. Tensile failure through either of the constitutive materials, however, indicates that the interface bond is stronger than the tensile strength of both constitutive materials, which is desirable.



(a) (b) (c) (d)

From: ASTM (2017), Figure 3 (18)

Figure 5. Direct tension test failure modes: (a) concrete tensile failure, (b) interface bond failure, (c) grout tensile failure, and (d) glue adhesion failure

The test is easily conducted in the field and is already used as an acceptance criterium for bond strength and evaluating surface preparation quality (19). The governing Ohio DOT specification for Post-tensioning specifies the use of the pull-off test to evaluate the quality of surface preparation “in case of dispute” (20). The direct tension test is considered one of the better methods for evaluating bond strength because it only introduces tension to the system (21) Other methods, such as the slant shear compression and split tensile stress tests, introduce indirect stresses to the system, which in turn means that the data gathered does not strictly relate to the bond performance, but also the performance of the materials.

For these experiments, a 20-inch by 20-inch by 4-inch thick OPC concrete slab was cast. Six days later, the prescribed surface preparation technique was performed, and the slab was ponded with water. On the seventh day from concrete casting, the ponded water was dumped off of the slabs so that the slab was free of standing water, and a 2-inch-thick grout overlay was placed on the substrate. Following grout casting, slabs were cured outside in ambient conditions. During the first 28-days after grout casting, if freezing conditions were predicted in the forecast, the specimens were brought inside to limit exposure to sub-freezing temperatures.

Pull-off testing was conducted on slabs at 7, 14, and 28-days after casting the grout. Testing was conducted by drilling a 2-inch diameter ring around the test site with a coring rig to a depth of 0.5-inches into the concrete substrate (Figure 6a). The test site surface was then ground with an angle grinder and scrubbed with a damp cloth to ensure a smooth surface. The metal test dolly was mechanically roughened using an angle grinder, attached to the test site using a 2-part epoxy adhesive, and allowed to cure per the manufacturer’s recommendations before testing (Figure 6b). At least three pull-off tests were conducted on each slab for each test period.

(a) (b)

Figure 6. Pull-off testing procedures: (a) coring and (b) testing

Ion Permeability Testing

Many methods have been developed to evaluate the permeability of concrete materials to chloride ions. These tests involve electrically-induced migration tests that use an electrical current to drive ions through the concrete sample (22,23), electrical resistivity measurements that correlate the resistivity of the sample to the chloride diffusion coefficient (14,24–26), and chloride profiling which measures the natural diffusion of chloride ions through a sample by dissolving the chlorides in solution and performing an equivalence point analysis with silver nitrate (27–30). Electrically-induced migration tests can be much faster than other methods (on the order of 1 week or less), but these tests enable unidirectional migration of chloride ions and do not necessarily accurately reflect the diffusion of chlorides ions through materials in-service, which may experience ion diffusion in any direction (12). Electrical resistivity tests are instantaneous and widely used for homogeneous OPC concrete samples (14,25,26,31). This research, however, seeks to define the permeability of ions along the concrete-grout interface of PT pour-backs, and resistivity measurements are not capable of registering accurate measurements along material interfaces and cannot be used in this case. For these reasons, chloride profiling was selected to measure chloride ion diffusion. Testing was performed in accordance with ASTM C1152, which provides the procedure for calculating the acid-soluble chloride content of individual samples, and ASTM C1156, which outlines the sampling protocol for building a chloride diffusion profile (29,30).

Specimen Preparation

Specimens for diffusion testing were 4-inch diameter by 4.5-inches tall cylinders composed of half concrete and half grout. This sample type is a deviation from the procedures listed in ASTM 1556 (typical samples are 4-inch by 8-inch cylinders of neat concrete or drilled cores), but it allows sampling along the interface region between concrete and grout. The concrete was first cast in one half of a plastic concrete cylinder mold. The following day, the half cylinder was demolded and moved to moist curing conditions (Figure 7a). Surface preparation was conducted on the half-face of the cylinder and the sample replaced in moist curing; surface preparation was either water blasting or wet sand-blasting (Figure 4).

When the concrete was three-days old, the concrete sample was placed back into a 4-inch by 8-inch cylinder mold, and grout was cast in the other half of the cylinder. Grout was mixed using a power drill with a mortar mixing attachment and a 5-gallon bucket in accordance with the manufacturers' recommendations. The specimens were allowed to cure in the moist cure room at 95-100 percent relative humidity and 72+/-2 degrees Fahrenheit until prepared for saltwater exposure. One face of each specimen was cut square with a diamond wet saw to ensure an even exposure surface. Then, a 70mm long portion was cut for use as the exposed specimen. The remaining portion of the cylinder was used to determine the initial chloride content of the constitutive materials and the material interface. Specimens were painted with one coat of epoxy paint using a foam roller along the cylindrical face and the bottom. After waiting for that coat of paint to cure (24 hours), a second coat of paint was applied in the perpendicular direction to the direction the paint was applied in the first coat. When the second coat of paint had cured, an orbital sander was used with a 60-grit sanding pad to remove any drips of epoxy paint that had dried on the exposure face of the specimen and rinsed. The painted specimens placed in a lime bath for 48-hours.

Saltwater Exposure

A 165 grams/Liter salt solution was prepared using distilled water and technical grade sodium chloride according to ASTM C1556. Four specimens were placed in a bucket, and 3.5 L of the salt solution was poured over the specimens such that the tops of the specimens were covered by at least 1.5 inches of the solution (Figure 7b). All specimens were initially submerged in the salt solution 21-days after concrete casting and remained submerged in the solution for 35 days. Samples were then removed from the salt solution and allowed to cure in the ambient air until profile grinding was conducted.

Chloride Profiling

Profile grinding was then conducted using a milling machine with a concrete coring bit (Figure 7c). Eight layers were ground in 1-millimeter increments in each constitutive material and along the concrete-grout interface of each specimen. At least 3 specimens were used to constitute a single sample in the depth profile to obtain at least 10 grams of powder. Samples were also milled from the disks set aside to determine the initial chloride concentration. The acid-soluble chloride content was then determined for each sample by digesting the powder in nitric acid and chemically titrating the solution with silver nitrate to determine the equivalence point – the volume of silver nitrate required to fully react with the chlorides in the sample (Figure 7d). The equivalence point was used to calculate the acid-soluble chloride content per ASTM C1152. The chloride diffusion parameters were then calculated using non-linear regression analysis for the profile of each material and the error function procedures listed in ASTM C1556.

(a) (b) (c) (d)

Figure 7. Ion Permeability Testing: (a) concrete cylinders before grout casting, (b) cylinders in salt solution, (c) milling samples, and (d) determining acid soluble chloride content

Shrinkage Potential and Overall Performance

To evaluate the overall performance of the pour-back materials, full-size mock-ups of a tendon anchorage region were constructed to assess the performance of the system. Mock-ups also allow the pour-back region to be placed in a state of restrained shrinkage, such as would be created in the field; shrinkage cracking could result in the pour-back separating from the concrete.

The pour-back mock-up was designed to meet ODOT Special Specification 855.17. The dimensions utilized would accommodate the placement of a VSL Type ECI 19-strand PT anchorage in the center with all of the clearance and clear cover requirements given by its specifications and the ODOT specification. A minimum of four-inches of concrete cover was provided along all sides of the pour-back. The angle given to the pour-back was 3.8:1 (Figure 8).

The pour-back region was formed by placing a foam block-out into the concrete forms during concrete casting (Figure 9a-b). Concrete was consolidated using a vibratory compactor. Surface preparation was conducted on the inside surface of the pour-back, and grout was cast seven days after the concrete placement. The grout was mixed using a mortar mixer according to the grout manufacturers' recommendations. After the grout was cast, the blocks were covered with a plastic tarp for initial curing. Blocks were monitored for cracking, and the widths of any cracks were photographed and measured with a feeler gauge. At the conclusion of the curing period, each block was cored along the concrete-grout interface to visually inspect the interface (Figure 9c). Cracks along the top of the interface were sealed with an epoxy adhesive before coring.

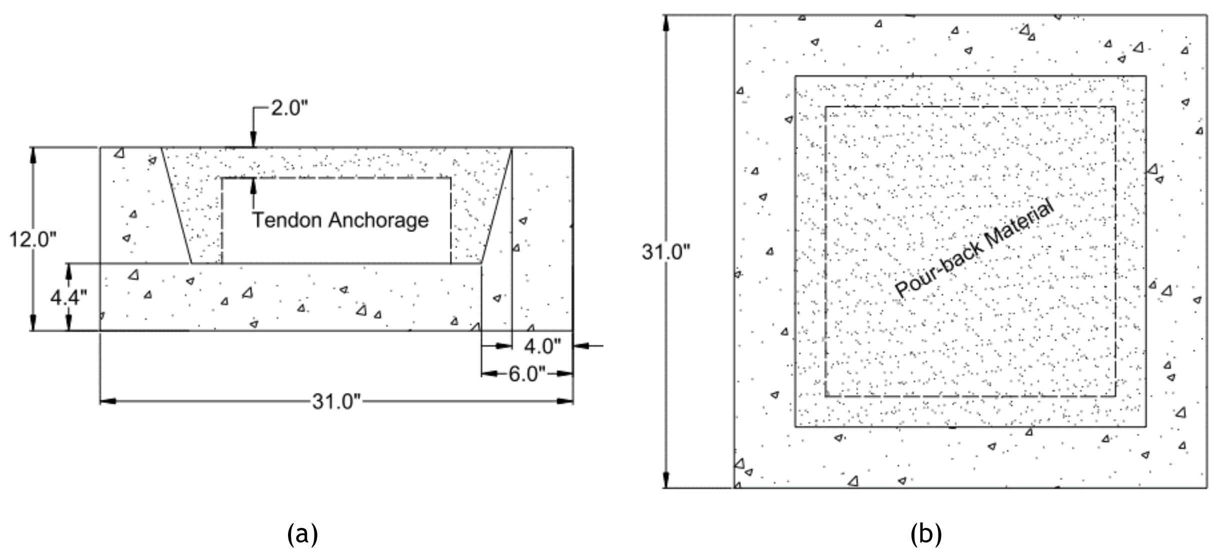


Figure 8. Anchorage Mock-up Plans: (a) front section view and (b) plan view

(a) (b)

(c)

Figure 9. PT Anchorage Mock-ups: (a) Foam anchorage block-out, (b) demolded concrete substrate, and (c) mock-ups during coring

RESEARCH FINDINGS AND CONCLUSIONS

Results

Chloride Profiling
Chloride profiles were measured for three constitutive materials and four interface types after 35 days of saltwater exposure. The apparent diffusion coefficient, D_a, is shown for each sample type in Figure 10. The other results are summarized in Table 4. An example of the measured chloride profile and non-linear regression is shown for concrete in Figure 11; full results are given in Appendix 1. The sampling methodology for determining the depth profile for each material and calculating the chloride diffusion parameters was based on ASTM C1556 (30). The chloride content of each sample was measured according to ASTM C1152 (29). Each data point represents the average of a minimum of three samples at an average depth from the exposed surface. The initial chloride content of each material before salt water exposure, C_i, is shown for each material. A non-linear regression analysis was performed on each material's chloride profile per ASTM C1556 to calculate two diffusion parameters – the projected surface chloride content, C_s, and the apparent diffusion coefficient, D_a. C_s is the estimate of the chloride content of the material at its exposed face. D_a provides an indication of the ease of chloride penetration into cementitious mixtures; the lower the D_a value, the greater resistance the material has to the diffusion of ions

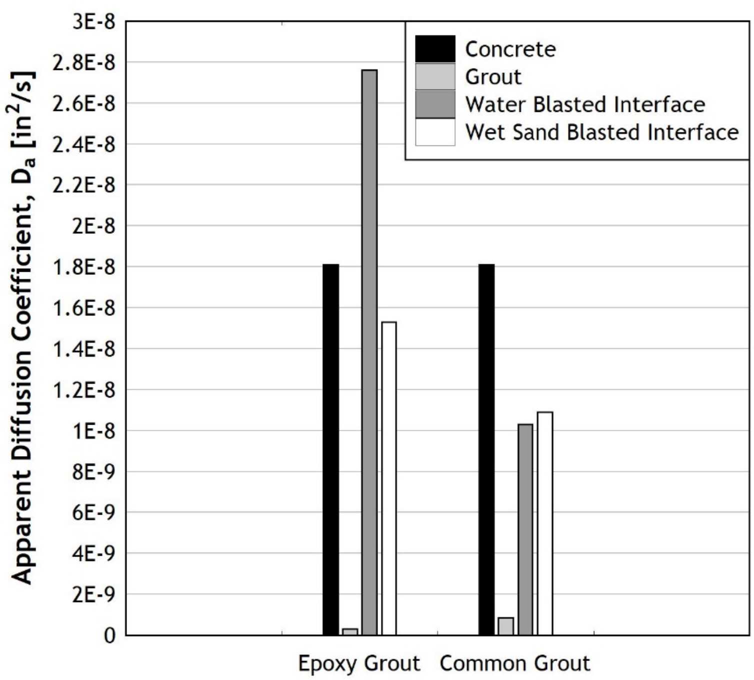


Figure 10. Apparent Diffusion Coefficients

Table 4. Chloride Profiling Results Summary

Material		Initial Chloride Content, C_i [% sample weight]	Calculated Surface Chloride Content, C_s [% sample weight]	Average Apparent Diffusion Coefficient, D_a [in^2/s]
Concrete		0.0217	0.8141	1.807E-8
Epoxy Grout		0.0088	0.1907	3.072E-10
Grout		0.0053	1.0151	8.676E-10
Interface Specimens	Water-blasted Epoxy Grout	0.0195	0.5520	2.760E-8
	Sand-blasted Epoxy Grout	0.0195	0.4983	1.531E-8
	Water-blasted Common Grout	0.0195	0.8785	1.026E-8
	Sand-blasted Common Grout	0.0195	0.7733	1.090E-8

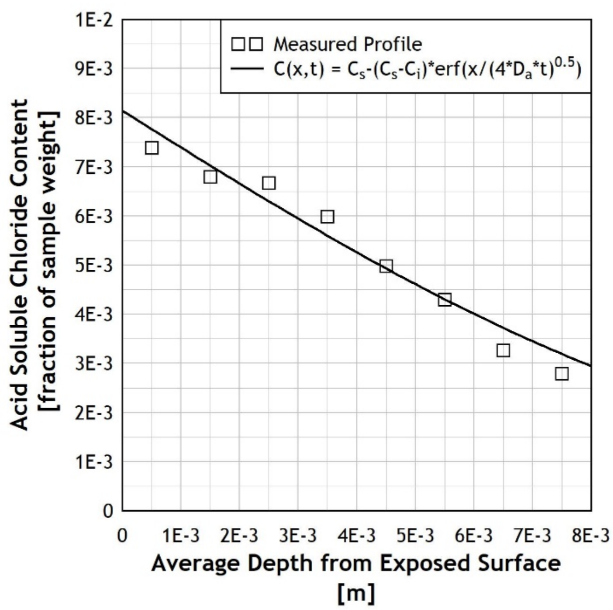


Figure 11. Concrete Chloride Diffusion Profile

The initial chloride concentrations range from 0.0053% by mass sample (common grout) to 0.0217% by mass sample (concrete); previous studies categorize values less than 0.035% as negligible (27). The initial chloride measurements verify the expectation that there are no significant sources of chlorides present in the constitutive materials; ions present in excess of these negligible values are those introduced by the exposure solution.

The calculated surface chloride contents, C_s, range from 0.1907-1.015% by mass sample and are in line with values reported in the literature for concrete mixes containing fly ash exposed to saltwater for the same amount of time and calculated according to the same non-linear regression analysis procedure (27,28). The lowest C_s recorded is that of epoxy grout (0.1907%). This is likely due to the low concentration of chlorides throughout the sample; chlorides diffused through the sample at a rate such that only the first two layers exhibited chloride contents significantly above the initial chloride content.

The apparent diffusion coefficient, D_a, for the concrete was 1.807e-8 square inches per second; this value is consistent with apparent diffusion coefficients for ordinary Portland cement (OPC) concrete with similar cementitious materials replacement exposed to saltwater for 35 days (12). Both the epoxy and common grout materials exhibited very low diffusion coefficients compared to those of OPC concrete (about 1.5 orders of magnitude lower than the other experimental groups), indicating that chlorides encounter relatively substantial resistance to diffusion in both grout materials. The D_a for each common grout interface was slightly more than half the D_a of concrete alone. The D_a for the common grout interfaces, regardless of surface preparation, are lesser than that for the epoxy grout interfaces, suggesting that the common grout provides greater resistance to ion diffusion. The D_a for water-blasted epoxy grout interface was 30% greater than the D_a for concrete alone, and the Da for sand-blasted epoxy grout interface was 27% less than the D_a for concrete alone.

To illustrate these apparent diffusion coefficients, the time required to initiate corrosion of mild steel reinforcement was modeled in Life-365, a concrete life cycle assessment model developed by the concrete industry stakeholders. The apparent diffusion coefficient for each material was input, and chloride exposure was modeled based on the chloride exposure of urban highway bridge in Columbus, Ohio (Figure 12). Diffusion was modeled with a 12-inch square concrete column and 2-inches of concrete clear cover. Concrete had the lowest predicted time to corrosion initiation at 11 years. Common grout followed at 81 years, and epoxy grout would require more than 150 years of exposure to initiate corrosion. Slight improvements in the diffusion coefficient can mean significant changes in the predicted service life of the structure.

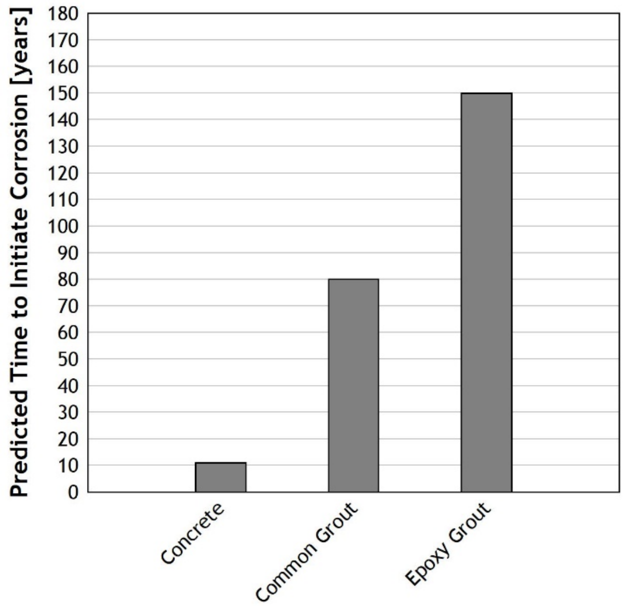


Figure 12. Predicted time to Initiate Corrosion from Calculated Diffusion Coefficients

Field Sample Chloride Contents

The chloride contents of five different samples taken from an in-service bridge in Cincinnati, Ohio are shown in Table 5 by both percent mass of total sample and percent by mass of cement for an assumed typical mix design. Because the actual mix design used for this concrete is unknown, there is some uncertainty in the cement mass used in the calculations; a range of values is provided to describe the likely scenarios. The average value was determined using a concrete mix design for a moderate strength concrete with a specified strength of 4,400 psi and a water to cement ratio of 0.5 as given by Mehta and Monteiro (8). These qualities are comparable to the requirements listed for class QC1 and QC2 concrete from Ohio DOT Specification 499.03 and are similar to ODOT specifications for concrete at the time of construction in 1998 (32). (The specified concrete design used in pier cap construction required a design strength of 5,500 psi, which means the design cement content is highly likely to fall within the predicted range of values.) The upper limit represents concrete with the minimum cement content allowed by specification 499.03 (520 pounds per cubic yard), and the lower limit represents concrete with a high cement content (860 pounds per cubic yard) as given by Mehta and Monteiro (8). Similarly, the cement content of the grout was estimated by calculating the minimum cement content (or maximum w/cm) allowed for PT grout by the Federal Highway Administration specification for PT Tendon Install and Grouting (33); though this document was published after the bridge’s construction, it is used here as a reference to estimate the w/cm content. The calculated value should represent the minimum chloride content present in the samples. A standard water content of 15% by mass of grout was assumed, corresponding to 10 pounds of mixing water per 55-pound sack of pre-bagged grout mixture. This is a typical recommended amount of mixing water for flowable grout.

Samples were taken from different locations in the anchorage corrosion protection system during a remediation project in July 2020. Figure 13 shows the location of samples 1-3, harvested from the north face of pier 2. Samples 4 and 5 were harvested from the south face of pier 2 by the contractor; specific locations were not identified. Further details about each sample are included in Table 5.

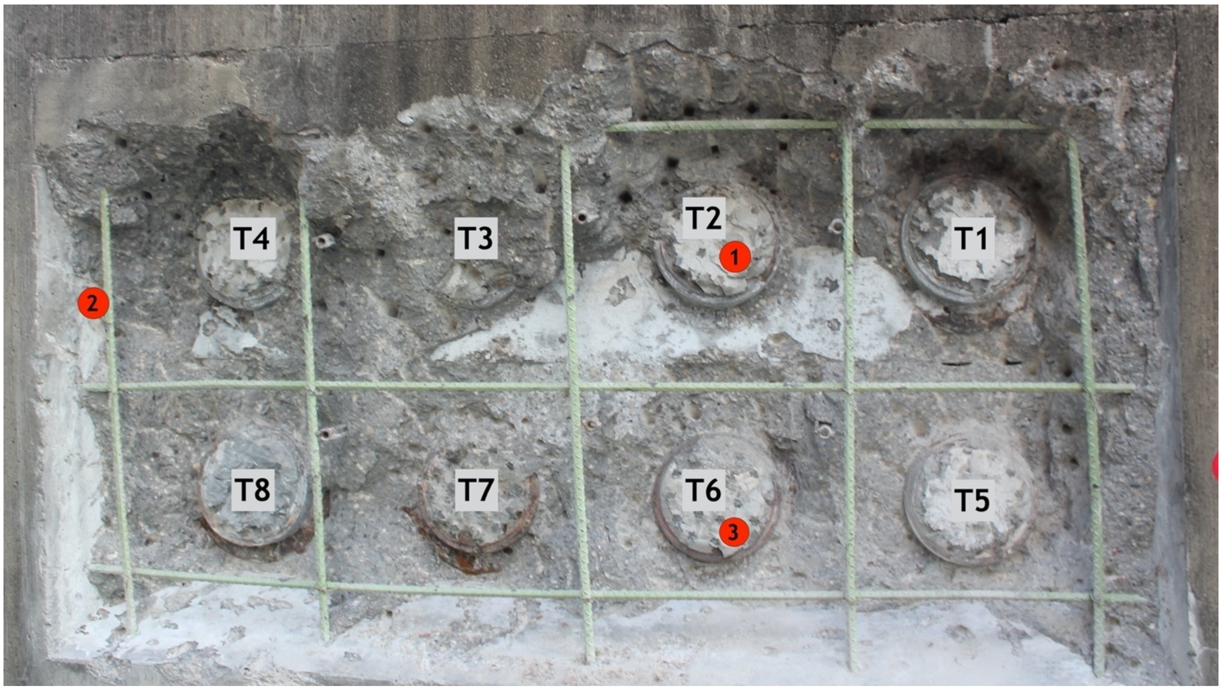


Figure 13. Harvested field sample locations

Table 5. Field Sample Chloride Contents

Sample Number	Sample Material	Sample Location	Chloride Content [% sample mass]	Chloride Content [% by mass of cement]
1	Grout	Grout taken from inside tendon T2 grout cap, Pier 2, north face	0.0230	0.067*
2	Concrete	Concrete from pour-back interface near tendon T4, from an average depth of 3 inches, Pier 2, north face	0.0371	0.253** Range: 0.178-0.378***
3	Grout	Grout taken from inside tendon T6 grout cap, Pier 2, north face	0.0160	0.047*
4	Concrete	Concrete taken from pier 2, south face	0.0371	0.253** Range: 0.178-0.378***
5	Grout	Grout taken from Pier 2, south face	0.0159	0.047*

*Assumes cement = 34.2% mass grout for a 0.45 w/cm ratio grout (33), with 10 lb mixing water per 55lb sack pre-bagged dry grout mix

**Value based on an assumed typical mix design. Assumes cement = 14.7% mass concrete for a moderate strength, 0.5 w/cm ratio concrete (8).

***Range provided to include all reasonable values. Lower limit assumes cement = 20.8% mass concrete; upper limit assumes cement = 9.83% mass concrete.

Typical initial chloride contents for concrete not exposed to salts are between 0.001 and 0.004% by mass of concrete (12), so any chlorides in excess of this threshold are likely from external sources, such as de-icing salts. The initial chloride contents were not measured at the time of bridge construction. Current standards place the maximum recommended chloride content to avoid reinforcement corrosion between 0.06 and 0.10% by mass of cement for prestressed concrete structures (28). The threshold represents the chloride content at which prestressing steel will likely begin to corrode.

Both of the tested concrete samples (Samples 2 and 4) had chloride contents above 0.10% mass of cement; one grout sample had a chloride content above 0.06% by mass cement.

Both concrete samples had elevated chlorides. Sample 2 came from approximately 3-inches deep into the pour-back region - deeper than the minimum clear cover for reinforcing steel in the structure (Figure 14). The measured chloride content (0.253% by weight cement) was greater than the recommended maximum value of 0.1%. Sample 4 came from the interface region of a concrete pour-back; measured chloride contents were identical to Sample 2 (0.253% by weight cement) - greater than the maximum recommended level (0.1%). The chloride content of Sample 2 is concerning because it represents concrete deeper than the concrete clear cover. One possible explanation is that the chlorides diffused along the interface between the pour-back and the main pier.

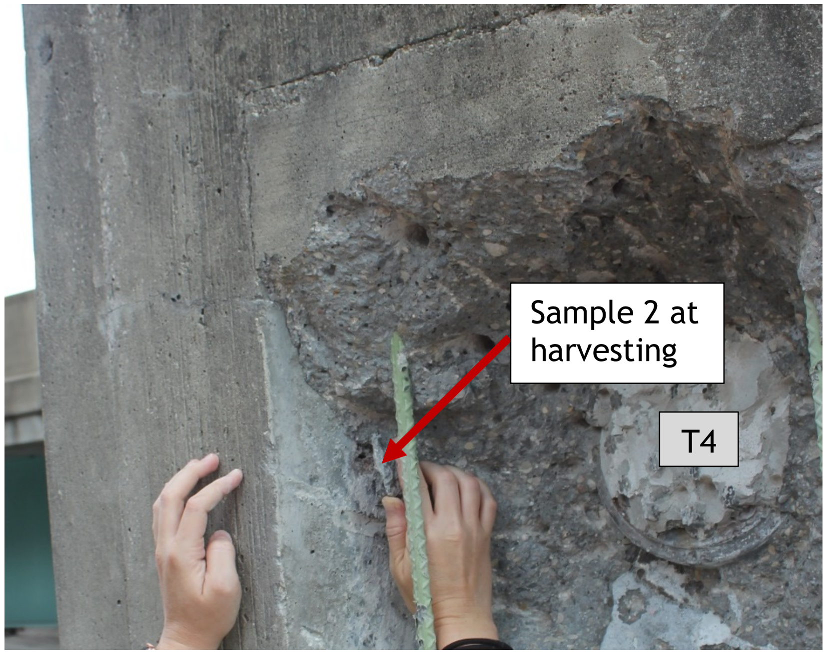


Figure 14. Sample 2 harvest location

Three samples of tendon grout were evaluated. Sample 1 was taken from the grout at the end of a tendon, adjacent to prestressing strands. It had a chloride content just above the least threshold of 0.06% mass of cement, and at harvesting, the sample showed discoloration from minor corrosion (Figure 15). The source of the chlorides is unknown; additional investigation would be required to attempt to identify the source. The other samples of tendon grout (Samples 3 and 5) did not have a chloride content above the threshold level or show signs of corrosion.

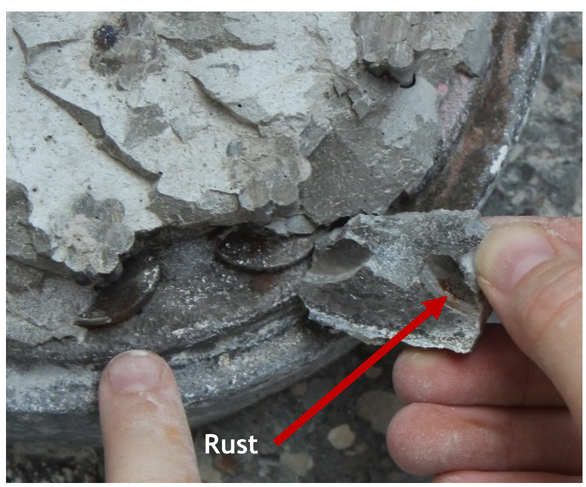


Figure 15. Photo of Sample 1 - evidence of rust in T2 grout cap

Pull-off Testing

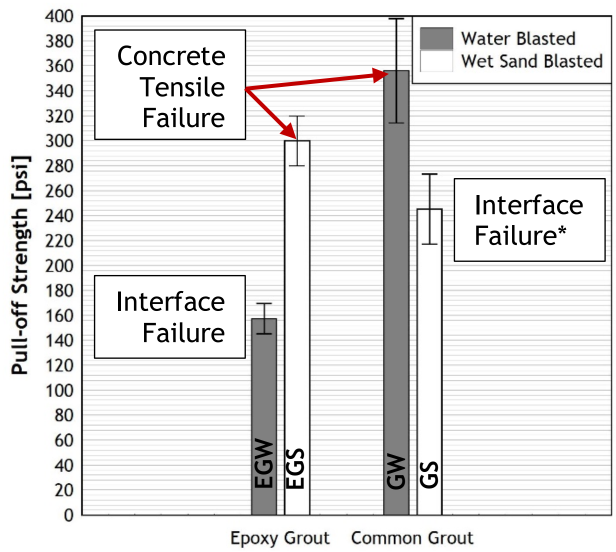
Two sets of pull-off slabs were cast and tested. The first set was cast in late August. A second set was cast mid-October for two reasons: 1) poor bond between the overlay and the substrate in the sand-blasted common grout slab sample was evident, but the cause could not be identified, and 2) to capture early-age pull-off strengths. Distinct ambient conditions between the two slab sets were influential in the testing. The August grout specimens were cast when the average daily temperature was approximately 80°F, but the October specimens were cast when the average daily temperature was approximately 45°F.

Figure 16 presents 28-day pull-off testing; all data is from the first set specimens (August), except for sand-blasted common grout. The greatest pull off strengths were associated with tensile stress failures in the concrete, and the lower pull-off strengths occurred with interface bond failures. Of the two slabs exhibiting interface bond failures, EGW (epoxy grout, water blasted) had the lower pull-off strength at 158 psi, which is lower than the currently specified minimum value of 175 psi. GS (common grout, sand blasted) exhibited a higher strength at 245 psi. The other two experimental groups exhibited concrete tensile failures at 300 psi for EGS and 356 psi for GW, indicating that the developed bond strength was higher than the tensile strength of the constitutive materials.

Figure 17 presents the pull-off test results over time for the second set of slabs (October casting). Pull-off strengths for the epoxy grout slabs had little variation at each sampling age and exhibited similar pull-off strengths after 7 days, though all pull-off values were below the ODOT specified minimum of 175 psi (Figure 17a). It is noteworthy that the epoxy grout pull-off strengths from the October slabs (Figure 17) are substantially – 50-75 percent – less than the pull-off strengths noted for the August specimens (Figure 16), and the observed failure mode was consistently interface failure. It is believed ambient conditions played a role in the strength development of the bond. For the October specimens grout materials were mixed at temperatures within the manufacturers' recommendations and were largely cured outside in ambient conditions, though slabs were brought inside if freezing temperatures were predicted.

Many attempts to perform the pull-off tests resulted in adhesive failure of the test dolly (Figure 18c); "adhesive failures" occurred when the test dolly separated from the test site before a tensile failure occurred in any part of the test specimen. Glue adhesion failures were prevalent in the common grout test specimens (Figure 17b); only the GS experimental group at 28-days failed at the pour-back interface. Due to the numerous adhesion failures, it is not possible to characterize the bond strength development over time. However, as the exhibited failure mode was epoxy adhesion failure, the interface strengths for these specimens was at least this value. It cannot be determined how much stronger the interface bond strength would be, but the upper bound of the recorded test data is consistent with the other slabs. It is likely that GW and GS test specimens met the 175-psi minimum bond strength after 14-days. The 28-day test results of the October specimens indicate a lower strength than was indicated by the August specimens but still exceed the specified minimum strength. It is likely, however, that the bond strength and failure mode were affected by the different ambient curing conditions from the August specimens; it is expected, but cannot be verified with the current data, that warmer conditions would have increased the bond strength and caused a concrete tensile failure.

Figure 18a shows a typical concrete tensile failure; most concrete tensile failure planes were observed to occur approximately 0.5 inches from the interface and were generally parallel to the interface plane. Some surface variation resulted from the distribution of coarse aggregates in the test area. No tensile failures were observed in either the common grout or epoxy grout portion of the test specimens. Failures occurring at the interface of the two materials provide a measure of the bond strength and are termed “interface failures” (Figure 18b).



* October test specimens

Figure 16. 28-Day Pull-off Test Results

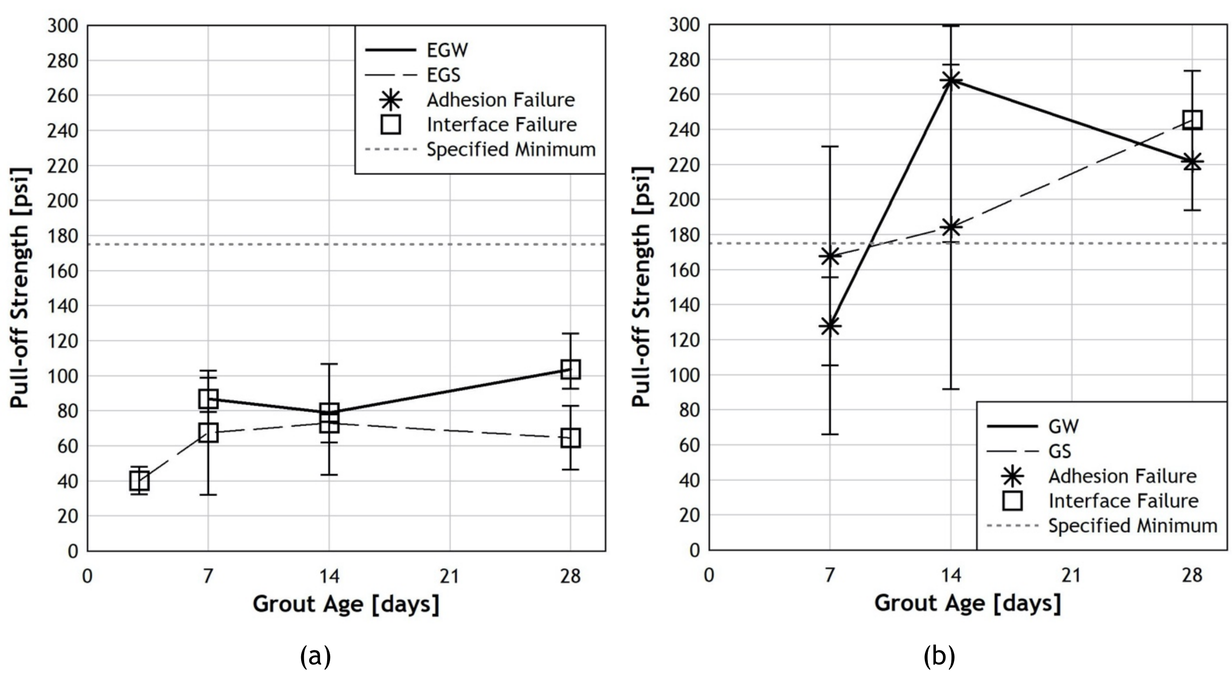


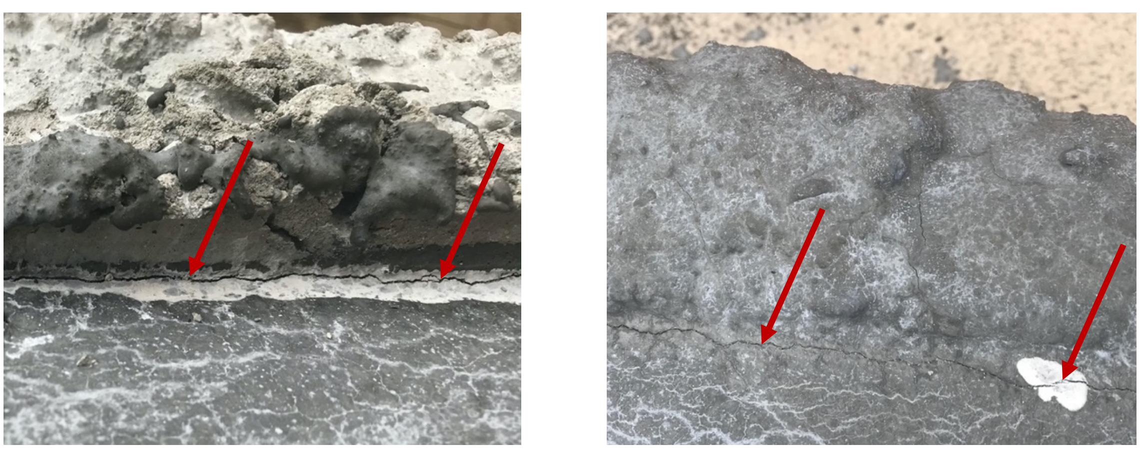
Figure 17. Pull-off Strength Over Time – October Specimens

(a) (b) (c)

Figure 18. Pull-off Test Failure Modes: (a) concrete tensile failure, (b) grout-concrete interface failure, and (c) epoxy adhesion failure

Anchorage Mock-ups

One anchorage mock-up was cast for each experimental group (Figure 21). Approximately 48-hours after the grout was placed, small cracks began to appear at the interface between the concrete and grout in the common grout specimens. These cracks could have been reflective cracks or the result of grout shrinkage. These cracks were monitored throughout the curing process. At the time when the mock-ups were cored, an approximately 0.4-millimeter-wide crack was documented with a feeler gauge consistently around the edge of each common grout pour-back, both in locations where the grout spilled over the anchorage region and in regions where the grout was below the concrete (Figure 19). No cracks were observed in epoxy grout specimens. Coring was planned to determine the depth of these cracks and compare between experimental groups. The cracks were stabilized with epoxy adhesive, but due to the vibrations introduced during coring, most of the cores separated along the concrete-grout interface, prohibiting conclusive crack depth and post-extraction examination (Figure 20).

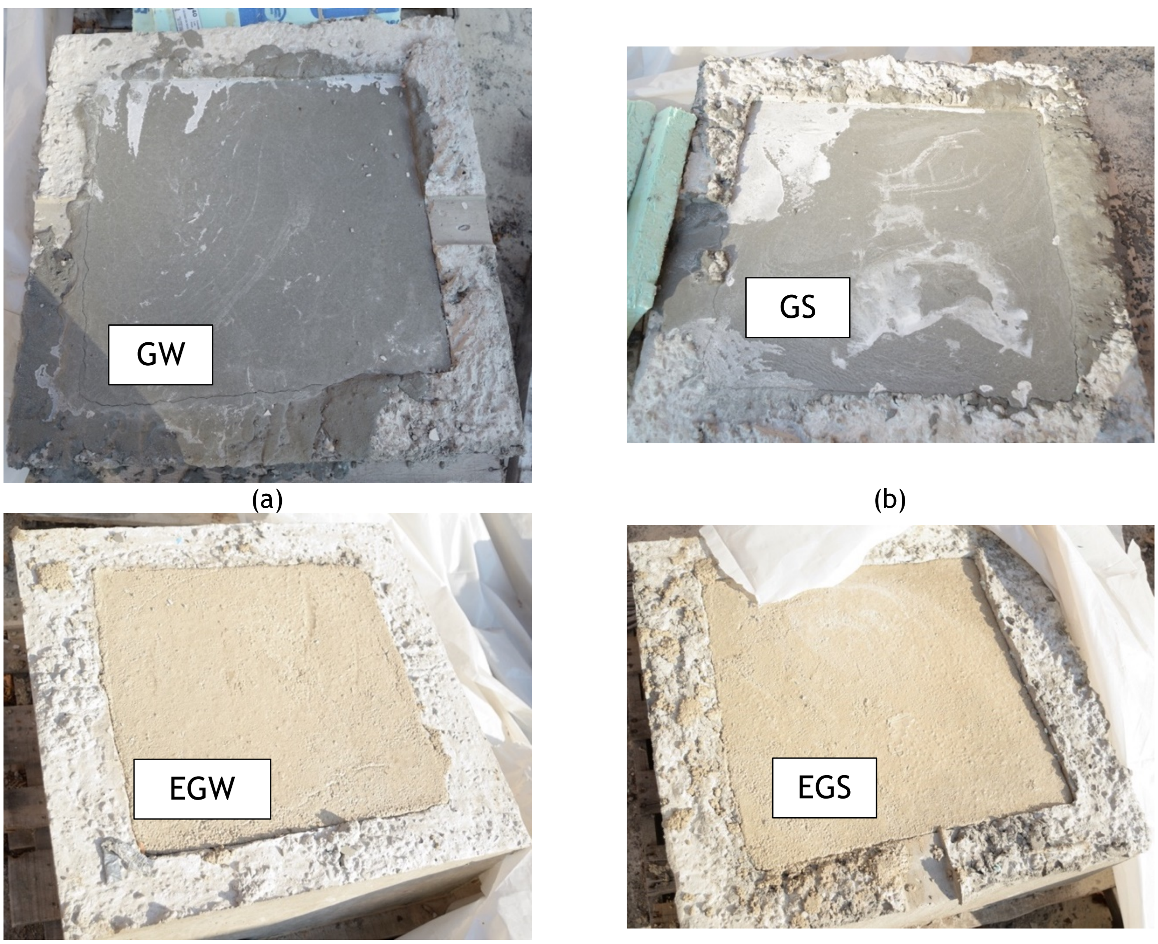


(a) (b)

Figure 19. Typical 0.4mm cracks in common grout mock-ups: (a) crack in recessed grout area and (b) crack in grout spill-over area

(a) (b) (c)

Figure 20. Mock-up Coring: (a) typical sealed crack, (b) typical epoxy grout mock-up core, and (c) typical common grout mock-up core



(c) (d)

Figure 21. Mock-ups 28-days after grout casting: (a) GW, (b) GS, (c) EGW, and (d) EGS

Discussion

For the purposes of specifications and approval testing, it is desirable understand the relationship between the bond strength and the chloride permeability of a given interface. These two parameters may be related because they both depend heavily on the porosity of the interface (15,34). The surface preparation of the interface is thought to influence the porosity of the interface (15). Thus, the surface preparation should have a significant impact on both the interfacial mechanical strength and ion permeability. To examine this idea, the results of the 28-day pull-off test were plotted against the apparent diffusion coefficients calculated from the chloride profiling for the interface test specimens (Figure 22). Also plotted on this graph are the average diffusion coefficients for the constitutive materials and the average between the constitutive materials. The average diffusion coefficient is negatively correlated with resistivity to chloride ion intrusion; a higher diffusion coefficient would mean higher chloride ion permeability as the material provides less resistance to ion intrusion. Thus, a lower apparent diffusion coefficient is desirable.

The common grout interface values had consistent diffusion coefficients for both surface preparation groups, but the water-blasted common grout interface exhibited much higher pull-off strength. Both surface preparations exhibited diffusion coefficients very close to the average diffusion coefficient between concrete and grout, suggesting that the surface preparation does not have a large impact on the permeability of the interface for common grout overlays.

The water-blasted epoxy grout had a much lower bond strength and much higher diffusion coefficient, while the sand-blasted epoxy grout group had a higher bond strength and lower diffusion coefficient. The water-blasted epoxy grout had a much higher diffusion coefficient than even the constitutive concrete material, and both points were far from the average apparent diffusion coefficient of epoxy grout and concrete. The results indicate that a more abrasive surface preparation technique provides a stronger bond with decreased opportunity for chloride permeation in epoxy grout pour-backs.

Particularly noteworthy is the common grout specimens with water-blasted surface preparations had high pull-off strengths (Figure 16) exceeding the specified minimums. These specimens also exhibited the greatest resistance to ion diffusion. While not causally related, greater pull-off strength does correlate to greater resistance to chloride ion intrusion.

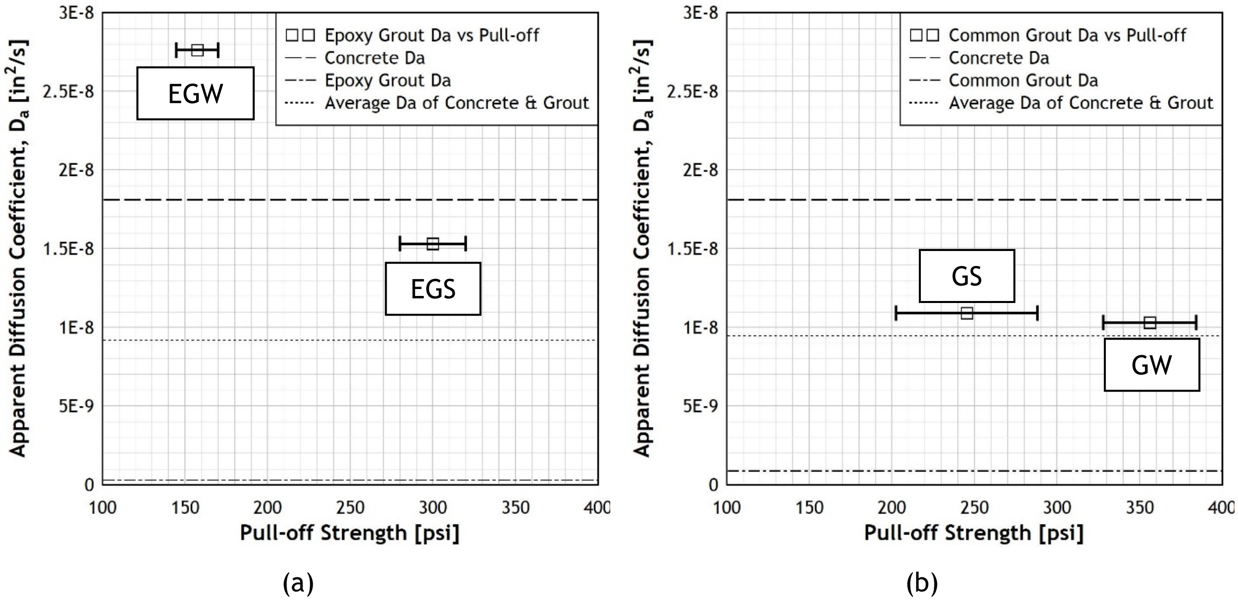


Figure 22. Apparent Diffusion Coefficient vs Pull-off Strength, 28-day: (a) Epoxy Grout Interface and (b) Common Grout Interface

Moisture Content vs Surface Roughness

In interpreting these results an important factor to consider is the bond adhesive mechanics of the overlay materials at both the micro-scale and the macro-scale. Characteristics at the micro-scale are influential to the ion permeability of the interface; the macro-scale characteristics contribute to bond strength.

On the micro-scale, common (cementitious) grout utilizes the cement hydration reaction to form hydration products that interact with the surface of the concrete substrate. The material interface in this situation behaves like the interfacial transition zone (ITZ) between cement paste and coarse aggregates in concrete, which typically reaches 10-50 micrometers from the surface of the aggregate (8).

For common grout pour-backs, the moisture content of the concrete substrate is most influential to the quality of the bond between layers; it is critical for the concrete substrate to contain sufficient moisture so that water will not be wicked out of the fresh grout, inhibiting the hydration process (35) (This is also why the moisture content of aggregates is taken into account in concrete mix design.) If moisture is wicked from the fresh grout, the interface does not sufficiently hydrate and becomes a plane of mechanical weakness. Sufficient moisture content in the substrate will enable the concrete substrate and the grout overlay to continue the hydration process after initial set and allow the formation of hydration products along the interface (6). In this case, the moisture content would play a large role in the density of hydration products along the material interface. The density of hydration products along the interface would strongly impact the permeability of the interface but may not impact the bond strength on the macro-scale.

For this study, the moisture content of the slab prior to common grout casting was kept constant following both surface preparation procedures and leading up to the placement of the pour-back. Water was ponded on the slabs for 24-hours prior to grout casting, and the standing water was removed before casting grout. It would be expected that the density of cement hydration products is similar for all common grout test specimens. Consequently, the diffusion coefficient would be similar regardless of the surface preparation technique for common grout specimens.

In epoxy grout pour-backs, alternatively, cement hydration is not a factor, so surface preparation is more important for bond mechanics. The epoxy that serves as the “cement” permeates the concrete surface and fills any voids. Because wet sand blasting is more abrasive, it is understood that the surface would be slightly rougher than a similar pressure of water blasting, allowing the epoxy compound to better penetrate the surface of the substrate. A better interlock between the layers would better prohibit ion migration on the micro-scale and increase bond strength on the macro-scale. It is hypothesized that, for this reason, the epoxy grout sand-blasted specimens had greater pull-off strengths versus those prepared with water-blasting.

The effect of temperature at casting

As noted above, the epoxy grout pull-off strengths for the October specimens were only 30-50% of the strength reported for specimens cast in August. This is likely due to the ambient temperature at casting. The August grout specimens were cast when the average daily temperature was approximately 80°F, but the October specimens were cast when the average daily temperature was approximately 45°F. This temperature is above the epoxy grout manufacturer’s minimum temperature recommendation of 40°F. It was observed that during the October casting the epoxy grout had a much lower flow and greater viscosity than when cast in a higher temperature. Additionally, the temperature of the concrete substrate was approximately equal to the ambient temperature. It is hypothesized that the epoxy grout cooled when it came into contact with the substrate, resulting in an increased viscosity. As a result, it can be expected that the epoxy would not penetrate the substrate as well due to this higher viscosity (36). Reduced penetration of the epoxy would prohibit good adhesion between the pour-back and the substrate, decreasing the bond strength.

Conclusion

Pour-backs require a material that is dimensionally stable, durable, and resistant to chloride ion intrusion. Epoxy grout with a wet-sand blasted substrate best meets these criteria. The mock-ups indicate that epoxy grout pour-backs are more resistant to cracking at early ages than common grout. Early-age cracking can significantly affect the long-term performance of the structure. Additionally, epoxy grout by itself had the lowest apparent diffusion coefficient of any material tested (Figure 10). The sand-blasted epoxy grout interface had a comparable apparent diffusion coefficient and pull-off strength to the common grout groups (Figure 22). Balancing all the considerations – pull-off strength, chloride permeability, and dimensional stability – epoxy grout seems to be the better performing material.

RECOMMENDATIONS FOR IMPLEMENTATION

Two surface preparations and two grout materials were evaluated for their performance as durable pour-back materials.

Recommendations:

- Continue to specify epoxy grout pour-back for dimensional stability
- Specify wet sand blasting surface preparation at 3,000psi.
- Inspect pour-backs following construction and initial curing for cracking.
- Consider ambient conditions prior to casting pour-back, especially in cold temperatures close to the manufacturer's minimum. Temperature of the substrate may detrimentally impact bond and performance.

Pull-off strength testing may suggest that common grouts out-perform epoxy grouts in terms of mechanical strength, however, epoxy grouts provide improved dimensional stability, reducing the likelihood of cracking at the interface. Wet sand blasting surface preparation improved the performance of epoxy grout pour-backs.

While all experimental work was performed within the bounds of the grout manufacturers' specified temperature and humidity ranges, significant effects were noted between the August and October specimens, suggesting that ambient conditions played a large role in the bond development between the pour-back material and the substrate. This observation was noted in both surface preparations. Investigation of these effects were not within the scope of this effort, but should be considered as influential in the durability of pour-backs.

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APPENDIX – FULL RESULTS

Compressive Strength Testing Full Results

Table 6. 4x8 Concrete Cylinder Compressive Strength Testing Results				
Concrete Cast August 24				
	Date:	9/19/2020		
		Compressive stress at failure [psi]	**f'c**	
Age at Testing	**Cylinder Number**		**Average f'c, psi**	**Stdev**
21-days	1	4875	4807	65.21
	2	4745		
	3	4801		
Concrete Cast October 20				
	Date:	10/27/20		
7-days	1	3857	3839	26.16
	2	3820		
	Date:	11/17/2020		
28-days	1	4916	4896	28.13
	2	4876		
	Date:	11/24/2020		
35-days	1	4864	5094	326.1
	2	5325		

Table 7. 28-day 2x2 Grout Cube Compressive Strength Testing Results				
Common Grout				
		Compressive Stress at Failure [psi]		
Cube Number	**Load, P [lb]**		**Average**	**Standard Deviation**
1	36481	9120	9023	512
2	37918	9480		
3	33881	8470		
Epoxy Grout				
		Compressive Stress at Failure [psi]		
Cube Number	**Load, P [lb]**		**Average**	**Standard Deviation**
1	61538	15385	15234	505
2	58684	14671		
3	62588	15647		

Chloride Profiling Full Results

Table 8. Chloride Profiling Full Results

Material		Average Layer Depth, x [mm]	Chloride Content, Cxt [% sample weight]	Initial Chloride Content, Ci [% sample weight]	Calculated Surface Chloride Content, Cs [% Sample Weight]	Apparent Diffusion Coefficient, Da [m^2/s]
Concrete		0.5	0.7390	0.0217	0.8141	1.184E-11
		1.5	0.6796			
		2.5	0.6674			
		3.5	0.5991			
		4.5	0.4980			
		5.5	0.4297			
		6.5	0.3261			
		7.5	0.2791			
Epoxy Grout-3-day		0.5	0.1249	0.0088	0.1907	2.012E-13
		1.5	0.0283			
		2.5	0.0177			
		5.5	0.0106			
		6.5	0.0142			
		7.5	0.0106			
Grout		0.5	0.8042	0.0053	1.0151	5.684E-13
		1.5	0.4116			
		3	0.1239			
		4.5	0.0071			
		6	0.0141			
		7.5	0.0088			
Interface Specimens	Water-blasted Epoxy Grout	1	0.4965	0.0195	0.5520	1.808E-11
		3	0.4407			

Table 8. continued						
Material		**Average Layer Depth, x [mm]**	**Chloride Content, Cxt [% sample weight]**	**Initial Chloride Content, Ci [% sample weight]**	**Calculated Surface Chloride Content, Cs [% Sample Weight]**	**Apparent Diffusion Coefficient, Da [m^2/s]**
Interface Specimens	Water-blasted Epoxy Grout	5	0.3681	0.0195	0.5520	1.808E-11
		7	0.2583			
	Sand-blasted Epoxy Grout	1	0.4568	0.0195	0.4983	1.003E-11
		3	0.3240			
		5	0.2805			
		7	0.1784			
	Water-blasted Common Grout	1	0.7822	0.0195	0.8785	6.724E-12
		3	0.5404			
		5	0.3714			
		7	0.2587			
	Sand-blasted Common Grout	1	0.6836	0.0195	0.7733	7.139E-12
		3	0.4958			
		5	0.3419			
		7	0.2278			

Pull-off Test Full Results

Table 9. Pull-off Test Full Results - August Specimens

Specimen	Date	Test Site Number	Strength	Failure Mode
EGW	4-Sep	1	115.5	Epoxy Adhesion
		2	116	Epoxy Adhesion
	9-Sep	Retest 1	125.4	Interface Failure in Concrete
		Retest 2	215.6	Epoxy Adhesion
		3	213.6	Epoxy Adhesion
	10-Sep	Retest 2	>580.2	Maxed out tester (not cored deep enough, so much more grout resisting)
		Retest 3	245.4	Epoxy Adhesion (bond had cured for 3 days)
	11-Sep	4	156.3	Interface Failure in Grout
		5	168.1	Interface Failure in Grout
		6	<5.0	Failure in grout -> Indicates damage during coring and was hanging by a thread
	28-Sep	7	165.5	Interface Failure in Grout
		8	163.9	Interface Failure in Grout
		9	143.1	Interface Failure in Grout
EGS	9-Sep	1	179.1	Epoxy Adhesion
		2	146.3	Epoxy Adhesion
		3	111.7	Epoxy Adhesion
	10-Sep	Retest 1	168	Epoxy Adhesion
		Retest 2	279.9	Interface Failure
		Retest 3	346.3	Concrete Tensile Failure
	11-Sep	4	400.4	Interface Failure, took 1-2mm of concrete consistently with it
		5	412.3	Interface Failure, took 1-2mm of concrete consistently with it
		6	120.6	Concrete Tensile Failure, approx 3/4" from interface

***Table 9**. continued*				
Specimen	**Date**	**Test Site Number**	**Strength**	**Failure Mode**
EGS	28-Sep	7	184.7	1/2 Concrete, 1/2 Interface
		8	304.2	Concrete Tensile Failure
		9	278.2	Concrete Tensile Failure
		10	317.6	1/2 Concrete, 1/2 Interface
GW	9-Sep	Retest 1	175.7	Epoxy Adhesion
		2	194.4	Epoxy Adhesion (bond had cured for 3 days)
		3	158.9	Epoxy Adhesion (bond had cured for 3 days)
	10-Sep	Retest 1	181.4	Epoxy Adhesion
		Retest 2	137.2	Epoxy Adhesion
		Retest 3	241.3	Epoxy Adhesion
	11-Sep	4	206.5	Epoxy Adhesion
		5	279	Epoxy Adhesion
		6	282.2	Concrete Tensile Failure, 2 1/2" deep into conc (cored too deep)
	28-Sep	7	382	Concrete Tensile Failure
		8	313.9	Concrete Tensile Failure
		9	402.5	1/2 Concrete, 1/2 Interface
		10	326.2	Interface Failure
GS	9-Sep	1	Null	Failed During Coring
		2	Null	Failed During Coring
		3	Null	Failed During Coring
		4	Null	Failed During Coring
	28-Sep	5	Null	Failed During Coring
		6	Null	Failed During Coring
		7	Null	Failed During Coring
		8	Null	Failed During Coring

Table 10. Pull-off Test Full Results - October Specimens

Specimen	Date	Test Site Number	Strength	Failure Mode
EGW	30-Oct	1	0	Interface in grout
		2	36.4	1/2 in interface, 1/2 in grout
		3	40.9	Interface in grout
	3-Nov	4	91.2	Interface in grout
		5	71.5	Interface in grout
		6	85.6	Interface in grout
		7	99.7	Interface in grout
		8	0	Interface in grout
	10-Nov	9	51.8	Epoxy adhesion
		10	78.2	Interface in grout
		11	107.1	Interface in grout
	24-Nov	12	106.1	Interface in grout
		13	125.6	Interface in grout
		14	121.2	Interface in grout
		15	79.4	Interface in grout
		16	86.9	Interface in grout
EGS	30-Oct	1	36.9	Interface in grout
		2	0	Interface in grout
		3	34.5	Interface in grout
		4	49.1	Interface in grout
	3-Nov	5	45.8	Interface in grout
		6	36.7	Interface in grout
		7	115.9	Interface in grout

Table 10. continued				
Specimen	**Date**	**Test Site Number**	**Strength**	**Failure Mode**
EGS	3-Nov	8	0	Interface in grout
		9	71.7	Interface in grout
	10-Nov	10	62	Interface in grout
		11	60.2	Interface in grout
		12	79.1	Interface in Grout - some epoxy on side of core
		13	84.7	interface in Grout - some epoxy on side of core
		14	78.8	Interface in grout
	24-Nov	15	53.1	Interface in grout
		16	44.8	Interface in grout
		17	79.7	Interface in grout
		18	80.4	Interface in grout
GW	30-Oct	1	0	Epoxy adhesion
		2	45.4	Epoxy adhesion
	3-Nov	3	107.4	Epoxy adhesion - glued on 10/28
		4	172.2	Epoxy adhesion - glued on 10/28
		5	112.9	Epoxy adhesion - glued on 10/28
		6	99.6	Epoxy adhesion
		7	117.4	Epoxy adhesion
		8	157.2	Epoxy adhesion
		9	132.5	Epoxy adhesion
	10-Nov	10	119.6	Epoxy adhesion
	12-Nov	11	89.4	Epoxy adhesion - glued on 11/9
		12	264.6	Epoxy adhesion - glued on 11/9
		13	300.6	Epoxy adhesion - glued on 11/9
		14	239.7	Epoxy adhesion - glued on 11/9

Table 10. continued				
Specimen	**Date**	**Test Site Number**	**Strength**	**Failure Mode**
GW	24-Nov	15	91.6	epoxy adhesion - glued on 11/19
		16	218.6	Epoxy adhesion - glued on 11/19
		17	224	Epoxy adhesion - glued on 11/19
		18	245.7	Epoxy adhesion - glued on 11/19
		19	199.4	Epoxy adhesion - glued on 11/19
GS	30-Oct	1	90.3	Epoxy adhesion
	3-Nov	2	249.8	Epoxy adhesion - glued on 10/28
		3	262.3	Epoxy adhesion - glued on 10/28
		4	128.8	Epoxy adhesion - glued on 10/28
		5	208.9	Epoxy adhesion - glued on 10/28
		6	132.2	Epoxy adhesion
		7	103.9	Epoxy adhesion
		8	126.9	Epoxy adhesion
		9	129.5	Epoxy adhesion
		10	51.4	Epoxy adhesion
	10-Nov	11	132.2	Epoxy adhesion
		12	133.9	Epoxy adhesion
	12-Nov	13	82.7	Epoxy adhesion - glued on 11/9
		14	264	Epoxy adhesion - glued on 11/9
		15	206.3	Epoxy adhesion - glued on 11/9
	24-Nov	16	214.9	Interface
		17	281.7	Interface
		18	127.1	Interface
		19	235.3	Interface w/ 1/3 in concrete
		20	249.5	Concrete

Table 11. Grout Product Names

Label	**Product**
Common Grout	BASF Masterflow 928
Epoxy Grout	Pilgrim Permacoat Magmaflow Grout Pak