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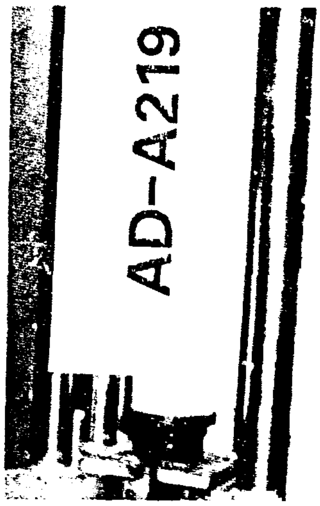

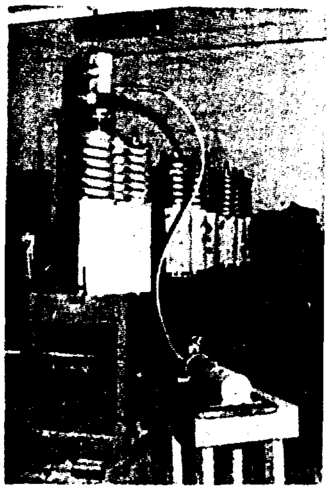

REMR RESEARCH PROGRAM

REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-CS-23

EVALUATION OF POLYESTER RESIN, EPOXY, AND CEMENT GROUTS FOR EMBEDDING REINFORCING STEEL BARS IN HARDENED CONCRETE

by

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GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

COVER PHOTOS:

TOP — Anchor pullout strength test

BOTTOM — Creep tests on air-cured specimens

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Rehabilitation of hydraulic structures usually includes removal and replacement of deteriorated concrete. Dowels are normally used to anchor the new concrete to the existing concrete and to position vertical and horizontal reinforcing steel in the replacement concrete. The purpose of this investigation was to evaluate the effectiveness of cement, epoxy, and polyester resin grouts used to embed reinforcing steel bars in hardened concrete under a variety of placing and curing conditions. The following parameters were determined for each grout: (a) physical characteristics of the grouts, (b) effects of temperature and moisture on early service performance, (c) long-term pullout strength under varying curing conditions, (d) creep strain of grout under sustained loading in both wet and dry environments, and (e) effects of hole roughness and cleanliness on grout performance.

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Beyond 1 day age, all grouts developed pullout strengths approximately equal to the ultimate strength of the reinforcing-bar anchor when the grouts were placed under dry conditions, regardless of curing conditions. With the exception of the polyester resin grout placed under submerged conditions, pullout strengths were essentially equal to the ultimate strength of the anchor when the grouts were placed under wet or submerged conditions.

The overall average pullout strength of polyester resin grout placed and cured under submerged conditions was 35 percent less than the strength of the same grout placed and cured under dry conditions. The largest reductions in pullout strength, approximately 50 percent, occurred at ages of 6 months and 16 months. Also, the overall average pullout strength of polyester resin grout placed and cured under submerged conditions was approximately one-third less than the strength of epoxy and cement grout placed under wet and submerged conditions, respectively, and cured under submerged conditions.

Polyester-resin-grouted anchors exhibited significantly higher creep than that exhibited by epoxy- and cement-grouted anchors under both wet and dry conditions. Consequently, creep data should be considered in the selection of an anchorage grout where the frictional resistance and bond between the surfaces of the two masses to be anchored together are important.

Extra care should be taken to clean all percussion-drilled holes prior to grouting, particularly when epoxy or cement grout is to be used as the anchoring material.

Although the epoxy grout performed well in these tests when placed in wet holes, it should be noted that the manufacturer does not recommend placement under submerged conditions. This recommendation and the significantly reduced pullout capacity of polyester resin grout under submerged conditions appear to make cement grout the logical choice for submerged applications.

PREFACE

The study reported herein was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), under Civil Works Research Work Unit 32303, "Application of New Technology to Maintenance and Minor Repair," for which Mr. James E. McDonald is Principal Investigator. This work unit is part of the Concrete and Steel Structures Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program sponsored by HQUSACE. Mr. Jesse A. Pfeiffer, Jr., is the REMR coordinator in the Directorate of Research and Development, HQUSACE. The Overview Committee at HQUSACE for the REMR Research Program consists of Mr. James E. Crews and Dr. Tony C. Liu. Technical Monitor for this study was Dr. Liu.

This study was monitored by the Structures Laboratory, US Army Engineer Waterways Experiment Station (WES) and conducted by the Singleton Materials Engineering Laboratory (SME), Tennessee Valley Authority, under Support Agreement WESSC-85-01/TV-66369A. All testing was conducted under the direct supervision of Mr. J. Floyd Best, Supervisor, Concrete and Soils Unit, and under the general supervision of Mr. William H. Childres, Laboratory Supervisor, SME. The study was performed under the general supervision of Messrs. Bryant Mather, Chief, Structures Laboratory (SL), WES, and Kenneth L. Saucier, Chief, Concrete Technology Division (CTD), SL, and under the direct supervision of Mr. McDonald, CTD. Messrs. Best and McDonald prepared this report. Program Manager for REMR is Mr. William F. McCleese, CTD. The report was published by the Information Technology Laboratory, WES, with final editing by Mrs. Gilda Miller.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
centipoises	0.001	pascal-seconds
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
fluid ounces	0.02957353	litres
fluid ounces per cubic yard	0.038680715	litres per cubic metre
fluid ounces per pound (mass)	65.1896	millimetres per kilogram
foot pounds (force)	1.355818	newton metres
inches	25.4	millimetres
kips (force)	4.448222	kilonewtons
kips per square inch	6.894757	megapascals
pounds (force) per square inch	0.006894757	megapascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (mass) per cubic yard	0.5932764	kilograms per cubic metre

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F-32). To obtain kelvin (K) readings, use: K = (5/9)(F-32) + 273.15.

EVALUATION OF POLYESTER RESIN, EPOXY, AND CEMENT GROUTS FOR EMBEDDING REINFORCING STEEL BARS IN HARDENED CONCRETE

PART I: INTRODUCTION

Background

1. Rehabilitation of navigation locks usually includes removal and replacement of deteriorated concrete on lock walls. Dowels are normally used to anchor the new concrete facing to the existing concrete walls and to position vertical and horizontal reinforcing steel in the concrete facing. In most cases, these dowels are embedded in drill holes using prepackaged polyester resin grouts. Field pullout tests on anchors installed under dry conditions indicate this to be a satisfactory procedure.

2. Failures of anchors embedded in polyester resin grout under wet conditions have been reported. Prepackaged polyester resin was used in 1976 to embed steel anchor bolts underwater in the stilling basin at Old River Control Structure (McDonald 1980). These bolts were used to anchor prefabricated steel modules of 1/2-in.* steel plate positioned between the downstream row of baffles and the end sill. A diver inspection about 8 months following completion of the repairs reported a number of anchors broken flush with the module plate, flush with the grout, or pulled completely out of the concrete. Additional failures were reported in subsequent inspections.

3. Cement grouted anchors were specified for lock wall stabilization at Lock 3, Monongahela River (Krysa 1982). As an option, the contract allowed the use of resin-grouted anchors. The contractor proposed a hybrid system using resin grout within the anchorage length in rock and cement grout within the concrete lock wall. The manufacturer of the polyester resin recommended a 2-1/4-in.-diam drill hole within the anchorage length for proper mixing of the 1-3/4-in.-diam cartridge with a 1-1/4-in.-diam bar. A 4-1/2-in.-diam drill hole was used within the lock wall. The anchors were installed and grouted under wet conditions. Using this procedure resulted in the contractor being unable to stress 35 anchors in the middle and river walls to the design load.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

4. A failed anchor was removed from the middle wall and closely examined for any possible explanation of the failures. The general appearance of the bar in the anchorage zone indicated the polyester resin grout had not bonded to the bar. The lower 5 ft had a light gray material lodged between the deformations of the bar that appeared to be polyester resin. However, this grout was soft and pliable, and could easily be removed from the bar. In other reaches of the bar, the grout was not soft, and it was harder to remove from the bar. The contractor claimed that improper mixing occurred because the hole was enlarged due to the caving of the hole in the poor rock. To determine if the 2-1/4-in.-diam hole was possibly being enlarged during drilling, the hole from which the failed anchor was removed was grouted with a reddish grout, and a core boring was taken. The core showed the hole was consistently 2-1/4-in. in diameter.

5. In the interest of better consistency and progress in the anchor installation, the Corps recommended a portland-cement grout system be used to anchor the bars. The contractor began to drill a 4-1/2-in.-diam hole full length and used cement grout. The anchors were tensioned after 9 days and the stressing length grouted. This produced more consistent results and far fewer failures. This method was used to install approximately one-fourth of the anchors on the middle wall and three-fourths of the anchors of the river wall.

Purpose and Scope

6. The purpose of this investigation was to evaluate the effectiveness of different types of grouts used to embed reinforcing steel bars in hardened concrete under a variety of placing and curing conditions. Such bars are frequently used as dowels to anchor new concrete to existing concrete when making repairs to locks and dams.

7. Since the ambient conditions and construction methods may vary from site to site, a program was developed to determine the following parameters for each grout tested.

Phase 1 - Physical Characteristics of the Grouts

Phase 2 - Effects of Temperature and Moisture on Early Service Performance

Phase 3 - Long-Term Pullout Strength Under Varying Curing Conditions

Phase 4 - Creep Strain of Grout Under Sustained Loading in Both Wet and Dry Environments

Phase 5 - Effects of Hole Roughness and Cleanliness on Grout Performance

8. The most commonly used materials for grouting steel dowels in existing concrete have been cement grouts and polyester resin systems. Epoxy grouts, although more costly, have also been used with success. Since at least one epoxy manufacturer now claims his product can be satisfactorily placed in damp environments (but not submerged), it was decided to include the epoxy grout with the cement and polyester resin grouts for this investigation.

PART II: LABORATORY INVESTIGATION

9. A study was initiated in April 1985 to evaluate selected grout systems for embedment of anchors in concrete. Three generic types of grout were tested: a portland cement-water grout with an expansive grout additive and accelerator; a two-component epoxy system mixed with silica sand; and a polyester resin grout preproportioned by the manufacturer and sold in mylar-encased cartridges. The cement and epoxy grouts could be pumped into the drill hole with the bar in the place or under dry conditions could be poured into the hole prior to inserting the reinforcing bar. The polyester grout cartridges were first dropped into a drill hole, after which the reinforcing bar was inserted with enough force to break the mylar capsule, and the bar was then rotated in the hole at 100 rpm for 30 sec to mix the grout. The manufacturer of the polyester resin stated that the grout could be placed and cured underwater or in the dry, whereas the epoxy manufacturer did not recommend underwater placement. Instead, they suggested removal of excess water from the drill hole prior to grouting, then resubmerging the test specimens after grouting. The grout manufacturer's recommendations were followed in preparation of test specimens.

10. With the exception of Phase 1, test specimens generally consisted of 6- by 18-in. concrete cylinders into which 3/4-in.-diam reinforcing bars were grouted to a depth of 15 in. in a nominal 1-1/8-in.-diam hole. Specimens were fabricated and stored under both dry and submerged conditions (Figures 1 and 2). Pullout strength tests were conducted at seven different ages ranging from 1 day to 32 months.

11. Phase 1 testing was structured to determine the physical characteristics of the grouts to be evaluated, in addition to the properties of the concrete and steel reinforcing bars used to fabricate the pullout test specimens. Tensile and elongation tests were conducted on steel reinforcing bars, and compressive strength and modulus of elasticity were determined for the concrete. Each of the three grouts evaluated were tested for the following properties: gel time or time of setting, viscosity of the polyester resin and epoxy, tensile strength, compressive strength, modulus of elasticity, bond strength using the slant-shear method, shrinkage/expansion, and thermal compatibility with concrete.

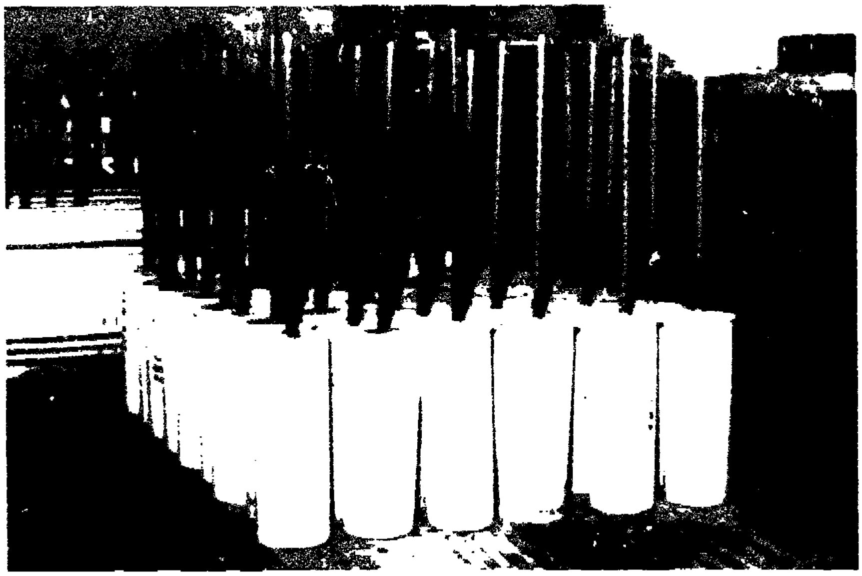


Figure 1. Pullout test specimens stored under dry conditions

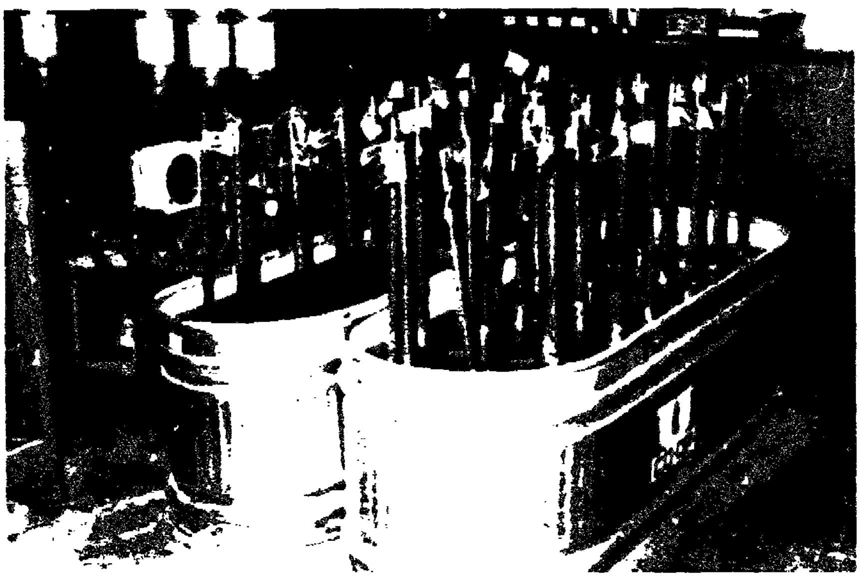


Figure 2. Pullout test specimens stored under submerged conditions

12. Phase 2 testing attempted to compare the effects of temperature and moisture on the placement and early service performance of the grouts. Pull-out strength tests were conducted at ages of 1, 3, and 7 days for anchors grouted under the following conditions.

Grout Placing Conditions	Curing Temperature, °F	Curing Condition after Grouting
Dry	70	Continuously dry
Submerged*	70	Continuously submerged
Submerged*	40	Continuously submerged
Dry	70	Continuously submerged
Dry	40	Continuously submerged

* Except for epoxy placed under wet conditions.

Exceptions to the above testing parameters were made in the "submerged" placing of the epoxy grout in which the concrete specimen was wet but not submerged. Also, the continuously submerged curing conditions for both the epoxy and polyester resin grouts placed in dry holes were not begun until the grout had air cured for 24 hr. Figures 3 and 4 show a typical underwater installation for the polyester resin grout, and Figure 5 illustrates the method of underwater pressure grouting used for the cement grout.

13. Testing for Phase 3 was similar to that for Phase 2, except that no specimens were cured at 40° F, and testing ages were of longer durations of 1, 3, 6, 16, and 32 months. Similar to Phase 2, the three specimens for Phase 3 were tested at each age for each curing and placing condition and are summarized in the following tabulation:

Placing Condition	Curing Condition
Submerged*	Continuously submerged
Submerged*	Alternating wet-dry (7-day cycles)
Dry	Continuously submerged
Dry	Continuously dry
Dry	Alternating dry-wet (7-day cycles)

* Except for epoxy placed under wet conditions.

Figure 3. Placing polyester resin grout cartridge in drill hole under submerged specimen

Figure 4. Spinning reinforcing bar into submerged drill hole containing grout cartridge

Figure 5. Pressure grouting with cement grout under submerged conditions

The same exceptions for Phase 2 apply relating to the wet placing of epoxy grout and the commencement of submerged curing for the epoxy and polyester resin grouts.

14. Phase 4 was confined to measuring the long-term creep strain of specimens grouted and cured under both wet and dry conditions. Six specimens were grouted with each of the three test grouts. Three anchors were embedded in dry, percussion-drilled holes, and the other three were embedded underwater (except for the epoxy) also in percussion-drilled holes. Pullout specimens grouted dry were subjected to air curing during creep tests while those grouted in wet or submerged conditions were subjected to submerged curing during the tests. The lower end of each cylinder was sawed off to expose the steel bar extremity so movement at this end could be monitored using a dial extensometer. Approximately 1 week after grouting, each pullout specimen was subjected to a sustained load of 60 percent of the yield strength of the

reinforcing steel bar. Deflections of the anchor at the end of the specimen opposite the loaded end were measured periodically during the 6-month test period. Figures 6 and 7 show creep test setups for both dry and submerged curing.

15. Limited testing in Phase 5 evaluated the effects of hole roughness and cleanliness on 28-day pullout strengths. Vertical holes drilled with both diamond-tipped core barrels and rotary percussion bits were grouted under water (except for the epoxy, for which the specimens were removed and holes drained of excess water). One-half of the holes were cleaned of debris and cuttings prior to grouting and the remaining one-half were left uncleaned. Pullout tests were then conducted after 28 days of submerged curing.

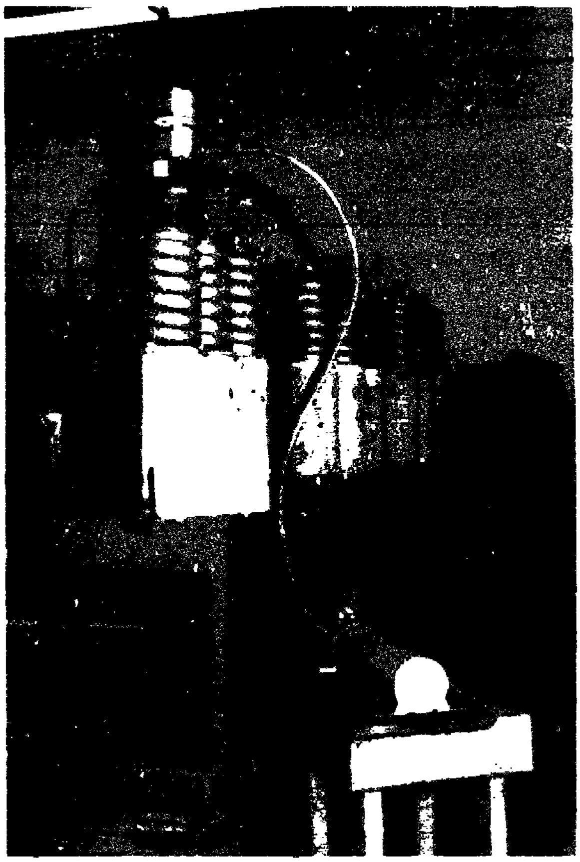


Figure 6. Typical setup for creep tests on air-cured specimens

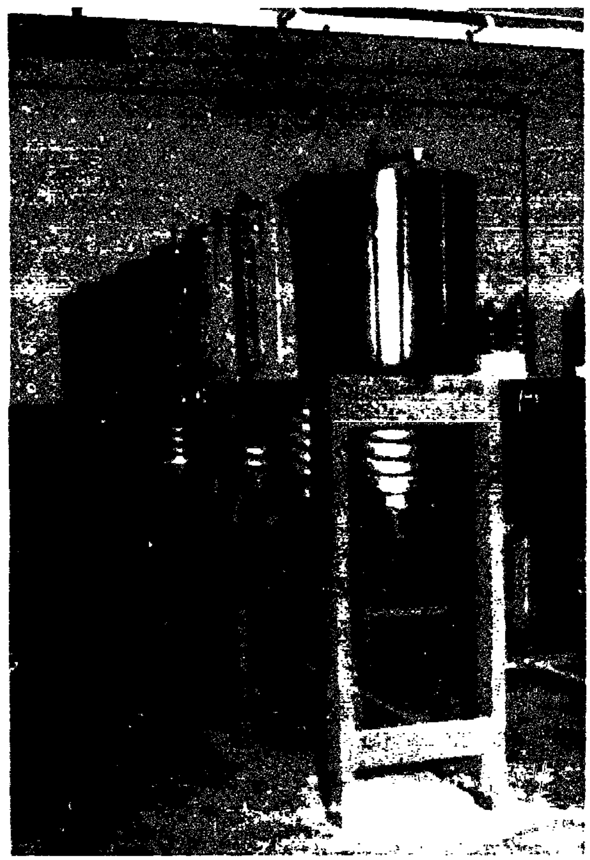


Figure 7. Creep tests on submerged specimens

PART III: TESTS RESULTS

16. Mixture proportions for the concrete used to fabricate the pullout test cylinders are shown in Table 1 along with proportions used for the cement and epoxy anchor grouts. The polyester grout is preproportioned in mylar cartridges and needs no blending prior to being placed in the anchor hole. However, since a bulk grout was needed to fabricate specimens for physical characteristics in Phase 1, a sample of polyester resin grout said to contain the same components as the cartridges was obtained from the resin manufacturer. Mechanical properties of the grade 60 reinforcing steel bars, determined in accordance with the American Society for Testing and Materials (ASTM) A 370-86a (ASTM 1987h) are shown in Table 2.

Physical Characteristics of the Grouts

Time of setting

17. Time of setting for the three grout types was determined in accordance with ASTM C 807-83 (ASTM 1987d). Results of these tests are shown in Table 3. As expected, cooler temperatures increased the setting time for the polyester resin and cement grouts. The epoxy grout manufacturer recommended two different grout products for testing at 70° and 40° F, however. The Epoxy A for use at moderate to warm temperatures had an initial setting time of 5 hr 15 min at 70° F, while Epoxy B set after 1 hr 10 min at 40° F. Since initial and final set occur essentially at the same time for the epoxy and polyester grouts, final set was determined only for the cement grout.

Viscosity

18. The viscosity or flowability of both the epoxy and polyester grouts was determined in accordance with ASTM D 2393-86 (ASTM 1987i). Results of these tests, conducted at 70° and 40° F are shown in Table 4. Flowability of both grouts was good at 70° F but decreased as expected at 40° F. The epoxy was still considered quite pourable at 40° F with the approximate consistency of syrup. The polyester resin was thicker being roughly equivalent to honey in consistency. It was considered moderately pourable at 40° F.

Tensile and compressive strength

19. All specimens were fabricated in dry molds then placed in the moist curing room (immediately for the cement, after 24-hr air curing for the epoxy

and polyester) until the time of testing. Compressive strength tests were conducted in accordance with ASTM C 39-86 (ASTM 1987f) and ASTM C 109-86 (ASTM 1987g). Results of these tests are shown in Table 5. Tensile tests were performed in accordance with ASTM C 307-83 (ASTM 1987c) for the cement grout (Figure 8) and ASTM D 638-84 (ASTM 1987e) for the epoxy and polyester grouts (Figure 9). Results of these tests are shown in Table 6. While the polyester grout had the highest 28-day compressive strength, the epoxy grout

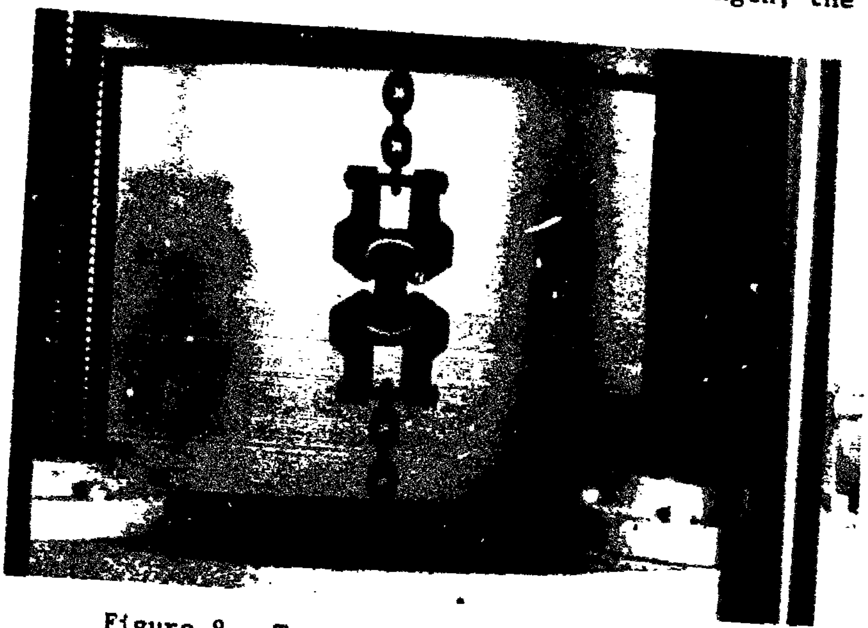


Figure 8. Tensile testing of cement grout

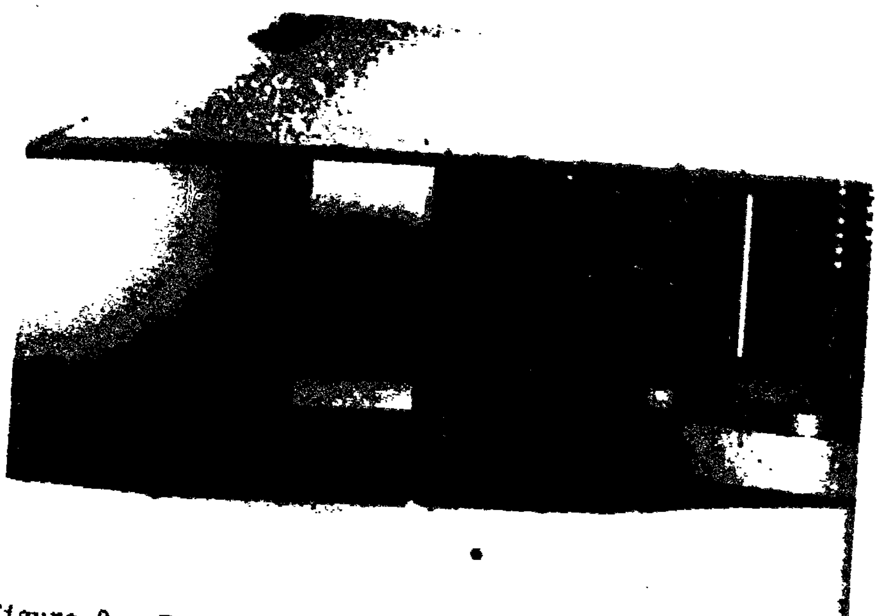


Figure 9. Tensile testing of epoxy and polyester grouts

was higher in tensile strength and also had the highest ratio of tensile to compressive cube strength at 38 percent. Comparative ratios for the polyester and cement grouts were approximately 15 and 5 percent, respectively. Ratios of cube strength to cylinder strength ranged from about 1.2 for the epoxy and polyester grouts to about 1.5 for the cement grout.

20. To determine if wet or dry curing has a significant effect on compressive strength of the anchor grouts, 2-in. cubes were made for continuous storage in both submerged and laboratory air conditions. Individual test results for both types of curing are shown in Table 7. Average test results for specimens cured under submerged conditions are shown in Figure 10. After a curing period of 32 months, the submerged-cured polyester specimens averaged 37 percent less strength than air-cured specimens while the epoxy experienced a similar reduction of 26 percent (Table 7). Strengths of submerged cement cubes were about 5 percent higher than that of companion air-cured specimens.

<u>Modulus of elasticity</u>

21. Elastic moduli shown in Table 8 are similar for the three grout types, although the epoxy modulus is slightly lower than that of the cement and polyester grouts. The modulus of elasticity was determined by ASTM C 469-87 (ASTM 1987j), using the electronic compressometer shown in Figure 11.

<u>Slant shear bond strength</u>

22. Slant-shear bond strength tests, conducted in accordance with ASTM C 882-78 (1983) (ASTM 1987a), were performed on specimens fabricated and cured

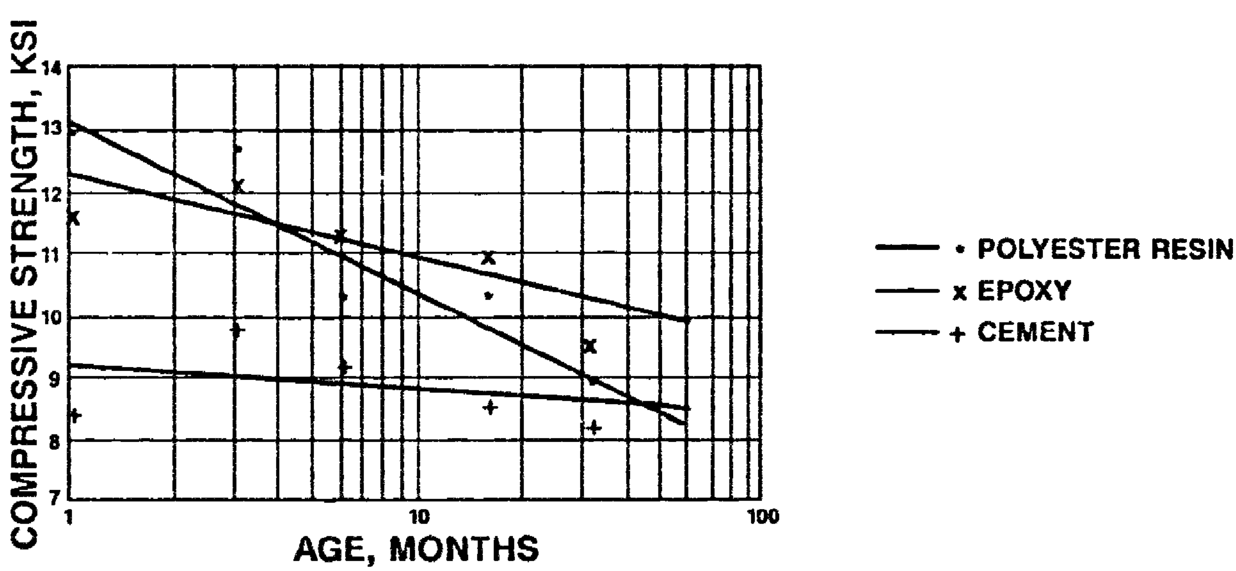


Figure 10. Results of compressive strength tests on submerged specimens

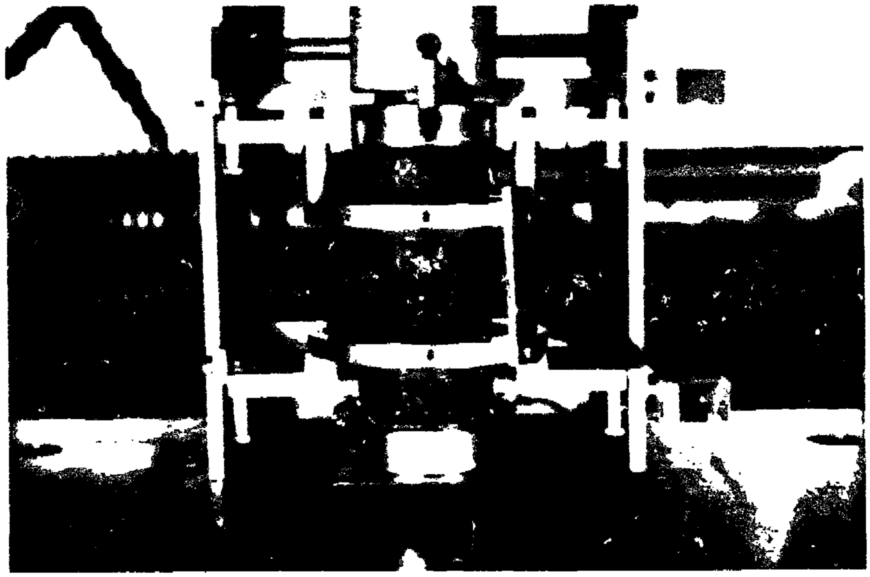


Figure 11. Typical setup for modulus of elasticity

under both wet and dry conditions. The two bonded cylinder halves were tested at ages up to 28 days using the standard cylinder compression test (Figure 12). Test results are shown in Table 9.

23. A significant correlation existed between dry bond strength and testing age for both the cement and polyester resin grouts. Bond strengths for the polyester resin grout were considerably higher than those for the cement grout but lower than the epoxy grout at all testing ages for dry conditions (Figure 13). No significant correlation existed between the dry bond strength and age of the epoxy grout although there was a trend toward a slight reduction with age.

24. A significant correlation existed between wet bond strength and testing age for the cement and polyester resin grouts. The bond strength of polyester resin specimens, fabricated by applying the resin to wet concrete surfaces and immediately submerging in water, decreased from 1,660 psi at 1 day to 1,270 psi at 28 days age. The wet bond strength of polyester resin specimens at 28 days was approximately 50 percent less than the dry bond strength. The cement grout specimens were fabricated by applying the grout to wet concrete surfaces and allowing the grout to reach initial set prior to submerging. Bond strength increased from 610 psi at 1 day to 2,440 psi at 28 days age.

25. The epoxy grout specimens were fabricated by applying the epoxy to

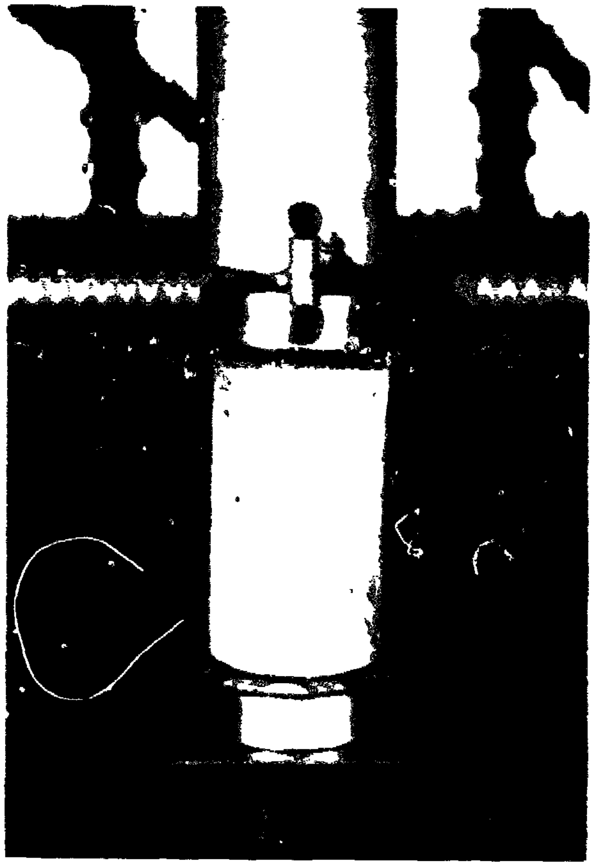


Figure 12. Slant-shear bond strength tests

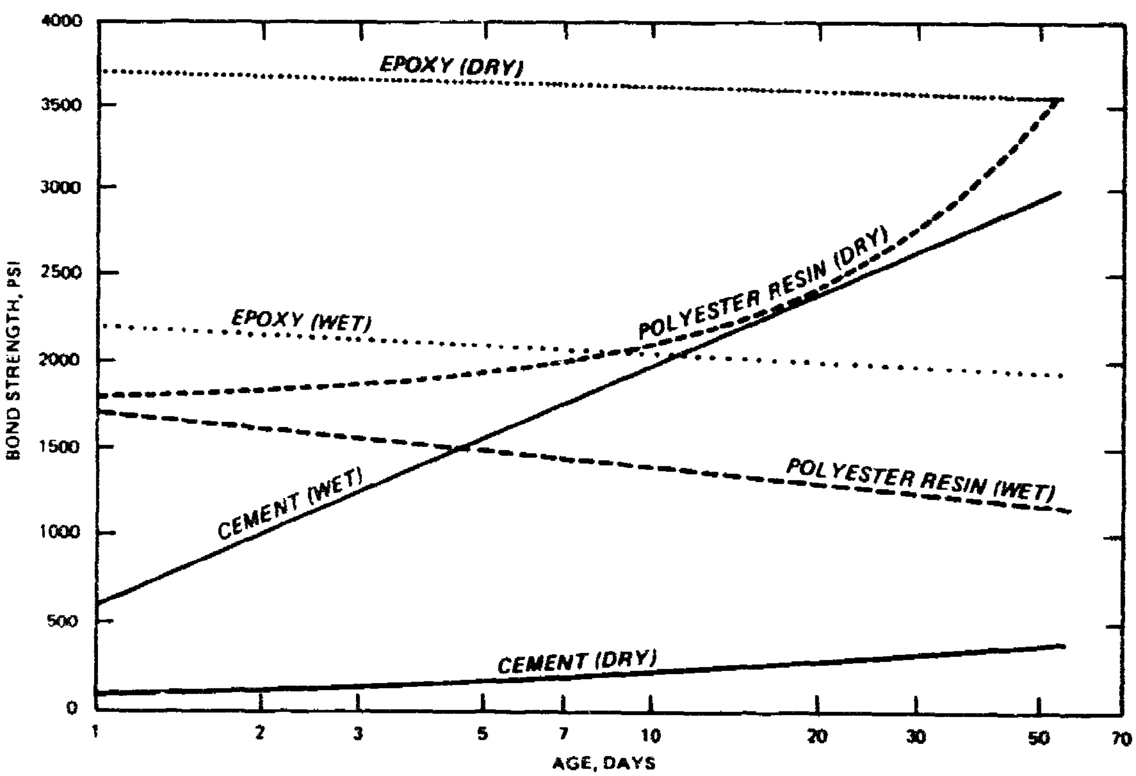


Figure 13. Results of slant-shear bond strength tests on grouts placed and cured under wet and dry conditions

wet concrete surfaces, allowed to air cure for 7 days, then submerged until tested. There was no significant correlation between the wet bond strength of epoxy grout and testing age, although a trend toward a slight reduction with time was indicated. Wet bond strengths of the epoxy ranged from 1,640 to 2,350 psi with an overall average of 2,100 psi, approximately 40 percent less than the average dry bond strength.

Shrinkage/expansion of grouts

26. Volume change of the grouts as determined by the light projection method (ASTM C 827-87 (ASTM 1987k) are shown in Table 10. Both the polyester resin and epoxy grouts showed volume decreases of over 2 percent at initial set while the cement grout with the expansive additive exhibited 0.5 percent expansion. The shrinkage of the polyester and epoxy grouts is likely due to cooling from peak reaction temperatures. After 2 days of additional air curing, the polyester resin showed no further shrinkage while the epoxy volume decreased an additional 2.5 percent and the cement grout volume was reduced by 1 percent. Since the epoxy generates higher reaction temperatures than the polyester resin, the additional epoxy shrinkage probably represents further cooling to room temperature while drying shrinkage is the probable cause of the cement grout volume reduction.

27. Shrinkage of the magnitude measured in these tests is not likely to occur in field use, since the concrete structure should serve as a heat sink for transferring reaction temperatures from the polyester resin and epoxy grouts. The structure should also act as an autogenous curing medium for the cement grout, thus reducing drying shrinkage.

Thermal compatibility with concrete

28. Table 11 includes an evaluation of the adhesion of a 1/2-in. layer of each grout placed on a concrete test block. The test method, ASTM C 884-78 (1983) (ASTM 1987b), specifies stripping of forms after 24 hr and air curing for 7 days followed by 24-hr cycles of alternating freezing and thawing. However, in each of the polyester resin and the cement grouts, the topping layer became unbonded before the specimen could be exposed to the first cycle of freezing while the epoxy withstood only one freeze-thaw cycle before concrete cracking occurred. Figures 14 through 19 show the delamination at the edges of some overlays and the amount of concrete adhering to the topping layer after failure. The test is not considered to be representative for evaluating anchorage grouts due to the smoothness of the top of the concrete

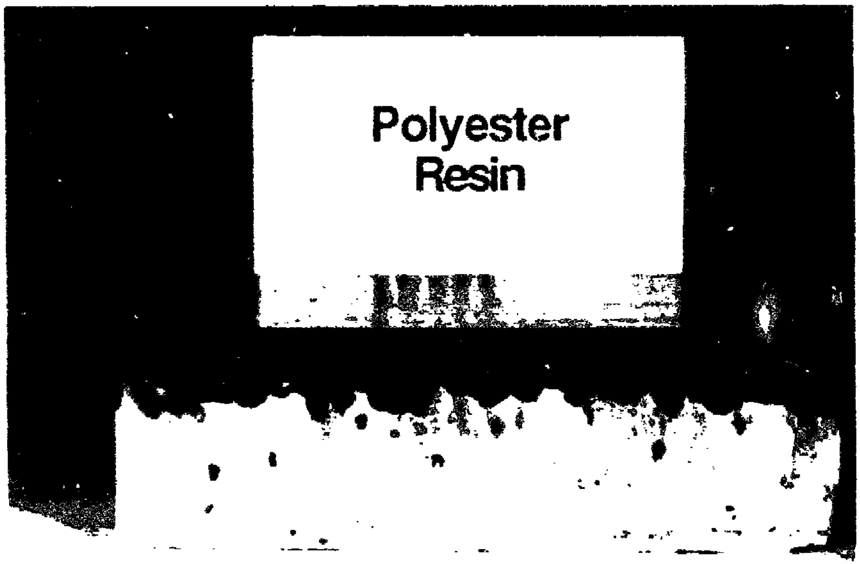


Figure 14. Polyester resin thermal compatibility test (profile)

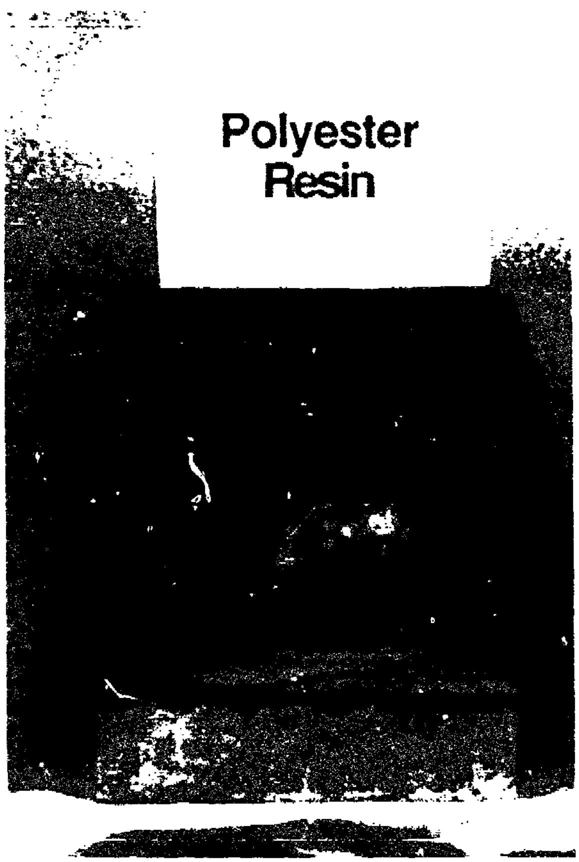


Figure 15. Polyester resin thermal compatibility test (contact surfaces)

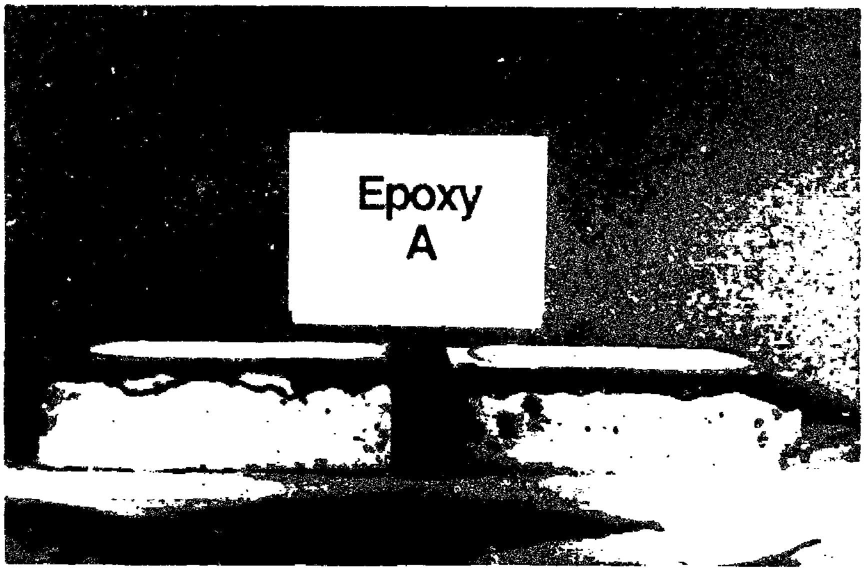


Figure 16. Epoxy A thermal compatibility test
(profile)

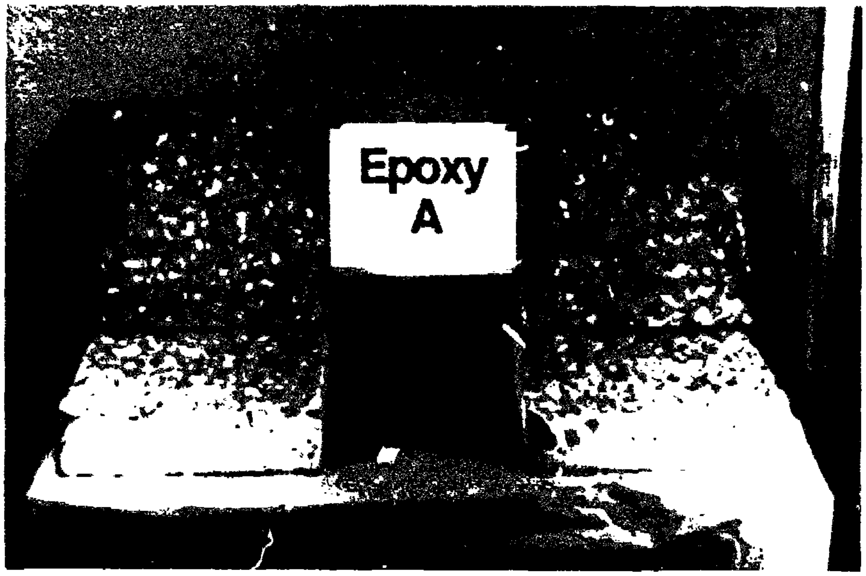


Figure 17. Epoxy A thermal compatibility test
(contact surfaces)

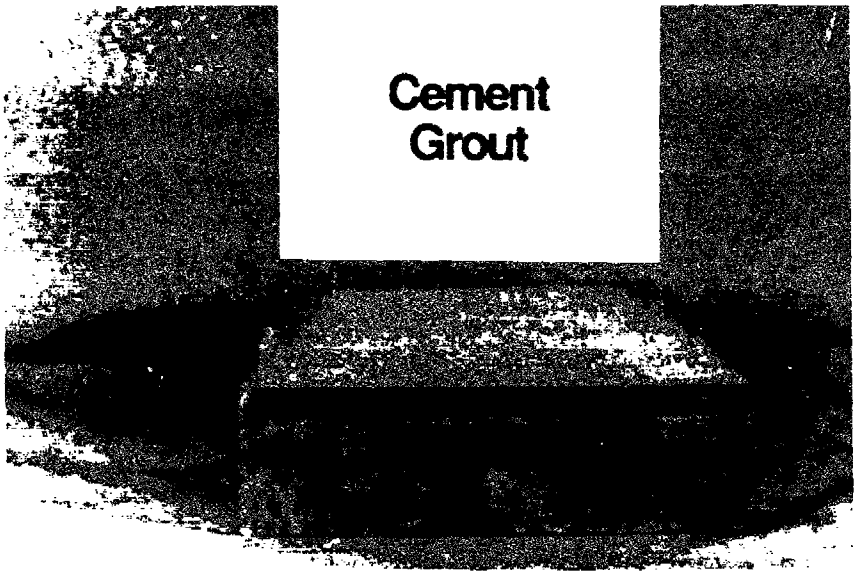


Figure 18. Cement grout thermal compatibility test (profile)

Figure 19. Cement grout thermal compatibility test (contact surfaces)

test block and the possibility that residual laitance may be present. However, the tests did illustrate the ability of the epoxy to develop a tenacious bond even under adverse conditions.

Pullout Strength Tests

29. Pullout strength tests were conducted on specimens fabricated and cured under both wet and dry conditions at eight different ages ranging from 1 day to 32 months (Figure 20). Individual test results for 10 different sets of conditions are shown in Table 12, parts a through e, and Table 13, parts a through e.

Early-age tests

30. With the exception of the cement grout tested at 1 day, all grouts developed early-age pullout strengths approximately equal to the ultimate strength of the steel bar when the grouts were placed under dry conditions, regardless of curing conditions. The pullout strengths of all grouts were generally lower for wet placement and curing conditions in comparison with dry conditions. This trend was particularly evident for the pullout strength of the polyester resin grout which was approximately 30 percent lower under submerged conditions (Figure 21). In comparison, the pullout strength of the epoxy was approximately 8 percent lower under wet conditions. While the pullout strength of the cement grout was lower under submerged conditions at ages of 3 and 7 days, the overall average was essentially the same for both submerged and dry conditions. Grout placement and curing at 40° F appeared to have little effect on the pullout strength of any of the grouts tested after 1 day age. Only the cement grout exhibited significantly lower pullout strengths at 1 day when compared to results at later ages.

Long-term tests

31. Results of pullout strength tests to determine long-term performance of embedment grouts at 70° F show that the cement, epoxy, and polyester resin grout systems perform well when the specimens were grouted under dry conditions (Figures 22a through 22c). The pullout strengths for all tests were essentially equal to the ultimate strength of the bar.

32. The results of tests on specimens grouted under submerged or wet

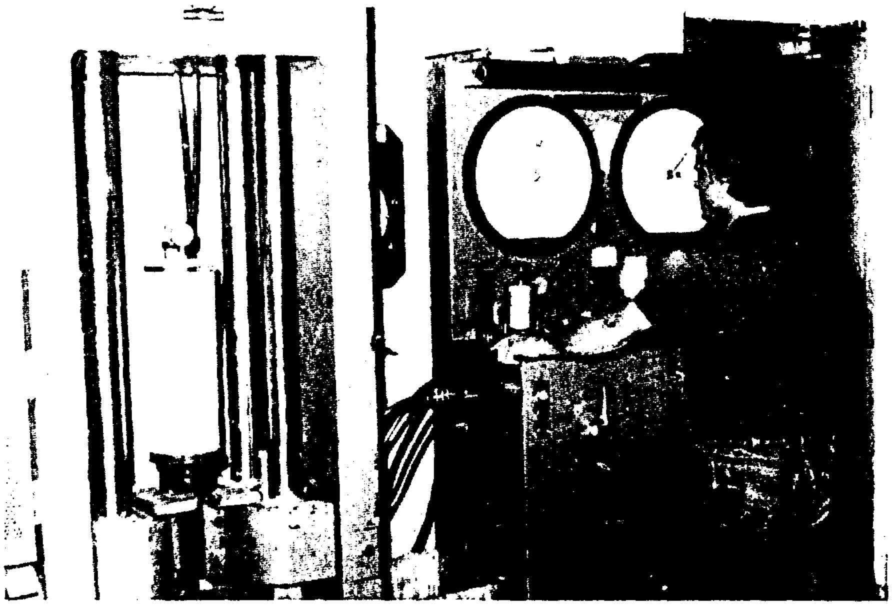


Figure 20. Typical anchor pullout strength test

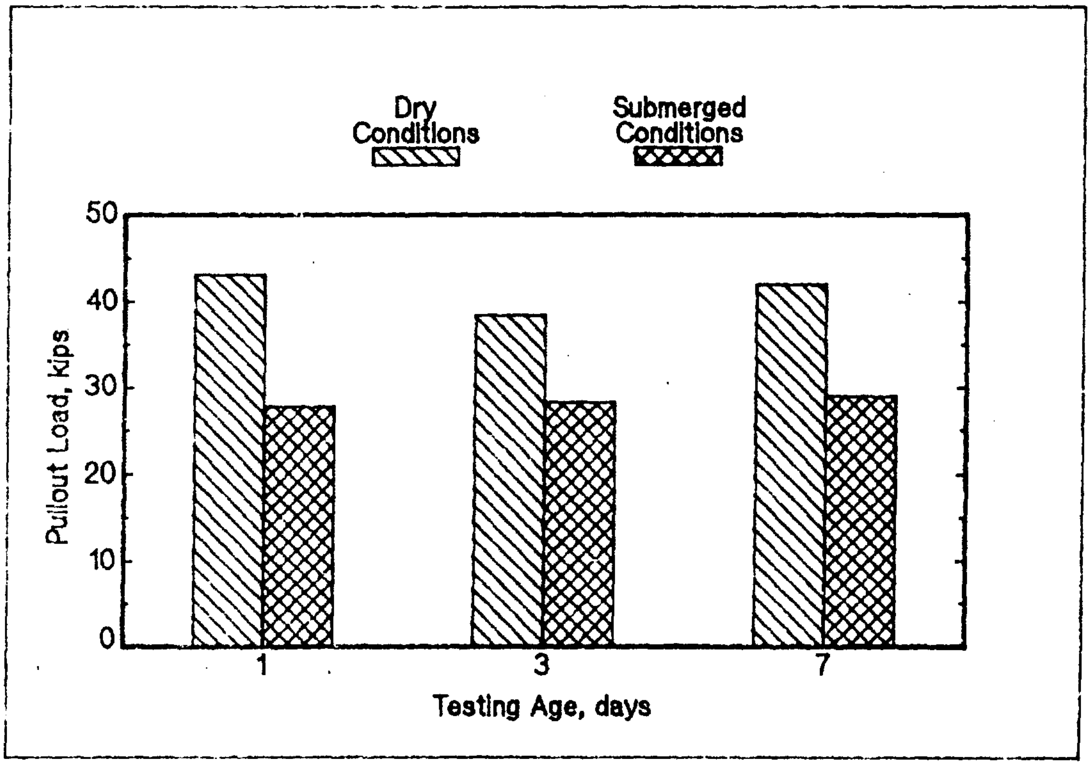
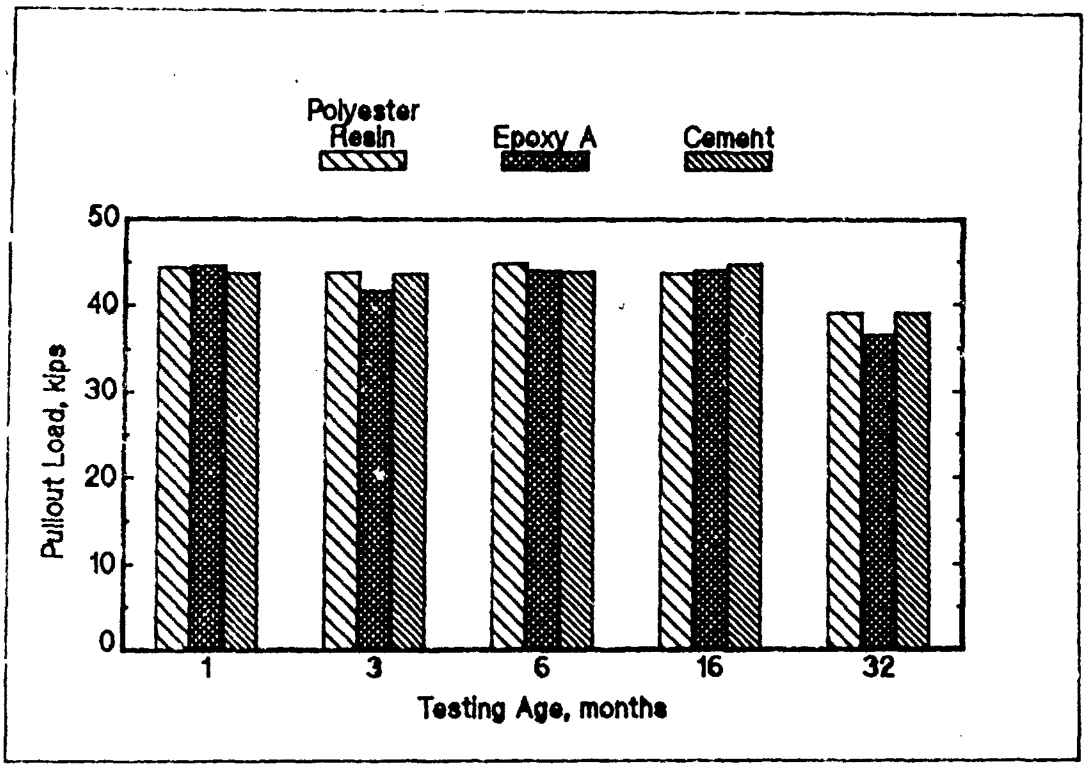
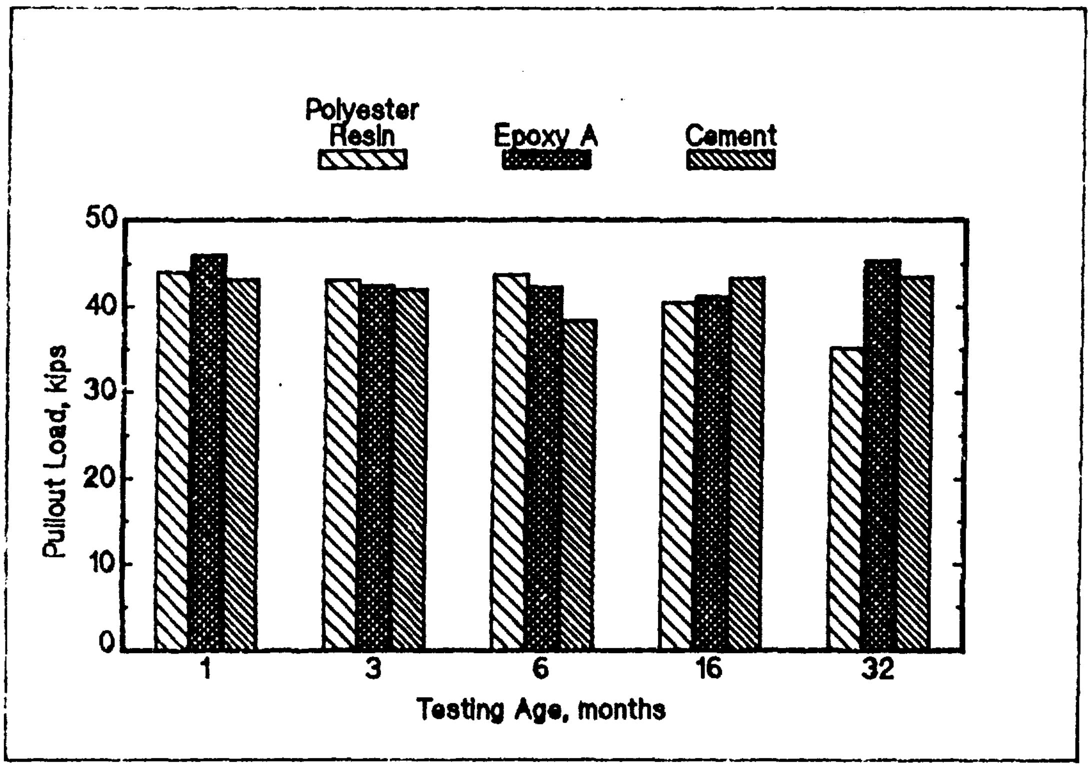


Figure 21. Effect of submerged placing and curing on the early-age pullout strength of polyester resin grout

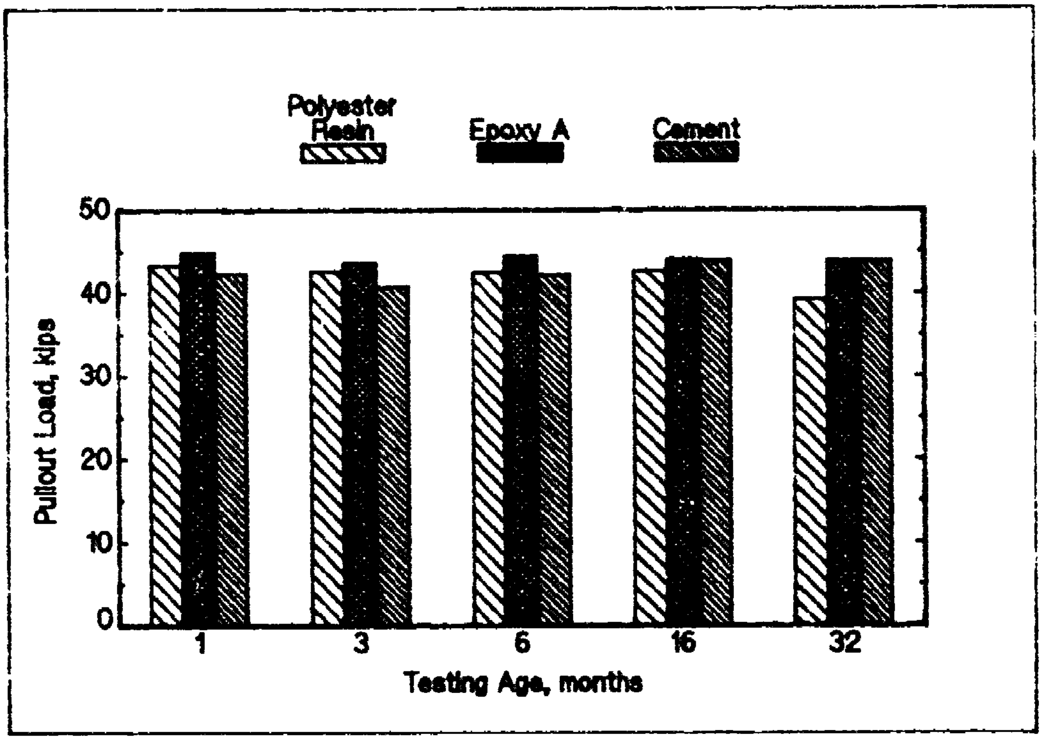


a. Specimens grouted and cured under dry conditions



b. Specimens grouted under dry conditions and cured under submerged conditions

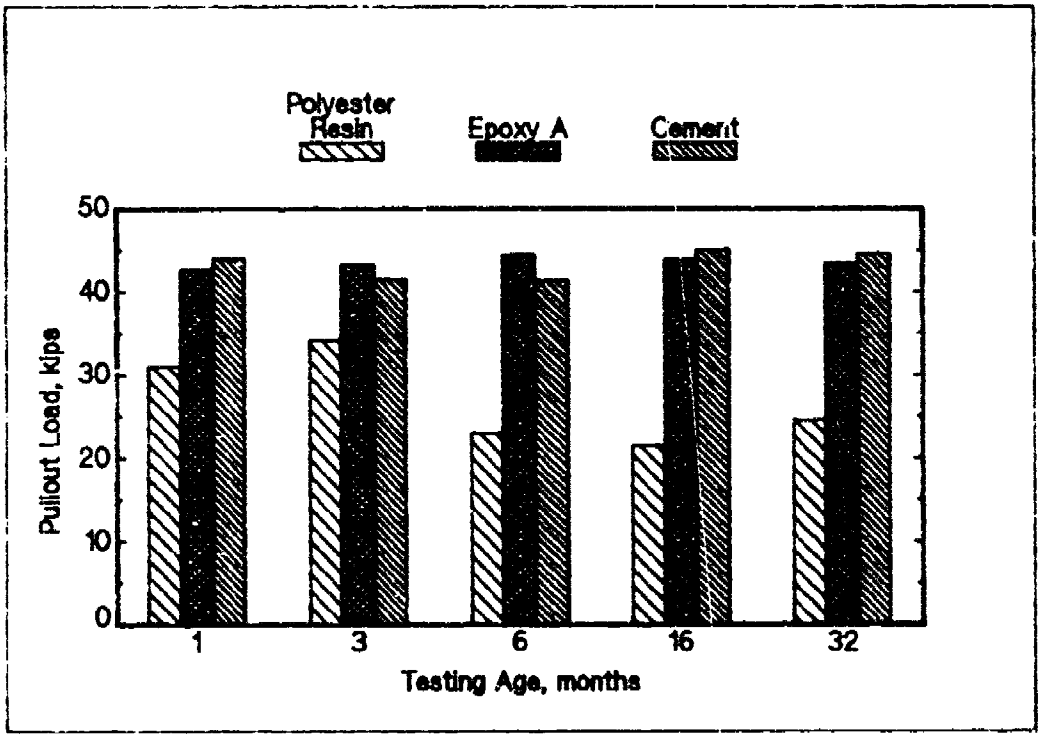
Figure 22. Results of pullout strength tests on specimens grouted under dry conditions and cured under a variety of conditions (Continued)



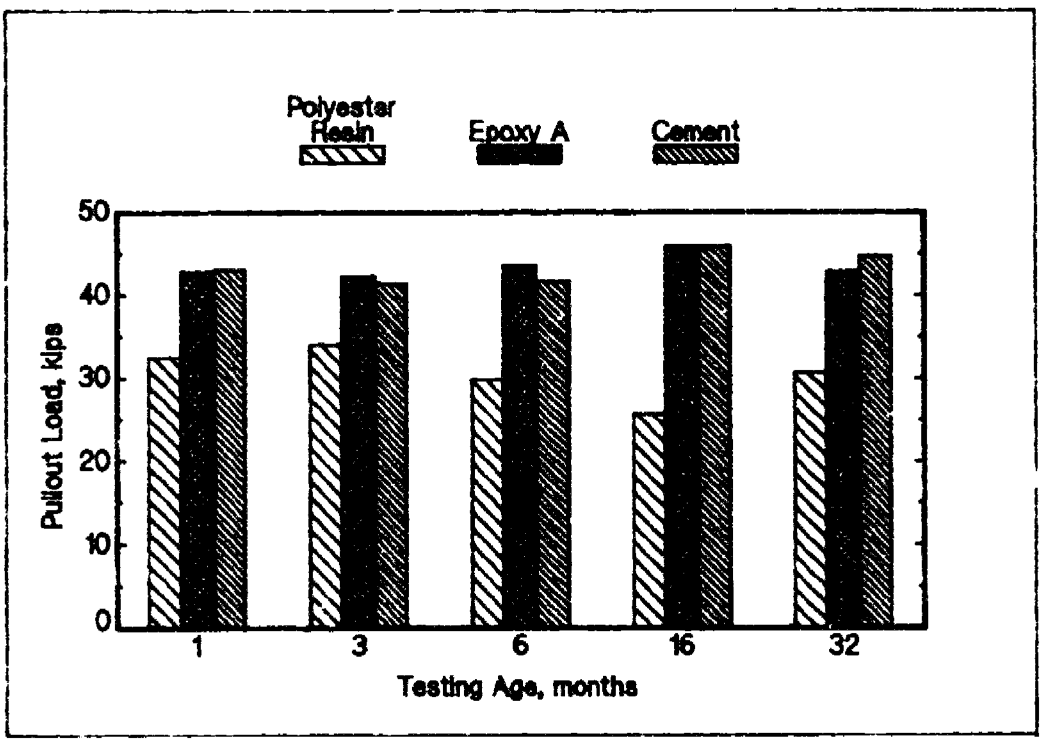
c. Specimens grouted under dry conditions and cured under alternating submerged and dry conditions

Figure 22. (Concluded)

conditions are shown in Figures 23a and 23b. With the exception of the polyester resin grout placed under submerged conditions, pullout strengths were essentially equal to the ultimate strength of the rebar. The average long-term pullout strength of polyester resin specimens placed and cured under submerged conditions was 38 percent less than the strength of polyester resin specimens placed and cured under dry conditions (Figure 24). The largest reductions in pullout strength, approximately 50 percent, occurred at ages of 6 months and 16 months. Similar strength reductions were obtained for the polyester resin grout placed under submerged conditions and cured under alternating wet and dry conditions. Alternating 7-day cycles of submerged and dry curing of polyester resin specimens placed under submerged conditions resulted in approximately 10 percent higher pullout strengths compared to submerged curing. Also, the overall average pullout strength of polyester resin specimens placed and cured under submerged conditions was approximately one-third less than the strength of epoxy and cement specimens placed under



a. Specimens grouted under wet conditions and cured under submerged conditions



b. Specimens grouted under wet conditions and cured under alternating submerged and dry conditions

Figure 23. Results of pullout strength tests on specimens grouted under wet conditions and cured under a variety of conditions

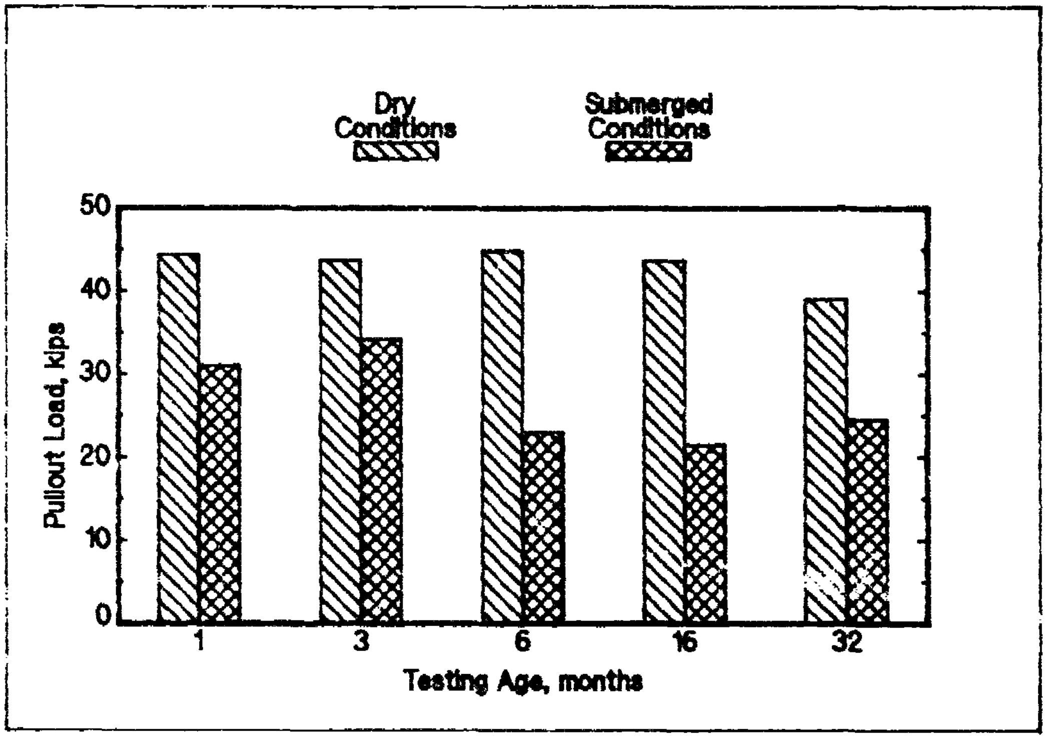


Figure 24. Effect of submerged placing and curing on the long-term pullout strength of polyester resin grout

wet and submerged conditions, respectively, and cured under submerged conditions (Figure 25).

33. At concrete ages less than 16 months, several pullout specimens failed due to the concrete cylinders splitting. Since the restraining area of the concrete cylinder is considerably smaller than would be encountered in actual field conditions, it was decided to restrain the concrete with a steel jacket into which sulfur capping compound was placed to provide a greater side thrust restraint. This additional restraint appears to have eliminated the concrete splitting mode of failure for the 16- and 32-month tests.

Creep Tests

34. Creep tests were initiated by subjecting pullout specimens to a sustained load of 60 percent of the yield strength of the reinforcing steel bar. Deflections of the bar at the end of the specimen opposite the loaded end were measured periodically during the loading period. Creep test results

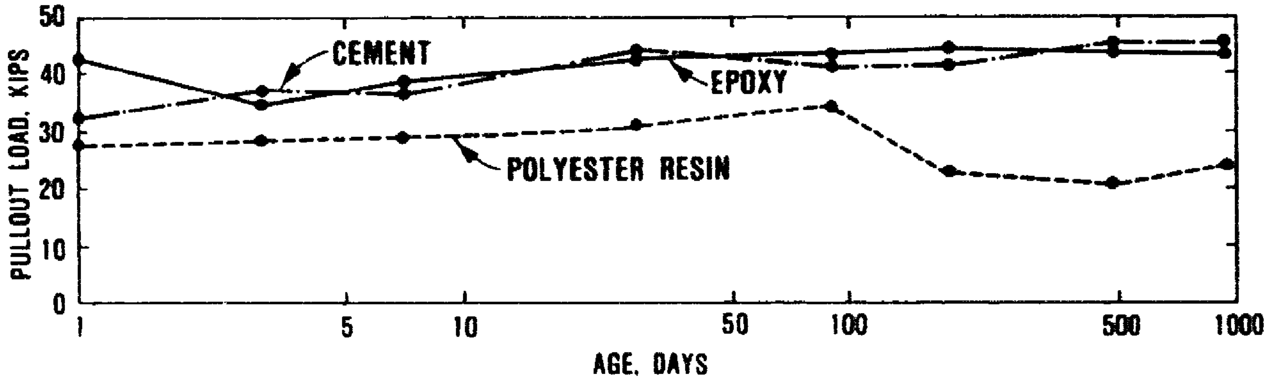


Figure 25. Summary of results of pullout tests on specimens placed and cured under wet conditions at 70° F

are tabulated in Table 14, parts a through f. Bar deflection versus time under load is plotted in Figure 26.

35. After 6 months under load, the cement and epoxy grouts placed, cured, and tested under dry conditions exhibited very low bar slippage, averaging 0.0013 and 0.0008 in., respectively. In comparison, the polyester resin grout exhibited an average bar slippage of 0.0305 in., approximately 30 times higher than the cement and epoxy grouts.

36. Results of creep tests on specimens fabricated and tested under wet conditions followed a similar trend. After 6 months under load, the average bar slippage for the cement and epoxy grouts was 0.0028 and 0.0033 in., respectively, or two to three times higher than results under dry conditions. Polyester resin grout specimens, fabricated and cured under wet conditions, exhibited significant slippage; in one case the bar pulled completely out of the concrete after 14 days under load. After 6 months under load, the two remaining specimens exhibited an average bar slippage of 0.0822 in., approximately 30 times higher than the cement grout.

Effects of Hole Conditions

37. Results of limited tests to determine the effects of hole roughness and cleanliness on pullout strength are shown in Tables 15 and 16. Leaving cuttings and debris in the percussion-drilled holes resulted in reduced pullout strengths for all three grouts (Figure 27). The epoxy-grouted specimens exhibited the largest reduction, an average of 71 percent compared with clean

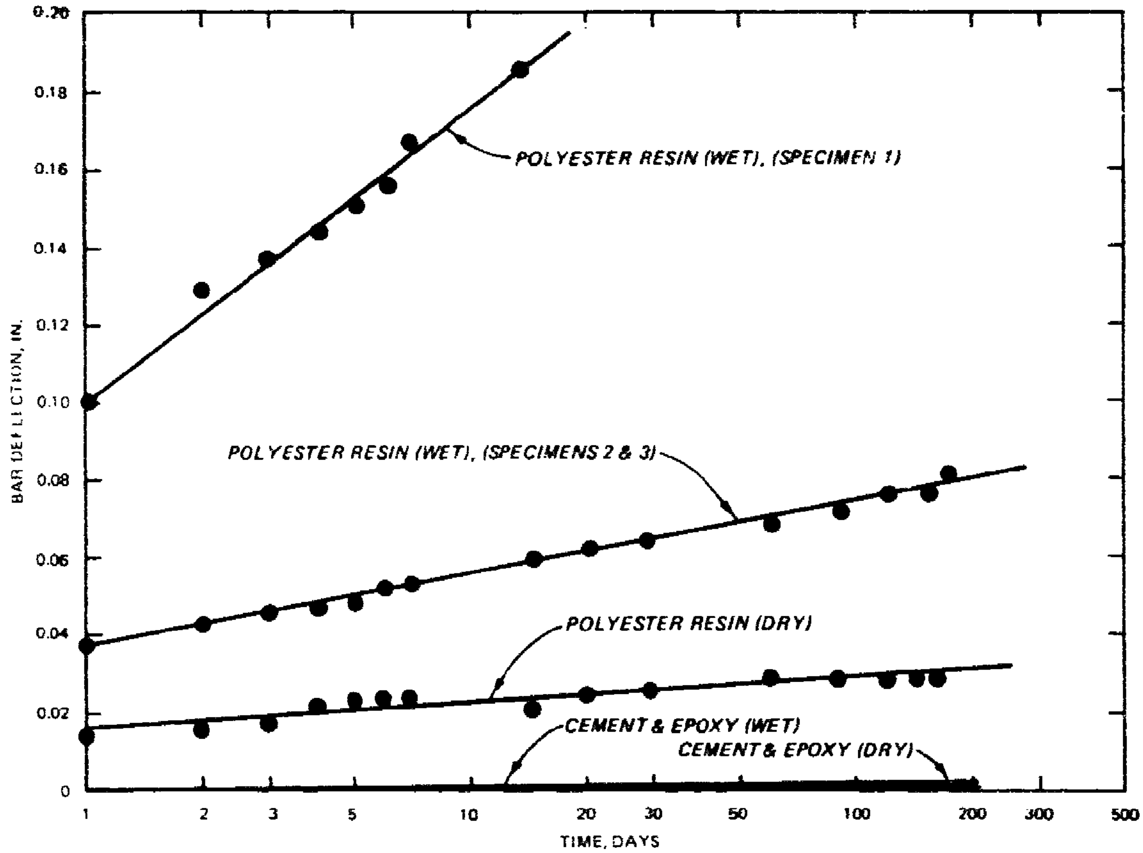


Figure 26. Results of creep tests on specimens grouted and cured under wet and dry conditions

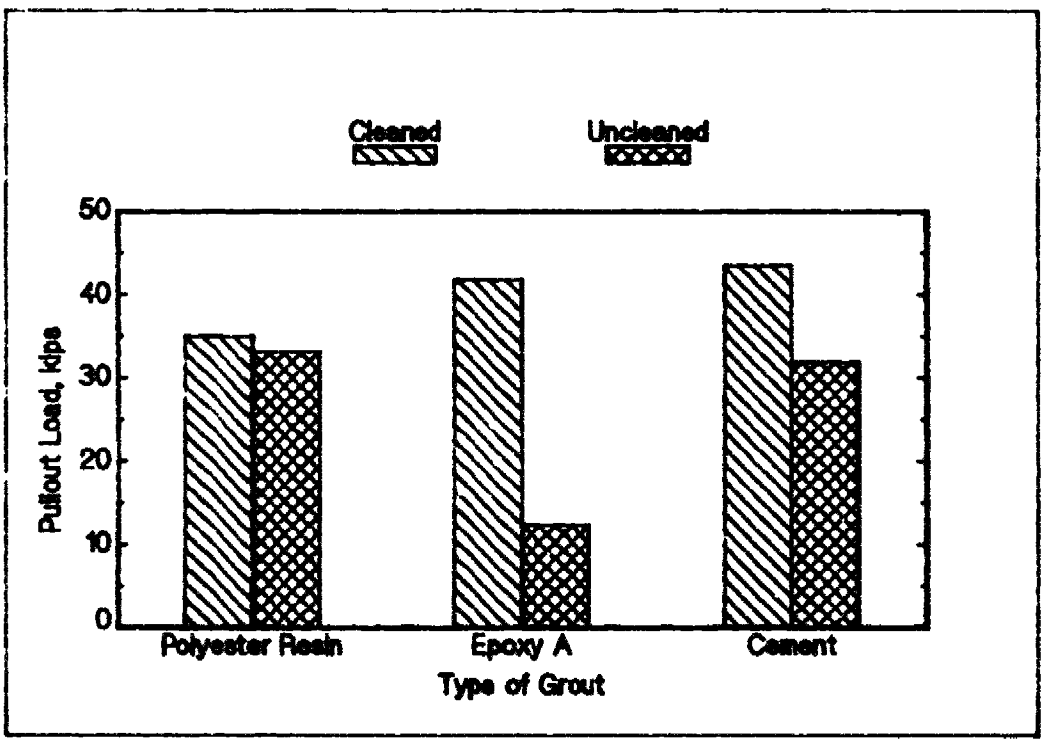


Figure 27. Effect of hole cleanliness on pullout strength of percussion-drilled specimens

holes similarly grouted. The cement- and polyester-resin-grouted specimens exhibited smaller reductions, averaging 27 and 5 percent, respectively.

38. In contrast to percussion-drilled specimens, core-drilled specimens exhibited little variation in pullout capacity between cleaned and uncleaned holes (Figure 28). The cement-grouted specimens exhibited the largest variation, a 12-percent reduction in pullout strength for the uncleaned holes. The relatively small variations in pullout strength between cleaned and uncleaned holes was attributed to the small amount of debris generated by the core barrels and the extreme fineness of the cuttings.

39. With the exception of the specimens with uncleaned holes that were epoxy grouted, the type of drilling had little effect on the average pullout strength (Figures 29 and 30). Epoxy grouting of uncleaned, percussion-drilled holes resulted in an average reduction in pullout capacity of 72 percent compared to similar specimens with core-drilled holes.

Conclusions

40. Beyond 1 day age, all grouts developed pullout strengths approximately equal to the ultimate strength of the reinforcing-bar anchor when the grouts were placed under dry conditions, regardless of curing conditions. With the exception of the polyester resin grout placed under submerged conditions, pullout strengths were essentially equal to the ultimate strength of the anchor when the grouts were placed under wet or submerged conditions.

41. The overall average pullout strength of polyester resin grout placed and cured under submerged conditions was 35 percent less than the strength of polyester resin placed and cured under dry conditions. The largest reductions in pullout strength, approximately 50 percent, occurred at ages of 6 months and 16 months. Also, the overall average pullout strength of polyester resin grout placed and cured under submerged conditions was approximately one-third less than the strength of epoxy and cement grout placed under wet and submerged conditions, respectively, and cured under submerged conditions.

42. Polyester-resin-grouted anchors exhibited significantly higher creep than that exhibited by epoxy- and cement-grouted anchors under both wet and dry conditions. Consequently, creep data should be considered in the

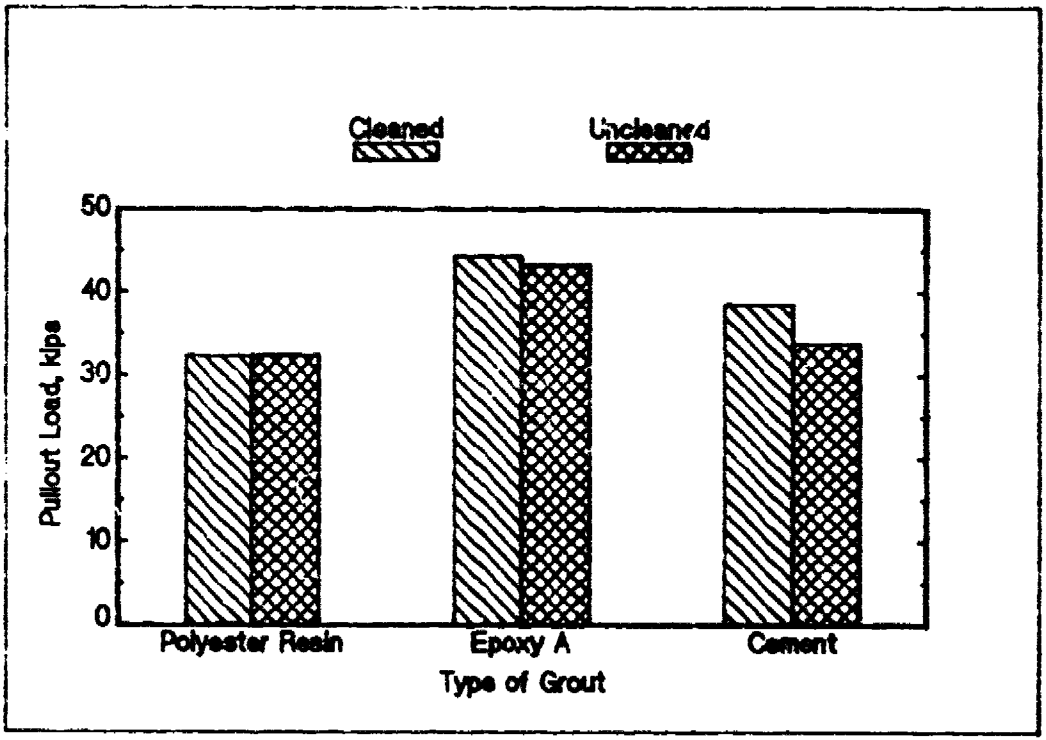


Figure 28. Effect of hole cleanliness on pullout strength of core-drilled specimens

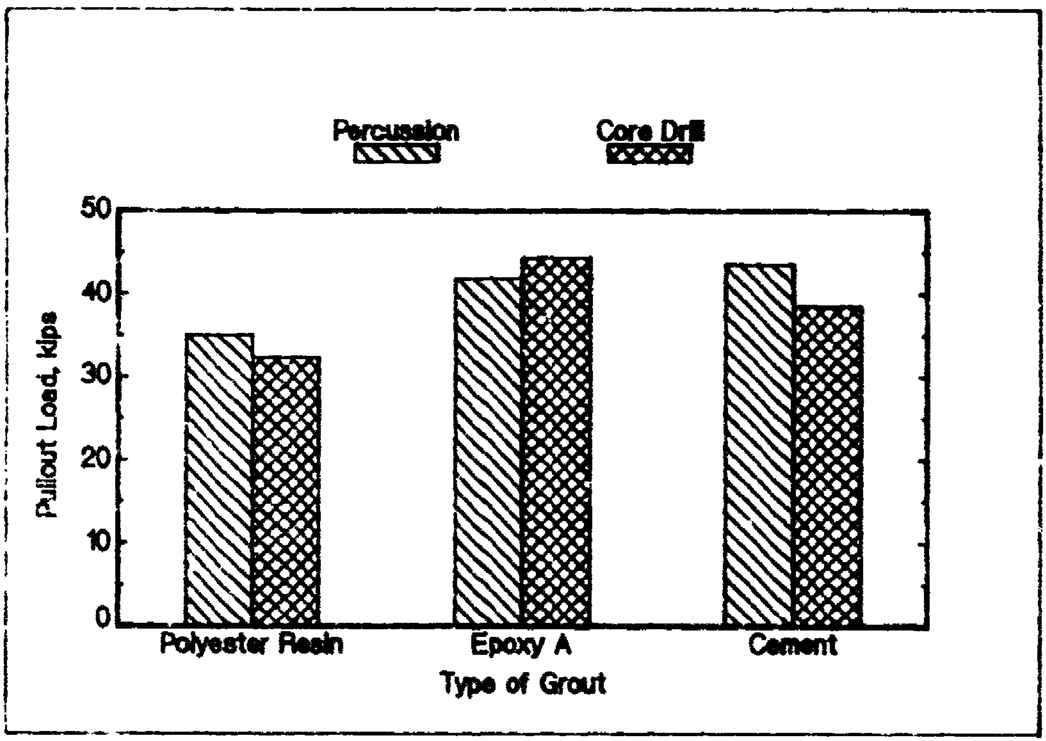


Figure 29. Effect of type of drilling on pullout strength of specimens with cleaned holes

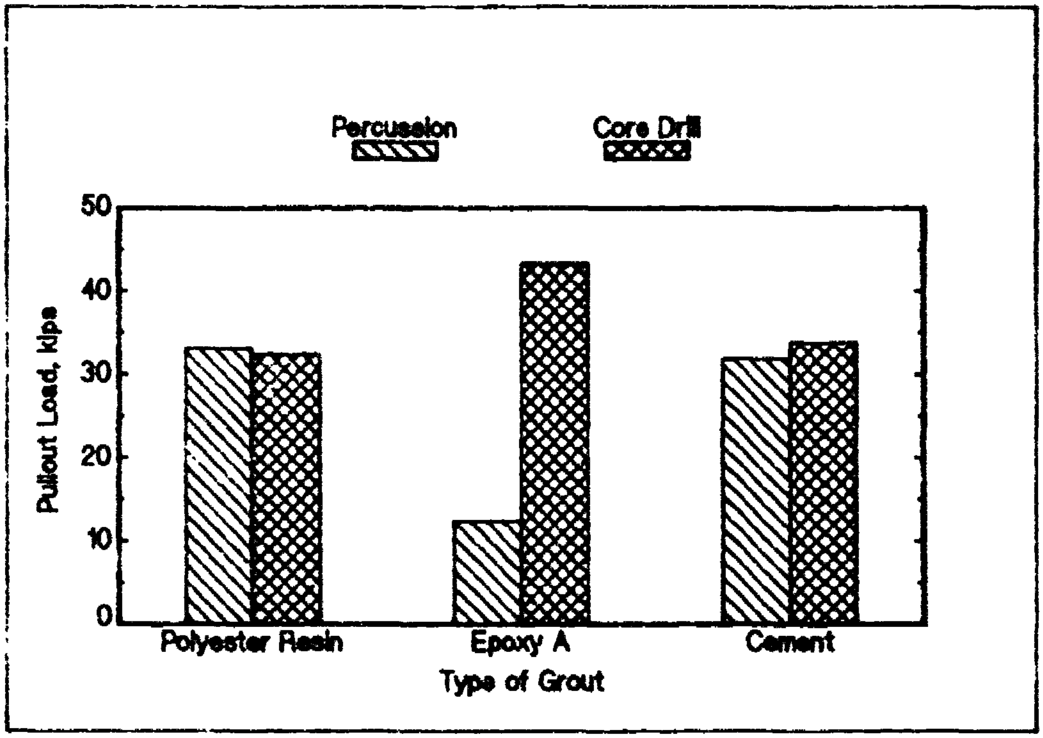


Figure 30. Effect of type of drilling on pullout strength of specimens with uncleaned holes

selection of an anchorage grout where the frictional resistance and bond between the surfaces of the two masses to be anchored together are important.

43. Extra care should be taken to clean all percussion-drilled holes prior to grouting, particularly when epoxy or cement grout is to be used as the anchoring material.

44. Although the epoxy grout performed well in these tests when placed in wet holes, it should be noted that the manufacturer does not recommend placement under submerged conditions. This recommendation and the significantly reduced pullout capacity of polyester resin grout under submerged conditions appear to make cement grout the logical choice for submerged applications.

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b. Designation C 884-78 (1983). "Test Method for Thermal Compatibility Between Concrete and an Epoxy-Resin Overlay."

c. Designation C 307-83. "Test Method for Tensile Strength of Chemical-Resistant Mortar, Grouts, and Monolithic Surfacings."

d. Designation C 807-83. "Test Method for Time of Setting of Hydraulic Cement Mortar by Vicat Needle."

e. Designation D 638-84. "Test Method for Tensile Properties of Plastics."

f. Designation C 39-86. "Test Method for Compressive Strength of Cylindrical Specimens."

g. Designation C 109-86. "Test Methods for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens)."

h. Designation A 370-86a. "Test Methods and Definitions for Mechanical Testing of Steel Products."

i. Designation D 2393-86. "Test Method for Viscosity of Epoxy Resins and Related Components."

j. Designation C 469-87. "Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression."

k. Designation C 827-87. "Test Method for Early Volume Change of Cementitious Mixtures."

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McDonald, J. E. 1980. "Maintenance and Preservation of Concrete Structures; Repair of Erosion-Damaged Structures," Technical Report C-78-4, Report 2, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Table 1

Mixture Proportions

Concrete	
Cement, lb/yd^3	750.0
Fly ash, lb/yd^3	75.0
Water, lb/yd^3	300.0
Fine aggregate, lb/yd^3	932.0
Coarse aggregate, lb/yd^3	1,843.0
Air-entraining admixture, oz/yd^3	10.0
Water reducing admixture, oz/yd^3	41.2
Slump, in.	3.5
Entrained air, percent	5.9
28-day compressive strength, psi	7,220.0
28-day modulus of elasticity, psi × 10^6	4.89
Cement Grout	
Cement, parts by weight	1.0
Water, parts by weight	0.44
Expansive additive, percent by weight of cement	0.25
Accelerator, oz/100 lb cement	20.0
28-day compressive cube strength, psi	7,875.0
Epoxy Grout	
Epoxy A	
Component A, parts by volume	2.0
Component B, parts by volume	1.0
20-30 silica sand, parts by volume	3.0
Epoxy B	
Component A, parts by volume	1.0
Component B, parts by volume	1.0
20-30 silica sand, parts by volume	2.0

Table 2

Tensile Strength of No. 6 Reinforcing Bars (ASTM A 370-86a (ASTM 1987h))

Test		Yield Load, psi	Ultimate Load, psi	Elongation, percent
1		62,050	101,800	16
2		62,270	101,100	15
3		62,270	102,000	14
	Average	62,200	101,600	15

Table 3

Time of Setting/Gel Time of Polyester Resin, Epoxy, and Cement Grouts

	Time of Setting, hr:min (ASTM C 807-83 (ASTM 1987d))			
	Initial		Final	
Grout Type	70° F	40° F	70° F	40° F
Polyester resin	0:35	2:45	*	*
Epoxy A	5:15	n/a	*	*
Epoxy B	n/a	1:10	*	*
Cement	4:15	7:30	7:30	8:00+

* Final set for polyester resin and epoxies same as initial set using Vicat method.

Table 4

Viscosity of Polyester Resin and Epoxy Grouts

	Brookfield Viscosity, centipoise (ASTM D 2393-86 (ASTM 1987i))					
	Component A		Component B		Mixed	
Grout Type	70° F	40° F	70° F	40° F	70° F	40° F
Polyester resin*	640	4,900	—	—	1,140	54,000
Epoxy A	14,000	61,000	310	1,600	5,800	29,500

* Polyester resin has only one liquid component mixed with a dry filler/ activator combination.

Table 5

Compressive Strength of Polyester Resin, Epoxy, and Cement Grouts

Grout Type	Compressive Strength,* psi (ASTM C 109-86 (ASTM 1987g), C 39-86 (1987f))									
	1 day		3 days		7 days		14 days		28 days	
	2 in. Cube	3×6 in. Cyl	2 in. Cube	3×6 in. Cyl	2 in. Cube	3×6 in. Cyl	2 in. Cube	3×6 in. Cyl	2 in. Cube	3×6 in. Cyl
Polyester resin	12,125	10,145	12,040	11,145	13,290	10,780	12,725	10,165	14,085	11,210
Epoxy A	10,715	7,490	11,375	10,165	11,100	9,695	11,115	10,270	11,350	9,955
Cement	2,865	--	4,505	--	5,180	3,910	6,875	4,520	7,875	5,060

* Average of 3 tests.

Table 6

Tensile Strength of Polyester Resin, Epoxy, and Cement Grouts

Grout Type	Tensile Strength,* psi (ASTM C 307-83 (ASTM 1987c), D 638-84 (ASTM 1987e))				
	1 day	3 days	7 days	14 days	28 days
Polyester resin	1,860	1,930	2,060	2,050	2,165
Epoxy A	4,125	4,225	3,610	4,320	4,310
Cement	250	300	430	415	380

* Average of 3 tests.

Table 7

Compressive Strength of Submerged and Air-Cured 2-in.-Cube Specimens

Test Age		Polyester Resin	Epoxy A	Cement
		Specimens Cured in Air		
28 days		13,500	12,000	6,750
		13,250	11,800	6,500
		--	11,875	6,750
	Average	13,375	11,890	6,665
90 days		14,000	12,750	6,250
		13,500	12,750	6,225
		--	12,625	6,625
	Average	13,750	12,710	6,365
6 months		12,250	12,250	7,500
		12,250	12,250	7,425
		--	12,250	7,565
	Average	12,250	12,250	7,495
16 months		12,750	12,250	7,750
		13,750	12,750	7,750
		--	13,000	7,500
	Average	13,750	12,665	7,665
32 months		13,500	12,875	8,125
		14,500	13,000	7,500
		--	13,125	8,000
	Average	14,000	13,000	7,875
		Specimens Submerged in Water		
28 days		13,000	11,500	8,625
		12,750	11,750	8,325
		--	12,000	--
	Average	12,875	11,750	8,475
		12,500	12,250	9,750
90 days		12,750	12,250	10,000
		--	12,125	--
	Average	12,625	12,210	9,875

(Continued)

Note: Only two tests shown at some ages due to insufficient materials.

Table 7 (Concluded)

Test Age		Polyester Resin	Epoxy A	Cement
		Specimens Submerged in Water (Continued)		
6 months		10,000	11,250	9,000
		10,500	11,300	9,000
		--	11,750	9,750
	Average	10,250	11,435	9,250
16 months		10,250	10,750	8,250
		10,250	10,750	9,000
		--	11,750	--
	Average	10,250	11,085	8,625
32 months		8,750	9,750	8,250
		9,000	9,750	8,350
		--	9,500	--
	Average	8,875	9,670	8,300

Table 8

Modulus of Elasticity of Polyester Resin, Epoxy, and Cement Grouts

Grout Type	Modulus of Elasticity,* psi × 10^6 (ASTM C 469-87 (ASTM 1987j)) 1 day	3 days	7 days	14 days	28 days
Polyester resin	1.57	1.70	1.75	1.56	1.79
Epoxy A	1.43	1.38	1.36	1.33	1.38
Cement	--	--	1.74	1.70	1.98

* Average of 3 tests.

Table 9

Slant Shear Bond Strength of Polyester Resin, Epoxy, and Cement Grouts

Grout Type	Placing Condition	Curing Condition	Slant Shear Bond Strength,* psi (ASTM C 882-78 (1983) (ASTM 1987a)) 1 day	3 days	7 days	14 days	28 days
Cement	Wet	Submerged	607	1,150	1,960	2,277	2,444
	Dry	Submerged	42	77	99	**	**
	Dry	Air	92	156	182	237	308
Polyester resin	Wet	Submerged	1,660	1,616	1,500	1,243	1,266
	Dry	Submerged	1,325	1,385	1,347	1,150	1,173
	Dry	Air	1,918	1,800	1,897	2,279	2,708
Epoxy A	Wet	Submerged	2,371	2,043	1,642	2,583	1,852
	Dry	Submerged	3,609	2,942	2,815	3,150	2,324
	Dry	Air	3,822	3,558	3,388	3,881	3,541

* Average of 3 tests.
** No bond at 14- or 28-day tests.

Table 10

Shrinkage/Expansion of Polyester Resin, Epoxy, and Cement Grouts

Grout Type	Volume Change,* percent (ASTM C 827-87 (ASTM 1987k))	
	At Initial Set	After 2-day Cure
Polyester resin	-2.01	-2.01
Epoxy A	-2.64	-5.18
Cement	+0.50	-0.50

* Average of 2 tests.

Table 11

Thermal Compatibility Between Concrete and Grout Overlays

Grout Type	Evaluation of Bond (ASTM C 884-78 (1983) (ASTM 1987b))
Polyester resin	Bond failure had occurred when forms were stripped at 24 hr. Little to no concrete adhering to resin overlay
Epoxy A	Specimens cracked after one cycle of freezing and thawing. Failure occurred along a horizontal crack plane near the top surface of concrete. Approximately 1/2 in. of concrete adhered to the epoxy overlay. A considerable amount of aggregate was fractured in the plane of failure
Cement	Bond failure occurred during the 7-day air cure. Failure was observed 4 days after placing grout overlay on concrete surface. Failure was essentially at the overlay interface, with little adhesion of concrete to the grout

Table 12

Results of Early-Age Pullout Strength Tests

Grout Type	Age days	Maximum Load, lb	Deflection at Max Load, in.	Failure Mode*
a. Wet Placing and Submerged Curing at 70° F				
Polyester resin	1	27,290	0.076	A
	1	31,350	0.090	A
	1	24,520	0.236	A
Average		27,720	0.134	
Epoxy A	1	43,210	0.038	C
	1	44,500	0	B
	1	40,790	0	B
Average		42,830	0.013	
Cement	1	33,760	0.097	A
	1	28,660	0.085	A
	1	33,940	0.103	A
Average		32,120	0.095	
Polyester resin	3	21,790	0.390	A
	3	33,080	0.014	C
	3	29,910	0.013	C
Average		28,260	0.139	
Epoxy A	3	35,480	0.002	C
	3	32,160	0.003	C
	3	36,900	0.001	C
Average		34,850	0.002	
Cement	3	37,250	0.005	A
	3	39,230	0.002	A
	3	35,670	0.001	A
Average		37,380	0.003	
Polyester resin	7	27,800	0.097	A
	7	25,170	0.140	A
	7	34,020	0.062	C
Average		29,000	0.100	
Epoxy A	7	34,910	0	C
	7	40,900	0	B
	7	39,390	0	C
Average		38,400	0	
Cement	7	37,310	0.050	C
	7	32,420	0.025	A
	7	39,850	0.003	B
Average		38,530	0.026	

(Continued)

* A - Bar and grout plug pulled out of drilled hole.
B - Bar broke.
C - Concrete cylinder split.

Table 12 (Continued)

Grout Type	Age days	Maximum Load, lb	Deflection at Max Load, in.	Failure Mode
b. Wet Placing and Submerged Curing at 40° F				
Polyester resin	1	25,190	0.366	A
	1	35,550	0.293	A
	1	38,970	0.074	C
Average		33,240	0.244	
Epoxy B	1	44,800	0	B
	1	45,230	0	B
	1	44,950	0.005	C
Average		44,990	0.002	
Cement	1	8,280	0.010	A
	1	11,130	0.008	A
	1	8,690	0.008	A
Average		9,370	0.009	
Polyester resin	3	26,660	0.160	C
	3	25,390	0.038	A
	3	25,390	0.030	C
Average		25,810	0.076	
Epoxy B	3	39,840	0.001	C
	3	43,150	0.005	C
	3	42,760	0.003	B
Average		41,920	0.003	
Cement	3	39,030	0.047	A
	3	40,850	0.038	A
	3	26,130	**	A
Average		35,340	0.043	
Polyester resin	7	30,830	0.100	A
	7	32,290	0.080	C
	7	36,790	0.100	C
Average		33,300	0.093	
Epoxy B	7	41,530	0.002	B
	7	42,490	0	B
	7	42,600	0.001	B
Average		42,210	0.001	
Cement	7	39,800	0.040	A
	7	39,630	0.070	A
	7	39,660	0.020	A
Average		39,700	0.043	

(Continued)

** Computer malfunction; no data recorded.

Table 12 (Continued)

Grout Type	Age days	Maximum Load, lb	Deflection at Max Load, in.	Failure Mode
c. Dry Placing and Submerged Curing at 70° F. (Epoxy A and polyester-resin-grouted specimens air cured 24 hr prior to submerging. Ages shown are after beginning submerged curing.)				
Polyester resin	1	43,250	0.070	C
	1	41,690	0.010	C
	1	36,400	0.070	C
Average		40,450	0.050	
Epoxy A	1	44,250	0	B
	1	44,030	0	C
	1	43,370	0.004	C
Average		43,880	0.001	
Cement	1	33,440	0.020	A
	1	32,230	0.030	A
	1	30,680	0	A
Average		32,120	0.017	
Polyester resin	3	44,420	0.020	C
	3	45,480	0.100	C
	3	41,200	0.210	C
Average		43,700	0.110	
Epoxy A	3	44,570	0	B
	3	44,250	0	C
	3	44,810	0	B
Average		44,540	0	
Cement	3	40,180	0.050	A
	3	42,280	0.030	A
	3	44,730	0.050	A
Average		42,400	0.043	
Polyester resin	7	40,630	0.130	C
	7	41,100	0.150	C
	7	36,680	0.100	C
Average		39,470	0.127	
Epoxy A	7	43,630	0	C
	7	44,480	0	B
	7	40,140	0.001	C
Average		42,750	0	
Cement	7	45,500	0	B
	7	41,140	0	B
	7	44,840	0.001	B
Average		43,830	0	

(Continued)

Table 12 (Continued)

Grout Type	Age days	Maximum Load, lb	Deflection at Max Load, in.	Failure Mode
d. Dry Placing and Submerged Curing at 40° F. (Epoxy B and polyester-resin-grouted specimens air cured 24 hr prior to submerging. Ages shown are after beginning submerged curing.)				
Polyester resin	1	41,630	0.360	C
	1	41,030	0.060	B
	1	44,300	0.100	B
Average		42,320	0.173	
Epoxy B	1	43,440	0.013	C
	1	44,950	0.001	B
	1	43,890	0	B
Average	1	44,090	0.005	
Cement	1	9,550	0.007	A
	1	9,520	0.007	A
	1	10,200	0.004	A
Average		9,760	0.006	
Polyester resin	3	44,260	0.070	B
	3	35,600	0.030	C
	3	40,020	0.180	C
Average		39,960	0.093	
Epoxy B	3	42,290	0.100	C
	3	44,400	0.002	C
	3	42,940	0	C
Average		43,210	0.034	
Cement	3	37,770	0.030	A
	3	39,000	**	A
	3	37,360	0.010	A
Average		38,040	0.020	
Polyester resin	7	43,970	0.070	C
	7	45,100	0.070	B
	7	45,580	0.052	B
Average		44,880	0.064	
Epoxy B	7	41,280	0.001	B
	7	41,260	0.003	C
	7	45,850	0.001	B
Average		42,800	0.002	
Cement	7	45,700	0	B
	7	43,290	0.001	C
	7	41,230	0.001	B
Average		43,410	0.001	

(Continued)

** Computer malfunction; no data recorded.

Table 12 (Concluded)

Grout Type	Age days	Maximum Load, lb	Deflection at Max Load, in.	Failure Mode
e. Dry Placing and Curing at 70° F				
Polyester resin	1	41,230	0.090	C
	1	44,010	0.070	C
	1	44,250	0.080	C
Average		43,160	0.080	
Epoxy A	1	42,000	0	C
	1	37,130	0.002	C
	1	39,000	0.001	C
Average		39,380	0.001	
Cement	1	20,960	0.170	A
	1	31,800	0.180	A
	1	27,740	0.230	A
Average		26,830	0.193	
Polyester resin	3	38,560	0.077	C
	3	38,170	0.062	C
	3	38,570	0.070	C
Average		38,430	0.070	
Epoxy A	3	44,310	0	B
	3	44,700	0	C
	3	44,000	0	C
Average		44,340	0	
Cement	3	40,680	0.002	A
	3	37,260	0.002	A
	3	40,500	0	A
Average		39,480	0.001	
Polyester resin	7	41,060	0.050	C
	7	44,000	0.070	C
	7	41,040	0.230	C
Average		42,030	0.117	
Epoxy A	7	43,000	0	C
	7	40,220	0.001	C
	7	44,000	0.001	C
Average		42,410	0.001	
Cement	7	41,260	0.360	C
	7	40,920	0.120	A
	7	42,090	0.370	A
Average		41,420	0.283	

Table 13

Results of Long-Term Pullout Strength Tests

Grout Type	Age months	Maximum Load, lb	Failure Mode*
a. Wet Placing and Submerged Curing			
Polyester resin	1	31,000	A
	1	31,000	A
	1	31,000	A
Average		31,000	
Epoxy A	1	45,000	B
	1	42,000	B
	1	41,000	C
Average		42,670	
Cement	1	45,000	B
	1	45,000	B
	1	42,000	C
Average		44,000	
Polyester resin	3	32,000	A
	3	36,000	A
	3	34,500	C
Average		34,170	
Epoxy A	3	44,200	B
	3	41,200	B
	3	44,100	B
Average		43,170	
Cement	3	41,700	B
	3	41,400	B
	3	41,200	B
Average		41,430	
Polyester resin	6	17,000	A
	6	22,000	A
	6	30,000	A
Average		23,000	
Epoxy A	6	45,200	B
	6	45,000	C
	6	43,000	C
Average		44,400	
Cement	6	42,000	C
	6	42,000	C
	6	40,000	C
Average		41,330	

(Continued)

* A - Bar and grout plug pulled out of drilled hole.
B - Bar broke.
C - Concrete cylinder split.

Table 13 (Continued)

Grout Type	Age months	Maximum Load, lb	Failure Mode
Polyester resin	16	19,000	A
	16	21,500	A
	16	24,000	A
Average		21,500	
Epoxy A	16	44,500	B
	16	43,500	B
	16	43,500	B
Average		43,830	
Cement	16	45,000	B
	16	45,000	B
	16	45,000	B
Average		45,000	
Polyester resin	32	26,500	A
	32	20,000	A
	32	27,000	A
Average		24,500	
Epoxy A	32	45,000	B
	32	42,500	B
	32	42,500	B
Average		43,330	
Cement	32	43,000	B
	32	44,500	B
	32	46,000	B
Average		44,500	

(Continued)

Table 13 (Continued)

Grout Type	Age months	Maximum Load, lb	Failure Mode
b. Wet Placing and Alternating Submerged-Dry (7-day cycles) Curing			
Polyester resin	1	33,000	A
	1	31,000	A
	1	33,500	A
Average		32,500	
Epoxy A	1	38,500	C
	1	45,000	B
	1	45,000	C
Average		42,830	
Cement	1	42,000	B
	1	42,000	B
	1	45,200	B
Average		43,070	
Polyester resin	3	33,000	C
	3	33,500	A
	3	35,500	C
Average		34,000	
Epoxy A	3	44,700	B
	3	40,800	B
	3	41,200	B
Average		42,230	
Cement	3	40,000	C
	3	40,000	C
	3	44,000	B
Average		41,330	
Polyester resin	6	27,000	A
	6	27,000	A
	6	35,500	A
Average		29,830	
Lpoxy A	6	42,500	B
	6	45,000	C
	6	43,000	C
Average		43,500	
Cement	6	43,000	C
	6	40,000	C
	6	42,000	C
Average		41,670	

(Continued)

Table 13 (Continued)

Grout Type	Age months	Maximum Load, lb	Failure Mode
Polyester resin	16	38,000	A
	16	16,000	A
	16	23,000	A
Average		25,670	
Epoxy A	16	45,500	B
	16	46,000	B
	16	46,000	B
Average		45,830	
Cement	16	46,000	B
	16	46,000	B
	16	45,500	B
Average		45,830	
Polyester resin	32	24,000	A
	32	24,500	A
	32	26,000	A
Average		30,670	
Epoxy A	32	43,500	B
	32	43,000	B
	32	42,000	B
Average		42,830	
Cement	32	45,000	B
	32	45,000	B
	32	44,000	B
Average		44,670	

(Continued)

Grout Type	Age months	Maximum Load, lb	Failure Mode
c. Dry Placing and Submerged Curing (Epoxy A and polyester-resin-grouted specimens air cured 24 hr prior to submerging. Ages shown are after beginning submerged curing.)			
Polyester resin	1	43,000	B
	1	46,000	B
	1	43,000	C
Average		44,000	
Epoxy A	1	46,000	B
	1	46,800	B
	1	45,000	B
Average		45,930	
Cement	1	43,500	B
	1	44,500	B
	1	41,500	C
Average		43,170	
Polyester resin	3	42,500	A
	3	42,500	A
	3	44,300	A
Average		43,100	
Epoxy A	3	44,800	B
	3	41,300	B
	3	41,200	B
Average		42,430	
Cement	3	44,100	C
	3	41,000	B
	3	40,800	B
Average		41,970	
Polyester resin	6	45,000	C
	6	43,500	C
	6	42,500	C
Average		43,670	
Epoxy A	6	42,000	B
	6	42,000	B
	6	42,800	B
Average		42,270	
Cement	6	40,000	C
	6	35,000	C
	6	40,000	C
Average		38,330	

(Continued)

Table 13 (Continued)

Grout Type	Age months	Maximum Load, lb	Failure Mode
Polyester resin	16	34,500	A
	16	43,500	B
	16	43,500	A
Average		40,500	
Epoxy A	16	41,000	B
	16	41,000	B
	16	41,500	B
Average		41,170	
Cement	16	43,500	B
	16	44,000	B
	16	42,500	B
Average		43,330	
Polyester resin	32	34,000	A
	32	33,000	B
	32	38,500	A
Average		35,170	
Epoxy A	32	45,500	B
	32	45,000	B
	32	45,500	B
Average		45,330	
Cement	32	44,000	B
	32	44,000	B
	32	42,500	B
Average		43,500	

(Continued)

Table 13 (Continued)

Grout Type	Age months	Maximum Load, lb	Failure Mode
d. Dry Placing and Curing			
Polyester resin	1	45,000	A
	1	43,000	A
	1	45,000	C
Average		44,330	
Epoxy A	1	45,000	B
	1	43,500	B
	1	45,000	B
Average		44,500	
Cement	1	42,500	B
	1	43,000	B
	1	45,500	B
Average		43,670	
Polyester resin	3	44,600	C
	3	42,300	C
	3	44,300	A
Average		43,730	
Epoxy A	3	41,600	B
	3	41,800	B
	3	41,500	B
Average		41,630	
Cement	3	45,000	B
	3	41,500	B
	3	44,300	B
Average		43,600	
Polyester resin	6	44,500	A
	6	45,000	B
	6	45,000	B
Average		44,830	
Epoxy A	6	42,000	B
	6	45,000	B
	6	45,000	B
Average		44,000	
Cement	6	45,000	B
	6	44,000	B
	6	42,500	B
Average		43,830	

(Continued)

Table 13 (Continued)

Grout Type	Age months	Maximum Load, lb	Failure Mode
Polyester resin	16	42,500	A
	16	44,000	A
	16	44,500	A
Average		43,670	
Epoxy A	16	45,000	B
	16	42,500	B
	16	44,500	B
Average		44,000	
Cement	16	45,000	B
	16	44,500	B
	16	44,500	B
Average		44,670	
Polyester resin	32	36,000	A
	32	39,000	B
	32	42,000	B
Average		39,000	
Epoxy A	32	35,000	B
	32	36,000	B
	32	38,500	B
Average		36,500	
Cement	32	41,000	B
	32	33,000	C
	32	43,000	B
Average		39,000	

(Continued)

Table 13 (Continued)

Grout Type	Age months	Maximum Load, lb	Failure Mode
e. Dry Placing and Alternating Dry-Submerged (7-day cycle) Curing			
Polyester resin	1	43,500	A
	1	45,500	C
	1	43,000	B
Average		43,330	
Epoxy A	1	46,800	B
	1	43,800	B
	1	44,000	B
Average		44,870	
Cement	1	46,000	B
	1	43,000	B
	1	38,000	C
Average		42,330	
Polyester resin	3	44,200	C
	3	40,800	C
	3	43,000	C
Average		42,670	
Epoxy A	3	41,300	B
	3	45,000	B
	3	44,500	B
Average		43,600	
Cement	3	39,000	C
	3	42,300	B
	3	41,000	B
Average		40,770	
Polyester resin	6	41,000	C
	6	44,000	C
	6	42,500	B
Average		42,500	
Epoxy A	6	43,000	B
	6	45,000	B
	6	45,300	B
Average		44,430	
Cement	6	42,500	C
	6	42,000	C
	6	42,000	B
Average		42,170	

(Continued)

Table 13 (Concluded)

Grout Type	Age months	Maximum Load, lb	Failure Mode
Polyester resin	16	43,000	A
	16	43,500	A
	16	41,500	A
Average		42,670	
Epoxy A	16	44,000	B
	16	44,000	B
	16	44,000	B
Average		44,000	
Cement	16	43,000	A
	16	45,000	B
	16	43,500	B
Average		43,830	
Polyester resin	32	42,500	A
	32	35,000	A
	32	40,000	A
Average		39,170	
Epoxy A	32	45,000	B
	32	44,000	B
	32	42,500	B
Average		43,830	
Cement	32	45,000	B
	32	43,000	B
	32	43,500	B
Average		43,830	

Table 14

Creep Test Results

Age	Deflection, in. Specimen 1	Specimen 2	Specimen 3	Average
a. Cement Grout, Dry Placing and Curing Conditions. (Specimens grouted 8 days prior to loading.)				
10 min	0.0	0.0	0.0005	0.0
20 min	0.0	0.0	0.0005	0.0
30 min	0.0	0.0005	0.0005	0.0
40 min	0.0	0.0005	0.0005	0.0
50 min	0.0	0.0005	0.0005	0.0
60 min	0.0	0.0005	0.0005	0.0
2 hr	0.0	0.0005	0.0005	0.0
3 hr	0.0	0.0005	0.0005	0.0
4 hr	0.0	0.0005	0.0005	0.0
5 hr	0.0	0.0005	0.0005	0.0
6 hr	0.0	0.0005	0.001	0.001
7 hr	0.0	0.0005	0.001	0.001
1 day	0.0	0.0005	0.001	0.001
2 day	0.0	0.0005	0.001	0.001
3 day	0.0	0.0005	0.001	0.001
4 day	0.0	0.0005	0.001	0.001
5 day	0.0	0.0005	0.001	0.001
6 day	0.0	0.001	0.001	0.001
7 day	0.0	0.001	0.001	0.001
2 week	0.0	0.001	0.001	0.001
3 week	0.0	0.001	0.001	0.001
4 week	0.0	0.001	0.001	0.001
2 month	0.0005	0.001	0.0015	0.001
3 month	0.0005	0.0015	0.0015	0.001
4 month	0.0005	0.0015	0.0015	0.001
5 month	0.0005	0.0015	0.0015	0.001
6 month	0.0005	0.002	0.0015	0.001

(Continued)

Table 14 (Continued)

Age	Deflection, in. Specimen 1	Specimen 2	Specimen 3	Average
b. Epoxy A Grout, Dry Placing and Curing Conditions. (Specimens grouted 8 days prior to loading.)				
10 min	0.000	0.0	0.0	0.0
20 min	0.000	0.0	0.0	0.0
30 min	0.0015	0.0	0.0	0.0
40 min	0.0015	0.0	0.0	0.0
50 min	0.0015	0.0	0.0	0.0
60 min	0.0015	0.0	0.0	0.0
2 hr	0.0015	0.0	0.0	0.0
3 hr	0.0015	0.0	0.0	0.0
4 hr	0.0015	0.0	0.0	0.0
5 hr	0.0015	0.0	0.0	0.0
6 hr	0.0015	0.0	0.0	0.0
7 hr	0.0015	0.0	0.0	0.0
1 day	0.0015	0.0	0.0	0.0
2 day	0.0015	0.0	0.0	0.0
3 day	0.0015	0.0	0.0	0.0
4 day	0.0015	0.0	0.0	0.0
5 day	0.0015	0.0	0.0	0.0
6 day	0.0015	0.0	0.0	0.0
7 day	0.0015	0.0	0.0	0.0
2 week	0.002	0.0	0.0	0.001
3 week	0.002	0.0	0.0	0.001
4 week	0.002	0.0	0.0	0.001
2 month	0.002	0.0	0.0	0.001
3 month	0.002	0.0	0.0	0.001
4 month	0.0025	0.0	0.0	0.001
5 month	0.0025	0.0	0.0	0.001
6 month	0.0025	0.0	0.0	0.001

(Continued)

Table 14 (Continued)

Age	Deflection, in. Specimen 1	Specimen 2	Specimen 3	Average
c. Polyester Resin Grout, Dry Placing and Curing Conditions. (Specimens grouted 8 days prior to loading.)				
10 min	0.003	0.005	0.004	0.004
20 min	0.006	0.012	0.006	0.008
30 min	0.008	n/a	0.007	0.008
40 min	0.0085	0.013	0.0075	0.010
50 min	0.010	0.014	0.008	0.011
60 min	0.010	0.014	0.008	0.011
2 hr	0.0105	0.014	0.008	0.011
3 hr	0.105	0.014	0.008	0.011
4 hr	0.012	0.015	0.009	0.012
5 hr	0.012	0.016	0.010	0.013
6 hr	0.013	0.017	0.011	0.014
7 hr	0.014	0.017	0.012	0.014
1 day	0.015	0.018	0.013	0.015
2 day	0.016	0.019	0.014	0.016
3 day	0.018	0.020	0.016	0.018
4 day	0.020	0.022	0.018	0.020
5 day	0.023	0.023	0.0195	0.022
6 day	0.023	0.0235	0.020	0.022
7 day	0.023	0.024	0.020	0.022
2 week	0.024	0.0245	0.021	0.023
3 week	0.0255	0.026	0.0225	0.025
4 week	0.0265	0.0265	0.023	0.026
2 month	0.0295	0.0285	0.026	0.028
3 month	0.031	0.029	0.027	0.029
4 month	0.032	0.030	0.0275	0.030
5 month	0.0325	0.030	0.028	0.030
6 month	0.033	0.030	0.0285	0.031

(Continued)

Table 14 (Continued)

Age	Deflection, in. Specimen 1	Specimen 2	Specimen 3	Average
d. Cement Grout, Submerged Placing and Curing Conditions. (Specimens grouted 7 days prior to loading.)				
10 min	0.0	0.0	0.0	0.0
20 min	0.0	0.0	0.0	0.0
30 min	0.0	0.0	0.0	0.0
40 min	0.0	0.0	0.0	0.0
50 min	0.0	0.0	0.0	0.0
60 min	0.0	0.0	0.0	0.0
2 hr	0.0	0.0005	0.001	0.001
3 hr	0.0	0.0005	0.001	0.001
4 hr	0.0	0.0005	0.001	0.001
5 hr	0.0	0.0005	0.001	0.001
6 hr	0.0	0.0005	0.001	0.001
7 hr	0.0	0.0005	0.001	0.001
1 day	0.0	0.0005	0.001	0.001
2 day	0.0	0.0015	0.001	0.001
3 day	0.0	0.0015	0.001	0.001
4 day	0.0	0.0015	0.001	0.001
5 day	0.0	0.0015	0.001	0.001
6 day	0.0	0.0015	0.001	0.001
7 day	0.0	0.0015	0.001	0.001
2 week	0.0	0.002	0.001	0.001
3 week	0.0	0.003	0.001	0.001
4 week	0.0	0.003	0.001	0.001
2 month	0.0	0.0035	0.001	0.002
3 month	0.0	0.005	0.002	0.002
4 month	0.0	0.0055	0.002	0.003
5 month	0.0	0.0055	0.002	0.003
6 month	0.0	0.0065	0.002	0.003

(Continued)

Table 14 (Continued)

Age	Deflection, in. Specimen 1	Specimen 2	Specimen 3	Average
e. Epoxy A Grout, Wet Placing and Submerged Curing Conditions. (Specimens grouted 8 days prior to loading.)				
10 min	0.0	0.0	0.0	0.0
20 min	0.0	0.0	0.0	0.0
30 min	0.0	0.0	0.0	0.0
40 min	0.0	0.0	0.0	0.0
50 min	0.0	0.0	0.0	0.0
60 min	0.0	0.0	0.0	0.0
2 hr	0.0	0.0	0.0	0.0
3 hr	0.0	0.0	0.0	0.0
4 hr	0.0	0.0	0.0	0.0
5 hr	0.0	0.0	0.0	0.0
6 hr	0.0005	0.0	0.0	0.0
7 hr	0.0005	0.0	0.0	0.0
1 day	0.0005	0.0	0.001	0.001
2 day	0.0005	0.0	0.001	0.001
3 day	0.0007	0.0	0.001	0.001
4 day	0.0012	0.0	0.0015	0.001
5 day	0.0015	0.0	0.0015	0.001
6 day	0.0015	0.0	0.0015	0.001
7 day	0.0015	0.0	0.0015	0.001
2 week	0.0015	0.0	0.0015	0.001
3 week	0.0015	0.0	0.0025	0.001
4 week	0.002	0.0	0.003	0.002
2 month	0.002	0.0	0.003	0.002
3 month	0.002	0.0	0.003	0.002
4 month	0.007	0.0	0.003	0.003
5 month	0.007	0.0	0.003	0.003
6 month	0.007	0.0	0.003	0.003

(Continued)

Table 14 (Concluded)

Age	Deflection, in. Specimen 1	Specimen 2	Specimen 3	Average*
f. Polyester Resin Grout, Submerged Placing and Curing Conditions. (Specimens grouted 8 days prior to loading.)				
10 min	0.001	0.080	0.024	0.013
20 min	0.002	0.112	0.030	0.016
30 min	0.0025	0.1275	0.036	0.019
40 min	0.0035	0.1345	0.037	0.020
50 min	0.0035	0.141	0.038	0.021
60 min	0.0035	0.147	0.039	0.021
2 hr	0.004	0.1725	0.0445	0.024
3 hr	0.005	0.178	0.049	0.027
4 hr	0.006	0.184	0.053	0.030
5 hr	0.007	0.196	0.059	0.032
6 hr	0.008	0.210	0.063	0.036
7 hr	0.008	0.218	0.065	0.037
1 day	0.009	0.234	0.067	0.038
2 day	0.011	0.321	0.076	0.044
3 day	0.013	0.338	0.080	0.047
4 day	0.012	0.351	0.082	0.047
5 day	0.014	0.3675	0.085	0.050
6 day	0.0155	0.374	0.089	0.053
7 day	0.017	0.408	0.090	0.054
2 week	0.021	0.452	0.099	0.059
3 week	0.0245	0.100**	0.1035	0.064
4 week	0.028		0.1035	0.066
2 month	0.030		0.1095	0.070
3 month	0.031		0.1145	0.073
4 month	0.035		0.1185	0.077
5 month	0.036		0.1185	0.077
6 month	0.042		0.1225	0.082

* Average of Specimens 1 and 3.
** Stopped test on this day. Did not repeat.

Table 15

Results of Pullout Strength Tests on Percussion-Drilled Specimens

Grout Placing Condition	Curing Condition	Curing Temp, °F	Type of Grout	Age days	Maximum Load, lb	Type of Failure*
Holes cleaned before placing grout						
Submerged	Submerged	70	Polyester resin	28	35,000	C
Submerged	Submerged	70	Polyester resin	28	35,000	C
Submerged	Submerged	70	Polyester resin	28	35,000	C
Average					35,000	
Wet	Submerged	70	Epoxy A	28	41,000	C
Wet	Submerged	70	Epoxy A	28	42,500	B
Wet	Submerged	70	Epoxy A	28	42,000	C
Average					41,800	
Submerged	Submerged	70	Cement	28	45,000	C
Submerged	Submerged	70	Cement	28	43,000	C
Submerged	Submerged	70	Cement	28	42,400	C
Average					43,500	
Holes not cleaned before placing grout						
Submerged	Submerged	70	Polyester resin	28	30,500	A
Submerged	Submerged	70	Polyester resin	28	36,500	A
Submerged	Submerged	70	Polyester resin	28	32,200	A
Average					33,100	
Wet	Submerged	70	Epoxy A	28	12,000	A
Wet	Submerged	70	Epoxy A	28	11,000	A
Wet	Submerged	70	Epoxy A	28	14,000	A
Average					12,300	
Submerged	Submerged	70	Cement	28	44,200	C
Submerged	Submerged	70	Cement	28	20,000	A
Submerged	Submerged	70	Cement	28	31,500	C
Average					31,900	

* A - Bar and grout plug pulled out of drilled hole.
B - Bar broke.
C - Concrete cylinder split.

Table 16

Results of Pullout Strength Tests on Core-Drilled Specimens

Grout Placing Condition	Curing Condition	Curing Temp, °F	Type of Grout	Age days	Maximum Load, lb	Type of Failure*
Holes cleaned before placing grout						
Submerged	Submerged	70	Polyester resin	28	29,000	A
Submerged	Submerged	70	Polyester resin	28	43,000	C
Submerged	Submerged	70	Polyester resin	28	25,000	A
Average					32,300	
Wet	Submerged	70	Epoxy A	28	46,000	B
Wet	Submerged	70	Epoxy A	28	45,000	B
Wet	Submerged	70	Epoxy A	28	42,000	B
Average					44,300	
Submerged	Submerged	70	Cement	28	34,000	C
Submerged	Submerged	70	Cement	28	45,000	C
Submerged	Submerged	70	Cement	28	36,500	C
Average					38,500	
Holes not cleaned before placing grout						
Submerged	Submerged	70	Polyester resin	28	28,000	A
Submerged	Submerged	70	Polyester resin	28	32,300	A
Submerged	Submerged	70	Polyester resin	28	30,000	A
Average					32,400	
Wet	Submerged	70	Epoxy A	28	45,000	B
Wet	Submerged	70	Epoxy A	28	41,000	C
Wet	Submerged	70	Epoxy A	28	44,000	B
Average					43,300	
Submerged	Submerged	70	Cement	28	35,000	C
Submerged	Submerged	70	Cement	28	34,000	C
Submerged	Submerged	70	Cement	28	32,500	C
Average					33,800	

* A - Bar and grout plug pulled out of drilled hole.
B - Bar broke.
C - Concrete cylinder split.