EPOXY AND CEMENT-TYPE COMPOUNDS FOR GROUTING

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ABSTRACT: Comparative tests were conducted to establish reasonable design stresses a) for use of epoxy-polysulphide materials in grouting rebars in existing concrete sidewalks to anchor concrete parapet bridge rail, and b) for use of cement-type materials for grouting bolts in abutments on anchor spans of cantilever bridges. These included impact pull-out tests for epoxy grout at -14 F and room temperature, and static pull-out tests for all materials. Design stresses were established for all materials tested, and the feasibility of using epoxy grout and mortar was as demonstrated. It is also recommended on the basis of comparison of hex-head and swedge bolts (using a cement-type grout), that only the former be used in concrete abutments of cantilever bridges. Recommended construction practice is outlined.

KEY WORDS: epoxy, epoxy resins, mortars, grout, grouting, cement grouts, anchor bolts, anchorages, bridge abutments, bridge rails, shear forces, shear stress, testing.

FOREWORD

In January 1965, the Research Laboratory was contacted verbally by P. A. Nordgren concerning the possibility of attaching concrete parapet bridge railing to existing bridge sidewalks without the necessity of removing the entire sidewalk. The problem was referred to the Concrete and Structures Units of the Laboratory for study.

On February 18, 1965 a report by C. J. Arnold was transmitted by the Research Laboratory to Mr. Nordgren suggesting possible use of epoxy resin grout for anchoring the reinforcing bars. It suggested that if he was interested, he might submit a request to W. W. McLaughlin for a laboratory test program to establish whether use of this material would be feasible.

On May 13, 1965 Mr. McLaughlin received a letter from N. C. Jones stating that it was planned to replace railing on the bridge carrying I 96 over the Thornapple River near Grand Rapids, that they would like to use epoxy grout for this purpose, and asking for advice as to the type of epoxy to use.

In his reply of June 2, 1965 Mr. McLaughlin mentioned one type of epoxy resin that might be applicable to the problem, and also noted the need for a test program involving determination of certain physical properties of epoxy resin mortar under varying temperature conditions before recommending this method of construction as acceptable and feasible. On June 16, 1965 Mr. McLaughlin received a request from Mr. Nordgren for a test program and the problem was assigned to the Research Laboratory on June 17, 1965. A meeting was held on June 24, 1965 in the Bridge Construction office to clarify and detail the purpose and conditions of the test program.

By request of H. B. LaFrance, an interim memorandum covering certain urgent summary information was transmitted by the Research Laboratory to Mr. Nordgren on March 2, 1966. This information was submitted to the Bureau of Public Roads for approval on March 7, 1966 and in reply they agreed in principle that the method is feasible, but required more information on certain factors before making final determination. Such information was supplied by the Office of Construction, whereupon C. B. Laird announced in Construction Circular Letter 1966-9, dated March 31, 1966, that the Bureau of Public Roads had, in essence, approved this method for attaching new parapet rail posts to existing sidewalks. The following work constitutes the Research Laboratory's final report on the completed investigation.

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The testing program described here was requested by the Bridge Construction Division in a letter of June 16, 1965. The tests were conducted by the Research Laboratory Division, as a cooperative effort by the Structures Unit of the Physical Research Section and the Concrete and Bituminous Unit of the Materials Research Section.

The objectives of the program were to establish reasonable design stresses for the following applications: a) epoxy-polysulphide materials for grouting steel rebars in existing concrete sidewalks to anchor new concrete parapet bridge rail, and b) cement-type materials for grouting bolts in abutments on anchor spans of cantilever bridges.

Research in Other States

Several other states have shown considerable interest in the use of epoxies in highway construction, and their work will be summarized here to provide background on the materials, before proceeding with discussion of the Research Laboratory's tests.

New York has published results of its Physical Research Project 13 on epoxy bonding compounds in two reports.[1,2] These deal with development of epoxy formulations and with physical and comparative testing of epoxy "Formulation G," in standard laboratory tests as well as quarter-scale composite beam tests. Formulation G is essentially the same material used in the Michigan tests, an epoxy-polysulfide grout covered by Federal Specification MMM-G-650a, so the results pertaining to that formulation are of particular interest. The following statements, taken from the abstracts of the New York reports, apply to Formulation G:

1. "In properly prepared adhesion specimens of steel-to-mortar, with an epoxy adhesive, the mortar is the weakest component of the cured system....

2. "...Epoxy resins from different manufacturers are interchangeable in the formulation described in this report, provided that they are within the limits of epoxide equivalent weight and viscosity specifications.

3. "There appears to be no deterioration of cured epoxy due to age or moisture, at normal atmospheric temperatures, at least up to a 7 month period.

4. "The epoxy formulation described in this report does not hinder proper concrete curing and vice versa.

5. "The major strength of the epoxy formulation described in this report is developed within the first three days....

6. "...Freeze-thaw cycling of steel to mortar adhesion specimens did not affect the epoxy, only the mortar.

7. "Concrete T-beams, consisting of a slab glued to a stem with epoxy, proved equal in static tests only, to monolithic T-beams of the same dimensions.

8. "A single composite steel-to-concrete beam, using the epoxy as a shear connector, developed 10/11 of the ultimate flexural strength of a like beam in which stud connectors were used. The epoxy glued beam showed better interaction at high loads.

9. "The epoxy formulation described in this report proved superior to a mortar slurry in a grouting application as demonstrated by a series of pull-out tests. The epoxy was more easily applied, and showed much greater bond strength between the steel inserts and concrete cores which were tested....

10. "...At low temperatures the curing of the epoxy formulations is temporarily interrupted. At temperatures above +60°F curing once again continues, and the material gains strength with time....

11. "...Concrete additives presently used by New York State have no deleterious effect on the curing of the adhesive system....

12. "...Changes in the normal thickness of an adhesive layer that would be used for field construction will not seriously affect the strength of the structural system....

13. "...Solvents reduce the viscosity of the formulation materially, but also degrade the strength of the structural system. It is recommended that solvents not be used for field applications.

14. "Creep of a composite unit, consisting of a concrete slab glued to steel beams using Formulation G, was insignificant during a 6-2/3 month testing period."

Arizona has completed a project to evaluate epoxy resins in reinforced concrete under dynamic loads.[3] This was to determine the effect of dynamic or repeating loads on epoxy-joined composite T-beams. Eight beams were tested, of which six were epoxy-joined and two stud-connected; two of the beams were subjected to creep tests as well. It was concluded that creep was insignificant, and stated that "considering that the dynamic loads were equal and greater than the loads that would occur in highway bridges and assuming that the design guides mentioned in the Static Load Test Report were followed, it is concluded that epoxy joined composite T-beams can be used with confidence in highway bridge construction."

New York and Connecticut are cooperating in the construction of a pair of 1500-ft Interstate highway bridges, precasting the components and gluing them together.[4] "Precast concrete piles will have epoxy splices; abutments and caps will be fixed by epoxies to the piles; precast girders will be made continuous by having their ends glued together, and the concrete deck will be of composite construction, also by virtue of epoxies."

The structures are reportedly designed to carry a 217-ton crane that swings a 47-ton load, and also 25-cu yd scrapers while they haul a total of 800,000 cu yd of earth during road construction. These structures were designed for minimum construction time. The two highway departments and the Bureau of Public Roads agreed to the glued design. Cost of the structures is reportedly the same as or less than the cost for conventional steel Interstate highway bridges in the area.

Scope and Theory of Michigan Tests

Phase 1. Epoxy-polysulphide grout (Federal Specification MMM-G-650a) was used to secure deformed bars and threaded rods in holes drilled in concrete blocks. Several combinations of rod and bar size, hole diameter, and depth were tested. Pull-out tests were conducted both statically and under impact at room temperature, with limited low temperature impact tests as well. Double shear-bond tests were also made. Epoxy-polysulphide mortar, using Federal Specification MMM-B-350a binder, and grout were compared in identical static, room temperature tests. Results were applied to development of anchorages for 3/4- and 1-in. diam ASTM A 15 hard grade rebars for use in new concrete parapet bridge rail, as established in a meeting at the Bridge Construction Office on June 24, 1965.

Phase 2. Chem-Comp, Embeco, and Lumnite mortars were compared in double shear-bond tests as well as static, room temperature pull-out tests. Embeco mortar was then used in a comparison of swedge and hex-head bolts in similar pull-out tests. Results were applied to development of anchorages for 1- and 1-1/2-in. diam ASTM A 307 bolts for use in anchor spans of cantilever bridges, as also established in the meeting of June 24. Chem-Comp is an expansive-type cement used in place of normal portland cement. Lumnite is a high alumina cement with early strength gain properties. Embeco is a frequently used, metallic admixture with expansive properties to eliminate shrinkage.

Laboratory type pull-out tests using a universal testing machine result in a uniform support of the test blocks excluding an area of 3-1/2 by 6-5/8 in. near the bars that are being pulled, which prevents spalling of large cones from the concrete. It remains to be shown theoretically or by large-scale field tests that the concrete will not fail in the manner described, when anchorage depths are greater than a certain critical value which will be called h_c. The following assumptions were used in the development of the theoretical value for h_c:

1. The anchorages of individual bars or bolts are sufficiently separated for each to develop at least 60 percent of the strength that it would if isolated.

2. Tensile failure will occur on a conical surface with a total angle of at least 60^o at the apex. This angle is less than is usually encountered in spall failures, and should lead to conservative results.

3. The resultant of the forces acting on the conical surface is vertical.

4. The ultimate compressive strength of the concrete f'_c is equal to 3500 psi, and the ultimate tensile strength is equal to $0.08\ f'_c$.

Using these four assumptions, it can be shown that the critical depth of anchorage h_c which must be exceeded to prohibit conical tensile failure, is given by the expression

$$h_c^2 = 0.00085\ P$$

where P is the applied load. Table 1 has been prepared using this expression, to show critical anchorage depths for bolts and rebars of interest in this study. If designed anchorage depths exceed the values shown in the table, they should not be subject to conical tensile failure, especially since the area of the conical surface increases as the square of the embedment for any given cone angle, while the shear bond area increases only linearly.

TABLE 1
COMPUTED VALUES FOR CRITICAL MINIMUM EMBEDMENT, h_c TO PREVENT TENSILE FAILURE ON A 60° CONICAL SURFACE WHEN f'_c = 3500 psi AND ULTIMATE TENSILE STRENGTH IS 0.08 f'_c

Anchorage Required	Bolt/Bar Diam, in.	Steel Type (ASTM Designation)	Cross-Sectional Area, sq in.	Min. Tensile Strength, psi	Ultimate Load, lb	Adjusted Ultimate Load, lb[b]	h_c, in. [c]
Rebar	3/4	A 15 hard grade	0.44	80,000	35,200	58,700	7.1
	1	A 15 hard grade	0.79	80,000	63,200	105,000	9.4
Bolt	1	A 307	0.61[a]	55,000	33,600	56,000	6.9
	1-1/2	A 307	1.41[a]	55,000	77,500	129,000	10.5

(a) Failure for threaded fasteners is based on stress area, slightly greater than the root area.

(b) Load adjusted to account for 40-percent reduction in concrete capacity, due to interaction of stress fields from nearby anchorage.

(c) Based on adjusted load.

TABLE 2
COMPOSITION OF GROUTING MIXTURES

Type	Proportions by Weight
Epoxy-Polysulphide Mortar	1 mixed MMM-B-350a binder 2 dry masonry sand
Epoxy-Polysulphide Grout	Type B MMM-G-650a grout manufactured with 25-percent mineral filler
Chem-Comp Mortar	1 Chem-Comp cement 2.8 sand 0.53 water
Lumnite Mortar	1 Lumnite cement 2 sand 0.42 water
Embeco Mortar	1 Embeco admixture 1 portland cement (Type I) 1 sand 0.38 water

Test Blocks and Grouting Materials

All concrete test blocks were 9 by 9 by 12 in., of high early strength mix, cured a minimum of 14 days in the moist room before drilling, with average compressive strength at time of test about 7400 psi. Holes were drilled by a large drill press to maintain alignment perpendicular to the block faces. Epoxy materials were tested after 7 days of room temperature cure, and cement-type mortars after 14 days in the moist room. Concrete surfaces were prepared by brushing with water, and allowed to dry before application of bonding agent. Steel surfaces were wire brushed where necessary and cleaned with trichloroethylene solvent.

The epoxy mortar used in the tests consisted of an epoxy-polysulphide binder and fine dry masonry sand, mixed 1 to 2 by weight. The binder met the requirements of Federal Specification MMM-B-350a. The epoxy grout used was a combination of the same binder with 25-percent mineral filler, and met the requirements of Federal Specification MMM-G-650a, Type B. Compositions of the various grouting mixtures are given in Table 2.

EPOXY-POLYSULPHIDE GROUT AND MORTAR (Phase 1)

Initial work on the project consisted of double shear-bond tests on the materials. These tests require specimens that are small and relatively inexpensive to prepare. Test materials are used to bond two sawed concrete blocks together, as shown schematically in Figure 1. The blocks are clamped securely in place, and a vertical load is applied to the test material by a testing machine until failure occurs along or near one of the adjacent block faces.

The tests were intended to establish the relative shear-bond strengths of the materials, and also to determine nominal stress values for use in the design of pull-out tests that were to follow. During testing, it became apparent that in many cases, one of the two faces was bearing far more load than the other at the time of failure. This means that the stress values obtained can be in considerable error, since the values are based upon equal load distribution to the two faces. The tests yielded average stress values of about 750 and 1000 psi for the epoxy grout and mortar, respectively. It was decided to use the results of the double shear-bond tests only as rough approximations of stresses to be expected in the subsequent pull-out tests, since the change from planar to cylindrical geometry, as well as the effect of bar deformations and threads, could be expected to increase bond strengths.

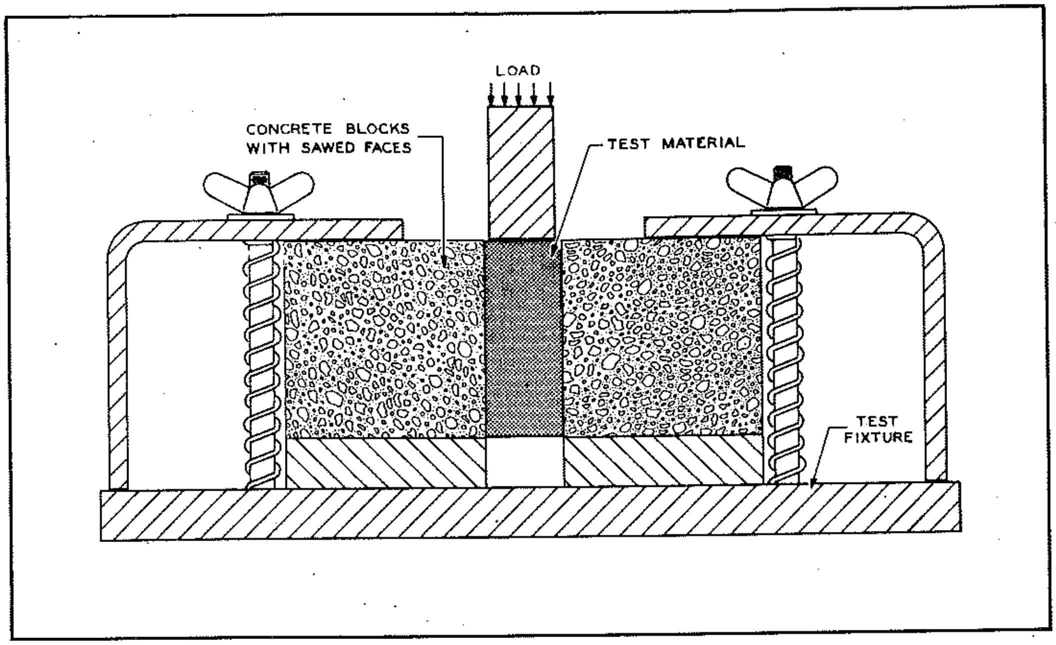
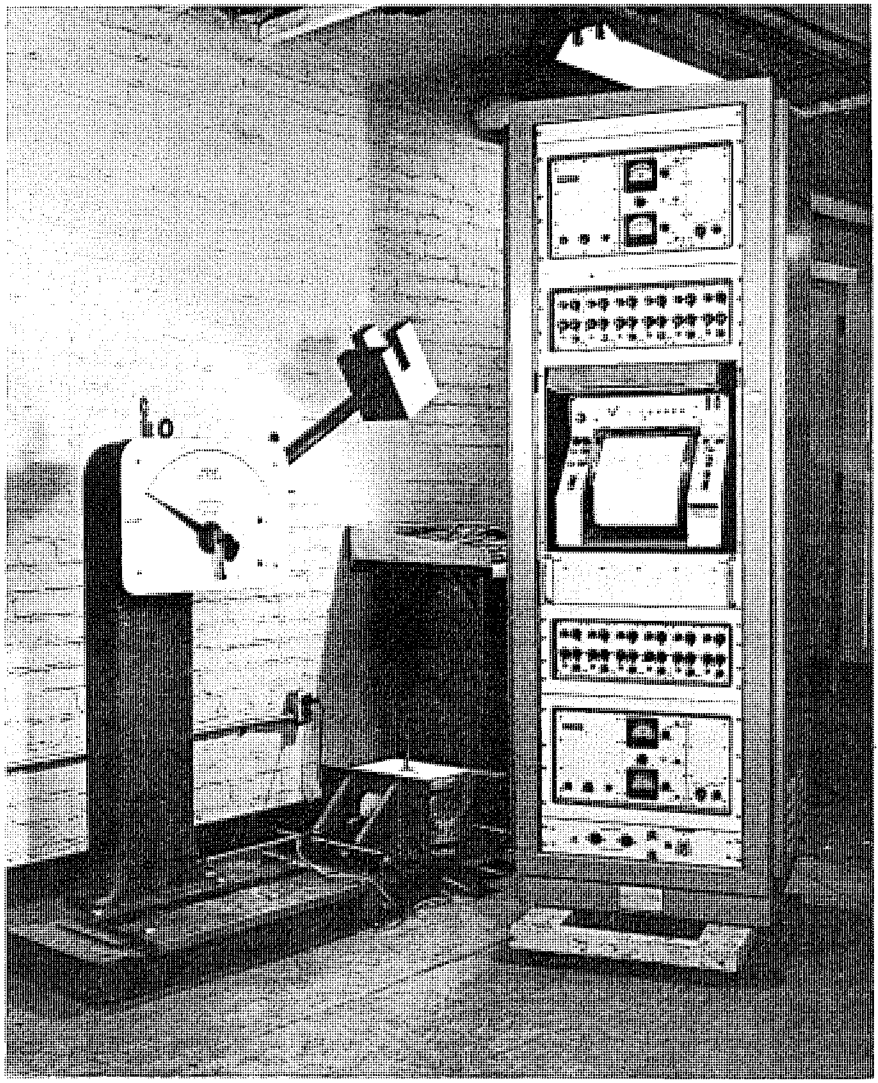


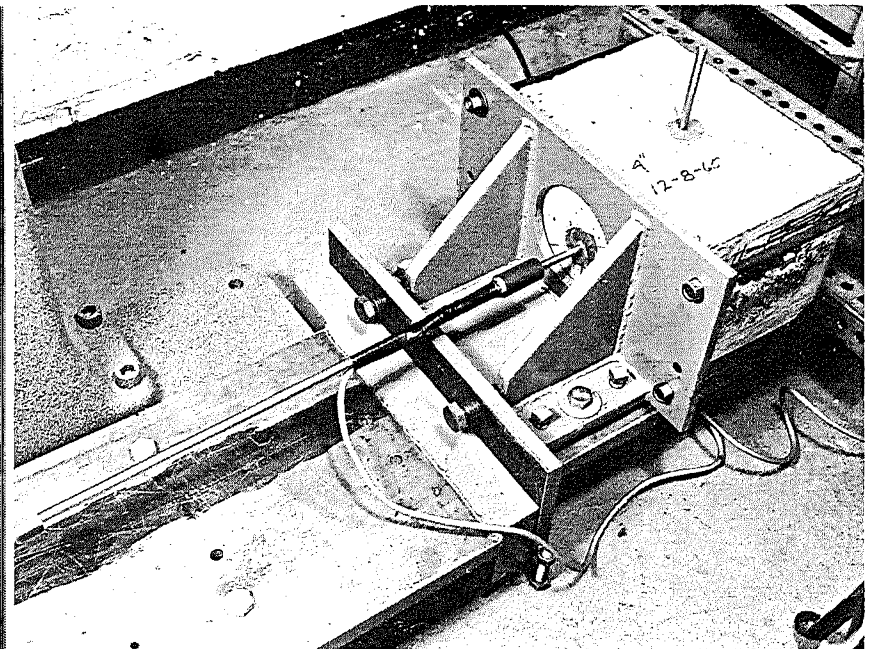
Figure 1. Schematic diagram of double shear-bond test.

Impact Tests

The main problem here was development of a method, and design and construction of test fixtures, to do quantitative impact testing of bars grouted into concrete. The Structures Lab is equipped with a Riehle impact tester with sufficient capacity to break 3/8-in. diam high strength bolts in tensile impact. An attachment for the machine was designed and built that would secure and position the test blocks for impact pull-out of 3/8-in. threaded rods. An instrumented drawbar was made to transfer the hammer blow axially to the threaded rod. The drawbar was calibrated in a universal testing machine. The test fixture with a sample mounted and the drawbar in place is shown in Figure 2. Recording was done on a Honeywell high speed light beam oscillograph. The entire setup, ready for test, is also shown in Figure 2. All tests were run with the 60-lb hammer dropped from a height of 4 ft which caused the load to peak and return to zero within less than 0.002 sec.

Impact tests were run with epoxy grout only, on 3/8-in. threaded rods set in 1/2-in. diam holes of various depths. No impact tests were run on epoxy mortar because the grain size of the sand used in the mortar required a minimum clearance of about 1/4 in. around the rod, leading to an unrealistic ratio of bonding agent volume to rod area, for rods as small as 3/8 in.





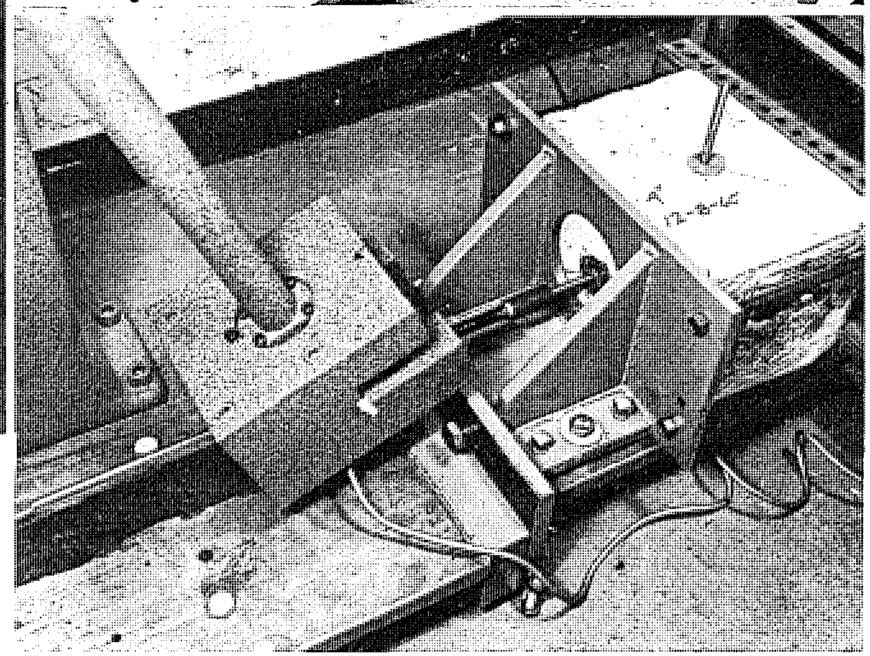


Figure 2. Impact testing apparatus (left) ready for test, including Riehle Model PI-2 impact tester with 60-lb hammer, special fixture for holding blocks, instrumented drawbar, and Honeywell recording system. At right, impact test fixture is shown with sample and drawbar in place (top), and impact hammer is shown approaching drawbar (bottom).

In the first series of impact tests, threaded cold-rolled steel rods were grouted 1-1/2, 2, 2-1/2, 3, 4, and 5 in. deep and tested to determine allowable stresses for further tests. Embedment of 2 in. or more resulted in fracture of the rods rather than pull-out. The 1-1/2-in. embedment resulted in spall-type concrete failure, nearly full depth. Stresses developed in these tests indicated that steel with a minimum ultimate strength of 150,000 psi should result in extraction of threaded rods at depths of 2 to 2-1/2 in. Nine high-strength threaded rods were prepared, grouted in 1/2-in. diam holes (three each at 1-1/2, 2, and 2-1/2 in.), cured, and tested. Although all failures (other than rod failures) were in the concrete, shear-bond stresses between epoxy grout, concrete, and steel at the time of failure have been calculated for comparison. Results of the tests are shown in Table 3, and typical failures in Figure 3. Failure was due to concrete spalling and cracking in the 1-1/2- and 2-in. embedments. All three tests at 2-1/2-in. embedment caused failure of the high strength steel rods, with little or no damage to concrete or grout. The 1-1/2- and 2-in. embedments where concrete failure occurred developed average nominal shear bond stresses of 2780 and 2960 psi, respectively, at the grout-concrete interface during impact. Most of the grout remained attached to the steel after testing. No failure occurred at the steel-grout interface.

Three additional samples were prepared for cold impact testing. High strength threaded steel rods were grouted 2 in. deep, cured, and then placed overnight in a freezer at -14 F. Styrofoam insulation was placed over the rods to prevent rapid warming of the grout area when the blocks were removed for testing. Impact tests were run within 10 minutes of removal from the freezer, which did not allow significant warming of the 9 by 9 by 12 in. concrete blocks. Results of these tests are also given in Table 3. Failures occurred in the concrete in all cases, and were similar to failures in room temperature tests shown for 2-in. embedment in Figure 3. Average nominal shear bond stress at the grout-concrete interface was not significantly different from the room temperature tests.

J. D. Kriegh and E. G. Endebrock [5] reported static tests, at -7 F, of an epoxy-joined composite T-beam, 17-1/2 ft long, composed of a 12I50 steel beam and a 40- by 4-in. concrete slab. It was concluded that the T-beam performed as well at -7 F as did other T-beams of the same cross-section tested at room temperature.

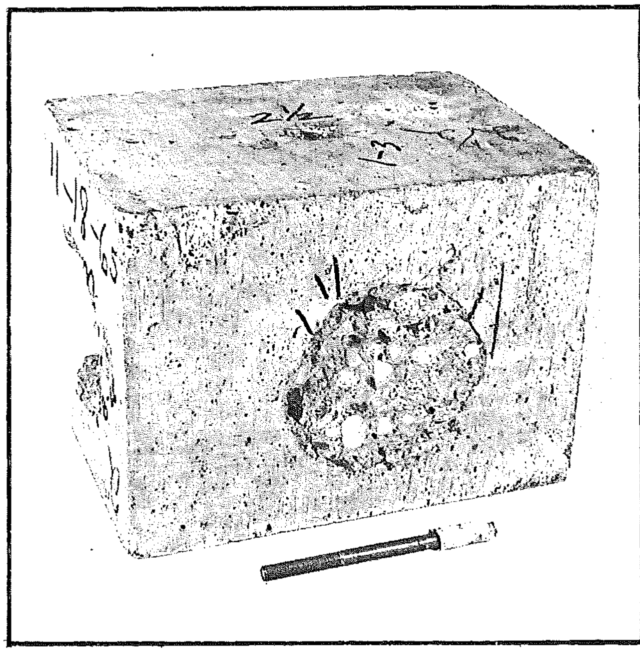
In some of the Research Laboratory's tests where rods were broken by impact, there was sufficient steel to rethread. Three such samples were then subjected to static pull-out, with the result in all cases that the rod failed again with no damage to the concrete or grout. Another sample with 2-1/2-in. embedment where the rod had failed by impact was re-threaded, replaced in the impact machine, and given two more blows of about 1-ft hammer fall, which resulted in some visible damage to the block in the grout area. The rod was then pulled out with the universal testing machine at a load of 6250 lb, which resulted in splitting of the block. Fig-

TABLE 3
IMPACT PULL-OUT TEST RESULTS WITH EPOXY GROUT
3/8-in. diam threaded rods set in 1/2-in. ND holes

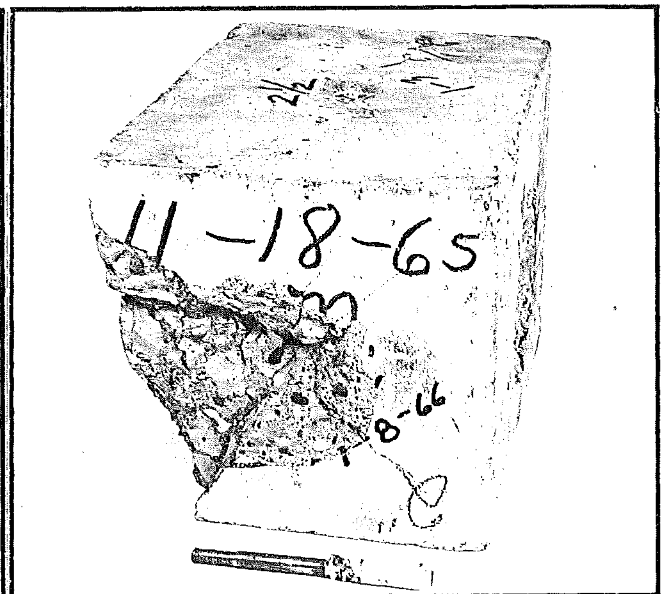
	Embedment Depth, in.	Ultimate Load, lb	Interface Shear-Bond Stress, psi*		Type of Failure
			Grout-Concrete	Grout-Steel	
AT ROOM TEMPERATURE	1-1/2	7,100	2,630	3,950	Spall nearly full-depth
		8,100	3,000	4,500	Spall about half-depth
		7,300	2,700	4,050	Spall about half-depth
	Avg	7,500	2,780	4,170	
	2	10,800	3,000	4,500	Spall about half-depth, block broken
		10,500	2,920	4,370	Grout-concrete bond, some spall
		10,700	2,970	4,460	Spall nearly full-depth, block broken
	Avg	10,670	2,960	4,440	
	2-1/2	10,600	2,360	3,530	Rod broken, grout and concrete intact
		10,800	2,400	3,600	Rod broken, grout and concrete intact
		10,600	2,360	3,530	Rod broken, grout and concrete intact
	Avg	10,670	2,370	3,550	
AT -14 F	2	10,600	2,940	4,420	Spall, block cracked
		9,300	2,580	3,870	Spall, block cracked
		10,600	2,940	4,420	Spall, block cracked
	Avg	10,170	2,820	4,240	

*Stresses based on actual hole diameter, 1/16 in. larger than nominal diameter.

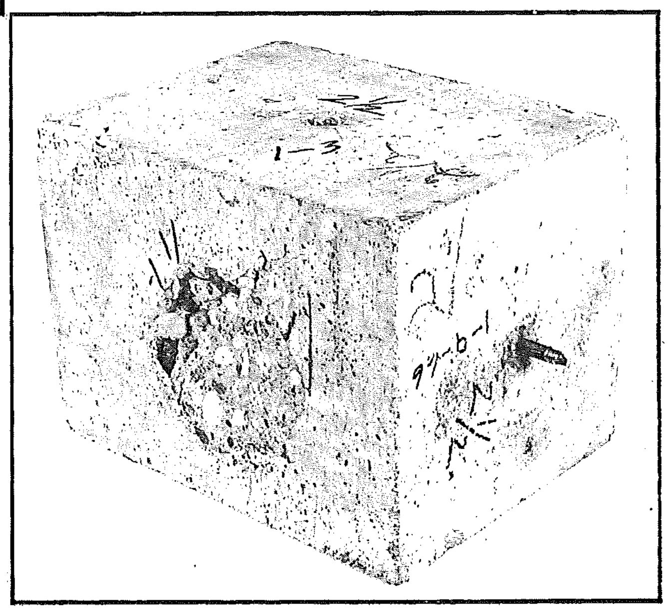
ure 4 shows the rod and grout after pull-out, with progressive damage to the 1/2 in. of grout near the block face evidently caused by the repeated impacts. The limited extent of damage to the grout, even after such severe treatment and failure of the concrete block, illustrates the reserve strength of this material. In none of the tests did the grout fail by shattering under impact nor by slipping out of the concrete.



1-1/2-in. embedment



2-in. embedment



2-1/2-in. embedment

Figure 3. Samples after impact pull-out tests, one of which resulted in concrete spalling (top left), another in spalling and concrete failure top right), and a third in failure of the rod (bottom right). In all cases, threaded 3/8 in. diam high-strength rods were embedded in 1/2-in. diam holes, using epoxy grout.

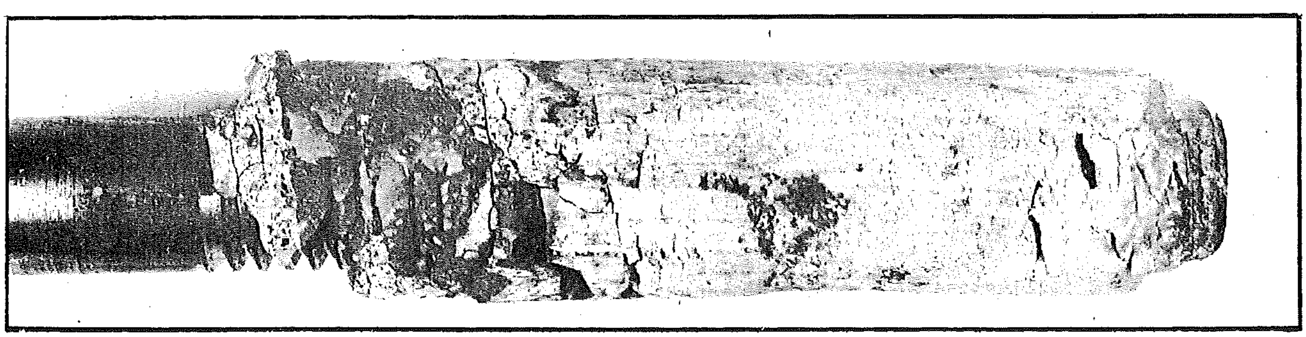


Figure 4. Appearance of threaded rod and grout with 2-1/2 in. embedment, after the following treatment: a) impact hammer dropping 4 ft caused fracture of high-strength rod, b) rod was then rethreaded and given two more blows with 1-ft hammer fall causing some damage to concrete and grout, and c) rod was then pulled from block with universal testing machine, requiring a load of 6250 lb, and this split the block.

Static Pull-Out Tests

Room temperature, static pull-out tests were conducted on various threaded and deformed bars set with epoxy grout. Results of the tests are given in Table 4, and typical specimens shown after test in Figure 5. The tests on threaded rods resulted in average shear-bond stress, at the concrete-grout interface, of about 1800 psi, which is roughly 50 percent lower than indicated in the impact tests. This difference is undoubtedly due to the extremely short duration of the force pulse in the impact tests.

The tests with 1/2-in. diam rebars resulted in block fracture in several instances, so that corresponding stresses can be regarded only as minimum values. Data are sufficient to establish minimum average nominal shear-bond stresses exceeding 1450 psi at the concrete-grout interface, where most of the failures occurred. No total failures occurred at the steel-grout interface, where average nominal shear-bond stresses exceeded 2000 psi.

Application of epoxy grout to reinforcement for concrete parapet bridge rails requires deformed bars of up to 1 in. diam. To determine whether there was any adverse effect from large bar size, three samples were prepared with 1-in. diam rebars--two in newly drilled 1-1/4-in. diam holes, and the third in the only remaining intact test block, in which there already was a 1-3/4-in. diam hole that had previously been used for pull-out of hex-head bolts with Embeco mortar. The bars were set with epoxy grout, cured, and tested. These tests resulted in block fracture as expected, with the results shown in Table 4. The sample in the 1-3/4-in. hole failed at a relatively low load, and it is believed that the block may have been cracked in the Embeco tests. The two bars set in the newly drilled 1-1/4-in. holes developed average shear-bond stress of 1230 psi at the concrete-grout interface before the blocks fractured.

The final series of tests was a comparison of epoxy-polysulphide grout and mortar. Deformed bars 1/2 in. in diameter were set in 1-in. diam holes, 1-3/4 in. deep. Three samples were tested for each material. Hole diameter is established by the required 1/4-in. clearance all around the bar to permit entry of the masonry sand contained in the mortar. Test results are shown in Table 5, and typical specimens after pull-out in Figure 6. The short embedment lengths in these tests were to ensure pull-out without block fracture or steel failure. Since the only variable in this series of tests was the grouting agent, and the modes of failure for the two

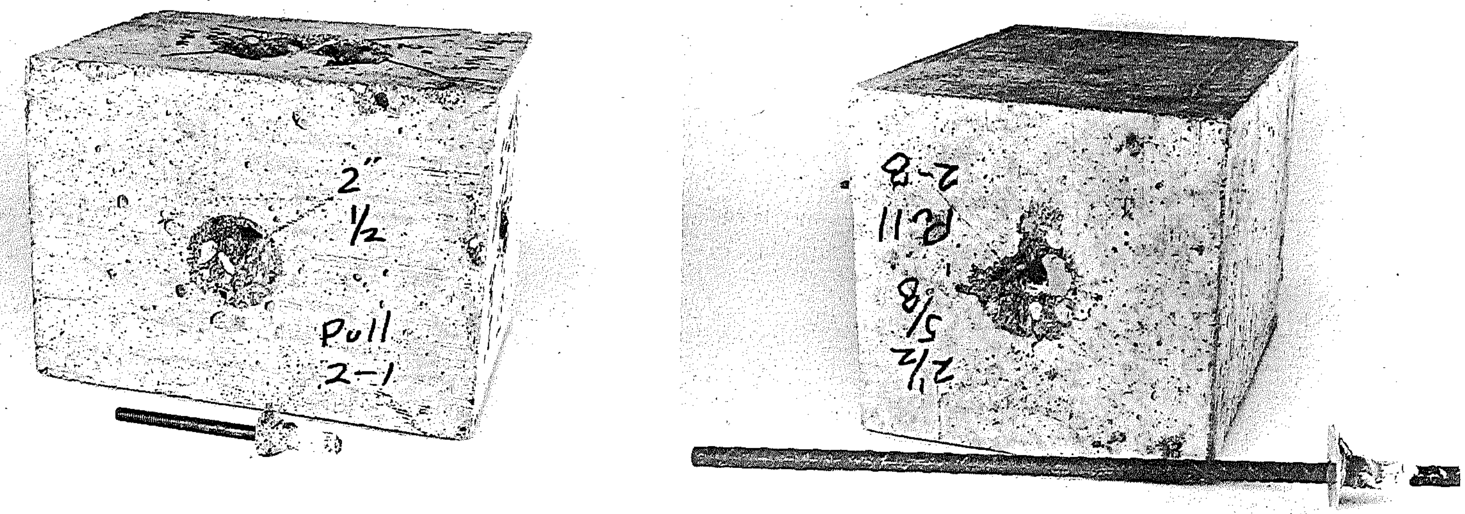
TABLE 4
STATIC PULL-OUT TESTS WITH EPOXY GROUT

	Rod/Bar Diam, in.	Hole Dimensions, in.		Ultimate Load, lb	Interface Shear-Bond Stress, psi[b]		Type of Failure[c]
		ND	Depth		Grout-Concrete	Grout-Steel	
THREADED RODS	3/8	1/2	2	7,700	2,140	3,210	Grout-concrete bond
				7,400	2,060	3,080	Grout-concrete bond, spall
				7,200	2,000	3,000	Grout-concrete bond, grout-steel bond, spall
	1/2	5/8	2-1/2	7,900	1,460	1,980	Grout-concrete bond, spall
				7,300	1,330	1,820	Grout-concrete bond, spall
				10,600	1,930	2,650	Block broken
DEFORMED BARS	1/2	5/8	1-1/2	4,850	1,470	2,020	Block broken
				5,300	1,610	2,210	Grout-concrete bond, spall
			2	5,800	1,320	1,810	Spall
				5,650	1,280	1,770	Block broken
				8,100	1,840	2,530	Block broken
			2-1/2	9,050	1,650	2,260	Grout-concrete bond, spall
			3	11,700	1,770	2,440	Block broken
				8,600	1,300	1,790	Block broken
				7,500	1,140	1,560	Grout-concrete bond, grout-steel bond, spall
				8,600	1,300	1,790	Grout-concrete bond, grout-steel bond
	1	1-1/4	3	16,750	1,350	1,770	Block broken
			3-1/4	14,700	1,100	1,440	Block broken
		1-3/4	3	12,300[a]	720[a]	1,300	Block broken

[a] The test hole in this block had previously been used for pull-out test of 1-in. hex-head bolt with Embeco, and may have been damaged in that test. All other test blocks were destroyed in testing.

[b] Stresses based on actual hole size, 1/16 in. larger than nominal diameter.

[c] Major portion of failure underlined for emphasis.



3/8-in. threaded rod, 1/2-in. ND hole

1/2-in. deformed bar, 5/8-in. ND hole

Figure 5. Typical specimens after static pull-out tests, using epoxy grouts.

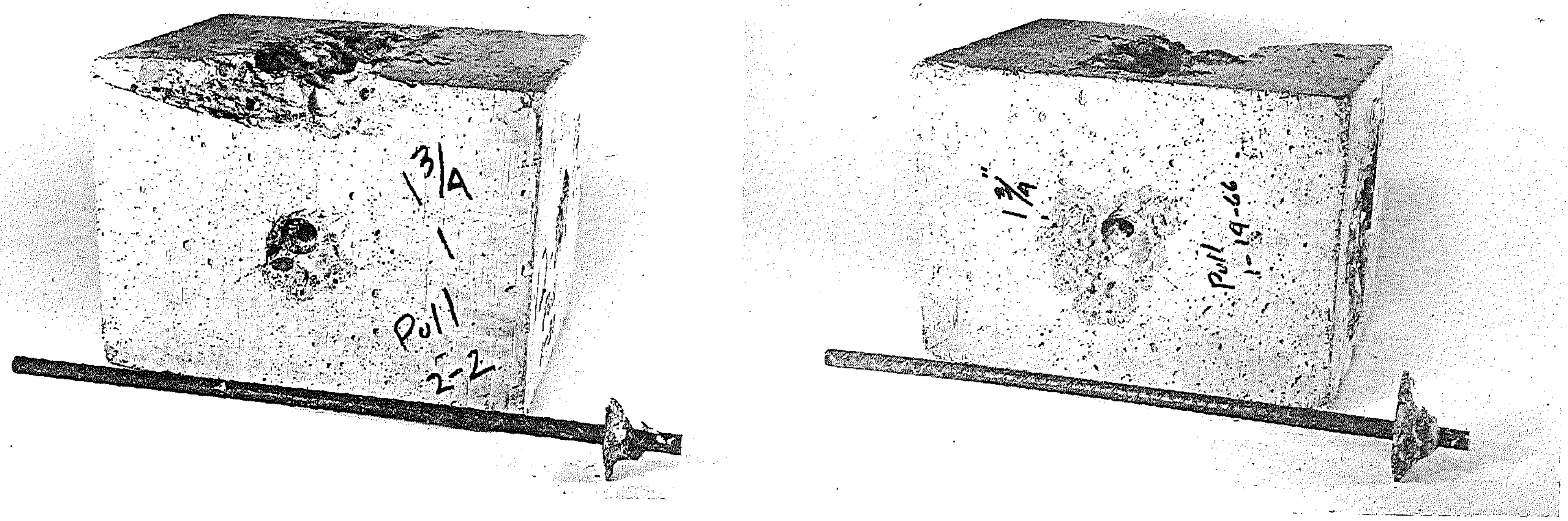


Figure 6. Typical samples of epoxy mortar (left) and grout (right), after pull-out. Both materials were used to set 1/2-in. rebars 1-3/4-in. deep in 1-in. ND holes.

materials were nearly identical, the failure load is the only parameter required for comparison. Average loads at failure were 6080 and 4680 for the mortar and grout, respectively.

The grout components containing filler are premixed by the supplier and it is probable that the resin or binder used in the grout in these tests is from a different batch than the binder used in the laboratory to prepare the mortar. Grout and mortar prepared from the same batch of binder might be expected to result in materials of more nearly equal strength.

TABLE 5
STATIC PULL-OUT TESTS OF DEFORMED BARS
WITH EPOXY-POLYSULPHIDE COMPOUNDS
1/2-in. bars, 1-3/4 in. deep in 1-in. ND holes

Material	Sample No.	Ultimate Load, lb	Type of Failure
Mortar	1	5,950	Epoxy-steel bond
	2	6,950	Epoxy-steel bond
	3	5,350	Epoxy-steel bond, spall
	Avg	6,080	
Grout	4	4,600	Epoxy-steel bond, spall
	5	4,850	Epoxy-steel bond, spall
	6	4,600	Epoxy-steel bond, spall
	Avg	4,680	

Anchorage Design

Tests of epoxy-polysulphide grout with 1/2-in. diam rebars indicate failure values of shear-bond stress at the grout-concrete interface of about 1450 psi, including cases where blocks fractured. The limited tests on 1-in. diam rebars gave minimum average values of 1230 psi before the blocks fractured. Deeper embedment should have a beneficial effect on an anchorage as a whole, since surface spalling of the concrete would have a relatively smaller effect than in the shallow embedments that could be tested in the laboratory. Generally, then, the large masses of concrete and deep embedments that would exist in a field installation should lead to higher nominal values of shear-bond stress than are obtainable in laboratory tests. Thus, 1000 psi is considered a reasonably conservative design value for allowable shear-bond stress at the concrete-grout interface for either epoxy mortar or grout. The average shear-bond stress developed at the steel grout interface was 2000 psi in the 1/2-in. rebar tests, with no failures occurring at this interface. Therefore, as long as the surface area of the hole is less than or equal to twice the embedded surface area of the bar, a shear-bond failure should not take place at the steel-grout interface.

From a construction point of view, hole sizes large enough to allow 1/4-in. clearance all around the bar would seem suitable. The volume of bonding agent would then be kept small, the "glue line" relatively thin, but there would still be room to allow use of mortar as an alternate to grout if desired, since the tests show the mortar to be as strong or stronger than the grout. The unit cost of epoxy mortar also should be considerably less than the grout.

Although the tests were limited in size and scope, the data are considered sufficient to justify the design of workable anchorages, subject to the limitations just listed, and Table 8 was prepared on that basis. Slight variations in hole size and depth possibly can be made as required, provided that the minimum or critical depth h_c is kept in mind for the application at hand, and that stresses on all surfaces are considered.

CEMENT-TYPE MORTARS (Phase 2)

Initial work on this phase of the project consisted of double shear-bond tests, run concurrently with those for the epoxy materials. Mix data are given in Table 2. The unsatisfactory nature of the tests was discussed in Phase 1 and will not be repeated here. The results indicated shear-bond strengths below 170 psi for all three materials. This value was used only as a rough approximation in designing the pull-out tests that followed. The Embeco expansive mortar has been used extensively by the Highway Department for grouting of anchor bolts. The Chem-Comp expansive cement and Lumnite high alumina cement were thought to be two good possible alternates.

Static Pull-Out Tests

The first series of pull-out tests was designed to indicate relative shear-bond strengths of the three materials. Hex-head machine bolts of 1/2 and 1 in. diam were grouted into drilled holes in test blocks. Bolts were placed in the holes at required depths, mortar poured in around the bolts, and tamped in place. A typical alignment fixture is shown in Figure 7 and test results in Table 6. Figure 8 shows the samples with 1/2-

in. diam bolts after pull-out. Failures were similar for the three materials, although the samples prepared with Embeco had spalled slightly more. Results from the 1/2-in. bolt tests show no significant difference in shear-bond strengths for the three materials.

All tests of samples with 1-in. diam bolts grouted 6 in. deep resulted in failure of the concrete blocks, as indicated in the table. The results from the 6-in. embedments are therefore not conclusive in themselves. The magnitude of shear-bond developed prior to block failure is interesting, however, since it is considerably greater than the values obtained from the 1/2-in. bolts at 2-1/2-in. embedment, where the blocks did not fail.

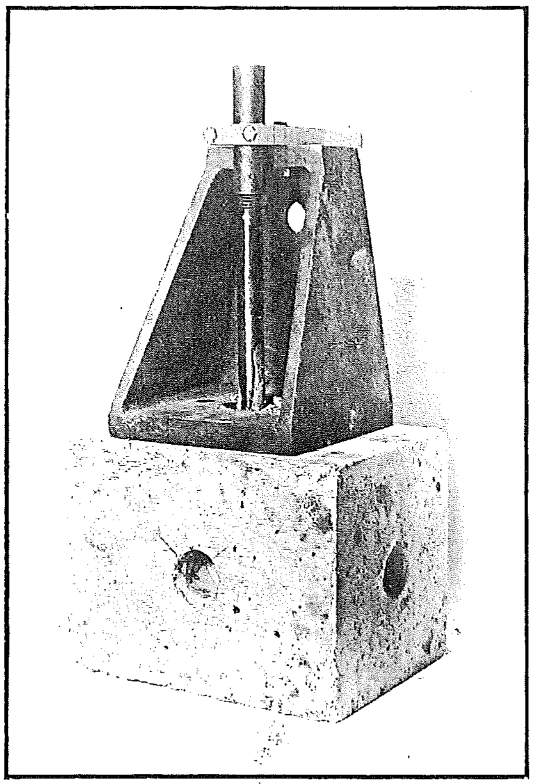


Figure 7. Typical fixture for alignment of bolts perpendicular to block face.

Although the average compressive strengths of the concrete blocks used with Embeco were only about 5 and 10 percent greater than the blocks used with Chem-Comp and Lumnite, respectively, the Embeco samples developed pull-out strengths prior to block failure of nearly 50 percent more than the other materials. No absolute statements can be made on the basis of so few samples, but it may be that Embeco mortar distributes stresses more evenly within the blocks. For this reason, and also because Embeco is perhaps the most familiar to Michigan contractors and Department personnel, it was used for the rest of the tests. Lumnite or Chem-Comp would evidently be suitable alternates to Embeco, from a standpoint of shear-bond strength.

The next series of tests was a comparison of 1-in. hex-head bolts with 1-in. swedge bolts, grouted with Embeco, in 1-3/4-in. diam drilled holes of 2, 3, and 4 in. depths. Results of the tests are shown in Table 7 with results of the earlier 6-in. embedment tests included from Table 6 for comparison. The magnitude of shear-bond stress at failure is consistently lower for the swedge bolts than for the hex-head bolts. Several

TABLE 6
STATIC PULL-OUT TESTS OF HEX-HEAD BOLTS
WITH CEMENT-TYPE MORTARS

Mortar	Bolt Diam., in.	Hole Dimensions, in.		Ultimate Load, lb	Shear-Bond Stress psi	Type of Failure
		ND	Depth			
CHEM-COMP	1/2	1	2-1/2	3,680	440	Shear-bond, slight spall
				3,500	420	Shear-bond
				6,800	810	Shear-bond, slight spall
				Avg	560	
	1	1-3/4	6	22,900	670	Block broken
				21,500	630	Block broken
				28,250	830	Block broken
				Avg	710*	
EMBECO	1/2	1	2-1/2	2,900	350	Shear-bond, spall
				5,400	650	Shear-bond, spall
				4,550	540	Shear-bond, spall
				Avg	510	
	1	1-3/4	6	38,050	1,110	Block broken
				30,300	890	Block broken
				36,500	1,070	Block broken
				Avg	1,020*	
LUMNITE	1/2	1	2-1/2	4,930	590	Shear-bond, spall
				4,000	480	Shear-bond, slight spall
				3,650	430	Shear-bond, slight spall
				Avg	500	
	1	1-3/4	6	27,250	800	Block broken
				20,000	590	Block broken
				23,150	680	Block broken
				Avg	690*	

*For comparison only, since all blocks failed.

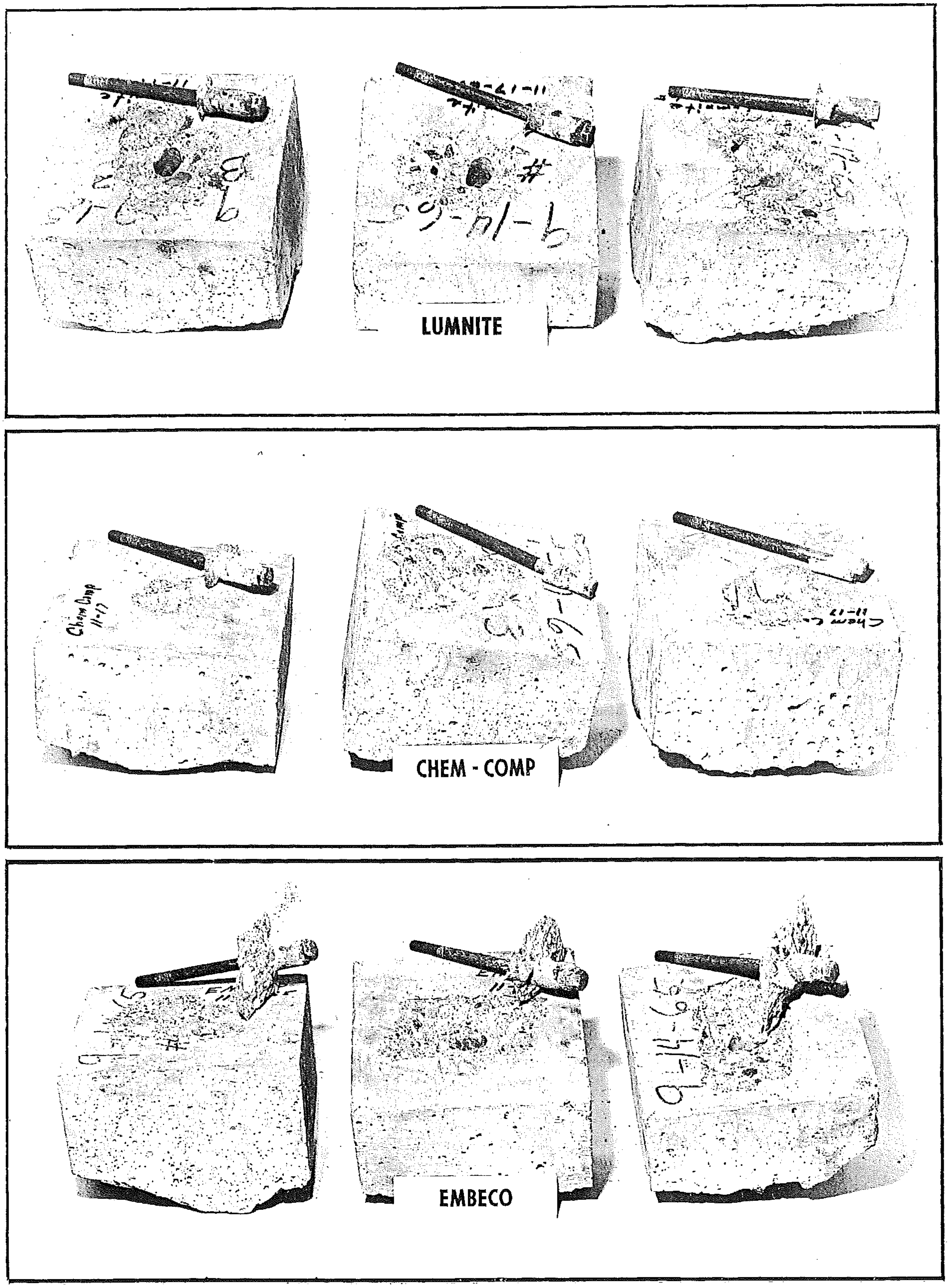


Figure 8. Samples after pull-out (1/2-in. diam bolts, 2-1/2-in. deep in 1-in. ND holes).

of the tests resulted in block failure prior to pull-out, so the corresponding shear-bond stresses can be considered only as minimum values. It should be noted here, again, that stresses developed by the hex-head bolts at deeper embedments, prior to block failure, were greater than stresses developed at lesser embedments where blocks did not fail. Evidently a compressive force is induced in the grout by the bolt heads, causing a corresponding increase in effective bond. This is also suggested by the failure of the test blocks, which split as if wedged open.

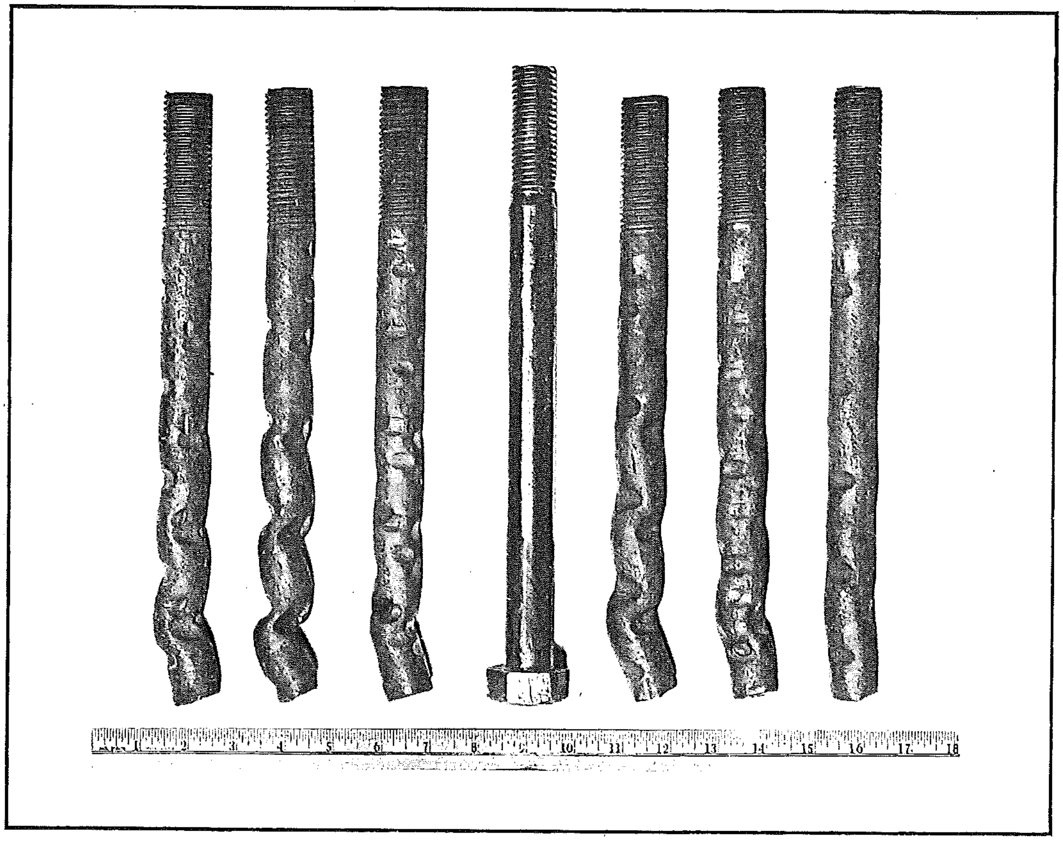


Figure 9. Typical bolts used in the tests. Note lack of uniformity in the amount of deformation of swedge bolts.

Bolt Procurement

Several pertinent facts were discovered as a result of the comparison of machine and swedge bolts. First: swedge bolts are not a readily available stock item, and must be obtained on order from a very limited group of suppliers, who generally make them up as requests are received. Second: they are not uniform in amount of deformation, as can be clearly seen in Figure 9. Third: they do not develop as much pull-out strength as ordinary machine bolts, as can be seen in Table 7. Conversely, ma-

TABLE 7
STATIC PULL-OUT TESTS OF 1-IN. HEX-HEAD AND SWEDGE BOLTS
Anchored with Embeco mortar in 1-3/4 in. ND holes

	Hole Depth, in.	Ultimate Load, lb	Shear-Bond Stress, psi(a)	Type of Failure
HEX-HEAD BOLTS	2	8,750	765	Shear-bond, at mortar-concrete interface
		3,030	265	Shear-bond, at mortar-concrete interface
		4,800	420	Shear-bond, at mortar-concrete interface
		Avg	480	
	3	11,480	670	Block broken
		7,950	465	Shear-bond, at mortar-concrete interface
		8,800	515	Shear-bond, at mortar-concrete interface
		Avg	550	
	4	14,300	630	Block broken
		14,850	650	Block broken
		Avg	640	
	6(b)	38,050	1,110	Block broken
		30,300	885	Block broken
		36,500	1,070	Block broken
		Avg	1,020	
SWEDGE BOLTS	2	4,450	390	Shear-bond, at mortar-concrete and mortar-steel interfaces
		4,200	370	Shear-bond, at mortar-concrete and mortar-steel interfaces
		3,800	330	Shear-bond, at mortar-concrete and mortar-steel interfaces
		Avg	365	
	3	8,000	470	Shear-bond, at mortar-concrete and mortar-steel interfaces
		7,100	415	Shear-bond, at mortar-concrete and mortar-steel interfaces
		6,650	390	Shear-bond, at mortar-concrete and mortar-steel interfaces
		Avg	425	
	4	9,250	405	Shear-bond, at mortar-concrete and mortar-steel interfaces
		9,050	400	Block broken
		Avg	405	

(a)Stresses based on actual hole diameter, 1/16 in. larger than 1-3/4 in. ND.
(b)Entries extracted from Table 6 for comparison purposes.

chine bolts are readily available from many hardware suppliers, and are uniform in size and shape. The type of head on the bolt should not significantly affect pull-out strength; however, most bolt manufacturers have discontinued square-head bolts, so the great majority of machine bolts available in the future will be hex-head.

Anchorage Design

The tests show average shear-bond stresses for 1-in. diam hex-head bolts with Embeco mortar (Table 7), exceeding 550 psi for 3-in. depth, 640 psi for 4-in. depth, and 1050 psi for 6-in. depth. This indicates the increasing effect of the bolt head at deeper embedments. Therefore, 750 psi is believed to be a reasonably conservative design stress for shear-bond in anchorages for 1-and 1-1/2-in. diam ASTM A 307 steel hex-head bolts, set 6 in. or deeper with Embeco. Drilled holes must be large enough to allow the bolt heads to enter and tamping to be done. The tests in this phase of the study were quite limited in scope, but are considered sufficient to justify the design of anchorages for the 1- and 1-1/2-in. bolts required in bridge abutments. Table 8 has been prepared, based upon these assumptions and test results.

CONCLUSIONS AND RECOMMENDATIONS

Epoxy-Polysulphide Grout and Mortar (Phase 1)

Although the test program was not extensive, it was deemed sufficient to establish the feasibility of the use of epoxy-polysulphide materials for highway construction, provided that reasonable stresses and configurations are used. Impact does not seem to be a problem with these materials, either at room temperature or at temperatures usually encountered in Michigan winters, since all failures in the impact tests were in the concrete, rather than in the epoxy material.

It is recommended that anchorages for concrete parapet bridge rail be constructed as indicated in Table 8, using either epoxy mortar or grout, with binder and grout meeting Federal Specification Nos. MMM-B-350a and MMM-G-650a, Type B, respectively. This should develop the minimum tensile strength of ASTM A 15 hard grade rebars.

Cement-Type Mortars (Phase 2)

This program has established the beneficial effect of bolt heads in developing shear-bond stress in anchorages involving cement-type grouts.

It was also found that hex-head bolts developed more pull-out strength than swedge bolts, and that square-head bolts have been discontinued by most bolt manufacturers. It is recommended, therefore, that only hex-head machine bolts be specified for use in concrete abutments of cantilever bridges. Embeco mortar is recommended although Chem-Comp and Lumnite mortars are evidently suitable from a standpoint of shear-bond strength. Anchorages should be constructed as shown in Table 8 to develop minimum tensile strength of ASTM A 307 bolts.

TABLE 8
RECOMMENDED HOLE SIZES AND DEPTHS
TO DEVELOP MINIMUM TENSILE STRENGTH
OF DEFORMED BARS OR BOLTS

Bar/Bolt Diam, in.	Steel Type (ASTM Designation)	Grouting Agent	Hole Dimensions, in.	
			ND	Depth
Deformed Bars (concrete parapet bridge rail and similar applications)				
3/4	A 15 hard grade	Epoxy mortar or grout	1-1/4	9
1	A 15 hard grade	Epoxy mortar or grout	1-1/2	14
Bolts (abutments for cantilever bridges and similar applications)				
1	A 307	Embeco mortar*	1-3/4	9
1-1/2	A 307	Embeco mortar*	2-3/4	12

*Chem-Comp or Lumnite mortars should be equally suitable from a shear-bond strength standpoint.

Recommended Construction Practice

Holes in concrete were washed with water, brushed to remove loose dirt, and allowed to dry in the laboratory tests. Field work may require different cleaning methods. The important consideration is that the concrete surface be clean and dry. The fine dust that clings to the surface should be removed by some method. A cylindrical brush and a cloth swab should be sufficient, if it is desired to exclude wetting. Compressed air, if used to blow loose particles out of the holes, should be free of oil because it can weaken the bond. Steel should be wire-brushed to remove loose scale and rust, then washed with solvent, and allowed to dry before embedment. The epoxy materials used with rebars can be easily poured into the prepared holes before bars are inserted. The cement-type mortar should be tamped around the hex-head bolts. The grouted or mortared bars may require some support to hold them vertical while the epoxy is hardening.

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