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USE OF EPOXIES FOR GROUTING REINFORCING BAR DOWELS IN CONCRETE

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SUMMARY

The behavior of reinforcing bar dowels grouted in concrete using epoxy was evaluated. The bars were submitted to pullout forces to determine the maximum load capacity, the load-slip behavior and the type of failure. The objective of the project was to develop some guidelines for the use of epoxies in grouting dowels in structures to be repaired or strengthened. In Phase 1 the influence of cleaning procedures on the pullout strength of dowels grouted with a low viscosity epoxy was determined. The results showed that the cleaning procedure can significantly affect the strength. It was found that the best results were obtained when the hole was cleaned with a stiff brush and thoroughly vacuumed. In Phase 2, the basic variables considered were viscosity, grouting position and epoxy brand or manufacturer. The concrete strength, diameter of the dowels, embedment length, diameter of the holes, and cleaning procedure were not varied. It was found that all epoxies used gave satisfactory results. For overhead and horizontal dowels, gel epoxies were easiest to work with.

some of the tests in Phase 2. Protex Industries Incorporated, Sika Corporation, Rocky Mountain Chemical Company, and Hilti Incorporated provided materials for tests in Phase 2. Their assistance was a significant factor in the timely and successful completion of the project.

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CHAPTER 1

INTRODUCTION

1.1 Object and Scope

In this investigation, the use of epoxies for grouting reinforcing bar dowels in concrete was evaluated. Pullout tests were used to determine the maximum load capacity, the load slip behavior, and the type of failure. In the first phase of the study, the variables considered were cleaning procedure, dowel diameter, embedment length, and concrete strength. All dowels were grouted using the same epoxy. In the second phase, the basic variables considered were viscosity, grouting position, and epoxy brand or manufacturer. The concrete strength, diameter of the dowels, embedment length, diameter of the holes, and type of rebars were not intentionally varied. The aim of the project was to determine guidelines for the use and applicability of epoxies in repair and strengthening of concrete structures.

1.2 Background

The use of epoxy in structural applications in the United States has grown substantially during the last three decades. The primary use of epoxy resins in the 1950's was in sealing joints and small cracks. Epoxy grouts are now used for many load-carrying applications. Examples include bonding of fresh concrete to hardened concrete in overlaying highway pavements, bonding of hardened concrete segments in assembling precast prestressed bridge systems, and connections between steel and concrete in composite and panel structures.

1. Fracture/yielding of dowel (bolt or bar);
2. Pullout/excessive slip of dowel;
3. Cone failure of concrete; and
4. Splitting of concrete.

More than one of these mechanisms can contribute to the failure of an anchorage system although one of them may be the principal or triggering mechanism.

1.3.1 Fracture/Yielding of Dowel. If the strength of the reinforcing bar is to be fully utilized, it must yield before failure occurs in the concrete or the epoxy.

1.3.2 Pullout/Excessive Slip of Dowel. The transfer of load from the dowel to the surrounding concrete may be affected by four factors [1]:

1. The mechanical key on the grout/concrete interface;
2. The bond stress along the grout/concrete interface;
3. The mechanical key on the grout/dowel interface; and
4. The bond stress along the grout/dowel interface.

It should be noted that these four factors are affected by the type of anchor used, the transverse reinforcement in the concrete, the grouting material used, and the positions of the individual anchors relative to one another and to a free edge.

Most manufacturers' brochures mention that cleaning of the hole is important. Oil and dirt on the surface must be avoided and occasionally rinsing the hole with water is recommended. The first phase of this study is directed toward evaluating cleaning procedures. It is likely application of a pullout load, a stress cone with an initial depth of about two-tenths of the total embedment length is formed. (Fig. 1.2).

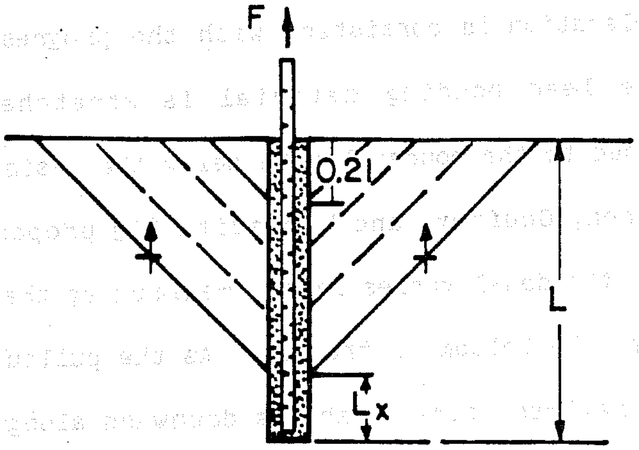


Fig. 1.2 Single-cone theory [1]

The load is resisted by stresses acting along the interface between the cone and the concrete surrounding the cone. As the load is gradually increased, a greater portion of the embedded bar is mobilized to transfer stresses to the concrete. As the depth to which stresses are transferred increases, larger and larger stress cones are formed. The enlargement of stress cones continues until the bottom of the cone is near the end of the bonded bar (Lx in Fig. 1.2). At this point, any increase in load produces a failure with the cone breaking away from the concrete mass along the surface of the last cone formed. The failure cone will almost always be slightly shallower than the embedment length of the bar. Daws' observations seem to agree with most of the failures observed in the pullout tests reported herein and elsewhere.

Lee, Mayfield, and Snell [2] theorized that the failure of an anchor begins with the failure of the bonding material nearest to where

The angle, ϕ, as defined in Fig. 1.1, is regarded to be a function of the embedment length by many researchers. The relationship between L and ϕ is complex and nonlinear. The weaknesses in the bonding material and the concrete can also influence this angle. Often, the inclined angle of a failure cone varies continuously around the cone. In any case, the angle appears to vary up to 25 degrees from a 45 degree angle assumed for simplicity.

The "disc-cone" theory [4] is based on the concept that the pullout load is partly resisted by shear stresses along the surface of a lower cone and partly resisted by flexural stresses in a concrete "disc" connected to the top of the lower cone.

The Double-Cone Mechanism. In a series of pullout tests involving block-ended and debonded (upset-end) reinforcing bars grouted with a polyester resin (Fig. 1.4), Lee, Mayfield, and Snell [2] studied concrete double-cones (Fig. 1.5) that were pulled from test blocks. The tests involved hole diameters of 0.8, 0.9, and 1.0 in., and embedment depths of 3, 4, and 5 in.

The lower six-tenths of the bar above the block end was found to be in the area of the lower "effective cone." The inclined angles ranged from 54 degrees to 70 degrees for embedment lengths of 3.0 to 4.9 in. The observations of the failure cones and the appearance of only minor surface cracking support the proposition that the bottom "effective cone" forms the primary resisting surface while the shallower top cone is only secondary in contributing to the ultimate load resistance.

1.3.4 Splitting of Concrete. The failure modes discussed above are based on the assumption that the dowel is embedded in relatively massive concrete or the concrete is restrained so that splitting is prevented. If adequate restraint is not present, the concrete member in which the anchor is embedded may split into several parts and no cone is developed. The failure planes can radiate from the embedded bar splitting the side cover over the anchored bar or splitting the concrete element into which the bar is anchored. This type of failure cannot be explained by a cone failure theory. Not much attention had been paid to this type of failure in the U.S., but it is a type of failure that should not be ignored in the analysis and design of dowel anchorage systems.

1.4 Other Parameters

Embedment Length. It is generally safe to assume that pullout resistance is directly related to embedment length [5]. However, there are indications [3,6] that the relationship is not linear. After a certain embedment depth is reached, the performance of the anchor may not be improved with further increase in length. The elongation of the anchor will cause spalling at the surface of the concrete member. It has been proposed that for fully bonded rebars, the load is transferred over only a relatively small upper portion of the embedment length [2]. This practical distance, referred to as the "effective length," is normally between 6 and 12 in.

Size of Dowel. Most studies have been conducted using a given size of bar. Since bond surface is directly proportional to the bar size, it such instruction is given by the grout manufacturer, the recommended methods are either wire brushing followed by vacuuming or flushing the hole with compressed air. Any hole preparation method that creates a clean, rough, bondable surface compatible with the grout material used is acceptable.

Grout Material. Generally, organic grouts such as polyester and epoxy perform better than traditional cement grouts [6,7,8,9,10]. Organic grouts usually have higher compressive and tensile strengths compared to cement grouts. Some epoxy grouts have tremendous adhesion relative to cement grouts. This may explain why dowels grouted with organic materials tend to displace less under a given pullout force than do those grouted with cement grouts [6,7,9]. Structural behavior of dowels grouted with different brands of epoxy have been reported to be different. In a large installation, this means actual laboratory or field pullout tests are needed to gather specific structural performance characteristics. Loss of bond due to fire effects may need to be considered [11,19].

Dowel or Anchor Spacing. Based on the cone failure theory, the strength an anchor can develop in the concrete is reduced if the cones overlap. If a cone angle of 45 degrees and uniform spacing are assumed, a minimum spacing of two times the embedment length is required to prevent interference. One study recommended a minimum distance of 20 times the bar diameter to avoid stress interference [12]. With "flat" cone failure surfaces, greater spacings may be required to avoid interference.

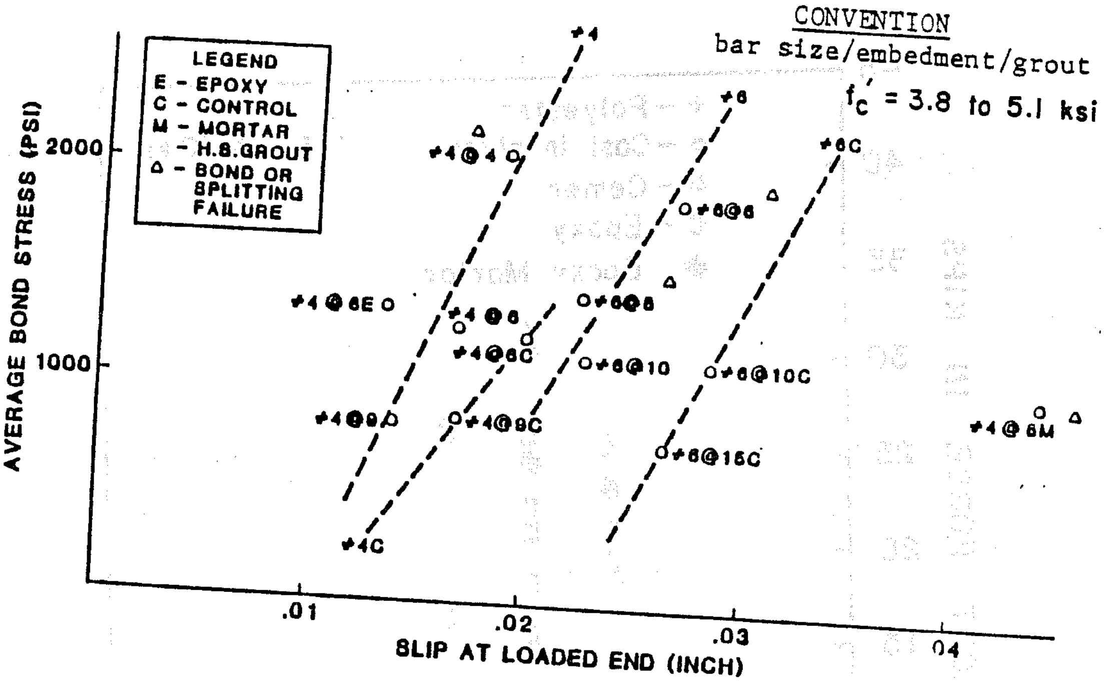


Fig. 1.6 Bond stress vs slip [7]

In general, if a dowel fails primarily along the concrete/grout interface or the grout/dowel interface in a pullout test, the results apply only to the particular grout and installation technique employed. If the failure is along the surface of a concrete cone, the interface behavior is less important. The diversity of results from different tests can be seen in a summary of five dowel tests (Fig. 1.7).

If a particular type of grout, anchor, and installation method (a dowel "system") is used, the effects of varying embedment length, concrete strength, bar size, and hole size can be evaluated. This "system" approach is used by many grout manufacturers for specific application recommendations.

1.6 Current Design Guidance

1.6.1 ACI Standard Specification on Epoxy. ACI Committee 503 published a "Standard Specification for Bonding Hardened Concrete, Steel, Wood, Brick, and Other Material to Hardened Concrete with a Multi-component Epoxy Adhesive" (503.1-79). This specification basically urges designers to follow the advice of the manufacturer of the specific epoxy selected. In general, it recommends sandblasting all surfaces to be bonded, although scarifying, waterblasting, and acid etching may be used. The surfaces are to be blown clean by oil and water-free compressed air. Epoxy should be used when the temperature is between 60 and 100°F.

In "Use of Epoxy Compounds with Concrete" (ACI 503R-73), it was mentioned that the difference in thermal expansion between cured epoxy and concrete can cause stresses to develop along the interface. Epoxy elongates as little as 0.2% to as much as 50% compared to about 0.01% for concrete when stressed. Generally, chemicals attack epoxy, but it appears concrete is more susceptible to chemical attack than most types of epoxy.

1.6.2 ACI 349-80 Appendix B - Steel Embedments. From the ACI 349 report on Code Requirements for Nuclear Safety Related Concrete Structures [15], several sections relating to anchorages are summarized below.

For tension anchors:

The design strength of concrete P_d for any anchorage shall be based on a uniform tensile stress of $4\phi\sqrt{f'_c}$ acting on an creep. Daws [1] gave a rule-of-thumb embedment formula to calculate embedment length. With bonded embedment length in millimeters and design load, P, in British tonnes (2,200 lb), the equation is

$$\text{Bond length} = (50 + 25P)\ \text{mm}.$$

Preparation of Hole for Dowel. The diameter of the drilled hole should be just large enough to allow proper placement of the rebar and grout. Large holes cannot be justified economically. Holes should be drilled with a rotary percussion drill whenever possible to create a rough surface. If core- or diamond-drilling is required, redrilling by a rotary percussion drill is recommended. Pre-formed holes are not recommended unless redrilling is done.

Holes must be free of dust. Wire-brushing, compressed-air flushing, and water-flushing have been mentioned as good methods. If possible, a method should be employed to obtain the effects created by sandblasting.

Dowel Size and Spacing. Previous studies indicate that bar diameters should be greater than 1/2 in. and less than 1 in. Daws [1] also recommended that a maximum load of 55 kips per bar be allowed for a reinforcing bar anchorage system.

Dowel spacing can be determined by three methods: (1) a chart developed by the epoxy manufacturer, (2) a minimum of two times the embedment length, and (3) some multiple of dowel diameter. Stowe [12] recommended using a spacing of 20 times the bar diameter.

CHAPTER 2

PULLOUT TEST PROGRAM

2.1 Introduction

A total of 101 reinforcing bar dowels grouted with epoxy in hardened concrete were tested. In the first phase, the hole cleaning method was the main parameter investigated. The effects of embedment length and bar size were also investigated. In the second phase, the prime variable was the viscosity of epoxy obtained from several manufacturers and the influence of grouting position of dowels in hardened concrete. The strength of the concrete and the steel, the length of embedment, the diameter of the dowel, and the cleaning procedure were maintained constant.

The test apparatus and procedure were designed to permit concrete failure cones to develop without restraint from the loading apparatus. The ultimate load at failure was recorded in all tests and load-slip relationships were obtained for most tests.

2.2 Materials

Concrete. For the initial 18 pullout tests in Phase 1 in which the effectiveness of different cleaning procedures was studied, a 10 in. thick slab, 5 x 8 ft in plan was cast on the ground next to the laboratory. The compressive strength of the concrete was about 4800 psi at the time of testing (40 days). The slab contained no reinforcement.

The remainder of the bars in Phase 1 were anchored in 24 x 24 x 42 in. concrete blocks, or 24 in. cubes. The nominal compressive and provides the classification of epoxies by type, grade, class, and color.

Type I- For use in bonding hardened concrete and other materials to hardened concrete.

Type II- For use in bonding freshly mixed concrete to hardened concrete.

Type III- For use in bonding skid resistant materials to hardened concrete and as a binder in epoxy mortars or epoxy concretes.

Three grades of epoxy systems are defined according to their flow characteristics and are distinguished by the viscosity and consistency requirements as outlined in Table 2.1.

Table 2.1 Classification of Epoxies Graded According to Viscosity

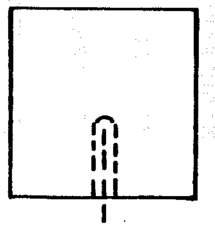
GRADE	Max Temp = 73°F (+1.8°F) Viscosity (poise)
Grade I	20 -low viscosity
Grade II	100 -medium viscosity
Grade III	high viscosity sagging consistency 0.25 in.

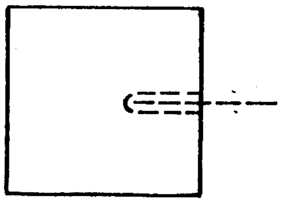
Three classes are defined according to the range of temperatures for which they are suitable. Class A for use below 40°F, class B for use between 40 to 60°F and class C for use above 60°F. All the epoxies used in this program were class C.

Table 2.2 Details of Epoxies - Phase 2

Brand-Grade		Description	Grouting Position	Color				Mix Ratio (by volume) A:B
				Part A	Part B	Part C	Final	
1	3	gel	overhead-horizontal	white	black		grey	2:1
1	2	liquid with sand	horizontal	light amber	dark amber	yellow sand	dark grey	2.6:1*
2	1	liquid	vertical	translucent	translucent		translucent	2:1
2	2	medium viscosty	horizontal	white	black		grey	1:1
2	3	gel	overhead	white	black		grey	2:1
3	1	liquid	vertical	straw	amber		amber	2:1
3	3	gel	overhead	white	dark grey		concrete grey	2:1
4	3	gel-light paste	vertical	off white	black		light grey	3.5:1
5	-	cartridges	vertical	capsules			dark grey	-
cement grout		cement-sand grout	vertical	cement	white sand	water	dark grey	-

*A+B:C = 1:4.7 to 6.7 (by weight)


OVERHEAD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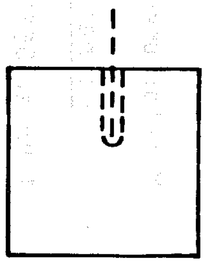
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Characteristics of Brand 2. From Brand 2, three viscosities were used meeting grades 1, 2, and 3 of ASTM C881. According to the manufacturer of epoxy Brand 2, liquid epoxy (grade 1) is intended for injection, spray, broom and/or squeegee application. Medium viscosity (grade 2) is intended for trowel or brush applications. The viscosity of this epoxy is achieved by inert mineral filler.

Epoxy gel (grade 3) is produced for trowel or caulking gun application. Grade 3 gel also contains inert mineral fillers that increase the viscosity to the range specified by ASTM. The basic use for this product is in bonding hardened concrete and other materials such as steel, aluminum, wood, and glass to hardened concrete.

Property	Grade 1	Grade 2	Grade 3
Pot Life 73°F	38 min	36 min	39 min
Viscosity (poise)	9	28	non-sag
Bond 2 days	3400 psi	3550 psi	3450 psi
Bond 14 days	3413 psi	3770 psi	4000 psi
Color	amber	grey	grey

Characteristics of Brand 3. Brand 3 liquid (grade 1) is a two-component, moisture-insensitive, high strength epoxy adhesive. The working time at 73°F is 30 min. It is intended for gravity feed and/or pressure injection. The mixed product has the consistency of lightweight oil. Seventy-five percent of the ultimate strength is reached within two days at 73°F and 50% relative humidity. This product is intended to be used with or without aggregate fillers. To prepare mortar, the mixed epoxy is blended with one and a half parts or more of that are mixed by rotating and driving the dowel into the cartridge (placed in the hole) with a special rotary drill. The cartridge offers the advantages of (1) speed, (2) clean working conditions with no mixing needed, and (3) fast setting time of 10 min for temperatures around 68°F. It is not recommended for installation at temperatures below 23°F.

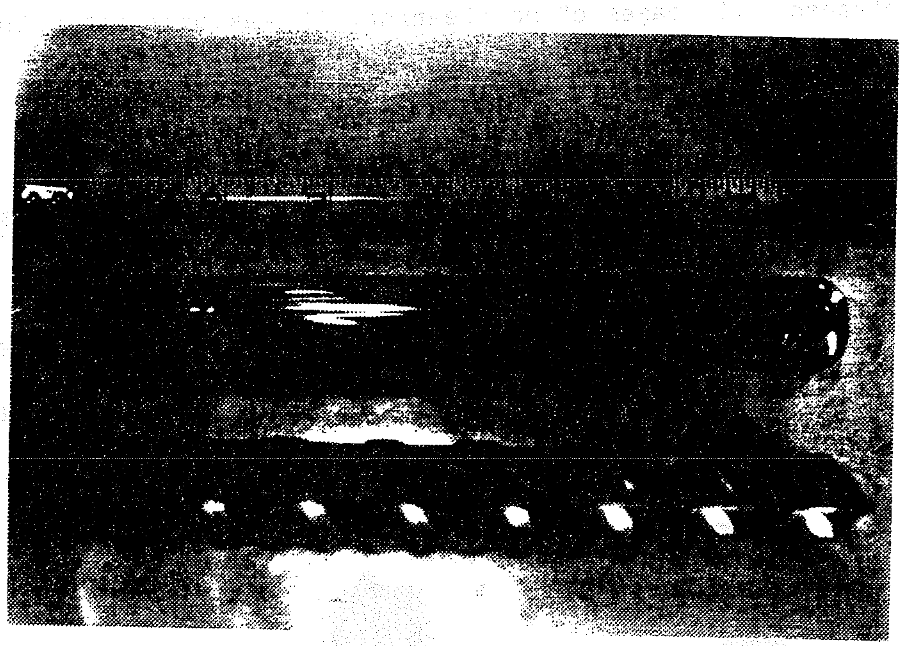


Fig. 2.1 Cartridges

Cement grout. The grout used was a "soupy" mix of type II portland cement, sand, and water. The mix ratio by volume for cement to sand to water was 2:1:0.75. With these proportions the average compressive strength obtained from two 3 x 6 in. cylinders at 28 days was 1.7 ksi.

2.4 Preparation of Test Specimens

2.4.1 Drilling. A rotary hammer was used to drill all holes. For #6 bars, a 1-in. and for #4 bars, a 3/4-in. drill bit was used. For the

Table 2.3 Test Program - Phase 1, Cleaning Methods

Series	Cleaning Method	Base	f'_c	Bar	Embedment	#Tests
A.1	as drilled	slab	4800	#6	3, 6 in.	6
A.2	syringe	slab	4800	#6	3, 6 in.	6
A.3	vacuum from top	slab	4800	#6	3, 6 in.	6
B.1	as-drilled	block	4100	#6	8 in.	2
B.2	vacuum from top	block	4100	#6	6 in.	5
			2900	#6	3 in.	4
C.1	vacuum to bottom	block	4200	#6	6 in.	2
			3100	#6	3 in.	2
C.2	stiff bottle brush	block	4200	#6	6 in.	2
			3100	#6	3 in.	2
C.3	wire brush	block	4200	#6	6 in.	2
D	cast-in-place	block	3300	#6	3, 6 in.	5
E	stiff bottle brush	block	2500	#4	3 in.	3
			4300	#4	3 in.	2
			3100	#4	3, 6 in.	3
			3300	#6	3, 6 in.	7
F	stiff bottle brush	block	3400	#6	3, 6 in.	7
			3100	#6	3, 6 in.	3

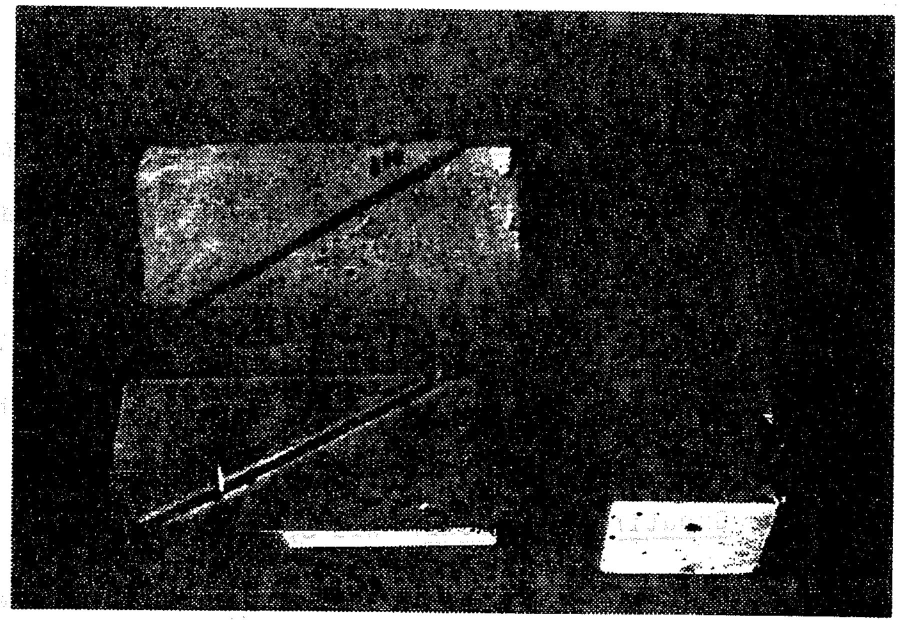
variable. For the tests using cartridges, a special chisel end was ground on the end driven into the cartridge.

2.4.4 Preparation and Quality Control of Epoxy.

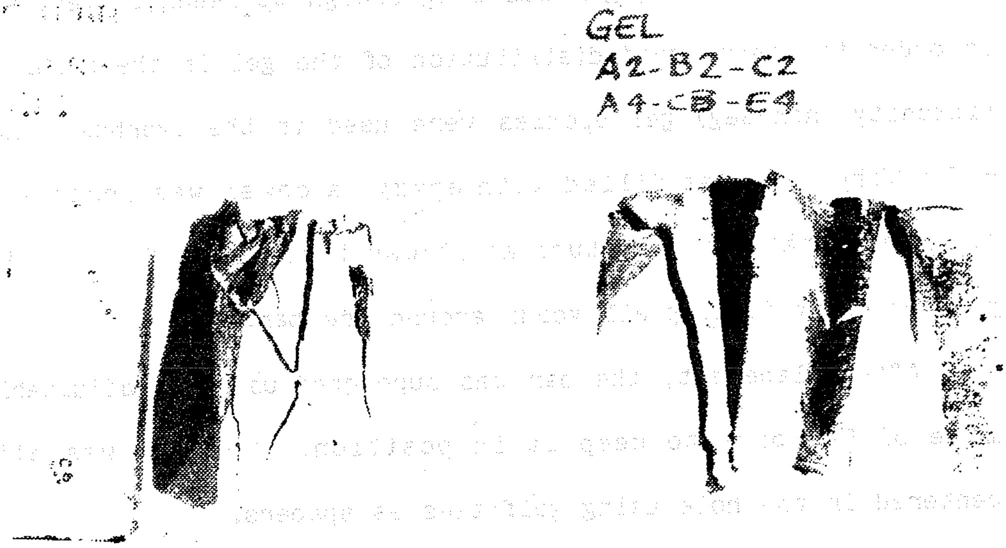
Mixing. All the manufacturers recommended the same mixing procedure and mixing equipment. Quantitites of parts A and B of the epoxy were measured by weight and were mixed using a paddle made up of a wire bent to shape, fitted to a hand drill. The wire paddle was satisfactory for the small quantities used in this study but for mixing large amounts of epoxy special paddles available from some manufacturers should be used.

The epoxy was mixed at medium speed (400 to 600 rpm) for 3 to 4 min as suggested by the epoxy manufacturers. The best indicator of good mixing is uniform color and absence of air bubbles. To ensure the best results, the mixing procedure must be given careful attention. The temperature should also be carefully noted since it can alter the pot life. Although the pot life of brands may differ, in general, the higher the temperature the shorter the working time and the greater the early strength gain.

Slant shear tests. The purpose of conducting slant shear tests was to provide indication of the epoxy quality at the beginning and end of the epoxying operation. The specification used was AASHTO Designation T237-72I [18]. Slant shear blocks, 2 x 2 x 5 in. were cast in plastic molds. The mix by weight is 33% type II portland cement, 13% water, and 54% ottawa sand. The blocks were moist-cured a minimum of two days and were not used until they were at least 28 days old. The bonding surfaces of the blocks were sandblasted. In some early tests,



a) before placing epoxy.



b) after testing.

Fig. 2.3 Slant shear blocks.

4 was classified as high viscosity epoxy, it was a very pourable light paste.

Horizontal. Medium and high viscosity epoxies were used for horizontal bars. A caulking gun similar to that described for overhead casting was used. The hole was filled to about 60% of its depth. The bar was placed as before to ensure distribution of the epoxy around the bar. Golf tees were used to maintain alignment. The lower part of the edge of the hole under the bar was covered with tape to avoid the loss of epoxy. Losses were greater with grade 2 epoxy.

2.5 Loading Apparatus

A 60-ton hydraulic ram was used to load all dowels. The load was monitored using pressure gages connected to the ram. These pressure gages were calibrated on a static dead-weight pressure testing device. Hydraulic hand pumps were used throughout the program. The dial gages used to measure the displacements at the loaded end of the dowels could be read to 1/1000 of an inch.

2.5.1 Loading Plate. The loading plate is shown in Fig. 2.4. Two gages rested on a square aluminum rod 16 in. long that was first attached to the bar about one inch above the surface of the concrete. After attaching the rod to the bar the loading plate was lowered over the bar. Where the concrete surface was rough, a layer of gypsum grout was placed between the ring and the concrete to assure uniform load transfer around the entire ring. The hydraulic ram, chuck plate and chucks were placed on the bar. Dial gages were fastened to posts welded to the loading plate and were set to lean against the aluminum rod.

The octagonal loading plate was 1-in. thick, grade 50 steel. An octagonal ring at the edge of the plate was formed using 1 x 2 in. plates. The distance from the center of the plate to the center edge of each side was 10 in. A 1-in.-diameter center hole was drilled to allow the dowel to pass through. The distance from the 1/2-in. hole for the dail gages to the nearest support edge of the loading plate was three inches.

Two posts were welded on the surface of the plate so that dial gages could be attached. Calibrations for plate deflection were made to allow nonlinear corrections to the bar slip readings.

2.5.2 Beam Loading System. Some bars tested in Phase 1 were loaded using a beam loading system. The beam loading system (Fig. 2.5) was used to eliminate the correction for ring or plate deflections and to minimize the effects of the pressure exerted by the edges of the loading ring. The beams rested on the concrete surface on 1/2-in.-thick 3 x 3 in. plates placed at the ends of the beams.

2.5.3 Test Procedure. The load was applied slowly. Dial indicators were read at 1300 lb increments until failure. When cracks did not propagate into any other test surfaces in the block, the test continued until the dowel completely pulled out or when no additional load could be sustained. When cracking appeared to extend into another block face containing an untested bar, loading was stopped and the bar was cut with a torch.

Pressure and dial gage readings were recorded at each load increment. To determine bar slip, the two dial gage readings (corrected for plate deflection) at each load increment were averaged.

CHAPTER 3

TEST RESULTS - PHASE 1, CLEANING METHODS

3.1 General Observations

The test program with various cleaning methods was summarized in Table 2.3. Load-slip plots were obtained for all tests. In some cases slip at the maximum load could not be read accurately when the bar failed suddenly.

Most dowel failures in this program can be characterized as tension failures (cracking) along cone-shaped surfaces. This is evident from an inspection of dowels which appeared to fail in bond but after an examination of the base blocks, cracks along cone-shaped surfaces were discovered. This points to the potential danger of replacing a dowel that apparently failed in bond because cracks may have formed below the apparently undamaged concrete surface.

In a few cases complete splitting of concrete base (weak or unrestrained concrete) or excessive slip (sliding) between concrete and epoxy (inadequately cleaned hole) was observed.

Generally, dowels installed in shallow holes (3 in.) tended to fail in "simple" well-defined cones while dowels installed in deep holes (6 in.) tended to fail in several different ways, as shown in Fig. 3.1.

3.1.1 Series A. In the 18 pullout tests conducted on the slab, two cleaning methods (1) blowing the concrete dust out of the hole with a household syringe (Fig. 3.2) and (2) vacuuming (light vacuum) from the top of the hole (Fig. 3.3) were compared with no cleaning (as drilled).

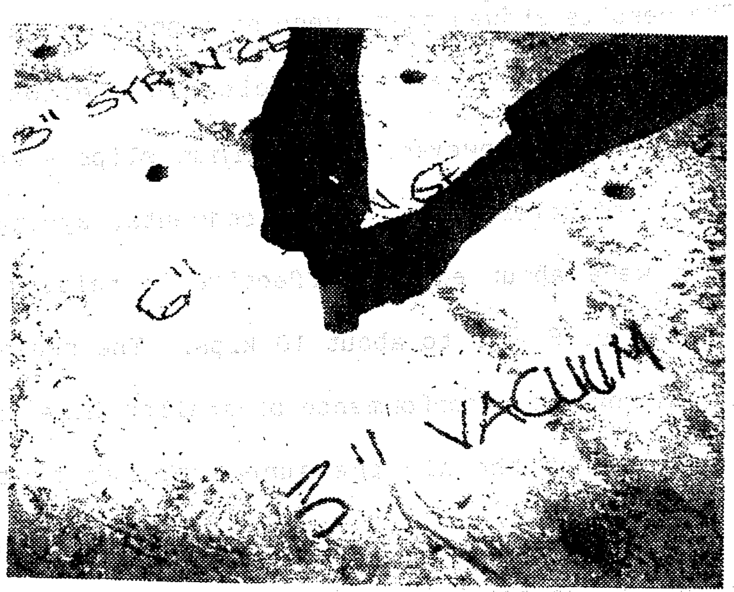


Fig. 3.2 Syringe cleaning.

Fig. 3.3 Top vacuum cleaning.

Table 3.1 Comparisons of As-Drilled, Syringe, and Light Vacuum Cleaning, Series A, #6 Bars.

Series	Cleaning Method	Embedment, in.	f'_c, psi	Maximum Load, kips	Slip @ Max Load, in.
A.1	none	6	4800	17.2	0.11
				15.2	0.10
				17.2	0.10
A.2	syringe	6	4800	18.6	0.06
				15.2	0.05
				14.6	0.06
A.3	vacuum from top	6	4800	15.9	0.06
				13.3	0.02
				15.9	0.04
A.1	none	3	4800	6.9	0.02
				6.6	0.05
				5.3	0.02
A.2	syringe	3	4800	9.3	0.03
				10.6	0.04
				9.3	0.03
A.3	vacuum from top	3	4800	10.6	0.02
				10.6	0.03
				9.9	0.02

Table 3.2 Summary - Test Results. Series B-F

Series	Embedment in.	f'_c, ksi	Load @ 0.01 in., slip, k	Max Load, k	Slip @ Max Load, in.	$\frac{u^*}{\sqrt{f'_c}}$	p^+, k	Failure† Pattern
B.1 - no cleaning (#6)								
	8.25	2.4	5.4	17.2	0.086	13.5	2.30	fc, ec
	8.25	2.4	13.2	19.9	0.098	15.7	2.69	fc, ec
B.2 - light vacuum from top of hole (#6)								
	8.25	2.4	8.2	15.9	0.133	12.5	2.16	fc, ec
	6.5	4.0	11.4	16.6	0.076	12.9	2.20	c, eb
	6.25	4.0	11.8	17.9	0.079	12.5	2.48	c, eb
	6.25	4.0	16.6	17.9	0.039	12.5	2.48	c, eb
	6.0	4.0	13.2	16.6	0.105	13.9	2.38	c, eb
	3.25	2.9	5.2	7.4	0.083	13.3	2.28	c, ec
	3.13	2.9	5.9	6.6	0.071	12.5	2.14	c
	3.0	2.9	3.6	6.0	0.024	11.8	2.03	c, eb
	3.13	2.9	5.7	6.6	0.016	12.5	2.14	c
C.1 - vacuum to bottom of hole (#6)								
	6.25	2.6	14.0	29.8	0.044	23.4	4.03	c, s
	6.13	2.6	24.2	27.2	0.047	21.8	3.74	c, eb
	3.25	3.1	9.3	11.3	0.017	19.9	3.42	c
	3.0	3.1	9.3	10.6	0.014	20.2	3.47	c
C.2 - vacuum + stiff brush (#6)								
	6.25	4.2	18.2	34.5	0.034	27.1	4.03	c
	6.25	4.2	31.2	37.8	0.101	29.7	3.74	fc, eb
	3.25	3.1	-	12.6	-	22.2	3.42	c
	3.25	3.1	10.1	11.9	0.087	20.9	3.47	c
C.3 - vacuum + stiff brush + wire brush (#6)								
	6.25	4.2	22.6	37.8	0.121	29.7	5.10	c, eb
	6.0	4.2	26.5	30.5	0.016	25.0	4.17	c
D - cast-in-place (#6)								
	6.0	3.3	15.0	21.2	0.049	26.1	3.37	c
	6.0	3.3	8.1	21.2	0.065	26.1	3.37	ec
	3.0	3.3	3.0	8.0	0.034	19.7	2.53	c
	3.25	3.3	4.2	9.3	0.054	21.1	2.74	c
	2.5	3.3	3.8	8.0	0.060	23.6	3.04	c

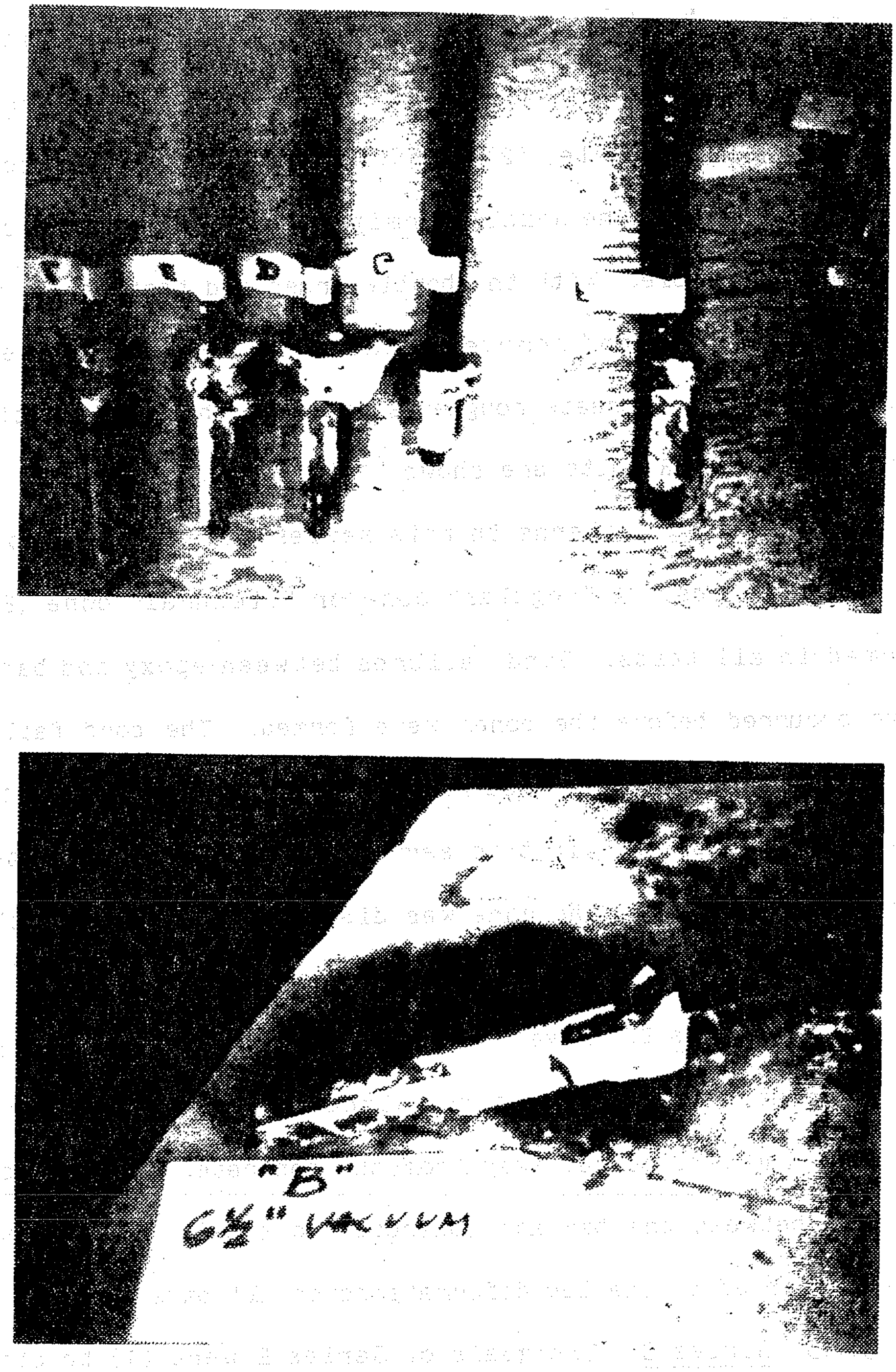


Fig. 3.5 Bond failure patterns (Series B).

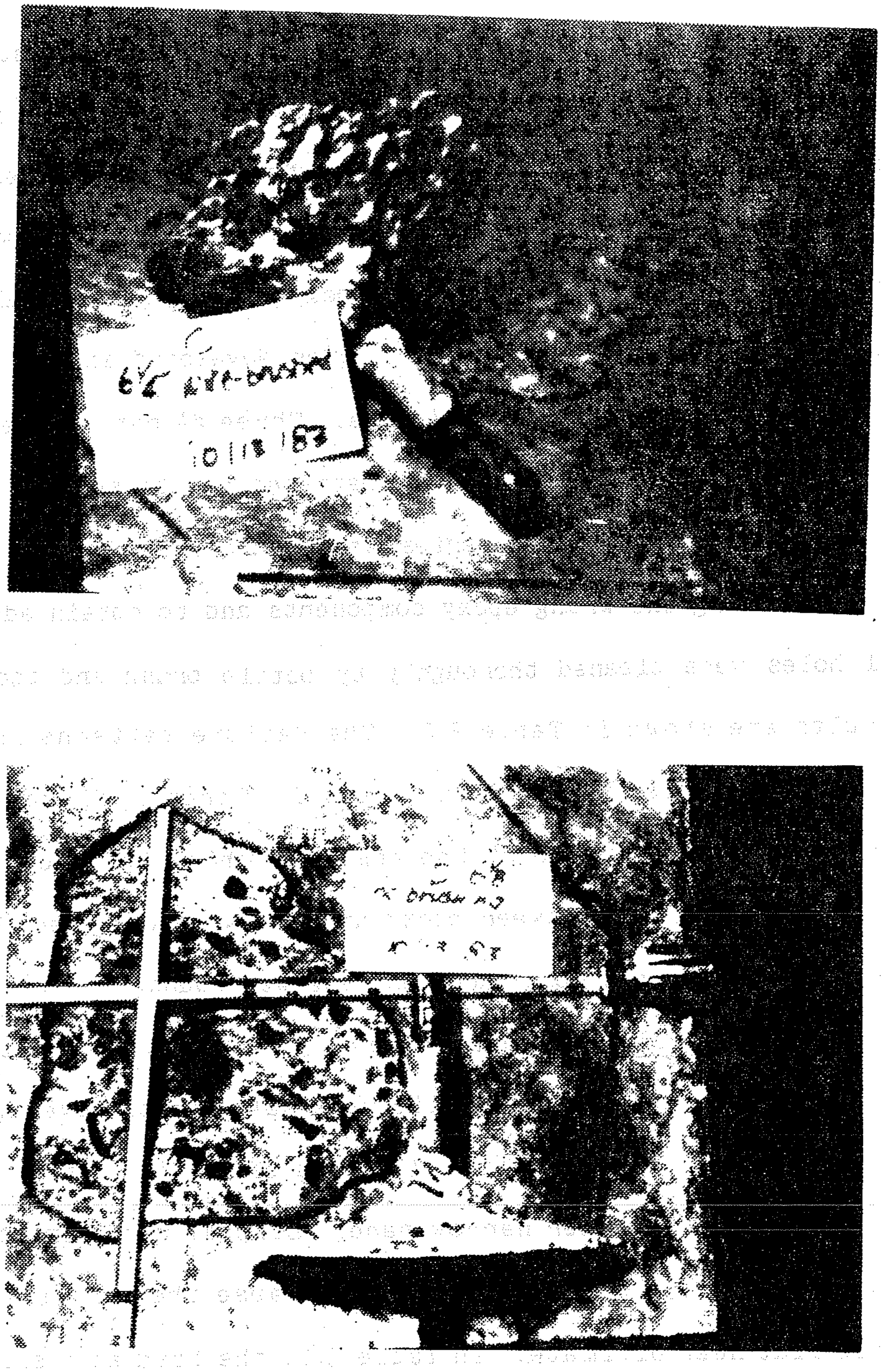


Fig. 3.6 Combination cone and bond failure (Series C).

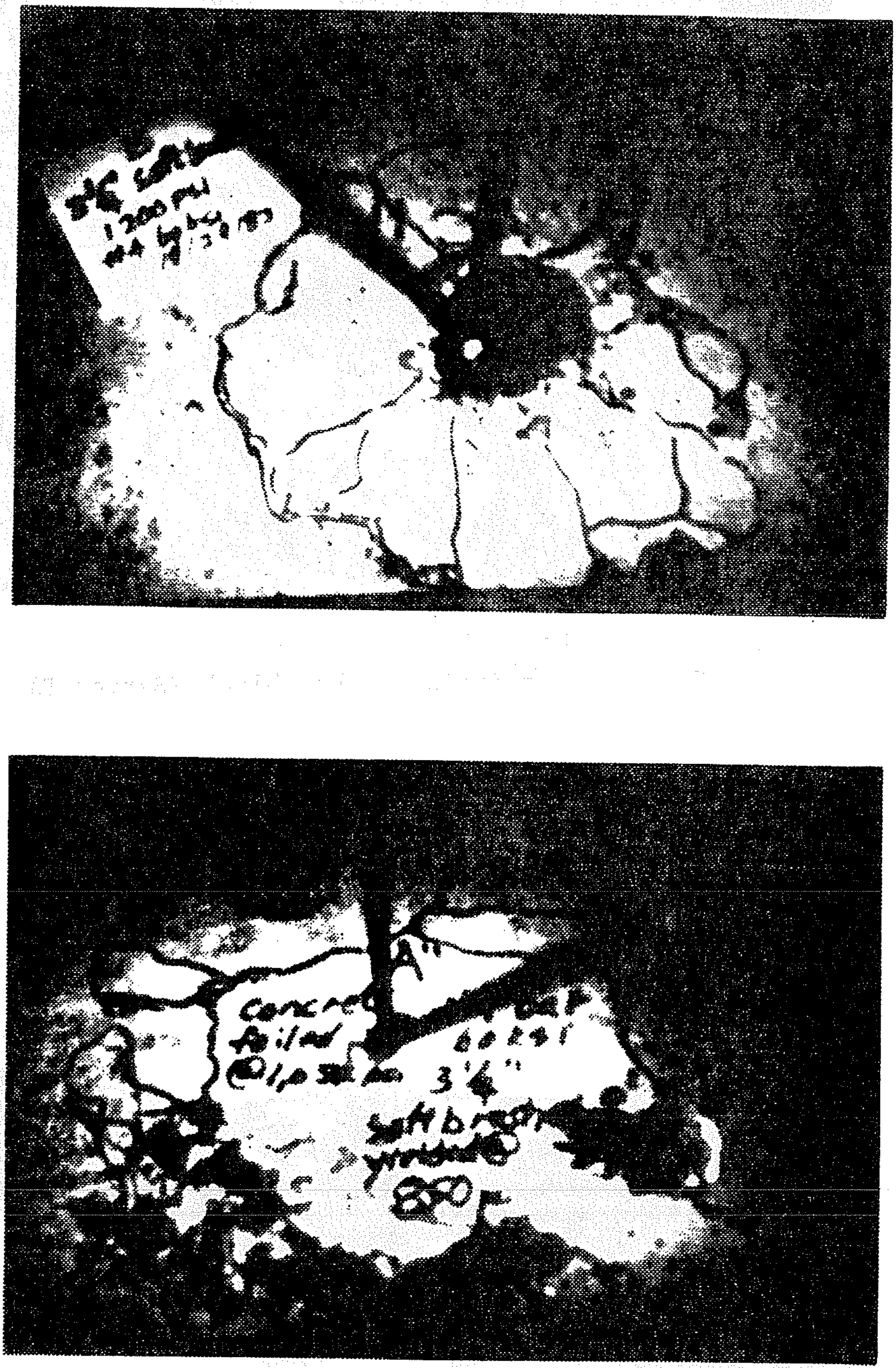


Fig. 3.7 Failure of #4 bars installed in brush-cleaned holes.

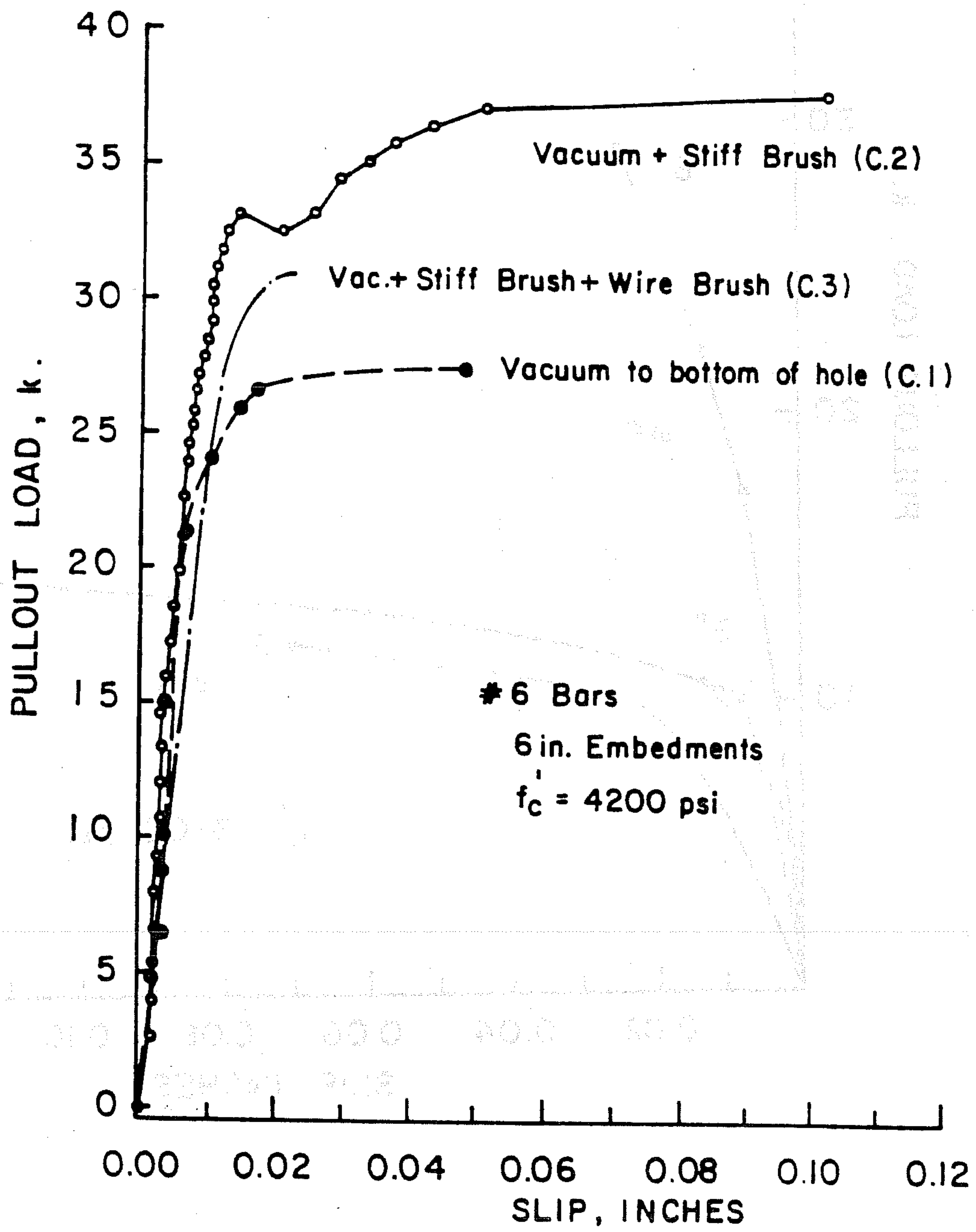


Fig. 3.10 Load-slip curves (Series C).

3.2 Comparison of Test Results

The data obtained from bars anchored in the slab (Series A) indicated that sloppy hole cleaning methods using a syringe or casual vacuuming were equally ineffective and had little influence on the overall performance of epoxy-grouted dowels. This was especially true for dowels installed in deep holes (6 in.). Those results were not further analyzed since tests on other cleaning methods were conducted. The data from 43 tests in Series B through F were included in the comparisons. A few were excluded where instrument errors were encountered or where failure by bar fracture or yielding occurred. The plate and beam loading methods gave comparable results and no further comparisons of loading methods will be discussed.

Because there were several different concrete strengths used in this program, all force parameters, including maximum load, critical load, steel stress, were normalized by the factor $\sqrt{3000/f'_c}$ in the following discussion so that all comparisons were based on comparable concrete tensile strength. This adjustment has been used by many researchers to normalize data for specimens governed by shear or tensile failure in the concrete. In this chapter, bond stress is defined as the load divided by the hole surface area (epoxy/concrete interface).

3.2.1 Cleaning Methods. The effects of different cleaning methods are compared in terms of maximum load vs slip at maximum load (Fig. 3.12) and maximum load per unit embedment length (Fig. 3.13). It can be seen from Fig. 3.12 that the performance of the dowel was generally improved by more thorough cleaning of the drilled hole. Brushing to

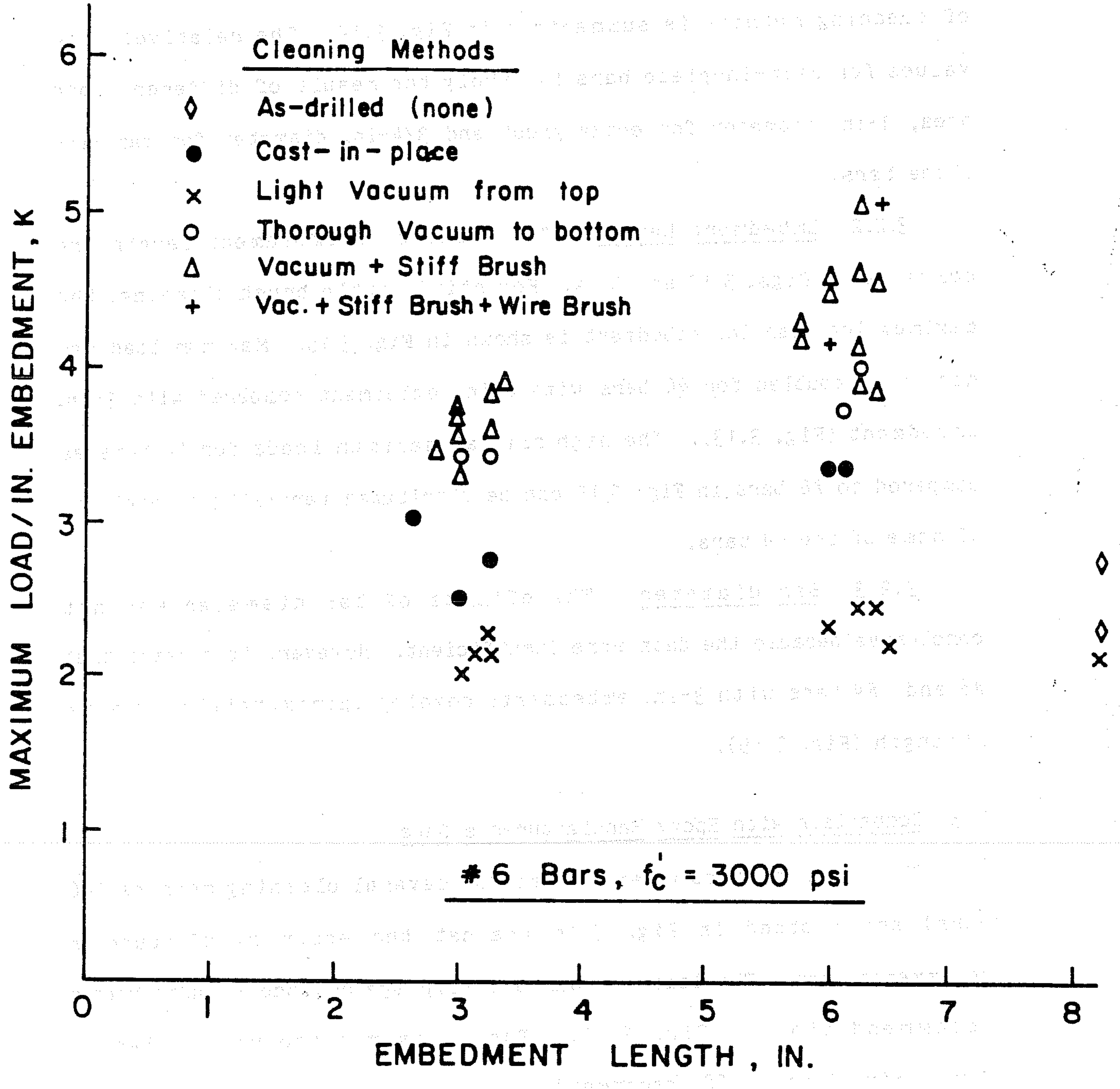


Fig. 3.13 Effect of cleaning - maximum load per unit length of embedment.

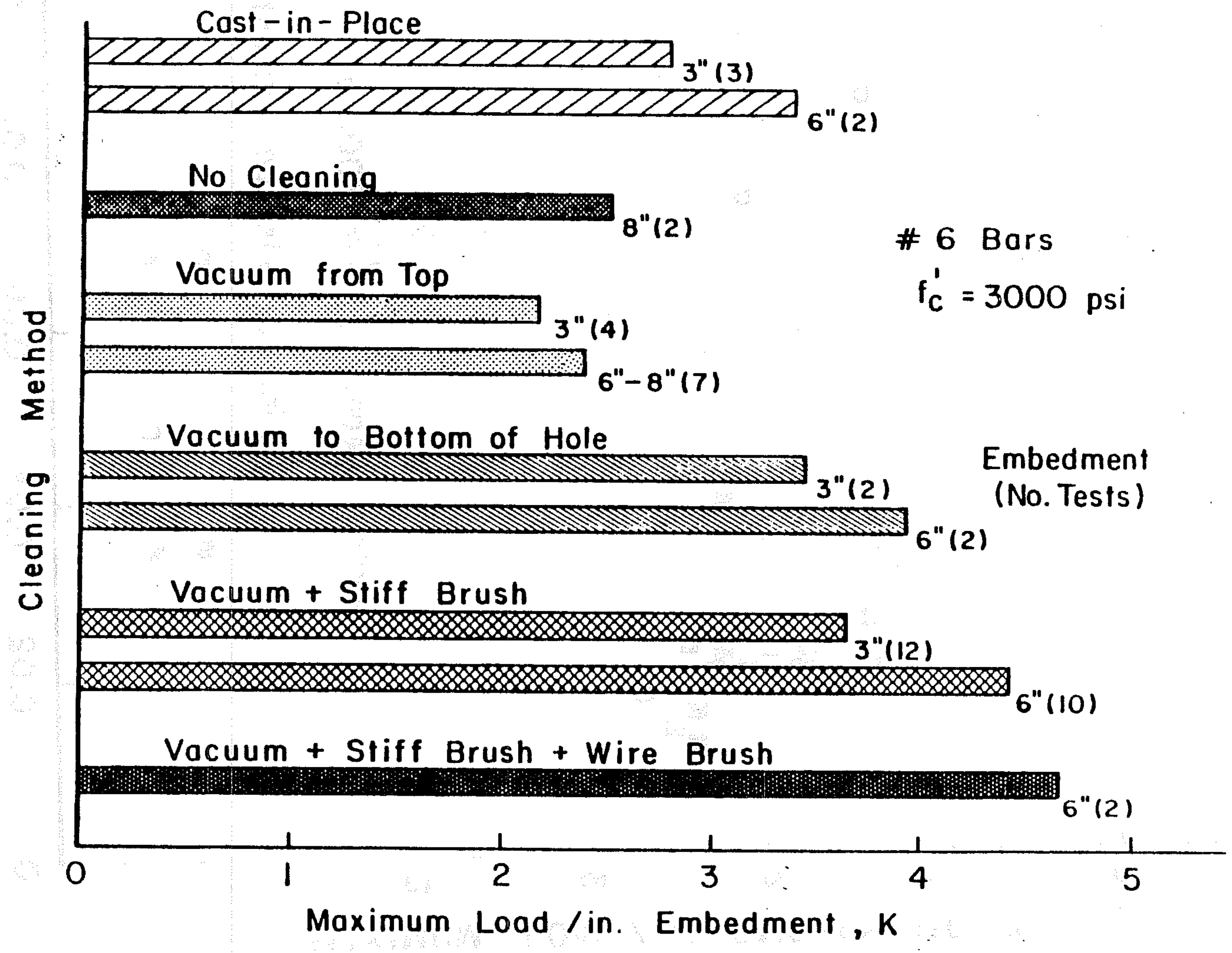


Fig. 3.14 Comparison of pullout capacity per unit embedment length for different cleaning methods.

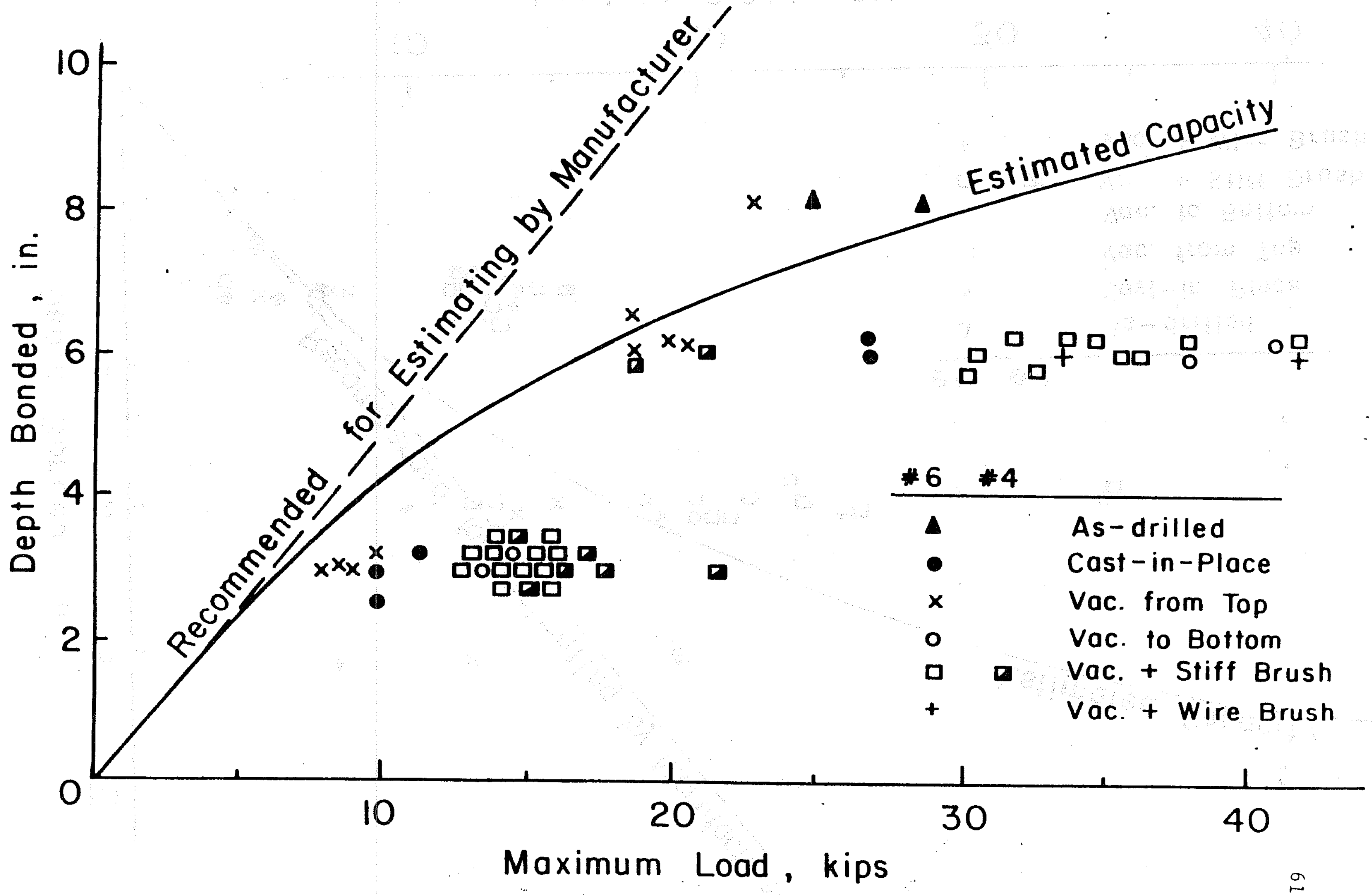


Fig. 3.16 Comparison of maximum loads with manufacturers recommendations [8].

> Holes.....drilled using either percussive or rotary machine...Dry-drilled holes should be blown out using oil-free compressed air or vacuumed, to remove residue.

All test data were adjusted to represent 5000 psi concrete which is the strength on which the manufacturer's recommendation is based.

It can be seen in Fig. 3.16 that for embedments of 3 in., the maximum loads associated with all cleaning methods are equal to or higher than the epoxy manufacturer's recommended values. A few tests in which no cleaning or in which vacuuming from the top was employed were lower than the manufacturer's estimated capacity but all were greater than values recommended for estimations. In Fig. 3.17, the test data for loads at 0.01 in. slip are plotted. It can be seen that, for a given embedment depth and correct cleaning techniques, the load recommended by the epoxy manufacturer is approximately at the level of the load at 0.01-in. slip. Comparing Figs. 3.16 and 3.17, it can be seen that there is a margin between recommended values and failure. Only in the case of poor cleaning and short bonded lengths were the test values at 0.01-in. slip above the line recommended for estimating embedment depth. Therefore it is likely that the use of the manufacturer's recommendations for this epoxy would result in dowels with adequate strength and low slip under load.

In a similar pullout test program [6] involving eighteen #6 and three #8, grade 60 deformed bars grouted with different materials in 6-in.-deep rotary hammer (carbide-tipped bit) drilled holes, the following observations were made:

CHAPTER 4

TEST RESULTS - PHASE 2, TYPE OF EPOXY

4.1 General Observations

Table 4.1 provides a summary of the tests in Phase 2. The load and slip at failure, the load at 0.01-in. slip, and the failure patterns are listed. Typical failure patterns are shown in Figs. 4.1 through 4.8. Load-slip curves were plotted for all tests. Typical curves for two series are shown in Figs. 4.9 and 4.10. In most tests, there was considerable variation in load-slip curves although the maximum loads did not vary greatly. Average curves are shown based on average slip values for a given load level for the tests in each group. With only three tests in each group, the average is quite sensitive to the rather large variations found among some tests.

4.2 Comparison of Results

Overhead grouting. Average load slip plots for the gels used for grouting overhead bars are shown in Fig. 4.11. Although Brand 1 exhibited greater stiffness in the early stages of loading, all three brands reached about the same ultimate strength and the same slip at failure.

Horizontal grouting. Average load-slip plots for the gel of Brand 1 is compared with medium viscosity epoxy of Brand 2 and with Brand 1, plus sand used in horizontal grouting are compared in Fig. 4.12. It is very difficult to make a conclusive statement from the comparison between Brands 1 and 2 due to the scatter of results from those tests.

Fig. 4.1 Double cone and partial bond failure. Epoxy Brand 1 (grade 3). Overhead grouting.

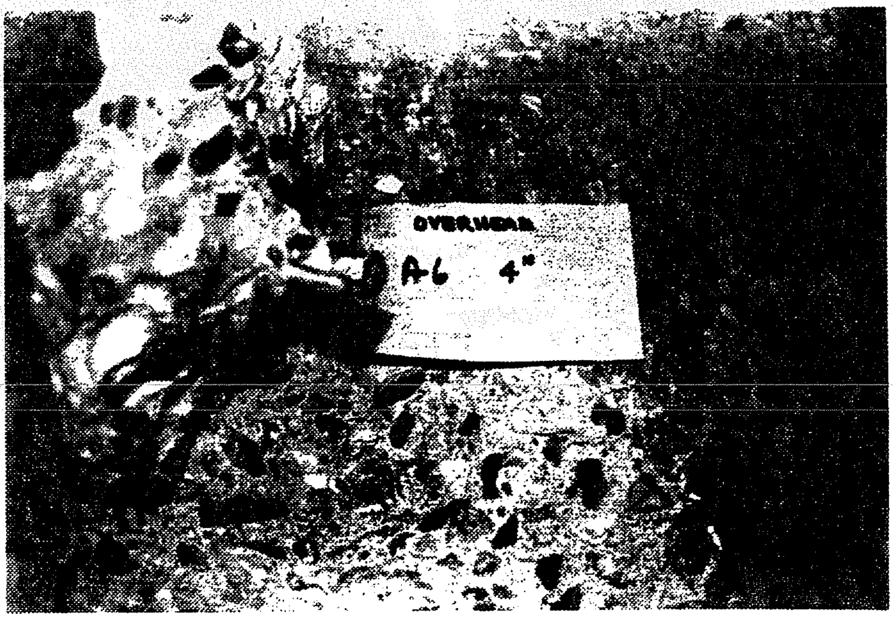


Fig. 4.2 Typical double cone plus bond failure. Epoxy Brand 3 (grade 3). Overhead grouting.

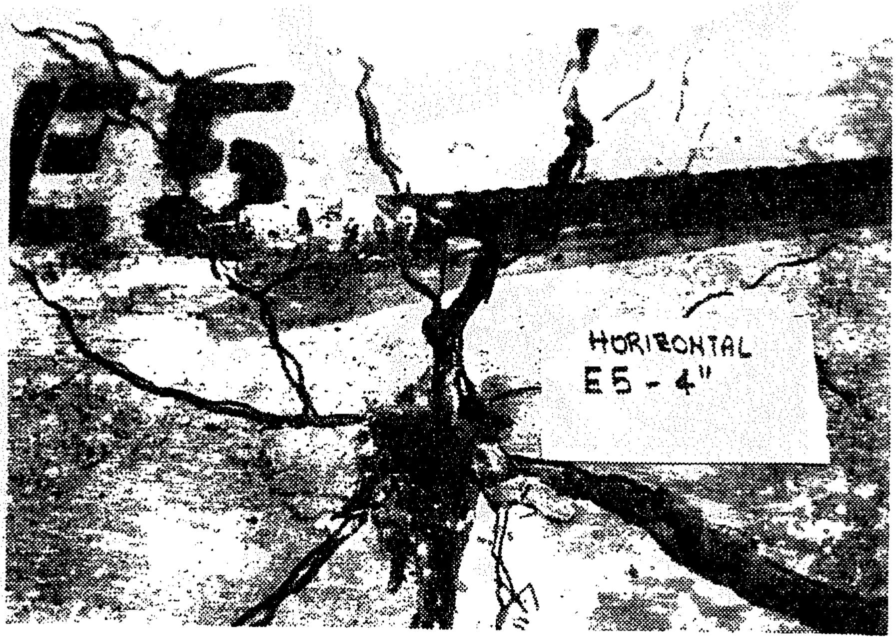


Fig. 4.5 Typical splitting failure. Brand 1 plus sand (grade 2). Horizontal grouting.

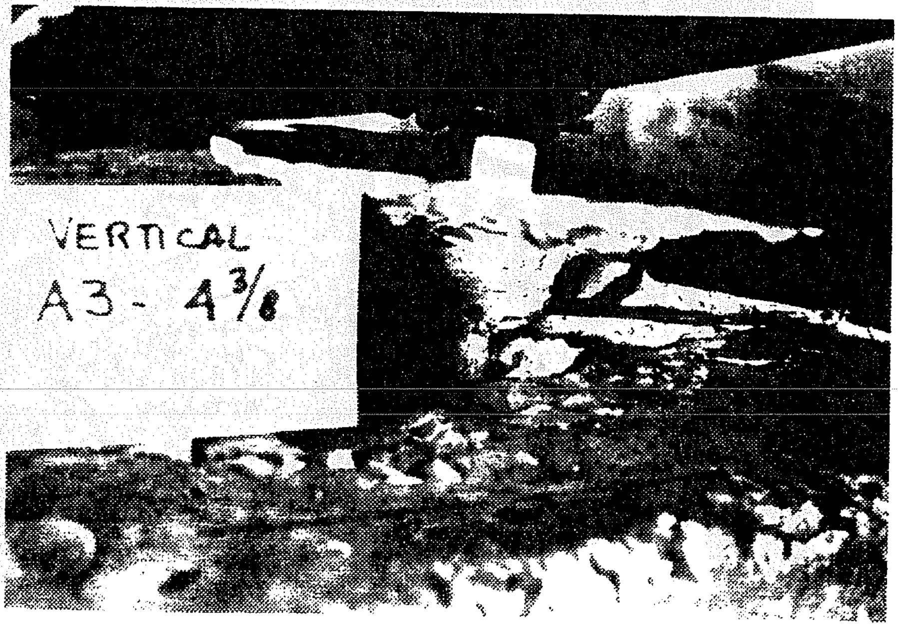


Fig. 4.6 Double cone plus bond failure. Epoxy Brand 2 (grade 1). Vertical grouting.

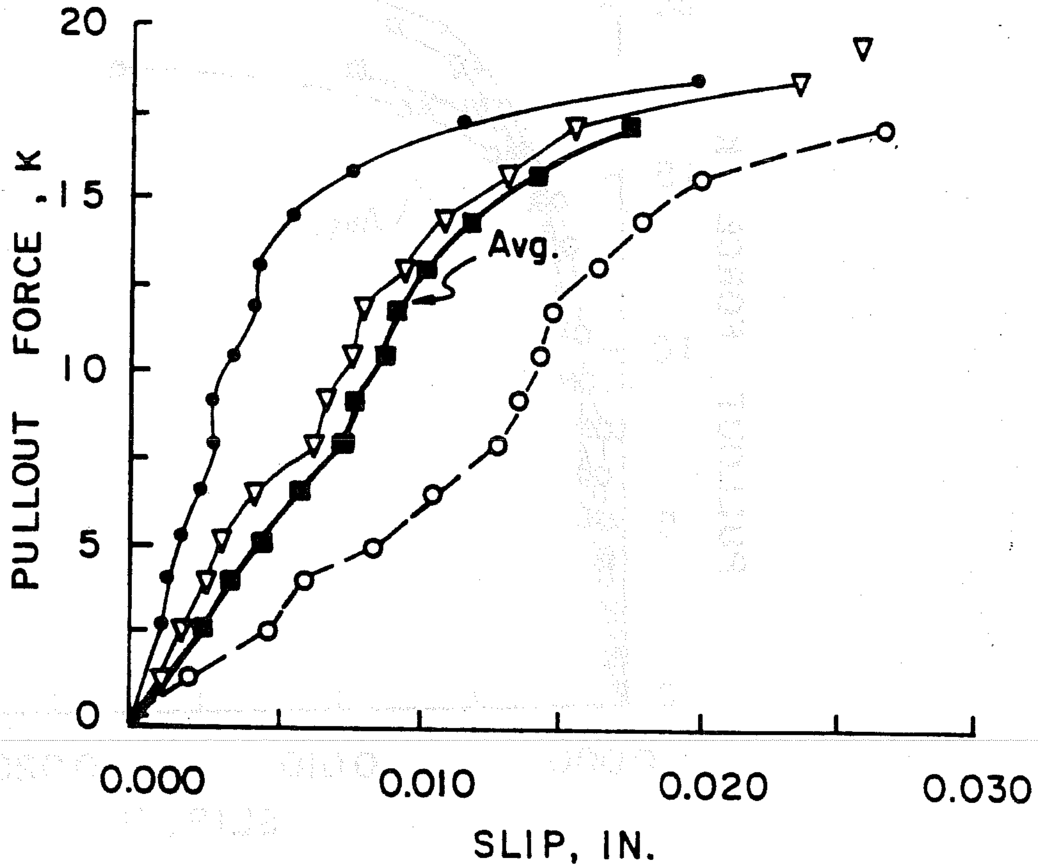


Fig. 4.9 Load-slip relationship for epoxy Brand 2, gel. Overhead grouting.

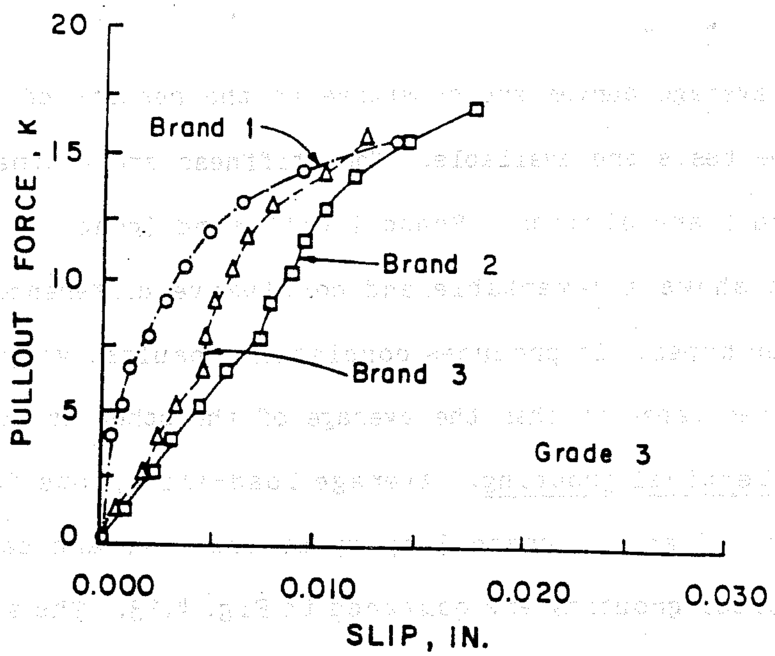


Fig. 4.11 Comparison of gels used in overhead grouting position.

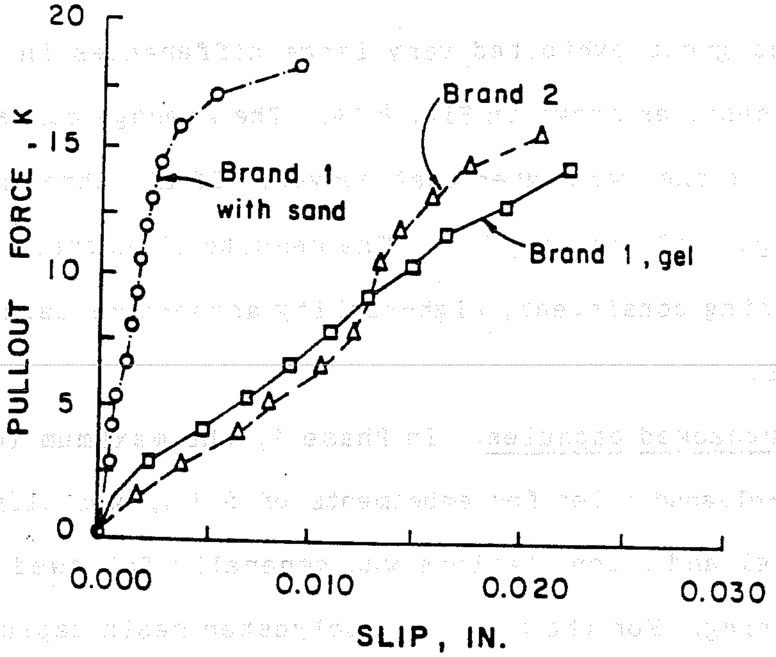


Fig. 4.12 Comparison of epoxies used in horizontal grouting position.

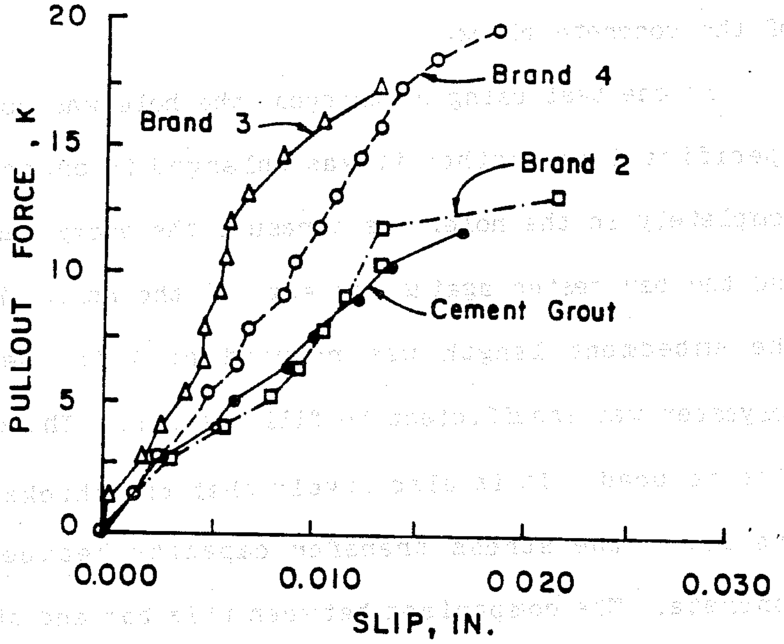


Fig. 4.13 Comparison between cement grout and epoxies. Vertical position.

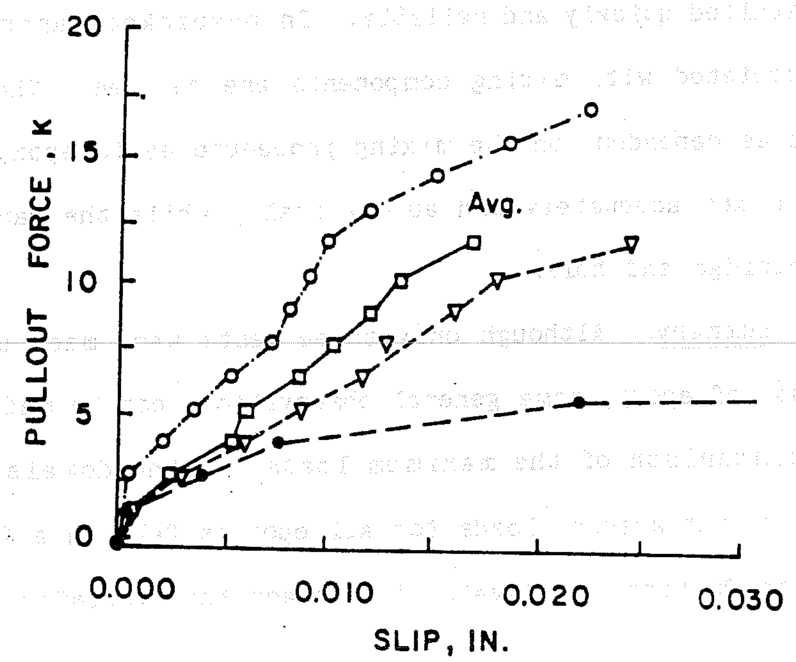


Fig. 4.14 Load-slip relationship for portland cement grout. Vertical position.

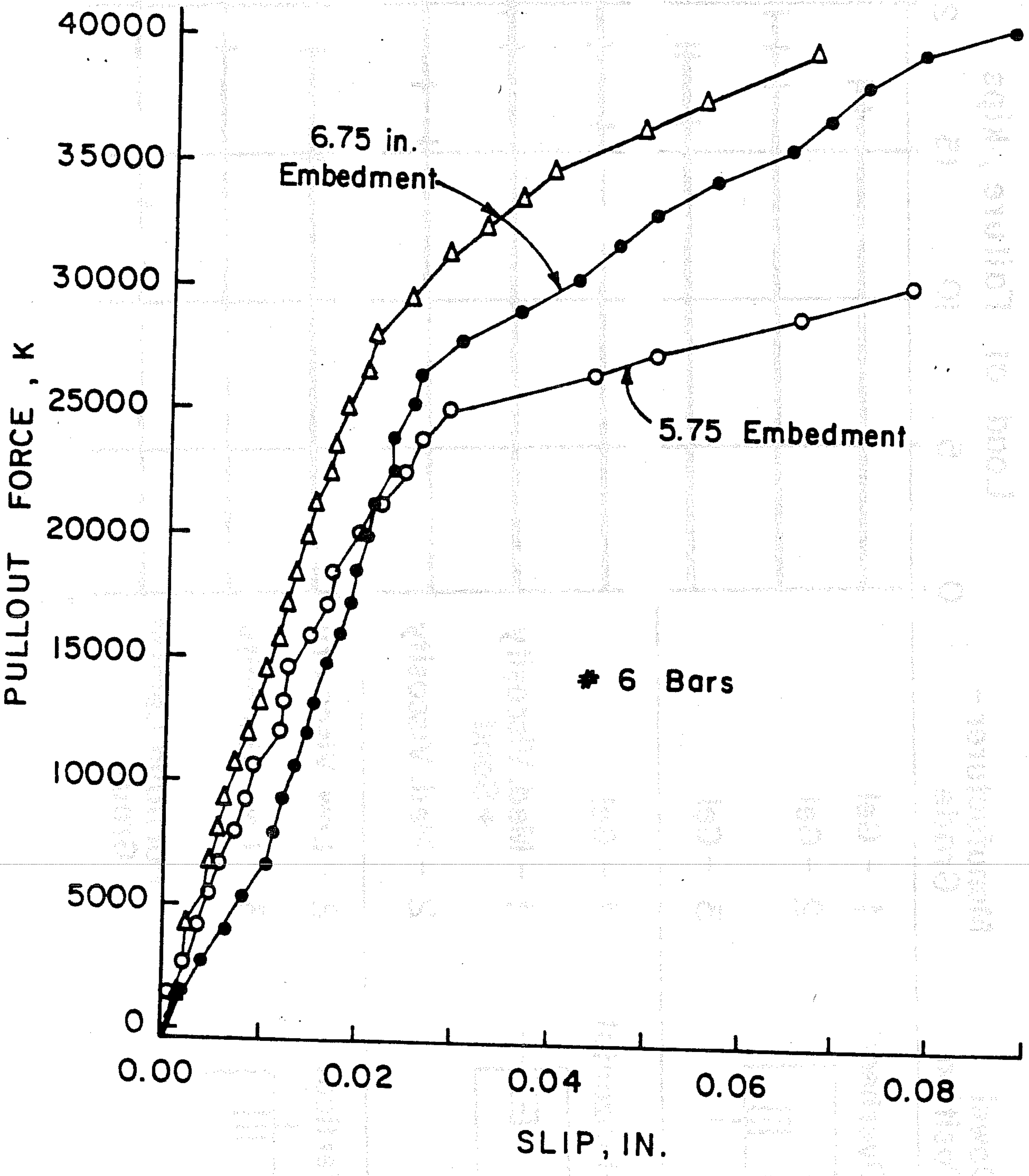


Fig. 4.15 Load slip relationship. Prepacked Cartridges. Vertical grouting position.

obtained if reputable manufacturers are selected and care is taken in the installation of the dowel.

For overhead casting, the use of a caulking gun facilitated the job and avoided entrapping air bubbles. The nozzle was introduced up to the end of the hole and the injection operation was started while the nozzle was pulled back out of the hole. In this way the entire hole was filled with epoxy and no air was entrapped. For overhead grouting, it is mandatory to use non-sagging epoxy. In some brands there was slight sagging but it did not seem to significantly influence the results. The addition of silica sand for increasing the viscosity and/or reducing the overall cost is permitted in some brands and will probably lead to an improvement in performance.

Medium viscosity epoxies presented some problems in horizontal grouting. The epoxy tended to ooze out of the hole producing an uneven distribution of the epoxy around the bar and a shorter (but unknown) effective embedment length. Therefore, non-sag (high viscosity) epoxy should be used in horizontal holes to avoid the inconvenience of sealing the space around the bar during the grouting operation.

Liquid epoxies were most appropriate for vertical grouting. Medium viscosity epoxies may be useful in keeping the bar aligned vertically without the need for additional spacers. The disadvantage in using medium-viscosity epoxy is the necessity of a caulking gun. Liquids can be fed by gravity and mixed easily. Some liquid epoxies were very thin and permitted entrapped air to escape rapidly.

In some brands, proportioning is not easy to achieve by volume and the availability of a scale is necessary at the job site. This inconvenience has been succussfully avoided by packing the exact amount of each component in separate containers. At least one of the containers is generaly large enough for mixing both products.

Handling and mixing epoxy can be very messy and epoxy can be spilled if appropriate care is not taken. Since epoxy is an irritant to the skin, gloves and goggles are the minimum protection required. Benzoil peroxide is the basic common hardener in component B, but in some brands the irritant odor of this product is very strong and more penetrating than in others. Therefore, it is necessary to have working areas well ventilated.

4.3.3 Packaging, Shipping, and Storage Safety. Some manufacturers have excellent packaging procedures. The components are packed in different containers and wrapped in plastic to avoid confusion in mixing.

Since the epoxies, especially the hardener (part B), are highly corrosive, safety lids on cans should be provided to avoid spills or broken containers during shipping and storage. Some manufacturers use clips on the edge of the cap cover to ensure safe handling and shipping.

Manufacturers' mixing procedures should be followed very carefully. In some cases, cans and labels are similar and the possibility of mixing different products of the same brand is likely to occur, especially at the job site with unskilled labor.

the hole and the workmanship of placing epoxy in the hole and dispersing it thoroughly along the hole and dowel.

Design and detailing of dowels must be related to field operations. Special care should be taken in selecting epoxies from companies with a reputation for testing their products for quality control. Even with reliable epoxies the results can not be guaranteed because the end product depends on the cleanliness, mixing, and grouting procedures followed in the field.

There are some prepack systems on the market that produce good results using a polyester resin which is less sensitive than epoxy to mixing. The adhesive prepack system consists of two sealed glass tubes containing both components that are mixed by rotating and driving the dowel into the hole with a special rotary drill. The quickness and neatness of this work makes it attractive for field operations although the cost of the cartridges is higher and a special rotary drill with a device for gripping the bar is required. The attachment developed for rebars is primarily for short dowels because it becomes quite unwieldy for long dowels. A disadvantage is that there is no parallel test, such as the slant shear test, that can be used to check the effectiveness of the adhesive used or the installation procedure followed. It is recommended that the number of the cartridge batch and the working time used be recorded in case of any problem. This information can be related to tests done in the laboratory of the manufacturer during production.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary

The load-carrying and failure mechanisms of epoxy-grouted dowels often are not fully understood by structural engineers. There have been attempts to categorize the behavior of grouted dowels. Single-cone, disc-cone (flexural cone), and double-cone mechanisms have been proposed. To better understand the performance of dowels, 69 #4 and #6 dowels were tested to determine the effect of hole cleaning procedures. An additional 32 dowels were tested using various epoxy grouts. The behavior of grouted dowels was complex and in most cases no single mechanism explained the behavior.

5.2 Conclusions

1. Syringe-air blowing and vacuuming from the top of the hole were found to be no better than no cleaning at all, especially where 6-in. or greater embedment depths were involved. By using a nozzle that could reach all parts of the hole, thorough vacuuming improved the dowel pullout strength considerably. Still more effective was cleaning with a stiff bottle brush and hard toothbrush. Coupled with thorough vacuuming, this brush cleaning procedure resulted in a pullout strength doubling that of dowels in as-drilled holes (no cleaning). The effects of roughening the walls with a steel wire brush was inconclusive but did not appear to substantially improve the pullout strength.

available from some manufacturers should be used to achieve good mixing, especially for large batches of epoxy.

8. Although the effectiveness of the slant shear test is questionable, it is the only well defined test available and is recommended for quality control. However, the engineer should consider requiring load tests of a selected fraction of dowels. Such tests to a load level less than the expected capacity of the dowel (probably 40 to 50% of the design load) should give a good indication of the quality of all operations in the grouting procedure as well as an indication of the epoxy quality.

9. The design of grouted dowels generally has been conservative and will probably continue to be so until further research results in reliable rational or empirical methods for determining performance. Some researchers have defined the failure of a dowel to occur at a loaded-end slip of 0.01 in.. This load is approximately one-half the ultimate pullout load in most cases. A conservative approach is justified since dowels serve as connectors, which in many instances may determine the overall performance of an entire structure.

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