HIGHWAY RESEARCH REPORT

EVALUATION OF CONCRETE ANCHOR BOLTS

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STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

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STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

5900 FOLSOM BLVD., SACRAMENTO 95819

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Report No. 19601 -
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Dear Sir:

Submitted herewith is a research report titled:

EVALUATION OF CONCRETE ANCHOR BOLTS

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REFERENCE: Nordlin, E. F., Ames, W. H., and Post, E. R., "Evaluation of Concrete Anchor Bolts," State of California, Department of Public Works, Division of Highways, Materials and Research Department. Research Report 19601 - 762500 - 36390, June 1968.

ABSTRACT: A study was conducted to determine the effectiveness of various types of concrete anchorage devices. This was to be accomplished by comparing the axial pullout strengths of cast-in-place bolts and friction anchors. Static axial load tests were conducted on cast-in-place bolts, epoxied-in-place and grouted-in-place threaded rods, and seven types (five brands) of commercially available friction type concrete anchorage devices. Constant axial load tests were conducted on the epoxied-in-place threaded rods and all of the friction type anchors. It was found that the strength of epoxied and grouted-in-place rods and of commercial friction type anchors was dependent on the loading rate, whereas the strength of cast-in-place bolts was independent of the loading rate. Because of this, it was not possible to obtain a direct correlation between static axial pullout strengths of cast-in-place bolts and the other types of anchors tested. Performance characteristics and test results for each type of anchorage device are discussed individually.

KEY WORDS: Anchors, anchor bolts, testing, loading tests, axial loads, concretes, epoxy resins, grout, friction bolt.

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INTRODUCTION

In highway construction, there are several uses for concrete anchorage devices, such as attaching sign frames, electroliers, and guard railing to existing concrete bridge structures.

This project was an attempt to provide comparative guide information on the effectiveness of some of the commonly used devices for such applications.

SUMMARY AND CONCLUSIONS

The research work reported herein was limited to the application of static and sustained axial loads on cast-in-place bolts, epoxied-in-place threaded anchor rods and reinforcing steel, grouted-in-place threaded anchor rods and reinforcing steel, and five commercially available proprietory friction type concrete anchorage devices.

It was found, under these test conditions, that 5/8-inch and 1-inch diameter cast-in-place bolts with ample edge distance and embedment would develop the bolt strength. Neither epoxied-in-place nor grouted-in-place anchors (threaded rods and reinforcing steel) were found to be reliable in the development of anchor rod or bar strength under sustained axial loads. None of the friction type anchors were found to develop the bolt strength for either 5/8-inch or 1-inch diameters under sustained axial loads.

Under actual conditions encountered in highway construction, a concrete anchorage device is not generally subjected to purely axial loading conditions, particularly in critical applications. Therefore, further research is necessary before a quantitative evaluation of concrete anchorage devices can be made. Due to the infinite number of loading combinations that may be encountered, this would require a very extensive investigation.

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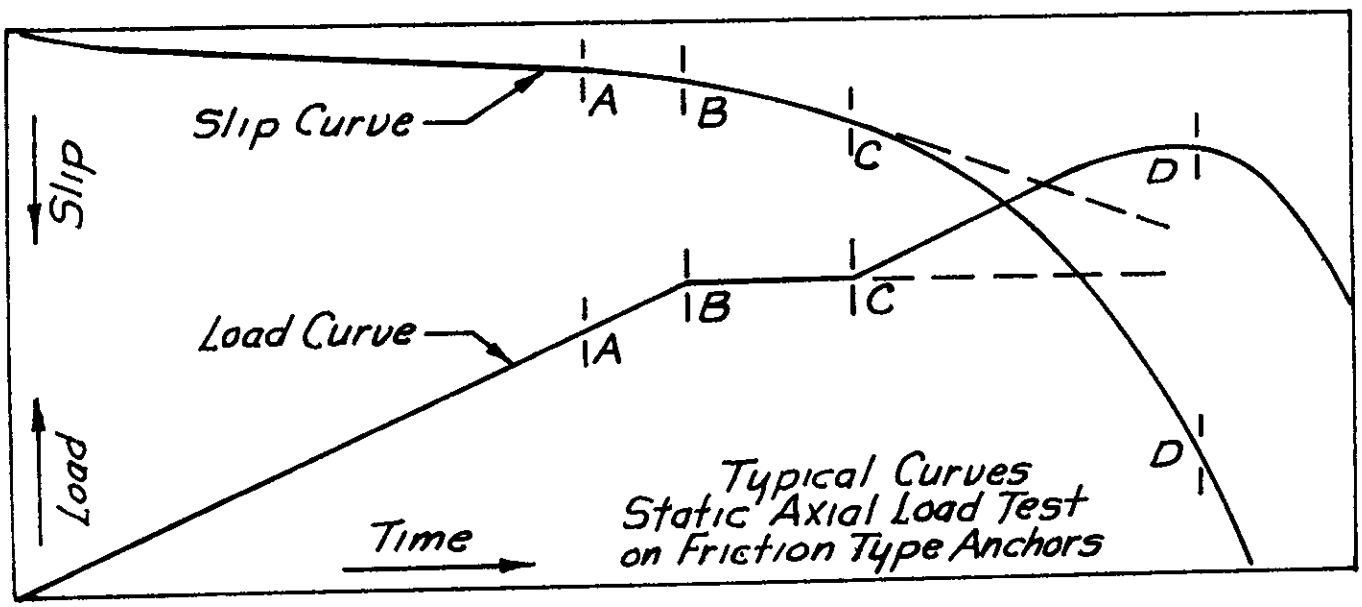
GENERAL DISCUSSION

The original intent of this research project was to develop reliable criteria on the effectiveness of various types of concrete anchorage devices. This was to be accomplished by obtaining a direct comparison of the axial pullout strengths between cast-in-place bolts which were selected as the standard and various types of friction anchors. The variables selected are diameter of the anchor, concrete edge distance, and anchor embedment depth.

Midway through the testing phase of the project, it was concluded that there is no direct correlation between the static axial pullout strengths of cast-in-place bolts and friction type anchors. In addition to the previously mentioned variables, the strength of the cast-in-place bolts is independent of the loading rate, whereas it was found that the strength of the friction type anchors is dependent upon the loading rate, as indicated in the following diagram. For a majority of the static tests conducted on friction type anchors, a graphical plot of axial load and anchor slippage relative to the concrete test slab was recorded continuously and simultaneously by use of a recording oscillograph.



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It is not obvious from the diagram just what magnitude of axial load the friction anchor is capable of resisting without taking into consideration the slippage of the anchor. Point "A" which indicates the extent of the linearity of the slip curve appears to be the maximum load the anchor can resist without a continual slippage if the load were to be held constant. When the load was increased (slightly) to point "B" and then held constant, the anchor would continue to slip. If the load is not increased at point "C" but held constant for a longer period of time, the anchor would slip as indicated by the dashed line. At point "D" when the axial pullout strength of the anchor is incipient, the slippage of the anchor is usually excessive. Because the permissible magnitude of slippage for friction type anchors subjected to axial loads and when used for various applications has not been defined, a large portion of the test data concerning slippage has been omitted from this report except where it has been used to specifically illustrate a point. In any event, it can be concluded that the actual effective axial strength of friction type anchors will be less than their ultimate static axial pullout strength.

The friction type anchors were subjected to various magnitudes of sustained axial load in an attempt to locate the load at which the slippage of the anchors was negligible. The AASHO design working load[1] currently used in highway construction was selected as the minimum constant load the anchors would be subjected to. This design working load for 5/8 and 1-inch diameter bolts is 4.0 and 11.8 kips, respectively. All of the friction anchors tested exhibited the characteristic of slipping when subjected to sustained axial loads. Due to the large number of tests conducted and for clarity, the discussions for each type anchor are individually presented under Topic Heading "Discussion of Individual Anchor Types."

The concrete anchor tests reported herein cover only those that were subjected to static and sustained axial loads. However, in actual highway construction the concrete anchors are generally subjected to a combination of axial and shear loads; therefore, it is felt that further research is necessary before a quantitative evaluation of the concrete anchors under these conditions can be made. If the anchors are tested in this manner, it is felt that the constant type load tests would yield the best results. To maintain a constant load as the anchor slips (which proved to be unfeasible utilizing springs in this research project) the axial and lateral loads might be applied by dead weights through some type of lever system.

1. $P_{(allow.)} = 1.45\ f_{(allow.)}\ A_{(root)}$ The allowable stress (f_a) for an A307 Grade A bolt is equal to 13.5 ksi and is increased 45% for wind or seismic loadings.

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In addition to various combinations of axial and shear load, the following variables should be taken into consideration:

1. Concrete Strength
2. Concrete Edge Distance
3. Anchor Embedment Depth
4. Anchor Diameter
5. Ambient Temperature
6. Grout Mix (with and without Admixtures)
7. Epoxy Mix
8. Roughness of Concrete Hole
9. Weathering Effect

As evident, this would involve an extensive and large research project.

GENERAL TESTING PROCEDURES

A. Axial Load Tests

1. Static Axial Load Test

The testing apparatus used to conduct the concrete anchor axial pullout tests is shown in Figure 1.

A hydraulic jack was used to apply the axial load to the concrete anchors through one of two calibrated tensile load cell pulling bars. The pulling bar was coupled to the anchor by a sleeve. To maintain a direct pull on the anchor, the hydraulic jack was swivel-mounted on a simple supported built-up beam.

The supported span length of the beam could be varied from 15 to 24 inches. The minimum span length was never less than twice the embedment depth of the anchor. This was considered to be a sufficient distance so that the beam supports would not have an influence upon the development of a potential concrete failure cone.

The magnitude of the axial load applied to the anchor was obtained by use of 2-cross strain gages mounted on each of the two pulling bars. A 25 kip pulling bar, which has a load sensitivity of 3.64 pounds per microinch of strain, was used in pulling the 5/8-inch diameter anchors; whereas, a 60 kip pulling bar, which has a load sensitivity of 11.00 pounds per microinch of strain, was used in pulling the 1-inch diameter anchors.

The relative movement of the anchor with respect to the concrete slab was measured by the use of two displacement transducers. The transducers are mounted on each end of a 12-inch long channel shaped cross arm. The cross arm

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was then placed over the anchor bolt (or an extension rod from the anchor) and held firmly in place by jam nuts on each side.

The applied axial load to the anchor which was converted automatically from the strain measurements and the corresponding relative anchor movements with respect to the concrete test slab were recorded continuously and simultaneously by use of a recording oscillograph. The applied loading rate was controlled by manual operation of a pressure regulating hydraulic valve. Also, a constant load could be maintained to an accuracy of ± 1/2 percent of the pressure valve setting.

The oscillograph was used only during the testing of the post-placed friction concrete anchors. The pullout or tensile strength of the cast-in-place bolts was determined by manually converting the strain measurements obtained by use of an SR-4 Strain Indicator.

2. Constant Axial Load Test

The testing apparatus used to apply a sustained axial load to the various types of post-placed friction concrete anchors was set up as shown in Figure 2.

A hydraulic jack mounted on a spacing support was used to initially apply a load to the concrete anchor through a pulling steel rod. When the desired test load was reached, a lockoff nut was snugged down against the top of a compressive load cell. The load on the hydraulic jack was then released - thus, the load on the anchor was maintained by the springs. For small anchor movements (slip) the spring (or springs) will maintain a nearly constant load. Four leveling screws were used to help maintain lateral stability of the springs. A set of concentric springs (1 outer and 1 inner spring) with a load capacity of 12 kips was used for the 5/8-inch diameter anchor tests; whereas, two sets of concentric springs with a load capacity of 27 kips were used for the 1-inch diameter anchor tests.

The axial load on the anchor at any time could be measured by use of the compressive load cell and a strain indicator. The load cells used each had a sensitivity of 10 pounds per microinch of strain.

Two indicator dials mounted on a crossarm were used to measure the relative movement of the anchor with respect to the concrete test slab at any time.

B. Concrete Test Slabs

Reinforced concrete test slabs were constructed to simulate field structures in which bolt anchorage devices might

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be installed. Dependent upon the planned anchorage embedment depth, the concrete slabs varied in thickness from 6 to 12 inches, in length from 76 to 244 inches, and in width from 24 to 36 inches.

Bolt anchorage devices are frequently placed in sparsely reinforced concrete structures wherein the concrete alone supplies most of the resistance to the applied anchorage loads. To preclude the influence of reinforcing steel, except that which would normally be encountered, number 4 reinforcing bars were placed only in the longitudinal edges of the concrete slabs, 2 inches from the top and bottom. This placement of reinforcing also eliminated the possibility of the test results being influenced by some anchorages being located closer to reinforcement than others.

The concrete used for the test slabs conformed to and was placed in accordance with the July 1964 State of California Standard Specifications. The mix design used was Class "A", which is currently used in California Division of Highways bridge construction, and no admixtures were used. Specifications for this mix include 6 sacks of Type II Portland Cement per yard, 1½ inch maximum size aggregate, and a slump of 3 to 4 inches. The minimum Class "A" 28 day concrete compressive strength is specified as 3,000 psi. Prior to placement of the concrete, the foundation soil was saturated so that no curing water would be absorbed by the soil. The concrete was cured by use of a white pigmented membrane curing compound sprayed on the top exposed surfaces supplemented by a covering of polyethylene plastic sheeting material. Three 6" x 12" concrete cylinders were made for each of the test slabs.

Two methods were used to drill the concrete anchor holes. A rotary-percussion drill-hammer and carbide tipped bits were used to drill holes up to 1-1/8 inches in diameter. A rotary drill and diamond tipped coring bits were used to drill the 1-5/8 inch diameter holes.

DISCUSSION OF INDIVIDUAL ANCHOR TYPES

A. Cast-in-Place Bolts

This phase of the study was conducted to determine the static axial pullout strength of 5/8 and 1-inch diameter machine bolts (A307 - Grade A - Zinc Plated) integrally placed with the concrete at various edge distances and embedment depths.

The results of this study indicate that, with 4250 psi concrete strength, cast-in-place anchor bolts will develop an axial pullout strength at least equal to their specified minimum tensile strength if they are placed with the minimum edge

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distances and embedment depths listed below:

Bolt Diameter (in)	Edge Distance (in)	Embedment Depth (in)
5/8	3	3
1	3	7
1	5	6
1	7+	5

During placement of the concrete, the bolts were held in position and alignment at various edge distances and embedment depths by wooden templates, as shown in Figure 3. The minimum center to center spacing of the bolts was 12 inches or that greater distance which would allow a 45-degree concrete failure cone to develop when the bolt embedment depth was greater than 6 inches.

To be assured of a good bond existing between the bolts and concrete, the bolts were cleaned with a Socal solvent just prior to placement of the concrete.

The test data obtained for the 5/8 and 1-inch diameter cast-in-place anchor bolts which were placed at various edge distances and embedment depths is shown in Tables 1 and 2, respectively.

The relationships existing between the axial pullout strengths and the parameters of edge distance and embedment depth, as illustrated graphically in Figure 4 and as shown in Tables 1 and 2, indicate the following:

1. <u>5/8-inch Diameter Anchors</u> (Table 1 and Figure 4)

   a. Concrete coning failures occurred predominately at an embedment depth of 2½ inches. The angle of the failure cone varied from 25 to 40 degrees from the horizontal for a mode value of 30 degrees. Also, plastic yielding of the bolts was apparent at approximately 14 kips.

   b. For an embedment depth of 2½ inches, an increase in strength of 24 percent was obtained in going from a 3 to 5 inch edge distance.

   c. For embedment depths of 2½ inches and greater, no significant difference in strength existed for edge distances of 5 inches and greater.

   d. The tensile strength of the bolt, which averaged 18.8 kips, was developed for edge distances and embedment depths equal to and greater than 3 and 4 inches, respectively.

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2. <u>1-inch Diameter Anchors</u> (Table 2 and Figure 4)

   a. Concrete cone failures occurred for embedment depths of 6 inches and less. The angle of the cone failures varied from 25 to 35 degrees.

   b. Regardless of embedment depth, no significant difference in the strength of the anchor system existed for edge distances of 7 inches and greater.

   c. For embedment depths equal to and less than 4 inches, no significant difference in the strength of the anchor system existed for edge distances equal to 3 inches and greater.

   d. As apparent from Figure 4, for embedment depths greater than 4 inches, a considerable difference in the strength of the anchor existed for the various edge distances.

B. Epoxied-in Place Anchors

This phase of the study was conducted to determine the static axial pullout strength of 5/8 and 1-inch diameter threaded rods (A307 - Grade A) and reinforcing bars (A15) epoxied-in-place at various edge distances and embedment depths. As a supplement to this study, tests were conducted on the two sizes of threaded rods to determine the magnitude of anchor slippage versus time under essentially constant applied axial loads.

A commercially available California Specification F28 epoxy was used as the bonding medium between the anchors and concrete. Before placing the anchors, the holes were filled partially full with the epoxy. The threaded rods or reinforcing bars were then slowly forced by hand into the epoxy to the bottom of the hole. To maintain the anchors in vertical alignment, it was necessary to support the anchors by small side boards for 15 to 20 minutes. Prior to conducting the static pullout tests, the epoxy was allowed to cure a minimum of 7 days.

The pullout strengths obtained for the 5/8 and 1-inch diameter epoxied-in-place anchors when subjected to static axial loads are shown in Tables 3, 4, and 5. At the time the tests were conducted, the ambient temperature varied from 50 to 60 degrees Fahrenheit.

As apparent from Table 3, the mode of failure which occurred was tensile rupture of the 5/8-inch diameter threaded rods. Therefore, it appears that the variable edge distances and embedment depths greater than 3 and 4 inches, respectively, have no influence on the strength of the anchorage system.

The mode of failure which occurred for the 1-inch diameter threaded rods was a combination of bond between the

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epoxy and concrete and tension in the concrete by coning. Under these conditions, the variables edge distance and embedment depth have a considerable influence on the strength of the anchorage system. In all instances the pullout strengths obtained were less than the corresponding pullout strengths for the cast-in-place 1-inch diameter threaded anchor bolts. This seems logical since an initial bond failure between the epoxy and concrete would allow the anchor to slip some distance prior to the concrete actually coning. For embedment depths of 9 inches the average obtained pullout strength was approximately 5 percent greater than the required 33.4 kip minimum ultimate strength for ASTM A307 Grade A bolts.

The mode of failure in the 5/8 and 1-inch diameter reinforcing bar anchors was tensile, occurring adjacent to the butt welds in the 2-inch long threaded rod extension sections. The ultimate loads obtained, however, were slightly less than the threaded rod tensile strengths obtained in previous tests, probably due to reduction of the threaded rod cross-sectional area, as a result of the butt welding.

Whenever the 5/8 and 1-inch threaded rod anchors were subjected to essentially constant applied exial loads, an excessive magnitude of slippage occurred, as illustrated graphically in Figure 5. At the time these tests were conducted, the ambient temperature varied from 60 to 105 degrees Fahrenheit. The mode of failure for constantly applied axial loads was bond between the epoxy and concrete. (Figure 6). The bond failures cannot logically be attributed to either smooth or unclean hole surfaces as the percussion type carbide tipped bits used to drill the concrete holes produced a rough textured interface which was flushed clean with water and blown dry with compressed air prior to placing the anchors in the holes. Had it been feasible to maintain an absolutely true constant applied axial load, the anchors would doubtless have slipped at an even faster rate than shown in Figure 5. It was further observed that, as the ambient temperature increased, the rate of slippage increased. Thus, it appears that the ability of the epoxy to resist axial loads may be dependent upon temperature.

It is not known at this time just what effect aging of the epoxy will have upon the static axial pullout strength of the anchors. Also, as previously noted from the sustained axial load tests, temperature affected the anchor's slippage rate. Therefore, it is felt that further tests should be conducted to evaluate these two variables.

It is conceivable that at higher temperature there may be a reduction in viscosity or hardness of the epoxy thereby permitting it to yield more than at lower temperatures. There is some indication from visual observations that shrinkage of the epoxy may be a very significant factor in its effectiveness in the subject applications, and that it may be necessary to use a mineral aggregate filler to minimize shrinkage.

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C. Grouted-in-Place Anchors

This phase of the study was conducted to determine the static axial pullout strength of 5/8 and 1-inch diameter threaded rods (ASTM A307 Grade A, Zinc plated) and reinforcing bars (A15) grouted-in-place at various edge distances and embedment depths. The grout was batched according to the 1964 Standard Specifications of the California Division of Highways. Admixtures were not used. The pullout strengths obtained are shown in Tables 6, 7, and 8. At the time the tests were conducted, the ambient temperature was 50 to 60 degrees Fahrenheit.

The mode of failure for the 5/8-inch diameter grouted-in-place anchors, with edge distances of 3 inches and greater and for embedment depths of 6 inches and greater, was tensile in the rod. The mode of failure for anchors embedded 4 inches was the grout-to-anchor bond. This type of failure may have been influenced by the relatively poor workability of the grout and consequent inadequate consolidation.

In each test of 1-inch grouted-in-place anchors, failure of both the grout-to-concrete bond and the grout-to-anchor bond occurred. The pullout strengths obtained were considerably less than those obtained for the cast-in-place bolts, apparently due to grout shrinkage. It seems likely that if the grouted-in-place 5/8-inch diameter anchors had been tested at some later date, subsequent shrinkage might have also appreciably reduced their strength.

The 5/8 and 1-inch diameter reinforcing bars were grouted-in-place at 5-inches edge distance and at 9-inches embedment. The mode of failure for these anchors was the same as for the grouted-in-place threaded rods of equal diameters and embedment depth.

D. Type F-1 Concrete Anchor

1. Description

The type F-1 anchors tested in this project consisted of three variations of the same mechanical design. Lateral compressive forces are developed between the anchor and concrete as the anchor is expanded over a round tapered steel cone, which is restrained by the bottom of the hole. The lateral expansion of the inner end of the anchor is permitted by longitudinal slots every 90 degrees. The anchor's gripping capacity is increased by circumferential sawtoothed bearing surfaces. The three variations are illustrated below.

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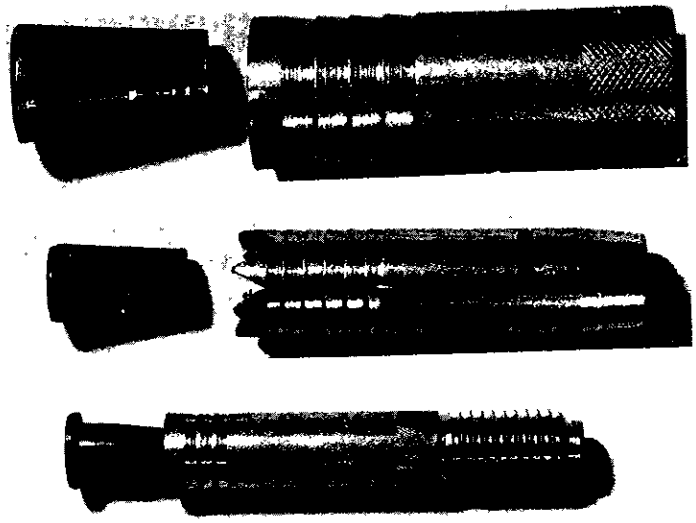

F-1-a: Nondrilling

F-1-b: Self-drilling

F-1-c: Nondrilling

Type F-1 Concrete Anchors

2. Discussion

This phase of the study was conducted to determine the static axial pullout strength of 5/8-inch type F-1 concrete friction anchors. The manufacturer's recommended anchor embedment depths were used in all tests. The edge distance of the F-1-a anchors was varied to determine the effect of this parameter on the anchor's pullout strength. Additional tests were performed to determine the magnitude of the anchor slippage versus time under sustained axial loads.

Some difficulty was encountered in installing the F-1-b anchors by hand. Using a 20-ounce hammer, two or more anchors were required to drill one hole. The cutting teeth of the anchors flattened out as shown by the anchors labeled "A" in Figure 7. The extent of the damage is apparent by comparison with a new anchor, labeled "D". No difficulty was encountered, however, when using a 12-ounce hammer in the installation of the anchors, and relatively slight damage was done to the anchor's teeth as shown by the anchors labeled "B".

When using an electric hammer, with F-1-b anchors, the cutting teeth were worn down considerably, as shown by the anchors labeled "C" in Figure 7. However, in no instance with the electric hammer was more than one F-1-b anchor needed to drill a hole.

The static and constant axial load test results obtained for the 5/8-inch F-1 anchors are shown in Table 9.

Edge distance did not significantly influence the pullout strength of F-1-a anchors when tested in 3,830 psi strength concrete, apparently due to the shallow embedment depth (2-9/16 inches).

The maximum static axial load that the F-1-a anchor was capable of supporting, prior to an excessive magnitude of slippage, averaged 9 kips. This load, referred to as the "Limiting Condition" in Table 9, was measured from the oscillograph

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recordings and is defined as that load at which the slippage of the anchor begins to increase rapidly for small increases in the static axial load. However, this phenomena may have little significance when one considers the response of the anchor under a sustained axial load. It appears, from the limited amount of data obtained, as shown on Figure 8, that the F-1-a anchor will commence to slip under a sustained axial load between 6 to 8 kips.

Generally, a metal galling failure, as illustrated in Figure 9, occurred on the outermost bearing surfaces of the F-1-a anchors, thereby allowing the anchors to be pulled out of the concrete holes. This tends to indicate that the strength of anchorage system may be independent of the concrete strength greater than 3,800 psi. Two of the circumferential sawtooth bearing surfaces apparently were not in contact with the concrete as illustrated in Figure 9.

On the other hand, concrete cone type failures occurred for all the F-1-b anchors. These anchors could not be pulled out of the concrete, apparently due to the hardness of the heat-treated cutting teeth with the added bonus that galling of the metal is prevented. Failure of the F-1-c anchors occurred by the concrete cracking. Since the bearing surface area of the F-1-c anchor is considerably less than that for either the F-1-a or F-1-b anchor, the lateral stresses on the concrete are bound to be considerably higher and more localized. This most likely accounts for the concrete cracking for the F-1-c anchor and not for the other two.

The F-1-a concrete anchors showed evidence of corrosion to a considerable degree after having been in place only three months prior to being tested. The F-1-b and F-1-c anchors were tested shortly after installation, therefore no evaluation of their corrosion resistance was made. The corrosion cannot be attributed to proximity of the reinforcing steel since the only reinforcing steel in the test slabs was along the longitudinal edges. Since no admixtures were used in the concrete mix, the corrosion cannot be attributed to this cause. It is probable that corrosion would be more of a problem in the position tested than in horizontal or vertical overhead applications as the hole serves as a trap for surface water that falls thereon.

E. Type F-2 Concrete Anchor

1. Description

The F-2 anchor is a nondrilling friction anchor with a male connection. The anchor consists of a steel body, two steel wedges with attached pins, a nut, and a tabbed washer. The anchor body has two tapered recesses opposite each other at the base and a slot running the length of the steel body from each recessed section to the exposed end of the anchor. The steel wedges fit in the recessed sections, and the attached pins fit in the longitudinal slots. The washer tabs fit into the slots and bear against the wedge pins. After the anchor is placed in the hole, the nut is tightened. This tends to pull the anchor out of the hole through bearing of the washer on the concrete face while the tabs

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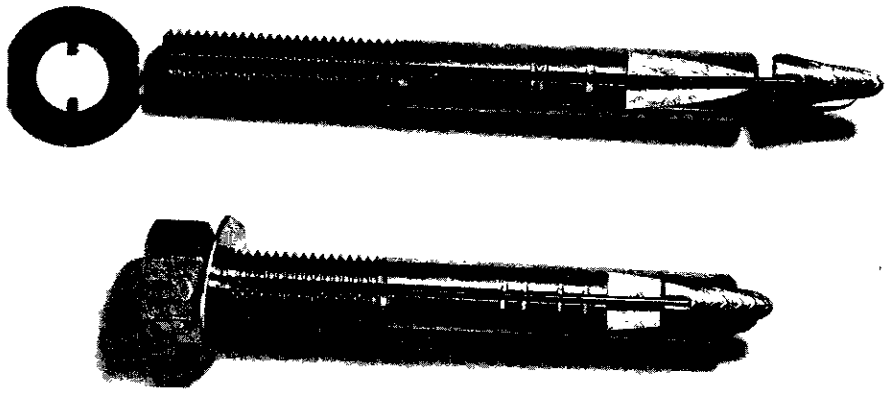
on the washer restrain the wedges through the wedge pins. The wedges are in turn forced against the sides of the hole by the tapered surfaces at the anchor base, thereby developing frictional resistance to withdrawal of the anchor body.



Type F-2 Concrete Anchor

2. Discussion

This phase of the study was conducted to determine the static axial pullout strength of 5/8 and 1-inch diameter type F-2 concrete anchors placed at various edge distances and embedment depths. In addition, tests were conducted on 5/8 and 1-inch diameter anchors to determine the magnitude of anchor slippage versus time under sustained axial loads.

As recommended by the manufacturer, all holes were drilled to the nominal diameter of the bolt. Some experimentation with oversize holes indicates that the 5/8-inch anchors cannot be set by hand when the holes are drilled 1/16-inch or more oversize and the 1-inch anchors cannot be set when the holes are 1/8-inch or more oversize.

While placing and seating the anchors, it was observed that the washer tabs in most test installations were not of sufficient strength to initially set the anchor wedges. The tabs bent, as shown in Figure 10, and often sheared off and became jammed in the threads. This made it difficult either to back off or further tighten the nut. The anchors often pulled out a considerable distance before seating, as shown in Figure 10. This frequently required the use of spacers to avoid running out of threads. Tables 10 and 11 list the desired embedment depths and several of the corresponding actual seated embedment depths obtained when using the furnished tab washers. It was found that the anchor wedges could initially be set better by using a nail punch (or screwdriver) and a hammer. However, even when supplemented by this procedure, seating of the anchors by turning the nut two or three full turns, as indicated by the manufacturer, was not always successful.

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The F-2 anchors corroded to a considerable degree after having been in place approximately 5 months prior to testing.

a. 5/8-Inch Diameter Type F-2 Anchors

The static axial pullout strengths obtained for the 5/8-inch diameter F-2 anchors are shown in Table 10.

Several of the anchors which were initially embedded 2½ inches could not be seated and were pulled out of the concrete holes by hand tightening. The pullout strength of the anchors that did seat (2½ inches and less) was extremely low.

Edge distances and embedment depths equal to and greater than 3 and 4 inches respectively did not have any effect on the anchor's pullout strength. The primary mode of failure at these distances occurred as the result of the anchors being pulled out of the concrete holes at an average axial load of 14.5 kips. This pullout strength is approximately 16 percent greater than the required 12.5 kip minimum tensile strength for A307 - Grade A bolts. However, such a comparison may have little significance since the 5/8-inch diameter F-2 anchors slipped whenever they were subjected to sustained axial loads. The magnitude of anchor slippage versus time under various applied loads is shown in Figure 11. It is readily apparent that very inconsistent test results were obtained. It appears that the variable edge distance had no effect on the test results. For sustained axial loads of 6.1 kips and less, Tests 1A, 1B, 2A, and 4 had practically no slippage; Tests 2B and 6B had a moderate amount of slippage; and Tests 3 and 6A had an excessive amount of slippage. For sustained axial loads of approximately 8 kips, it appears that slippage was inevitable.

b. 1-Inch Diameter Type F-2 Anchor

The test data of the static axial pullout strengths obtained for 1-inch diameter Type F-2 concrete anchors is shown in Table 11.

It is not apparent what effect the variable edge distance had upon the axial pullout strength of the anchors since the actual seated embedment depths were not measured for all the tests conducted. However, it is readily apparent from Table 11 that if much difference existed between the initial and actual seated embedment depths, a reduction in anchor pullout strength occurred.

The maximum pullout strengths obtained for the 1-inch diameter F-2 anchors agree quite closely with the test results obtained for the cast-in-place bolts up to the point where the primary mode of failure was either the concrete coning or cracking. However, such a comparison may have little significance because the 1-inch diameter

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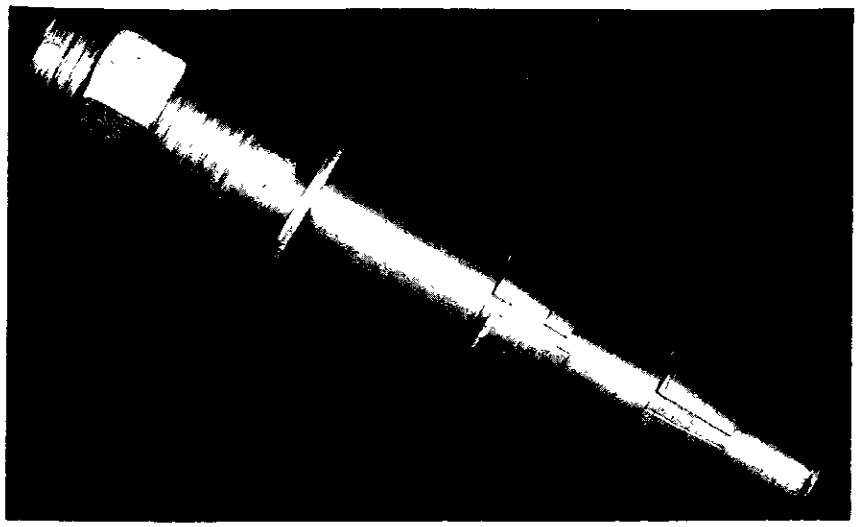
F-2 anchors slipped whenever they were subjected to sustained axial loads. The magnitude of anchor slippage versus time under various applied loads is shown in Figure 12. As can be seen from the graph, the anchors were not stable under the comparatively lower applied axial loads which varied in magnitude from 12.3 to 10.5 kips. Had it been possible to maintain constant loads, slippage would have occurred at even a faster rate.

F. Type F-3 Concrete Anchor

1. Description

The Type F-3 anchor, shown below, is a nondrilling friction anchor with a double set of split ring wedges. As the nut is tightened, lateral compressive forces are developed between the anchor and concrete as the split ring wedges are forced outward over the tapered sections of the anchor.



Type F-3 Concrete Anchor

2. Discussion

Tests were conducted on the 5/8-inch diameter Type F-3 double unit concrete anchor to determine the anchor's static axial pullout strength and the magnitude of anchor slippage versus time when subjected to a sustained axial load.

The static axial pullout strengths obtained for the anchors are shown in Table 12. From the limited number of tests conducted, it is not possible to reach any conclusions regarding the effect of edge distance and embedment depth on the anchor's axial pullout strength. At an initial embedment depth of 4 inches, the 9.4 kip average axial pullout strength obtained was quite low when compared to the 12.5 kip required minimum tensile strength for 5/8-inch diameter ASTM A307 - Grade A bolts. The low pullout

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strengths were most likely due to the anchor's double unit wedging action, as the top set of wedges were within 2 inches of the concrete surface. The lateral forces from the top set of wedges may have caused the concrete to crack sooner than it would have if only a single unit anchor was used.

Results obtained for the static axial pullout tests may have little significance since slippage occurred when the anchors were subjected to sustained axial loads. The magnitude of anchor slippage versus time under sustained axial loads is shown in Figure 13.

G. Type F-4 Concrete Anchor

1. Description

The Type F-4 concrete friction anchor is a non-drilling type anchor consisting of a series of tapered iron alloy cones and lead expansion sleeves with only the cone at the interior end of the anchor threaded to transmit the anchor forces into the concrete. For the tests described herein, three units were used as recommended by the manufacturer for a 1-inch diameter bolt. Lateral compressive forces are developed between the concrete and anchor as the lead sleeves are expanded over the tapered cones by use of a setting tool. Each unit of the anchor (cone and lead sleeve) is set individually.

Type F-4 Concrete Anchor

2. Discussion

This phase of the study was conducted to determine the axial pullout strength of 1-inch diameter Type F-4 concrete anchors placed at various edge distances and embedment depths. Static axial pullout test results are listed in Tables 13 and 14. Table 13 also includes a record of anchor slippage in inches at various load increments sustained for a few minutes. Figure 14 shows the results of two sustained axial load tests lasting 20 hours.

The ability of the F-4 anchors to resist axial loads may be more dependent upon the ambient temperature and applied rate of loading than on the variables edge distance and embedment depth. An apparent effect of temperature was observed

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in comparing the pullout strengths obtained for anchors having a 5-inch edge distance and 6-inch embedment depth when tested at different ambient temperatures. For a test conducted during December when the ambient temperature was 40 to 50 degrees Fahrenheit, a pullout load of 28.0 kips (Table 13) was obtained; whereas, for two tests conducted during June when the ambient temperature was 90 to 105 degrees Fahrenheit, an average pullout load of 20.5 kips (Table 14) was obtained even though the concrete at this time had a higher compressive strength. This phenomenon may be due to a combination of concrete shrinkage and a change in mechanical properties of the lead as a result of an increase in ambient temperature.

The applied rate of loading had a significant influence upon the strength of the F-4 anchors. The average pullout axial loads obtained for anchors having an edge distance of 7 inches and an embedment depth of 6 inches was 34.2 kips which is slightly greater than the required minimum tensile strength for 1-inch diameter A307 bolts. This implies that anchors tested under the above conditions would be adequate since the minimum strength of the bolt was exceeded; however, referring to Table 13, it is apparent that during the tests and whenever the axial loads were sustained for a short time interval, the anchors continued to slip. Further tests were conducted to verify slippage of the anchors versus time under sustained axial loads for several hours. As shown in Figure 14, slippage of anchors occurred quite rapidly for initial loads of 12.0 and 14.9 kips. These loads are only slightly higher than the working design load of 11.8 kips currently used in highway construction. Had it been possible to maintain constant loads, slippage would have occurred at even a faster rate.

Other test results of anchors placed at various edge distances and at embedment depths of 4 and 6 inches are shown in Table 14. The axial pullout loads obtained were considerably less than those obtained for the cast-in-place A307 bolts.

From visual observations of the failures, the smoothness of the concrete holes did not significantly reduce the strength of the anchorage system. As illustrated in Figure 15 the typical anchor pullout failure occurred primarily as a result of the lead shields shearing and extruding between the anchor alloy cones and concrete. In no instance did the concrete actually fracture until the anchor had slipped about 1/2 of an inch.

H. Type F-5 Concrete Friction Anchors

1. Description

The Type F-5 concrete friction anchor is a non-drilling type anchor consisting of a series of tapered iron alloy cones and lead expansion sleeves with a steel ring placed in between.

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The cone at the interior end of the anchor is threaded to transmit the anchor forces into the concrete. For the tests described herein, three units were used. Lateral compression forces are developed between the concrete and anchor as the lead sleeves are expanded over the tapered cones by use of a setting tool. Each unit of the anchor (cone and lead sleeve) is set individually.

Type F-5 Concrete Anchor

2. Discussion

This phase of the study was conducted to determine the static axial pullout strength of 5/8-inch diameter Type F-5 concrete anchors placed at various edge distances and embedment depths. Tests were also conducted to determine the magnitude of anchor slippage versus time under sustained axial loads.

The results obtained for the static axial pullout tests are shown in Table 15. At the time of the tests the strength of the concrete was 4,560 psi, and the ambient temperature was 40 to 50 degrees Fahrenheit. For the same edge distances and embedment depths, the axial pullout strengths obtained for the Type F-5 anchors were approximately equal to the axial pullout strengths obtained for 5/8-inch diameter cast-in-place (A307 Grade A) bolts. However, such a comparison may have little significance for two reasons:

a. When the Type F-5 anchors were subjected to sustained axial loads, slippage occurred. The magnitude of anchor slippage versus time is shown in Figure 16. At 70 hours and an average load of 4.5 kips, which is only 4 percent greater than the allowable working design load, slippage of the anchors was minor. Under an axial load of 9.5 kips, excessive slippage of the anchor occurred.

b. Since the shrinkage and thermal volume changes of the concrete apparently reduced the pullout strengths obtained

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for the F-4 anchors, a similar type expanded lead anchor, it seems likely that the F-5 anchor would have exhibited the same trend, had further tests been conducted at a higher ambient temperature.

The design of the F-5 anchors and F-4 anchors is very similar except that the F-5 anchors have a steel ring placed over each alloy cone prior to insertion of the lead expansion sleeves as shown in Figure 17. Tests conducted on the F-5 anchors by other investigators made the following statement regarding the effectiveness of the small ring, "Tests to determine the effect of the small ring used by one manufacturer showed that the ring increased the load at failure as much as 30 or 40 percent in this brand of anchor so long as the failure was due to the anchors slipping in the concrete." (Ref. 1). We are not able to directly verify this statement because no tests were conducted on 5/8-inch diameter anchors without rings; however, upon examination of the anchors after the pullout tests, it appears as shown in Figure 17 that the rings, in most instances, restrained the lead from shearing or extruding. One weakness of the F-4 anchor was that under sustained axial loads the lead sheared and extruded to such an extent that the anchors were erratic in their behavior, as shown in Figure 14. Thus, from the limited test information available, it is felt that the rings, to some extent, increase the effectiveness of the anchors by restraining extrusion of the lead expansion sleeves.

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REFERENCES

1. Adams, Robert F., "Some Factors Which Influence the Strength of Bolt Anchors in Concrete," Proceedings of the American Concrete Institute, Vol. 52, 1955-56, pp. 131-138.

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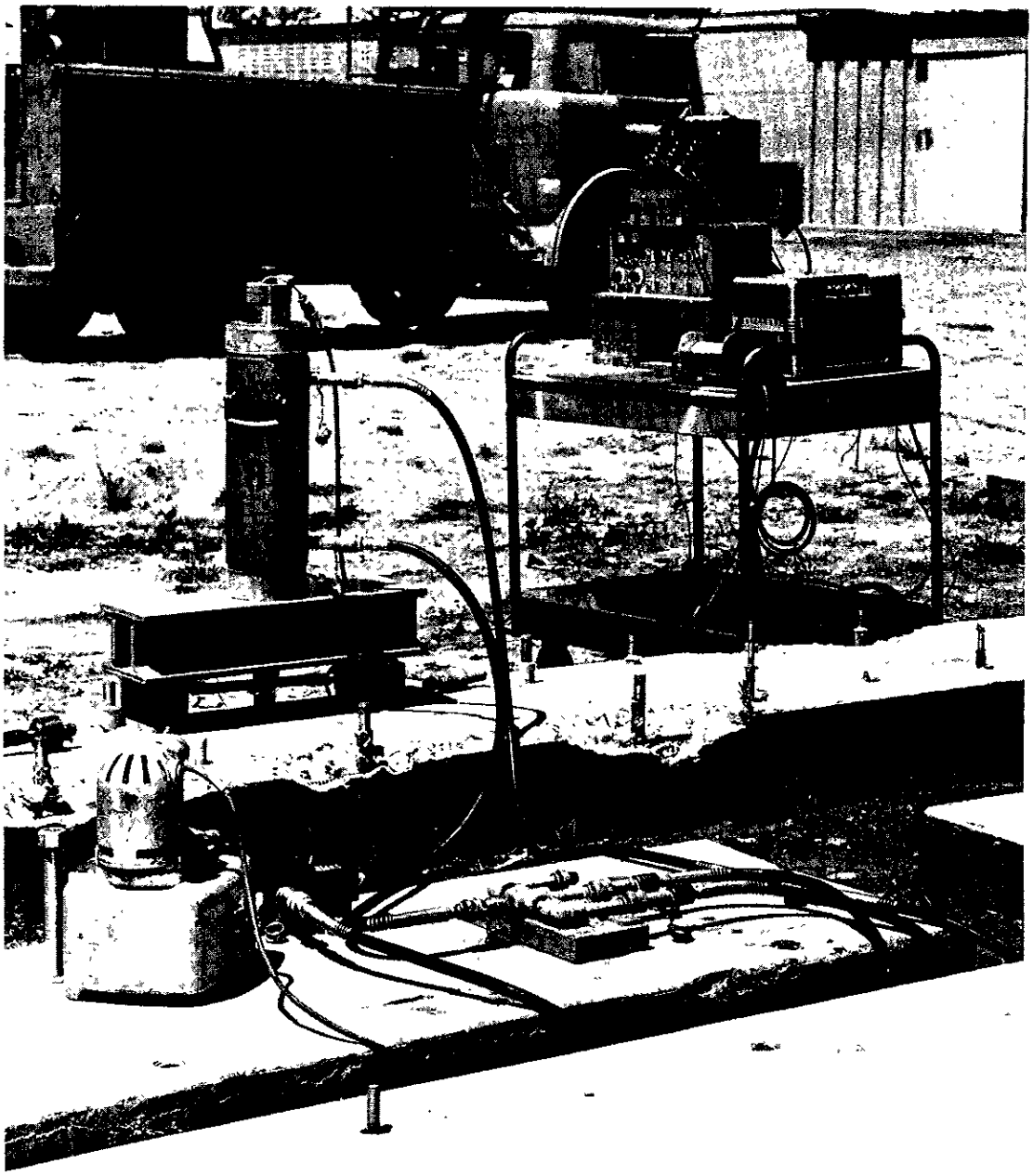
FIGURE 1



Static Axial Load Test Apparatus

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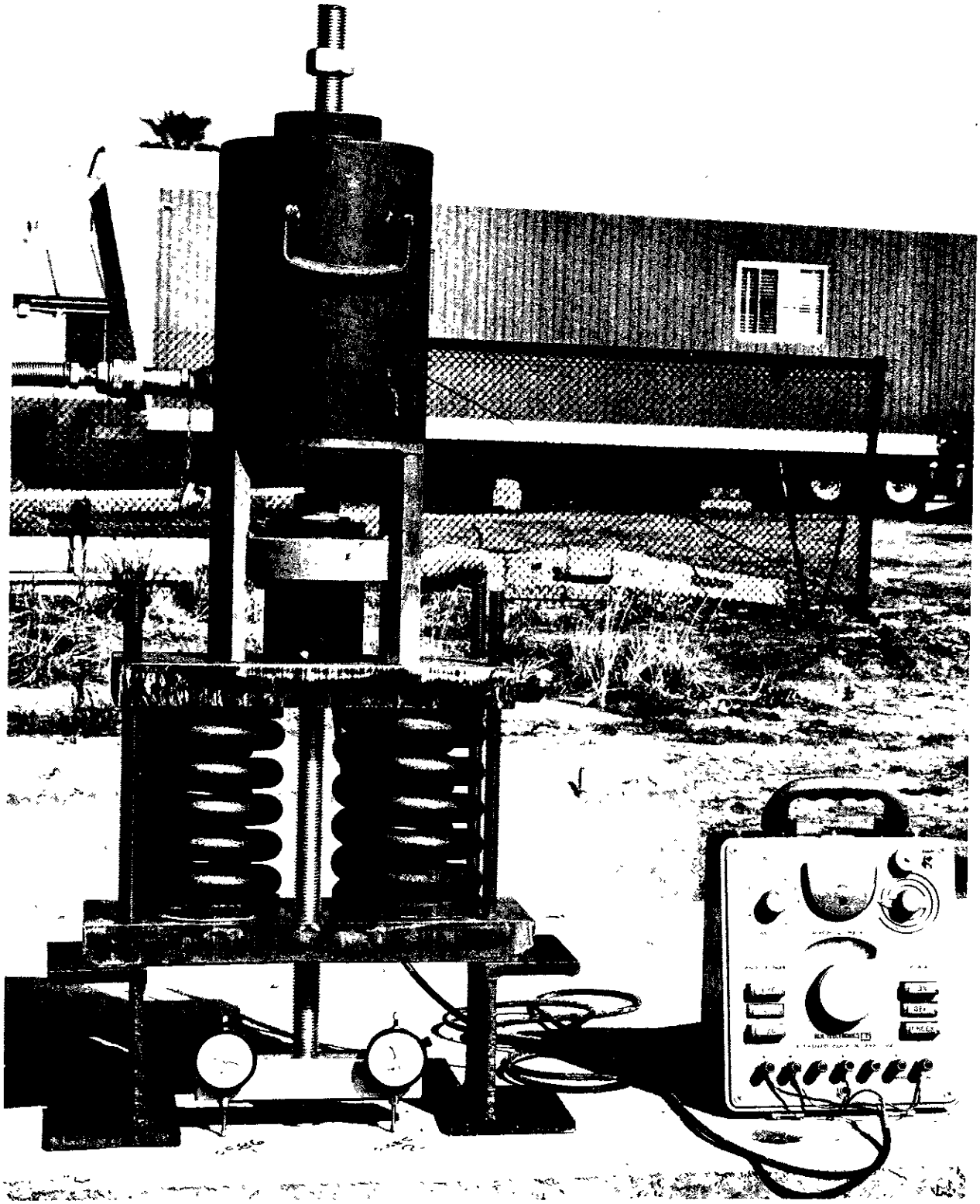
FIGURE 2



Sustained Axial Load Testing Apparatus. A 1-inch diameter Type F-4 concrete anchor is being tested.

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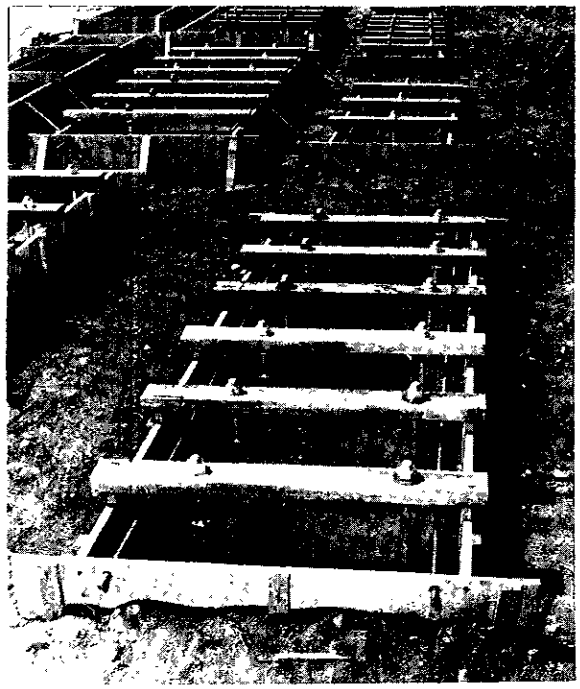
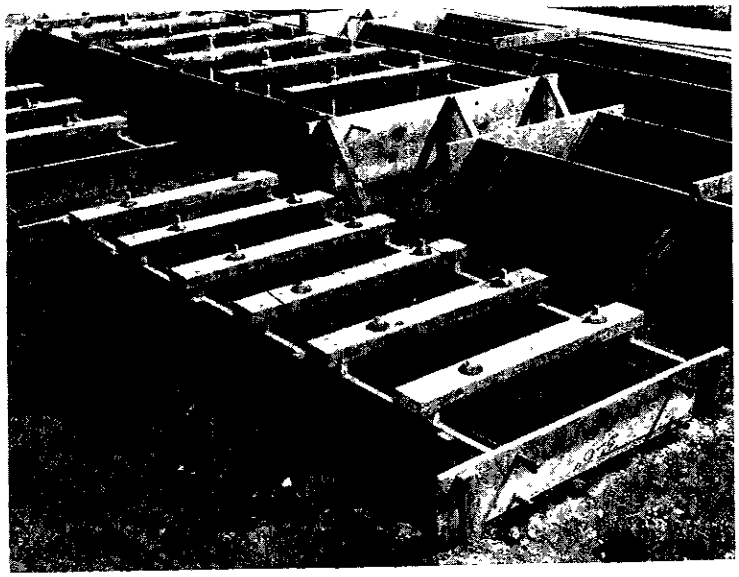
FIGURE 3





Method used to hold the bolts in position and alignment at various edge distances and embedment depths.

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Figure 4

STATIC AXIAL LOAD TESTS
CAST-IN-PLACE ANCHOR BOLTS
(A 307 - GRADE A - ZN. PLATED)

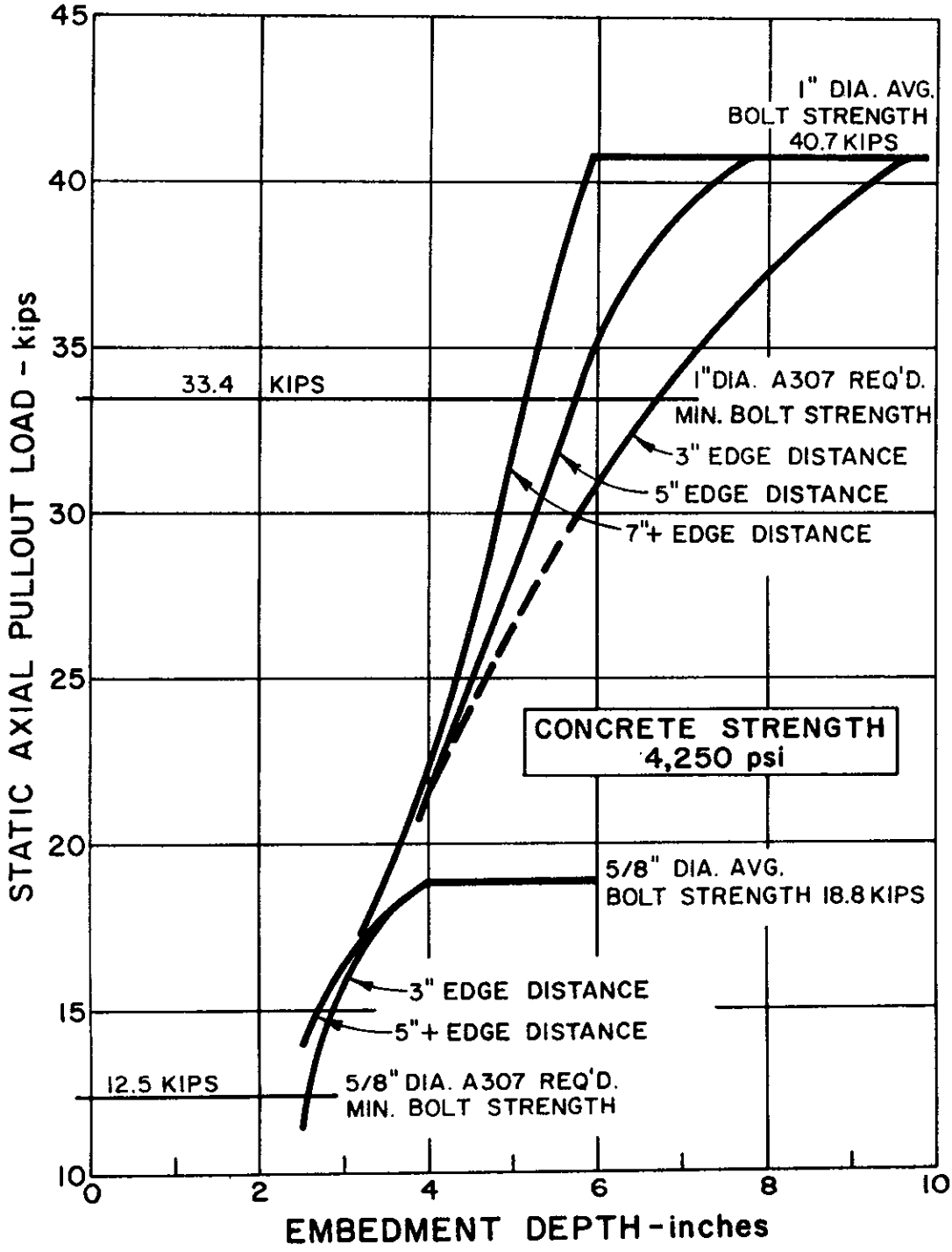

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Figure 5

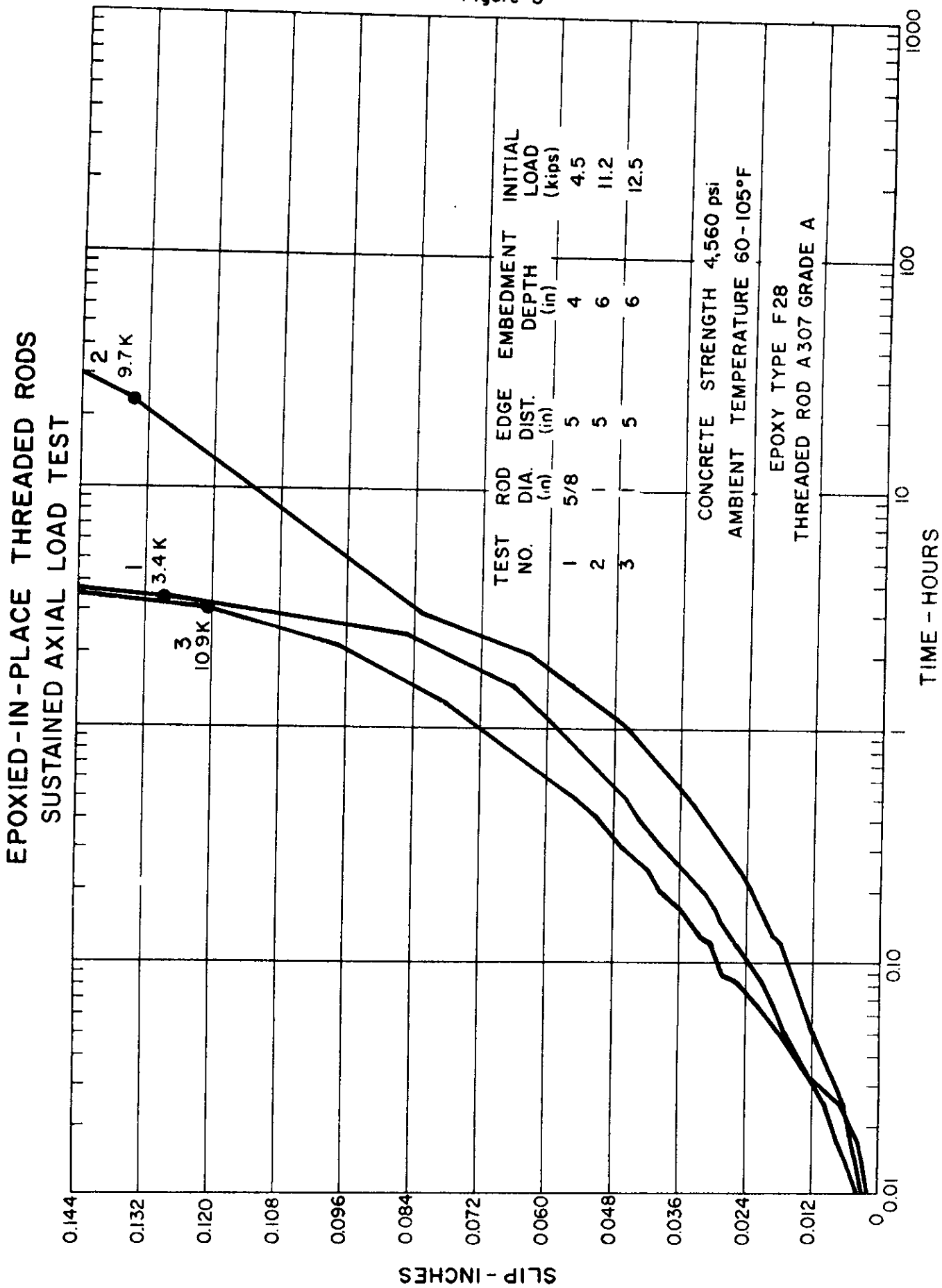

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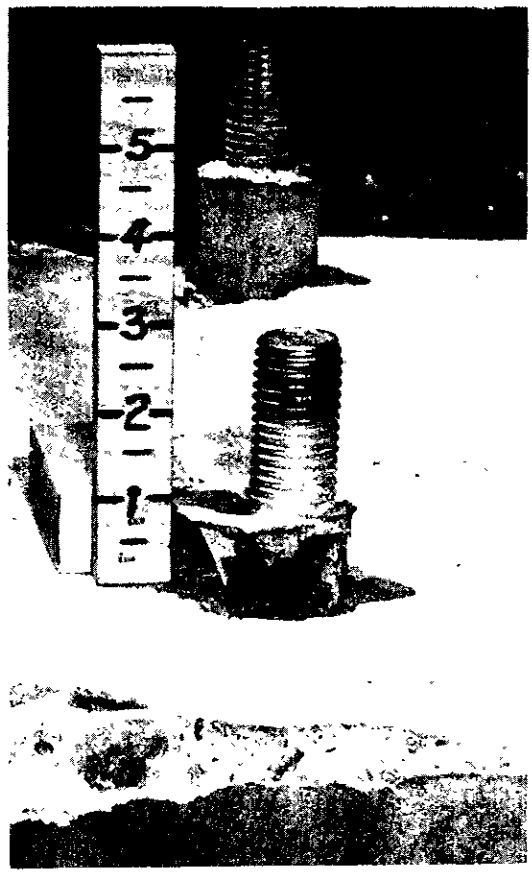
FIGURE 6



Load	10.2 kips	Load	1.3 kips
Time	4.5 hrs.	Time	46.8 hrs.
Slippage	0.194 in.	Slippage	1.10 in.

Sustained load test failures of an epoxied-in-place threaded rod.

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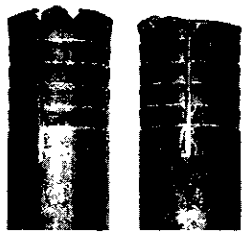
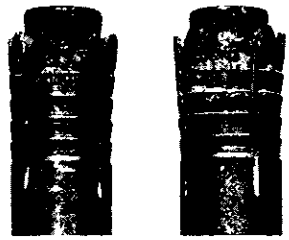
FIGURE 7



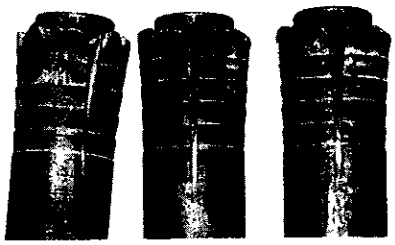
A

Hand Driven
20 oz. Hammer



B

Hand Driven
12 oz. Hammer



C

Electric Hammer
Driven

D

New

Damage to drilling teeth of F-1-b anchors.

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TYPE F1a CONCRETE ANCHORS
SUSTAINED AXIAL LOAD TEST

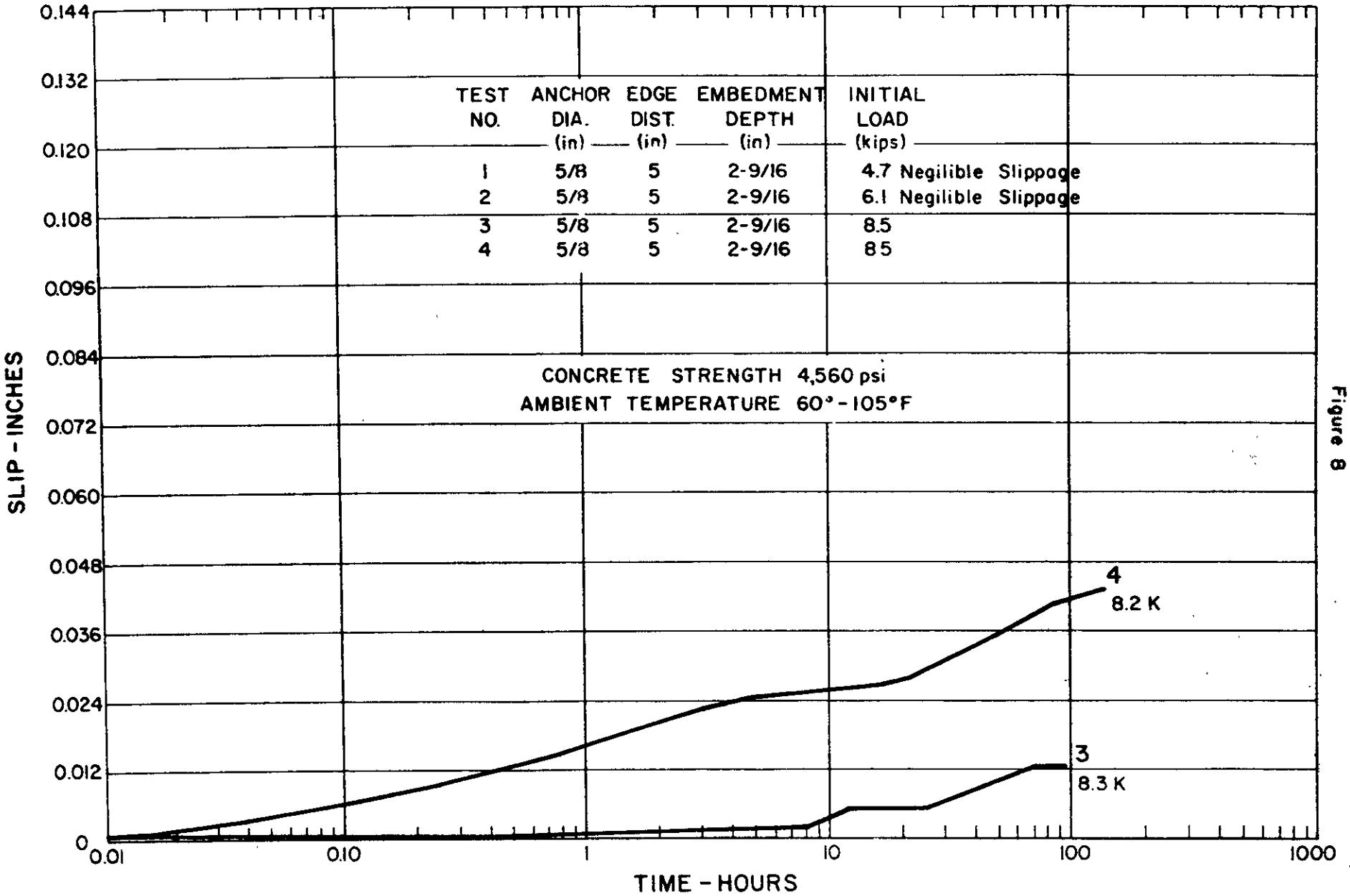
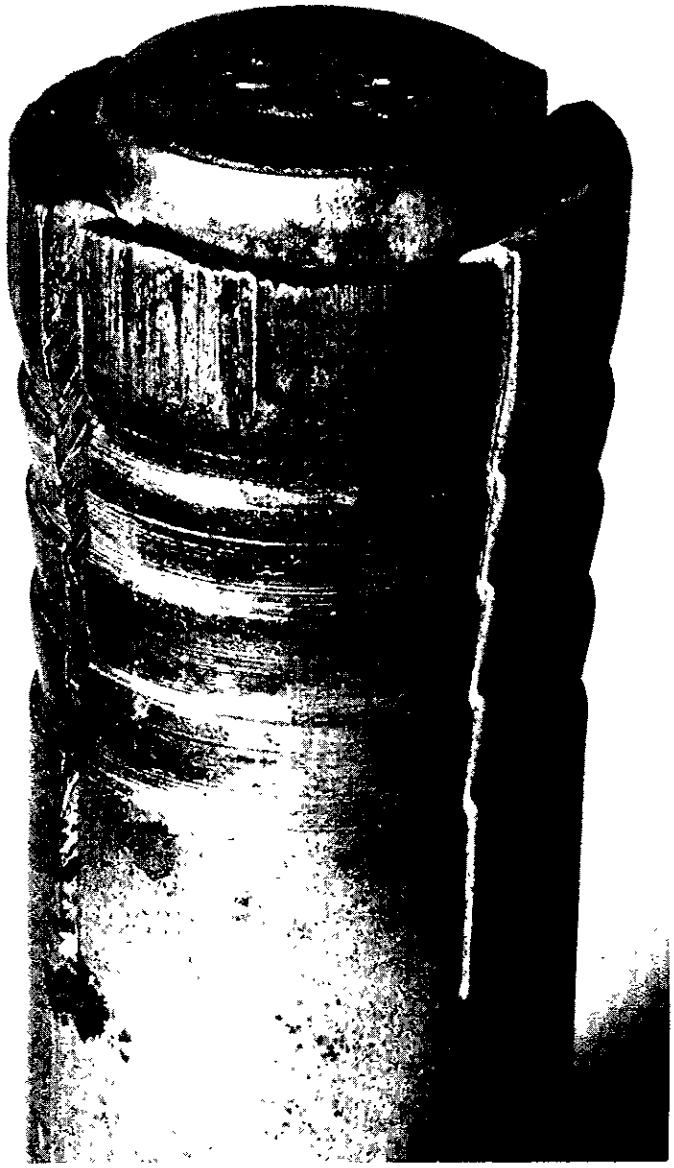


Figure 8

FIGURE 9



Tested Type F-1-a anchor that pulled out of the concrete. Note the metal galling failure at the tip of the anchor.

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FIGURE 10

Type F-2 concrete anchor. The anchor pulled out 2 inches prior to seating. Note how the washer tabs are bent.

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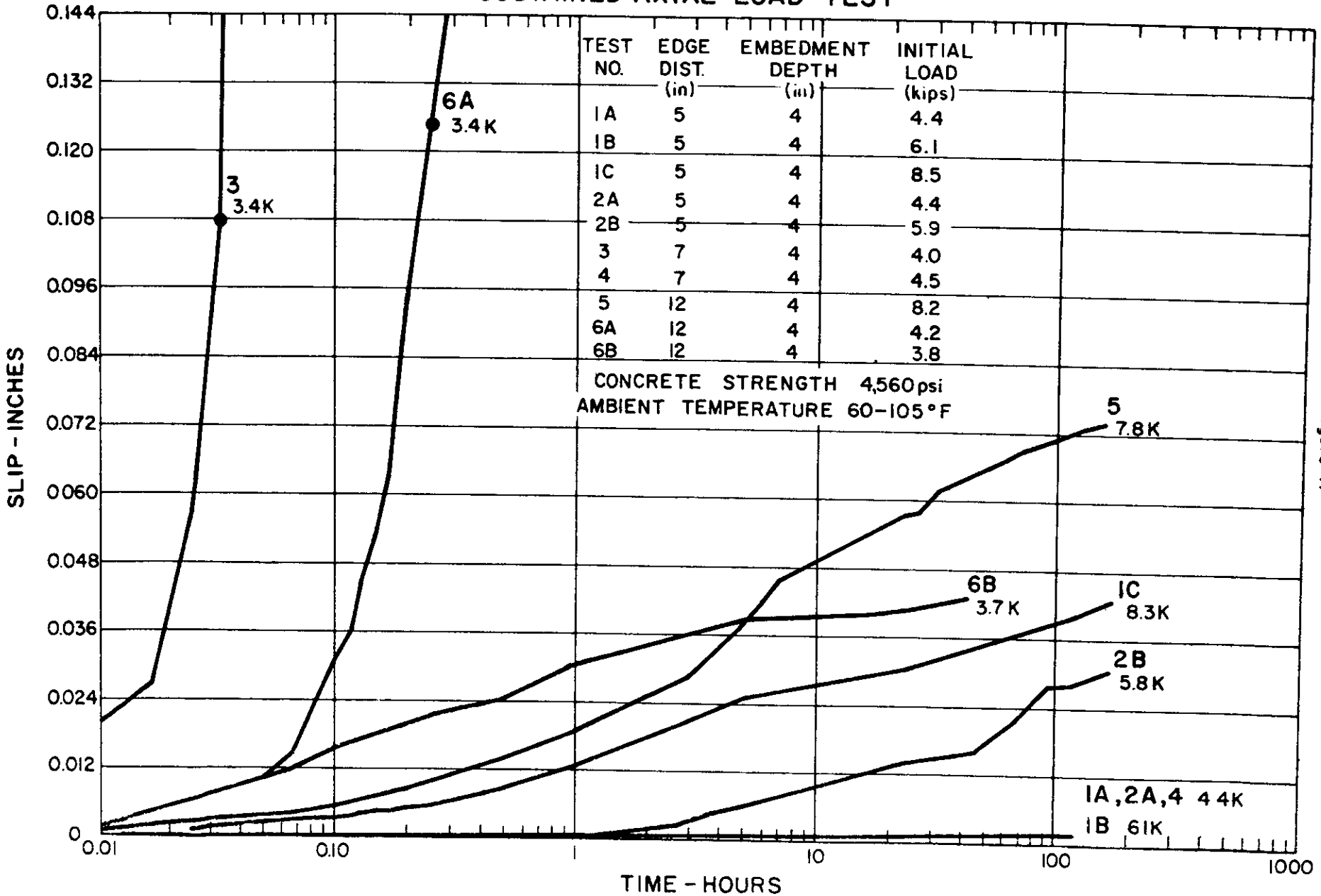
TYPE F2

5/8 INCH DIA. CONCRETE ANCHORS

SUSTAINED AXIAL LOAD TEST



TEST NO.	EDGE DIST. (in)	EMBEDMENT DEPTH (in)	INITIAL LOAD (kips)
1A	5	4	4.4
1B	5	4	6.1
1C	5	4	8.5
2A	5	4	4.4
2B	5	4	5.9
3	7	4	4.0
4	7	4	4.5
5	12	4	8.2
6A	12	4	4.2
6B	12	4	3.8

CONCRETE STRENGTH 4,560 psi
AMBIENT TEMPERATURE 60-105°F

Figure 11

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TYPE F2
1 INCH DIA. CONCRETE ANCHORS
SUSTAINED AXIAL LOAD TEST

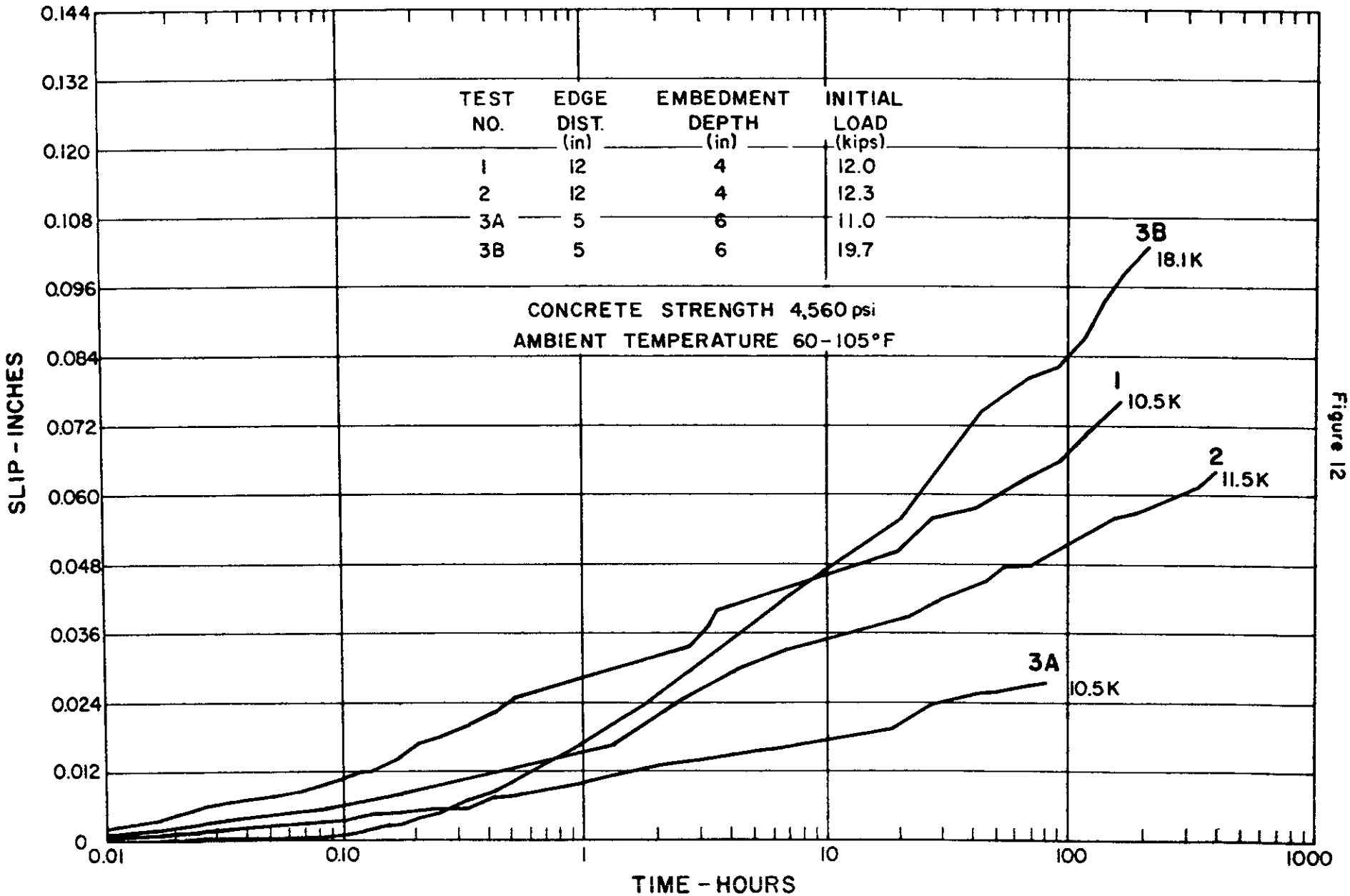

Figure 12

TYPE F3
$\frac{5}{8}$ INCH DIA. CONCRETE ANCHOR
SUSTAINED AXIAL LOAD TEST

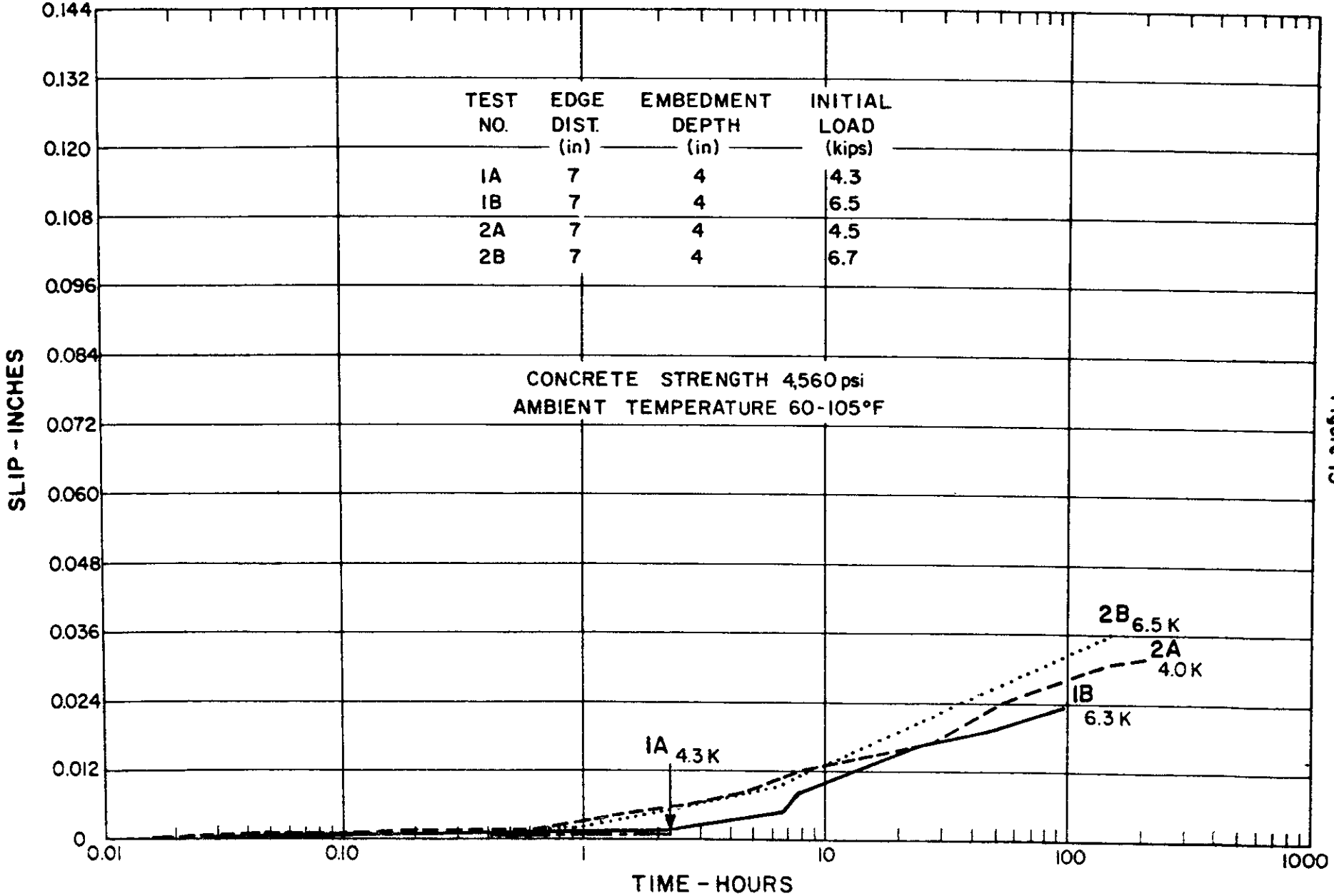

Figure 13

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TYPE F4

1 INCH DIA. CONCRETE ANCHOR

SUSTAINED AXIAL LOAD TEST

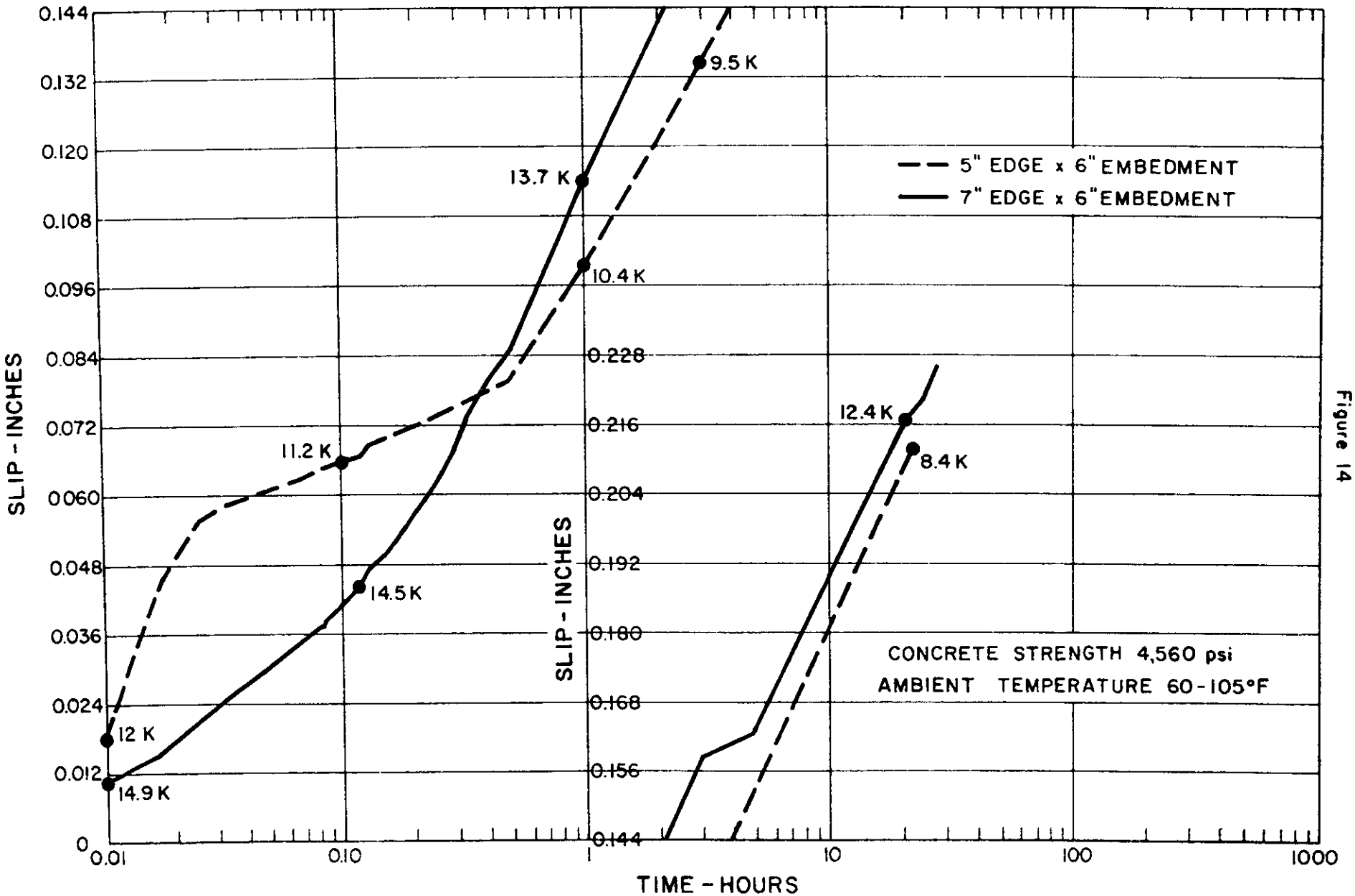

Figure 14

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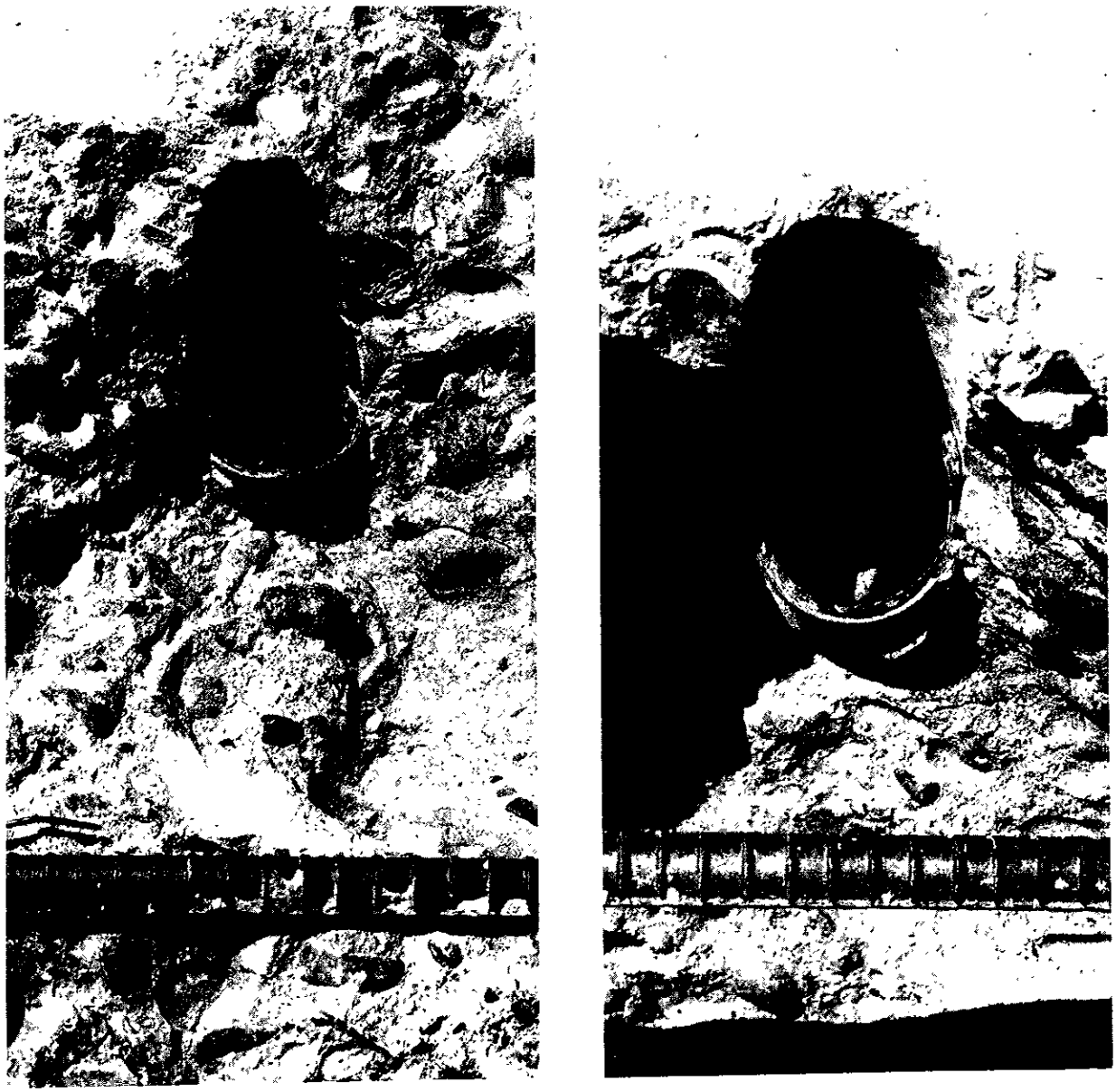
FIGURE 15



1-inch diameter F-4 anchor installation site showing lead sleeve after extruding and shearing failure.

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TYPE F5

$\frac{5}{8}$ INCH DIA. CONCRETE ANCHOR

SUSTAINED AXIAL LOAD TEST

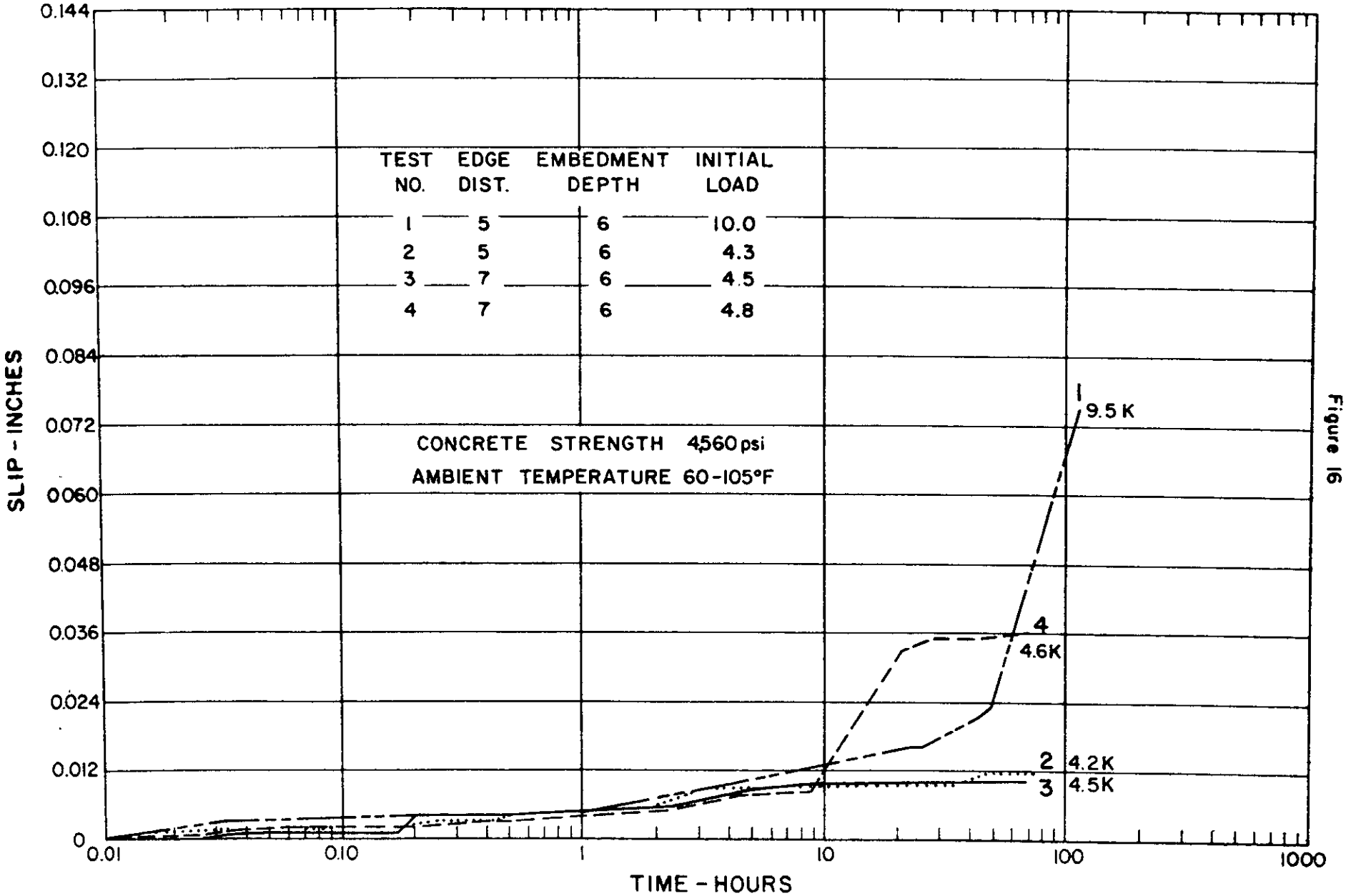

Figure 16

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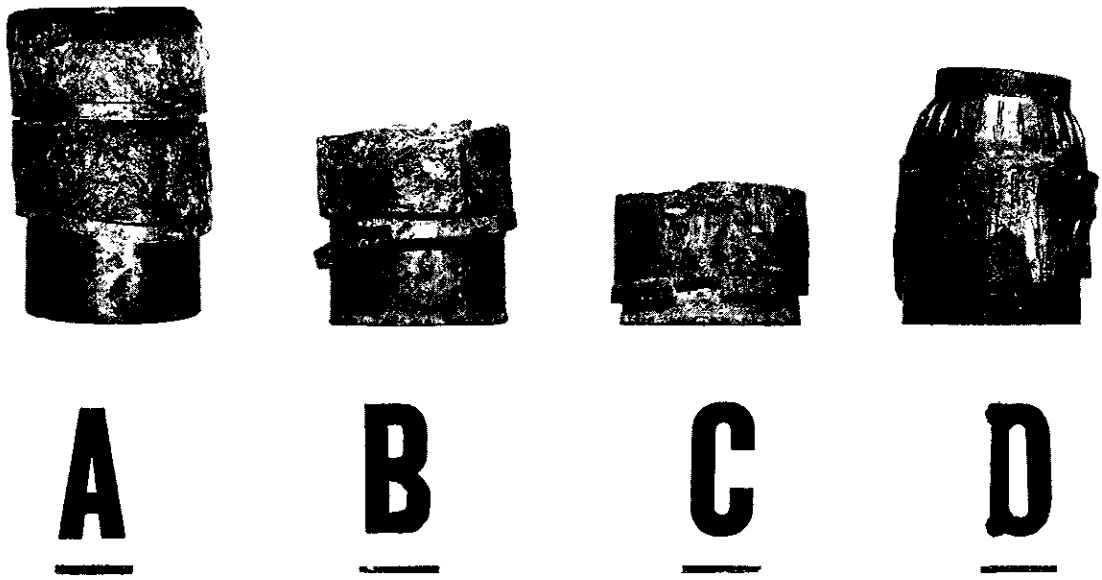
FIGURE 17



Type F-5 Type F-5 Type F-5 Type F-4

Effect of Type F-5 anchor's steel ring on extrusion and shearing of lead sleeve. Note that the steel rings on anchors marked A, B, and C prevented the lead shields from shearing or extruding. The anchor marked D (Type F-4 without steel ring) sheared and extruded.

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TABLE 1

STATIC AXIAL LOAD TEST RESULTS

5/8-INCH DIAMETER CAST-IN-PLACE BOLT ANCHOR

(Zinc Plated ASTM A307 Grade A)

Concrete Strength 4250 psi

EDGE DIST (in)	EMBED. DEPTH (in)	PULLOUT LOAD (kips)	TYPE OF FAILURE			
			CONCRETE		BOLT	
			CONED	CRACKED	YIELDED	BROKE
3	2½	10.5	40°	-	-	-
3	2½	11.5	35°	-	-	-
3	2½	11.8	30°	-	-	-
5	2½	14.1	25°	-	X	-
5	2½	15.0	30°	-	X	-
5	2½	13.9	30°	-	X	-
7	2½	14.4	30°	-	X	-
7	2½	13.7	30°	-	X	-
7	2½	12.8	30°	-	X	-
3	4	19.0	35°	-	X	-
3	4	18.9	-	-	-	X
3	4	18.4	-	X	X	-
5	4	18.5	-	-	-	X
5	4	18.9	-	-	-	X
5	4	18.7	-	-	-	X
7	4	18.7	-	-	-	X
7	4	18.1	-	-	-	X
7	4	19.1	-	-	-	X
3	6	19.5	-	-	-	X
3	6	19.7	-	-	-	X
3	6	16.5*	-	-	-	X
5	6	19.1	-	-	-	X
5	6	19.1	-	-	-	X
5	6	20.3	-	-	-	X

* Pullout appears questionable.

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TABLE 2

STATIC AXIAL LOAD TEST RESULTS

1-INCH DIAMETER CAST-IN-PLACE BOLT ANCHOR

(Zinc Plated ASTM A307 Grade A)

Concrete Strength 4250 psi

EDGE DIST. (in)	EMBED. DEPTH (in)	PULLOUT LOAD (kips)	TYPE OF FAILURE			
			CONCRETE		BOLT	
			CONED	CRACKED	YIELDED	BROKE
5	2½	12.2	25°	-	-	-
5	2½	11.9	25°	-	-	-
5	2½	14.5	25°	-	-	-
7	2½	14.3	25°	-	-	-
7	2½	15.2	25°	-	-	-
7	2½	14.2	25°	-	-	-
5	4	19.3	35°	-	-	-
5	4	22.7	30°	-	-	-
5	4	22.5	30°	-	-	-
7	4	20.8	35°	-	-	-
7	4	20.9	35°	-	-	-
7	4	22.6	30°	-	-	-
12	4	23.3	30°	-	-	-
12	4	24.4	30°	-	-	-
12	4	24.1	30°	-	-	-
3	6	31.4	35°	-	-	-
3	6	32.4	35°	-	-	-
3	6	28.6	35°	-	-	-
5	6	33.5	30°	-	-	-
5	6	33.7	35°	-	-	-
5	6	39.3	35°	-	X	-
7	6	44.7	35°	X	X	-
7	6	39.2	-	-	-	X
9	6	42.5	-	X	X	-
9	6	39.8	-	-	-	X
12	6	39.2	-	-	-	X
12	6	37.8	-	-	-	X
12	6	40.5	35°	X	X	-

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TABLE 2

STATIC AXIAL LOAD TEST RESULTS

1-INCH DIAMETER CAST-IN-PLACE BOLT ANCHOR

(Zinc Plated ASTM A307 Grade A)

Concrete Strength 4250 psi

EDGE DIST. (in)	EMBED. DEPTH (in)	PULLOUT LOAD (kips)	TYPE OF FAILURE			
			CONCRETE		BOLT	
			CONED	CRACKED	YIELDED	BROKE
3	9	38.7	-	-	-	X
3	9	38.1	-	-	-	X
3	9	40.0	-	X	X	-
5	9	40.0	-	-	-	X
5	9	41.8	-	-	-	X
5	9	40.0	-	-	-	X
7	9	39.4	-	-	-	X
7	9	43.4	-	-	-	X
7	9	40.3	-	-	-	X
9	9	43.9	-	-	-	X
9	9	37.5	-	-	-	X
9	9	43.4	-	-	-	X

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TABLE 3

STATIC AXIAL LOAD TEST RESULTS

5/8-INCH DIAMETER EPOXIED-IN-PLACE THREADED RODS

(ASTM A307 Grade A)

Hole Diameter = 7/8-inches Concrete Strength = 3930 psi

Epoxy Type F28

EDGE DIST. (in)	EMBED. DEPTH. (in)	PULLOUT LOAD (kips)	TYPE OF FAILURE MATERIAL ROD	MATERIAL CONCRETE	BOND EPOXY TO CONC.
3	4	16.7	-	X	X
3	4	18.7	X	-	-
3	4	15.3	-	X	X
5	4	17.6	X	-	-
5	4	13.0	-	-	X
3	6	18.5	X	-	-
3	6	18.7	X	-	-
3	6	17.2	X	-	-
5	6	9.8	-	-	X
5	6	17.3	X	-	-
5	6	13.7	-	-	X
3	9	19.2	X	-	-
3	9	18.9	X	-	-
3	9	16.1	X	-	-
5	9	18.8	X	-	-
5	9	19.2	X	-	-
5	9	19.4	X	-	-

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TABLE 4

STATIC AXIAL LOAD TEST RESULTS

1-INCH DIAMETER EPOXIED-IN-PLACE THREADED RODS

(ASTM A307 Grade A)

Epoxy Type F28

Hole Diameter = 1-1/8 in. Concrete Strength = 3930 psi

EDGE DIST (in)	EMBED DEPTH (in)	PULLOUT LOAD (kips)	TYPE OF FAILURE		
			MATERIAL		BOND
			ROD	CONCRETE	EPOXY TO CONC.
3	4	15.7	-	30° Cone	-
3	4	16.5	-	30° Cone	-
5	4	20.2	-	31° Cone	X
5	4	15.8	-	31° Cone	X
3	6	22.5	-	27° Cone	X
3	6	20.0	-	25° Cone	X
5	6	30.0	-	25° Cone	X
3	9	38.0	X	-	-
3	9	36.7	-	X	X
3	9	33.0	-	X	X
5	9	36.0	-	30° Cone	X
5	9	35.0	-	30° Cone	X
5	9	31.3	-	20° Cone	X

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TABLE 5

STATIC AXIAL LOAD TEST RESULTS

EPOXIED-IN-PLACE REINFORCING STEEL BARS (A15)

Concrete Strength 3930 psi

Epoxy Type F28

REBAR DIA (in)	HOLE DIA. (in)	EDGE DIST. (in)	EMBED. DEPTH (in)	ULTIMATE LOAD kips	TYPE OF FAILURE REBAR	THREAD ROD (1)	CONC. CONE	EPOXY CONC. BOND
5/8	7/8	5	9	16.3	-	X	-	-
5/8	7/8	5	9	12.1	-	X	-	-
5/8	7/8	5	9	18.1	-	X	-	-
1	1-1/8	5	9	37.2	-	X	-	-
1	1-1/8	5	9	37.4	-	X	-	-
1	1-1/8	5	9	39.4	-	X	-	-

(1) In order to pull the rebar, it was necessary to butt weld 2-inch long threaded rod sections (ASTM A307 - Grade A) to the rebar sections.

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TABLE 6

STATIC AXIAL LOAD TEST RESULTS

5/8-INCH DIAMETER GROUTED-IN-PLACE THREADED RODS

(Zinc Plated ASTM A307 Grade A)

Hole Diameter = 1-1/8 in. Concrete Strength 3930 psi

EDGE DIST. (in)	EMBED. DEPTH (in)	GROUT STR. (psi)	PULLOUT LOAD (kips)	TYPE OF FAILURE BOND STEEL GROUT	BOND GROUT CONC.	MATERIAL ROD	MATERIAL CONC.
3	4	5910	10.5	X	-	-	-
3	4	5910	9.2	-	X	-	-
3	4	5910	10.0	X	-	-	-
5	4	5910	12.7	X	-	-	-
5	4	5910	12.4	X	-	-	-
5	4	5910	10.3	X	-	-	-
3	6	3730	18.5	-	-	X	-
3	6	3730	14.7	X	X	-	-
3	6	3730	18.0	-	-	X	-
5	6	3730	14.7	X	X	-	-
5	6	3730	18.6	-	-	X	-
5	6	3730	19.4	-	-	X	-
3	9	3910	19.2	-	-	X	-
3	9	3910	19.3	-	-	X	-
3	9	3910	18.6	-	-	X	-
5	9	3910	17.2	-	-	X	-
5	9	3910	17.3	-	-	X	-
5	9	3910	17.5	-	-	X	-

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TABLE 7

STATIC AXIAL LOAD TEST RESULTS

1-INCH DIAMETER GROUTED-IN-PLACE THREADED RODS

(Zinc Plated ASTM A307 Grade A)

Hole Diameter = 1-5/8 in. Concrete Strength = 3930 psi

EDGE DIST. (in)	EMBED. DEPTH (in)	GROUT STR. (psi)	PULLOUT LOAD (kips)	TYPE OF FAILURE: BOND: STEEL GROUT	BOND: GROUT CONC.	MATERIAL: ROD	MATERIAL: CONC.
3	4	5910	6.7	X	X	-	-
3	4	5910	7.7	X	X	-	-
3	4	5910	4.0	X	X	-	-
5	4	5910	6.3	X	X	-	-
5	4	5910	8.5	X	X	-	-
5	4	5910	7.2	X	X	-	-
3	6	3730	15.7	X	X	-	-
3	6	3730	11.3	X	X	-	-
5	6	3730	18.5	X	X	-	-
5	6	3730	17.1	X	X	-	-
5	6	3730	14.6	X	X	-	-
3	9	3910	22.7	X	X	-	-
3	9	3910	18.6	X	X	-	-
3	9	3910	26.8	X	X	-	-
5	9	3910	27.0	X	X	-	-
5	9	3910	22.4	X	X	-	-
5	9	3910	21.0	X	X	-	-

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TABLE 8

STATIC AXIAL LOAD TEST RESULTS

GROUTED-IN-PLACE REINFORCING STEEL BARS (ASTM A15)

Concrete Strength	3930 psi
Grout Strength	3800 psi
Edge Distance	5 inches
Embedment Depth	9 inches

REBAR DIA. (in)	HOLE DIA (in)	PULLOUT LOAD (kips)	TYPE OF FAILURE: BOND		MATERIAL		
			STEEL GROUT	GROUT CONC.	REBAR	THREADED ROD (1)	CONC.
5/8	1-1/8	18.0	-	-	-	X	-
5/8	1-1/8	18.3	-	-	-	X	-
5/8	1-1/8	16.3	-	-	-	X	-
1	1-5/8	29.0	X	X	-	-	-
1	1-5/8	29.0	X	X	-	-	-
1	1-5/8	26.4	X	X	-	-	-

(1) In order to pull the rebar, 2-inch long threaded rods (ASTM A307 Grade A) were butt welded to the rebar sections.

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TABLE 9

STATIC AXIAL LOAD TEST RESULTS

5/8-INCH DIAMETER TYPE F-1 CONCRETE ANCHORS

TYPE ANCHOR	CONCRETE STRENGTH (psi)	EDGE DIST. (in)	EMBED DEPTH (in)	LIMITING COND. SLIP (in)	LIMITING COND. LOAD (kip)	PULLOUT STR. SLIP (in)	PULLOUT STR. LOAD (kip)	AVG. LOAD (kip)	TYPE FAILURE
F 1-a	3,830	3	2-9/16	0.047	10.5	0.100	12.2		Concrete Coned
				0.042	10.4	0.100	12.3		Anchor Pulled Out
				0.041	7.2	0.100	10.7	11.7	Anchor Pulled Out
		7	2-9/16	0.044	9.2	0.077	10.7		Anchor Pulled Out
				0.031	7.5	0.040	7.5		Anchor Pulled Out
				0.035	8.0	0.100	13.5	10.6	Anchor Pulled Out
		12	2-9/16	0.042	10.3	0.100	12.4		Concrete Coned
				0.040	9.0	0.100	11.5		Anchor Pulled Out
				0.036	9.8	0.100	13.7	12.5	Anchor Pulled Out
F 1-b (hand hammered)	4,520	12	2-1/2	-	-	-	10.5		20° Concrete Cone
				-	-	-	11.5		20° Concrete Cone
				-	-	-	12.0		20° Concrete Cone
				-	-	-	11.2		20° Concrete Cone
				-	-	-	14.4	11.9	20° Concrete Cone
F 1-b (machine hammered)	4,520	12	2-1/2	-	-	-	7.4		Shallow Cone
				-	-	-	11.8	9.6	30° Concrete Cone
F 1-c	4,790	5	2-3/4	-	-	-	10.1		Concrete Cracked
				-	-	-	8.9		Concrete Cracked
				-	-	-	10.9		Concrete Cracked
				-	-	-	9.0		Concrete Cracked
				-	-	-	12.0		Concrete Cracked
				-	-	-	10.3	10.2	Concrete Cracked

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TABLE 10

STATIC AXIAL PULLOUT TEST RESULTS

5/8-INCH DIAMETER TYPE F-2 CONCRETE ANCHORS

Concrete Strength 4560 psi

EDGE DISTANCE (in)	INITIAL EMBEDMENT (in)	SEATED EMBEDMENT (in)	ANCHOR SLIPPAGE (in)	APPLIED LOAD (kips)	COMMENTS
3	2½	NC	-	-	(Anchors failed to seat sufficiently
3	2½	NC	-	-	(and pulled out during hand tightening.
3	2½	2	0.085	4.7	Concrete cracked parallel to slab edge.
5	2½	NC	0.280	2.2	6-inch diameter shallow cone
5	2½	1-3/4	0.550	1.4	Shallow surface cone
3	4	NC	0.275	13.2	Concrete cracked
3	4	NC	0.315	16.9	Concrete cracked
5	4	3-1/4	0.190	11.1	Anchor pulled out - concrete did not fail
5	4	3-7/8	0.430	15.5	Anchor pulled out - concrete did not fail
12	4	NC	0.205	14.8	Concrete cracked
12	4	NC	-	-	Anchor pulled out during hand tightening
12	4	NC	0.180	14.9	Anchor pulled out
3	6	NC	0.330	16.1	Bolt broke in threaded section
3	6	NC	0.435	13.1	Anchor pulled out
5	6	NC	0.530	15.7	Anchor pulled out
5	6	NC	0.335	14.1	Anchor pulled out
7	6	NC	0.430	14.3	Anchor pulled out

NC - Not Checked.

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TABLE 11

STATIC AXIAL PULLOUT TEST RESULTS

1-INCH DIAMETER TYPE F2 CONCRETE ANCHORS

Concrete Strength 4560 psi

EDGE DISTANCE (in)	INITIAL EMBEDMENT (in)	SEATED EMBEDMENT (in)	ANCHOR SLIPPAGE (in)	APPLIED LOAD (kips)	COMMENTS
3	2½	NC	0.165	9.2	Concrete cone - 25 degrees
3	2½	NC	0.090	11.9	Anchor pulled out
5	2½	NC	0.185	12.3	Concrete cone - 25 degrees
5	2½	NC	0.125	13.3	Concrete cone - 25 degrees
3	4	3-3/4	0.235	18.6	Concrete cone - 30 degrees
3	4	3-3/8	0.180	10.8	Concrete cracked parallel to slab edge
5	4	3-3/4	0.255	18.3	Concrete cone - 25 degrees
5	4	3-3/8	0.260	19.8	Concrete cone - 35 degrees
7	4	NC	0.260	20.2	Concrete cone
7	4	2½	0.135	13.8	Concrete cone
7	4	NC	0.315	21.9	Concrete cracked
3	6	NC	0.220	22.1	Concrete cracked
3	6	4-3/4	0.160	16.4	Concrete cracked
5	6	NC	0.375	27.2	Concrete cracked
5	6	NC	0.355	30.1	Concrete cracked
5	6	NC	0.105	36.8	Concrete cracked
7	6	NC	-	36.6	Concrete cracked
7	6	3-7/8	0.255	22.0	Concrete cracked

NC - Not Checked.

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TABLE 12

STATIC AXIAL PULLOUT TEST RESULTS

5/8-INCH DIAMETER TYPE F3 CONCRETE ANCHORS

Concrete Strength 4560 psi

Initial Embedment Depth = 4 inches

EDGE DIST. (in)	SEATED EMBED DEPTH (in)	PULLOUT LOAD (kips)	REMARKS
3	NC	10.6	Concrete cracked
3	NC	9.3	Concrete cracked
3	NC	9.6	Concrete cracked
7	3¼	7.8	Concrete cracked

NC = Not Checked.

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TABLE 13

STATIC AXIAL LOAD TEST RESULTS

1-INCH DIAMETER TYPE F4 CONCRETE ANCHORS

Concrete Strength 3930 psi

Ambient Temperature 40 - 50° F

7" Edge Distance
6" Embedment Depth

Load (k)	Movement (in)	Time (min)
5	0.011	0.42
5	0.013	0.77
9	0.065	1.02
9	0.073	1.12
9	0.078	1.24
10	0.083	1.57
10	0.086	1.70
10	0.087	2.16
10	0.097	3.17
15	0.168	3.56
15	0.183	3.75
15	0.199	4.28
15	0.208	5.23
15	0.215	6.03
20	0.301	6.85
20	0.332	8.36
20	0.347	10.02
20	0.355	11.83
20	0.371	19.12

34.0 Pullout Strength

7" Edge Distance
6" Embedment Depth

Load (k)	Movement (in)	Time (min)
10	0.068	1.08
10	0.080	1.14
10	0.086	1.23
10	0.089	1.35
10	0.095	1.74
10	0.103	1.95
10	0.106	2.08
12.5	0.119	2.34
12.5	0.132	2.57
14	0.140	2.64
14	0.156	2.81
14	0.166	3.05
15	0.170	3.10
15	0.196	3.44
15	0.206	3.66
15	0.220	3.90
15	0.228	4.01
15	0.246	4.53
15	0.253	4.95
16.25	0.257	5.04
16.25	0.266	5.53
17.25	0.270	5.60
17.25	0.293	6.14
17.25	0.303	6.60
17.25	0.322	6.90
17.25	0.340	6.98
17.25	0.346	7.62
17.25	0.359	8.26
17.25	0.362	8.46
17.25	0.364	8.75

34.5 Pullout Strength

5" Edge Distance
6" Embedment Depth

Load (k)	Movement (in)	Time (min)
5	0.007	0.38
5	0.009	0.64
7	0.021	0.80
7	0.033	1.84
7	0.038	3.84
10	0.070	4.10
10	0.078	4.35
10	0.085	4.77
10	0.096	6.81
10	0.101	7.11
12	0.112	7.36
12	0.129	8.35
12	0.150	10.35
12	0.174	17.80
12	0.189	21.60
12	0.198	23.30

Preloaded Anchor to 25^k

12.25	0.009	0.32
12.25	0.009	0.46
12.25	0.009	0.66
12.25	0.009	1.44
16	0.012	1.75
16	0.012	1.94
16	0.014	3.20
16	0.015	3.80
16	0.019	4.88
16	0.020	5.46
16	0.022	6.66
16	0.023	7.24

28.0 Pullout Strength

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TABLE 14

STATIC AXIAL LOAD TEST RESULTS

1-INCH DIAMETER TYPE F4 CONCRETE ANCHORS

Concrete Strength 4560 psi

Ambient Temperature 95 - 100° F

EDGE DISTANCE (in)	EMBEDMENT DEPTH (in)	Pullout Strength SLIP (in)	LOAD (kips)	AVG. LOAD (kips)	REMARKS
3	4	0.240	12.0		Concrete cracked
3	4	0.305	9.4		Concrete cracked
3	4	0.245	9.2		Concrete cracked
3	4	0.265	8.7		Concrete cracked
3	4	0.475	9.6		Concrete cracked
3	4	0.255	9.9	9.8	Concrete cracked
5	4	0.335	13.4		Anchor pulled out
5	4	0.540	11.6		Anchor pulled out
5	4	0.560	16.1		Anchor pulled out
5	4	0.380	12.9		Concrete cracked
5	4	0.630	15.2	13.8	Anchor pulled out
7	4	0.135	13.0		Anchor pulled out; concrete spalling
7	4	0.440	13.6		Anchor pulled out; concrete spalling
7	4	0.240	11.8	12.8	Anchor pulled out; concrete spalling
3	6	0.155	12.5		Anchor pulled out; concrete cracked
3	6	0.730	16.8		Concrete cracked
3	6	0.635	13.2	14.2	Anchor pulled out
5	6	0.520	20.2		Anchor pulled out
5	6	0.520	20.8	20.5	Anchor pulled out

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TABLE 15

STATIC AXIAL LOAD TEST RESULTS

5/8-INCH DIAMETER TYPE F5 CONCRETE ANCHOR

Concrete Strength 4560 psi

Ambient Temperature 40 - 50° F

EDGE DISTANCE	EMBEDMENT DEPTH	PULLOUT LOAD	TYPE FAILURE
3	3	9.5	Concrete
3	3	10.0	Concrete
3	3	11.0	Concrete
5	3	13.3	Concrete
5	3	13.0	Concrete
5	3	14.3	Concrete
3	4	17.7	Concrete
3	4	17.0	Concrete
5	4	16.7	Anchor pulled out
5	4	18.5	Concrete
5	4	18.7	Pulling bolt broke
7	4	19.0	Pulling bolt broke
7	4	19.0	Pulling bolt broke
7	4	18.6	Pulling bolt broke
12	4	19.5	Pulling bolt broke
3	6	18.0	Pulling bolt broke
3	6	19.2	Pulling bolt broke
3	6	18.5	Pulling bolt broke
5	6	18.8	Pulling bolt broke

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