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The results of direct tension, direct shear, and combined tension and shear tests on two common types of cast-in-place concrete inserts, ferrule loop and ductile cast-iron, from four major manufacturers are presented. Tests were performed at the minimum edge distance recommended by manufacturers and also at half of that distance using both 5000 psi concrete and a low strength, 3500 psi concrete. A detailed test method, California Test 682, was developed and written for determining ultimate tensile strength of cast-in-place inserts, and a revised California Department of Transportation Standard Specification for cast-in-place inserts was written. A table for recommended design loads for tension and shear was also prepared. Plots of ultimate load vs. edge distance were prepared, and also an interaction curve for combined tension and shear loading was developed.

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EVALUATION OF CAST-IN-PLACE CONCRETE INSERTS USED IN NEW PORTLAND CEMENT CONCRETE STRUCTURES

91-02

Performed by ..... Structural Materials Branch

Supervised by ..... J. Jay Folsom, P.E.

Principal Investigator ..... Roger L. Stoughton, P.E.

Co-Investigators ..... John P. Dusel, P.E. and
Abbas Abghari, Ph.D., P.E

Report Prepared by ..... Abbas Abghari, Ph.D., P.E.

Roger L. Stoughton
Roger L. Stoughton
Senior Materials and
Research Engineer

REGISTERED PROFESSIONAL ENGINEER
ROGER L STOUGHTON
No. C14897
Exp. 3-31-93
CIVIL
STATE OF CALIFORNIA

EARL SHIRLEY, Chief
Division of New Technology,
Materials and Research

STATE OF CALIFORNIA • DEPARTMENT OF TRANSPORTATION

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English Unit	Multiply By	To Get Metric Equivalent
Length	inches (in) or (")	25.40	millimetres (mm)
		.02540	metres (m)
	feet (ft) or (')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2)	.09290	square metres (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litre (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph)	.4470	metres per second (m/s)
	feet per second (fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lb)	4.448	newtons (N)
	kips (1000 lb)	4448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1356	joules (J)
Bending Moment or Torque	inch-pounds (in-lb)	.1130	newton-metres (Nm)
	foot-pounds (ft-lb)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (°F)	$\frac{°F - 32}{1.8} = °C$	degrees celsius (°C)
Concentration	parts per million (ppm)	1	milligrams per kilogram (mg/kg)

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EVALUATION OF CAST-IN-PLACE CONCRETE INSERTS USED IN NEW PORTLAND CEMENT CONCRETE STRUCTURES

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1. INTRODUCTION

1.1 PROBLEM

There are presently no independent specifications to address special concerns of cast-in-place concrete inserts. General requirements for anchorage devices are contained in California Department of Transportation (Caltrans) Standard Specifications (10), Section 75-1.03, Miscellaneous Bridge Metal. Section 75-1.03 was written for mechanical expansion anchors which are quite different anchorage devices from cast-in-place inserts. The minimum sustained tensile test loads specified in this section were developed for mechanical expansion anchors where creep of the anchor under sustained load is the main concern. There are no requirements in this section for either a minimum tensile or shear strength for cast-in-place inserts. Only limited unverified data from manufacturers have been available to designers, providing little assurance that their designs would be realistic. For combined shear and tension loading conditions or for cases where inserts must be installed close to the edge of a concrete structure, limited design information was available. In addition some types of inserts are inappropriate for use by Caltrans, but are not excluded in the specification. Thus, Section 75-1.03 is inadequate for cast-in-place concrete inserts. Further, there has been no list of approved inserts from which contractors could choose, and no appropriate test method by which concrete inserts could be evaluated.

1.2 OBJECTIVES

The objectives of this research project were to:

1. Determine the ultimate tension (pull-out), and ultimate shear strengths of two common types (cast iron and ferrule loop) from four popular brands of cast-in-place inserts installed at various edge distances.
2. Determine the effect of a low compressive strength concrete on the performance of two sizes of the two types of inserts tested.
3. Determine the effect of combined tension and shear loading on the performance of inserts.
4. Prepare a test method by which cast-in-place inserts can be evaluated.
5. Prepare a comprehensive specification from which the acceptability of cast-in-place inserts can be determined.
6. Provide a listing of the cast-in-place inserts tested in this project which meet the proposed specifications and would be acceptable for use in future Caltrans contracts.
7. Develop comprehensive guidelines for designers to follow when inserts are required.

1.3 Background

1.3.1 General

Cast-in-place concrete inserts are commonly used to permanently anchor fixtures to the surface of new concrete structures. They may also be used for attaching temporary bracing or construction equipment for lifting and moving prefabricated concrete structural components during construction. Since these inserts are installed in fresh concrete only, their use requires the knowledge of the exact location prior to concrete placement. To install these types of inserts, they are either attached securely to formwork prior to placing concrete, or wiggled into the fresh concrete in the proper position on exposed surfaces before the concrete begins to harden. For temporary construction applications, inserts must be set 1 inch below the surface of the concrete. For permanent installations, inserts may be either set flush with the surface of the new concrete or recessed slightly by using plastic or steel adaptor plugs.

At the time the research proposal was prepared, a literature search was performed to determine if a suitable specification for cast-in-place inserts was already available. No comprehensive specification or reports on previous research were found. A listing of all known manufacturers and companies marketing cast-in-place inserts in the United States was obtained and brochures and catalogs were requested from each manufacturer. Literature and samples of inserts were requested from manufacturers. It was determined that three basic types of cast-in-place inserts, <u>ferrule</u>, <u>cast</u>, and <u>coil</u> were readily available.

1.3.2 Classifying Different Types of Cast-In-Place Inserts

More than 50 inserts from six major companies Acme, Burke, Dayton Superior, Richmond, Star, and Williams were classified by general appearance and characteristics. The inserts were grouped into the following three categories:

1. Ferrule Inserts

A steel sleeve (ferrule) with ribs machined on its outside is tapped to accept Universal National Coarse (UNC) threads. High-strength reinforcing wires bent in various configurations are resistance welded to the steel ferrule to help distribute the load to the concrete. The various types of ferrule inserts (distinguished from one another by the different configurations of the high-strength wire resistance welded to the ferrule) are shown in Figures 1, 2, 3 and 4 and are as follows:

Plain This insert, Figure 1, consists of only the ferrule itself. No reinforcing wire is used to carry the load. The ferrule is tapped with UNC threads. The end opposite the tapped end is closed to prevent entry of fresh concrete.

Thin slab This type, Figure 2, is produced by resistance welding either struts or loops to the sides of the ferrule in a plane perpendicular to the axis of the bolt. This type of insert is used where the depth of embedment is extremely limited.

Figure 1.
Plain Ferrule Insert

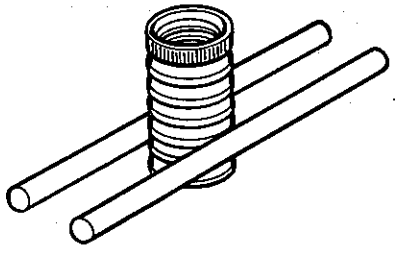


Figure 2.
Thin Slab Ferrule Insert

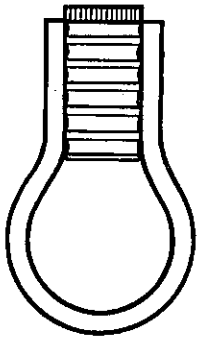


Figure 3.
Ferrule Loop Insert

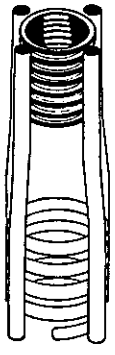


Figure 4.
Expanded Coil Ferrule Insert

Loop This type of ferule insert, Figure 3, is produced by resistance welding a single loop to the ferrule sides in a plane parallel to the axis of the bolt.

Expanded coil This type, Figure 4, is furnished with either two or four struts welded to the ferrule in a plane parallel to the axis of the bolt. Welded to the lower inside portion of the struts is an expanded helically wound coil of wire. Because of the limited use of this anchor type, it was not tested in this study.

2. Cast Inserts

These inserts are manufactured from grey cast iron, ductile cast iron, or zinc alloy, and are cast in various shapes and tapped to accept UNC threads. Various types of cast inserts are shown in Figure 5 and are as follows:

Grey cast iron Inserts made from grey cast iron should not be used as anchorage devices which will be subjected to shock or vibratory loads, as this type of cast iron is weak in tension and is brittle. No grey cast-iron inserts (Figure 5-a) were tested as this type is not permitted for use in Caltrans contracts.

Ductile cast iron Ductile cast iron possesses inherent virtues, such as good machinability, corrosion resistance, wear resistance and reasonable ductility; it provides a good alternative material for insert use. According to present requirements in the Caltrans Standard Special Provision 75.50, cast iron inserts

must be either malleable cast iron conforming to ASTM Specification of designation A47, Grade 35018, or ductile cast iron. A typical ductile cast iron insert is shown in Figure 5-b.

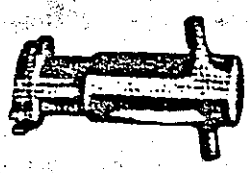
Zinc alloy The die-cast zinc alloy inserts (Figure 5-c) are not permitted to be used in Caltrans contracts because of the potential problem of galvanic action between dissimilar metals - the insert body and the steel bolt. Thus, no further evaluation of this type of insert was considered.

3. Coil Inserts

These are typically comprised of a helically wound coil of wire which acts as a "nut". High-strength reinforcing wire bent in various configurations is resistance welded to the coil nut. This insert (Figure 6) requires the use of special bolts or rods having threads shaped to fit the contour and diameter of the wire from which the coil nut is formed and will not accommodate bolts or rods with standard national coarse threads. Although coil inserts are frequently used for formwork, they are not acceptable for permanently attaching fixtures to structures. Coil inserts were not tested in this research project and no further evaluation of these inserts was done.

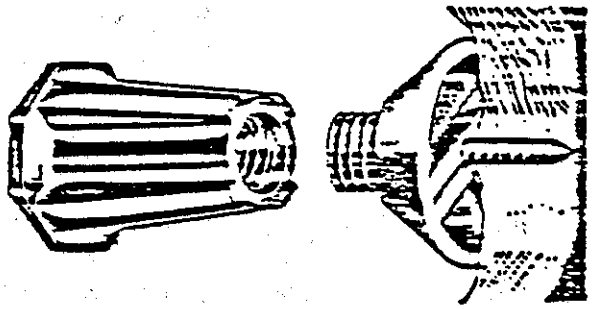
Different categories of cast-in-place inserts and various types of inserts within each category are summarized in Table 1.

Only the two commonly used inserts, steel ferrule with a steel wire loop resistance



(a) Gray Cast-Iron Insert

(b) Ductile Cast-Iron Insert



(c) Typical Die-Cast Zinc Insert

Figure 5. Typical Cast Insert

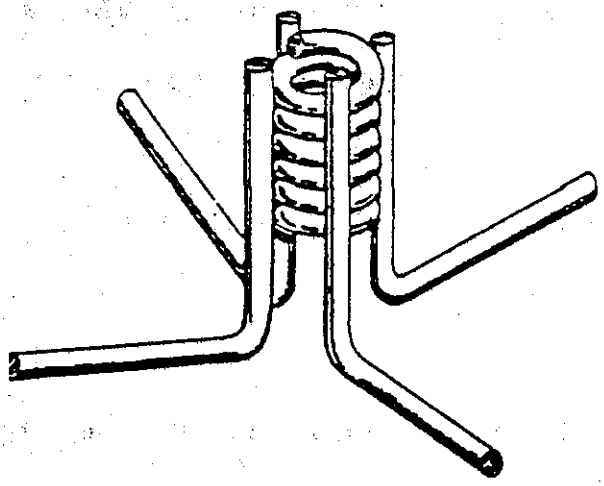


Figure 6. Typical Coil Insert

welded to the ferrule (ferrule loop insert) and the cast-iron threaded insert made of ductile cast iron, were chosen for evaluation in this research project and, because of the limitation of time and funds, other types of inserts were not tested.

Table 1. Types of Cast-In-Place Concrete Inserts

Category	Type
Ferrule	Plain Thin Slab Loop Expanded Coil
Coil	Thin Slab Loop Single Lift Coil Tie Expanded Coil
Cast	Grey Cast iron Ductile Cast iron Die-cast Zinc Alloy

2. Conclusions

The following conclusions were drawn from the results of this research project:

2.1 Standard Test Method and Standard Specification

2.1.1 Standard Test Method

A comprehensive standard test method California Test 682, titled "Method for Determining Ultimate Tensile Strength of Cast-In-Place Concrete Inserts" was written and is included in Appendix G. The key sections of the test method necessary to obtain consistent, reliable results are:

1. Preparation of test specimens, installation procedure, minimum edge distance, and minimum spacing.
2. Test procedure requirement of applying recommended torque, loading rate, and data recording.
3. Specific requirements for the use of unreinforced concrete to prepare test specimens.
4. Acceptance criteria which require the successful results from a minimum of three replicate test samples of any one of insert brand and size. Conditions which would allow for retesting of an insert which initially failed are also detailed.

2.1.2 Revised Standard Specification

Recommendations to revise section 75-1.03, "Miscellaneous Bridge Metal," of January 1988 version of Caltrans Standard Specifications (10) were made (11) based on the results of this research and the extensive metallurgical evaluation of cast-iron inserts done by Charles B. Kendrick (6). The recommended specification with appropriate revisions which relates to cast-in-place inserts is contained in Appendix H.

2.2 Insert Classification

Although many types of cast-in-place concrete inserts are available, only two common types, ferrule loop and cast iron are allowed for use by Caltrans as specified in the Caltrans Standard Special Provisions B75.50, Miscellaneous Bridge Metal, 10-18-88, (11).

2.3 List of Approved Cast-In-Place Inserts

Based on the results of tests conducted in this research project, a list of inserts which were tested in this project and complied with the standard special provision for cast-in-place inserts (Appendix H) is included in Table 2 . Only 1/2" and 1" inserts (ferrule loop and cast-iron) were tested in this project. The intermediate sizes were approved based on the manufacturers test results and the results of tests on 1/2" and 1" inserts done in this project.

Table 2. List of Approved Cast–in–Place Concrete Inserts

TYPE / STUD DIAMETER / MANUFACTURER		FERRULE LOOP					CAST IRON				
		1/2"	5/8"	3/4"	7/8'	1"	1/2"	5/8"	3/4"	7/8"	1"
BURKE	MODEL NO.	N.M.	N.M.	N.M.	N.M.	N.M.	(404) NO–033	(404) NO–034	(404) NO–035	(404) NO–036	(404) NO–038
	MIN. EDGE DISTANCE						6"	8"	8"	12"	12"
	MIN. EMBEDMENT DEPTH						2–1/2"	3"	3–5/8"	4–1/4"	4–3/4"
DAYTON SUPERIOR	MODEL NO.	F–42	F–42	F–42	F–42	F–42	F–5	N.A.	N.A.	N.A.	N.A.
	MIN. EDGE DISTANCE	6"	8"	8"	12"	12"	6"				
	MIN. EMBEDMENT DEPTH	3"	3–3/4"	3–3/4"	6–1/4"	6–1/4"	2–3/4"				
MEADOW STEEL	MODEL NO.	FL–500	FL–625	FL–750	FL–875	FL–100	N.M.	N.M.	N.M.	N.M.	N.M.
	MIN. EDGE DISTANCE	6"	8"	8"	12"	12"					
	MIN. EMBEDMENT DEPTH	2–7/8"	3–5/8"	3–5/8"	5–5/8"	6–1/8"					
RICHMOND	MODEL NO.	LF	LF	LF	N.M.	N.M.	HI–TENSILE	HI–TENSILE	HI–TENSILE	HI–TENSILE	HI–TENSILE
	MIN. EDGE DISTANCE	6"	8"	8"			6"	8"	8"	12"	12"
	MIN. EMBEDMENT DEPTH	4–1/4"	4–1/4"	4–1/4"			2–3/4"	3–7/8"	3–7/8"	4–1/4"	4–1/4"

NOTES:
1) ONLY 1/2" AND 1" INSERTS (FERRULE LOOP AND CAST IRON) WERE TESTED. THE INTERMEDIATE SIZES WERE APPROVED BASED ON THE MANUFACTURERS TEST RESULTS AND THE RESULTS OF TESTS ON 1/2" AND 1" INSERTS PERFORMED BY CALTRANS OFFICE OF TRANSPORTATION MATERIALS AND RESEARCH.
2) BURKE FERRULE LOOP INSERTS: NOT TESTED BY CALTRANS OFFICE OF TRANSPORTATION MATERIALS AND RESEARCH.
3) N.M. = NOT MANUFACTURERED, N.A. = NOT APPROVED

2.4 Direct Tension Tests (5000 psi concrete)

Test results showed that the ultimate tensile capacity of 1/2" ferrule loop inserts cast in concrete were very close to the ultimate tensile capacity of the inserts when tested directly. In all cases either the loop wire or the weld failed with a small tension cone of concrete.

The tensile capacity of 1" ferrule loop inserts cast in concrete were much larger than the ultimate tensile capacity of inserts when tested directly. This is due to the larger ferrule embedded into concrete. The failure mode was a larger cone with either a weld or a loop failure. In general there was not a large variation in the ultimate loads for different brands of ferrule loop inserts tested. The ultimate loads also did not depend on the orientation of the loop relative to the edge of the concrete slab. The ultimate tensile loads for different brands of 1/2" cast-iron inserts were close, and the mode of failure for both the 3" and 6" edge distances was a tension cone with either a weld or a loop failure. However, for the 1" cast-iron insert, there was a large difference in the ultimate loads (Dayton Superior was about 40% lower than the other brands). The mode of failure was a tension cone, however, in most cases with a 12" edge distance, the Burke cast-iron insert failed at the threaded part. Plots of ultimate tensile load versus edge distance showed that the ultimate tensile load increased as the edge distance increased.

2.5 Direct Shear Tests (5000 psi concrete)

In general there was not a large variation in the ultimate shear loads for different brands of ferrule loop inserts. The mode of failure for the 1/2" ferrule loop at 3" edge distance and for the 1" ferrule loop at 6" edge distance was a shear cone. With the 1/2" ferrule loop at 6" edge distance, the threaded stud failed and with the 1" ferrule loop at 12" edge distance, a large shear cone developed.

The variation in the ultimate shear loads for different brands of 1/2" cast iron was not very large, however, for 1" inserts there was a significant difference. The mode of failure for 1/2" cast iron at 3" edge distance and for 1" cast iron at 6" edge distance was a shear cone. The 1/2" cast iron at 6" edge distance failed in the threaded stud and for the 1" cast iron at 12" edge distance either a shear cone or failure of the threaded portion of the insert occurred.

The ultimate shear loads of all inserts installed at manufacturer's recommended edge distances (1/2" inserts at 6" and 1" inserts at 12" edge distance) were greater than the ultimate shear load of an A307 bolt. Plots of ultimate shear load versus edge distance showed that the ultimate shear load increased as the edge distance increased.

2.6 Direct Tension and Shear for Low Strength Concrete

The ultimate tension and shear loads of the inserts in 3500 psi concrete were mostly

lower than those of 5000 psi concrete. The plot of ultimate load versus square root of concrete strength, $\sqrt{f'c}$, showed a linear relationship.

2.7 Direct Tension and Shear Tests of Inserts with Different Corrosion Protection Coatings

The results of a very limited number of tests performed on inserts with different corrosion protection coatings showed that the ultimate tensile and ultimate shear capacity of hot-dip galvanized ferrule loop inserts were about 20% and 10% lower than those of the plain insert (insert with no coating), respectively. However; due to the very limited number of tests conducted, reliable conclusion can not be drawn from the results.

2.8 Combined Tension and Shear Loading Tests

Test results showed that the equation recommended by Prestressed Concrete Institute, PCI (8) is a better approximation than the American Institute of Steel Construction, AISC (7), equation for the combined tension and shear loading of the inserts tested in this project, Figures 32, and 33 section 6.

2.9 Insert Tests

2.9.1 Corrosion Test

Since little or no corrosion was observed on the inserts tested, it appeared that the 1000 hours salt spray test was an insufficient amount of time to observe a significant amount of corrosion on the inserts.

2.9.2 Direct Tension Tests of Ferrule Loop Inserts

Test results showed that the strength of the weld between the wire and the ferrule was adequate for 1/2" inserts; however, weld failure was observed in all 1" ferrule loop inserts tested.

3. Recommendations

3.1 Adoption of a Revised Standard Specification and Test Method

The California Test 682 (Appendix G) and the modified standard specification, Section 75-1.03 (Appendix H) should be adopted by Caltrans for testing and evaluating cast-in-place concrete inserts. Only cast-in-place inserts satisfying the criteria in the revised Caltrans Standard Specification Section 75-1.03 should be used.

3.2 Recommended Types of Cast-In-Place Concrete Inserts

It is recommended that only two types of inserts, cast-iron and ferrule loop, be allowed for use in Caltrans projects, with appropriate corrosion protection, as specified in the revised Caltrans Standard Specification, Section 75-1.03 (Appendix H).

3.3 Design Loads for Cast-In-Place Concrete Inserts

Based on the results of tests performed in this project and the manufacturers' recommended values, shear and tension design loads were determined under static loading conditions. Based on the manufacturers' recommendations a safety factor of 4:1 has been used for ferrule loop inserts, and for cast iron a safety factor of 3:1 has been used. Table 3 contains the design loads for the minimum edge distance recommended by the manufacturers. To determine the design loads for other edge

Table 3. Design Loads for Cast-In-Place Concrete Inserts

STUD DIAMETER	MINIMUM EDGE DISTANCE	FERRULE LOOP		CAST IRON	
		TENSION (kips)	SHEAR (kips)	TENSION (kips)	SHEAR (kips)
1/2"	6"	1.50	1.26	1.60	1.70
5/8"	8"	1.80	2.00	2.70	2.70
3/4"	8"	1.80	3.00	3.80	4.00
7/8"	12"	4.20	4.00	5.00	5.00
1"	12"	4.20	5.25	5.60	6.00

NOTE:
1) DESIGN SHEAR LOADS FOR FERRULE LOOP TYPE INSERTS ARE BASED ON THE ULTIMATE SHEAR CAPACITY OF STANDARD A307 BOLTS WITH A SAFETY FACTOR OF 4:1
2) DESIGN SHEAR LOADS FOR CAST IRON TYPE INSERTS ARE BASED ON THE ULTIMATE SHEAR CAPACITY OF STANDARD A307 BOLTS WITH A SAFETY FACTOR OF 3:1
3) DESIGN LOADS ARE BASED ON THE MANUFACTURER'S RECOMMENDED VALUES AND RESULTS OF TESTS CONDUCTED BY CALTRANS OFFICE OF TRANSPORTATION MATERIALS AND RESEARCH. ALL LOADS HAVE BEEN NORMALIZED TO CORRESPOND TO A CONCRETE COMPRESSIVE STRENGTH OF 3250 psi.

distances the ultimate loads from Table 4, section 6 can be used with safety factors of 4:1 and 3:1 for ferrule loop and cast-iron inserts respectively.

4. Implementation

It is the responsibility of the Caltrans Office of Structure Design to implement the recommendations of this research. Recommended changes to the current specification in Appendix H will be implemented by the Specifications Unit of the Office of Structure Design. California Test 682 (Appendix G), a standardized test procedure by which the ultimate tensile strength of cast-in-place inserts can be evaluated, has been written and submitted for publication. Revisions to the current Memo to Designers (12), will be made by the Office of Structure Design with assistance from the Office of Transportation Materials and Research (OTM&R).

5. Test Conditions

5.1 Testing Program

The following are the type of tests conducted in this project:

1. Short-term direct tension tests with inserts installed at various edge distances for each insert type.
2. Short-term direct shear tests with inserts installed at various edge distances for each insert type.
3. Combined tension and shear loading tests with inserts installed at various edge distances for each insert type.
4. Short-term direct tension, and shear tests to determine the effect of low compressive strength concrete on the performance of each insert type.
5. Short-term direct tension and shear tests to determine the effect of various corrosion resistant coatings on the performance of each insert type.
6. Corrosion tests (1000 hour salt fog spray - ASTM B177) on inserts cast in concrete to determine the performance of various corrosion protection coatings.

All tests were conducted by the Structural Materials Research Unit of the Structural Materials Branch of the Caltrans Office of Transportation Materials and Research in Sacramento, California.

5.2 Test Specimens

5.2.1 Cast-In-Place Concrete Inserts

5.2.1.1 Description of Inserts

Cast-in-place inserts from four of the major manufacturers were evaluated in this research study. The manufacturers were Acme (now Meadow Steel Products), Burke, Dayton Superior, and Richmond. Two types of inserts were chosen to be tested, the steel ferrule loop and the ductile cast-iron. Acme only manufactures the ferrule and coil type of insert; therefore, only the Acme FL-500 and FL-100 ferrule loop inserts (Figure 7) were tested. Burke only sells ferrule loop inserts that are manufactured by other companies (Acme, Dayton Superior, etc.); therefore, only the Burke Hi-Tensile cast-iron inserts (Figure 8) were tested. Inserts manufactured by Dayton Superior that were tested were the F-42 ferrule loop (Figure 9) and the F-5 Threaded Insert (Figure 10) cast-iron insert. The Richmond LF type of ferrule loop (Figure 11) and the Hi-Tensile cast-iron (Figure 12) inserts were tested.

5.2.1.2 Installation of Inserts

All inserts were installed in small unreinforced concrete slabs according to manufacturer's instructions. Inserts were installed at the manufacturer's recommended minimum edge distance and also at half that distance. A minimum

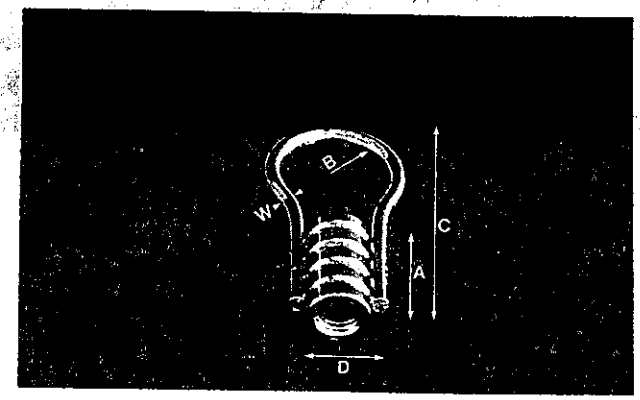


Figure 7. ACME Ferrule Loop Insert
FL500 Stud Diameter 1/2"
FL100 Stud Diameter 1"

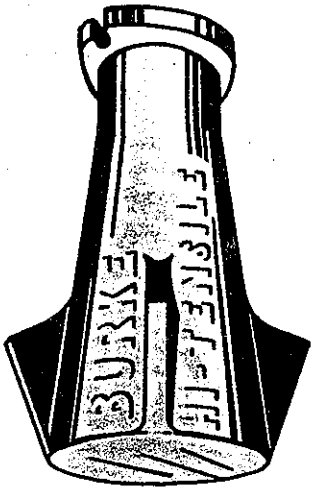


Figure 8. Burke Hi-Tensile Cast-Iron Insert

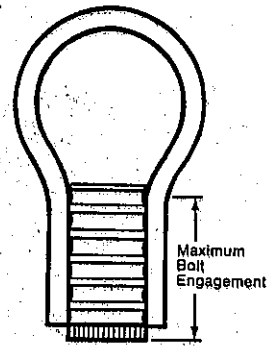


Figure 9. Dayton Superior Ferrule Loop Insert (F-42)

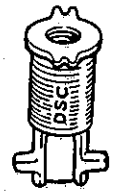


Figure 10. Dayton Superior Cast-Iron Threaded Insert

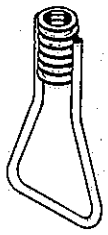


Figure 11. Richmond Ferrule Loop Insert

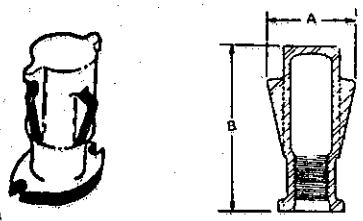


Figure 12. Richmond Rocket Cast-Iron Insert

spacing of 3.4 times the embedment depth was provided. Plastic setting plugs were used to secure the inserts to the bottom form of the concrete test slab. The setting plugs were nailed in the proper position to a sheet of 3/4" plywood that was placed in the bottom of the forms. The forms were then sprayed with a form release agent. Before inserts were threaded onto the setting plug, white grease was applied to the insert's internal threads to insure easy disassembly and to help prevent seepage of concrete paste into the insert cavity. After the inserts were threaded onto the setting plugs, a final check was made to make sure that the inserts and setting plugs were fastened securely. While vibrating the concrete during the pour, care was taken not to displace the inserts.

5.2.2 Concrete Slabs

The ready-mix concrete used for all test slabs was obtained at a local batch plant and transported approximately six miles by a concrete mix truck to the OTM&R where the test slabs were cast. The aggregate used, Fair Oaks river-run, conformed to the 1" maximum grading in Section 90-3.04, "Combined Aggregate Gradings" of the Caltrans Standard Specifications (10). Inserts were installed in 3′ x 8 ′ unreinforced concrete slabs. Slab thickness varied with the stud diameter of the insert. For all 1/2" diameter inserts, 8" thick slabs were used and for 3/4, and 1" diameter inserts, test slabs were 15" thick. The concrete used throughout the project was the Caltrans "Class A" which contained 564 pounds of Type II Modified portland cement per cubic yard (6-sack mix). The mix was designed for a 3" slump. All test slabs were cured according to

the requirements of Caltrans Standard Specifications Section 90-7.03 "Curing Structures" (10) by spraying concrete curing compound (chlorinated rubber) on the top surface of the slabs. While pouring the test slabs, twenty- eight 6" x 12" concrete cylinders were made and cured with the slabs in accordance with ASTM C39 (1) for determining the compressive strength of the concrete. After 14 days, the forms were removed and the slabs were turned over. The concrete cylinders were tested after 7, 14, 28 days and until the required compressive strength was reached. The average compressive strength of test slabs at each age was obtained by testing two test cylinders. The compressive strength of concrete at the time of insert testing for all tests (except for tests with low strength concrete) was between 4550 and 5800 psi. For tests performed in low strength concrete, the compressive strength at the time of insert testing was between 3250 and 4259 psi.

5.3 Testing Equipment and Procedure

5.3.1 Short-Term Direct Tension Tests

5.3.1.1 Test Equipment

A schematic of the tension testing apparatus is shown in
Figure 13. As shown, a movable frame supported the loading ram and load cell. The movable frame rested on an interchangeable base bearing ring. A base bearing ring with a radius greater than 1.7 times the embedment depth, ED, of the insert was used

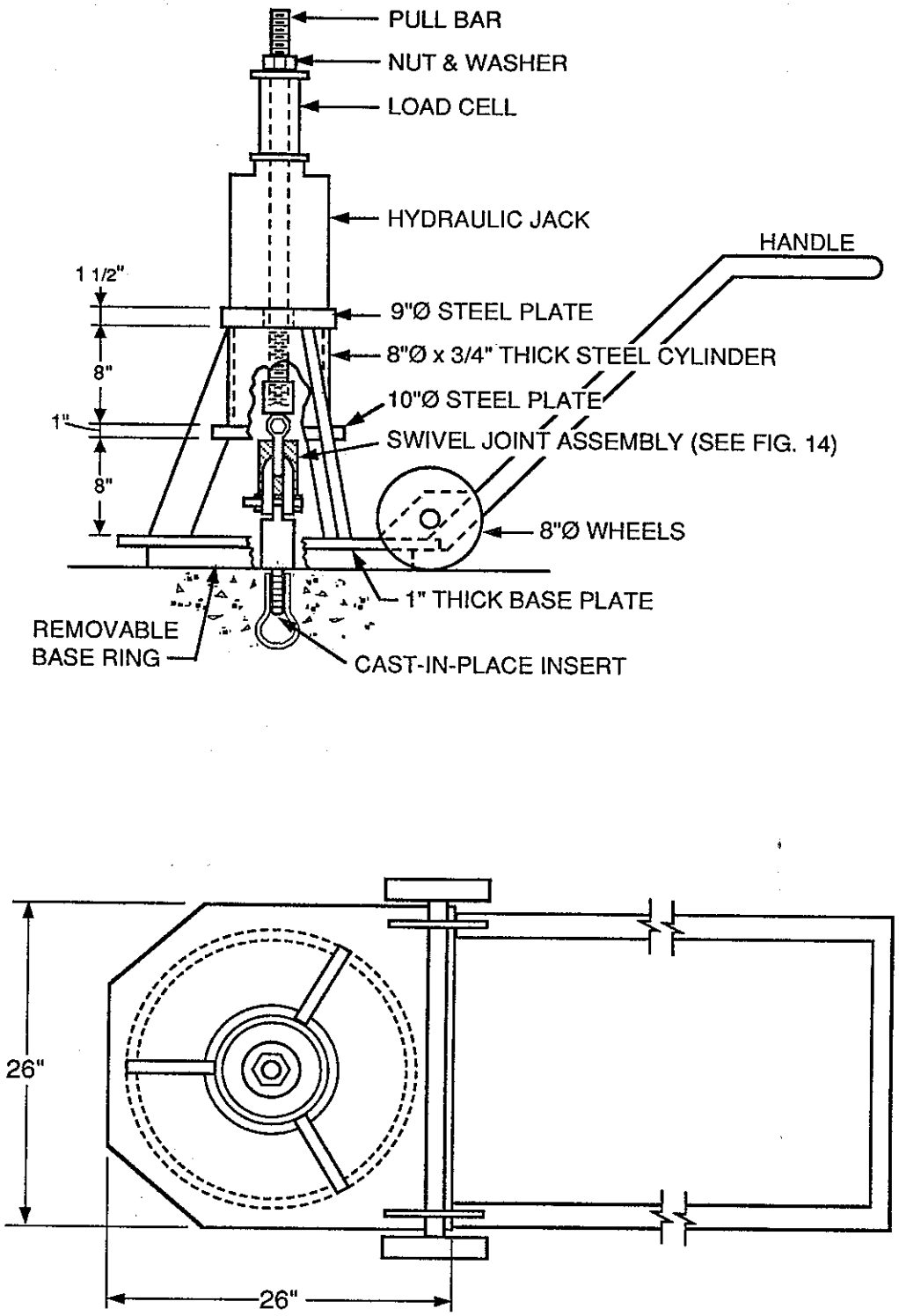


Figure 13. Portable testing apparatus for conducting short-term ultimate tension load tests.

to prevent interference with the concrete failure. A 120-kip single- acting ram was used to apply tensile load to the insert. To eliminate transfer of bending moment during loading, a swivel assembly (Figure 14) was used to connect the insert to a pull rod which extended through the loading ram and load cell and was locked off with a nut and washer. The insert was loaded through a load collar which simulated a base plate. The load collar was held firmly against the concrete by applying the manufacturer's recommended torque to the bolt. A special fixture was attached to the load collar for mounting two linear potentiometers for displacement measurements (Figure 14). The ends of the potentiometer shafts were placed on metal pads located on the concrete surface to provide a stable and smooth surface for displacement measurements. The accuracy of the potentiometers was ± 0.001". The two potentiometer outputs were electronically averaged and plotted as one value on the XY recorder along with the corresponding tensile load obtained from the load cell. On a second XY recorder, the tensile load versus time was plotted.

5.3.1.2 Test Procedure

After the concrete reached the required strength, setting plugs were removed (setting plugs were left in the insert until testing to prevent water and dirt from entering the insert cavity). After removing the setting plug, a threaded rod (ASTM - A307) was fully screwed into the insert. The load collar was then placed over the insert and was tightened against the concrete surface using a washer and nut. The nut was torqued according to the manufacturer's torque requirement or as described later in California

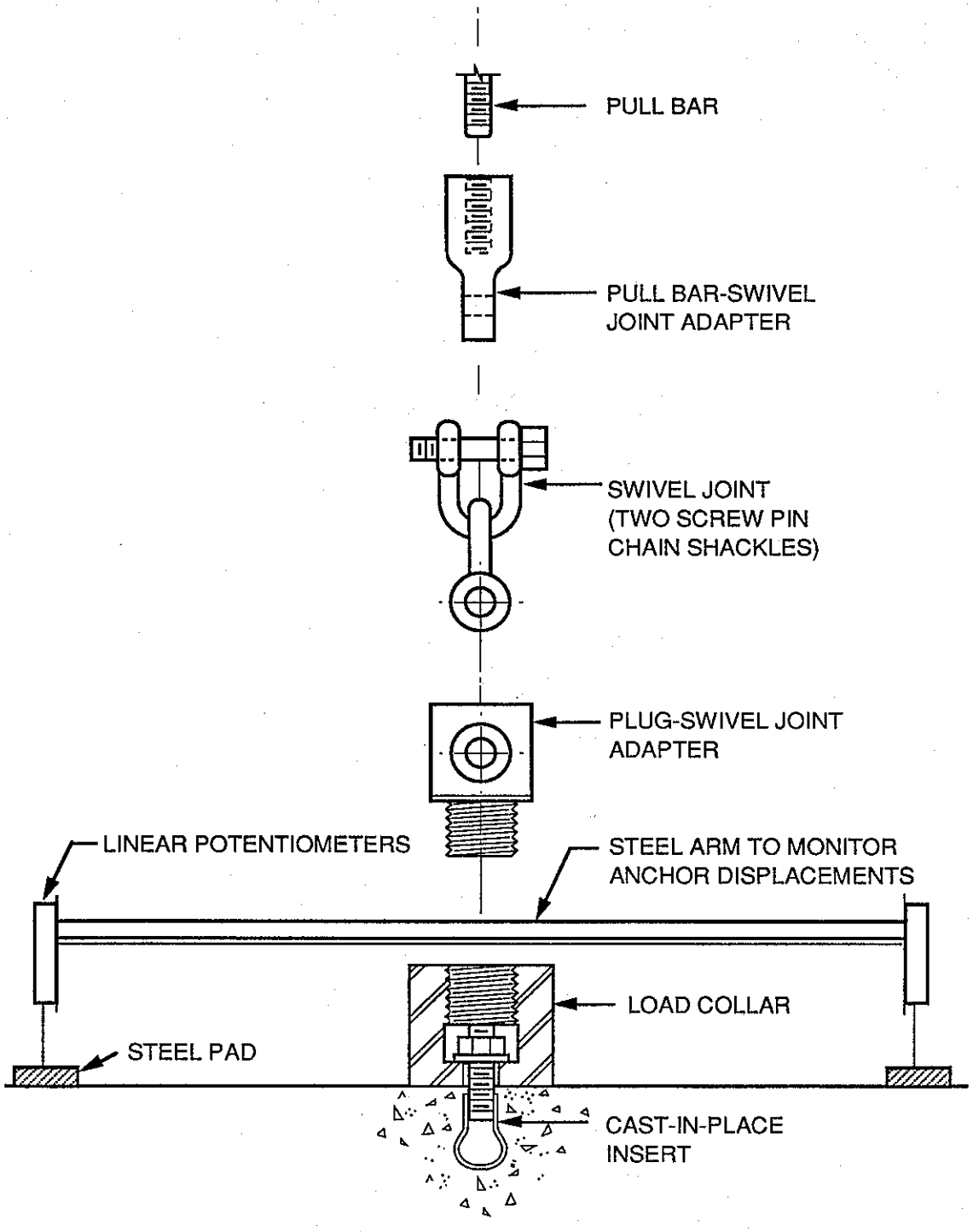


Figure 14. Expanded view of the swivel joint assembly on the portable testing apparatus for tension tests

Test 682, Method for Determining Ultimate Tensile Strength of Cast-In-Place Concrete Inserts (Appendix G). The tension test machine was then assembled over the insert. Before attaching the swivel assembly to the load collar, the potentiometer fixture was carefully attached to the load collar, and the steel pads were placed under the shafts of the potentiometers. All the wires were connected as shown in Figure 15 and recorders were zeroed. The insert was then preloaded to about 5% of the estimated ultimate load to remove slack from the test assembly. At this time the insert was loaded to failure at one of the following rates: 1/2" inserts, 2.5 kips per second; 3/4" inserts, 2.8 kips per second; and 1" inserts, 3.15 kips per second. These rates of loading were determined based upon ASTM E488-76 (2), Tests for Strength of Anchors in Concrete and Masonry Elements. However, the rate of loading in the California Test 682 has been lowered to correspond to ASTM E488-88 (3). A tension test setup is shown in Figure 16.

The same test equipment and procedures were used for low strength concrete tests and for inserts with different corrosion protection coatings.

Five replicate tests were performed at each edge distance for each manufacturer. Ferrule loop inserts had three replicate tests with the wire loop oriented perpendicular to the edge of the concrete and two with the wire loop oriented parallel to the edge. The same orientation was applied to any cast-iron insert where it was applicable. The inserts were tested to determine the ultimate loads and the effect of the insert orientation in short-term tensile pullout. The following information was

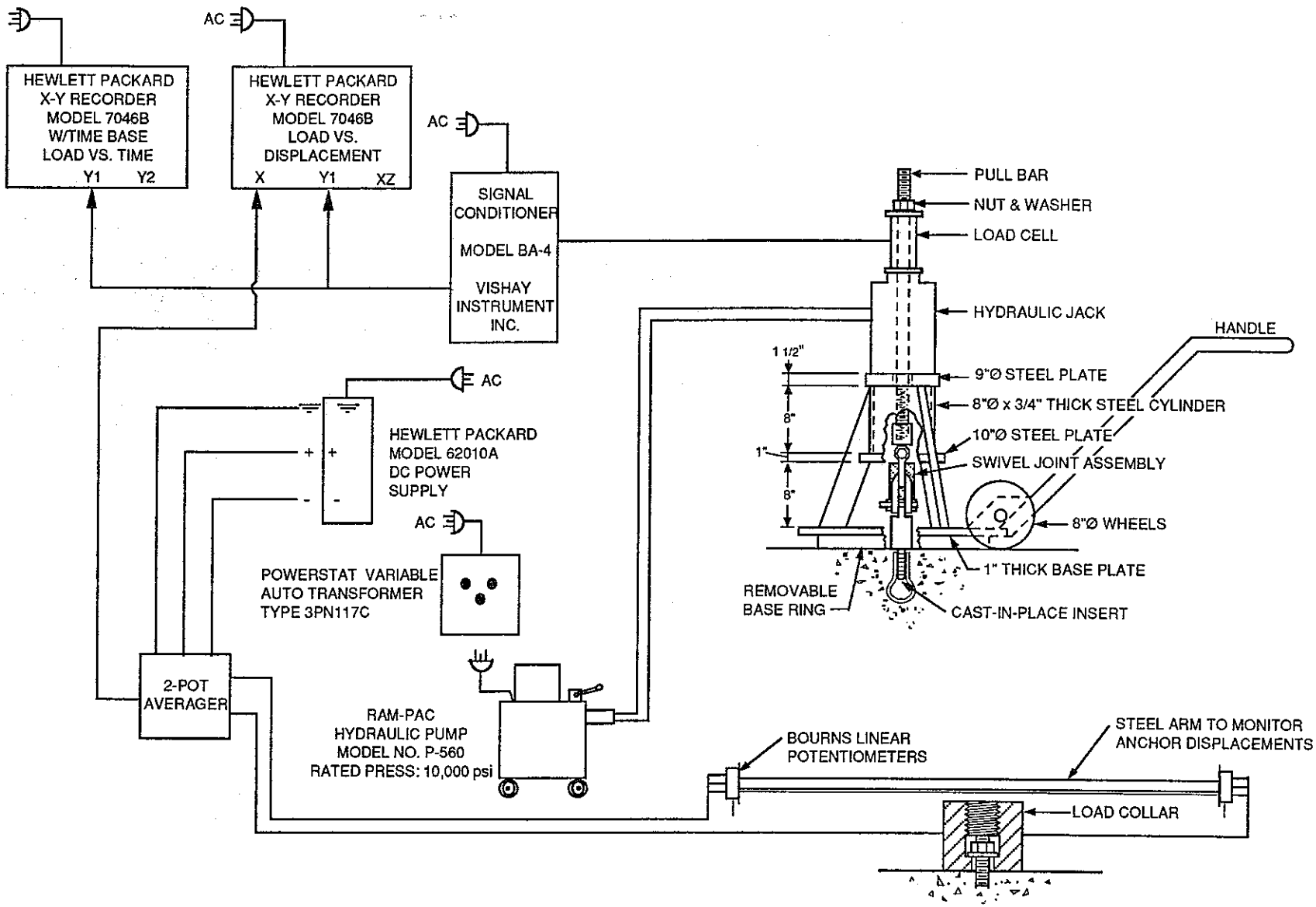


Figure 15. Schematic of tension test setup

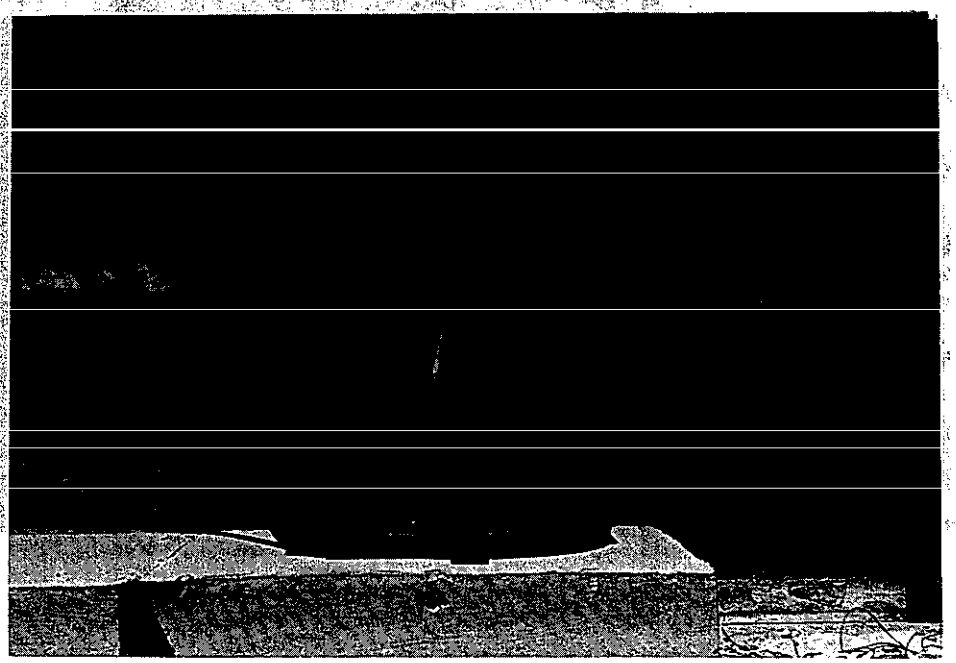


Figure 16. Tension test setup

recorded for each test: test number, date of test, type of insert, insert size, manufacturer, type of threaded rod, edge distance, insert orientation, type of loading, loading rate, preload, torque, concrete strength, and type of failure.

5.3.2 Short-Term Direct Shear Tests

5.3.2.1. Test Equipment

The apparatus used for shear tests is shown in Figures 17 and 18. It consisted of a three-piece adjustable steel frame, a pull rod, a hydraulic ram, a load cell to measure the load, and two potentiometers to measure the displacement. A 120-kip single acting ram was used to load the inserts in direct shear. The loading ram and load cell were supported on a plywood platform resting on the forks of a small hand operated forklift (Figure 18). The adjustable frame consisted of two L-shaped legs, positioned and clamped against the concrete edge, an equal distance from the insert (one on each side of the insert), and a crossarm, sitting on angle supports welded to the front of the two legs. The crossarm provided a bearing surface for the hydraulic ram to act against. The pull rod extended through the crossarm, hydraulic ram, and load cell and was locked off with a nut and washer. A steel shear plate with a replaceable threaded bushing was welded to the end of the pull rod (Figure 19). The steel shear baseplate was held firmly against the concrete. Two linear potentiometers with an accuracy of $\pm$ .001" were attached to the shear baseplate to measure the displacements during loading. A heavy steel block was used as a reference for measuring

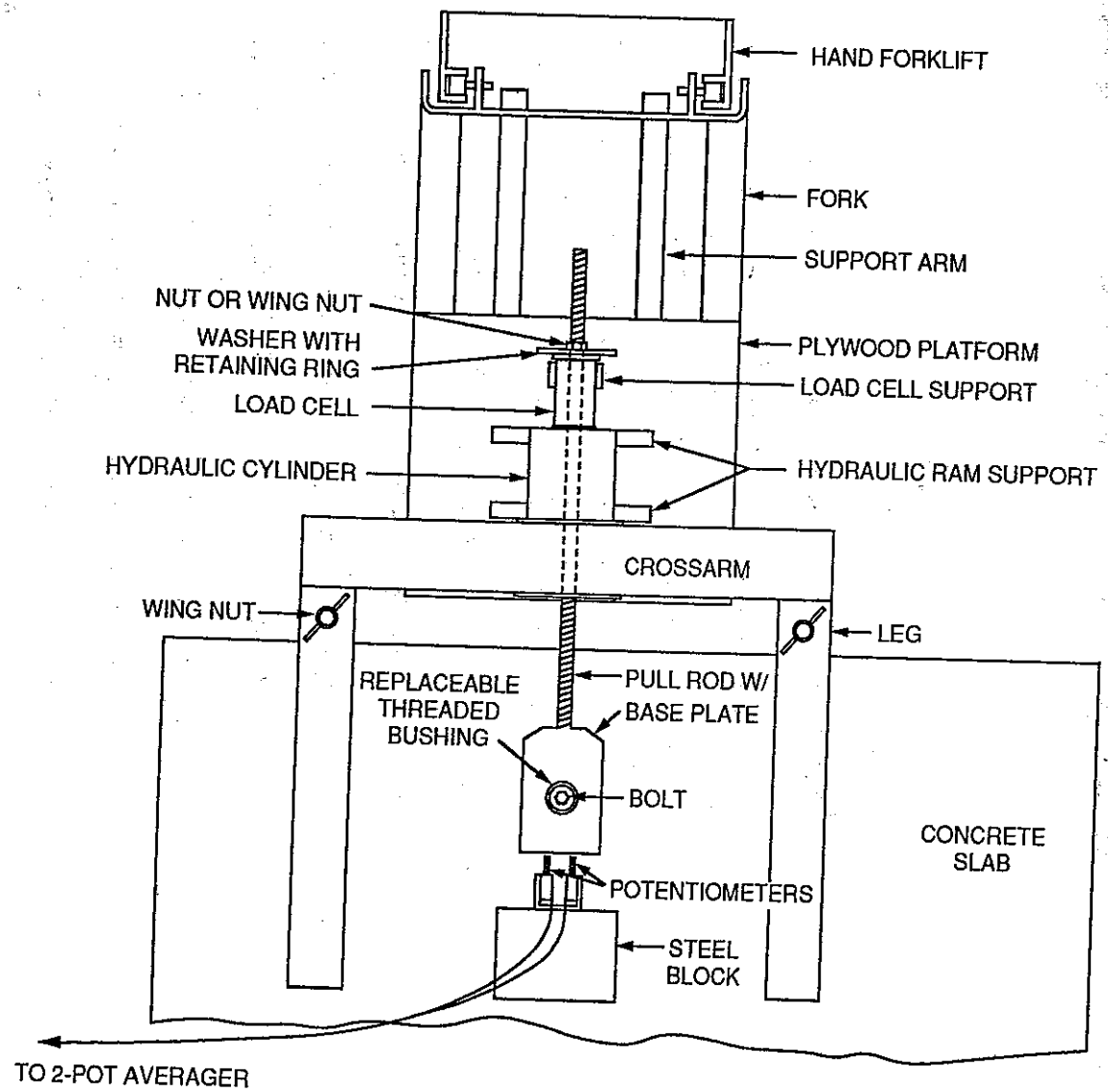


Figure 17. Top view of shear machine

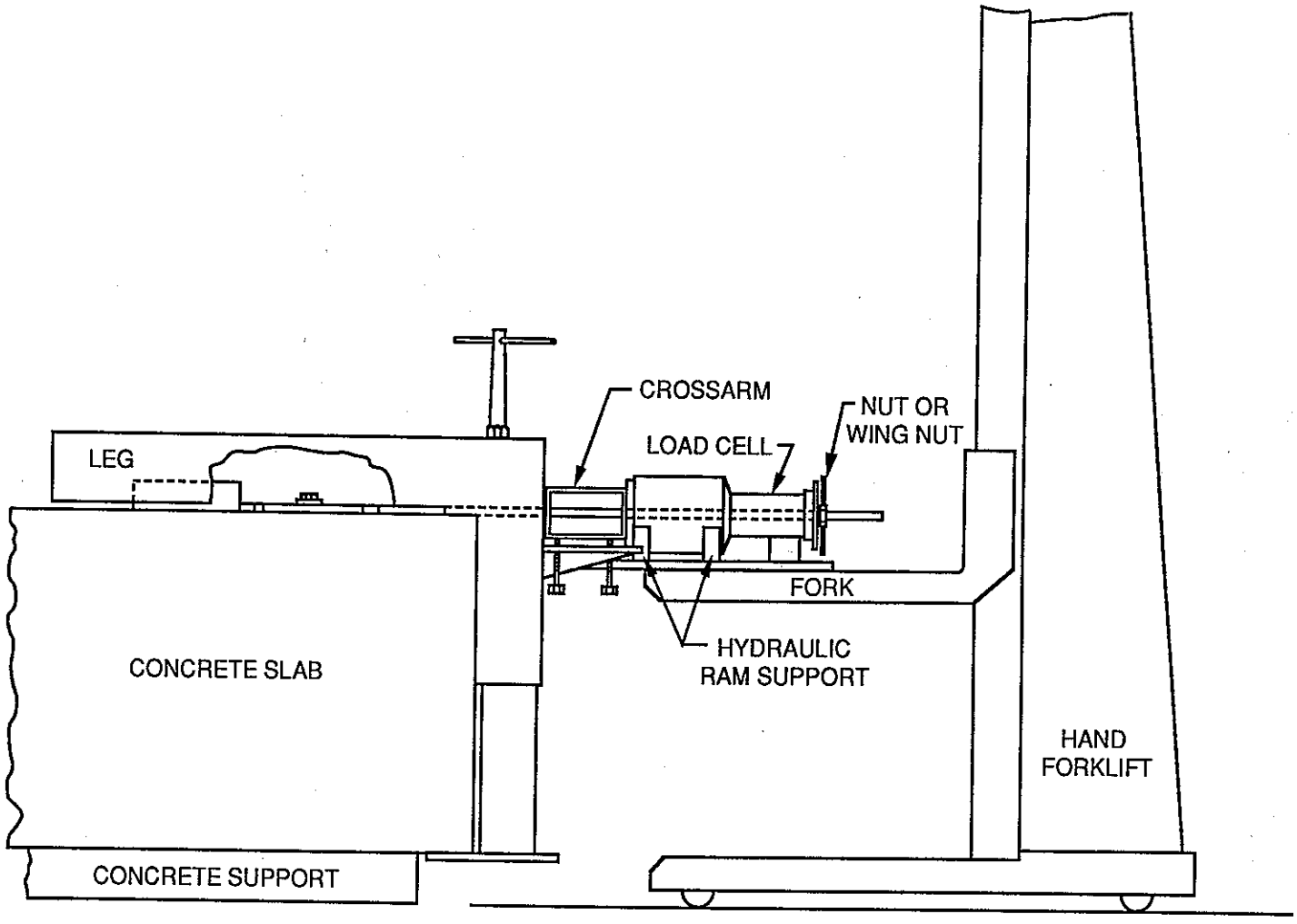


Figure 18. Side view of shear machine

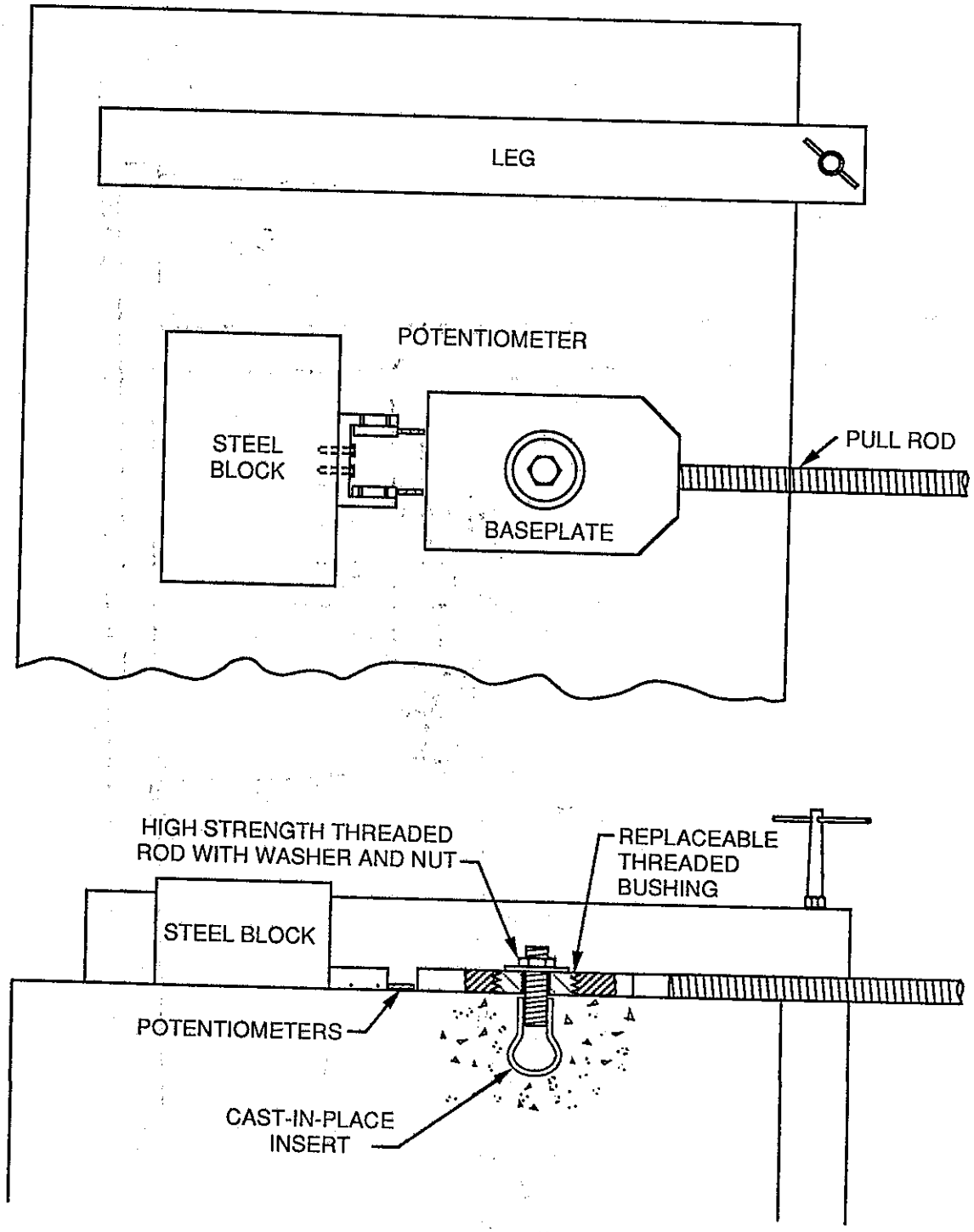


Figure 19. Top and side view of shear machine baseplate

displacements. The two potentiometer outputs were electronically averaged and plotted as one value on the XY recorder along with the corresponding shear load obtained from the load cell. On a second XY recorder, the shear load versus time was plotted.

5.3.2.2 Test Procedure

After the concrete reached the required strength, setting plugs which were left in the insert to prevent water and dirt from entering the cavity of the insert were removed. Then, a high strength threaded rod (ASTM - A193B7) was screwed into the insert until it bottomed out or a minimum of one stud diameter thread engagement was reached. The shear plate was then placed over the insert and was tightened against the concrete surface using a washer and nut. The nut was torqued according to the manufacturer's torque requirement.

The shear test machine was then assembled as shown in Figures 17 and 18. The heavy steel block was moved up to the potentiometers until they were fully compressed and then backed off about 1/8 to 1/4". All the wires were connected and the recorders were zeroed. The insert was then preloaded to about 5% of the estimated ultimate load. At this time the insert was loaded to failure at one of the following rates: 1/2" inserts, 2.5 kips per second; 3/4" inserts, 2.8 kips per second; and 1" inserts, 3.15 kips per second. These rates of loading were determined based on ASTM E488-76, Tests for Strength of Anchors in Concrete and Masonry Elements (2).

A shear test setup is shown in Figure 20.

The same test equipment and procedures were used for low strength concrete tests and for inserts with different corrosion protection coatings.

Five replicate tests were performed at each edge distance for each manufacturer. Ferrule loop inserts had three replicate tests with the wire loop oriented perpendicular to the edge of the concrete and two with the wire loop oriented parallel. The same orientation was applied to any cast-iron inserts where applicable. Inserts were tested to determine ultimate loads and the effects of insert orientation in short-term shear tests. The following information was recorded for each test: test number, date of test, type of insert, insert size, manufacture, type of threaded rod, edge distance, insert orientation, type of loading, loading rate, preload, torque, concrete strength, and type of failure.

5.3.3 Combined Tension and Shear Loading Tests

5.3.3.1 Test Equipment

The apparatus used for combined shear and tension tests is shown in Figures 21, 22, 23. The apparatus consisted of a four-piece adjustable steel frame, two pull rods, two hydraulic rams, two load cells to measure the tension and the shear load, and four potentiometers to measure the tension and shear displacements. The adjustable frame

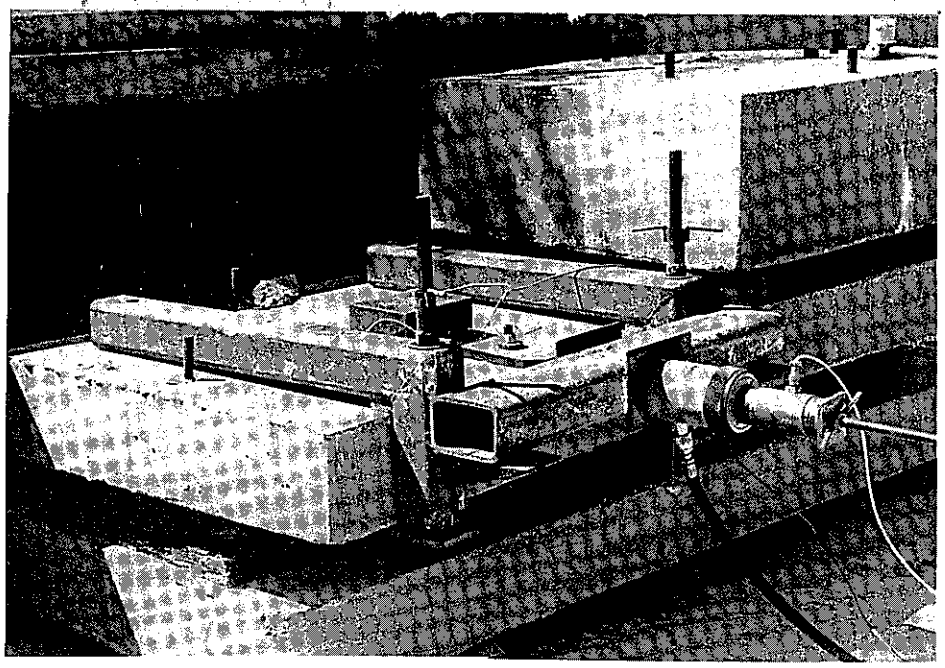


Figure 20. Shear test setup

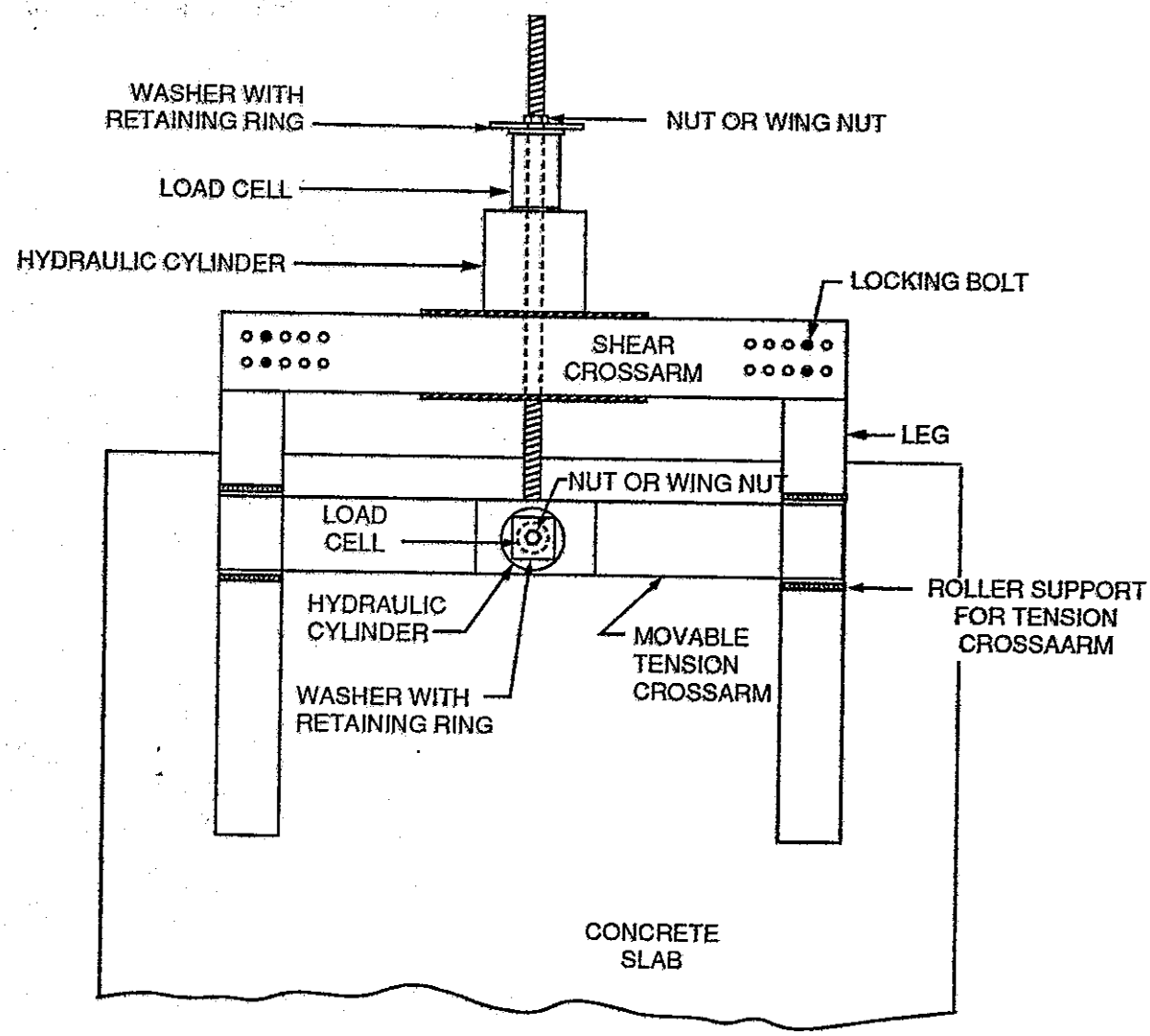


Figure 21. Combined testing machine (top view)

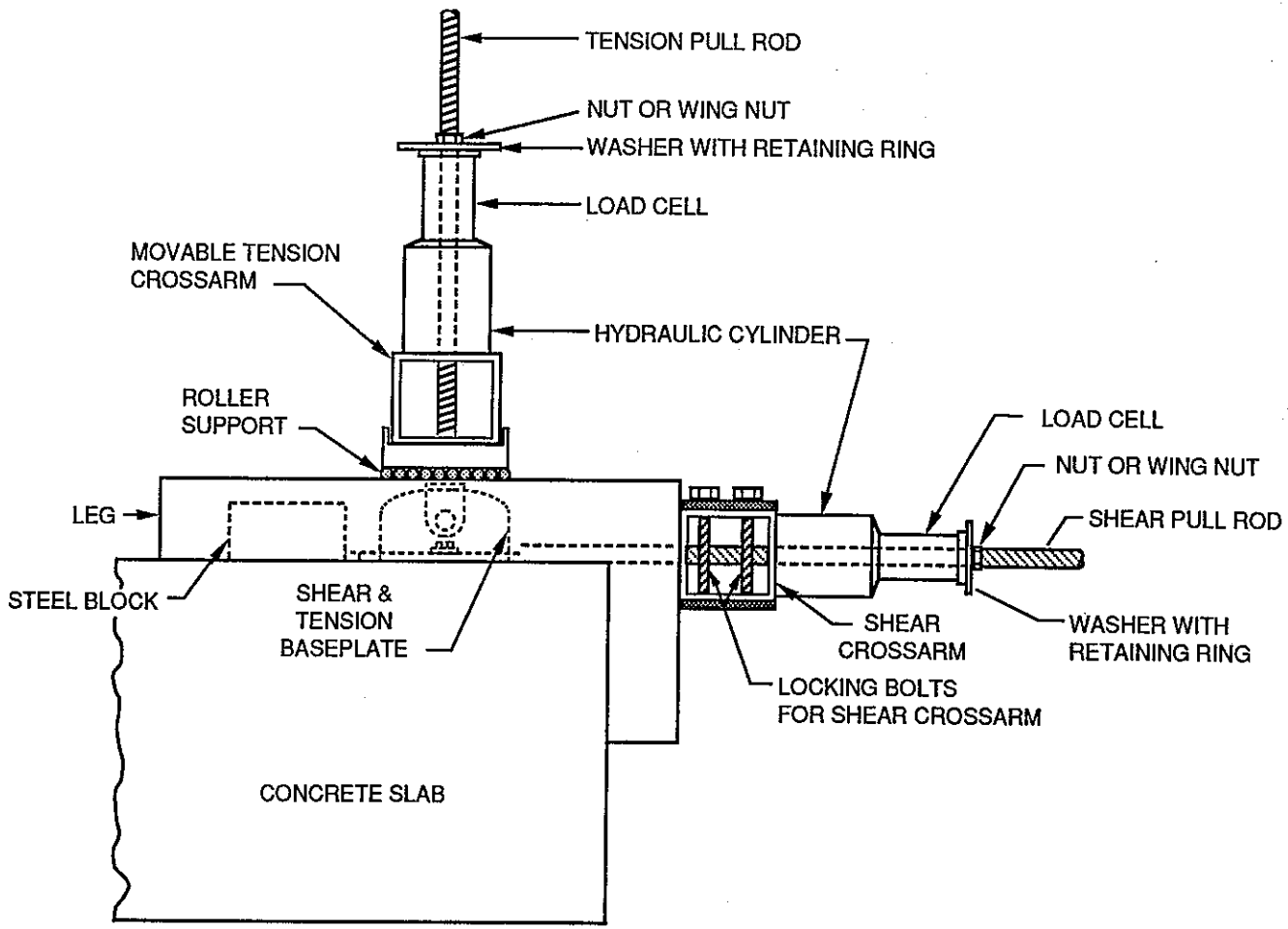


Figure 22. Side view of combined testing machine

consisted of two L-shaped legs, positioned and clamped against the concrete edge, each an equal distance from the insert (one on each side of the insert), and two crossarms, one for tension and one for shear. The tension crossarm, which was supported by two rollers, one on each side of the arm (Figure 21), supported the tension loading ram and load cell. The rollers allowed the tension assembly to move horizontally, parallel to the direction of shear, with very little effort. The adjustable shear crossarm was bolted to the front of the two legs and supported the shear loading ram and load cell. A 120-kip single acting ram was used to load the insert in tension and a 75-kip single acting ram was used to load the insert in direct shear. The shear pull rod extended through the crossarm, hydraulic ram, and load cell and was locked off with a nut and washer. A steel loading plate with a replaceable threaded bushing was welded to the end of the pull rod. If the bushing became damaged, it was replaced, thus providing the same pull plate conditions for each test. The steel shear plate was held firmly against the concrete by torquing the threaded stud to the manufacturer's recommended value. The tension pull rod was also attached through a swivel joint to the shear plate and extended through the crossarm, hydraulic ram, and load cell and was locked off with a nut and washer (Figure 23). Four linear potentiometers were attached to the loading plate so that displacement readings in the horizontal and vertical directions could be obtained. Two of the four potentiometers were used to measure displacements in the vertical direction, and two measured displacements in the horizontal direction. A heavy steel block was used to provide a stable and smooth surface from which horizontal displacement readings could be referenced. Two metal pads placed on the concrete surface

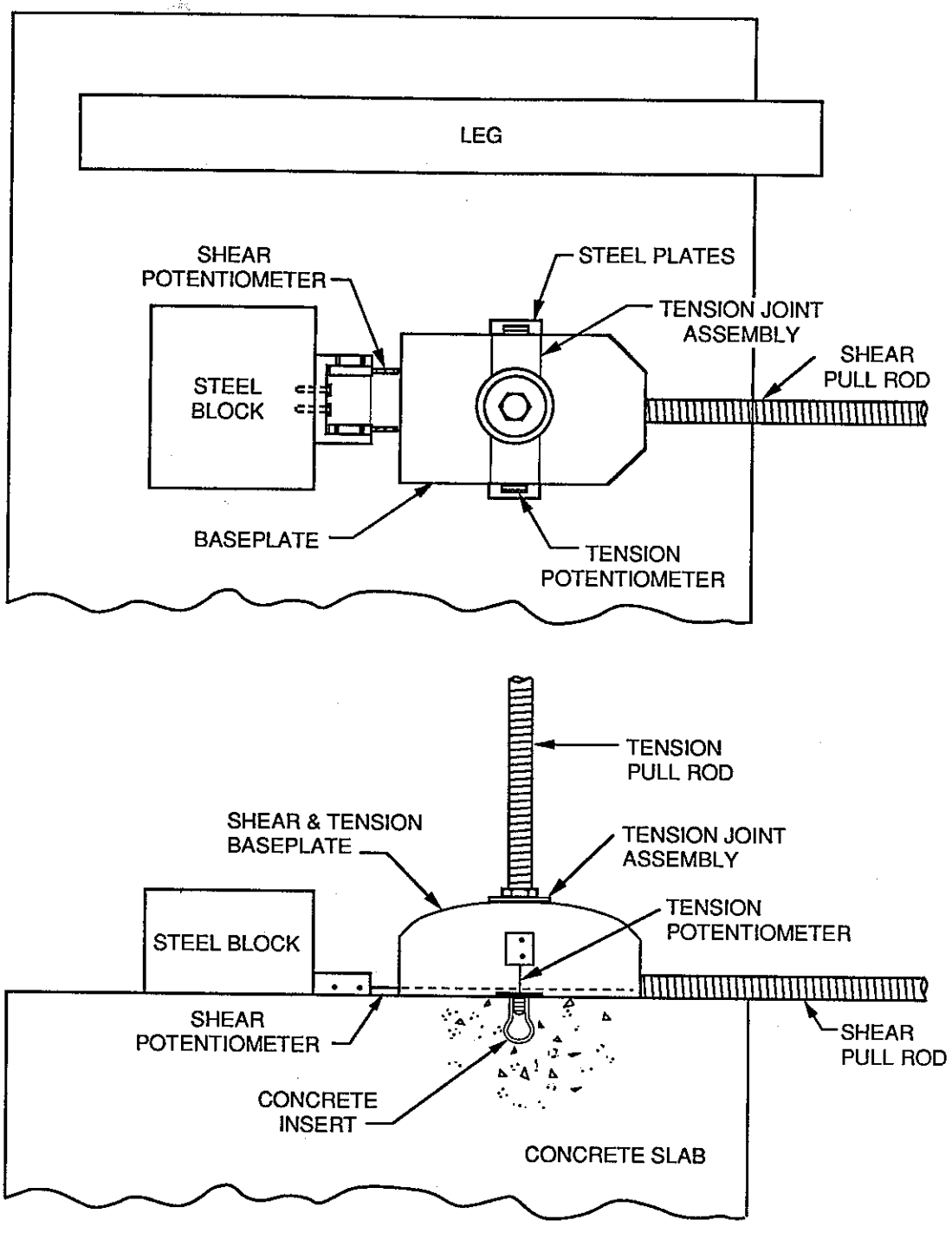


Figure 23. Top and side view of the loading plate on the combined testing machine

provided a stable and smooth surface to reference vertical displacements. The pads were coated with a light oil to allow horizontal movement of the potentiometers. The outputs of the two potentiometers in each direction were electronically averaged and plotted along with the corresponding tension and shear loads using two XY recorders. Graphs of tension and shear load versus time were plotted on another XY recorder. A Campbell 21X data logger was also used to store the data during the test.

5.3.3.2 Test Procedure

After the concrete reached the required strength, setting plugs which were left in the insert to prevent water and dirt from entering the insert were removed. Then, a high strength threaded rod (ASTM - A193B7) was screwed into the insert until it bottomed out or a minimum of 1" thread engagement was reached. The shear plate was placed over the insert and was tightened against the concrete surface using a washer and nut. The nut was torqued according to the manufacturer's torque requirement.

The combined test machine was then assembled as shown in Figures 21 and 22. The heavy steel block was moved up to the potentiometers until they were fully compressed and then backed off about 1/8 to 1/4". All the wires were connected and the recorders were zeroed. The insert was preloaded in tension and shear to about 5% of the estimated ultimate loads. The insert was then loaded in tension to about 25, 50, or 75% of the ultimate tension load. Then, while the tension load was held constant, the insert was loaded in shear to failure at one of the following rates: 1/2"

inserts, 2.5 kips per second; and 1" inserts, 3.15 kips per second. These rates of loading were determined based on the ASTM E488-76, Tests for Strength of Anchors in Concrete and Masonry Elements (2). A combined test setup is shown in Figure 24. Theoretically the load path to failure should not affect test results, i.e., the same results are expected if the shear load is constant and the insert is loaded in tension to failure. However, because of the nature of the testing machine it was decided to hold the tension constant and load the insert in shear to failure.

Three replicate tests were performed at each edge distance for each type of insert tested. The following information was recorded for each test: Test number, date of test, type of insert, insert size, manufacturer, type of threaded rod, edge distance, type of loading, loading rate, preload, torque, concrete strength, and type of failure.

5.3.4 Direct Tension Tests of Ferrule Loop Inserts

A total of fifteen direct tension tests were performed on the Dayton Superior, Meadow Steel (ACME), and Richmond 1/2" and 1" ferrule loop inserts. Direct tension testing of these inserts was performed to determine a representative average ultimate strength and mode of failure.

The cast-in-place insert was braced laterally (Figure 25), to prevent transfer of shear to the weld between the wire and the ferrule. An A307 steel threaded rod was fully screwed into the ferrule loop insert. This assembly was installed in a universal

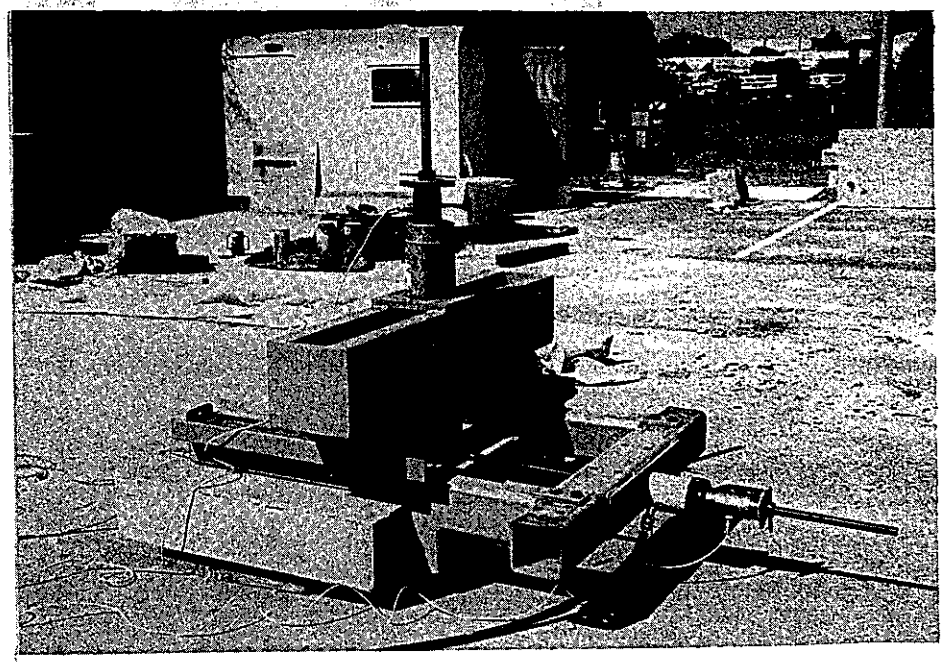


Figure 24. Combined tension and shear loading test setup

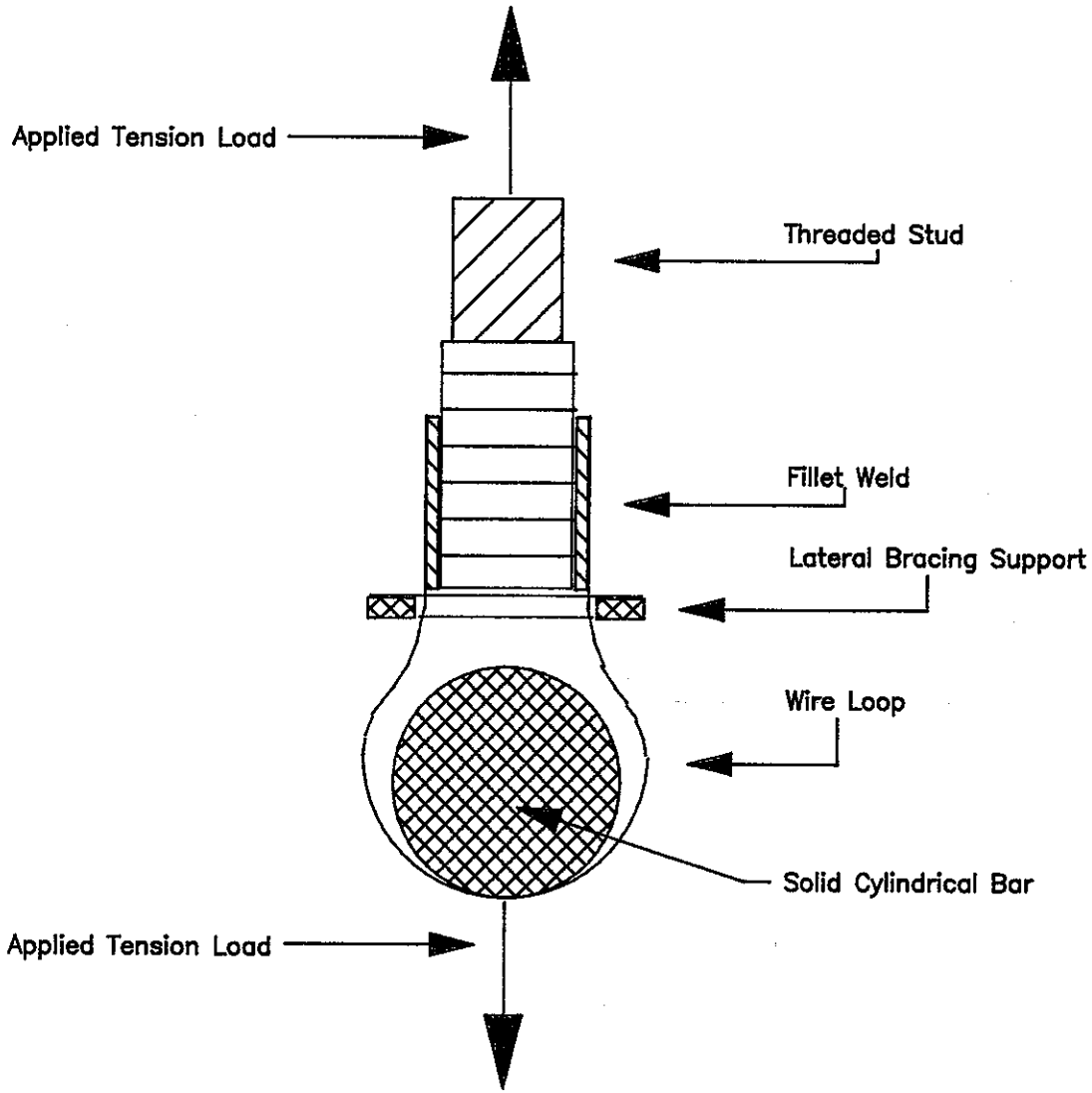


FIGURE 25. DIRECT TENSION TESTING OF FERRULE LOOP INSERTS

tension testing machine (Figure 26) and the insert was then loaded at 3000 lb/min until failure occurred. The ultimate load and the mode of failure were recorded.

5.3.5 Corrosion Tests

Eighteen 1/2-in. ferrule loop and cast iron cast-in-place inserts, manufactured by the Richmond Screw Anchor Company, were tested for corrosion. These inserts were separated into four groups depending on the various types of corrosion protection coatings: plain; zinc plated; stainless steel; and galvanized.

The Caltrans Class A concrete (564 lbs of cement per cubic yard) was poured into 6" x 8" plastic cylinders. The inserts were wiggled into the fresh concrete in the proper position on the exposed surface before the concrete began to harden. The cylinders were stripped seven days after pouring. At this time a 1/2" diameter hot-dip galvanized A307 threaded rod was fully screwed into the insert. A 1/4" x 6" x 6" steel plate, a washer, and a nut, all hot-dip galvanized to ASTM A153 specifications (4), were also attached to the inserts (as shown in Figure 27) prior to placement in the salt spray (fog) chamber.

The total test assembly was then subjected to a salt spray (fog) test ASTM B117 (5). To prevent water from accumulating on any part of the assembly, the specimen was placed at a 30-degree angle (from the vertical plane) in the test chamber. One cylinder from each group was extracted from the salt spray (fog) chamber at 250

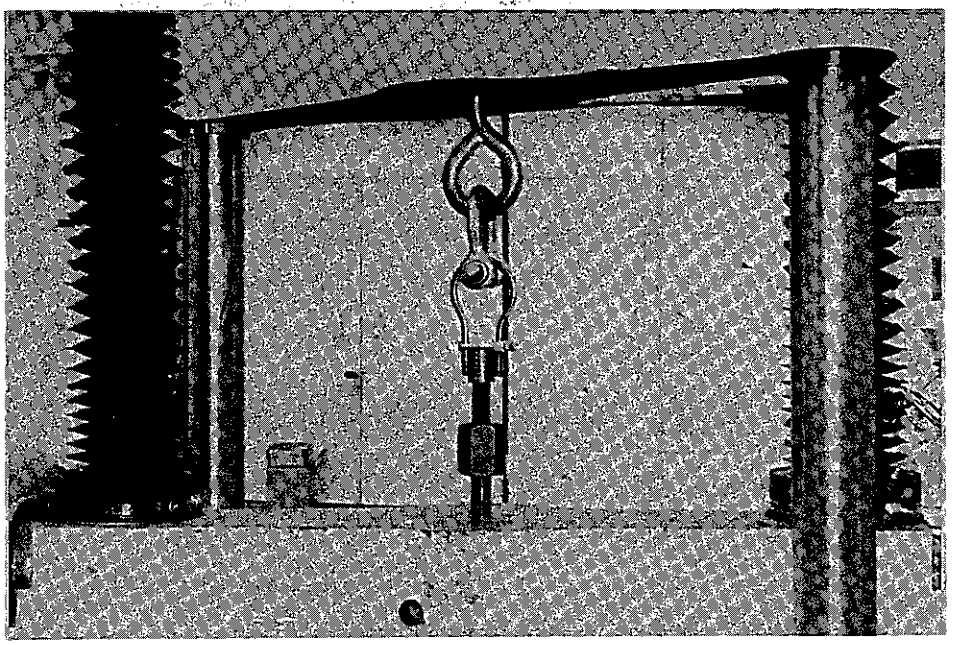


Figure 26. Tension test setup of ferrule loop insert.

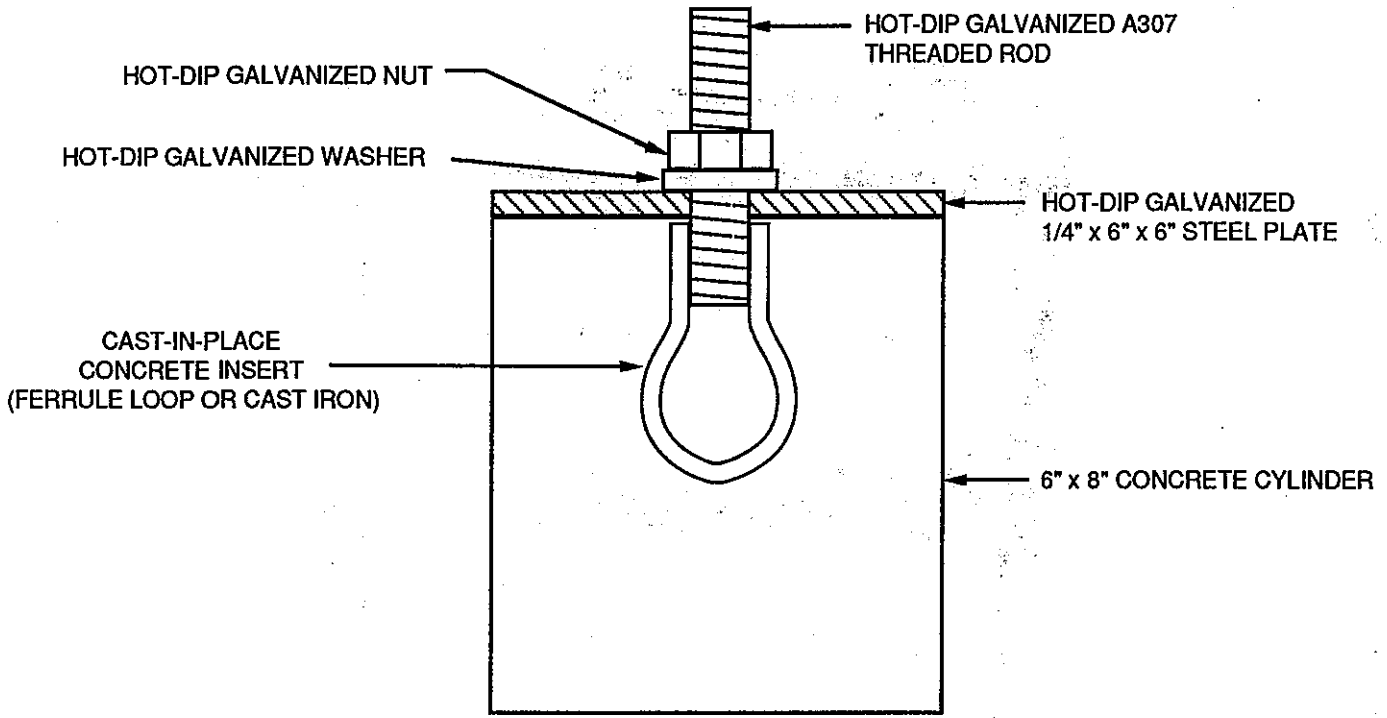


Figure 27. Corrosion test assembly for evaluating cast-in-place inserts

hours and 500 hours, and split open to determine the extent of corrosion of the insert. At the end of 1000 hours, the remaining cylinders were removed, split open, and examined for traces of corrosion.

6. Test Results

6.1 Direct Tension and Direct Shear Tests

Direct tension and direct shear tests were conducted using 5000 ± psi concrete and also using a 3500 ± psi concrete (for use of inserts where the load is applied before the concrete reaches its full strength). Direct tension and direct shear tests were also carried out using inserts with different corrosion protection coatings.

6.1.1 Test Results With 5000 psi Concrete

The results of direct tension tests are shown in Figures B-1 through B-24 in Appendix B.

The results of direct shear tests are shown in Figures C-1 through C-24 in Appendix C.

Table A-1 in Appendix A is the summary of test data for tension and shear tests. As shown on the graphs and Table A-1, compressive strength of the concrete varied from 4550 to 5800 psi. In order to compare the test results, the average ultimate loads obtained from the plots of load versus displacement were normalized to correspond to a compressive strength of 5000 psi. The following equation (8) was used to normalize the data:

$$S_{5000} = S\sqrt{5000/f'c}$$

where S is the average ultimate tension or shear obtained from the test results, f'c is

the compressive strength of the corresponding test slab, and S_{5000} is the normalized value of tension or shear corresponding to a compressive strength of 5000 psi.

Table 4 is the summary of average ultimate loads (tension and shear) of cast-in-place concrete inserts normalized to a compressive strength of 5000 psi after disregarding results which were either larger or smaller than one standard deviation from the original average. Different modes of failure are also shown in Table 4 and they are as follows:

"Tension cone" indicates that the insert pulled out of the concrete with a cone of concrete.

"Tension cone with weld failure" means that the resistance weld between the wire loop and the ferrule failed either on one side or on two sides and there was a tension cone in concrete. In this case, as the load approached the ultimate, cracks developed in the concrete and at some point, the weld failed.

"Tension cone with loop failure" means that the wire loop failed either on one side or on two sides and there was a tension cone in concrete. In this case, as the load approached the ultimate, cracks developed in the concrete and at some point, the wire loop failed in tension.

"Shear cone" implies that the concrete failed with a shear cone.

Bolt failure means that the bolt or the threaded stud failed in shear tests. In some shear tests, the threaded portion of the cast-iron insert failed.

A summary of average ultimate load and the manufacturer's recommended working

Table 4. Summary of Test Results for Cast-in-Place Concrete Inserts

Concrete Compressive Strength, f'c, = 5000 psi

SIZE	TYPE	SLAB THICKNESS	EDGE DISTANCE	MANUFACTURER	TENSION TEST RESULTS				SHEAR TEST RESULTS	
					CAST-IN-CONCRETE		DIRECT TENSION		CAST-IN-CONCRETE	
					ULTIMATE LOAD, Tu kips	FAILURE MODE	ULTIMATE LOAD, Tu kips	FAILURE MODE	ULTIMATE LOAD, Su kips	FAILURE MODE
1/2"	CAST IRON	8"	3"	BURKE	8.78	TC	NOT TESTED	NOT TESTED	7.74	SC
				DAYTON SUPERIOR	7.52	TC	NOT TESTED	NOT TESTED	6.40	SC
				RICHMOND	8.86	TC	NOT TESTED	NOT TESTED	7.48	SC
			6"	BURKE	10.77	TC	NOT TESTED	NOT TESTED	11.85	BF
				DAYTON SUPERIOR	10.35	TC	NOT TESTED	NOT TESTED	11.75	BF
				RICHMOND	11.79	TC	NOT TESTED	NOT TESTED	11.30	BF
	FERRULE LOOP	8"	3"	DAYTON SUPERIOR	9.41	TC, WF	8.23	LF	6.20	SC
				MEADOW STEEL	8.99	TC, LF	9.08	LF	6.33	SC
				RICHMOND	9.49	TC, LF	9.06	LF	7.07	SC
			6"	DAYTON SUPERIOR	10.61	TC, WF	8.23	LF	11.00	BF
				MEADOW STEEL	10.27	TC, LF	9.08	LF	10.95	BF
				RICHMOND	9.56	TC, LF	9.06	LF	10.84	BF
3/4"	FERRULE LOOP	15"	4"	RICHMOND	17.17	TC, LF	NOT TESTED	NOT TESTED	13.56	SC
			8"	RICHMOND	18.57	TC, LF	NOT TESTED	NOT TESTED	20.30	SC
1"	CAST IRON	15"	6"	BURKE	27.77	TC	NOT TESTED	NOT TESTED	24.00	SC
				DAYTON SUPERIOR	20.10	TC	NOT TESTED	NOT TESTED	20.07	SC
				RICHMOND	23.34	TC	NOT TESTED	NOT TESTED	19.96	SC
			12"	BURKE	28.73	I	NOT TESTED	NOT TESTED	39.42	I
				DAYTON SUPERIOR	20.80	TC	NOT TESTED	NOT TESTED	42.43	SC
				RICHMOND	28.51	TC	NOT TESTED	NOT TESTED	50.18	SC
	FERRULE LOOP	15"	6"	DAYTON SUPERIOR	27.43	TC, WF	19.27	WF	19.58	SC
				MEADOW STEEL	24.32	TC, LF	11.67	WF	19.33	SC
			12"	DAYTON SUPERIOR	27.65	TC, WF	19.27	WF	30.41	SC
				MEADOW STEEL	25.55	TC, LF	11.67	WF	37.96	SC

NOTES: 1) The concrete compressive strength, f'c, of slabs tested ranged from 4550 psi to 5800 psi. All the results have been normalized to correspond to a compressive strength of 5000 psi.

$$\left(S_{5000} = S\sqrt{\frac{5000}{f'c}} \right).$$ S = Ultimate Shear Load, S_{5000} = Normalized Ultimate Shear Load

2) I = Insert Failed at Threaded Portion. LF = Loop Failed. WF = Weld Failed. BF = Bolt Failed.

TC = Tension Cone
SC = Shear Cone

load for cast-in-place concrete inserts is shown in Table 5. Loads have been normalized to correspond to a concrete compressive strength of 4000 psi. The concrete strengths used in the manufacturer's tests ranged from 3000 to 4100 psi. A factor of safety, F.S.= 4:1, has been used for all ferrule loop inserts (except for Richmond, F.S.=3:1), and a factor of safety of 3:1 has been used for all cast-iron inserts (except for Richmond F.S.=4:1) by the manufacturers to determine the recommended working loads. The ultimate load of inserts versus edge distance are shown in Figures 28 and 29.

6.1.2 Test Results With Low Strength Concrete

The results of tension and shear tests with low strength concrete are shown in Figures D-1 through D-8 in Appendix D. Table A-2 in Appendix A is the summary of test data. The compressive strength of tested slabs ranged from 3250 to 4259. So the average ultimate loads were normalized to correspond to a compressive strength of 3500 psi, and results are shown in Table 6. The ultimate load versus edge distance is shown in Figures 30 and 31.

6.1.3 Test Results of Inserts With Different Corrosion Protection Coatings

The results of tension and shear tests on hot-dip galvanized and stainless steel ACME ferrule loop inserts and on Dayton Superior mechanically galvanized cast iron are shown in Figures E-1 through E-6 in Appendix E. Table 7 is the summary of the

Table 5. Summary of Ultimate Load and Manufacturer Recommended Working Load for Cast–in–Place Concrete Inserts

Concrete Compressive Strength, f'c, = 4000 psi

SIZE	TYPE OF LOAD	EDGE DISTANCE	ULTIMATE LOAD (DETERMINED BY TESTS CONDUCTED BY TRANSLAB), kips						AVERAGE ULTIMATE LOAD kips	STANDARD DEVIATION kips	AVG LOAD MINUS STANDARD DEVIATION kips
			CAST IRON			FERRULE LOOP					
			BURKE	DAYTON SUPERIOR	RICHMOND	DAYTON SUPERIOR	MEADOW STEEL	RICHMOND			
1/2"	TENSION	6"	9.63	9.26	10.55				9.81	0.54	9.27
						9.49	9.19	8.55	9.08	0.39	8.69
	SHEAR	6"	11.85	11.75	11.30				11.63	0.24	11.39
						11.00	10.95	10.84	10.93	0.07	10.86
3/4"	TENSION	8"						16.61	16.61	0	16.61
	SHEAR	8"						20.30	20.30	0	20.30
1"	TENSION	12"	25.70	18.6	25.50				23.27	3.30	19.97
						24.73	22.85		23.79	0.94	22.85
	SHEAR	12"	35.26	37.95	44.88				39.36	4.05	35.31
						27.20	33.95		30.58	3.38	27.20
			MANUFACTURER RECOMMENDED WORKING LOAD, kips								
1/2"	TENSION	6"	1.73	1.73	2.43				1.97	0.33	1.64
						1.73	2.00	3.26	2.33	0.66	1.67
5/8"	TENSION	8"	3.00	2.31	3.35				2.89	0.43	2.45
						2.08	2.96	4.18	3.07	0.86	2.21
3/4"	TENSION	8"	4.22	2.89	3.35				3.49	0.55	2.94
						2.08	3.56	4.23	3.29	0.90	2.39
7/8"	TENSION	12"	5.54	3.46	4.70				4.57	0.85	3.71
						4.62	5.85		5.24	0.62	4.62
1"	TENSION	12"	6.81	3.46	4.70				4.99	1.38	3.61
						4.62	4.94		4.78	0.16	4.62

NOTES: 1) The concrete compressive strength, f'c, of slabs tested ranged from 4550 psi to 5800 psi. All the results, including the manufacturer recommended working loads, have been normalized to correspond to a compressive strength of 4000 psi.

$$\left(T_{4000} = T\sqrt{\frac{4000}{f'c}} \right), \quad T = \text{Ultimate Tensile Load}, \quad T_{4000} = \text{Normalized Ultimate Tensile Load}$$

2) A factor of safety of 4:1 has been used for all ferrule loop inserts (except for Richmond: F.S.= 3:1), and a factor of safety of 3:1 has been used for all cast-iron inserts (except for Richmond: F.S.= 4:1)

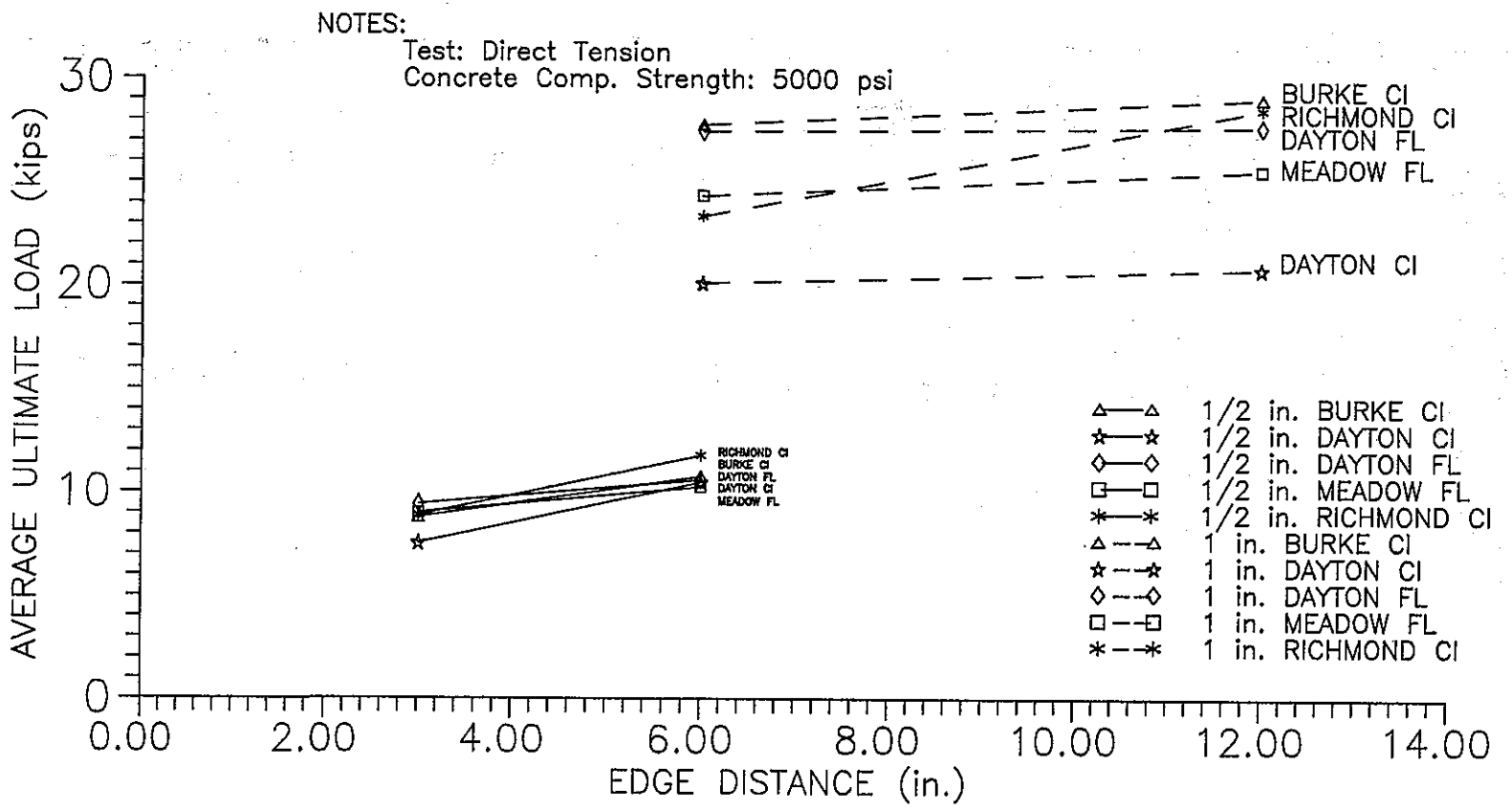


Figure 28. Average normalized ultimate load vs. edge distance for cast-in-place concrete inserts.

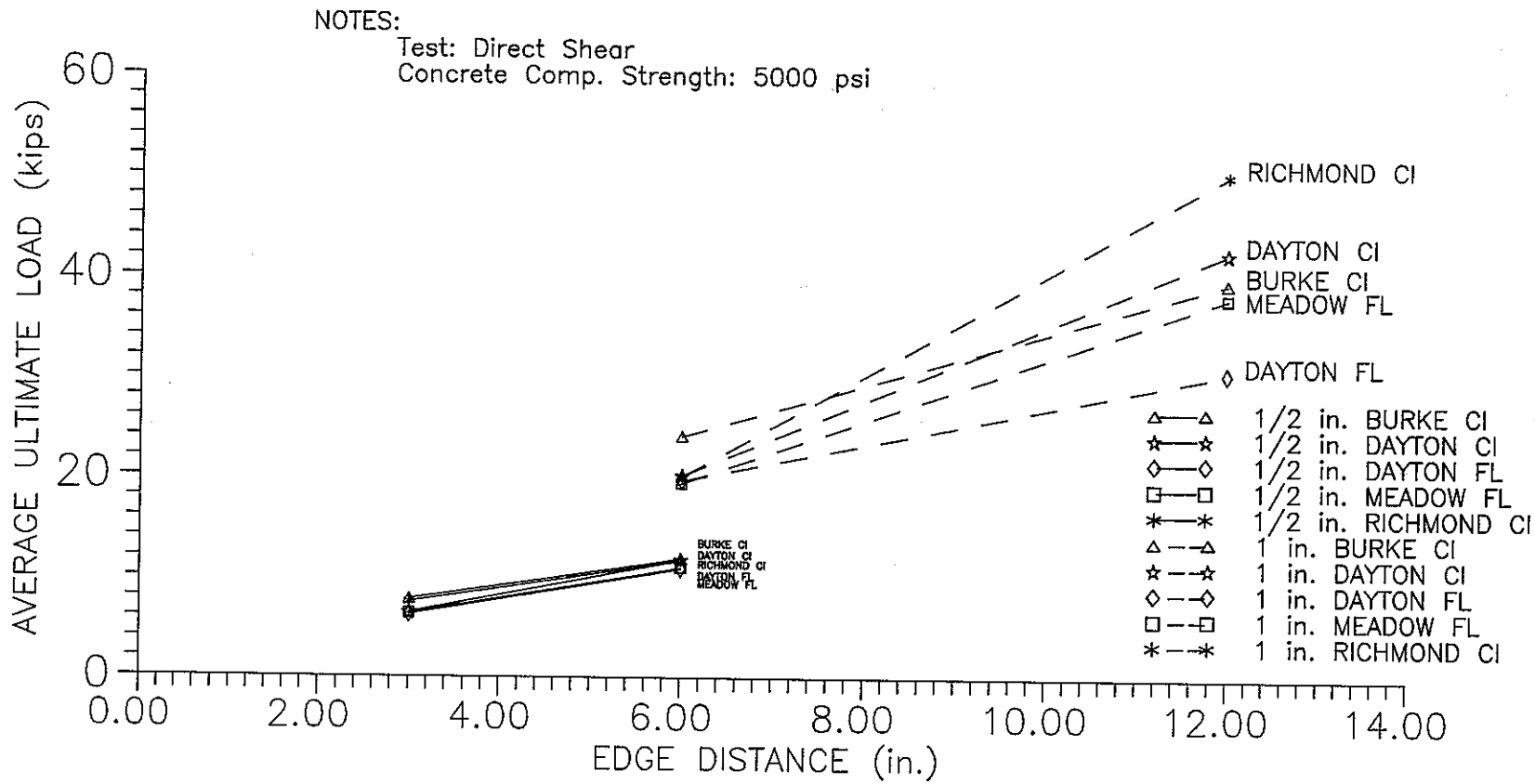


Figure 29. Average normalized ultimate load vs. edge distance for cast-in-place concrete inserts.

Table 6. Summary of Test Results for Cast-in-Place Concrete Inserts

Concrete Compressive Strength, f'c = 3500 psi

SIZE	TYPE	SLAB THICKNESS	EDGE DISTANCE	MANUFACTURER	TENSION TEST RESULTS		SHEAR TEST RESULTS	
					ULTIMATE LOAD, Tu (kips)	FAILURE MODE	ULTIMATE LOAD, Su (kips)	FAILURE MODE
1/2"	CAST IRON	8"	3"	DAYTON SUPERIOR	7.73	TC	6.57	SC
			6"		9.21	TC	10.59	BF
	FERRULE LOOP	8"	3"	MEADOW STEEL	6.90	TC	4.88	SC
			6"		9.47	TC	11.10	BF
1"	CAST IRON	15"	6"	DAYTON SUPERIOR	13.56	TC	17.69	SC
			12"		17.21	TC	33.24	SC
	FERRULE LOOP	15"	6"	MEADOW STEEL	22.30	TC, LF	13.87	SC
			12"		24.32	TC, LF	33.01	SC

NOTE: The concrete compressive strength, f'c, of slabs tested ranged from 3250 psi to 4257 psi. All the results have been normalized to correspond to a compressive strength of 3500 psi.

$$\left(S_{3500} = S\sqrt{\frac{3500}{f'c}} \right),$$

S = Ultimate Shear Load S_{3500} = Normalized Ultimate Shear Load

TC = Tension Cone LF = Loop Failure
SC = Shear Cone BF = Bolt Failure

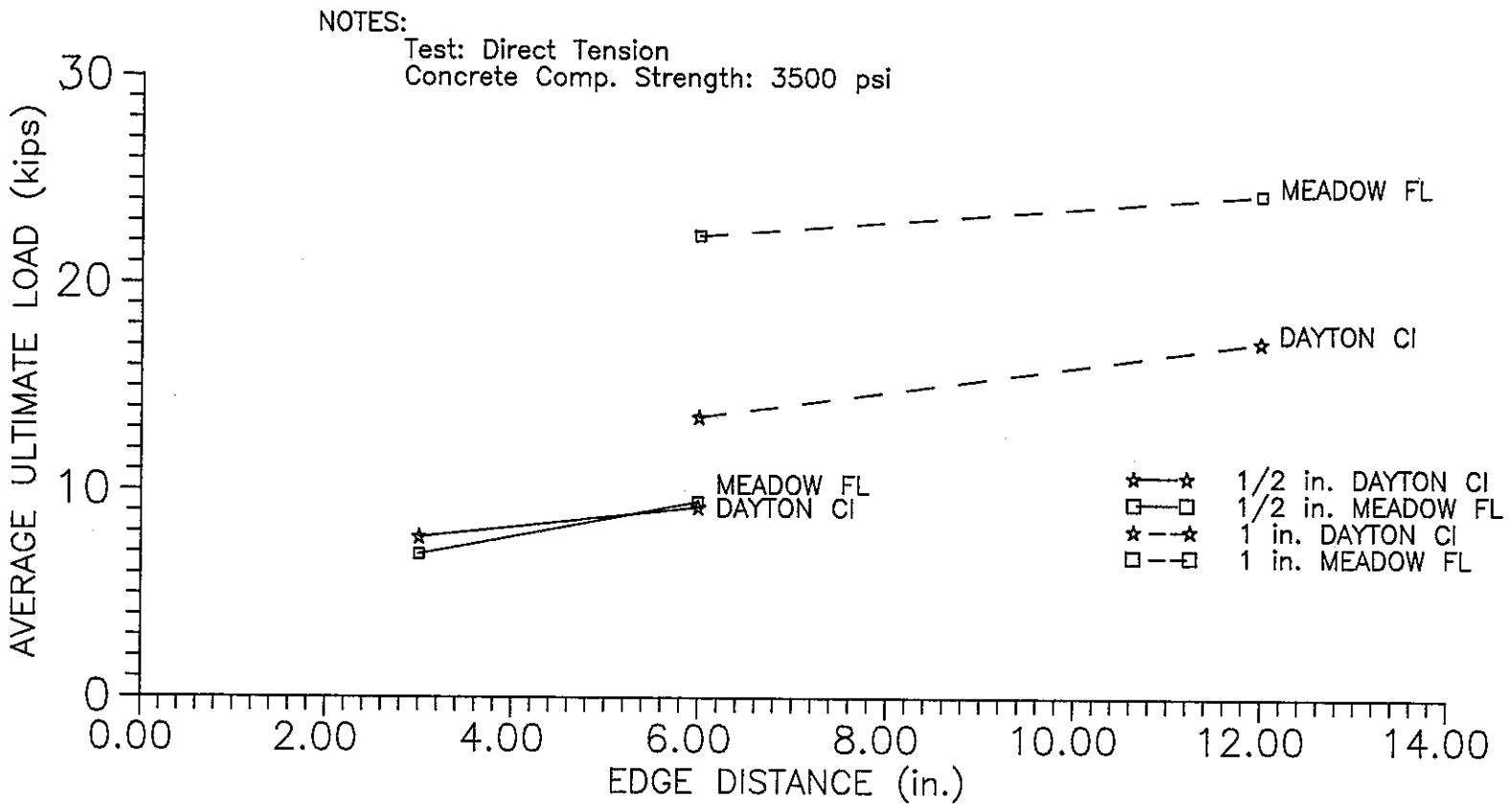


Figure 30. Average normalized ultimate load vs. edge distance for cast-in-place concrete inserts.

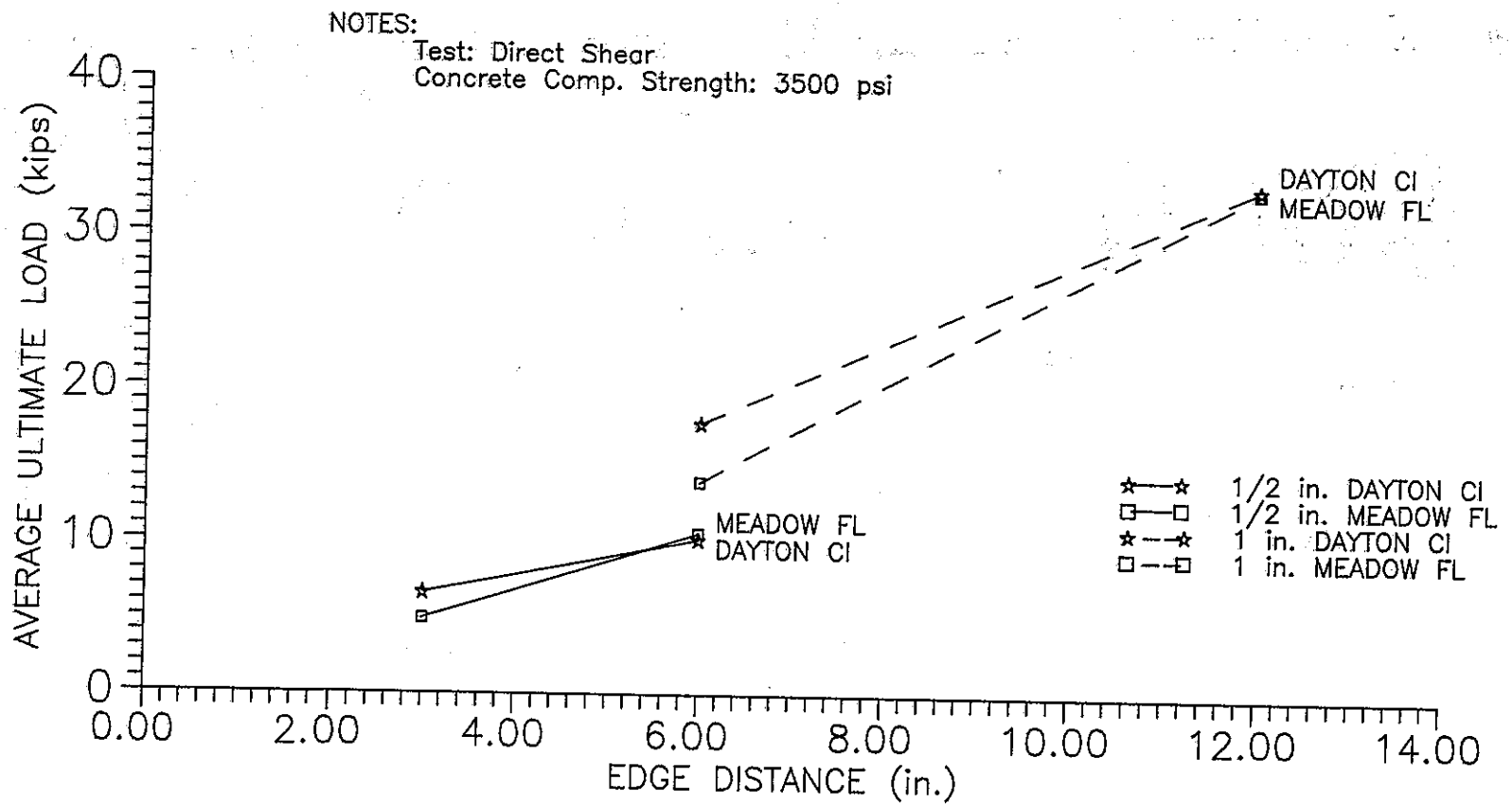


Figure 31. Average normalized ultimate load vs. edge distance for cast-in-place concrete inserts.

Table 7. Summary of Test Results for Cast-In-Place Concrete Inserts with Different Types of Corrosion Protection Coatings

SIZE	TYPE OF LOAD	EDGE DIST	ULTIMATE LOADS DETERMINED BY TRANSLAB				
			CAST IRON		FERRULE LOOP		
			DAYTON SUPERIOR		MEADOW STEEL (ACME)		
			PLAIN (KIP)	MECH. GALVANIZED (KIP)	PLAIN (KIP)	HOT-DIP GALVANIZED (KIP)	STAINLESS STEEL (KIP)
1/2 "	TENSION	3 "	7.52	6.98	8.99	7.50	10.72
	SHEAR	3 "	6.40	7.16	6.33	5.81	6.56

NOTE: ULTIMATE LOAD VALUES HAVE BEEN NORMALIZED TO CORRESPOND TO A CONCRETE COMPRESSIVE STRENGTH OF 5000 psi.

average ultimate loads normalized to 5000 psi concrete compressive strength. The table also includes the results of the same inserts with no corrosion protection coating.

6.2 Results of Combined Tension and Shear Tests

The results of combined tension and shear tests are shown in Figures F-1 through F-32 in Appendix F. For each insert at a specified edge distance, the insert was loaded to failure in shear while the tension load was kept constant at approximately .25Tu, .50Tu, and .75Tu. Tu is the average ultimate tension load for the insert at the corresponding edge distance obtained from direct tension tests. Table A-3 in Appendix A is the summary of test data. The average ultimate shear loads were then normalized to correspond to a compressive strength of 5000 psi. The relationships between S/Su (S is the average ultimate shear from combined loading tests, Su is the average ultimate shear from direct shear tests) and T/Tu (T is the applied tension from combined tests, and Tu is the average ultimate tension from direct tension tests) are shown in Figures 32 and 33. The solid line on Figure 32 represents the equation:

$$(T/Tu)^{4/3} + (S/Su)^{4/3} = 1$$

This is similar to equation 5.13-8: $(P_u/\Phi P_c)^{4/3} + (V_u/\Phi V_c)^{4/3} = 1$, recommended by Prestressed Concrete Institute (PCI) (8). As shown the data are widely scattered, however, the equation is close to average for all tests.

NOTE:
Failure Mode: Concrete Failed

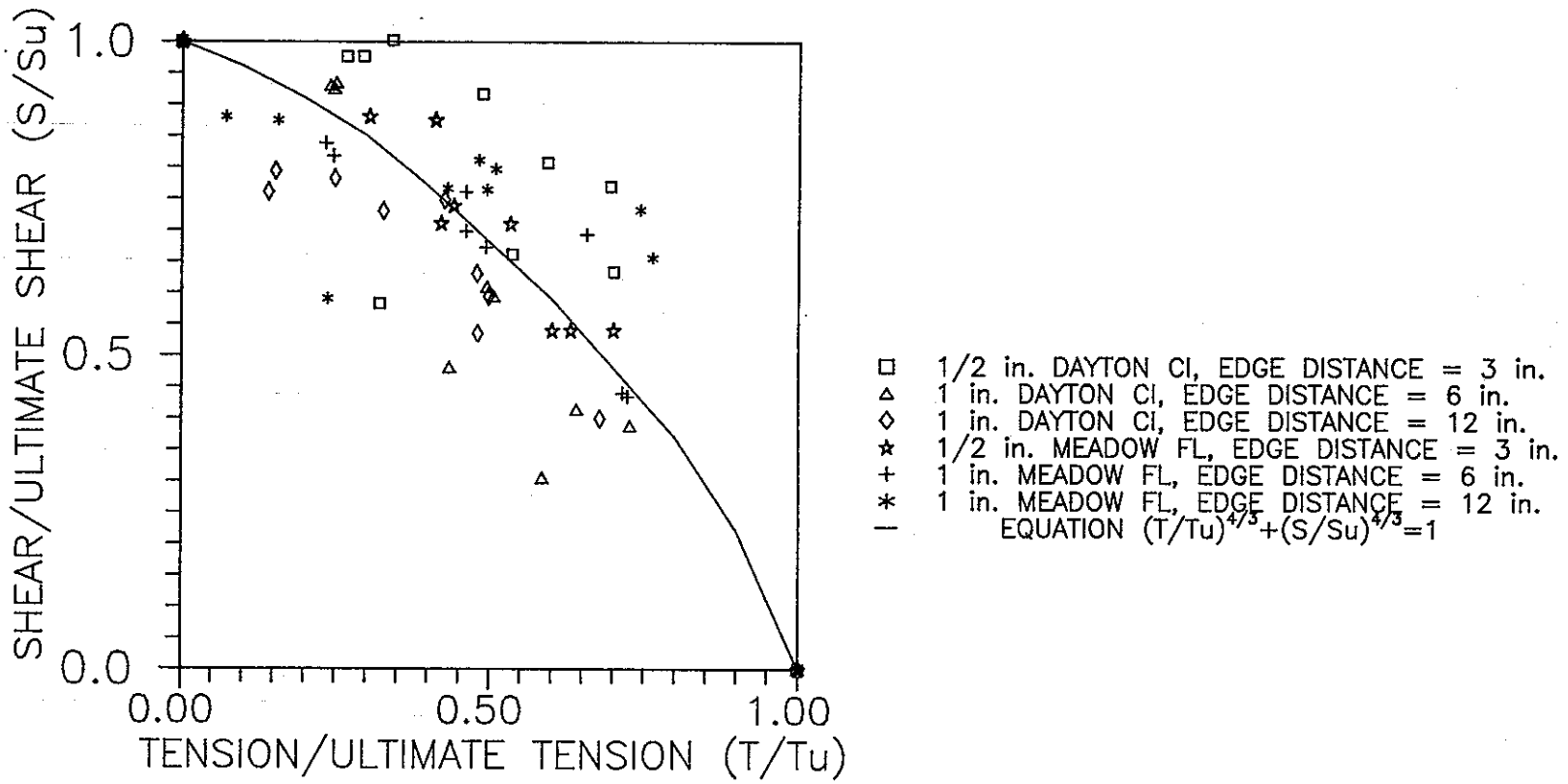


Figure 32. Results of combined tests for cast-in-place concrete inserts.

NOTE:
Failure Mode: Threaded Rods Failed

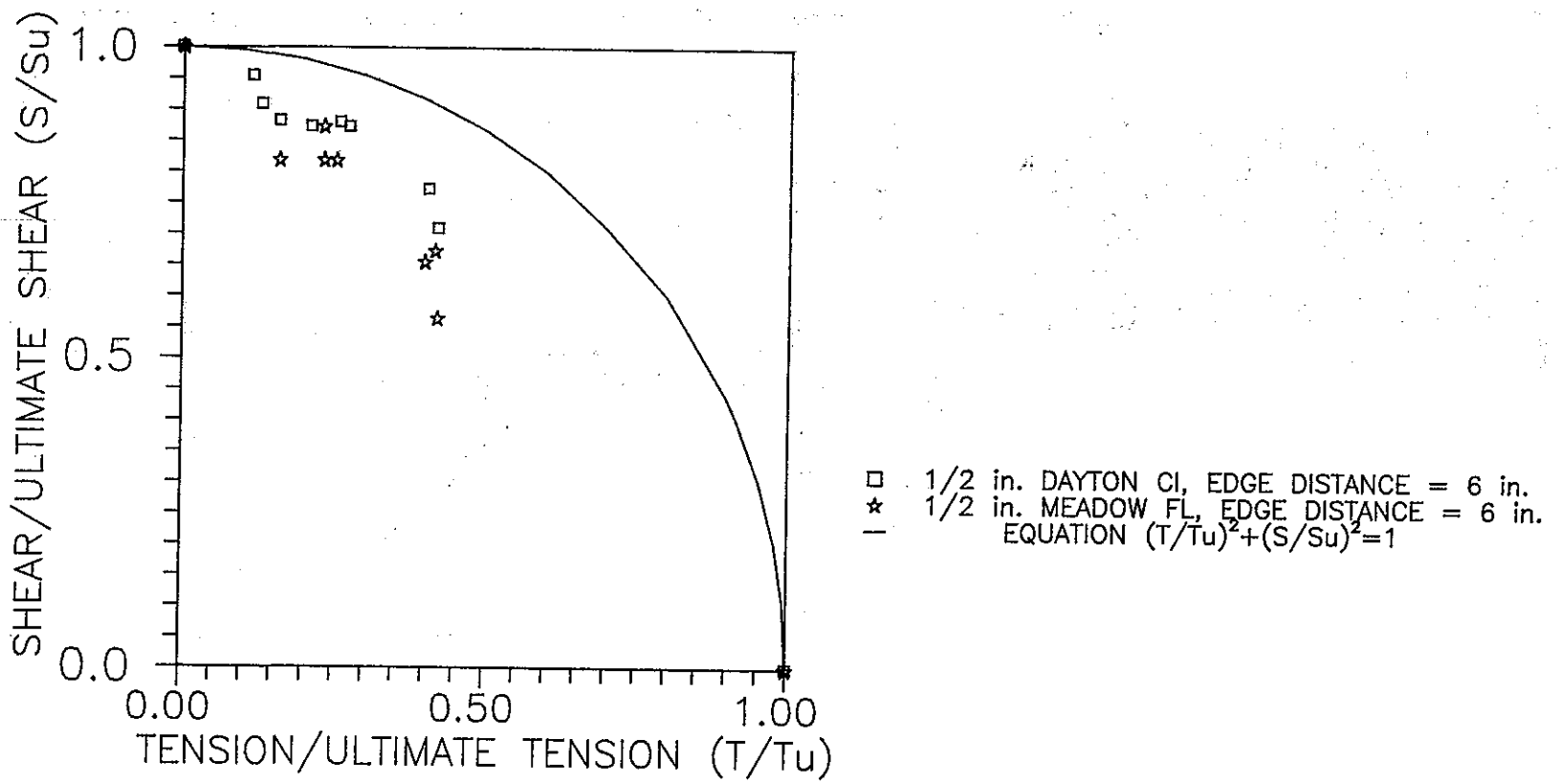


Figure 33. Results of combined tests for cast-in-place concrete inserts.

The solid line on Figure 33 is plotted from the equation:

$$(T/T_u)^2 + (S/S_u)^2 = 1$$

It is similar to the equation listed in the AISC Steel Construction Manual (AISC) (7): $(f_t/F_t)^2 + (f_v/F_v)^2 = 1$. As shown, all data points are below the solid line.

6.3 Results of Direct Tension Tests of Ferrule Loop Inserts

The results of direct tension tests of ferrule loop inserts are shown in Table 8.

6.4 Results of Corrosion Tests

Eighteen 1/2-in. cast-in-place inserts, manufactured by Richmond Screw Anchor Company, were tested for corrosion according to procedure outlined in section 5.3.5. A summary of the test results is presented in Table 9.

By examining the test results, 1000 hours appears to be an insufficient amount of time to observe significant amounts of corrosion on the inserts. It is recommended that the salt spray (fog) test be carried out for substantially longer than 1000 hours. However, due to time limitations and funding, further salt spray (fog) testing is beyond the scope of this project.

Table 8. Results of Direct Tension Testing of Selected Ferrule Loop Cast-in-Place Inserts

SIZE	DAYTON SUPERIOR		MEADOW STEEL (ACME)		RICHMOND	
	Ult. Load, Tu (Kips)	Failure Mode	Ult. Load, Tu (Kips)	Failure Mode	Ult. Load, Tu (Kips)	Failure Mode
1/2 "	8.23	Loop Failure	9.08	Loop Failure	9.06	Loop Failure
1 "	19.27	Weld Failure	11.67	Weld Failure	N/A	N/A

NOTE: Ferrule Loop Inserts Were Directly Tested Using a Universal Testing Machine (Ferrule Loop Inserts Were Not Cast In Concrete).

Table 9. Salt Spray (Fog) Chamber Test Results for Richmond Ferrule Loop and Cast Iron Concrete Inserts

		Number of Hours Within the Salt Spray (Fog) Chamber		
		250	500	1000
Zinc Plated	FL	A	A	A
Stainless Steel	FL	A	A	A
Plain	FL	C	C	C
	CI	B	B	B
Galvanized	FL	A	A	A
	CI	A	A	A

NOTE: A: No Corrosion
B: Mildly Corroded – Top Surface of Insert Only
C: Mildly Corroded – Throughout insert

FL: Ferrule Loop Insert
CI: Cast Iron Insert

7. Discussion of Test Results

7.1 Direct Tension Tests

Five replicate tests were conducted at each edge distance for each insert. Ferrule loop inserts had three replicate tests with the wire loop oriented perpendicular to the edge of the concrete and two with the wire loop oriented parallel. The same orientation was applied to the Dayton Superior cast-iron insert. Test results showed that the orientation of the loop relative to the edge of the concrete did not have much effect on the ultimate load for all edge distances.

There was not much variation in the ultimate load for different brands of the 1/2" ferrule loop and cast iron. The ultimate loads for 1/2" ferrule loop and cast iron were also close. The mode of failure for 1/2" ferrule loop at 3" and 6" edge distances was tension cone with mostly a weld failure for Dayton Superior and loop failure for Meadow Steel and Richmond, Figure 34, and 35.

The mode of failure for 1/2" cast iron at 3" and 6" edge distance was tension cone, Figure 36. The ultimate load changed a maximum of 27% when the edge distance increased from 3" to 6".

The mode of failure for 1" ferrule loop at 6" and 12" edge distances was tension cone with weld failure for Dayton Superior and loop failure for Meadow Steel, however,

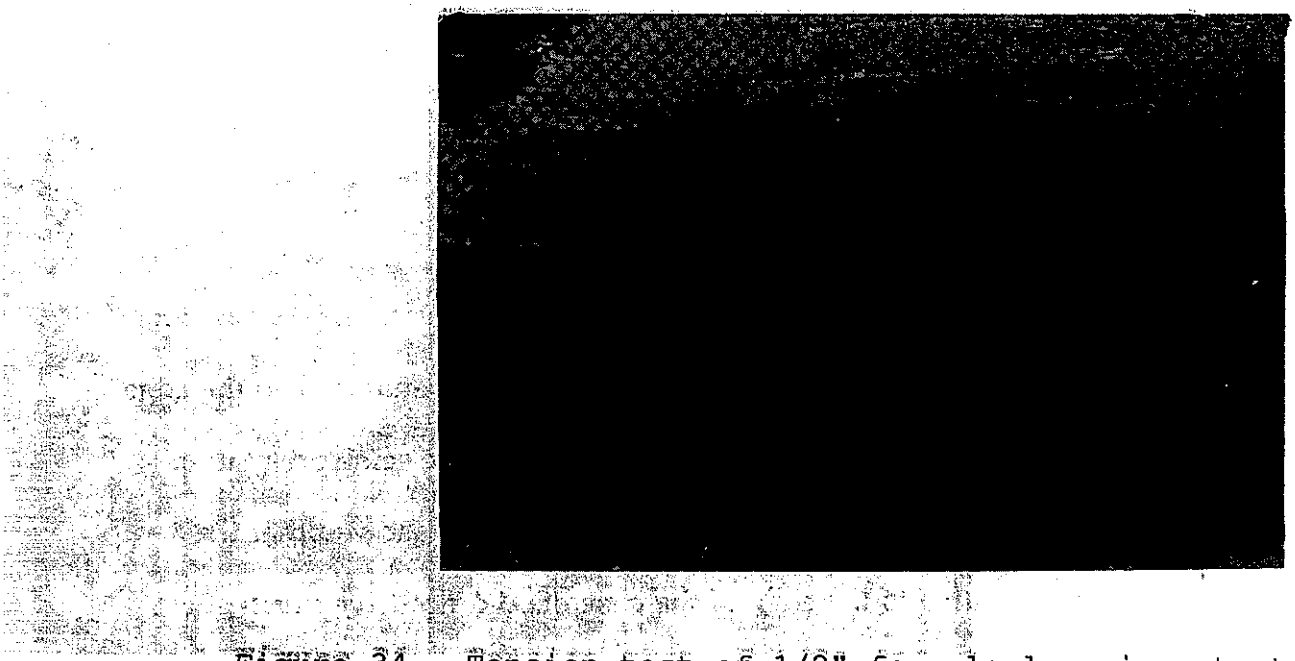


Figure 34. Tension test of 1/2" ferrule loop insert at 3" edge distance with weld failure.

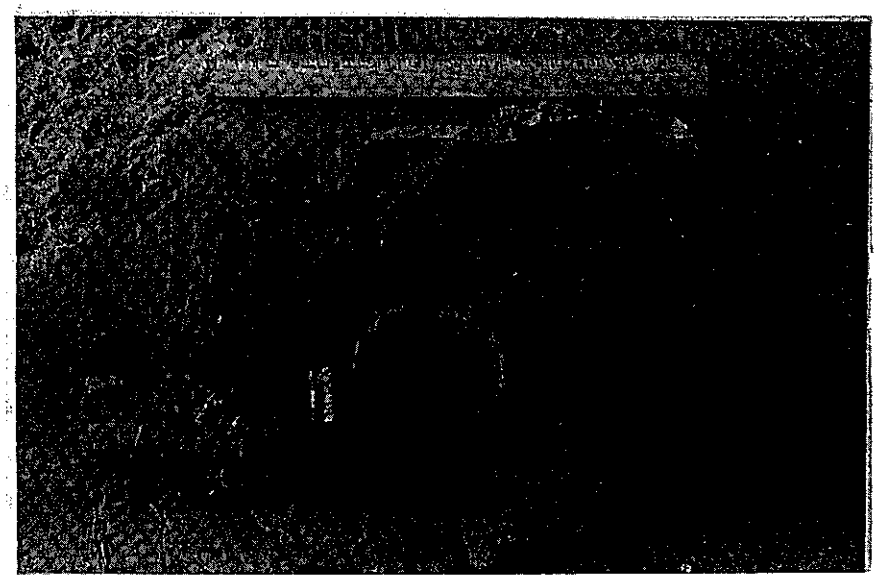


Figure 35. Tension test of 1/2" ferrule loop insert at 6" edge distance with loop failure.

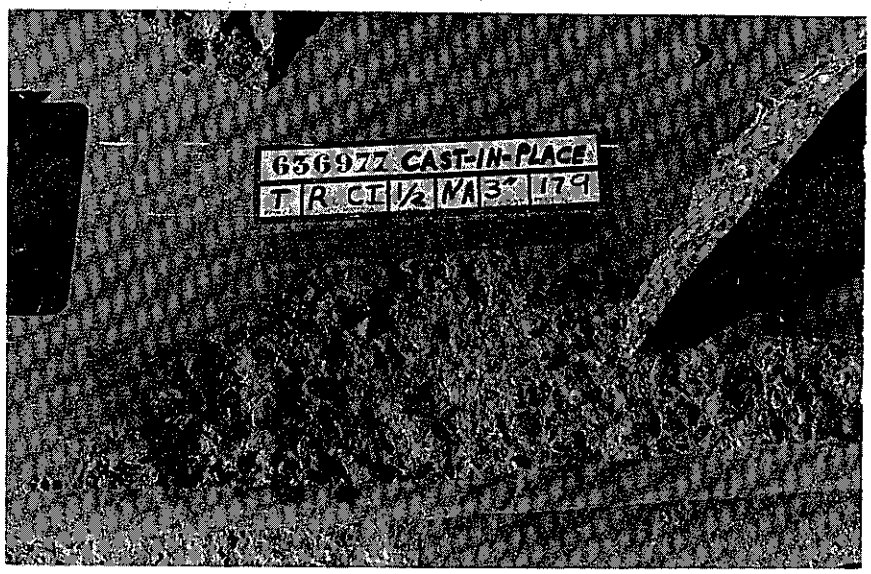


Figure 36a. Tension test of 1/2" cast-iron insert at 3" edge distance.

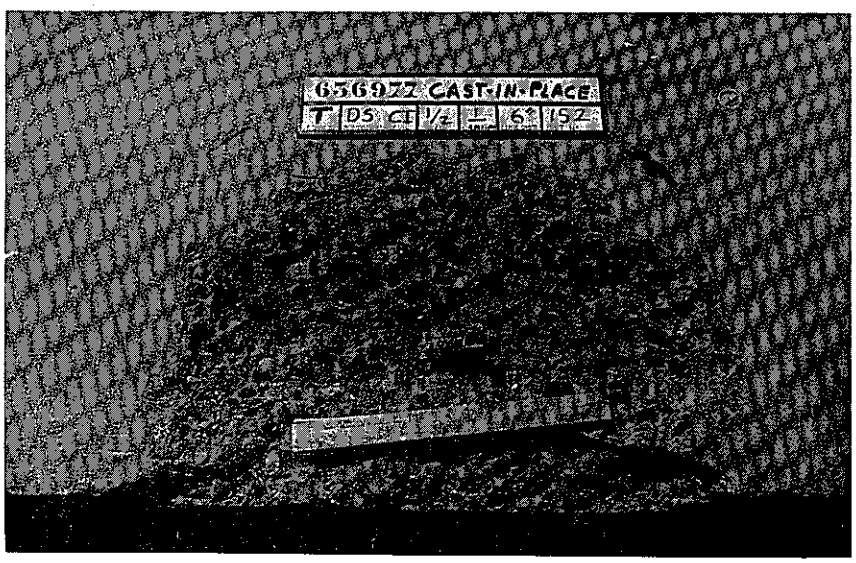


Figure 36b. Tension test of 1/2" cast-iron insert at 6" edge distance.

Dayton Superior had a higher ultimate load (The 1" Dayton Superior weld strength was about 40% more than that of Meadow Steel when both inserts were tested in direct tension). The modes of failure are shown in Figures 37 and 38. The Dayton Superior cast-iron insert had the lowest tensile load (about 40% lower than other brands tested). The mode of failure was a tension cone. In most cases, the Burke cast-iron insert failed at the threaded portion when tested at 12" edge distance. Different modes of failure are shown in Figures 39, and 40. In all cases, the tension cones had a 30 to 45 degree angle with the horizontal plane.

There was not much difference in the ultimate load for 1" inserts (maximum 18%) when the edge distance was increased from 6" to 12". The displacement of different brands of cast-iron inserts at ultimate load were nearly the same (about 0.025") and were less than that of ferrule loop inserts. This was about 0.035" for ACME, 0.03" to 0.07" for Dayton Superior, and 0.05" to 0.1" for Richmond ferrule loop inserts. Test results (Table 5) show that the recommended working loads by manufacturers are conservative.

The range of the manufacturer's ultimate tensile loads (normalized to a concrete compressive strength of 4000 psi) is compared with the ultimate loads required by Caltrans (Appendix H) in Table 10.

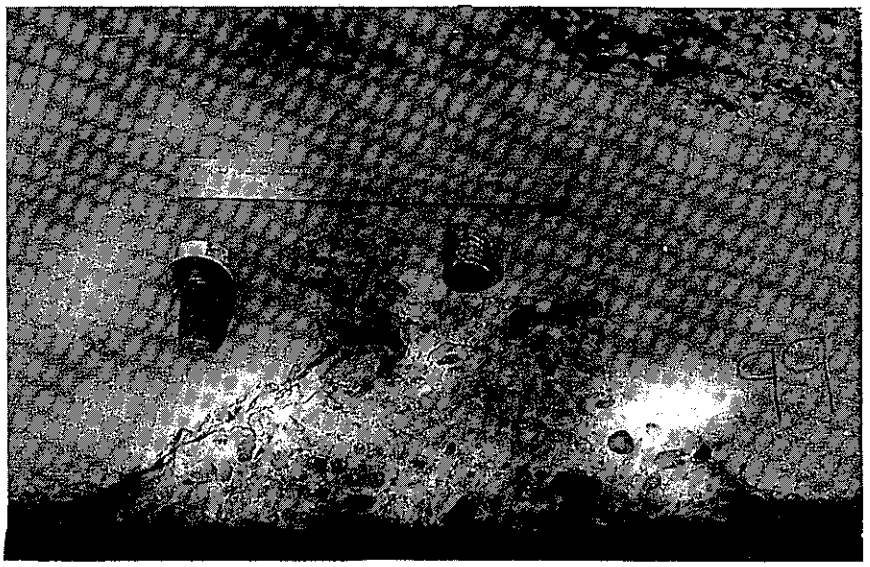


Figure 37. Tension test of 1" ferrule loop insert at 6" edge distance with weld failure.

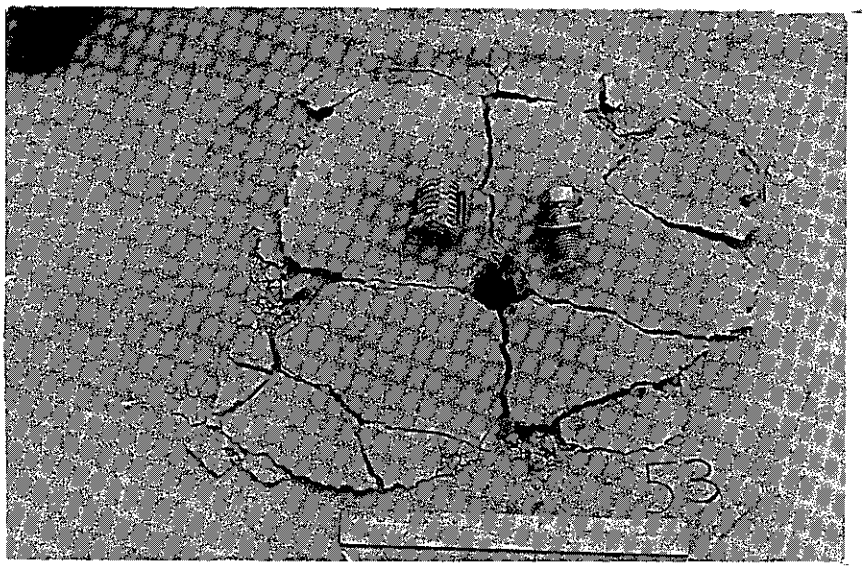


Figure 38. Tension test of 1" ferrule loop insert at 12" edge distance with loop failure.

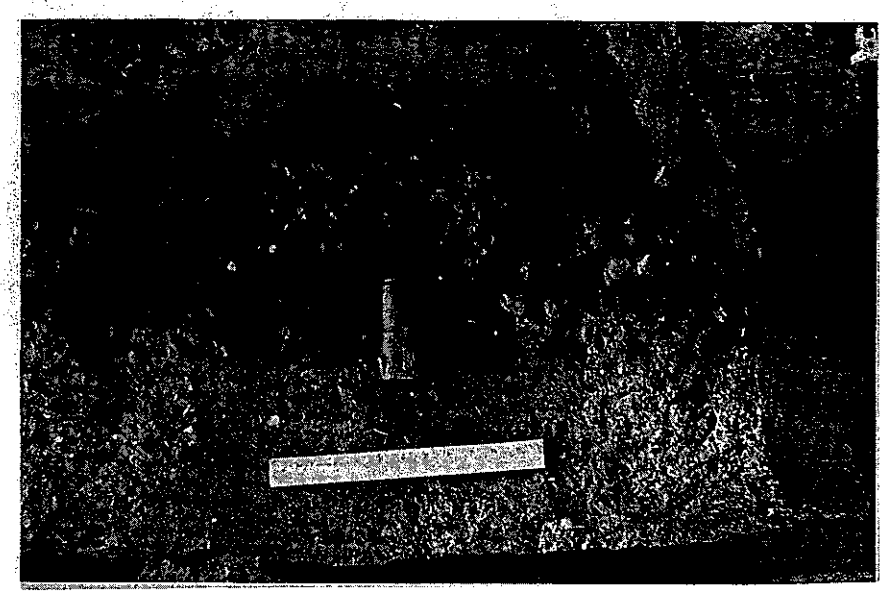


Figure 39. Tension test of 1" cast-iron insert at 6" edge distance.

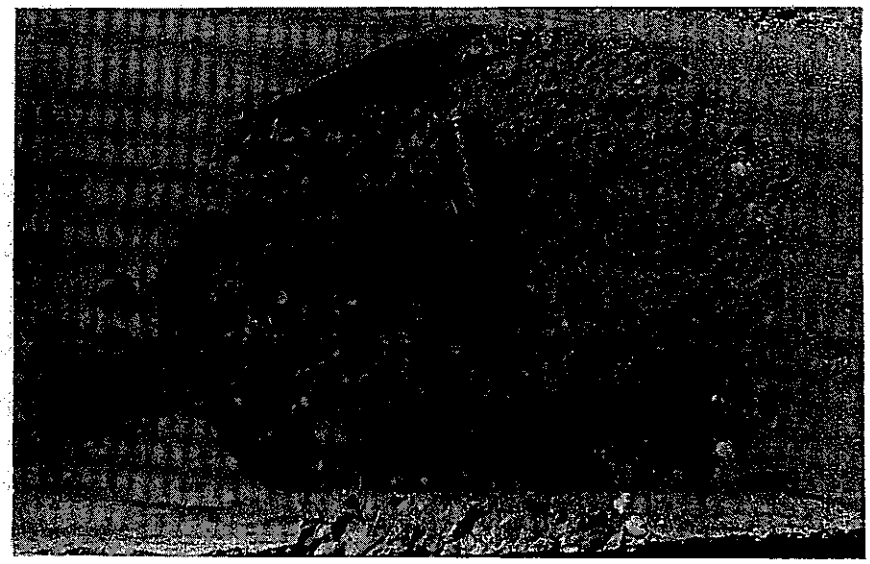


Figure 40. Tension test of 1" cast-iron insert at 12" edge distance.

Table 10. Comparison of Ultimate Tensile Loads Recommended by Manufacturers with Ultimate Tensile Loads Required by Caltrans

Stud	Ultimate Tensile Strength, lb Ferrule Loop				Ultimate Tensile Strength, lb Cast–Iron			
Dia. in.	Dayton Superior	Richmond	ACME	Caltrans	Burke	Dayton Superior	Richmond	Caltrans
1/2	6900	9500	8000	6900	5200	5200	9700	5200
5/8	8300	12100	11900	8300	9000	6900	13400	9000
3/4	8300	12300	14200	8300	12600	8700	13400	12600
7/8	18500		23400	18500	16600	10400	18800	16600
1	18500		19800	18500	20400	10400	18800	18800

Note:

Ultimate loads have been normalized to correspond to a concrete compressive strength of 4000 psi.

7.2 Direct Shear Tests

Five replicate tests were conducted at each edge distance for each insert. Ferrule loop inserts had three replicate tests with the wire loop oriented perpendicular to the edge of the concrete and two with the wire loop oriented parallel. The same orientation was applied to the Dayton Superior cast-iron insert (other cast-iron inserts were symmetric). Test results showed that the orientation of the loop relative to the edge of the concrete did not have much effect on the ultimate load.

The ultimate shear load for different brands of 1/2" ferrule loop inserts and 1/2" cast-iron inserts were close. The ultimate load increased about 40% when edge distance increased from 3" to 6".

The mode of failure of 1/2" inserts (ferrule loop and cast iron) at 3" edge distance was shear cone (Figure 41), and the 1/2" insert at 6" edge distance caused failure of the threaded stud (ductile failure), Figure 42. In general cast-iron inserts had higher ultimate loads than the ferrule loop inserts.

The mode of failure of 1" inserts at 6" edge distance was shear cone, Figure 43, and for 1" inserts at 12" edge distance either shear cone or failure of the threaded portion of the insert, Figure 44. In all cases the shear cones had about 45 degree angle with the horizontal plane.

Test results (Table 5) show that the working loads recommended by manufacturers

Figure 41. Shear test of 1/2" ferrule loop insert at 3" edge distance.

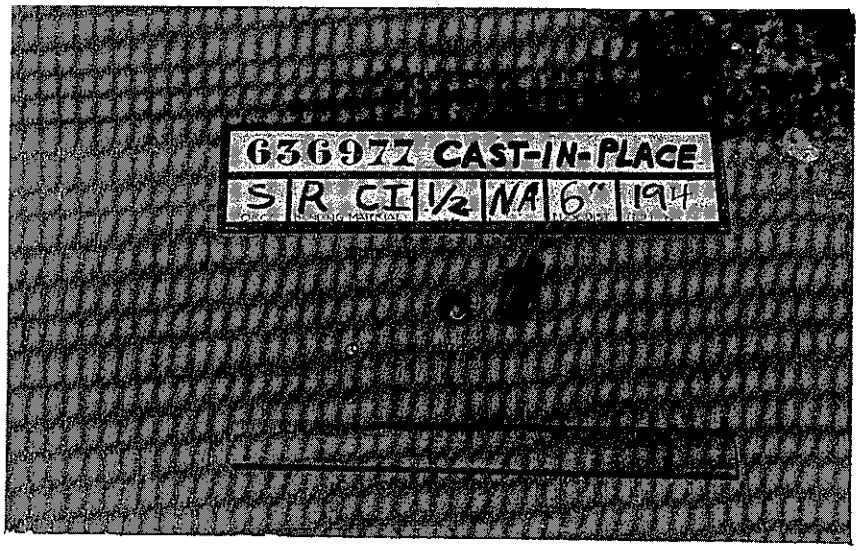


Figure 42. Shear test of 1/2" cast-iron insert at 6" edge distance.

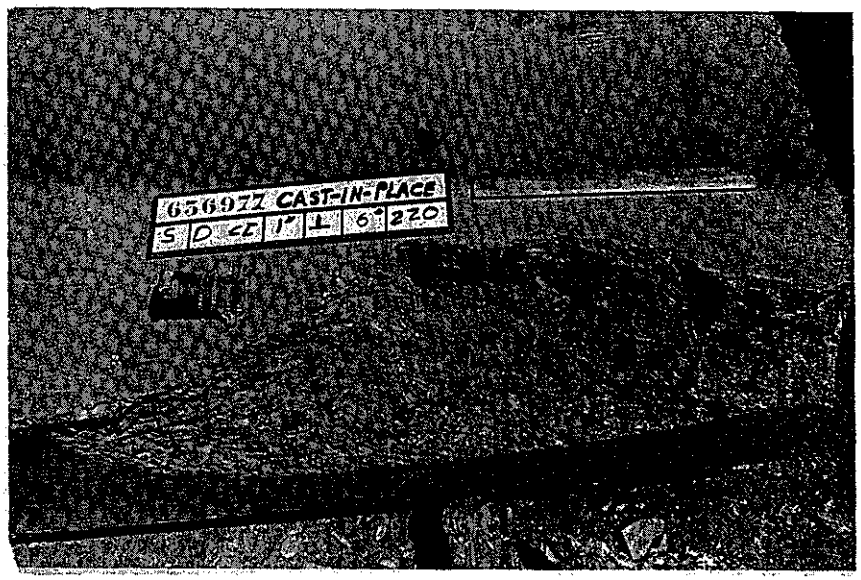


Figure 43. Shear test of 1" cast-iron insert at 6" edge distance.

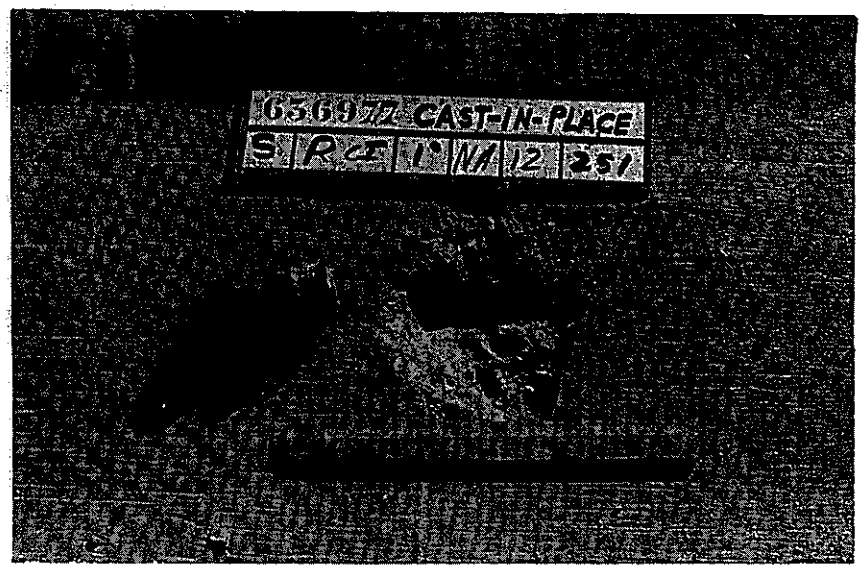


Figure 44. Shear test of 1" cast-iron insert at 12" edge distance.

are conservative.

7.3 Direct Tension and Direct Shear Tests With Low Strength Concrete

Only one brand of ferrule loop (Meadow Steel) and one brand of cast iron (Dayton Superior) were tested. As expected, the ultimate loads were mostly lower than those of 5000 psi concrete. Plots of ultimate load versus square root of concrete strength, Figures 45 and 46, show that the variation of ultimate load as a function of $\sqrt{f'c}$ is approximately linear. This relationship has been used throughout this project to normalize the results.

7.4 Direct Tension and Shear Tests of Inserts With Different Corrosion Protection Coatings

The results of very limited number of tests performed on inserts with different corrosion protection coatings showed that the ultimate tensile and ultimate shear capacity of hot-dip galvanized ferrule loop inserts were about 20% and 10% lower than those of the plain insert (insert with no coating) respectively.

7.5 Combined Tension and Shear Loading Tests

The results of combined tension and shear tests were first normalized and then on a nondimensionalized interaction curve S/Su versus T/Tu was plotted. Two interaction

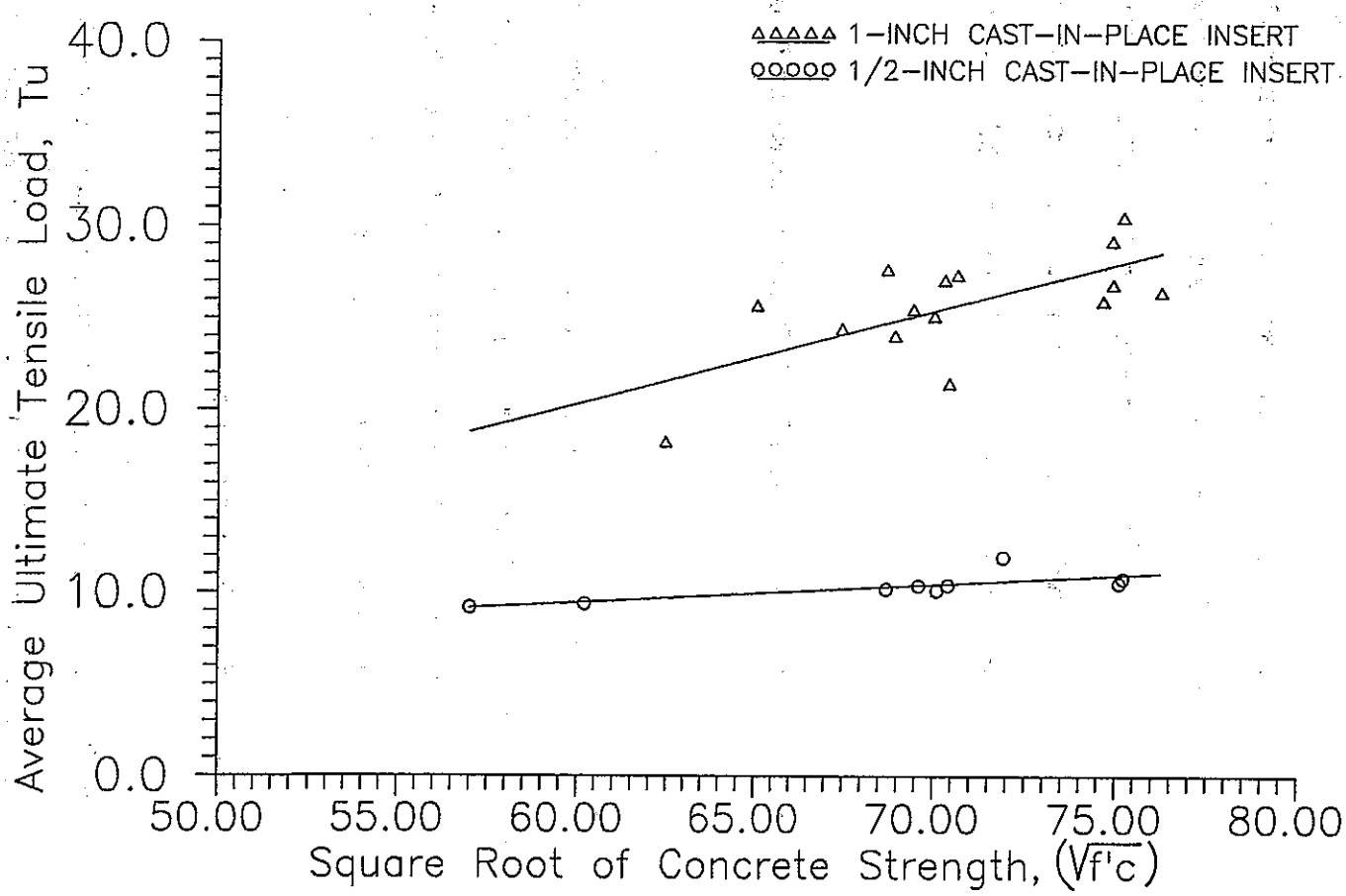


Figure 45. Average Ultimate Tensile Load vs. Square Root of Concrete Compressive Strength.

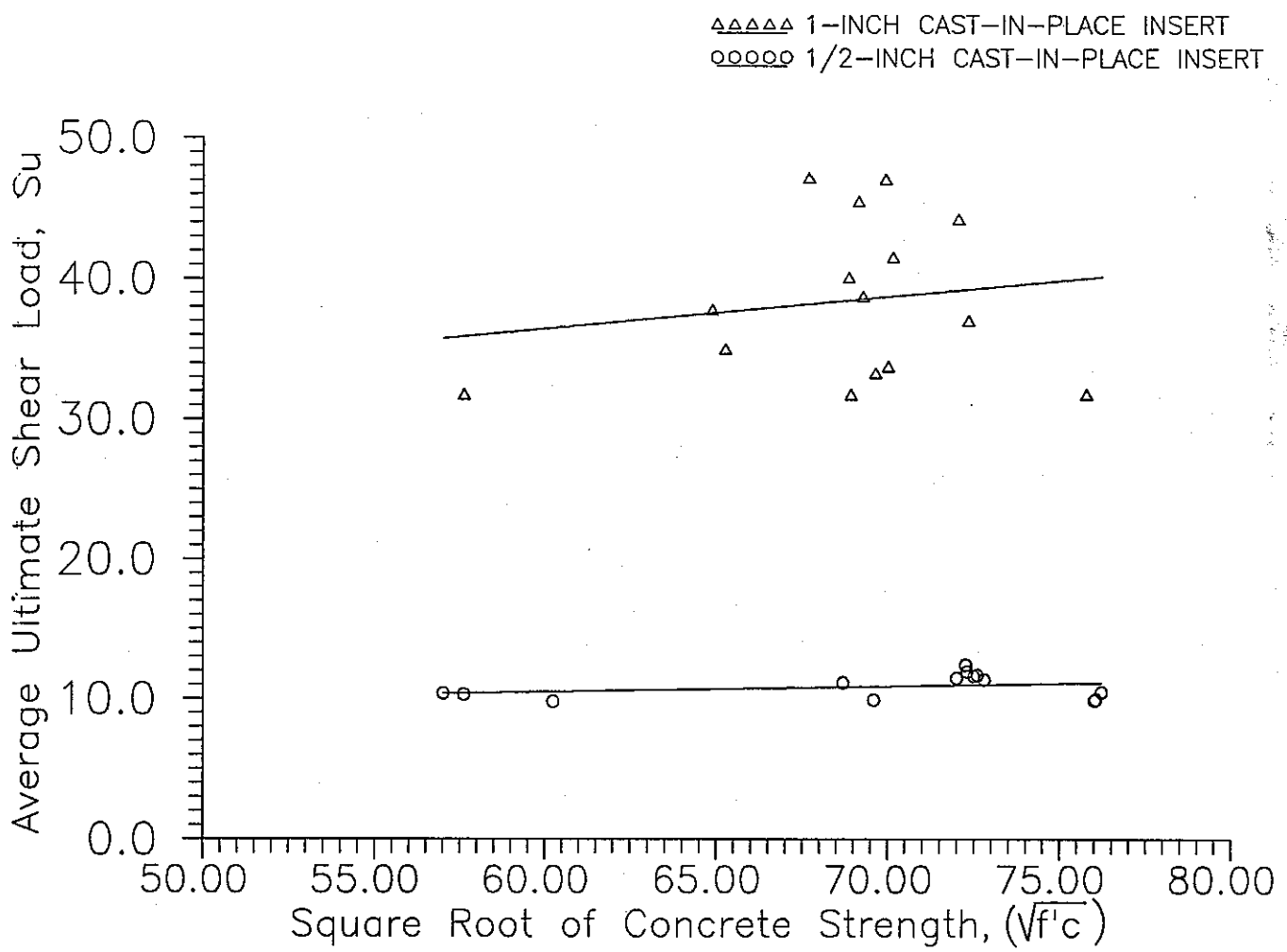


Figure 46. Average Ultimate Shear Load vs. Square Root of Concrete Compressive Strength.

curves were developed for two different modes of failure: concrete failure and threaded rod failure.

Along with research data, the interaction equation representing concrete strength: $(T/T_u)^{4/3} + (S/S_u)^{4/3} = 1$, was plotted as solid line in Figure 32. The data are widely scattered, however, this equation seems to represent an average of the data gathered in this research.

In Figure 33, the interaction equation representing strength of bearing-type fasteners: $(T/T_u)^2 + (S/S_u)^2 = 1$, was plotted along with research data. It seems that all research data points are below this equation.

From test results plotted, it is apparent that without using appropriate reduction factors, either equation could result in an unconservative design.

7.6 Insert Tests

7.6.1 Corrosion Test

By examining the limited test results, the zinc plated, stainless steel, and galvanized ferrule loop and cast-iron inserts showed little or no corrosion. The plain cast-iron insert showed mild corrosion along the top surface of the insert only. The plain ferrule loop insert was found to be mildly corroded throughout the insert (Table 9).

However, 1000 hours appears to be an insufficient amount of time to observe a significant amount of corrosion on the inserts.

7.6.2 Direct Tension Tests of Ferrule Loop Inserts

In all tests conducted on 1/2" ferrule loop inserts, the wire failed. This indicates that the strength of the weld between the wire and the ferrule was adequate. However, weld failure was observed in all 1" ferrule inserts tested. Although the weld strength of the Meadow Steel inserts was about 40% lower than the weld strength of the Dayton Superior, the ultimate loads of the two brands of insert were very close when tested in concrete.

The ultimate tensile loads of 1/2" inserts cast in concrete was very close to the ultimate tensile capacity of the inserts when tested directly; however, the tensile capacity of 1" ferrule loop inserts cast in concrete was much larger than the ultimate tensile capacity of inserts when tested directly which is due to the larger ferrule embedded into concrete.

8. References

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2. American Society of Testing and Materials, ASTM Designation E488-76, "Tests for Strength of Anchors in Concrete and Masonry Elements," Book 18.

3. American Society of Testing and Materials, ASTM Designation E488-88, "Standard Test Methods for Strength of Anchors in Concrete and Masonry Elements," Book 04.07.

4. American Society of Testing and Materials, ASTM Designation A153-82 (1987), "Specification for Zinc Coating (Hot-Dip) on Iron and Steel Hardware," Book 01.06, 15.08.

5. American Society of Testing and Materials, ASTM Designation B 117-85, "Standard Method of Salt Spray (Fog) Testing," Book 02.05.

6. Kendrick, C. B., "Cast Iron Bolt Anchor Inserts for Concrete," Advisory Report to Office of Transportation Laboratory, contract No. 54F736, May 11,1988.

7. Manual of Steel Construction, 8th edition, American Institute of Steel Construction (AISC), Chicago 1986, p 5-121.

8. PCI Design Hand Book - Precast and Prestressed Concrete, 2nd edition, Prestressed Concrete Institute, Chicago 1978, p 5-24 through 5-26.

9. Richard, T. W., E. F. Carpenter, and E. V. Leyendecker, "Design Loads for Inserts Embedded in Concrete," Building Research Division, Institute for Applied Technology, National Bureau of Standards, Washington, D.C. May 1972.

10. "Standard Specifications," California Department of Transportation, January 1988.

11. Standard Special Provisions B75.50, Miscellaneous Bridge Metal, California Department of Transportation, October 18,1988.

12. Structures Design Memo 21-41, titled "Anchorage to Concrete," California Department of Transportation, July, 1989.

9. Appendices

Appendix A. Summary of Test Data

Table A-1. Summary of Direct Tension and Direct Shear Test Data

Concrete Compressive Strength 5000 ± psi

TABLE A-1. SUMMARY OF DIRECT TENSION AND DIRECT SHEAR TEST DATA

CO.	SIZE inch	INSERT TYPE	TEST TYPE	EDG DIS in	DIR.	BOLT TYPE	PRE-LOAD lb.	TORQUE lb-ft	CONCRETE STRENGTH psi	ULTIMAT LOAD 1000 lb	TEST DATE	TYPE OF FAILURE *	THREAD ENGAGE. (in)	TEST NO.
M	1/2	FL	T	3	+	A307	500	40	5640	9.30	5-4-87	W1.P	1.00	18
E				3	+	"	"	"	5650	10.20	5-5-87	W2	"	27
A	2.5	2-7/8"		3	+	"	"	"	5640	9.40	5-4-87	W2	"	19
D	kip	INSERT		3	//	"	"	"	"	9.65	"	TC	"	16
O	per	EMBEDMENT		3	//	"	"	"	"	9.60	"	W1.P	"	17
W	sec			6	+	"	"	"	"	10.80	"	W1.W	"	23
		MANUFACTU		6	+	"	600	80	4850	10.30	3-30-87	W1.W	"	2
S		RECOMMEND		6	+	"	300	"	"	10.40	"	W1.W	"	3
T		SAFE WORK		6	//	"	600	"	"	10.40	"	TC	"	4
E		LOAD		6	//	"	"	"	"	9.75	"	R1.P	"	5
E		TENSION												
L		2025 lb.	S	3	+	A325	500	80	5780	7.00	5-13-87	SC	1.00	51
		@ 3000psi		3	+	"	"	"	"	7.35	5-12-87	SC	"	39
*				3	+	"	"	"	"	6.80	"	SC	"	43
*				3	//	"	"	"	"	6.60	5-13-87	SC	"	46
A				3	//	"	"	"	"	6.10	"	SC	"	50
C				6	+	"	"	"	"	11.30	5-12-87	I	"	42
M				6	+	"	300	"	5775	6.50	5-11-87	I	"	34
E				6	+	"	"	"	"	11.05	"	I	"	35
*				6	//	"	500	"	5800	10.50	5-12-87	I	"	38
*				6	//	"	"	40	5780	6.70	"	B	"	41
				6	//	A193.B7	"	80	5230	11.80	7-26-89	B	"	355
	1	FL	T	6	+	A307	1000	360	5570	21.30	5-27-87	SLC	1-1/4	54
				6	+	"	"	"	"	22.58	"	W2	"	52
	3.15	6-1/8"		6	+	A307 TR	"	290	4890	26.60	5-24-88	LC.W2	1-3/4	206
	kip	INSERT		6	//	A307	"	360	4550	24.40	7-15-87	W2	1-1/4	73
	per	EMBEDMENT		6	//	"	"	"	"	24.80	"	W2	"	74
	sec			12	+	"	"	"	"	26.70	"	W1.R1	"	72
		MANUFACTU		12	+	"	"	"	"	25.70	"	W2	"	71
		RECOMMEND		12	+	"	"	"	"	27.00	"	W2	"	70
		SAFE WORK		12	+	"	"	"	5570	25.95	5-27-87	W2	"	53
		LOAD		12	+	"	"	"	5610	26.85	5-28-87	W2	"	55
		TENSION		12	+	"	"	"	5810	28.30	6-3-87	W2	"	60*
		5000 lb.		12	//	"	"	"	"	27.00	"	TC.SLC	"	61
		@ 3000psi		12	//	A307 TR	"	"	4750	27.60	10-18-88	TC	1-1/2	270
			S	6	+	A325	600	680	4740	17.60	7-20-87	R2.SC	1-1/4	80
				6	+	A193.B7	1000	"	4960	23.80	5-26-88	SC.R1	1-9/16	225
				6	+	"	"	"	4990	20.40	5-27-88	SC.R2	1-1/8	228
				6	//	"	"	"	4960	19.40	5-26-88	SC.R2	1-1/4	226
				6	//	"	"	"	"	16.00	"	SC.R2	1-3/8	227
				12	+	A325	1500	"	4780	45.50	7-21-87	R2	1-1/4	84
				12	+	A193.B7	1000	"	4750	30.80	10-17-88	R2	1-1/2	267
				12	+	A193.B7	1000	"	4750	29.70	"	R1.W1	1-1/2	268
				12	//	A325	1500	"	4740	50.24	7-20-87	R2	1-1/4	83
				12	//	A193.B7	1000	"	4750	34.84	10-17-88	R2	1-1/2	269
				12	//	A193.B7	1000	"	5740	36.20	7-27-89	R2	1-1/2	357

TABLE A-1. SUMMARY OF DIRECT TENSION AND DIRECT SHEAR TEST DATA

CO.	SIZE inch	INSERT TYPE	TEST TYPE	EDG DIS in	DIR.	BOLT TYPE	PRE-LOAD lb.	TORQUE lb-ft	CONCRETE STRENGTH psi	ULTIMAT LOAD 1000 lb	TEST DATE	TYPE OF FAILURE *	THREAD ENGAGE. (in)	TEST NO.
B	1/2	CI	T	3	NA	A307	500	50	4910	8.32	3-28-88	TC	1.0	136B
U				3	NA	"	"	"	"	8.88	"	TC	"	137B
R	2.50	2-1/2"		3	NA	"	"	"	"	8.72	"	TC	"	138B
K	kip	INSERT		3	NA	"	"	"	"	8.88	"	TC	"	139
E	per	EMBEDMENT		3	NA	"	"	"	"	8.16	"	TC	"	140
	sec			6	NA	"	"	"	"	10.00	"	TC	"	147
				6	NA	"	"	40	4955	10.80	"	TC	"	151
		MANUFACTU		6	NA	"	"	"	"	10.80	"	TC	"	149
		RECOMMEND		6	NA	A307 TR	"	"	4720	9.68	6-29-88	TC	1-7/8	238
		SAFE WORK		6	NA	"	"	"	"	10.32	"	TC	1-1/2	239
		LOAD												
		TENSION	S	3	NA	A325	500	80	5230	7.88	4-8-88	SC	1.0	160
		1500 lb.		3	NA	"	"	"	"	8.24	"	SC	"	161
		SHEAR		3	NA	"	"	"	"	7.64	"	SC	"	162
		1600 lb.		3	NA	"	"	"	"	9.32	"	SC	"	163
		@ 3000psi		3	NA	"	"	"	"	6.76	"	SC	"	166
				6	NA	"	"	"	5270	13.00	4-11-88	SC	"	172
				6	NA	"	"	"	"	12.16	"	SC	"	173
				6	NA	A193.B7	"	"	4720	10.92	7-1-88	B	1-1/8	249
				6	NA	"	"	"	4850	10.88	8-29-88	B	1-1/2	261
				6	NA	"	"	"	4850	10.56	"	B	1-1/2	262
	1	CI	T	6	NA	A307	1000	360	4550	23.20	7-14-87	I	1-1/4	66
				6	NA	"	"	"	4820	29.30	12-3-87	LC	"	121
	3.15	4-3/4"		6	NA	"	"	"	4940	27.00	12-15-87	LC	"	123
	kip	INSERT		6	NA	"	"	"	"	26.60	"	LC	"	127
	per	EMBEDMENT		6	NA	"	"	"	"	29.20	"	LC	"	128
	sec			12	NA	"	"	"	4550	29.20	7-15-87	TC	"	69
		MANUFACTU		12	NA	"	"	"	4820	31.00	12-3-87	I	"	119
		RECOMMEND		12	NA	"	"	"	"	28.40	"	I	"	120
		SAFE WORK		12	NA	"	"	"	4940	30.80	12-15-87	I	"	124
		LOAD		12	NA	"	"	"	"	27.00	"	I	"	125
		TENSION		12	NA	"	"	"	"	23.40	"	I	"	126
		5900 lb.												
		SHEAR	S	6	NA	325	1000	360	4730	26.50	11-23-87	I.SC	1-1/4	113
		6000 lb.		6	NA	"	"	"	4800	27.20	11-30-87	I.SC	"	135
		@ 3000psi		6	NA	"	"	680	4960	24.40	5-26-88	SC	"	221
				6	NA	"	"	"	"	23.70	"	SC	"	222
				6	NA	"	"	"	"	23.60	"	SC	"	224
				12	NA	"	"	"	4800	39.50	12-30-87	I	"	136
				12	NA	"	"	"	"	38.00	"	I	"	137
				12	NA	A193.B7	"	"	5187	39.90	5-31-88	I	"	229
				12	NA	"	"	"	"	48.60	"	SLC	1-1/2	230
				12	NA	"	"	"	4850	25.80	8-30-88	B	1-5/8	264

TABLE A-1. SUMMARY OF DIRECT TENSION AND DIRECT SHEAR TEST DATA

CO.	SIZE inch	INSERT TYPE	TEST TYPE	EDG DIS in	DIR.	BOLT TYPE	PRE-LOAD lb.	TORQUE lb-ft	CONCRETE STRENGTH psi	ULTIMAT LOAD 1000 lb	TEST DATE	TYPE OF FAILURE *	THREAD ENGAGE. (in)	TEST NO.
D	1/2	FL	T	3	+	A307	500	40	5640	10.10	5-4-87	TC.R1.P	1.0	12
A				3	+	"	"	"	"	10.20	"	TC.R1.P	"	13
Y	2.50	3"		3	+	"	"	"	"	10.30	"	TC.R1.P	"	14
T	kip	INSERT		3	//	"	"	"	"	8.70	"	TC	"	15
O	per	EMBEDMENT		3	//	"	"	"	5650	9.40	5-5-87	TC	"	31
N	sec			6	+	"	"	"	"	11.23	"	TC.R1.P	"	24
		MANUFACTU		6	+	"	600	80	4850	10.40	3-30-87	LC	"	6
S		RECOMMEND		6	+	A307 TR	500	40	4720	10.40	7-1-88	TC.W1	1-1/4	250
U		SAFE WORK		6	//	A307	600	80	4850	9.90	3-30-87	LC.W.P	1.0	7
P		LOAD		6	//	"	"	"	"	11.23	"	R1.P	"	8
E		TENSION												
R		1800 lb.	S	3	+	A325	500	80	5780	6.90	5-13-87	SC	1.0	44
I		@ 3000psi		3	+	A193.B7	"	"	4720	6.50	6-30-88	SC	"	244
O				3	+	A325	"	"	5780	7.85	5-13-87	R1.SC	"	47
R				3	//	A193.B7	"	"	4720	5.04	6-30-88	SC	1-3/16	242
				3	//	A325	500	"	5780	5.90	5-13-87	SC	1.0	49
				6	+	"	300	"	5775	11.15	5-11-87	I	"	36
				6	+	A193.B7	500	"	5298	11.40	5-13-88	B	"	195
				6	+	A193.B7	"	"	4720	10.96	6-30-88	B	1-3/16	243
				6	//	A325	"	"	5250	13.40	5-13-88	B	5/8	196
				6	//	A193.B7	"	"	"	10.50	"	B	1.0	197
		CI	T	3	+	A307	500	50	4910	7.48	3-28-88	TC	7/8	141
				3	+	"	"	"	"	7.52	"	TC	"	142
		2-3/4"		3	+	"	"	"	"	7.36	"	TC	"	143
		INSERT		3	//	"	"	"	"	7.44	"	TC	"	144
		EMBEDMENT		3	//	"	"	"	"	7.44	"	TC	"	148
				3	//	A193.B7	"	80	5650	9.10	7-25-89	TC	"	353
		MANUFACTU		6	+	"	"	40	4955	10.84	3-30-88	TC.F	"	154
		RECOMMEND		6	+	"	"	"	"	9.88	"	TC.F	"	153
		SAFE WORK		6	+	"	"	"	"	10.72	"	TC	"	152
		LOAD		6	//	"	"	"	"	8.72	"	TC	"	155
		TENSION		6	//	"	"	50	4910	10.24	3-28-88	TC	"	145
		1800 lb.												
		@ 3000psi	S	3	+	A325	500	80	5230	6.72	4-8-88	SC	5/8	164
				3	+	"	"	"	"	6.08	"	SC	"	165
				3	+	A193.B7	"	"	4720	6.16	7-1-88		1-1/8	248
				3	//	A325	"	"	5270	7.04	4-11-88	SC	1/2	170
				3	//	"	"	"	"	6.44	"	SC	"	174
				6	+	A193.B7	"	"	4720	11.57	7-1-88	B	1-3/16	245
				6	+	"	"	"	"	11.16	"	B	1-3/8	246
				6	+	"	"	"	"	11.84	"	B		247
				6	//	A325	"	"	5230	12.12	4-6-88	SLC	7/8	159
				6	//	"	"	"	5270	10.84	4-11-88	SC	1/2	167

TABLE A-1. SUMMARY OF DIRECT TENSION AND DIRECT SHEAR TEST DATA

CO.	SIZE inch	INSERT TYPE	TEST TYPE	EDG DIS in	DIR.	BOLT TYPE	PRE-LOAD lb.	TORQUE lb-ft	CONCRETE STRENGTH psi	ULTIMAT LOAD 1000 lb	TEST DATE	TYPE OF FAILURE *	THREAD ENGAGE. (in)	TEST NO.
	1	FL	T	6	+	A307	1000	360	4900	26.40	8-19-87	R2,TC	1-1/4	99
D				6	+	"	"	"	"	29.10	"	W.P.TC	"	98
A	3.15	6-1/4"		6	+	"	"	"	"	31.50	"	R2,TC	"	97
Y	kip	INSERT		6	//	"	"	"	4550	27.60	7-14-87	W.P.TC	"	65
T	per	EMBEDMENT		6	//	"	"	"	4900	28.05	8-18-87	TC,R1	"	85
O	sec			6	//	"	"	"	"	27.00	"	TC	"	86
N				12	+	A325	"	360	5607	29.20	5-28-87	SLC	"	58
		MANUFACTU		12	+	"	"	"	5810	28.80	6-3-87	SLC	"	62
S		RECOMMEND		12	+	"	"	680	"	17.70	8-19-87	TC,R1,W1	"	96
U		SAFE WORK		12	+	A307	"	360	"	29.20	8-18-87	TC,R1,W1	"	89
P		LOAD		12	+	"	"	"	4550	26.80	7-15-87	TC,R1,W1	"	75
E		TENSION		12	//	"	"	"		21.30	5-28-87	SLC	"	57
R		4000 lb.		12	//	"	"	"	4820	25.20	12-3-87		"	116
I		@ 3000psi		12	//	"	"	"	4900	21.50	8-18-87	R2	"	87
O				12	//	"	"	"	"	28.00	"	TC,R1,P	"	88
R				12	//	"	"	"	"	25.80	8-19-87	TC,R1,P	"	95
				12	//	A193.B7	"	680	5650	30.50	7-25-89	TC	"	349
			S	6	+	A325	1000	360	4900	27.15	8-20-87	R2,SC		100
				6	+	"	600	680	4550	17.20	7-15-87	R2,SC		76
				6	+	"	"	"	"	20.00	"	R2,SC		77
				6	//	"	"	"	4740	17.70	7-20-87	R2,SC		79
				6	//	"	1000	"	"	20.60	"	R2,SC		81
				12	+	"	1500	"	4900	29.40	8-20-87	R2		103
				12	+	"	"	"	"	30.50	"	R2		102
				12	+	"	600	"	4740	29.90	7-20-87	R2		78
				12	+	A193.B7	1000	"	5740	27.40	7-27-89	R2		356
				12	//	A325	1500	"	4900	41.40	8-20-87	R2		101
				12	//	A193.B7	1000	"	4850	40.80	8-30-88	R2	1-1/4"	266
		CI	T	6	+	A307	1000	360	4550	18.00	7-14-87	TC		67
				6	+	"	"	"	4820	19.90	12-3-87	LC		118
		3-5/8"		6	+	"	"	"	4960	20.80	12-17-87	TC		132
		INSERT		6	+	"	"	"	"	20.50	"	TC		133
		EMBEDMENT		6	//	"	"	"	4820	16.40	12-3-87	LC		114
				6	//	"	"	"	"	20.00	"	LC		115
		MANUFACTU		6	//	"	"	"	4960	20.10	12-17-87	LC		134
		RECOMMEND		12	+	"	"	"	4550	17.90	7-14-87	LC		68
		SAFE WORK		12	+	"	"	"	4750	20.50	11-25-87	LC		112
		LOAD		12	+	"	"	"	4960	21.20	12-17-87	LC		130
		TENSION		12	//	"	"	"	4820	21.50	12-3-87	TC		117
		3000 lb.		12	//	"	"	"	4960	23.10	12-17-87	LC		129
		@ 3000psi		12	//	"	"	"	"	20.00	"	TC		131
			S	6	+	A325	1000	680	4920	19.80	5-25-88	SC	1.0	219
				6	+	A193.B7	"	"	4850	21.00	8-30-88	SC	1-3/8	265
				6	//	A325	"	"	4920	19.80	5-25-88	SC	1.0	220
				6	//	"	"	"	4960	20.20	5-26-88	SC	"	223
				12	+	"	"	"	4920	43.50	5-25-88	SLC	"	217
				12	+	A193.B7	"	"	5230	37.90	5-30-89	SLC	"	343
				12	+	A193.B7	"	"	5230	36.20	5-30-89	SLC	"	344
				12	//	A325	"	"	4920	39.60	5-25-88	SLC	1.0	216

TABLE A-1. SUMMARY OF DIRECT TENSION AND DIRECT SHEAR TEST DATA

CO.	SIZE inch	INSERT TYPE	TEST TYPE	EDG DIS in	DIR.	BOLT TYPE	PRE-LOAD lb.	TORQUE lb-ft	CONCRETE STRENGTH psi	ULTIMAT LOAD 1000 lb	TEST DATE	TYPE OF FAILURE *	THREAD ENGAGE. (in)	TEST NO.
R	1/2	FL	T	3	+	A307	500	40	5650	9.40	5-5-87	W.P		28
I				3	+	"	"	"	"	9.60	"	W.P		29
C	2.50	4-3/8"		3	+	"	"	"	"	10.00	"	W.P		30
H	kip	INSERT		3	//	A307 TR	"	"	4873	9.90	11-17-88	TC		276
M	per	EMBEDMENT		3	//	A307 TR	"	"	"	10.20	5-17-88	TC.W.P		175
O	sec			6	+	A307	"	"	5640	9.60	5-4-87	W.P		20
N				6	+	"	"	"	"	10.40	"	W.P		21
D				6	+	"	"	"	"	10.80	"	W.P		22
				6	//	"	"	"	5650	9.90	5-5-87	W.P		25
				6	//	"	"	"	"	10.80	"	W.P		26
			S	3	+	A193.B7	500	80	5250	7.52	5-13-88	SC.R1	1-1/8	198
				3	+	"	"	"	"	7.04	"	SC.R1	1-1/16	199
				3	+	"	"	"	"	6.88	"	SC.R1	"	200
				3	//	"	"	"	5190	7.64	5-17-88	SC.R1	1-1/8	201
				3	//	"	"	"	"	7.12	"	SC.R1	1.0	204
				6	+	A325	?	FINGER	4850	10.40	3-31-87	B		9
				6	+	"	500	80	5780	10.80	5-12-87	B		40
				6	+	A193.B7	"	"	5190	11.32	5-17-88	B	1.0	203
				6	//	A325	?	FINGER	4850	8.70	3-31-87	I.R2		11
				6	//	A193.B7	500	80	5190	11.68	5-17-88	B	1-1/16	202
		CI	T	3	NA	A307 TR	500	40	5180	10.20	5-10-88	TC	1-5/16	178
				3	NA	"	"	"	"	9.00	"	TC	1-1/4	179
		2-1/2"		3	NA	"	"	"	"	8.96	"	TC	"	180
		INSERT		3	NA	"	"	"	"	8.60	"	TC	1-1/16	181
		EMBEDMENT		3	NA	"	"	"	"	9.08	"	TC	1-5/16	185
				6	NA	"	"	"	"	11.20	"	TC	1-1/2	176
				6	NA	"	"	"	"	12.60	"	TC	1-7/16	177
				6	NA	"	"	"	"	11.96	"	TC	1-11/16	182
				6	NA	"	"	"	"	12.04	"	TC	1-3/16	184
			S	3	NA	A325	500	80	5222	9.68	5-11-88	SC	1-1/8	187
				3	NA	"	"	"	"	6.72	"	SC	"	189
				3	NA	"	"	"	"	7.76	"	SC	"	190
				3	NA	"	"	"	"	6.96	"	SC	"	191
				3	NA	"	"	"	"	8.20	"	SC	"	192
				6	NA	"	"	"	"	12.44	"	B	"	186
				6	NA	A193.B7	"	"	5250	11.10	5-13-88	B	"	193
				6	NA	"	"	"	"	11.50	"	B	1.0	194
				6	NA	"	"	"	4720	11.30	6-30-88	B	1-1/8	241

TABLE A-1. SUMMARY OF DIRECT TENSION AND DIRECT SHEAR TEST DATA

CO.	SIZE inch	INSERT TYPE	TEST TYPE	EDG DIS in	DIR.	BOLT TYPE	PRE-LOAD lb.	TORQUE lb-ft	CONCRETE STRENGTH psi	ULTIMAT LOAD 1000 lb	TEST DATE	TYPE OF FAILURE *	THREAD ENGAGE. (in)	TEST NO.
	3/4	FL	T	4	+	A307	600	175	4900	16.50	8-18-87	W1.R1	7/8	90
R				4	+	"	"	"	"	17.50	"	R2	"	91
I	3.15	4-1/2"		4	+	"	"	"	"	18.30	"	W1.R1	"	92
C	kip	INSERT		4	//	"	"	125	4890	13.30	5-24-88	TC	"	208
H	per	EMBEDMENT		4	//	"	"	"	"	13.50	"	TC	"	209
M	sec			8	+	"	"	"	"	17.20	"	TC.W2	"	211
O				8	+	"	"	"	4920	18.70	5-25-88	TC.W2	"	214
N				8	+	"	"	"	"	18.50	"	LC	"	215
D				8	//	"	"	175	4900	20.00	8-18-87	W1.R1	"	93
				8	//	"	"	"	"	18.30	"	W	"	94
				8	//	"	"	125	4890	17.20	5-24-88	TC.W2	"	210
				8	//	"	"	"	"	17.10	"	TC	"	212
			S	4	+	A325	600	275	4900	12.75	8-20-87	R1.SC	7/8	104
				4	+	"	"	"	"	13.80	"	R1.SC	"	105
				4	+	"	"	175	"	13.65	"	R1.SC	"	108
				4	//	"	"	"	"	14.70	"	R2.SC	"	106
				4	//	"	"	"	"	13.05	"	R2.SC	"	107
				8	+	"	"	"	"	20.10	"	I	"	110
				8	+	"	"	"	"	21.45	"	I	"	111
				8	+	"	"	290	4920	22.00	5-25-88	I	"	213
				8	//	"	"	"	4873	24.50	11-17-88	R1.I	"	274
				8	//	"	"	"	4873	14.00	"	I	"	275
	1	CI	T	6	NA	A307	1000	330	4720	23.50	6-28-88	LC	1-1/4	231
				6	NA	"	"	"	"	22.20	"	LC	"	232
	3.15	4-3/8"		6	NA	"	"	"	"	21.90	"	LC	"	233
	kip	INSERT		6	NA	"	"	"	"	22.70	"	LC	"	237
	per	EMBEDMENT		6	NA	A307 TR	"	290	4873	23.50	11-21-88	LC	"	277
	sec			12	NA	A307 TR	1000	290	4990	29.20	5-24-88	LC	2-3/4	204
				12	NA	"	"	"	"	25.50	"	LC	2-7/8	205
				12	NA	A307	1000	330	4720	29.00	6-28-88	LC	1-1/4	234
				12	NA	"	"	"	"	25.30	"	LC	"	235
				12	NA	"	"	"	"	28.60	"	LC	"	236
			S	6	NA	A193.B7	1000	680	4580	22.50	7-5-88	SC	1-1/4	256
				6	NA	"	"	"	"	20.10	"	SC	1-1/4	257
				6	NA	"	"	"	"	15.40	"	SC	1-7/16	258
				6	NA	"	"	"	"	18.10	"	SC	1-3/8	259
				6	NA	"	"	"	4890	15.60	11-14-88	SC	1-7/16	273
				12	NA	A193.B7	1000	680	4580	48.00	7-5-88	I	1-7/16	252
				12	NA	"	"	"	"	50.20	"	I	1-5/16	253
				12	NA	"	"	"	"	43.30	"	I	1-1/2	254
				12	NA	"	"	"	4890	43.80	11-14-88	I	"	271
				12	NA	"	"	"	"	50.40	"	SLC	1-7/16	272

TYPES of FAILURE

*B - BOLT OR THREADED ROD FAILED
F - FIN FAILED
I - INSERT FAILURE AT THREADS
LC - LARGE CONE (OUT TO RING)
P - WIRE PULLED THOUGH CONCRETE
R1 - RESISTANCE WIELD FAILED ON ONE SIDE OF THE INSERT
R2 - RESISTANCE WIELD FAILED ON BOTH SIDES OF THE INSERT
SC - SHEAR CONE
SLC - SLAB CRACK
TC - TENSION CONE
W - WIRE FAILED SOMEWHERE WITH IN CONCRETE
W1 - INSERT WIRE FAILED ON ONE SIDE OF THE INSERT
W2 - INSERT WIRE FAILED ON BOTH SIDES OF THE INSERT
DIR.- DIRECTION OF INSERT WITH RESPECT TO THE CONCRETE

Table A-2. Summary of Direct Tension and Direct Shear Test Data

Concrete Compressive Strength 3500 ± psi

TABLE A-2. SUMMARY OF DIRECT TENSION AND DIRECT SHEAR TEST DATA

CO.	SIZE inch	INSERT TYPE	TEST TYPE	EDG DIS in	DIR.	BOLT TYPE	PRE-LOAD lb.	TORQUE lb-ft	CONCRETE STRENGTH psi	ULTIMAT LOAD 1000 lb	TEST DATE	TYPE OF FAILURE *	THREAD ENGAGE. (in)	TEST NO.
	1/2	FL	T	3	//	A307 TR	500	40	3250	6.00	11-23-88	TC	1-3/8"	287
M				3	//	"	"	"	"	6.65	11-23-88	TC	"	288
E	2.50	2-7/8"		3	//	"	"	"	"	7.20	11-23-88	TC	"	289
A	kip	INSERT		6	//	"	"	"	"	9.15	11-23-88	TC/W	"	284
D	per	EMBEDMENT		6	//	"	"	"	"	9.30	11-23-88	TC	"	285
O	sec			6	//	"	"	"	"	9.10	11-23-88	TC	"	286
W			S	3	//	A193.B7	500	80	3250	4.80	11-23-88	SC	1-1/4"	278
S				3	//	"	"	"	"	4.70	11-23-88	SC	1-3/8"	279
T				3	//	"	"	"	"	4.50	11-23-88	SC	"	280
E				6	//	"	"	"	"	10.80	11-23-88	SC	"	281
E				6	//	"	"	"	"	9.80	11-23-88	SC	"	282
L				6	//	"	"	"	"	10.60	11-23-88	B	"	283
	1"		T	6	//	A307 TR	1000	290	4233	19.30	11-29-88	TC/W2	1-3/8"	293
*		6-1/8"		6	//	"	"	"	"	24.85	"	TC/W2	"	296
*	3.15	INSERT		6	//	"	"	"	"	24.20	"	W1/TC/R2	"	297
A	kip	EMBEDMENT		12	//	"	"	"	"	23.50	"	TC/W1/R1	"	292
C	per			12	//	"	"	"	"	26.50	"	TC/W1/R1	"	294
M	sec			12	//	"	"	"	"	27.00	"	TC/W2	"	295
E			S	6	//	A193.B7	1000	680	4210	15.00	11-28-88	SC	1-3/8"	290
*				6	//	"	"	"	4257	15.50	11-30-88	SC/R2	"	298
				6	//	"	"	"	"	18.80	"	SC/R2	"	299
				12	//	"	"	"	4210	37.80	11-28-88	R2	"	291
				12	//	"	"	"	4257	33.60	11-30-88	R2	"	300
				12	//	"	"	"	"	36.40	"	R2	"	301

TABLE A-2. SUMMARY OF DIRECT TENSION AND DIRECT SHEAR TEST DATA

CO.	SIZE inch	INSERT TYPE	TEST TYPE	EDG DIS in	DIR.	BOLT TYPE	PRE-LOAD lb.	TORQUE lb-ft	CONCRETE STRENGTH psi	ULTIMAT LOAD 1000 lb	TEST DATE	TYPE OF FAILURE *	THREAD ENGAGE. (in)	TEST NO.
	1/2	CI	T	3	//	A193.B7	500	40	3630	7.94	4-6-89	TC	1"	333
D				3	//	"	"	"	3630	7.75	4-6-89	TC	1"	334
A	2.50	2-3/4"		3	//	"	"	"	3630	7.87	4-6-89	TC	1"	335
Y	kip	INSERT		6	//	"	"	"	3630	9.33	4-6-89	TC	1"	330
T	per	EMBEDMENT		6	//	"	"	"	3630	9.46	4-6-89	TC	1"	331
O	sec			6	//	"	"	"	3630	9.38	4-6-89	TC	1"	332
N			S	3	//	A193.B7	500	80	3630	5.76	4-6-89	SC	1"	327
S				3	//	"	"	"	3630	6.73	4-6-89	SC	1"	328
U				3	//	"	"	"	3630	6.66	4-6-89	SC	1"	329
P				6	//	"	"	"	3320	10.38	4-5-89	B	1"	324
E				6	//	"	"	"	3320	10.24	4-5-89	B	1"	325
R				6	//	"	"	"	3630	9.81	4-6-89	B	1"	326
I														
Q	1"		T	6	//	A193.B7	1000	680	3900	12.00	4-7-89	TC	1-1/2"	*336
R		3-5/8"		6	//	"	"	"	3900	14.11	4-7-89	TC	1-1/2"	*337
	3.15	INSERT		6	//	"	"	"	3900	14.52	4-7-89	TC	1-1/2"	338
	kip	EMBEDMENT		6	//	"	"	"	4140	17.10	6-9-89	TC	1-1/2"	347
	per			6	//	"	"	"	4140	17.40	6-9-89	TC	1-1/2"	348
	sec			12	//	"	"	"	3900	18.17	4-7-89	TC	1-1/2"	339
				12	//	"	"	"	3900	18.63	4-7-89	TC	1-1/2"	340
				12	//	"	"	"	3900	17.88	4-7-89	TC	1-1/2"	341
			S	6	//	A193.B7	1000	680	3320	19.00	4-5-89	SLC	1-1/2"	*320
				6	//	"	"	"	3900	16.75	4-7-89	SC	1-1/2"	342
				6	//	"	"	"	4140	18.20	6-9-89	SC	1-1/2"	345
				6	//	"	"	"	4140	17.00	6-9-89	SC	1-1/2"	346
				12	//	"	"	"	3320	32.62	4-5-89	SLC	1-1/2"	321
				12	//	"	"	"	3320	32.12	4-5-89	SLC	1-1/2"	322
				12	//	"	"	"	3320	30.61	4-5-89	SLC	1-1/2"	323

TYPES of FAILURE

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*B - BOLT OR THREADED ROD FAILED
F - FIN FAILED
I - INSERT FAILURE AT THREADS
LC - LARGE CONE (OUT TO RING)
P - WIRE PULLED THOUGH CONCRETE
R1 - RESISTANCE WIELD FAILED ON ONE SIDE OF THE INSERT
R2 - RESISTANCE WIELD FAILED ON BOTH SIDES OF THE INSERT
SC - SHEAR CONE
SLC - SLAB CRACK
TC - TENSION CONE
W - WIRE FAILED SOMEWHERE WITH IN CONCRETE
W1 - INSERT WIRE FAILED ON ONE SIDE OF THE INSERT
W2 - INSERT WIRE FAILED ON BOTH SIDES OF THE INSERT
DIR.- DIRECTION OF INSERT WITH RESPECT TO THE CONCRETE

Table A-3. Summary of Combined Loading Test Data

Concrete Compressive Strength 5000 ± psi

TABLE A-3. SUMMARY OF TEST RESULTS FOR COMBINED SHEAR AND TENSION LOADING

COMBINED LOADING CD.	SIZE inch	INSERT TYPE	COMBINED LOADING EDGE DIST in	DIR	BOLT TYPE	PRE-LOAD lb.	TORQUE lb-ft	CONCRET STRENGT psi	COMBINED LOADING TENSION LOAD 1000 lb.	SHEAR LOAD 1000 lb	TEST DATE	COMBINED LOADING TYPE OF FAILURE *	THREAD ENGAGE. (in)	TEST NO.
	1/2	FL	3	//	A193	500	80	4734	3.60	6.00	1-13-89	SC	1-1/4"	T2
M			3	//	"	"	"	4747	3.60	5.40	1-20-89	SC	1-3/8"	T11
E	2.50	2-7/8"	3	//	"	"	"	5230	2.80	5.70	7-26-89	SC	1-3/8"	T67
A	kip	INSERT	3	//	"	"	"	-----	-----	-----	-----	-----	-----	T6**
D	per	EMBEDMENT	3	//	"	"	"	6170	4.20	5.00	6-13-89	SC	1-3/8"	T30
O	sec		3	//	"	"	"	6170	4.40	5.20	6-13-89	SC	1-3/8"	T32
W			3	//	"	"	"	5230	4.90	4.60	7-26-89	SC	1-3/8"	T68
			3	//	"	"	"	6170	6.00	3.80	6-13-89	SC	1-3/8"	T31
S			3	//	"	"	"	5230	5.80	3.50	7-26-89	SC	1-3/8"	T65
T			3	//	"	"	"	5230	6.44	3.50	7-26-89	SC	1-3/8"	T66
E			6	//	"	"	"	4708	3.00	9.00	12-30-88	THR. ROD	1-3/8"	T1
E			6	//	"	"	"	4743	8.00	6.20	1-18-89	SC	1-1/4"	T3**
L			6	//	"	"	"	4743	4.40	9.00	1-18-89	THR. ROD	1-3/8"	T4
			6	//	"	"	"	4745	4.40	9.60	1-19-89	THR. ROD	1-3/8"	T5
			6	//	"	"	"	4745	4.80	9.00	1-19-89	THR. ROD	1-3/8"	T7
			6	//	"	"	"	4745	4.80	9.00	1-19-89	THR. ROD	1-3/8"	T8
			6	//	"	"	"	4747	3.00	9.00	1-20-89	THR. ROD	1-3/8"	T9
			6	//	"	"	"	4747	7.60	7.20	1-20-89	THR. ROD	1-3/8"	T10
			6	//	"	"	"	4753	7.80	7.40	1-23-89	SC	1-3/8"	T12
	1"		6	//	A193	1000	680	5600	5.70	16.20	5-16-89	SC	1-3/8"	T13
*		6-1/8"	6	//	"	"	"	5600	6.00	15.80	5-16-89	SC	1-3/8"	T14
*	3.15	INSERT	6	//	"	"	"	5740	6.00	20.60	7-27-89	SC	1-3/8"	T73
A	kip	EMBEDMENT	6	//	"	"	"	5600	11.20	13.50	5-17-89	SC	1-3/8"	T16
C	per		6	//	"	"	"	5790	12.00	13.00	6-19-89	SC	1-3/8"	T60
M	sec		6	//	"	"	"	5740	11.20	14.70	7-27-89	SC	1-3/8"	T72
E			6	//	"	"	"	6170	17.60	8.40	6-13-89	SC	1-3/8"	T33
*			6	//	"	"	"	6170	17.40	8.50	6-13-89	SC	1-3/8"	T34
*			6	//	"	"	"	5740	16.40	13.40	7-27-89	SC	1-3/8"	T74
			12	//	"	"	"	6170	4.00	33.20	6-13-89	SC	1-3/8"	T36
			12	//	"	"	"	5900	5.60	21.90	6-20-89	TC	1-3/8"	T62
			12	//	"	"	"	5740	6.80	33.40	7-27-89	R2	1-3/8"	T75
			12	//	"	"	"	6170	11.00	29.10	6-13-89	R2	1-3/8"	T35
			12	//	"	"	"	5900	13.00	29.80	6-21-89	R2	1-3/8"	T63
			12	//	"	"	"	5900	12.30	30.80	6-21-89	SLC	1-3/8"	T64
			12	//	"	"	"	5790	16.30	24.90	6-19-89	R2	1-3/8"	T58
			12	//	"	"	"	5790	11.00	29.00	6-19-89	R2	1-3/8"	T59
			12	//	"	"	"	5900	19.00	27.80	6-20-89	SLC	1-3/8"	T61

TABLE A-3. SUMMARY OF TEST RESULTS FOR COMBINED SHEAR AND TENSION LOADING

COMBINED LOADING CO.	SIZE inch	INSERT TYPE	EDGE DIST in	DIR	BOLT TYPE	PRE-LOAD lb.	TORQUE lb-ft	CONCRET STRENGT psi	COMBINED LOADING TENSION LOAD 1000 lb.	SHEAR LOAD 1000 lb	TEST DATE	COMBINED LOADING TYPE OF FAILURE *	THREAD ENGAGE. (in)	TEST NO.
	1/2	CI	3	//	A193	500	80	5950	2.80	9.00	6-12-89	SC	1-1/2"	T26
D			3	//	"	"	"	4920	2.00	6.20	6-12-89	SC	1-1/2"	T47
A	2.50	2-3/4"	3	//	"	"	"	4920	2.20	6.20	6-12-89	SC	1-1/2"	T48
Y	kip	INSERT	3	//	"	"	"	5740	2.00	8.10	7-27-89	TC.SC	1-1/2"	T69
T	per	EMBEDMENT	3	//	"	"	"	5950	4.00	6.40	6-12-89	SC	1-1/2"	T25
O	sec		3	//	"	"	"	4920	2.40	3.70	6-16-89	SC	1-1/2"	T53
N			3	//	"	"	"	4920	4.00	4.20	6-16-89	SC	1-1/2"	T54
			3	//	"	"	"	4950	5.20	4.90	6-12-89	SC	1-1/2"	T24
S			3	//	"	"	"	4870	5.00	5.10	6-19-89	SC	1-1/2"	T55
U			3	//	"	"	"	4870	5.20	4.00	6-19-89	SC	1-1/2"	T56
P			6	//	"	"	"	5950	2.20	10.50	6-12-89	B	1-1/2"	T29
E			6	//	"	"	"	4920	3.40	10.00	6-16-89	B	1-1/2"	T49
R			6	//	"	"	"	4920	3.00	9.70	6-16-89	B	1-1/2"	T50
I			6	//	"	"	"	4920	4.00	9.60	6-16-89	B	1-1/2"	T51
O			6	//	"	"	"	4920	5.20	9.60	6-16-89	B	1-1/2"	T52
R			6	//	"	"	"	4870	4.50	10.00	6-19-89	B	1-1/2"	T57
			6	//	"	"	"	5950	7.70	8.50	6-12-89	B	1-1/2"	T27
			6	//	"	"	"	5950	8.00	7.80	6-12-89	B	1-1/2"	T28
	1"		6	//	A193	1000	680	5740	5.40	20.10	6-5-89	SC	2-1/8"	T22
		3-5/8"	6	//	"	"	"	5740	5.20	20.00	6-5-89	SC	2-1/8"	T23
	3.15	INSERT	6	//	"	"	"	4650	4.80	17.90	6-15-89	SC	2-1/8"	T44
	kip	EMBEDMENT	6	//	"	"	"	4650	9.80	11.50	6-15-89	SC	2-1/8"	T40
	per		6	//	"	"	"	4650	9.60	11.80	6-15-89	SC	2-1/8"	T41
	sec		6	//	"	"	"	5740	9.35	10.34	7-27-89	TC.SC	2-1/8"	T71
			6	//	"	"	"	4650	14.90	5.90	6-15-89	SC	2-1/8"	T38
			6	//	"	"	"	4650	15.70	7.50	6-15-89	SC	2-1/8"	T39
			6	//	"	"	"	5740	13.80	8.90	7-27-89	TC.SC	2-1/8"	T70
			12	//	"	"	"	5230	3.00	33.00	5-30-89	SC	2-1/8"	T18
			12	//	"	"	"	5740	3.40	36.10	6-5-89	TC	2-1/8"	T21
			12	//	"	"	"	4650	5.00	32.00	6-15-89	SC	2-1/8"	T42
			12	//	"	"	"	5740	9.50	34.00	6-5-89	SLC	2-1/8"	T19
			12	//	"	"	"	5740	7.30	33.20	6-5-89	SLC	2-1/8"	T20
			12	//	"	"	"	4650	9.60	23.90	6-15-89	SC	2-1/8"	T43
			12	//	"	"	"	4650	9.60	25.80	6-15-89	SC	2-1/8"	T45
			12	//	"	"	"	4650	8.50	21.90	6-15-89	SC	2-1/8"	T37
			12	//	"	"	"	4920	14.00	16.80	6-16-89	SC	2-1/8"	T46
			12	//	"	"	"							

TYPES of FAILURE

*B - BOLT OR THREADED ROD FAILED
F - FIN FAILED
I - INSERT FAILURE AT THREADS
LC - LARGE CONE (OUT TO RING)
P - WIRE PULLED THOUGH CONCRETE
R1 - RESISTANCE WIELD FAILED ON ONE SIDE OF THE INSERT
R2 - RESISTANCE WIELD FAILED ON BOTH SIDES OF THE INSERT
SC - SHEAR CONE
SLC - SLAB CRACK
TC - TENSION CONE
W - WIRE FAILED SOMEWHERE WITH IN CONCRETE
W1 - INSERT WIRE FAILED ON ONE SIDE OF THE INSERT
W2 - INSERT WIRE FAILED ON BOTH SIDES OF THE INSERT
DIR.- DIRECTION OF INSERT WITH RESPECT TO THE CONCRETE

Appendix B: Plots of Load Versus Displacement of Various Cast-In-Place Concrete Inserts from Direct Tension Tests.
Concrete Compressive Strength 5000 ± psi.

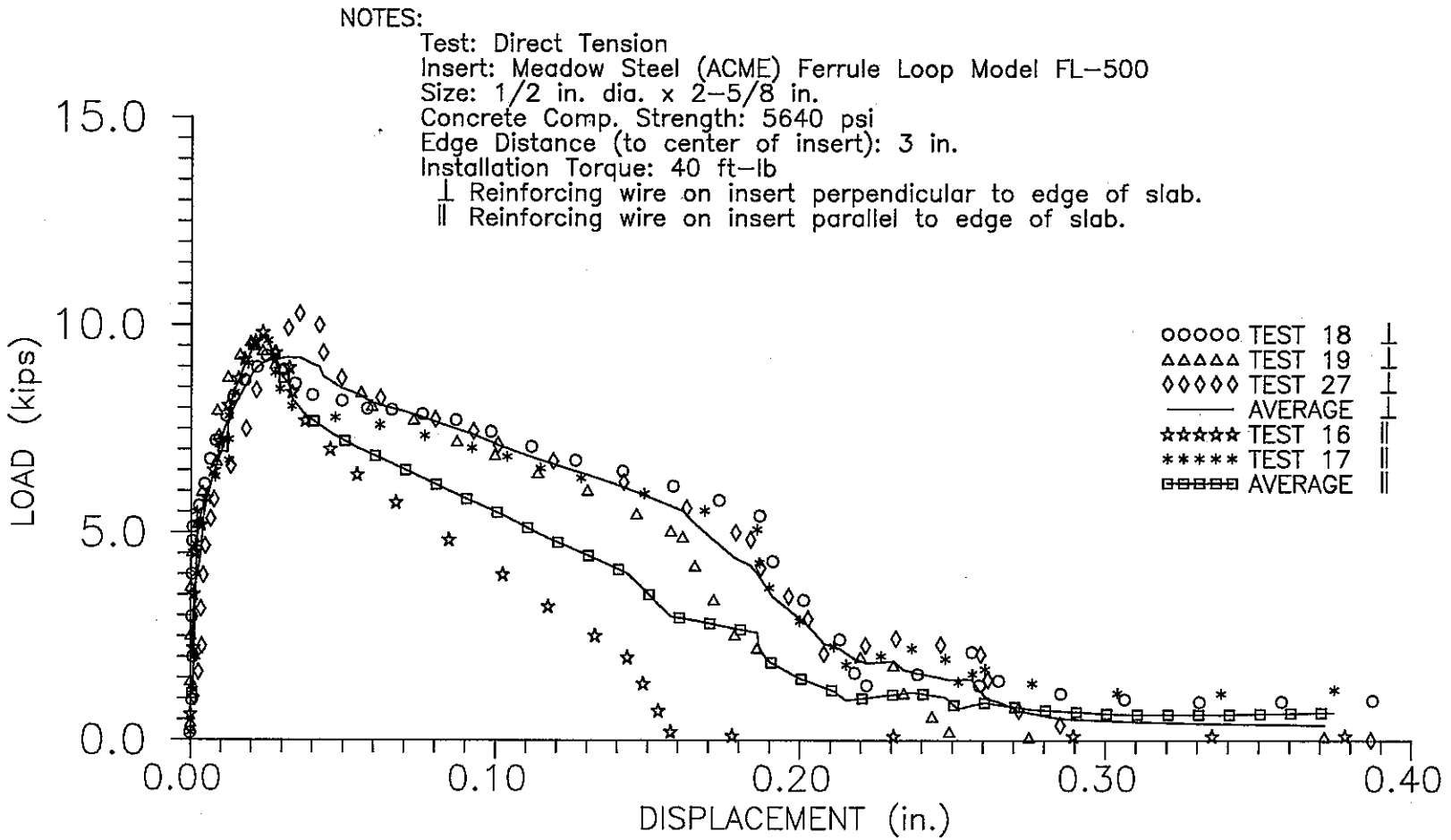

Figure B-1. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

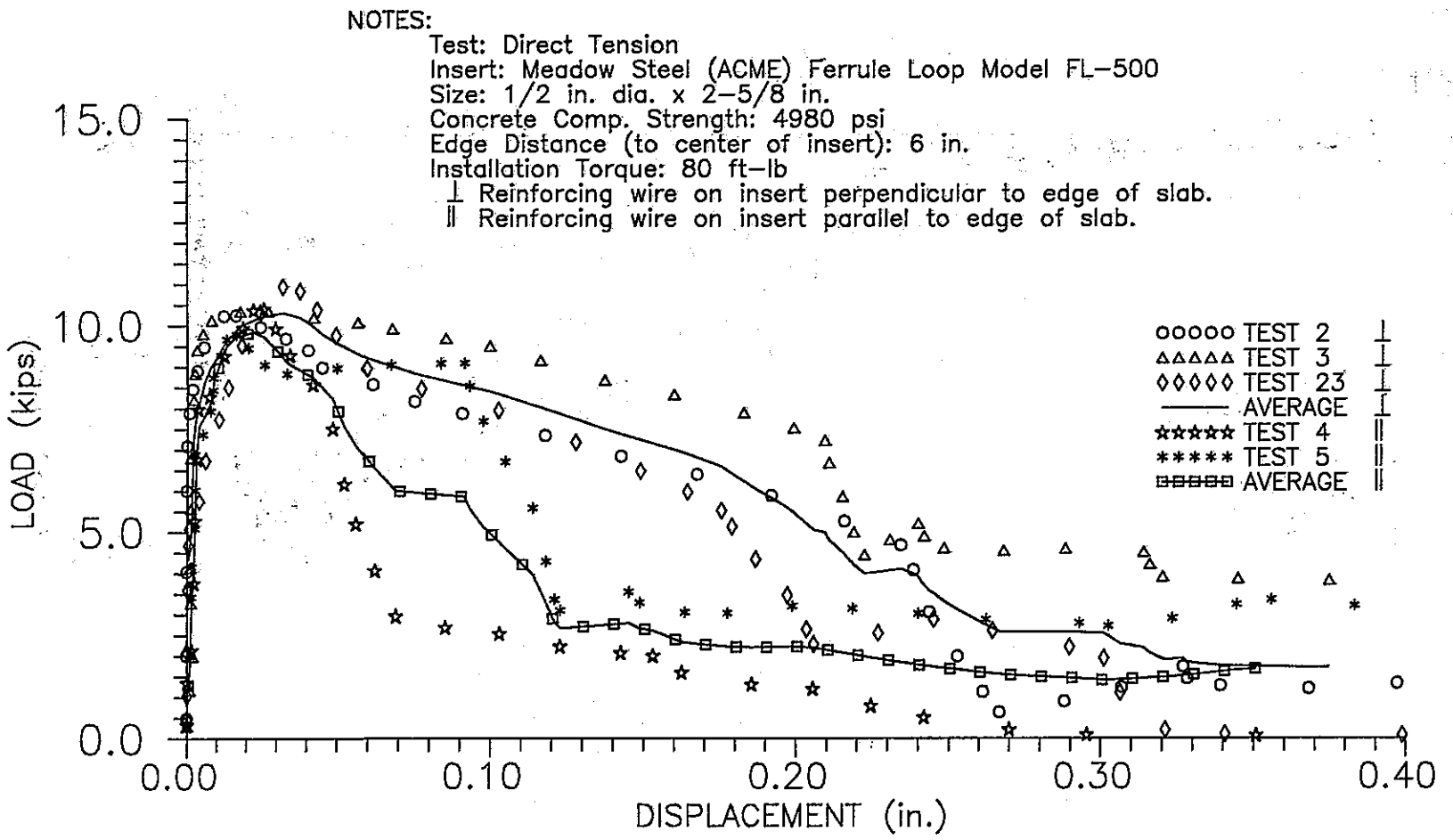

Figure B-2. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

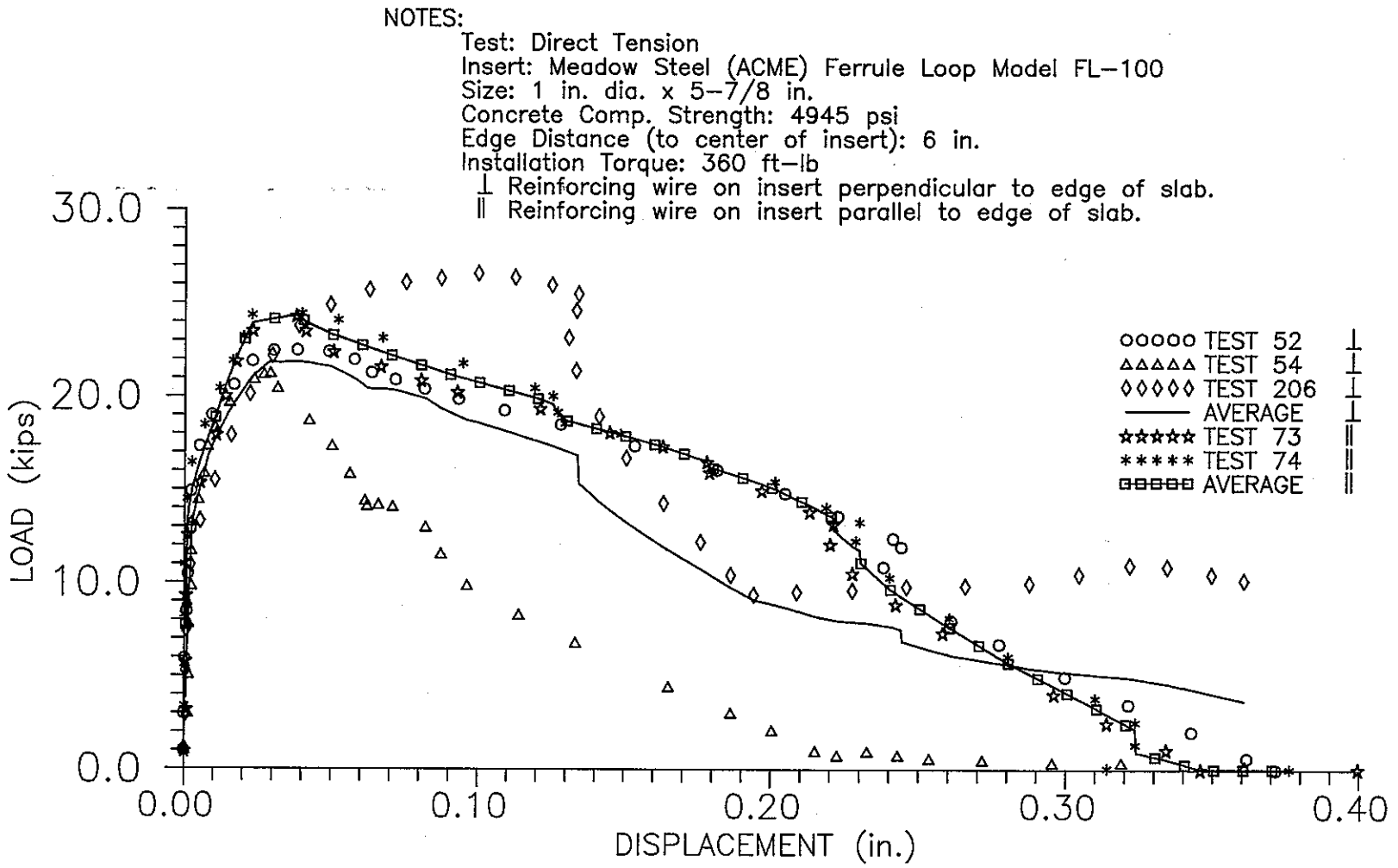

Figure B-3. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

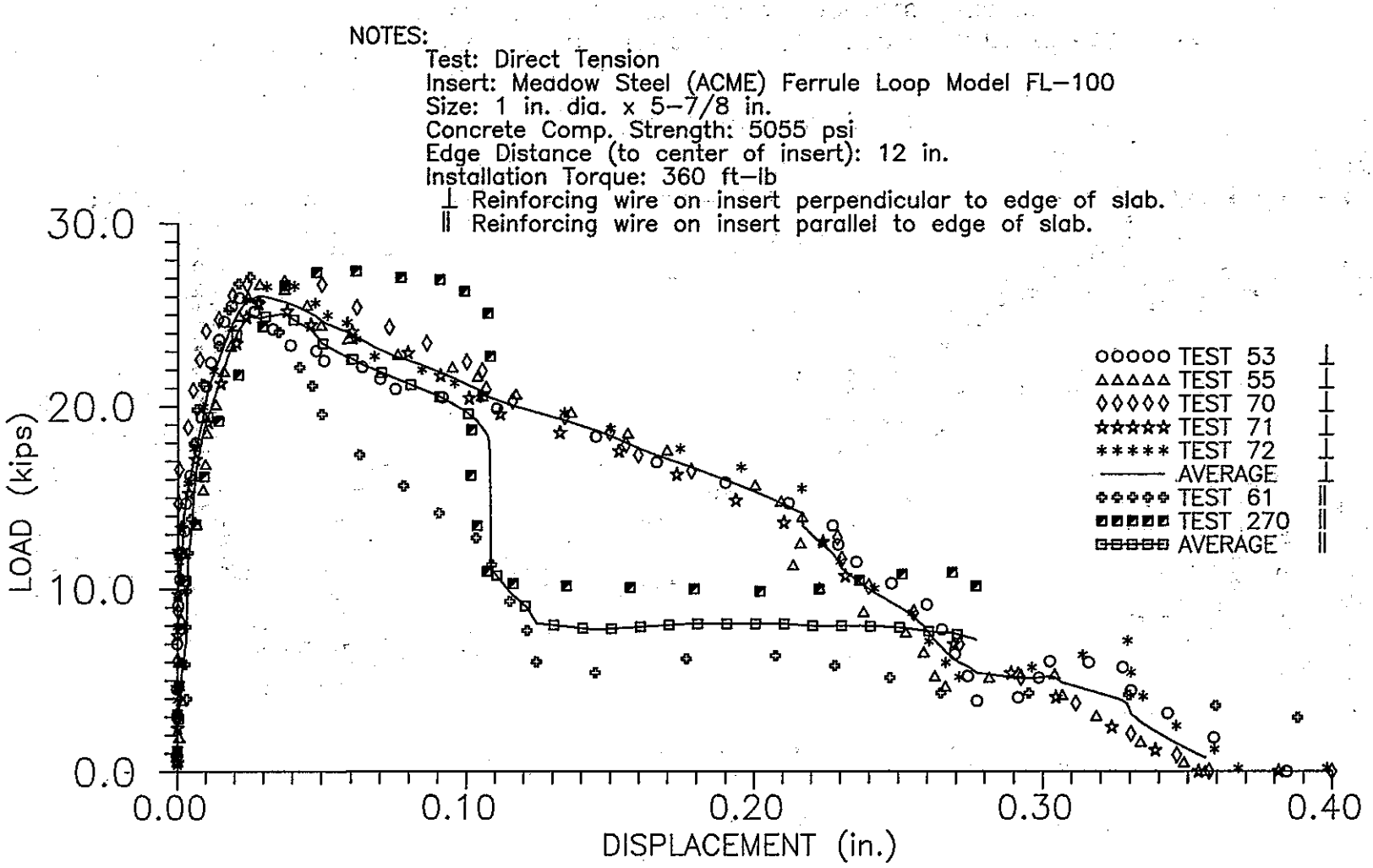

Figure B-4. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

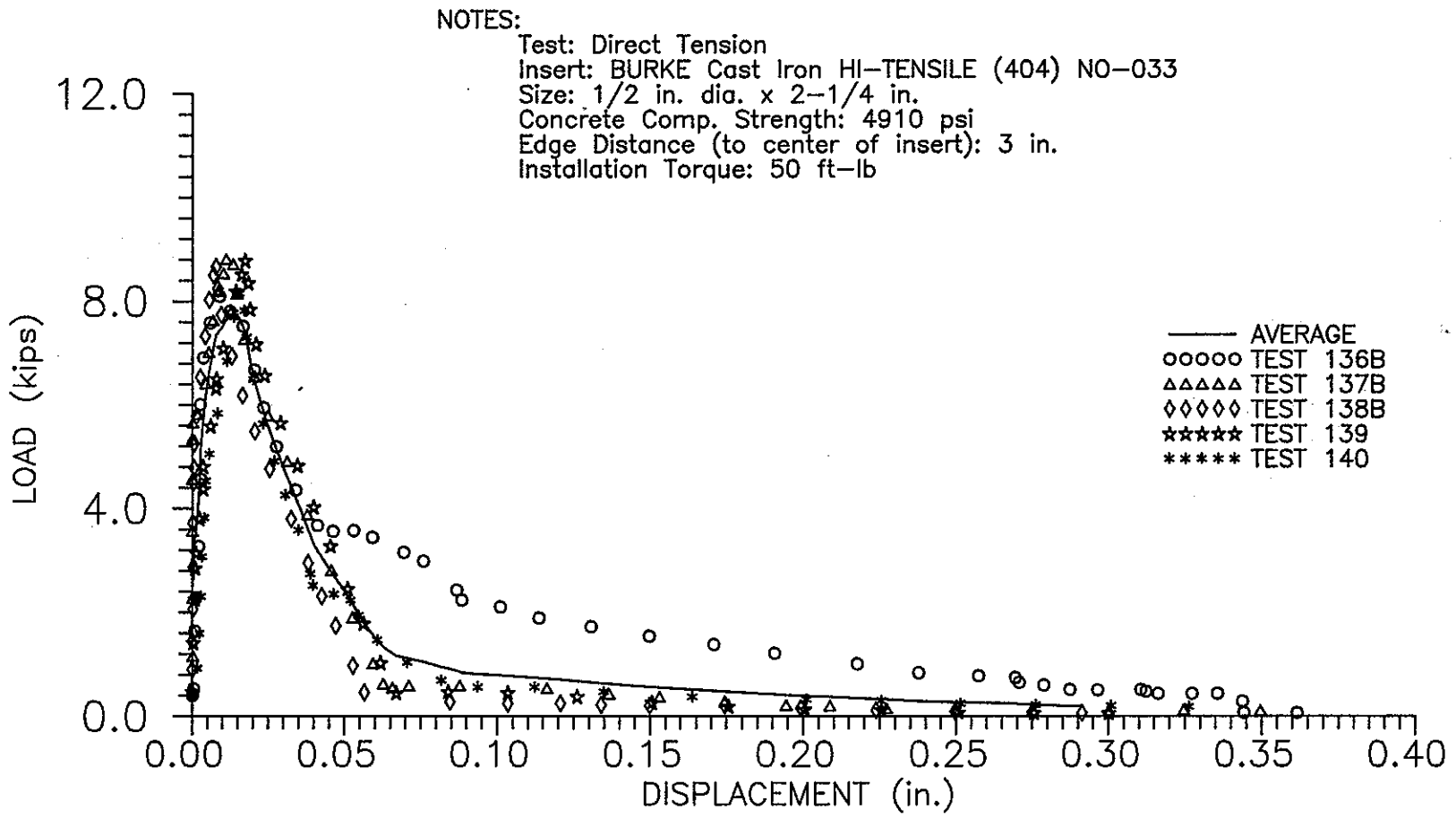

Figure B-5. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

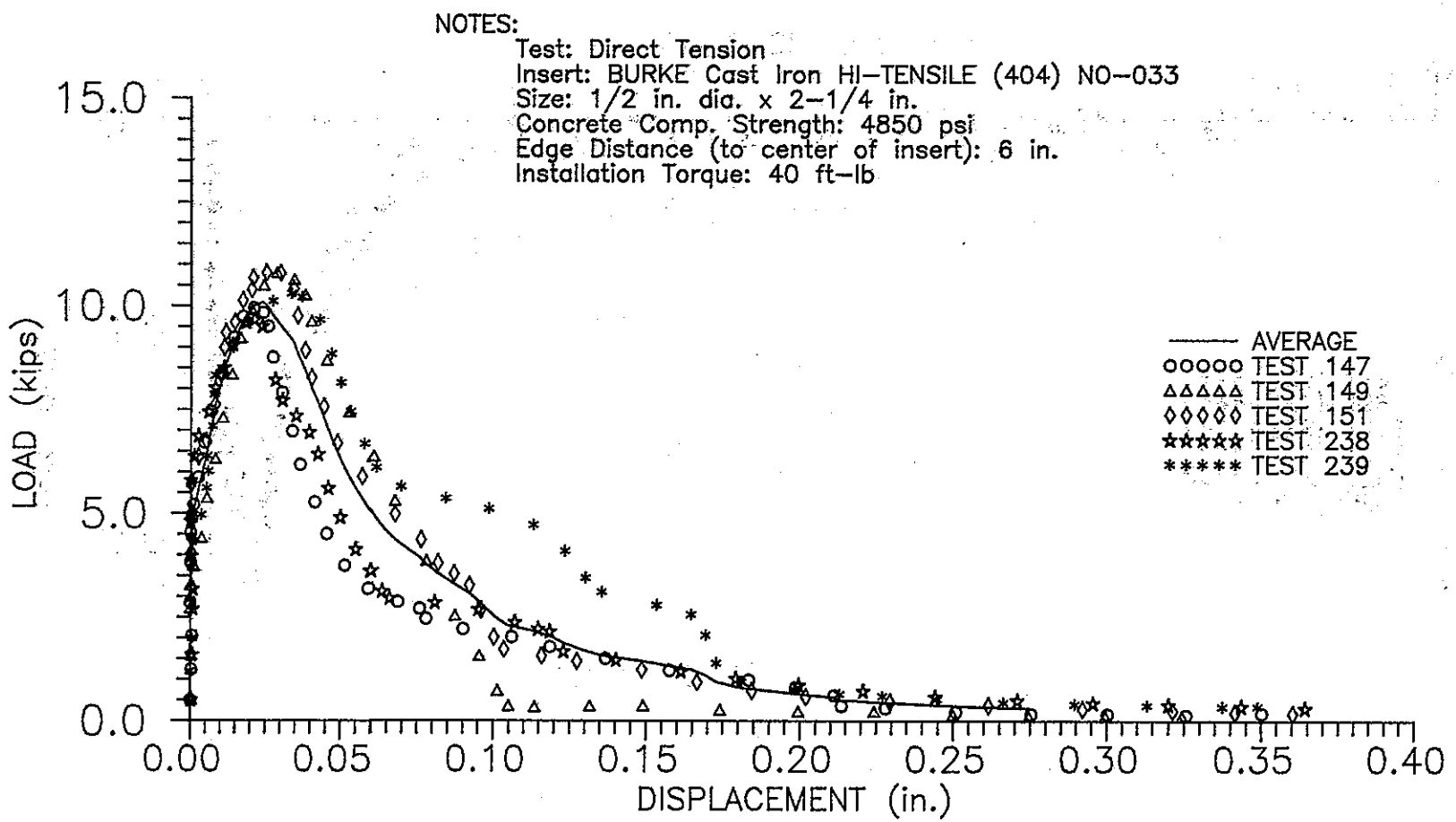

Figure B-6. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

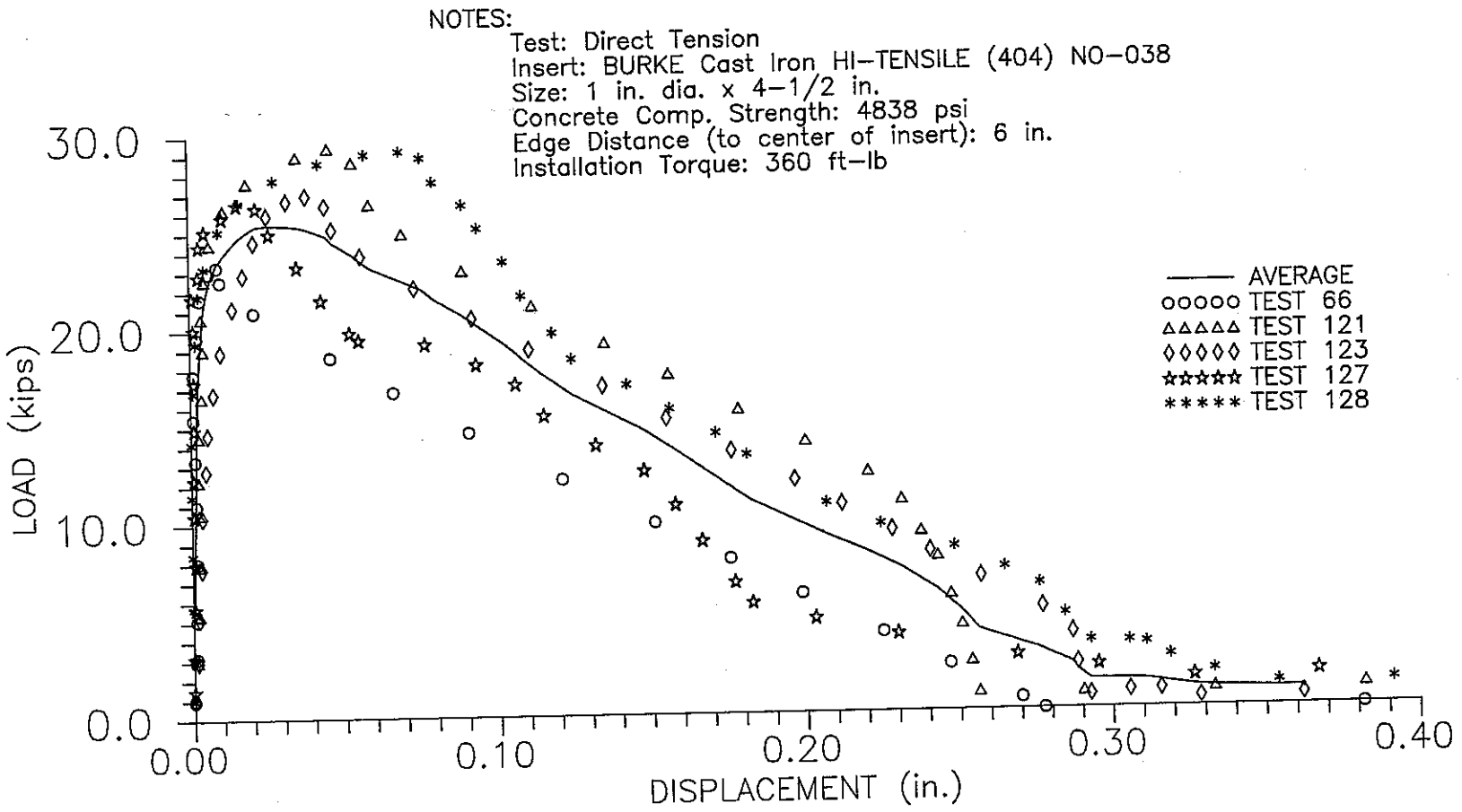

Figure B-7. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

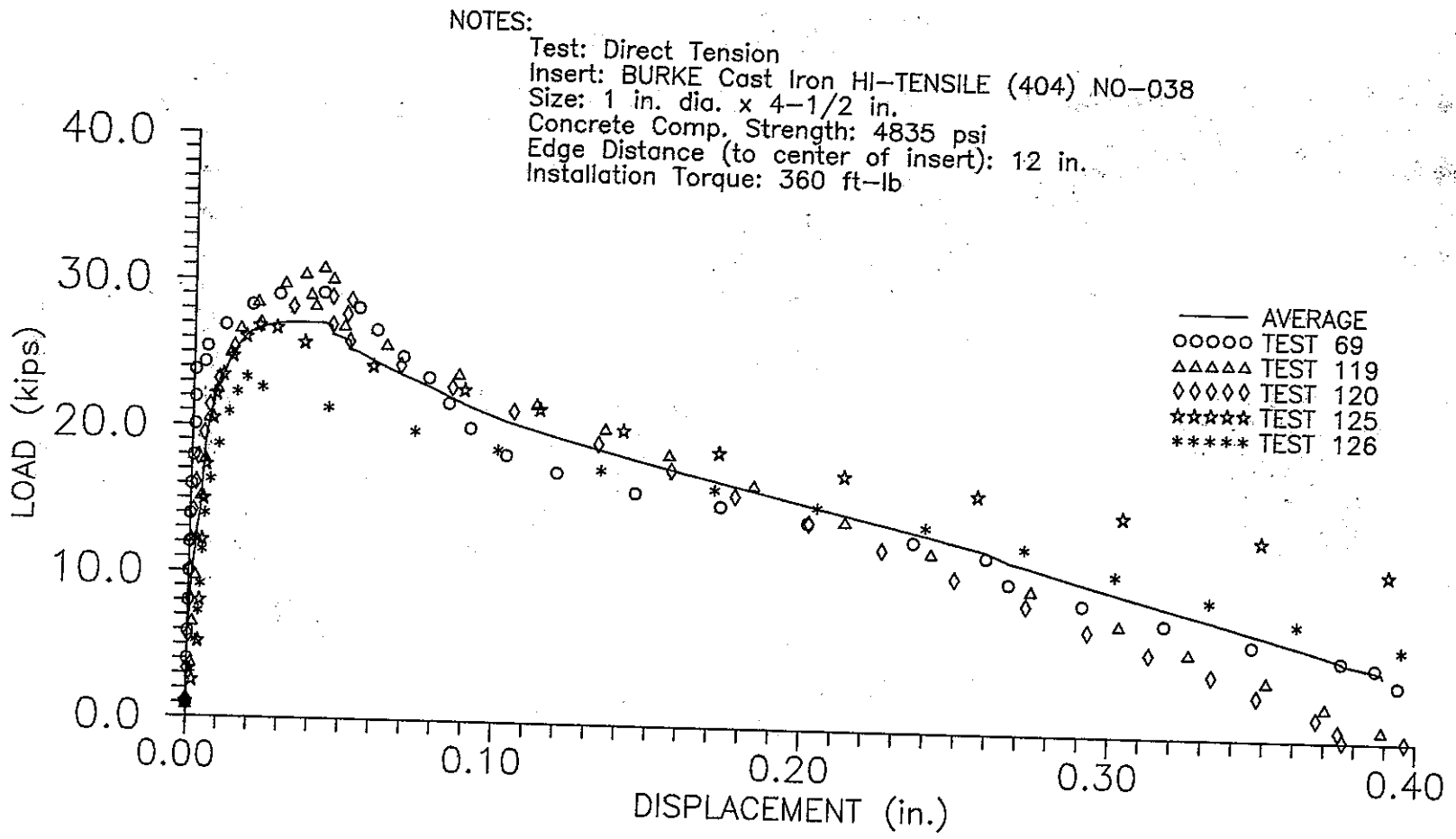

Figure B-8. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

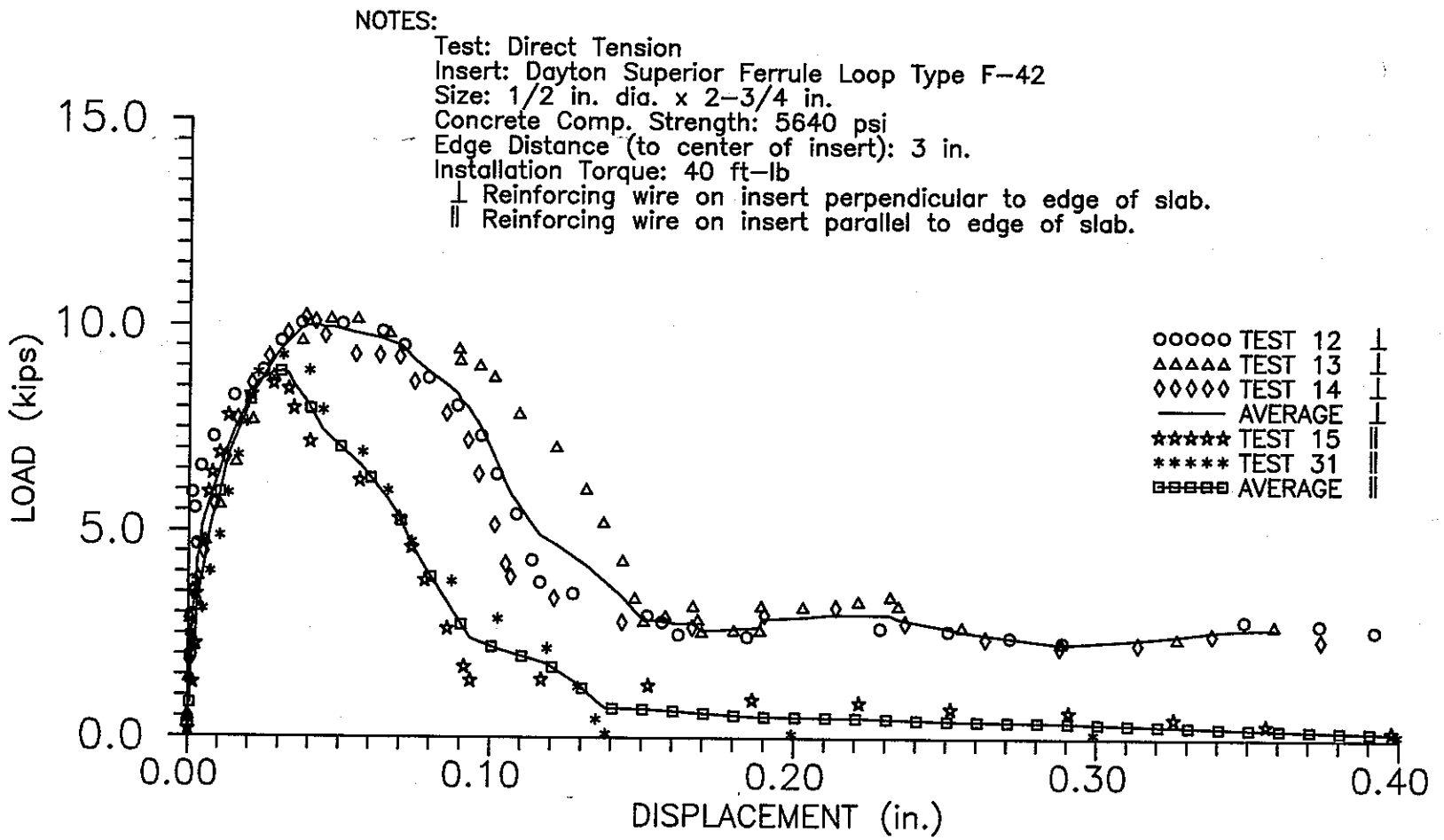

Figure B-9. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

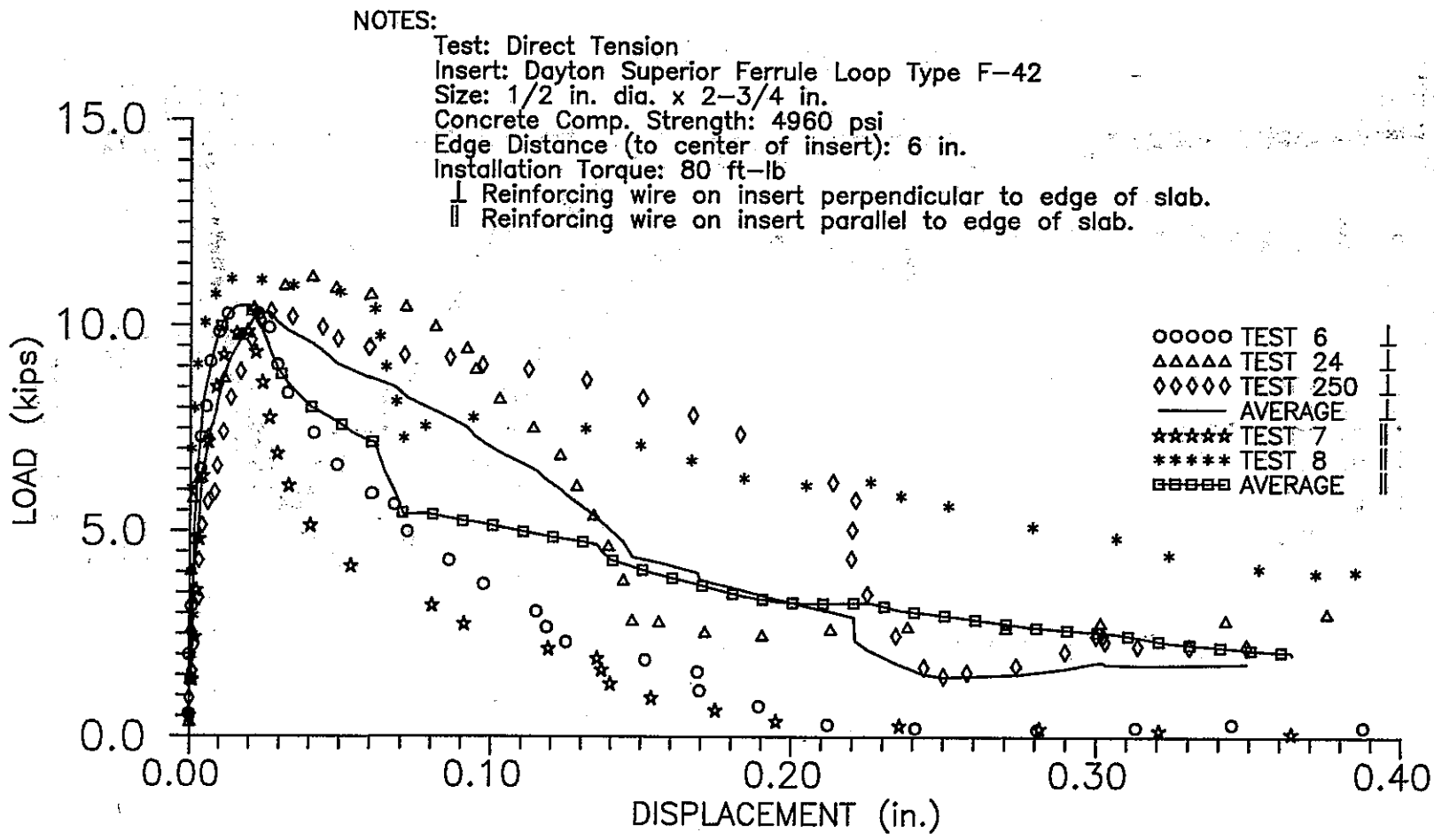

Figure B-10. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

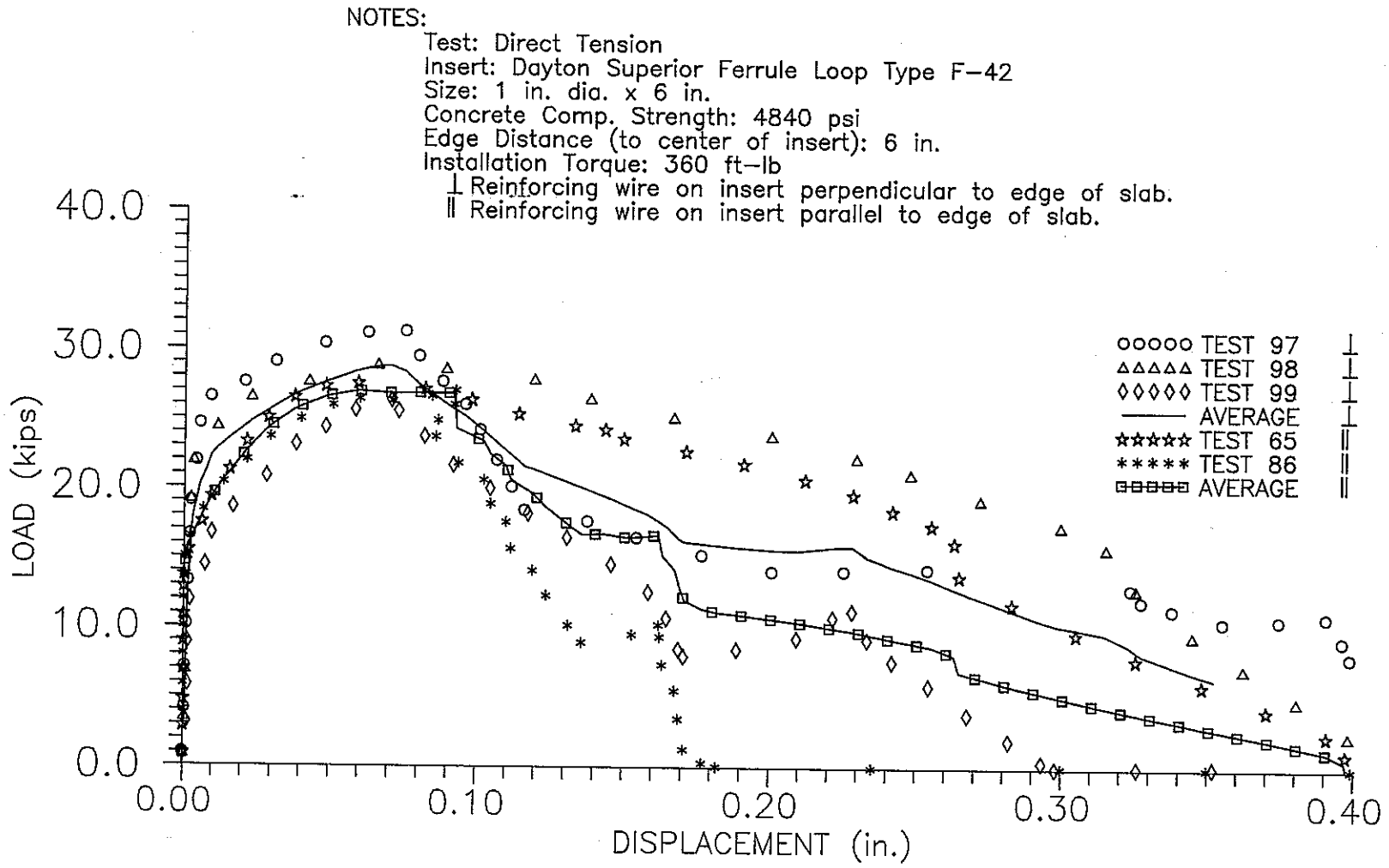

Figure B-11. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

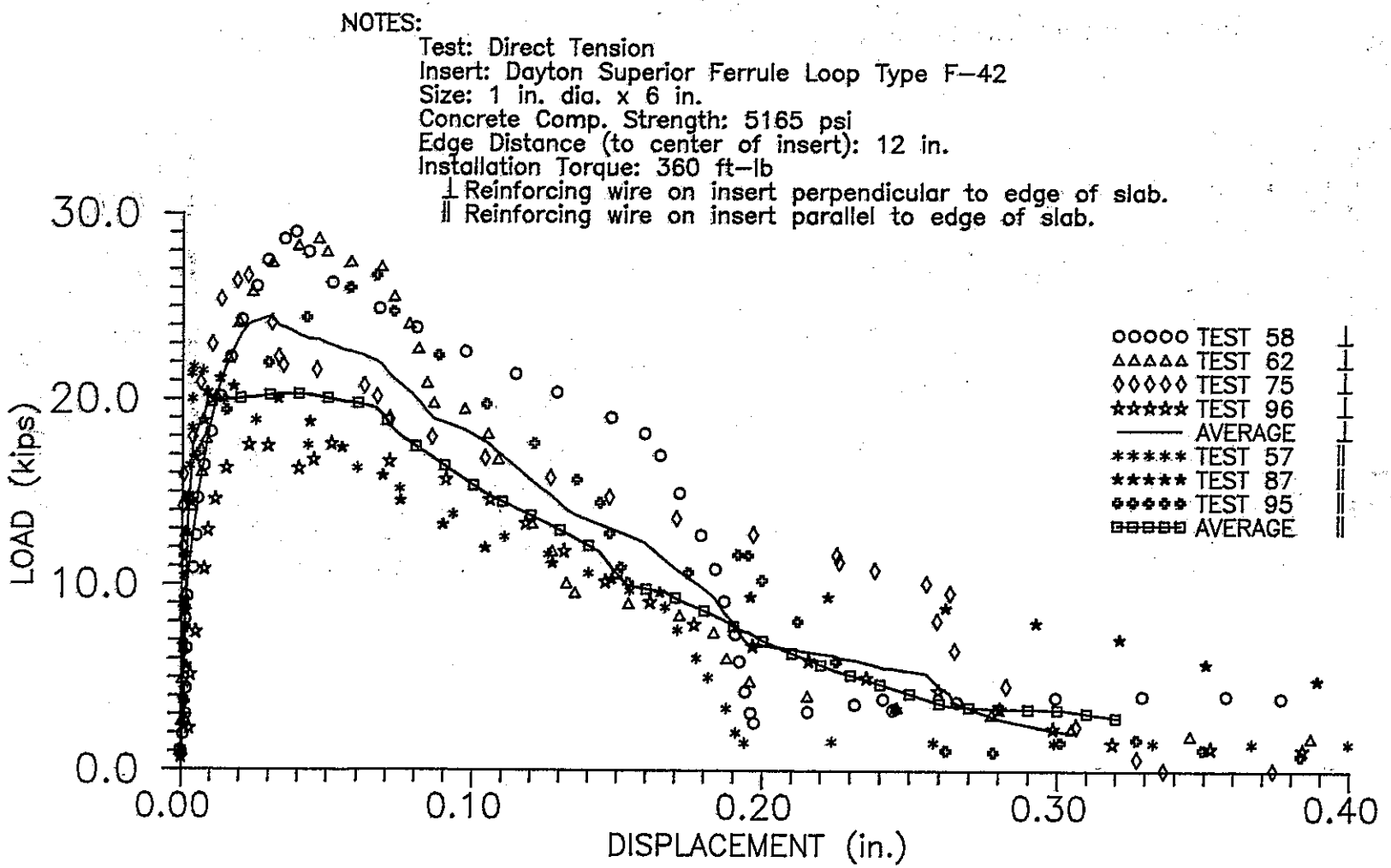

Figure B-12. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

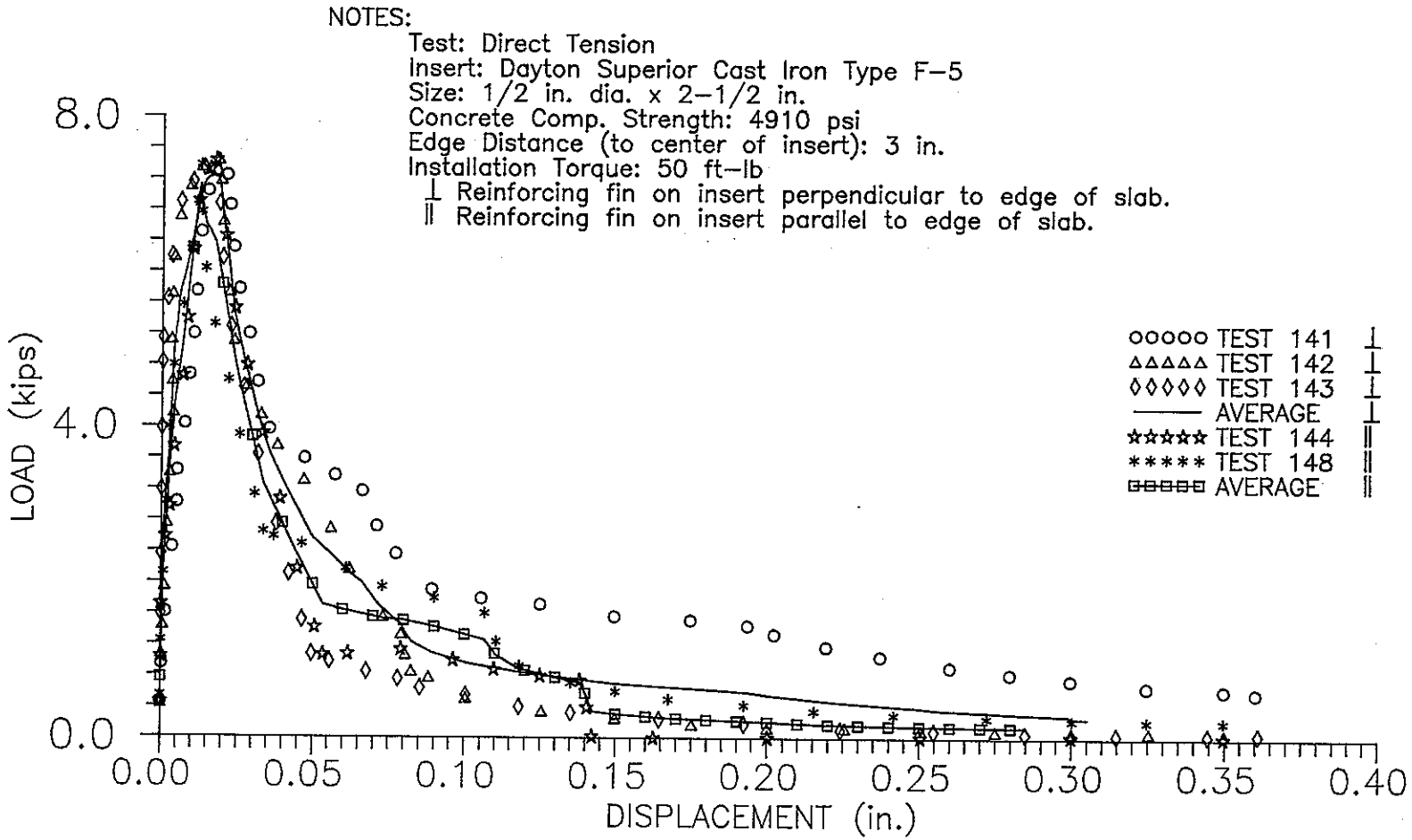

Figure B-13. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

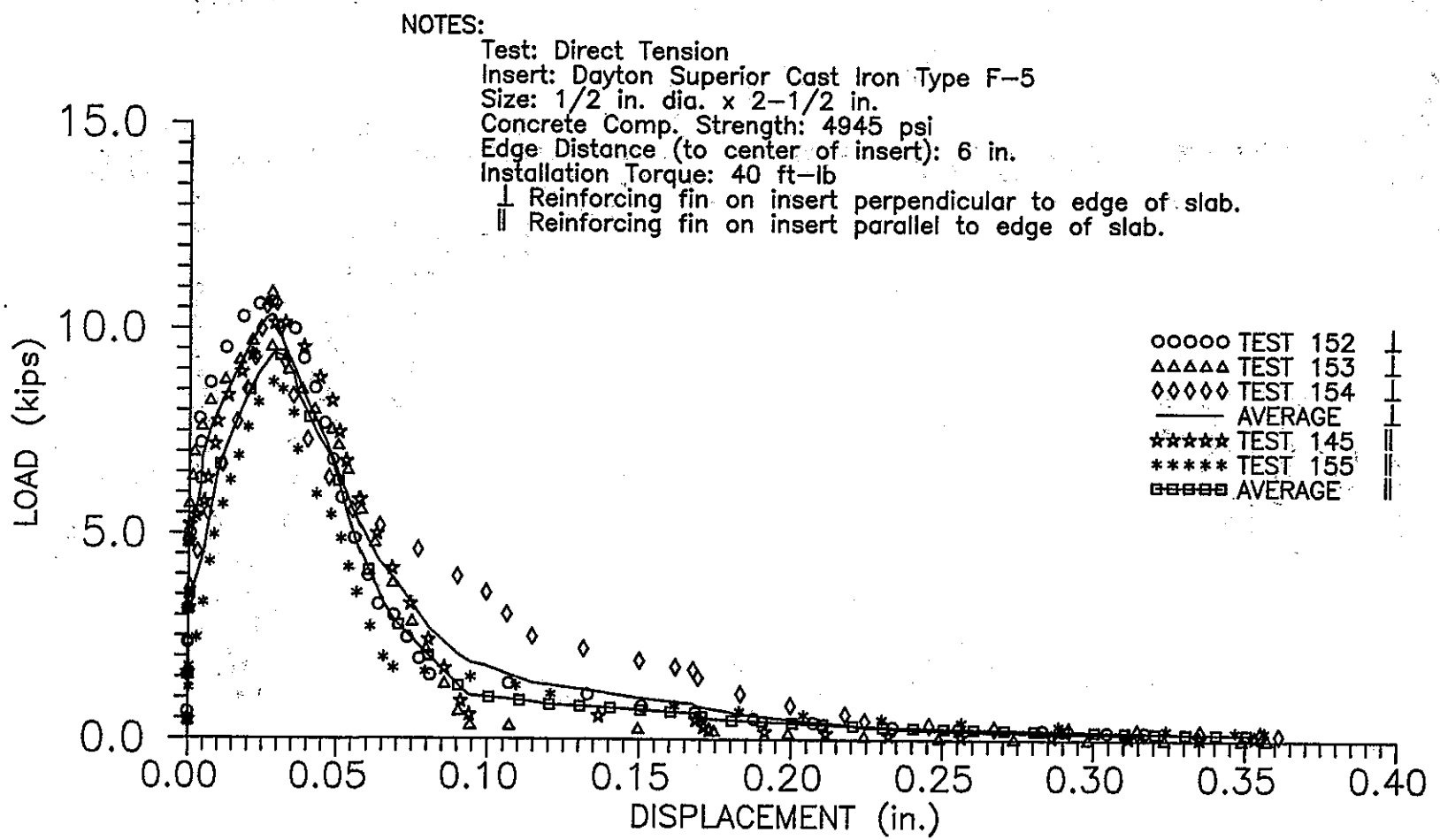

Figure B-14. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

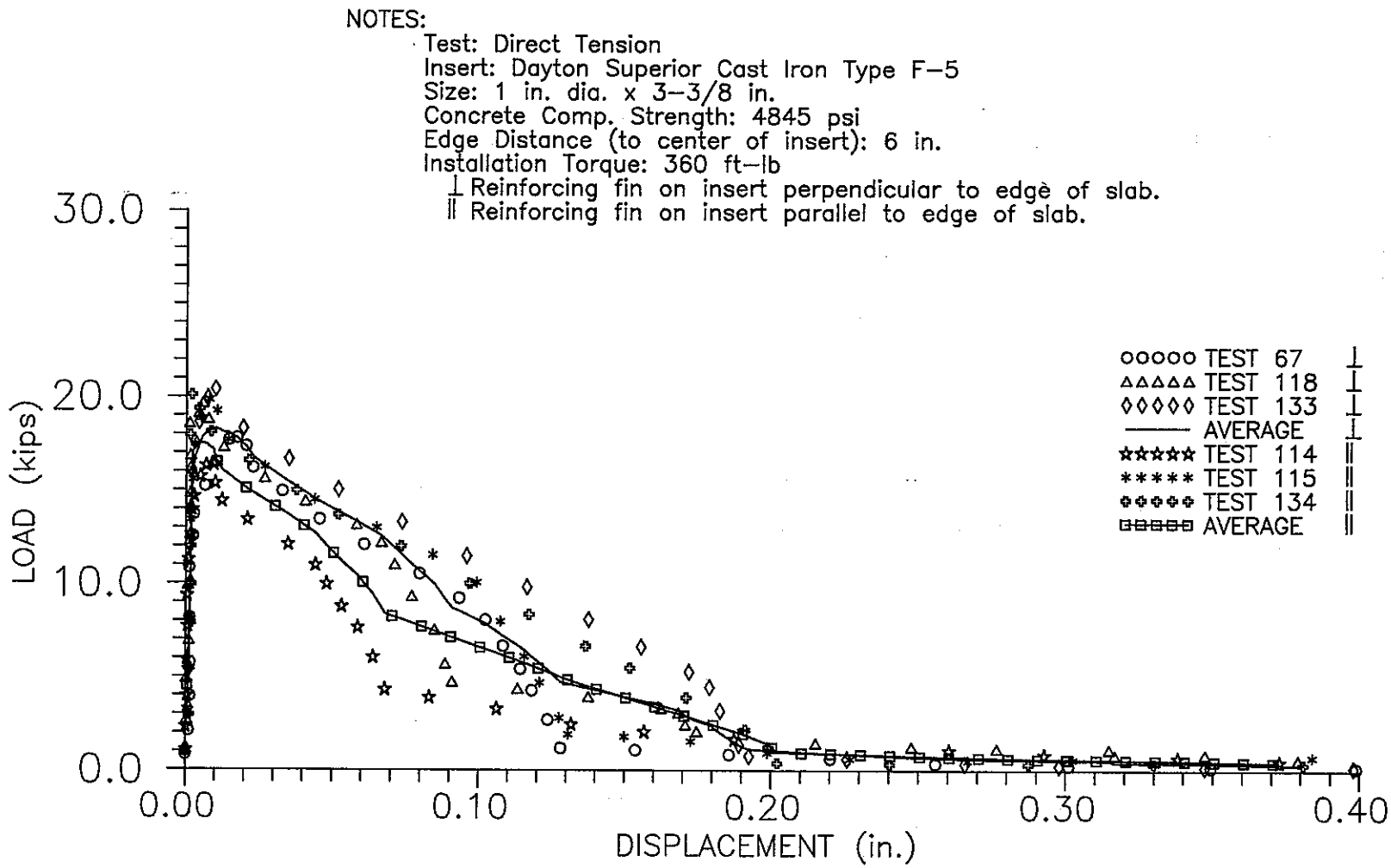

Figure B-15. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

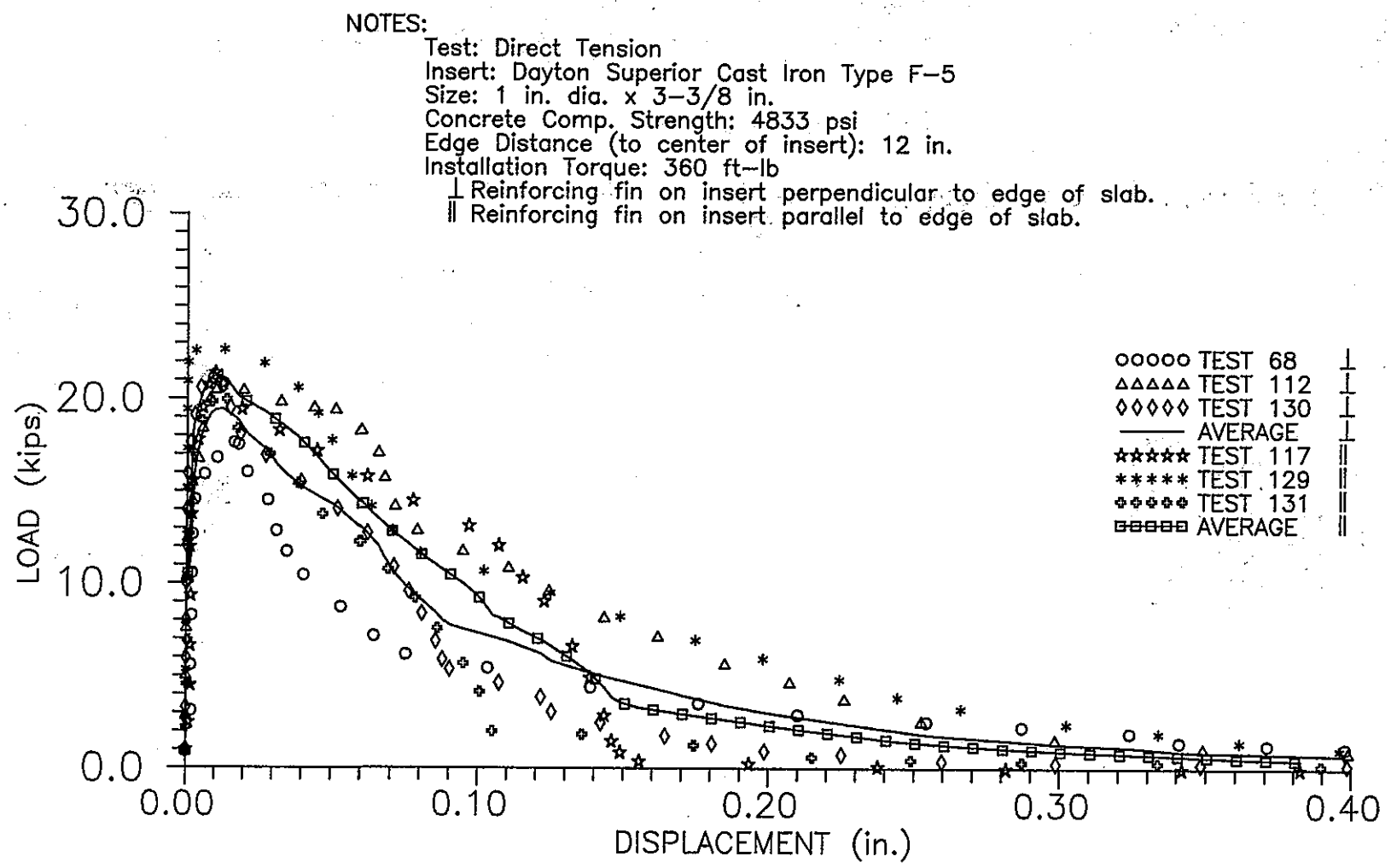

Figure B-16. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

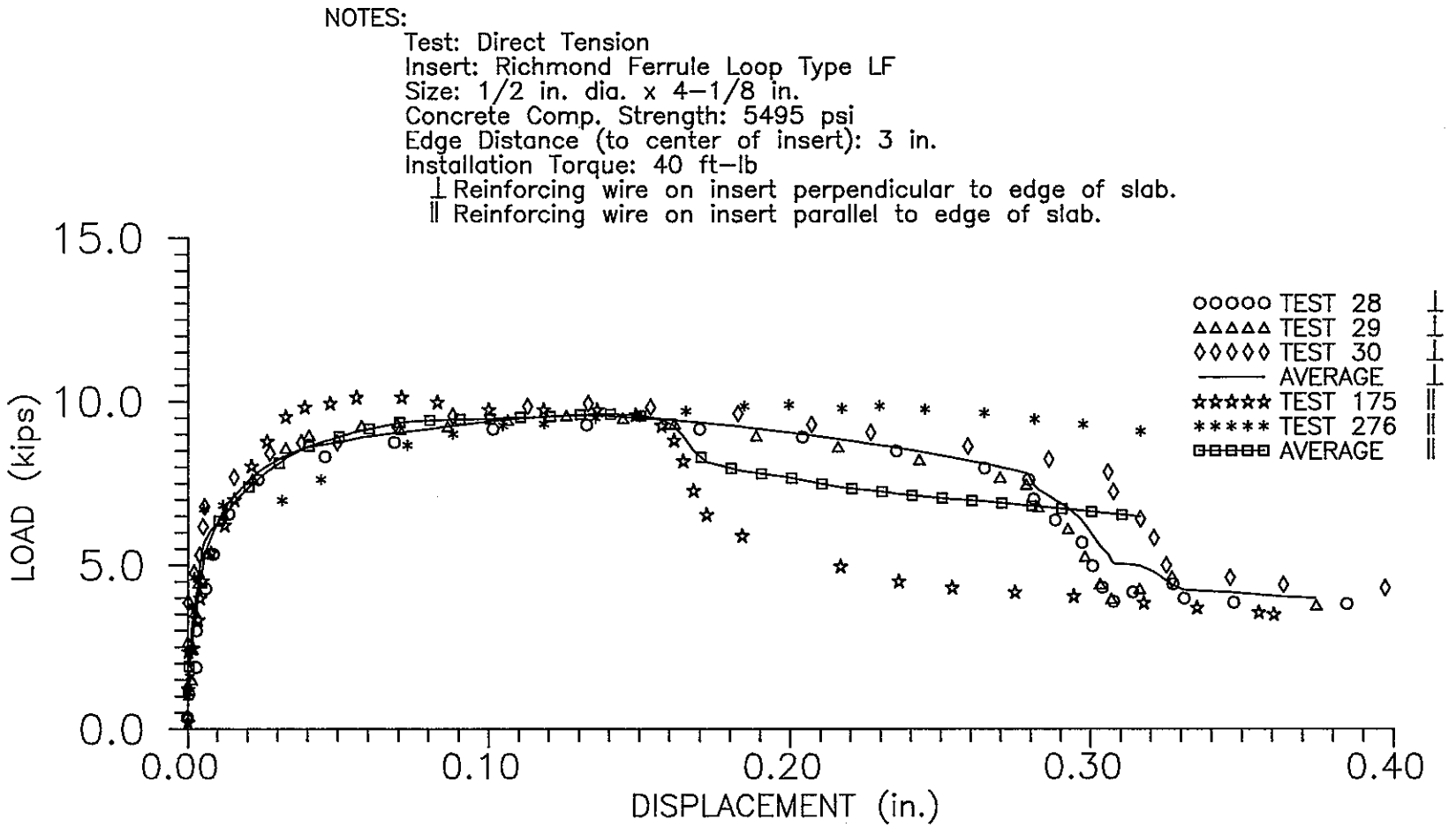

Figure B-17. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

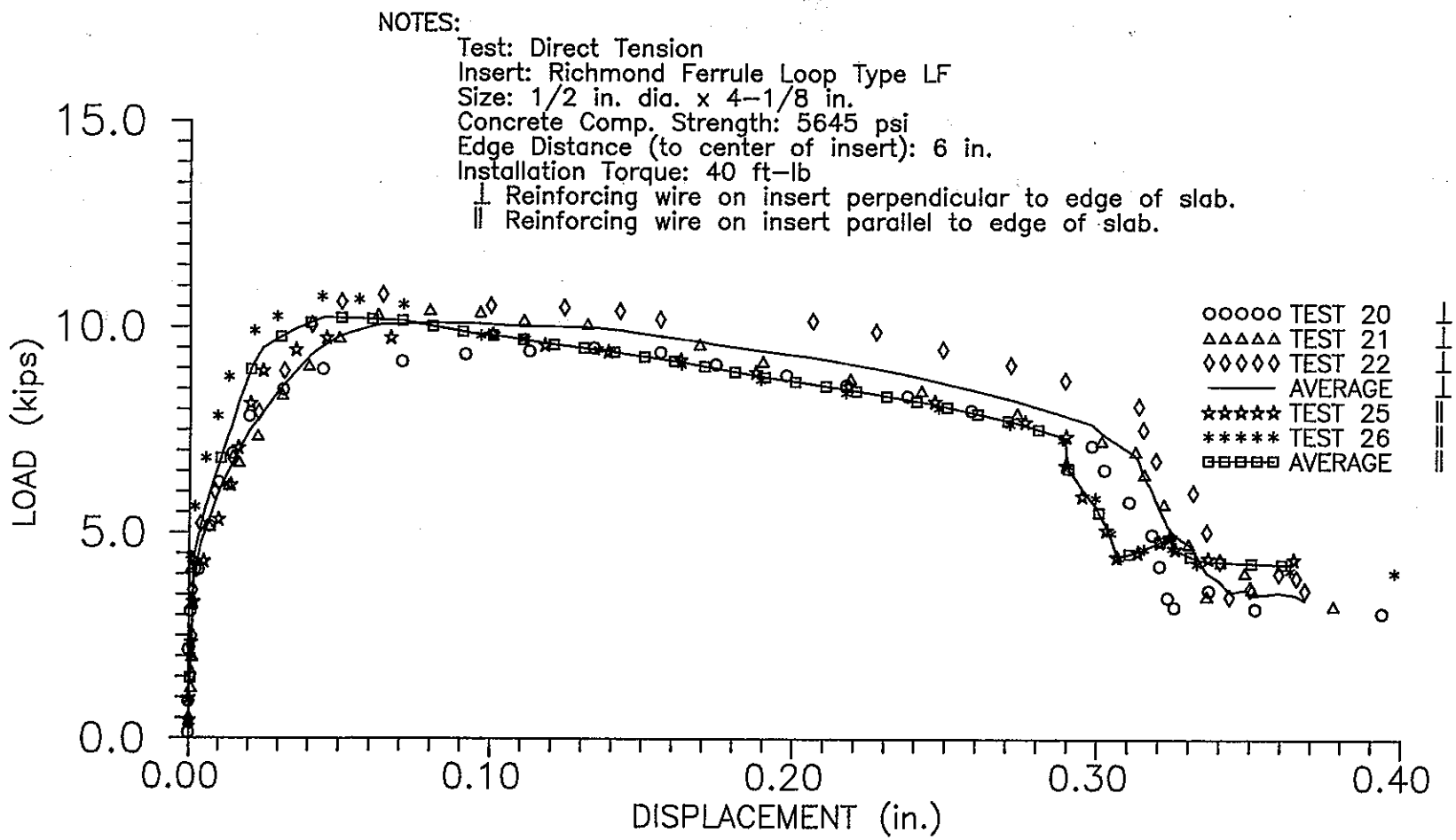

Figure B-18. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

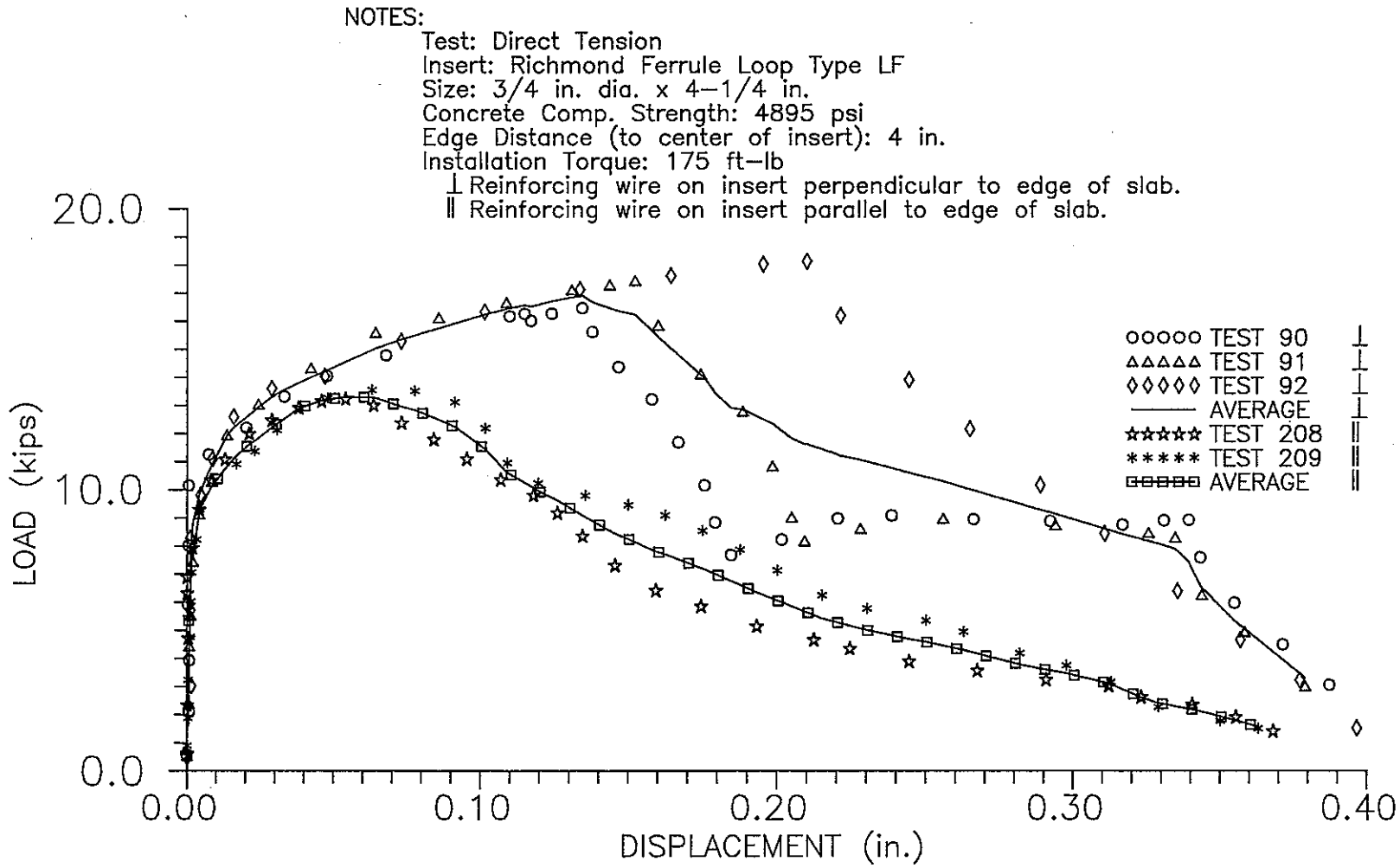

Figure B-19. Load vs. displacement for short–term direct tensile tests of cast–in–place concrete inserts.

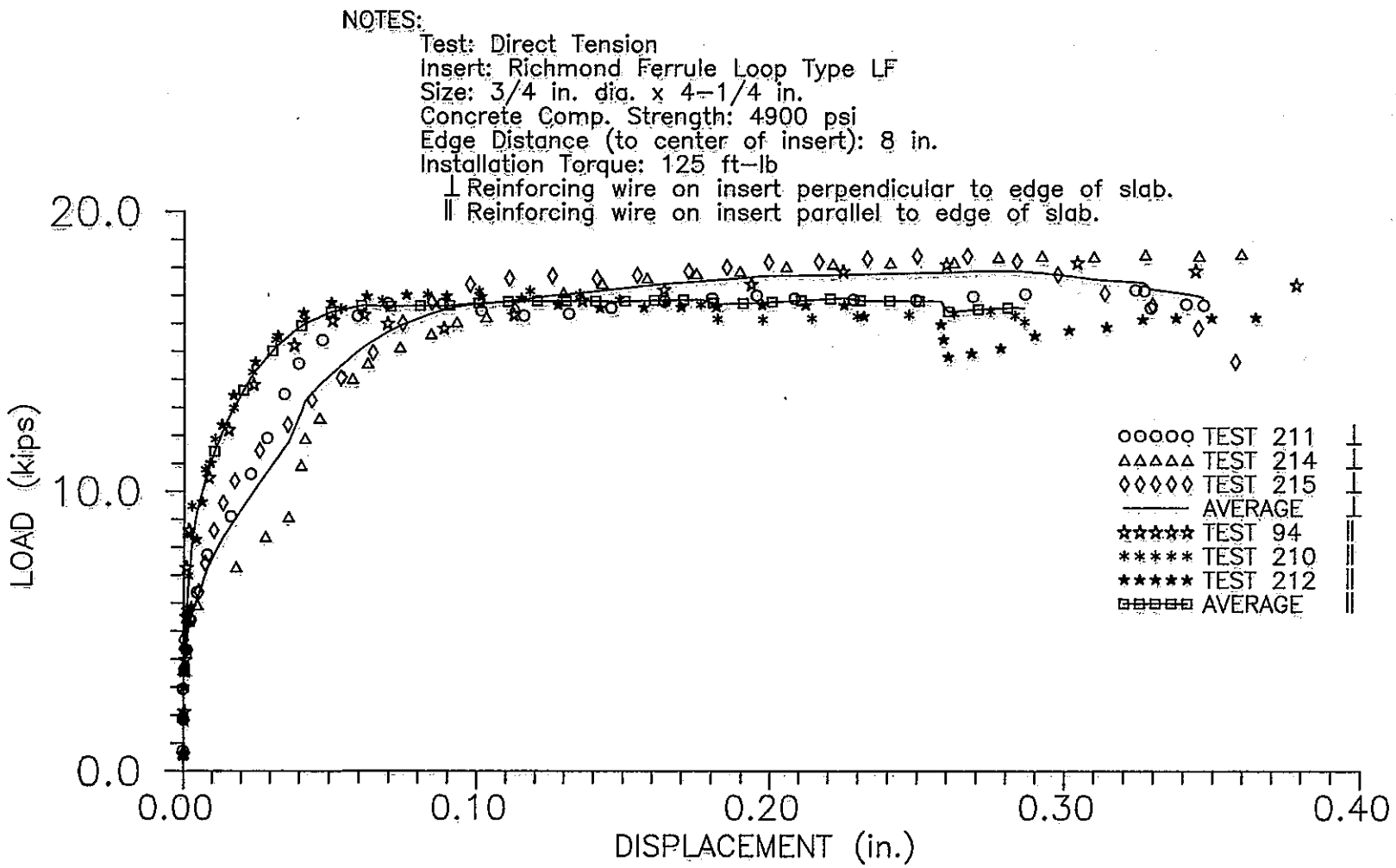

Figure B-20. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

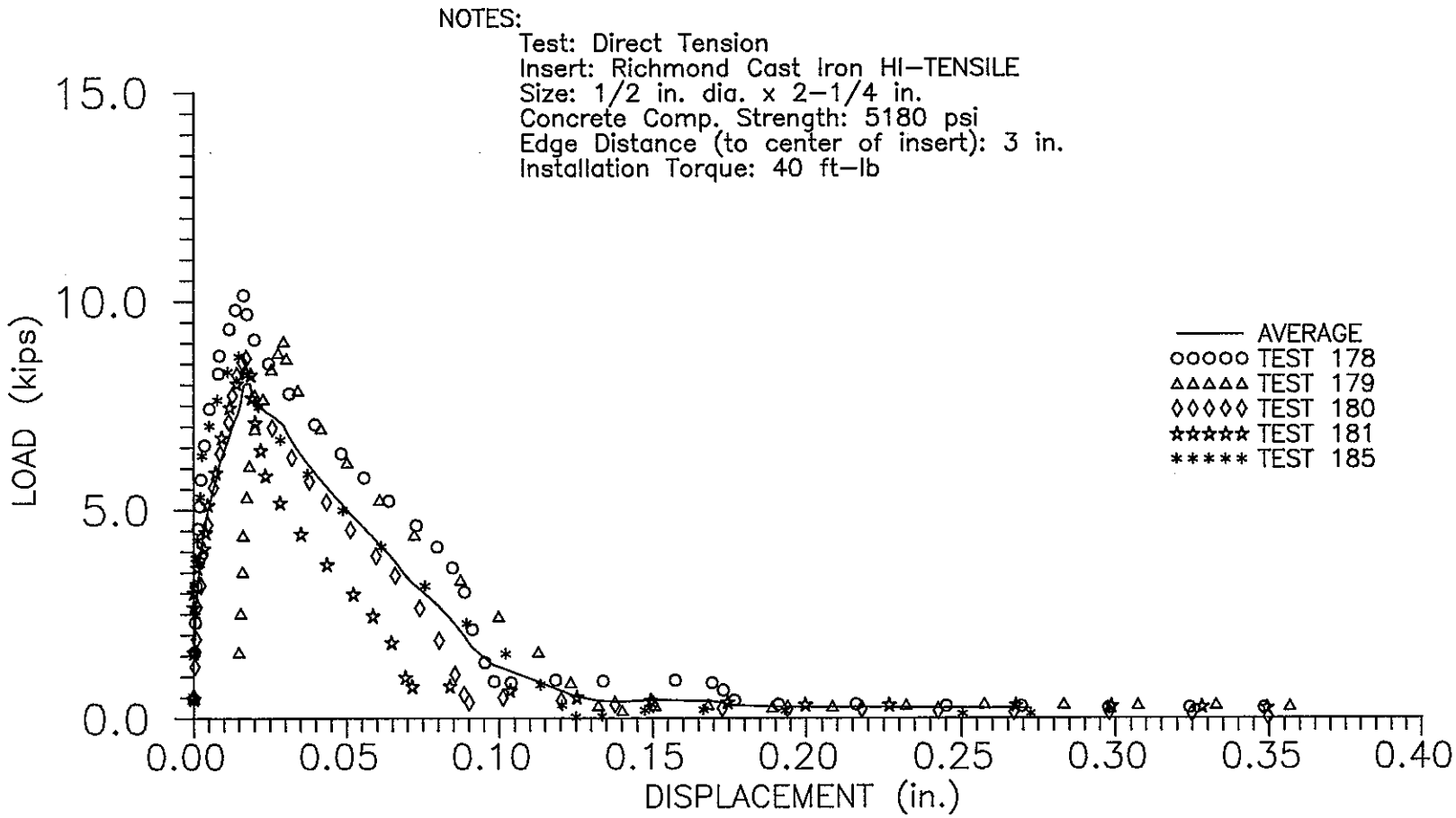

Figure B-21. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

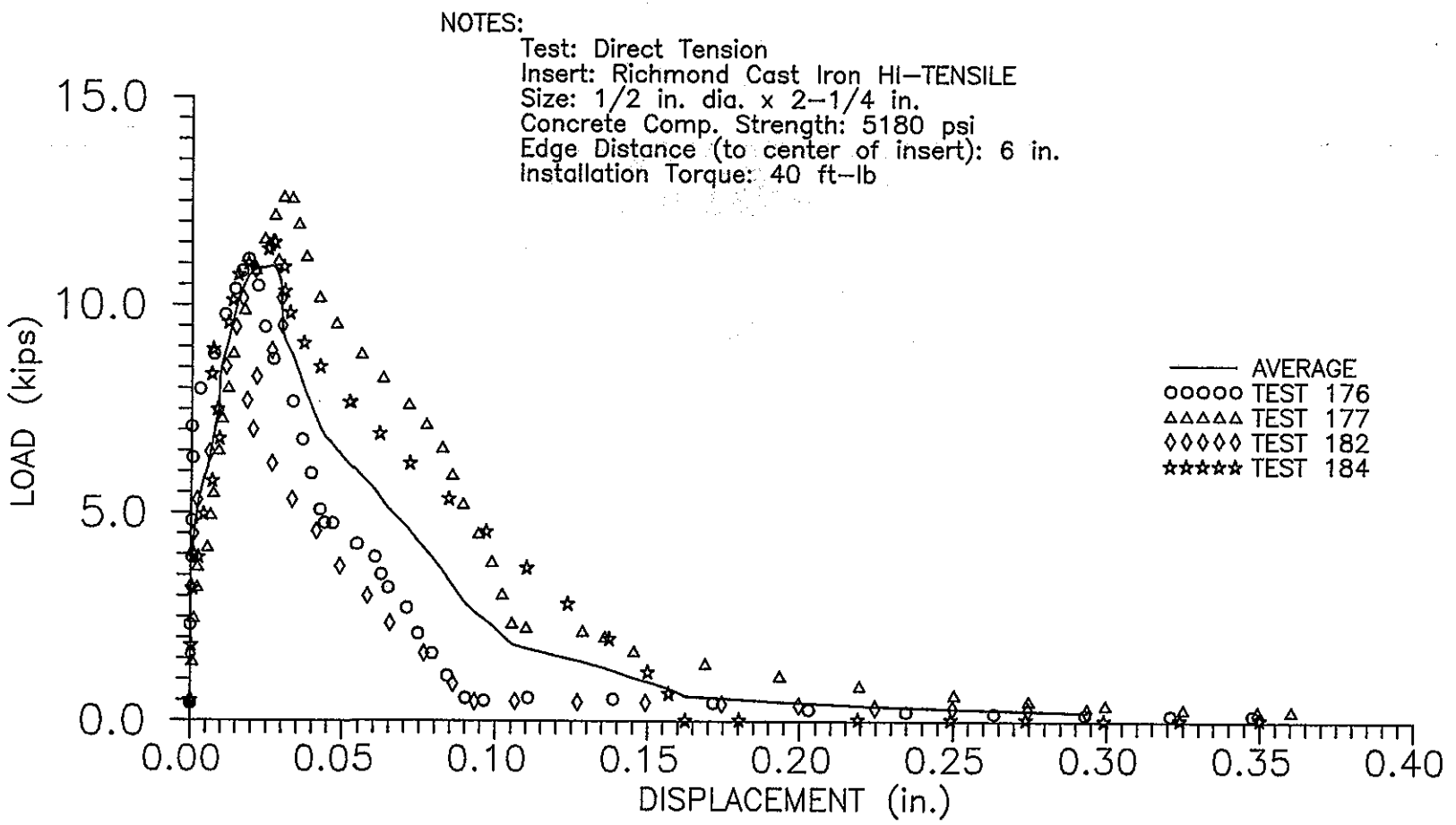

Figure B-22. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

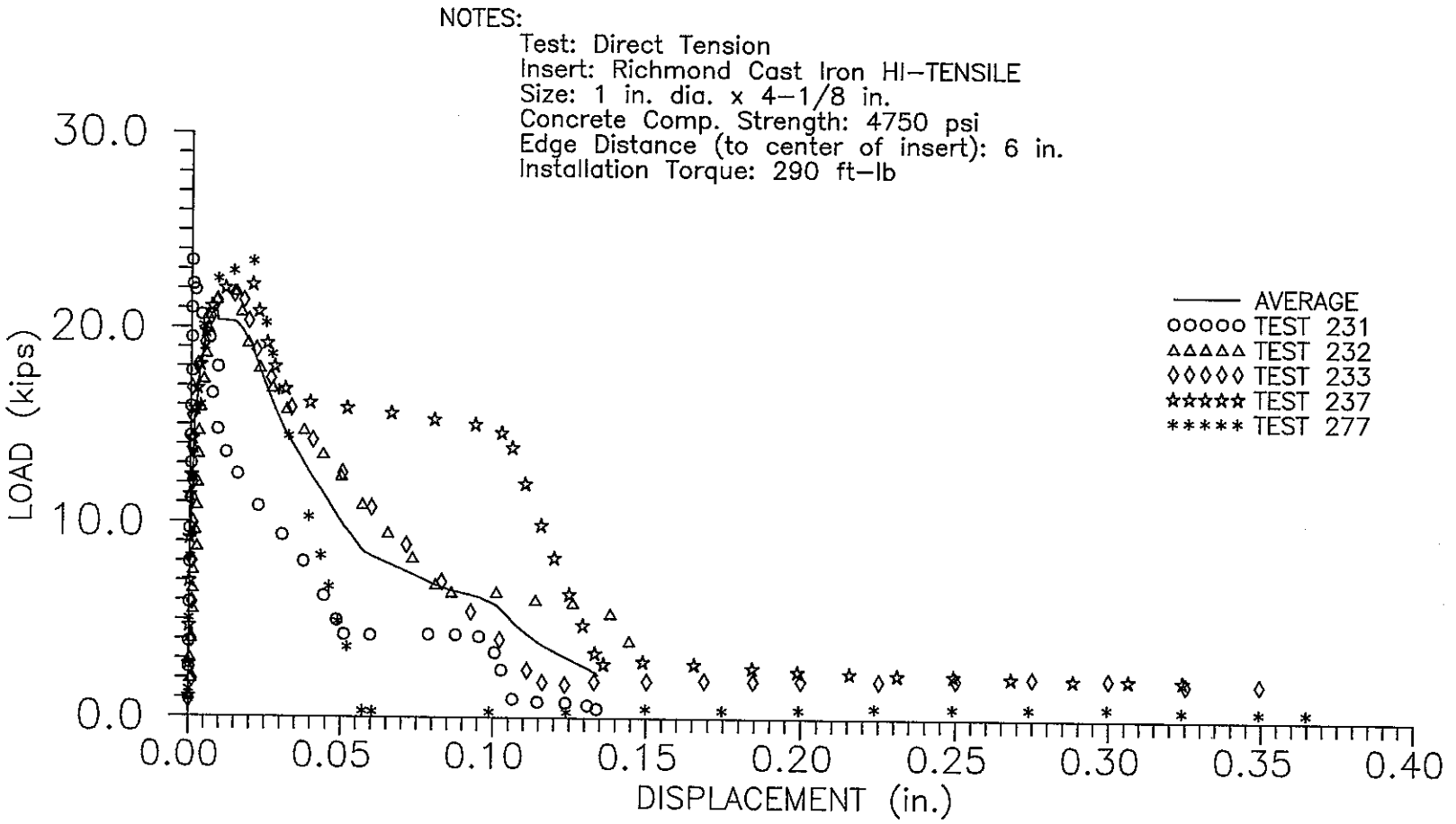

Figure B-23. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

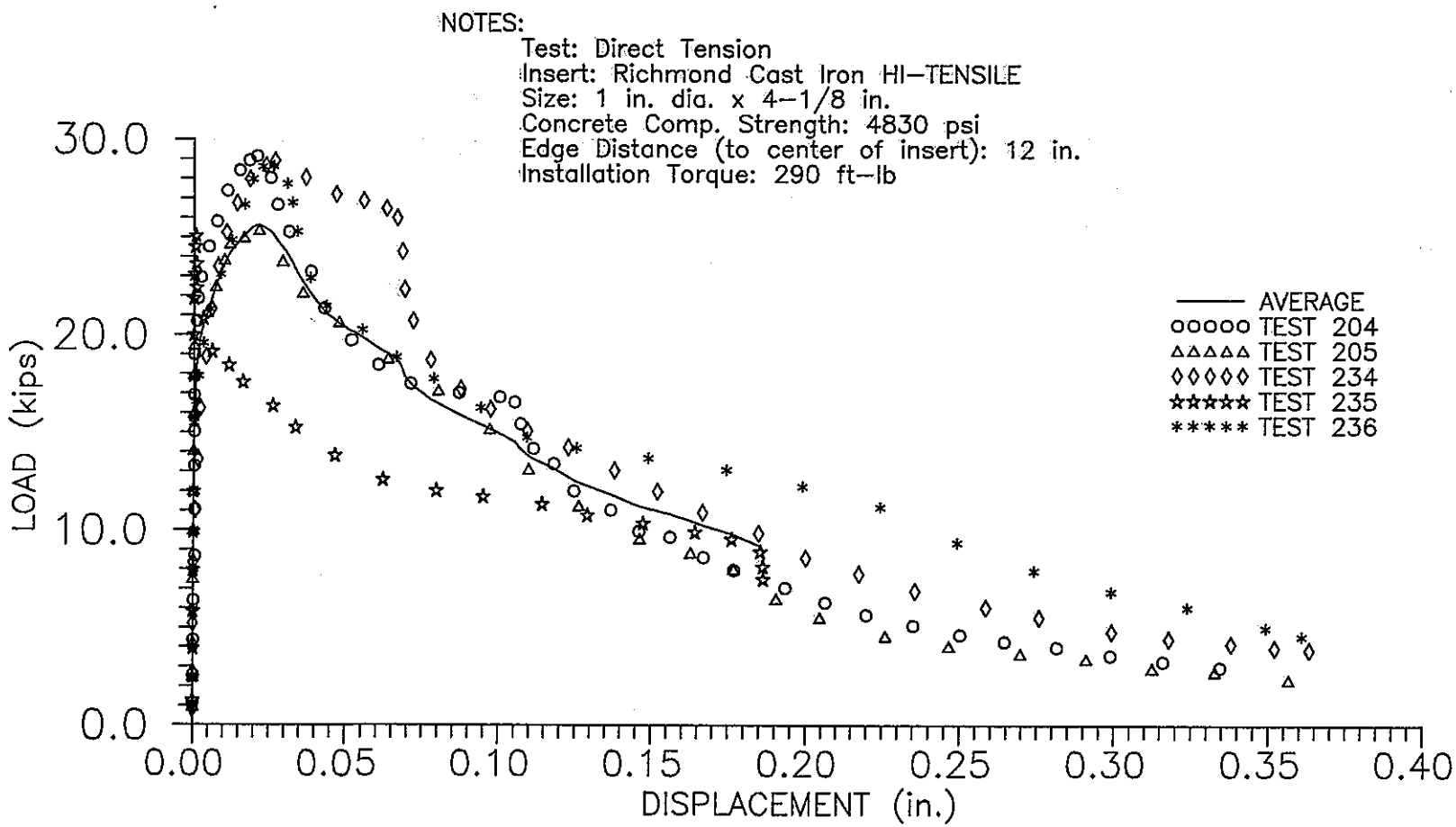

Figure B-24. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

Appendix C: Plots of Load Versus Displacement of Various Cast-In-Place Concrete Inserts from Direct Shear Tests.
Concrete Compressive Strength 5000 ± psi.

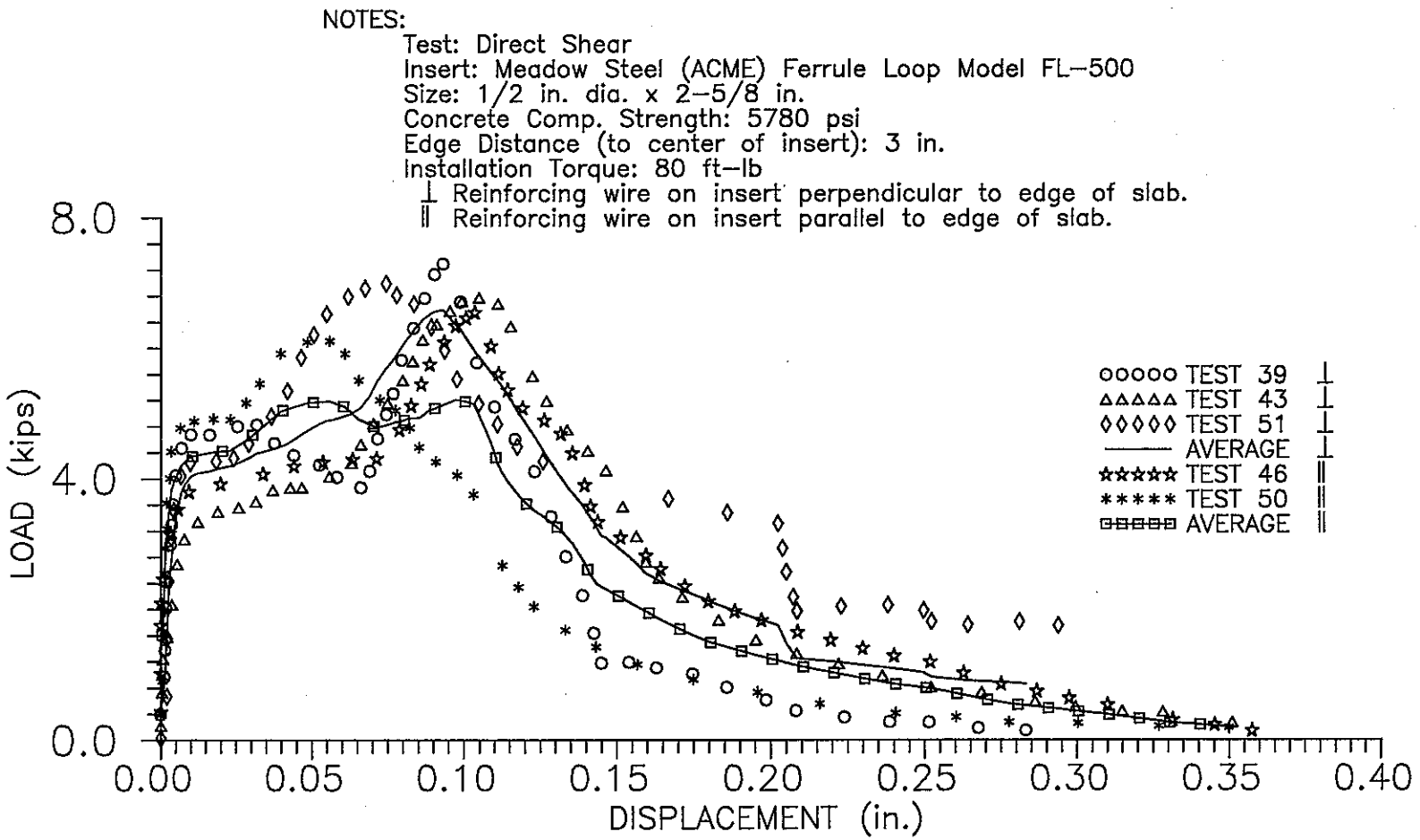

Figure C-1. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

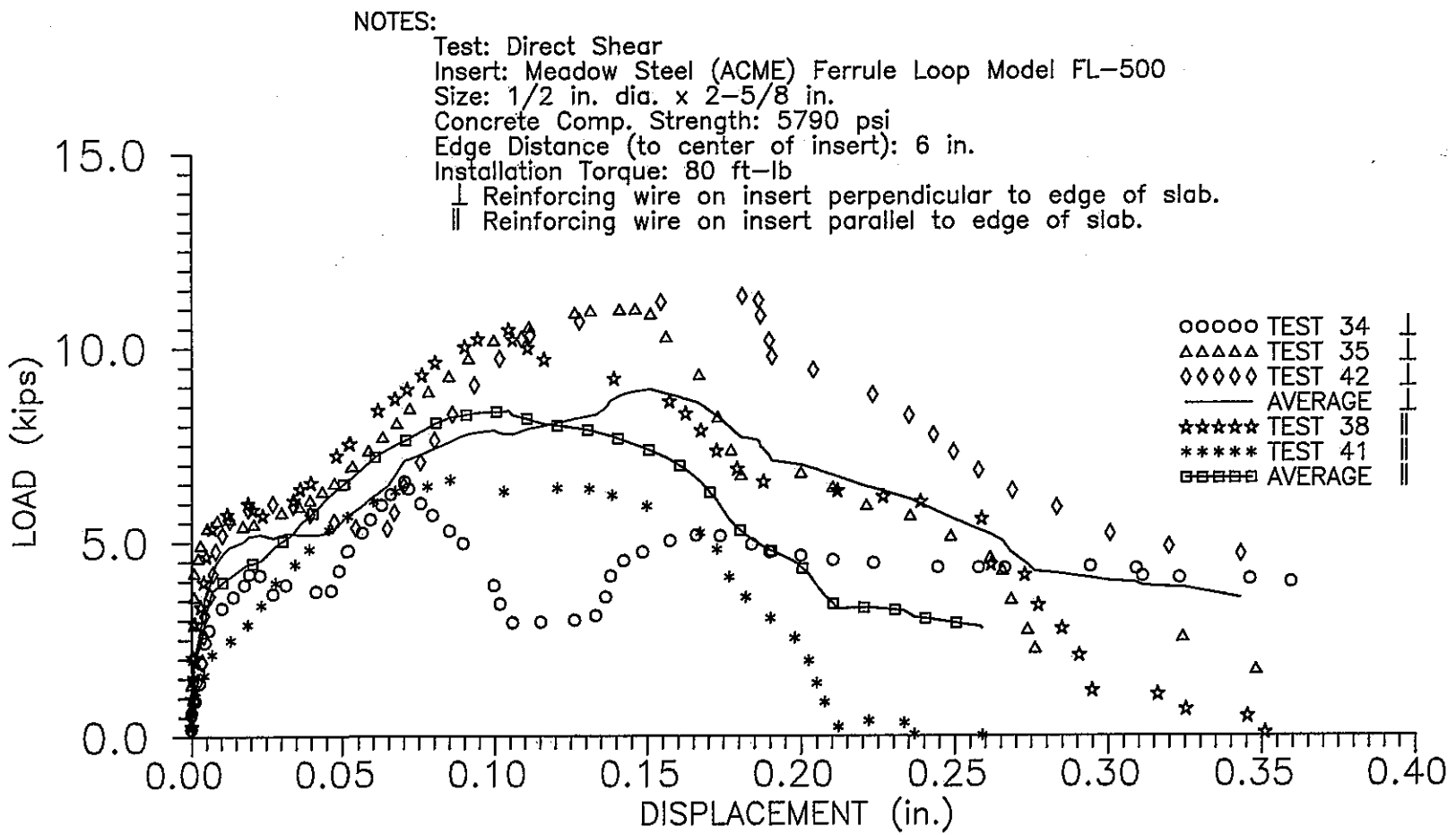

Figure C-2. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

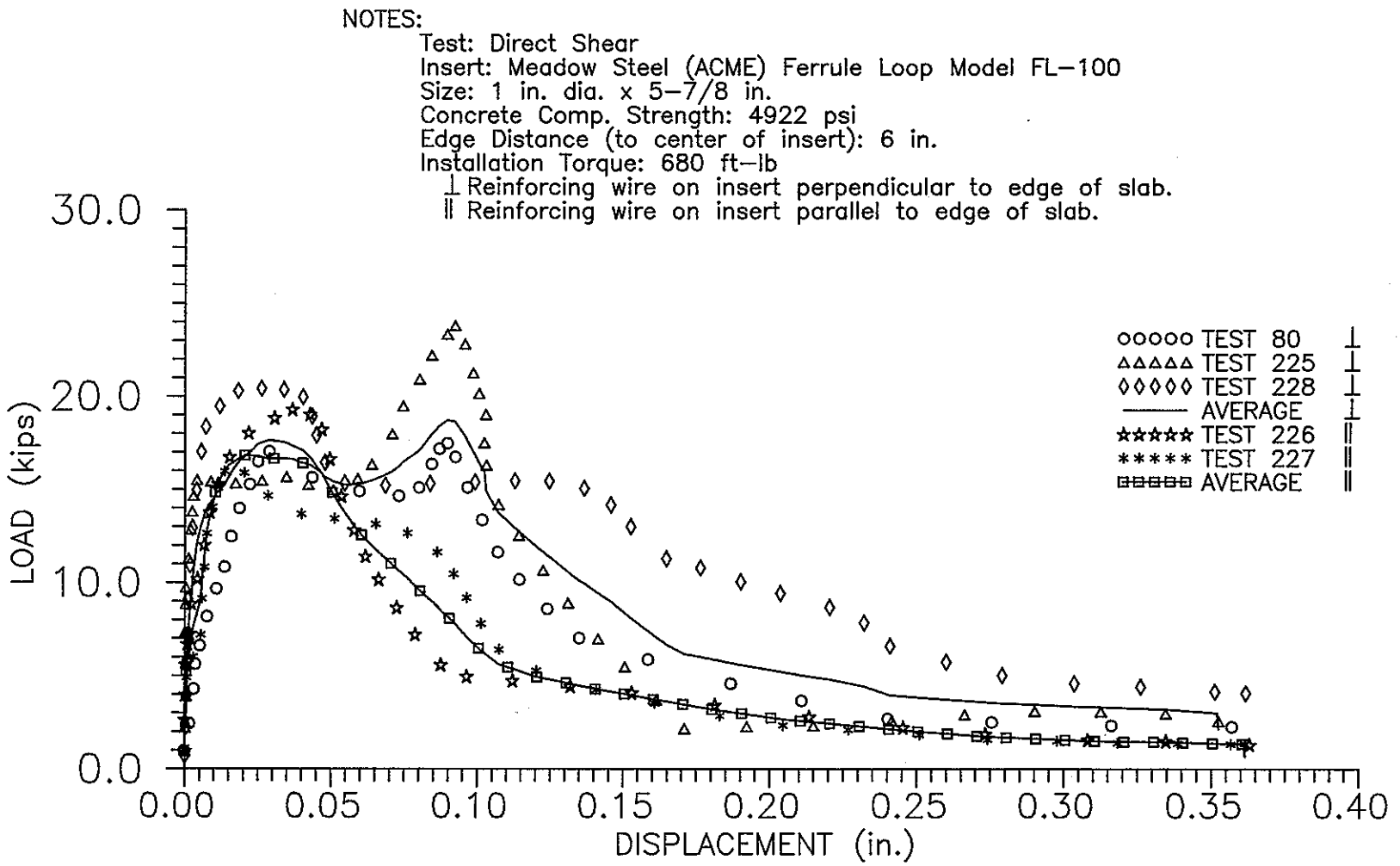

Figure C-3. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

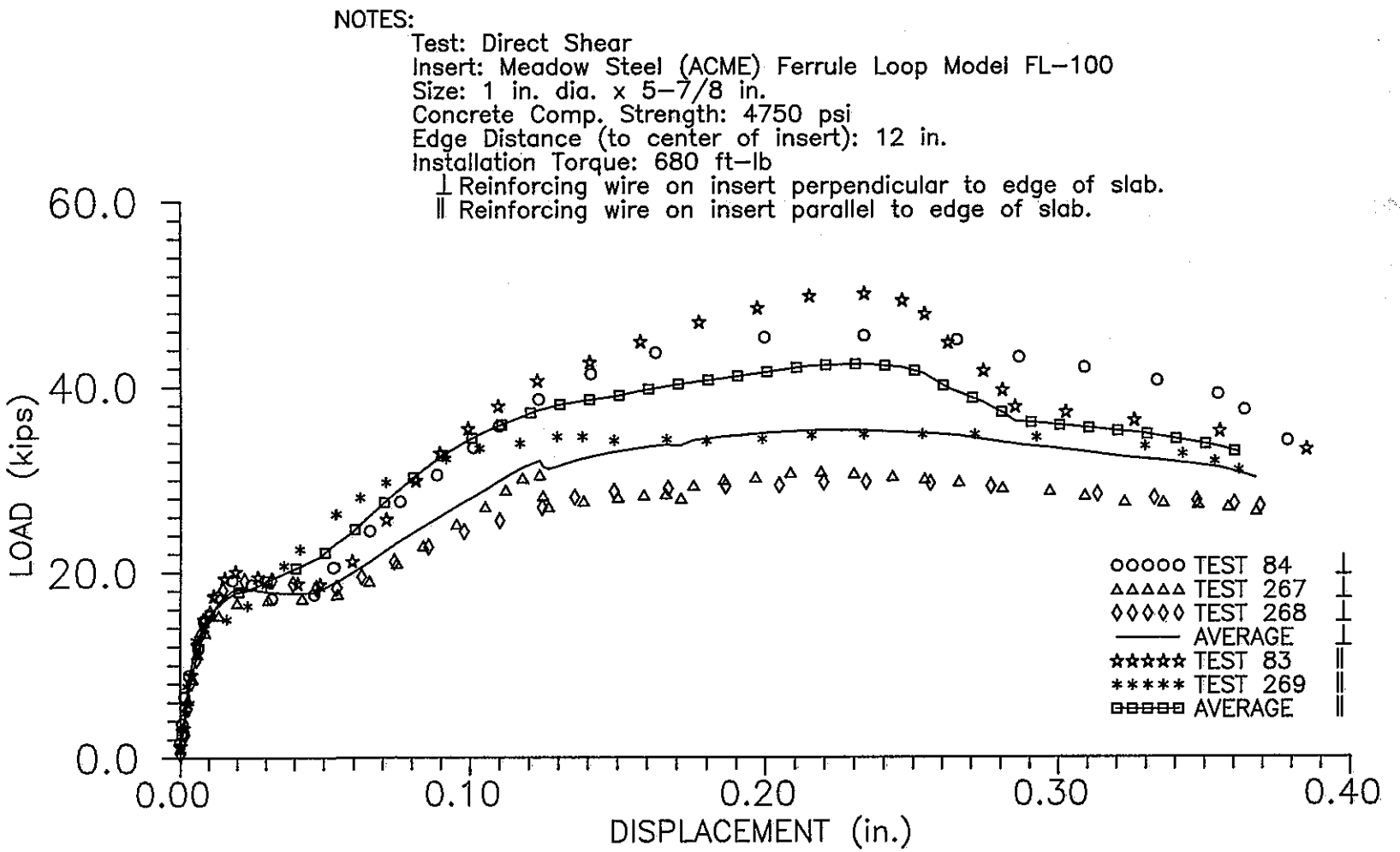

Figure C-4. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

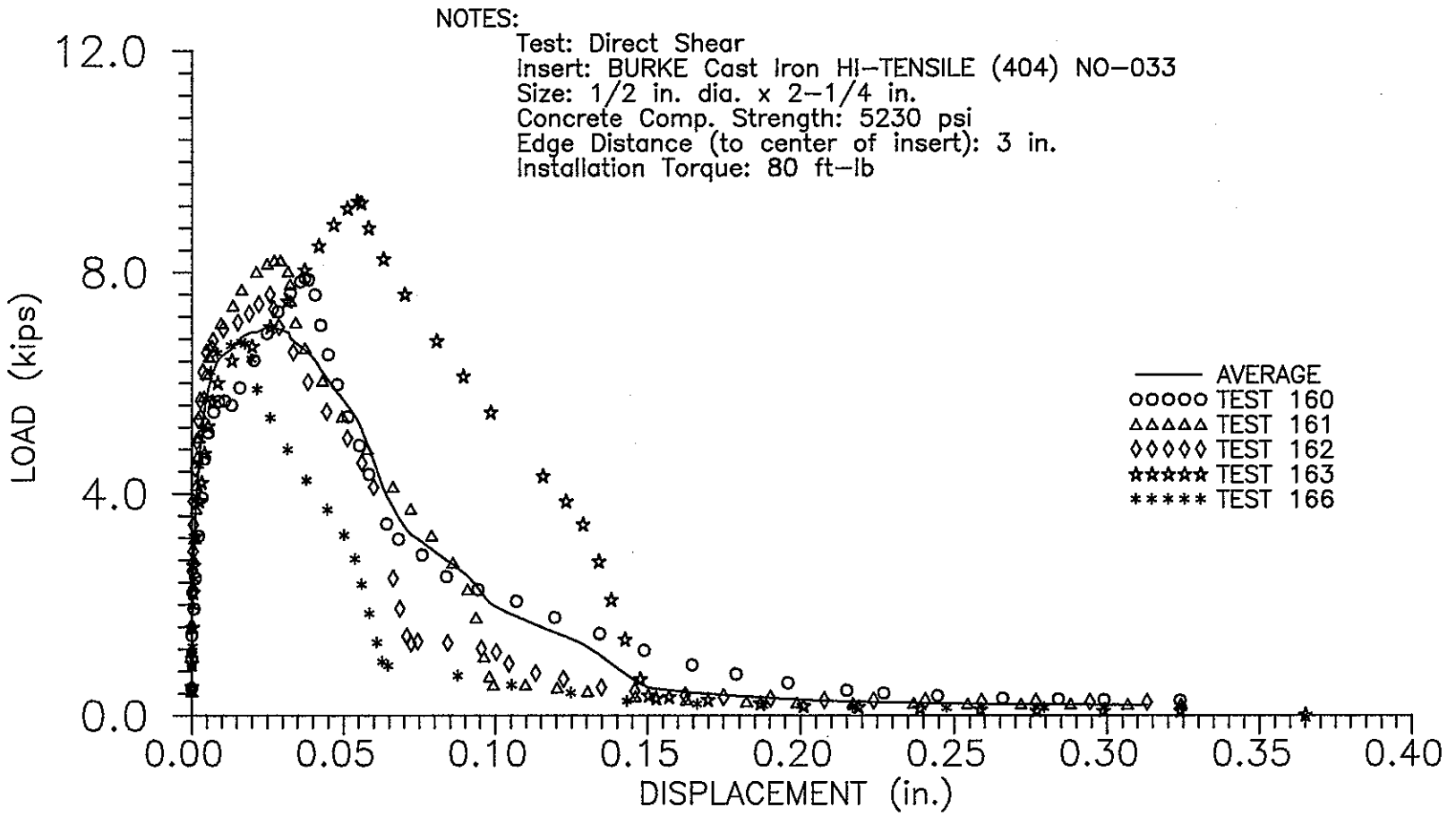

Figure C-5. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

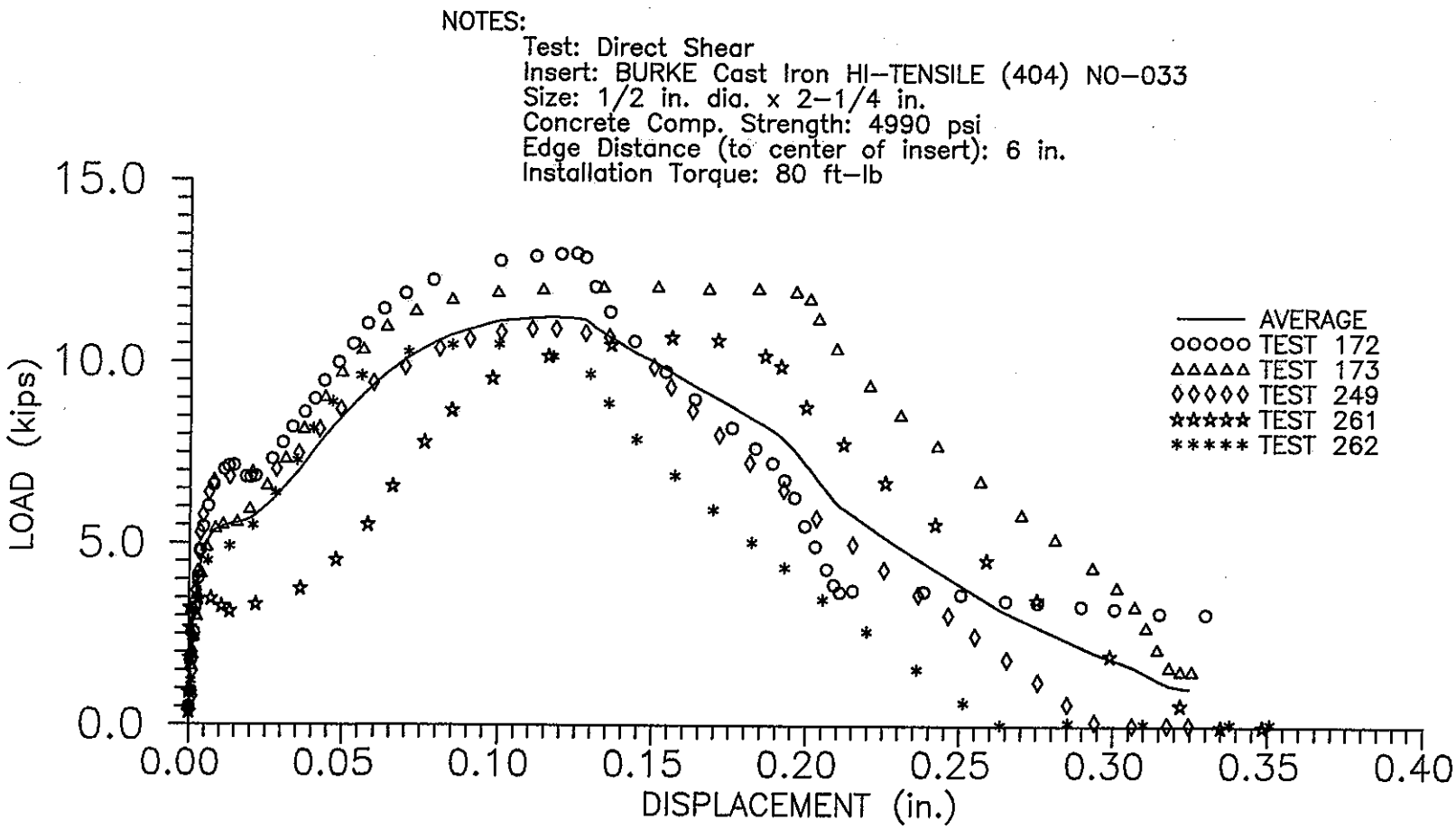

Figure C-6. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

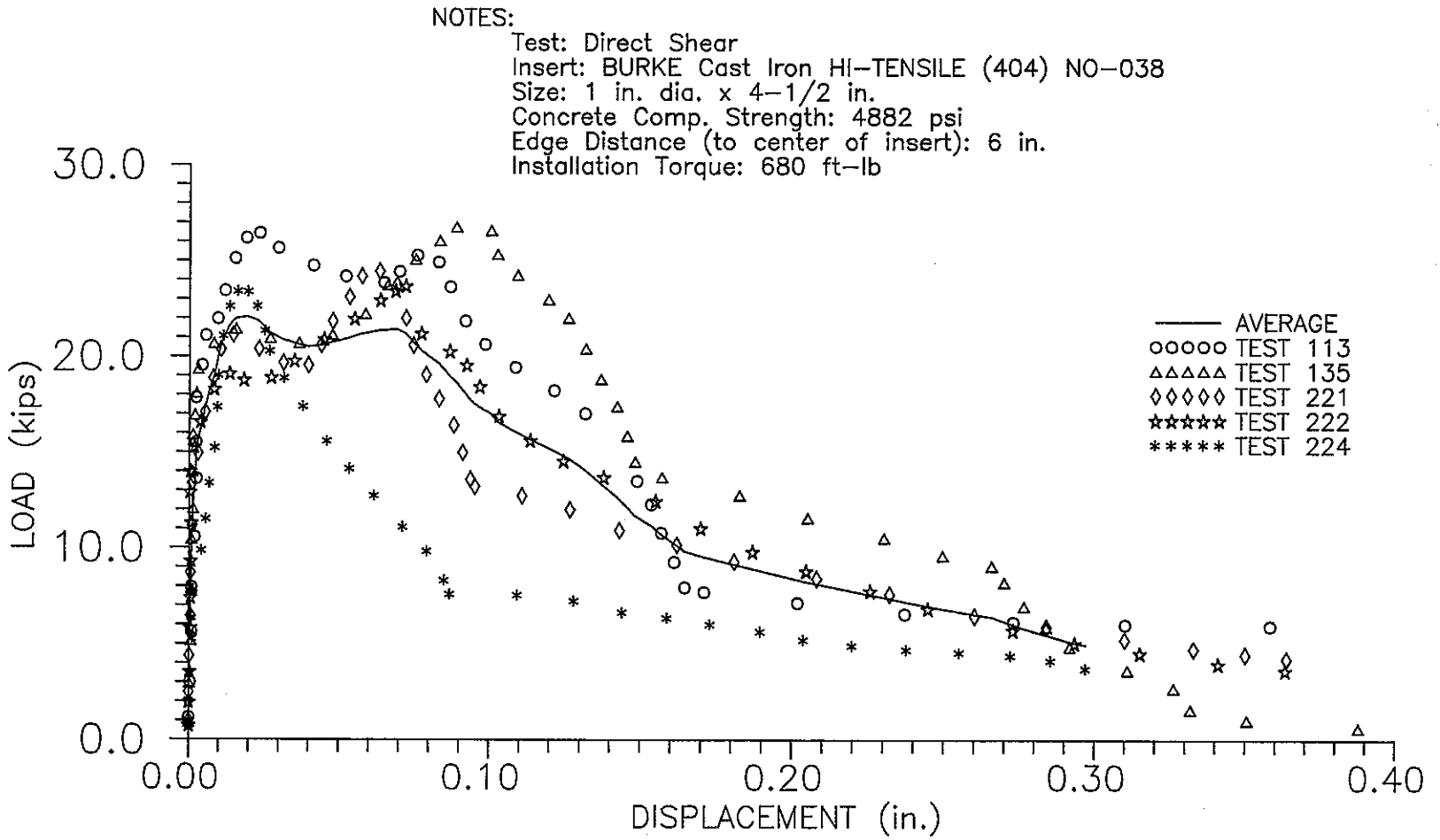

Figure C-7. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

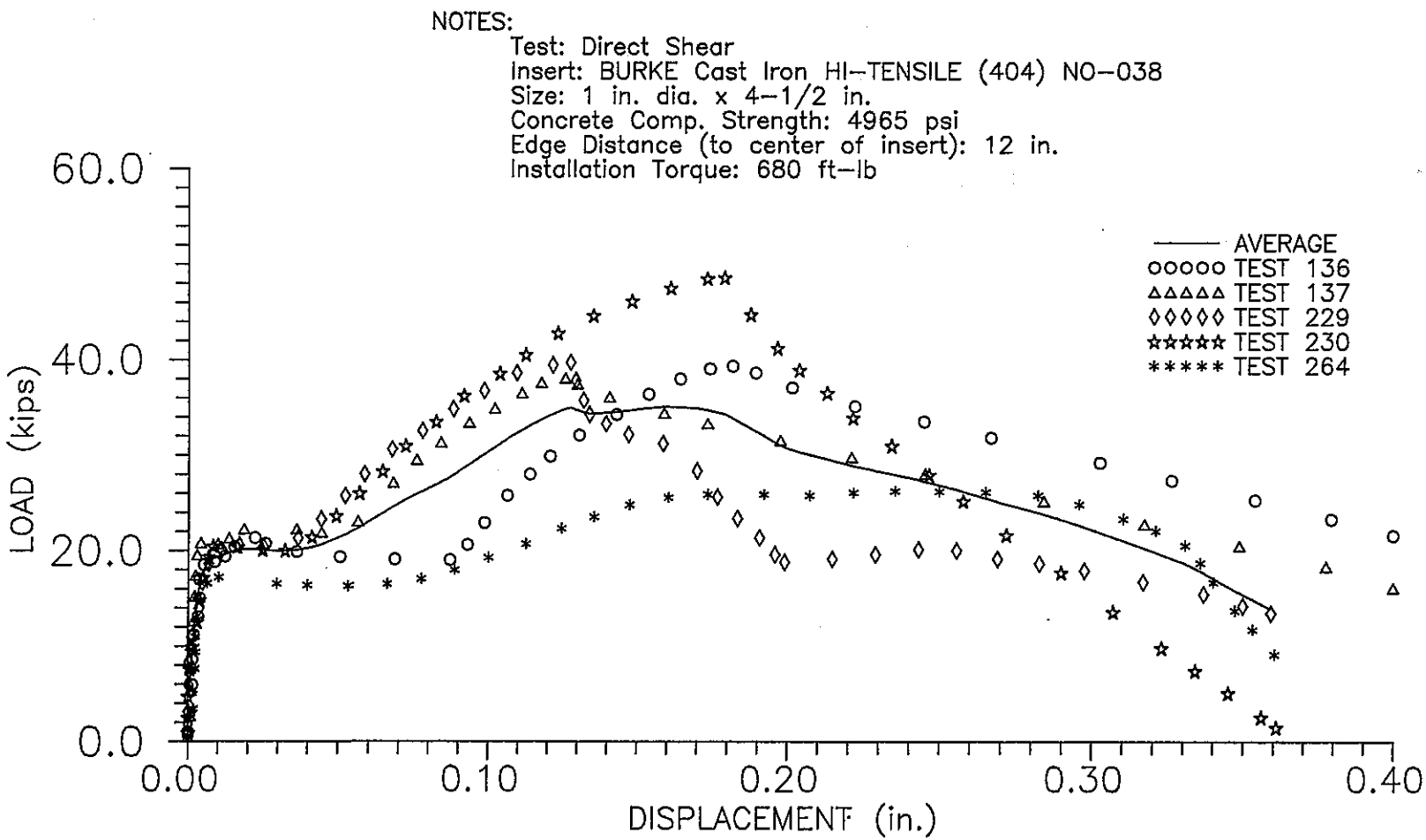

Figure C-8. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

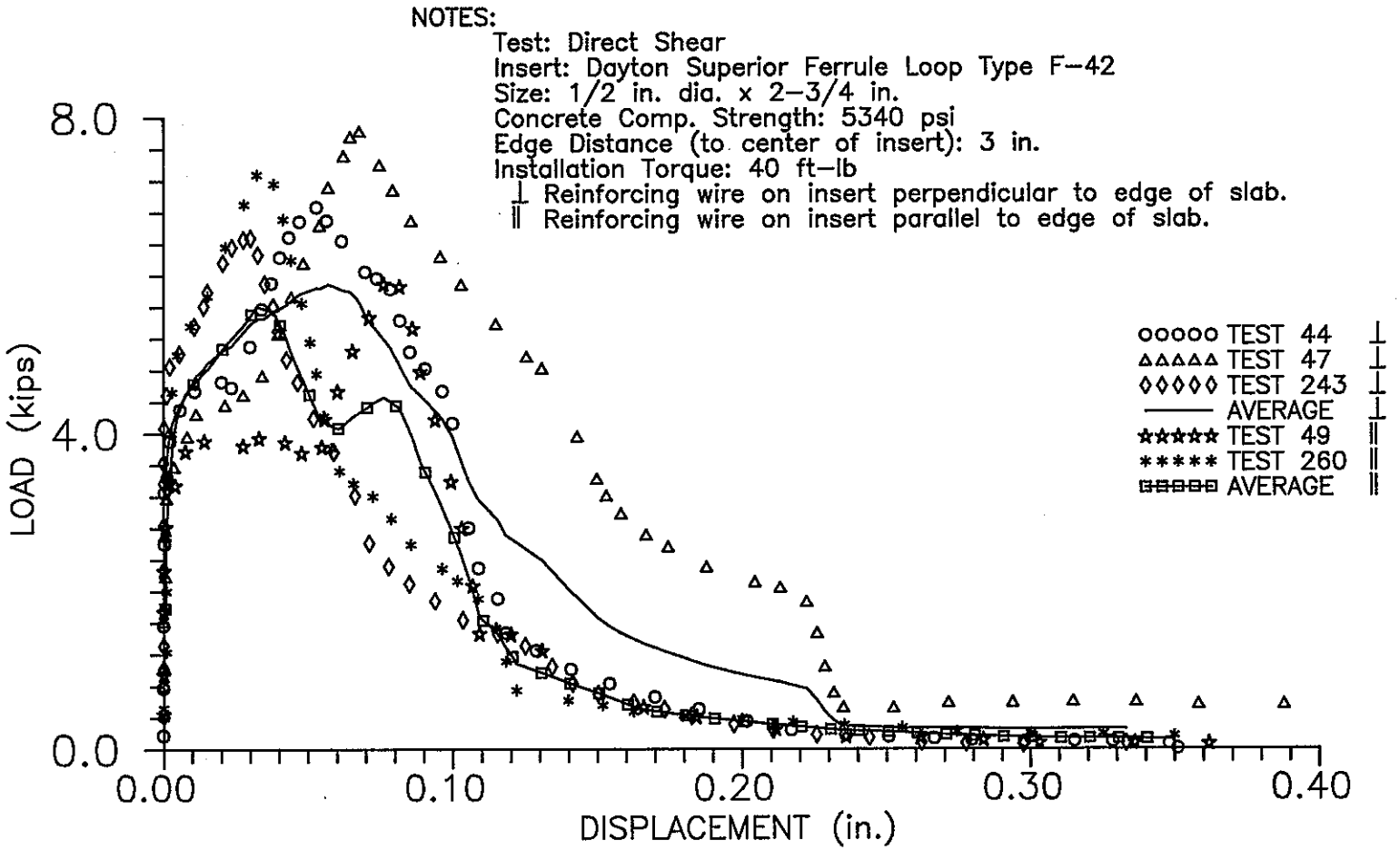

Figure C-9. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

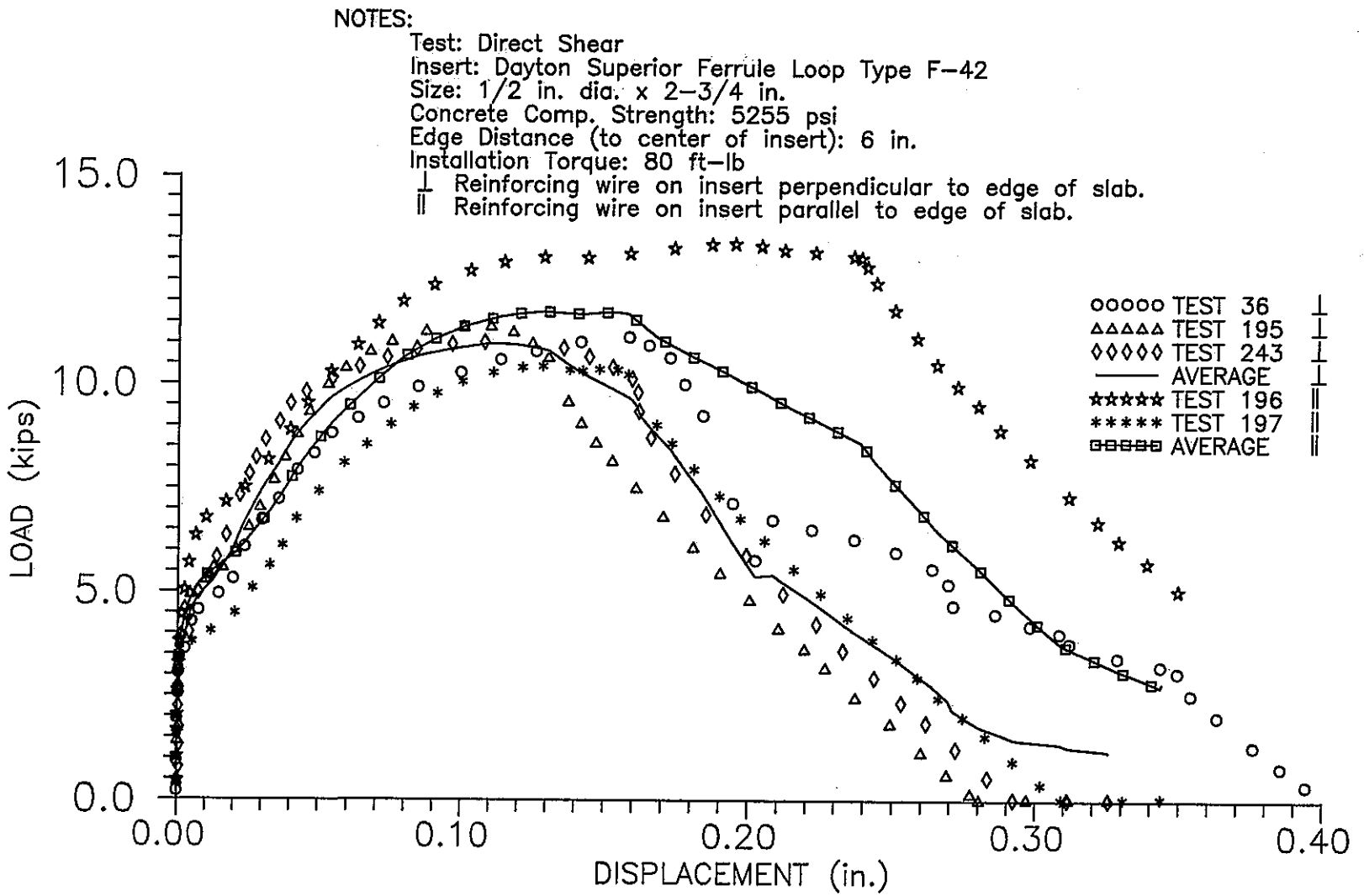

Figure C-10. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

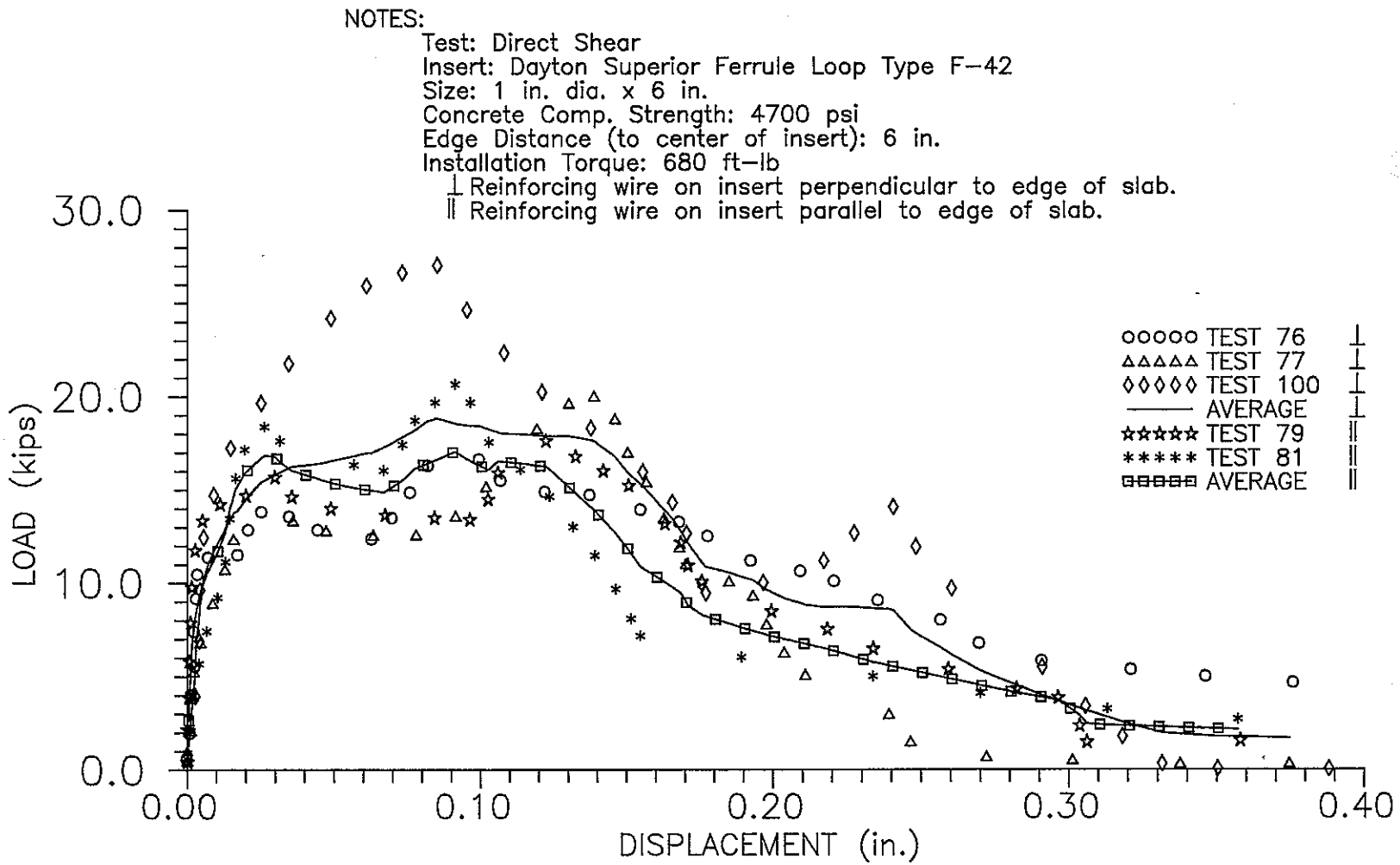

Figure C-11. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

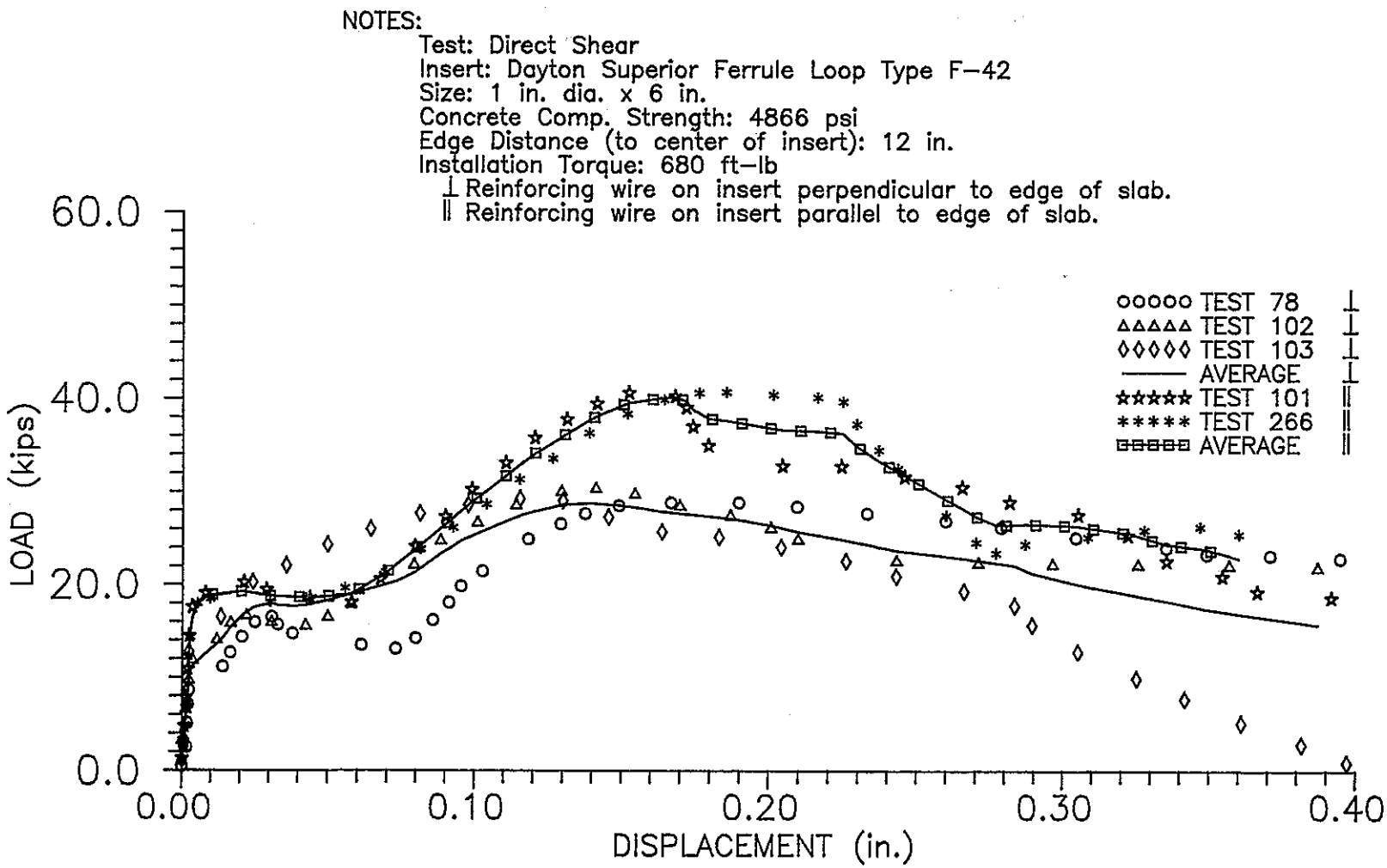

Figure C-12. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

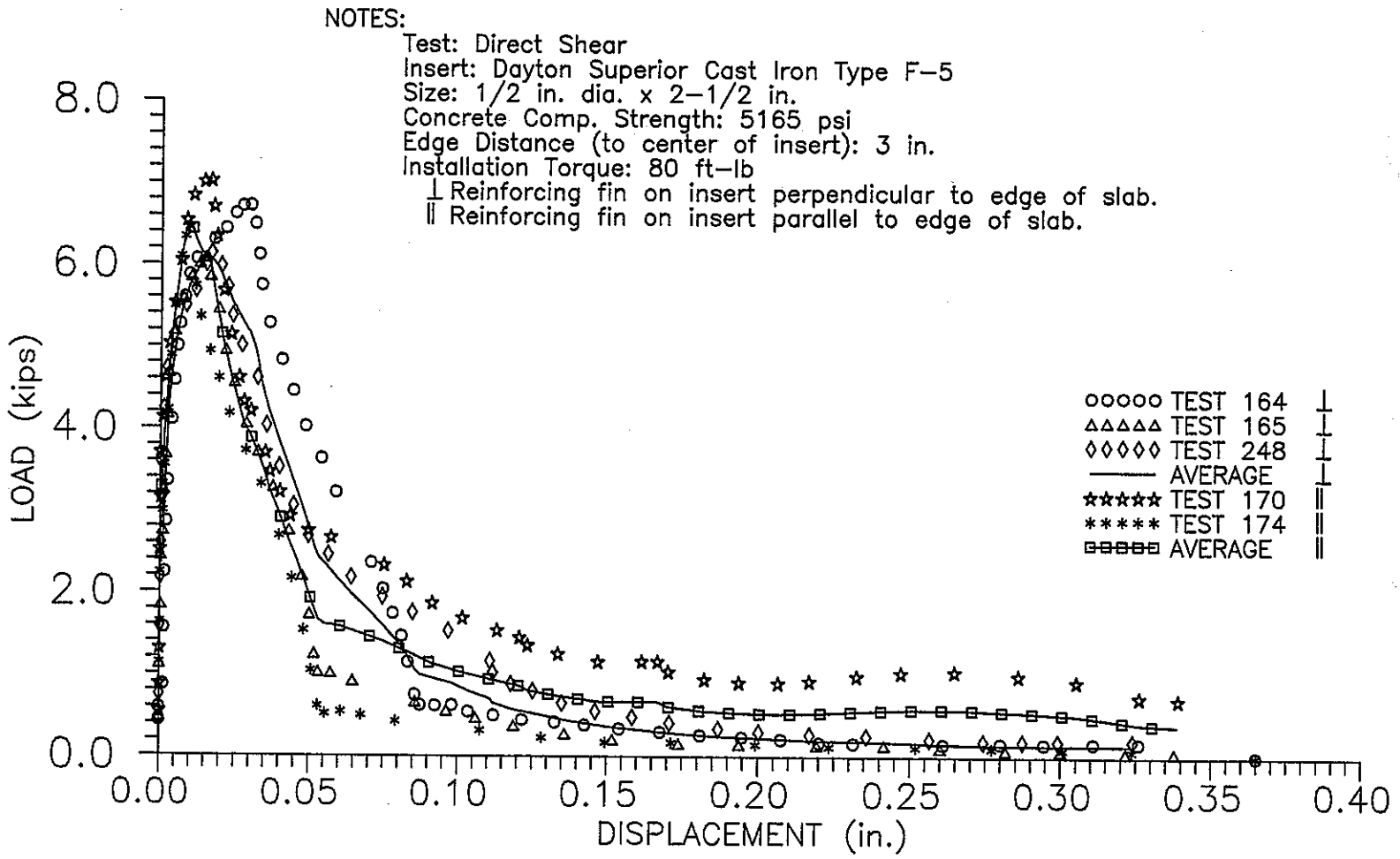

Figure C-13. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

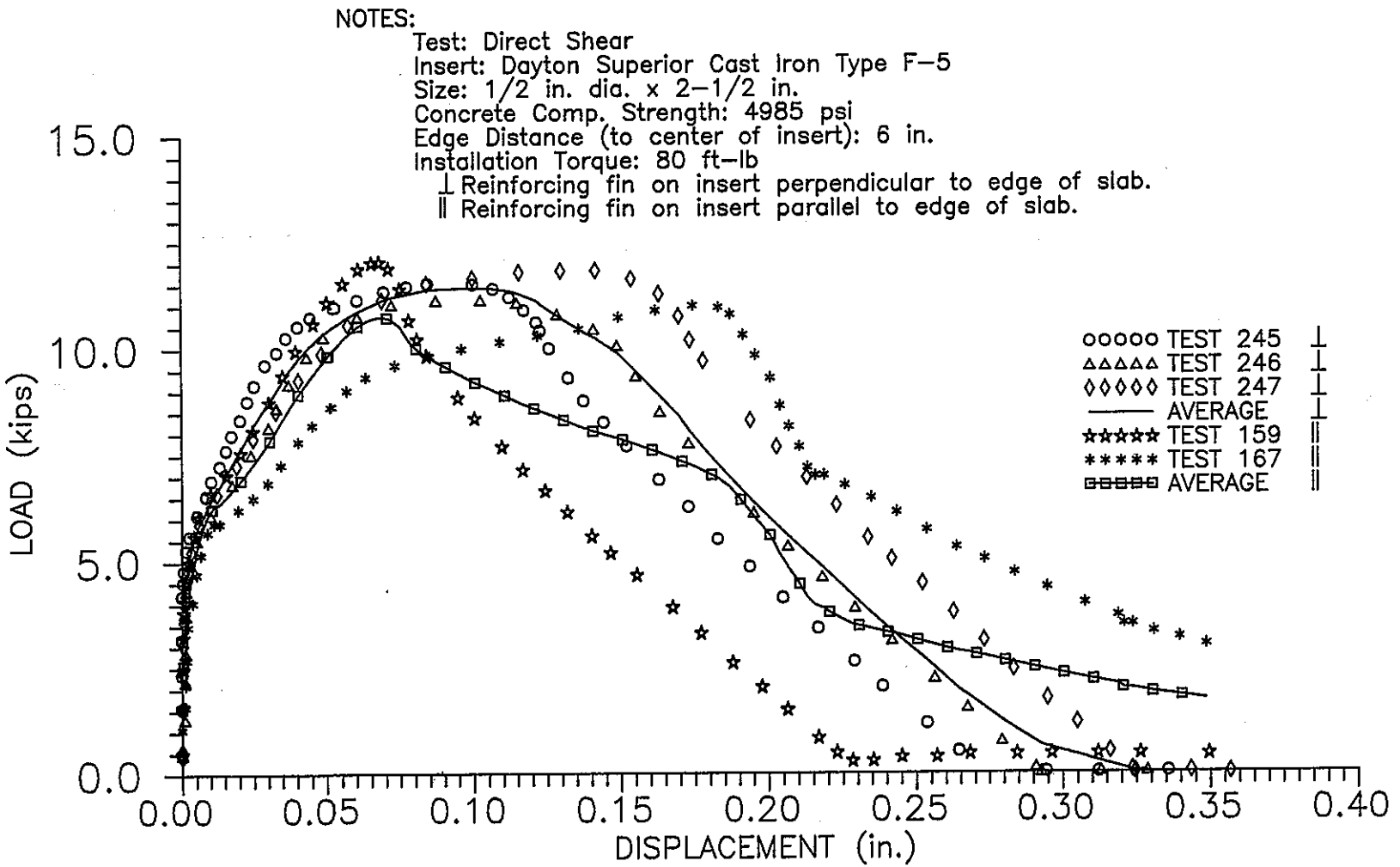

Figure C-14. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

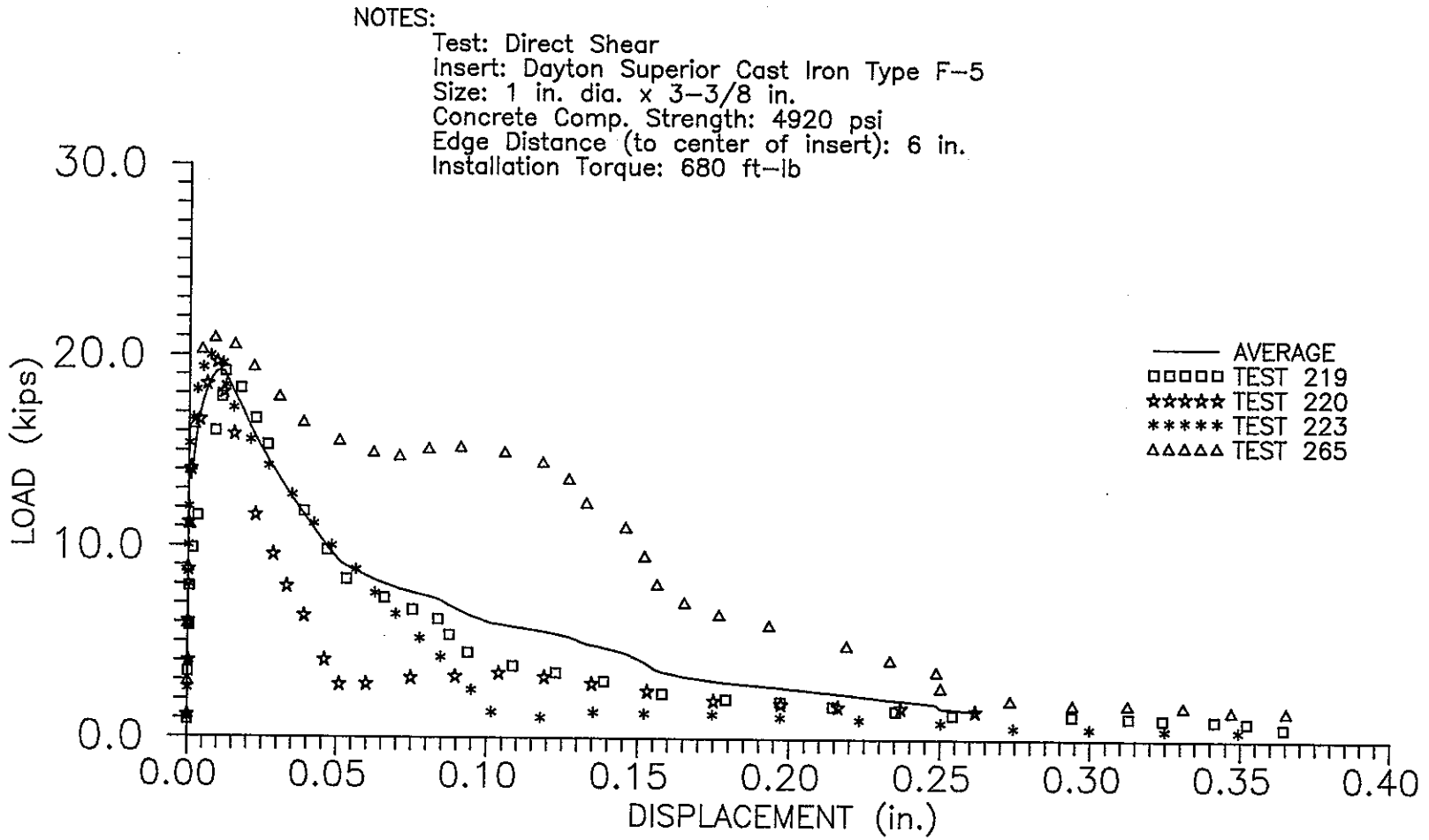

Figure C-15. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

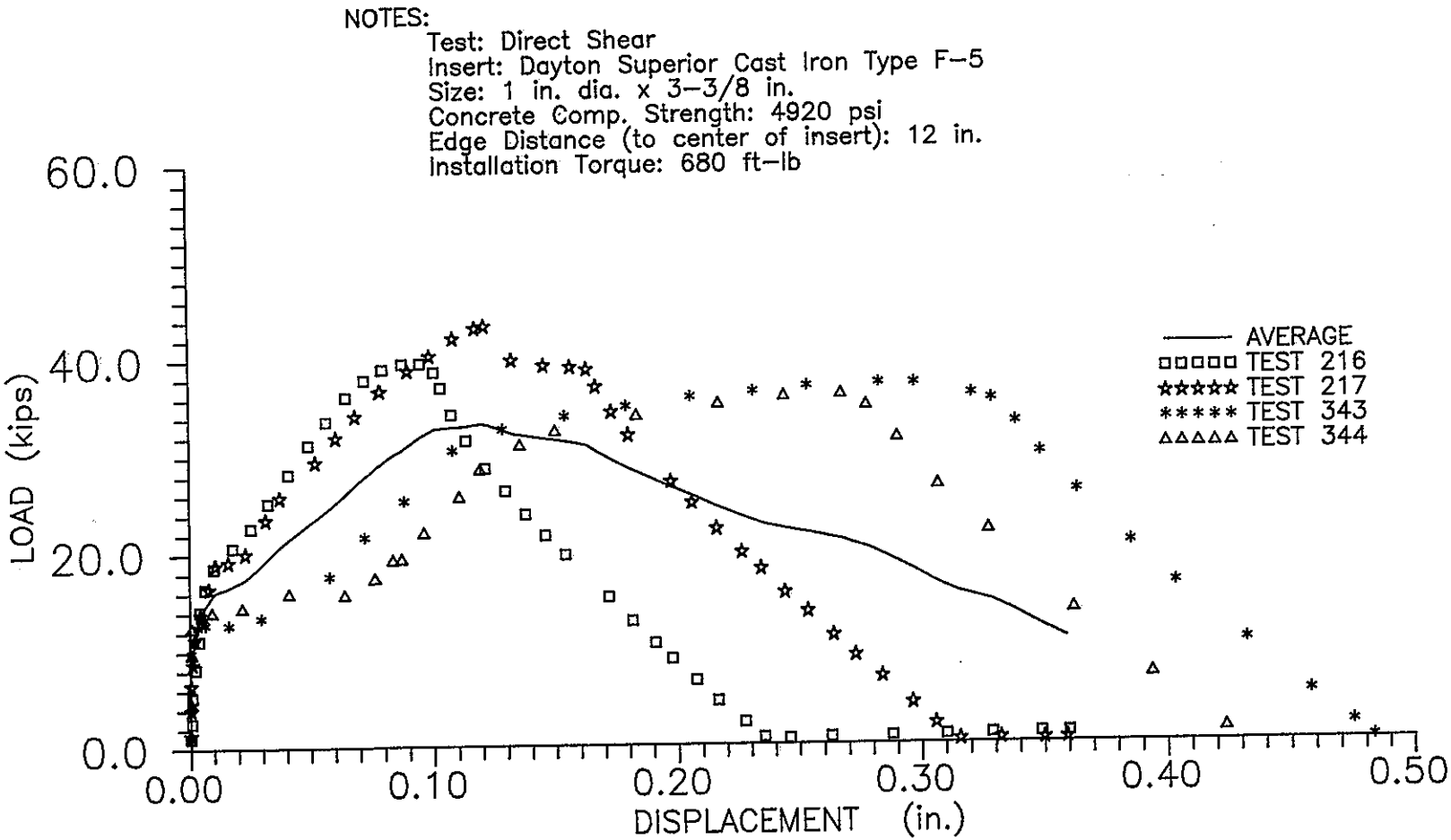

Figure C-16. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

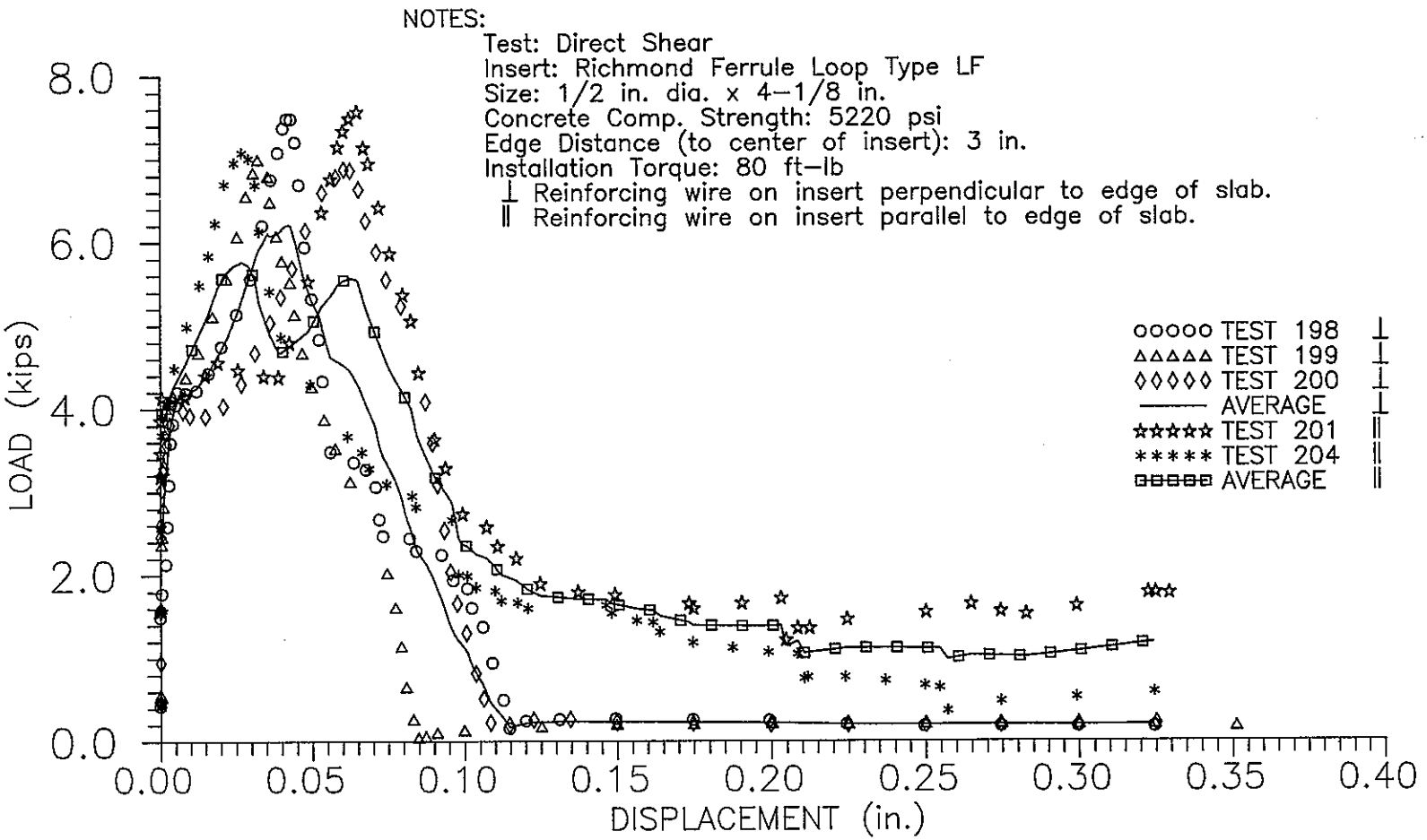

Figure C-17. Load vs. displacement for short–term direct shear tests of cast–in–place concrete inserts.

NOTES:
Test: Direct Shear
Insert: Richmond Ferrule Loop Type LF
Size: 1/2 in. dia. x 4–1/8 in.
Concrete Comp. Strength: 5145 psi
Edge Distance (to center of insert): 6 in.
Installation Torque: 80 ft–lb
⊥ Reinforcing wire on insert perpendicular to edge of slab.
‖ Reinforcing wire on insert parallel to edge of slab.

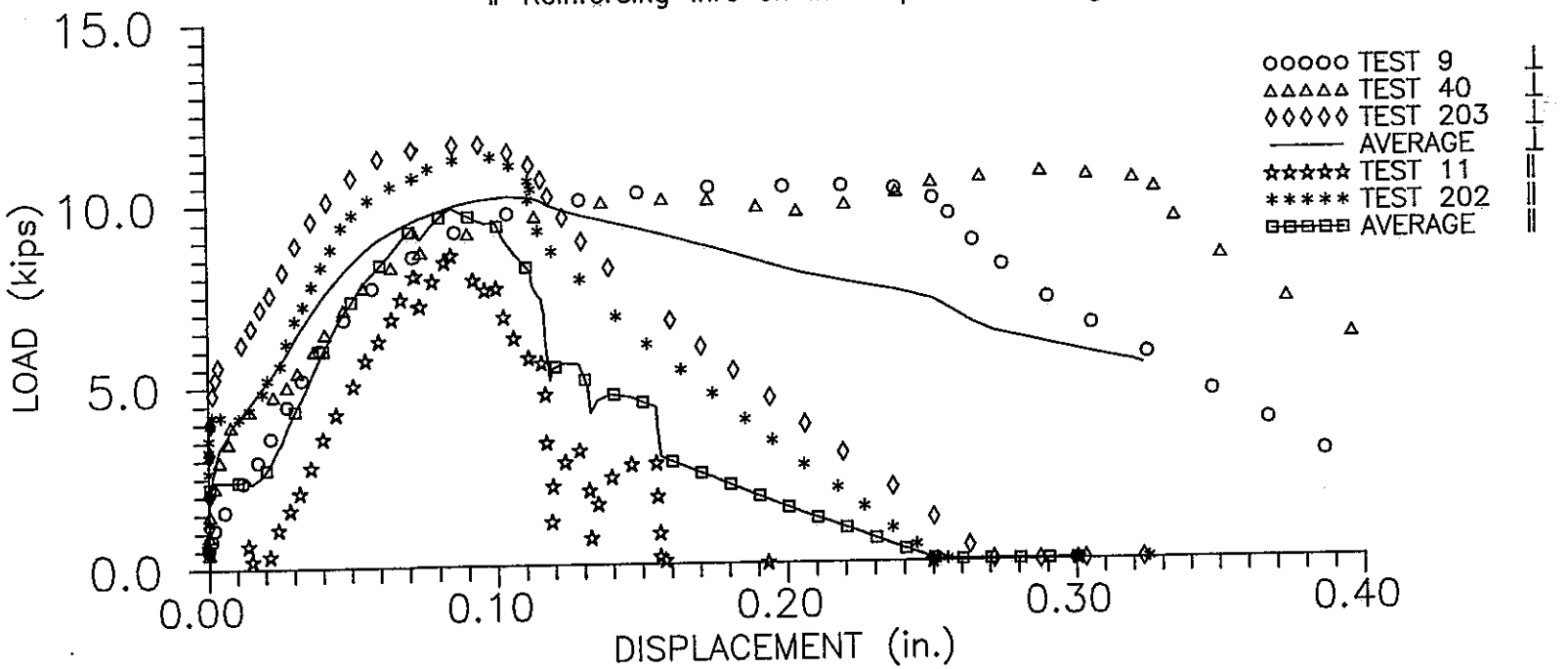

Figure C-18. Load vs. displacement for short–term direct shear tests of cast–in–place concrete inserts.

NOTES:
Test: Direct Shear
Insert: Richmond Ferrule Loop Type LF
Size: 3/4 in. dia. x 4–1/4 in.
Concrete Comp. Strength: 4900 psi
Edge Distance (to center of insert): 4 in.
Installation Torque: 290 ft–lb
⊥ Reinforcing wire on insert perpendicular to edge of slab.
‖ Reinforcing wire on insert parallel to edge of slab.

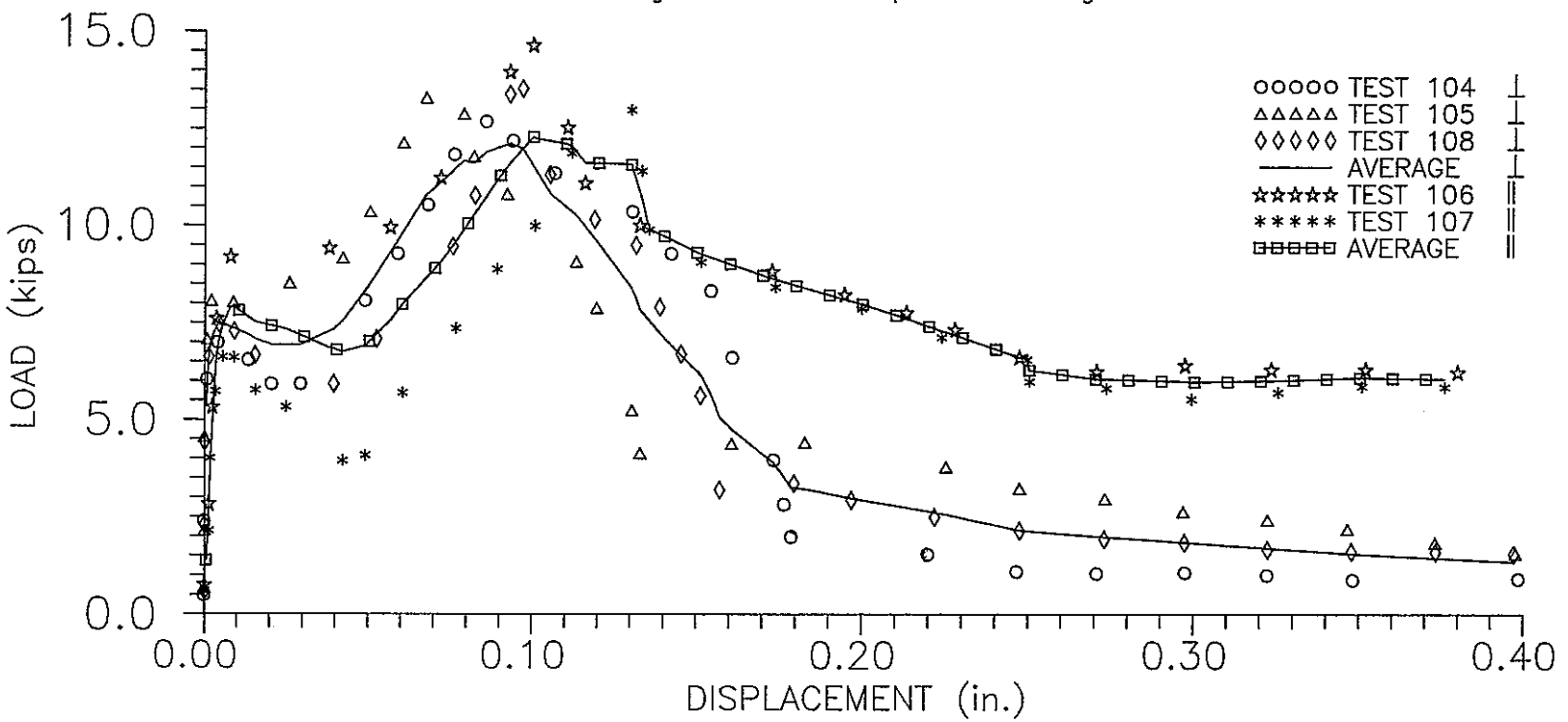

Figure C-19. Load vs. displacement for short–term direct shear tests of cast–in–place concrete inserts.

NOTES:
Test: Direct Shear
Insert: Richmond Ferrule Loop Type LF
Size: 3/4 in. dia. x 4–1/4 in.
Concrete Comp. Strength: 4893 psi
Edge Distance (to center of insert): 8 in.
Installation Torque: 290 ft–lb
⊥ Reinforcing wire on insert perpendicular to edge of slab.
‖ Reinforcing wire on insert parallel to edge of slab.

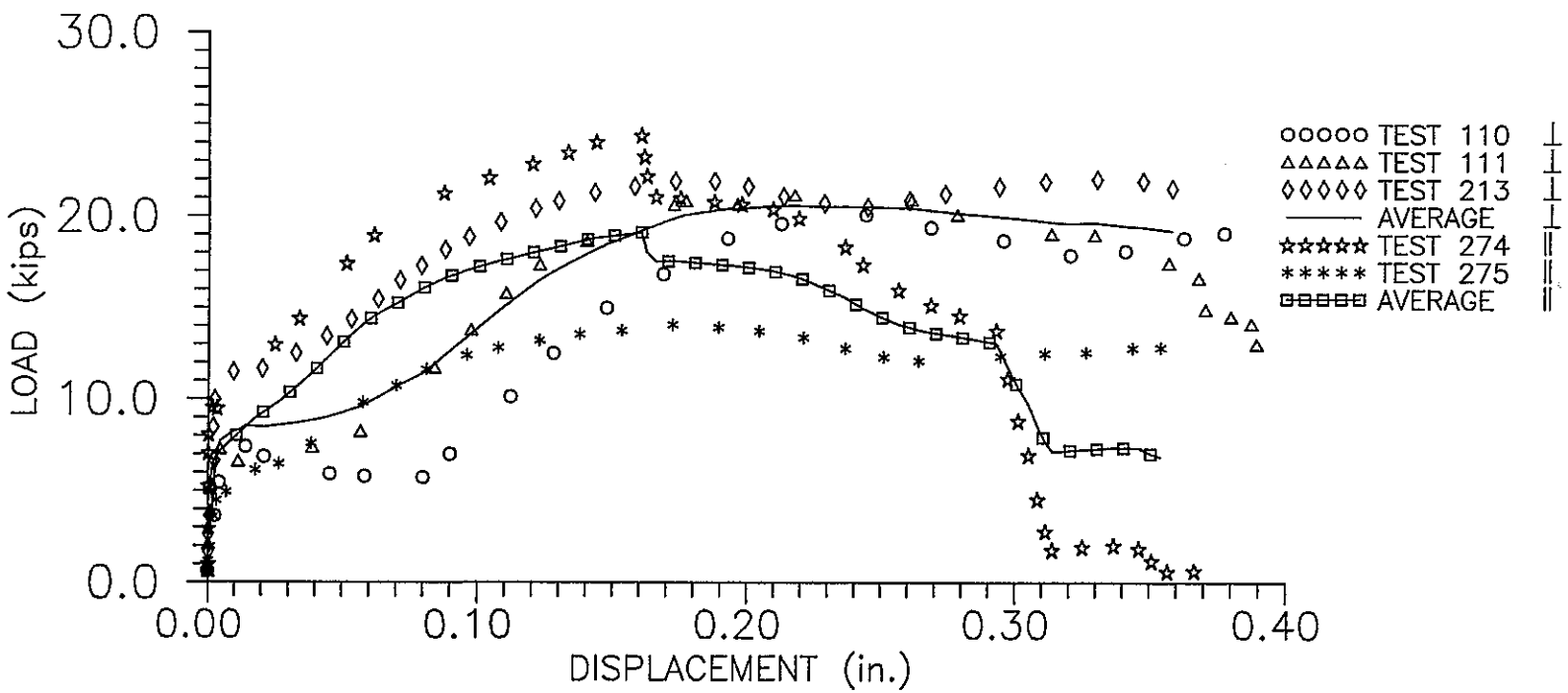

Figure C-20. Load vs. displacement for short–term direct shear tests of cast–in–place concrete inserts.

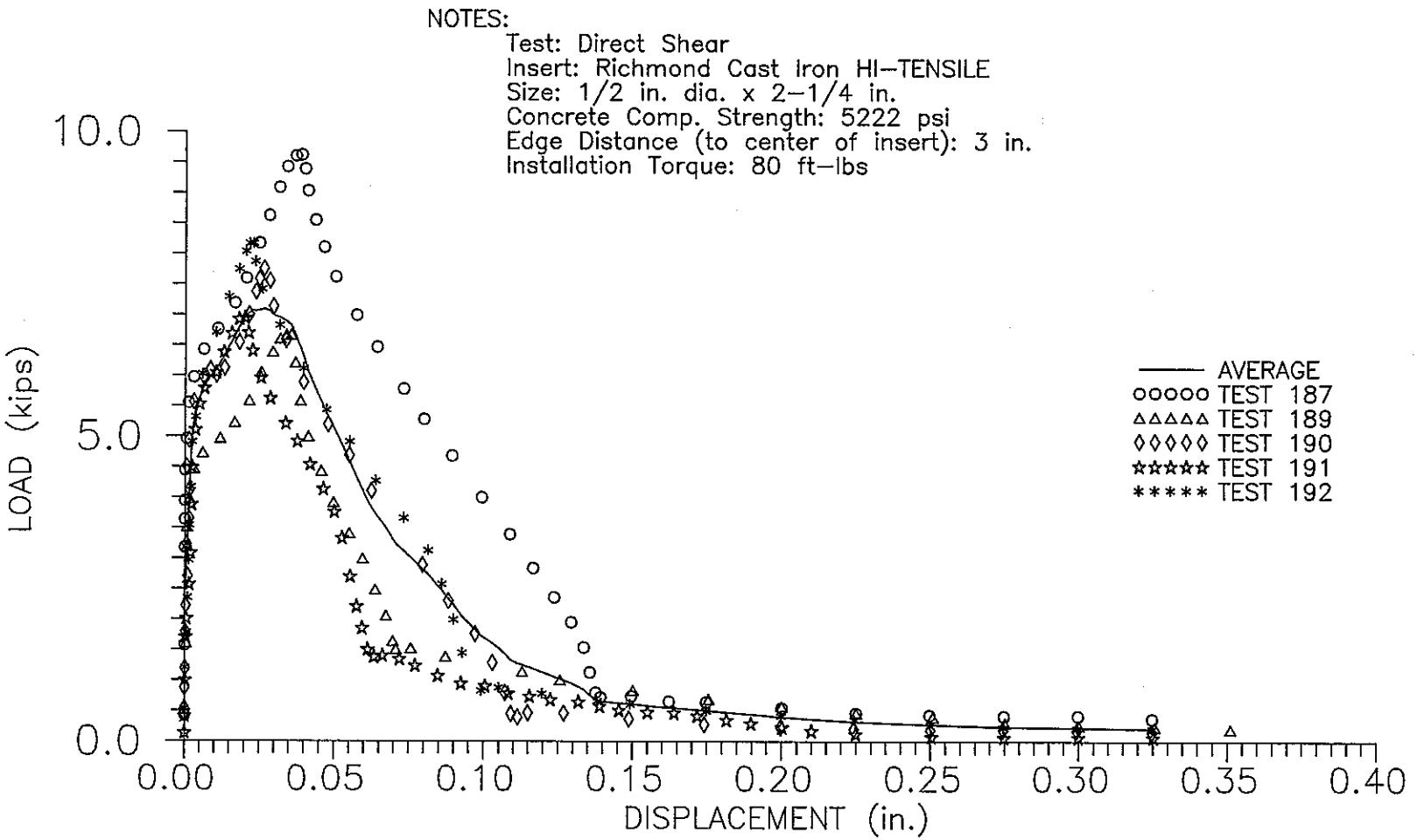

Figure C-21. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

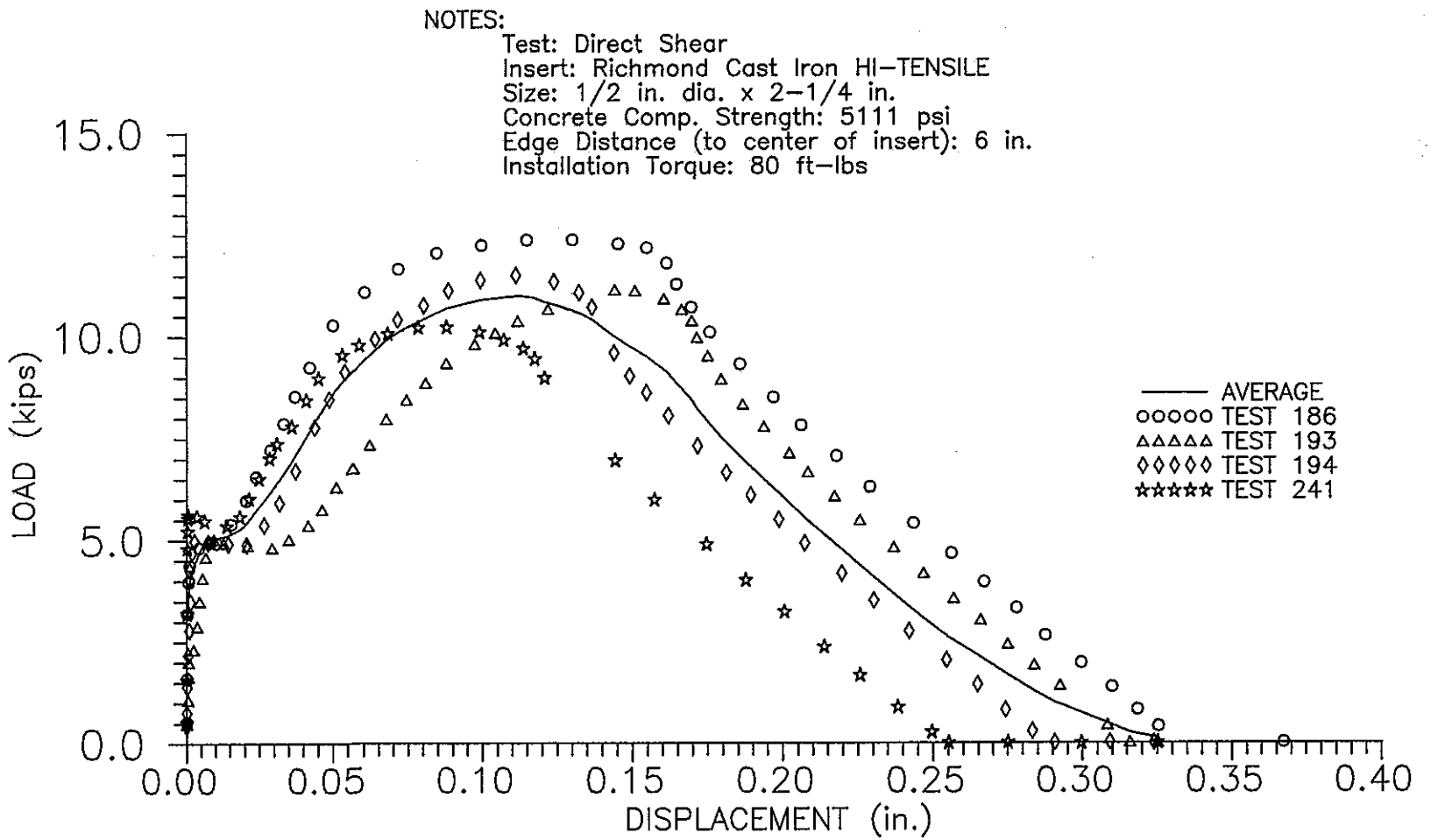

Figure C-22. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

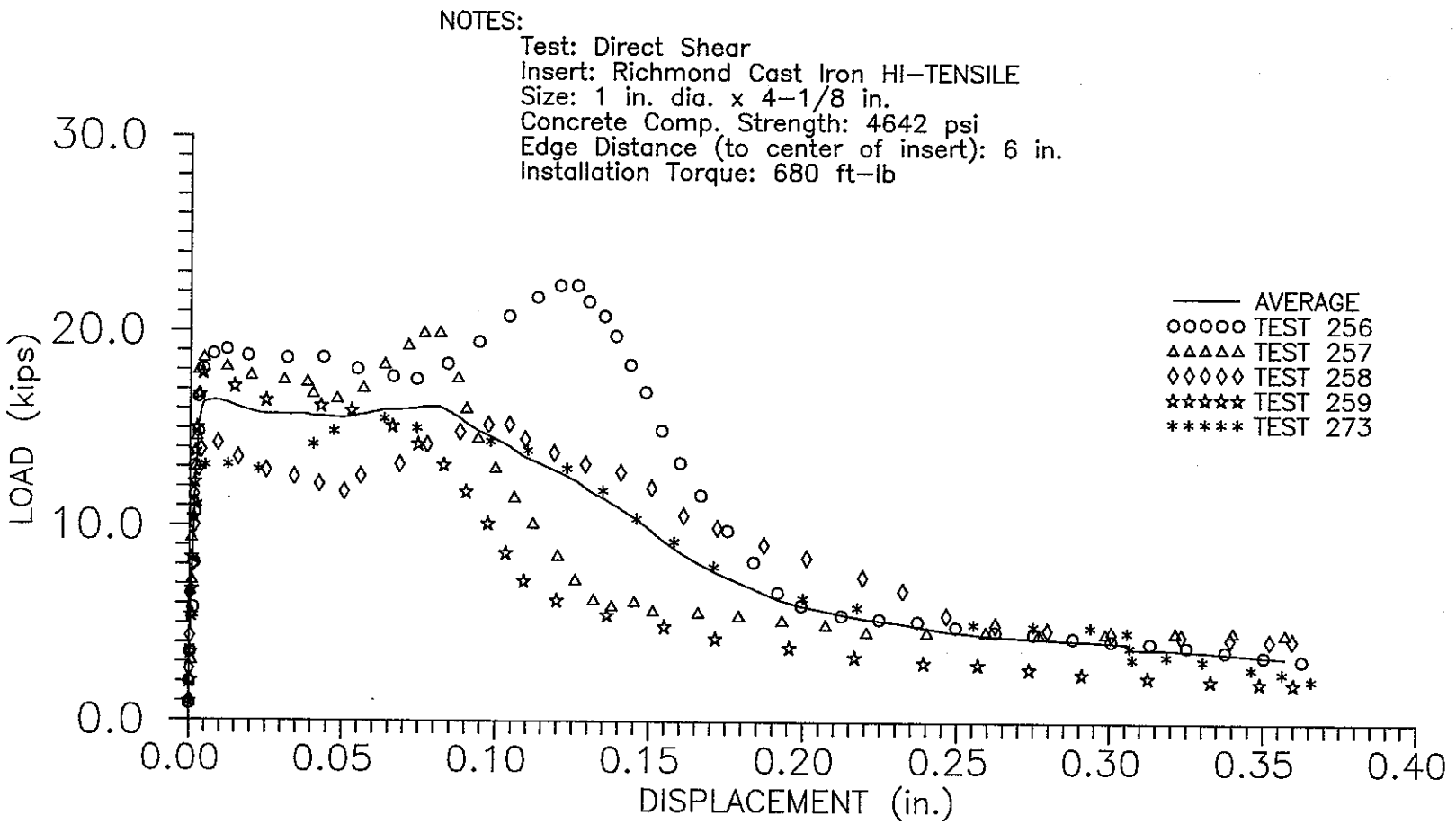

Figure C-23. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

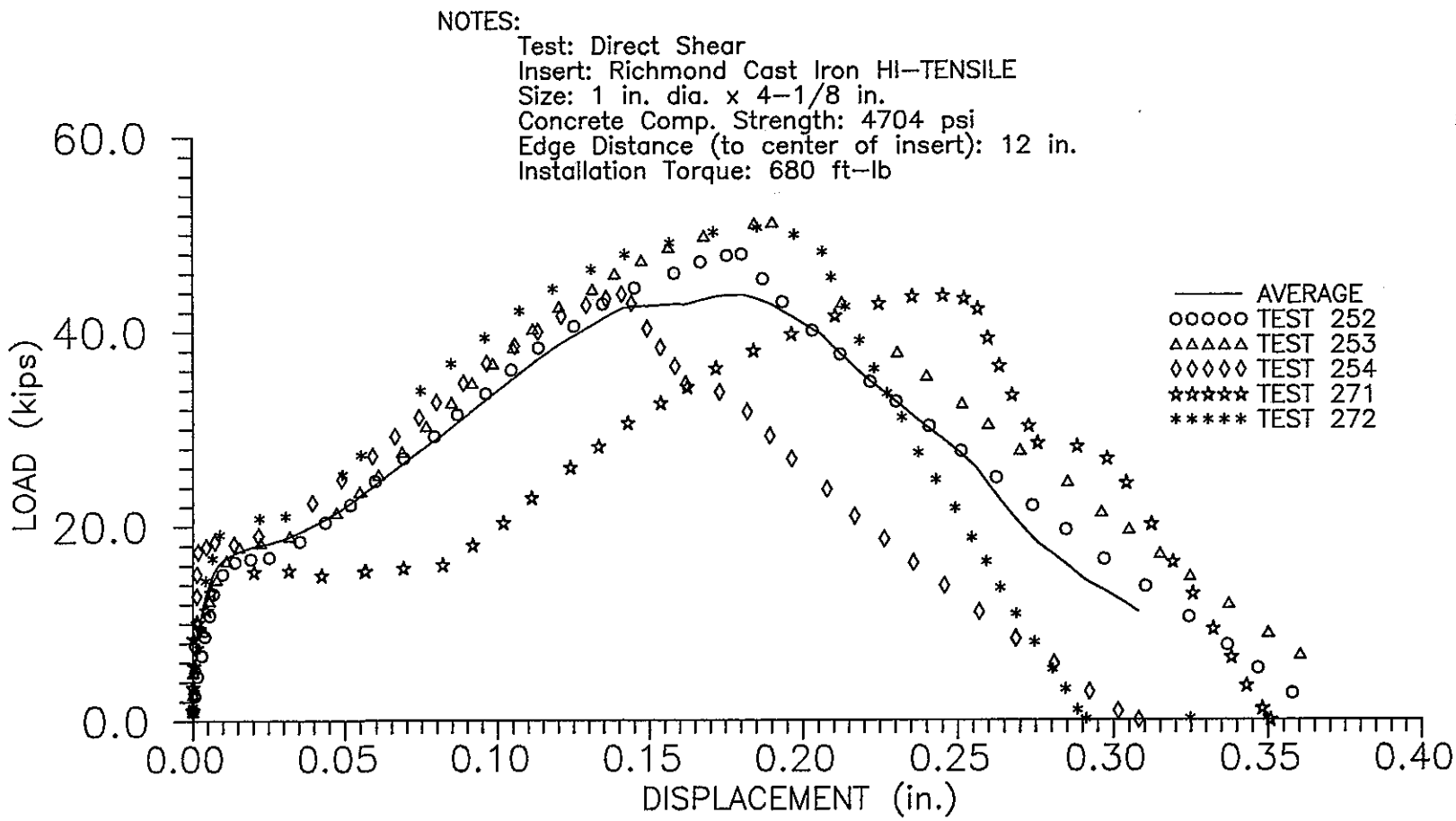

Figure C-24. Load vs. displacement for short–term direct shear tests of cast–in–place concrete inserts.

Appendix D: Plots of Load Versus Displacement of Various Cast-In-Place Concrete Inserts from Direct Tension and Direct Shear Tests. Concrete Compressive Strength 3500 ± psi.

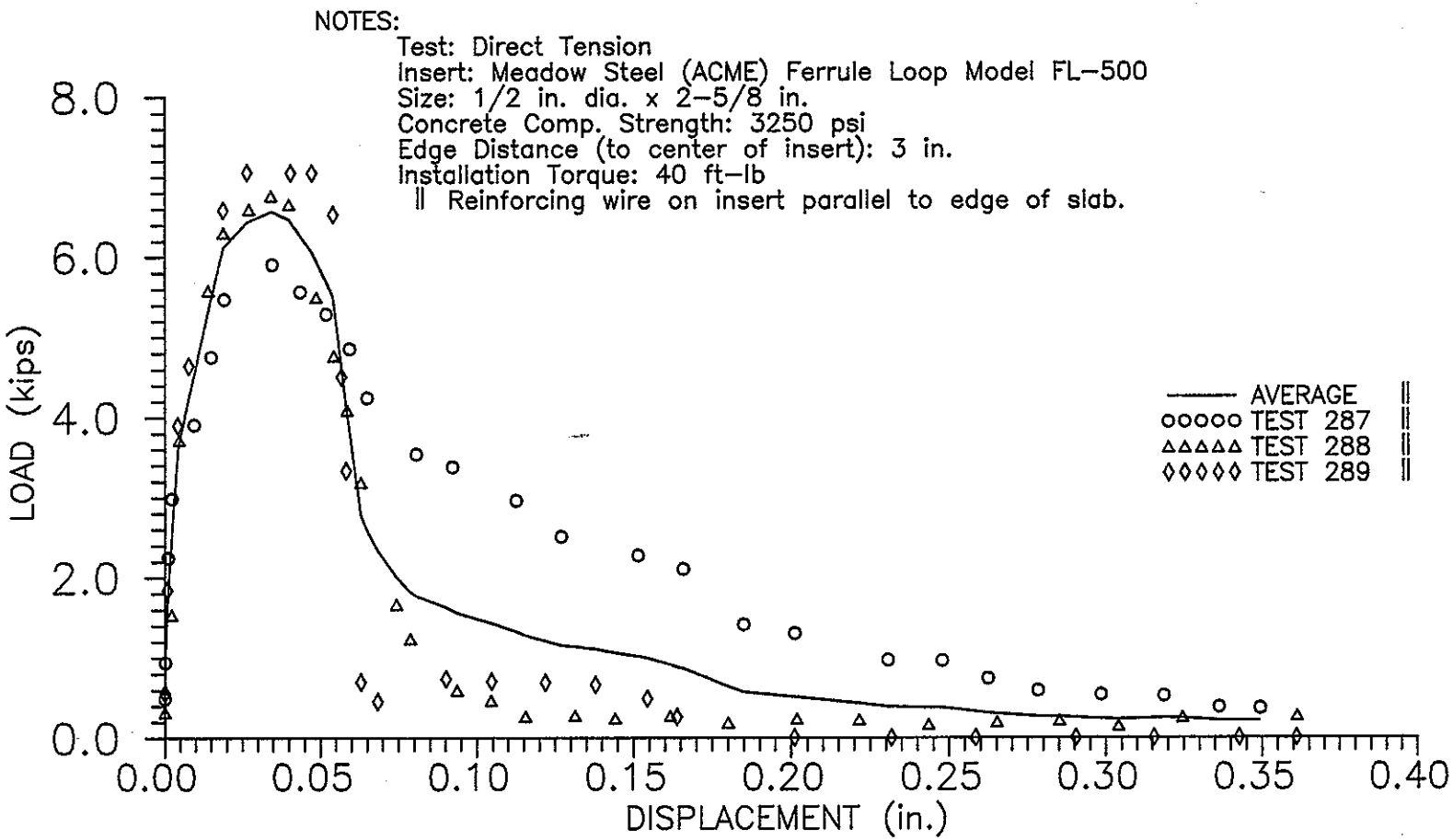

Figure D-1. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

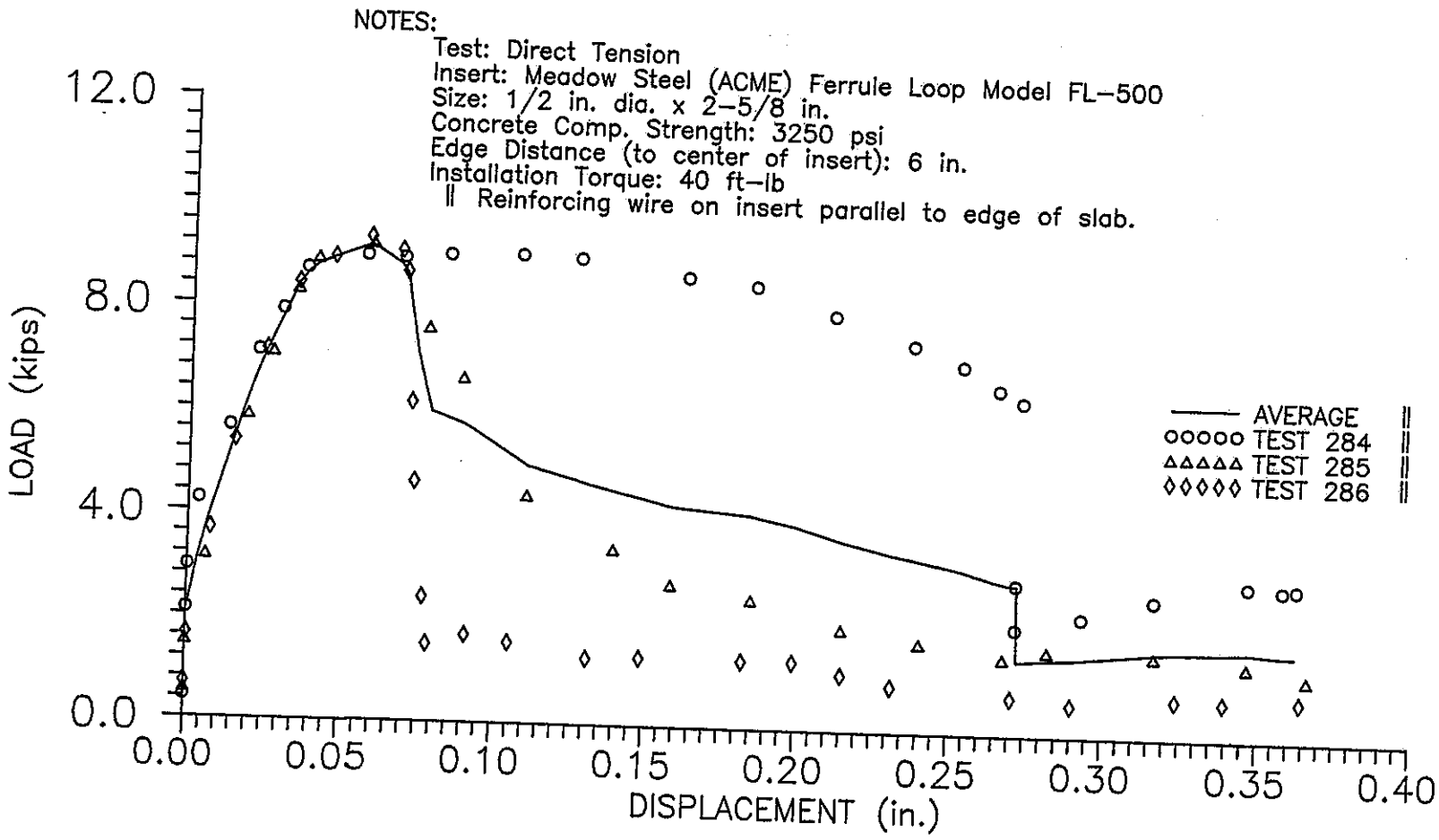

Figure D-2. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

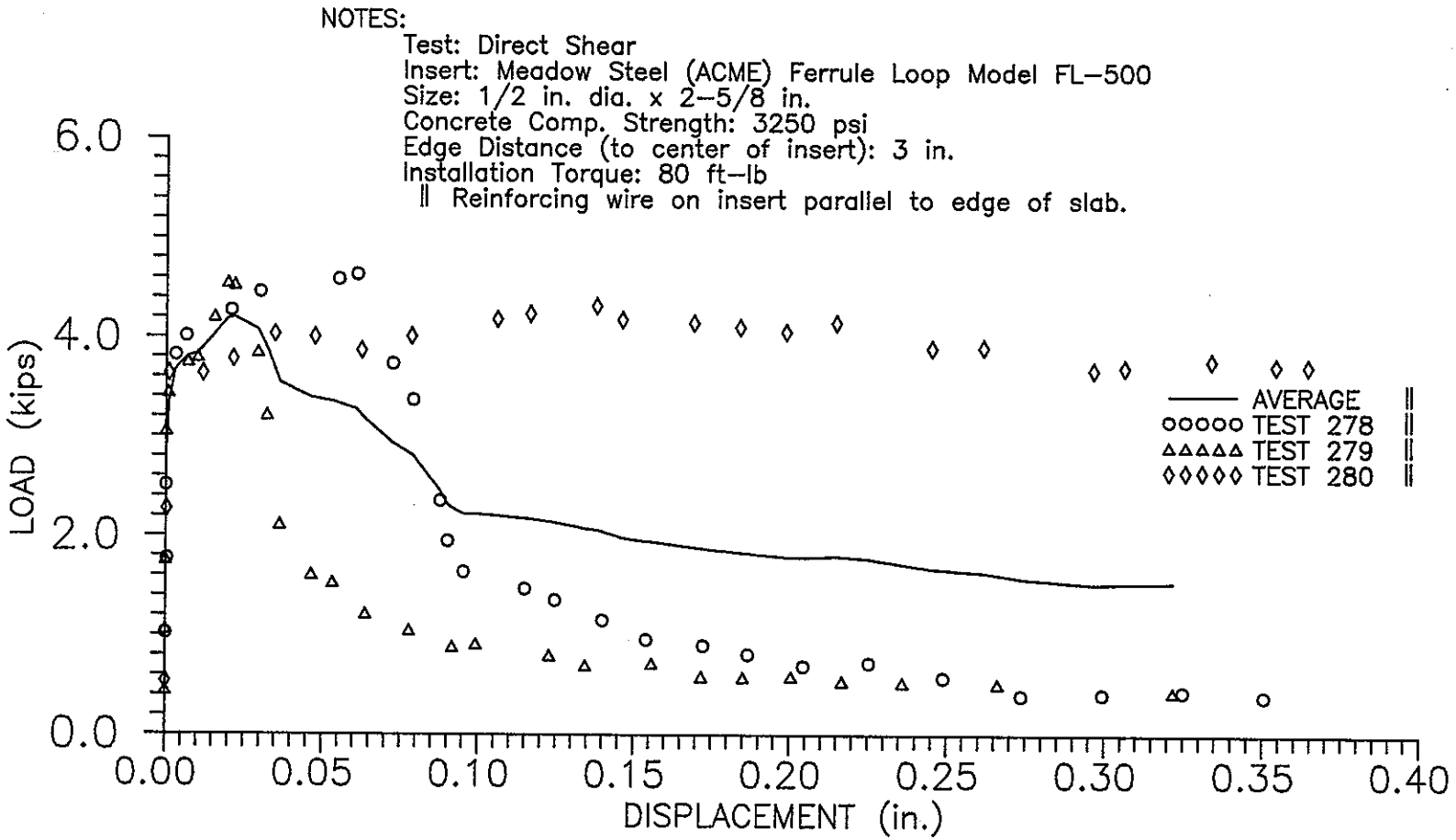

Figure D-3. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

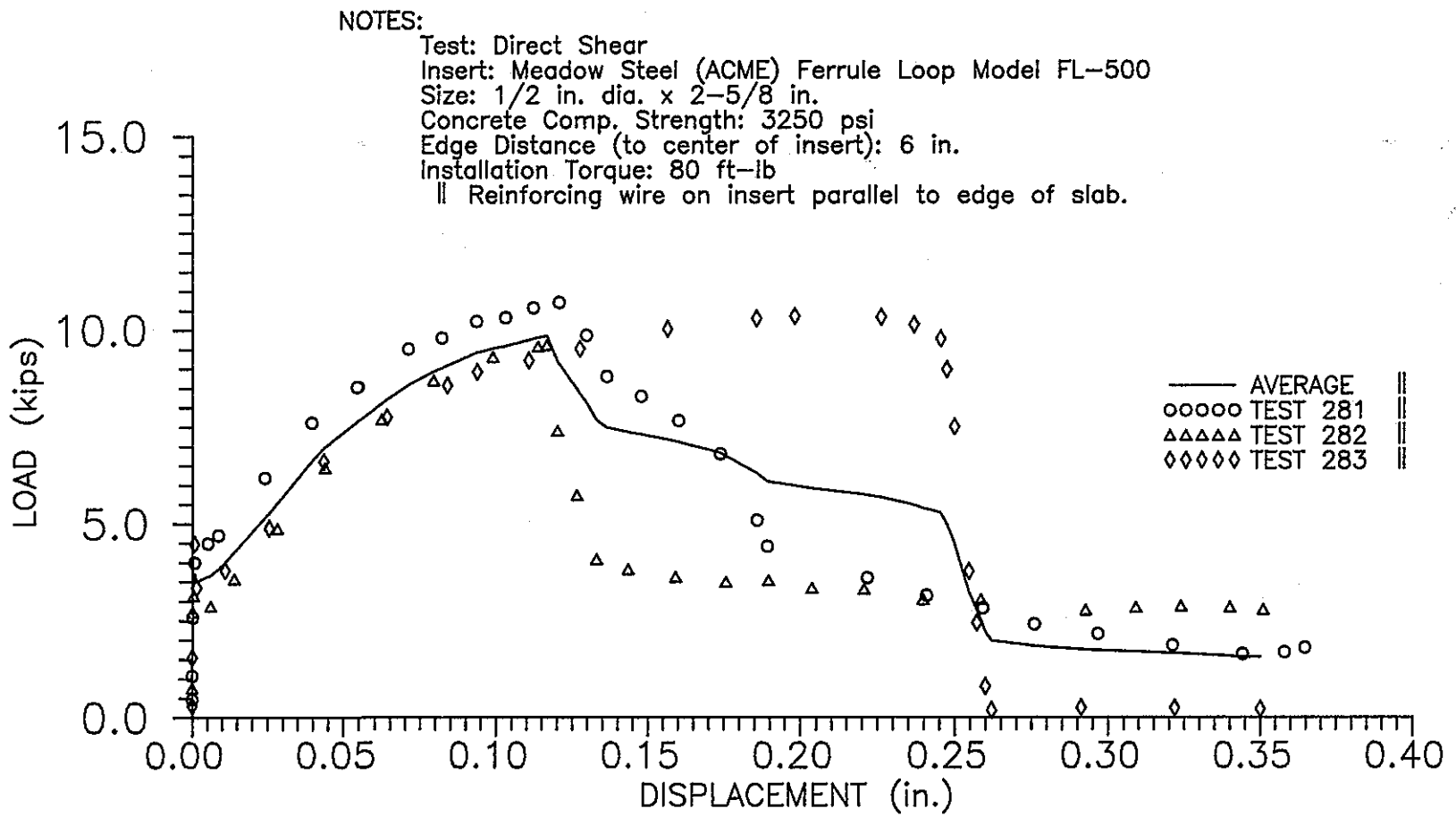

Figure D-4. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

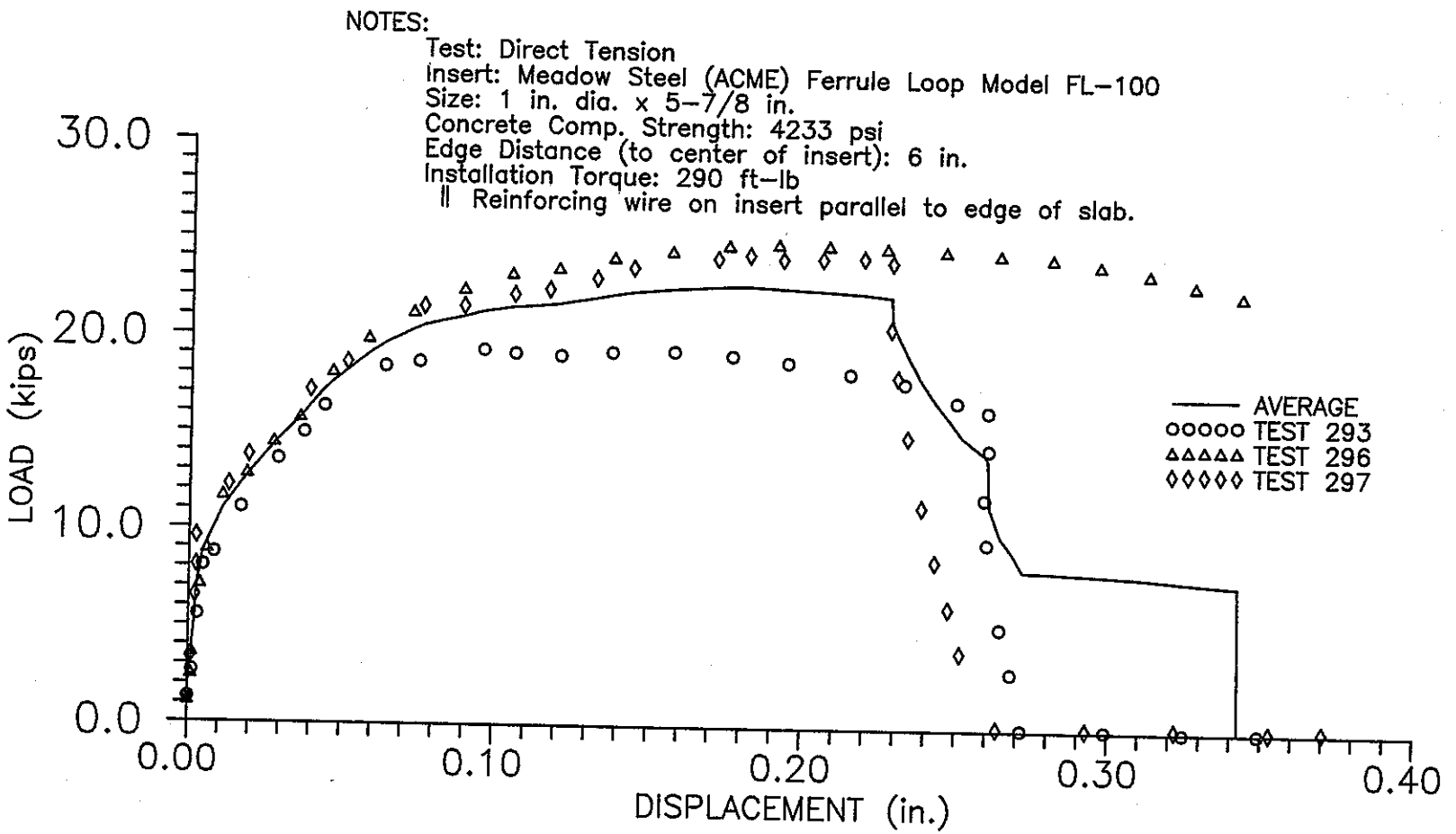

Figure D-5. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

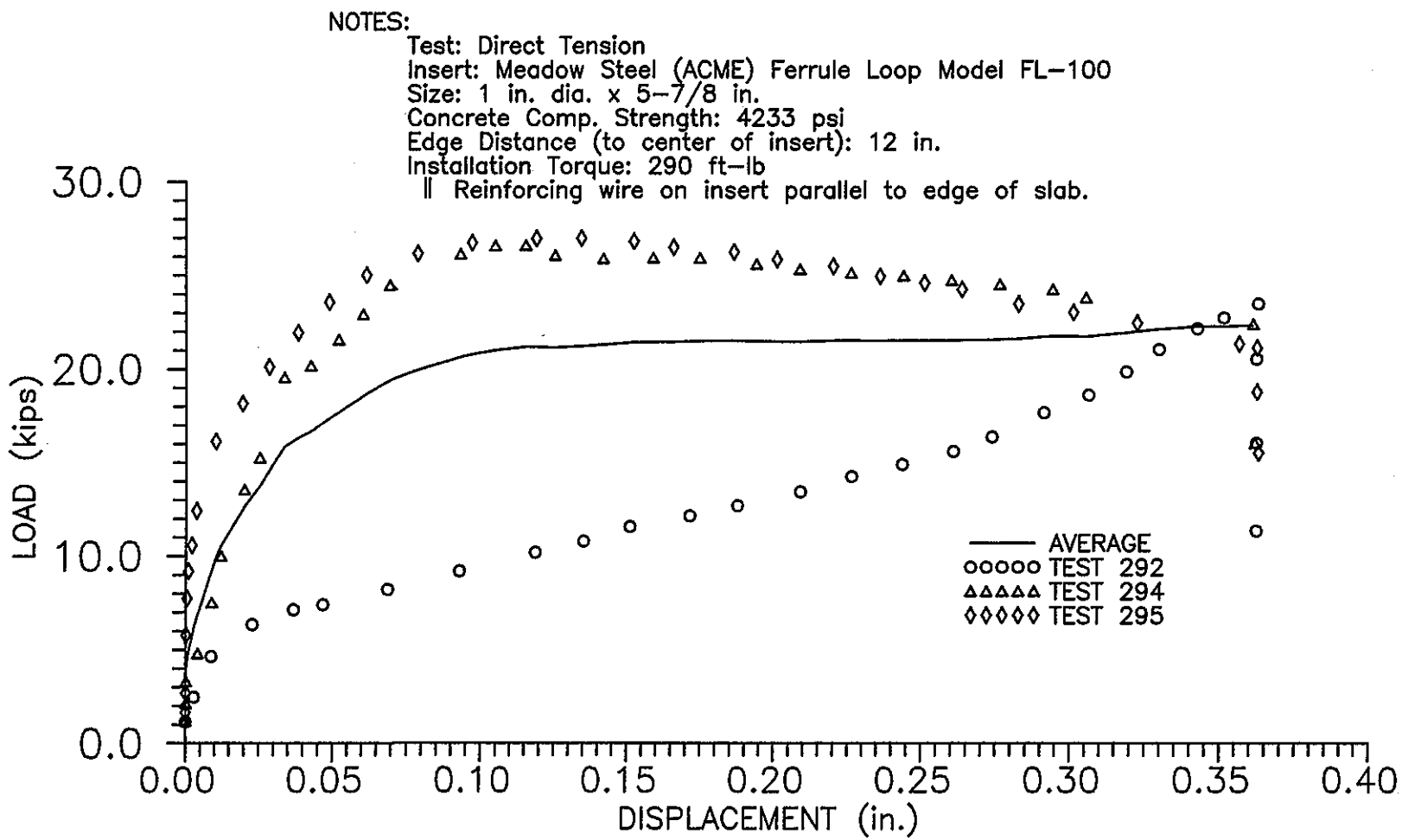

Figure D-6. Load vs. displacement for short-term direct tensile tests of cast-in-place concrete inserts.

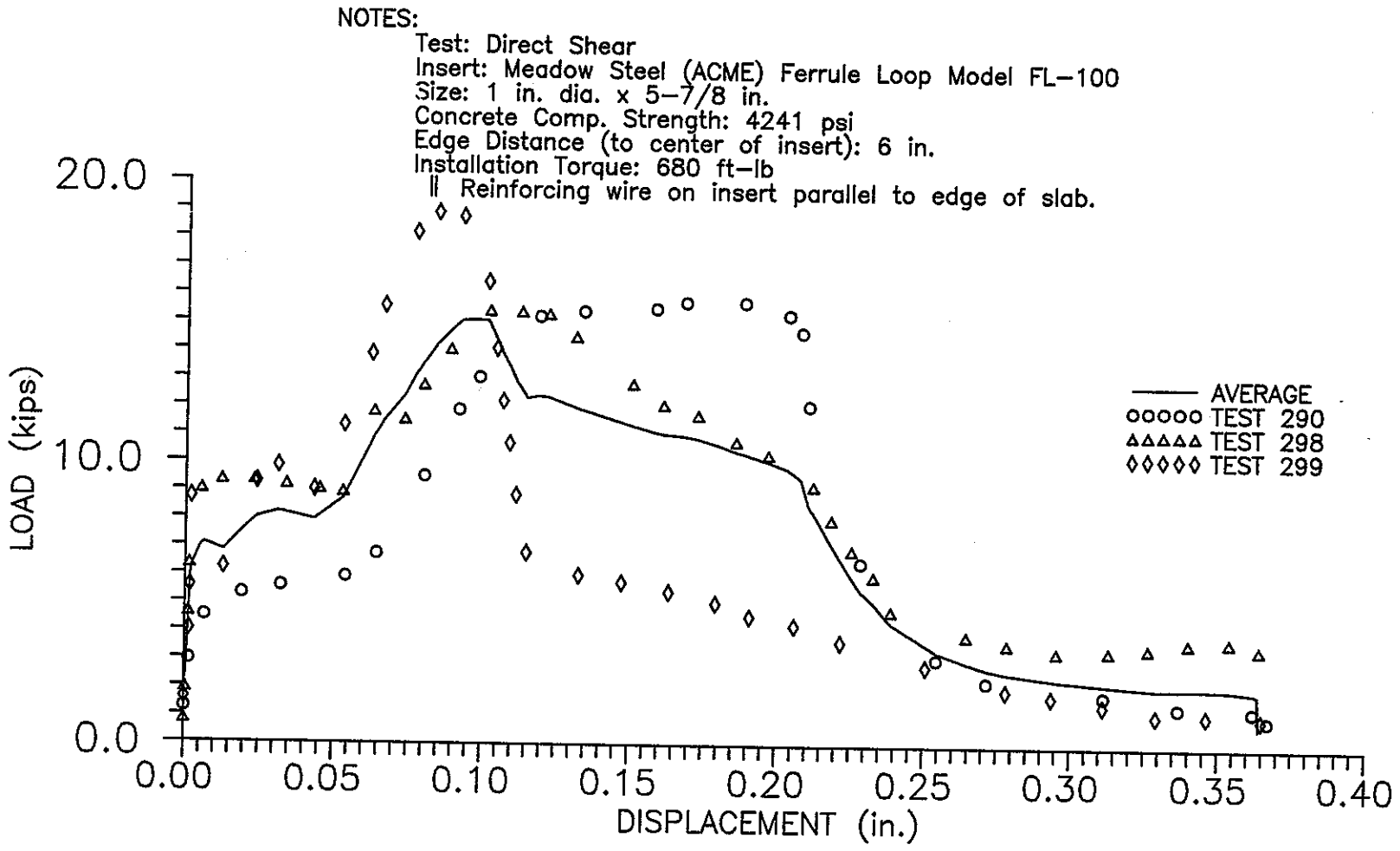

Figure D-7. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

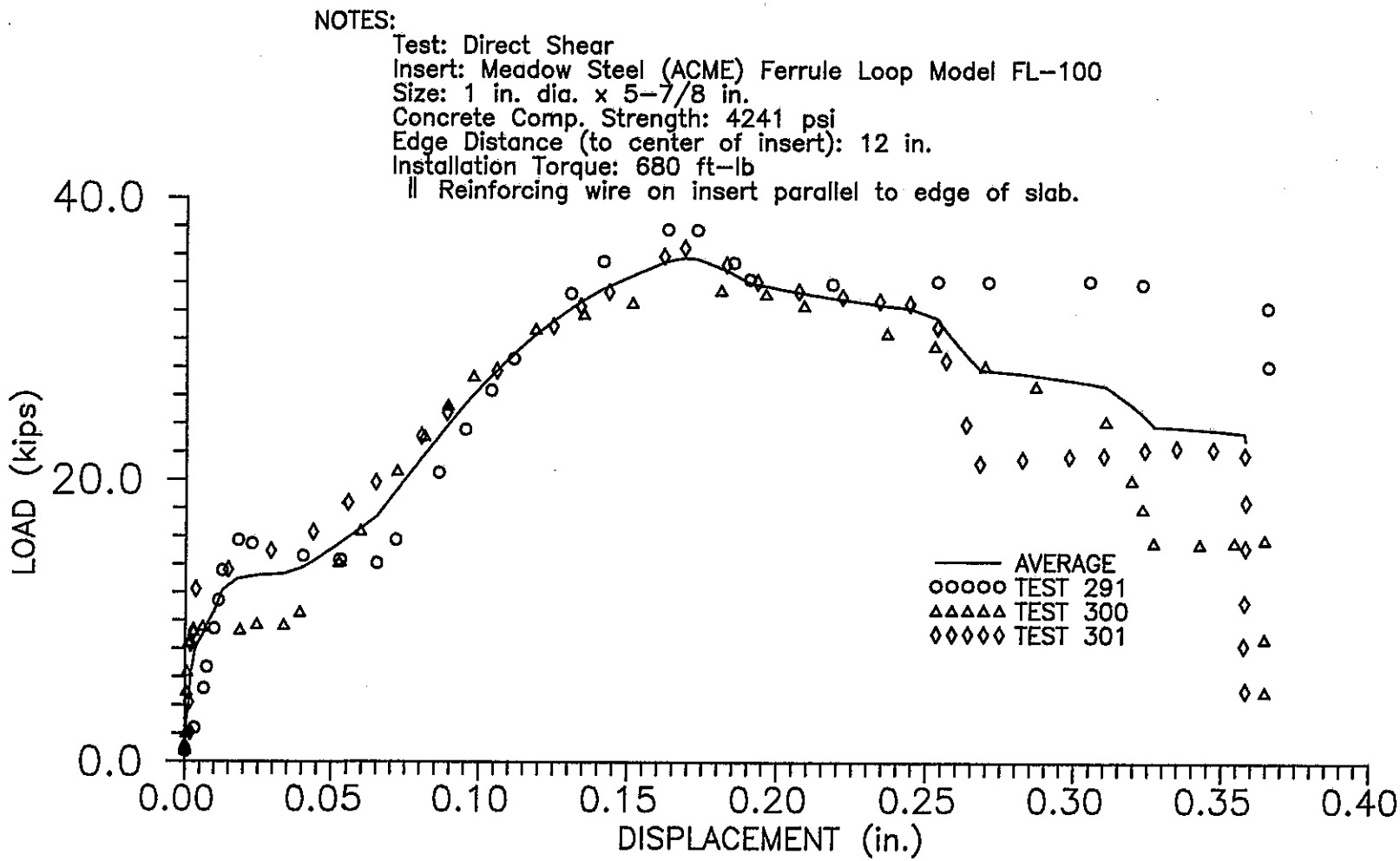

Figure D-8. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

Appendix E: Plots of Load Versus Displacement of Various Cast-In-Place Concrete Inserts (with Different Corrosion Protection Coatings) from Direct Tension and Direct Shear Tests.
Concrete Compressive Strength 5000 ± psi.

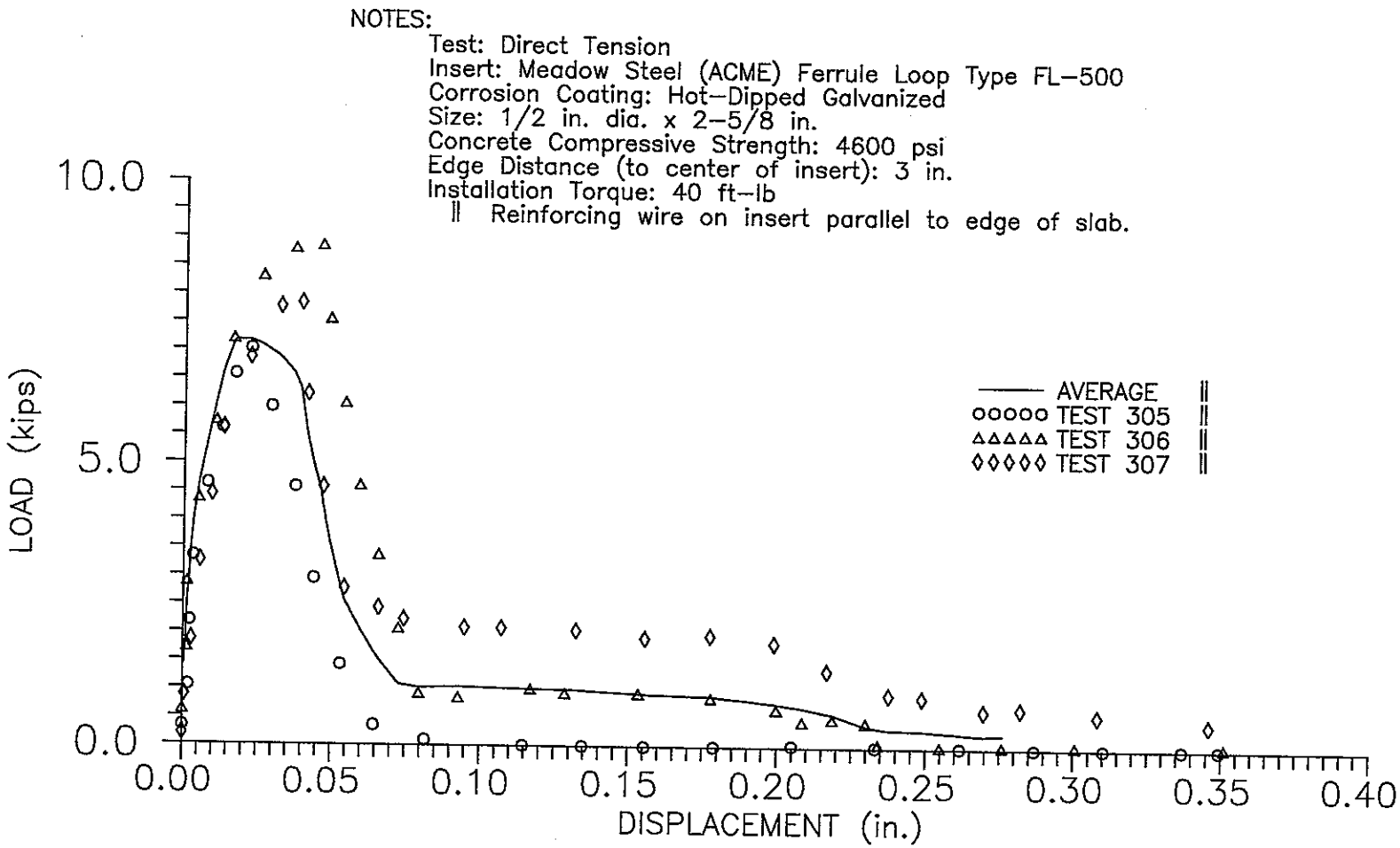

Figure E-1. Load vs. displacement for short-term direct tension tests of cast-in-place concrete inserts.

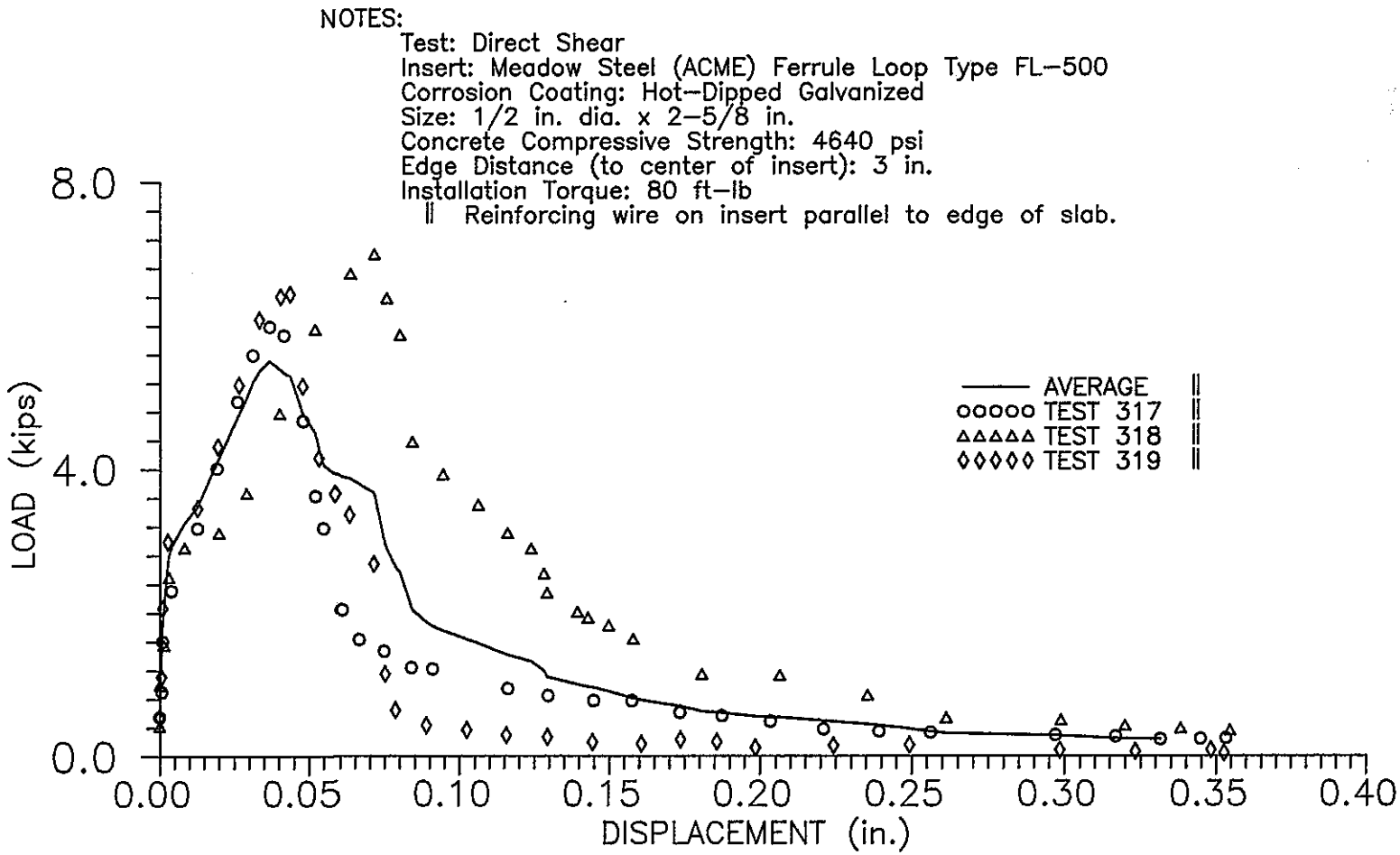

Figure E-2. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

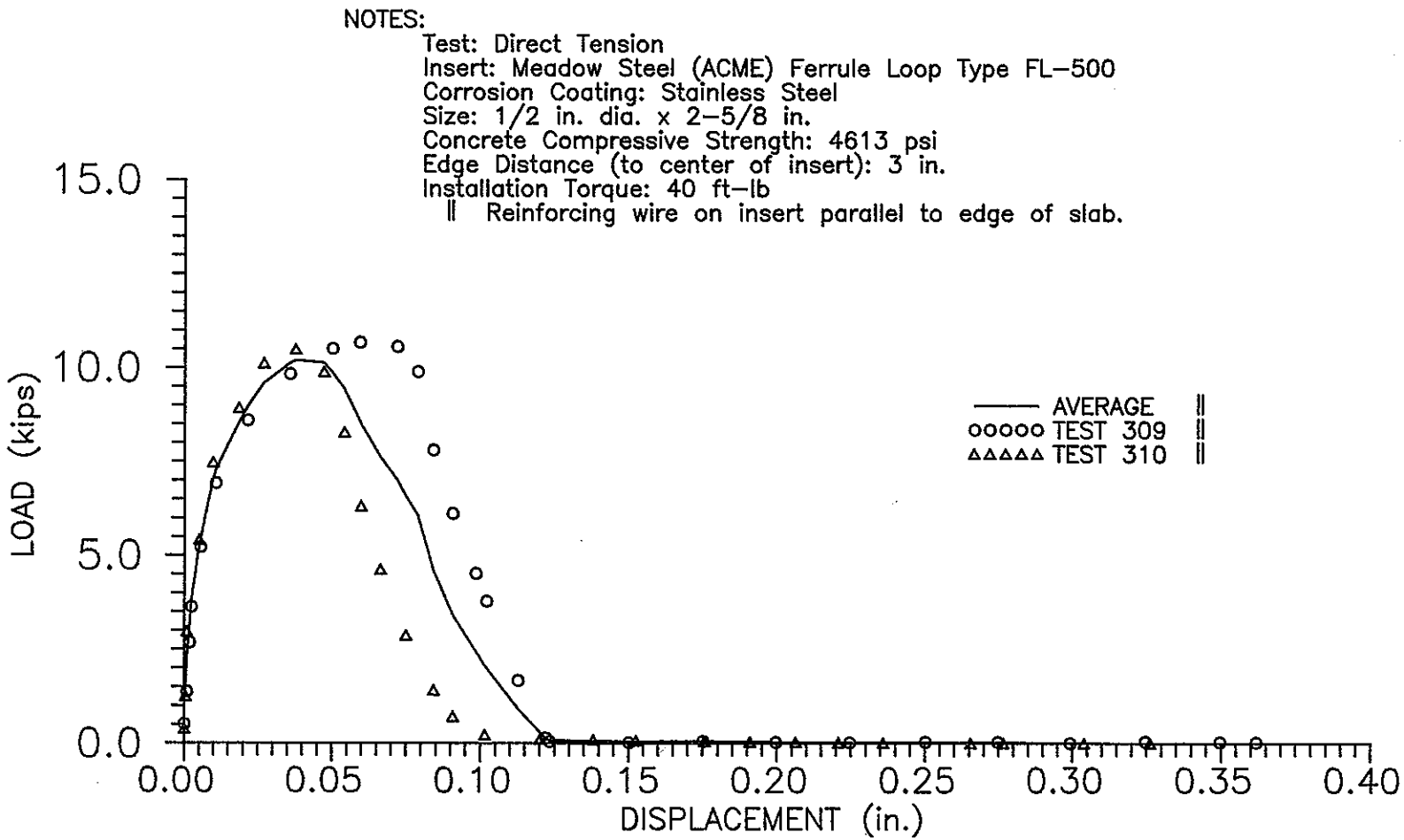

Figure E-3. Load vs. displacement for short-term direct tension tests of cast-in-place concrete inserts.

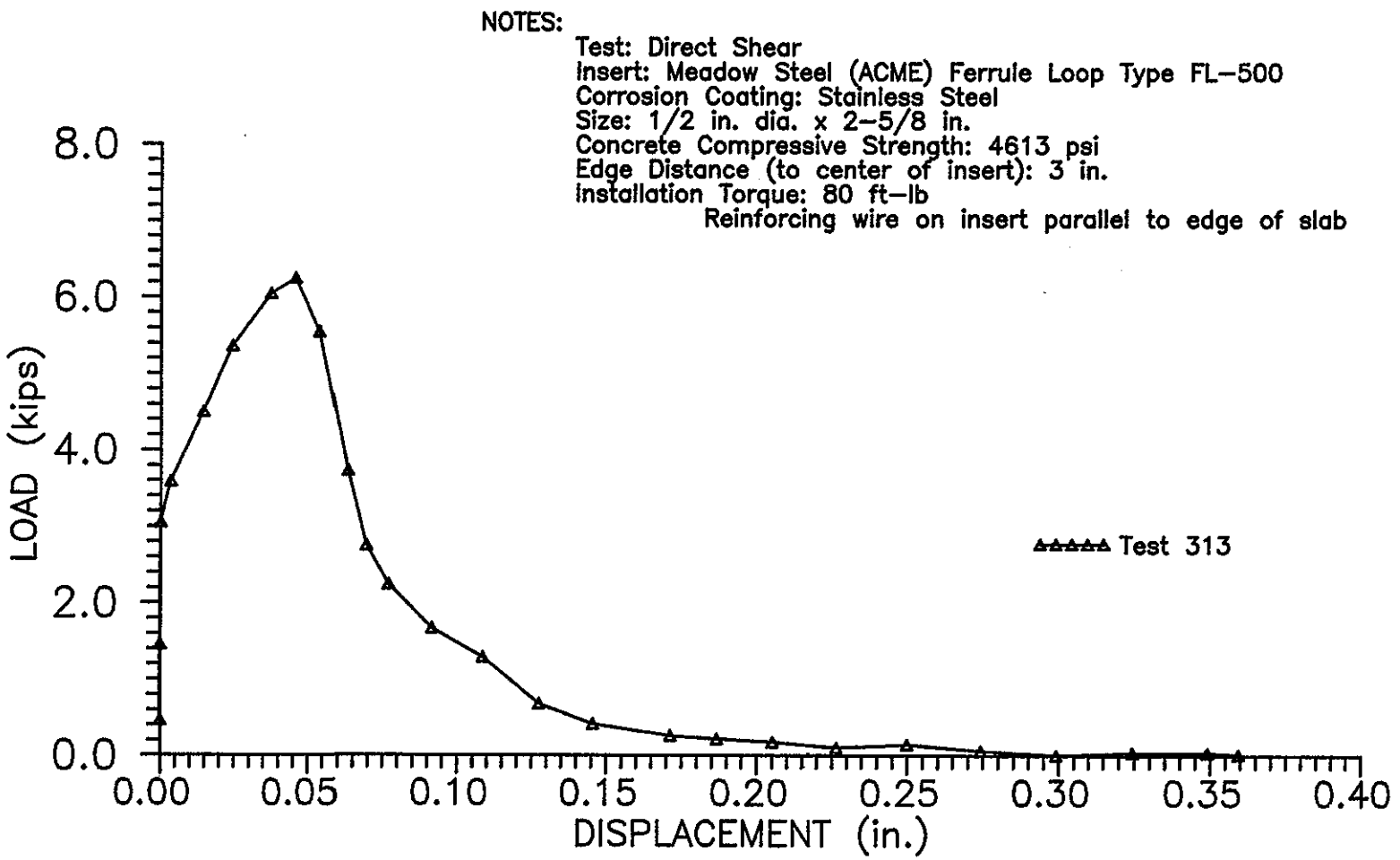

Figure E-4. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

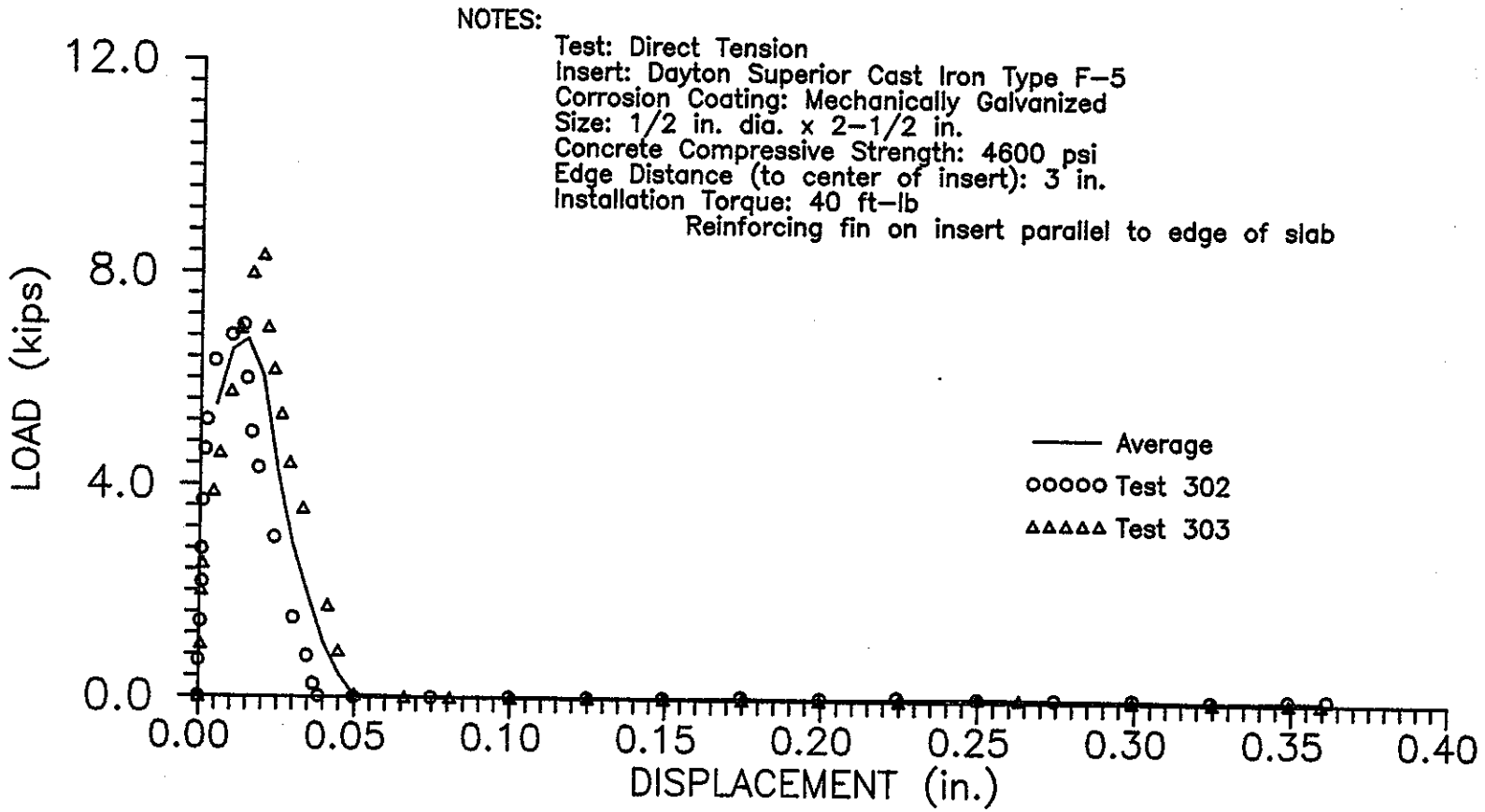

Figure E-5. Load vs. displacement for short–term direct tension tests of cast–in–place concrete inserts.

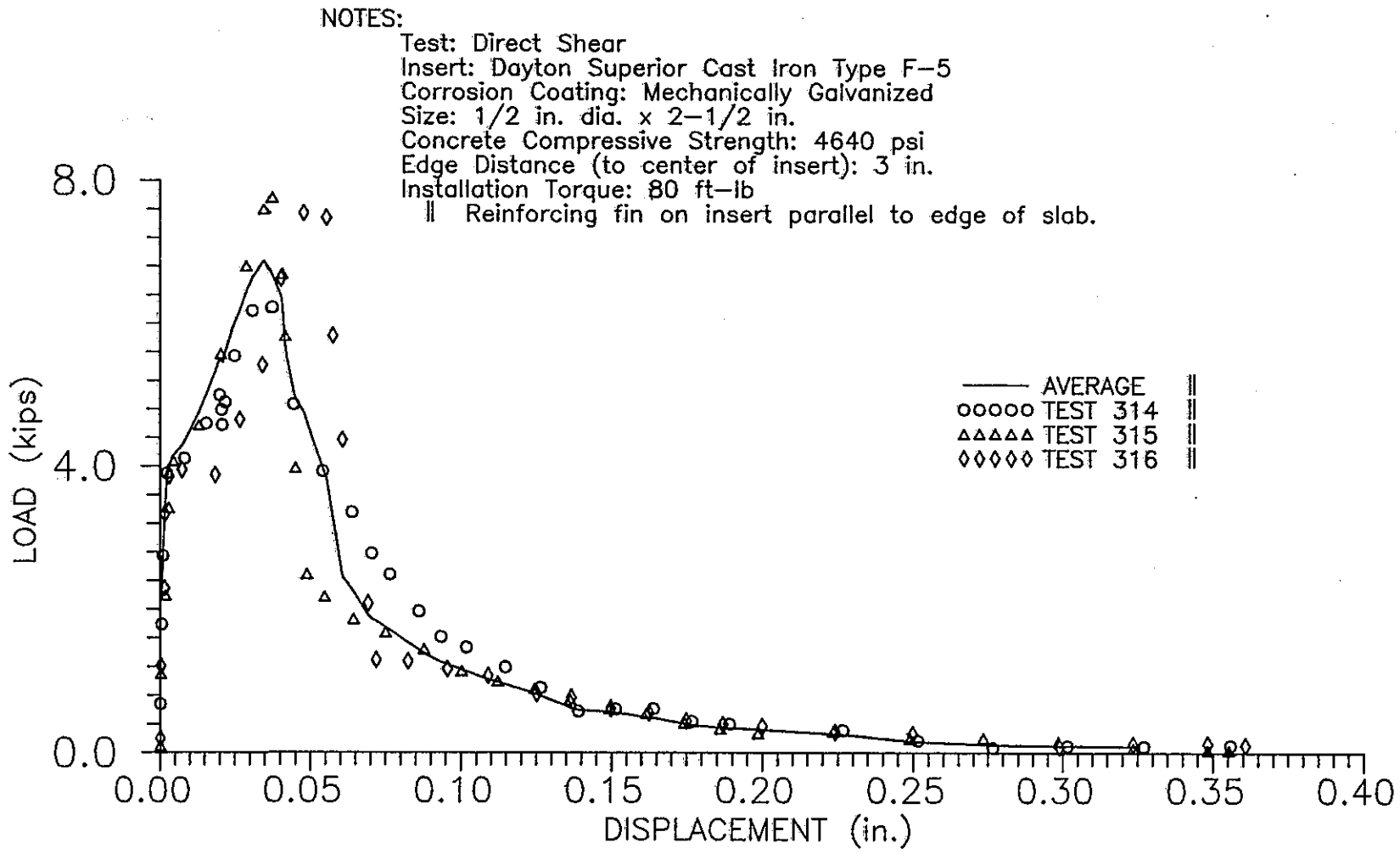

Figure E-6. Load vs. displacement for short-term direct shear tests of cast-in-place concrete inserts.

Appendix F: Plots of Load Versus Displacement of Various Cast-In-Place Concrete Inserts from Combined Tension and Shear Tests. Concrete Compressive Strength 5000 ± psi.

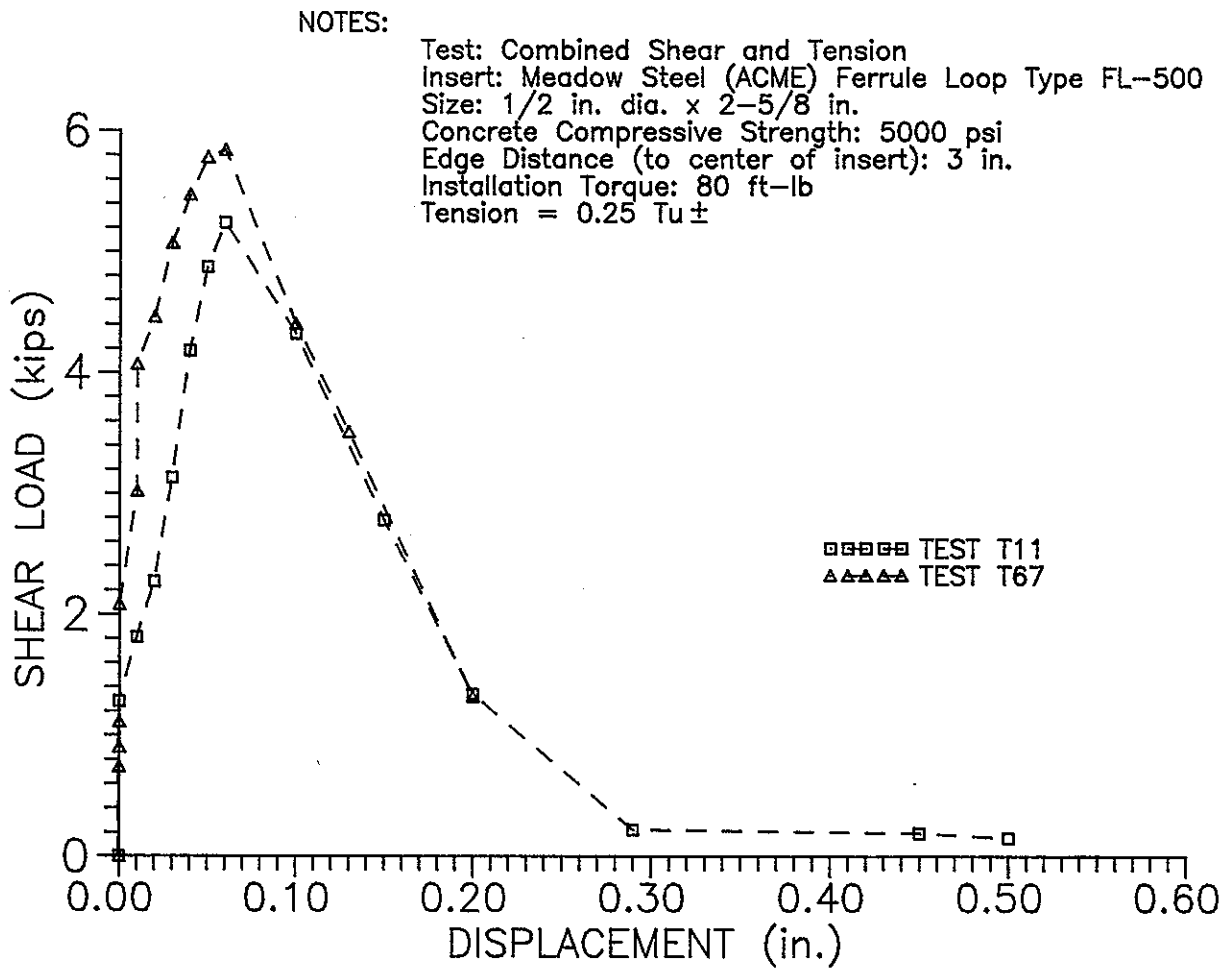

Figure F-1. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

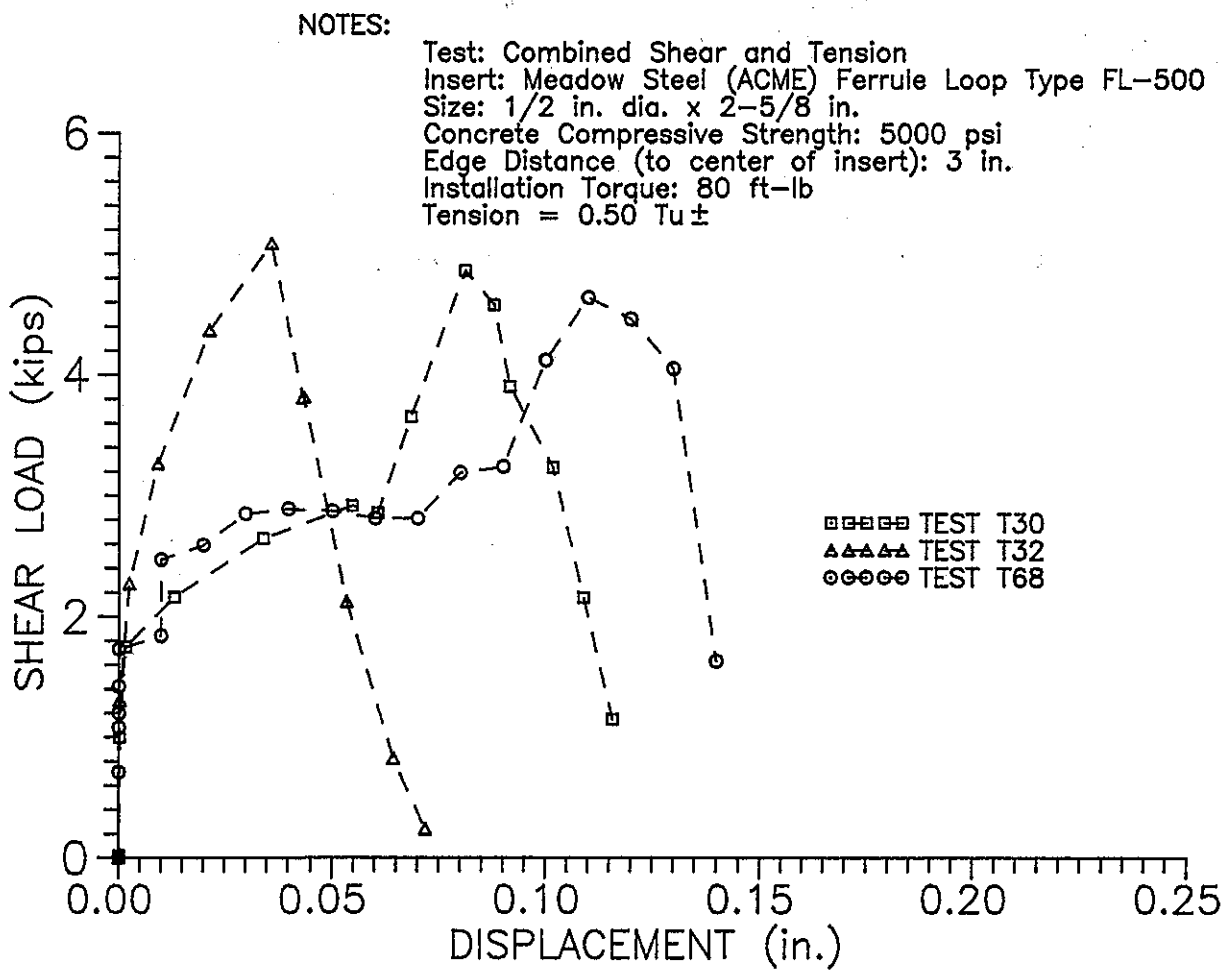

Figure F-2. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

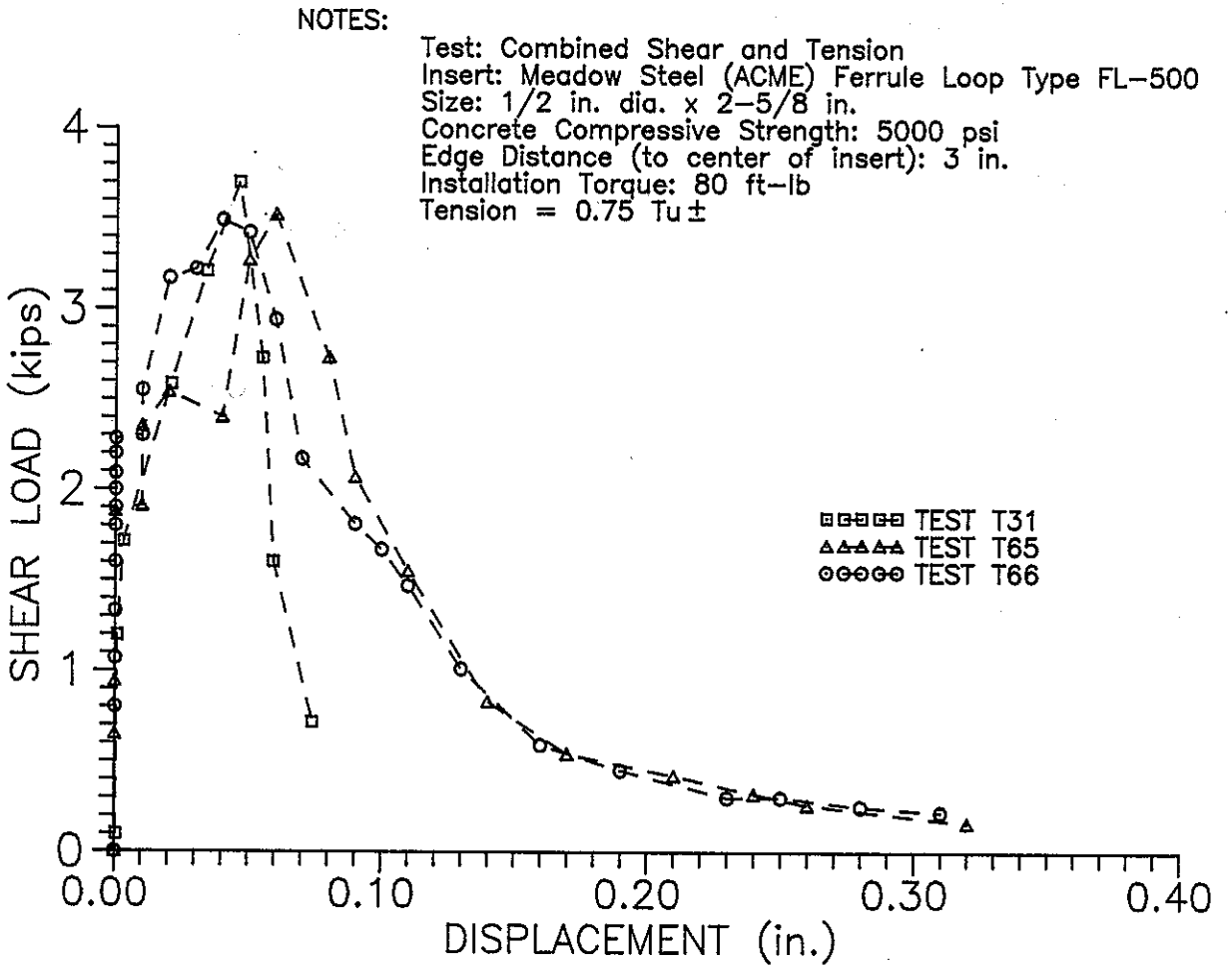

Figure F-3. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

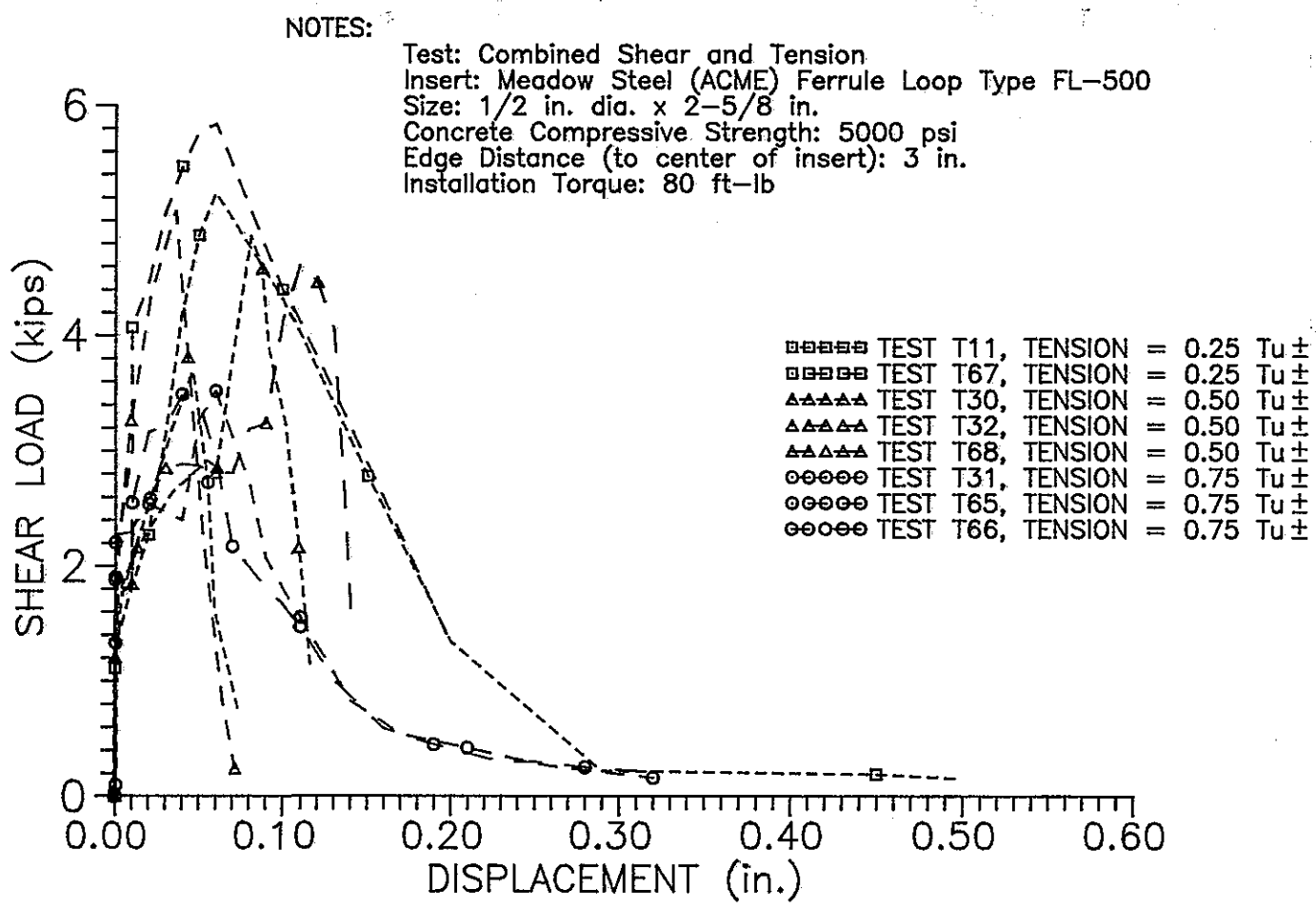

Figure F-4. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

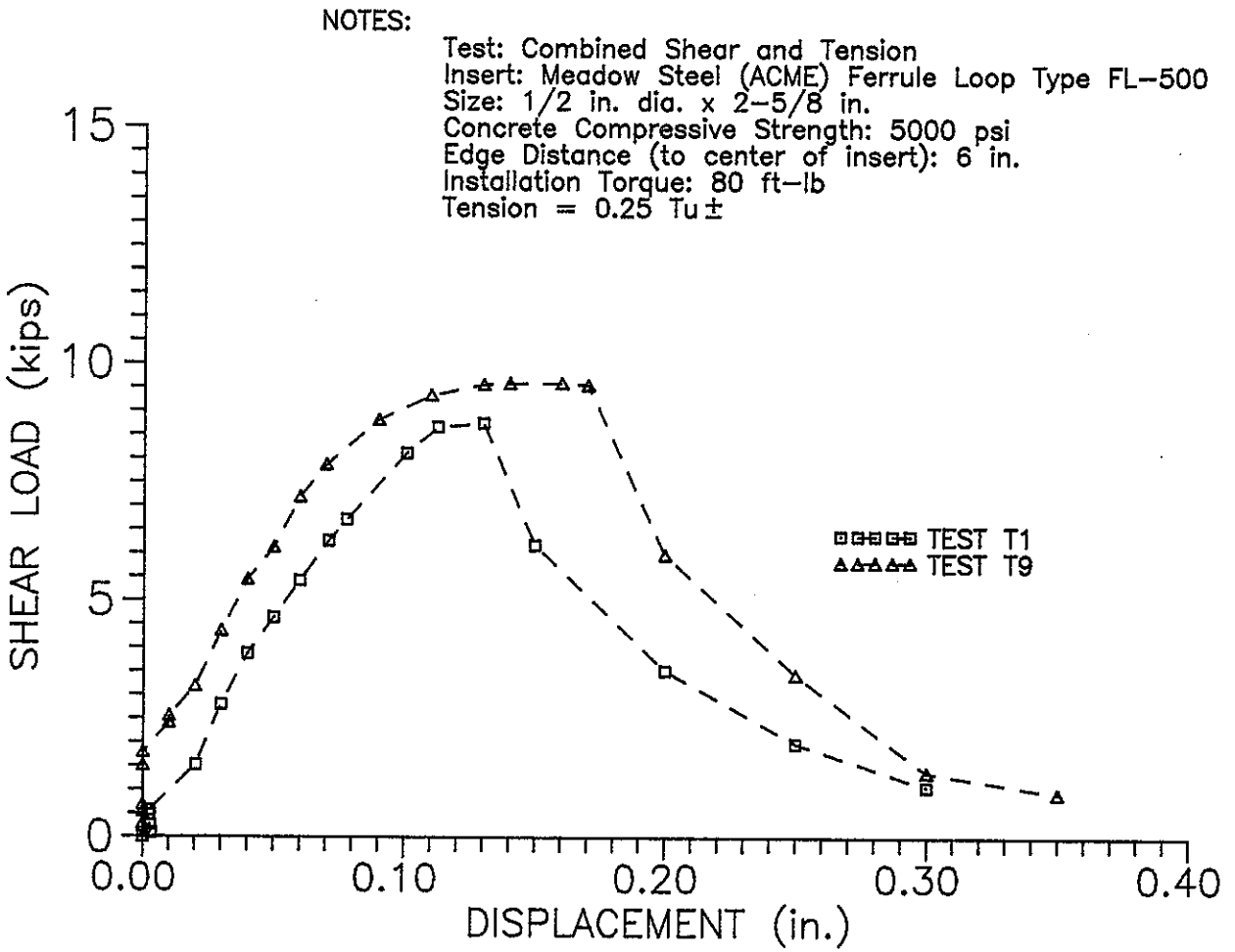

Figure F-5. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

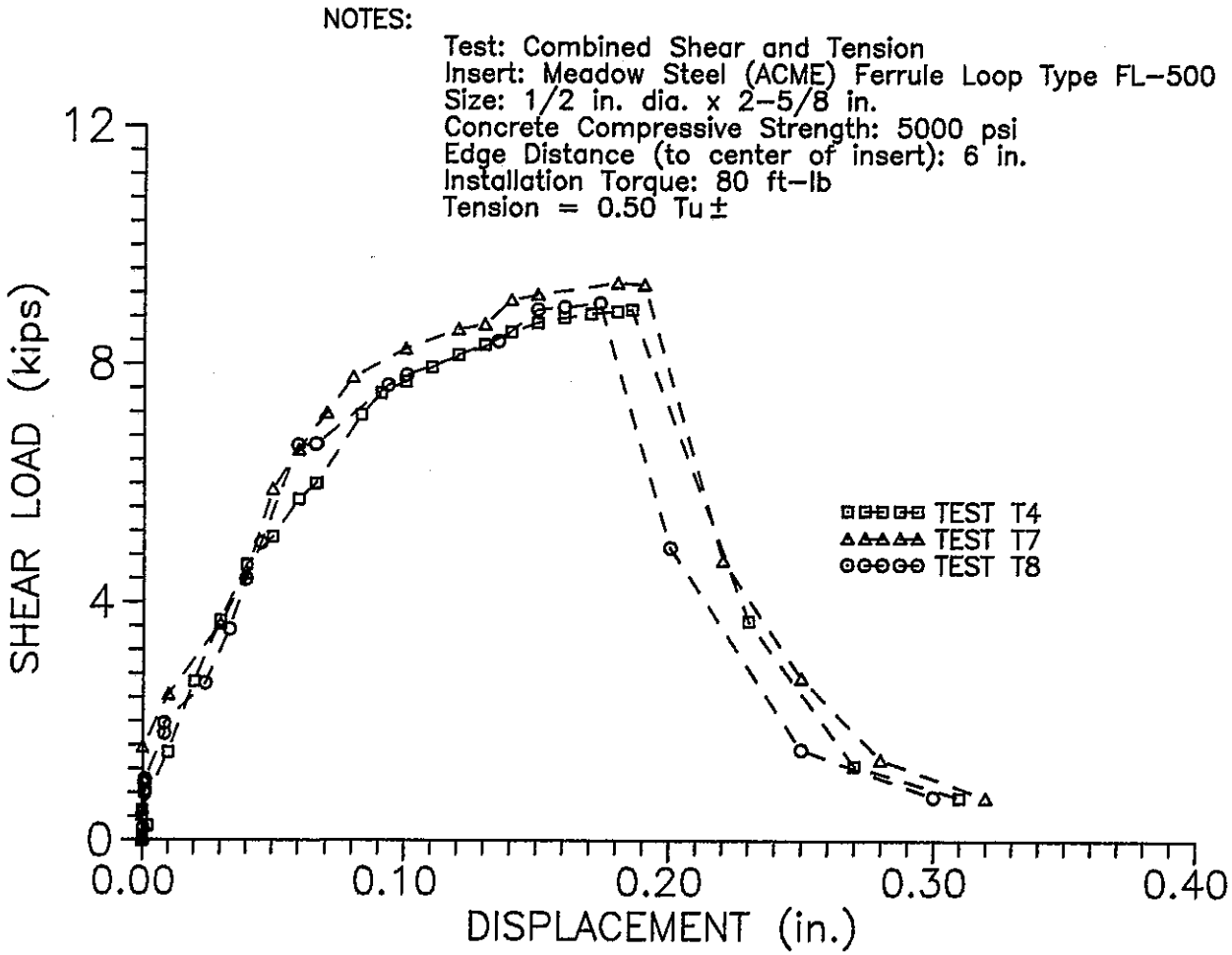

Figure F-6. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

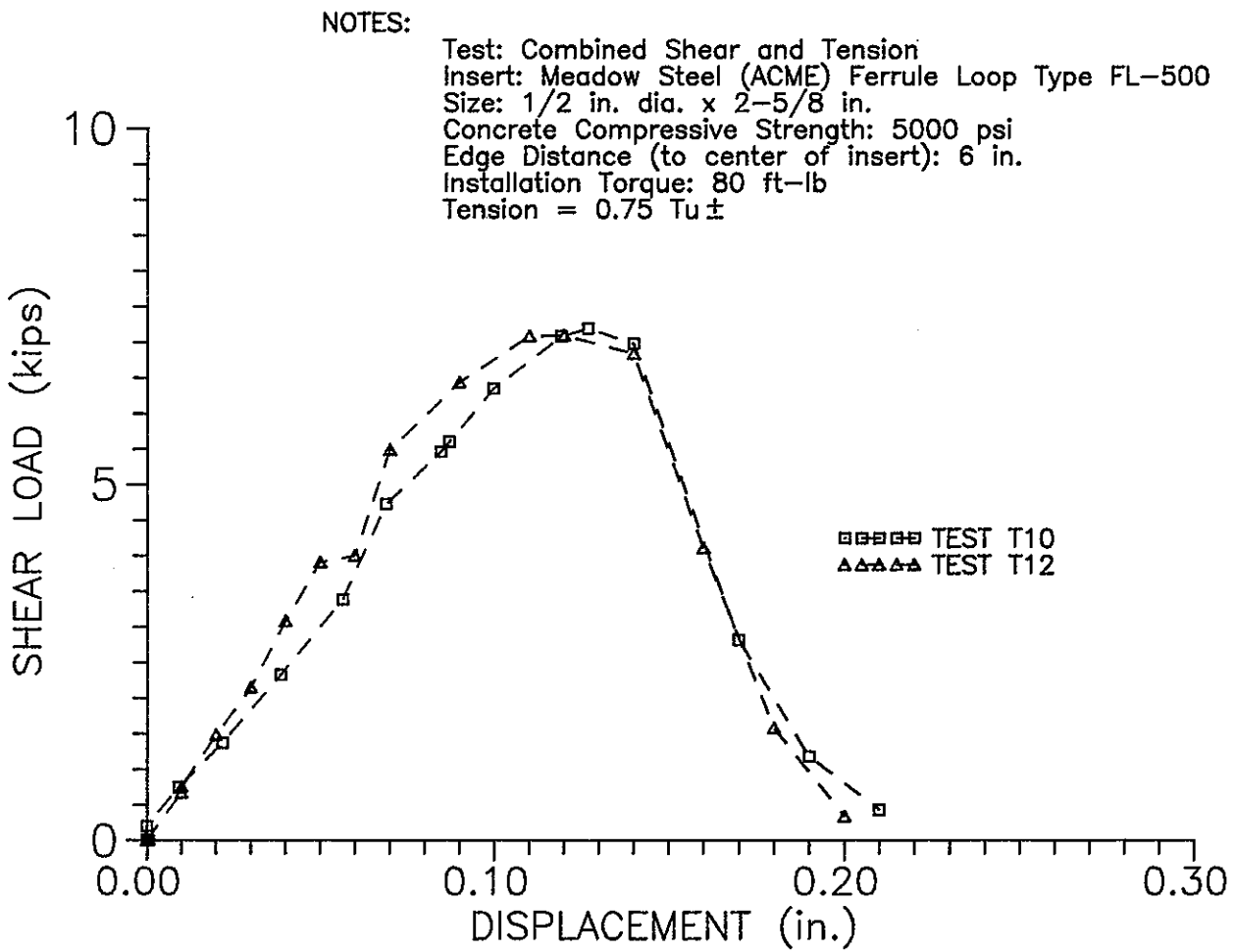

Figure F-7. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

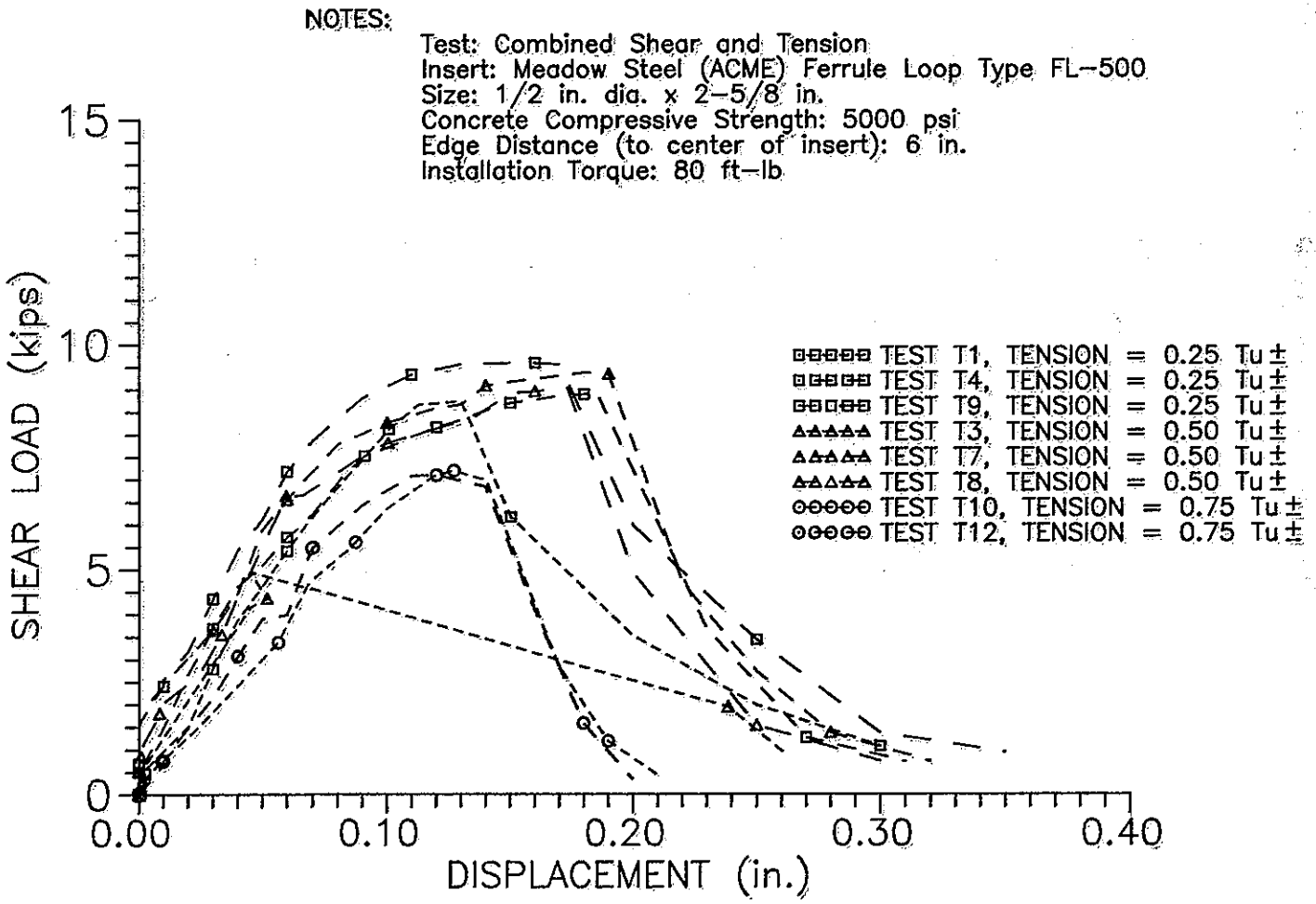

Figure F-8. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

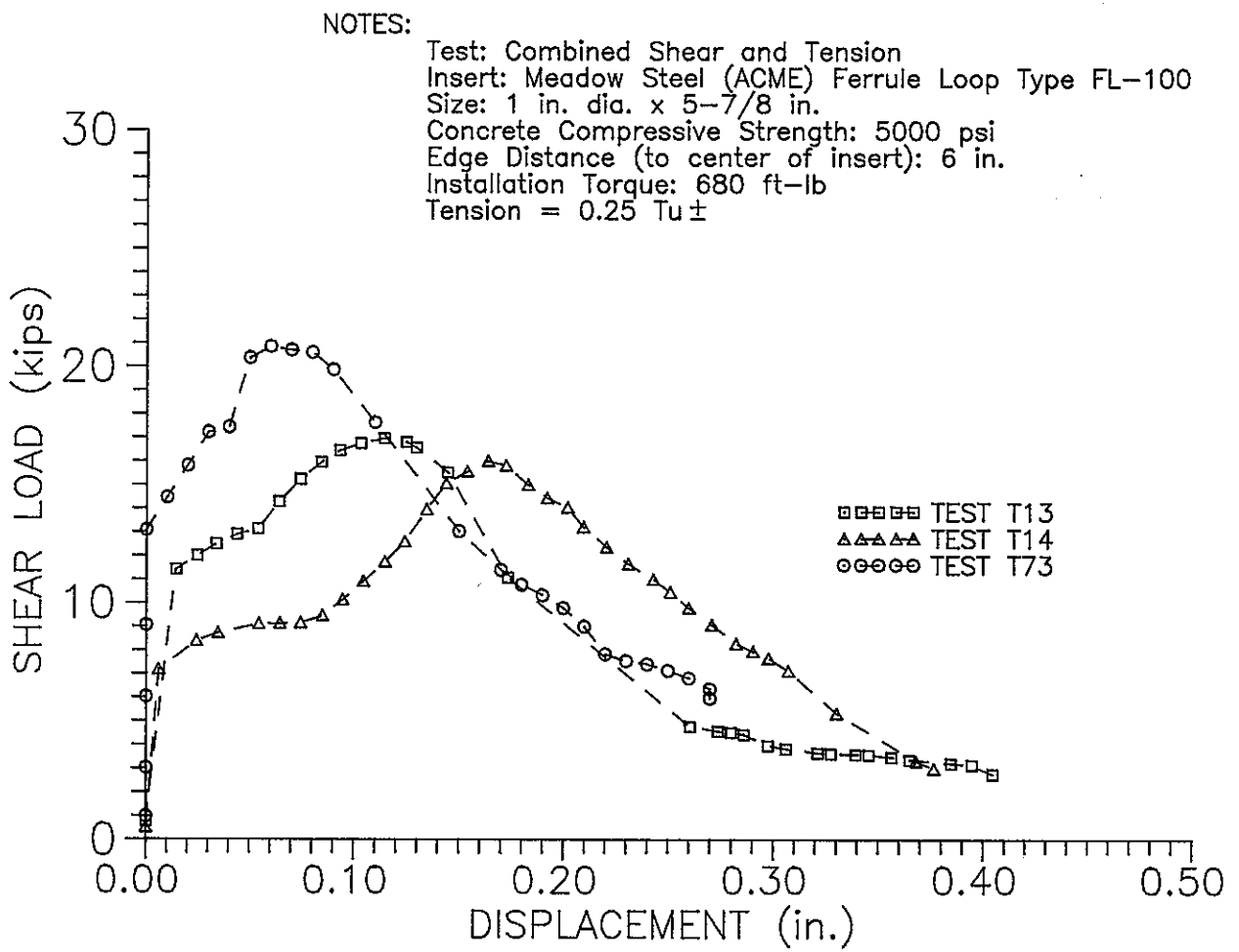

Figure F-9. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

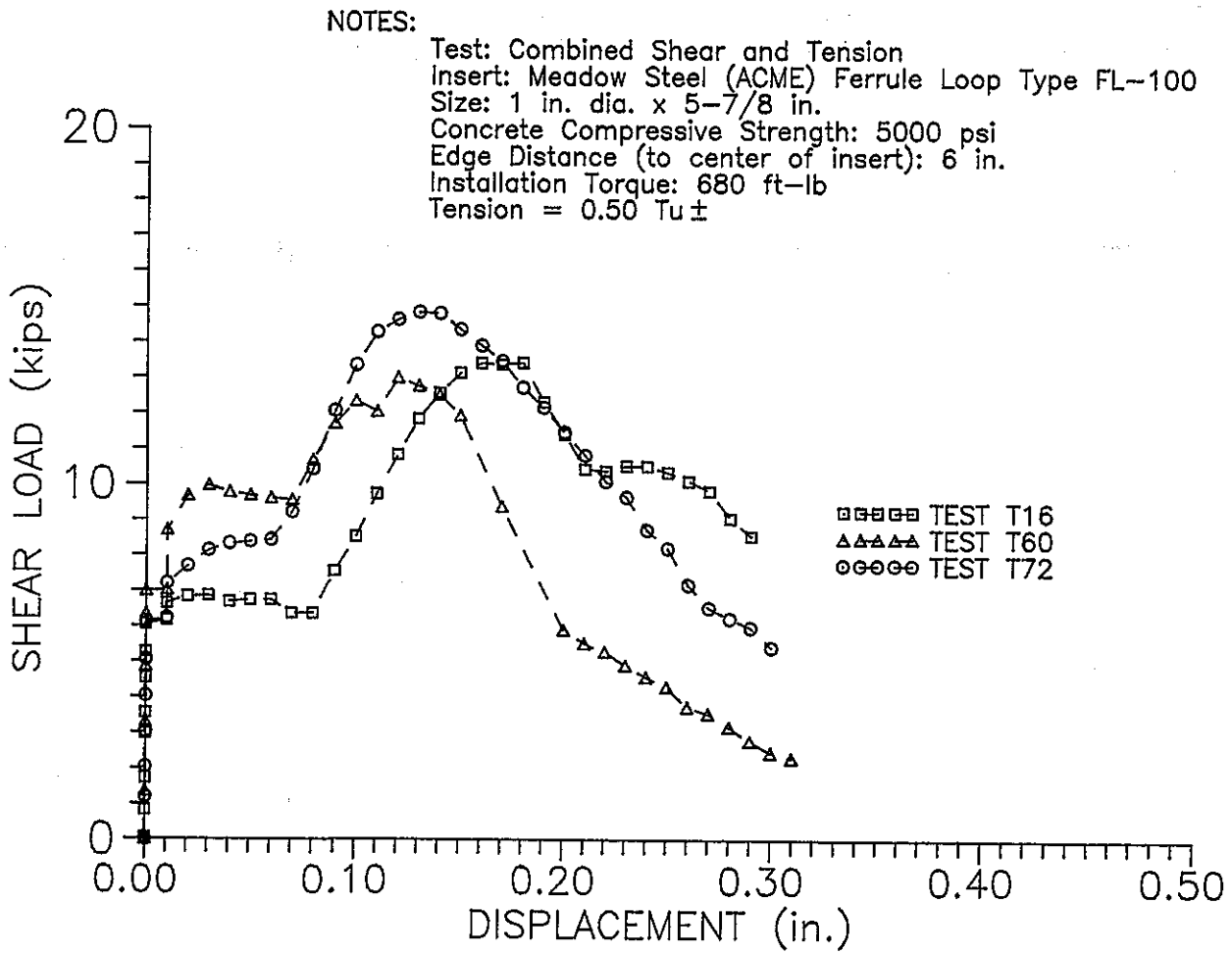

Figure F-10. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

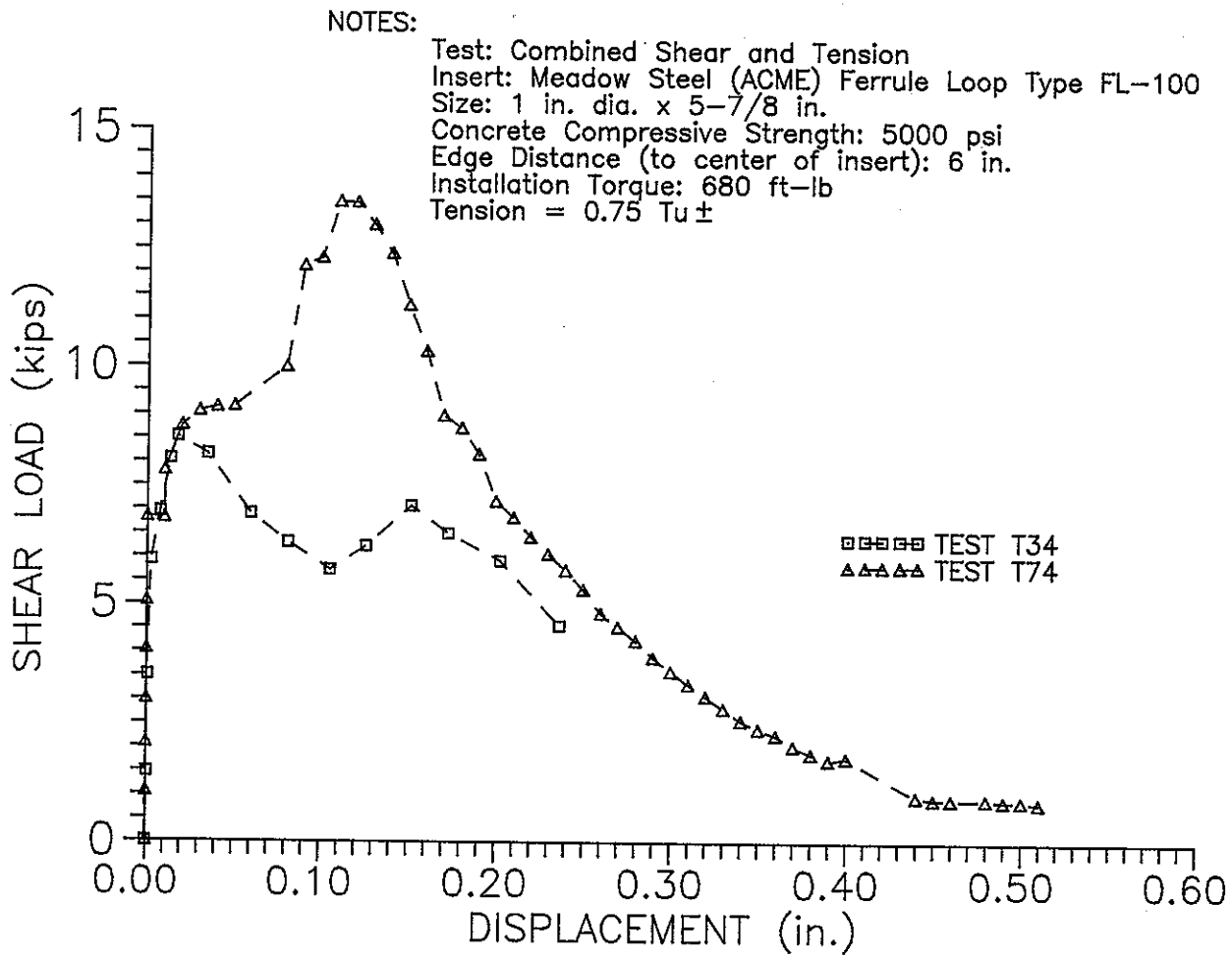

Figure F-11. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

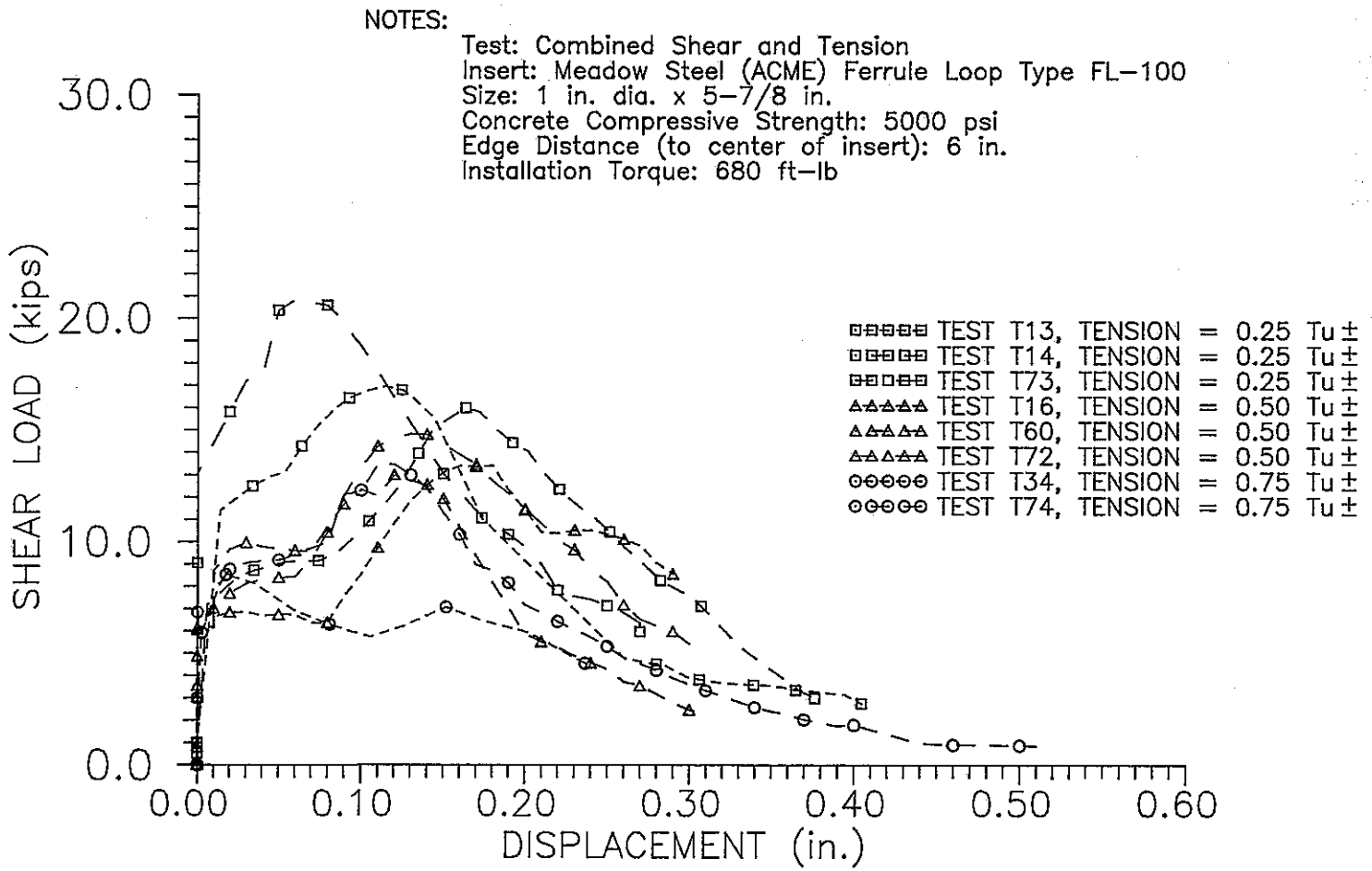

Figure F-12. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

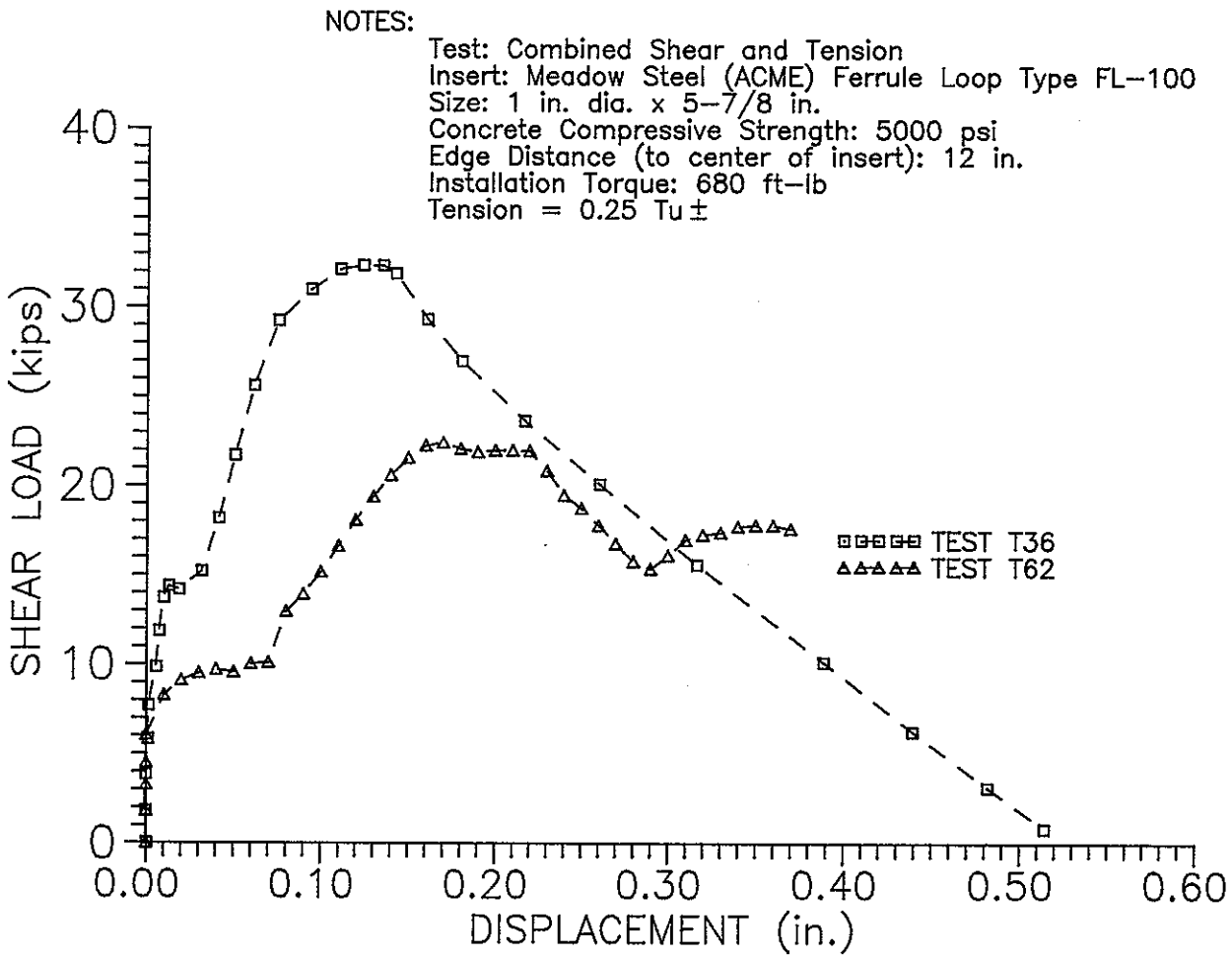

Figure F-13. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

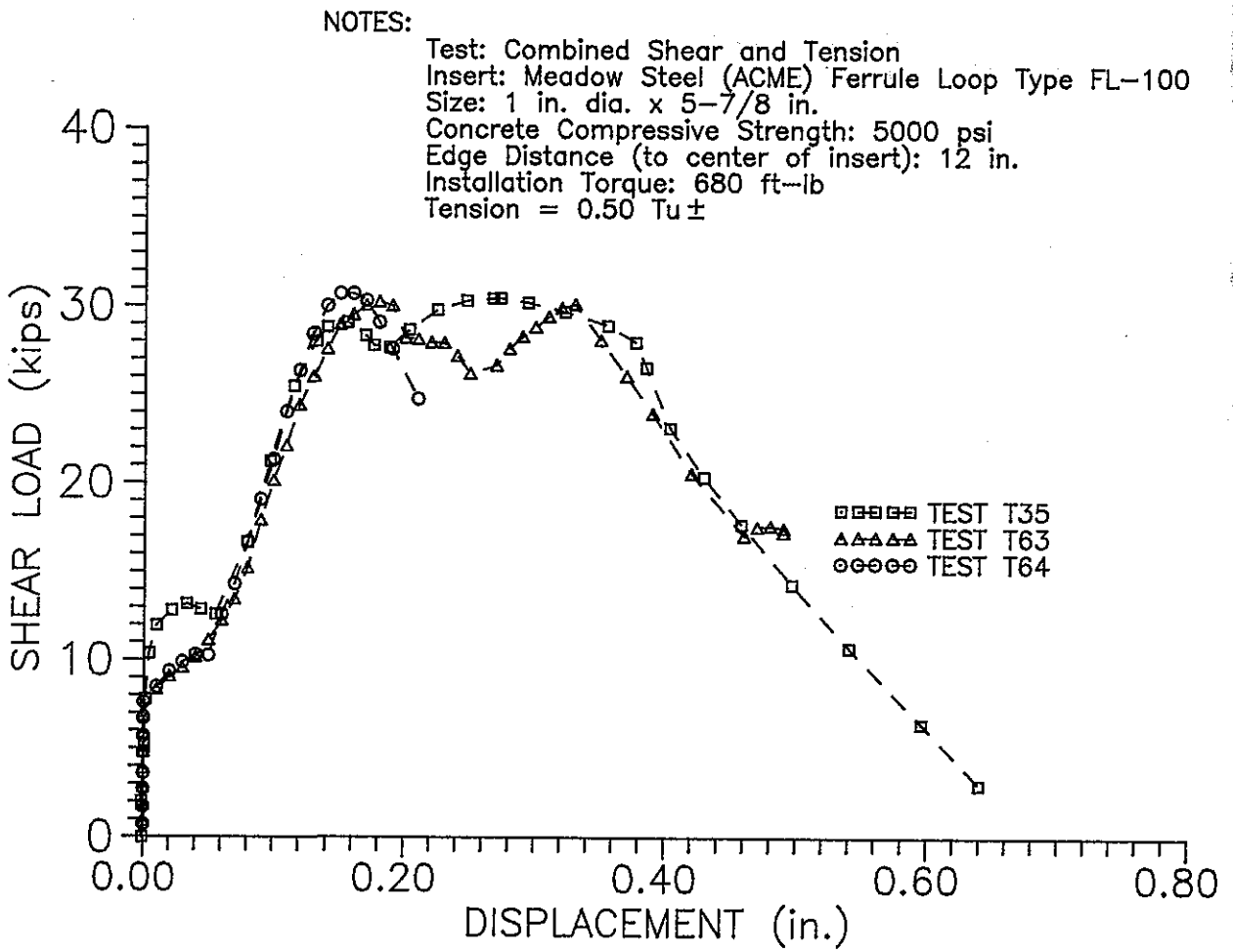

Figure F-14. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

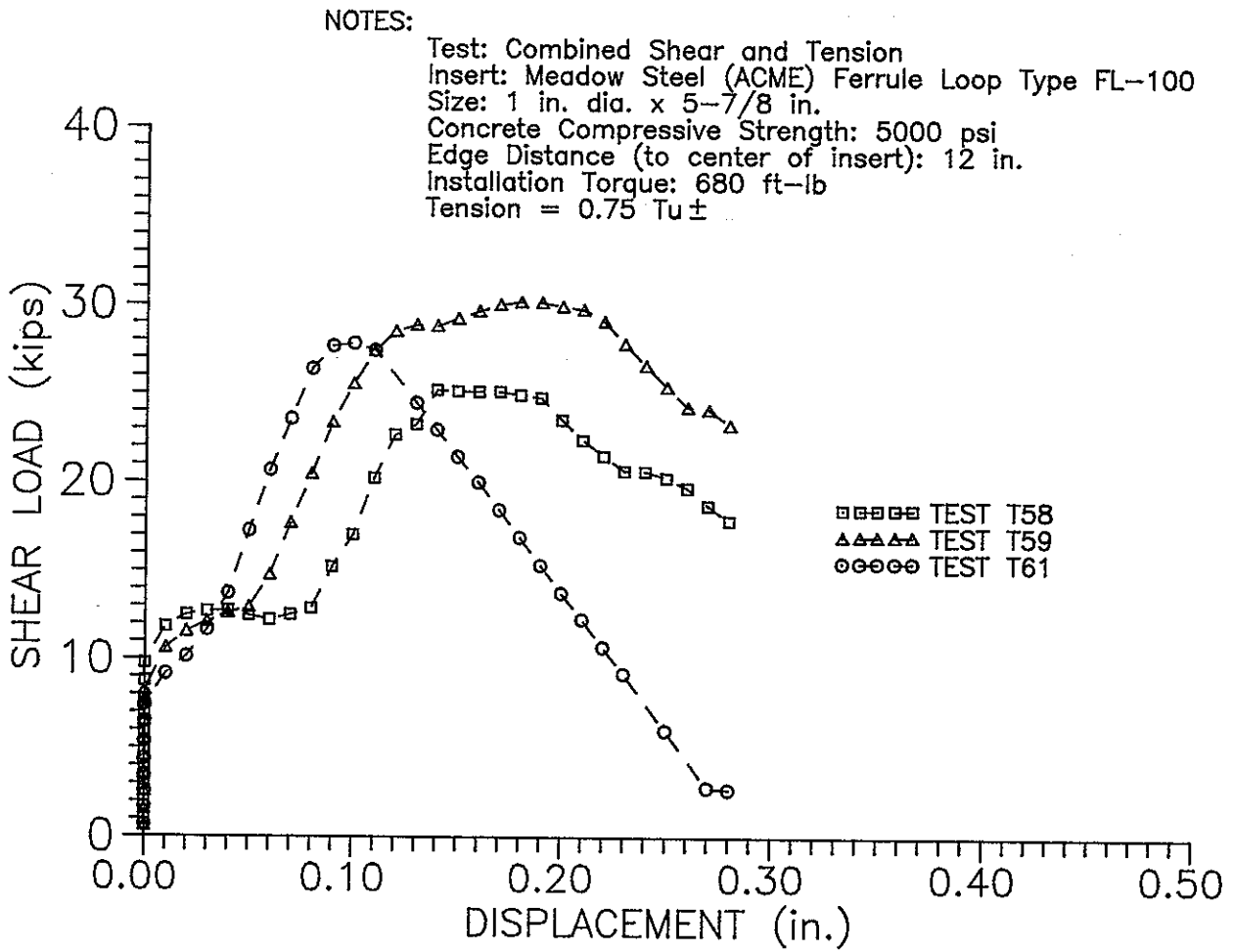

Figure F-15. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

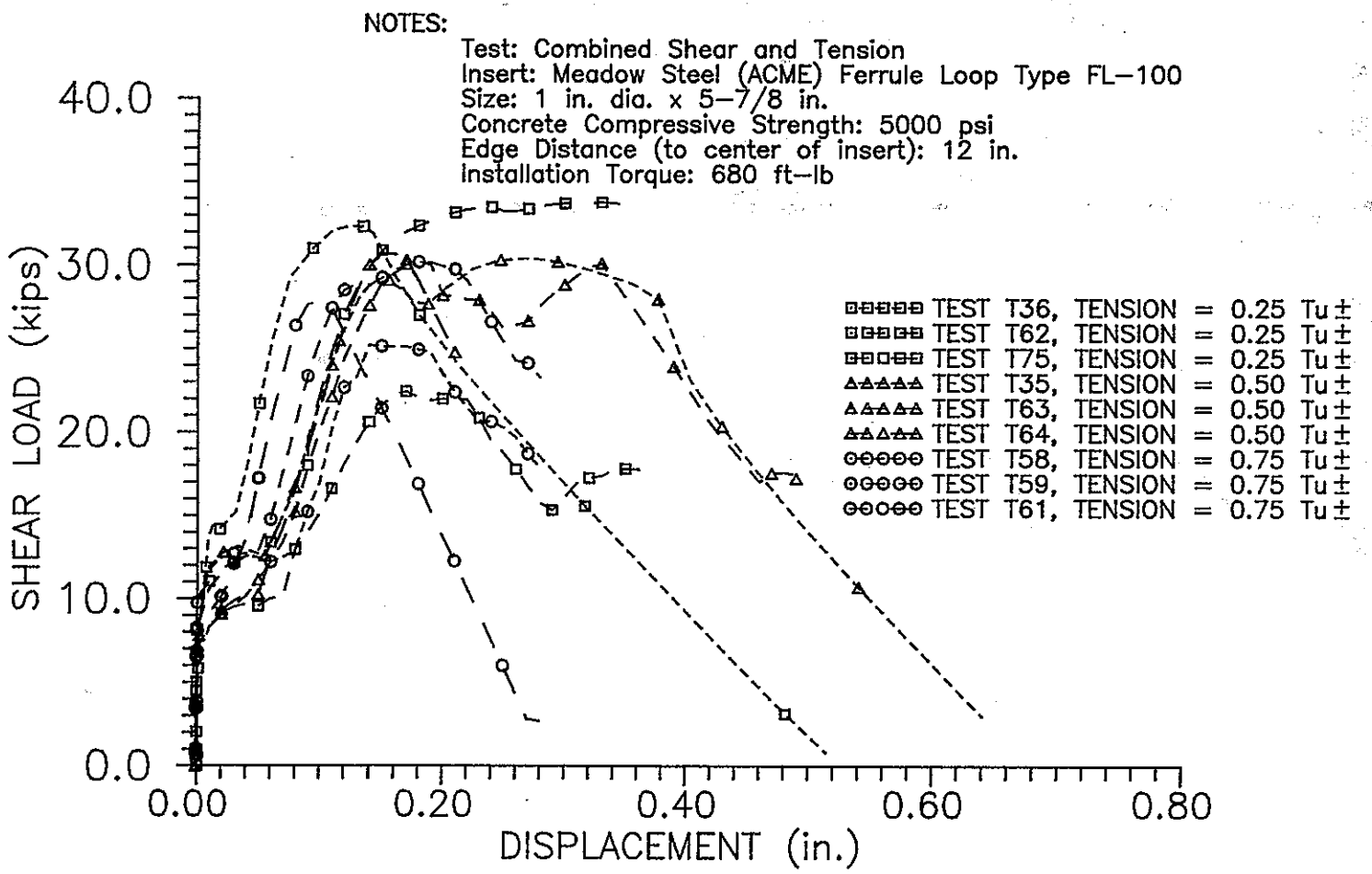

Figure F-16. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

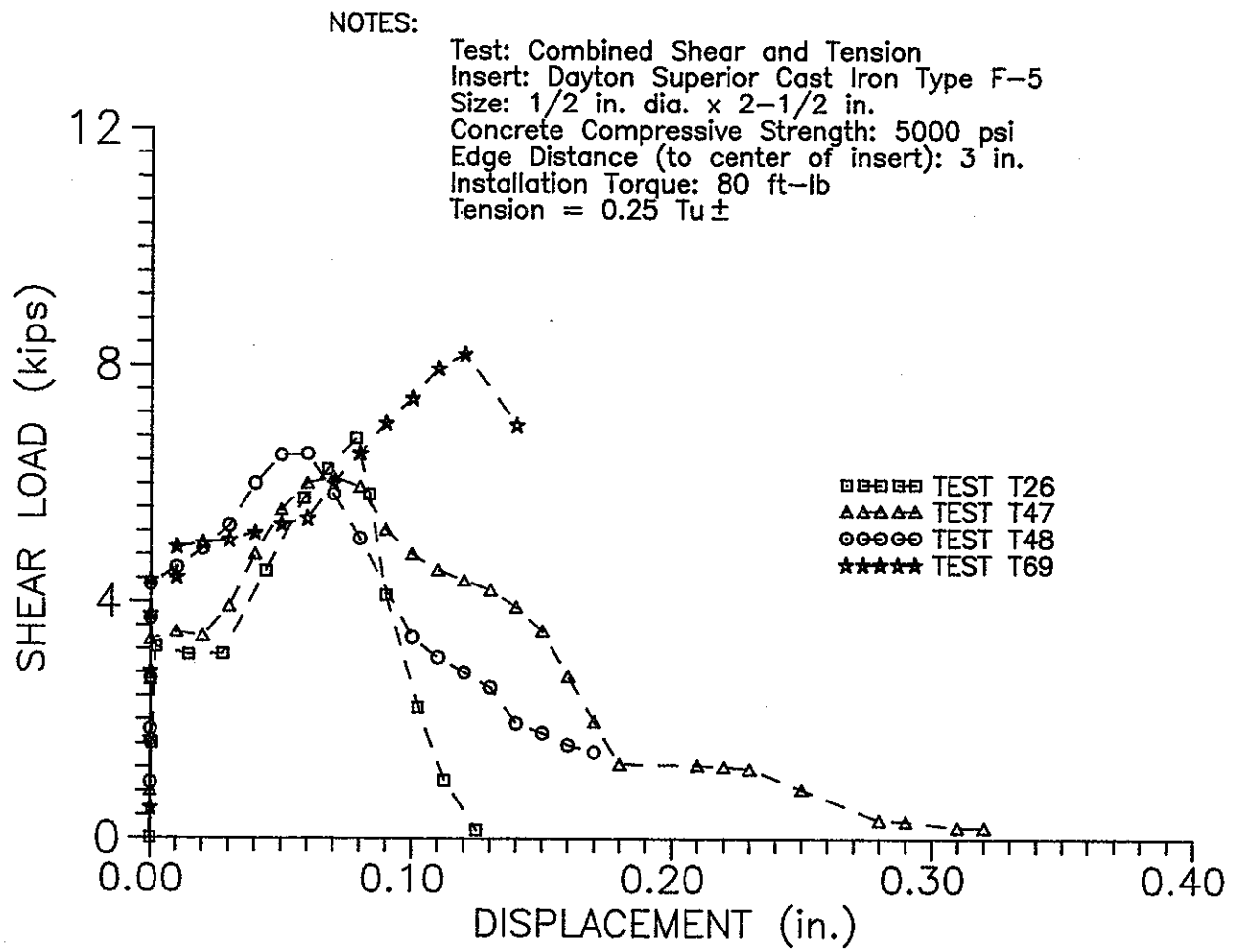

Figure F-17. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

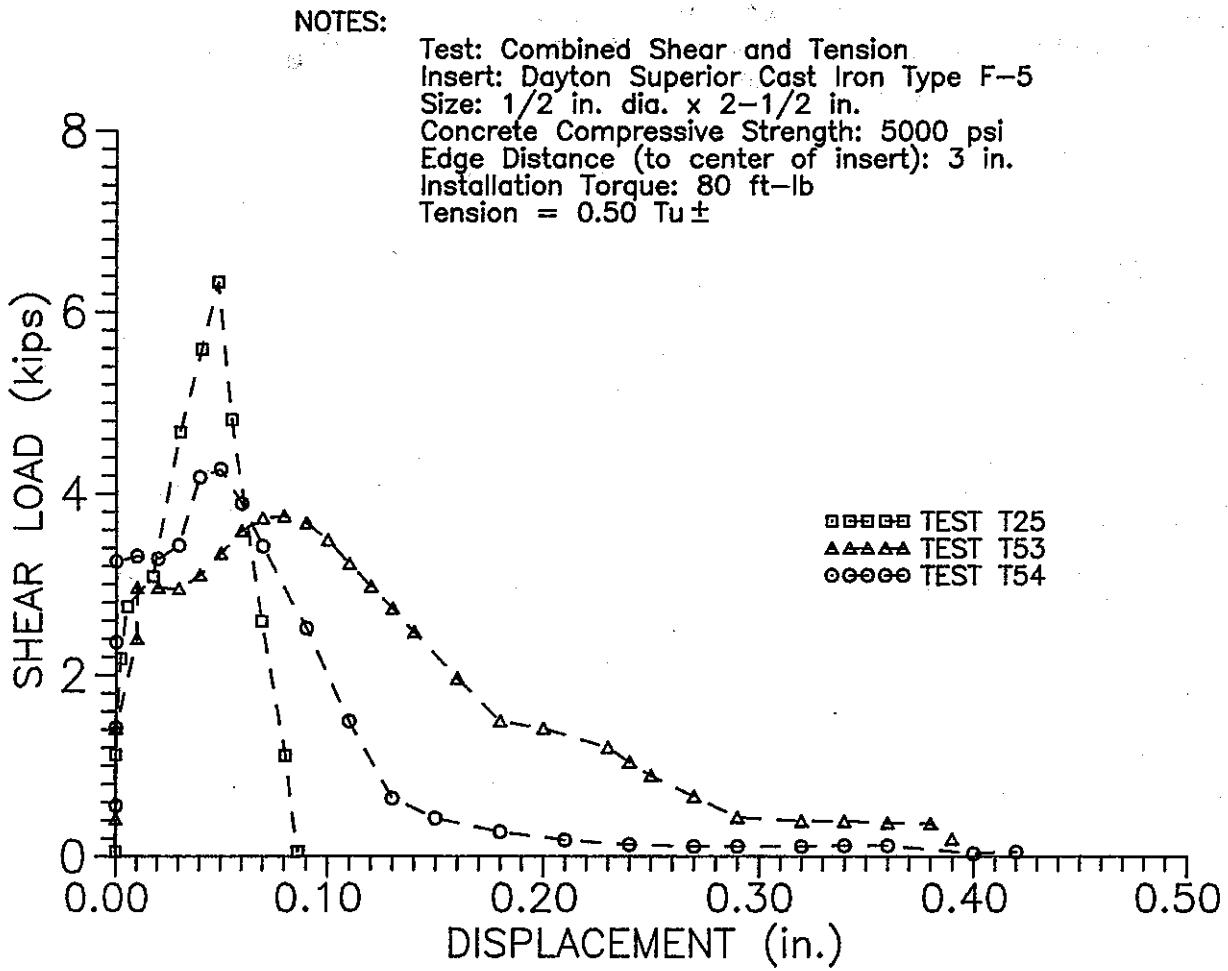

Figure F-18. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

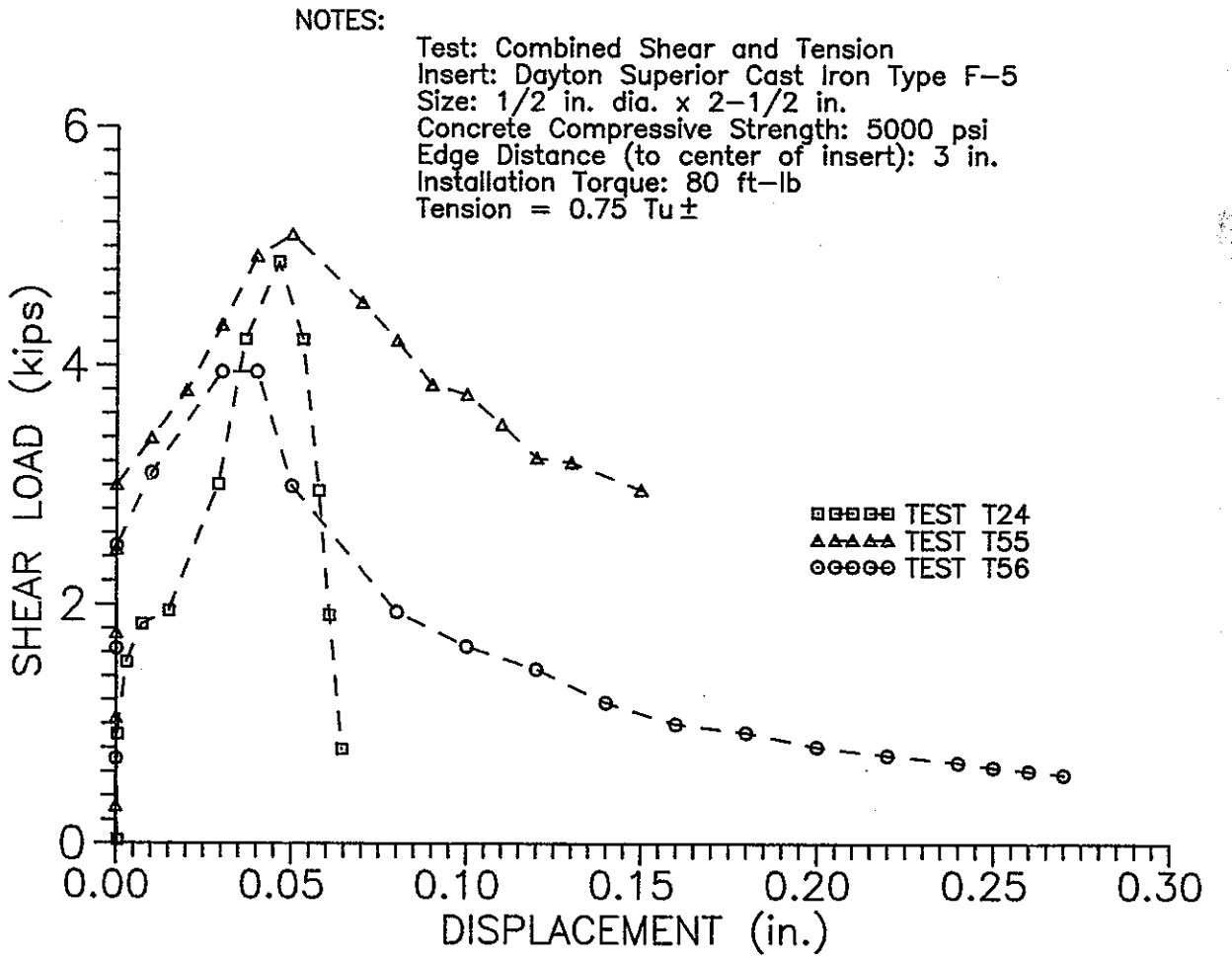

Figure F-19. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

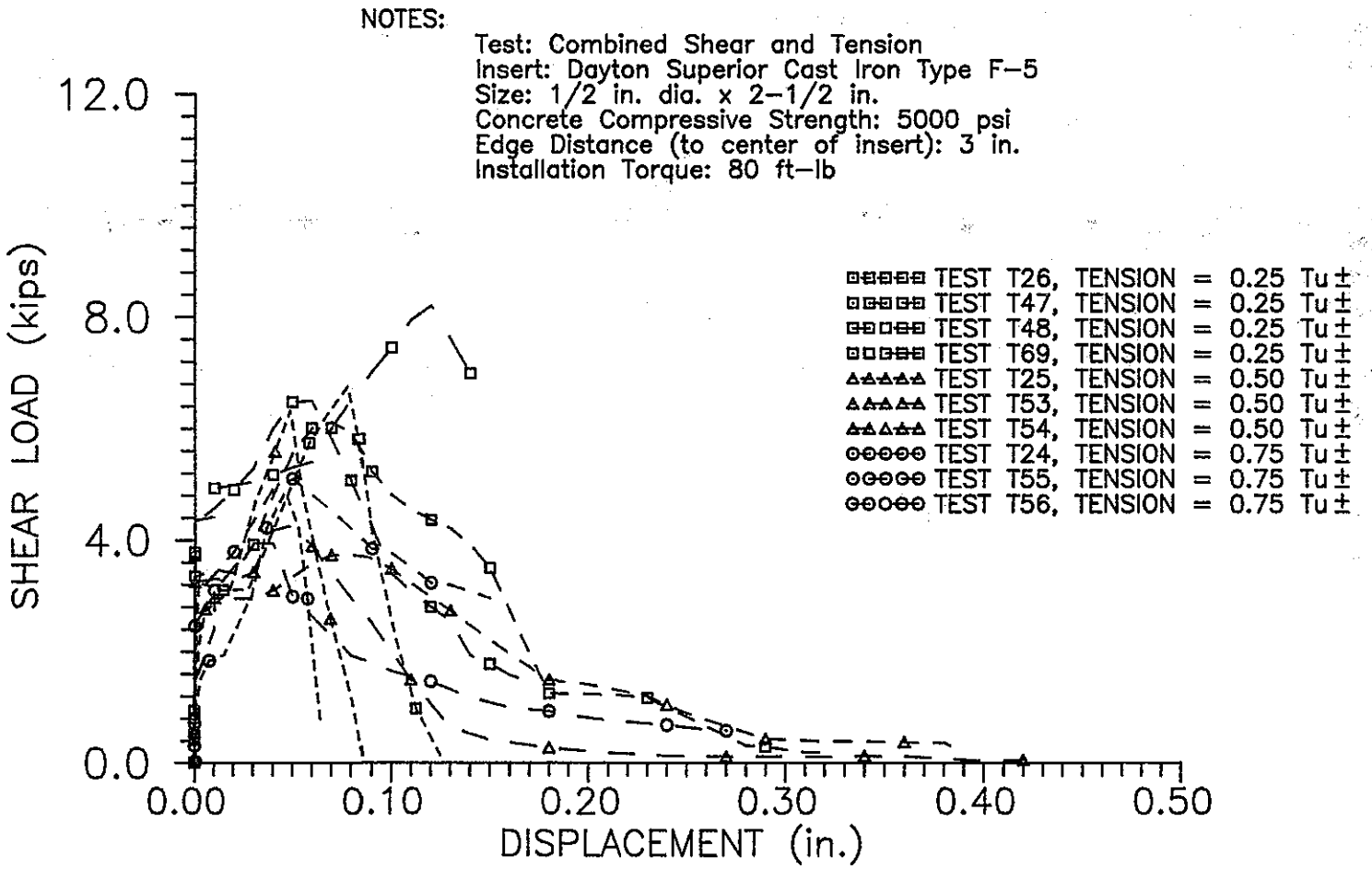

Figure F-20. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

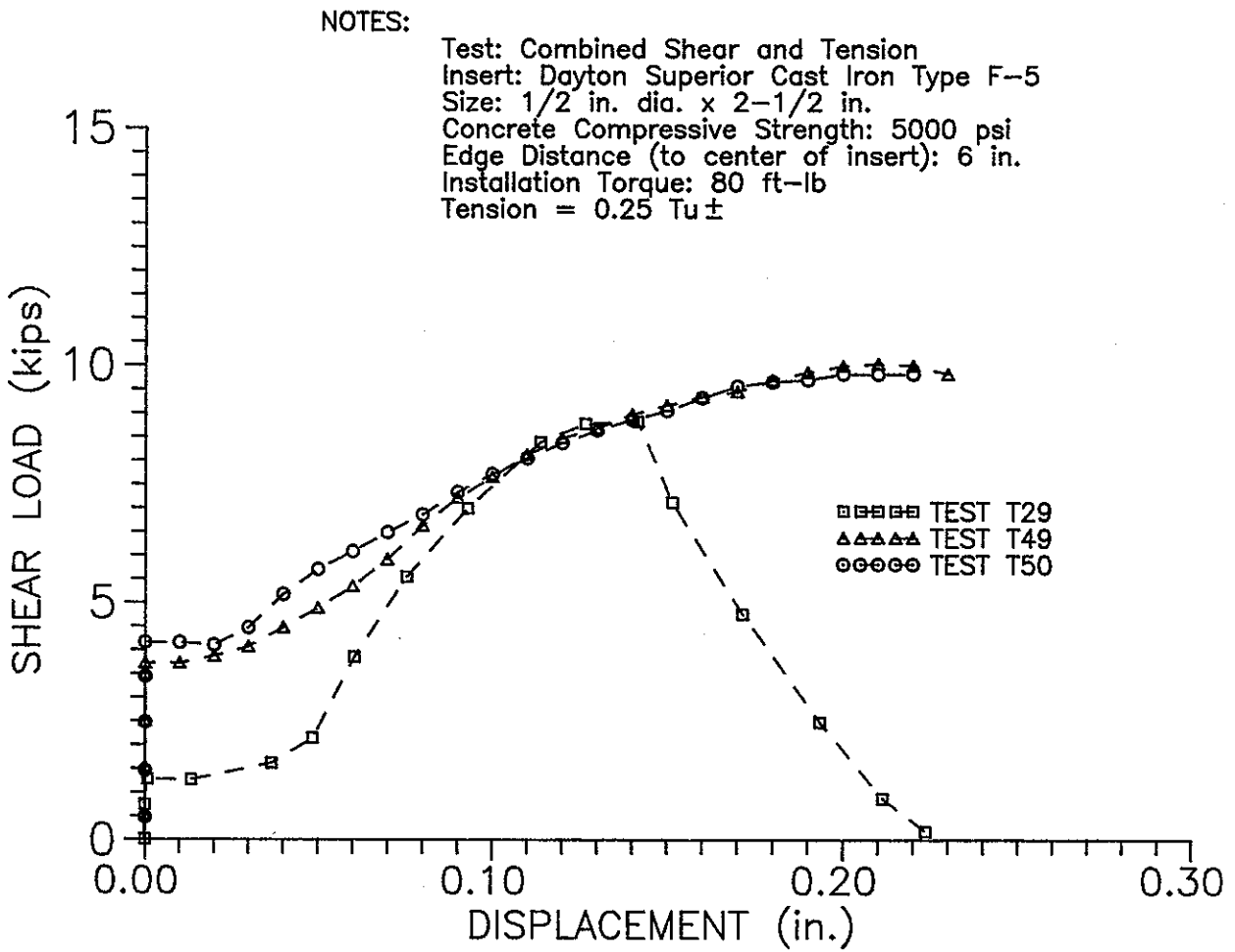

Figure F-21. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

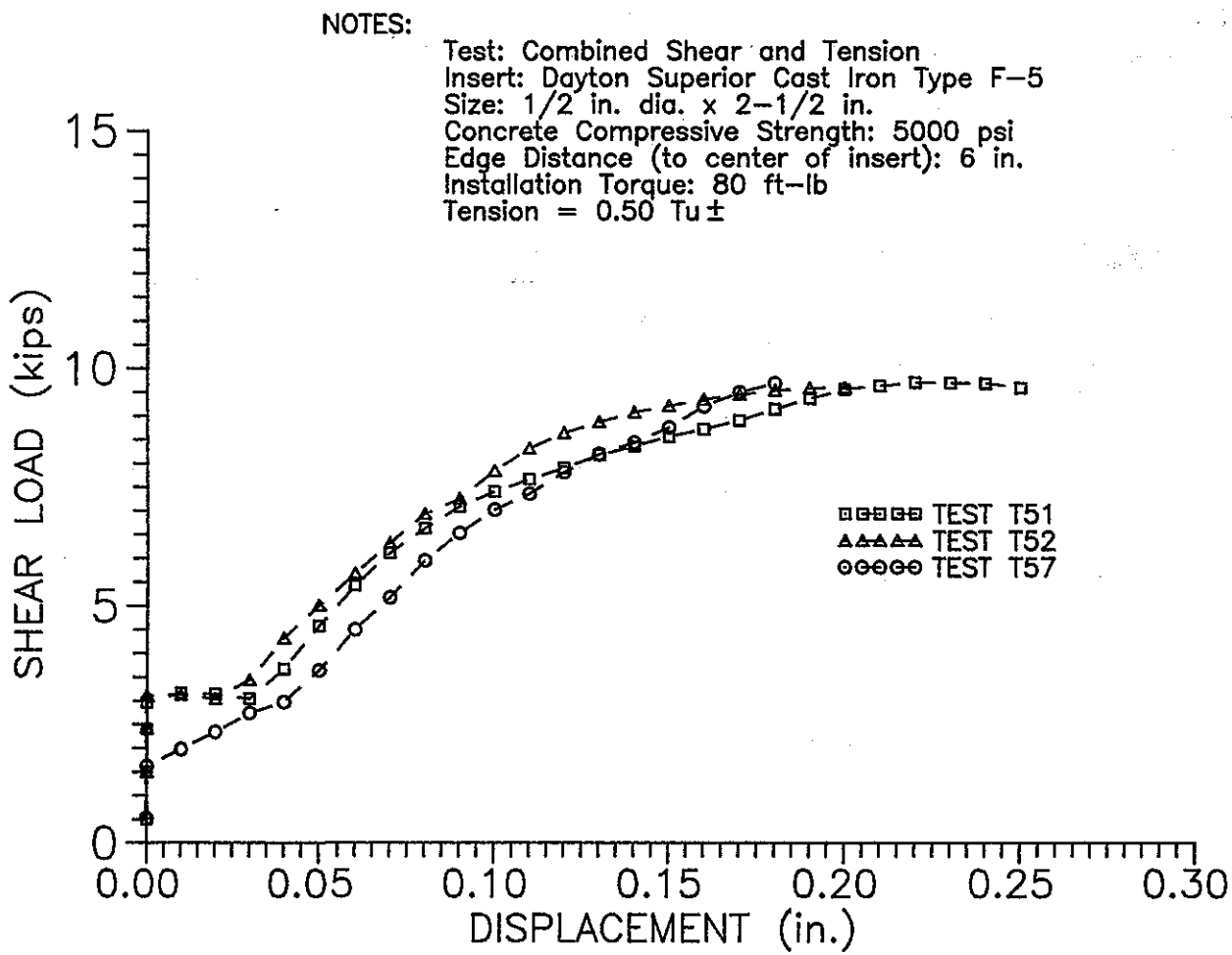

Figure F-22. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

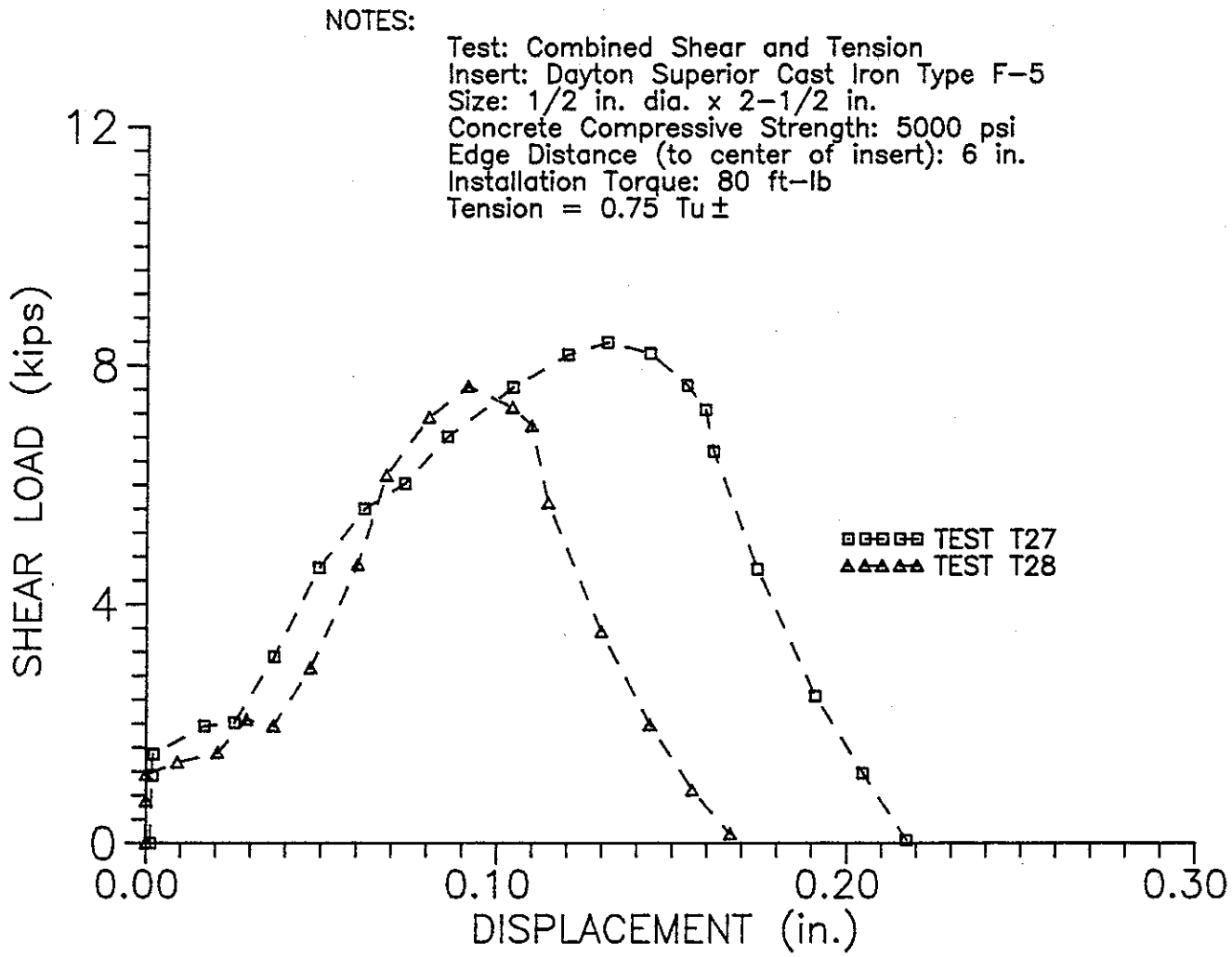

Figure F-23. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

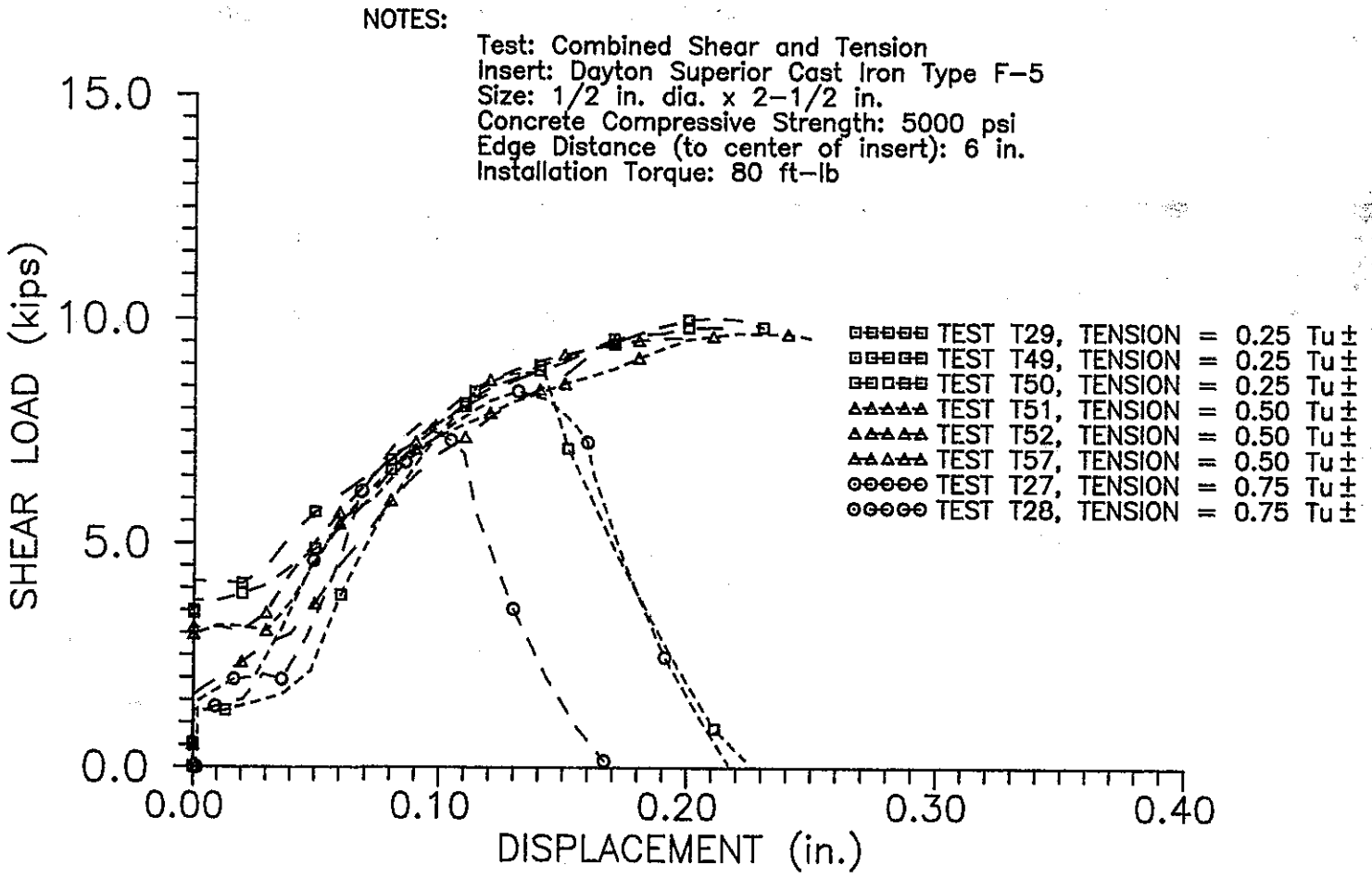

Figure F-24. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

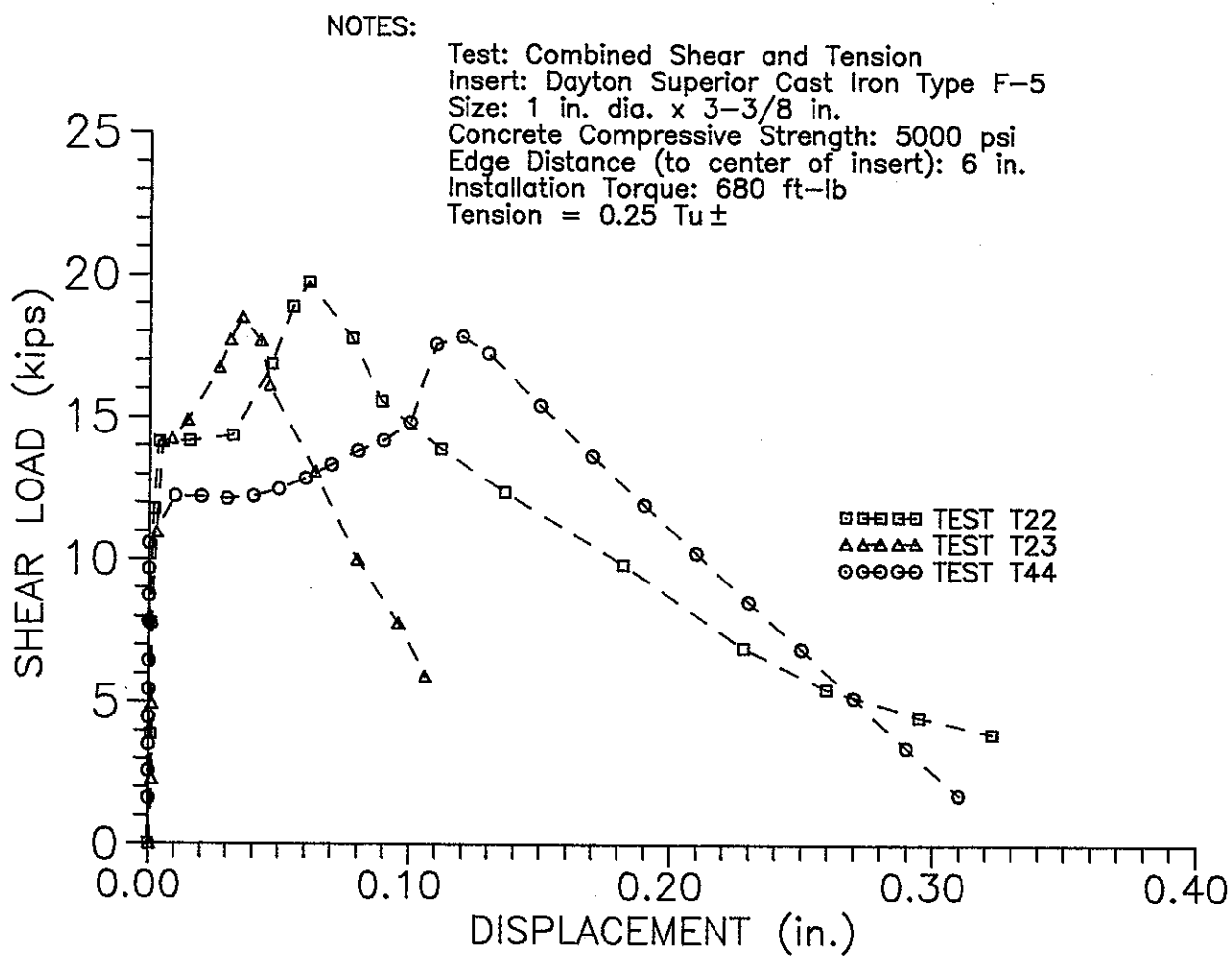

Figure F-25. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

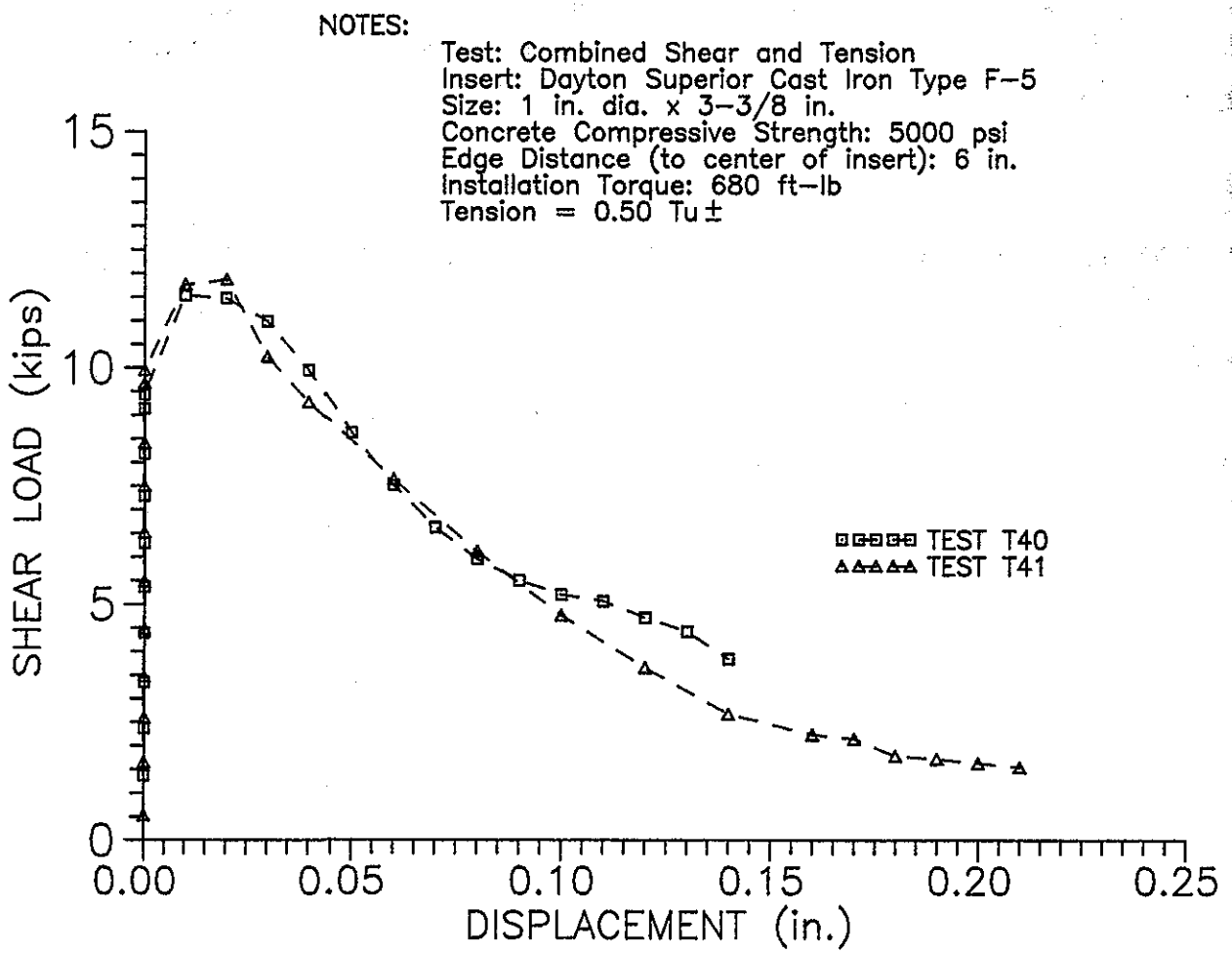

Figure F-26. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

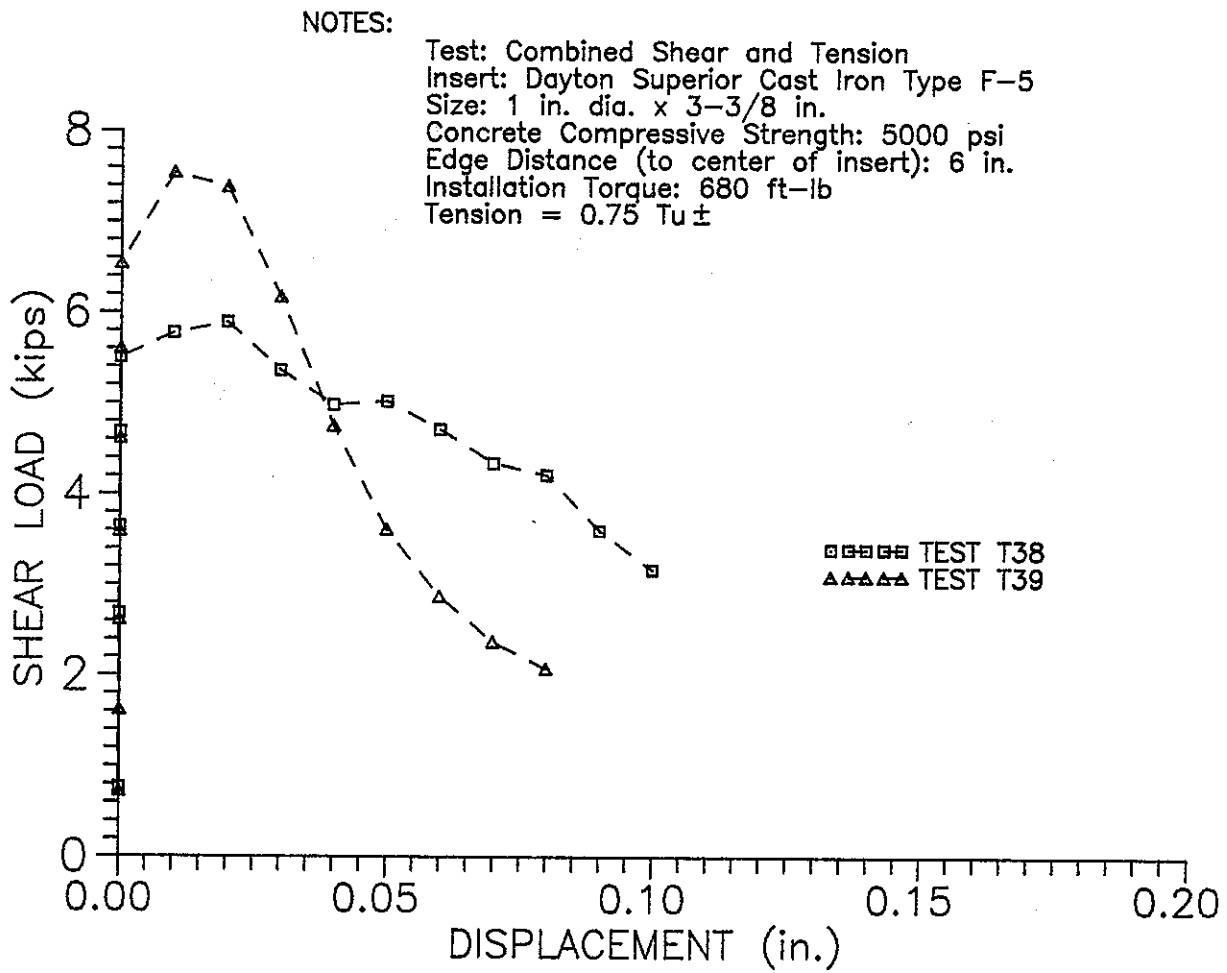

Figure F-27. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

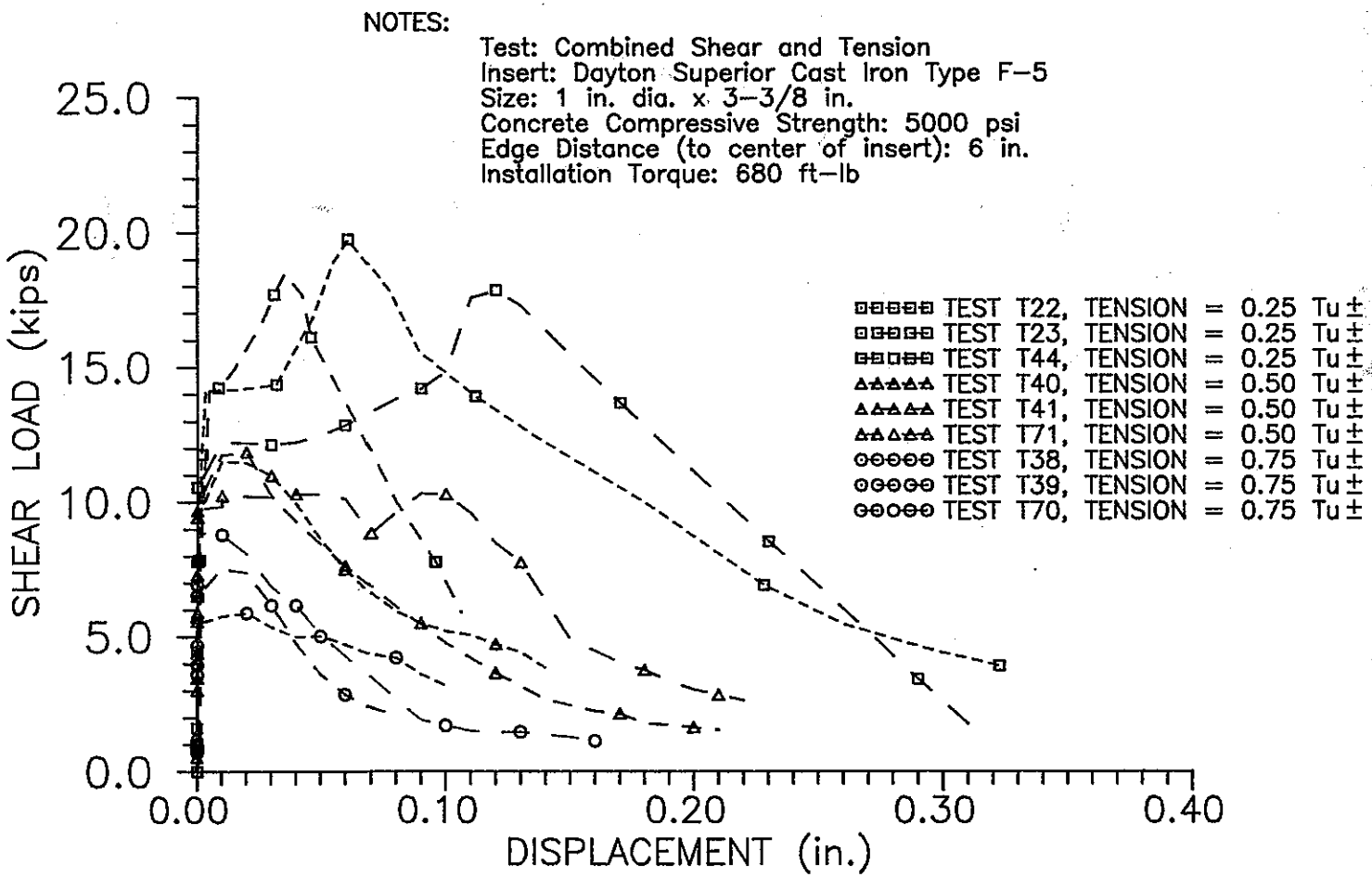

Figure F-28. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

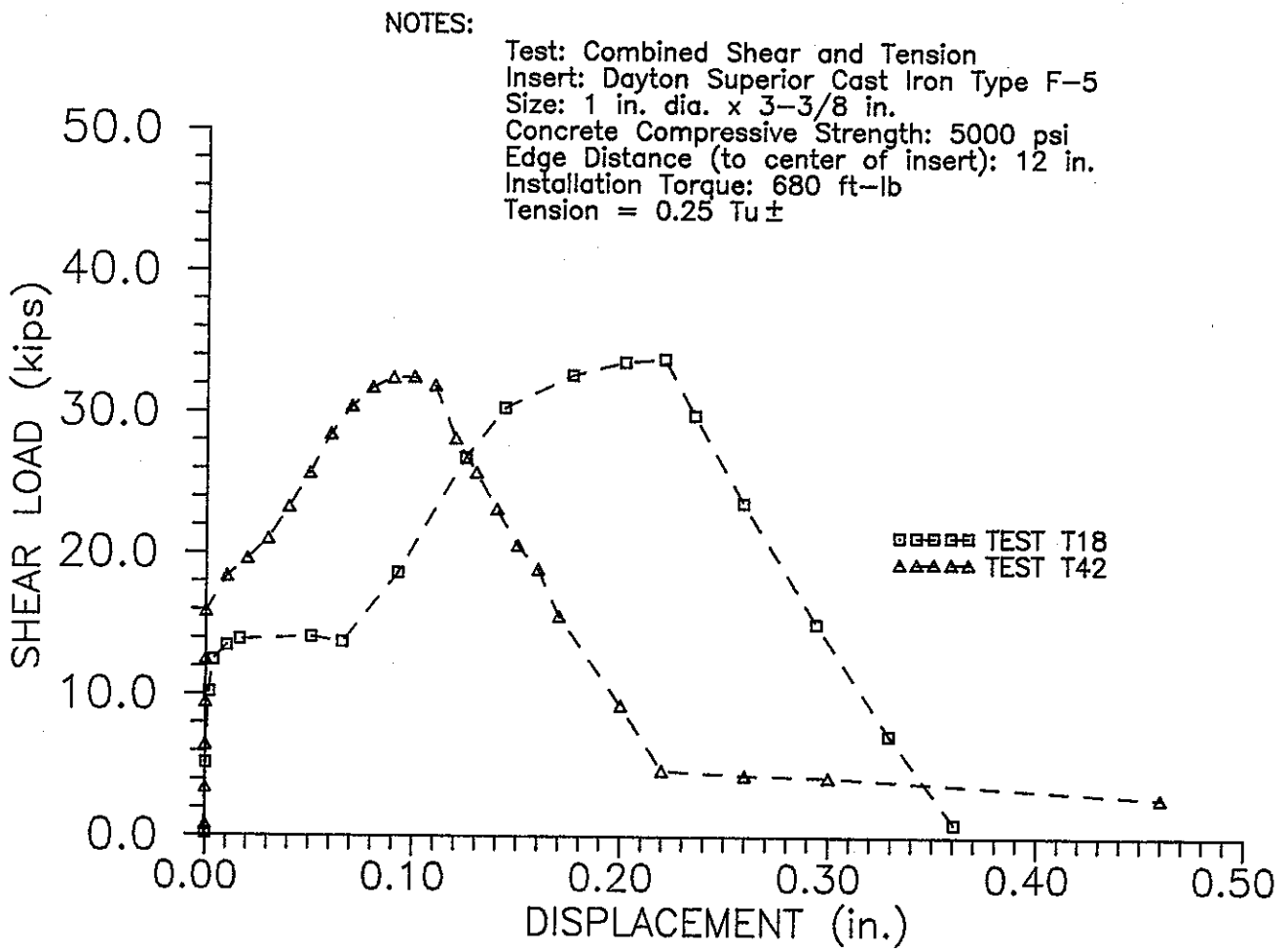

Figure F-29. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

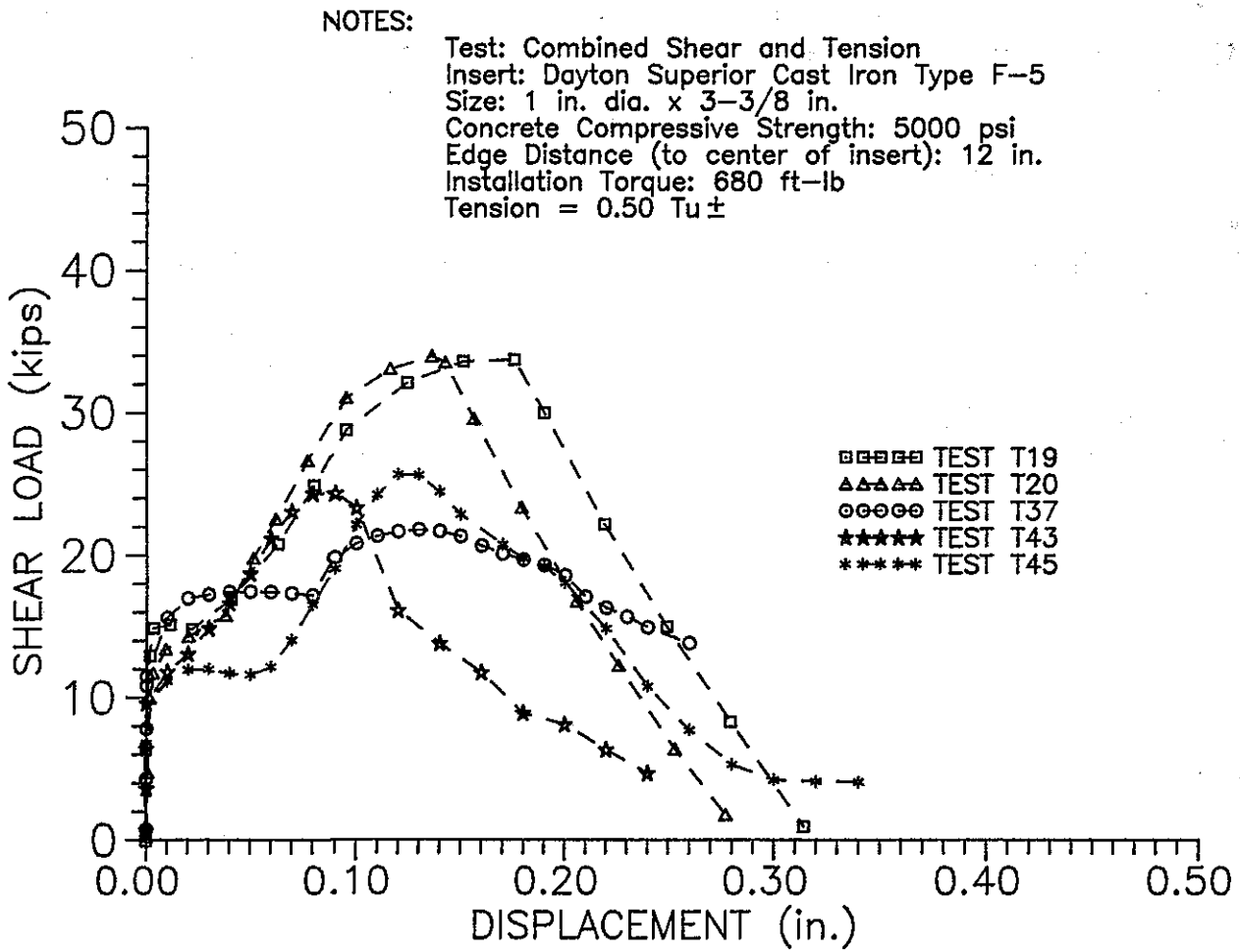

Figure F-30. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

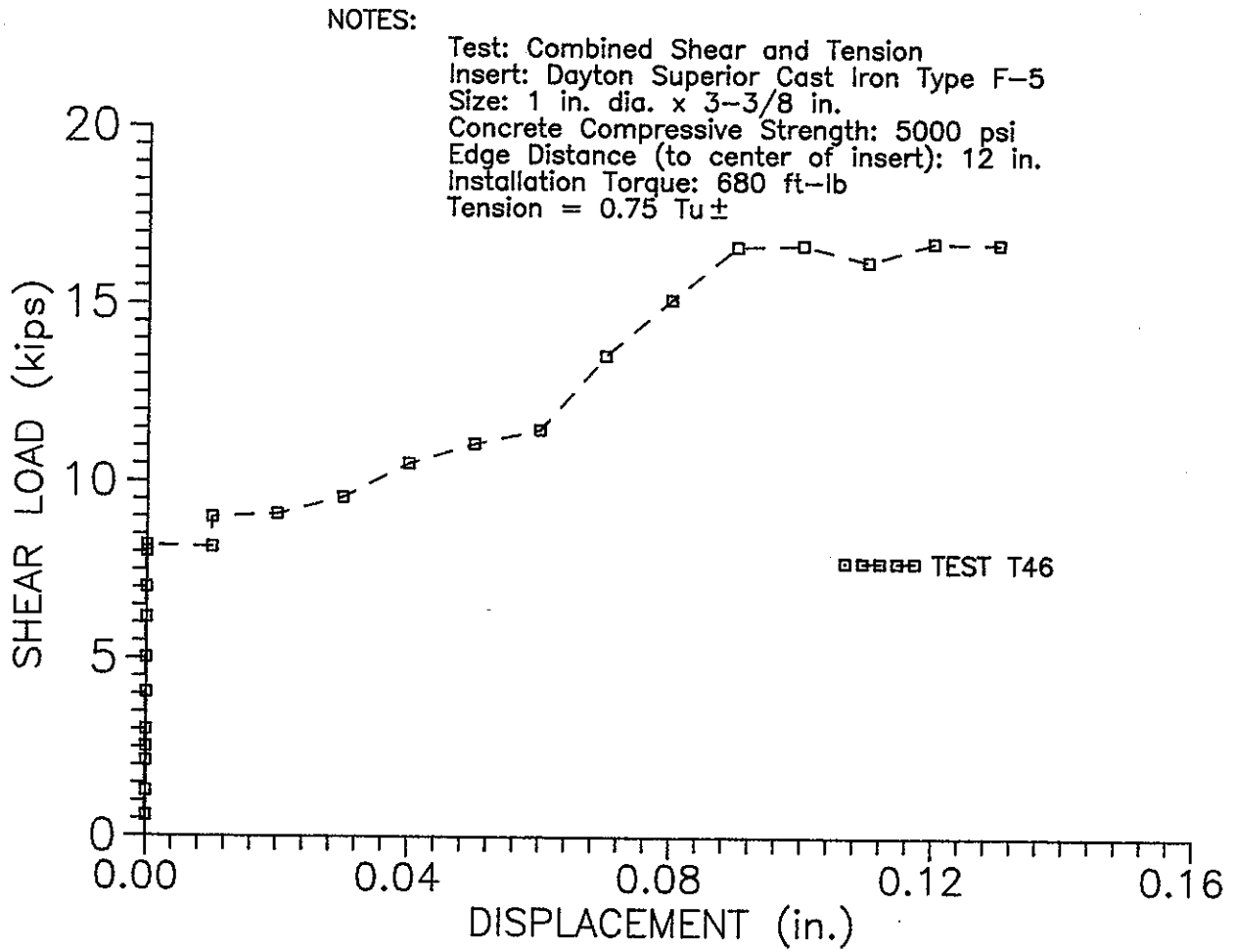

Figure F-31. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

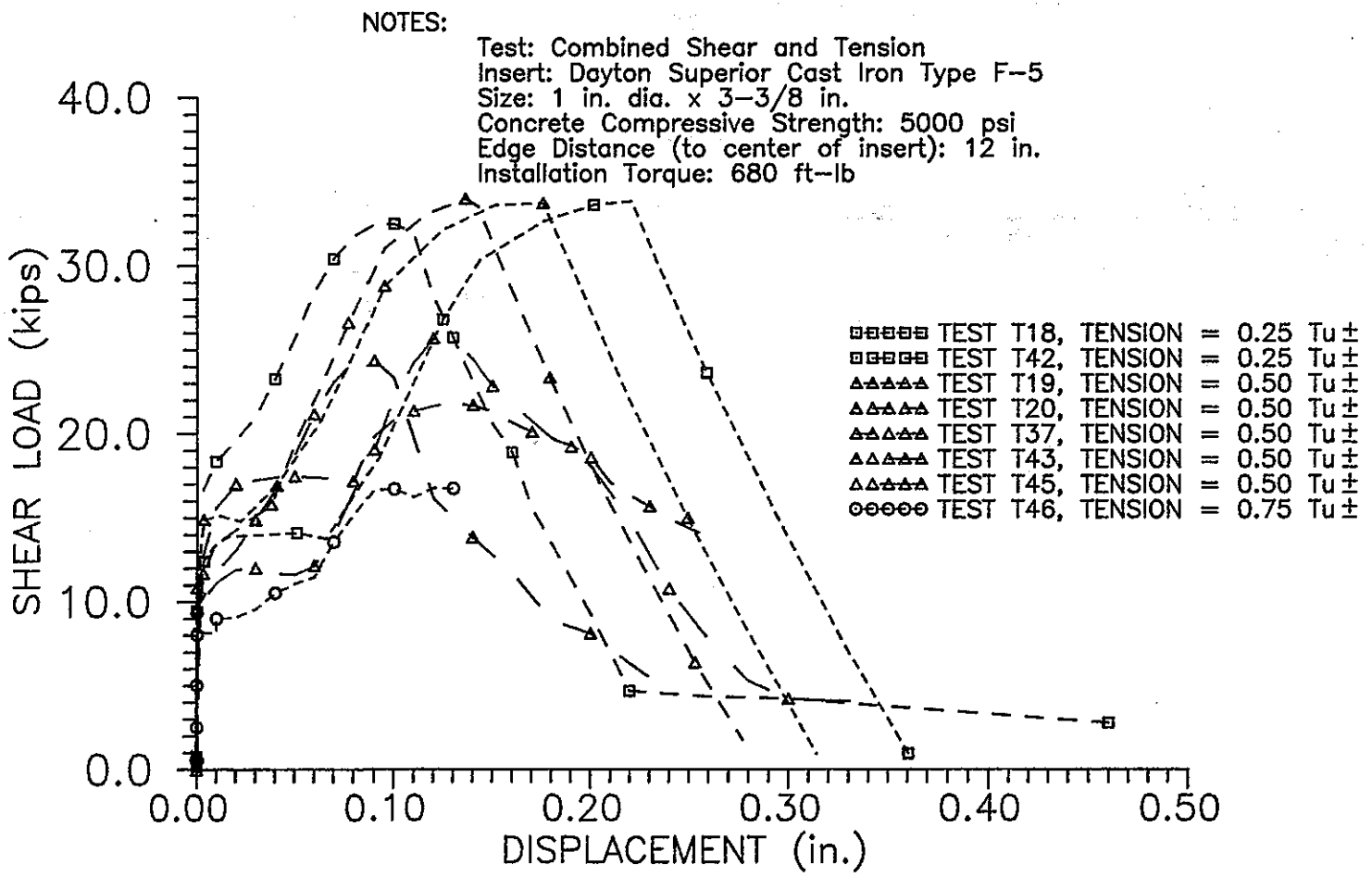

Figure F-32. Shear load vs. displacement for combined tests of cast-in-place concrete inserts.

Appendix G: California Test 682, "Method for Determining Ultimate Tensile Strength of Cast-In-Place Concrete Inserts.

California Test 682

METHOD FOR DETERMINING ULTIMATE TENSILE STRENGTH OF CAST-IN-PLACE CONCRETE INSERTS

A. SCOPE

This method describes the test procedure to be followed in determining the tensile strength of cast-in-place concrete inserts.

This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever chooses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Those using this standard do so at their own risk.

B. TEST APPARATUS

1. A testing apparatus, similar to that shown in Figure 1, capable of applying a tension load to a cast-in-place insert is required to perform this test. The base of the apparatus should contact the concrete surface outside the expected failure cone, so that it does not restrict the failure of the concrete. A base-bearing ring with a radius of $\sqrt{3}$ times the embedment depth, ED, from the center of the insert should be sufficient for this purpose.

2. Two shackles, a chain, or a multidirectional swivel assembly connecting the insert to the pull rod to eliminate the transfer of bending moment to the insert.

3. A hydraulic ram and pump, or suitable device capable of supplying a constant load rate and with an ultimate capacity exceeding the expected ultimate load of the insert.

4. A load cell or load-monitoring device capable of measuring the ultimate tensile force applied to the pull rod to within $\pm$ 1% of the applied load.

5. An XY recorder, a data logger or another suitable type of data acquisition system capable of plotting or recording load versus time at a rate greater than ten samplings per second.

C. PREPARATION OF TEST SPECIMENS

1. Cast-in-place insert installation
   a. Position and secure the inserts to the bottom form of the concrete test slab form using plastic setting plugs (setting plugs recess the

insert 1/4 inch from the concrete surface) while providing enough edge distance (minimum of $\sqrt{3}$ ED) and spacing between inserts (minimum of 2 $\sqrt{3}$ ED).

b. Prior to the installation of the insert, spray the forms with a form release agent and lubricate the internal threads of the insert with grease.

2. Concrete test specimen
Fabricate an unreinforced concrete test slab having sufficient size to provide adequate edge distance and spacing between inserts (see C.1.a.) to be tested. Minimum slab thickness shall not be less than:

a) 8 in. or overall insert length plus 2 in. for insert stud diameters up to and including 3/4 in.
b) 12 in. or overall insert length plus 2 in. for insert stud diameters greater than 3/4 in. and up to and including 1-1/2 in.

The concrete mixture shall contain 564 pounds of "Type II Modified" portland cement, per cubic yard, conforming to requirements in Section 90-2.01 of the Caltrans Standard Specifications. The coarse aggregate used shall be rounded of crushed gravel or crushed rock and the combined aggregate gradings shall conform to the 1-inch maximum grading in Section 90-3.04, "Combined Aggregate Grading". Admixtures shall not be used. The slump shall be between 3 to 5 inches. Concrete shall be cured in accordance with the provisions in Section 90-7.03 "Curing Structures" of the Standard Specifications. At the time of the tension test, the concrete shall have an age of not less than 21 days and a compressive strength of not more than 4000 psi.

D. TEST PROCEDURE

1. Calibrate the load cell.

2. Screw a high strength threaded rod (ASTM - A193B7) into the insert with a minimum of one stud diameter thread engagement.

3. Attach the load collar to the insert using a washer and nut and tighten the nut according to the manufacturer's torque requirement. The following equation, however, should be used to determine the required torque if it is not specified by the manufacturer.

$$T = (.2)dfy/12$$

where T = torque in ft-lbs, d = nominal bolt diameter in inches, and fy is the yield load of an A307 bolt in lbs.

4. Assemble the tension apparatus directly over the insert.

5. Remove slack from the test assembly by applying a tension load of about 5% of the estimated ultimate load of the insert/concrete system.

6. Apply the tension load at a rate of about 100 to 300 pounds per second until the insert fails. The load rate should be determined based on the stud size of the insert such that it takes over 60 seconds to reach the ultimate load.
7. Record load versus time throughout the test.

E. SAMPLING

1. Test at least three cast-in-place insert specimens per insert diameter. A satisfactory performance is obtained when all three inserts pass. Retesting is permitted only if one out of the three inserts tested failed. In this case 6 more of the same inserts should be tested. A satisfactory performance is obtained when all 6 inserts pass. No further retesting is allowed unless manufacturer has made changes in the insert design.

2. Any change in insert design or materials will require retesting.

F. REPORTING OF RESULTS

The report of test results shall include the following minimum information:

1. Test sponsor and test agency.
2. Dates of testing and report.
3. Identification of the insert including manufacturer, type and model number, dimensions, type of steel, type and thickness of corrosion protection coating, and other pertinent information.
4. The number of test specimens tested.
5. Plot of load versus time for each test.
6. The ultimate load of the system for each test.
7. Photographs of the test specimen.
8. The concrete mix design, type and gradation of aggregates used in the concrete, and unit weight and slump of the fresh concrete.
9. A physical description of the test slab including dimensions, locations of inserts, and method of curing used.
10. The compressive strength of the concrete and age of the test slab on the date of testing.
11. Description of the procedure followed to install the cast-in-place insert.
12. Illustration/photographs of testing equipment.
13. A list of observers who witnessed the qualification test with the signature and title of the person responsible for testing.

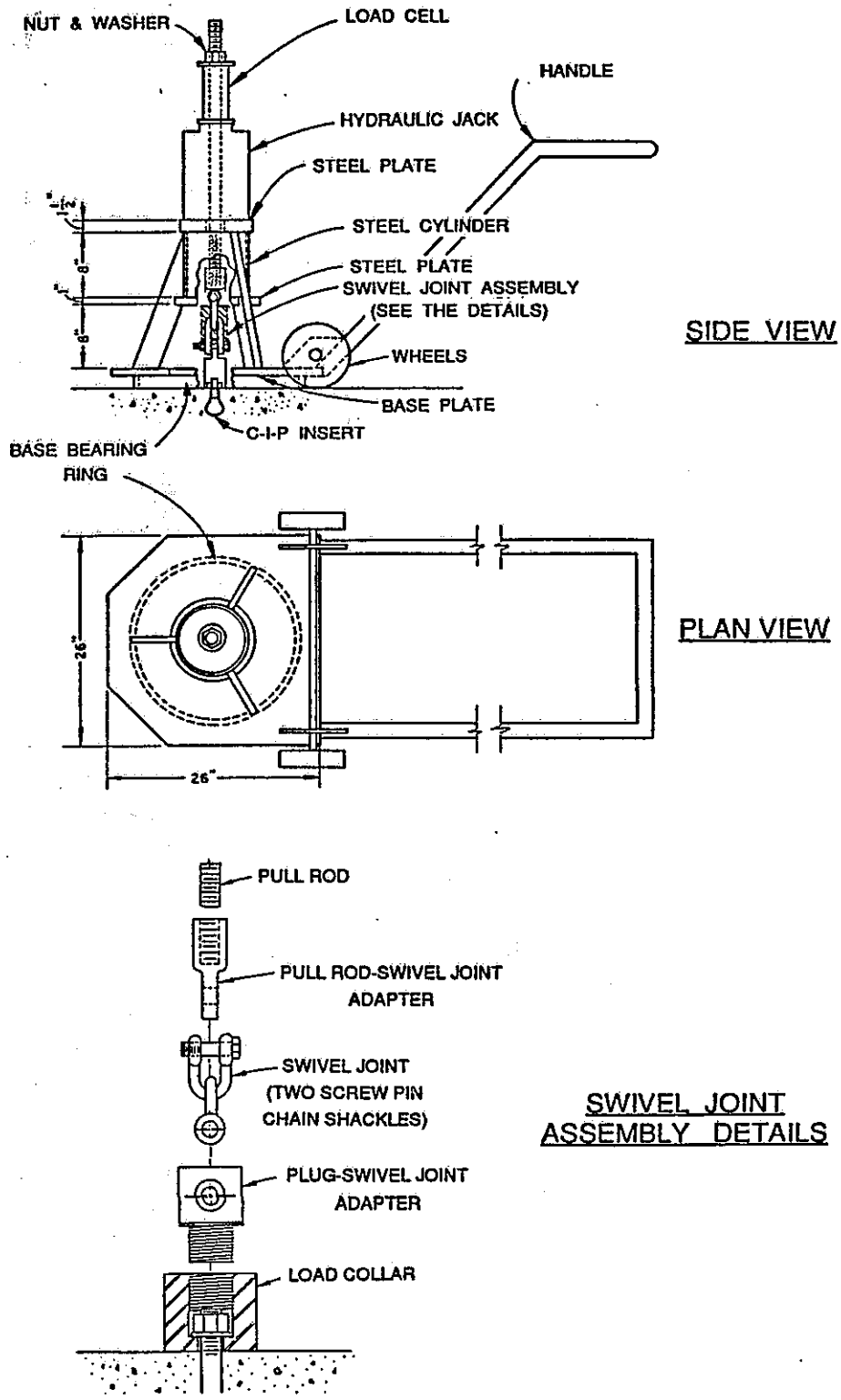

Figure 1. SCHEMATIC OF A TENSION TESTING APPARATUS

Appendix H: Recommended Revisions to Caltrans Standard Specifications Section 75-1.03, "Miscellaneous Bridge Metal.

Recommended Revisions to Caltrans Standard Specifications Section 75-1.03. " Miscellaneous Bridge Metal," January 88

Miscellaneous metal shall conform to the provisions in Section 75, " Miscellaneous Metal," of the Caltrans Standard Specifications and the following provisions for cast-in-place anchorage devices.

- Cast-in-place anchorage devices shall be ferrule loop or cast iron type.

- All metal parts of the anchorage devices, except iron castings for cast-in-place types, shall be fabricated from steel. Cast iron type anchorage devices shall be fabricated from malleable iron castings conforming to the requirements of ASTM Designation: A 47, Grade 35018, or ductile iron castings.

- All metal parts of the anchorage devices, except iron castings for cast-in-place types and mechanical expansion types, shall be hot-dip or mechanically galvanized. Iron castings shall be mechanically galvanized, and mechanical expansion types shall be coated with electrodeposited zinc conforming to the requirements of ASTM Designation: B 633.

- In corrosive environments and in environmental area III, cast-in-place anchorage devices shall be ferrule loop type fabricated from stainless steel conforming to the requirements of ASTM Designation: A 276 Type 304 or 316.

Cast-in-place type anchorage devices shall, when installed in accordance with the manufacturer's instructions and these specifications, and tested in accordance with California Test 682 in concrete with a maximum compressive strength of 4000 psi, withstand the minimum ultimate tensile load of:

Anchorage Device Stud Diameter (inch)	Ultimate Tensile Load, lb	
	Cast-Iron	Ferrule Loop
1	18800	18500
7/8	16600	18500
3/4	12600	8300
5/8	9000	8300
1/2	5200	6900

All concrete anchorage devices shall be subject to the approval of the Engineer. Approval of anchorage device types and sizes shall be contingent upon the Contractor submitting

to the Engineer sample concrete anchorage devices, manufacturer's installation instructions, and certified results of tests, either by a private testing laboratory or the manufacturer, indicating compliance with the above requirements. Anchorage devices previously tested and found to be in compliance with the above requirements and approved by the Engineer need not be retested.

Cast-in-place anchorage devices shall be installed according to the following torque chart:

Anchorage Device Stud Diameter (inch)	Installation Torque (lb-ft.)
1-1/4	700
1	350
7/8	230
3/4	150
5/8	80
1/2	40
3/8	17
1/4	4