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16. ABSTRACT

This report contains results of tests done to determine the effects which simultaneous combined shear and tension loads have on the ultimate strength capacity of various mechanical expansion anchors. The effects which small edge distances and low strength, early age concrete have on the ultimate strength of mechanical expansion anchors are also evaluated. Combined load interaction curves were developed from the test data and compared to interaction curves presented by manufacturers of mechanical expansion anchors (Molly and ITW Ramset/Red Head), the Prestressed Concrete Institute (PCI), and a curve commonly used by Caltrans designers.

It was found that ultimate shear and tension load capacities increased as edge distance was increased until the ultimate load reached a maximum. For the 1/2-inch and 3/4-inch anchor sizes and types evaluated, this plateau occurred at an edge distance between 7 and 9 inches. As expected, when shear and tension loads were applied simultaneously, ultimate shear and tension load capacities measured were smaller than values obtained from independent shear and tension tests. An interaction curve formula presented in the second edition of the PCI manual appears to fit the lower boundary of experimental data well and is less conservative than a common design procedure presently used by Caltrans. It can be used to completely design for shear and tension loads acting simultaneously. The current Caltrans design procedure results in more conservative numbers than the Molly interaction curve, PCI curve, or the actual research test data. Mechanical expansion anchor tests in low strength concrete resulted in ultimate loads which were reduced by a maximum of 50 percent.

17. KEYWORDS
Mechanical expansion anchor, shell internal plug, stud wedge, shear load, tension load, combined load, interaction curve, edge distance

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DEPARTMENT OF TRANSPORTATION

DIVISION OF NEW TECHNOLOGY,
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OFFICE OF STRUCTURAL MATERIALS

EFFECTS OF COMBINED LOADING AND EDGE DISTANCE ON THE PERFORMANCE OF MECHANICAL EXPANSION ANCHORS

FINAL REPORT # FHWA/CA/TL-93/10

CALTRANS STUDY # F86TL04

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17. KEY WORDS	18. DISTRIBUTION STATEMENT
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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)
		0.02540	metres (m)
	feet (ft) or (')	0.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.452×10^{-4}	square metres (m^2)
	square feet (ft^2)	0.09290	square metres (m^2)
	acres	0.4047	hectares (ha)
Volume	gallons (gal)	3.785	litre (l)
	cubic feet (ft^3)	0.02832	cubic metres (m^3)
	cubic yards (yd^3)	0.7646	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)	0.06309	litres per second (l/s)
Mass	pounds (lb)	0.4536	kilograms (kg)
Velocity	miles per hour (mph)	0.4470	metres per second (m/s)
	feet per second (fps)	0.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	0.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Density	pounds per cubic foot (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)	0.1130	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 (mg/kg)	parts per million (ppm)	1	milligrams per kilogram

TABLE OF CONTENTS

SUBJECT **PAGE NO.**

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Mechanical expansion anchors (MEAs) are metal devices that are inserted in drilled holes in hardened concrete to provide anchor points for various devices, brackets, and miscellaneous fixtures. They are expanded or wedged in a drilled hole to provide holding power by friction between metallic parts on the head of the anchor and the sides of the concrete hole. Some typical items that are frequently attached using mechanical expansion anchors include overhead signs, straps for securing utility conduits to bridge decks and soffits, wooden fender skirts to bridge column footings, glare screen posts to median barriers, steel angles to bridge decks at expansion joint corners, inspection ladders, facia panels to buildings, and crash cushions to concrete pavement.

The specification used by the California Department of Transportation (Caltrans) to determine whether a MEA is acceptable is Standard Specification 75-1.03 (8.1)*. The essence of this specification is a creep test, California Test 681 (8.2), which is used to determine movement of a MEA while it is being subjected to 48 hours of sustained tension loading. The magnitude of the sustained tensile test load is based on the stud diameter of the anchor. For an MEA to be acceptable, a maximum creep (total displacement) of 0.035 inch is permitted.

Comprehensive information and guidelines governing the use of MEAs installed in existing concrete structures at small edge distances and/or subjected to combined shear and tension loading are not available. An appropriate, realistic interaction formula and design guidelines must be developed from valid test data for these conditions before MEAs can be used with confidence and maximum economy.

1.1 <u>Problem Statement</u>:

Caltrans frequently specifies MEAs to be used in thin concrete slabs and bridge structures where edge distances are small and simultaneous combined shear and tensile loads are common. Subjecting MEAS to full design loads in relatively new concrete which has not cured long is frequently done. Due to the limited scope and funding of previous MEA research completed by Caltrans (8.3)(8.4), the effects of combined loading, limited edge distances, and strength of anchors installed in new concrete having a moderate compressive strength have not been investigated. According to design procedures presently accepted and used, these conditions have a significant influence on the load-carrying capability of MEAs; because such effects have not been thoroughly investigated, prudent designers must substantially reduce allowable design loads.

Under less-than-ideal conditions which are commonly encountered, designers

* Numbers in parentheses refer to the Reference List in Section 8.

certainly need to insure that loads permitted are safe and conservative. When both shear and tension loads are acting simultaneously, the designer must consider the interaction between short-term shear and tension loads, especially where there is minimal reinforcing steel in the concrete. No known design formulas, which address interaction between shear and tension loads that are applied simultaneously, have been thoroughly substantiated. Limited research and published data and unconfirmed empirical formulae are available for designers to use at their own risk.

1.2 Background:

Mechanical expansion anchors (MEAs) are commonly used for attaching minor and temporary fixtures to concrete structures. The MEAs may be subjected to independent tension and shear loads, or a combination of simultaneous shear and tension loads. Load-displacement curves for MEA's subjected only to short-term direct tensile loads have some similarities to load-displacement curves for steel (8.5). In the elastic portions of load-displacement plots of common drop-in-type or wedge-type MEAs (8.4), the upper end of the initial straight line (commonly called the proportional limit for steel) is defined herein as the slip point of a MEA system. A more complete discussion about the slip point is contained in Section 7.1, page 31. If the MEA is loaded past its slip point, failure will typically occur, due to the loss of friction between anchor's expansion head surface and concrete. The load at which the maximum resisting strength of the MEA is reached is known as the ultimate load. The slip point, associated with short term tensile loads, should not be confused with creep which is associated with long-term sustained loads.

In one previous Caltrans research study (8.6), the ability of anchor bars embedded in concrete to resist lateral loading was studied. It was found that nominal reinforcing provided little added shear resistance when anchor bars were loaded laterally toward the free edges of a concrete slab. Therefore, so that results of this study would be conservative, concrete specimens used in this research were unreinforced.

A Transportation Research Information Service (TRIS) literature search was conducted and no information pertaining to the effects of combined loading on mechanical expansion anchor performance was found.

1.3 Objectives:

The objectives of this research project were:

1. To determine the effects of edge distance on yield strength and ultimate strength of two common types of MEAs,

2. To determine the amount of reduction in shear and tension capacities of MEAs when both loads act simultaneously, and

3. To develop specifications and design guidelines which will insure satisfactory performance of MEAs at small edge distances when subjected to combined shear and tension loads.

1.4 Anticipated Benefits:

The guidelines and proposed specifications developed from this research will aid Caltrans designers in establishing safe but economical loads for MEAs when subjected to small edge distances and combined loading.

Designers will have valid test data on which to base future designs where MEAs are used at small edge distances and/or where combined loading is present. This will ensure that safe but economical allowable load values are used due to the realistic and verified interaction curves which have been established.

2. CONCLUSIONS

2.1 Effect of Edge Distance on Ultimate Load:

For tensile tests performed, in general, the ultimate tensile load was greater as the edge distance increased. For most 1/2-inch-diameter mechanical expansion anchors (MEAs) tested, when the edge distance reached 5 inches, no further increase in ultimate tension load occurred. For most 3/4-inch-diameter MEAs tested, when the edge distance reached 7 inches, no further increase in ultimate tension loads occurred.

For shear tests performed, the magnitude of the ultimate shear load also increased as the edge distance increased. In most shear tests done on 3/4-inch-diameter MEAs, the ultimate shear load reached a maximum constant value at an edge distance of nine inches. In shear tests done on 1/2-inch-diameter MEAs, ultimate shear loads were reached from between 5 and 7 inches.

Limited testing of four different MEA systems were performed in combined loading. Because of the limited edge distance tests conducted, no conclusions could be drawn regarding the effect which varying edge distance had on ultimate tensile load.

2.2 Effects of Low Compressive Strength Concrete on Ultimate Loads:

Tests performed on early-age concrete with low compressive strengths (2750 psi) resulted in ultimate shear and tension loads which were between 22 and 54 percent smaller than those recorded in tests using moderate strength concrete (f'c = 5000 psi). This was observed in tests where edge distances ranged from three to seven inches. Results of tests performed at edge distances of nine inches showed that there was no reduction in ultimate shear or tension loads, compared to the ultimate loads reached in concrete with a compression strength of 5000 psi.

2.3 Load Interaction Curves and Combined Loading Effects:
When combined loads were applied, the maximum ultimate tension load attained was less than that reached in tensile tests alone. The magnitude of simultaneous shear and tension loads which an anchor can withstand can be predicted using load interaction curves. Appropriate curves for common types and sizes of individual anchors are shown in Figures 20 through 23 (pages 42 - 45).

A summary of common current combined loading curves along with normalized test data found in this research is presented in Figure 23. A combined loading interaction curve (Figure 24, page 46) similar to what is currently used by Caltrans and recommended by Hilti and ITW Ramset/ Red Head, is suggested when designing for combined loading under static loading conditions, and results in a safe design.

3. RECOMMENDATIONS

As a result of findings from this research, the following recommendations are made:

MEAs Subjected to Tension or Shear Loads

- If MEAs cannot be located at edge distances greater than 12 stud diameters and combined shear and tension loads do not act simultaneously, the allowable load should be reduced in a straight line fashion from 100% at 12 stud diameters, to 50% at the minimum edge distance recommended by the manufacturer. This applies to situations where either direct tension loads or direct shear loads are acting, but simultaneous shear and tension loads are not present.
- If use of MEAs is planned in low-strength, early age concrete where an edge distance less than 12 stud diameters is available, it is recommended that load reduction factors commensurate with the strength and properties of the concrete be used. For MEAs installed and loaded in low strength (less than 3000 psi) early age (cured less than 21 days) concrete, as were tested in this research, an additional reduction factor of 0.50 should be applied to the design loads, for for edge distances less than 12 stud diameters.

MEAs Subjected to Combined Loading

- The use of a straight-line interaction curve for designing MEAs having combined loads, a practice presently followed by Caltrans engineers and recommended by Hilti and ITW Ramset/ Redhead, should be continued. This will ensure a conservative design of MEAs under static load conditions when simultaneous shear and tension loads are present.
- When selecting mechanical expansion anchors (MEAs) for use in situations where combined loads are present and an edge distance less than 12 stud diameters cannot be avoided, load-displacement and load-interaction curves should first be reviewed and a substantial load reduction factor applied.

- The use of MEAs subjected to simultaneous shear and tension loads under static load conditions is recommended in low-strength concrete only when a minimum edge distance of 12 stud diameters is available.
- If combined loading relationships found in this research are similar for other types of MEAs and manufacturers, then when the use of MEAs at an edge distance less than 12 stud diameters in low compressive strength concrete is required, a considerable reduction in allowable loads should be imposed.

Other Testing Recommended

If the use of other types of MEAs is desired, additional testing should be done to determine if the general load reduction factor, as recommended in Caltrans Bridge Design Aids (Appendix C), is appropriate.

Additional tests should be performed, if installation is to be in lightweight concrete, to determine what load reduction factors are appropriate.

4. IMPLEMENTATION

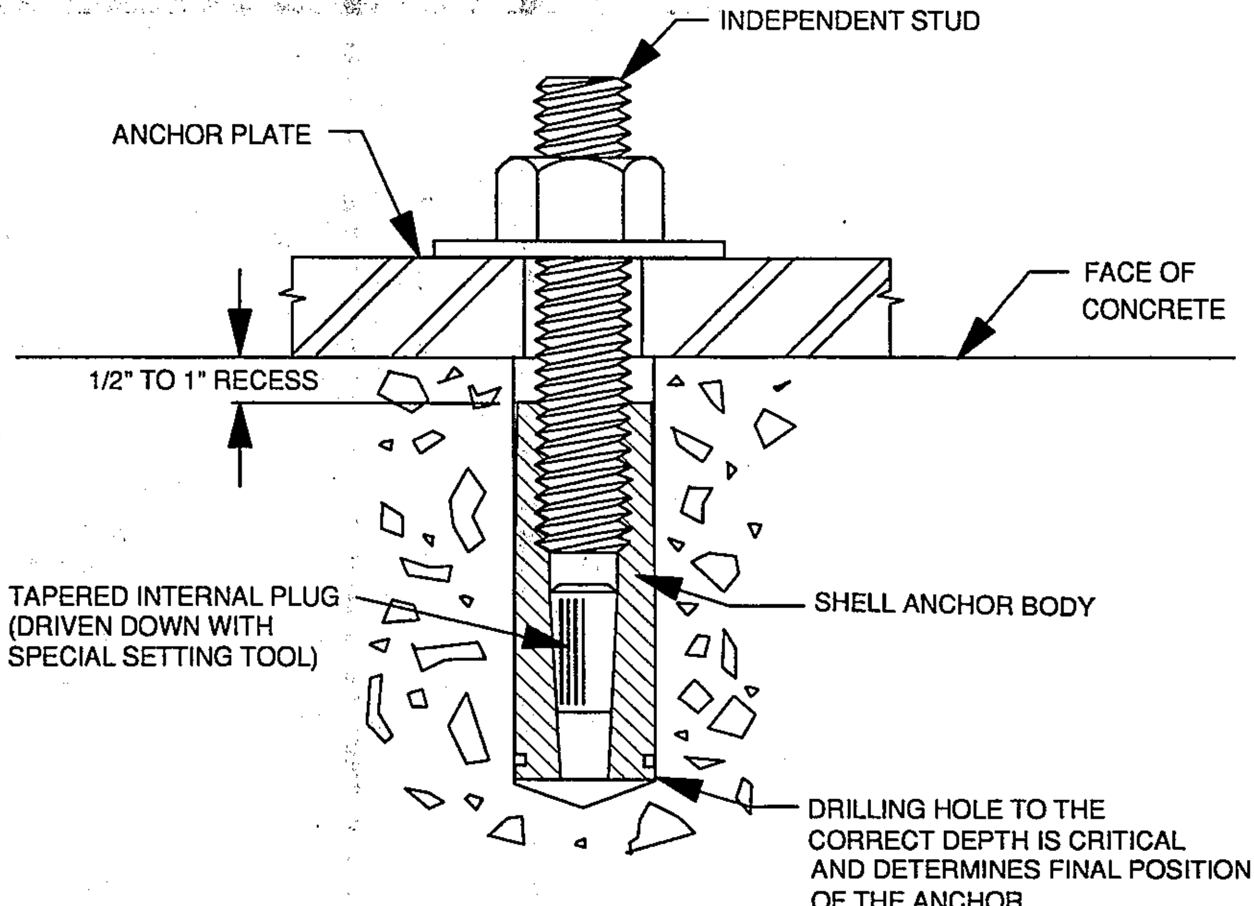
A copy of this report will be sent to design engineers of the Caltrans Division of Structures for implementation. Many of the significant findings have already been incorporated into the Anchorage to Concrete section of Bridge Design Aids (Appendix C) by the Caltrans Division of Structures. Updated lists of approved MEAs (8.9) which meet the present Caltrans specifications have been made available to Caltrans construction and design engineers. An anchorage manual is being planned in a future research project which will provide designer engineers with appropriate design methods that will account for a variety of load conditions to which MEAs are commonly subjected.

5. DESCRIPTION OF TEST PROGRAM

5.1 Summary of Work Performed:

In this research study, the effects of combined shear and tension loading on MEAs was determined for two common types and sizes of MEAs - the 1/2-inch and 3/4-inch shell internal plug and the stud wedge. Cross sectional views of these two anchor types are shown, installed, in Figures 1 and 2. All concrete test slabs were unreinforced and made from Caltrans Class A concrete containing 564 pounds (six sacks) of type II modified portland cement per cubic yard. A water-based curing compound was applied to slabs immediately after placing concrete. All slabs were eight inches thick. Both 4-foot X 8-foot and 4-foot X 3-foot slabs were used for testing.

Testing was segregated into three phases. In phase 1, independent tension and shear tests were performed to establish slip points (see Section 7.1, page 31 for explanation) and ultimate loads for common approved brands

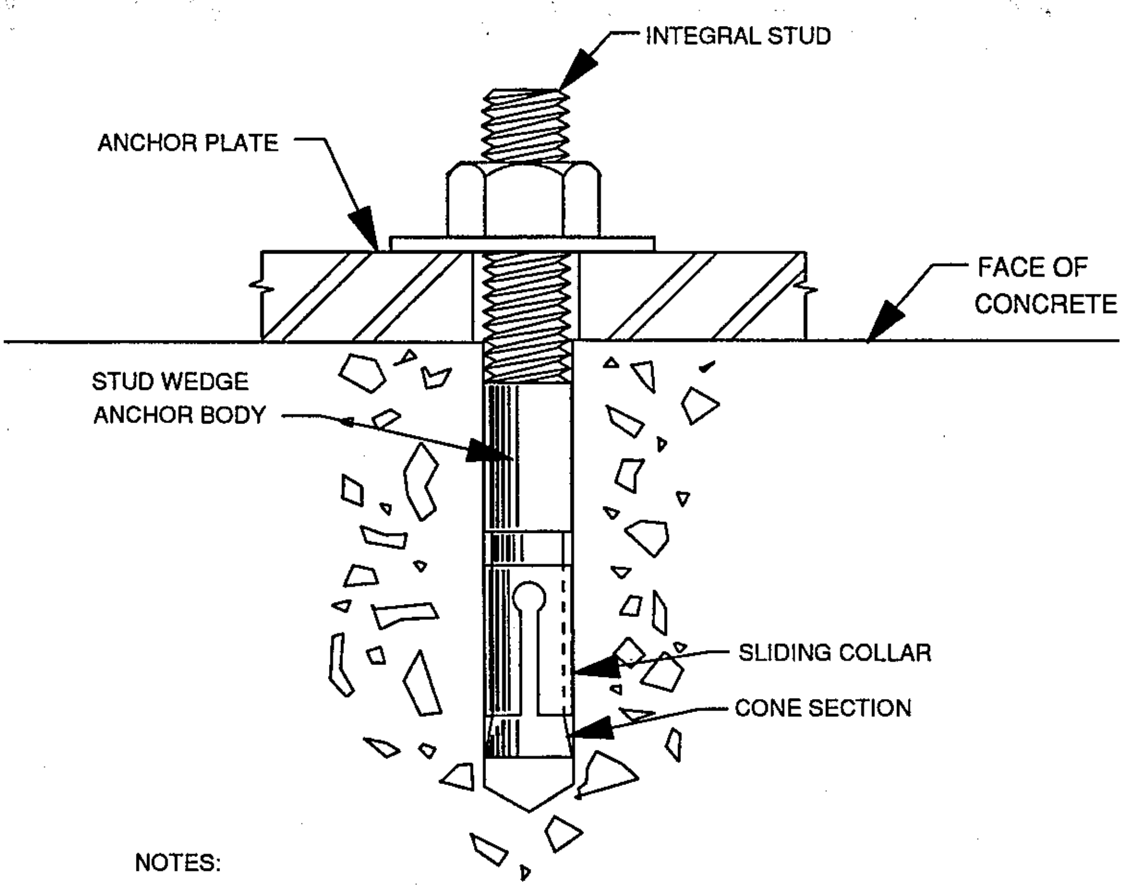


NOTES:

1) A SPECIAL INSTALLATION TOOL IS REQUIRED TO SET THIS TYPE OF MECHANICAL EXPANSION ANCHOR.

2) INDEPENDENT STUD, NUT AND WASHER ARE TYPICALLY NOT FURNISHED WITH SHELL ANCHORS.

Figure 1. Cross section of a typical shell internal plug-type mechanical expansion anchor.



NOTES:

1) TORQUE ON NUT IS REQUIRED TO SET ANCHOR.
2) NO SPECIAL INSTALLATION TOOL IS REQUIRED TO INSTALL.
3) AS NUT IS TIGHTENED, CONE IS PULLED UPWARD, EXPANDING COLLAR AGAINST SIDES OF HOLE.
4) HOLE DEPTH IS NOT CRITICAL.

Figure 2. Cross section of a typical stud wedge-type mechanical expansion anchor.

of MEAs. In phase 2, similar shear and tension tests were performed using low-strength, early-age concrete (2750 psi). Finally in phase 3, effects of simultaneously applied shear and tension loads on ultimate strength was determined, and combined loading interaction curves developed for limited anchor types and sizes.

5.1.1 Phase 1 - Independent Tension and Shear Tests Performed in Hardened Concrete: A total of 180 pure tension tests were performed on two sizes and two basic types of mechanical expansion anchors (MEAs). Also, 180 pure shear tests were conducted on the same two sizes and types of anchors to determine system slip points and ultimate strength. A summary of the number of tests conducted along with anchor sizes, model numbers, and edge distances used is shown in Table 1. The two types of common MEAs selected for testing were the shell internal plug and stud wedge. These were made by five manufacturers - Molly, Phillips (presently ITW Ramset/ Red Head), Rawlplug, and Star. Both 1/2 and 3/4-inch-diameter MEAs were tested from each of these two basic types. These particular anchors were chosen because they had previously been creep tested following procedures in California Test No. 681 (8.2) and were found to meet Caltrans requirements in Section 75-1.03 of the Standard Specifications (8.6). This creep evaluation is the primary requirement of the Caltrans Standard Specifications. Test slabs were allowed to cure until they obtained a compressive strenghth of 5000 psi. Edge distances were varied between three and nine inches. Edge distance is defined as the distance between the center of the anchor's stud and the edge of the concrete test slab. The test data from phase 1 was used to establish edge distance versus strength curves for shear and direct tension loads (Figures G1 through G24 in the Appendix G of this report).

5.1.2 Phase 2 - Independent Tension and Shear Tests Performed in Low Strength Concrete: To study the effect which low-strength, early-age concrete has on both shear and tensile strength of an MEA, 24 anchors were installed and tested by applying loads independently. Slabs were cured until they reached a compressive strength of 2750 psi. Curing time was reduced in order to produce low-strength concrete with a low modulus. This was done to simulate anchors installed in new structures and loaded at an early agee The 3/4-inch-diameter stud wedge anchor, Rawlplug No. 7440, was selected for use in all low-strength concrete tests. This particular brand of MEA was chosen because it is readily available, exhibited moderate creep, and yet is one of the MEAs previously creep tested and approved by Caltrans. These characteristics provided conservative values with which to analyze performance data from tension and shear loads. A summary of the number of tests done using low strength concrete and various parameters is contained in Table 2.

5.1.3 Phase 3 - Combined Shear and Tension Loading Tests Performed in Hardened Concrete: In order to determine the effect of combined loading on the slip point and ultimate load, 24 tests were performed in which tension and

Table 1. Number of independent tension and shear tests performed (5000 psi concrete).

Anchor Type/ Manufacturer/ Model No.	Test Type	Number of Tests at Given Edge Distance						
		3"	4"	5"	6"	7"	9"	Total
1/2 INCH DIA STUD WEDGE ANCHORS:								
Molly No. PB12-4	Tension	3	3	3		3		12
	Shear	3	3	3		3		12
Rawlplug No. 7422	Tension	3	3	3		3		12
	Shear	3	3	3		3		12
Star No. 3535-36000	Tension	3	3	3		3		12
	Shear	3	3	3		3		12
1/2 INCH DIA SHELL INTERNAL PLUG ANCHORS:								
Molly No. MDI-12	Tension	3	3	3		3		12
	Shear	3	3	3		3		12
Phillips No. RM-12	Tension	3	3	3		3		12
	Shear	3	3	3		3		12
Rawlplug No. 6308	Tension	3	3	3		3		12
	Shear	3	3	3		3		12
3/4 INCH DIA STUD WEDGE ANCHORS:								
Ramset No. T34434	Tension	3	3	3	3	3	3	18
	Shear	3	3	3	3	3	3	18
Rawlplug No. 7440	Tension	3	3	3	3	3	3	18
	Shear	3	3	3	3	3	3	18
Star No. 3555-42000	Tension	3	3	3	3	3	3	18
	Shear	3	3	3	3	3	3	18
3/4 INCH DIA SHELL INTERNAL PLUG ANCHORS:								
Molly No. MDI-34	Tension	3	3	3	3	3	3	18
	Shear	3	3	3	3	3	3	18
Ramset No. DS-34	Tension	3	3	3	3	3	3	18
	Shear	3	3	3	3	3	3	18
Rawlplug No. 6312	Tension	3	3	3	3	3	3	18
	Shear	3	3	3	3	3	3	18
							Total number of tests	360

Table 2. Number of tension and shear tests performed (low strength, early age concrete).

Anchor Type/ Manufacturer & Model No.	Test Type	Number of Tests at Given Edge Distance						
		3"	4"	5"	6"	7"	9"	Total
3/4-INCH-DIAMETER STUD WEDGE ANCHORS:								
Rawlplug No. 7440	Tension	3		3		3	3	12
	Shear	3		3		3	3	12
				Total number of tests				24

Table 3. Number of tests performed with combined shear and tension loading (5000 psi concrete).

Anchor Type/ Manufacturer & Model No.	33-1/3 or 66-2/3 Percent of Ultimate Shear Load	Number of Tests at Given Edge Distance						
		3"	4"	5"	6"	7"	9"	Total
1/2-INCH-DIAMETER STUD WEDGE ANCHORS:								
Star No. 3535-36000	33-1/3	3						3
	66-2/3	3						3
1/2-INCH-DIAMETER SHELL INTERNAL PLUG ANCHORS:								
Rawlplug No. 6308	33-1/3	3						3
	66-2/3	3						3
3/4-INCH-DIAMETER STUD WEDGE ANCHORS:								
Star No. 3555-42000	33-1/3		3					3
	66-2/3		3					3
3/4-INCH-DIAMETER SHELL INTERNAL PLUG ANCHORS:								
Molly No. MDI-34	33-1/3			3				3
	66-2/3			3				3
				Total number of tests				24

shear loads were simultaneouly applied to MEAs . Test slabs were cured until they attained a compressive strength of approximately 5000 psi. During each test, the shear load was first applied and held constant; the tension load was then applied and gradually increased until either the anchor or concrete failed. The values of constant shear loads applied were 33-1/3 % and 66-2/3 % of the average ultimate independent shear load obtained in this research for each particular brand of MEA. The limited data obtained provided ample points to produce a combined load interaction curve. A summary of the number of combined loading tests performed and various parameters is presented in Table 3.

Selection of MEA ypes and brands for the combined loading tests was based on their marginal but acceptable creep under a tension load. Anchors fully meeting Caltrans Standard Specifications (8.1), but exhibiting large but acceptable displacement during creep testing, were purposely selected for this research to insure data would be on the conservative side. The edge distance used in testing was the minimum edge distance specified by either the manufacturer or Caltrans (8.10) for the particular type of mechanical expansion anchor. However, the minimum edge distance specified was rounded up or down to the nearest whole inch when developing load-interaction curves.

6. TEST PROCEDURES AND EQUIPMENT

6.1 Mechanical Expansion Anchor Installation:

The first step prior to performing any testing was to prepare holes and install the anchors. This step was very important because holes which are not drilled to the proper diameter or thoroughly cleaned, or anchors which are not installed according to specifications will not perform satisfactorily or consistently. First, holes of appropriate depth and diameter as specified by the manufacturer were drilled perpendicular to the test slab. The depth of holes for the shell internal plug-type anchors was critical; hole depth for stud wedge-type anchors is not critical and could be slightly deeper than specified as a minimum. A summary chart of installation parameters used for anchors in this study is displayed in Appendix C. Holes were drilled as near to the day of testing as possible. Prior to installing MEAs, concrete dust from drilling was removed by vacuuming and blowing out the hole with compressed air.

The procedures for setting the two types of MEAs used in this study were significantly different. For a shell internal plug-type MEA, a stud with a nut on top was screwed into the body. A hammer was used to gently tap the top of the stud and drive the anchor body into the drilled hole. The top of the MEA body was recessed 1/2 inch below the concrete surface as required by Caltrans (8.8). The stud was then removed and a setting tool, specified by the manufacturer, was used to drive the internal plug down near the bottom of the

1.16.1 LOAD FACTORS

An essential feature of LFD, as stated in 1.0.2, Design Methods, requires raw design loads or related internal moments and forces to be modified by specified load factors (γ, gamma and β, beta), and computed material strengths to be reduced by specified reduction factor (ϕ , phi).

These are safety factors which ensure certain margins for variation. The three different kinds of factors are each set up for a distinct purpose, each independent of the other two. In this way, any one of them may be refined in the future without disturbing the other two.

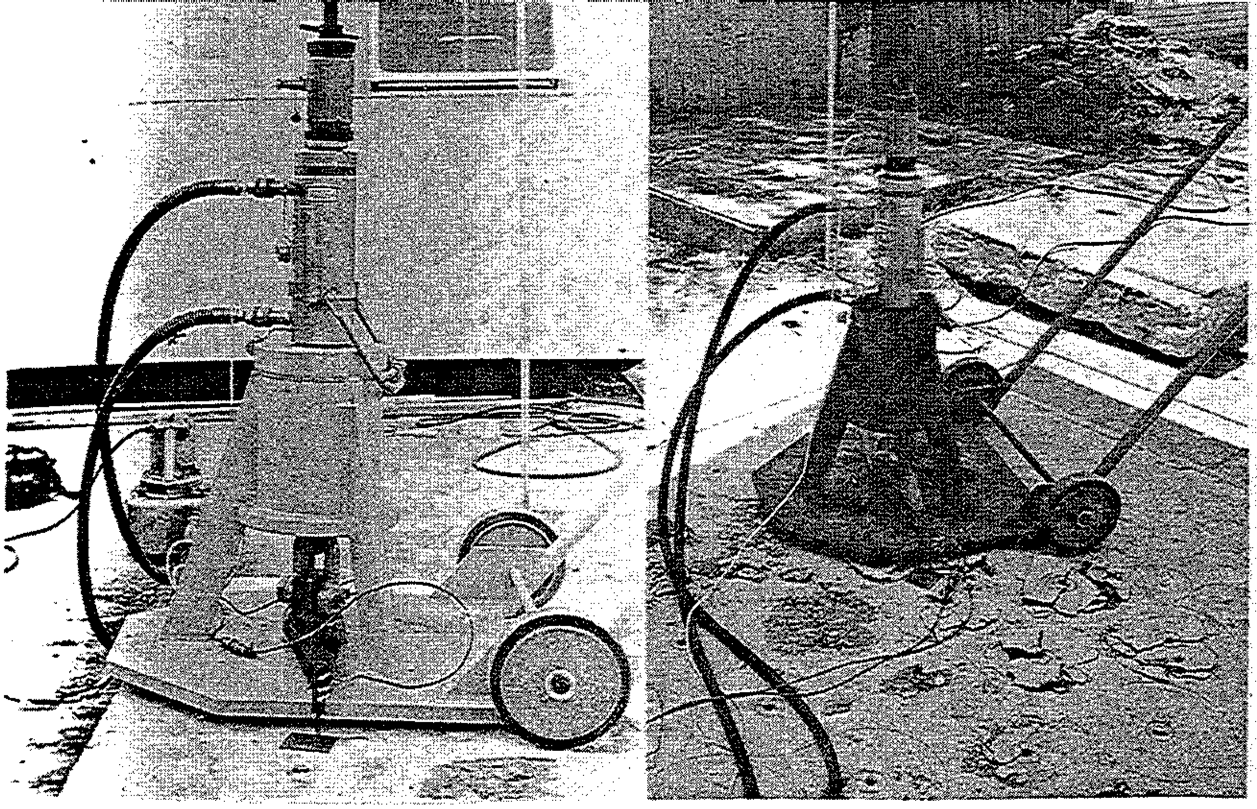
1.16.2 γ (Gamma) FACTOR

The γ (gamma) factor is the most basic of the three. It varies in magnitude from one load combination to another, but it always applies to all the loads in a combination. Its main effect is stress control that says we do not want to use more than about 0.8 of the ultimate capacity. Its most common magnitude, 1.3, lets us use 77%. Earthquake loads are not factored above 1.0 because we recognize that stresses in the plastic range are allowed, as long as collapse does not occur.

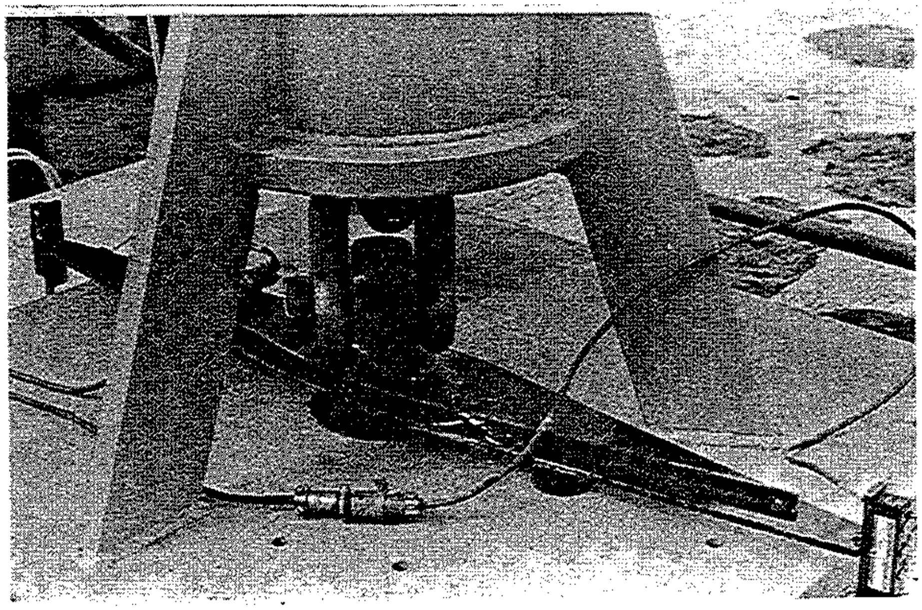
An example may be given to justify the use of gamma of 1.3 for dead load.* Assuming the live load being absent, the probable upper value of the dead load could be a minimum of 30% greater than calculated. For a simple structure this percentage may be as follows:

10% due to excess in weight.
5% due to misplaced reinforcement.
5% approximation in behavior of structure.
10% increase in stress, actual compared with calculated.
30% Total variation assumed to occur concurrently at the section most heavily stressed.

*"Notes on Load Factor Design for Reinforced Concrete Bridge Structures with Design Applications" by Portland Cement Association, Page AB-9.



a. View of assembled short-term ultimate tension test machine.



b. Close-up view of machine base showing swivel, plug-swivel adapter, displacement arm, linear potentiometers, and load collar.

Figure 3. Photographs of apparatus for conducting short-term ultimate tension load tests.

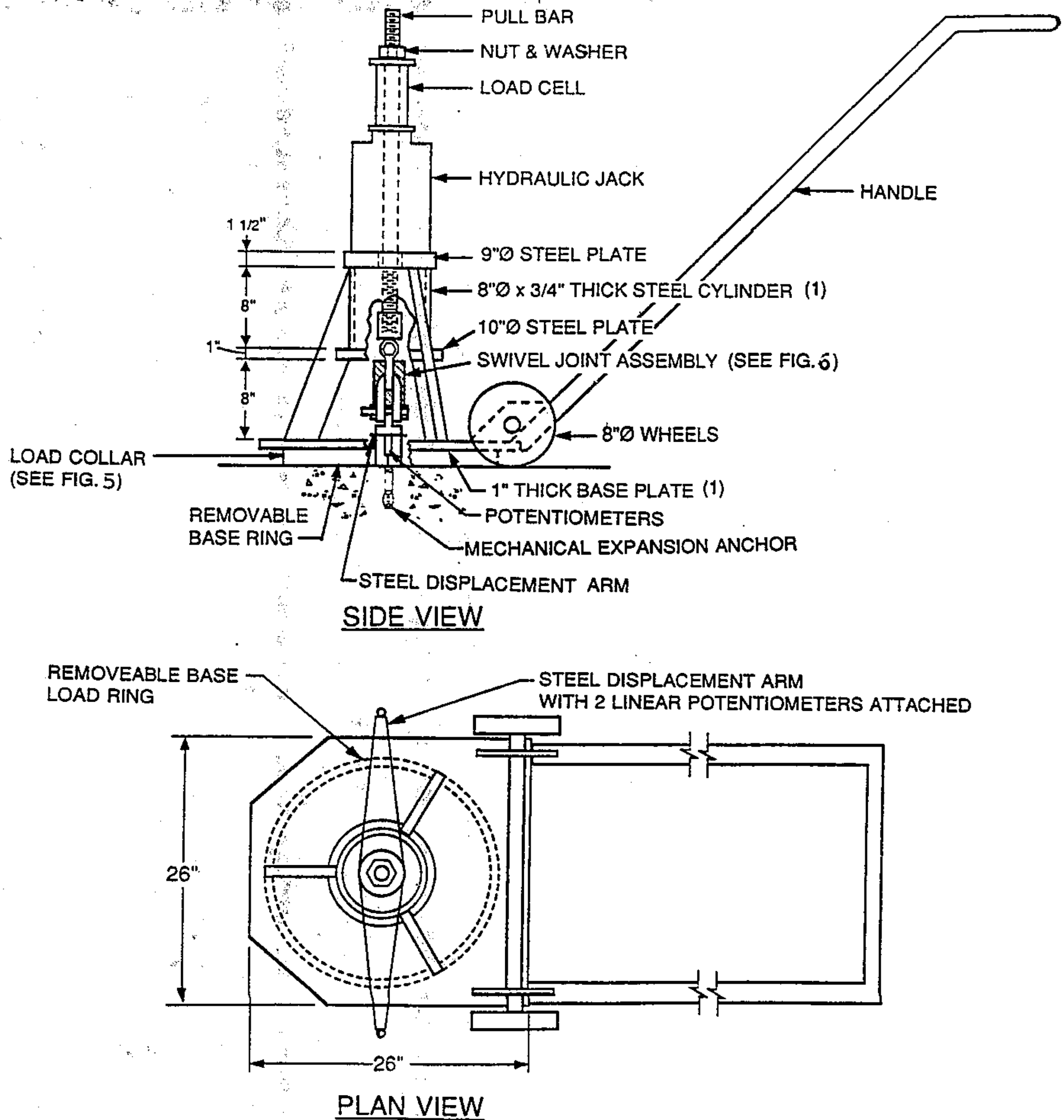
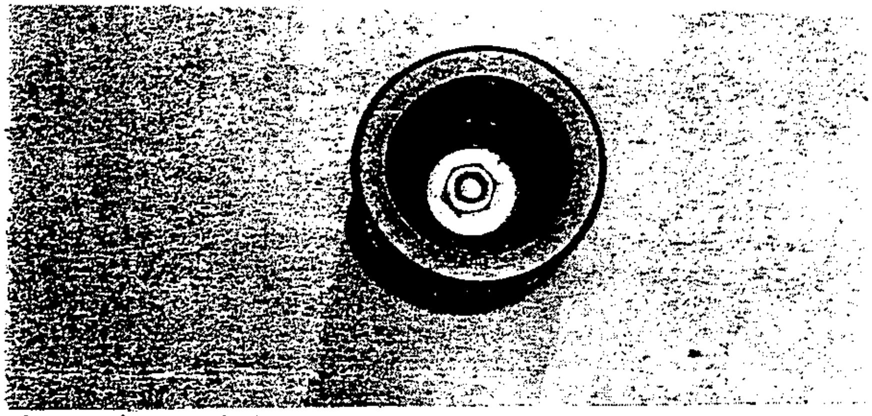
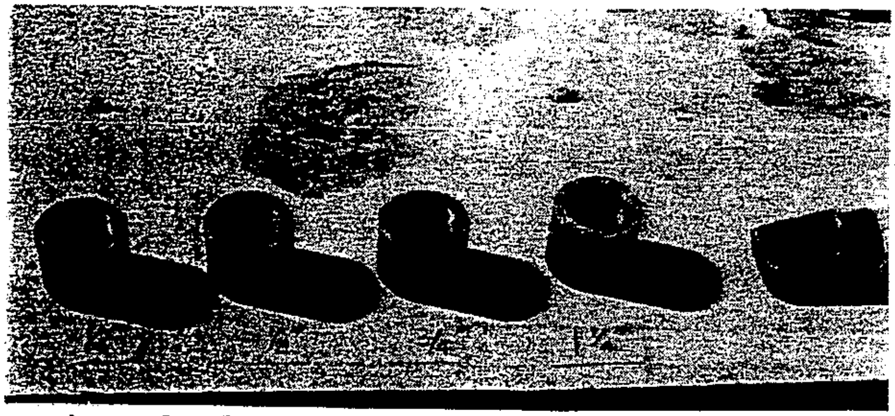


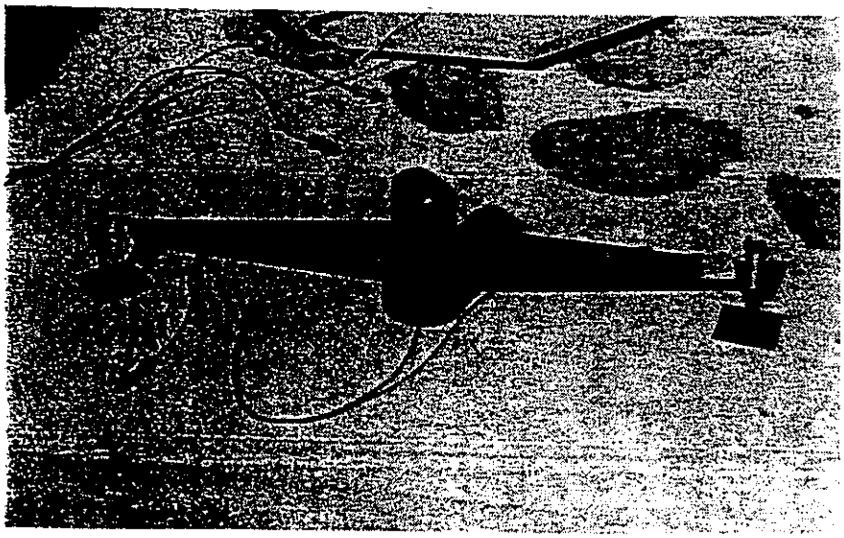
Figure 4. Apparatus for conducting short-term ultimate tension load tests.



a. Plan view of load collar with a mechanical expansion anchor installed.



b. Various load collars used for testing different sizes of mechanical expansion anchors.



c. Load collar shown in the assembled position with the displacement arm and linear potentiometers attached, and the plug-swivel adapter.

Figure 5. Load collars and the displacement arm used with the tension load testing appparatus.

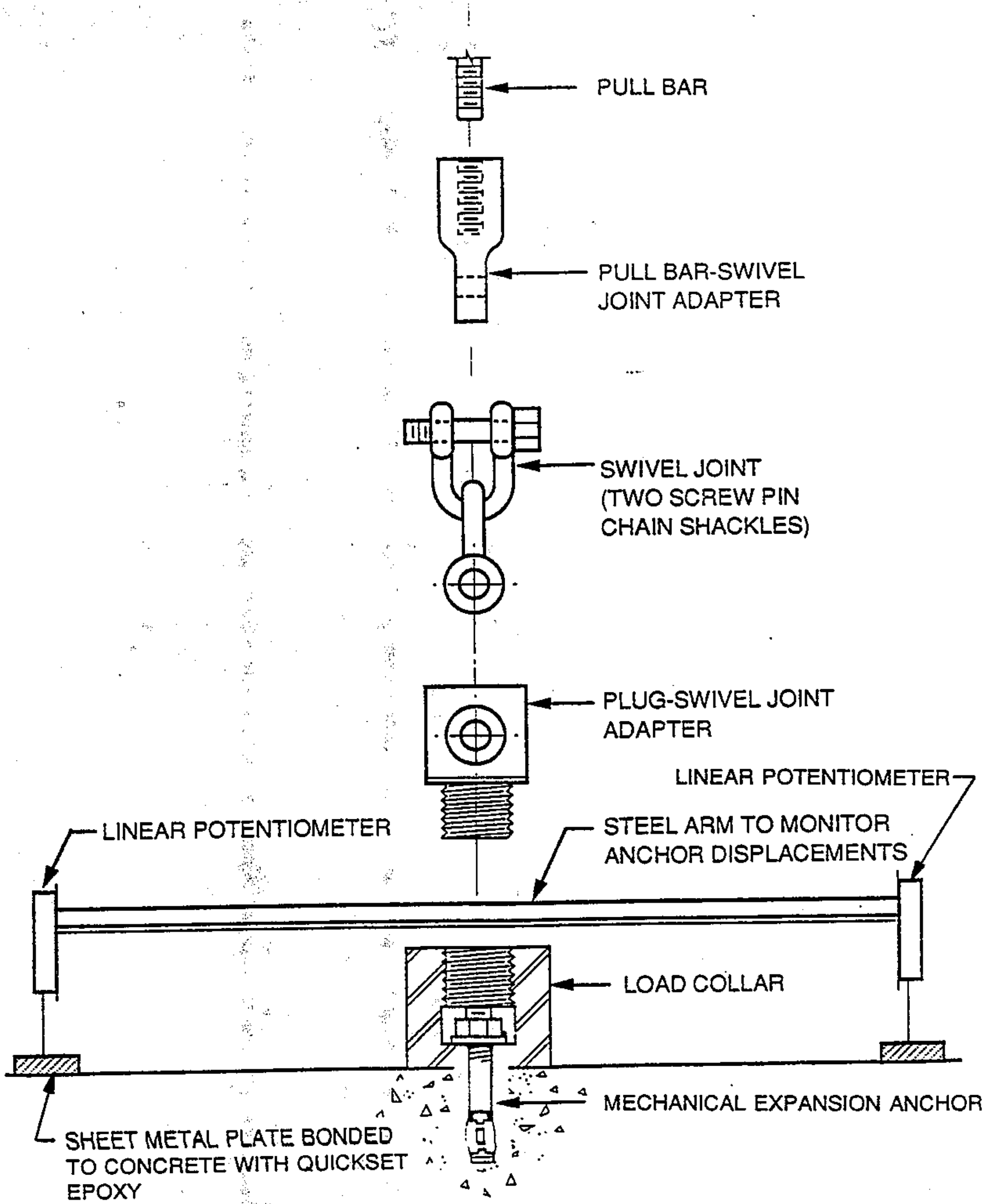


Figure 6. Expanded side view of the swivel joint assembly on the tension load testing apparatus.

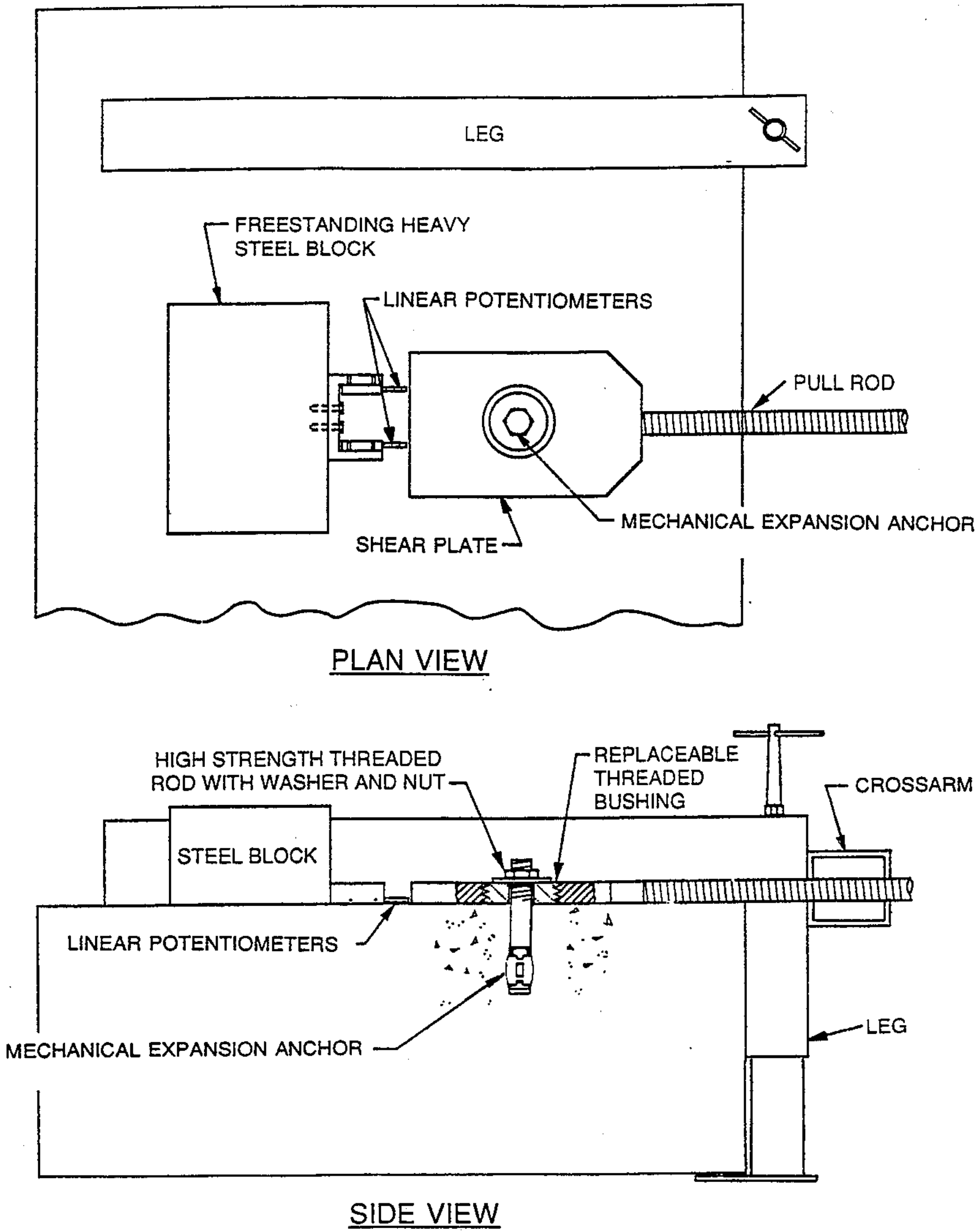


Figure 7. Plan and side views of key components of shear load testing apparatus.

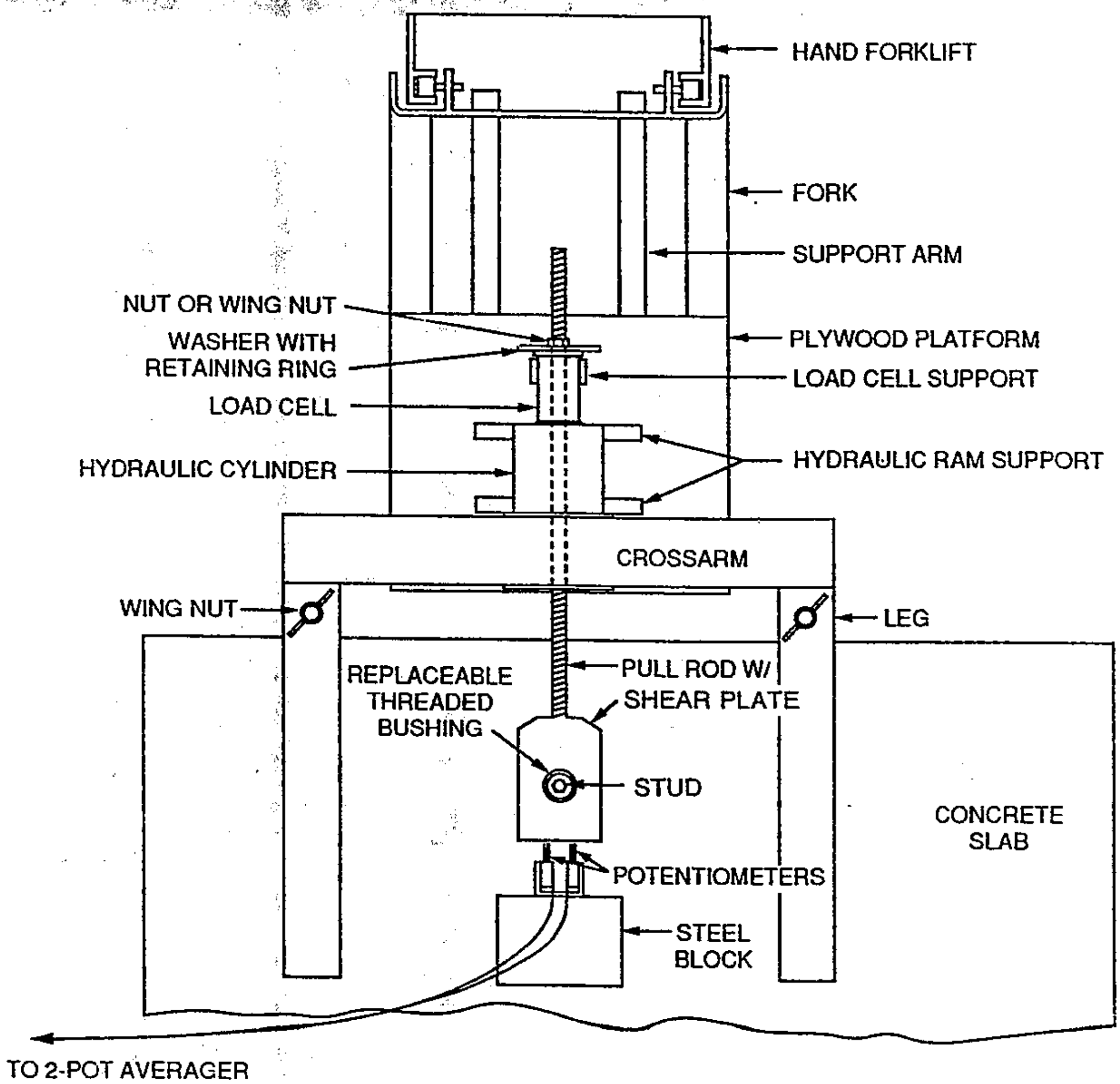


Figure 8. Plan view of shear load testing apparatus.

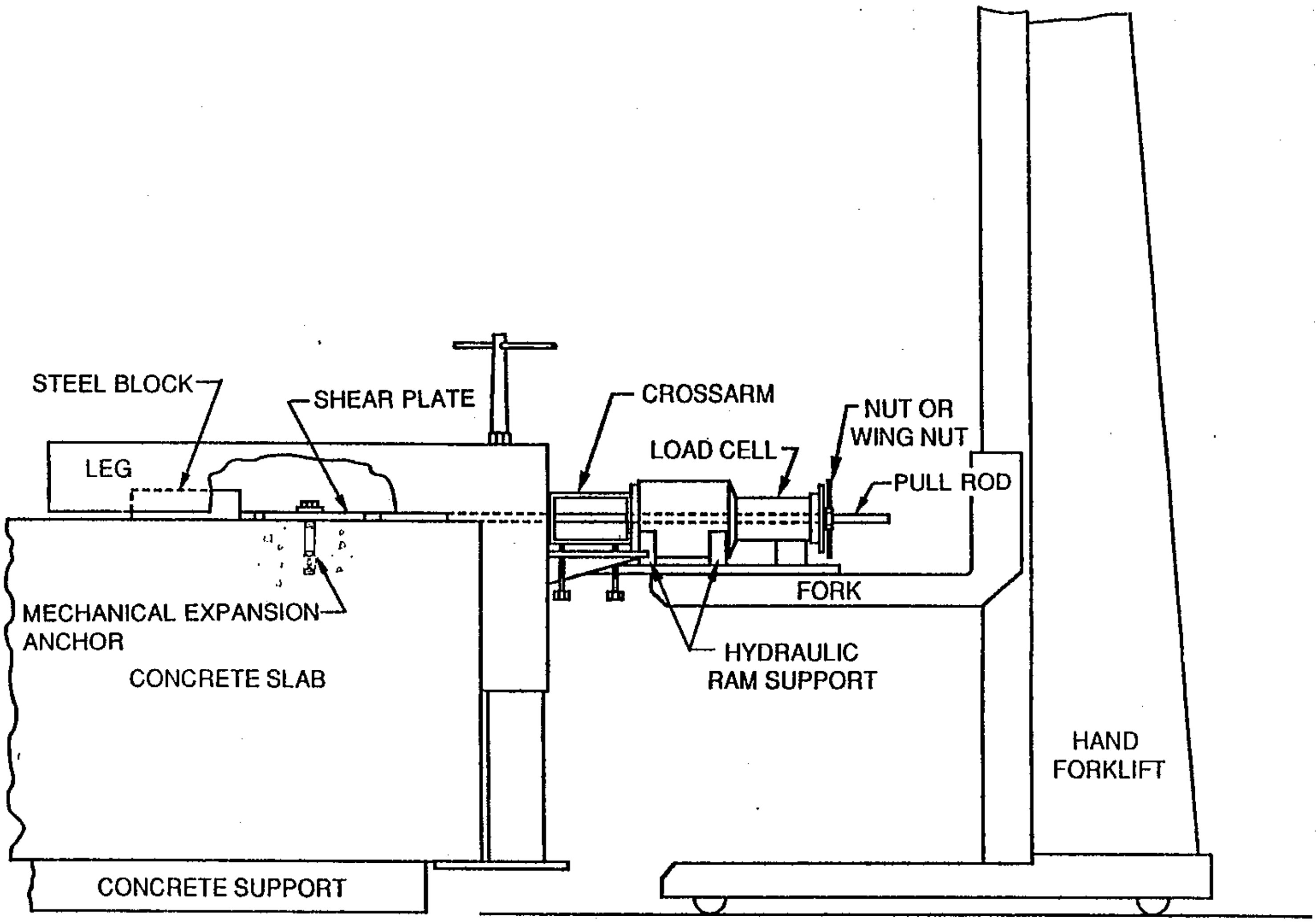


Figure 9. Side view of shear load testing apparatus.

Assembly: The first step in setting up the shear apparatus was to place the shear plate and integral pull rod on the surface of the concrete test slab and over the exposed anchor stud. A washer and nut were then installed onto the MEA stud. The nut was torqued to the manufacturer's specified installation value. In the case of the stud wedge-type MEA, torquing the upper nut not only sets the anchor head but also preloads the system. The legs of the shear apparatus were then placed so they straddled the anchor and shear plate and did not confine concrete around the anchor. The minimum distance maintained between the MEA body and either shear leg was equal to the edge distance multiplied by the tangent of 60 degrees (See Figure 10). The maximum distance available between shear legs was 36 inches. The shear legs were clamped firmly to the face of the slab. Legs were shimmed, if required, to insure that they had full bearing when the load was applied. The crossarm was threaded onto the pull rod and supported by a platform attached to the shear legs. When required, adjustments were made to the elevation of the crossarm with leveling screws. The center-hole hydraulic cylinder and load cell were slid onto the horizontal pull rod. Finally, a heavy step bushing washer and nut were placed onto the pull rod. These served as an end stop to transfer the load from the hydraulic cylinder to the pull rod. The last step in preparing the shear load apparatus for testing was to attach a pair of potentiometers or linear variable differential transformers (LVDTs) to a heavy steel shear block and situate the block so that the tips of the potentiometers or LVDTs would bear against the edge of the shear plate. Each potentiometer or LVDT was initially compressed so that its capacity to measure movement of the shear plate would be at least 0.60 inch during testing. A photograph of the assembled shear load testing apparatus is shown in Figure 11.

6.2.3 Combined Load Testing Apparatus: The testing apparatus used for combined loading was comprised of a shear testing frame similar to that used to conduct individual shear tests, except that a heavy crossarm and a pair of rollers, used to apply direct tensile load to the combination shear/tension base plate, were added. The apparatus is shown in Figures 12 through 14 and in photographs in Figure 15 and 16.
Assembly: As in the setup of the shear load testing apparatus, the legs of the combined load apparatus were placed so that there would be at least the minimum distance, as indicated in Figure 10, between them. The combination shear/tension base plate with integral shear pull rod was placed over the MEA stud, followed by a washer and nut. The nut on the anchor stud was then torqued. For the shear load portion of the test, the shear load crossarm, center-hole hydraulic cylinder and load cell were positioned as in the shear test. A stabilizer spring was inserted near the end of the shear pull rod adjacent to the load cell. The purpose of the spring was to smooth out the shear load rate during combined shear/tension load testing. The stabilizer spring is shown clearly in photographs in Figure 16.

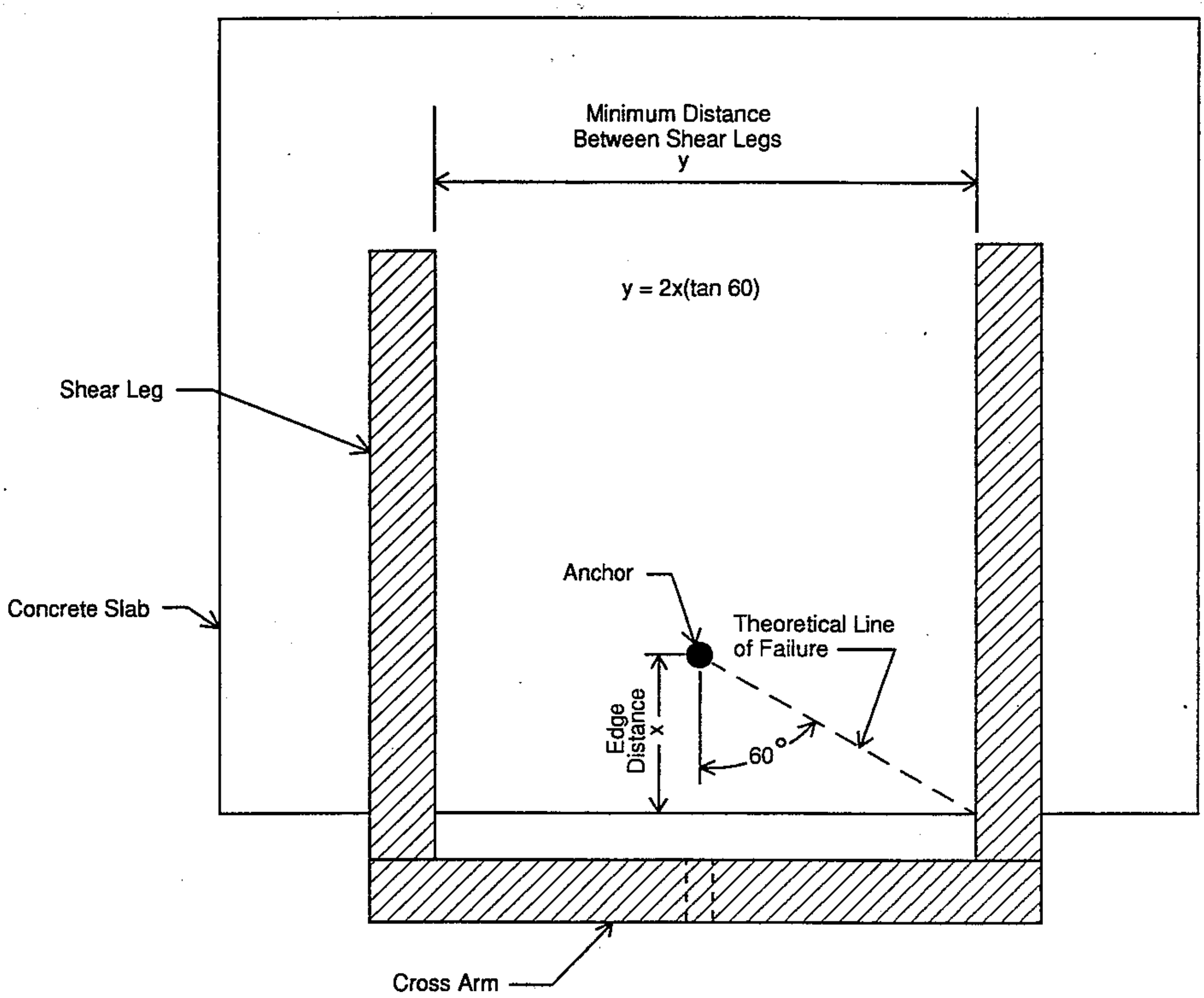
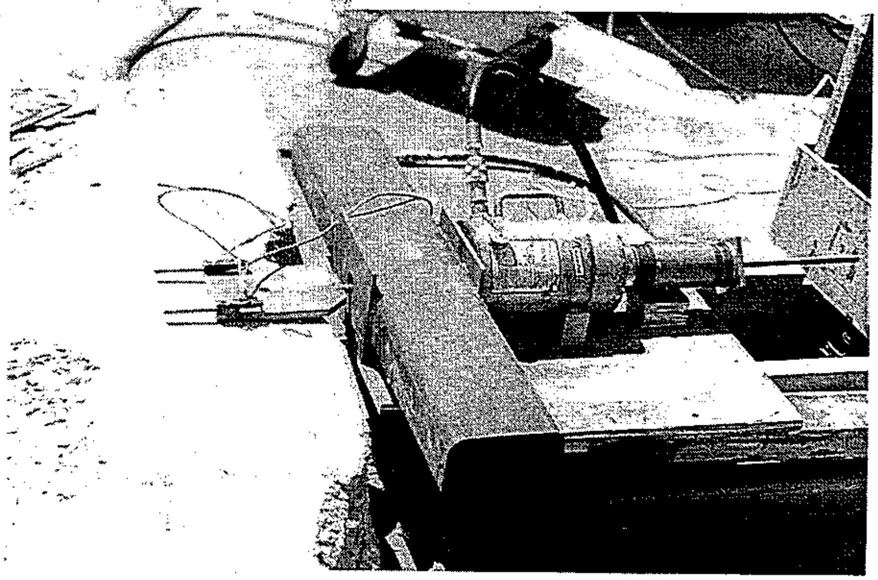


Figure 10. Plan view of minimum leg spacing of shear load test frame.



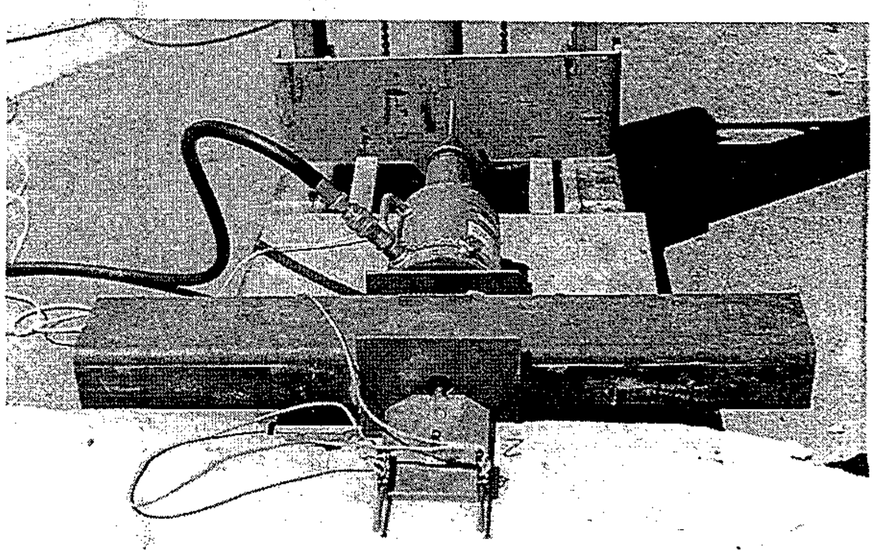


Figure 11. Photographs of shear load testing apparatus.

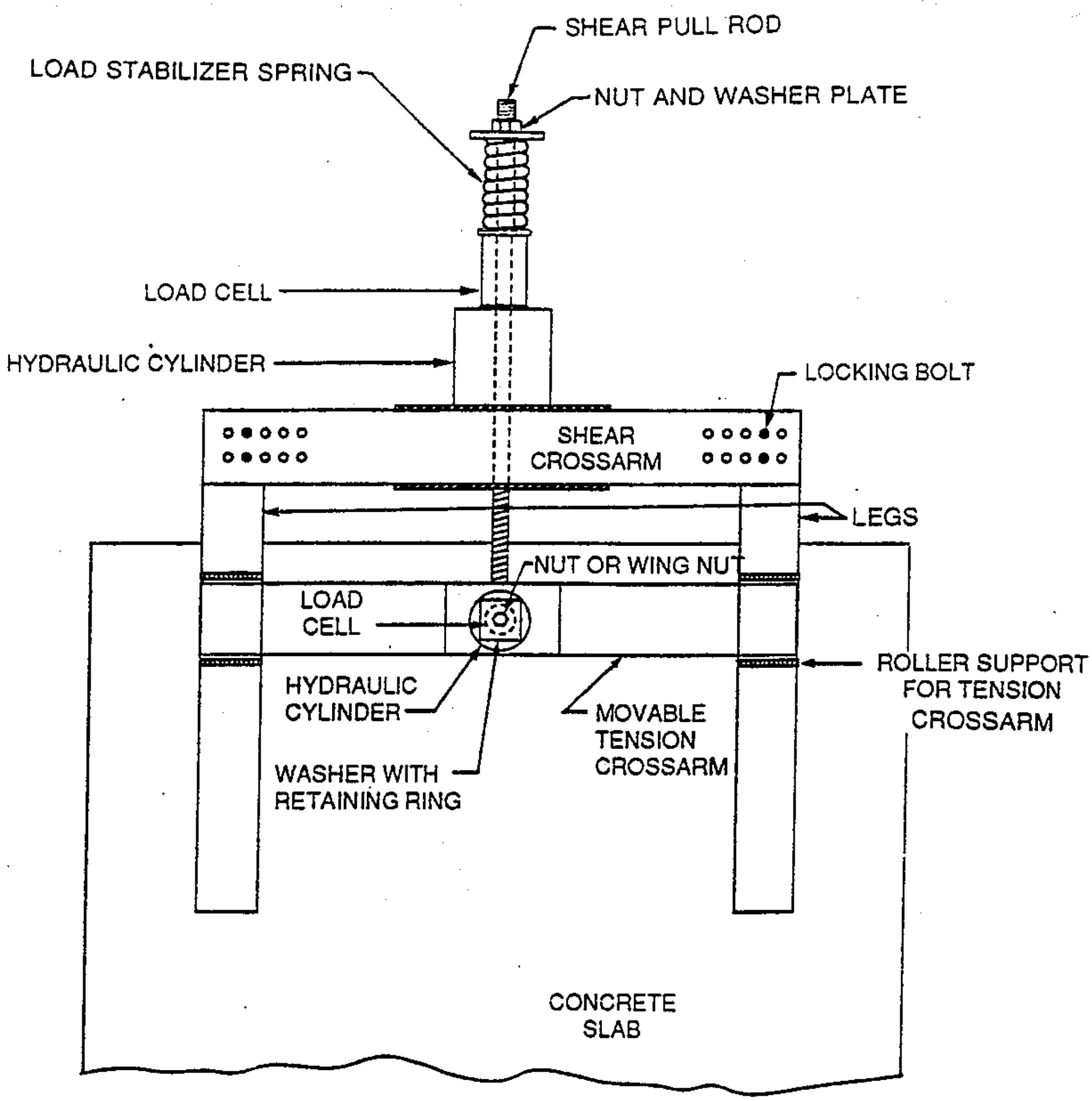


Figure 12. Plan view of combined load testing apparatus.

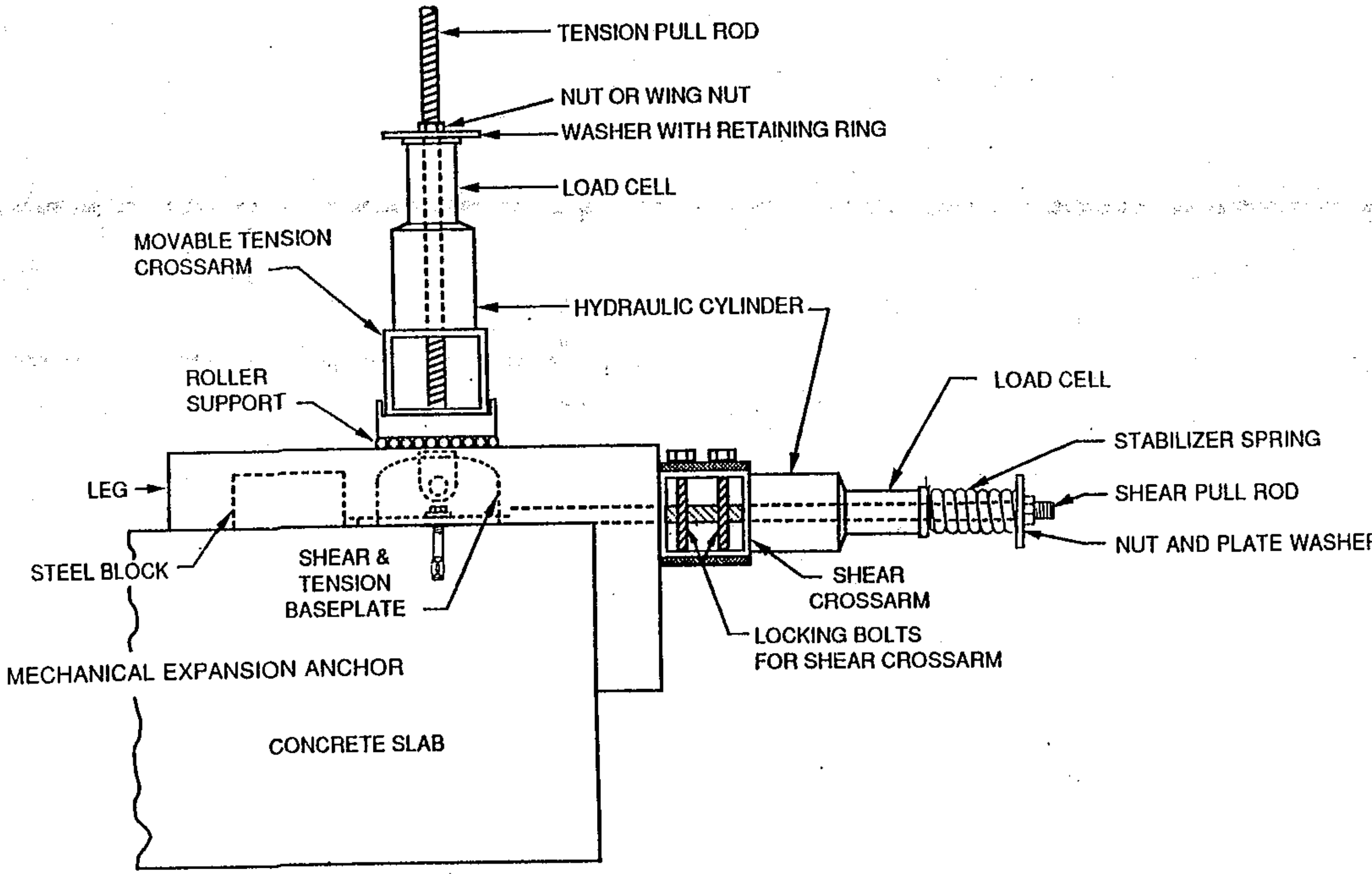


Figure 13. Side view of combined load testing apparatus.

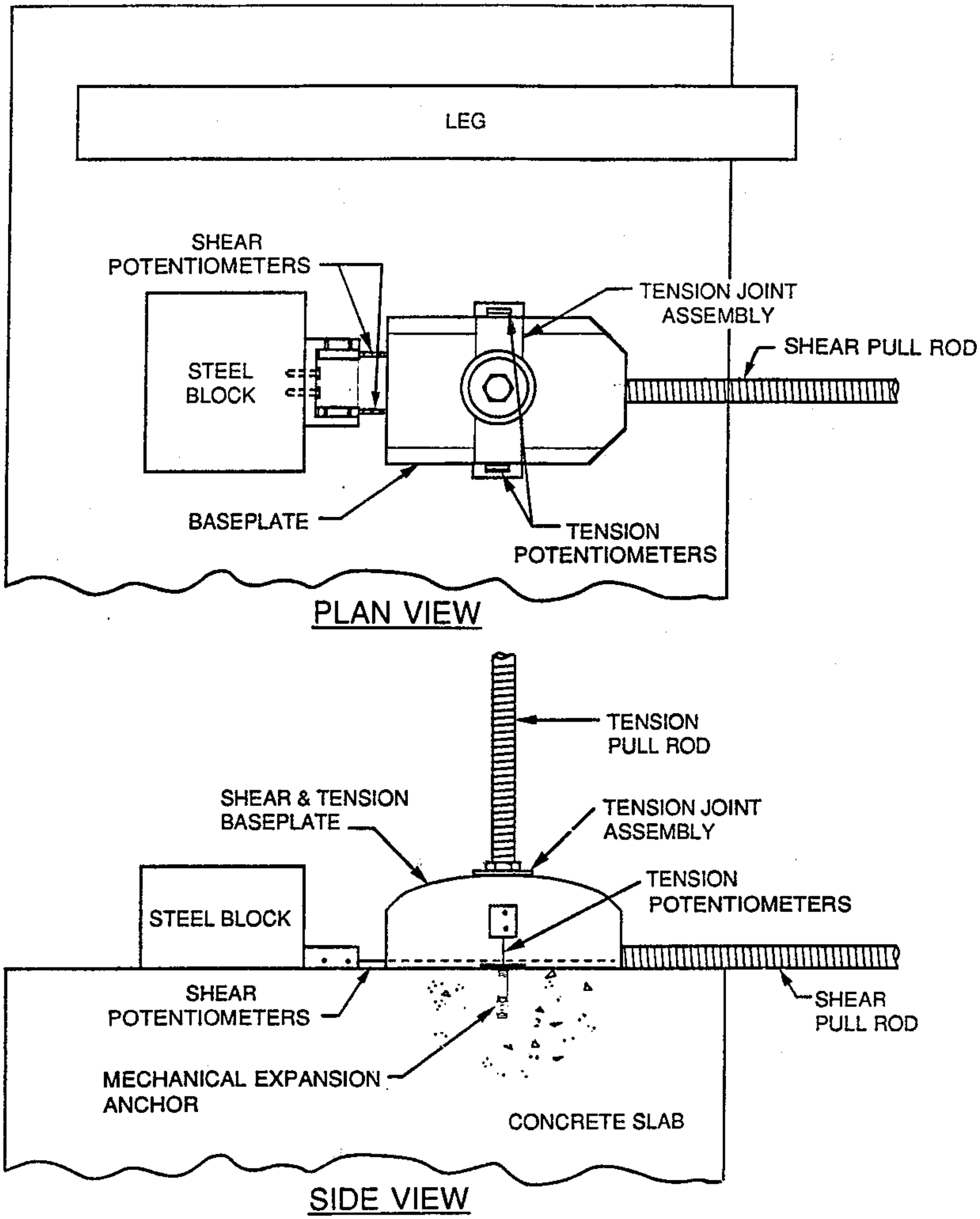


Figure 14. Plan and side view of the loading plate on the combined load testing apparatus.

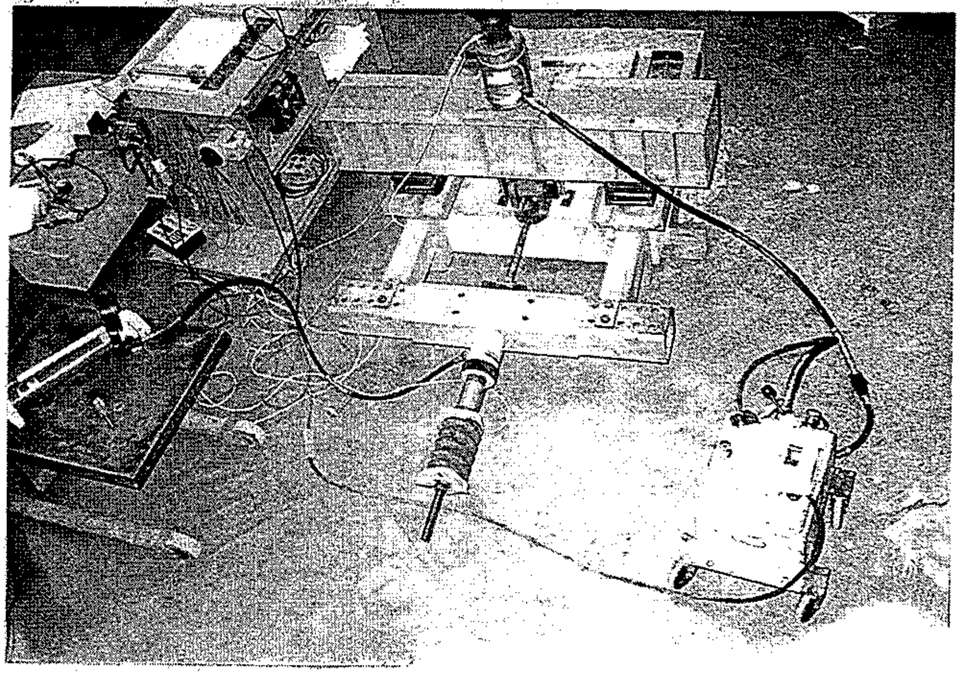


Figure 15. Combined load testing apparatus and data recording equipment.

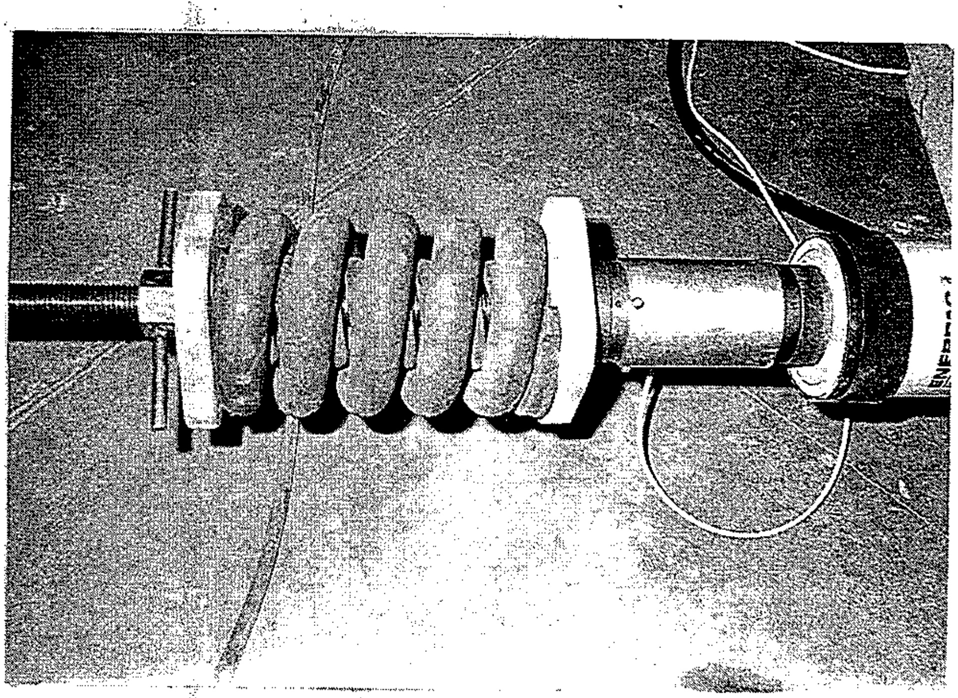


Figure 16. Close-up view of the stabilizer spring.

Next the coupler for the tension pull rod was attached to the top of the shear/tension base plate. Two pairs of linear potentiometers were attached to the base plate to monitor vertical movement due to tensile load on the anchor. As in shear testing, two LVDTs were mounted on the base plate and positioned against a heavy steel block in order to monitor the horizontal (shear) movement. To accommodate horizontal movement of the tension crossarm as the anchor moved horizontally due to shear loads, the crossarm was positioned on top of heavy rollers which were allowed to freely transverse on top of the hardened plates screwed to the tops of the legs. The tension crossarm also supported one center-hole hydraulic cylinder and load cell.

6.3 Recording Equipment:

During shear and tension testing, data were recorded by two Hewlett Packard (HP) Model 7046B X-Y Recorders. The data consisted of graphical plots of applied load versus time and applied load versus displacement. Prior to testing, the load cell and LVDTs were wired to the recorders (See Figures 17 and 18 for schematic diagrams of data acquisition equipment). The recorders were then calibrated to provide simultaneous and accurate traces of load, time and displacement.

For combined load testing, continuous traces of shear load versus time and tension load versus time were plotted by one recorder. Tension load versus tension displacement was recorded on the second recorder. Additionally, a data logger (Campbell Scientific Model 21X Micrologger) electronically recorded tension load and shear load versus time, tension load versus tension displacement, and shear load versus shear displacement. The shear displacement data were the only information that were not also recorded by the HP recorders. Duplicated data gathered by the Campbell micrologger served as a backup for pen plots made by the HP recorder. After testing, micrologger data were downloaded into an IBM personal computer and plotted. A schematic diagram of data acquisition equipment is shown in Figure 19.

6.4 Testing Procedures:

For all individual shear and tension tests, just prior to beginning each test, a preliminary load of 1/2 kip was applied to take up any slack in the mechanical equipment. This preload was applied manually by tightening the nut at the end of the pull rod. Each test was then run to failure using a hydraulic pump to apply the load at a rate of approximately one kip per second.

Combined loading tests were run by first applying a constant, predetermined shear force and then slowly increasing the tension force at a constant rate until failure occurred. For each anchor type, two tests were run, one each at fixed shear forces equal to 33-1/3 or 66-2/3 percent of the average ultimate shear load for that anchor type, in order to develop a combined load interaction curve. During testing, two different hydraulic pumps were used simultaneously to apply the independent tension and shear loads. The shear

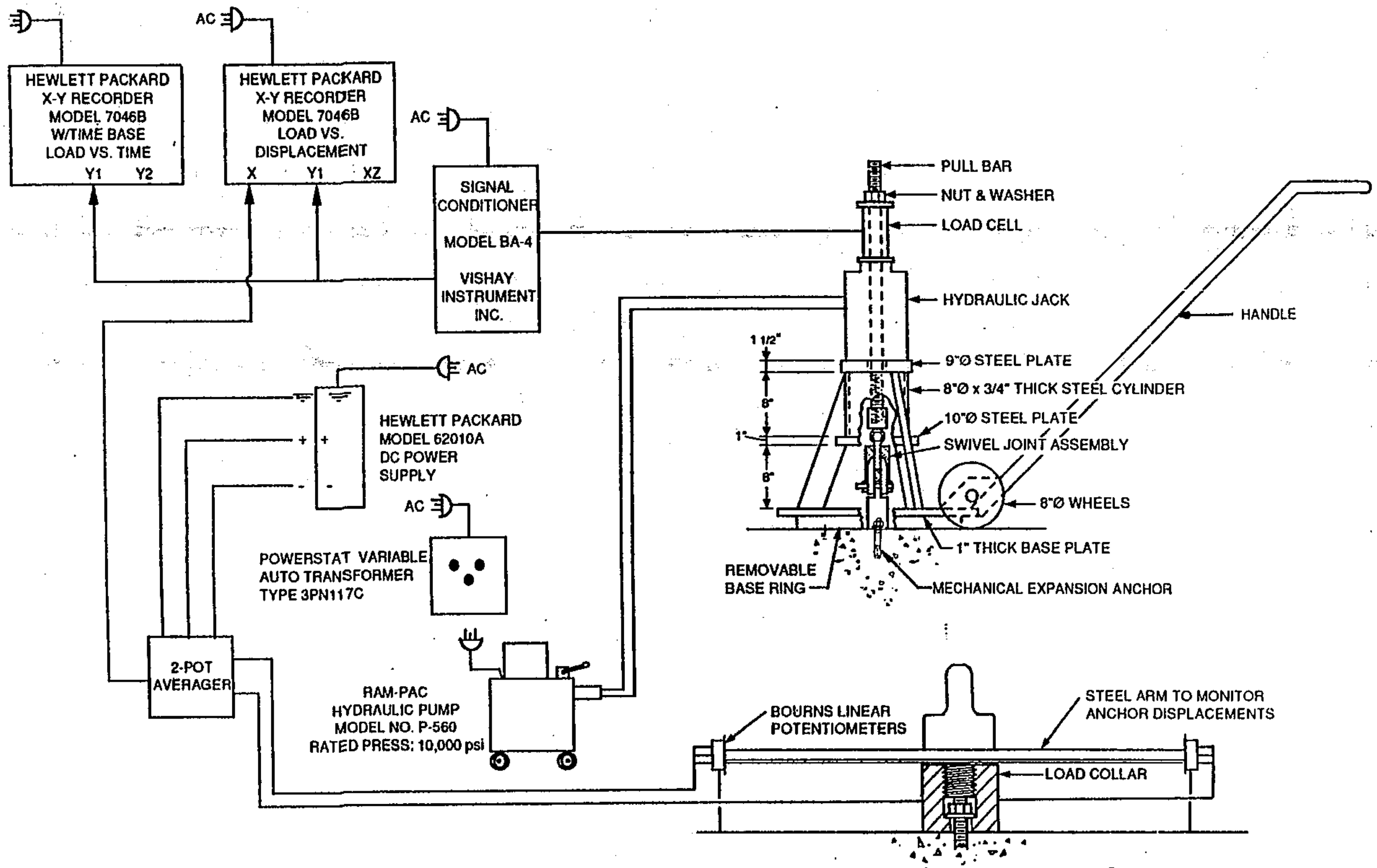


Figure 17. Schematic diagram of data acquisition equipment used in tension tests.

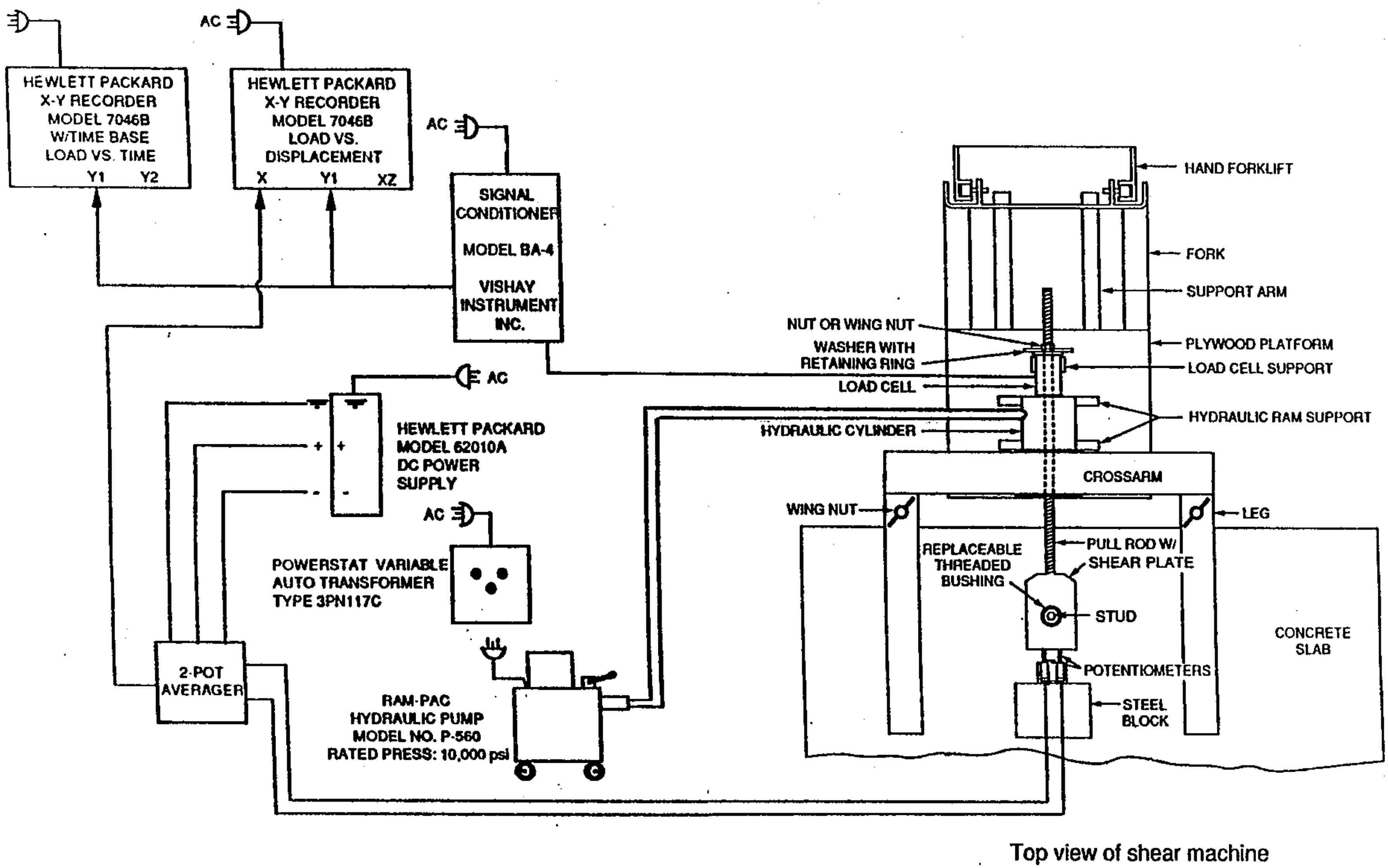


Figure 18. Schematic diagram of data acquisition equipment used in shear tests.

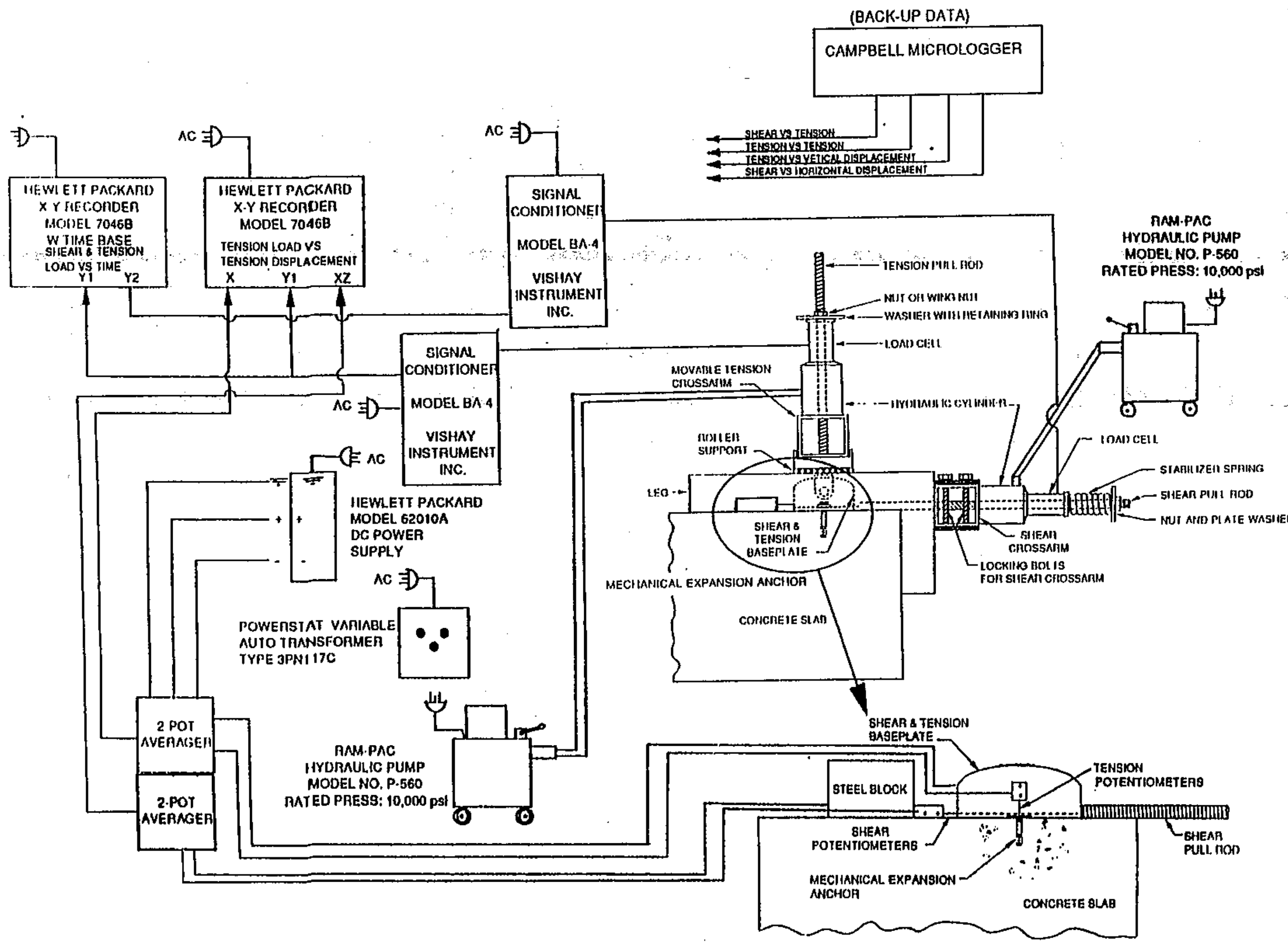


Figure 19. Schematic diagram of data acquisition equipment used in combined load tests.

load was applied first and held constant (either 33-1/3 or 66-2/3 percent of average ultimate shear); then the tension load was applied at a constant rate ranging from 1 kip per 2 to 6.67 seconds (see tension load vs. time graphs in Figures G36, G39, G43, G47, G51, G55, G59, and G63 of Appendix G). The magnitude of the shear load varied slightly above and below the desired shear value as the tension load was increased and failure occurred. A heavy spring was positioned near the end of the pull rod to assist in maintaining a constant shear load.

7. TEST RESULTS AND DISCUSSION

7.1 Discussion About Slip Point:

Load-displacement curves for tensile tests perfomed on mechanical expansion anchors (MEAs) typically contain a straight line at the start of the curve. The term slip point as defined in previous research (8.4) is meaningful only for anchors loaded in tension. The end of the straight portion of this line was defined as the slip point of the anchor system which is analogous to the proportional limit in a stress-strain curve for mild steel. The load-displacement curve typically continues to rise until the anchor reaches its ultimate load. This is the point where failure occurs due to loss of friction or when the applied tensile load exceeds the cone shear strength of the concrete.

When analyzing the test data from this study, sometimes there was no distinct slip point. The slip point values selected were therefore open to varying interpretations. It was difficult to define the slip point which would follow one particular rule such as a fixed percentage of the ultimate load or a certain change in slope. Slip points were established for tensile loading only and are presented in Table 4. They ranged broadly from 13 to 100 percent of the ultimate tensile load. In general, there were no trends relating slip point to the edge distance of the anchor tested. As a result, ultimate tensile strength was used instead of slip point to establish load interaction curves.

Attempting to establish meaningful slip points did not seem appropriate for anchors loaded in shear. Load-displacement curves typically rose gradually to an ultimate load without having a slip point. It was also futile to determine slip points for the combined loading tests.

7.2 Tension Test Results and Discussion:

For all series of tension tests, three replicate tests were conducted for each MEA type, chosen brand, and edge distance combination. Data were recorded graphically through plots of load versus displacement. Plots of the actual data are presented in odd-numbered Figures in Appendix G from Figure G1 through G23. Tension test curves typically were found to have a steep initial positive slope, until a value which is referred to as the slip point was attained. At this point the slope of the tension curve flattened, but continued to rise gradually until it reached an ultimate load. Tensions at slip points are shown in Table 4.

Table 4. Results of tension tests - Mean tensions at slip points (5000 psi concrete).						
Anchor Type/ Manufacturer/ Model No.	Slip Point Load (kips) at Various Edge Distances					
	3"	4"	5"	6"	7"	9"
1/2-INCH-DIA. STUD WEDGE ANCHORS:						
Molly No. PB12-4	3.8	2.0	2.9	---	4.0	---
Rawlplug No. 7422	4.4	1.2	1.0	---	4.0	---
Star No. 3535-36000	3.0	3.0	2.9	---	2.9	---
Group mean	3.7	2.1	2.3	---	3.6	---
1/2-INCH-DIA. SHELL INTERNAL PLUG ANCHORS:						
Molly No. MDI-12	2.6	2.9	3.2	---	3.5	---
Phillips No. RM-12	3.2	3.3	3.4	---	3.7	---
Rawlplug No. 6308	2.6	3.8	2.3	---	1.4	---
Group mean	2.8	3.3	3.0	---	2.9	---
3/4-INCH-DIA. STUD WEDGE ANCHORS:						
Ramset No. T34434	7.3	7.3	8.3	7.3	8.9	7.2
Rawlplug No. 7440	5.6	7.6	7.6	---	6.8	4.8
Star No. 3555-42000	6.6	5.3	5.2	7.4	6.5	5.4
Group mean	6.5	6.7	7.0	7.4	7.4	5.8
3/4-INCH-DIA. SHELL INTERNAL PLUG ANCHORS:						
Molly No. MDI-34	3.9	3.9	4.2	4.3	4.4	4.4
Ramset No. DS-34	9.6	9.2	7.8	12.2	9.2	7.5
Rawlplug No. 6312	4.3	9.5	11.2	8.0	6.8	6.7
Group mean	5.9	7.5	7.7	8.2	6.8	6.2
Note: Dashed line indicates no tests performed.						

An exact location for or fixed definition of a slip point was not possible to establish and therefore chosen slip point values could be slightly different because of the difference in interpretations and varied shapes of curves. Mean slip point loads for tension tests conducted in this research showed performance which varied among different manufacturers regardless of the type of MEA. Overall, the two types of anchors tested - stud wedge and shell internal plug - performed comparably.

Ultimate tension loads for 1/2-inch-diameter stud wedge MEAs tested in this research ranged from 5.1 to 7.6 kips as can be seen from results shown in Table 5. Shell internal plug MEAs having the same 1/2-inch-diameter stud size produced ultimate loads ranging from 3.7 to 6.7 kips. Both types of MEAs - the stud wedge-type and the shell internal plug-type - attained ultimate loads which were very similar. Mean ultimate loads for the 3/4-inch-diameter stud wedge MEAs ranged from 8.6 to 11.2 kips. The 3/4-inch-diameter shell internal plug-type MEA had mean ultimate loads ranging from 8.2 to 12.7 kips. Again for this size, mean ultimate loads for both MEA types at the same edge distances were very similar. Apparently, variability and inconsistency in tension test results at different edge distances may be due to variations in hole preparation and installation techniques used.

A comparison between mean shear and tension test results found in this research at an edge distance of 12 stud diameters, with manufacturers advertised ultimate load values at concrete compressive strengths of 3000 psi is shown in Table 5A.

Table 5A. Comparison of tension and shear ultimate loads (kips) of manufacturers' data with Caltrans mean research data.

Anchor size and Type	**Load Type**	*** Molly**	**** Phillips**	*** Ramset**	*** Rawlplug**	*** Star**	**Caltrans Research Data****
1/2-inch Stud Wedge	T	3.78			7.72	3.4	4.27
	S	7.35			6.9	N.A.	6.25
1/2-inch Shell Int. Plug	T	6.6	6.69		9.0		4.09
	S	5.5	5.09		6.64		6.25
3/4-inch Stud Wedge	T			10.8	10.7	6.8	7.9
	S			14.8	14.6	N.A.	12.5
3/4-inch Shell Int. Plug	T	10.0		11.6	13.9		8.9
	S	10.0		16.7	19.7		12.8

T = Tension ; S = Shear
* = 3000 psi concrete
** = values for higher strength concrete adjusted to 3000 psi

Table 5. Results of tension tests - Mean ultimate loads (5000 psi concrete).						
Anchor Type/ Manufacturer/ Model No.	Ultimate Tension Load (kips) at Various Edge Distances					
	3"	4"	5"	6"	7"	9"
1/2-INCH-DIA. STUD WEDGE ANCHORS:						
Molly No. PB12-4	5.4	5.9	5.9		6.4	
Rawlplug No. 7422	5.5	7.4	7.6		5.1	
Star No. 3535-36000	6.2	7.3	6.0		5.4	
Group mean	5.7	6.9	6.5		5.6	
1/2-INCH-DIA. SHELL INTERNAL PLUG ANCHORS:						
Molly No. MDI-12	5.9	3.7	6.1		5.6	
Phillips No. RM-12	5.3	5.2	6.4		6.5	
Rawlplug No. 6308	6.0	6.7	5.9		4.3	
Group mean	5.7	5.2	6.1		5.5	
3/4-INCH-DIA. STUD WEDGE ANCHORS:						
Ramset No. T34434	10.0	10.6	12.7	9.1	12.1	8.9
Rawlplug No. 7440	7.3	10.6	12.5	---	11.6	7.9
Star No. 3555-42000	8.4	7.8	7.4	9.8	9.9	9.3
Group mean	8.6	9.7	10.9	9.5	11.2	8.7
3/4-INCH-DIA. SHELL INTERNAL PLUG ANCHORS:						
Molly No. MDI-34	8.6	8.8	10.4	10.0	10.9	6.4
Ramset No. DS-34	10.1	11.2	11.6	12.2	12.6	10.9
Rawlplug No. 6312	5.8	10.7	13.4	13.5	14.5	10.0
Group mean	8.2	10.2	11.8	11.9	12.7	9.1

Notes:
(1) Failure modes for the various edge distances are given in Table 6.
(2) Dashed lines indicate tests which were not performed at the indicated edge distances.

When compared to ultimate loads attained in this research, most manufacturers advertised ultimate loads are higher. As manufacturers frequently do not use similar test procedures or apparatus when establishing these ultimate loads, unconservative values may result. Generally manufacturers recommend that ultimate loads be divided by 4 to establish appropriate design loads for static loading.

Caltrans designers use a load factor method to establish appropriate design values for anchorage devices. An explanation of the Caltrans load factor design approach is given in Appendix F. Current Caltrans allowable shear and tension design loads are shown in Appendix C.

The various failure modes observed when tension loading to ultimate consisted of concrete failure (including cone failure, cracking, spalling, catastrophic failure), anchor pullout, and stud wedge anchor collar failure. A summary of failure modes for tension tests is shown in Table 6. Photographs of these various types of failures are shown in Appendix A.

7.3 <u>Shear Test Results and Discussion:</u>
As with the tension test data previously described, shear test results are based on the mean value of three replicate tests. Data from each set of similar tests were averaged and plotted and are shown in even-numbered figures in Appendix G from G2 through G24. Test results are summarized in Table 7 and are based on these averaged test data.

The maximum shear load the MEA would support without failure (ultimate load) increased as edge distance increased. The increase was not proportional to the change in edge distance. Ultimate shear loads for 1/2-inch-diameter stud wedge MEAs ranged from 4.3 kips to 10.3 kips. Shell internal plug MEAs having 1/2-inch-diameter threaded studs had ultimate shear loads ranging from 3.5 kips to 10.5 kips. For the same edge distance, both types of MEAs performed comparably in most shear tests performed. MEA brands which were the poorest performers varied from test to test.

Ultimate shear loads for 3/4-inch-diameter stud wedge MEAs ranged from 5.5 kips to 22.1 kips. Ultimate shear loads for shell internal plug-type MEAs of the same diameter ranged from 4.5 kips to 20.3 kips. Stud wedge-type MEAs were fairly comparable but did slightly better than shell internal plug-type MEAs.

Failure modes at ultimate shear loading included concrete cracking (both wedge shaped failure planes, spalling, and catastrophic failure), and steel failure (shearing of the wedge-type anchor body or shell-type anchor stud). A summary of failure modes for shear tests performed is contained in Table 8. In Appendix A, photographs and descriptions of the various failure modes which were experienced are presented.

Table 6. Tension test results - Failure modes.

Anchor Type/ Manufacturer/ Model No.	Failure Modes of Tension Tests at Various Edge Distances					
	3"	4"	5"	6"	7"	9"
1/2-INCH-DIA. STUD WEDGE ANCHORS:						
Molly No. PB12-4	APO	CC	APO,CS		CC	
	CC	CC	CC		CC	
	CC	CC	CC		APO	
Rawlplug No. 7422	CC	CC	CC		CC	
	CC,AWC	CC,AWC	CC,AWC		CC,AWC	
	CC,AWC	CC,AWC	CC,AWC		APO,CCR	
Star No. 3535-36000	CC	CC	CC		APO	
	CC	CC	CC		APO	
	CC	CC	CC		CC	
1/2-INCH-DIA. SHELL INTERNAL PLUG ANCHORS:						
Molly No. MDI-12	APO	APO	APO		CC	
	APO	APO	APO		CC	
	CCR	APO,CS	APO,CS		CC	
Phillips No. RM-12	APO,CS	APO,CS	CC		CC	
	APO	CC	APO,CS		CC	
	CC	CC	APO,CS		CC	
Rawlplug No. 6308	APO,CCR	CW	AB,CS		AB,CS	
	CW	CW	AB,CS		NP	
	CW	CW	AST		AST	
3/4-INCH-DIA. STUD WEDGE ANCHORS:						
Ramset No. T34434	CC	CC	CC	CC	CC	APO
	CC	CC	CC	CC	CC	CC
	CC	CC	CF	CC	CC	CC
Rawlplug No. 7440	CC,AWC	CC	CC		CC	CC
	CC,AWC	CC	CC,AWC		CC,AWC	CC,AWC
	CC	CC,AWC	CC,AWC		CC,AWC	CC,AWC
Star No. 3555-42000	CC	CCR,APO	CCR	CC	CC	AWC
	CC	CCR,APO	CCR	CC	CC	CC
	CC	CC	CC	CC	CC	CC
3/4-INCH-DIA. SHELL INTERNAL PLUG ANCHORS:						
Molly No. MDI-34	APO	APO	APO,CCR	APO	APO	APO,CC
	CC	APO	APO,CS	APO	APO	APO
		APO	APO	APO	APO	APO,CS
Ramset No. DS-34		APO	APO,CS	APO,CCR	APO,CS	APO
		CC	APO,CCR	CC	CC	APO
		APO,CS	CC	CC	APO,CS	APO
Rawlplug No. 6312	APO	CC	CC	CC	CC	CC
	APO	CC	CC	CC	CC	CC
	APO	CC	CC	CC	CC	CC

Legend:

CC	= Cone Failure (A1)	APO	= Anchor Pull Out (A6)
CW	= Wedge Failure (A2)	AB	= Anchor Body Failure (A7)
CCR	= Cracking of Concrete (A3)	AST	= Stud Failure (A8)
CS	= Spalling (A4)	AWC	= Anchor Collar Failure (A9)
CF	= Catastrophic Failure (A5)	NP	= No photographic record of failure

Table 7. Results of shear tests - Mean ultimate loads (5000 psi concrete).

Anchor Type/ Manufacturer/ Model No.	Mean Ultimate Shear Loads (kips) at Various Edge Distances					
	3"	4"	5"	6"	7"	9"
1/2 INCH DIA STUD WEDGE ANCHORS:						
Molly No. PB12-4	5.4	7.5	7.8	---	10.3	---
Rawlplug No. 7422	4.3	5.7	8	---	8.5	---
Star No. 3535-36000	4.8	8	9	---	---	---
Group mean	4.8	7.1	8.3	---	9.4	---
1/2 INCH DIA SHELL INTERNAL PLUG ANCHORS:						
Molly No. MDI-12	5.2	4.9	9.1	---	10.5	---
Phillips No. RM-12	5.9	4.9	8.8	---	8.0	---
Rawlplug No. 6308	3.5	8.1	7.8	---	8.7	---
Group mean	4.9	6.0	8.6	---	9.1	---
3/4 INCH DIA STUD WEDGE ANCHORS:						
Ramset No. T34434	5.5	8.0	10.7	---	16.5	22.1
Rawlplug No. 7440	6.8	10.7	12.9	---	15.3	13.2
Star No. 3555-42000	5.7	7.6	11.6	11.7	15.4	---
Group mean	6.0	8.8	11.7	11.7	15.7	17.7
3/4 INCH DIA SHELL INTERNAL PLUG ANCHORS:						
Molly No. MDI-34	4.5	5.5	7.8	11.4	16.5	20.2
Ramset No. DS-34	6.0	9.2	10.8	9.7	13.5	20.3
Rawlplug No. 6312	5.7	8.8	13.3	13.5	14.3	14.0
Group mean	5.4	7.8	10.6	11.5	14.9	18.2

Notes:
(1) Failure modes for the various edge distances are given in Table 8.
(2) Dashed line indicates no tests performed.

Table 8. Shear test results - Failure modes.

Anchor Type/ Manufacturer/ Model No.	Failure Modes of Shear Tests at Various Edge Distances					
	3"	4"	5"	6"	7"	9"
1/2 INCH DIA STUD WEDGE ANCHORS:						
Molly No. PB12-4	CW	AB	AB		AB	
	CW	AB	AB		AB	
	AST	CW	AB		AB	
Rawlplug No. 7422	AWC,CW	AB,CS	CW		AB	
	AWC,CW	AWC,CW	AB,CS		AB	
	AWC,CW	AWC,CW	AB,CS		AB,CS	
Star No. 3535-36000	CW	CW	AB			
	CW	CW,AST	AB			
	CW	AST	AB			
1/2 INCH DIA SHELL INTERNAL PLUG ANCHORS:						
Molly No. MDI-12	CW	CW	APO		AB	
	CW	CW	CW		AST	
	CW	CW	AST		AB,CS	
Phillips No. RM-12	CW	CW	CW		AST	
	CW	CW	CW		AST	
	CW	CW	CW		AST	
Rawlplug No. 6308	APO,CCR	CW	AB,CS		AB,CS	
	CW	CW	AB,CS		NP	
	CW	CW	AST		AST	
3/4 INCH DIA STUD WEDGE ANCHORS:						
Ramset No. T34434	CW	CW	CW		CW	NP
	CW	CW	CW		NP	NP
	CW	CW	CW		NP	NP
Rawlplug No. 7440	CW	CW	NP		NP	AST
	CW	CW,AWC	NP		NP	AST
	CW	CW,AWC	CW		NP	AB
Star No. 3555-42000	CW	CW	CW	AWC	AST	CW
	CW	CW	CW	CS	AST	CW
	CW	CW	CW	CF	CW	CW
3/4 INCH DIA SHELL INTERNAL PLUG ANCHORS:						
Molly No. MDI-34	CW	CW	CW	CW	CW	CW
	CW	CW	CW	CW	CW	CW
	CW	CW	CW	CW	CW	CW
Ramset No. DS-34	CW	CW	CW	CW	CW	CS
	CW	CW	CW	CF	CW	AST,CS
	CW	CF	CW	CF	CW	CS
Rawlplug No. 6312	CW	CW	CW	AST	AST	AST
	CW	CW	CW	AST	AST	AST
	CW	CW	AST	CW	AST	AST

Legend:

CW = Wedge Failure (A2)
CS = Spalling (A4)
CF = Catastrophic Failure (A5)
APO = Anchor Pull Out (A6)
AB = Anchor Body Failure (A7)
AST = Stud Failure (A8)
AWC = Anchor Collar Failure (A9)
NP = No photographic record of failure

7.4 Low Strength Concrete Test Results and Discussion:
One mechanical expansion anchor (Rawlplug No. 7440, 3/4-inch-diameter stud wedge type) was selected and evaluated in independent tension and shear testing in low-strength, early age concrete (2750 psi). Plots of actual test data are presented in Figures G25 through G32 of Appendix G. Results were compared to those for similar anchors installed in concrete having moderate compressive strength (5000 psi). Test results presented in Table 9 show a decrease in both ultimate tension and shear loads for edge distances of 3, 5 and 7 inches, when compared to similar data from 5000 psi concrete shown in Tables 5 (page 34) and 7 (page 37). Decreases in ultimate strength ranged from 22 to 54 percent. However, at an edge distance of 9 inches, the MEA was not adversely affected by the lower compressive strength of the concrete.

7.5 Combined Loading Test Results and Discussion:
Data collected from combined loading tests is presented in Figures G33 through G63 in Appendix G. A summary of results from combined loading tests conducted is shown in Table 10. As expected, mean ultimate tension loads attained were smaller when a concurrent shear load was also present. Tests were performed at edge distances of either three inches, four inches, or five inches. When a constant shear load equal to 33-1/3 percent of the average ultimate shear load was applied, the ultimate tensile load capacity was from 2 to 32 percent less than when the tensile load was applied alone. When the shear load applied was 66-2/3 percent of the average ultimate independent shear load, the resulting ultimate tension load decreased from 20 to 69 percent of the independent ultimate tensile load value. The percent decrease did not vary proportionately to the edge distance of the MEA.

Results of combined load tests for 1/2-inch-diameter MEAs are plotted in Figures 20 and 21. In both cases, all data falls within a curved band. The band width seems somewhat narrower for the stud wedge-type MEA than for the 1/2-inch shell internal plug MEA, but the lower band limit is very similar for both 1/2-inch MEA types.

Combined loading test data for both types of 3/4-inch-diameter MEAs tested is presented in Figures 22 and 23. As can be seen, the performance of the 3/4-inch shell internal plug MEAs, in tension, appears to be somewhat better than the 3/4-inch stud wedge-type MEAs tested. Again, the data for both types of 3/4-inch MEAs is grouped within a slightly curved band.

If a constant tension load is present, it is estimated that the ultimate shear load attained would be similarly reduced.

A banded plot of all the combined loading test data obtained in this research project which has been normalized is shown in curve 5 in Figure 24. Other interaction curves shown along with the Caltrans data band are those recommended by two MEA manufactures, Molly (curve 1, Fig. 24) and ITW

Table 9. Tension and shear test results from low strength, early age concrete.

Anchor Type: 3/4-Inch-Diameter Stud Wedge M.E.A.
Anchor Manufacturer: Rawlplug No. 7440
Concrete Compressive Strength: 2750 psi

Test Type	Ultimate Shear or Tension Load (kips) at Various Edge Distances			
	3"	5"	7"	9"
Tension	5.7	7.1	7.9	8.0
Shear	4.3	5.9	10.3	15.1

Table 10. Combined loading results (5000 psi concrete).

Anchor Type/ Manufacturer/ Model Number	Edge Dist.	Percent of Ultimate Shear Load (held constant)	Shear Load (kips)	Ultimate Tension Load (kips)	Slip Tension Load (kips)
1/2-INCH-DIA. STUD WEDGE ANCHORS: Star No. 3535-36000	3"	0	---	6.2	3.0
		33-1/3	2.0	4.6	4.5
		66-2/3	4.0	1.9	1.8
		100	4.8	---	---
1/2-INCH-DIA. SHELL INTERNAL PLUG ANCHORS: Rawlplug No. 6308	3"	0	---	6.0	2.6
		33-1/3	1.6	6.0	4.4
		66-2/3	3.2	4.8	3.8
		100	3.5	---	---
3/4-INCH-DIA. STUD WEDGE ANCHORS: Star No. 3555-42000	4"	0	---	7.8	5.3
		33-1/3	2.9	5.3	4.2
		66-2/3	5.8	3.4	2.0
		100	7.6	---	---
3/4-INCH-DIA. SHELL INTERNAL PLUG ANCHORS: Molly No. MDI-34	5"	0	---	10.4	4.2
		33-1/3	3.4	9.0	6.5
		66-2/3	6.8	5.6	5.2
		100	7.8	---	---

Notes:

(1) In all combined load tests, a constant shear load (of either 33-1/3% or 66-2/3% of the maximum attained for shear only) was applied first; then an increasing tensile load was applied independently until failure occurred.

(2) In all combined shear/tension load tests, the concrete failed in the shape of a concrete wedge from the vertical face of the MEA (Failure Mode CW).

(3) Dashes indicate non-applicable categories.

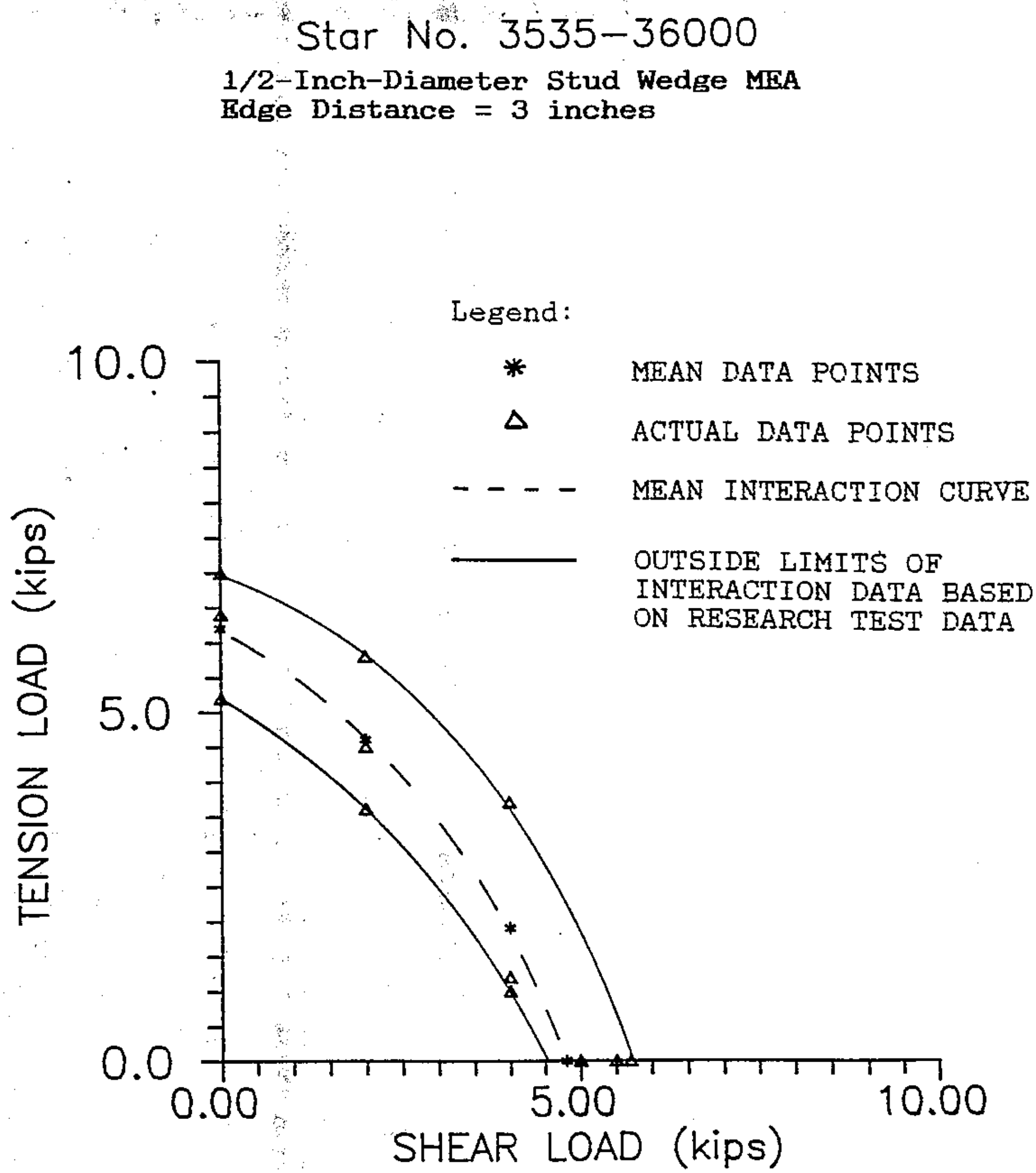


Figure 20. Combined loading interaction curve, 1/2-inch Star stud wedge.

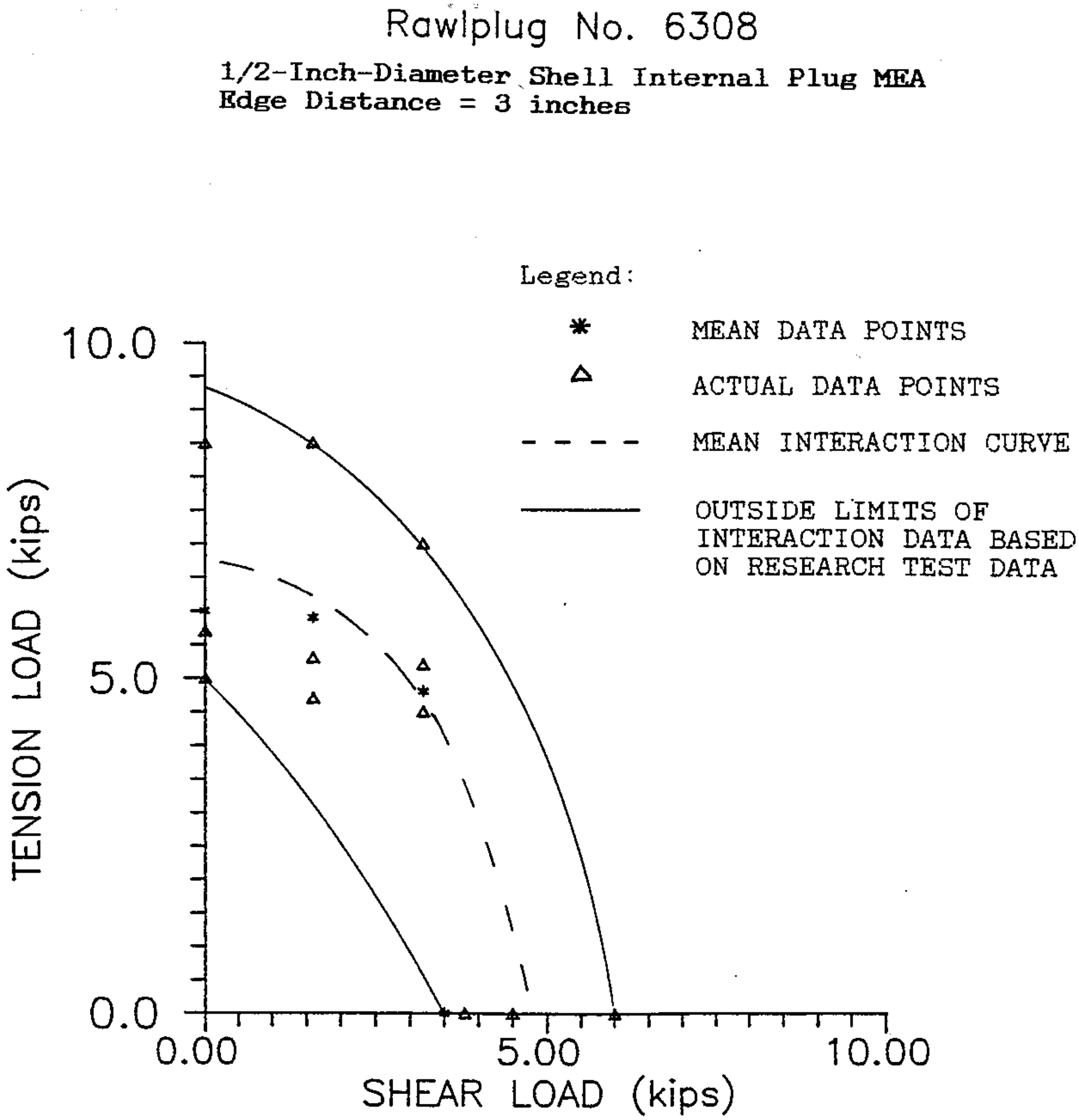


Figure 21. Combined loading interaction curve, 1/2-inch Rawlplug shell internal plug.

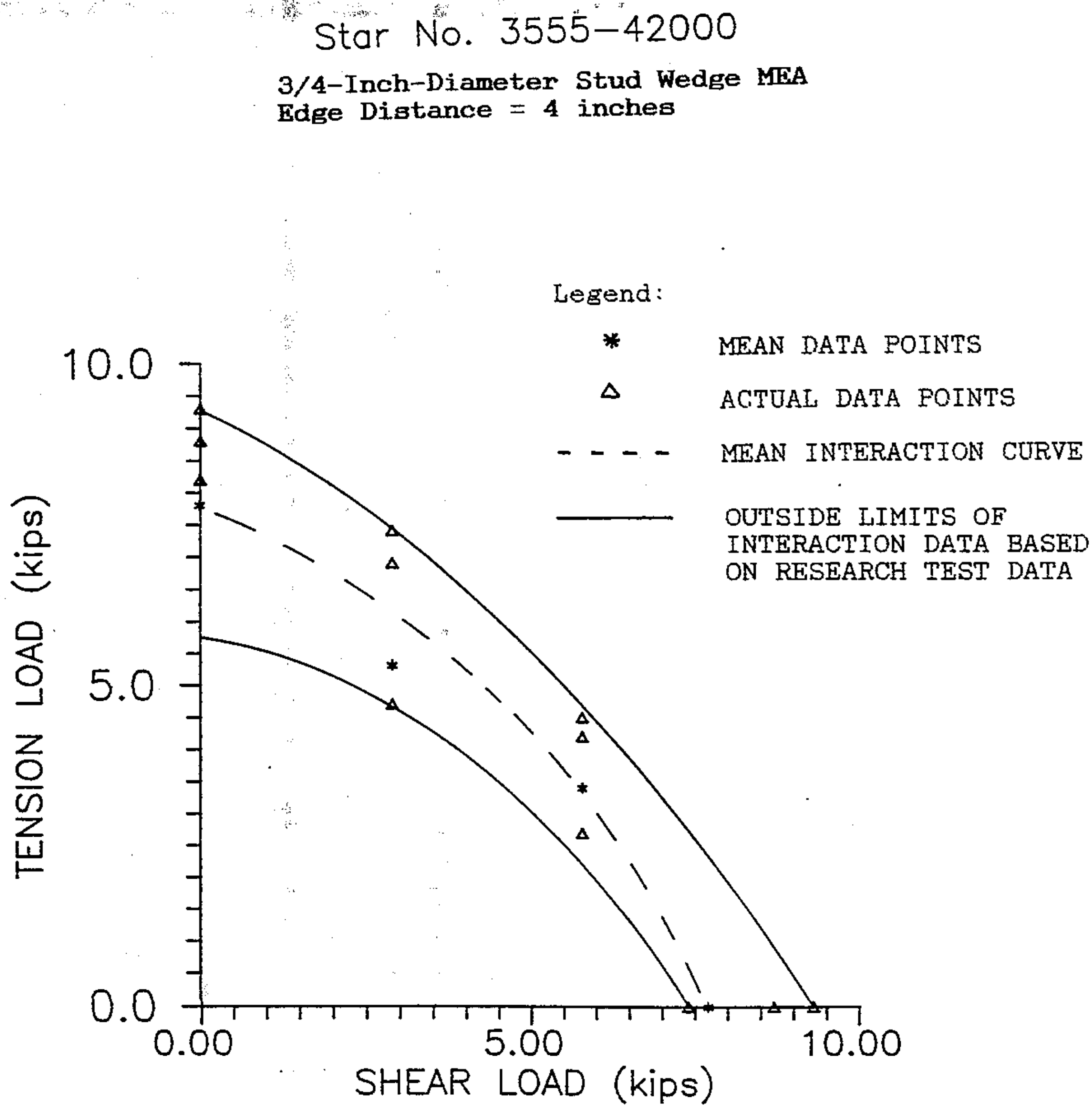


Figure 22. Combined loading interaction curve, 3/4-inch Star stud wedge.

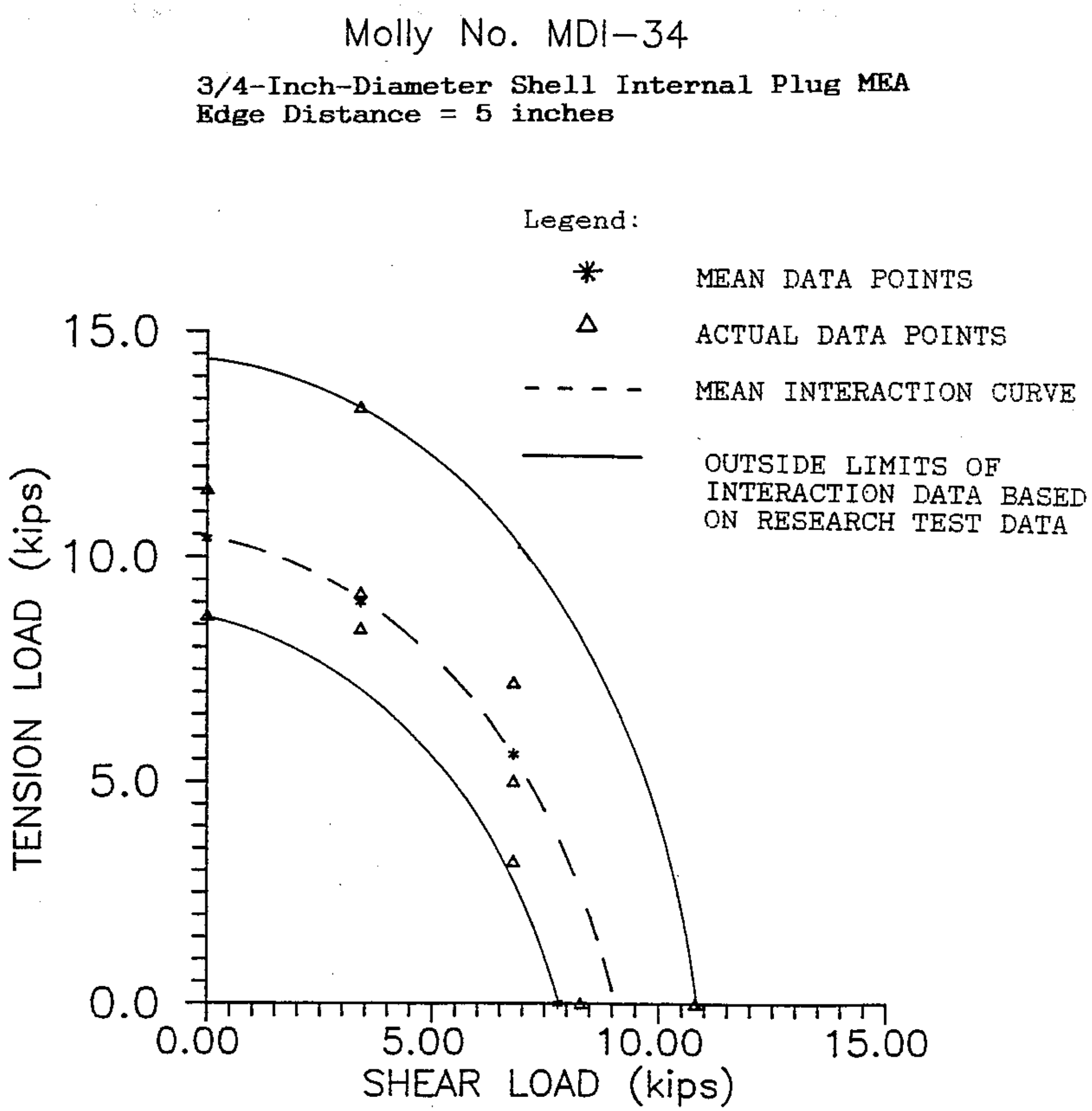
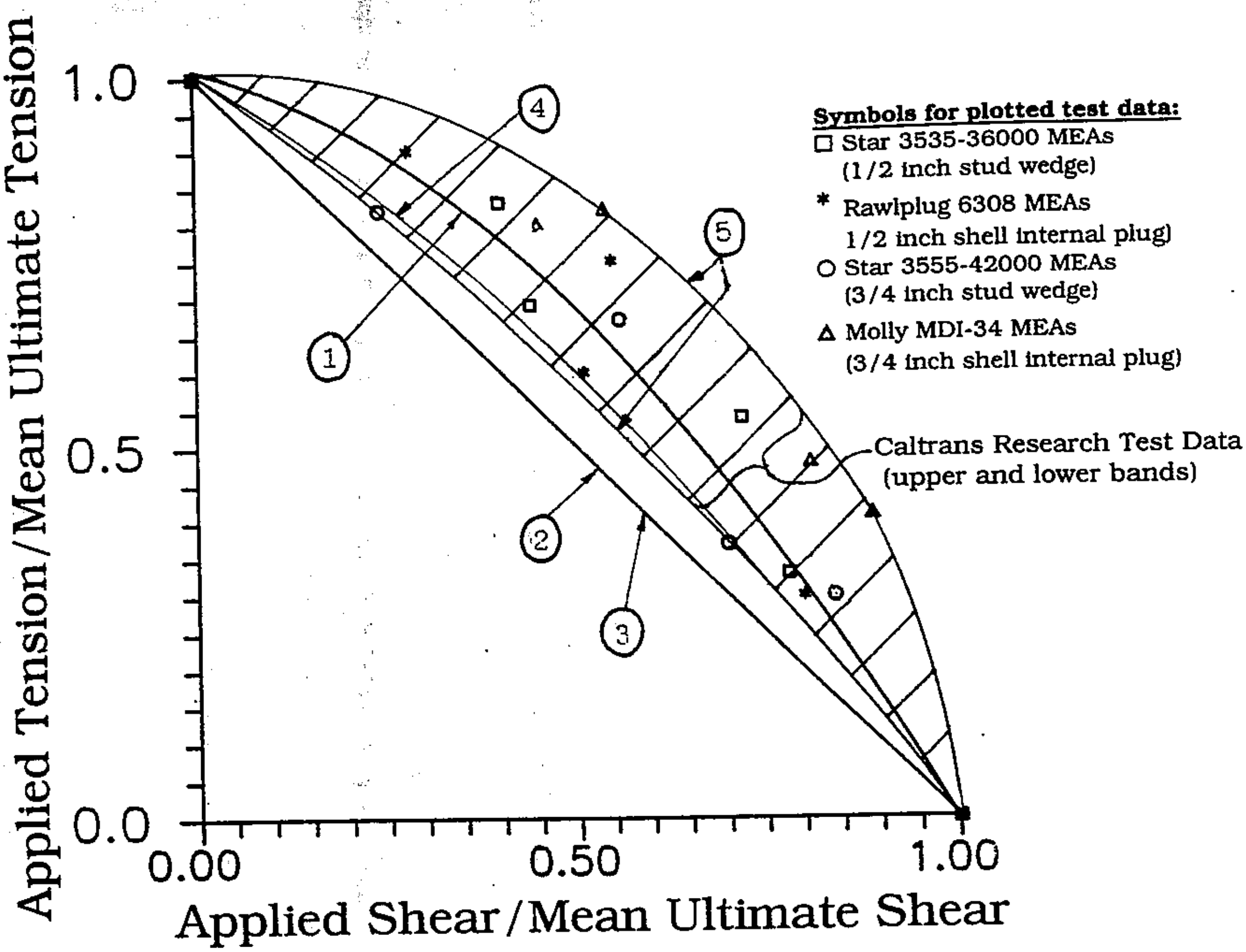


Figure 23. Combined loading interaction curve, 3/4-inch Molly shell internal plug.



Various combined load interaction curves plotted above:

1. Molly Interaction Curve:
   $(T/T_A)^{5/3} + (S/S_A)^{5/3} = 1$ (See Appendix F1)

2. ITW Ramset/Redhead and Hilti Interaction Curves: (See Appendix F1)
   •ITW Ramset/Redhead: $\frac{\text{T applied}}{\text{T allowable}} + \frac{\text{S applied}}{\text{S allowable}} \leq 1$

   •Hilti: $\frac{F_s \text{ applied}}{F_s \text{ allowable}} + \frac{F_t \text{ applied}}{F_t \text{ allowable}} \leq 1$

3. Current Caltrans Design Method:
   $(FSL/S_{DS}) + (FTL/T_{DS}) \leq 1.0$ (See Appendix C3)

4. Prestressed Concrete Institute Curve:
   $(P_u/\phi P_c)^{4/3} + (V_u/\phi V_c)^{4/3} \leq 1$ (See Appendix F1)

5. Caltrans Research Test Data (See plotted data and symbol index above)

Figure 24. Summary of combined loading interaction curves.

Ramset/ Red Head (formerly Phillips) and Hilti (curve 2, Fig. 24), the current Caltrans design curve (curve 3, Fig. 24), and a curve similar to the one recommended by the Prestressed Concrete Institute (8.7) (curve 4, Fig. 24). While the current Caltrans design formula would result in more conservative design values than either the Molly or PCI-like curve, it is apparent that this approach is warranted in this case. The Molly interaction curve falls approximately in the middle of the range of the research test data. The design approach presently used by Caltrans is similar to results obtained from the design curve recommended by the manufacturers ITW Ramset/ Red Head and Hilti. The symbols in the current Caltrans formula represent factored shear and tensile loads instead of actual shear and tensile loads as shown in the ITW Ramset/ Red Head or Hilti interaction curves. A description of factored shear and tension load terms used in the Caltrans design formula can be found in Appendix E.

The purpose of a shear/tension interaction curve is to determine acceptable combinations of shear and tension loads which act simultaneously on MEAs. To use a curve in Figure 24, calculate the decimal value of actual tension (or factored tensile load) to allowable tension and find the appropriate position on the y axis; then proceed horizontally to the intersection with the appropriate interaction curve and then vertically to the x axis intersection to determine the ratio of actual shear (or factored shear load) to allowable shear load. Appropriate formulae which are used to calculate allowable shear and tension loads are included in Appendix F. It would be expected that at edge distances of 12 times the MEA stud diameter, the allowable combined shear and tension loads would be near the maximum permitted for the two types of MEAs tested; allowable combined shear and tension loads would not be expected to exceed those found for edge distances of 12 stud diameters, when edge distances greater than 12 times the MEA stud diameter are encountered.

Slip loads actually increased in approximately one half of the combined loading tests from those determined in independent tests. The changes in slip load ranged from a 41 percent increase to a 62 percent decrease when combined loads were applied.

8. REFERENCES

8.1 California Standard Specifications, Section 75-1.03, pages 75-3 and 75-4, January 1988, California Department of Transportation.

8.2 California Test 681, "Method for Testing Creep Performance of Concrete Anchorage Devices", California Department of Transportation, March 1985.

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

8.4 Dusel, J.P. Jr., "The Evaluation of Mechanical Expansion Anchors Volumes I and II", California Department of Transportation, No FHWA/CA/TL-86/09, July 1986.

8.5 Van Vleck, Lawrence, "Materials For Engineering: Concepts and Applications", Addison-Wesley Publishing Company, Menlo Park, CA, 1982.

8.6 Swirsky, R.A., Dusel, J.P., et al., "Lateral Resistance of Anchor Bolts Installed in Concrete". State of California, Department of Transportation, Office of Transportation Laboratory, Research Report No. FHWA-CA-ST-4167-77-12, May 1977.

8.7 PCI Design Handbook, "Precast and Prestressed Concrete", 2nd edition, Prestressed Concrete Institute, pp 5-24 through 5-26, Chicago, 1978.

8.8 Bridge Design Aids, "Concrete Anchorages", pages 5-81 to 5-92, California Department of Transportation, March 1991.

8.9 Listing of Approved Mechanical Expansion Anchors and Resin Capsule Anchors, California Department of Transportation, Office of Structural Materials, July 8, 1993.

8.10 Caltrans Standard Special Provision 75.50B, T-05-07-90,"Miscellaneous Bridge Metal", California Department of Transportation.

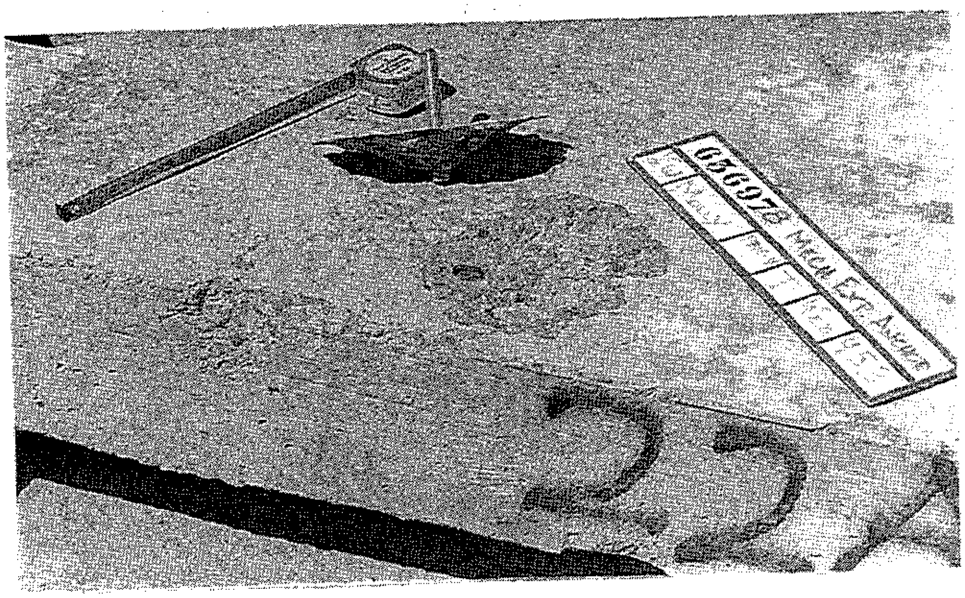
8.11 Hilti's Fastening Technical Guide, Anchor System Section, "Anchor Loading", Page 21, Catalog H-437C-4/91.

8.12 ITW Ramset/ Red Head's Fastening Handbook, "A Technical Manual for Architects and Engineers", General Information Section, Safety Factors, page A6, 1990.

8.13 Molly (Emhart)Fastening Systems Group, Technical Bulliten No. 209, page 1 of 1, 10/76.

9. APPENDICES A THROUGH G

APPENDIX A

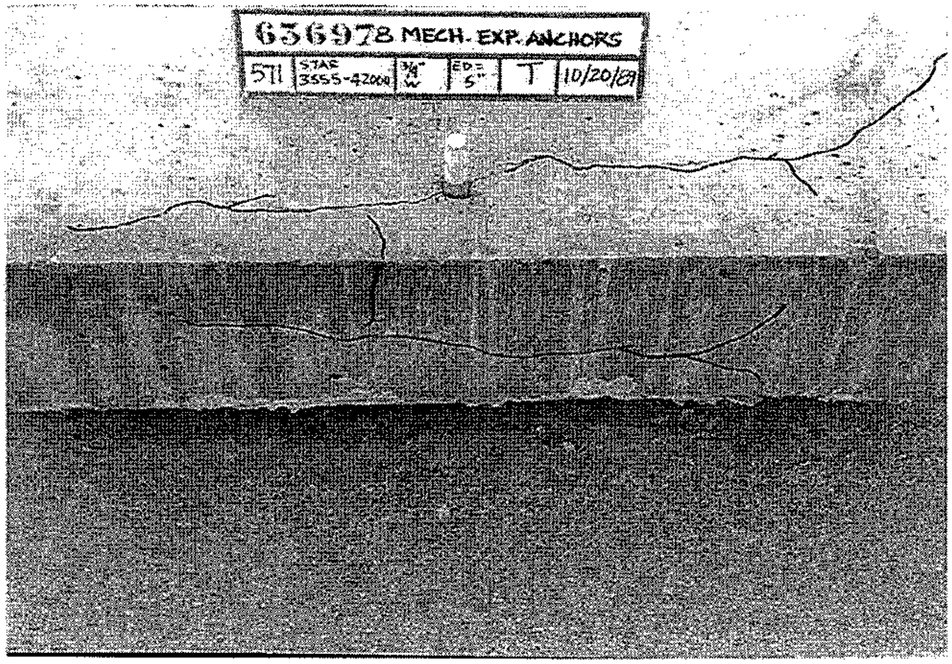


CONCRETE CONE FAILURE (CC)

This type of failure occurs frequently in tension tests; a cone-shaped piece of concrete is pulled from the concrete surface, generally after the anchor has slipped some. The conical piece is generally quite flat (apex angle of 120 degrees or more) and its height is only about 1/2 of the embedment depth of the anchor.

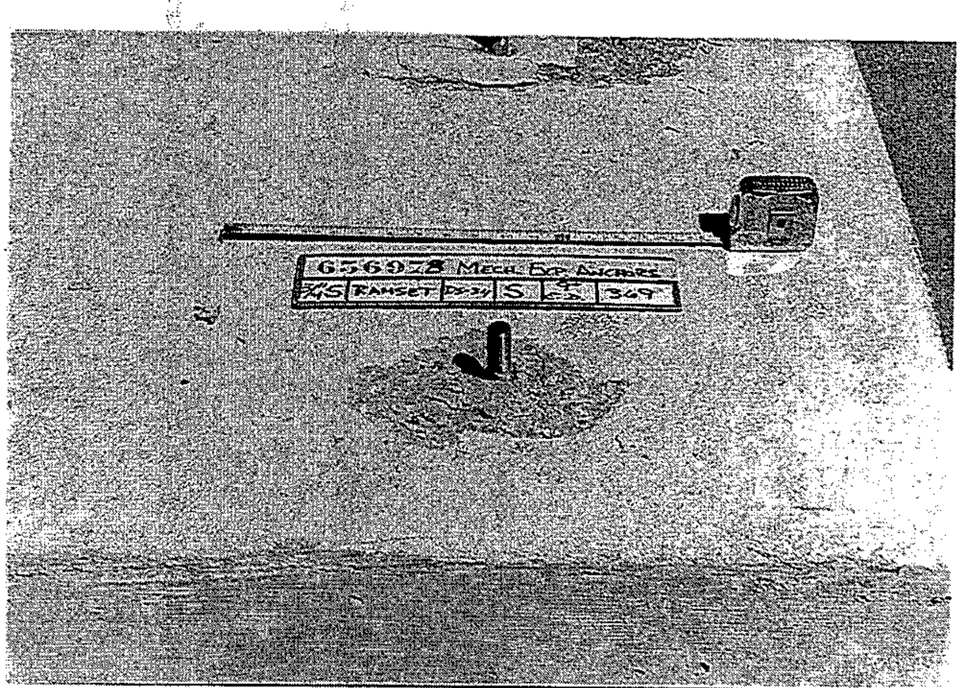
CONCRETE WEDGE FAILURE (CW)

This type of concrete failure is characterized by a wedge of concrete breaking off of the face of the concrete block. It occurs frequently in shear loading when the edge distance is small.



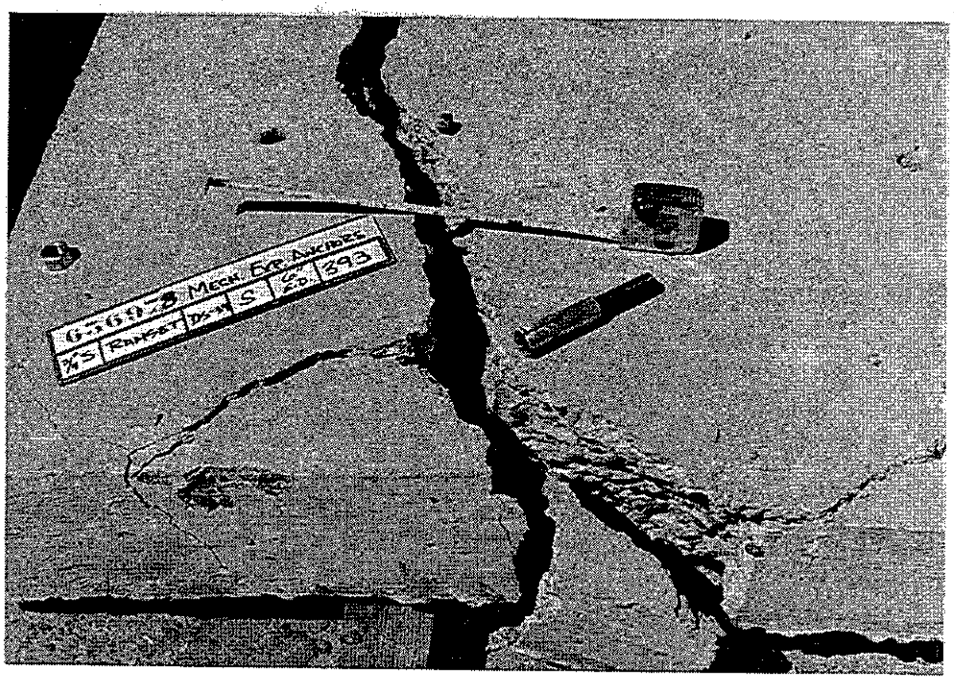
CRACKING OF CONCRETE (CCR)

This mode of failure is characterized by extensive deep cracks in the concrete radiating out from the anchor body. Usually, this failure mode occurs from tensile loading.



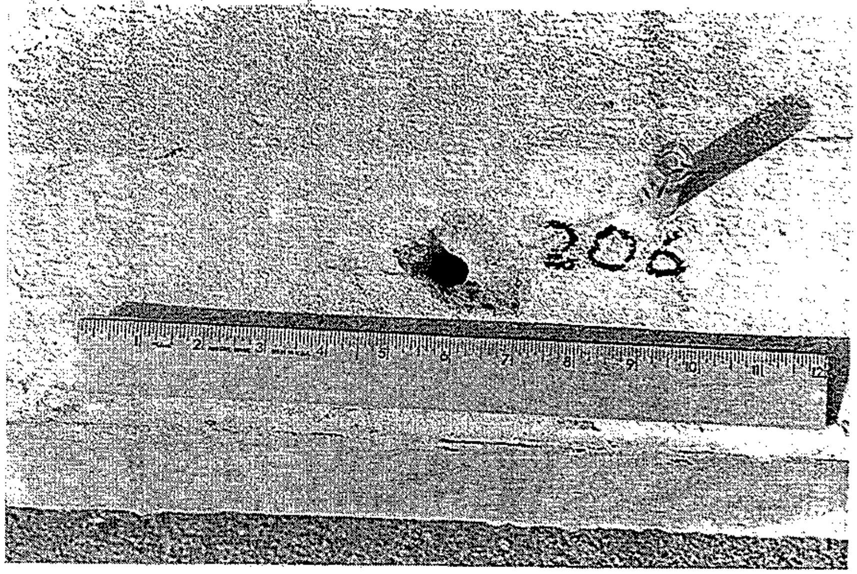
SPALLING (CS)

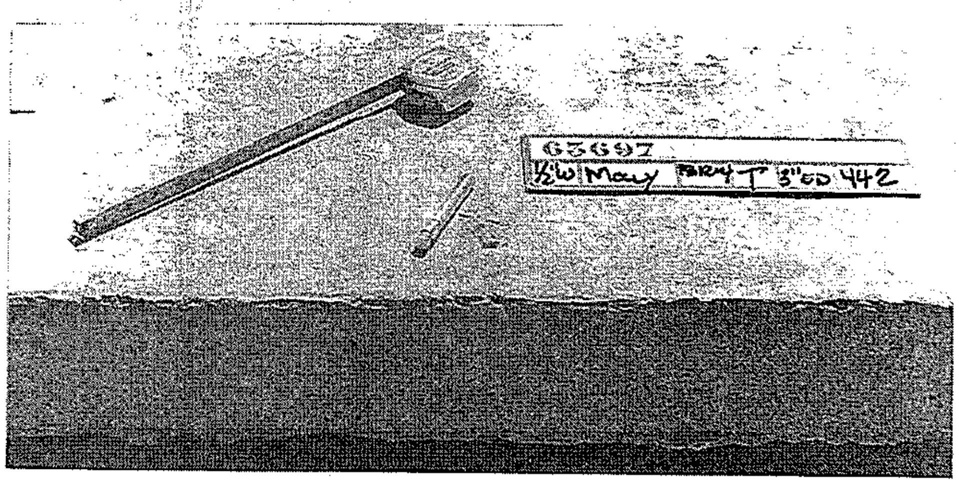
This mode of failure frequently occurs when high tensile loads are applied. It is characterized by initial anchor slippage followed by shallow surface spalling of concrete surrounding the anchor. As a tensile load is increased on the the anchor shaft, the anchor frequently pulls out or breaks.



CATASTROPHIC FAILURE (CF)

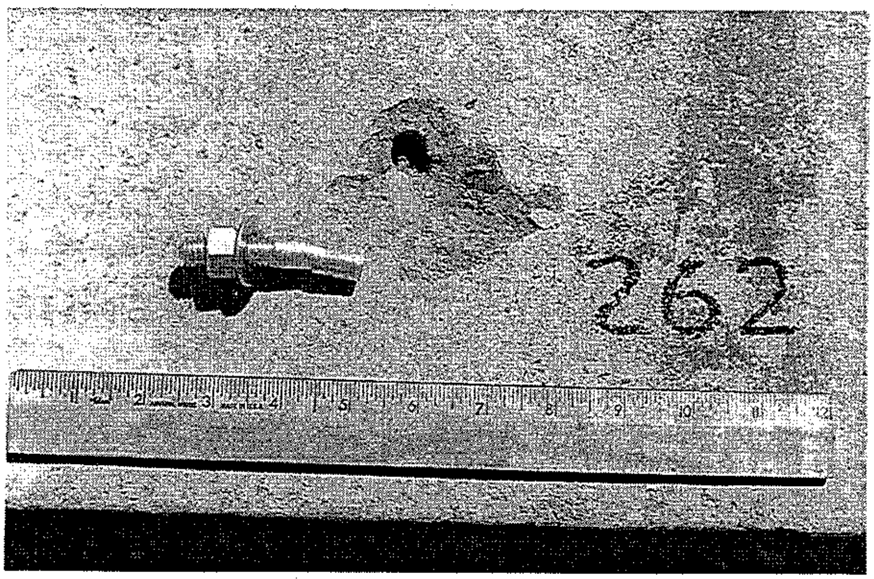
This failure mode is characterized by the concrete slab breaking into large pieces. It frequently occurred while performing shear tests with large diameter anchor studs and large edge distances.





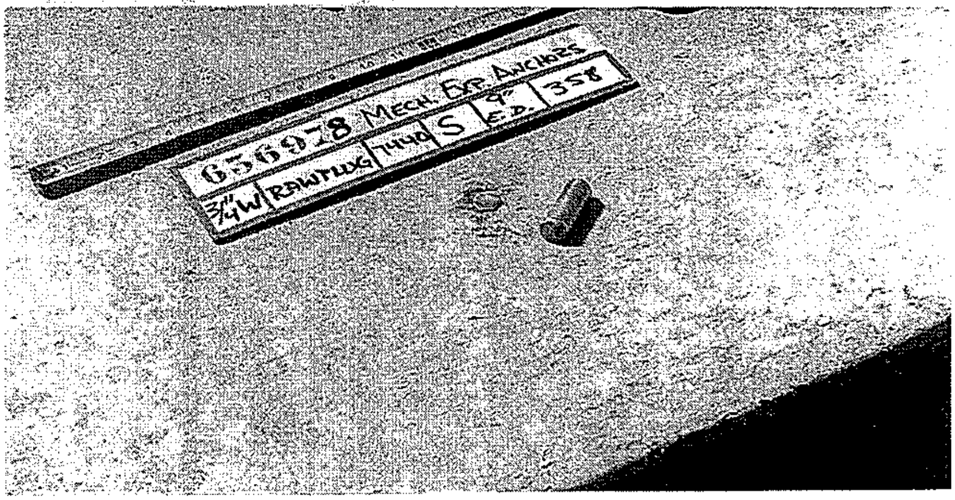
ANCHOR PULL OUT (APO)

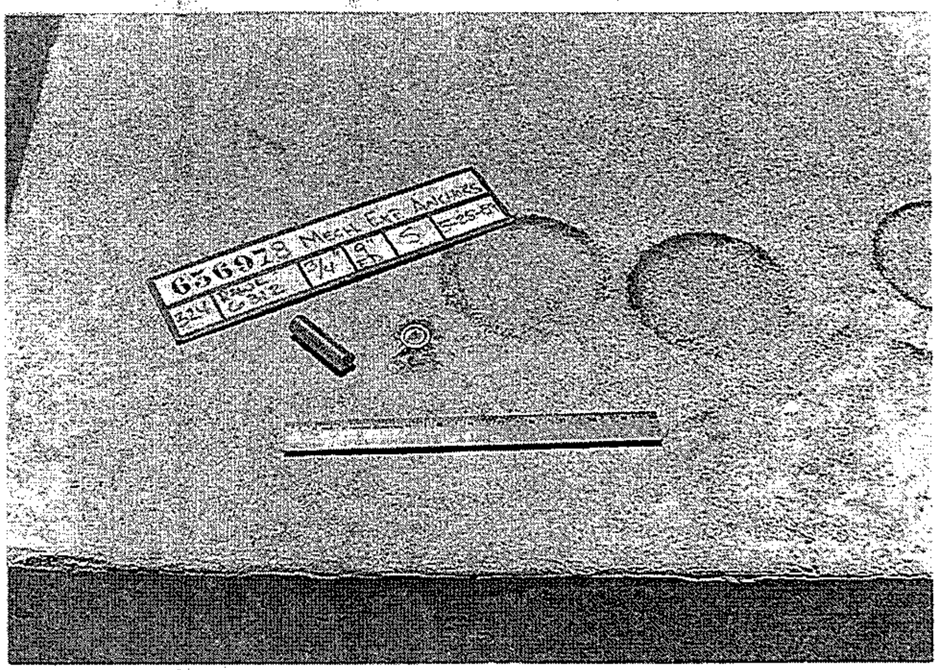
This failure mode occurs occasionally in tension tests on shell-type or stud-type MEAs when the anchor body does not develop adequate frictional resistance with the sides of the concrete hole. When a tensile load is applied, the anchor generally slips at a low load and eventually pulls out of its hole.



ANCHOR BODY FAILURE / STUD-TYPE ANCHOR (AB)

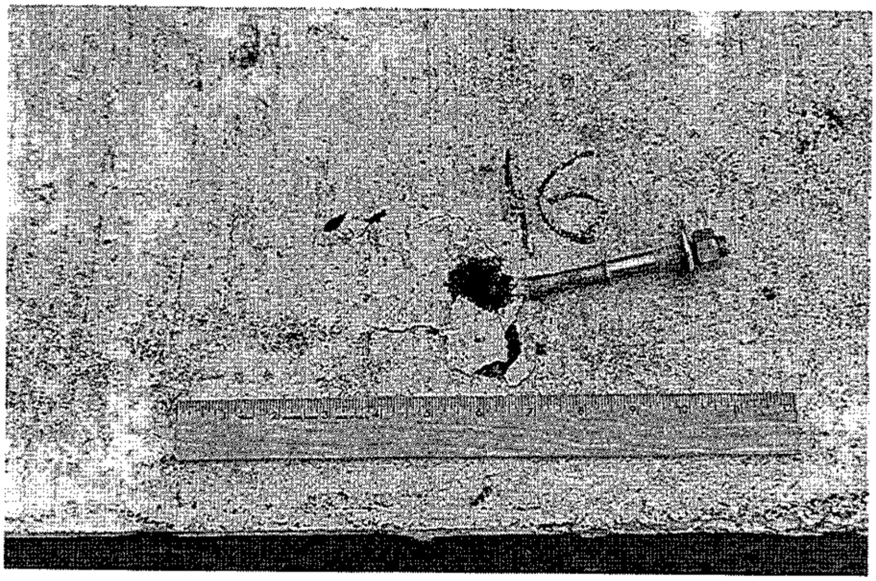
This mode of failure occurs in shear tests with stud wedge-type anchors. The anchor body fails at the point where the diameter of the anchor head is minimal at the top of the cone section.





STUD FAILURE / SHELL-TYPE ANCHORS (AST)

This mode of failure generally occurs in shear tests with either shell-type or stud-type anchors. The threaded stud shears off near the concrete surface. In most cases, this occurs with minimal slippage of the anchor.



STUD WEDGE ANCHOR COLLAR FAILURE (AWC)

This generally occurs in tensile loading in conjunction with other failure modes. With this type of failure, the collar slides off of the base cone during failure.

APPENDIX B

.c2.10-1.__ MISCELLANEOUS BRIDGE METAL;.--Miscellaneous metal shall conform to the provisions in Section 75, "Miscellaneous Metal," of the Standard Specifications and these special provisions.

2*

(Para. 2: List items and components only when not listed in Section 75-1.03. Include anchor bolts for future components paid under other items.)

Miscellaneous metal shall consist of the metal items listed in Section 75-1.03, "Miscellaneous Bridge Metal," of the Standard Specifications, and the following:

____
____
____

3

(Para. 3: Use for deck drain systems.)

Self-tapping screws shall be hex-head, stainless steel or monel metal, installed in holes drilled to fit the self-tapping screws.

4

(Para. 4: Use only when drainage piping will be in box girder cell or encased in concrete. Max. PVC diameter is 8", and max. exposure in cell for PVC is 20'.)

When drainage piping is enclosed in a box girder cell or encased in concrete, the Contractor shall have the option of substituting polyvinyl chloride (PVC) plastic pipe, with the same minimum bend radius as shown on the plans, for welded steel pipe. The polyvinyl chloride (PVC) plastic pipe shall be Schedule 40 conforming to the requirements of ASTM Designation: D 1785. If polyvinyl chloride (PVC) plastic pipe is substituted for welded steel pipe, the quantity of drainage piping will be computed on the basis of the dimensions and details shown on the plans and no change in the quantities to be paid for will be made because of the use by the Contractor of polyvinyl chloride (PVC) plastic pipe.

5

The third subparagraph of the eleventh paragraph of Section 75-1.03, "Miscellaneous Bridge Metal," of the Standard Specifications is amended to read:

5a

(Paras. 5a, 5b and 5c. Use in Climate Area I and II. Refer to Appendix 4C in PS&E Guide for area limits. Delete Paras. 5d and 5e.)

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

5b

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.

5c

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.

5d

(Paras. 5d and 5e. Use in corrosive environments and in Climate Area III. Refer to Appendix 4C in PS&E Guide for area limits. Delete Paras. 5a, 5b and 5c.)

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

5e

All metal parts of the anchorage devices shall be fabricated from stainless steel conforming to the requirements of ASTM Designation: A 276, Type 304 or 316.

Standard Specifications

STATE OF CALIFORNIA

BUSINESS, TRANSPORTATION AND HOUSING AGENCY

DEPARTMENT OF TRANSPORTATION

JULY, 1992

75-1.03 Miscellaneous Bridge Metal.—Miscellaneous bridge

Concrete anchorage devices for attaching equipment or fixtures to concrete shall conform to the following:

Concrete anchorage devices shall be mechanical expansion or resin capsule types installed in drilled holes or cast-in-place insert types. The anchorage devices shall be complete with threaded studs, hex nuts and cut washers. Thread dimensions for externally threaded concrete anchorage devices shall conform to ANSI Standard: B1.1 having a Class 2A tolerance. Thread dimensions for internally threaded concrete anchorage devices shall conform to the requirements in ASTM Designation: A 563.

Mechanical expansion anchors shall be the integral stud type or the shell type with internal threads and an independent stud. Self-drilling mechanical expansion anchors shall not be used.

All metal parts of anchorage devices shall be fabricated from steel, which shall be either corrosion resistant (stainless steel) or be protected with a corrosion resistant coating. The coating shall not have an adverse chemical reaction with concrete.

Mechanical expansion and resin capsule anchors shall, when installed in accordance with the manufacturer's instructions and these specifications and tested in accordance with California Test 681, withstand the application of a sustained tension test load of at least the following values for a period of at least 48 hours with a movement not greater than 0.035-inch: (75-3)

Stud Diameter (inches)	*Sustained Tension Test Load (pounds)*
1 1/4	31,000
1	17,900
7/8	14,400
* 3/4	5,000
5/8	4,100
1/2	3,200
3/8	2,100
1/4	1,000

* Maximum stud diameter permitted for mechanical expansion anchors. (75-4)

Cast-in-place inserts shall, when installed in accordance with the manufacturer's instructions and these specifications, and tested in accordance with California Test 682, withstand the following minimum ultimate tensile loads:

Stud Diameter (inch)	*Ultimate Tensile Load (pounds)*
1	16,000
7/8	11,600
3/4	7,200
5/8	6,600
1/2	4,200

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 one sample of each type of concrete anchorage device, 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.

Concrete anchorage devices shall be installed in the concrete as shown on the plans, as recommended by the manufacturer of the devices, and as specified herein, so that the attached equipment or fixtures will bear firmly against the concrete. Shell type mechanical expansion anchors shall be installed so that the top surface of the anchor body remains 1/2 to one inch below the surface of the concrete after expansion. After installation of shell type mechanical expansion anchors, and prior to mounting any equipment or fixture, the Contractor shall demonstrate in the presence of the Engineer that the expansion anchor is firmly seated within the above tolerances.

If the manufacturer's instructions do not include specific torque requirements, nuts used to attach equipment or fixtures shall be torqued to the following installation torque values in foot-pounds:

Installation Torque Values, (foot-pounds)

Stud Diameter (inches)	*Shell Type Mechanical Expansion Anchors*	*Integral Stud Type Mechanical Expansion Anchors*	*Resin Capsule Anchors and Cast-in-Place Inserts*
11/4	—	—	550
1	—	—	300
7/8	—	—	200
3/4	80	175	135
5/8	35	90	80
1/2	22	50	35
3/8	11	25	15
1/4	4	7	5

(75-5)

DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES
Office of Transportation Laboratory
P.O. Box 19128
Sacramento, California 95819

California Test 681
Revised September 1992

METHOD FOR TESTING CREEP PERFORMANCE OF CONCRETE ANCHORAGE DEVICES

A. SCOPE

This method describes the test procedure to be used for determining the creep performance of various concrete anchorage devices and bonding materials, including rebar dowels or threaded bars bonded with epoxy, resin capsule anchors, and mechanical expansion anchors.

B. DESCRIPTION OF TERMS

Creep—includes all movement associated with the installed concrete anchorage device that occurs while loading in tension and during the sustained tension loading periods, including short-term slip and creep. Elastic deformations are considered small and are also included in overall creep measurements.

C. TESTING APPARATUS

The following testing apparatus is required for evaluating creep:

1. A suitable hammer and setting tool, if required, for installing mechanical expansion anchors.
2. A testing apparatus, similar or equivalent to that shown in Figure 1, designed so that the anchorage device is loaded through a base plate beneath the nut on the threaded shaft of the device. The clear distance between the supports of the testing apparatus in contact with the concrete test slab and the expansion anchor stud shall be 3½ times the embedment depth for depths less than or equal to 6½ inches, and 2 times the embedment depth for depths greater than 6½ inches. The load collar with base plate attached and arms on which indicators are mounted shall be designed and built sufficiently rigid to minimize elastic deflections.
3. A pin or swivel connector near the base of the pull bar linkage to eliminate transfer of bending moment to the anchorage device.
4. A load cell or load monitoring device capable of measuring the external tensile force applied to the pull bar of the testing apparatus to within ±1% of the actual applied load.
5. Two dial indicators, linear variable differential transformers (LVDTs), or other suitable displacement gages per testing apparatus, capable of measuring linear displacement to within an accuracy of ±0.001 inch.
6. A suitable torque wrench.

D. PREPARATION OF TEST SPECIMENS

1. Concrete Test Specimen
   a. Fabricate an unreinforced concrete test specimen having sufficient size to provide adequate edge distance and spacing between anchors, as outlined in D.2.a., and to accommodate anchorage devices being tested. Minimum slab depth shall be the minimum required hole depth (see D.2.b.(3)) plus 4 hole diameters.
   b. Concrete used for the test slab shall contain 564 pounds of "Type II Modified" portland cement per cubic yard, and conform to requirements in Section 90-2.01 of the Caltrans Standard Specifications. The aggregate used shall be rounded or crushed gravel or crushed rock and conform to the 1-inch maximum grading in Section 90-3.04, "Combined Aggregate Gradings". Admixtures shall not be used. The maximum slump shall be 4 inches. Concrete shall be cured by either the water or curing compound method in accordance with the provisions in Section 90-7.03, "Curing Structures". At the beginning of each sustained direct tension test, the concrete shall have an age of not less than 21 days and a compressive strength of not more than 5000 psi.
2. Installation of Anchorage Devices
   a. Locate the hole positions on the concrete test specimen so as to provide a minimum edge distance of 6 hole diameters and a minimum spacing between holes (center to center) of 12 hole diameters.
   b. Drill holes to conform to the following requirements:
      (1) Use an impact rotary hammer drill with a carbide-tipped bit for drilling holes. Use the appropriate drill bit diameter as recommended by the an-

chor manufacturer or required by Caltrans specifications. Dimensions of the carbide tip on the drill bit shall conform to ANSI Specification B94.12.

(2) Drill holes so that their axes are normal to the plane of the concrete surface.

(3) The required hole depth shall be as follows:

— **mechanical expansion anchors**;
- for internally threaded shell drop-in type anchors, the hole depth shall result in the finished installation height of the top of the anchor body being 1/2 inch below the surface of the concrete.
- for integral stud-type anchors, the required hole depth is the minimum depth recommended by the manufacturer.

— **resin capsule anchors**; minimum hole depth small conform to recommendations by the manufacturer.

— **epoxy**; hole depth shall be as recommended by Caltrans.

c. After drilling the hole, remove dust and residue in the hole by blowing out with oil-free compressed air, using an OSHA-approved nozzle. Use of a brush or other instrument to loosen dust particles or water to wash out residual dust in hole is not permitted.

d. Install the anchor using tools and procedures recommended by the manufacturer.

e. Bond two small flat metal bearing plates to the surface of the concrete at an appropriate distance from the anchorage device so as to provide smooth surfaces for the contacts of the dial indicators or LVDTs.

f. Position the load collar with displacement indicators over the protruding stud. Install washer and nut onto the stud and apply appropriate installation torque to the nut using calibrated torque wrench. If the manufacturer of the anchor device has not recommended an installation torque value, the following will be used:

Installation Torque Values, (foot-pounds)

Stud Diameter (inches)	*Shell-Type Mechanical Expansion Anchors*	*Integral Stud-Type Mechanical Expansion Anchors*	*Resin Capsule Anchors, Bonded Dowels*
1¼	—	—	550
1	—	—	300
7/8	—	—	200
3/4	80	175	135
5/8	35	90	80
1/2	22	50	35
3/8	11	25	15
1/4	4	7	5

E. TEST PROCEDURE

1. Install two displacement indicators (LVDTs or dial indicators), one on each end of a rigid arm securely fastened to the load collar of the testing apparatus. Position indicators so as to measure displacements normal to the concrete surface. Tips of the indicators shall rest on bearing plates bonded to the concrete surface. Mount these indicators so that their shafts are equidistant from the concrete anchorage device and are not less than 12 hole diameters apart from each another.
2. Immediately after the required installation torque has been applied to set/preload the anchorage device being tested and indicators have been properly oriented, apply a 100-lb external tensile load to seat components of the testing apparatus. Record each indicator reading and average the two readings to obtain the initial mean indicator measurement.
3. Check the ambient temperature of the concrete test slab. It must be at least 70 °F during the test.
4. Apply the appropriate full sustained tension test load, shown in Section 75-1.03 of Caltrans Standard Specifications, at a uniform rate not to exceed 1000 pounds per minute, within 48 hours of installation of the anchorage device and after curing of any bonding material has occurred. This load shall be applied to the base plate of the test fixture so as to indirectly load the stud of the anchorage device.
5. Read and record each indicator again immediately after the specified sustained tension test load has been applied and average the values.
6. Maintain the sustained tension test load to within ±5% of the required value for the duration of the creep test.
7. Monitor displacement and actual sustained

load for at least 48 hours after applying the full test load. Read and record a minimum of 5 additional sets of displacement values at 2-hour intervals during the last 10 hours of testing. One of the required readings shall be made at 48 hours with the specified sustained tension test load applied. Determine and report the mean value for each set of displacement readings taken.

8. Subtract the 48-hour mean indicator value (E.7) of the fully loaded specimen from the initial mean indicator measurement (E.2) to determine the mean creep value for the anchorage device. Report this value (G.19).
9. At the conclusion of the 48-hour test, unload each anchor until a 100-lb. tension value remains; record and report a final mean displacement value.

F. SAMPLING

1. In order to qualify a particular brand and diameter of anchorage device, three replicate tests per diameter must be performed. For anchorage devices of a given diameter and design, a satisfactory performance for the particular embedment length tested will constitute acceptance of that length as well as all longer manufactured lengths. A satisfactory performance is obtained when all qualification tests performed on an anchorage device pass.
2. When a device fails to pass initial qualification testing, one retest shall be allowed. Double samples are required to be tested (6 replicate tests). If any failure occurs during retesting, the device is rejected and no further testing will be permitted.
3. Any changes in anchor design or materials from what was originally tested will void approval and require retesting.

G. REPORTING OF RESULTS

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

1. Test sponsor and test agency.
2. Dates of testing and report preparation.
3. A listing of observers of the qualification tests with the signature and title of the person responsible for testing.
4. Identification of the anchorage device including manufacturer, type and model number, type of steel used in anchor parts, thickness and type of corrosion protective coating, dimensions, and other pertinent information.
5. The number of specimens tested.
6. The concrete mix design, type of aggregates used in the concrete, and slump of the fresh concrete.
7. The compressive strength of the concrete and age, in days, of the test slab on the date creep testing was begun.
8. A physical description of the test slab including dimensions and method of curing used.
9. Photographs of the test specimen.
10. A drawing and photographs of the testing apparatus.
11. A description of the procedure, installation tools, and materials used to install the anchorage device, including installation torque.
12. The diameter of the carbide tip on the drill bit used, if required.
13. The depth of the drilled hole.
14. The depth of embedment of the anchorage device.
15. The length of time, in hours, from the installation of the anchorage device to the application of the sustained tension test load.
16. The temperature of the concrete slab during the creep test.
17. A description of the procedure used to apply and maintain the sustained tensile test load and actual rate of loading used.
18. A plot of mean indicator displacement values and corresponding tension loads as required per E.2, E.5, E.7 and E.9 with their respective elapsed test times.
19. The mean creep value for the anchorage device (E.8).

End of Test (3 pages) of Test 681

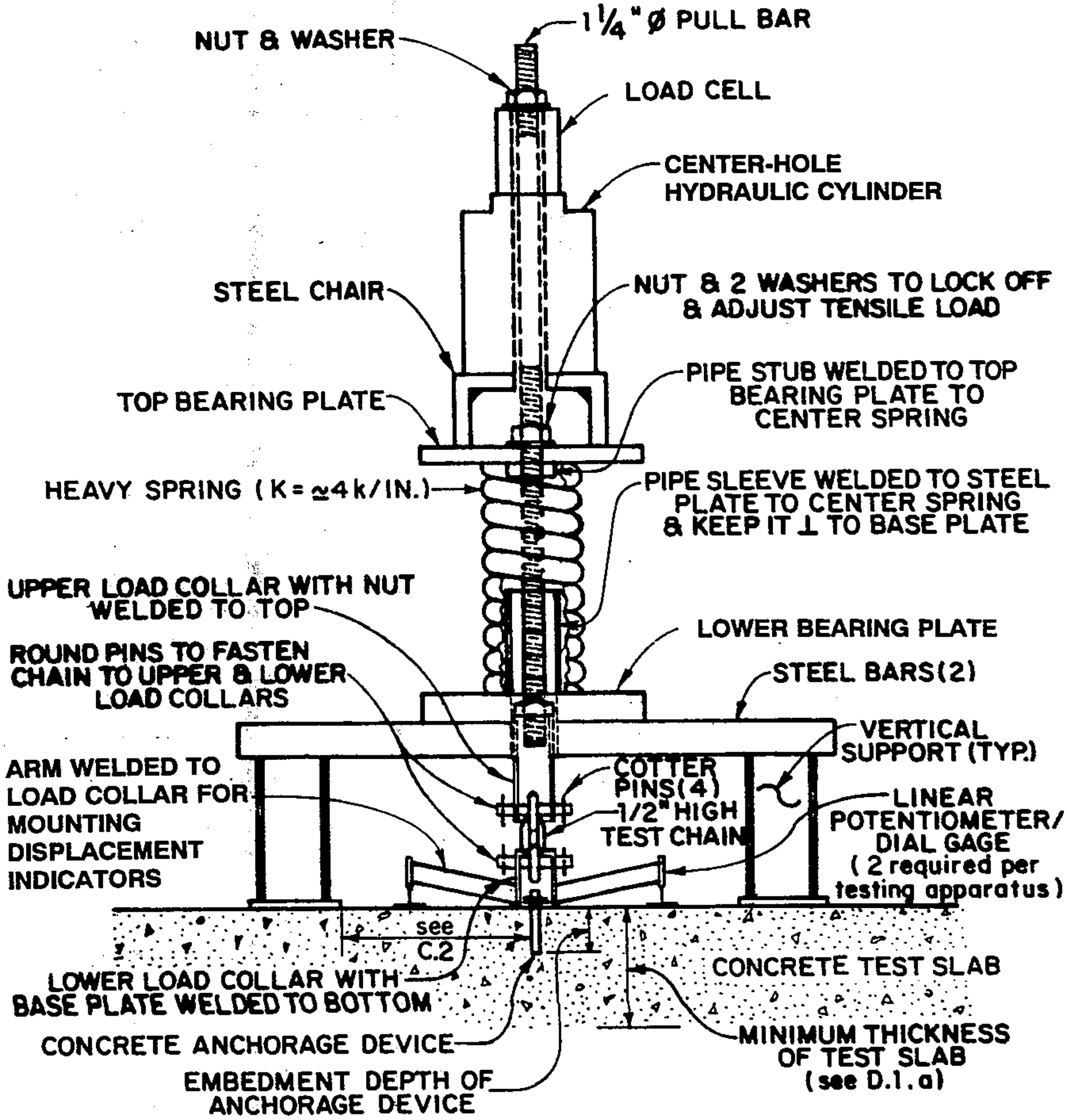


FIG. 1. EXAMPLE OF A SUITABLE CREEP TESTING APPARATUS

APPENDIX C

CALTRANS BRIDGE DESIGN AIDS, SECTION 5.A.1, <u>MECHANICAL EXPANSION ANCHORS</u>, PAGES 5-81 THROUGH 5-83

Anchorage to Concrete

Steel-to-concrete or concrete-to-concrete connections can be accomplished in various ways. This design aid has been prepared to describe the most widely used anchorage systems available and to assist the designer in selecting the system that is best suited for a particular application.

Loading and Design Requirements:

The design provisions of this design aid are based on the Load Factor Design method. Principles and requirements of the Bridge Design Specifications are applicable for all load combinations except as modified herein.

The designer is to determine the loading combinations and the corresponding load factors for each application.

A. Anchoring Into Existing Concrete

1. Mechanical Expansion Anchors

Mechanical expansion anchors (MEAs) are easy-to-use, readily available anchorage devices. MEAs are frequently used to anchor minor or temporary attachments such as signs, brackets, inspection ladders, safety railings, utility pipes, light fixtures, etc., to hardened concrete.

Material and installation methods of MEAs must comply with the requirements of section 75-1.03 of the Standard Specifications. Figure A.1 shows the only two types of MEAs that have been tested and approved by Translab.

a) Shell anchors with internal threads require an independent stud, nut, and washer. This type is stronger in tension.
b) Integral stud anchors are furnished with a nut and cut washer. This type is easier to install in a multi-hole base plate and is stronger in shear.

While the self-drilling variety of the shell anchors are not approved, other types of MEAs may be acceptable with prior testing. Resin capsule anchors (as discussed in a later section) may also be used as an alternative to MEAs.

Table A.1 lists the shear and tensile design strengths of shell and stud-type MEAs. When loaded in tension, these types of MEAs do not develop the yield strength of the stud. Instead, they generally fail by initial slipping followed by a concrete cone failure. Yield strength is then defined as the force after which the stud will slip at a higher rate as the load increases. The design strengths listed in Table A.1 include the strength reduction factor Φ.

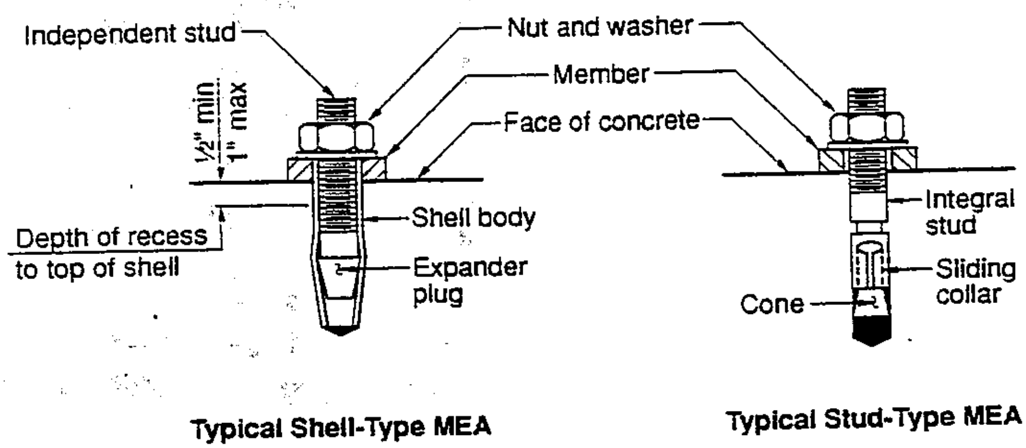


Figure A.1 – Common Types of Mechanical Expansion Anchors (MEA)

Table A.1 – Design Data for Shell and Stud-Type Mechanical Expansion Anchors

Stud diameter, inches	Shear strength, kips	Tensile strength, kips
¼	0.4	0.4
⅜	0.8	1.0
½	1.5	1.1
⅝	2.1	2.1
¾	2.4	2.4

The designer should take the following items in consideration when selecting Mechanical Expansion Anchors:

a) Design strengths shown in Table A.1 are for static load conditions only; when dynamic loading governs or for critical applications such as installations over traffic, resin capsule anchors, or grouted or bonded anchors are recommended.
b) Design strengths shown above are based on normal weight concrete having f'_c = 4000 psi: for f'_c = 3250 psi, multiply values by 0.85; for f'_c = 5000 psi multiply values by 1.17. For light weight concrete and other special conditions consult with Translab.
c) If a single MEA is used to hold an attachment, the design strengths allowed in Table A.1 should be reduced by one-half.

d) For both tension and shear, MEAs are considered 100% effective at edge distances of 6 hole diameters or greater (for this purpose the hole diameter can be considered equal to the nominal diameter of the stud plus ⅛"). Edge distance can be reduced down to 3 hole diameters if the design strength is also linearly reduced to 50%.

e) MEAs are considered 100% effective at centers-to-center spacings of 12 hole diameters or greater. Spacings can be reduced down to 6 hole diameters if the design strength is linearly reduced to 50%.

f) When combined loading is present

$$\frac{\text{Factored Shear Load}}{\text{Shear Design Strength}} + \frac{\text{Factored Tensile Load}}{\text{Tensile Design Strength}} \leq 1.0$$

g). To insure proper seating of shell type MEAs, the top of the shell body is recessed from ½ to 1 inch below the concrete surface, and an independent threaded stud rather than a headed bolt is required.

h) In corrosive environments, it is advisable to specify other anchorage systems. There is no pre-approved type of MEA for this environment. Stainless steel MEAs should be used only when approved on a job-by-job basis.

i) Because shell and stud-type MEAs cannot develop the yield strength of the stud, Caltrans limits the size of most MEAs to ¾ inches and the use to light applications. Sufficient concrete depth should be provided beneath the MEA assembly so that the driving force can be resisted during anchorage seating.

j) Figure A.2 shows a typical detail for MEAs to be used in the plans. The designer should indicate the size required. The plans should not show the depth or diameter of the hole.

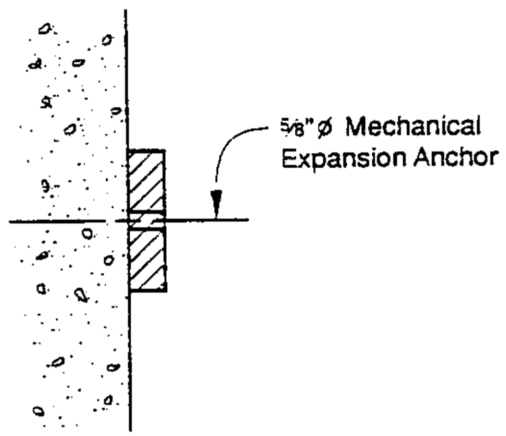


Figure A.2 – Typical Detail for MEA

APPENDIX D

SAMPLE OF DATA FOR DETERMINING COMPRESSIVE STRENGTH OF TYPICAL CALTRANS CLASS A CONCRETE

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
TRANSPORTATION LABORATORY

REPORT OF TEST ON
PORTLAND CEMENT CONCRETE

PR7

str-M+I's

SOURCE	EXPENDITURE AUTHORIZATION	SPECIAL DESIGNATION	ACTIVITY or OBJECT	AMOUNT
653214	636978		125	

CONTRACT NO. 65-636978 — RESIDENT ENGR. % PAUL REILLY

~~Structures~~ Dept. Rep. % BETH WEMPLE — Phone: 2317

TEST BY	DATE OF TEST	SAMPLE NO.	AGE	SKS / C.Y.	AREA OF CYL	TOTAL LOAD	LBS. PER SQ. IN. IND. CYL.	LBS. PER SQ. IN. IND. TEST*	CK BY
pm	10-27	2-8-1/2	8		283	96250	3400	3400	DS
		2-8-2/2 (64)			–	96000	3390		
pm	11-30	2-42-1/3	42		✓	115750	4090	4250	[illegible]
		✓ ✓ 2/3 (01)			✓	122500	4330		
		✓ ✓ 3/3			✓	122750	4340		
pm	12-7	2-63 1/3 (02)	(49) 63		✓	130000	4590	4740	[illegible]
		✓ 2/3 ✓			✓	137500	4860		
		✓ 3/3 ✓			✓	135250	4780		
pm	12-14	2-70-1/3 (06)	(56) 70		✓	123750	4370	4710	[illegible]
		✓ 2/3 ✓			✓	136250	4810		
		✓ 3/3 ✓			✓	140000	4950		
pm	12-19	2-75 1/3 (08)	(61) 75	✓	✓	140500	4960	4740	[illegible]
		✓ 2/3 ✓			✓	129750	4580		
		✓ 3/3 ✓			✓	132250	4670		
pm	12-21	2-63-1/2 (09)	63		✓	138250	4890	4950	[illegible]
		✓ ✓ 2/2			✓	142000	5020		

*Individual test is an average of 2 cylinders. ATSS. 497-2337
Reported By CONCRETE SECTION (916) 739-2337
Refer correspondence and calls to

E. C. SHIRLEY, Chief
TRANSPORTATION LABORATORY
By D.A. WONG

TL-507 (Rev. 11/86)

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION No. 102009
SAMPLE CARD
Field Sample of Portland Cement Concrete

DEC 21 1989 Contr. No. 636978
Fed. No.
Dist. LAB Co. Rt. P.M.
Limits of Work
DETER F'C
Res. Eng. or Supt.
Address
Contractor
Source of Materials:
Cement ATC Certificate No.
Fine Aggregate
Coarse Aggregate

Field Sample No.
Size of Specimen—Inches
Date Cast 10-19 [redacted]
Cement—Sacks per Cu. Yd.
Percent Air
Kelly Ball Penetration
Water—lbs. per Sack
Sampled From
Admixture

Remarks: BREAK ON 12-21

Sampled by REILLY Title PR7
ENCLOSURE WITH SAMPLE

APPENDIX E

EXPLANATION OF LOAD FACTOR DESIGN

1.16.1 LOAD FACTORS

An essential feature of LFD, as stated in 1.0.2, Design Methods, requires raw design loads or related internal moments and forces to be modified by specified load factors (γ, gamma and β, beta), and computed material strengths to be reduced by specified reduction factor (ϕ , phi).

These are safety factors which ensure certain margins for variation. The three different kinds of factors are each set up for a distinct purpose, each independent of the other two. In this way, any one of them may be refined in the future without disturbing the other two.

1.16.2 γ (Gamma) FACTOR

The γ (gamma) factor is the most basic of the three. It varies in magnitude from one load combination to another, but it always applies to all the loads in a combination. Its main effect is stress control that says we do not want to use more than about 0.8 of the ultimate capacity. Its most common magnitude, 1.3, lets us use 77%. Earthquake loads are not factored above 1.0 because we recognize that stresses in the plastic range are allowed, as long as collapse does not occur.

An example may be given to justify the use of gamma of 1.3 for dead load.* Assuming the live load being absent, the probable upper value of the dead load could be a minimum of 30% greater than calculated. For a simple structure this percentage may be as follows:

10% due to excess in weight.
5% due to misplaced reinforcement.
5% approximation in behavior of structure.
10% increase in stress, actual compared with calculated.
30% Total variation assumed to occur concurrently at the section most heavily stressed.

*" Notes on Load Factor Design for Reinforced Concrete Bridge Structures with Design Applications" by Portland Cement Association, Page AB-9.

1.16.3 β (Beta) FACTOR

The second factor, β (beta), is a measure of the accuracy with which we can predict various kinds of loads. It also reflects the probability of one load's simultaneous application with others in a combination. It applies separately, with different magnitudes, to different loads in a combination. For example, it is usually 1.0 for dead load. It varies from 1.0 to 1.67 for live loads and impact.

Due regard has been given to sign in assigning values to beta factors, as one type of loading may produce effects of opposite sense to that produced by another type. The load combinations with $\beta_D = 0.75$ are specifically included for the case where a higher dead load reduces the effects of other loads.*

The beta factors for prestressing force effects are set so that when multiplied by the respective gamma factor, the product is unity. Beta of 1.67 for live load plus impact from H loads reflects AASHTO's way of handling permit loads; the 1.00 and 1.15 for P loads reflect the Caltrans' way. (Both must be satisfied.) The extra 0.15 for P loads on widely spaced girders accounts for bonuses sometimes granted in Caltrans' permits.

1.16.4 ϕ (Phi) Factor

ϕ(phi), the third factor, relates to materials and is called either a capacity reduction factor or a strength reduction factor. Its purpose is to account for small adverse variations in material strength, workmanship, and dimensions. It applies separately to different materials, with different magnitudes for various load effects in reinforced concrete, and for various manufacturing processes in prestressed concrete. Since ϕ relates to materials rather than loads, its values are given in the various material specifications. For structural steel it is almost always 1.0. For concrete it varies from 0.7 to 1.0.

* Commentary on Building Code for Reinforced Concrete (ACI 318-77), Page 33.

APPENDIX F

TYPICAL DESIGN FORMULAE FOR DETERMINING ALLOWABLE COMBINED SHEAR AND TENSION LOADS ON MECHANICAL EXPANSION ANCHORS

1. **Hilti** (see reference 8.10):

$$\frac{F_s \text{ Applied}}{F_s \text{ Allowable}} + \frac{F_t \text{ Applied}}{F_t \text{ Allowable}} \leq 1$$

where: F_s = Shear load
F_t = Tension load

2. **ITW Ramset/ Red Head** (see reference 8.11)

$$\frac{T \text{ applied}}{T \text{ allowable}} + \frac{S \text{ applied}}{S \text{ allowable}} \leq 1$$

where: T = tension load
S = shear load

3. **Molly** (see reference 8.12)

$$(T/T_a)^{5/3} + (S/S_a)^{5/3} = 1$$

where: T = applied tensile load
T_a= maximum allowable tensile load (see Molly chart)
S = applied shear load
S_a= Maximum allowable shear load (see Molly chart)

4. **Prestressed Concrete Institute** (see reference 8.7)

$$(P_u/\phi P_c)^{4/3} + (V_u/\phi V_c)^{4/3} \leq 1$$

where: P_u = factored tension load
P_c = nominal tensile strength of concrete
V_u = factored shear strength
V_c = nominal shear strength of concrete
ϕ = strength reduction factor

APPENDIX G

SUMMARY GRAPHS OF TEST DATA

APPENDIX G

Figures G1 - G24

Graphs of Shear and Tension Test Data

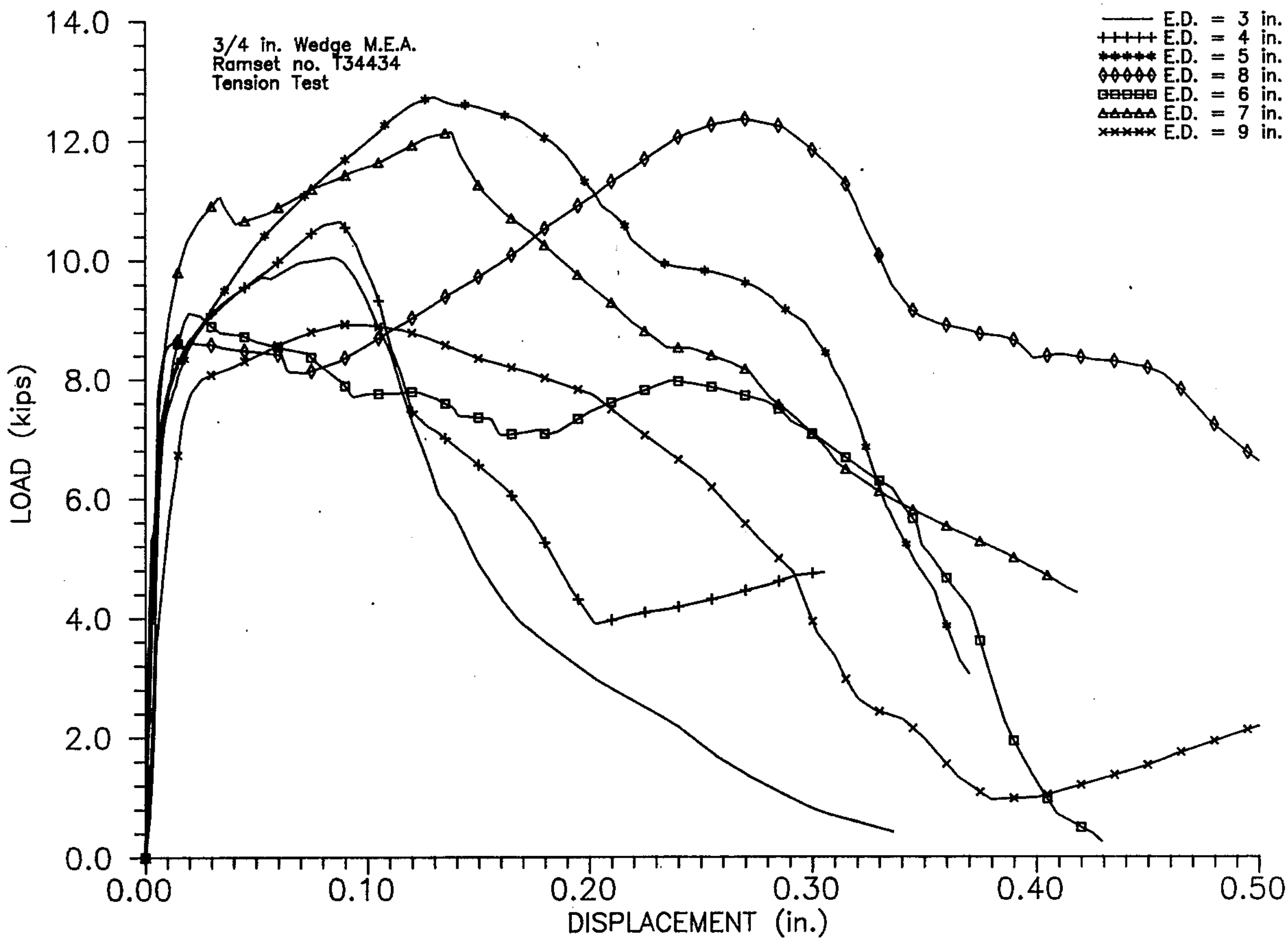


Figure G1. Average load vs. displacement for short term tensile tests at varying edge distances.

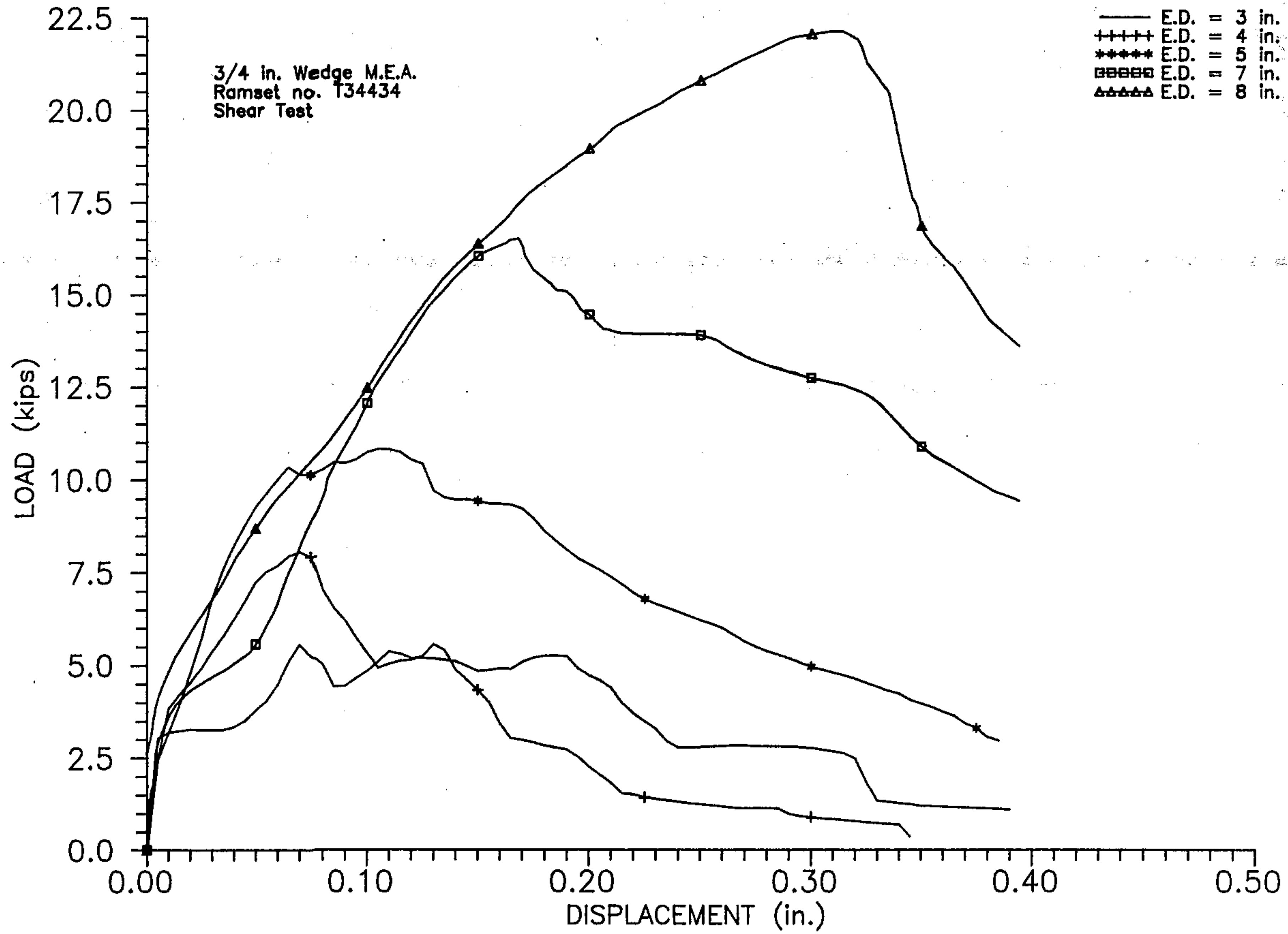


Figure G2. Average load vs. displacement for short term shear tests at varying edge distances.

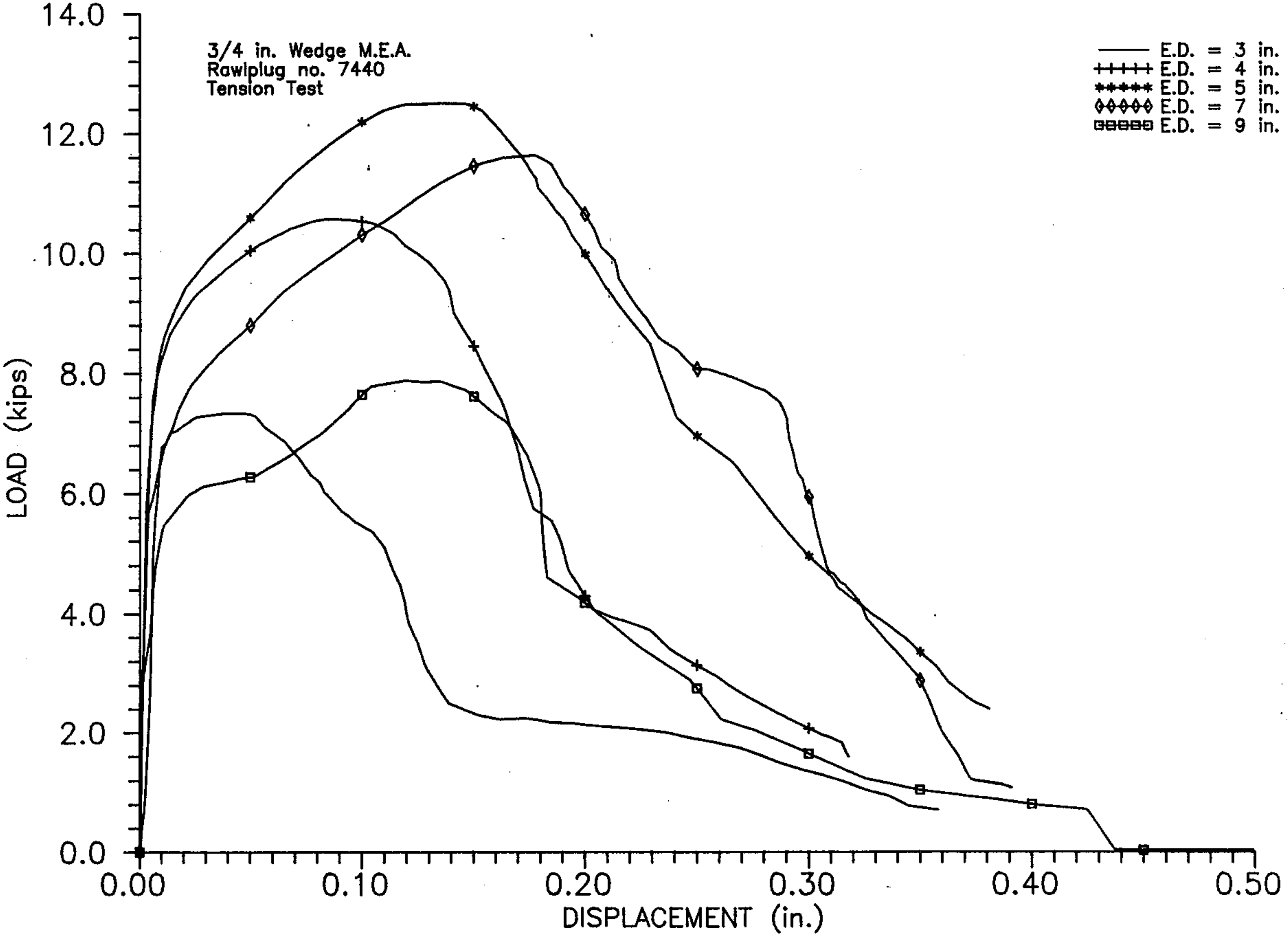


Figure G3. Average load vs. displacement for short term tensile tests at varying edge distances.

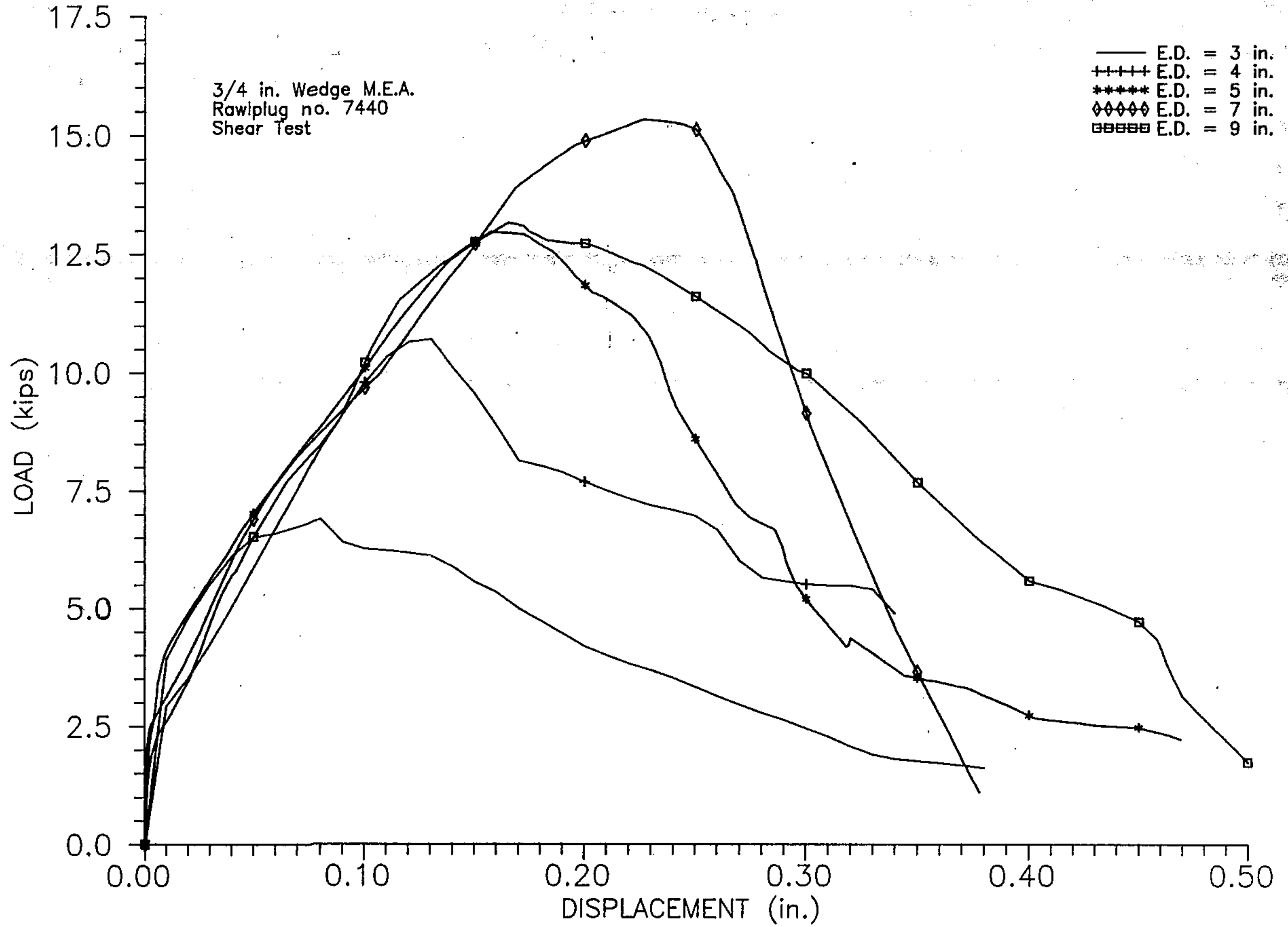


Figure G4. Average load vs. displacement for short term shear tests at varying edge distances.

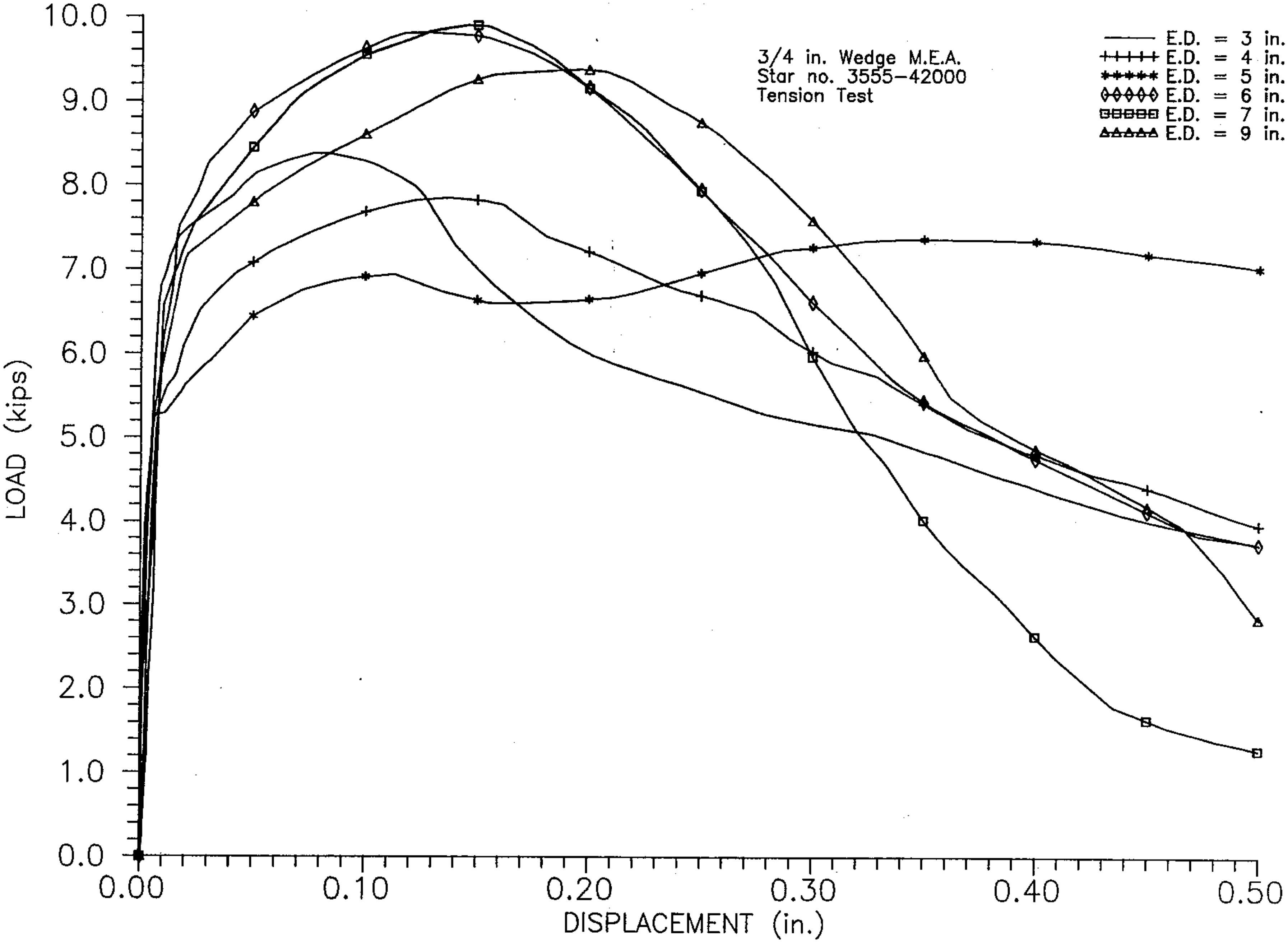


Figure G5. Average load vs. displacement for short term tension tests at varying edge distances.

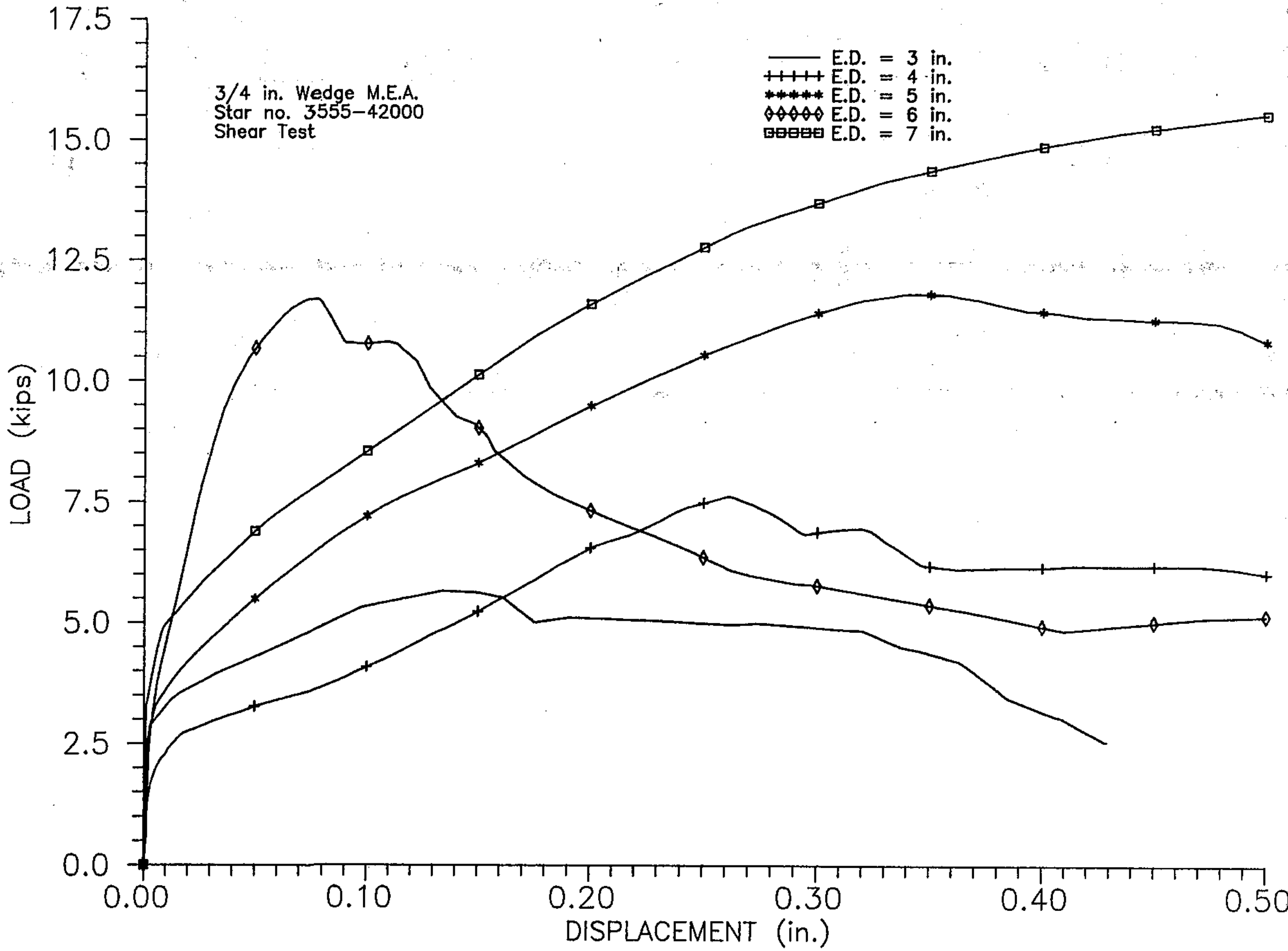


Figure G6. Average load vs. displacement for short term shear tests at varying edge distances.

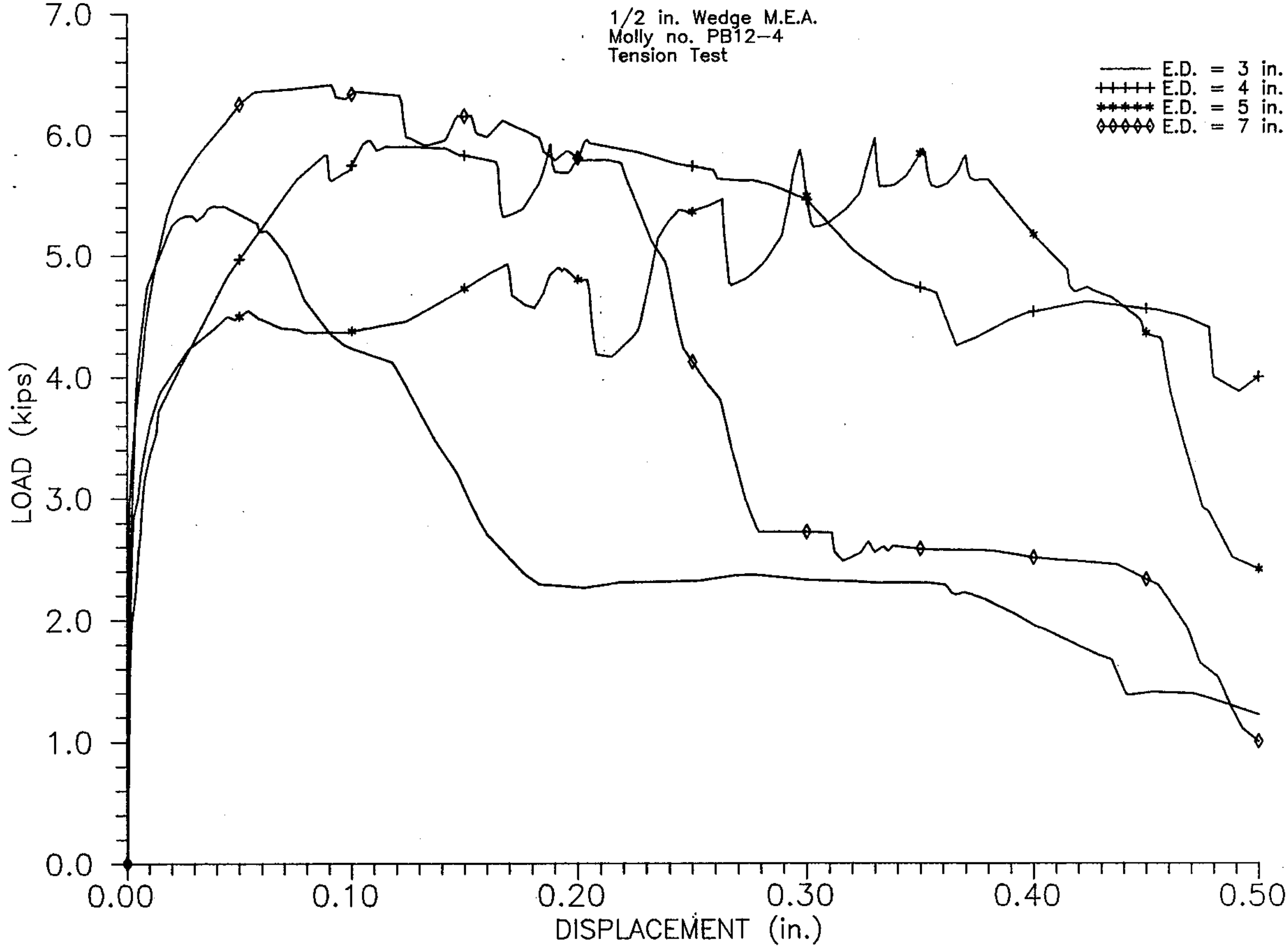


Figure G7. Average load vs. displacement for short term tension tests at varying edge distances.

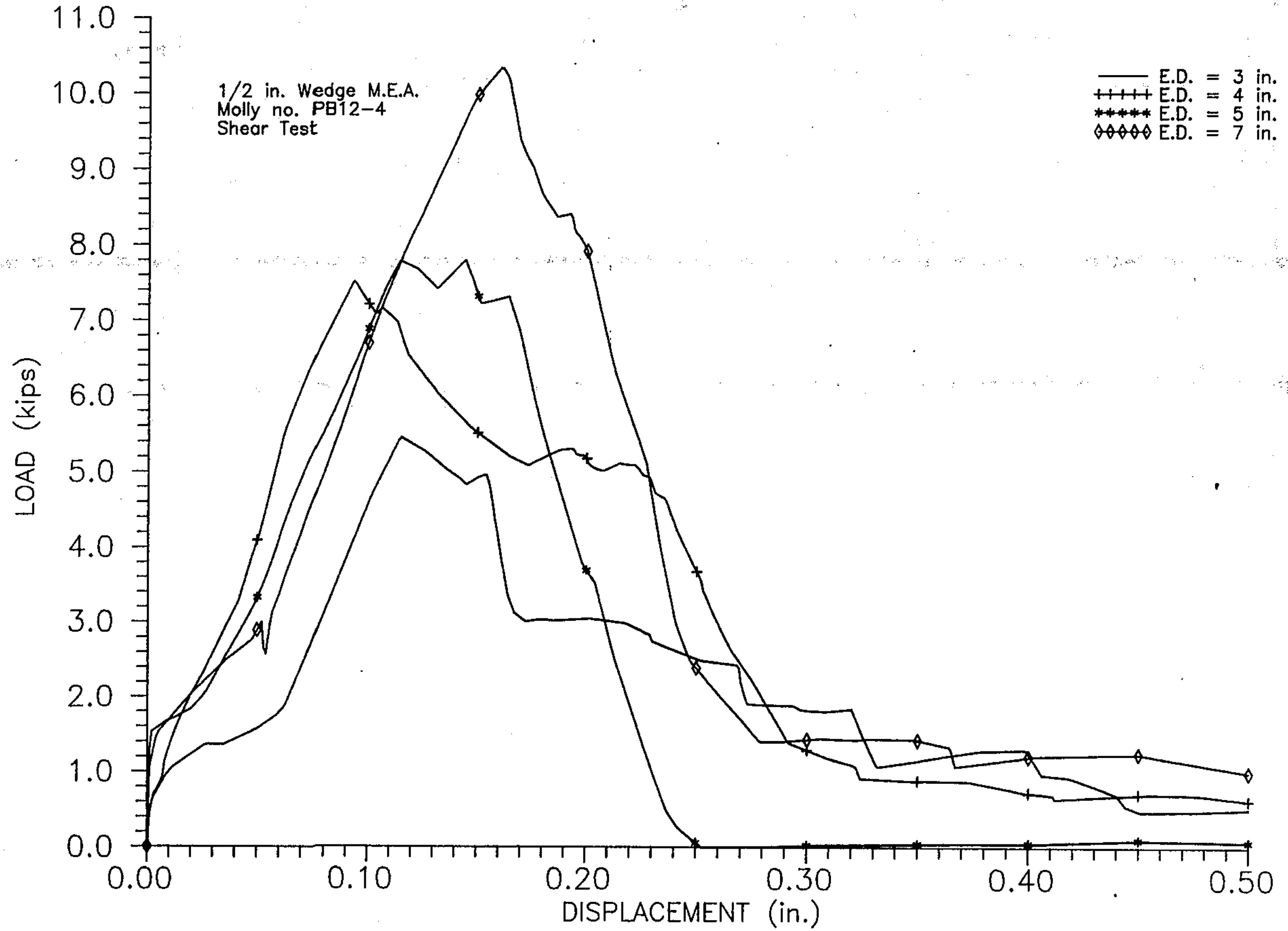


Figure G8. Average load vs. displacement for short term shear tests at varying edge distances.

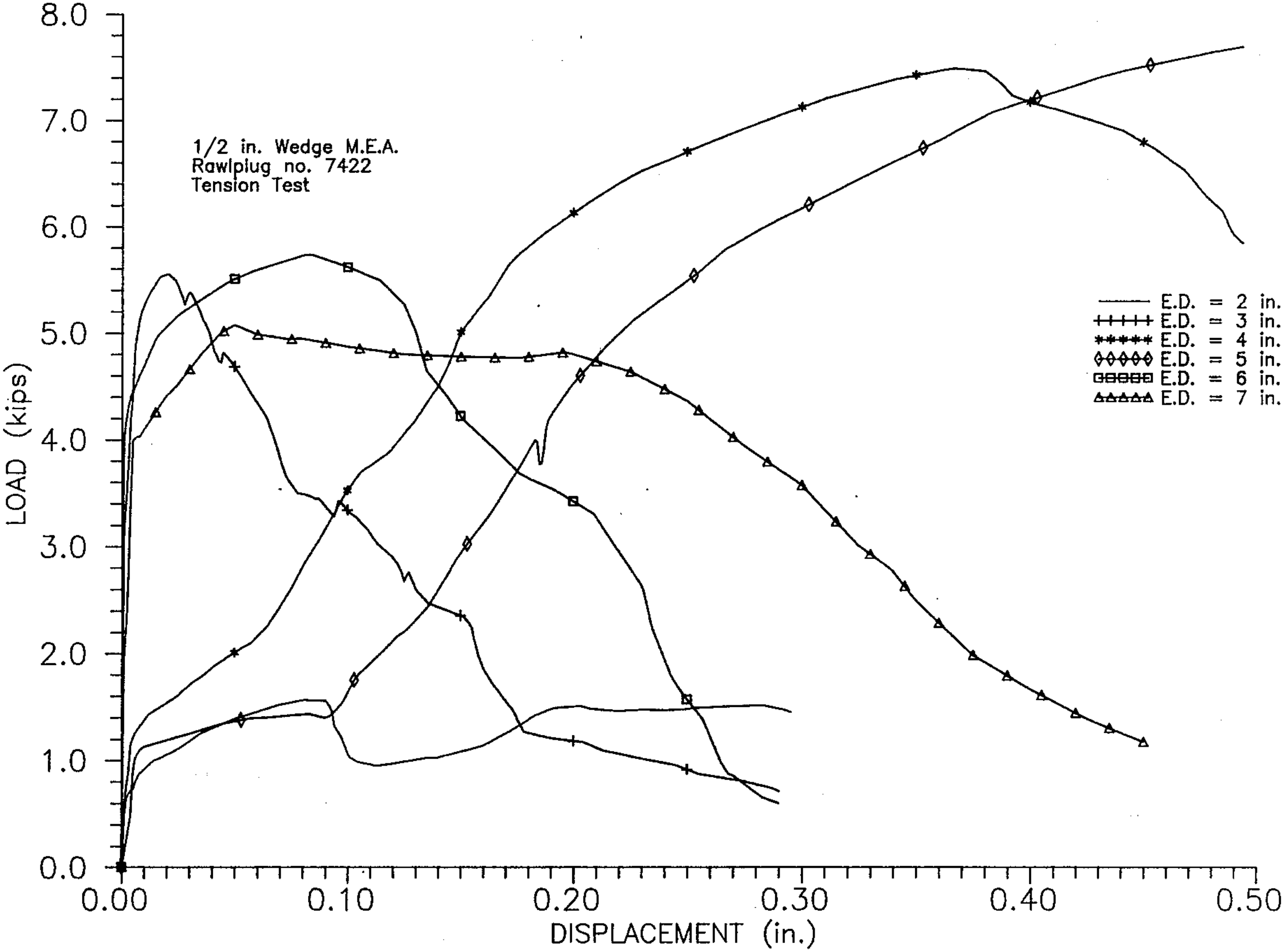


Figure G9. Average load vs. displacement for short term tensile tests at varying edge distances.

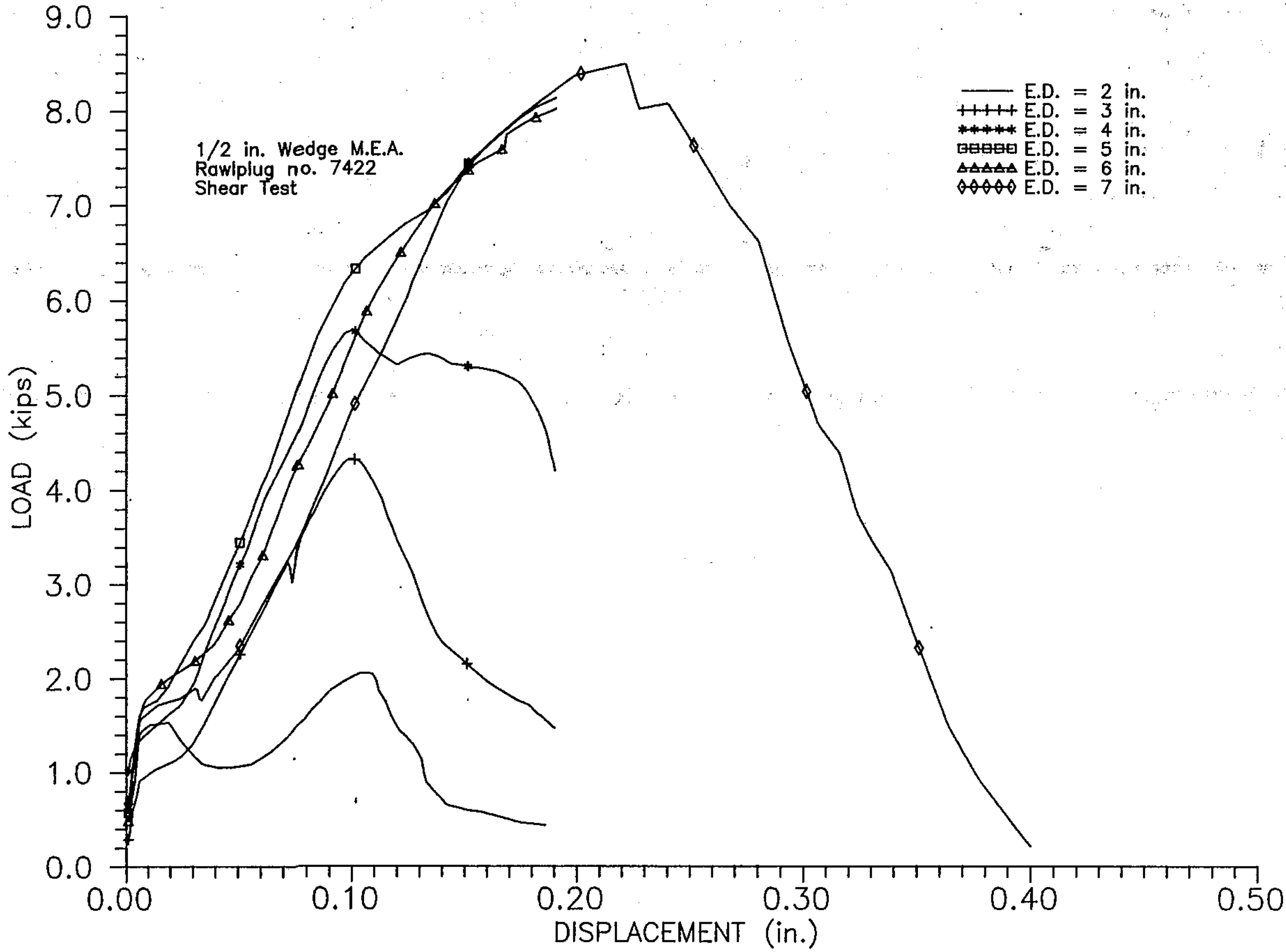


Figure G10. Average load vs. displacement for short term shear tests at varying edge distances.

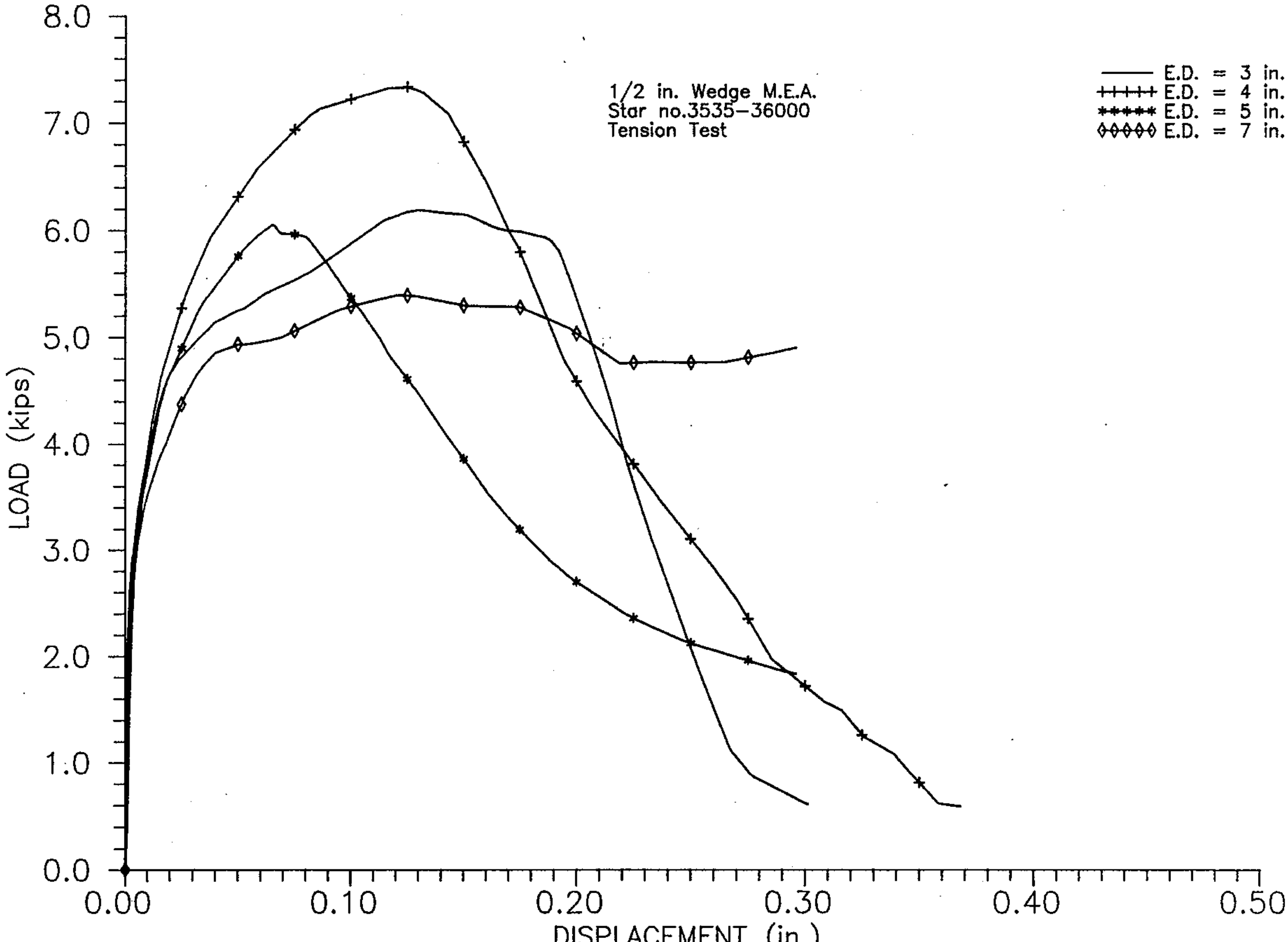


Figure G11. Average load vs. displacement for short term tension tests at varying edge distances.

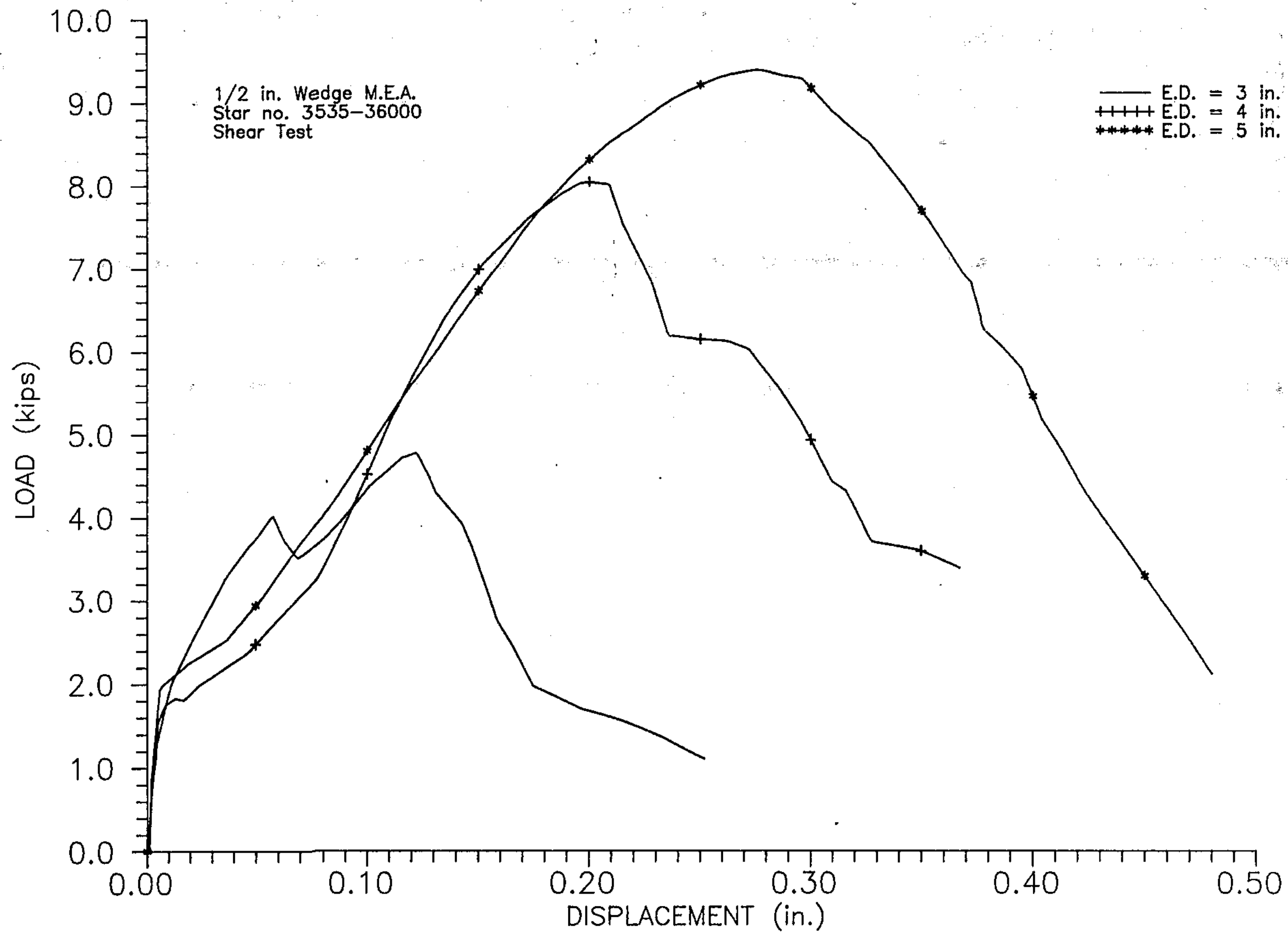


Figure G12. Average load vs. displacement for short term shear tests at varying edge distances.

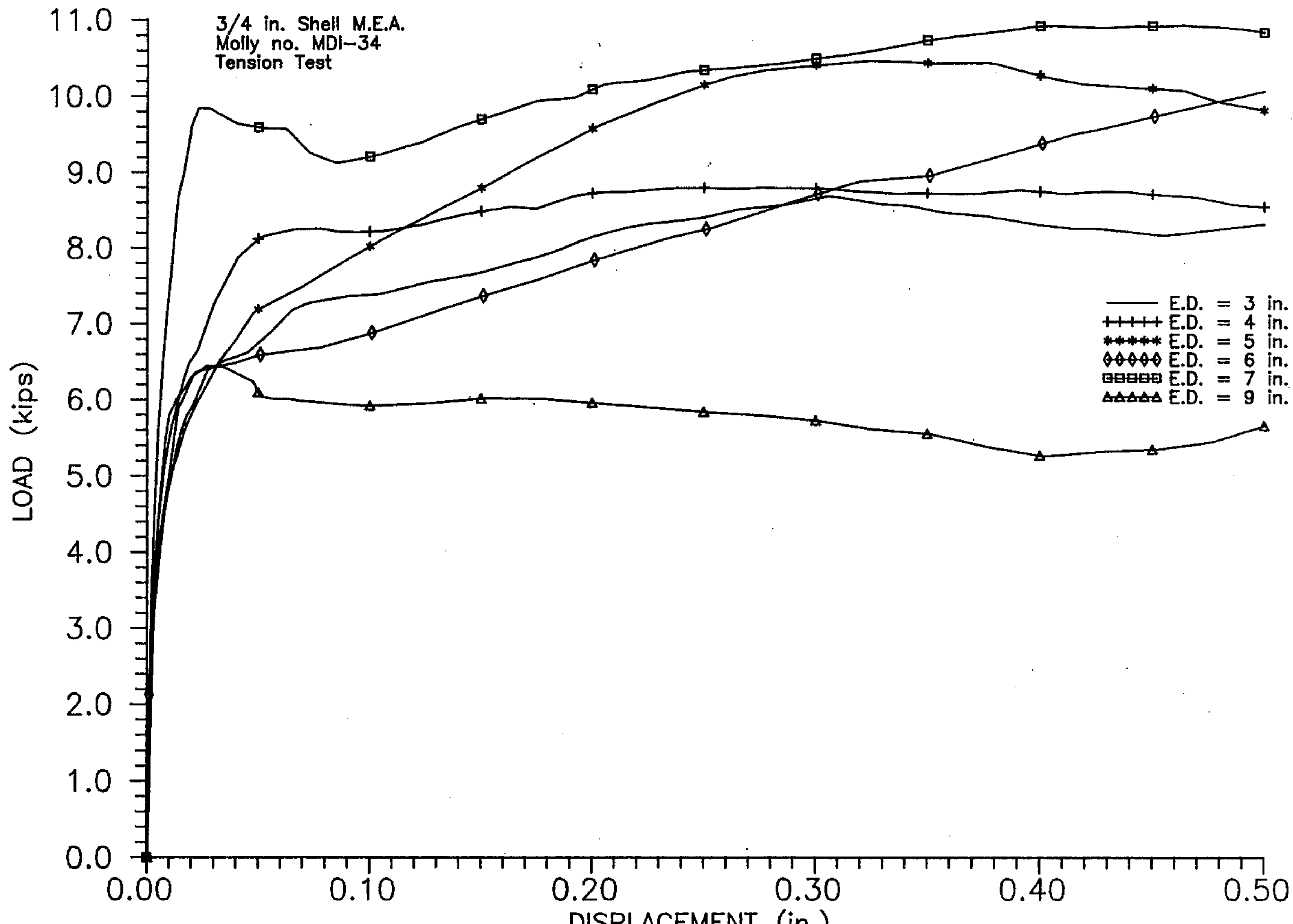


Figure G13. Average load vs. displacement for short term tension tests at varying edge distances.

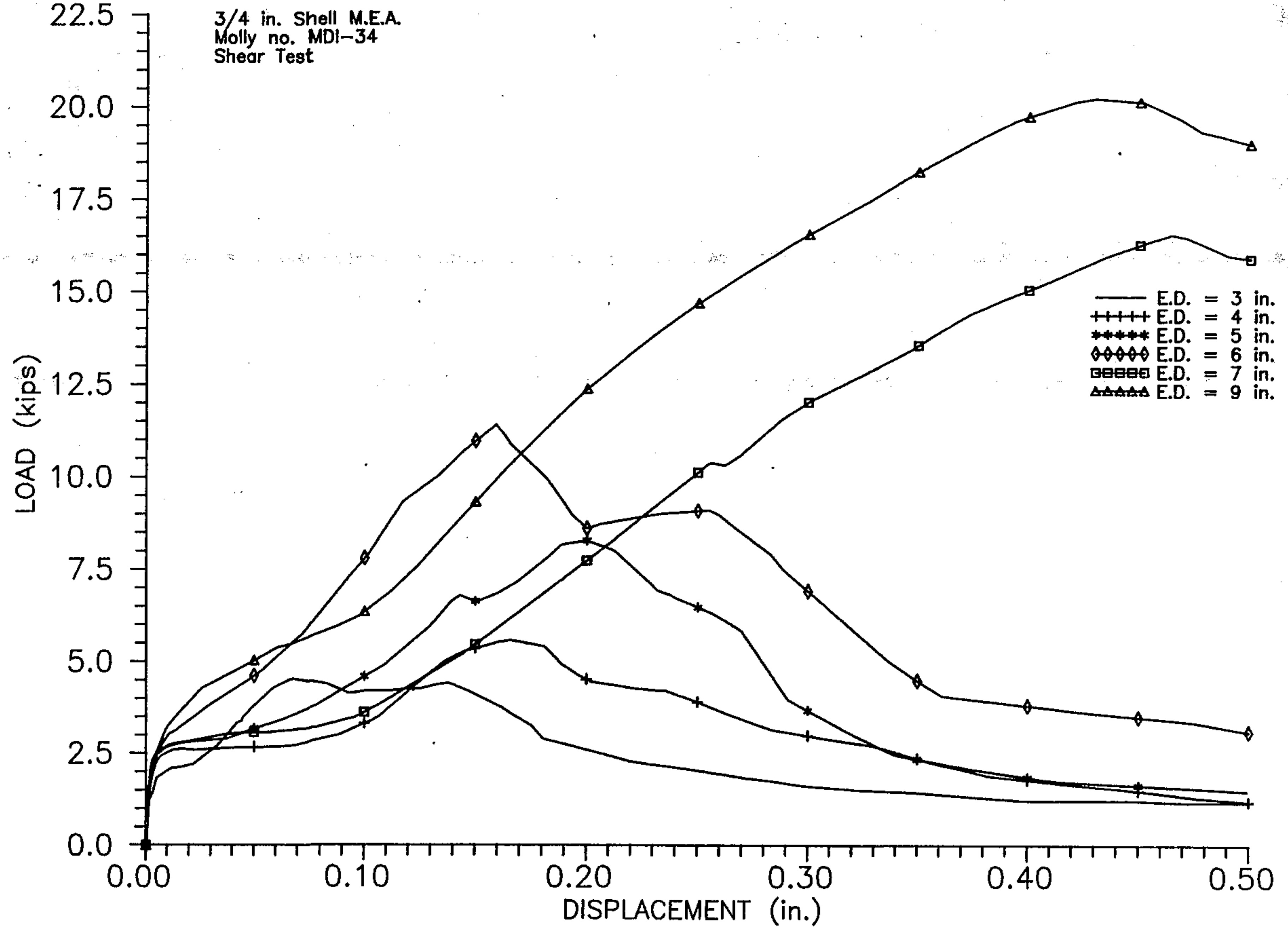


Figure G14. Average load vs. displacement for short term shear tests at varying edge distances.

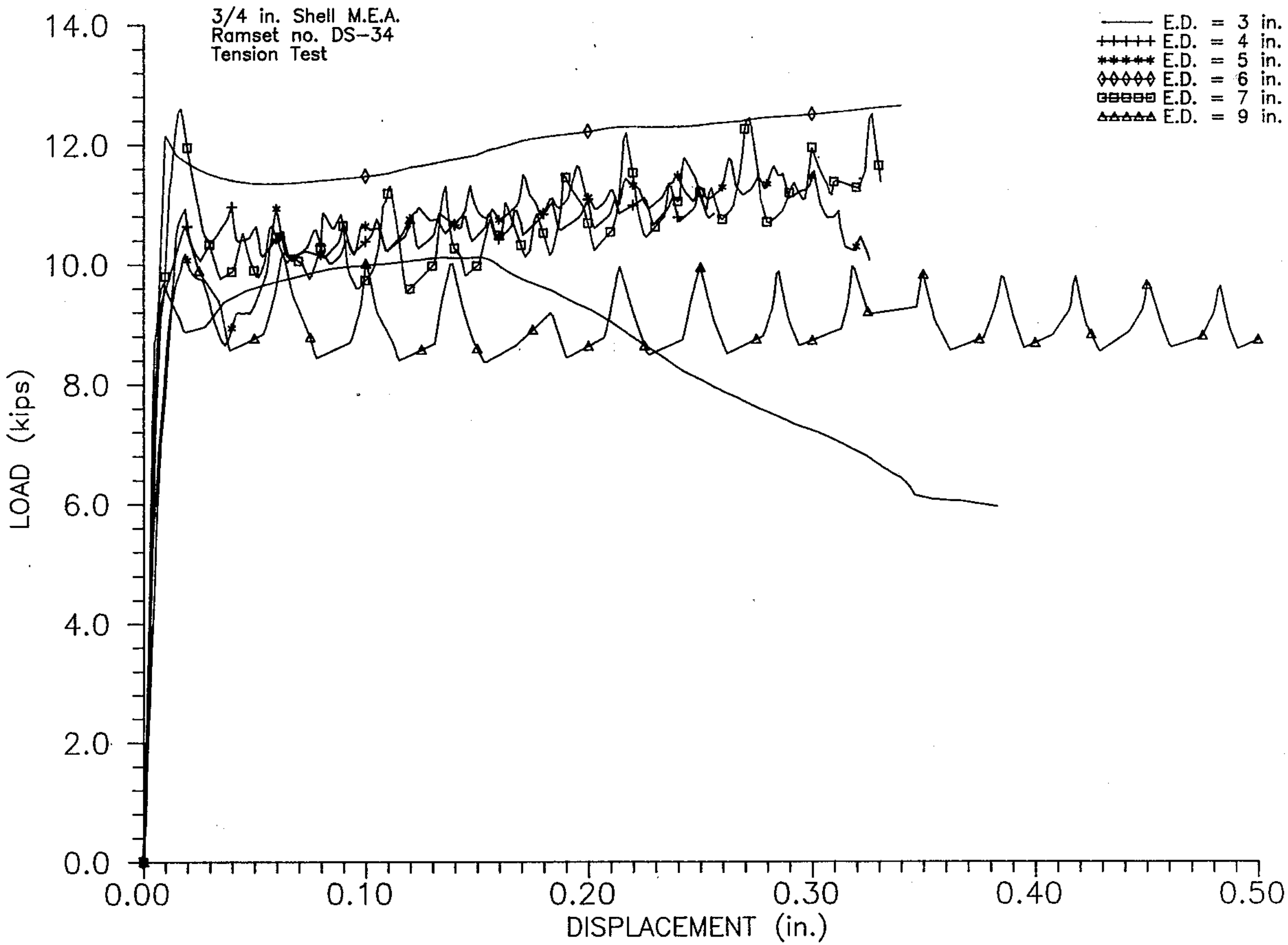


Figure G15. Average load vs. displacement for short term tensile tests at varying edge distances.

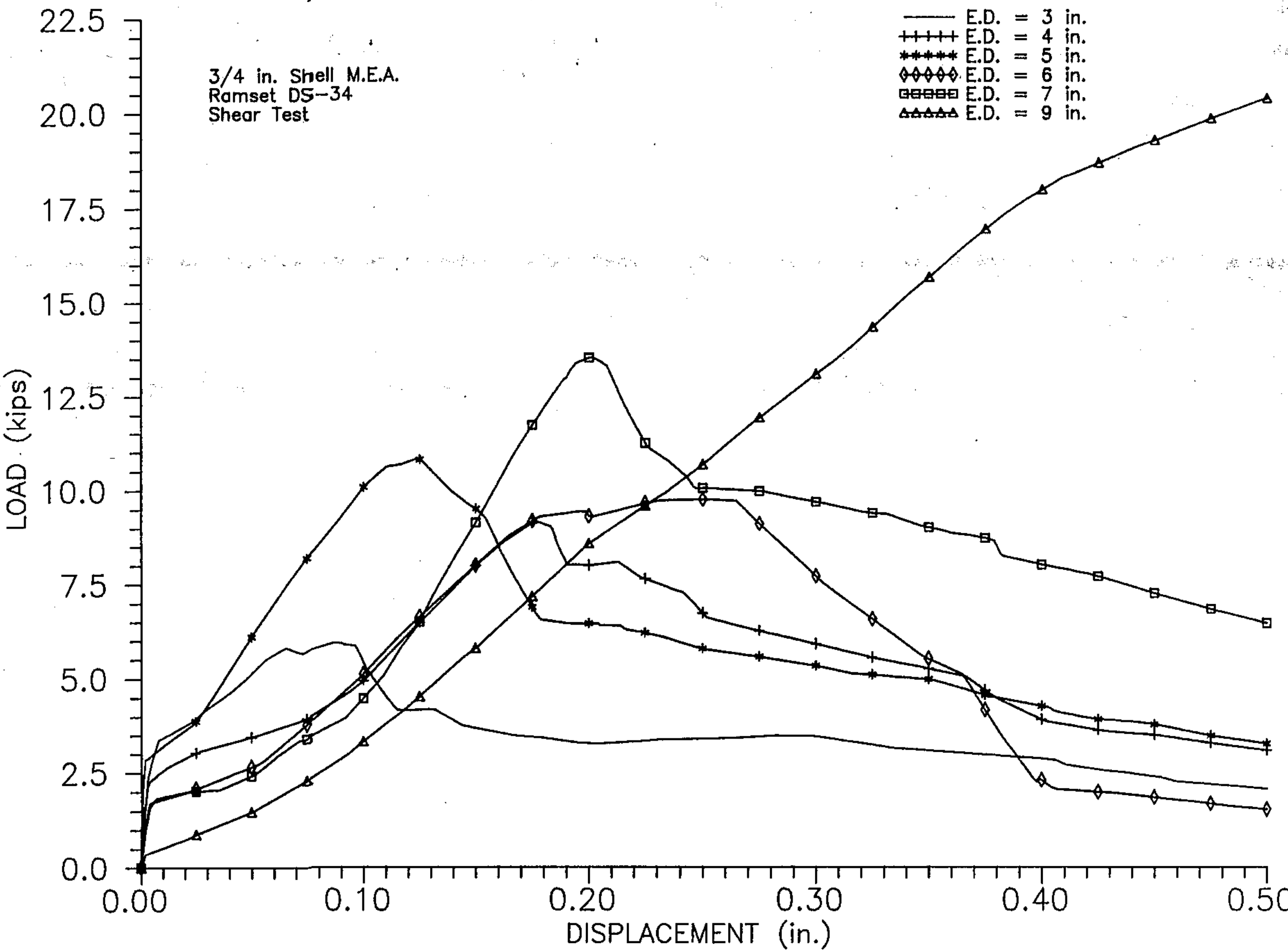


Figure G16. Average load vs. displacement for short term shear tests at varying edge distances.

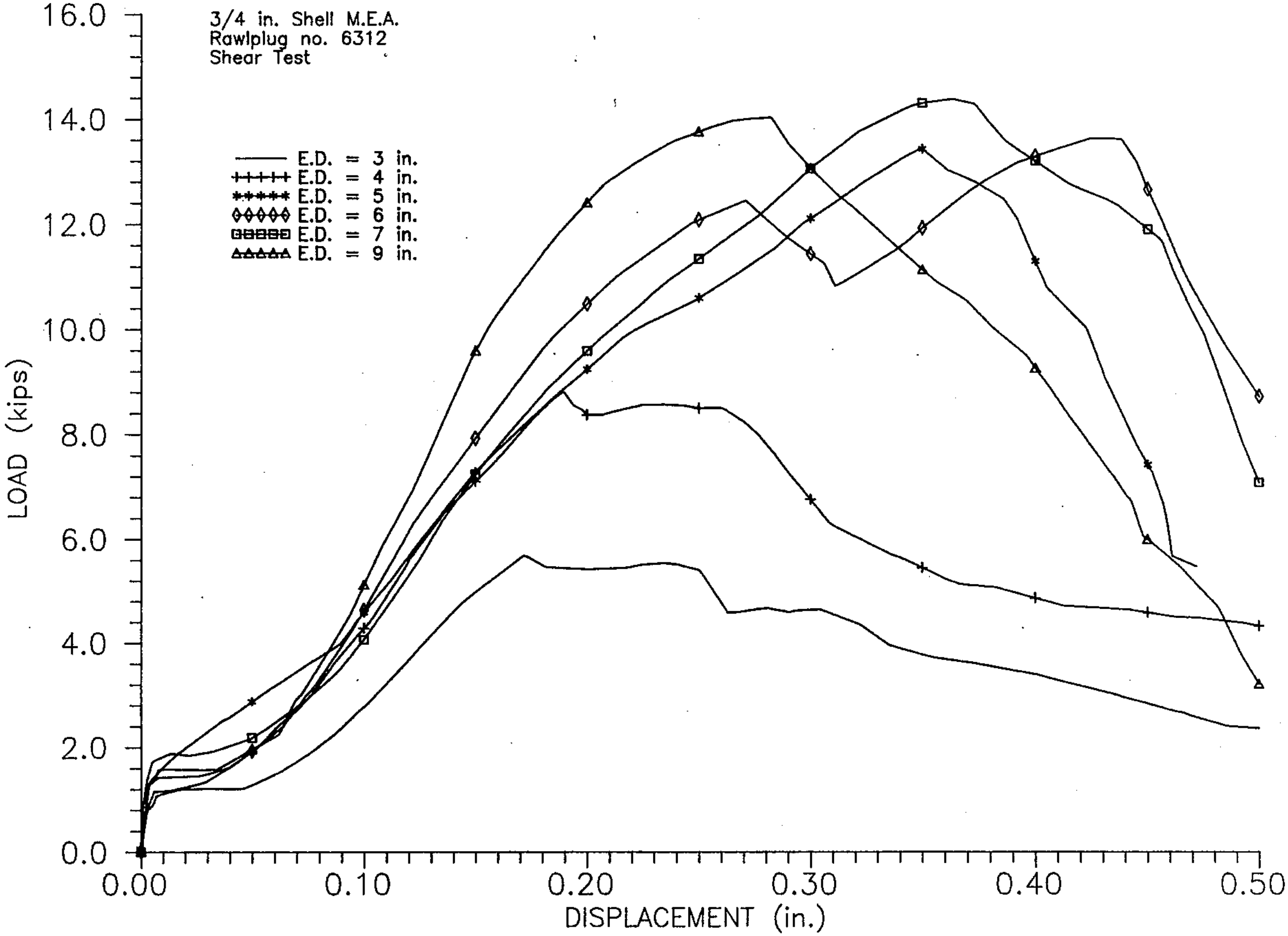


Figure G17. Average load vs. displacement for short term shear tests at varying edge distances.

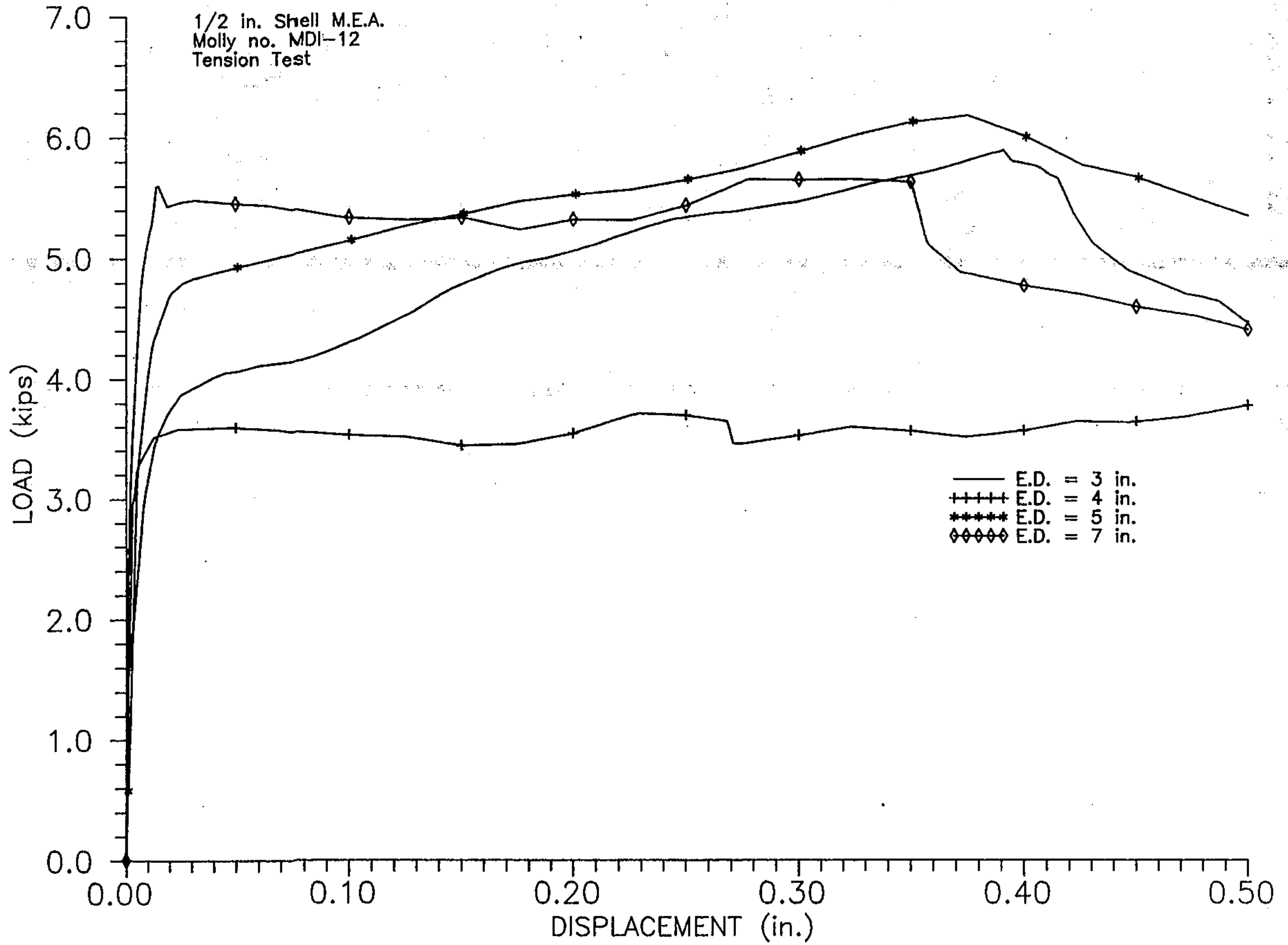


Figure G18. Average load vs. displacement for short term tension tests at varying edge distances.

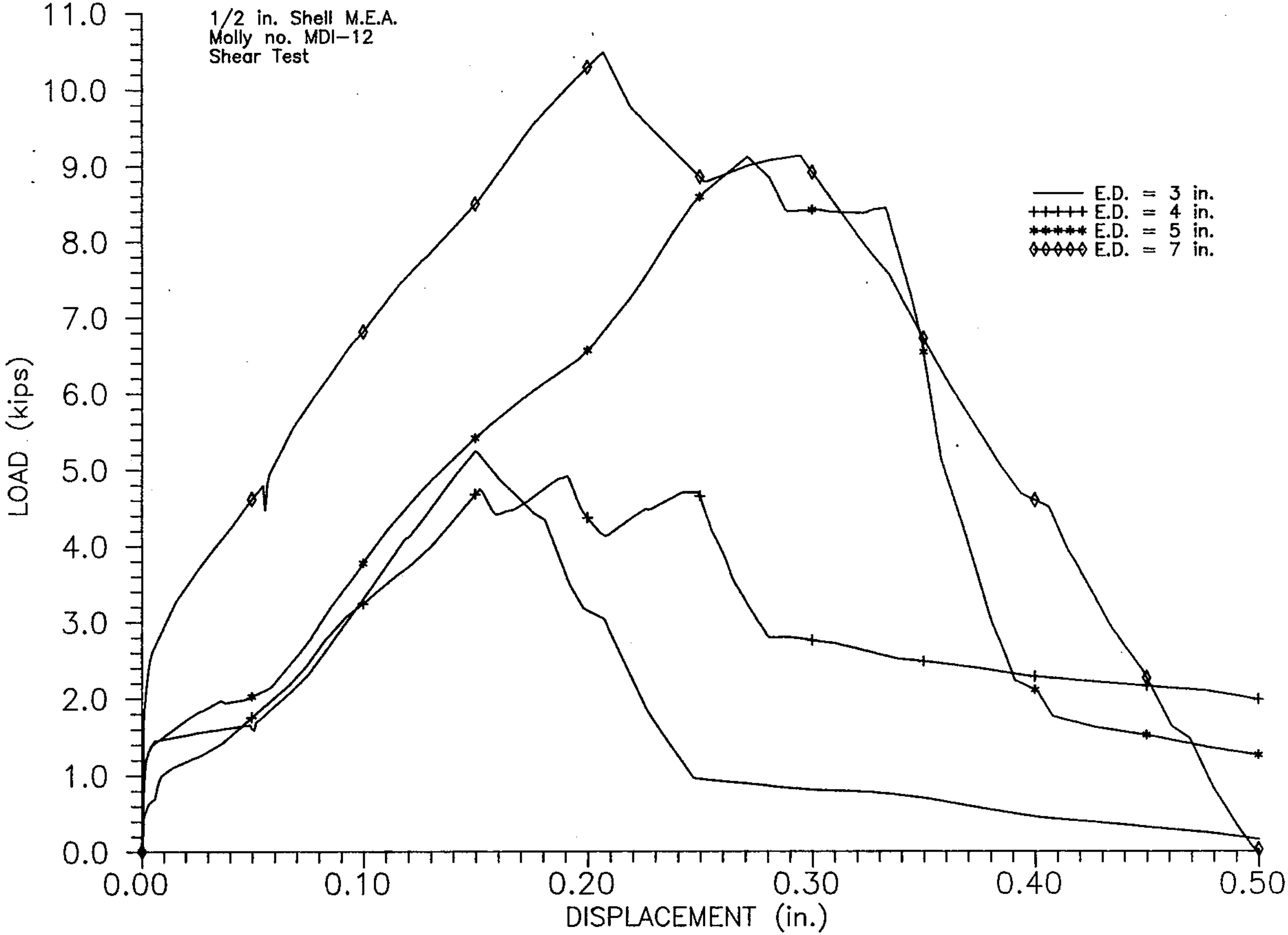


Figure G19. Average load vs. displacement for short term shear tests at varying edge distances.

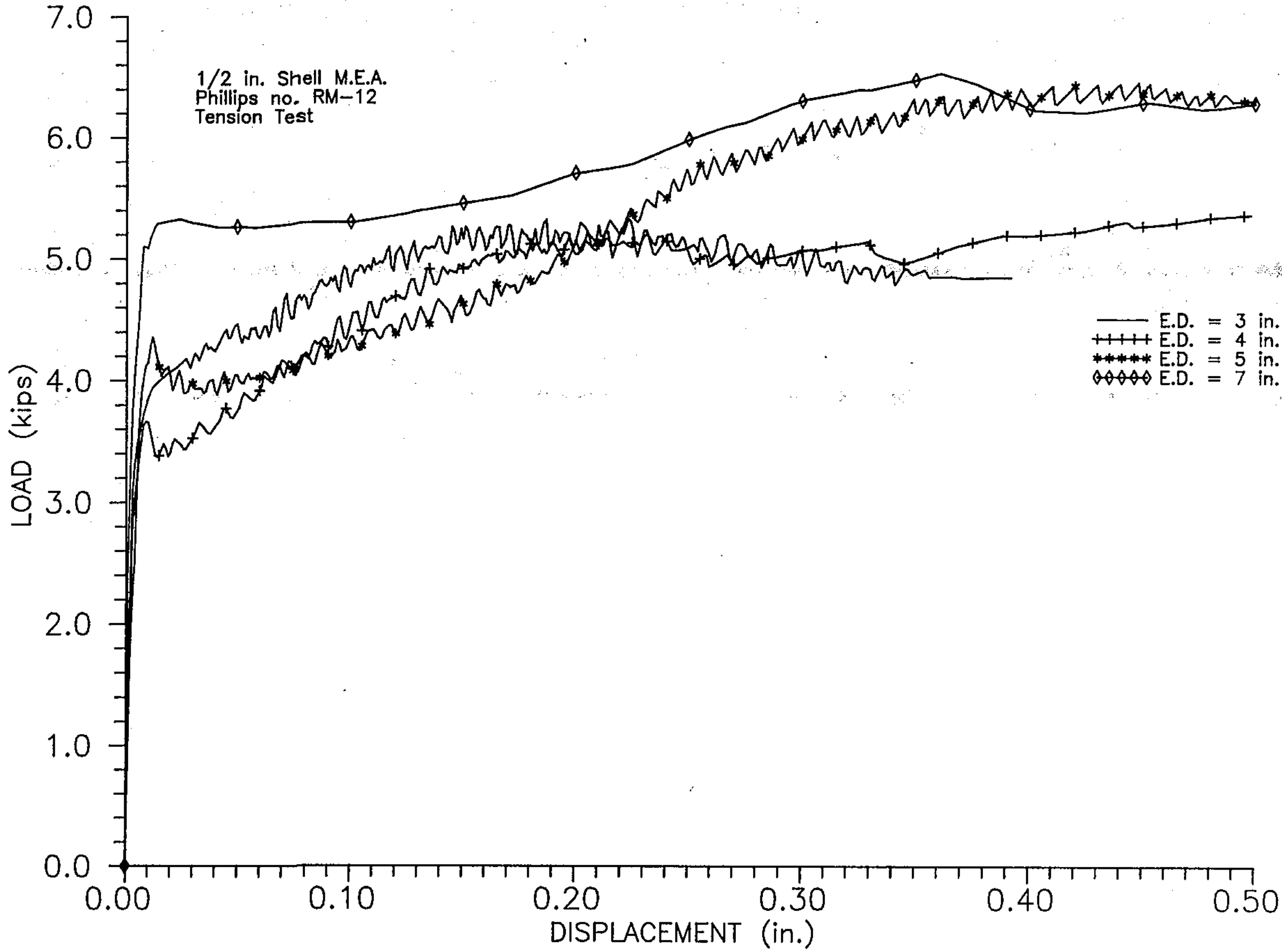


Figure G20. Average load vs. displacement for short term tensile tests at varying edge distances.

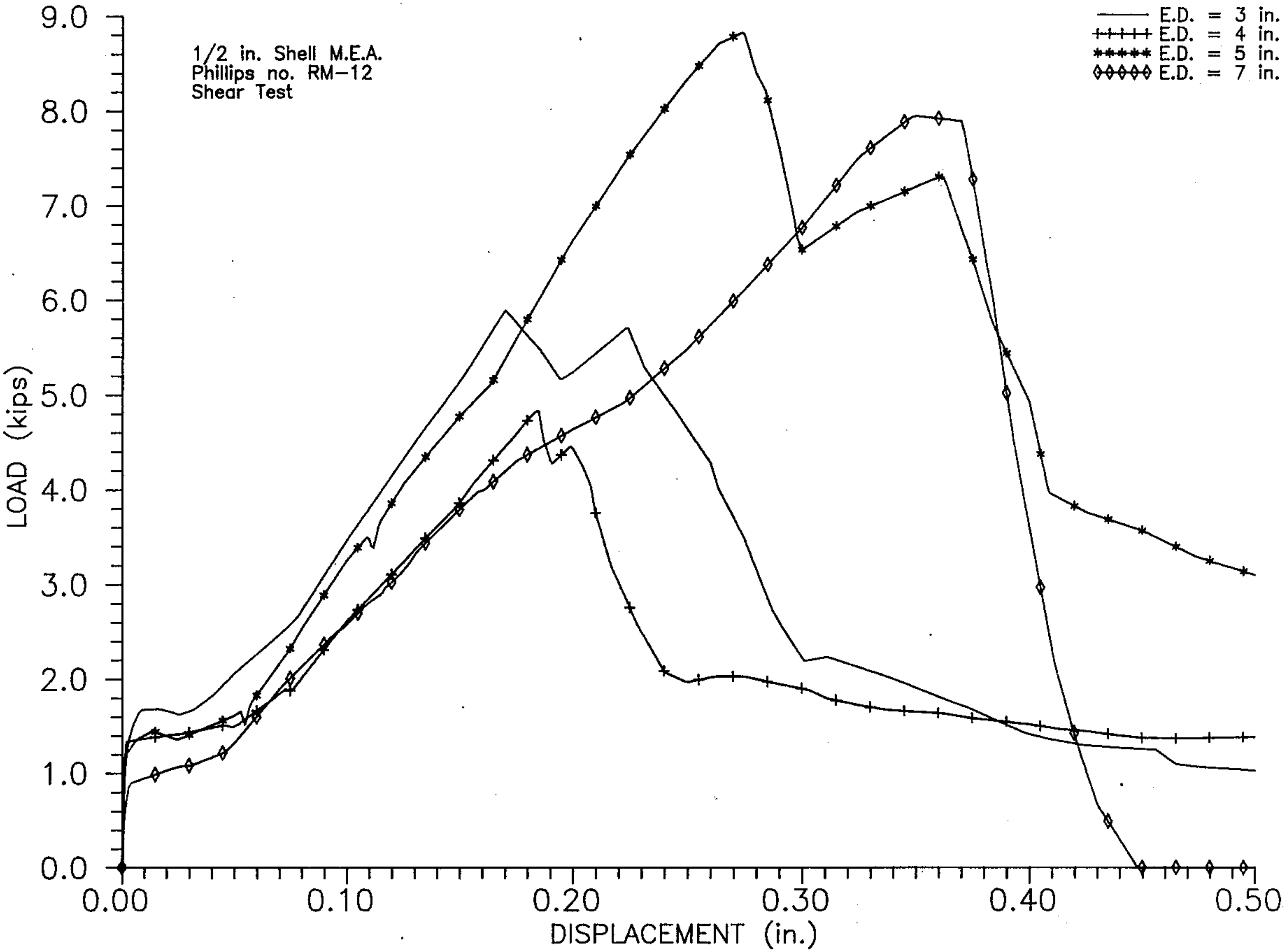


Figure G21. Average load vs. displacement for short term shear tests at varying edge distances.

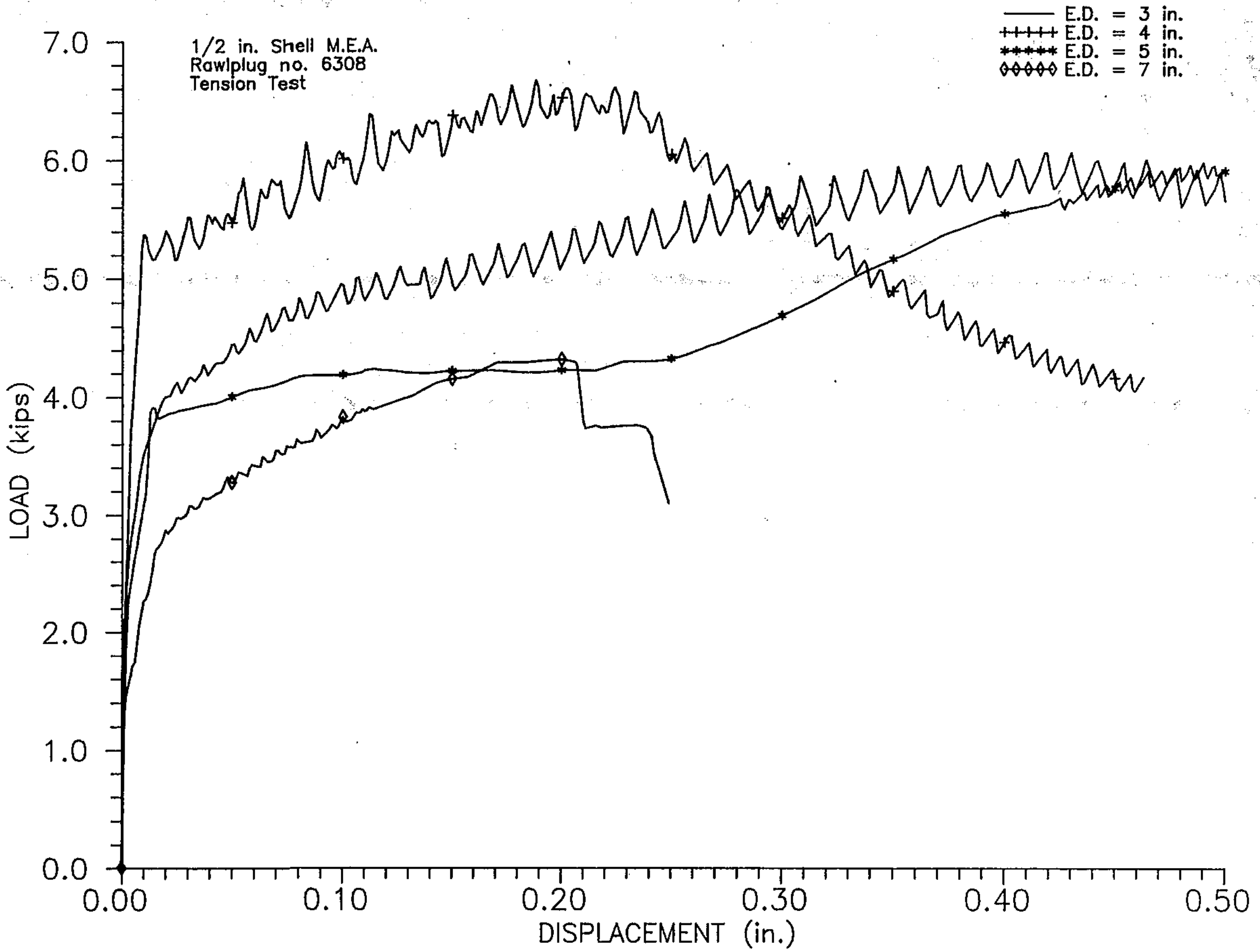


Figure G22. Average load vs. displacement for short term tension tests at varying edge distances.

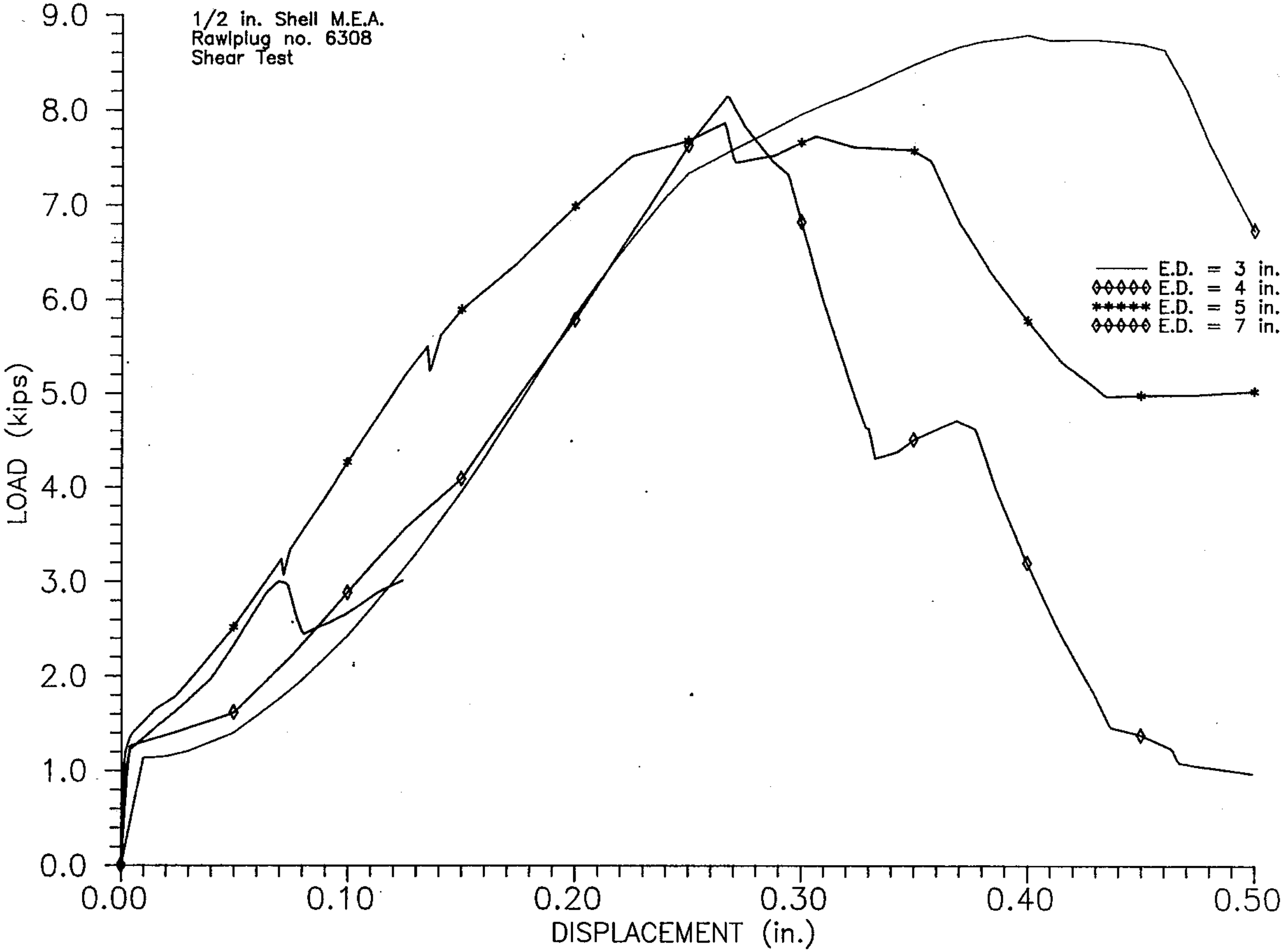


Figure G23. Average load vs. displacement for short term shear tests at varying edge distances.

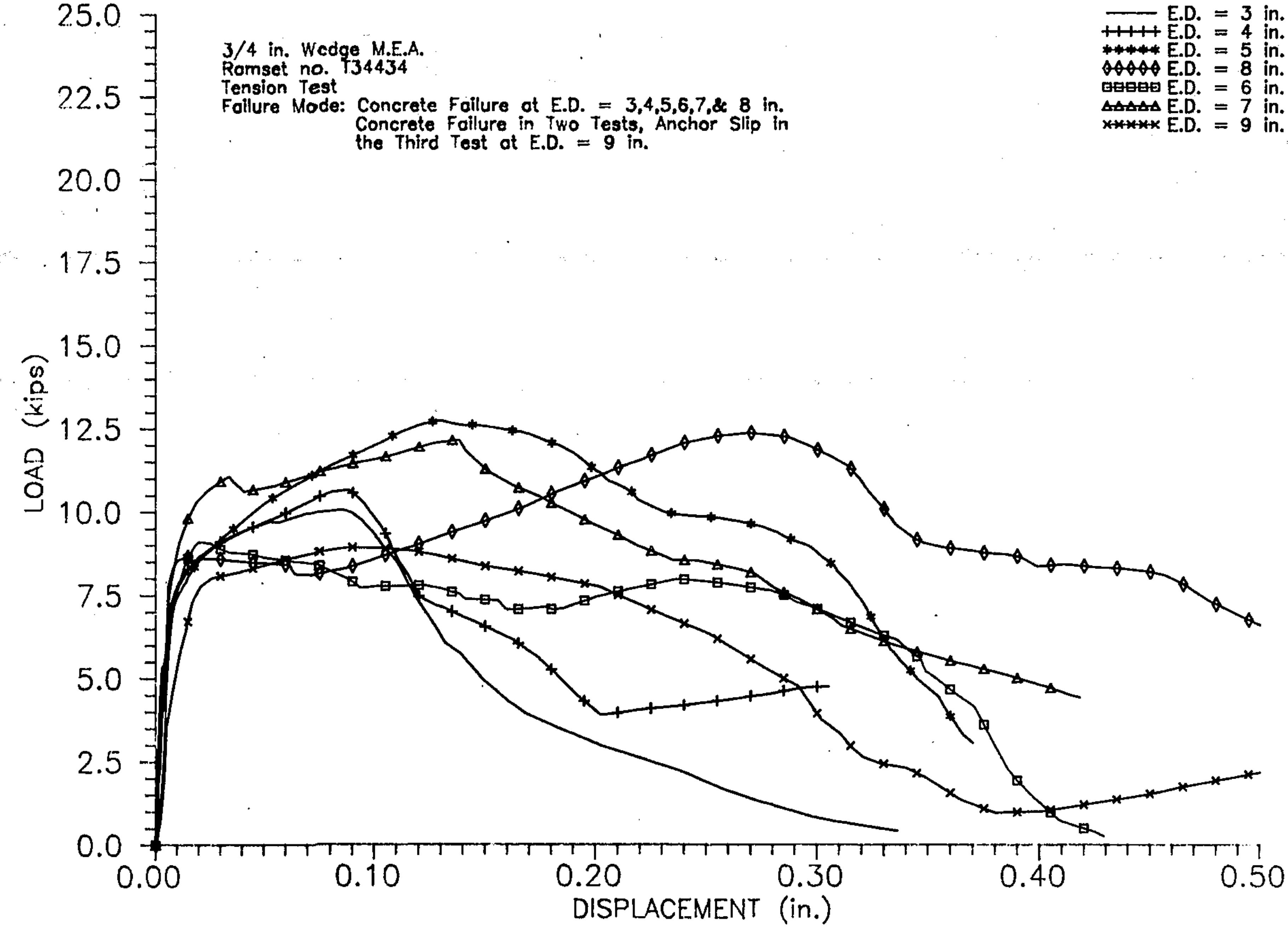


Figure G24. Average load vs. displacement for short term tensile tests at varying edge distances.

APPENDIX G

Figures G25 - G32

Graphs of Shear and Tension Test Data (Low-Strength, Early-Age Concrete)

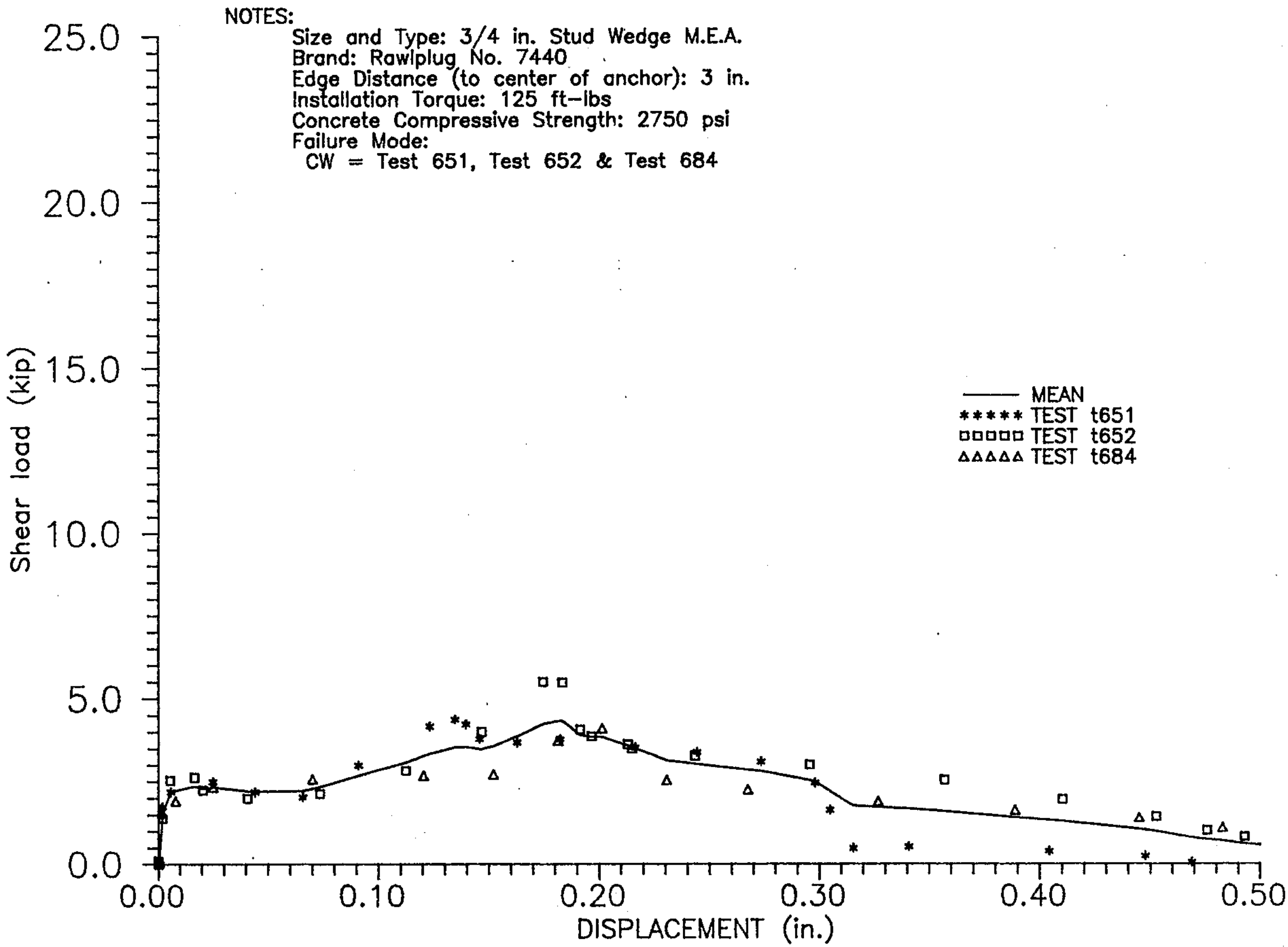


Figure G25. Load vs. displacement for short-term shear tests of mechanical expansion anchors.

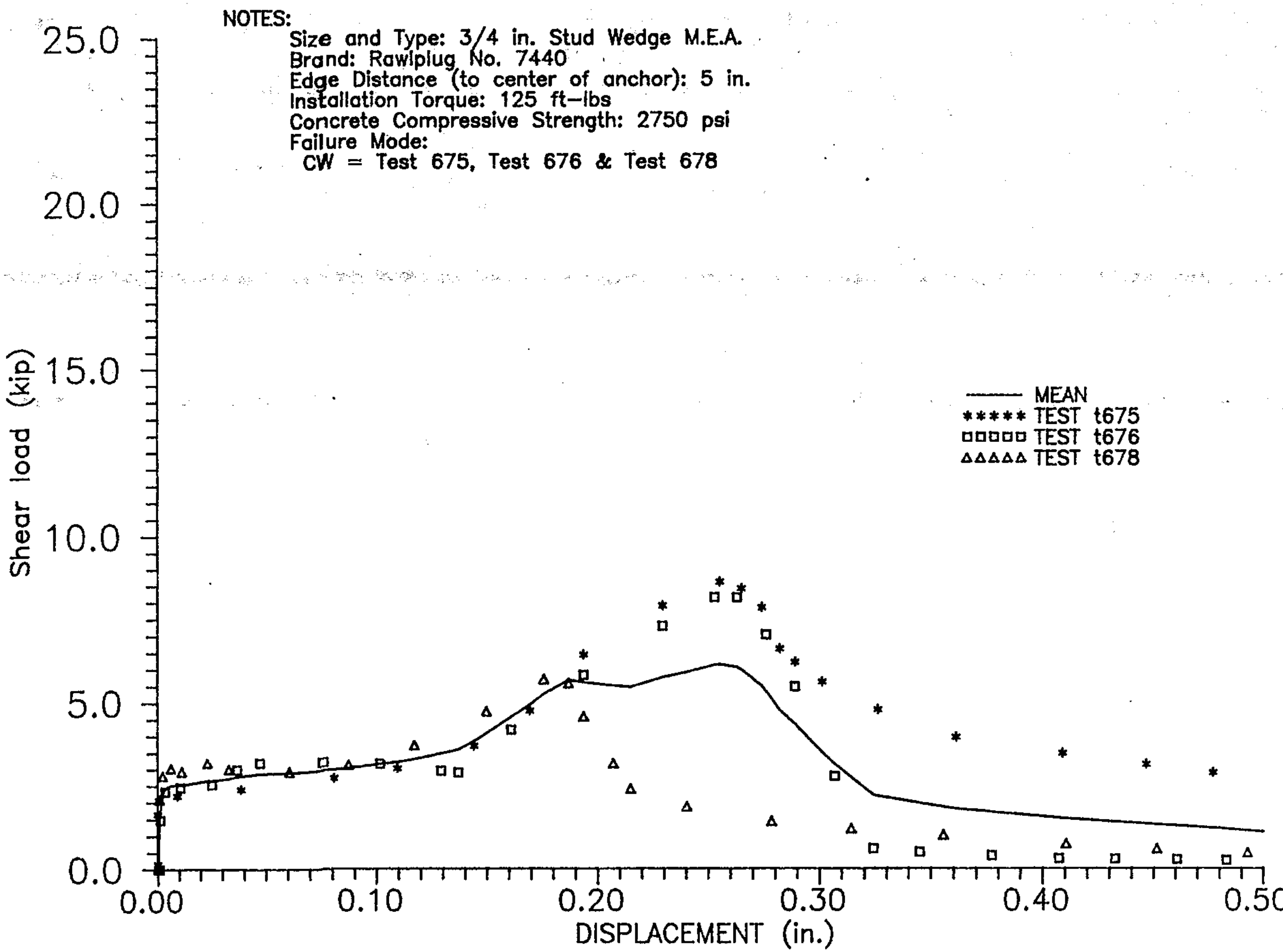


Figure G26. Load vs. displacement for short–term shear tests of mechanical expansion anchors.

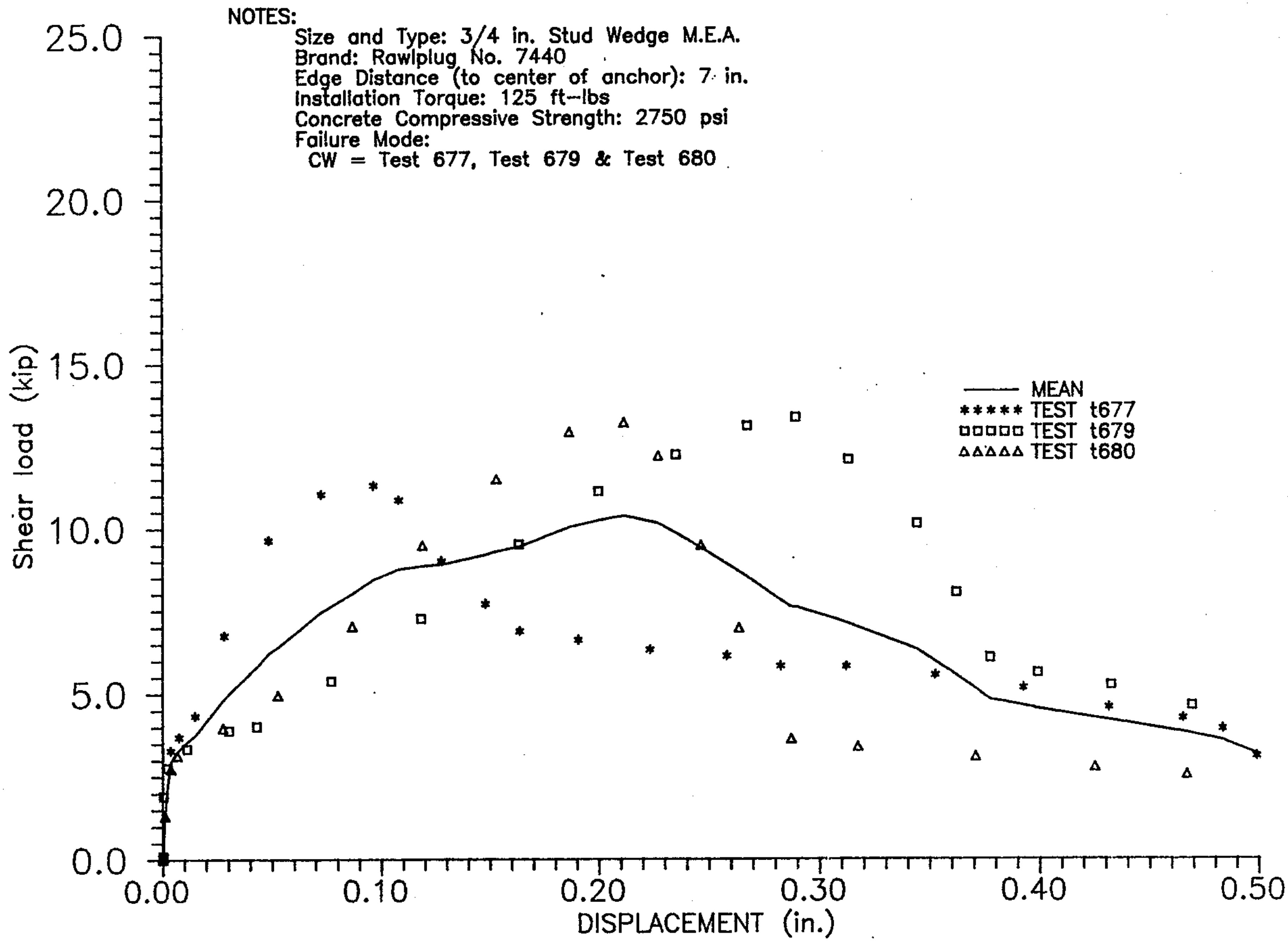


Figure G27. Load vs. displacement for short–term shear tests of mechanical expansion anchors.

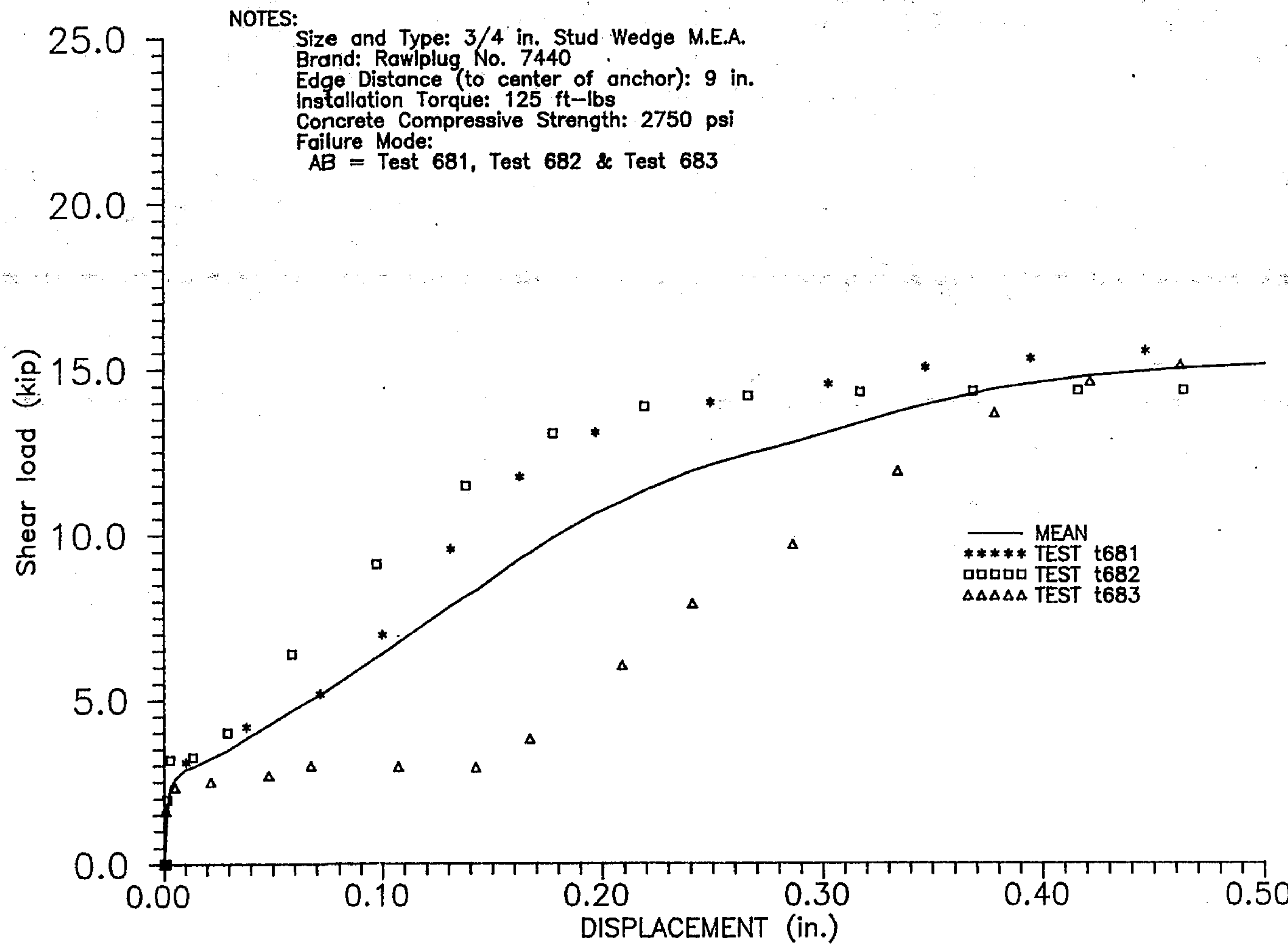


Figure G28. Load vs. displacement for short-term shear tests of mechanical expansion anchors.

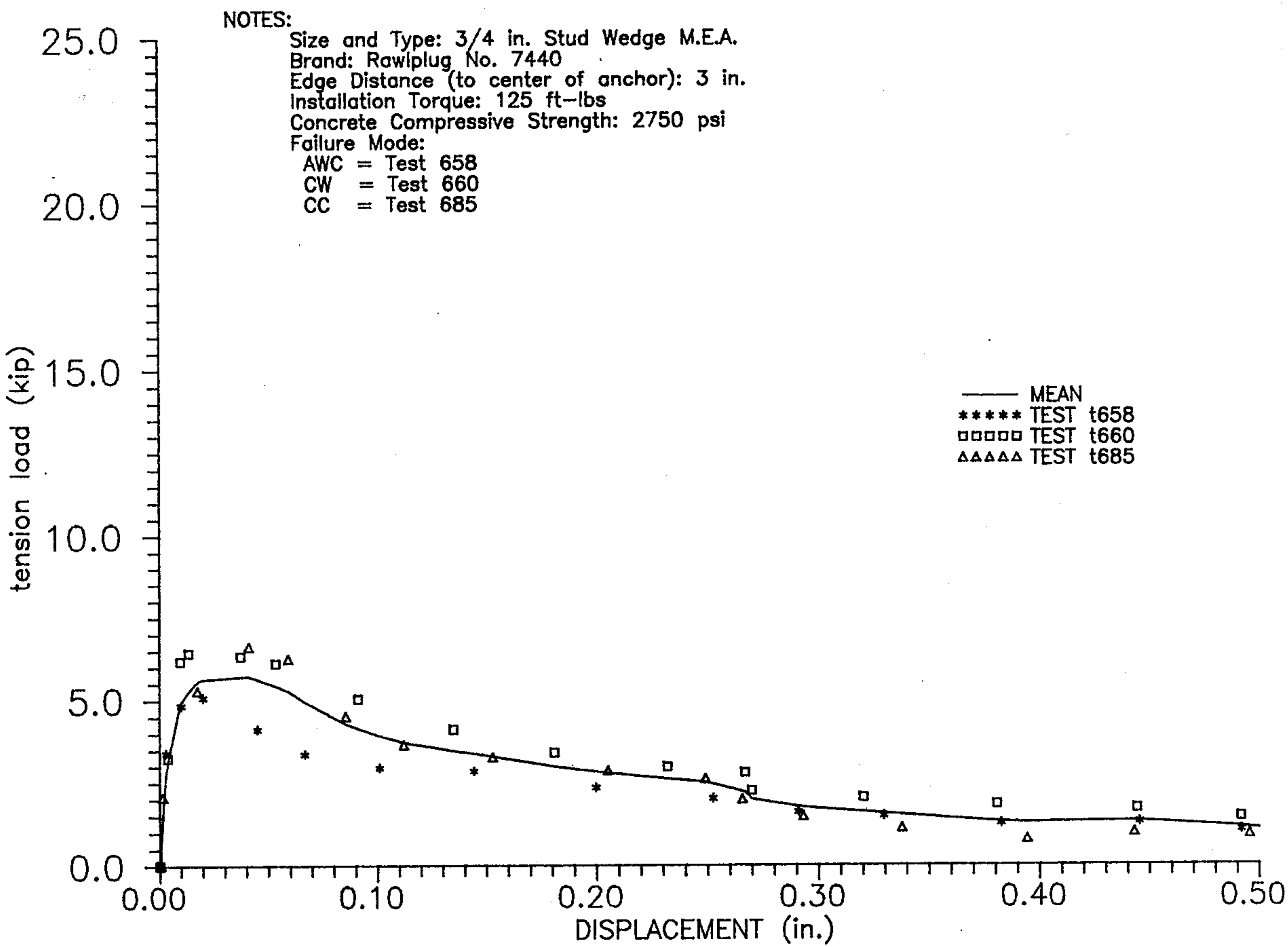


Figure G29. Load vs. displacement for short-term tension tests of mechanical expansion anchors.

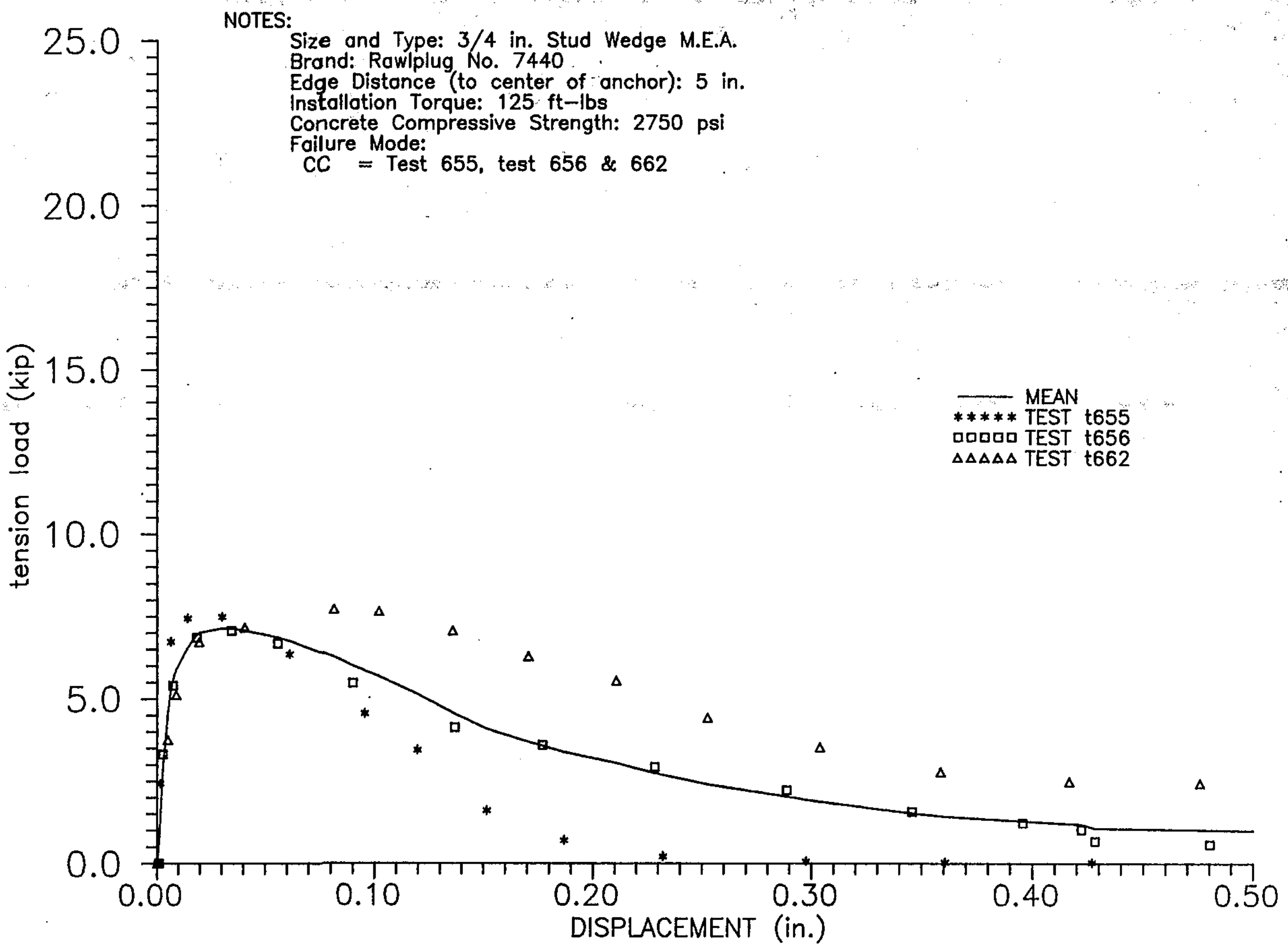


Figure G30. Load vs. displacement for short-term tension tests of mechanical expansion anchors.

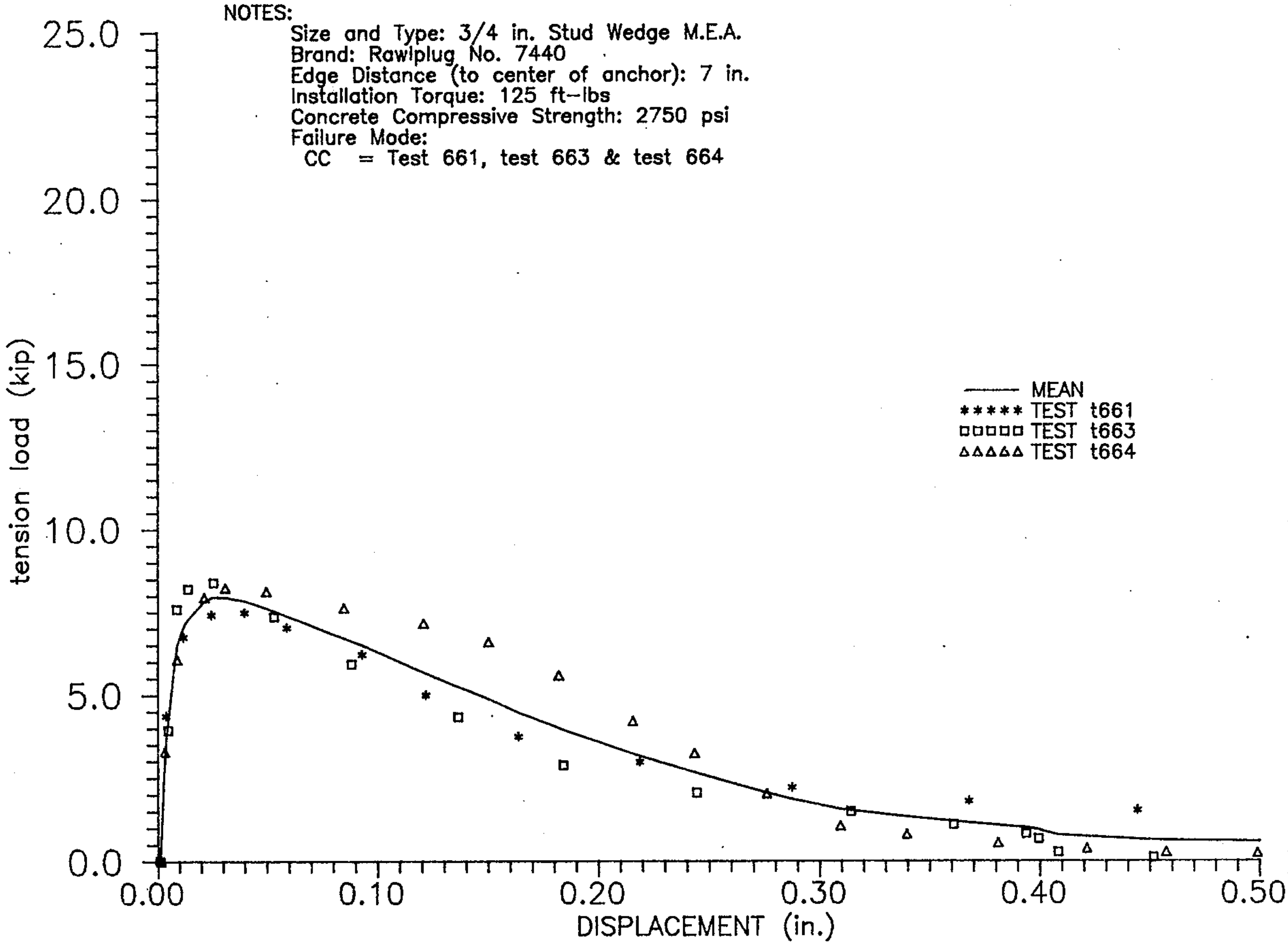


Figure G31. Load vs. displacement for short-term tension tests of mechanical expansion anchors.

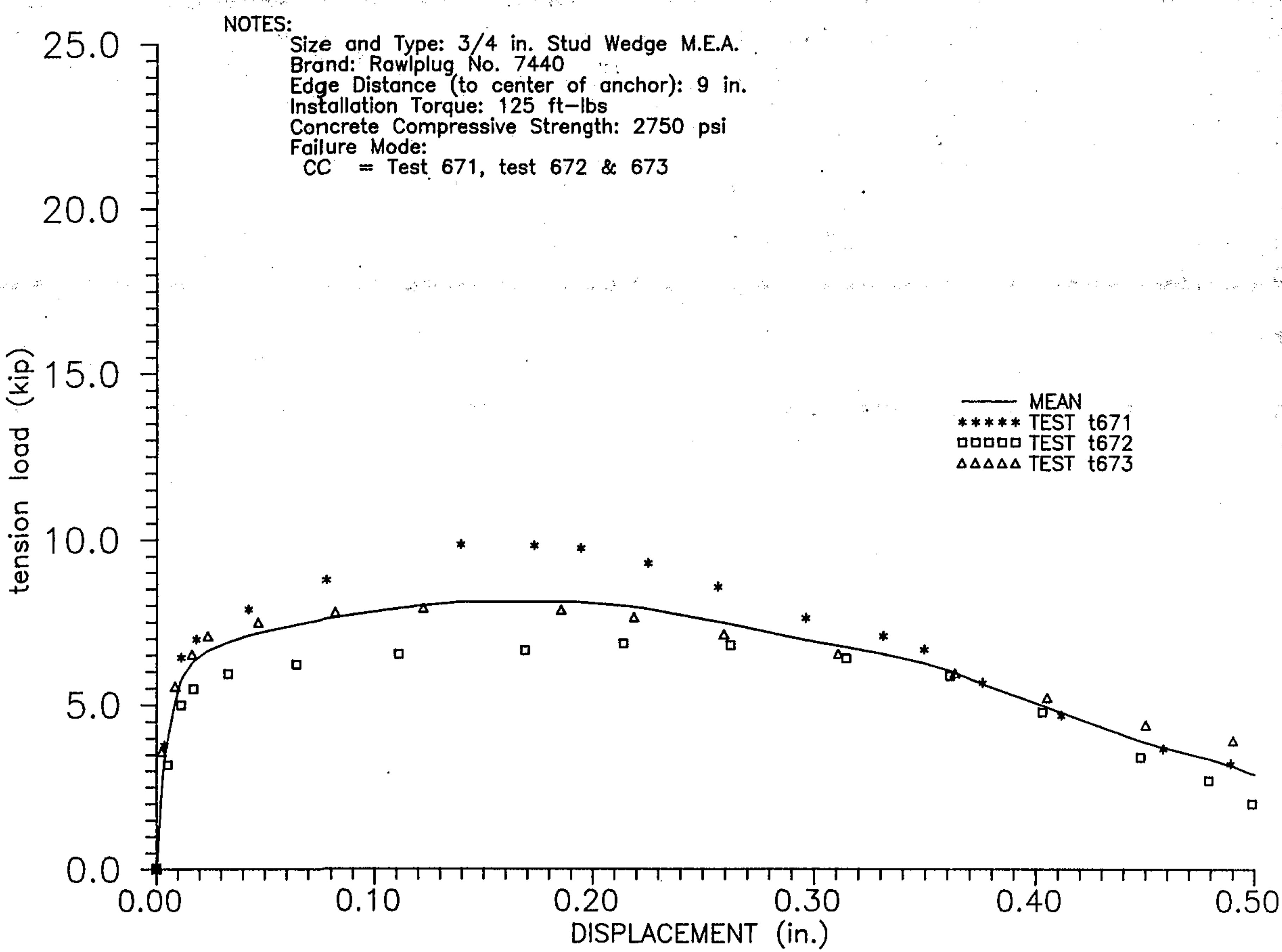


Figure G32. Load vs. displacement for short-term tension tests of mechanical expansion anchors.

APPENDIX G

Figures G33 - G63

Graphs of combined Load Test Data

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 1/2 in. Stud Wedge M.E.A.
Brand: Star 3535-36000
Edge Distance (to center of anchor): 3 in.
Installation Torque: 60 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 3SLSD, Test 2SLSD, & Test 1SLSD
1/3 Average Ultimate Shear Load: 2.0 kips

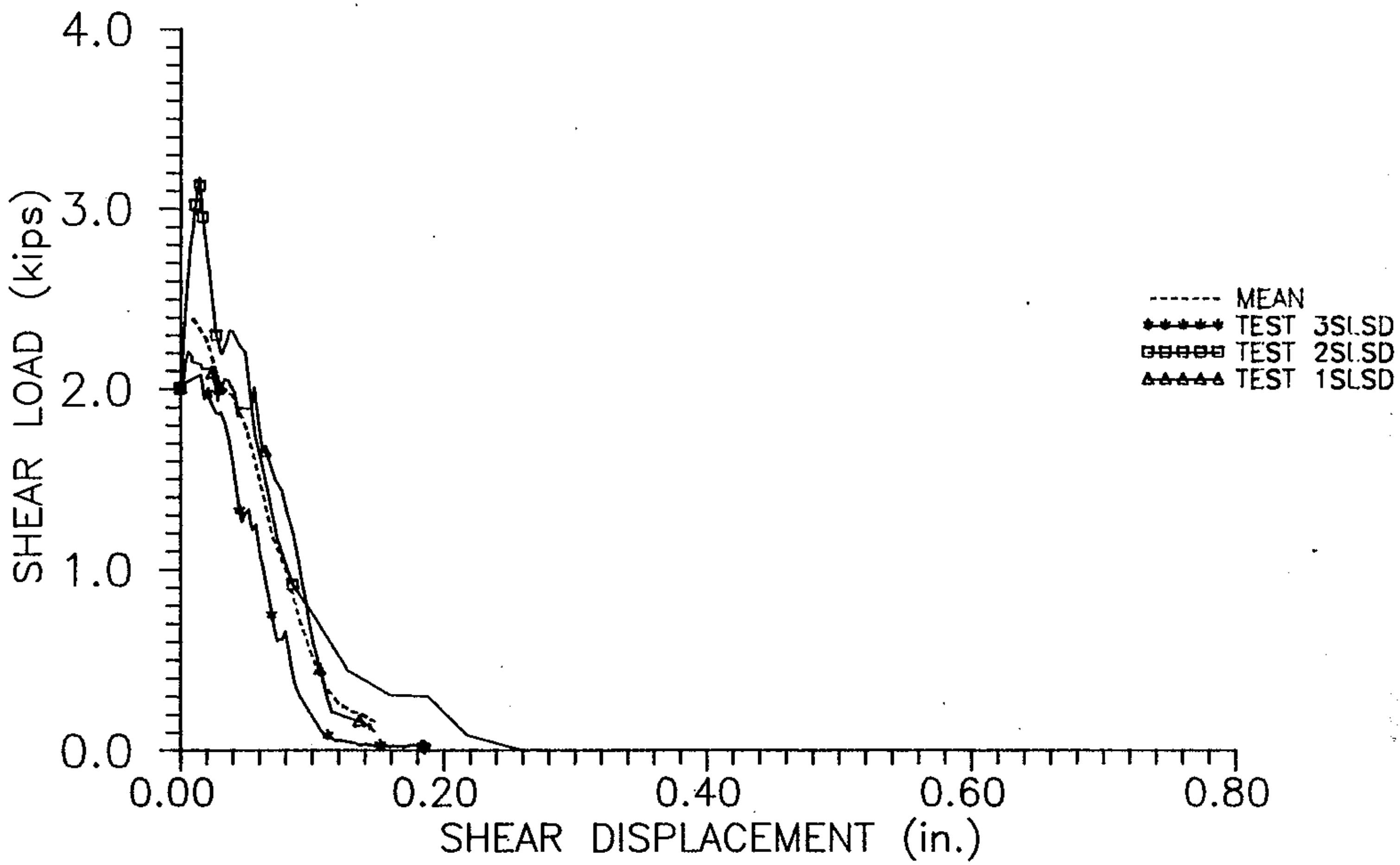


Figure G33. Load vs. displacement for short-term combined loading tests of mechanical expansion anchors.

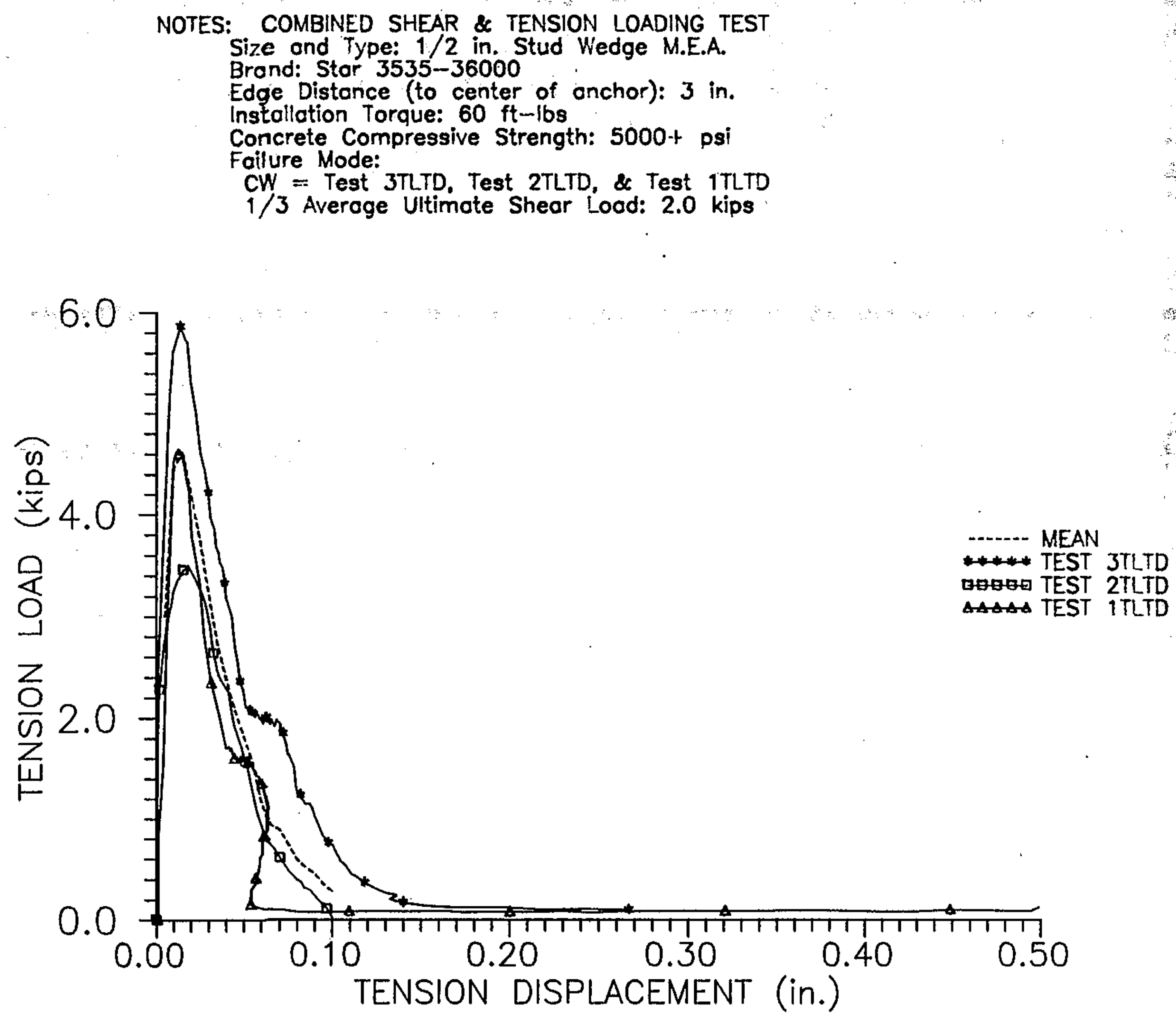


Figure G34. Load vs. displacement for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 1/2 in. Stud Wedge M.E.A.
Brand: Star 3535-36000
Edge Distance (to center of anchor): 3 in.
Installation Torque: 60 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 3SLTI, Test 2SLTI, & Test 1SLTI
1/3 Average Ultimate Shear Load: 2.0 kips

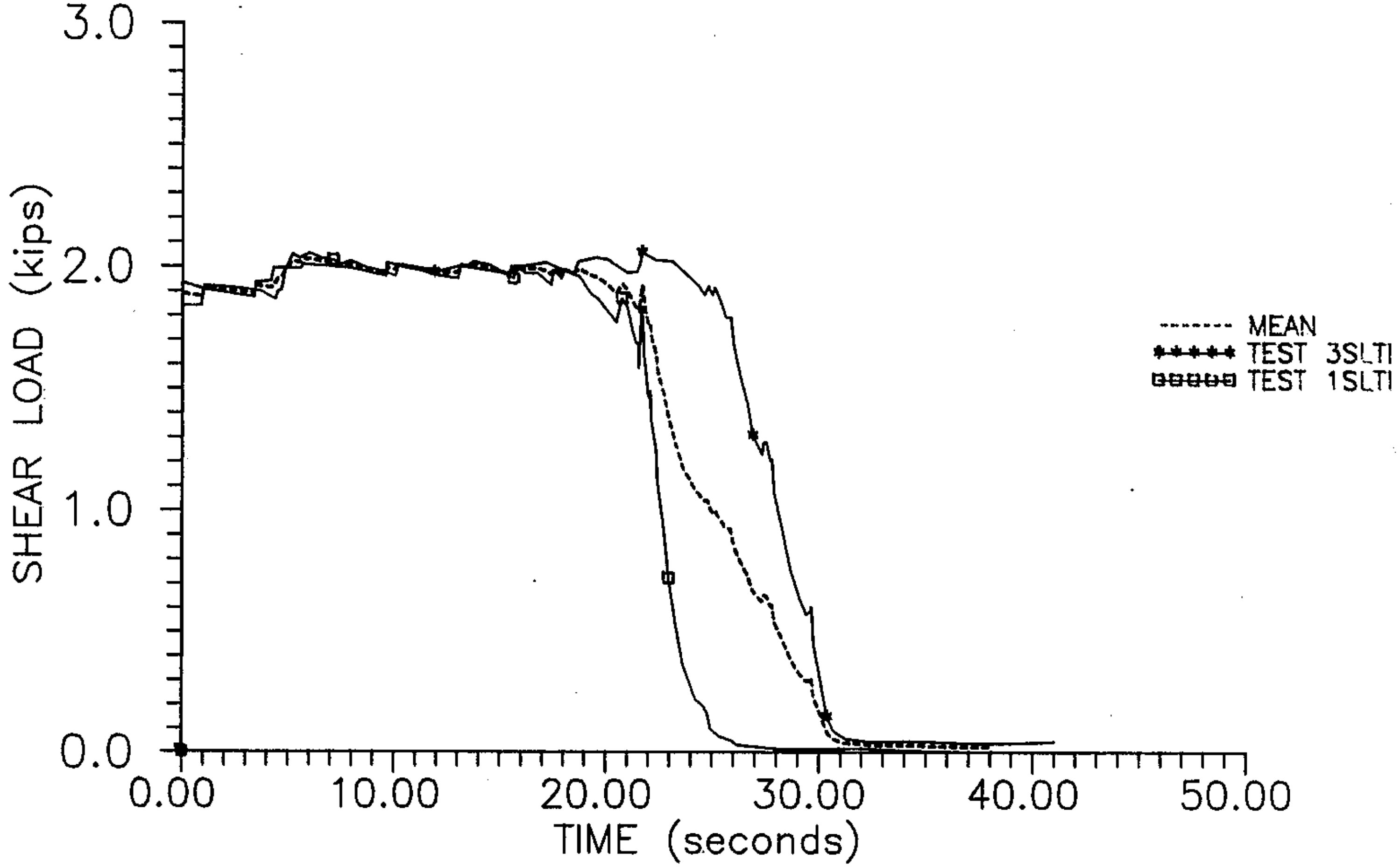


Figure G35. Load vs. time for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 1/2 in. Stud Wedge M.E.A.
Brand: Star 3535-36000
Edge Distance (to center of anchor): 3 in.
Installation Torque: 60 ft--lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 3TLTI, Test 2TLTI, & Test 1TLTI
1/3 Average Ultimate Shear Load: 2.0 kips

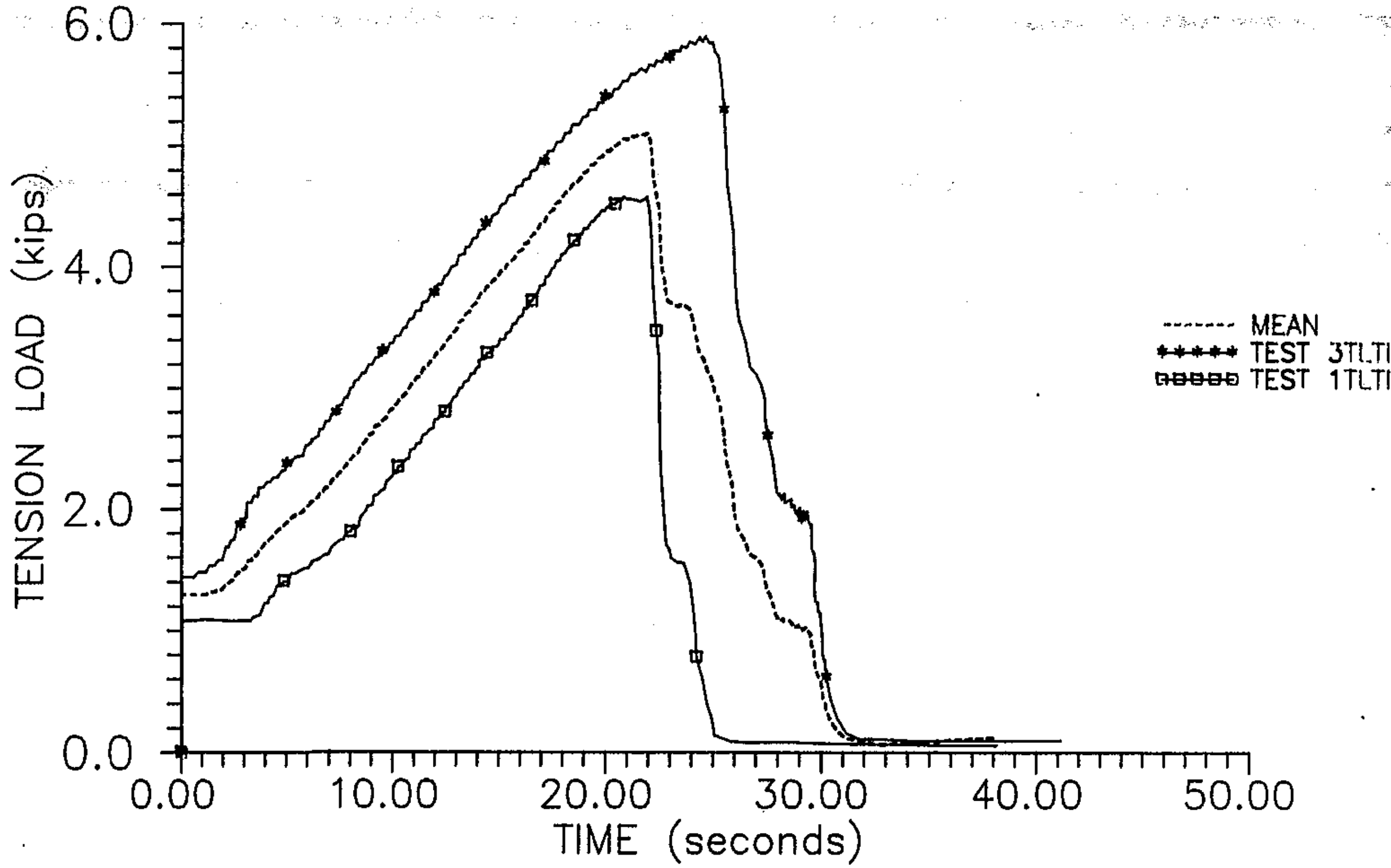


Figure G36. Load vs. time for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 1/2 in. Stud Wedge M.E.A.
Brand: Star 3535–36000
Edge Distance (to center of anchor): 3 in.
Installation Torque: 60 ft–lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 6TLTD, Test 5TLTD, & Test 4TLTD
(Test 5TLTD and Test 4TLTD failed under 2/3 average ultimate shear load)
2/3 Average Ultimate Shear Load: 4.0 kips

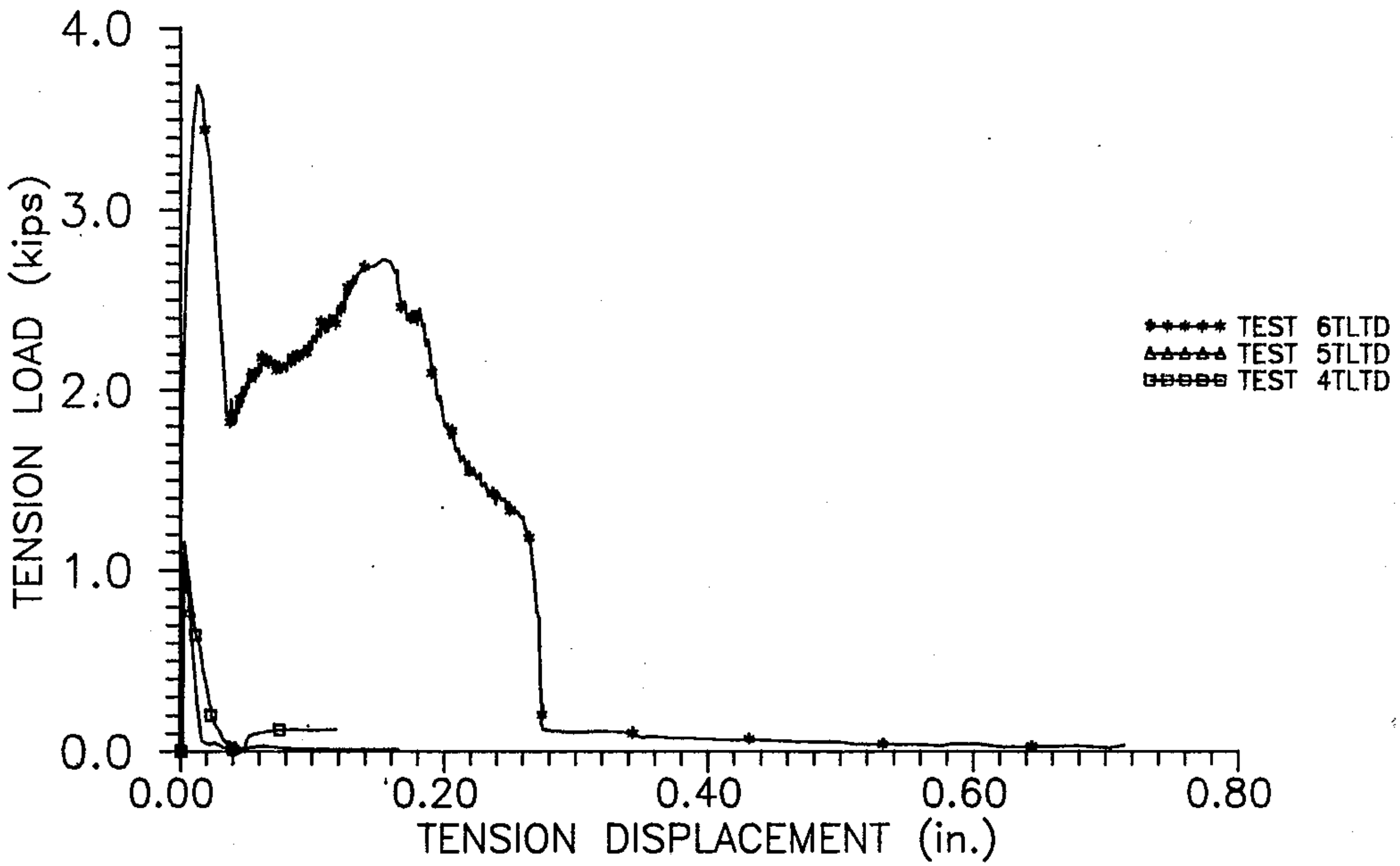


Figure G37. Load vs. displacement for short–term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 1/2 in. Stud Wedge M.E.A.
Brand: Star 3535–36000
Edge Distance (to center of anchor): 3 in.
Installation Torque: 60 ft–lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 6SLTI, Test 5SLTI, & Test 4SLTI
(Test 5SLTI and Test 4SLTI failed under 2/3 average ultimate shear load)
2/3 Average Ultimate Shear Load: 4.0 kips

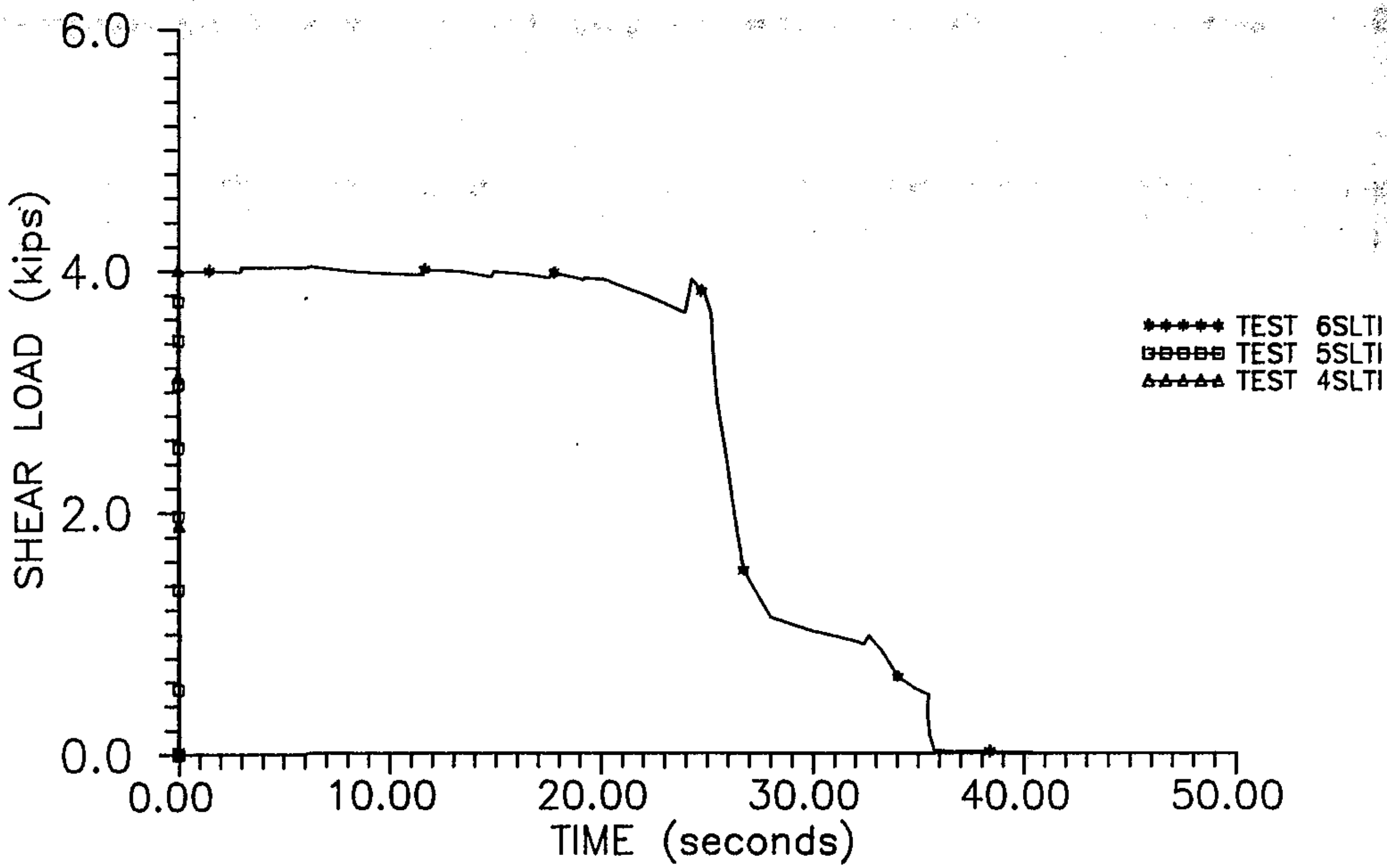


Figure G38. Load vs. time for short–term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 1/2 in. Stud Wedge M.E.A.
Brand: Star 3535–36000
Edge Distance (to center of anchor): 3 in.
Installation Torque: 60 ft–lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 6TLTI, Test 5TLTI, & Test 4TLTI
(Test 5TLTI and Test 4TLTI failed under 2/3 average ultimate shear load)
2/3 Average Ultimate Shear Load: 4.0 kips

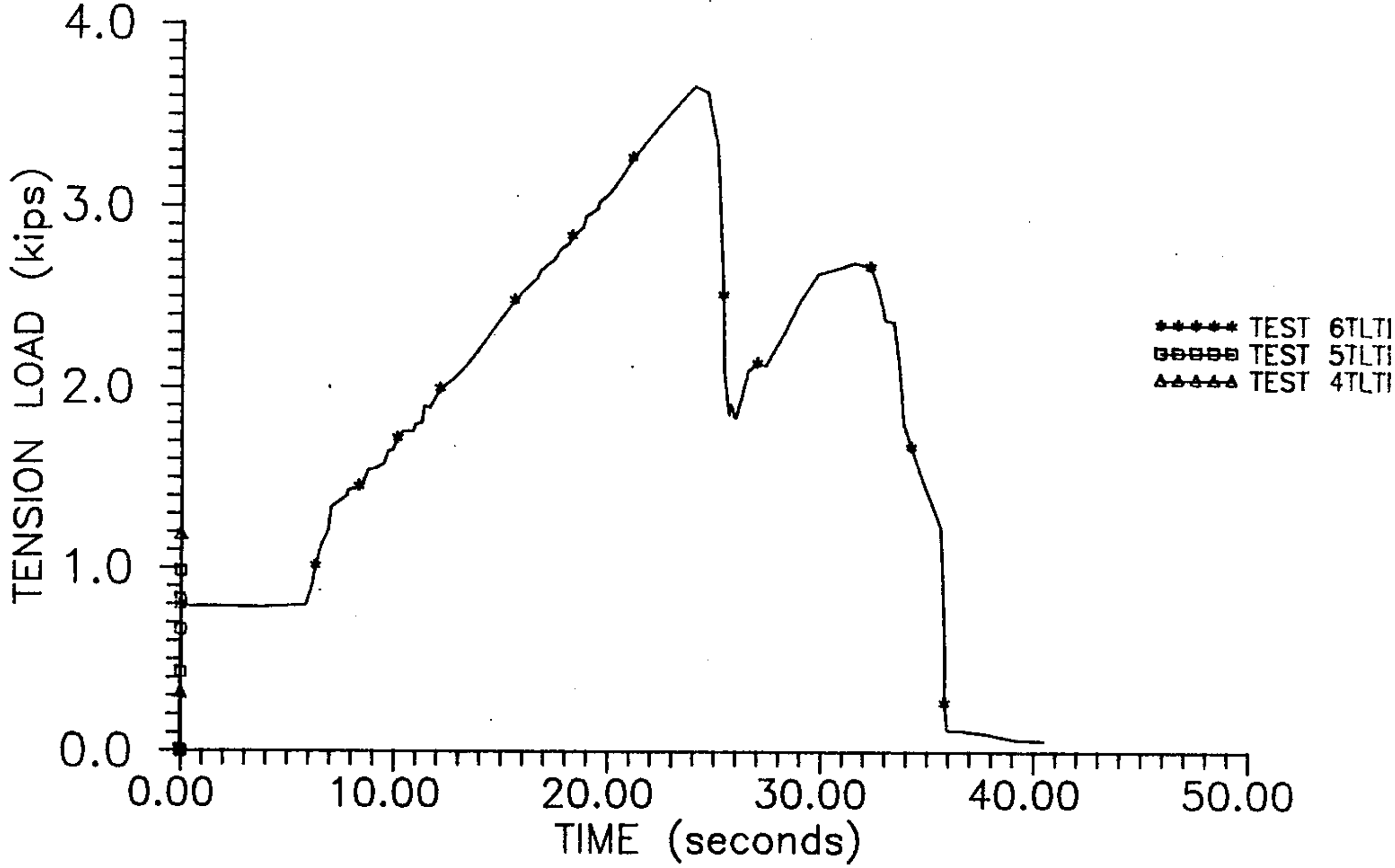


Figure G39. Load vs. time for short–term combined loading tests of mechanical expansion anchors.

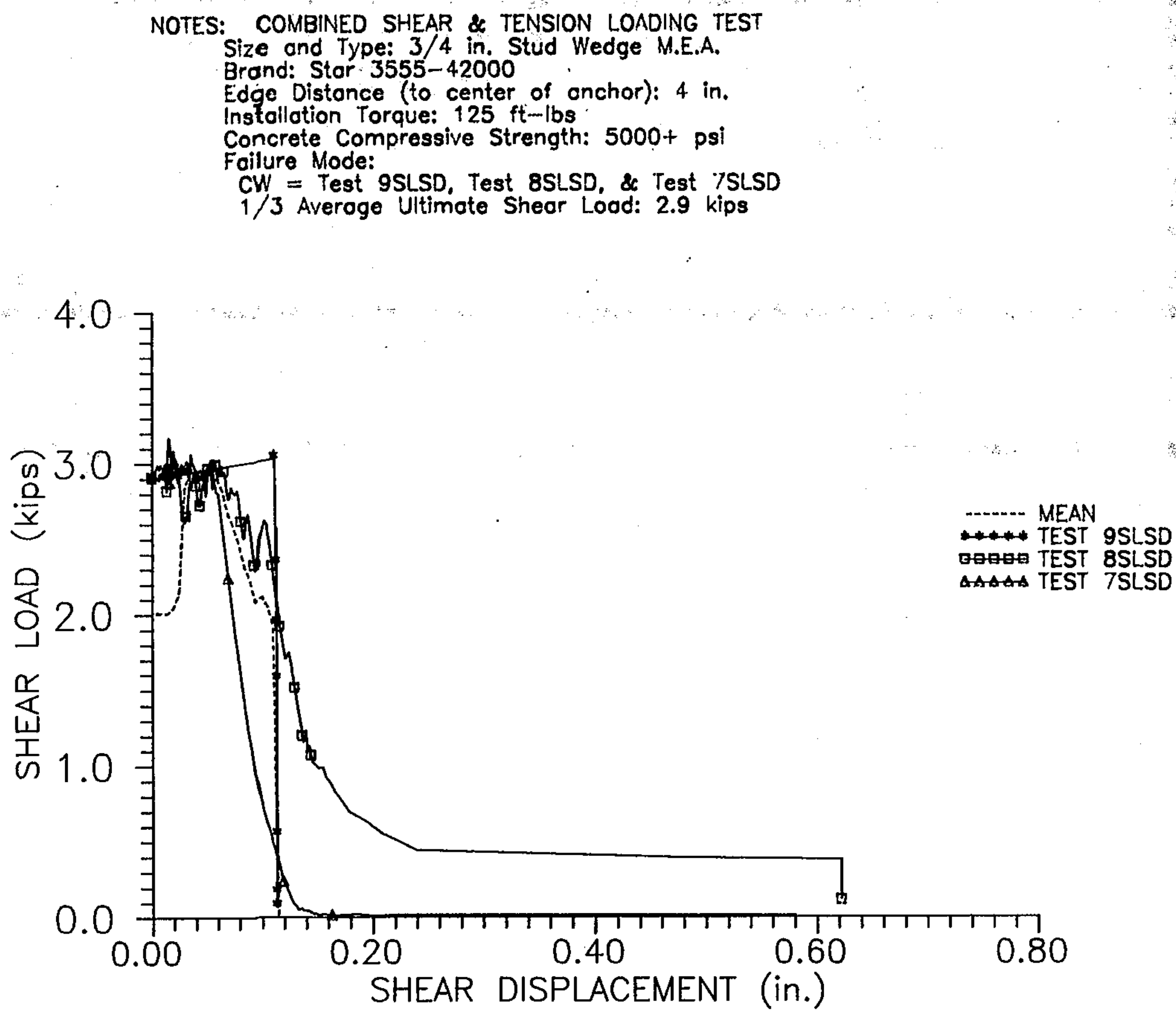


Figure G40. Load vs. displacement for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 3/4 in. Stud Wedge M.E.A.
Brand: Star 3555-42000
Edge Distance (to center of anchor): 4 in.
Installation Torque: 125 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 9TLTD, Test 8TLTD, & Test 7TLTD
1/3 Average Ultimate Shear Load: 2.9 kips

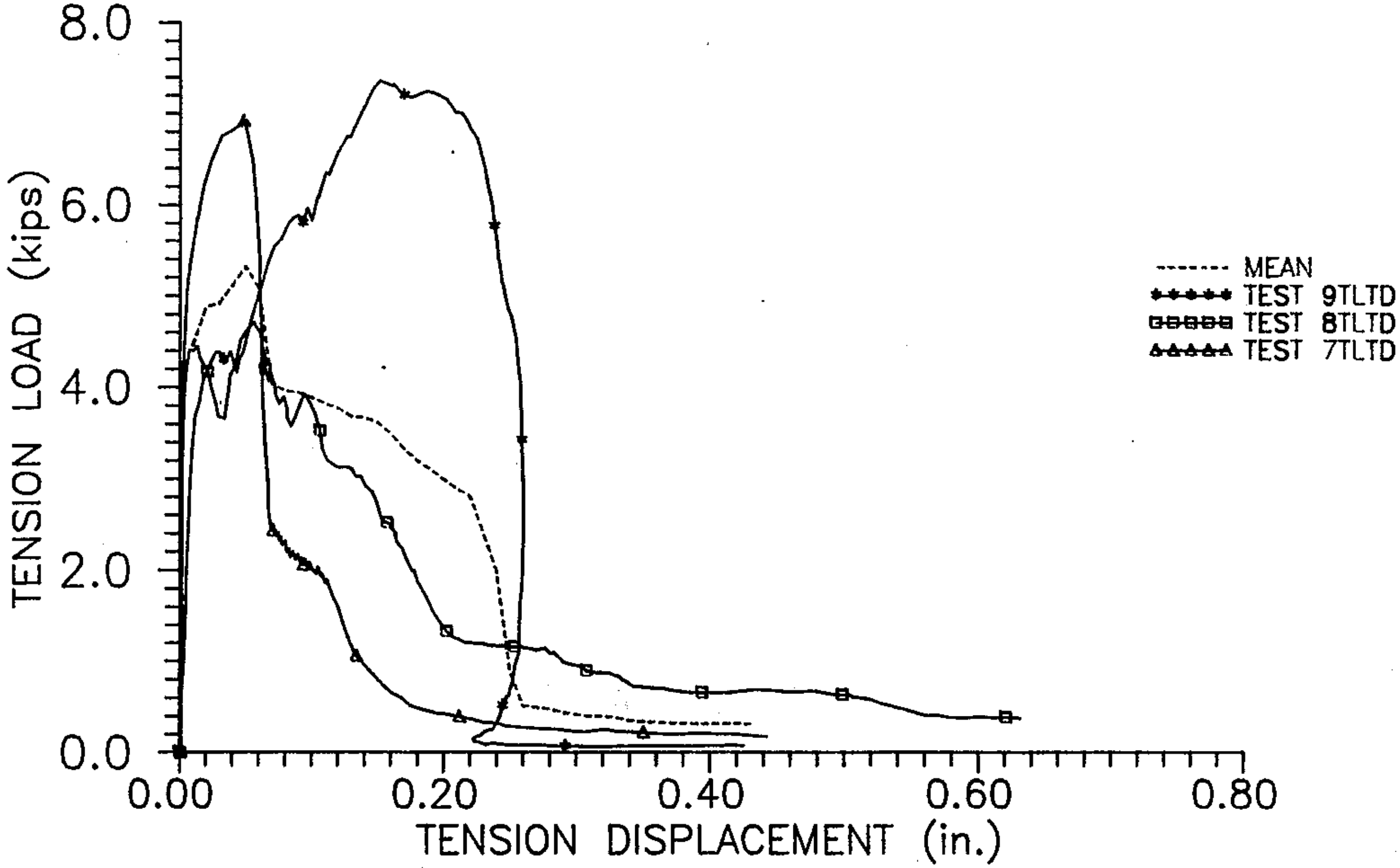


Figure G41. Load vs. displacement for short-term combined loading tests of mechanical expansion anchors.

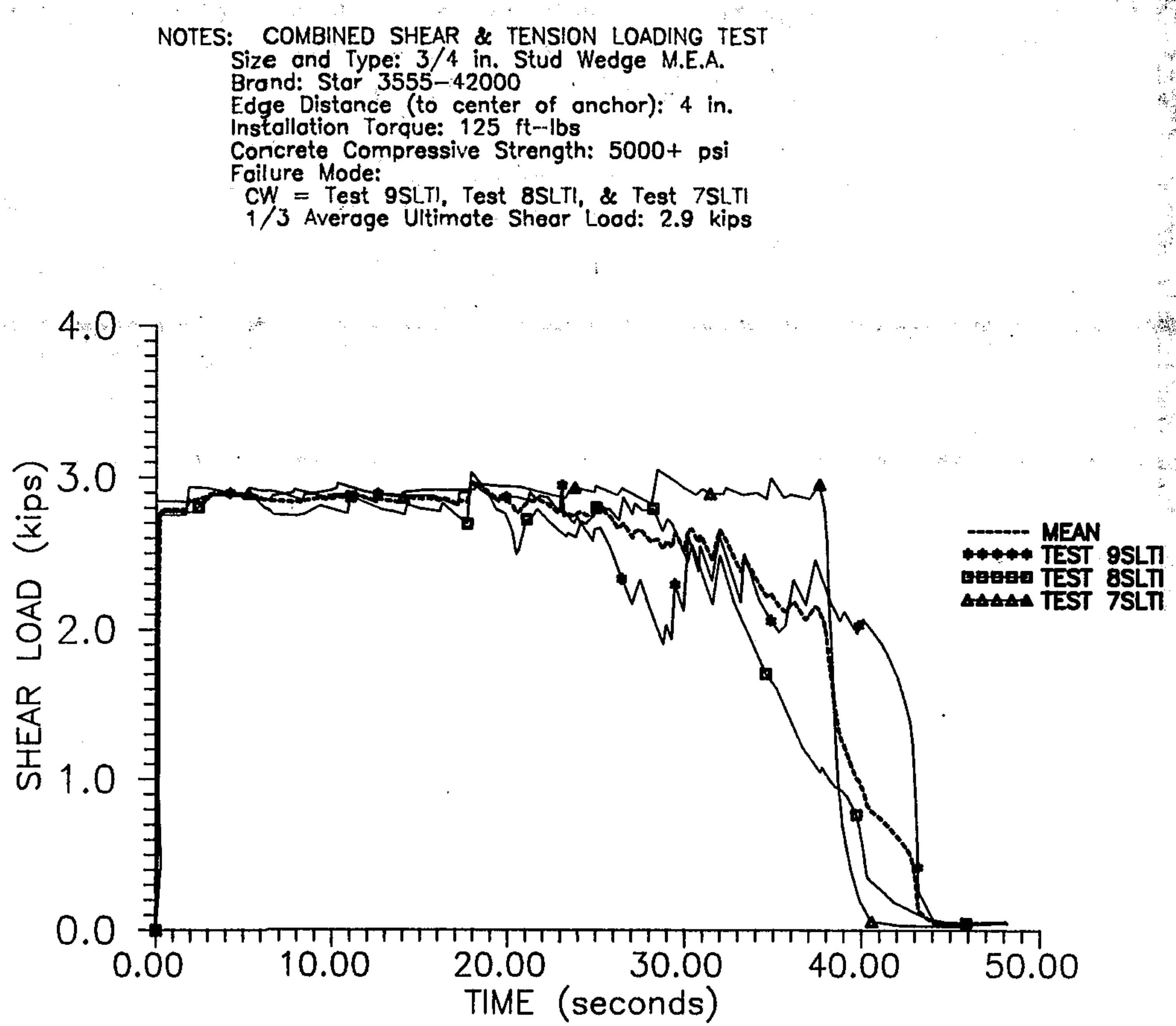


Figure G42. Load vs. time for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 3/4 in. Stud Wedge M.E.A.
Brand: Star 3555-42000
Edge Distance (to center of anchor): 4 in.
Installation Torque: 125 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 9TLTI, Test 8TLTI, & Test 7TLTI
1/3 Average Ultimate Shear Load: 2.9 kips

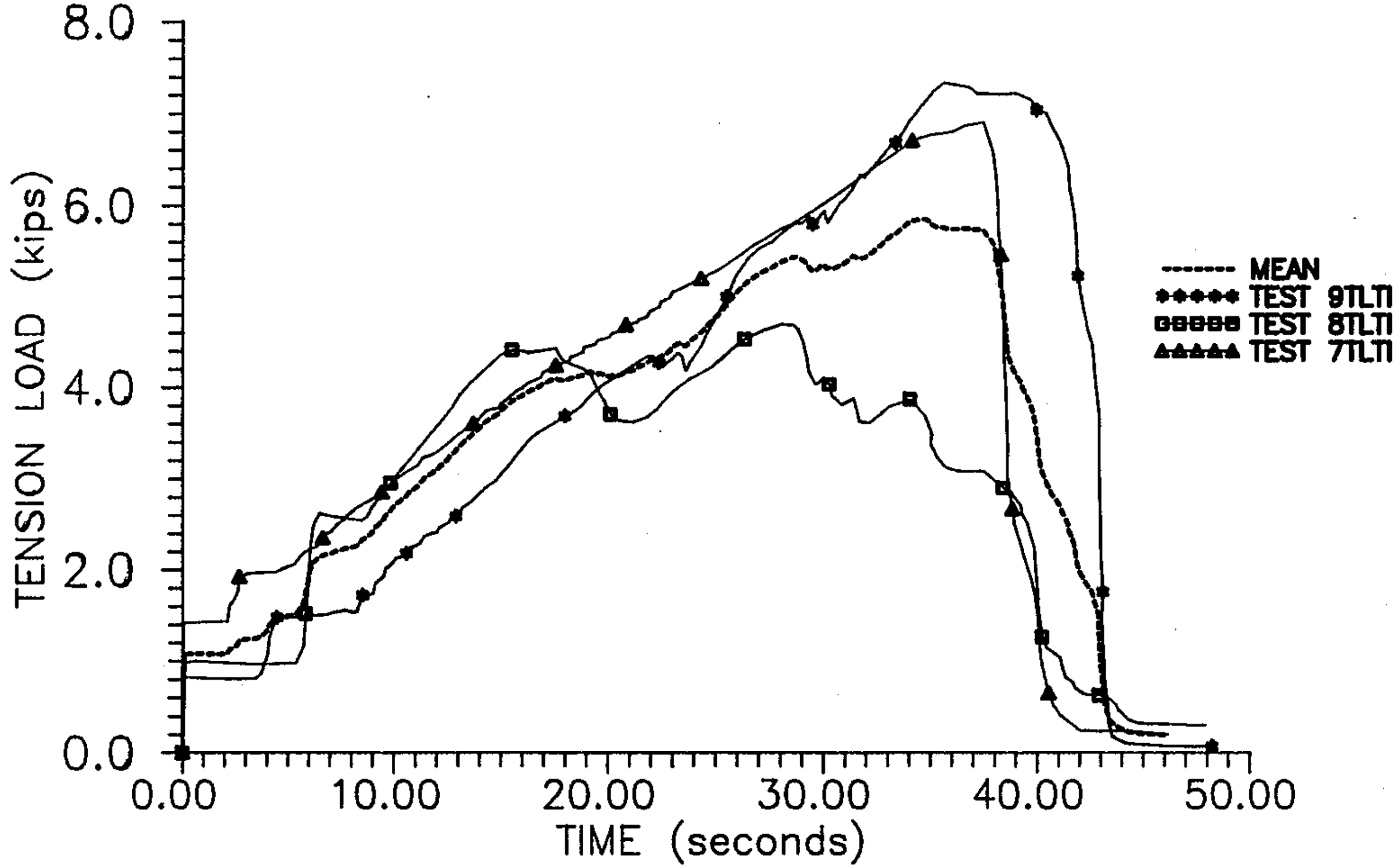


Figure G43. Load vs. time for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 3/4 in. Stud Wedge M.E.A.
Brand: Star 3555--42000
Edge Distance (to center of anchor): 4 in.
Installation Torque: 125 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 12SLSD, Test 11SLSD, & Test 10SLSD
2/3 Average Ultimate Shear Load: 5.8 kips

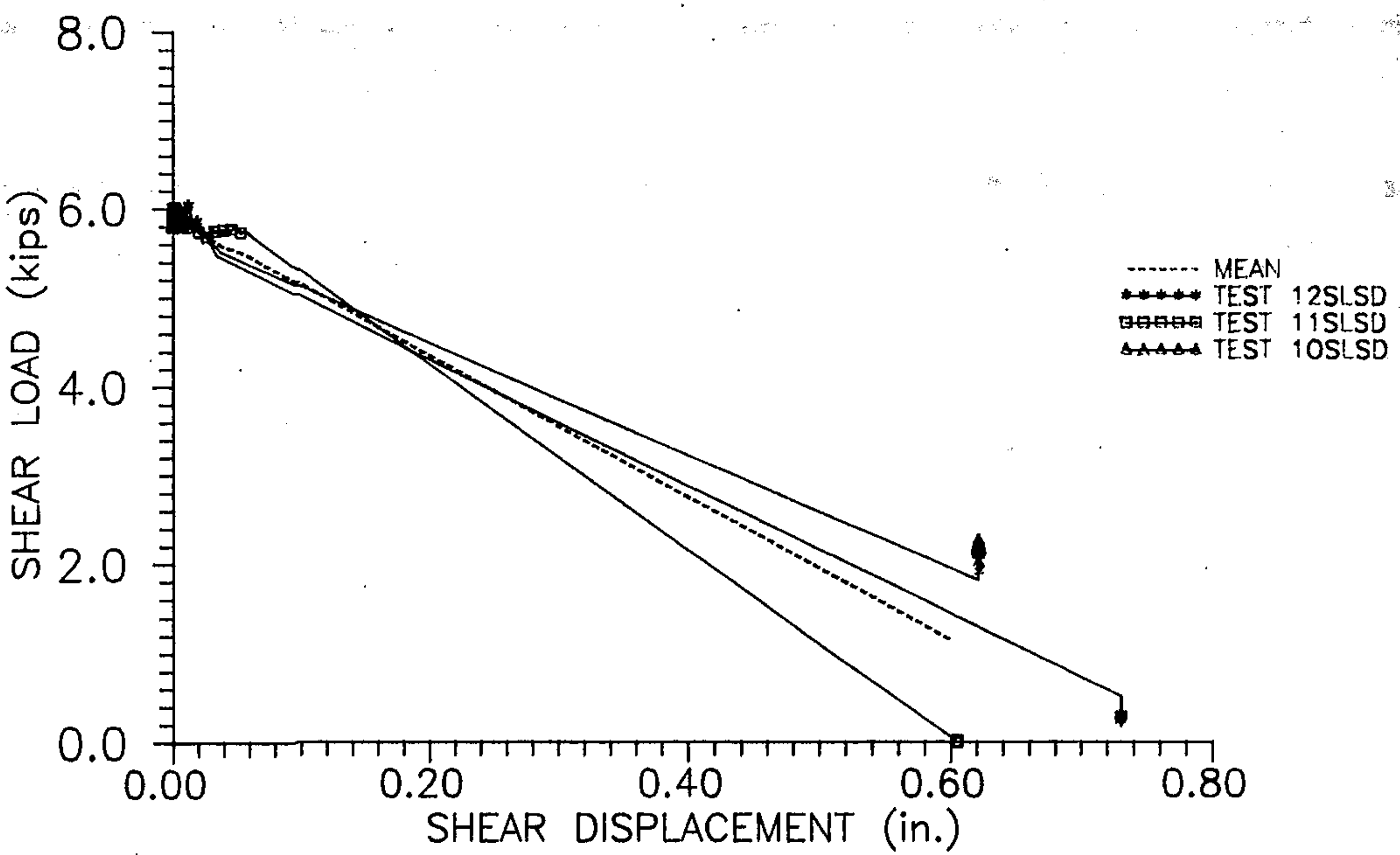


Figure G44. Load vs. displacement for short-term combined loading tests of mechanical expansion anchors.

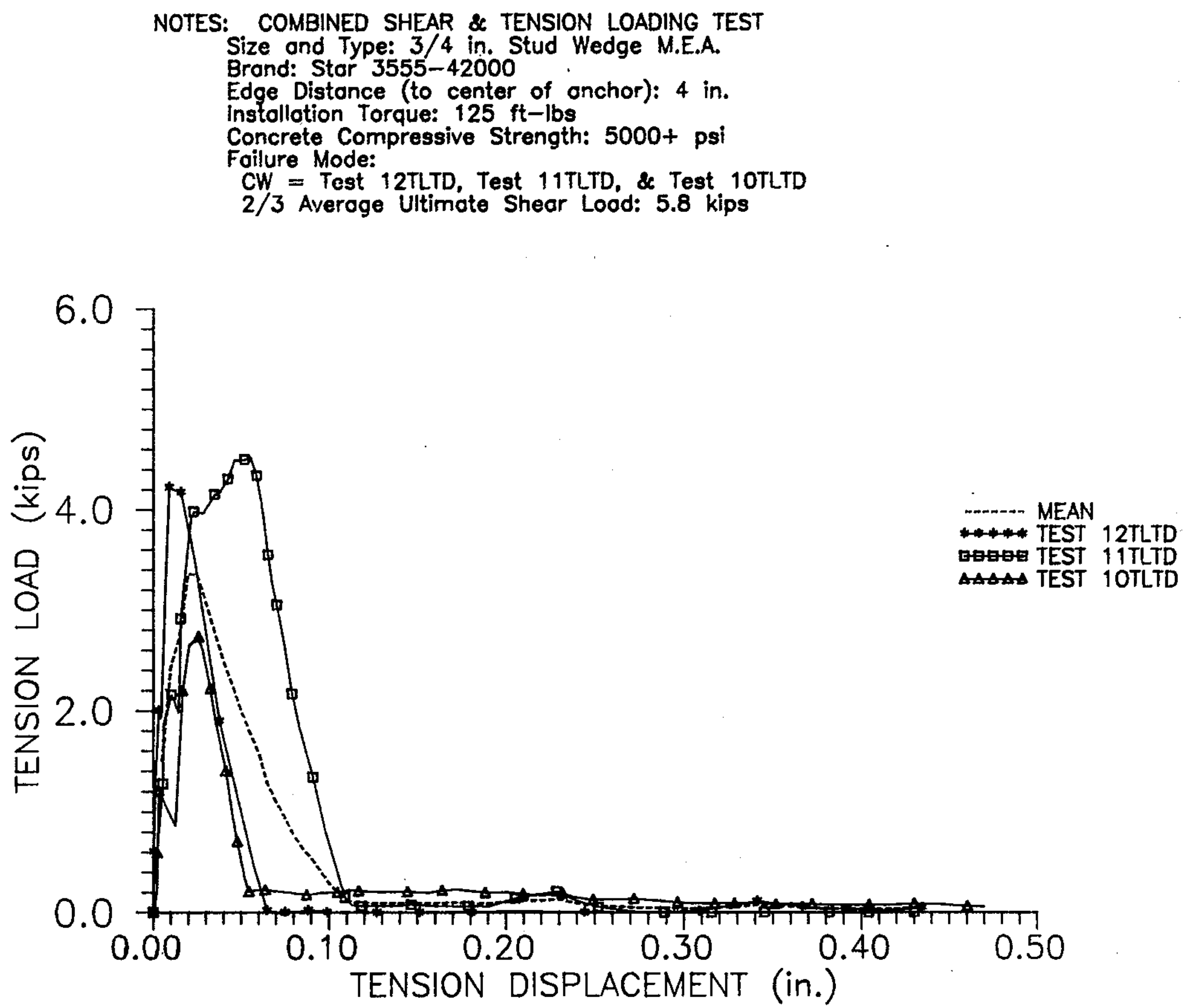


Figure G45. Load vs. displacement for short-term combined loading tests of mechanical expansion anchors.

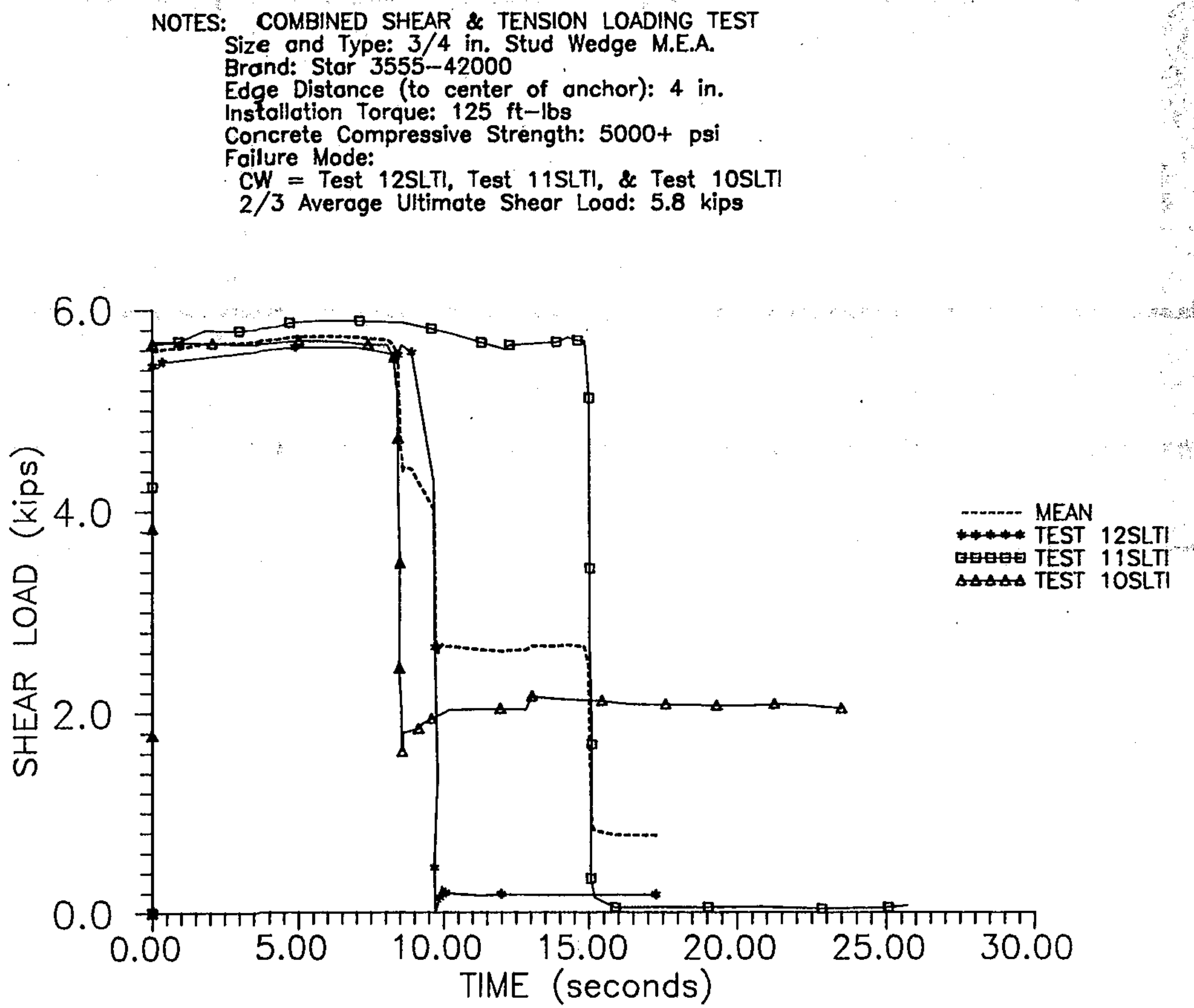


Figure G46. Load vs. time for short–term combined loading tests of mechanical expansion anchors.

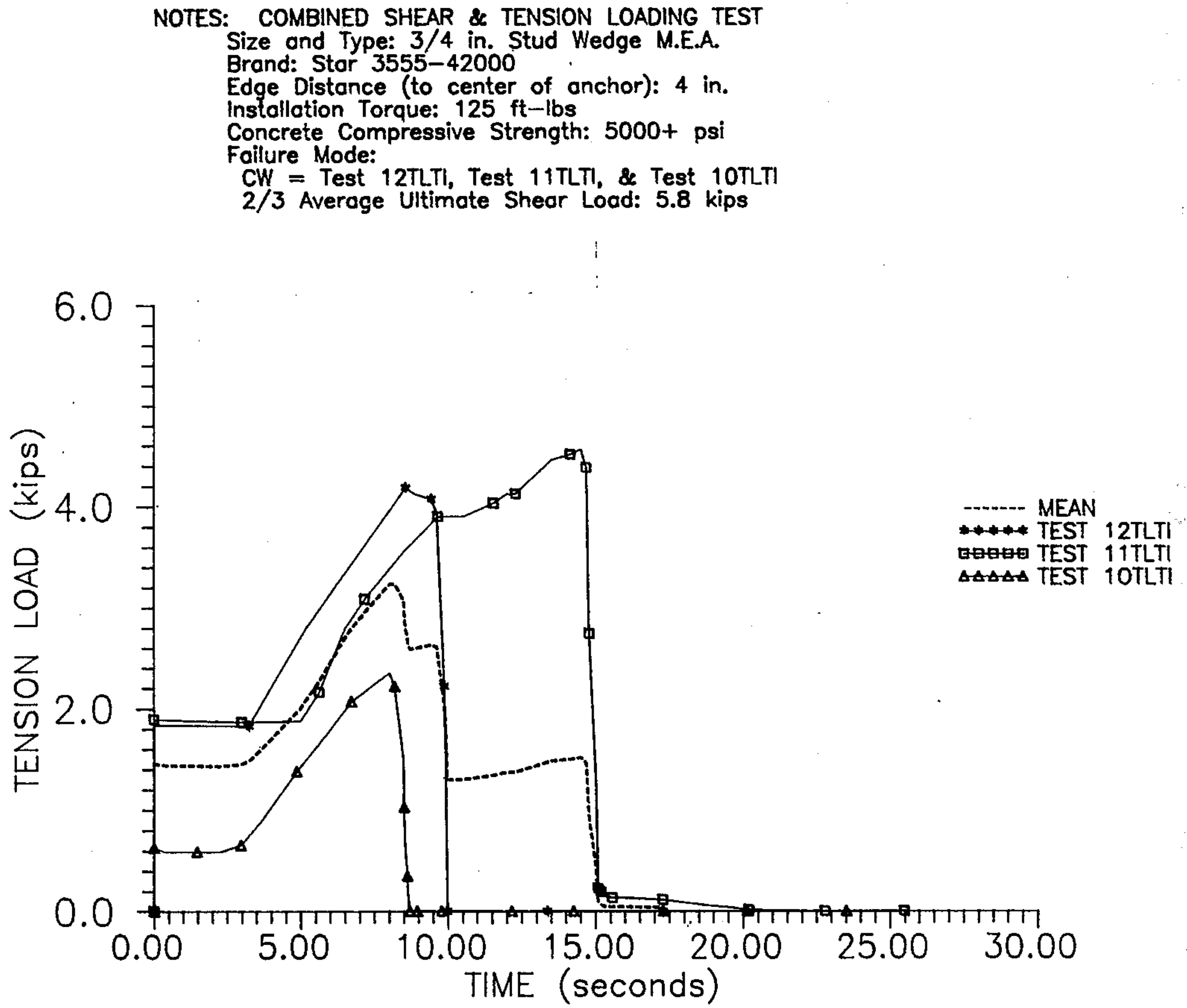


Figure G47. Load vs. time for short-term combined loading tests of mechanical expansion anchors.

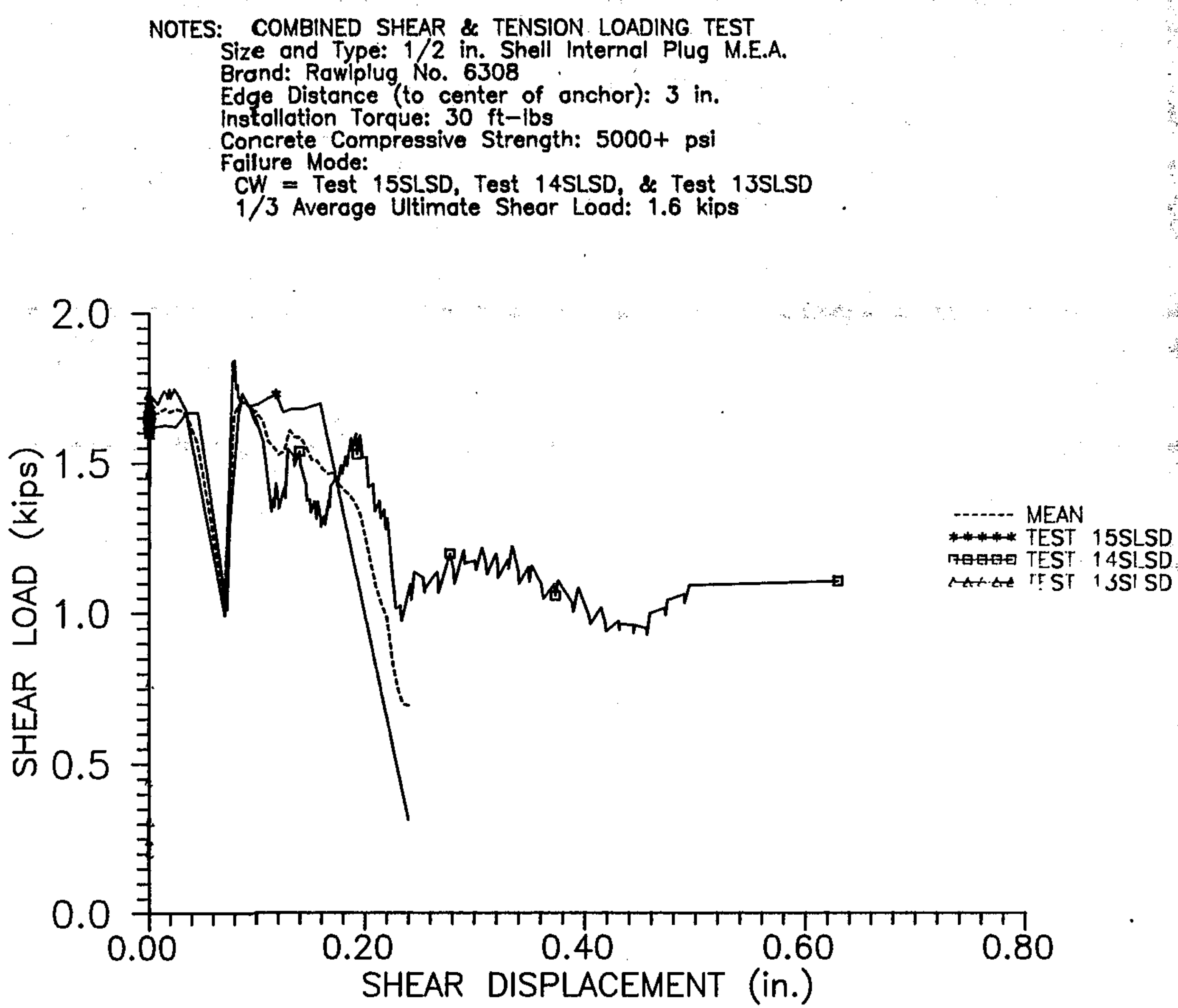


Figure G48. Load vs. displacement for short–term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 1/2 in. Shell Internal Plug M.E.A.
Brand: Rawlplug No. 6308
Edge Distance (to center of anchor): 3 in.
Installation Torque: 30 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 15TLTD, Test 14TLTD, & Test 13TLTD
1/3 Average Ultimate Shear Load: 1.6 kips

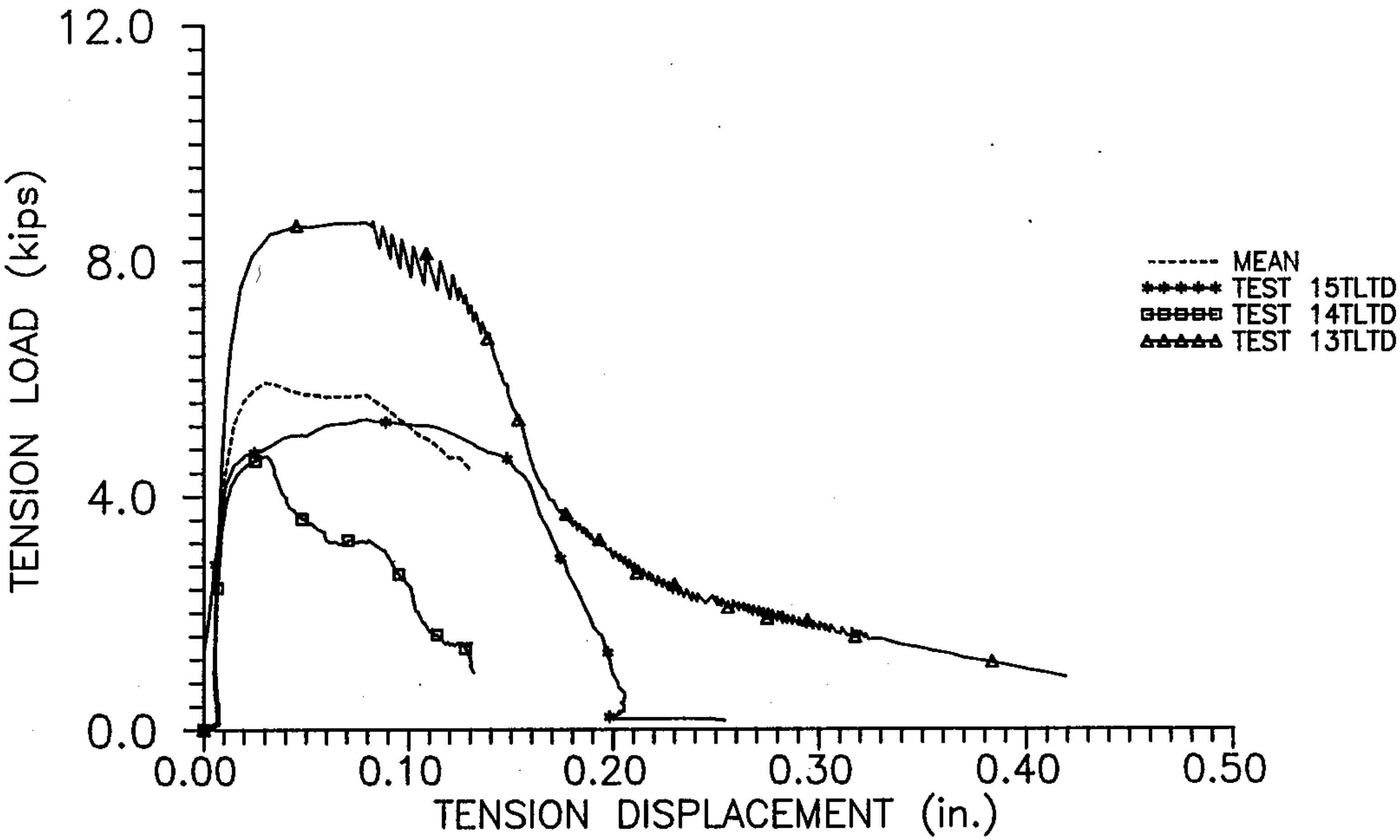


Figure G49. Load vs. displacement for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 1/2 in. Shell Internal Plug M.E.A.
Brand: Rawlplug No. 6308
Edge Distance (to center of anchor): 3 in.
Installation Torque: 30 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 15SLTI, Test 14SLTI, & Test 13SLTI
1/3 Average Ultimate Shear Load: 1.6 kips

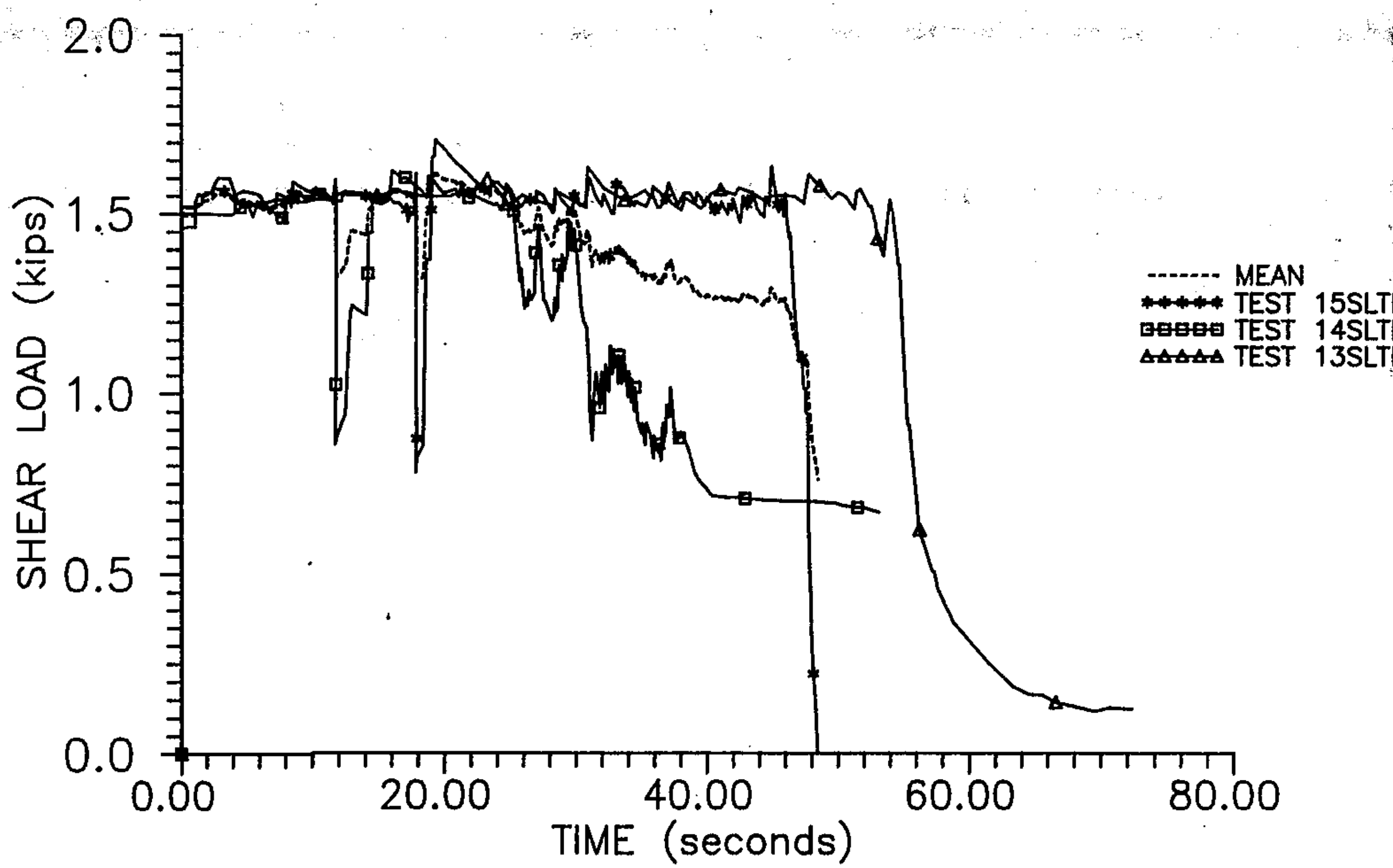


Figure G50. Load vs. time for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 1/2 in. Shell Internal Plug M.E.A.
Brand: Rawlplug No. 6308
Edge Distance (to center of anchor): 3 in.
Installation Torque: 30 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 15TITL, Test 14TITL, & Test 13TLTI
1/3 Average Ultimate Shear Load: 1.6 kips

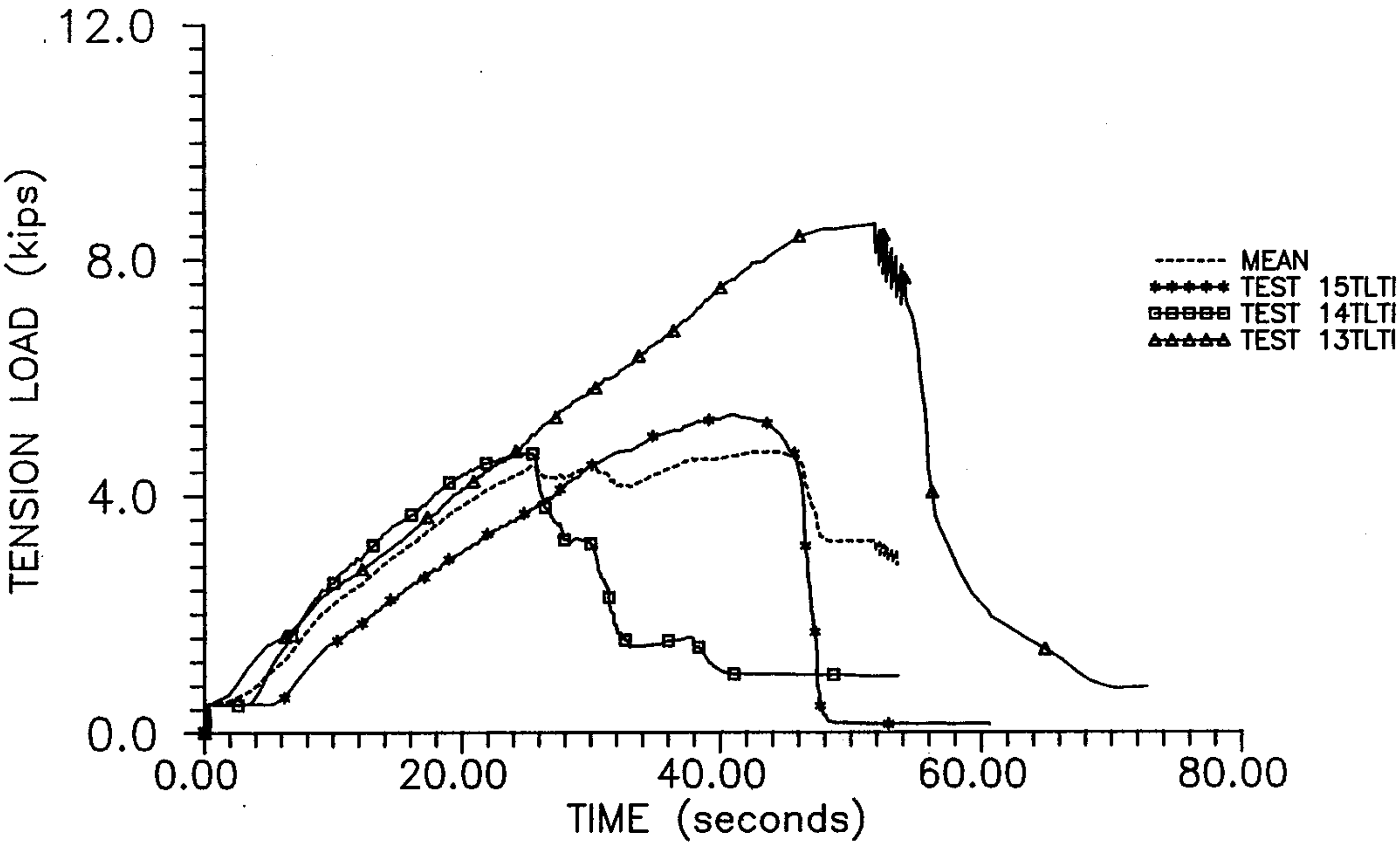


Figure G51. Load vs. time for short-term combined loading tests of mechanical expansion anchors.

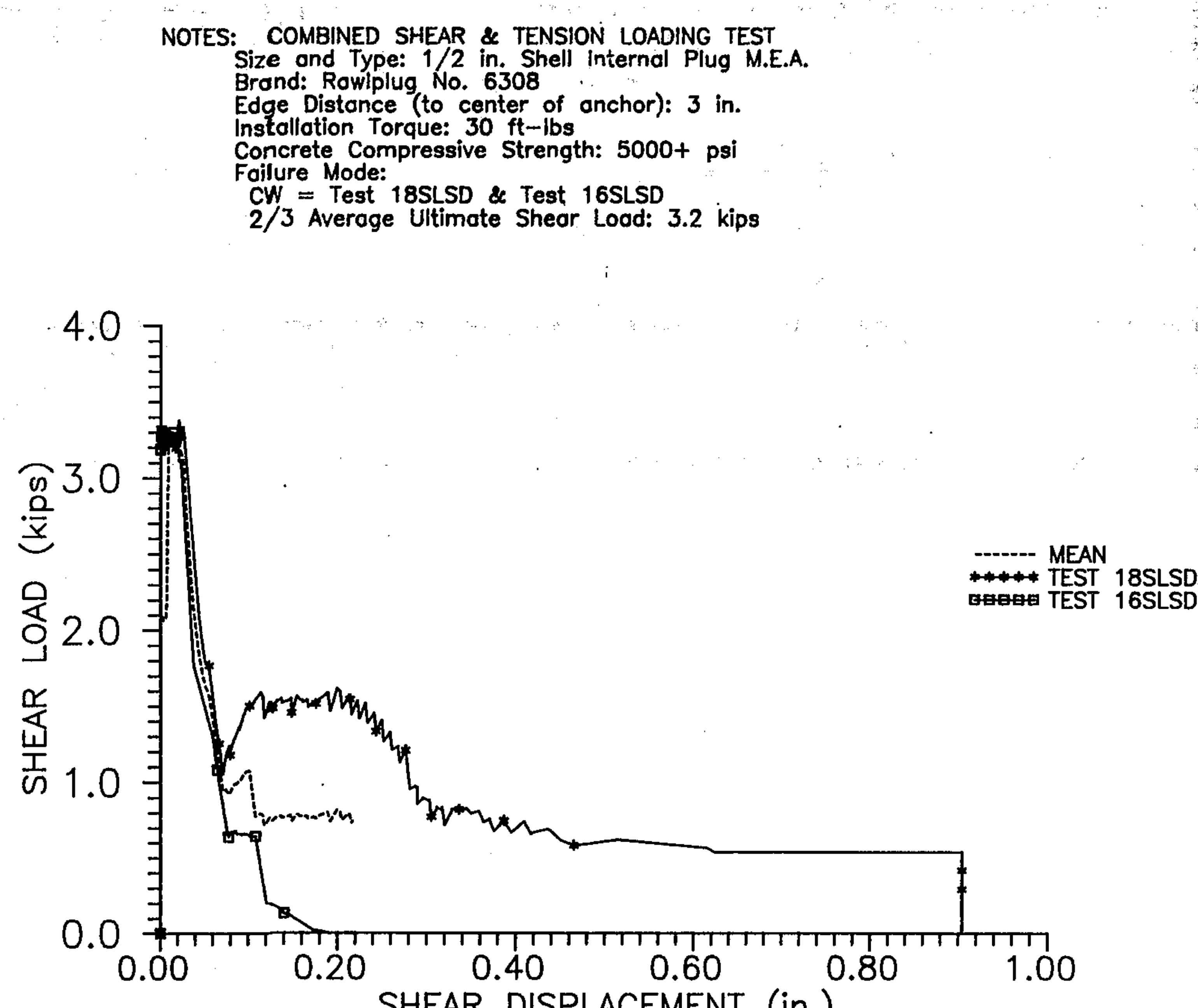


Figure G52. Load vs. displacement for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 1/2 in. Shell Internal Plug M.E.A.
Brand: Rawlplug No. 6308
Edge Distance (to center of anchor): 3 in.
Installation Torque: 30 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 18TLTD, Test 17TLTD, & Test 16TLTD
2/3 Average Ultimate Shear Load: 3.2 kips

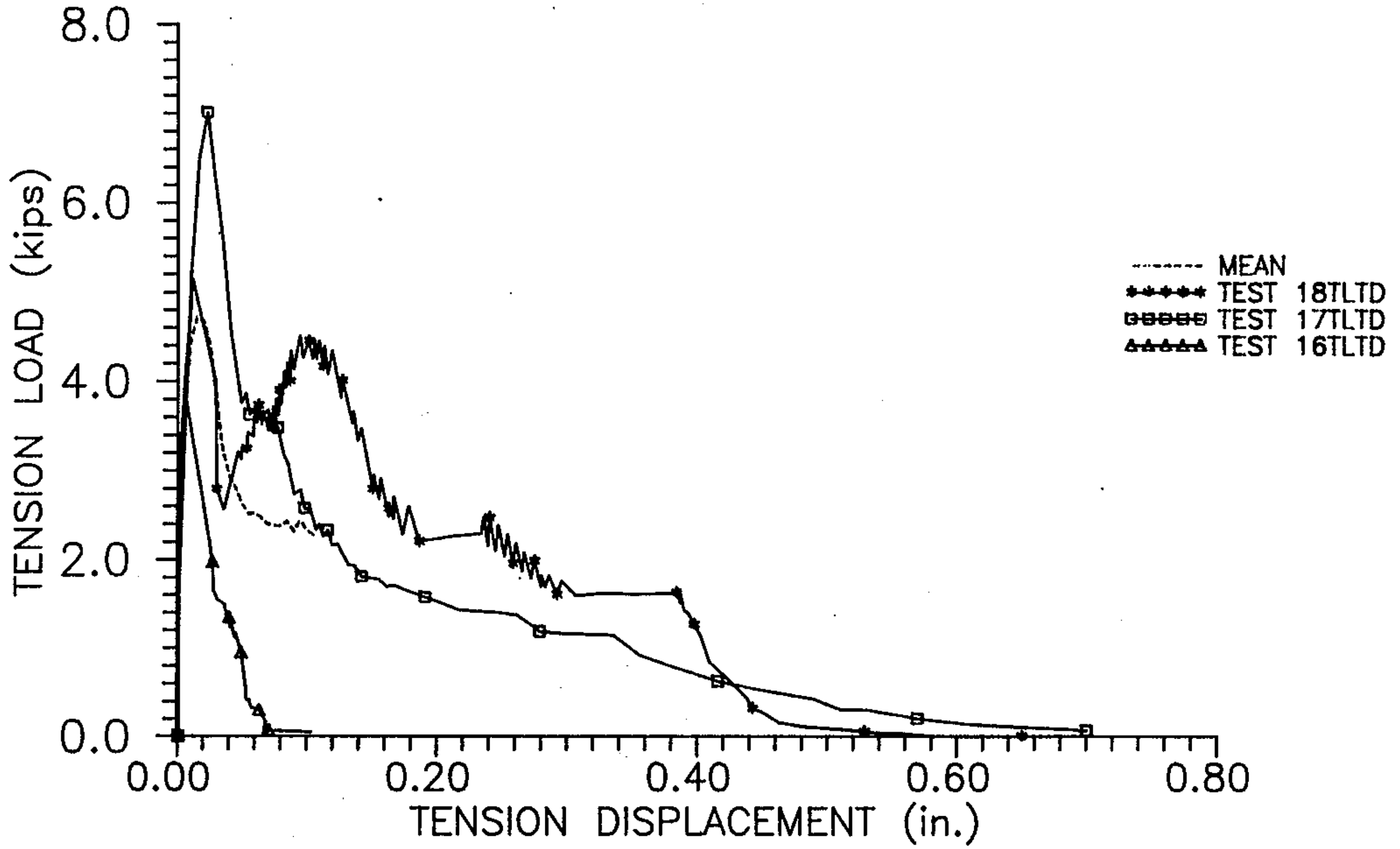


Figure G53. Load vs. displacement for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 1/2 in. Shell Internal Plug M.E.A.
Brand: Rawiplug No. 6308
Edge Distance (to center of anchor): 3 in.
Installation Torque: 30 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 18SLTI, Test 17SLTI, & Test 16SLTI
2/3 Average Ultimate Shear Load: 3.2 kips

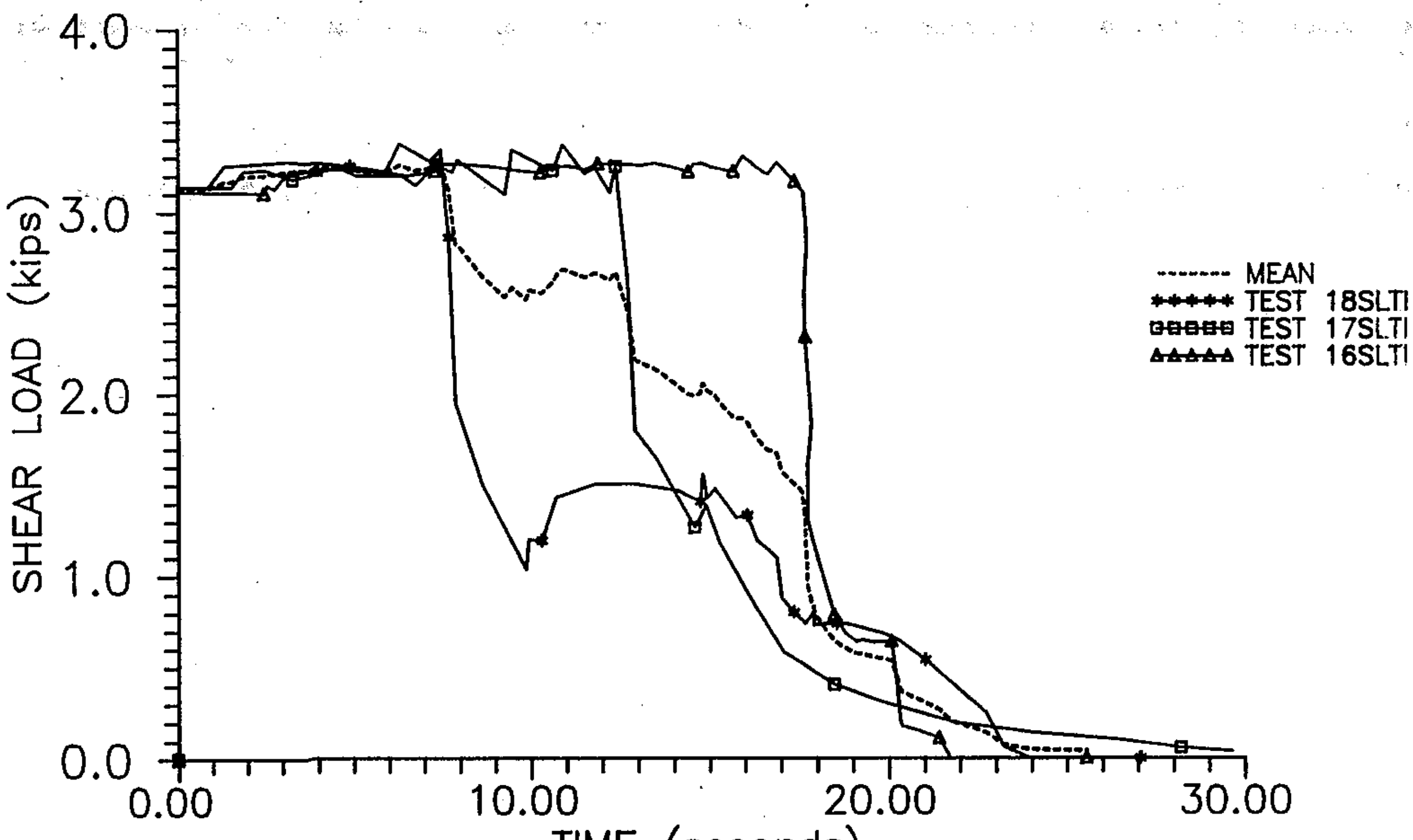


Figure G54. Load vs. time for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 1/2 in. Shell Internal Plug M.E.A.
Brand: Rawlplug No. 6308
Edge Distance (to center of anchor): 3 in.
Installation Torque: 30 ft–lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 18TLTI, Test 17TLTI, & Test 16TLTI
2/3 Average Ultimate Shear Load: 3.2 kips

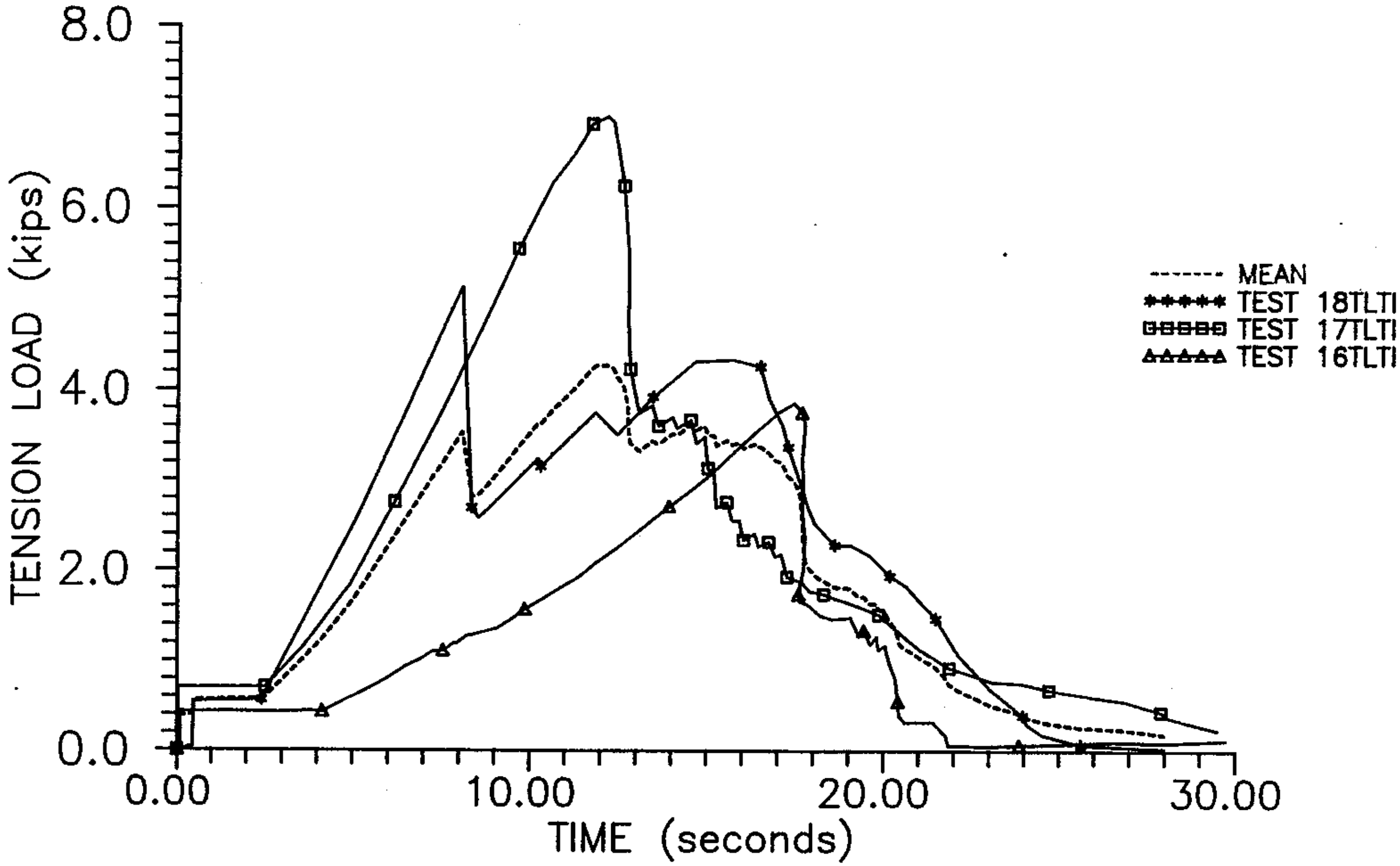


Figure G55. Load vs. time for short–term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 3/4 in. Shell Internal Plug M.E.A.
Brand: Molly No. MDI-34
Edge Distance (to center of anchor): 5 in.
Installation Torque: 80 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 21SLSD, Test 20SLSD, & Test 19SLSD
1/3 Average Ultimate Shear Load: 3.4 kips

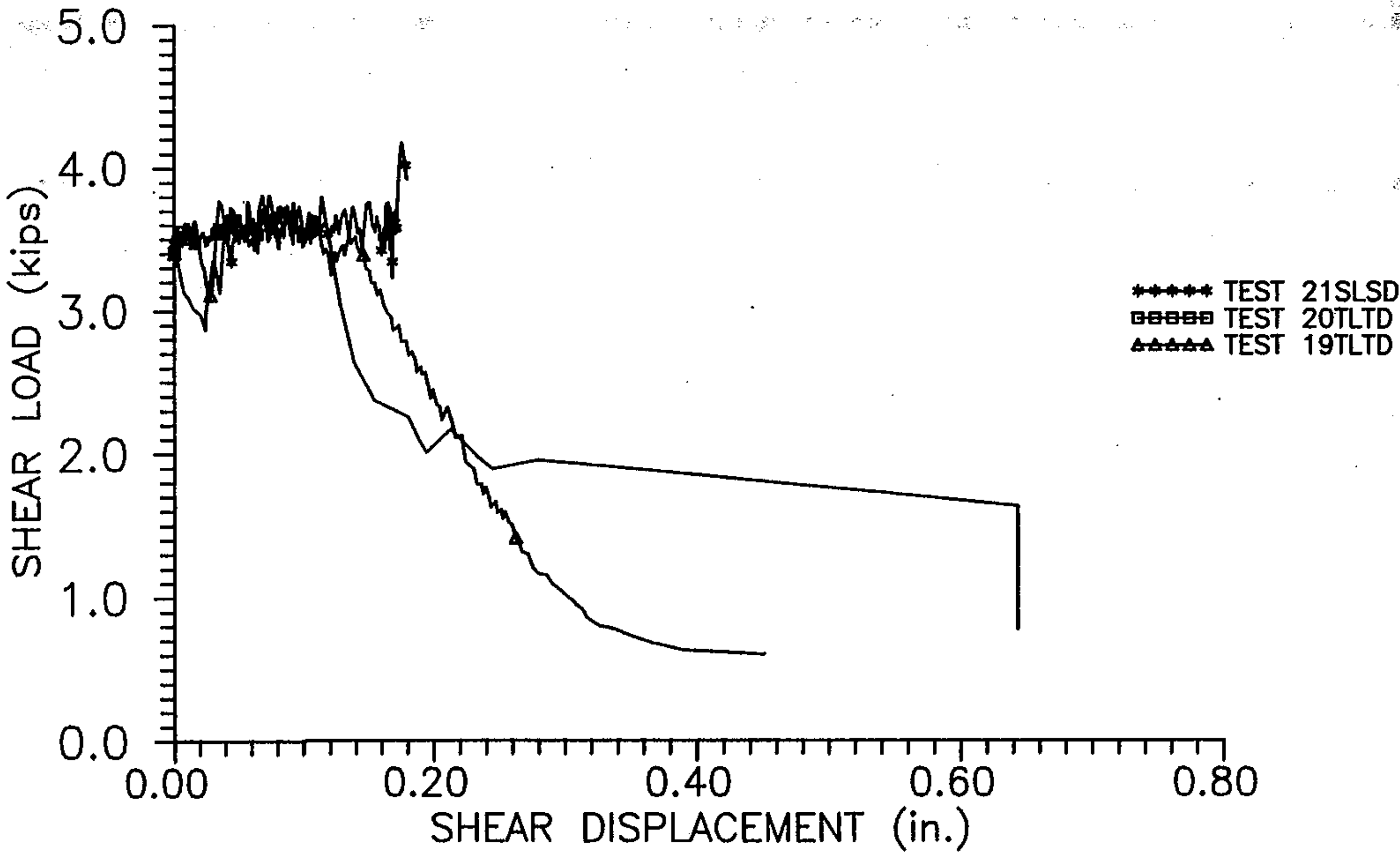


Figure G56. Load vs. displacement for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 3/4 in. Shell Internal Plug M.E.A.
Brand: Molly No. MDI-34
Edge Distance (to center of anchor): 5 in.
Installation Torque: 80 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 21TLTD, Test 20TLTD, & Test 19TLTD
1/3 Average Ultimate Shear Load: 3.4 kips

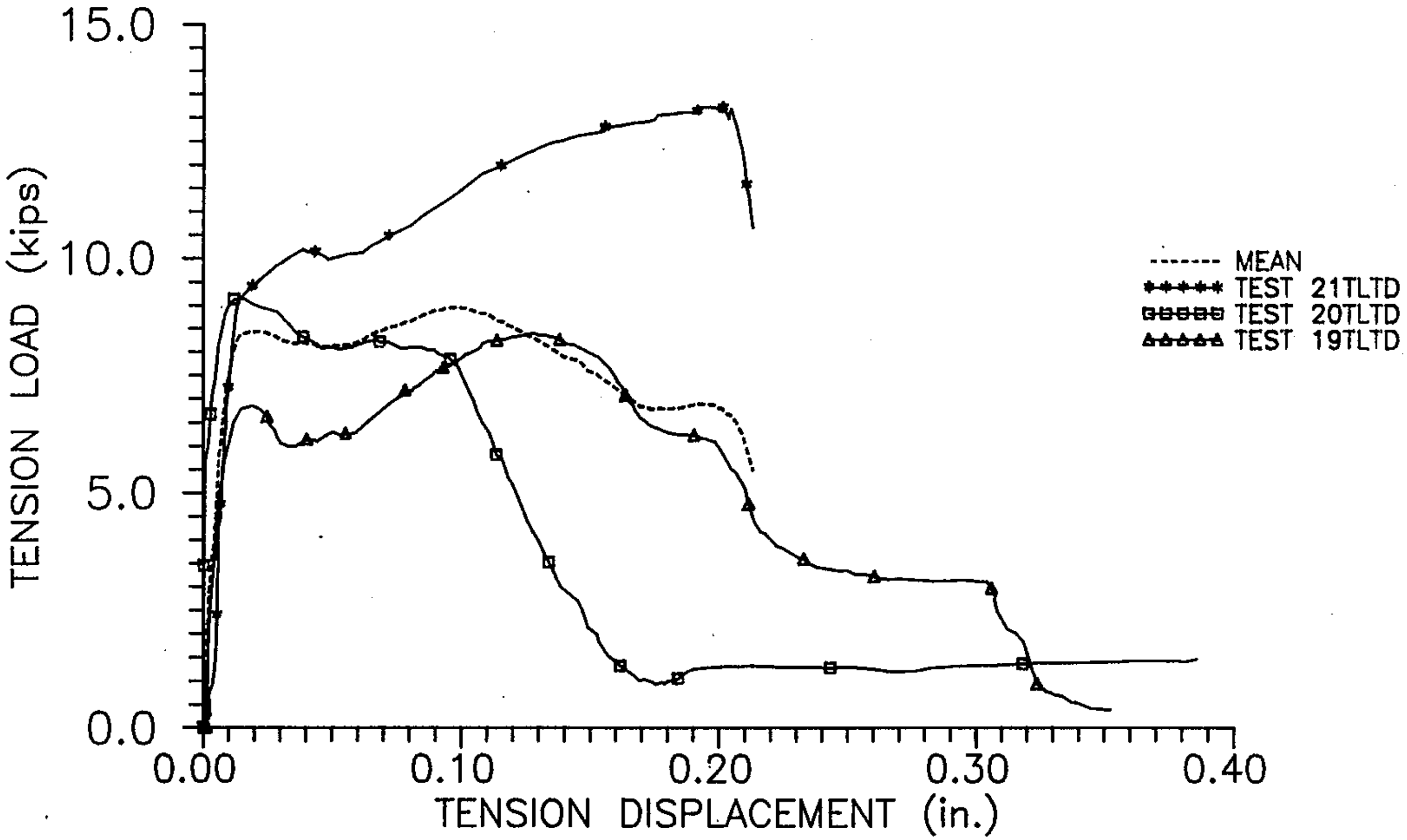


Figure G57. Load vs. displacement for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 3/4 in. Shell Internal Plug M.E.A.
Brand: Molly No. MDI-34
Edge Distance (to center of anchor): 5 in.
Installation Torque: 80 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 21SLTI, Test 20SLTI, & Test 19SLTI
1/3 Average Ultimate Shear Load: 3.4 kips

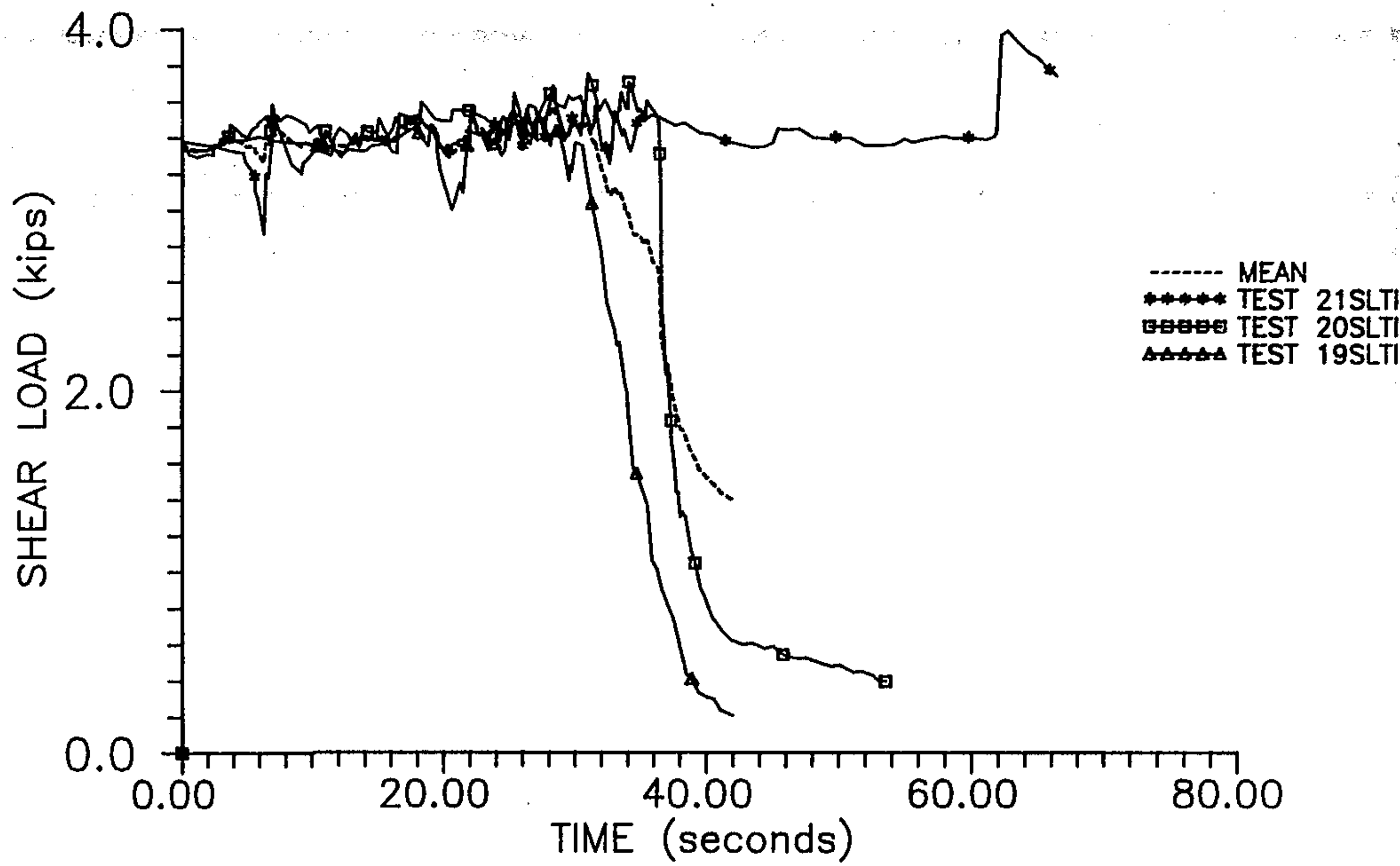


Figure G58. Load vs. time for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 3/4 in. Shell Internal Plug M.E.A.
Brand: Molly No. MDI-34
Edge Distance (to center of anchor): 5 in.
Installation Torque: 80 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 21TLTI, Test 20TLTI, & Test 19TLTI
1/3 Average Ultimate Shear Load: 3.4 kips

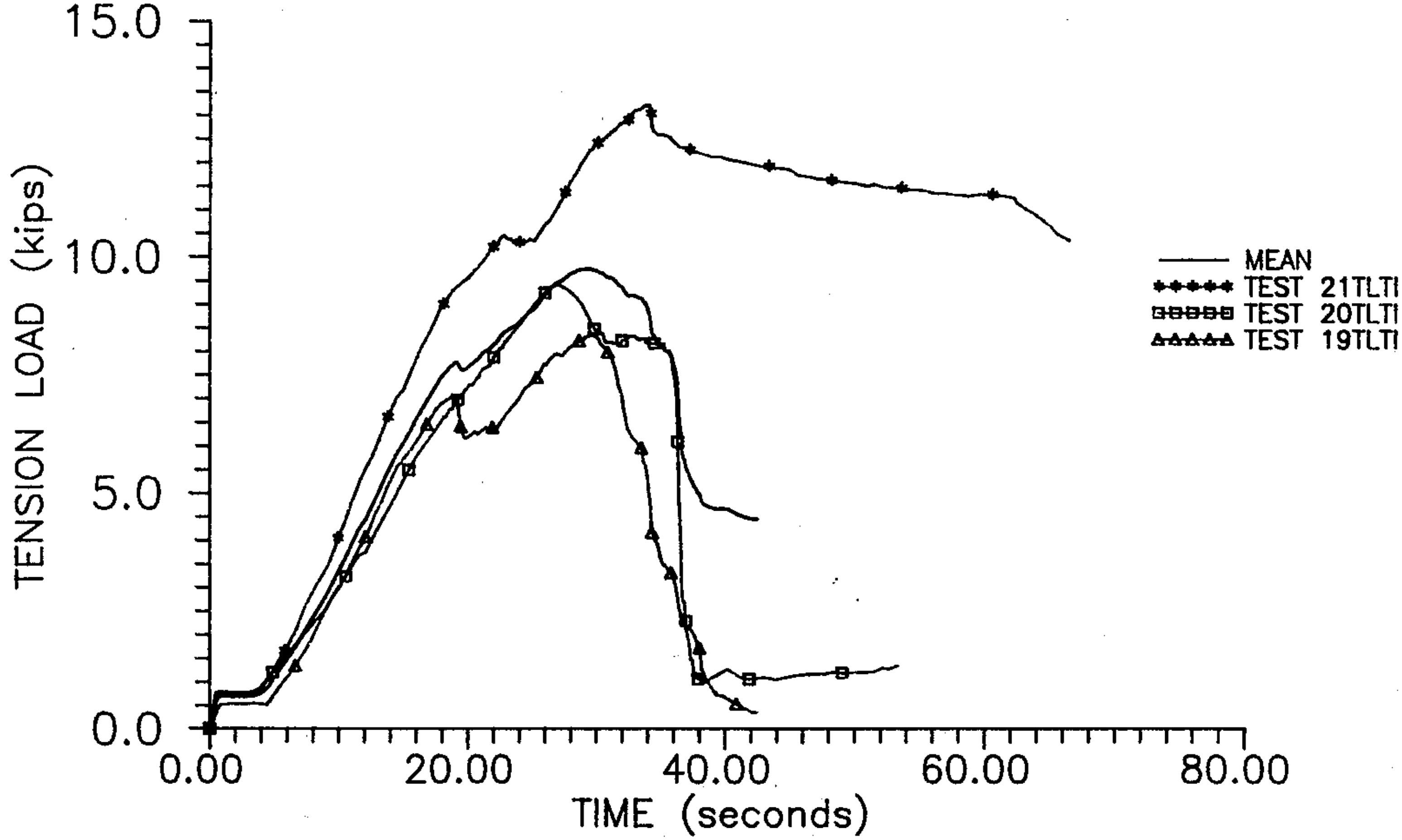


Figure G59. Load vs. time for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 3/4 in. Shell Internal Plug M.E.A.
Brand: Molly No. MDI–34
Edge Distance (to center of anchor): 5 in.
Installation Torque: 80 ft–lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 24SLSD, Test 23SLSD, & Test 22SLSD
2/3 Average Ultimate Shear Load: 6.8 kips

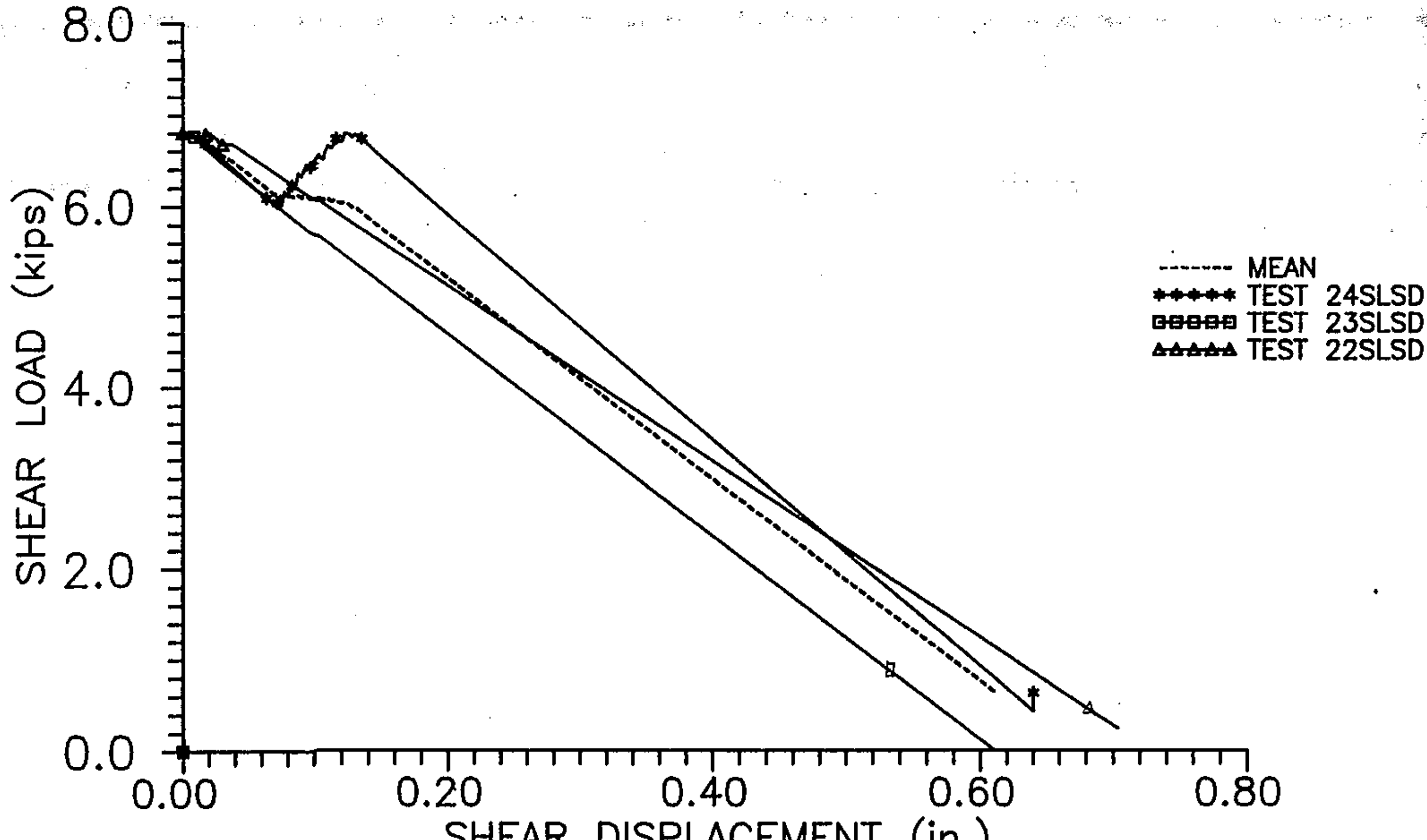


Figure G60. Load vs. displacement for short–term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 3/4 in. Shell Internal Plug M.E.A.
Brand: Molly No. MDI-34
Edge Distance (to center of anchor): 5 in.
Installation Torque: 80 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 24TLTD, Test 23TLTD, & Test 22TLTD
2/3 Average Ultimate Shear Load: 6.8 kips

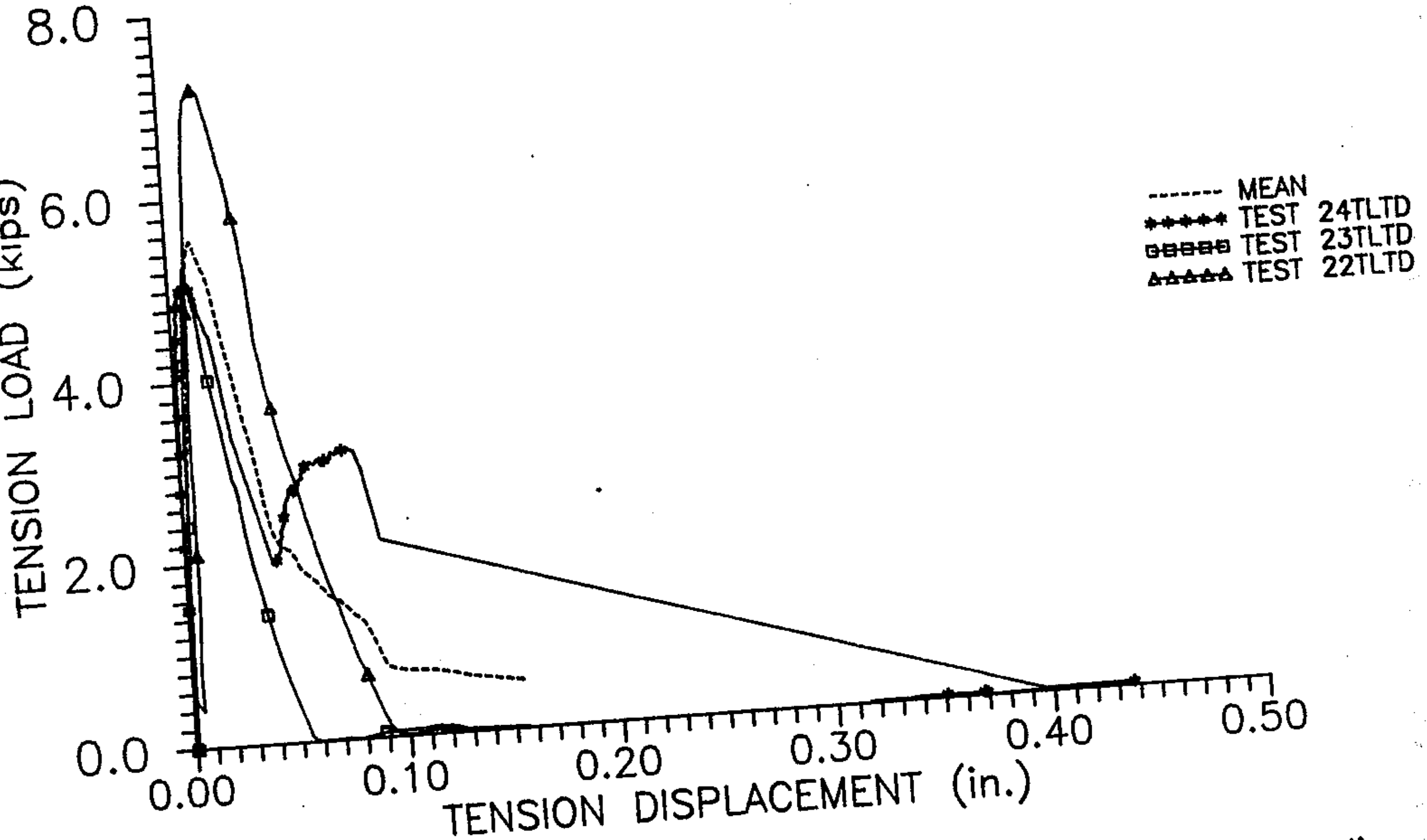


Figure G61. Load vs. displacement for short-term combined loading tests of mechanical expansion anchors.

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 3/4 in. Shell Internal Plug M.E.A.
Brand: Molly No. MDI-34
Edge Distance (to center of anchor): 5 in.
Installation Torque: 80 ft-lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 24SLTI, Test 23SLTI, & Test 22SLTI
2/3 Average Ultimate Shear Load: 6.8 kips

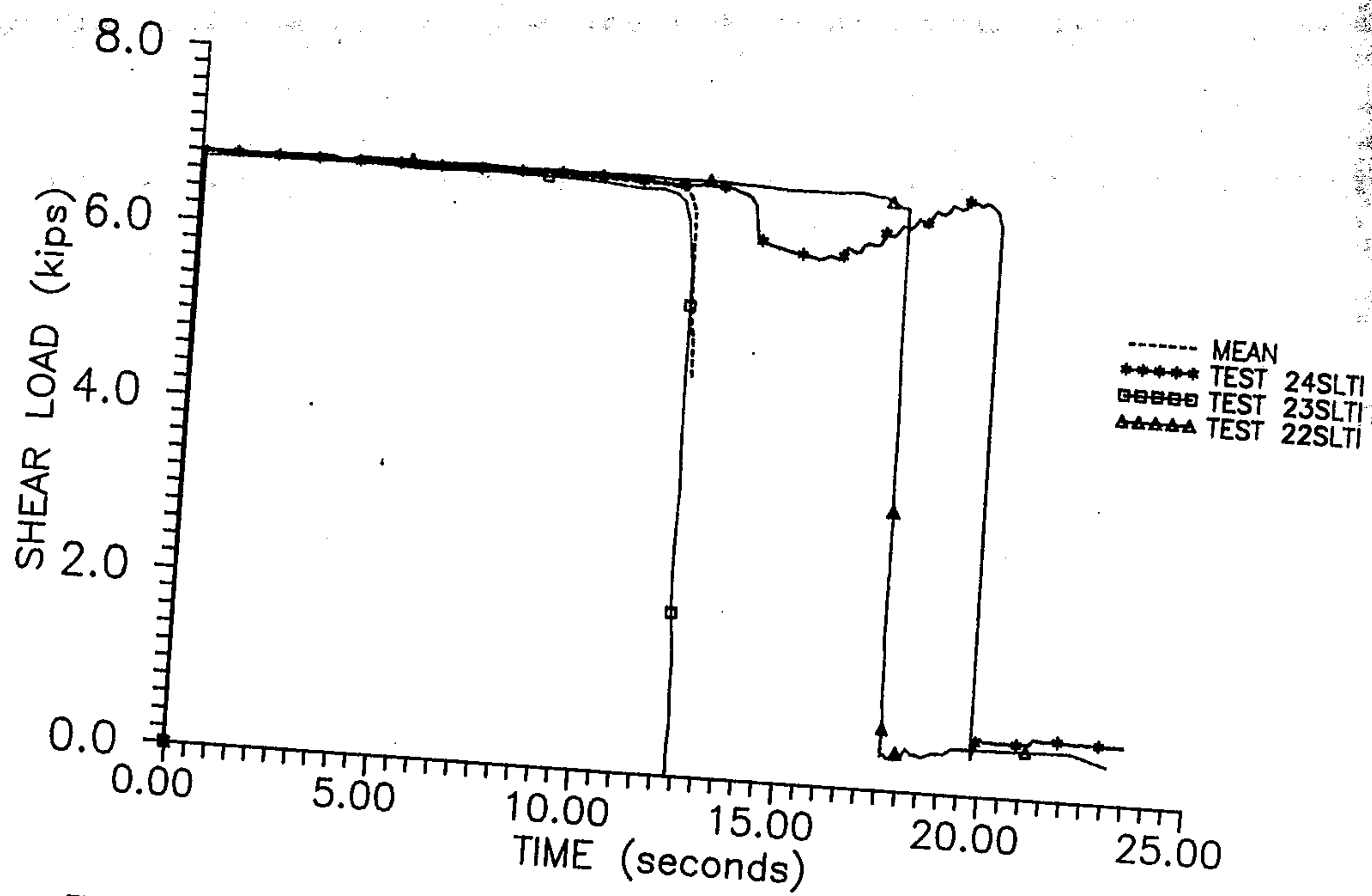


Figure G62. Load vs. time for shor[illegible]

NOTES: COMBINED SHEAR & TENSION LOADING TEST
Size and Type: 3/4 in. Shell Internal Plug M.E.A.
Brand: Molly No. MDI–34
Edge Distance (to center of anchor): 5 in.
Installation Torque: 80 ft–lbs
Concrete Compressive Strength: 5000+ psi
Failure Mode:
CW = Test 24TLTI, Test 23TLTI, & Test 22TLTI
2/3 Average Ultimate Shear Load: 6.8 kips

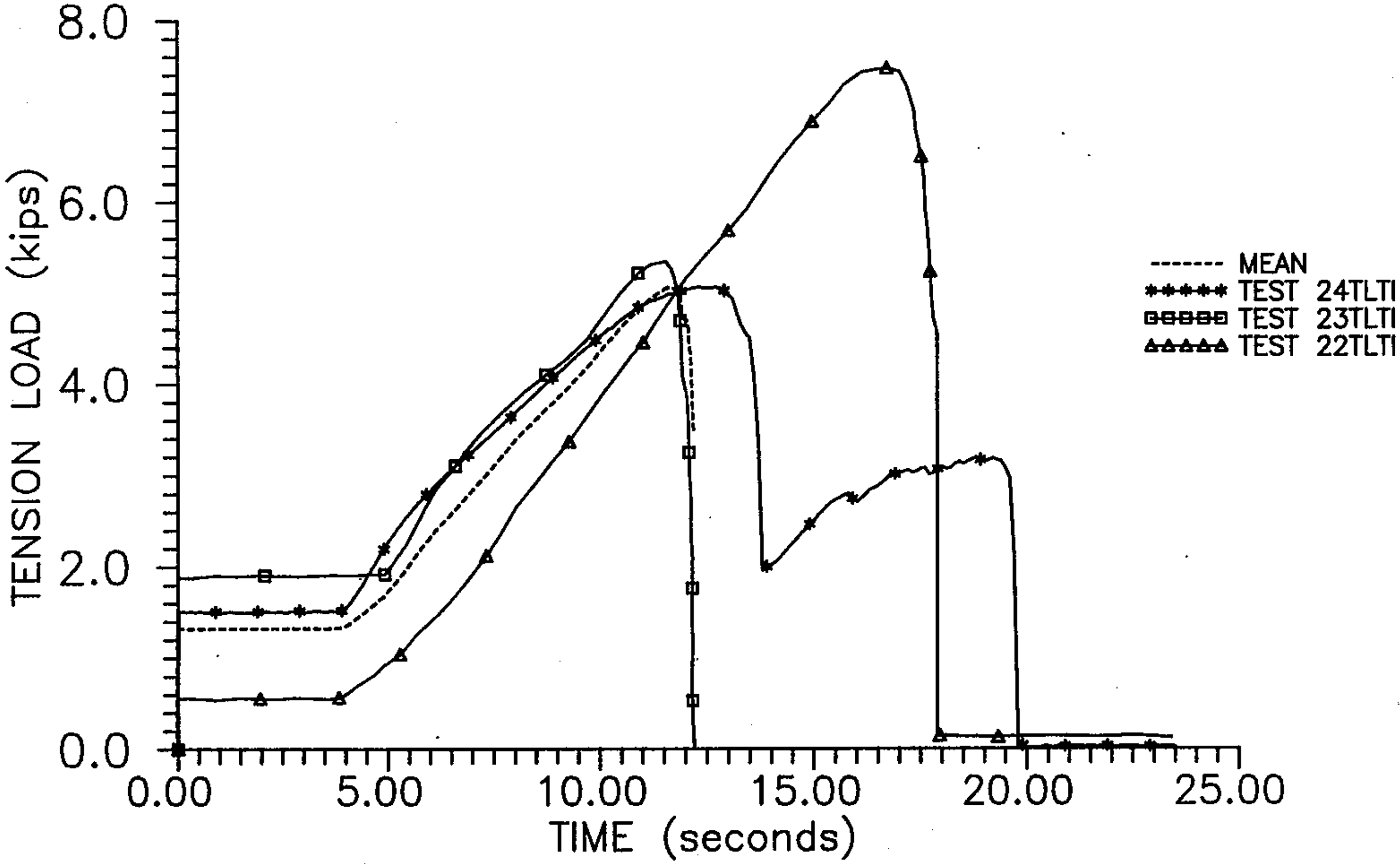


Figure G63. Load vs. time for short–term combined loading tests of mechanical expansion anchors.