SUMMARY REPORT

STATIC, DYNAMIC AND RELAXATION TESTING OF EXPANSION ANCHORS IN RESPONSE TO NRC I.E. BULLETIN 79-02

JULY 20, 1981

REPORT ON

STATIC, DYNAMIC AND RELAXATION TESTING OF EXPANSION ANCHORS

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1.0 Introduction

1.1 Background

On March 8, 1979, the U. S. Nuclear Regulatory Commission's, Office of Inspection and Enforcement issued I. E. Bulletin 79-02 entitled, "Pipe Support Base Plate Designs Using Concrete Expansion Anchor Bolts". Subsequently, Revision 1 of the bulletin was issued on June 21, 1979, Supplement 1 to Revision 1 was issued on August 20, 1979 and Revision 2 to the bulletin was issued on November 8, 1979.

The bulletin required a response from holders of operating licenses and holders of construction permits for power reactor facilities. The response was to include consideration of the effect of base plate flexibility on calculated expansion anchor loads; verification that all expansion anchors have a factor of safety of four or five (for wedge and shell type anchors respectively) as compared with manufacturer's recommended values for ultimate anchor capacities; a description of design requirements for expansion anchors subjected to cyclic loads; and verification by documentation that such design requirements have been met.

1.2 Purpose of Test Program

The purpose of the test program was to supplement the previous responses which had referred to these tests. The specific items addressed by these tests are the ultimate static capacities of various types of expansion anchors, load-displacement relationships for these anchors, behavior of expansion anchors subjected to simulated seismic events and other cyclic loads, base plate flexibility and its effect on anchor loads, and the phenomenon of relaxation (loss of anchor preload) with time. An overview of the test program is shown in Table 1.1.

2.0 Test Program and Results

The tests can be divided into four series.

Phase A - Static Tension Tests on Single Anchors

Phase B - Cyclic Tests on Anchored Plate Assemblies

Phase C - Static Tension Tests on Anchor Plate Assemblies

Phase D - Anchor Preload Relaxation Tests

2.1 Phase A, Static Tension Tests on Expansion Anchors

2.1.1 The purpose of static tension tests on single anchors installed in concrete or other embedment materials was to understand the behavior of expansion anchors with respect to their ultimate load capacities and their load displacement characteristics.

The important parameters which were investigated are:

- i) the type and size of anchor;
- ii) the embedment material;
- iii) the embedment depth; and
- iv) the prestressing of the anchor.

Table 1.1 lists all the static tests performed.

2.1.2 Test Apparatus

The testing apparatus is shown in Figure 2.1. The testing was performed in accordance with ASTM E-488.

The load was applied with a motorized hydraulic pump and was measured with a load cell mounted coaxially with the tension loading rod. The anchor displacement was measured with two linear variable differential transformers (LVDT's).

2.1.3 Procedure

The expansion anchors were installed according to the anchor manufacturer's instructions. The test data, which consisted of the applied load and anchor displacement, was electronically recorded. A load-displacement curve was plotted concurrently with the tests. The embedment depth, installation torque, testing torque, if any, the embedment material, the compressive strength when the test was conducted, and the mode of failure were recorded for each test. Any out-of-plumbness in the anchor installation was also recorded.

2.1.4 Test results

The ultimate tensile capacity for expansion anchors is shown in Figure 2.2 through 2.7. Each figure represents the results of testing a particular bolt size. Beneath each strength bar, the number of tests, the embedment depth, the embedment material, and the anchor manufacturer are listed. A discussion of anchor behavior based on the various anchor parameters follows:

2.1.4.1. Wedge Type Anchors

The load-displacement behavior of wedge type expansion anchors is shown in Figures 2-8 through 2-13. The effects of various parameters are discussed below:

2.1.4.1.1 Embedment Depth

Figure 2-8 shows the effect of embedment depth on anchor behavior. It is seen that the anchor capacity is higher for the longer embedment depth of eight times the diameter of the anchor bolt stud (8D) than for the smaller embedment depth of 4.5 times the anchor diameter (4.5D). It was also noted during the tests that the anchors with the smaller embedment depth tend to fail in the concrete cone pull-out test, whereas the anchors with the larger embedment depth fail in the pull-out of the anchor stud. This effect of embedment depth is in accordance with the expected behavior of anchors at varying embedment depths.

2.1.4.1.2 Installation torque

Two load displacement plots are drawn in Figure 2.9 for wedge type anchors having the same embedment depth and embedded in the same material but having different installation torques. It is noted that the mean maximum

load is the same for both test series and therefore the ultimate anchor capacity is unaffected by the magnitude of the installation torque.

The magnitude of the installation torque is seen to affect the initial portion of the load-displacement curve. At small displacement magnitudes, the curve for the higher installation torque appears to have a much higher proportional limit. The displacement at the maximum load also is observed to decrease slightly as the installation torque is doubled.

As the installation torque is increased, the load at which first significant additional displacement occurs should also increase. This fact can be verified by comparing Figures 2.9 and 2.10.

2.1.4.1.3 Testing Torque

Part of the total tension force existing in an anchor bolt during its service life is due to the tension introduced during installation. However, it is known that the initial anchor tension relaxes with time.

The testing program investigated the influence of anchor tension existing prior to the tension pullout test for wedge type anchors. These anchor types were installed

using torque control. Control of the bolt tension after installation was by application of a "testing torque". Of the test series conducted, a majority have been tested with a testing torque of zero. A zero test torque means the nut on the anchor is finger-tight. In cases where a testing torque greater than zero was applied to the anchor immediately before the tension pullout test, the torque magnitude was typically 50 to 60 percent of the installation torque.

Anchor load versus displacement curves, where the testing torque was varied, are shown in Figure 2.11. It is noted that no significant differences in gross behavior exist. The mean maximum load of the anchor appears to be insignificantly affected by a variation of the preload in the anchor.

To understand the effect of testing torque, the initial portions of the load displacement curves of Figure 2.11 are plotted on a magnified scale in Figure 2.12. It indicates that the anchor preload does affect the load displacement curve and the fashion in which the anchor tension increases as the applied load increases. By examining Figure 2.12, several effects can be attributed to anchor preload.

The most obvious effect is the manner in which the anchor initially carries an externally applied load. Anchors that were preloaded did not show displacement until the applied load exceeded the apparent anchor initial tension. Once the initial tension was exceeded, the behavior appears to be identical to that shown for the zero initial preload case.

Both load displacement curves drawn in Figure 2.12 could be represented by a bilinear approximation. The first major departure from linearity appears at about 2000 lbs, the load corresponding to the anchor pretension. The first departure from linearity is, therefore, associated with additional displacements after the anchor load exceeds the anchor pretension.

2.1.4.1.4 Concrete Strength

The behavior of the expansion anchors embedded in various strengths of concrete was investigated in this program. The load displacement behaviors of wedge anchors embedded in two different concrete strengths are shown in Figure 2-13. The measured pullout capacity of the anchor in the higher strength concrete is greater. Other characteristics of the load displacement curve do not appear to be affected by a change in the concrete compressive strength.

2.1.4.1.5 Effect of Embedment Material

Behavior of sleeve anchors embedded in concrete and in masonry is shown in Figure 2.18. It is apparent that the performance of the test anchor in concrete is superior to the same anchor embedded in masonry. The compressive strength of the Type M mortar and the compressive strength of the Concrete Masonry Units (CMU) are approximately the same. Although the M mortar is a much denser material than the CMU, the behavior shown in Figure 2.18 does not appear to be affected. Often the limiting factor in develop ing the tensile capacity of an anchor embedded in masonry is the cracking of the mortar joints or concrete masonry units (CMU) through the embedment hole.

Type N mortar has a lower compressive strength than Type M mortar (about 1/3 of Type M). The anchor capacity is affected by the lower strength mortar material, however, it appears that the initial portion of the load displacement curve and the ductility are not greatly influenced.

For the other generic anchor types, the tensile capacity and displacement behavior in masonry may not be as shown in Figure 2.18 when compared to concrete. However, wedge type anchors typically show the ductility depicted

in Figure 2.18 and also fail by excessive displacement. The self-drilling anchors were also frequently observed to pull out rather than to form a conical rupture cone dictated by the tensile capacity of the embedding material.

2.1.4.2 Sleeve Type Anchors

A sleeve type anchor is shown in Figure 2.14. The ultimate strength values of tension tests on sleeve type anchors are included in Figures 2.3 through 2.5. Figure 2.15 shows a typical load-displacement plot for sleeve type anchors. The behavior of sleeve type anchors is essentially similar to that of wedge type anchors; thus, the discussion on variation of embedment depth, installation torque, and concrete strength applies to sleeve type anchors.

2.1.4.3. Self-Drilling and Drop-In Anchors

Self-drilling and drop-in type anchors are shown in Figure 2.14. The behavior of these anchor types is generally less ductile and more brittle in nature than the wedge or sleeve anchor. Brittle behavior is defined as a failure that occurs abruptly with little warning or at small, less visible, displacements. Load transfer to the embedding material for the self-drilling and drop-in

anchors is accomplished by wedging the shell against the embedding material. The load carrying bolt is a separate element which is threaded into the shell. The bolt is not associated with the part of the anchor system that is wedged against the side walls of the hole.

The load displacement characteristics of the self-drilling and the "TZD" drop-in anchors are shown in Figures. 2.16 and 2.17 respectively. These anchors are usually embedded to a depth equal to the anchor shell length. The anchor shell is approximately four times the diameter of the bolt that threads into the shell.

Figures 2.16 and 2.17 show that the maximum loads for the self-drilling and drop-in anchor are achieved at an anchor displacement of less than 0.5 times the bolt diameter. Also, shortly after the maximum load is reached, the anchorage system fails, usually by rupturing the concrete in tension on a conical surface.

Shown in Figure 2.17 are test results for drop-in anchors where the anchor shell was observed to fracture in tension. Thus, shell fractures controlled the maximum load carrying capacity.

2.2 Phase B - Cyclic Tests on Anchored Plate Assemblies

2.2.1 Introduction

The objective of these tests was to investigate the behavior of expansion anchor plate assemblies while subjected to simulated seismic events and pipe transient loadings. The tests were performed using 1/2" diameter wedge, sleeve, self-drilling and drop-in type anchors embedded in reinforced concrete, concrete block and mortar joints. Table 2.1 summarizes the extent of the tests performed.

2.2.2 Test Apparatus

The plate assemblies consisted of one 1 1/2" x 12" x 12" steel plate (A-36) with four 1/2" diameter expansion anchors for each plate. The anchors were at the corners of the plate (spaced 9" apart) and were installed in accordance with manufacturers recommended procedures. Sleeve type and wedge type anchors were embedded at lengths of 2 1/4" and 4" (corresponding to 4 1/2 and 8 anchor diameters) and shell type anchors were installed so that the top of the shell was flush with the concrete slab or block wall surface. The concrete test slabs measured approximately 4 ft. by 11 ft. by 12" or 18" thick. They were reinforced with #6 bars (grade 60) spaced at 12" on center with 1 1/2" of cover. The concrete specimens had a specified minimum 28 day compressive strength of 3500 psi. The concrete block walls were approximately 4 ft. by 6 ft., consisting of solid concrete blocks weighing about 120 lbs/ft^3 with a measured mean compressive strength

of 2525 psi. A Type N mortar with a specified minimum 28-day compressive strength of 700 psi was used. The success of the tests using Type N mortar, negated the necessity to test anchors embedded in Type M mortar.

An electronically controlled servo-hydraulic ram was used to apply load to the anchored plate assembly. The ram and centroid of the anchor group were coaxial during each test. Each anchor was instrumented with a load cell beneath the anchor nut and a spring loaded linear variable differential transformer (LVDT). The LVDT measured anchor movement out of the embedded medium. A sketch of the test assembly is shown in Figure 2.19.

2.2.3 Procedure

Embedded depth, installation torque, preload, applied load, number of cycles, frequency and number of tests to be performed are shown in Table 2.1. Test Type 1 (no preload) was performed for each series. Test Type 2 (preload) was performed only if the anchor displacement was equal to or greater than 1/2" (1 diameter displacement) when a test Type 1 was completed. Similiarly, tests in mortar and concrete block using 8D embedded depth anchors were not conducted if the preceding 4½D embedded anchor tests passed the above displacement criteria. Also tests in Type M mortar were to be performed only if a test in Type N mortar for a given test series evidenced an anchor displacement of equal to or

greater than 1/2". At least two tests were conducted for each type tested.

The seismic load cycles represented five OBE seismic events followed by one SSE event. The fatigue load cycles represented the effect of pipe transient loadings experienced by the anchors during the life of the plant. For assemblies embedded in concrete, the applied assembly loads for seismic tests were 25% of the manufacturer's recommended ultimate capacities for the OBE events and 50% of the manufacturer's recommended ultimate capacities for the SSE event. For pipe transient test assemblies embedded in concrete, the applied assembly loads varied from 12.5% to 25% of the manufacturer's recommended ultimate capacities, depending on the number of cycles. For seismic tests conducted in solid concrete block and mortar joints, the applied assembly loads were consistent with individual anchor design loads for OBE and SSE events (since no manufacturer's data is available). One cycle is defined as the application of a tensile and then a compressive force, both equal to the applied assembly load. This load reversal allows for the effect of impact of the plate on the anchors.

For tests performed in concrete block, all four anchors of the plate assembly were embedded in the block itself. Where tests were conducted on anchors embedded in mortar, all four anchors of the plate assembly were embedded in the mortar joints.

2.2.4 Results

The results of the tests are shown in Table 2.2 and 2.3. The maximum anchor displacement is the maximum movement that occurred for all anchors tested in that particular test series and test type. As can be seen, the anchor displacements are, for the most part, very small if not negligible. For anchors embedded in concrete subjected to simulated seismic loads, 100 anchors were tested (25 plate assemblies). All exhibited anchor displacements of less than or equal to 1/2 of an anchor diameter (1/2") after five OBE events, and 96 anchors exhibited displacements of less than 1/2 of an anchor diameter after the SSE loads had been applied (96% of anchors tested). For anchors embedded in concrete and subjected to pipe transient loads, 44 bolts were tested (11 plate assemblies). Forty anchors exhibited anchor displacements of less than 1/2 of an anchor diameter (91% of total anchors tested). For anchors tested on concrete block walls (block and mortar) subjected to seismic loads, all 28 anchors (8 plate assemblies) showed anchor displacements of less than 1/2 of an anchor diameter.

The only test requiring preload was L-2, which showed negligible movement with the higher test preload (2150 lbs.). In one D-1 test, two anchors exhibited 0.5 inch displacements after the simulated SSE load was applied, as can be seen in Table 2.2. However, because of load attenuation during the test (due to equipment capacities) two additional D-1 tests

were performed and these exhibited little or no anchor displacement. A D-2 test was therefore, not required. All other anchors had a nominal preload of 500 lbs. (except test E-2, which was not required but which was performed after the pipe transient tests (L-2) had been performed). No tests in Type M mortar were required as all anchors tested in Type N mortar experienced movements of less than 0.5 inches.

It should be noted that no anchors experienced a concrete or mortar cone failure.

2.3 Phase C - Static Tension Tests on Anchored Plate Assemblies

2.3.1 Introduction

The purpose of the static load-deformation test on a flexible plate anchor assembly was to determine if prying action is a significant factor in the calculation of the anchor forces. Variation of the prying action effect with the load, if any, was also studied.

2.3.2 Test Apparatus

The anchor plate assembly consisted of a ½"x12"x12" plate attached to concrete with four 1/2-inch anchors. Three tests were done with wedge type anchors and three with self-drilling anchors. A tension load was applied to the assembly in the middle of the plate. A typical anchor plate assembly with instrumentation is shown on Figures 2.20 and 2.21.

The following three types of sensors were used in the tests:

1. Load cells which measured the load in the anchors.

2. Linear variable differential transformers (LVDT's) which measured the vertical displacements of each anchor head, two corners of the plate and one internal point along a diagonal.

3. Strain gages which measured the strain in the base plate.

2.3.3 Procedure

The expansion anchored plate assembly was installed according to the instructions of the anchor manufacturers. A tension load was applied in the middle of the plate. The applied load, the anchor forces, the anchor displacements, the plate displacements and the plate strains were recorded electronically at various stages of the applied load.

Three tests were conducted on plate assemblies with Hilti-wedge type anchors and another three tests were conducted on plate assemblies with Phillips self-drilling type anchors. The Hilti-wedge anchors were installed with 70 ft-lbs of installation torque each. After the installation torque reached 70 ft-lbs, the anchor nuts were loosened, then finger tightened, then tightened further to a torque of 45 ft-lbs. The assembly was then loaded to about a quarter of its ultimate capacity, unloaded, the anchor nut loosened, finger tightened, given a 1/8 turn, and reloaded. This provided data corresponding to test torques of 45 ft-lbs and 0 ft-lbs.

For plate assemblies with ITT-Phillips self-drilling anchors, the installation, loading, and unloading sequence was similar to the sequence for wedge type anchors, except that the

tightening of the anchor nuts before starting the loading sequence varied from finger tightening to an additional 3/4 turn of the nut.

2.3.4 Results

The test results for the three plate assemblies with Hilti wedge type anchors and the two plate assemblics with Phillips self-drilling anchors show that there is a prying action load of about 15%-20% of the applied load. One plate assembly with Phillips self-drilling anchors (Test No. 1) does not show any prying action. Figure 2.22 shows a plot of the applied load on the anchor plate assembly vs. the total anchor force for each of the six tests.

It is noted that:

a. The anchor force is higher in the early load stages due to the combination of anchor pretension and prying action;

b. The effect of prying action reduces as the applied load is increased; and

c. The increase in the anchor force due to the prying action is only about 15-20 percent. This increase is much lower than that in an assembly with regular steel

bolts, where the prying action effect is calculated to be about 110 percent. The reduction in the prying action effect in the plates with expansion anchors is due to the effective lower stiffness of expansion anchors installed in concrete.

2.4 Phase D - Anchor Preload Relaxation Tests

2.4.1 Introduction

When a concrete expansion anchor is installed, a preload will be induced on the anchor as a result of torquing the bolt or nut. It is known that a portion of the preload in the anchor dissipates over a period of time after installation. The purpose of these single anchor relaxation torque tests was to investigate the loss of anchor preload over time (relaxation).

The tests were performed on single anchors of varying types, and diameters, installed at various embedded depths and with various torques in concrete and mortar (Types N & M). The specific testing requirements are outlined in Table 2.4.

2.4.2 Test Apparatus

Single anchors were installed in unreinforced concrete (no reinforcement within a minimum depth of ten anchor diameters) and in Types N and M mortar.

2.4.3 Procedure

Single anchors were installed in concrete and mortar in accordance with manufacturers' recommended installation procedures. Installation torques are shown in Table 2.4. The nut or bolt of the anchors was loosened 1/8 of a turn and then retorqued to its original position. The torque required to return the nut or bolt to its original position was then

recorded as a measure of remaining preload in the anchor. One anchor for each set of tests performed was tested with a load cell under the nut or bolt head to establish a torque-tension relationship.

The anchors were retorqued at intervals of 12 [illegible]s, 24 hours, 7 days, 14 days and 28 days after initial installation. The anchor load and the average anchor torque versus time were plotted for each set of tests. (Figures 2.23 and 2.24 show typical load and torque plots.)

2.4.4 Results

The results are represented by Figures 2.23 and 2.24. The loss of preload at the end of 28 days was as little as 13% for a 3/4" diameter anchor embedded in mortar and as much as 54% for a 1/2" diameter anchor embedded in concrete. Overall, it appears that less relaxation occurred for anchors embedded in mortar than for those embedded in concrete.

2.5 Con usions

2.5.1 Phase A - Static Tension Tests on Single Anchors

The static tension tests on single anchors have provided a clear understanding of the anchor behavior under loading and the effect of various parameters on that behavior. It is noted that the prestressing of the anchor at the time of testing does not affect the ultimate load carrying capacity of the anchor.

2.5.2 Phase B - Cyclic Test on Anchored Plate Assemblies

The wedge, sleeve and shell type anchors tested in concrete and block walls exhibited insignificant anchor displacement when subjected to seismic or pipe transient loadings. It can, therefore, be concluded that anchors embedded in concrete can withstand cyclic loads up to 25% of manufacturer's ultimate capacity with a simulated OBE condition and 50% of manufacturer's ultimate capacity with a simulated SSE condition. It has been shown that anchors embedded in concrete block and mortar can withstand cyclic loads. The tests were conducted at load levels of 25% of the measured mean ultimate static capacity or greater.

It should be noted that anchor preload is not required for the anchors to withstand cyclic loading. The preload in the

anchors tested was generally not greater than 500 lbs. (0 preload) which is equivalent to tightening the nut or bolt approximately 1/8 of a turn after "hand" tight.

2.5.3 Phase C - Static Tension Tests on Anchored Plate Assemblies

The results of tests on a flexible base plate with four expansion anchors show that the prying action is of the order of 15-20 percent of the applied load. This increase is much lower than the expected increase in an assembly with regular steel bolts where the prying action force is calculated to be 110 percent. The reduction in the prying action force is due to the effective lower stiffness of expansion anchors installed in concrete.

2.5.4 Phase D - Anchor Preload Relaxation Tests

From the typical curves showing load or torque versus time (Figures 2.23 and 2.24), it can be seen that the anchor preload losses are most pronounced in the first 24 to 48 hours. However, it should be noted at this point that the relaxation phenomenon should not be of great concern when viewed in light of the cyclic test results which showed that preload is not required to withstand cyclic loading.

TABLES AND CHARTS
FOR
CHAPTERS 1 & 2

TABLE 2.1

DYNAMIC TESTS IN CONCRETE

LOAD TYPE	TYPE OF ANCHOR	ANCHOR DIAMETER (IN)	EMBEDDED DEPTH OF ANCHOR (IN)	INSTALLATION TORQUE (FT-LBS)	TEST (4) PRELOAD (LBS)	APPLIED ASSEMBLY LOAD ON 4 BOLT ASSEMBLY (LBS)	NUMBER OF CYCLES	FREQUENCY (Hz)	TOTAL NUMBER OF TESTS CONDUCTED	TEST IDENTIFICATION: TEST2 TYPE	TEST IDENTIFICATION: TEST SERIES
SEISMIC	WEDGE (HILTI)	1/2	2-1/4	60	0 0	± 5270 (a) ** - Pu/4 ± 10540 (b) ** - Pu/2	200 (a) 40 (b)	10	2 4	1a 1b	A
		1/2	4	70	0	± 10240 (a) - Pu/4 ± 20480 (b) - Pu/2	200 (a) 40 (b)	10	4	1	B
	WEDGE (WEJ-IT)	1/2	2-1/4	60	0	± 5270 (a) - Pu/4 ± 10540 (b) - Pu/2	200 (a) 40 (b)	10	4	1	D
	SLEEVE	HN-5560*	4	70	0 1525	± 10240 (a) - Pu/4 ± 10240 (b) - Pu/4	200 (a) 40 (b)	10	3 1	1 2	E
	SELF-DRILLING	1/2	2-1/32	----	0	± 8500 (a) - Pu/4 ± 17000 (b) - Pu/2	200 (a) 40 (b)	10	4	----	F
	DROP-IN	1/2	1-31/32	----	0	± 5780 (a) - Pu/4 ± 11560 (b) - Pu/2	200 (a) 40 (b)	10	3	----	H

1. Pu, ultimate pull-out capacity, is based on manufacturer's data in 3500 psi concrete.
2. Test type is denoted by (1), lower test preload of the test series and (2), higher test preload of the test series.
3. *Refers to Red Head Manufacturer Catalog number.
4. Preload of 5 0 lbs. is considered a "0" preload condition since it approximates a hand-tight condition plus 1/8 turn.
5. ** Refers to the corresponding applied applied assembly load with the corresponding number of cycles.

TABLE 2.1 (Cont'd.)

DYNAMIC TESTS IN CONCRETE

LOAD TYPE	TYPE OF ANCHOR	ANCHOR DIAMETER (IN)	EMBEDDED DEPTH OF ANCHOR (IN)	INSTALLATION TORQUE (FT-LBS)	TEST (4) PRELOAD (LBS)	APPLIED ASSEMBLY LOAD ON 4 BOLT ASSEMBLY (LBS)	NUMBER OF CYCLES	FREQUENCY (Hz)	TOTAL NUMBER OF TESTS CONDUCTED	TEST IDENTIFICATION	
										TEST2 TYPE	TEST SERIES
PIPE TRANSIENTS	WEDGE (HILTI)	1/2	2-1/4	60	0	± 2635 (a) - Pu/8	28500 (a)	4	2	1	I
						± 5270 (b) Pu/4	3000 (b)				
			4	70	0	± 5120 (a) - Pu/8	28500 (a)	4	2	1	J
						± 10240 (b) - Pu/4	3000 (b)				
	WEDGE (WEJ-IT)	1/2	2-1/4	60	0	± 2635 (a) - Pu/8	28500 (a)	4	2	1	K
						± 5270 (b) - Pu/4	3000 (b)				
	SLEEVE	HN-5560*	4	70	0	± 5120 (a) - Pu/8	28500 (a)	4	2	1	L
					2150	± 10240 (b) - Pu/4	3000 (b)		1	2	
	SELF-DRILLING	1/2	2-1/3.	-----	0	± 4250 (a) - Pu/8	28500 (a)	4	2	-----	M
						± 8500 (b) - Pu/4	3000 (b)				

1. Pu, ultimate pullout capacity, is based on manufacturer's data in 3500 psi concrete.

2. Test type is denoted by (a), lower test preload of the test series and (b), higher test preload of the test series.

3. *Refers to Red Head Manufacturer Catalog number.

TABLE 2.1 (Cont'd.)

SCOPE TESTED

DYNAMIC TESTS IN BLOCK & MORTAR

LOAD TYPE	TYPE OF ANCHOR	ANCHOR DIAMETER (IN)	EMBEDDED DEPTH OF ANCHOR (IN)	INSTALLATION TORQUE (FT-LBS)	TEST PRELOAD (LBS)	APPLIED ASSEMBLY LOAD (LBS) BLOCK	APPLIED ASSEMBLY LOAD (LBS) MORTAR	EMBEDMENT MATERIAL	NUMBER OF CYCLES	FREQUENCY (Hz)	TOTAL NUMBER OF TESTS CONDUCTED	TEST IDENTIFICATION TEST[1] TYPE	TEST IDENTIFICATION TEST SERIES
SEISMIC	WEDGE (HILTI)	1/2	2-1/4	50	0	On 4 Bolt Assembly ± 1580 (a) ± 3160 (b)	± 1580 (a) ± 3160 (b)	CMU	200 (a) 40 (b)	10	2	B1	A
								N-Mortar			1	N1	
	WEDGE (HILTI)	1/2	2-1/4	50	0	On 2 Bolt Assembly -----	± 790 (a) ± 1580 (b)	N-Mortar	200 (a) 40 (b)	10	1	N1	A
	SLEEVE	HN-5860*	4	50	0	On 2 Bolt Assembly -----	± 790 (a) ± 1580 (b)	N-Mortar	200 (a) 40 (b)	10	1	N1	E
	SLEEVE	HN-5860*	4	50	0	On 4 Bolt Assembly ± 1580 (a) ± 3160 (b)	± 1580 (a) ± 3160 (b)	CMU	200 (a) 40 (b)	10	2	B1	E
								N-Mortar			1	N1	

1. The alpha-numeric code identifies the test type. The letter indicates the embedment material, B-Concrete Masonry Units, N-Mortar.

2. * Refers to [illegible] Manufacturer Catalog number.

TABLE 2.2

CYCLIC TESTS FOR SEISMIC LOADING

SUMMARY OF TEST RESULTS

(Refer to Table A for Test Identification Description)

TEST IDENTIFICATION: TEST SERIES	TEST IDENTIFICATION: TEST TYPE	ANCHOR DIAMETER (IN)	TYPE OF ANCHOR	EMBEDDED DEPTH OF ANCHOR (IN)	TEST PRELOAD* (LBS)	EMBEDMENT MATERIAL	MAXIMUM ANCHOR SLIP IN INCHES AFTER 5 OBE LOAD SIMULATIONS PEAK LOAD ON ANCHOR 25% OF MANUFACTURER STATIC ULTIMATE	MAXIMUM ANCHOR SLIP IN INCHES AFTER 5 OBE LOAD SIMULATIONS FOLLOWED BY 1 SSE LOAD SIMULATION PEAK LOAD ON ANCHOR 50% OF MANUFACTURER STATIC ULTIMATE UNLESS NOTED	REMARKS
A	1a	1/2"	HILTI WEDGE	2-1/4"	0	Concrete	0.0"	0.12"	
A	1b	1/2"	HILTI WEDGE	2-1/4"	0	Concrete	0.03"	0.32"	
B	1	1/2"	HILTI WEDGE	4"	0	Concrete	0.13"	0.39"	
D	1	1/2"	WEJ-IT WEDGE	2-1/4"	0	Concrete	0.05"	0.15"	One assembly exceeded .30 criteria
F	1	1/2"	PHILLIPS SLEEVE	4"	0	Concrete	0.01"	0.25"	
E	2	1/2"	PHILLIPS SLEEVE	4"	1525	Concrete	0"	0"	
F		1/2"	PHILLIPS SELF-DRILLING	2.03"	0	Concrete	0.03"	0.11"	
M		1/2"	HILTI DROP-IN	1.97	0	Concrete	0.01"	0.01"	
A	[illegible]	1/2"	HILTI WEDGE	2-1/4"	0	Concrete Block	0.17"	0.21"	
A	[illegible]	1/2"	HILTI WEDGE	2-1/4"	0	N-Mortar	0.04"	0.04"	
E	[illegible]	1/2"	PHILLIPS SLEEVE	4"	0	Concrete Block	0	0	
F	[illegible]	1/2"	PHILLIPS SLEEVE	4"	0	N-Mortar Joint	0.07"	0.07"	

*Preload considered "0" if preload condition is 500 pounds or less.

TABLE 2.3

CYCLIC TESTS FOR PIPE TRANSIENTS LOADING

SUMMARY OF TEST RESULTS

(Refer to Table 2.2.1 for Test Identification Description)

TEST IDENTIFICATION		ANCHOR DIAMETER (IN)	TYPE OF ANCHOR	EMBEDDED DEPTH OF ANCHOR (IN)	TEST PRELOAD (LBS)	EMBEDMENT MATERIAL	MAXIMUM ANCHOR SLIP IN INCHES AFTER 28,500 CYCLES OF LOAD PEAK LOAD ON ANCHOR 12-1/2% OF MANUFACTURER STATIC ULTIMATE	MAXIMUM ANCHOR SLIP IN INCHES AFTER 28,500 CYCLES @ PEAK LOAD OF $P_{u\,manuf}$ x 12-1/2% FOLLOWED BY 3,000 CYCLES @ PEAK ANCHOR LOAD OF $P_{u\,manuf}$ x 25%	REMARKS
TEST SERIES	TEST TYPE								
I	1	1/2"	HILTI WEDGE	2-1/4"	0	Concrete	0.02"	0.03"	
J	1	1/2"	HILTI WEDGE	4"	0	Concrete	0.06"	0.13"	
K	1	1/2"	WEJ-IT WEDGE	2-1/4"	0	Concrete	0.03"	0.03"	
L	1	1/2"	PHILLIPS SLEEVE	4"	0	Concrete	0"	0"	One assembly exceeded .50 criteria
L	2	1/2"	PHILLIPS SLEEVE	4"	2150	Concrete	0.02"	0.02"	
M		1/2"	SELF-DRILLING	2.03	0	Concrete	0.01"	0.03"	

TABLE 2.4

SINGLE ANCHOR RELAXATION OF TORQUE TESTS

Type of Anchor	Anchor Diameter (inches)	Embedded Depth of Anchor (inches)	Installation Torque (ft. lbs.)	Embedment Material: Concrete (strength) (psi)	Embedment Material: Masonry Joint (Type of Mortar)	Total Test Required
Wedge (Hilti)	1/2	4	50	—	M	5
					N	5
			70	3500	—	5
Sleeve (Phillips)	*HN-5860	4	50	-	M	5
			70	3500	-	5
Self-Drilling	1/2	2-1/32	**		N	5
			**		M	5
			**	3500	-	5
Wedge (Hilti)	3/4	6	135	-	M	5
					N	5
			250	3500	—	5

* Refers to Red Head Catalog number.

** Install snugtight plus 1/4 turn.

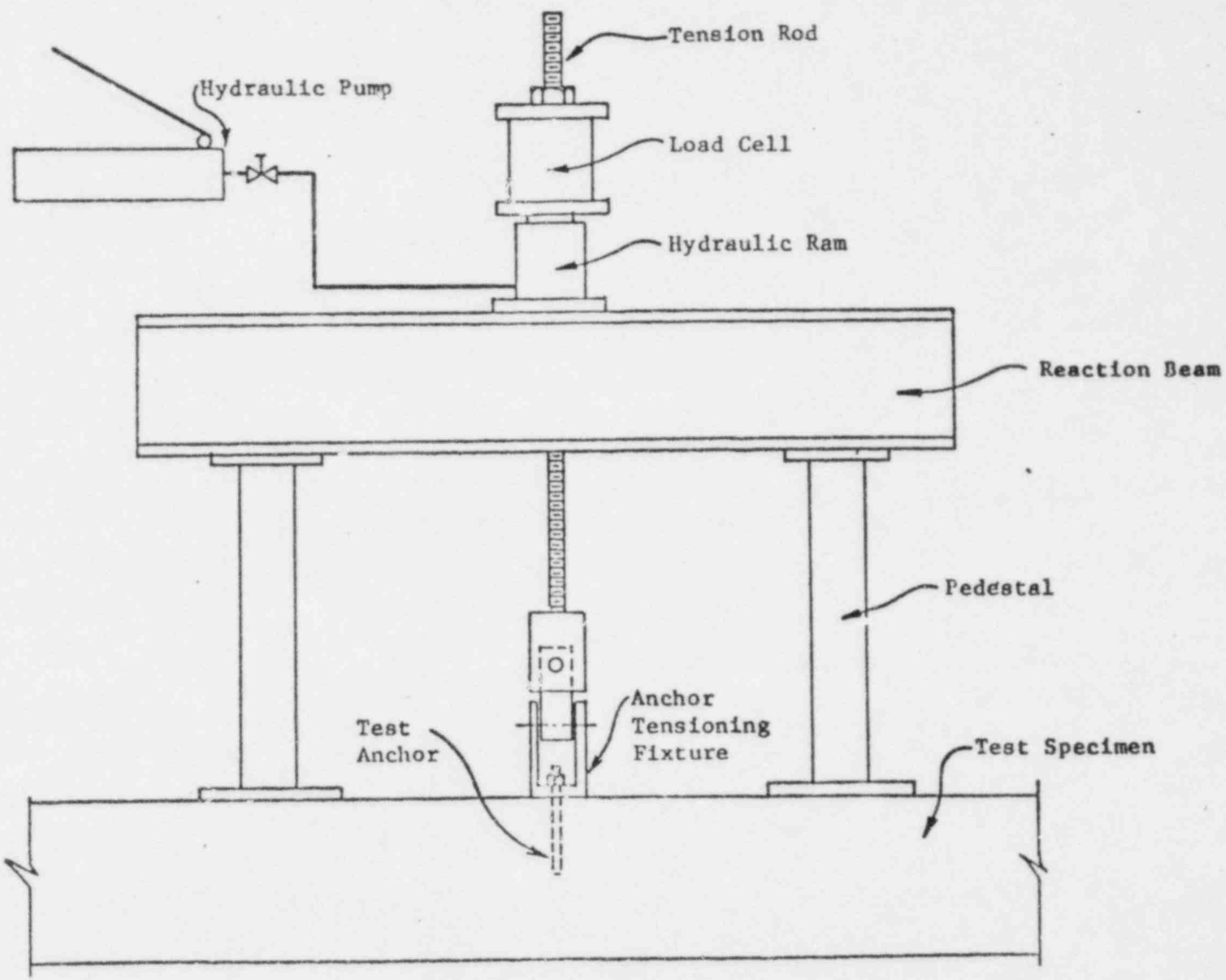
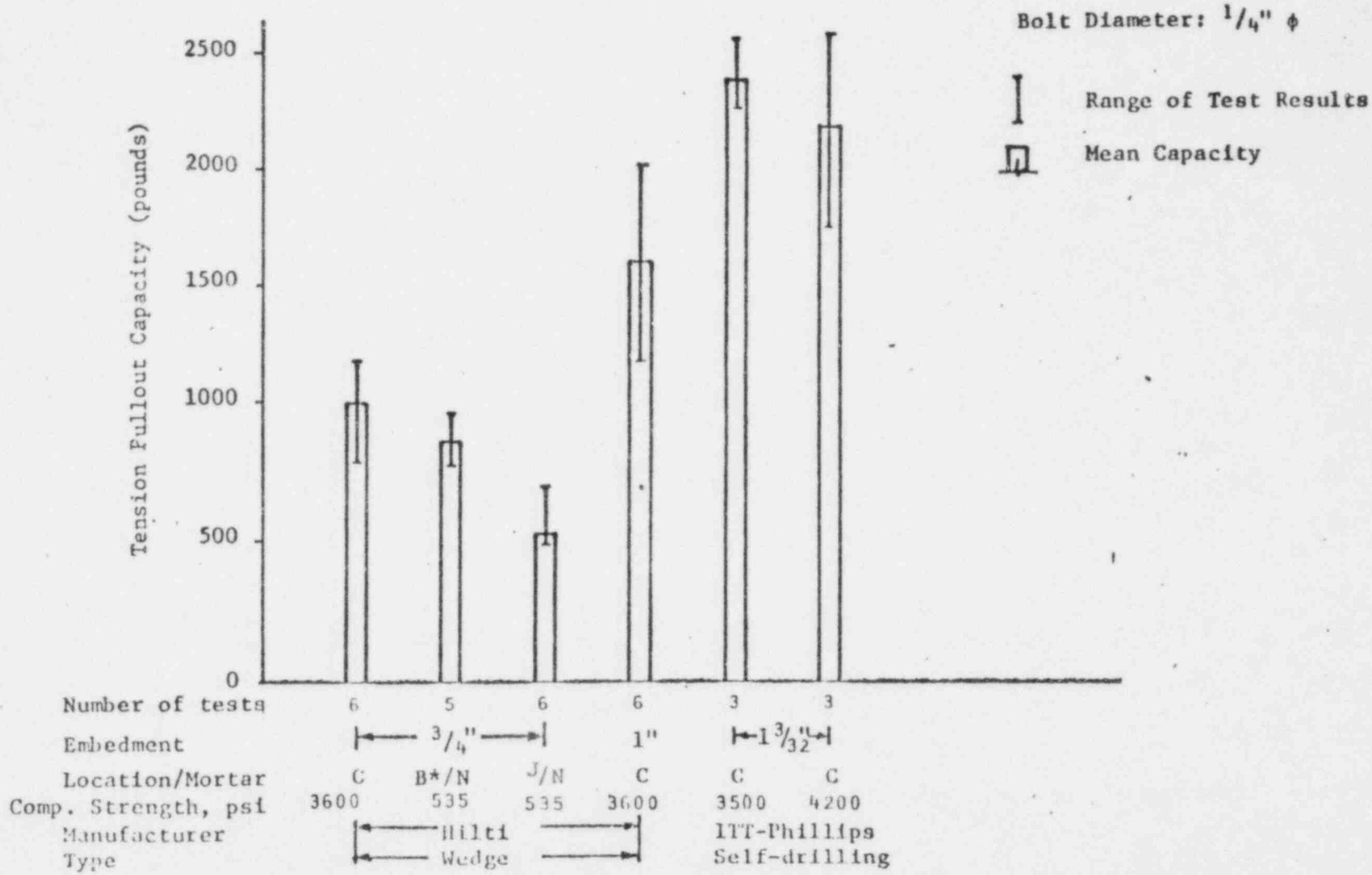
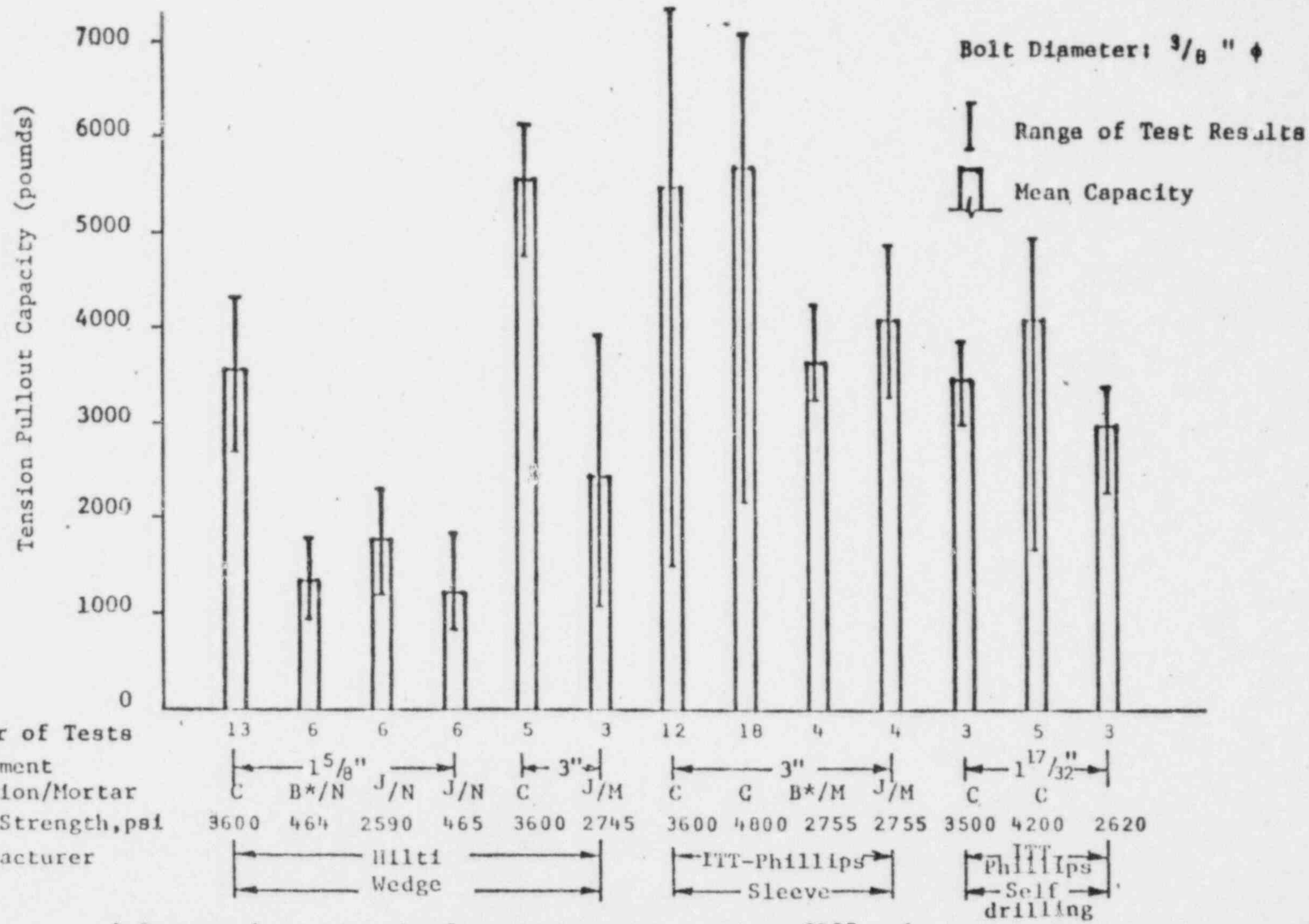


Fig. 2.1 Tension Pullout Loading Frame



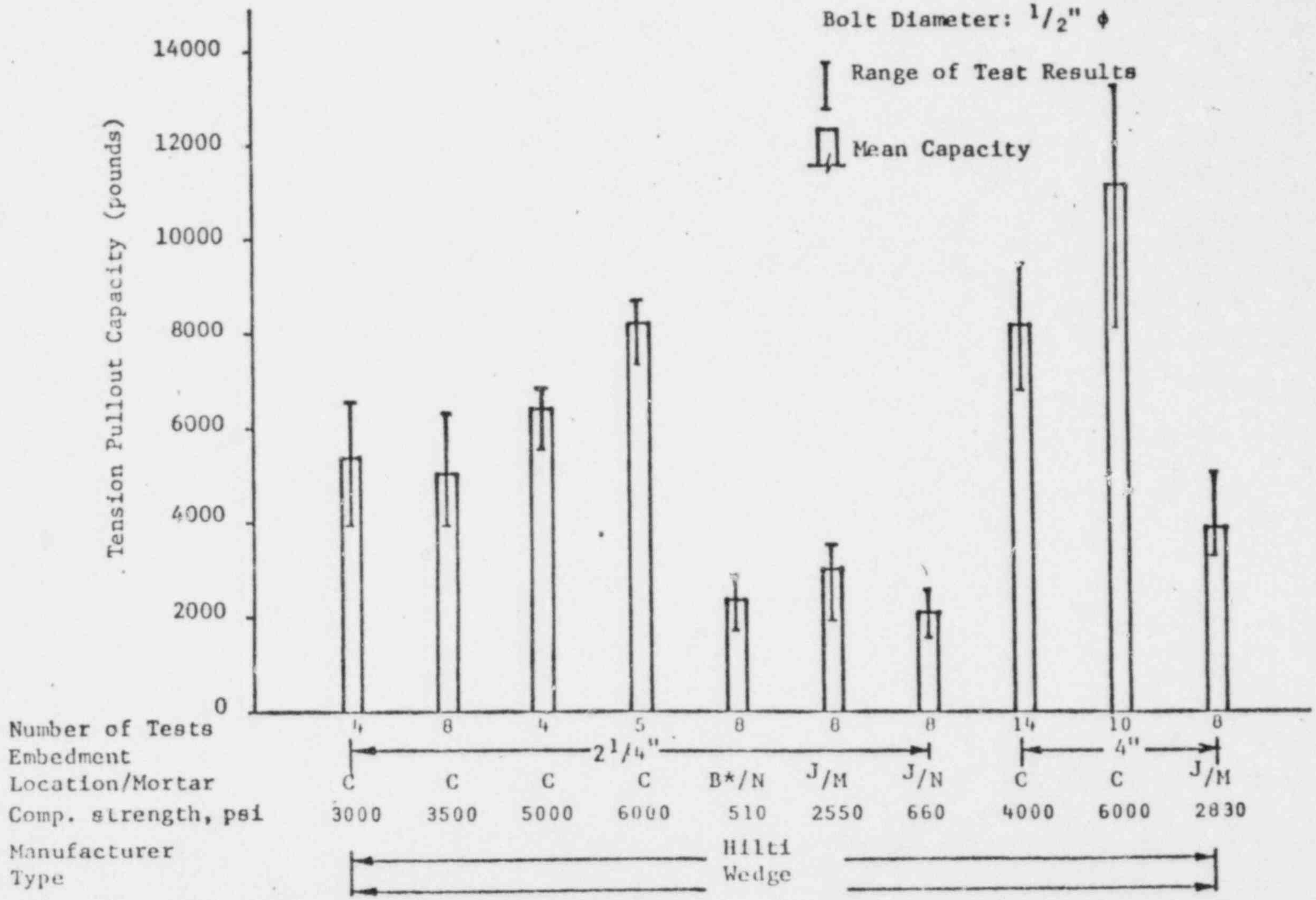
* Compressive strength of concrete masonry units: 2525 psi

Fig. 2.2 Comparison of 1/4 in. expansion anchors



* Compressive strength of concrete masonry units: 2525 psi

Fig. 2.3 Comparison of $^{3}/_{8}$ in. expansion anchors



* Compressive strength of concrete masonry units: 2525 psi

Fig. 2.4 Comparison of 1/2 in. expansion anchors

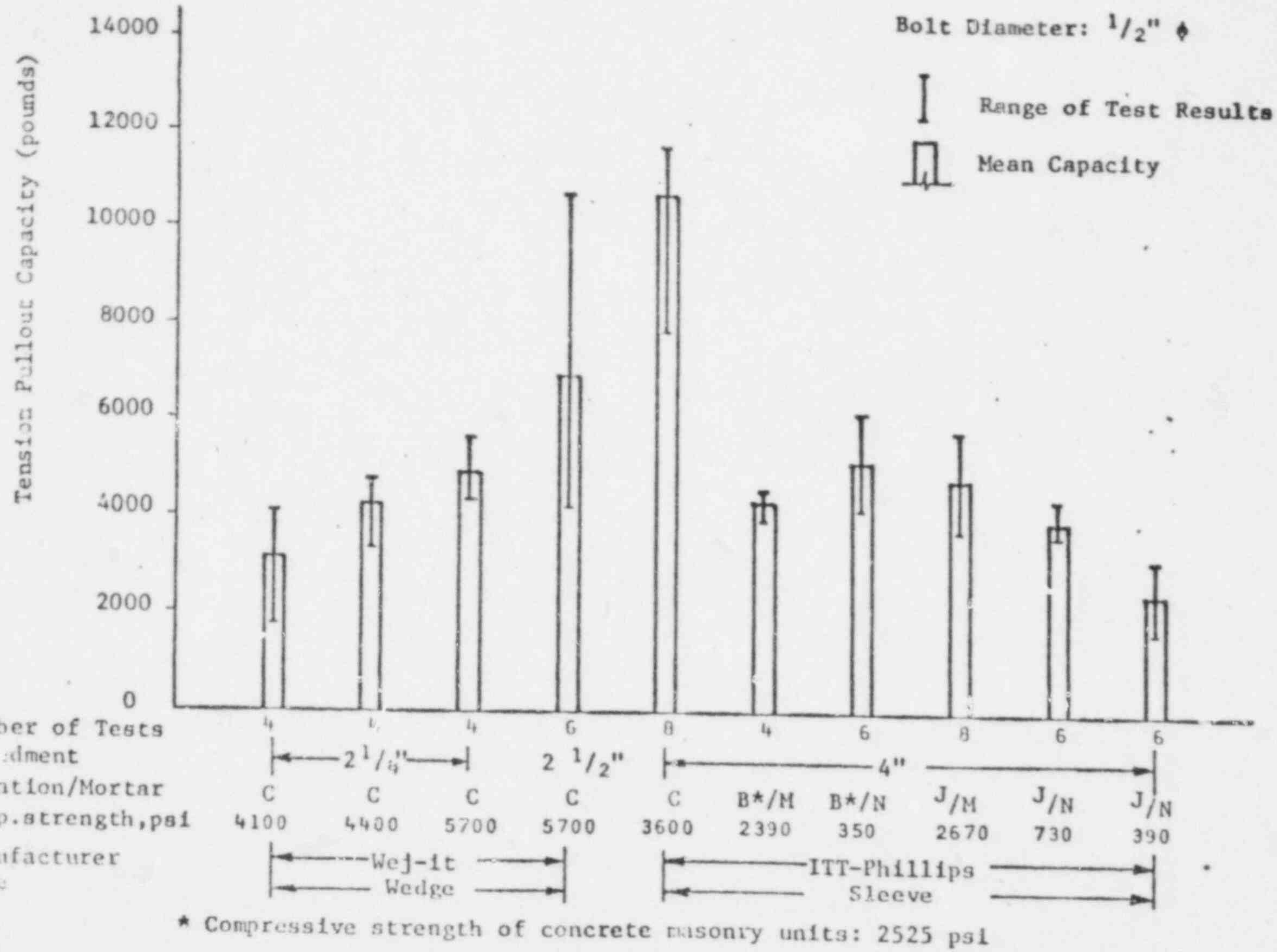
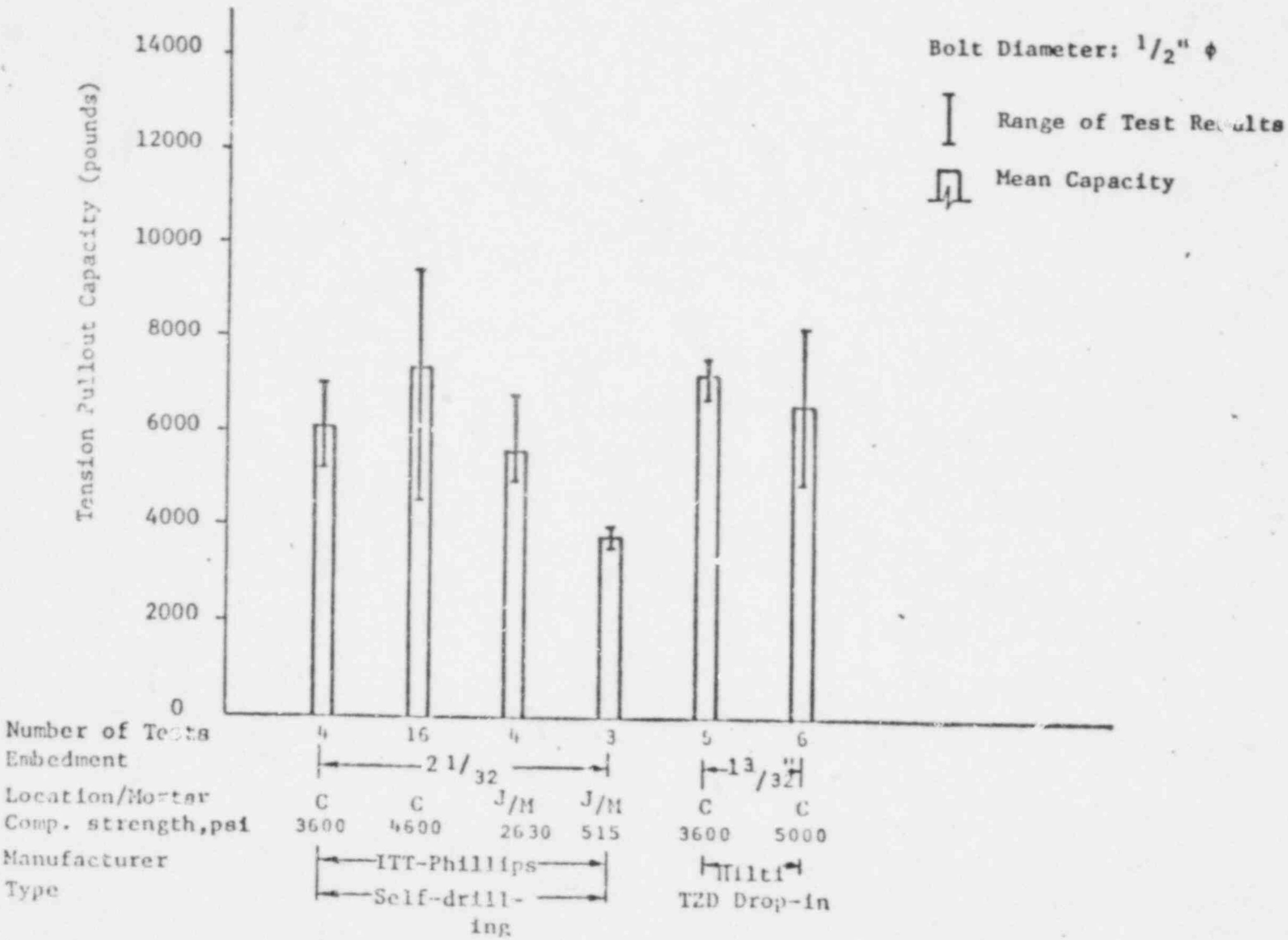


Fig. 2.4 (cont'd) Comparison of $^1/_2$ in. expansion anchors



* Compressive strength of concrete masonry units: 2525 psi

Fig. 2.4 (cont'd) Comparison of 1/2 in. expansion anchors

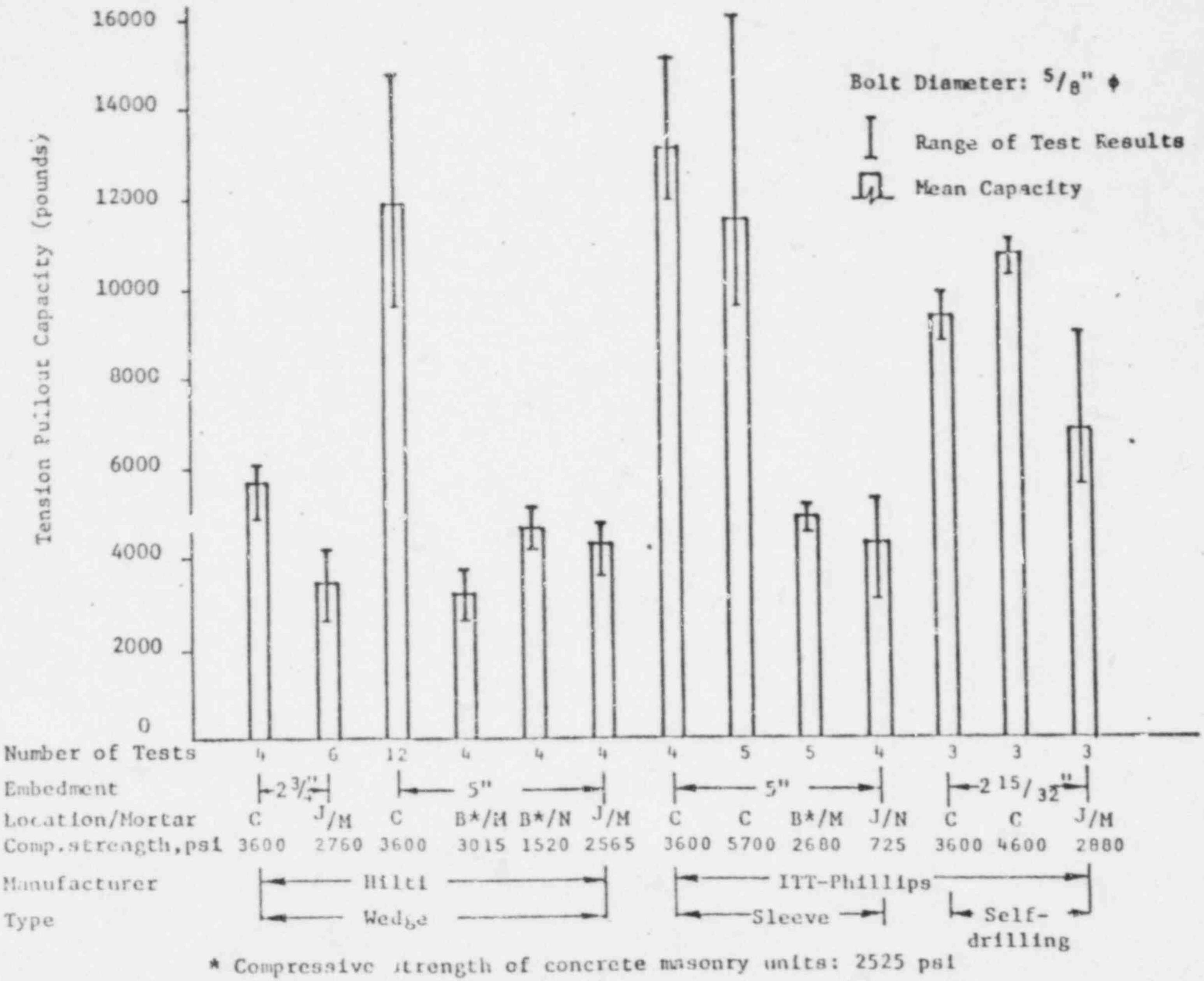
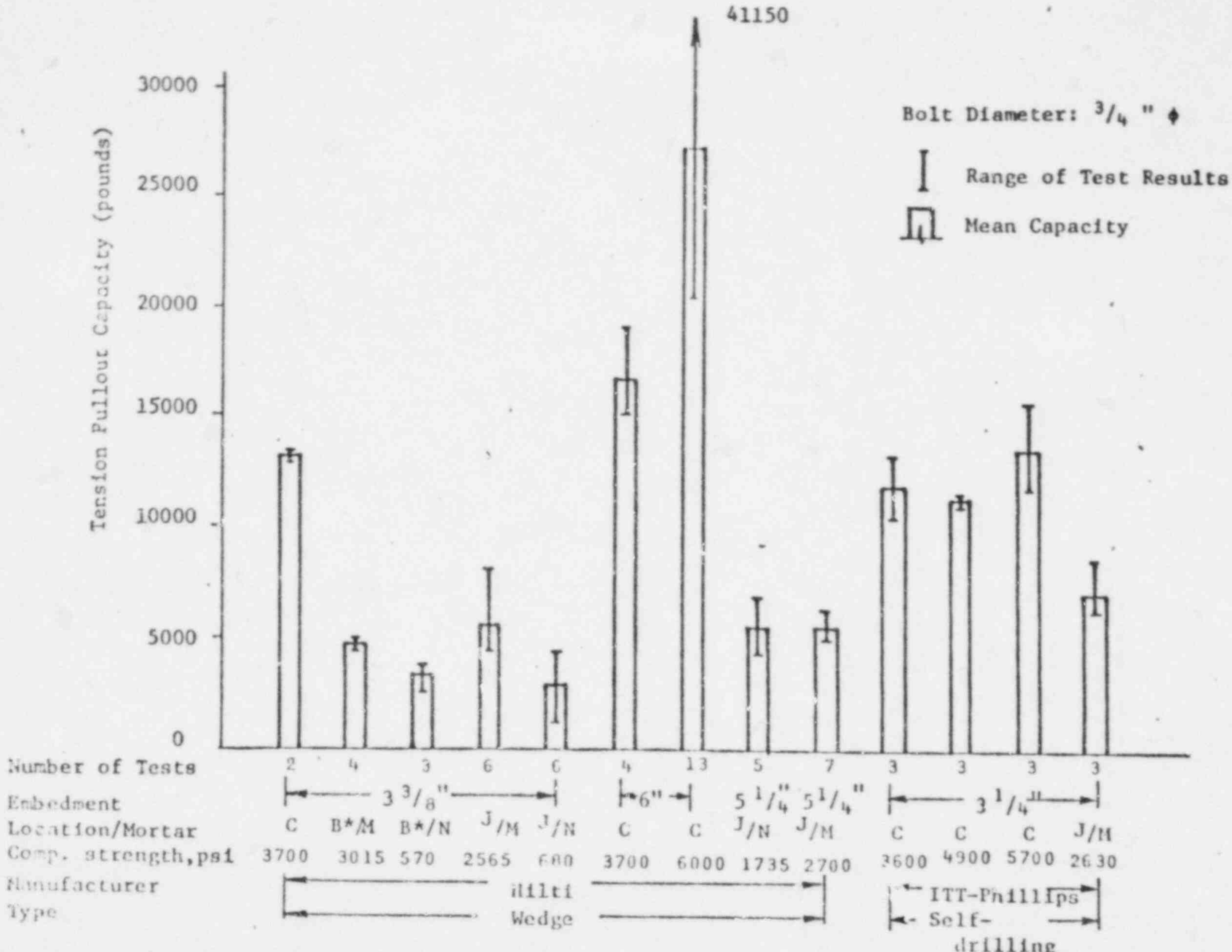


Fig. 2.5 Comparison of $^5/_8$ in. expansion anchors



* Compressive strength of concrete masonry units: 2525 psi

Fig. 2.6 Comparison of 3/4 in. expansion anchors

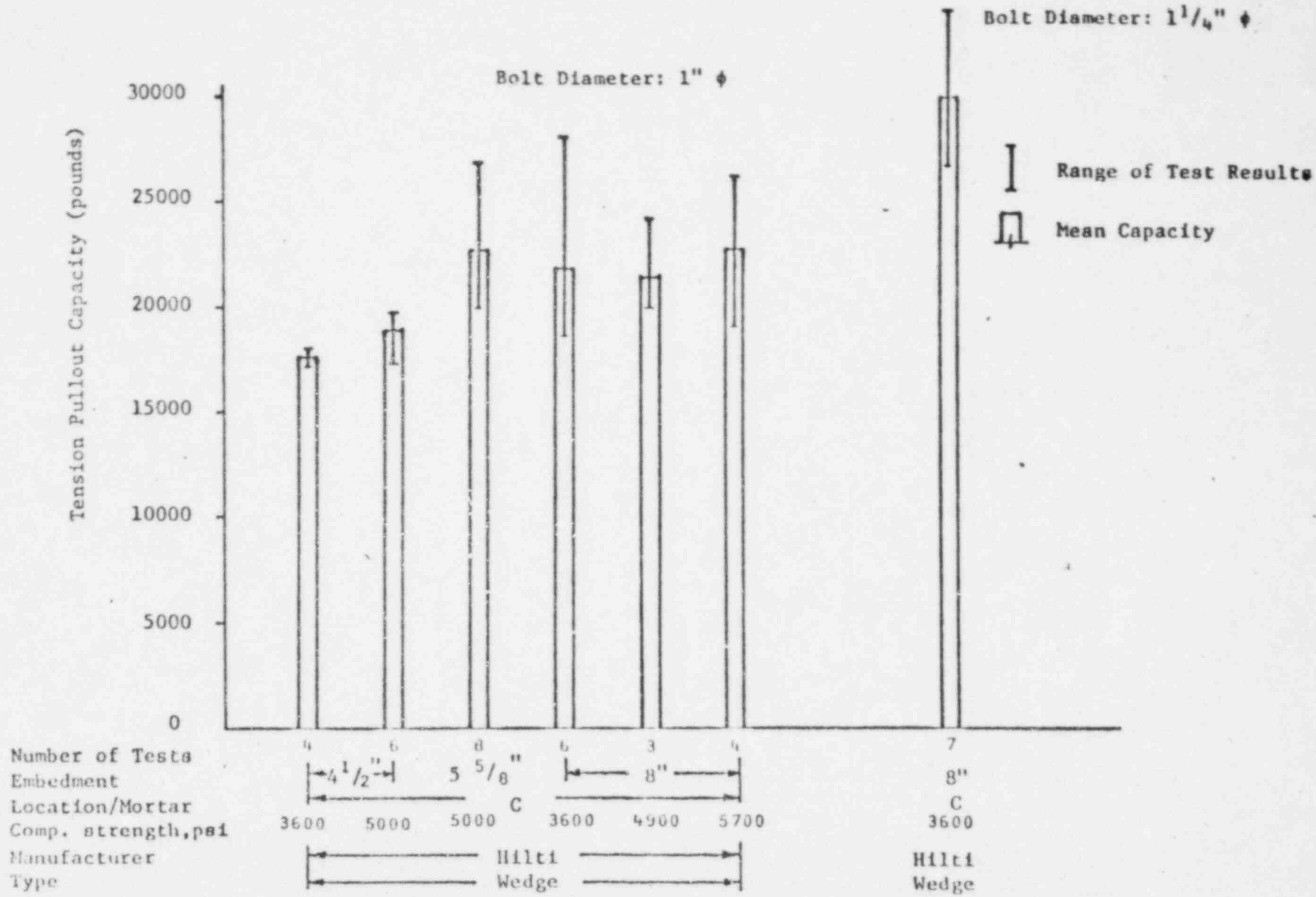


Fig. 2.7 Comparison of 1 in. and 1 1/4 in. expansion anchors

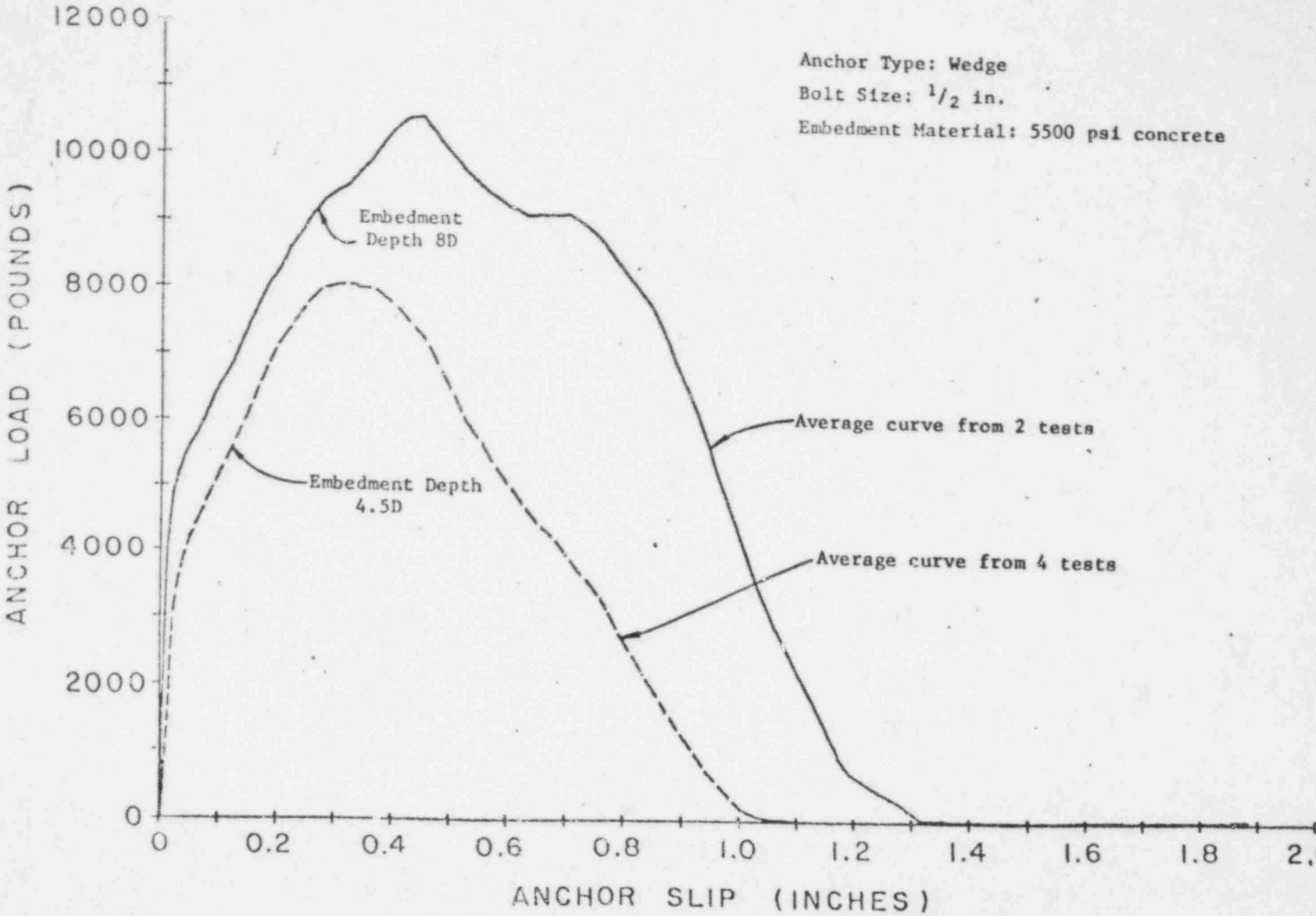


Fig. 2.8 Load slip behavior for wedge anchors embedded 4.5D and 8D

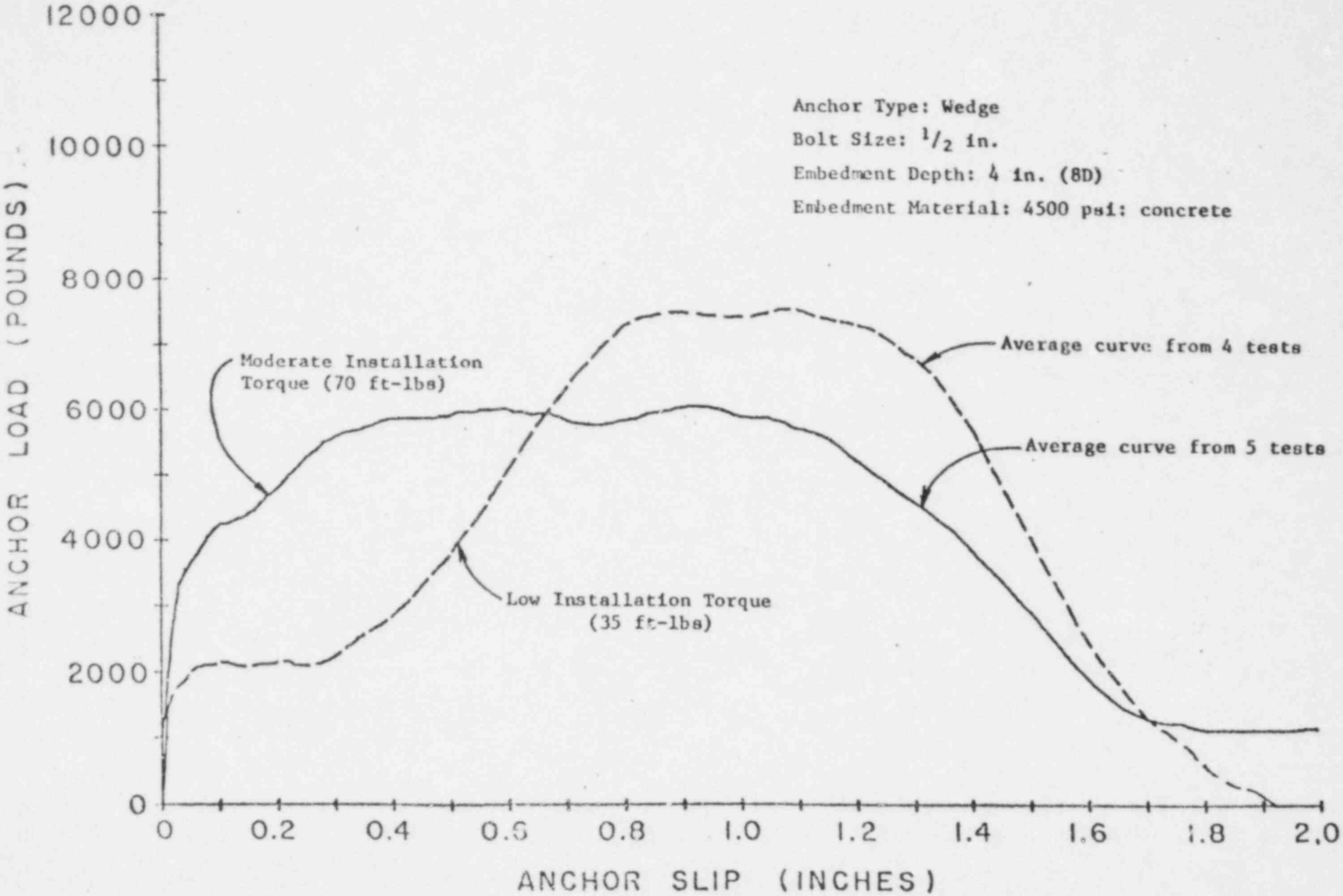


Fig. 2.9 Load slip behavior of wedge anchors installed with low and moderate installation torque

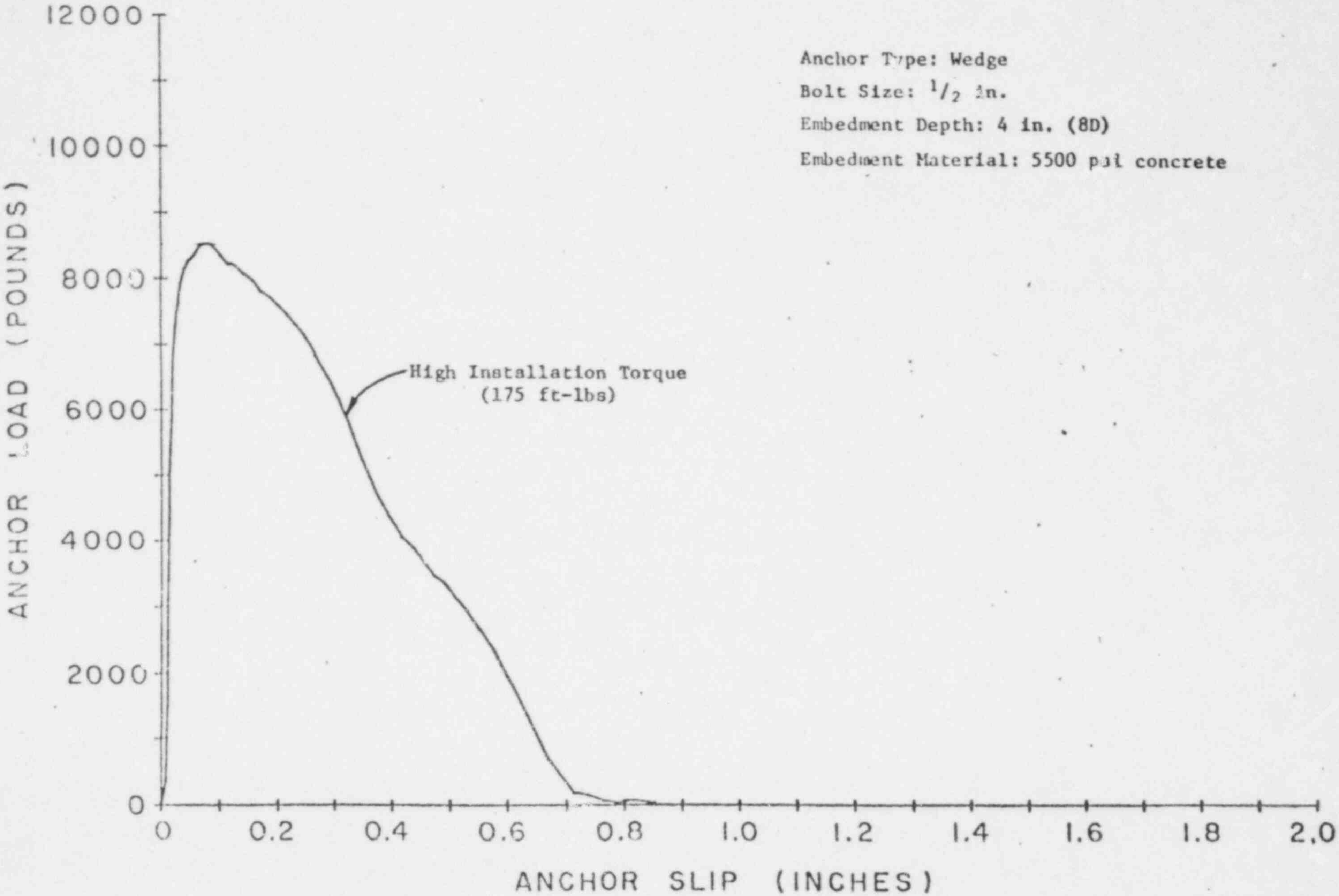


Fig. 2.10 Load slip behavior of wedge anchor installed with high installation torque

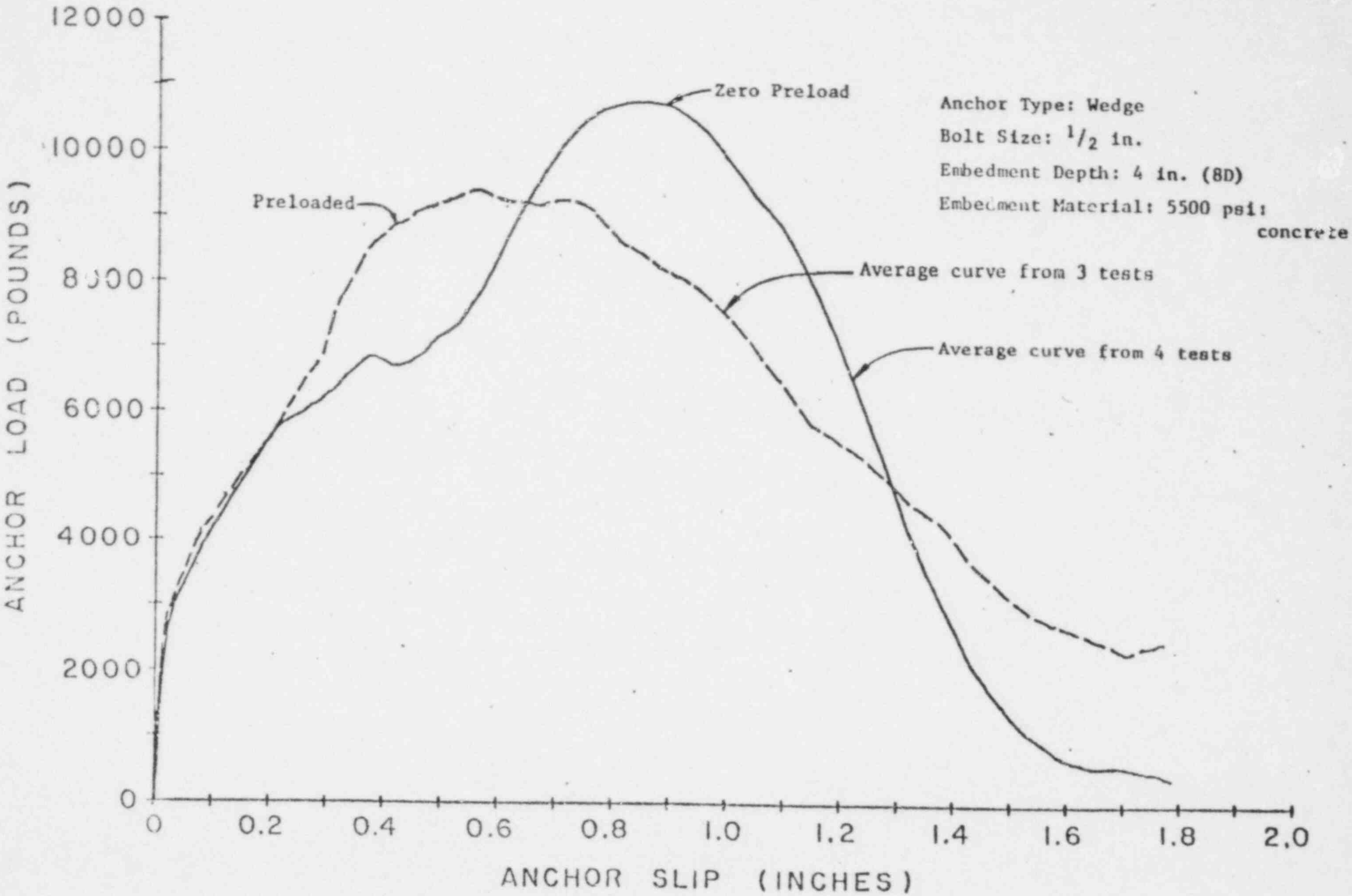


Fig. 2.11 Load Slip behavior of anchors tested with preload

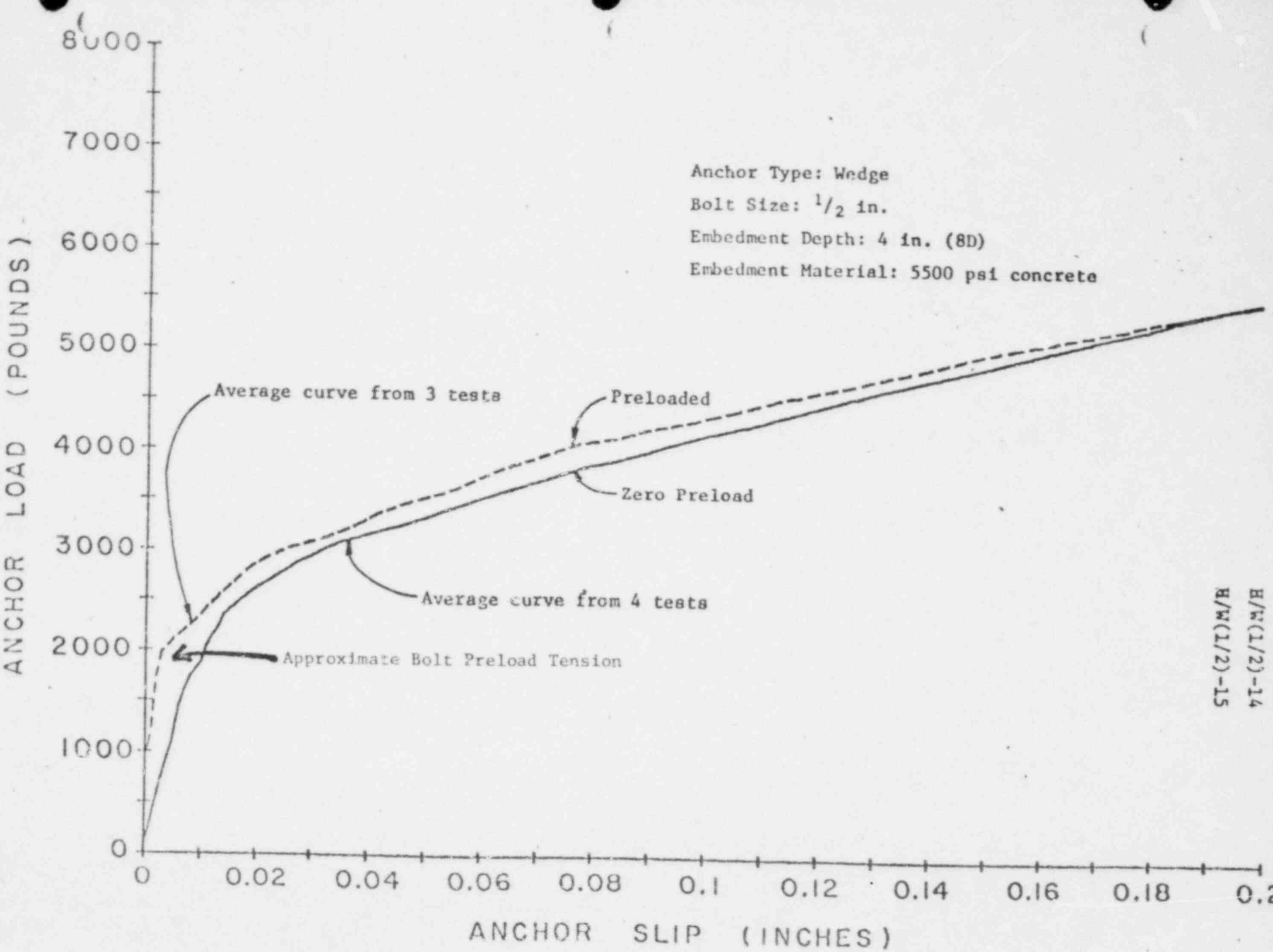


Fig. 2.12 Initial portion of load slip behavior for anchors with different bolt preloads

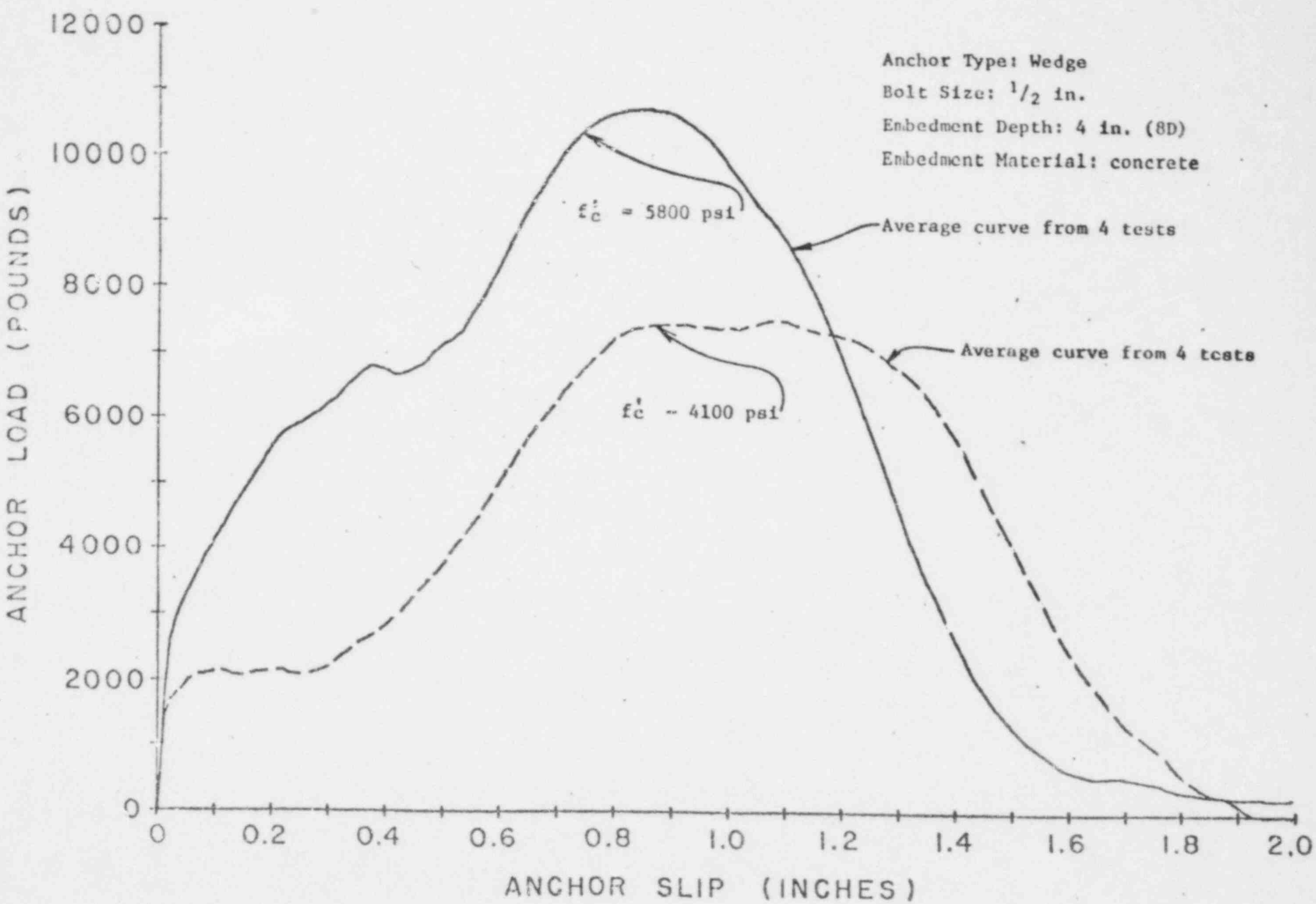
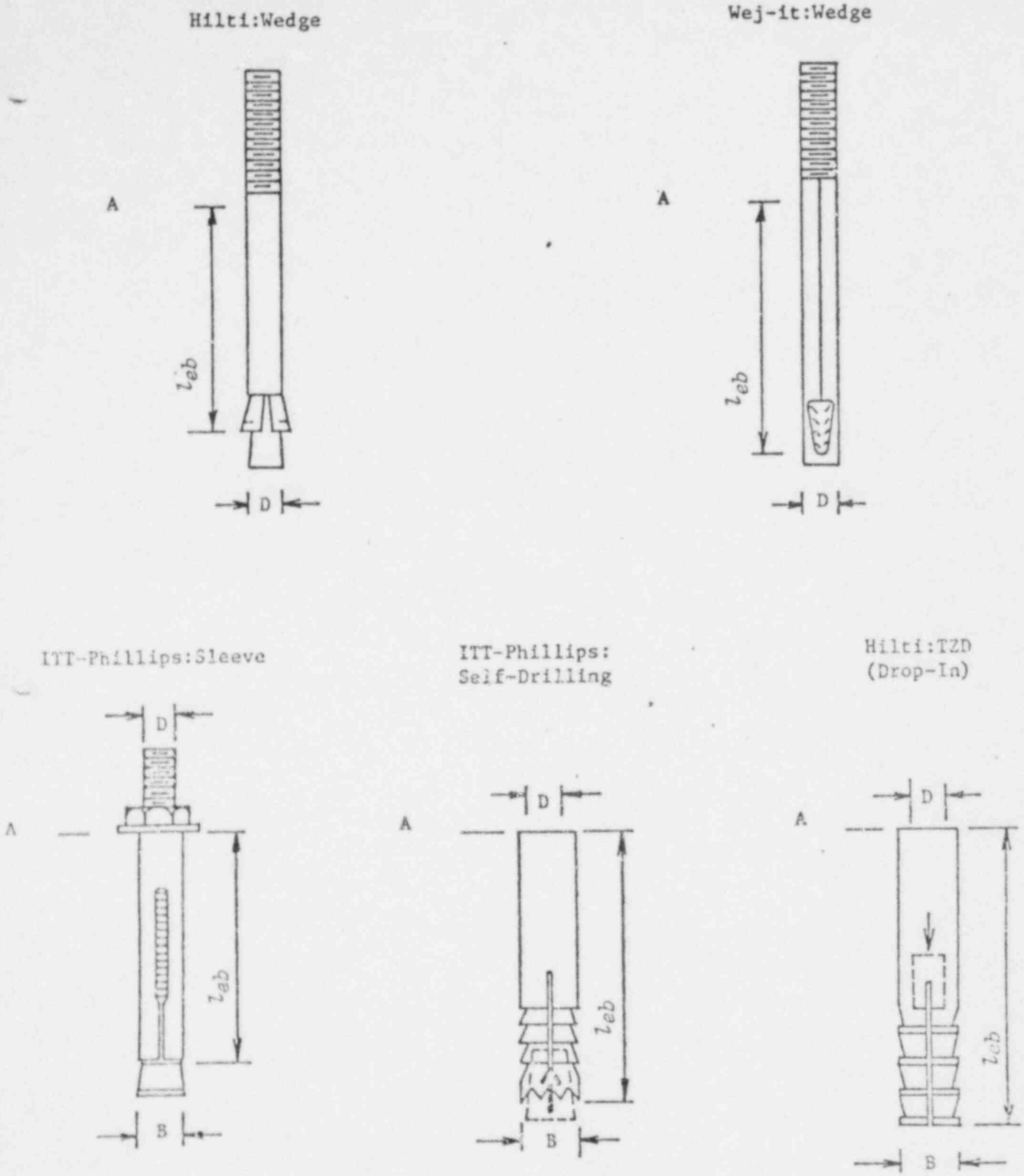


Fig. 2.13 Effect of concrete compressive strength



D = Bolt diameter
B = Drill bit diameter
A = Surface of embedding material
l_{eb} = Embedment depth

Fig. 2.14 Details of Generic Expansion Anchors

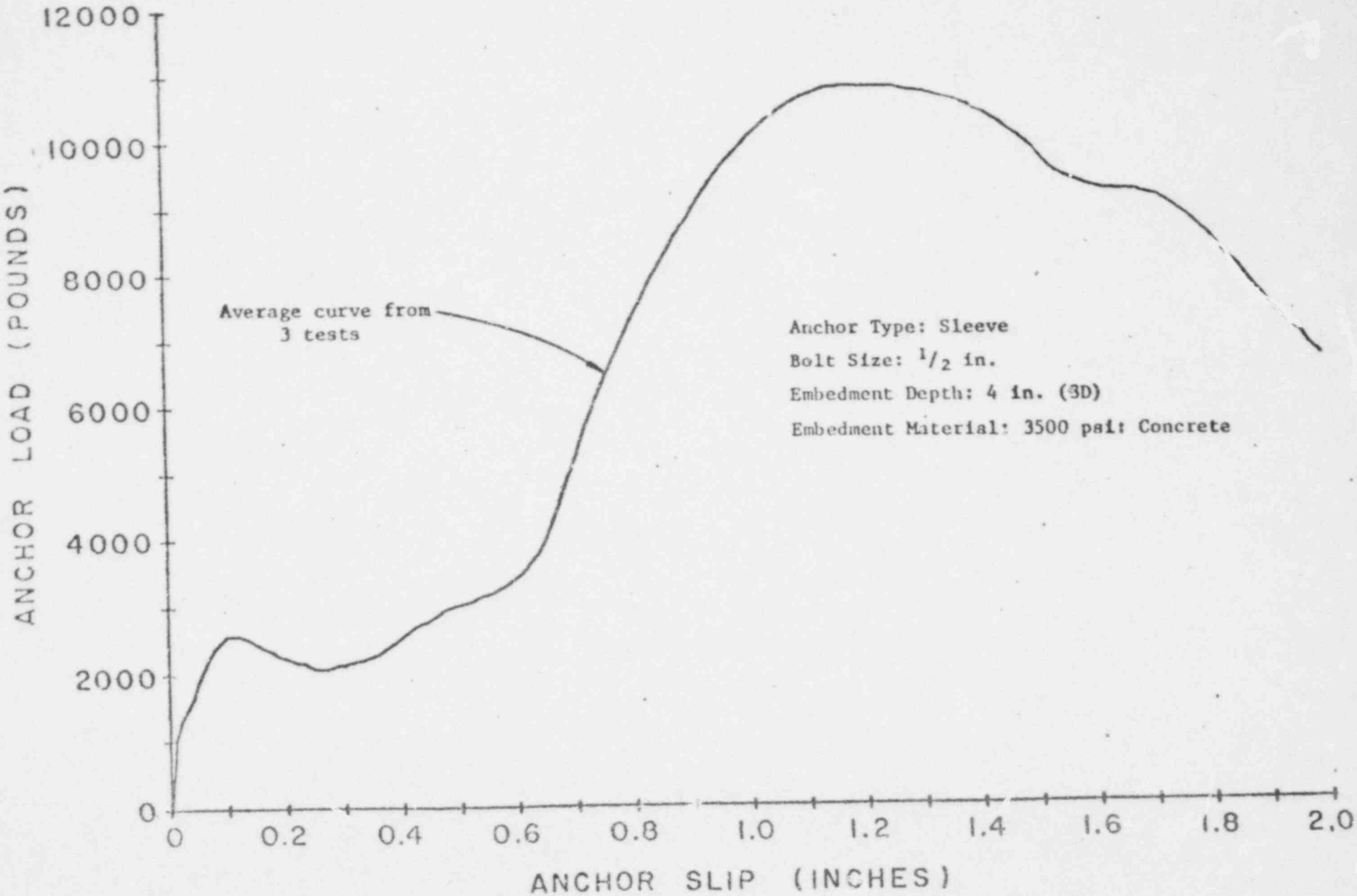


Fig. 2.15 Load slip characteristics of sleeve type anchors

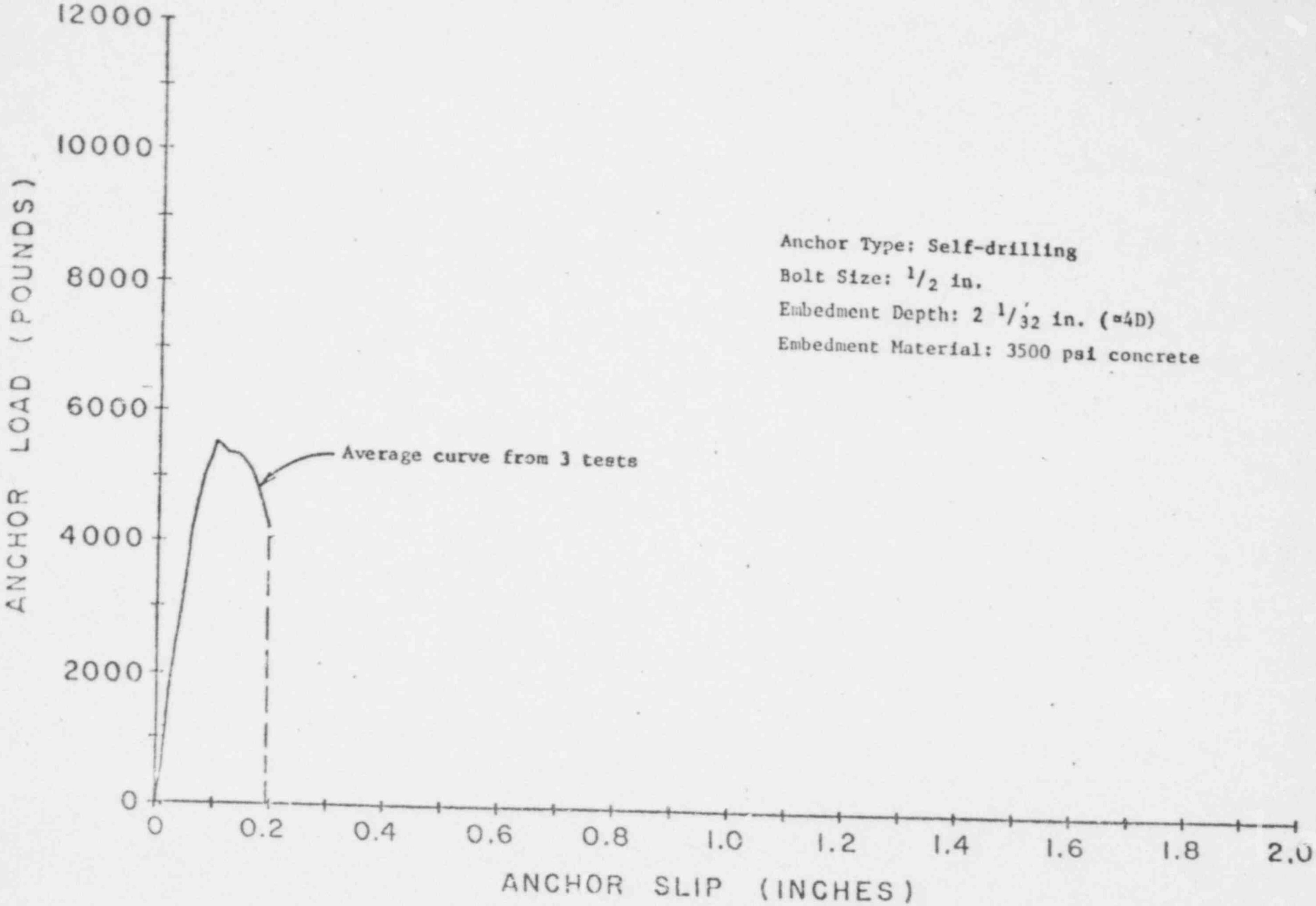


Fig. 2.16 Load displacement characteristics of self-drilling anchor

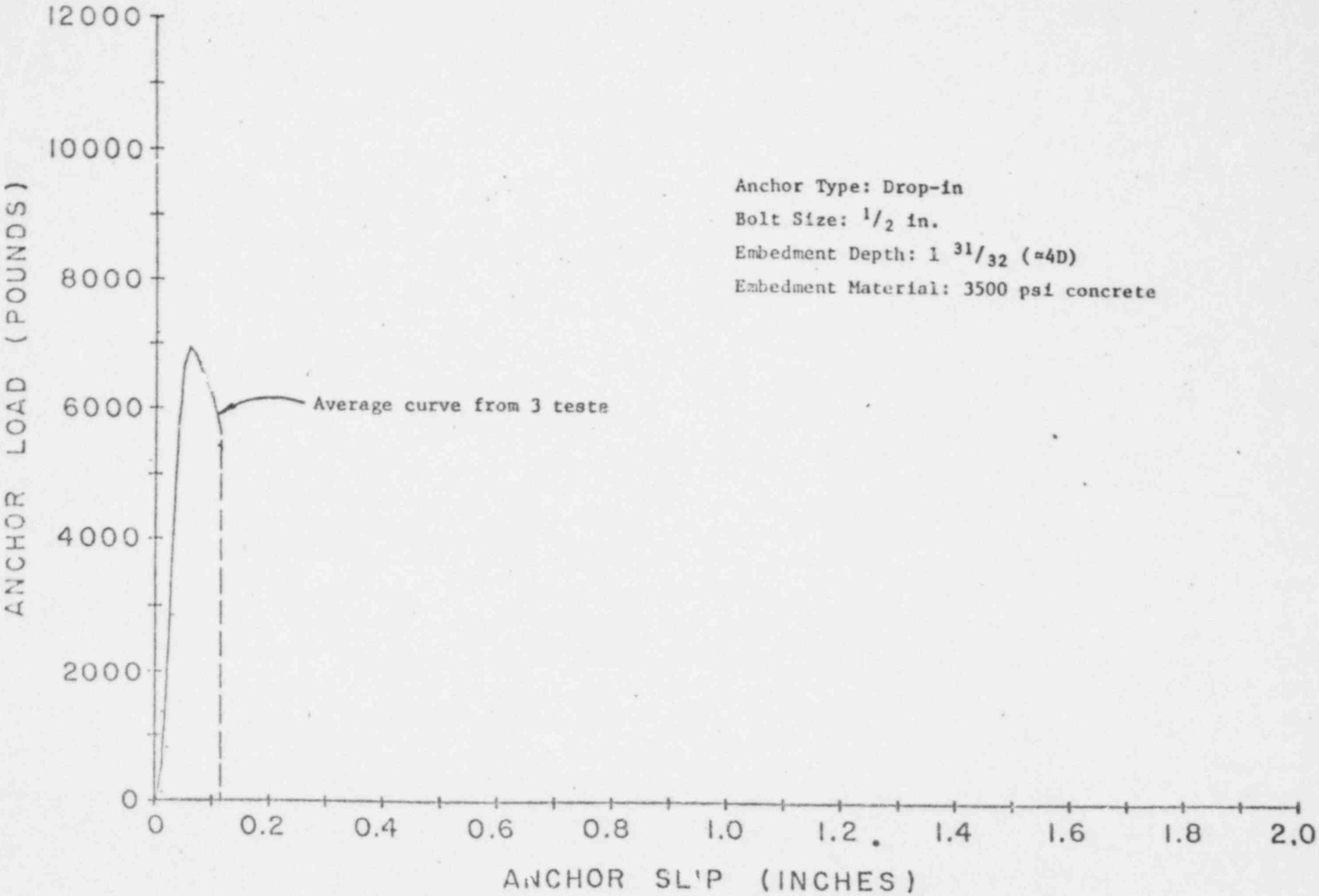


Fig. 2.17 Load displacement characteristics of "TZD" drop-in anchor

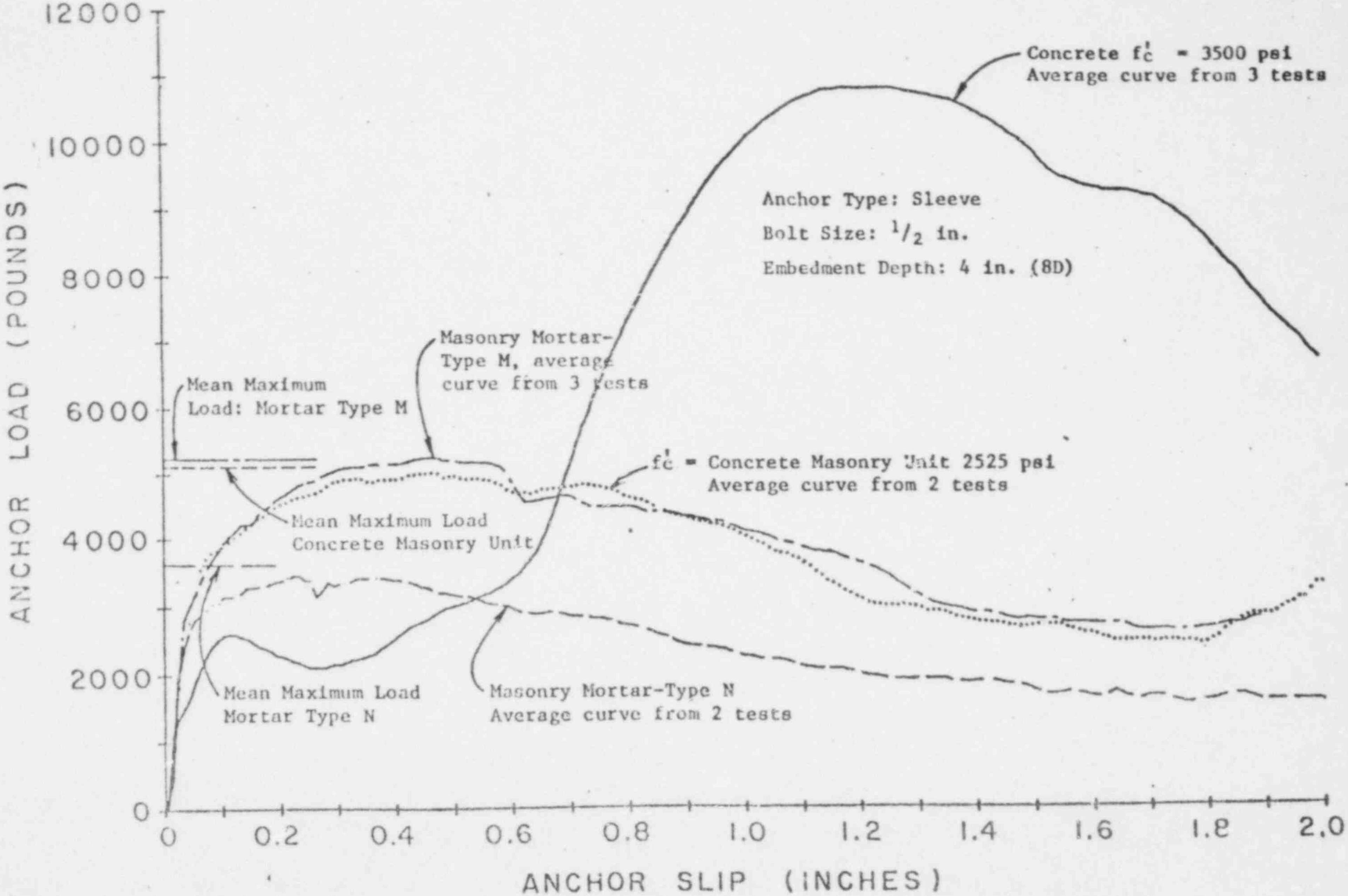


Fig. 2.18 Sleeve anchor embedded in concrete and concrete masonry

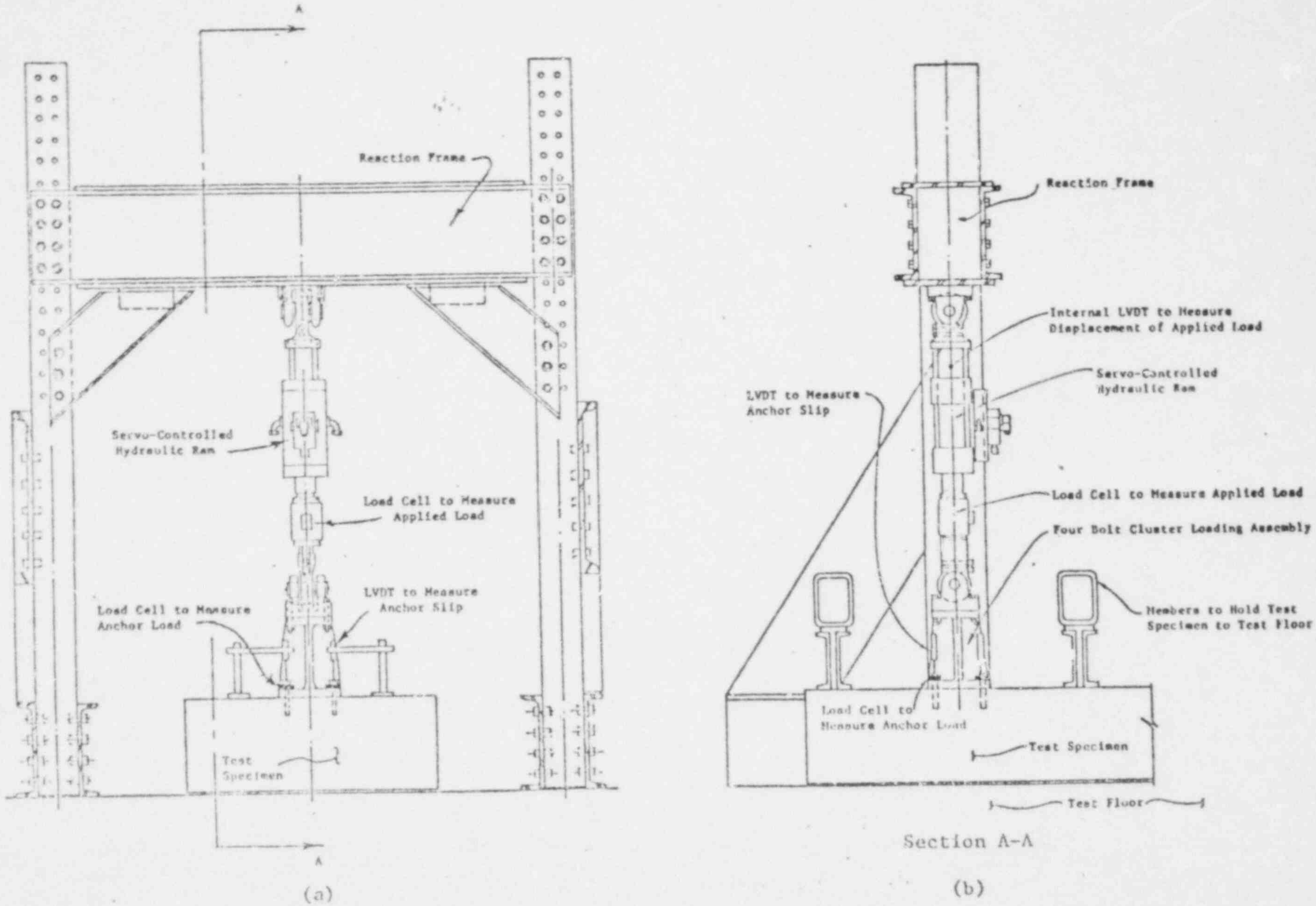


Fig. 2.19 Test Assembly for Cyclic Load Tests

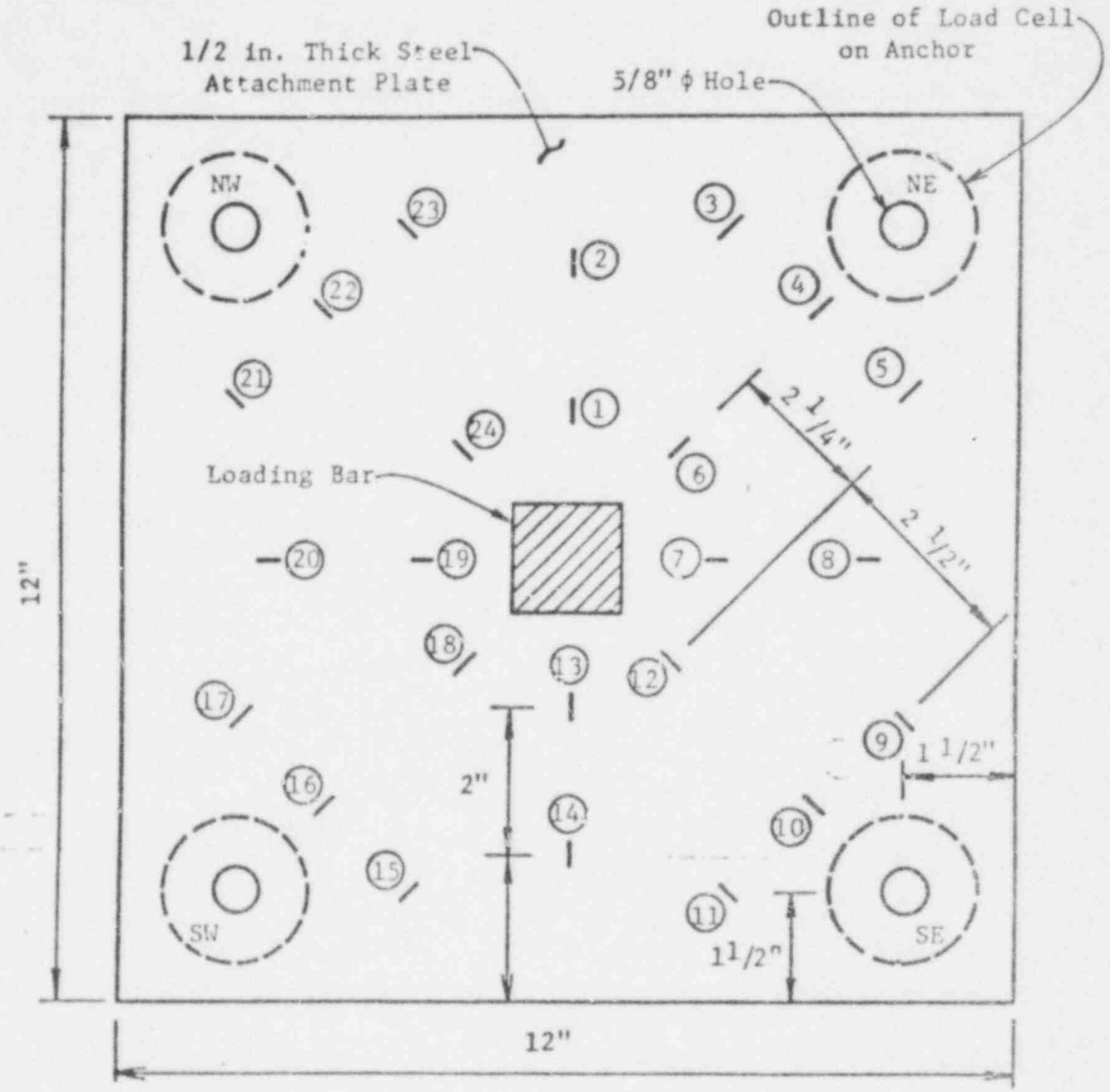


Fig. 2.20 Strain Gage Locations on Attachment Plate for Flexible Plate Tests

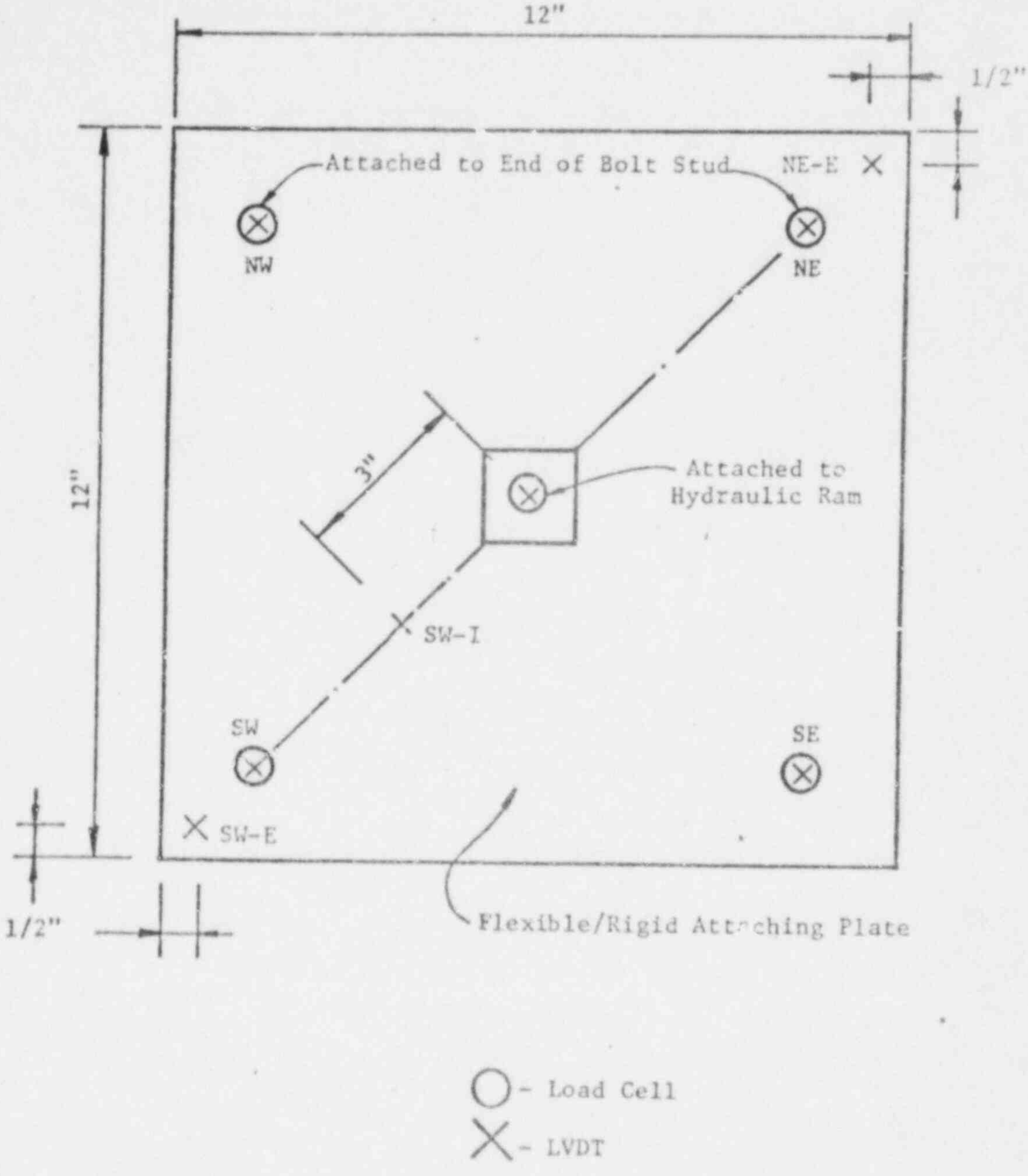


Fig. 2.21 Location of Displacement Transducers to Measure Anchor Slip and Plate Deflection

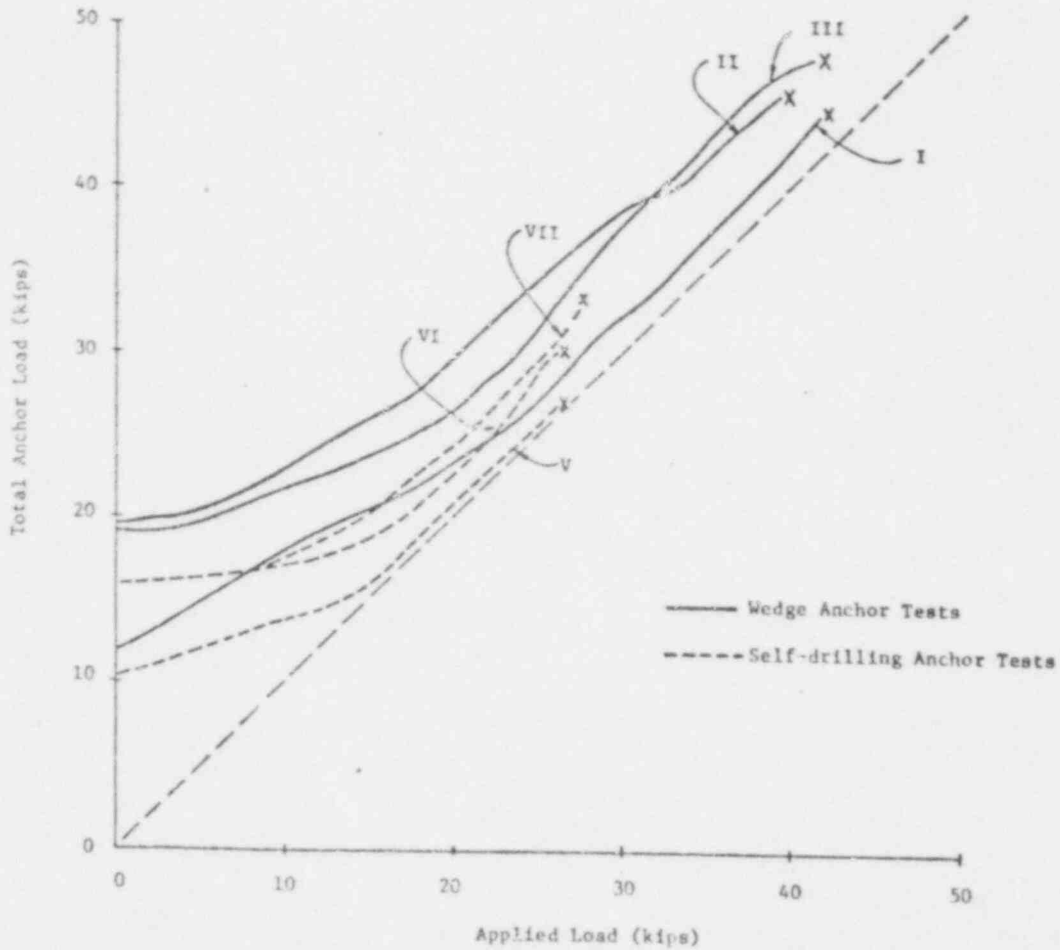


Fig. 2.22 Summary of Anchor Tension Versus Applied Load Relationships for Prying Action Tests

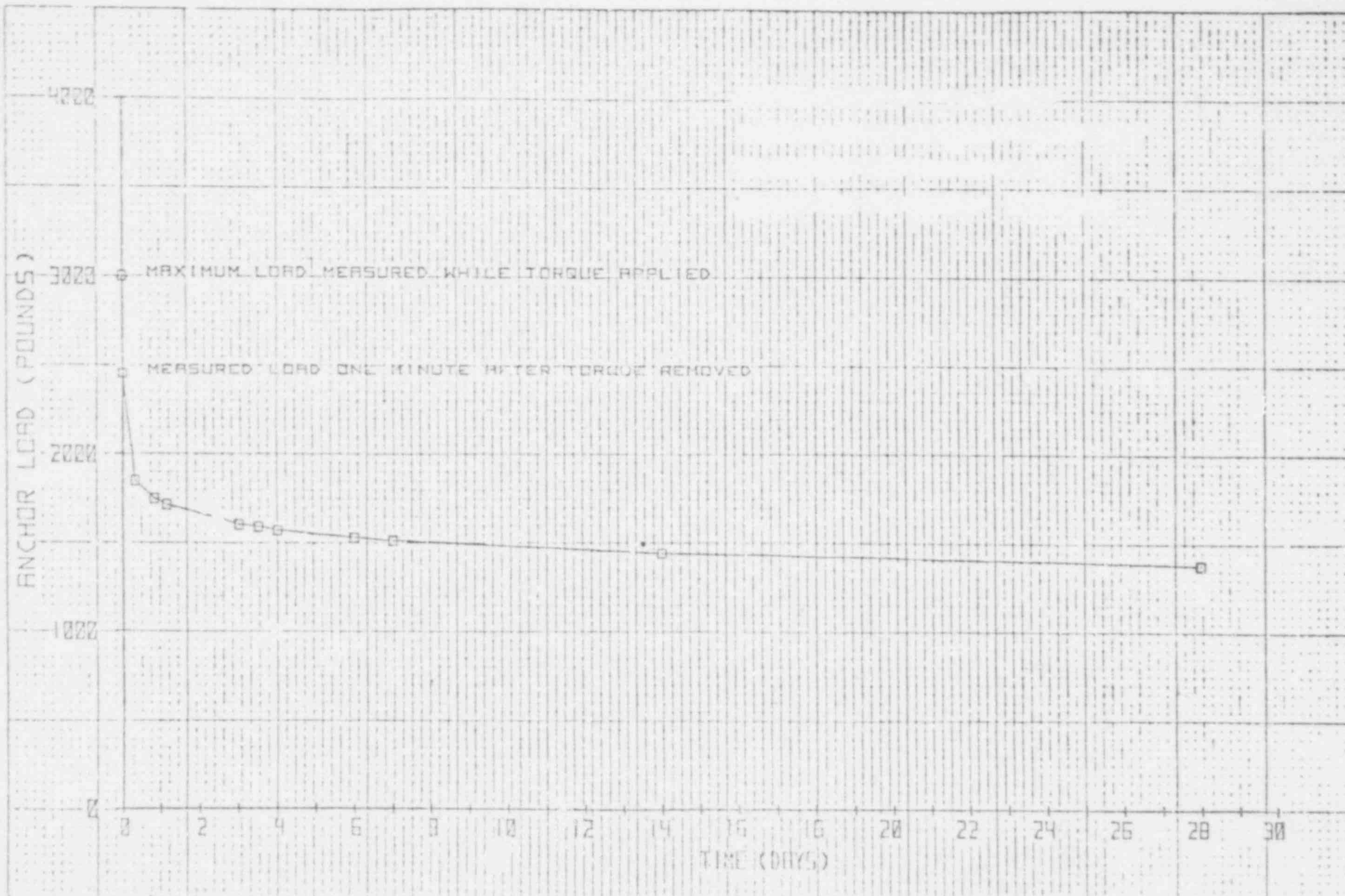


FIGURE 2.23
ANCHOR PRELOAD VS. TIME

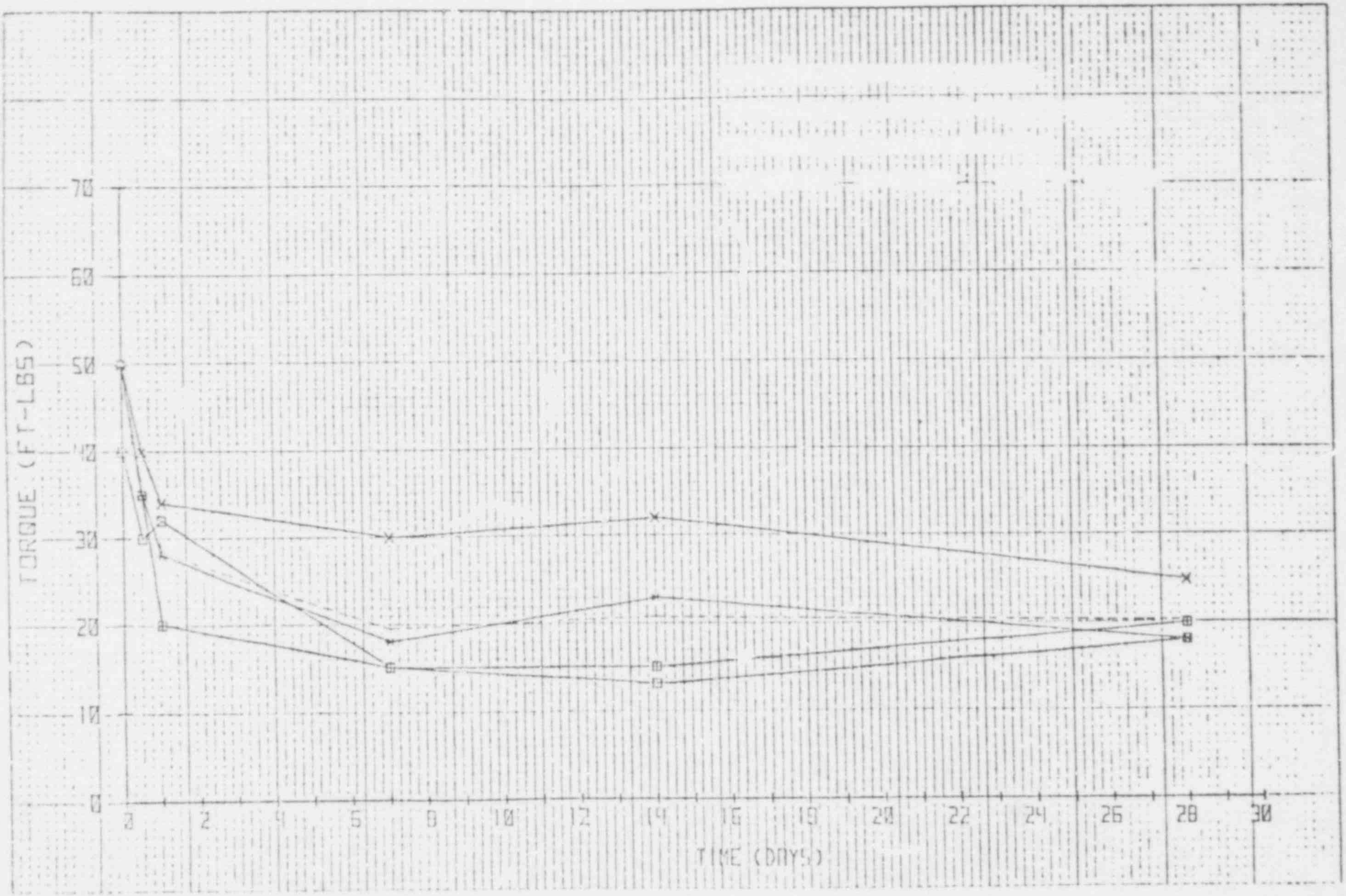


FIGURE 2.24
TORQUE VS. TIME