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TELEDYNE
ENGINEERING SERVICES

TECHNICAL REPORT

TR-3501-1, REVISION 1

SUMMARY REPORT

GENERIC RESPONSE TO USNRC I&E BULLETIN NUMBER 79-02

BASE PLATE/CONCRETE EXPANSION ANCHOR BOLTS

AUGUST 30, 1979

8008070331

THIS DOCUMENT CONTAINS
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UTILITY/TES OWNERS GROUP

TECHNICAL REPORT 3501-1
REVISION 1

SUMMARY REPORT
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BASE PLATE/CONCRETE EXPANSION ANCHOR BOLTS

AUGUST 30, 1979

TELEDYNE ENGINEERING SERVICES

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Technical Report
TR-3501-1

TELEDYNE
ENGINEERING SERVICES

American Electric Power Company

Boston Edison Company

Consolidated Edison

Detroit Edison Company

*Duke Power Company

Jersey Central Power and Light Company

Niagara Mohawk Power Corporation

Northeast Utilities Service Company

Omaha Public Power District

Philadelphia Electric Company

Prairie Island Generating Station of Northern States Power

Public Service Gas and Electric Company of New Jersey

Virginia Electric Power Company

Wisconsin Public Service Corporation

*Chairman of the Owner's Group

TELEDYNE ENGINEERING SERVICES

Technport
TR-35

ABSTRACT

eport presents the results of a generic program that responds, in pa/NRC IE Bulletin Number 79-02. The work was performed by Teledineering Services for a group of fourteen utilities.

perimental and analytical work was performed in this generic progrear-tension interaction tests and cyclic test of concrete expanchors was performed and a pre and post processor to an existte element program were developed to facilitate base plate analy

ortant general findings of this program are:

ncrete expansion anchor bolts which are not preloaded do t deteriorate when subjected to cyclic loading.

linear assumption for shear-tension interaction loading on ncrete expansion anchors is highly conservative. Actual rves for shear-tension interaction are presented here.

se plate flexibility should be considered in determining load on concrete expansion anchors.

sting performed under this program does not indicate a ason for applying different safety factors to different es of expansion anchors.

owing list identifies those utilities who are members of the/TES group.

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1.0 INTRODUCTION

Teledyne Engineering Services was authorized by fourteen utilities to provide engineering services which would assist the utilities in responding, in part, to USNRC I&E Bulletin 79-02, dated March 8, 1979. Bulletin 79-02 required response to a number of items associated with base plate flexibility and its concomitant effect on concrete expansion anchor bolts. It was determined by the Utility/TES group that a number of items in the bulletin were generic in nature and could be addressed more substantially by combining resources and technology.

The specific bulletin items addressed by the Utility/TES group are:

1. The experimental development of shear-tension interaction curves to properly apply the specified bulletin safety factors for combined loading.
2. Experimental determination of the adequacy of concrete anchor bolts that are not preloaded to withstand cyclic loading.
3. An analytical technique for determining the effect of base plate flexibility on concrete anchor bolt loading.

1.1 Owner's Group Responsibility

The Owner's Group was responsible for directing the efforts of TES and reviewing the specific tasks as they were performed and completed.

1.2 Initial NRC Meeting

On April 26, 1979, the Utility/TES group met with the NRC in Bethesda, Maryland to discuss this generic program and its applicability to Bulletin 79-02. Representatives from both I&E and NRR were in attendance and their general conclusion was "the proposed program would address the concerns over the base plate/anchor bolt installation in a fashion that is acceptable to NRC."

2.0 SCOPE OF WORK

The Owner's Group formalized the scope of work to be pursued by TES on April 12, 1979 at a Utility/TES meeting. The scope of work is separated into three Tasks, as follows.

2.1 Task 1 - Shear-Tension Interaction Curves

Under this Task, TES was authorized to develop shear-tension interaction curves for the concrete anchor bolts used by the participating utilities. These curves were developed using experimental techniques discussed in detail in Section 3 of this report. Where possible, TES took advantage of existing published data to reduce the number of tests required to be performed. In those cases where data made available by others was used, TES performed at least one test to verify the received data.

The development of shear-tension interaction curves is important since it provides the mechanism for generating a design curve for evaluating combined loading on anchor bolts. Prior to the development of these curves, the majority of data available was pure tension or pure shear. This required the use of linear interpolation between the tension and shear values or some assumptions as to the shape of the shear-tension interaction curve.

2.2 Task 2 - Cyclic Capability of Concrete Anchors

Under this Task, TES was authorized to perform cyclic tests of concrete anchor bolts used by the participating utilities. This task was undertaken to demonstrate that preload on the anchor was not the critical factor in the resistance of concrete anchor bolts to cyclic loading. It was felt that the critical factor was setting of the anchor (sleeve, wedge or shell) in the concrete. Further, since a given manufacturer uses the same design concept and manufacturing process for a line of anchor bolts, it was determined that size of the bolt was not a factor and the tests were performed for one size only. The size selected for testing was 3/4 inch which was generally the average size for all manufacturers used by the participating utilities. Also, confirmatory tests on 1/2 inch and one inch bolts were performed.

The cyclic test details are discussed in Section 4.0 of this report. Generally, the anchors were cycled at two frequencies with varying loads representative of a seismic event and normal operating vibration. The anchor was monitored during cyclic testing to determine if pullout was occurring and at the completion of the cyclic test, the anchor was pulled to destruction. The destructive test was performed to determine if any decay in the ultimate failure load occurred due to cycling.

This test was important since it was necessary to show that bolt preload was not an important factor affecting anchor bolt adequacy in a cyclic environment. The setting of the anchor bolt holding device (sleeve, wedge, shell) was determined to be the appropriate criteria. This would allow the utilities to demonstrate on a plant unique basis that the anchoring devices were set and eliminate any requirement to check preload. Further, determination as to the ultimate static capability of anchor bolts in a cyclic environment is important information in designing and evaluating anchor devices.

2.3 Task 3 - Development of Analytical Techniques for Base Plate - Anchor Bolt Analysis

Under this task, TES was authorized to develop an analytical tool that was capable of considering the effects of base plate flexibility, concrete-plate interaction and bolt stiffness. This tool was to be used by the participating utilities for analyzing existing base plates for which flexibility was not considered.

It was important that the program was easy to use, did not require considerable input or detailed evaluation of output. The ability to consider various base plate attachment types, non-uniform bolt configurations, and non-linear bolt stiffnesses was determined to be advantageous by the participating utilities. A detailed description of the computer program is included in Section 5.0 of this report. Part of the verification process of the developed program was to compare the results to that obtained by testing an actual base plate with concrete anchor bolts. The results of this comparison are also given in Section 5.0.

Using this program, TES developed a number of curves that can be used for the determination of anchor bolt loads for specific size base plates and specific types of anchor bolts. These curves also appear in Section 5.0 of this report.

3.0 TASK 1 - SHEAR - TENSION INTERACTION

3.1 Introduction

Although most manufacturers provide ultimate load data for pure tension and pure shear, few provide such data for combined loading cases. In order to develop such data, testing of certain expansion anchors in concrete was conducted. The number of tests for each manufacturer, type and size was determined by their use by members of the utility group and the quantity of data available from other sources. Table 3.1 outlines the manufacturer type and sizes that were tested. All testing complied with ASTM Specification E-488.

3.2 Objective and Scope

The major objective of the Shear-Tension Interaction test series was to develop data to be used to construct the shear-tension interaction curve, defining the ultimate load capability of each anchor for range of shear and tension loads.

It is important to recognize that the shear-tension interaction testing was performed to more represent field conditions than laboratory conditions. Expansion anchor installation and hole drilling was based on manufacturer's recommendations and this work was performed by a number of different individuals in order to introduce human variables similar to field installation. The slabs were drilled outside where the environmental conditions varied widely and would have an impact on the human factor. There was no attempt to make environmental conditions ideal nor was any more control of installation required than would be done at a field site using normal QC and QA procedures. This approach was used since the program was attempting to determine the adequacy of expansion anchors in existing generating facilities and tried to account for the variables associated with environment and human factor effects.

All records were made on two X-Y recorders, one plotting shear load versus tensile load, the other plotting tensile load versus tensile desplacement or shear load versus shear displacement in the case of pure shear tests.

TABLE 3.1

SHEAR-TENSION INTERACTION TEST MATRIX

Mfg/Type	Catalogue Designation	Size 1/4	3/8	1/2	5/8	3/4	7/8	1	1-1/4
Phillips									
*Snap Off	S		X		X		X		
Wedge	WS			X	X	X	X	X	X
Sleeve	HN		X	X	X	X			
Stud Anchor	JS					X			
Hilti									
Kwik Bolt	5500XXX	X	X	X	X	X		X	X
USM									
Parabolt	PB			X	X	X			
Wej-It									
Stud		X	X	X	X	X	X	X	X
Rawl									
*Snap Off	60XX			X		X			
Star									
Slug-In				X	X	X	X	X	
Ramset									
Wedge				X	X	X		X	
Sleeve				X	X	X			

*Manufacturer's input stated that Rawl Snap Off and Phillips Snap Off are identical, therefore all sizes were not tested for these types and the data is interchangeable.

3.3 Test Set-up

A special purpose testing machine was designed and built to simultaneously apply shear and tension loads to anchors installed in concrete slabs. The machine consisted of a supporting structure and two orthogonal hydraulic cylinders of 70,000 pound capacity each (see Figure 3.1). Loading of the anchors was applied through pinned joints and load-measuring links. A feedback control based on the measured load, load rate command and pre-selected shear-tension ratio was used to control the action of the hydraulic servo-valves (see Figure 3.2).

The concrete slabs were unreinforced concrete with a specified minimum compressive strength of 3000 lb/in^2 at 28 days and a size of 3-1/2 feet x 7 feet x 1 foot thick. The testing machine rested on the slab and the tensile and shear loads were reacted directly back into the slab.

A displacement transducer was supported separately on the concrete slab and measured the vertical displacement of the bolt, except in the case of all shear loading. In that case, the horizontal (shear) deflection of the shoe was measured relative to the slab.

Each hydraulic cylinder was coupled to a servo-valve driven by a force-feedback differencing servo-amplifier. The command signal, consisting of a ramp function, was simultaneously applied to each servo-amplifier. The level of the signal was controlled by the chosen shear/tension ratios. The rate of increase in the ramp's amplitude was set according to the size of the bolt so as to apply the ultimate load in a period of one minute or more from start of loading.

LEGEND

a. Tension Cylinder
b. Shear Cylinder
c. Tension Load Link
d. Shear Load Link
e. Baseplate Shoe
f. Rollers
g. Anchor (Test Item)
h. Concrete Slab

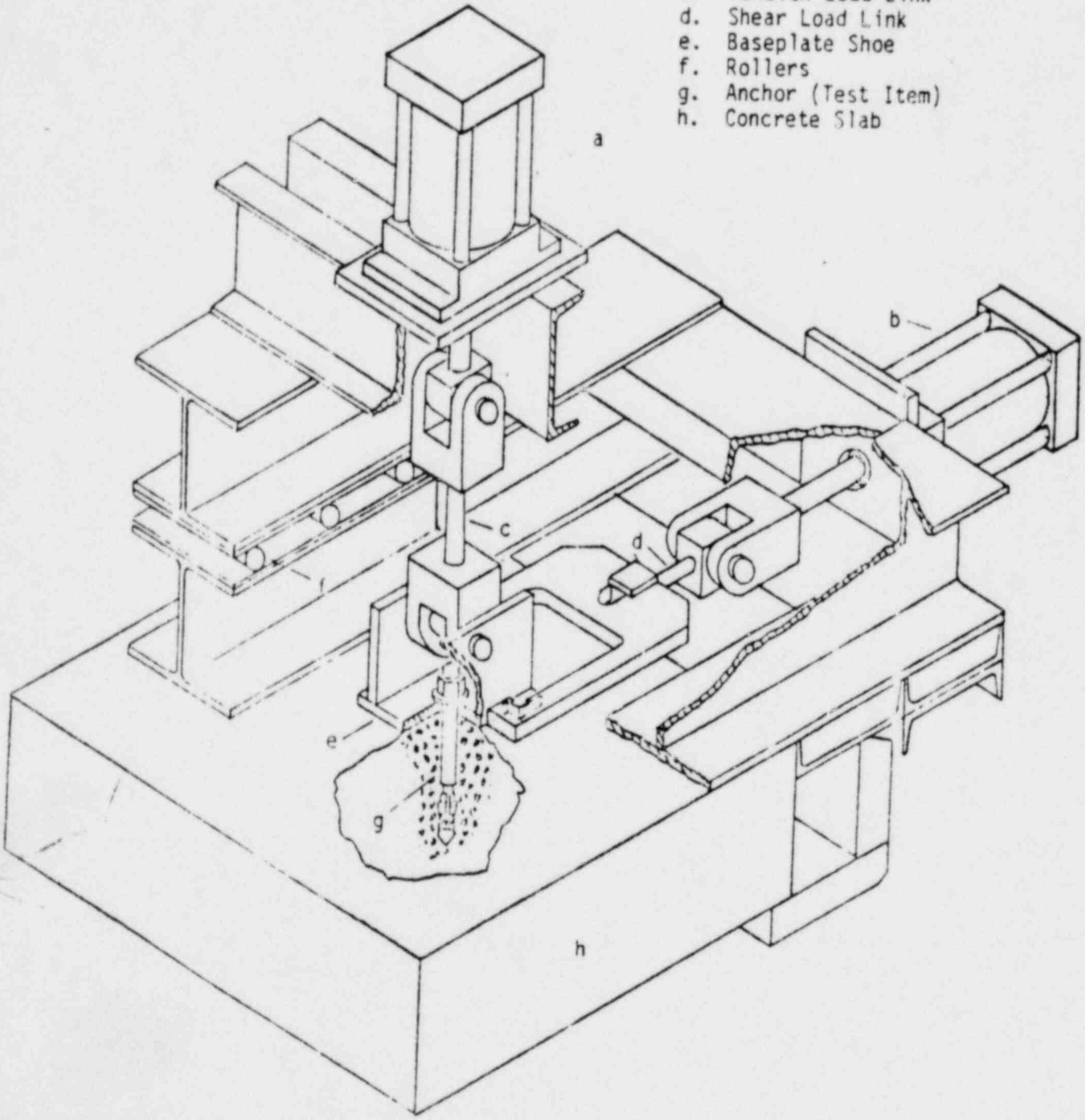


Figure 3.1 Overall View of Major Test Item Components (Sectioned for Clarity)

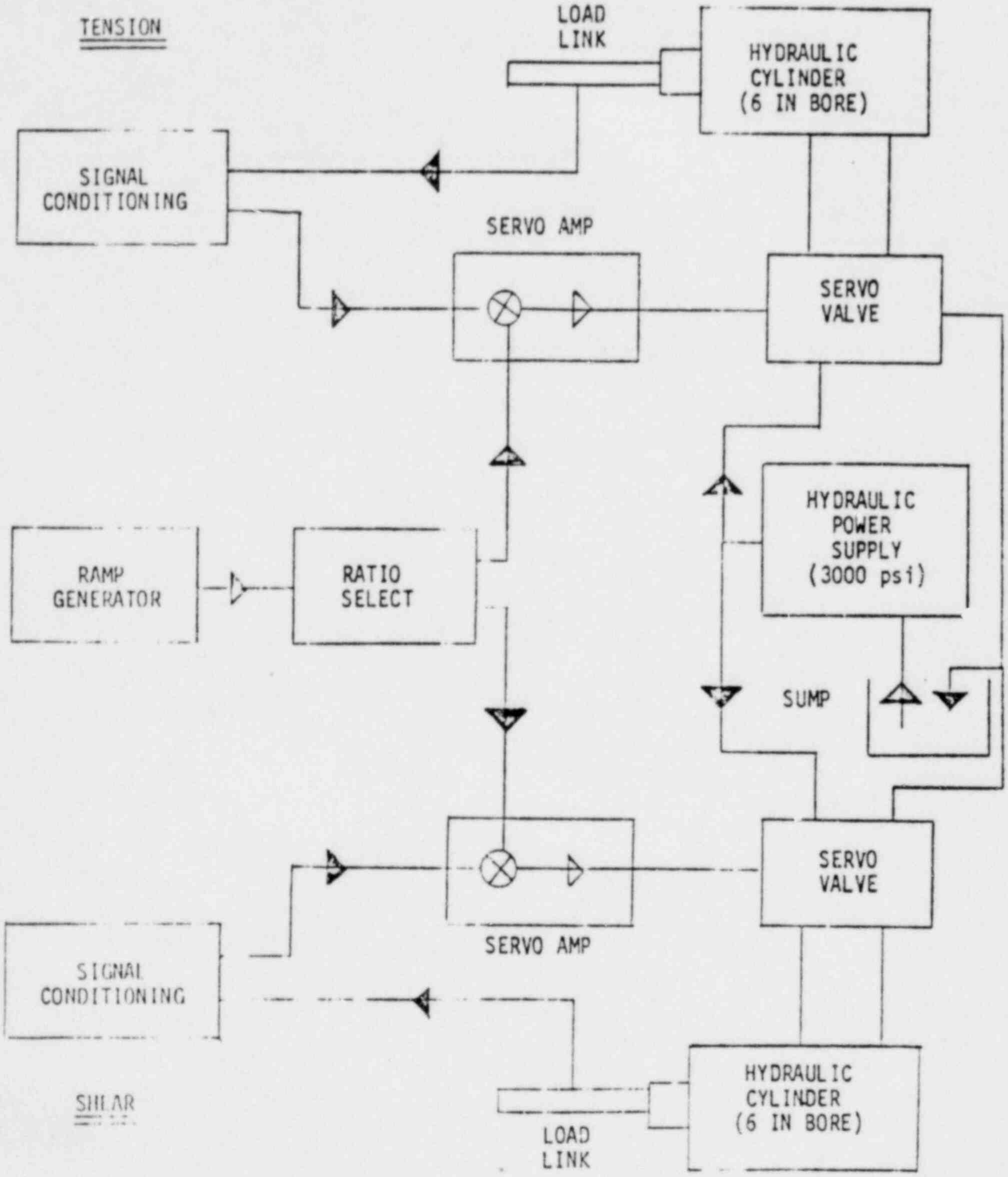


Figure 3.2 Schematic of Hydraulic Load Control

3.4 Test Hardware

All concrete slabs were more than 28 days old (since pouring) prior to testing. Holes were drilled according to manufacturers recommendations. Hole spacing was based on a minimum ten diameter radius. All holes were drilled using rotary-impact type drill motors and carbide bits (except for self-drilling types). Installation of the anchors followed manufacturer's recommendations. In most cases,[1] the embedment depth was the minimum recommended by the manufacturer for the particular bolt tested. Testing of the anchor was carried out within one day after installation.

Seven manufacturers were represented by the anchors tested. Bolt diameters ranged from 1/4 to 1-1/4 inches. Combined with the various types to be tested, this yielded a total of 46 different combinations.

3.5 Test Instrumentation

The load links (see Figure 3.3) were used for test control and test recording purposes; they provided both the feedback signal for load control purposes and the load signal for display of test results. Signal conditioning (excitation and signal amplification) was provided by Vishay 2100 series equipment. The combination of signal conditioning and load link was calibrated against a 1/4 percent NBS traceable load cell to 50,000 pounds.

Deflection (in either the shear or tensile loading directions) was provided by a Trans-Tek spring loaded DCDT (Direct Current Deflection Transducer) of one inch range. Calibration of the unit was performed by

[1] In five cases, the combination of available anchor length and fixture dimensions did not allow the exact recommended minimum embedment depth. Actual test embedments are given on Figures 3.5 through 3.50.

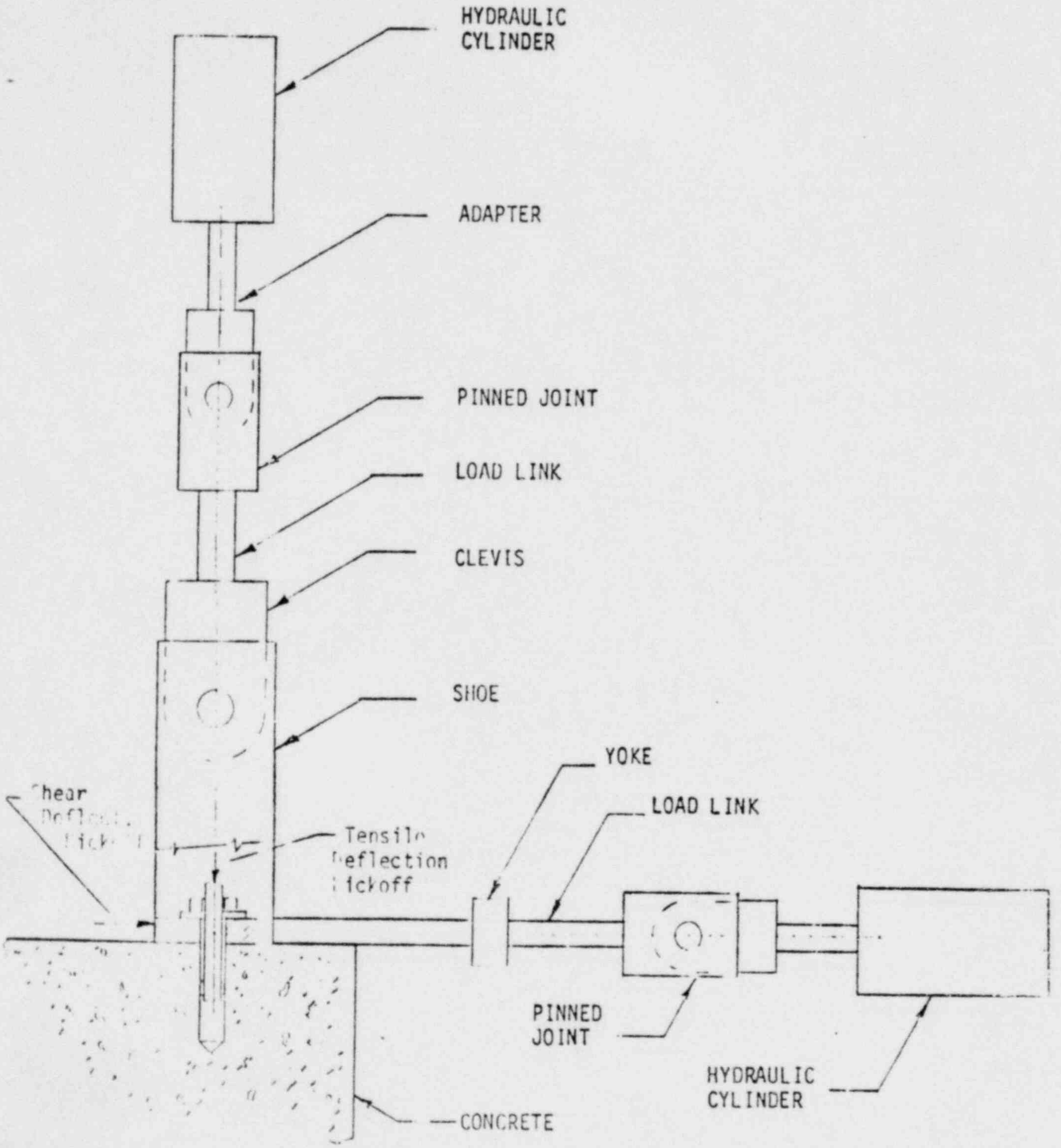


Figure 3.3 Setup for Load Application in Tension and/or Shear

inserting Gage Blocks between the bolt or shoe and the end of the transducer. This was accomplished before each day of testing and periodically as required for set-up adjustments. All initial readings were zeroed by mechanically positioning the transducer to its electrical zero position. This procedure allowed range changes during the course of a test without interruption for calibration.

Two X-Y recorders, Hewlett-Packard Model 7045, were used in the voltage-voltage mode to record the force and deflection data. Adjustments were made to the Vishay amplifier gains and excitation for the DCDT to produce transducer outputs resulting in full unit sensitivities. In this way, the calibrated attenuator controls of the recorders were used without the need for trimming (see Figure 3.4).

3.6 Test Procedure

Depending on the size of the anchor, it was installed before or after positioning the testing machine. Small sizes were installed with the machine in its final position. In either case, the shoe was placed over the anchor prior to setting the wedge (or torquing in the case of shell anchors). After a check of the load link zeros the shear yoke (connecting the shoe with the shear load link) was brought to contact and the tension clevis was pinned to the shoe. Thereafter, the deflection transducer was positioned and zeroed.

Testing was started by initiating the ramp function generator. Loading, as determined by the shear-tension ratio selector, was then applied at a uniform and simultaneous rate until failure. Failure in all cases was the inability to carry further loading in either direction. At that point, both loads were brought to zero. The observed failure mode was noted on the test record.

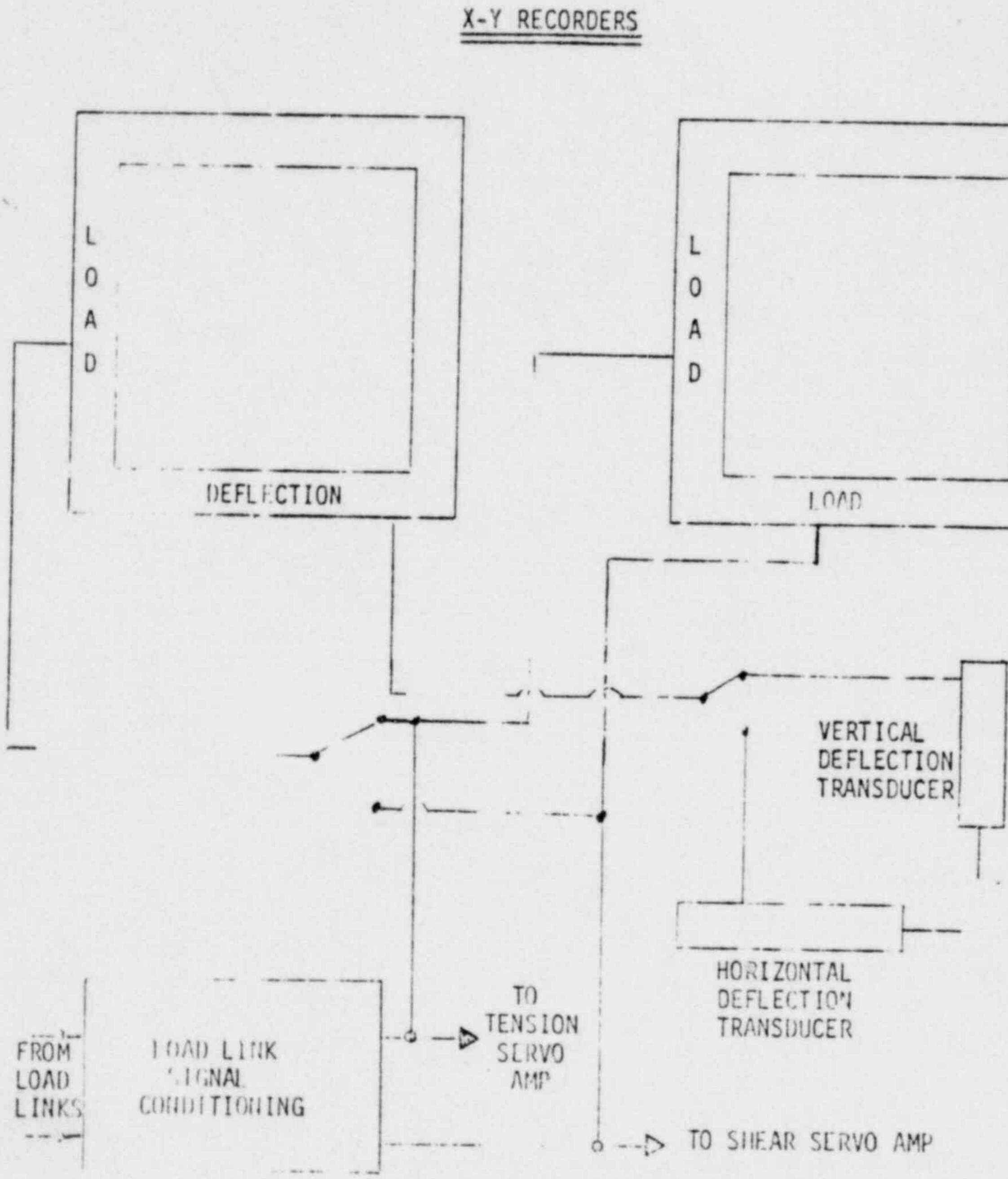


Figure 3.4 Schematic of Instrumentation Setup

Depending on the various factors, each test was performed at one of five different, preselected loading conditions:

a. All Tension (S/T = 0)

b. Tension equals (2.414) Shear (S/T = 0.414)

c. Tension equals Shear (S/T = 1.0)

d. Shear equals (2.414) Tension (S/T = 2.414)

e. All Shear (S/T = ∞)

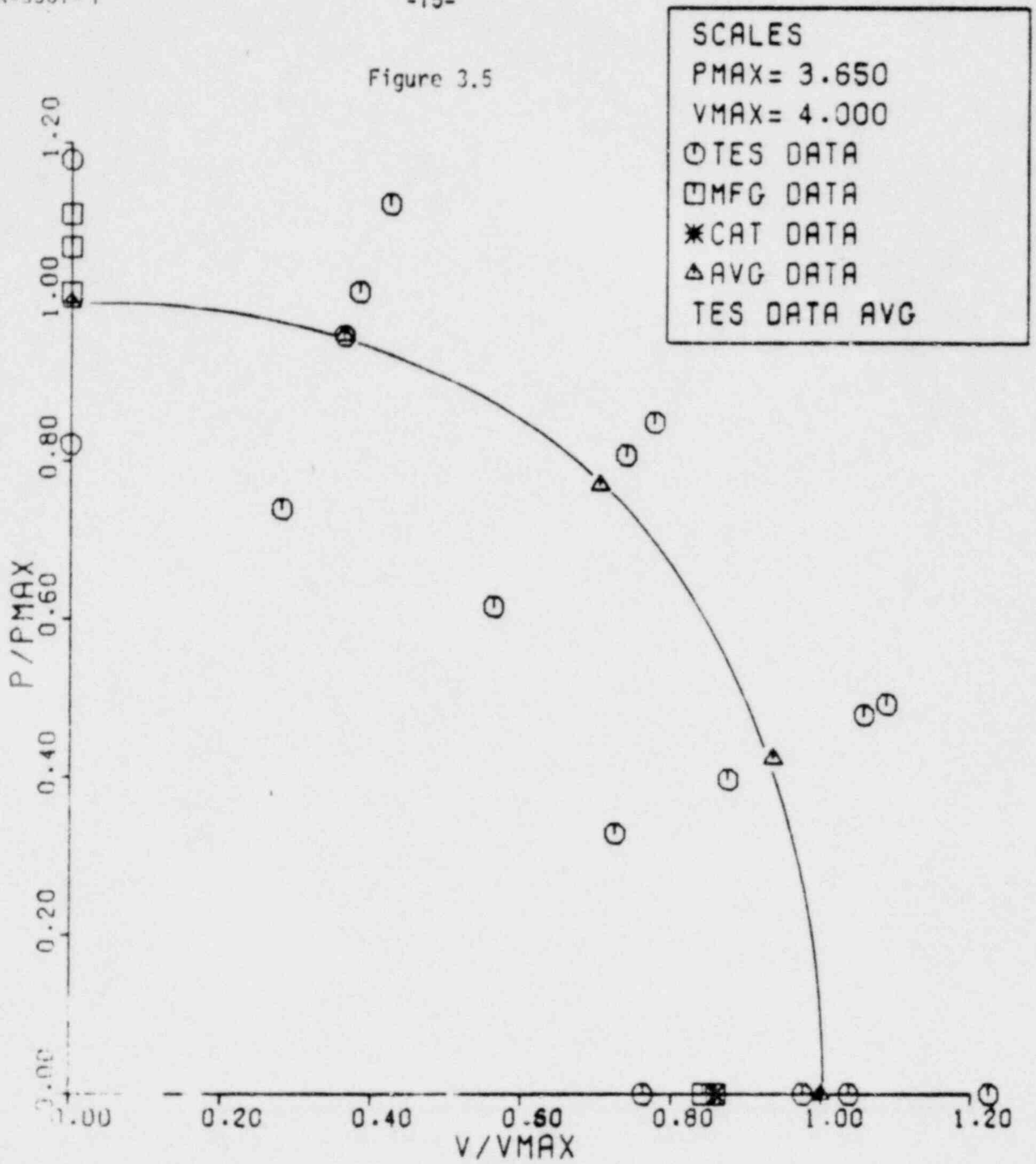
In all cases except all shear, the tensile load was plotted against the tensile (vertical) deflection as measured at the top of the bolt or stud. In the cases of all shear, the shear load was plotted against the shear (horizontal) deflection as measured at the aft end of the shoe (simulated base plate).

3.7 Shear-Tension Interaction Curves

Figure 3.5 through 3.50 represent shear-tension interaction curves for the bolt types and sizes shown in Table 3.1.

The ordinate represents the average tensile load divided by the ultimate tensile load and the abscissa represents the average shear load divided by the ultimate shear load. Tests performed by TES are shown as ○ on the curves; the average value of these tests, which are used as curve plot points, are shown as △ ; manufacturers catalogue data are shown as * ; additional manufacturer's data, independent data and FFTF data are shown as □. The manufacturer's data is not used in arriving at the average values but is given for comparison purposes.

Figure 3.5



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-3-79

BOLT MFG PHILLIPS BOLT TYPE SELF DRILL

BOLT DIA .375 EMBEDMENT NOM

TEST NO. 314-319.324-333.17-11.323

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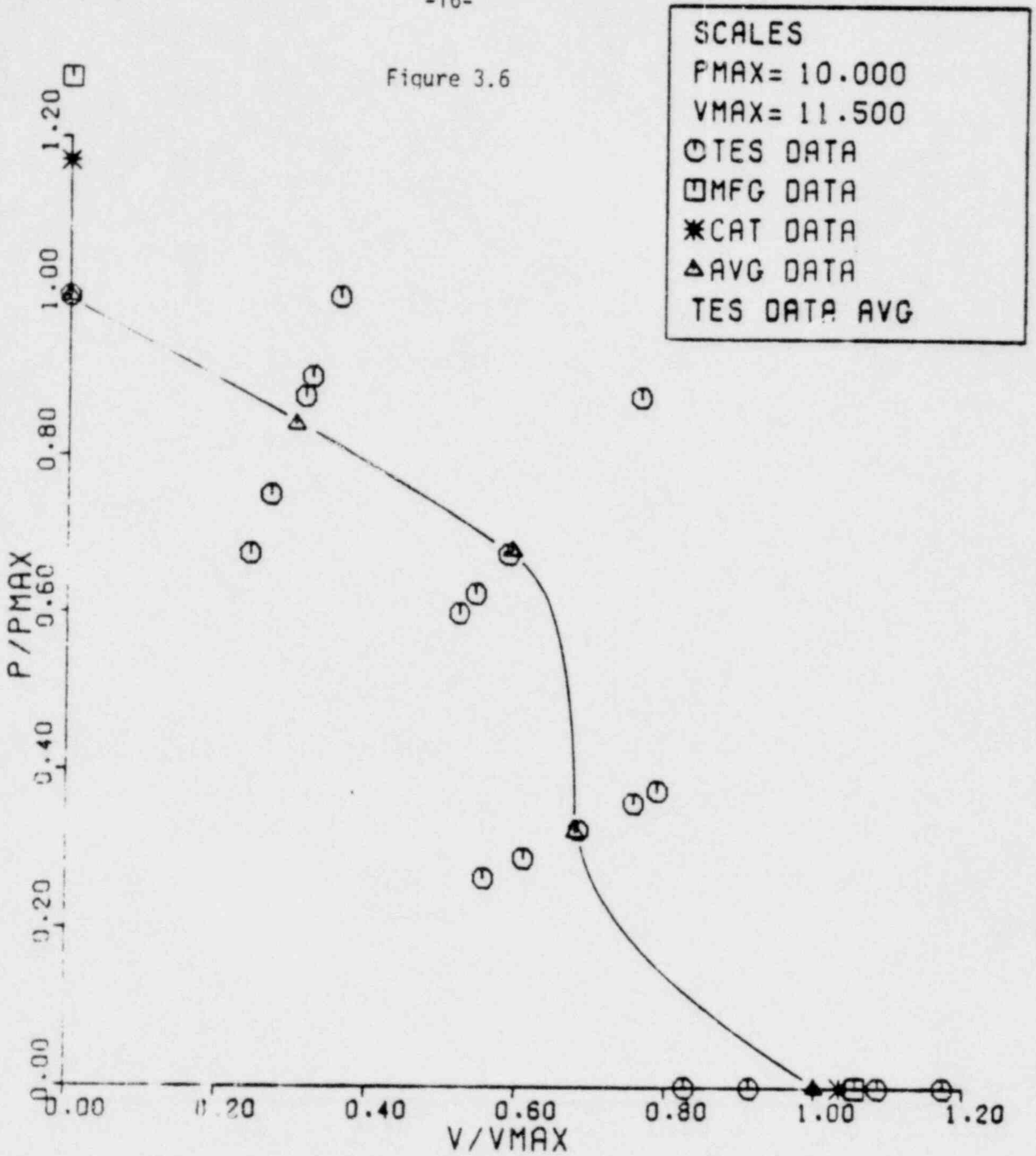
Figure 3.6



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-30-7

BOLT MFG PHILLIPS

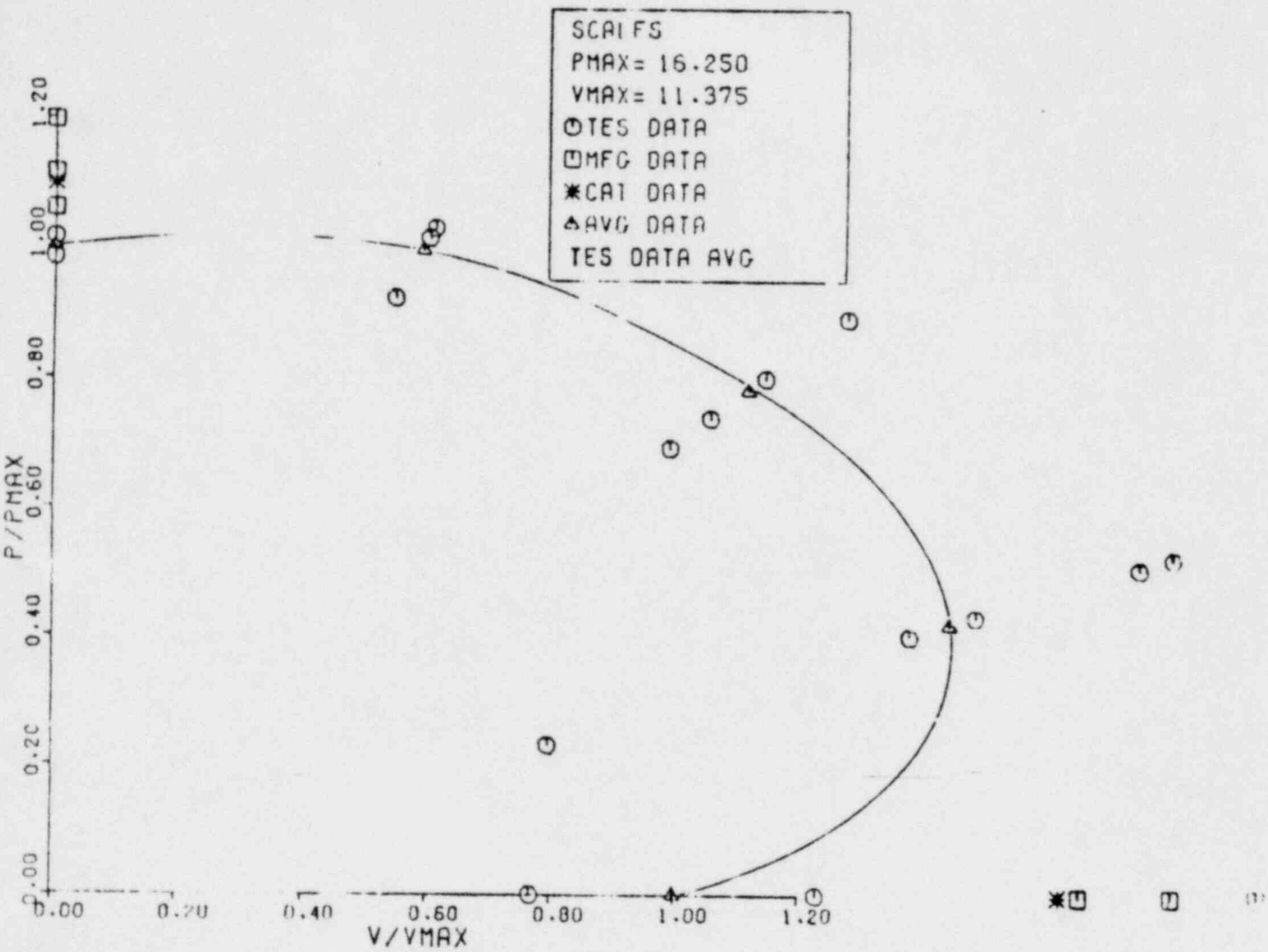
BOLT TYPE SELF-DRILL

BOLT DIA .625

EMBEDMENT NOM

TEST NO. 218-222,233-240,344,525-529,648,18-16,18

Figure 3.7



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-9-79

BOLT MFG PHILLIPS BOLT TYPE SELF DRILL

BOLT DIA .875 EMBEDMENT NOM

TEST NO. 452-456.462-471.17-9.25-12

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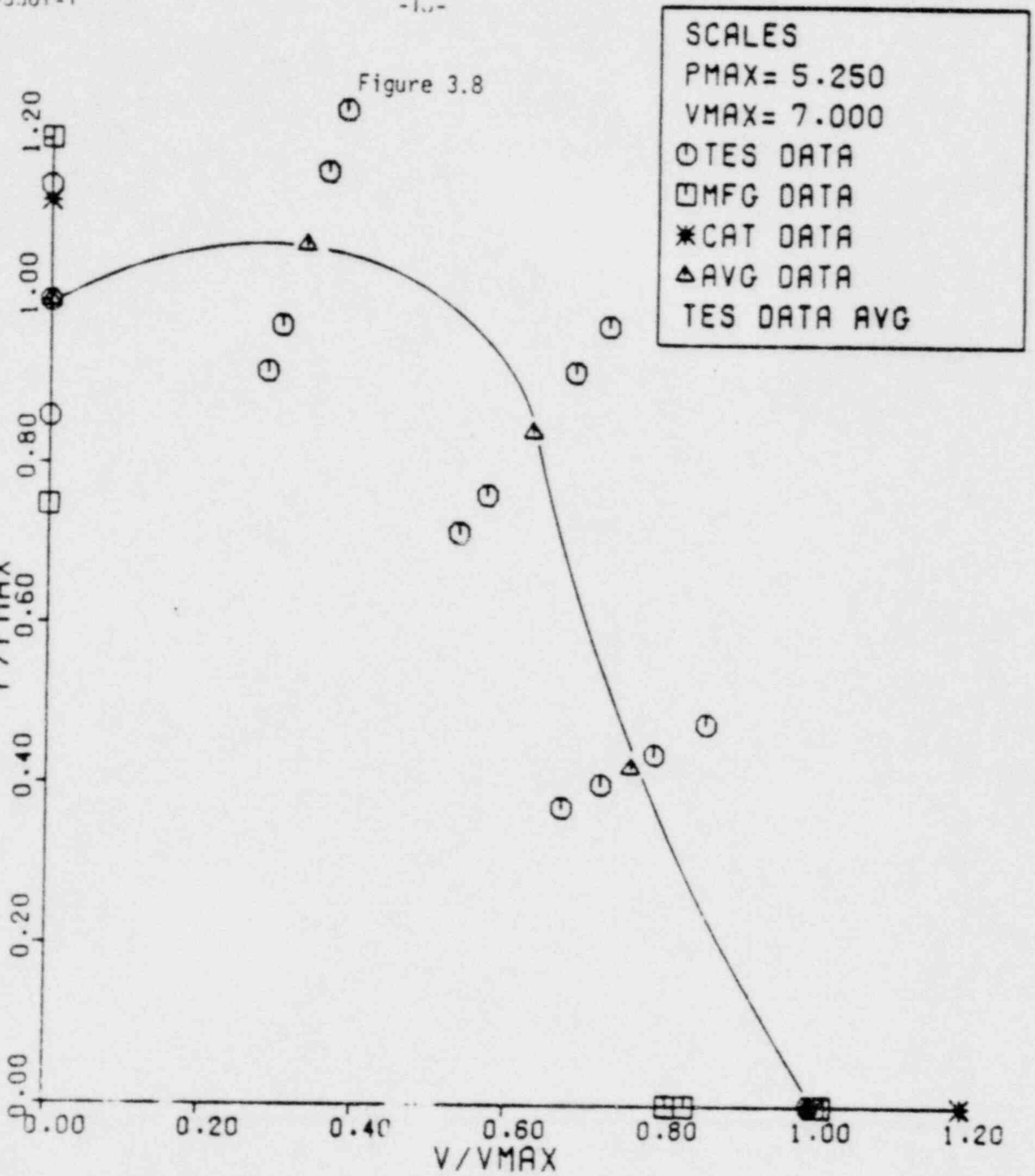
Figure 3.8



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-2-79

BOLT MFG PHILLIPS

BOLT TYPE WEDGE

BOLT DIA .50

EMBEDMENT 2.125

TEST NO. 243-252.262-264.18-4

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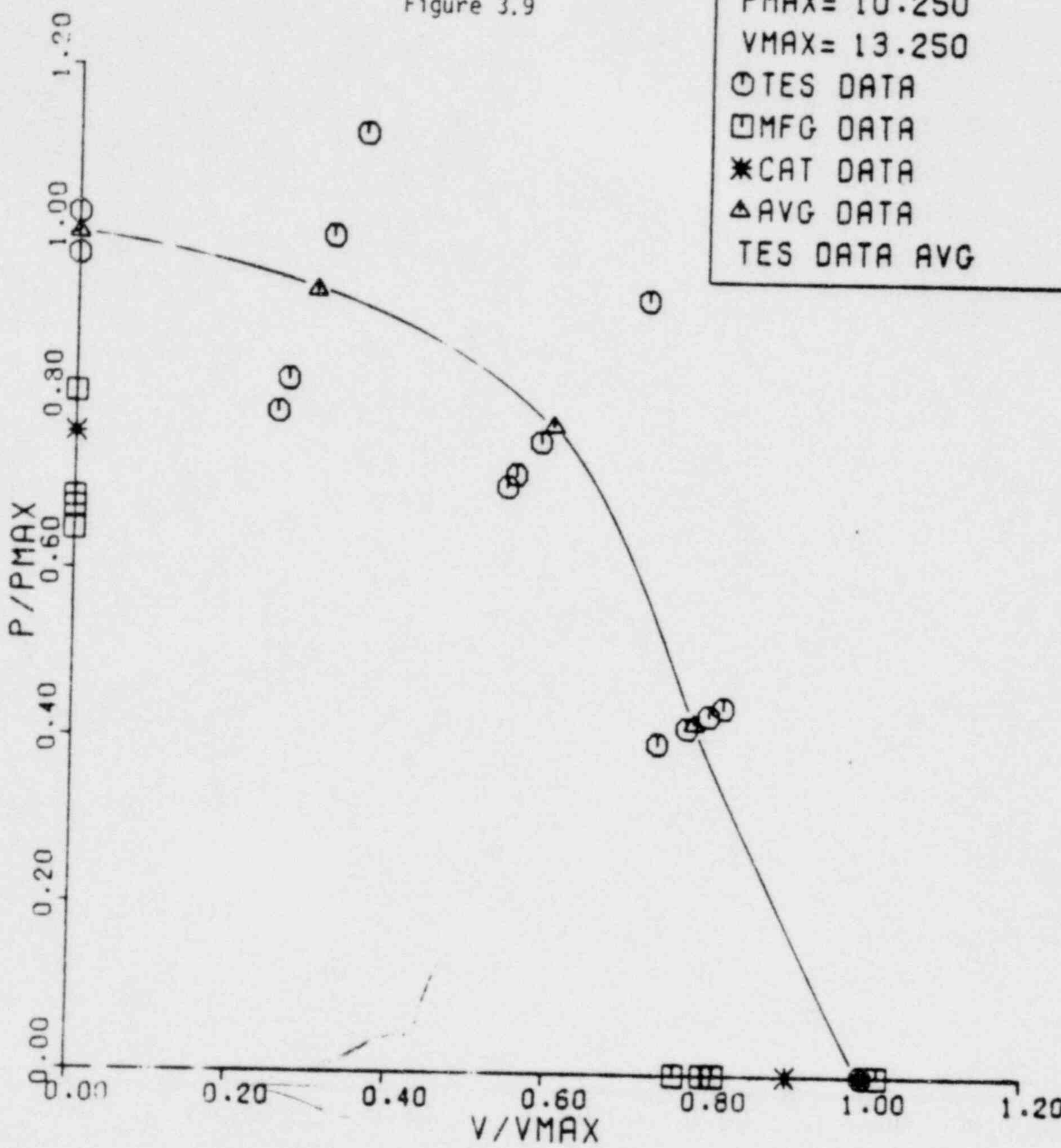
Figure 3.9



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-29-7

BOLT MFG PHILLIPS

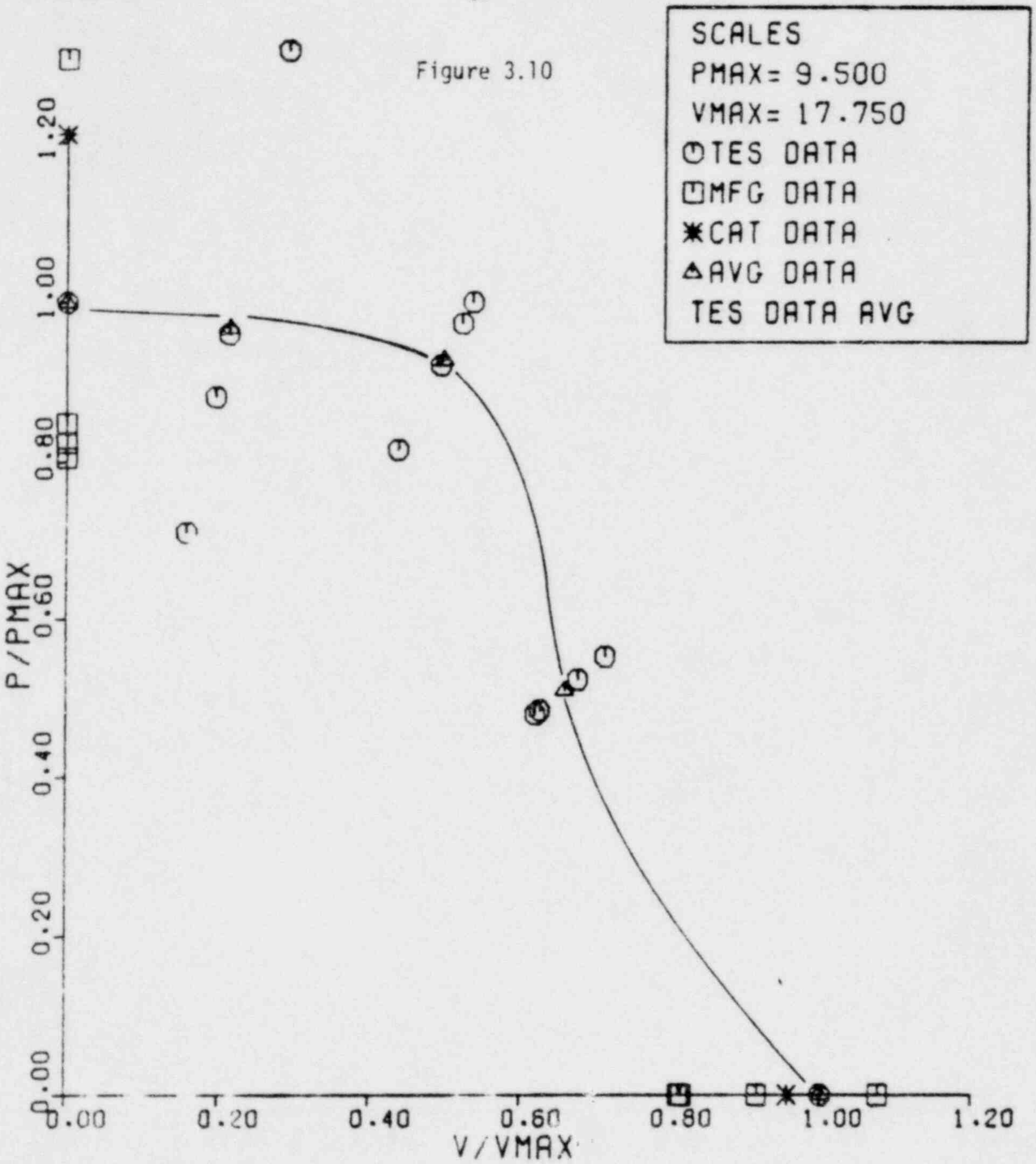
BOLT TYPE WEDGE

BOLT DIA .625

EMBEDMENT 2.750

TEST NO. 134-141,150-155,24-4

Figure 3.10



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-29-79

BOLT MFG PHILLIPS

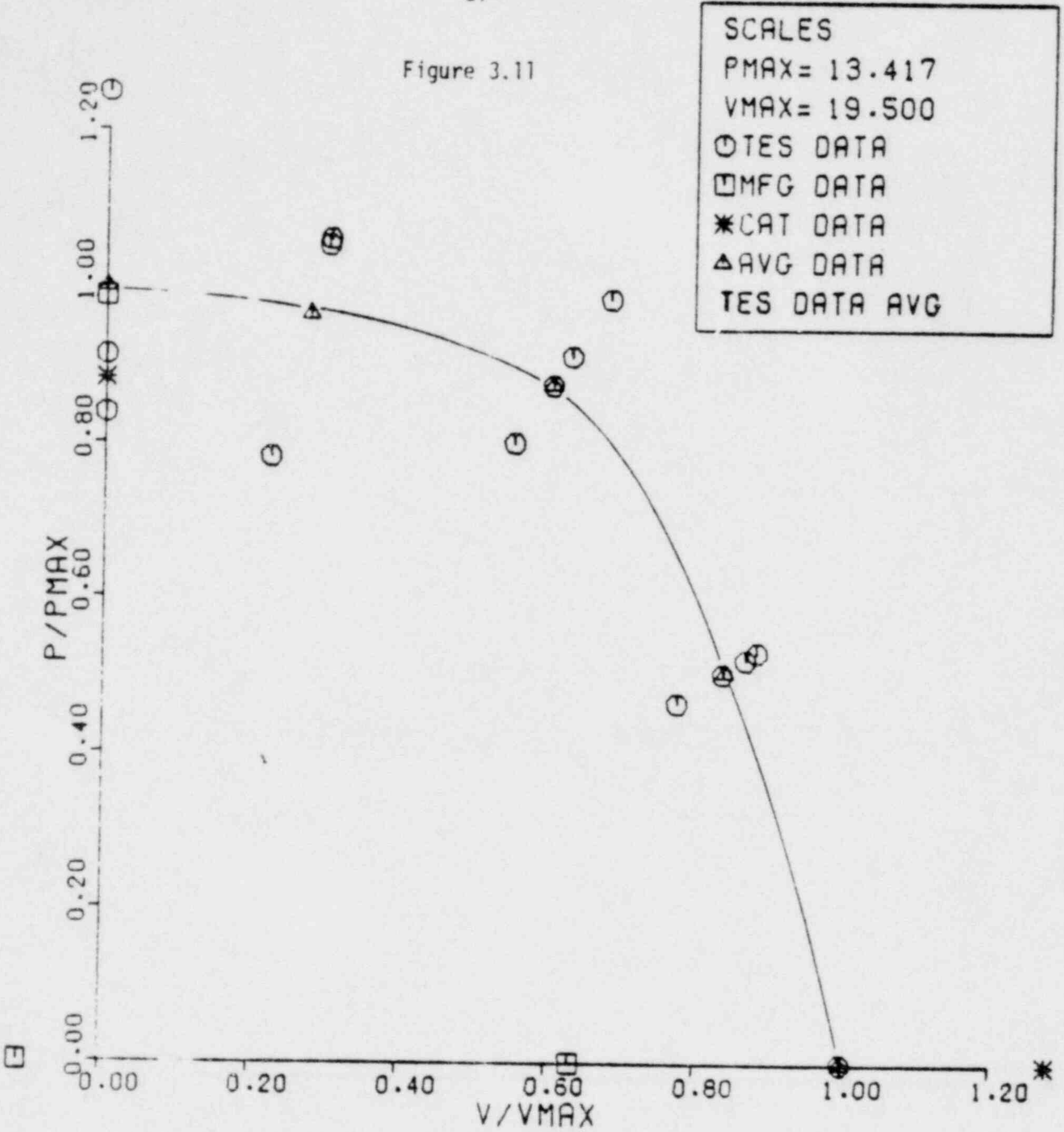
BOLT TYPE WEDGE

BOLT D.A .750

EMBEDMENT 3.250

TEST NO. 144-149.156-163

Figure 3.11



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-30-79

BOLT MFG PHILLIPS

BOLT TYPE WEDGE

BOLT DIA .875

EMBEDMENT 3.750

TEST NO. 196-201.211-214.642.23-9.23-8

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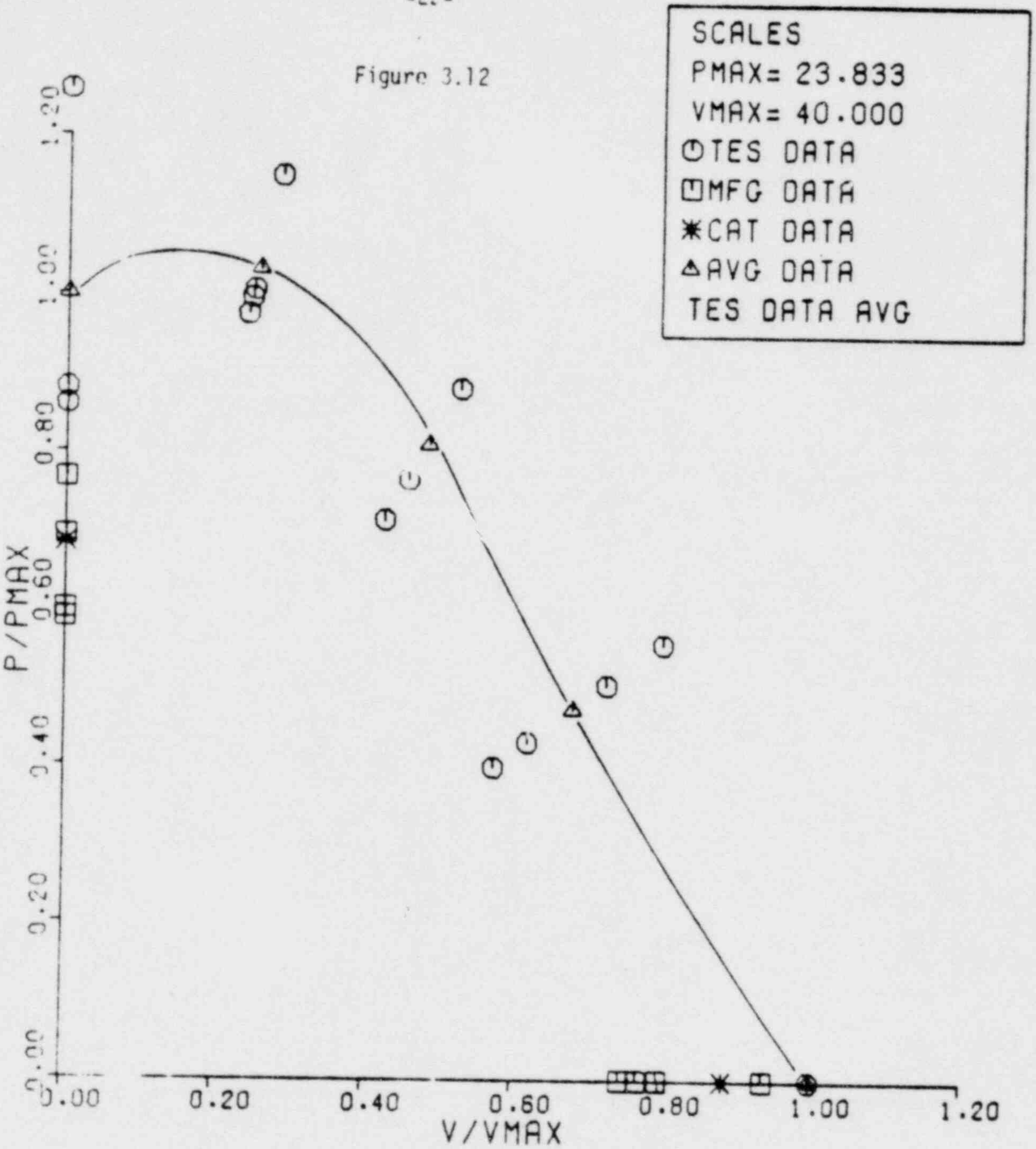
Figure 3.12



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-10-79

BOLT MFG PHILLIPS

BOLT TYPE WEDGE

BOLT DIA 1.0

EMBEDMENT 5.50

TEST NO. 472.473.477-481.535-539.636.19-8.23-11

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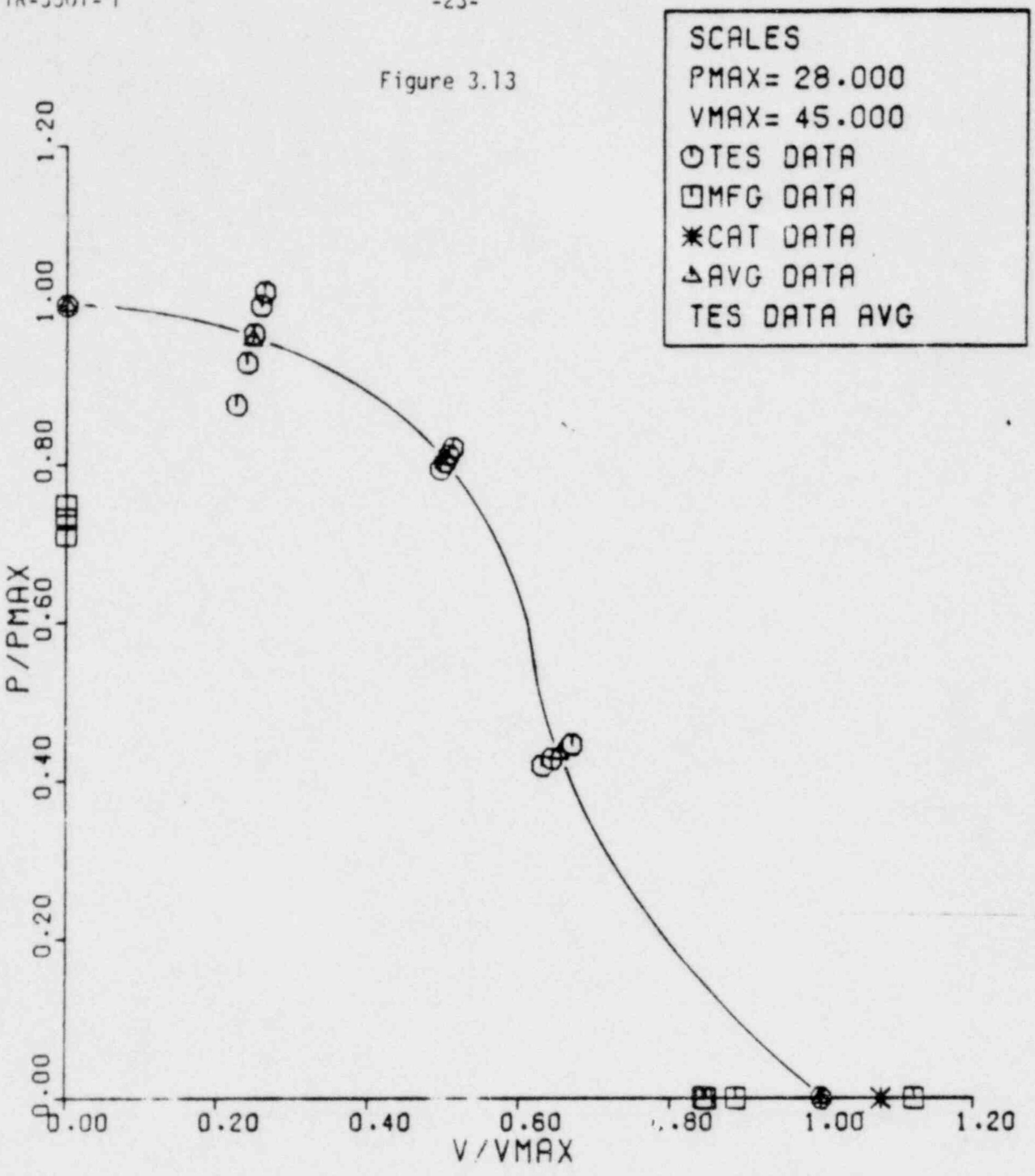
Figure 3.13



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-12-79

BOLT MFG PHILLIPS

BOLT TYPE WEDGE

BOLT DIA 1.250

EMBEDMENT 5.50

TEST NO. 588-590.599-605.613-615.618-620.19-6

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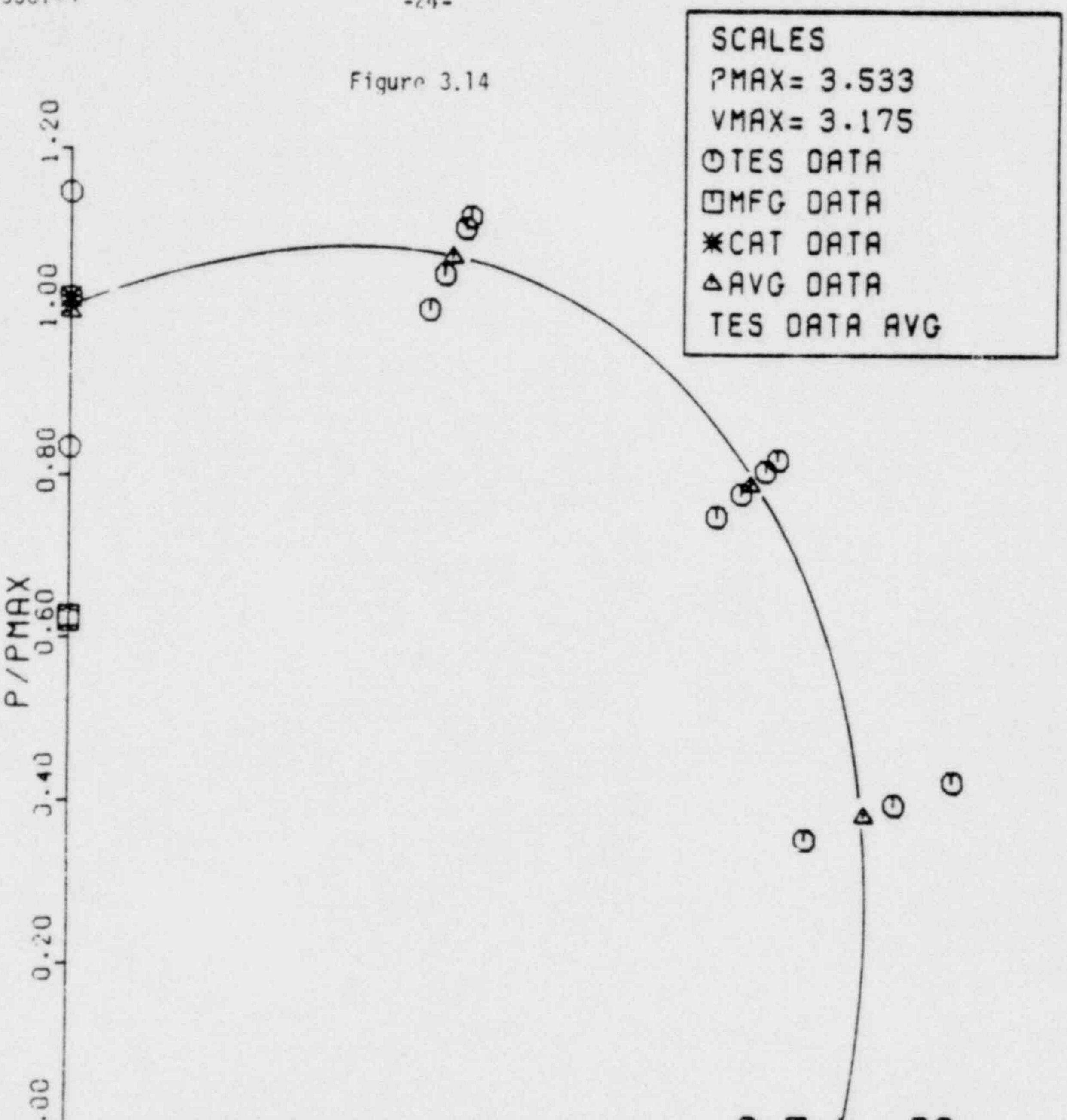
Figure 3.14



SHEAR-TENSION INTERACTION DIAGRAM

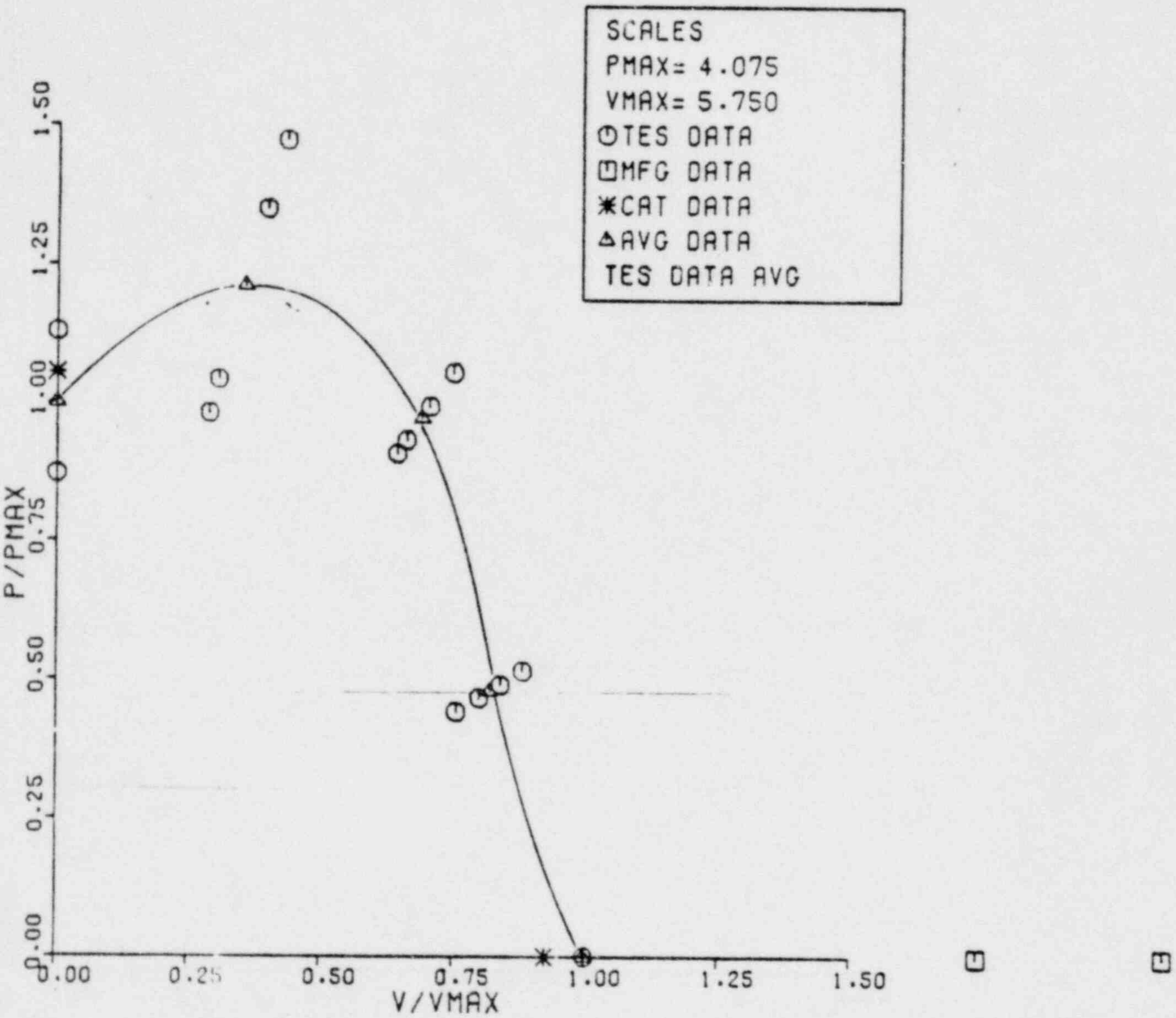
DATE 7-2-79

BOLT MFG PHILLIPS | BOLT TYPE SLEEVE

BOLT DIA .375 | EMBEDMENT 2.625

TEST NO. 267-273.284-290.638-640

Figure 3.15



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-5-79

BOLT MFG PHILLIPS

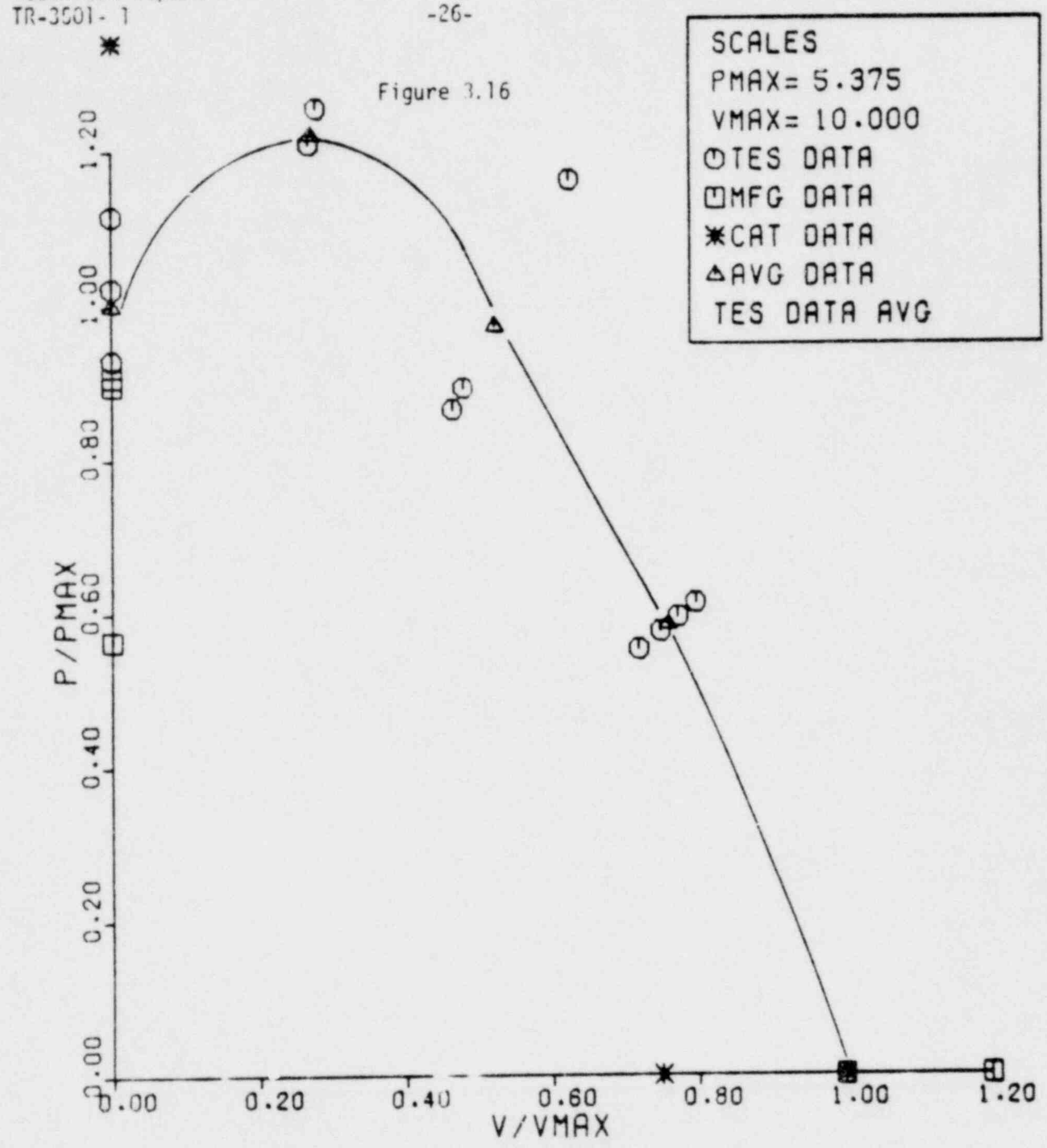
BOLT TYPE SLEEVE

BOLT DIA .5

EMBEDMENT 2.125

TEST NO. 274-283.365-368.18-3

Figure 3.16



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-2-79

BOLT MFG PHILLIPS

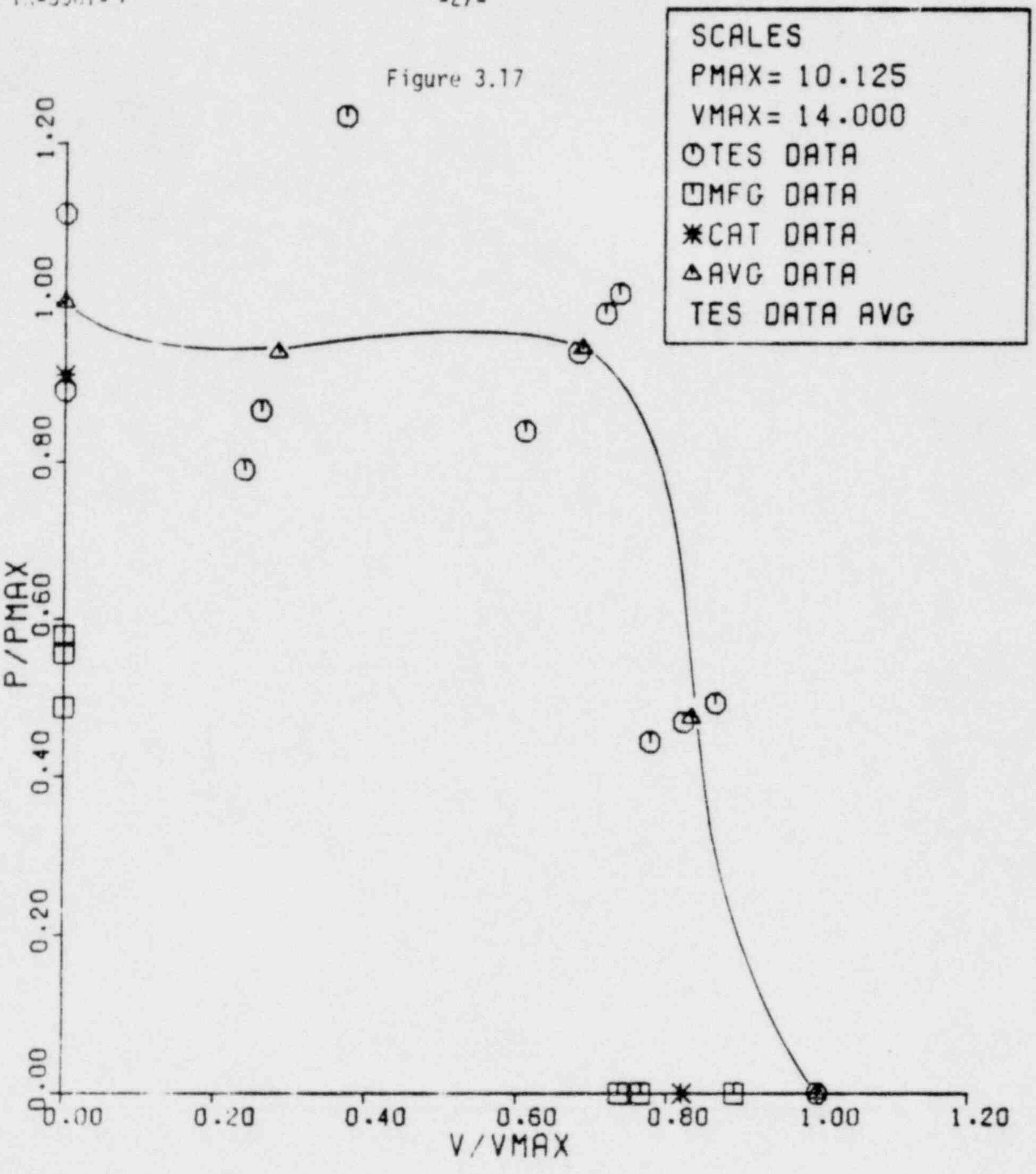
BOLT TYPE SLEEVE

BOLT DIA .625

EMBEDMENT 2.250

TEST NO. 291-298,308-313,17-6,24-3,24-2

Figure 3.17



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-10-79

BOLT MFG PHILLIPS

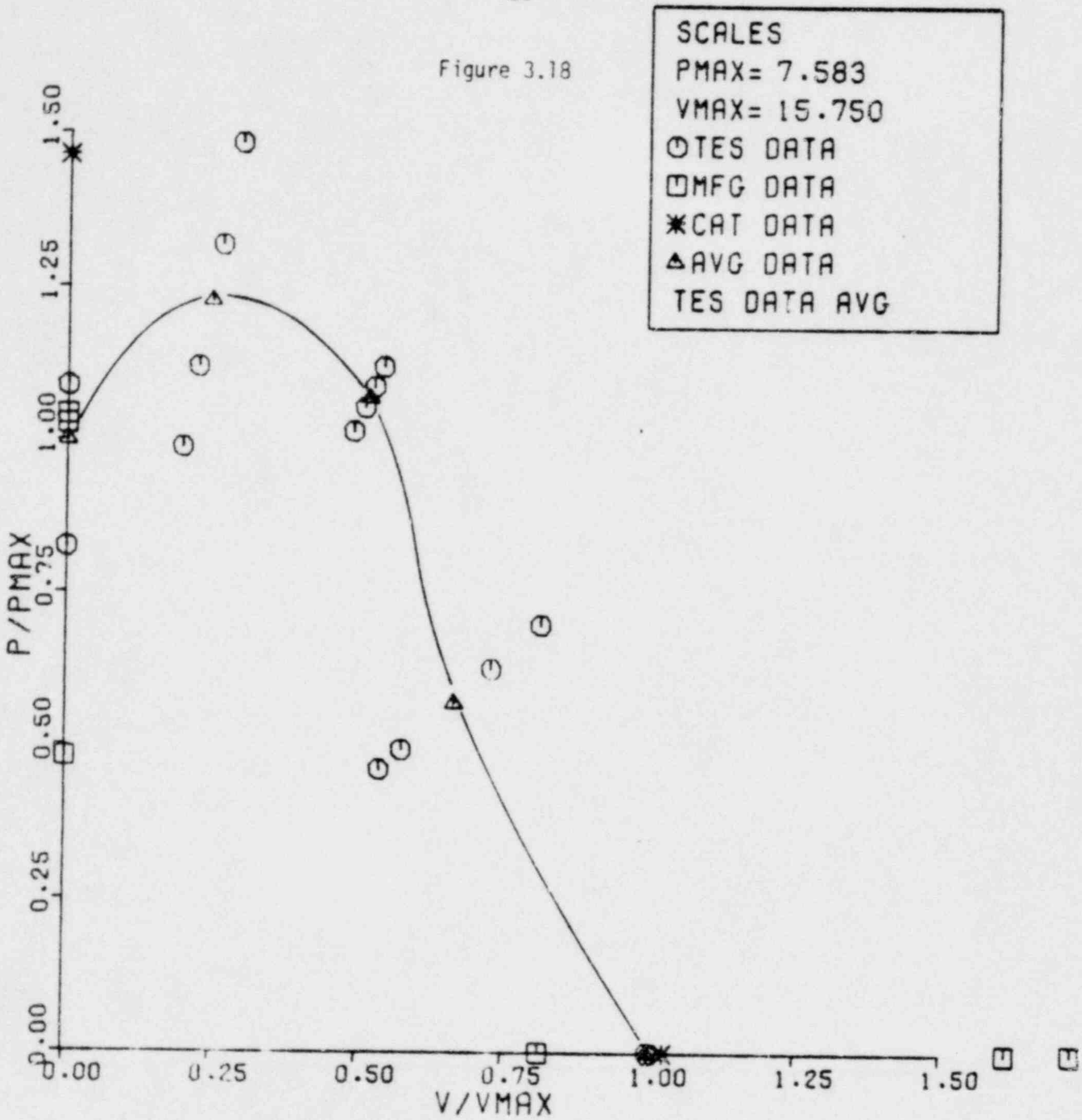
BOLT TYPE SLEEVE

BOLT DIA .750

EMBEDMENT 3.250

TEST NO. 502-508.541-545.625.641.23-7

Figure 3.18



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-10-79

BOLT MFG PHILLIPS

BOLT TYPE STUD-ANCHOR

BOLT DIA .750

EMBEDMENT 3.0

TEST NO. 513-519,560-565,624,25-10

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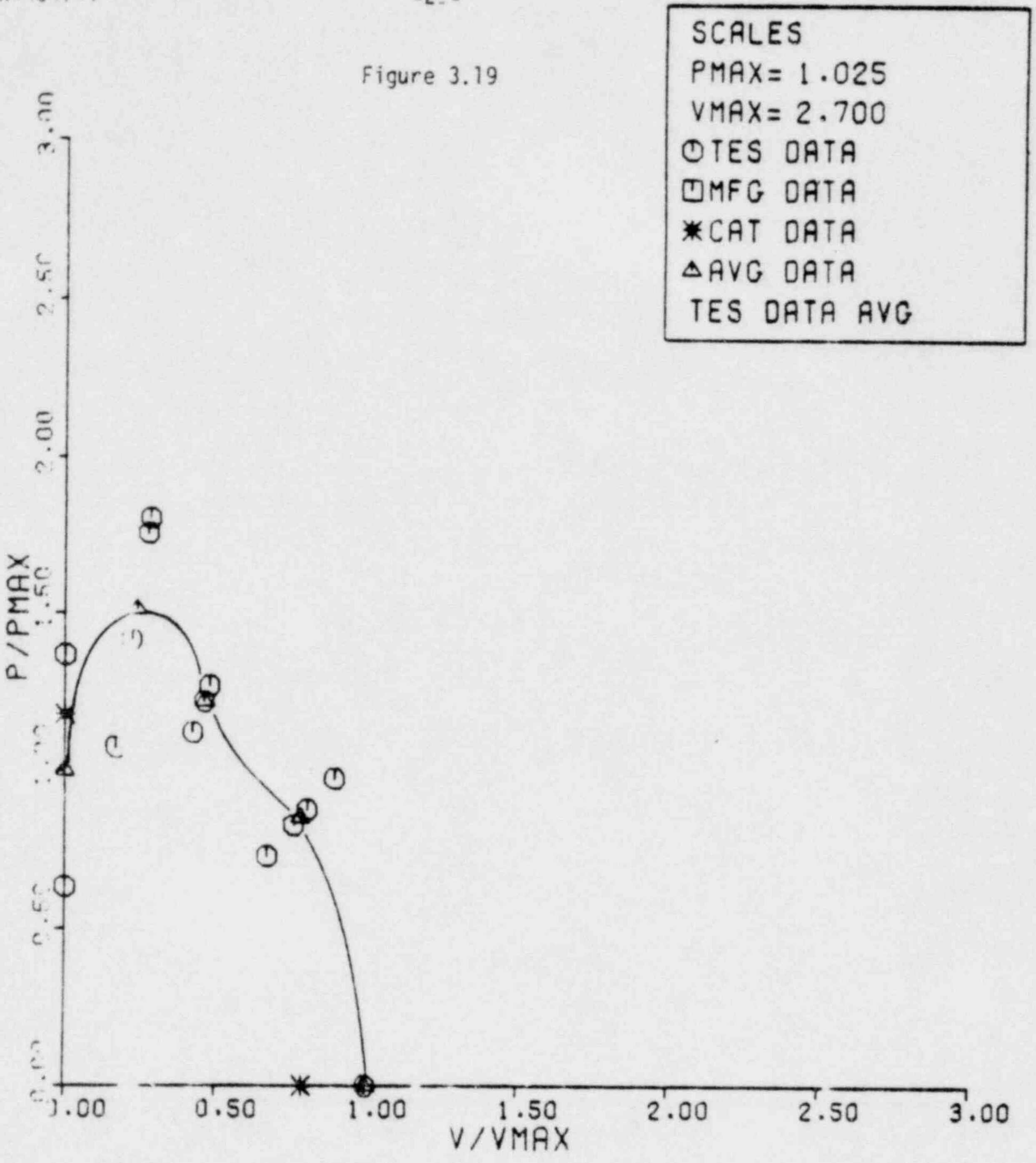
Figure 3.19



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-26-7

BOLT MFG HILTI

BOLT TYPE KWIK-BOLT

BOLT DIA .250

EMBEDMENT 1.125

TEST NO. 25-38.18-8

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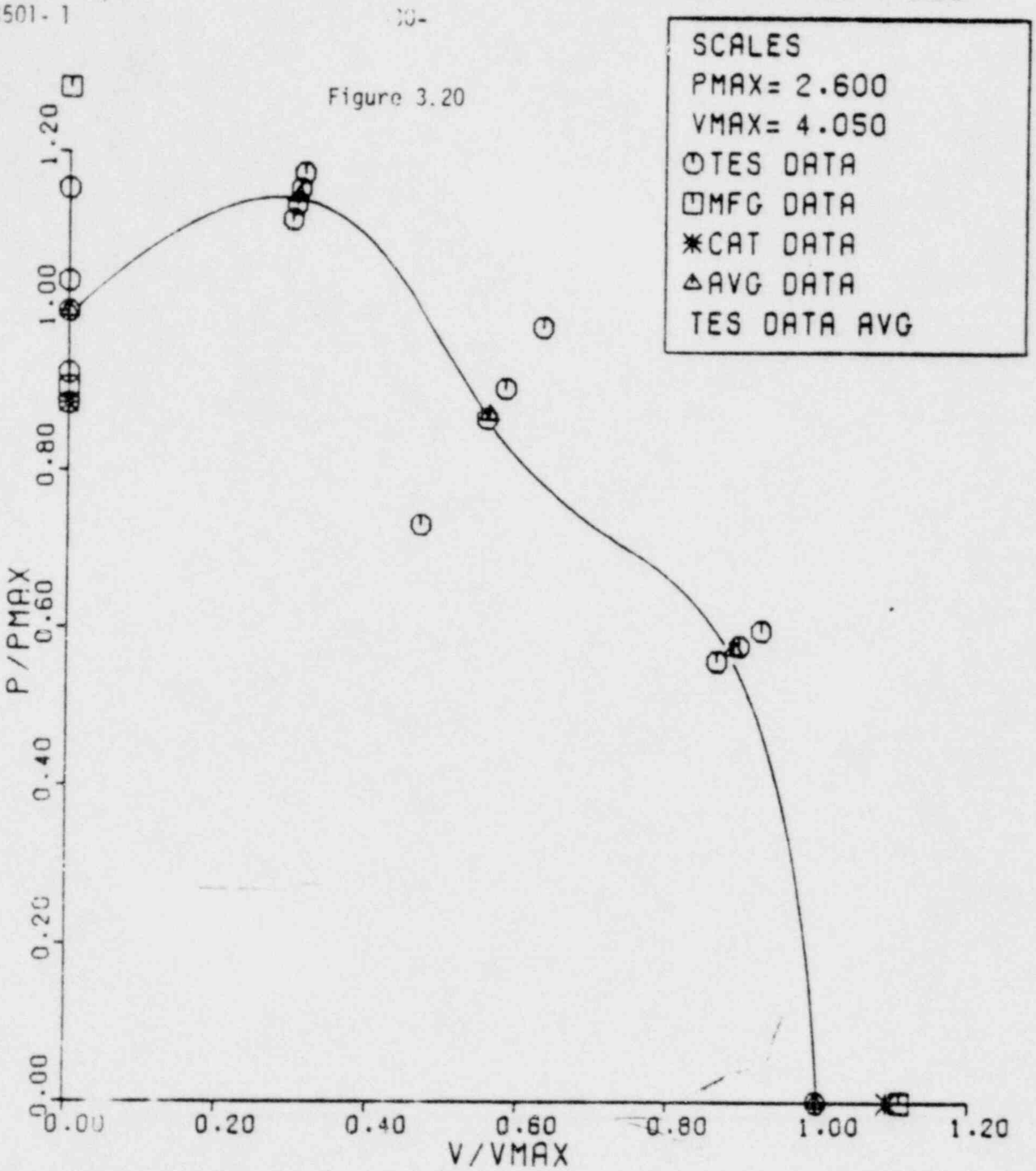
Figure 3.20



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-26-79

BOLT MFG HILTI

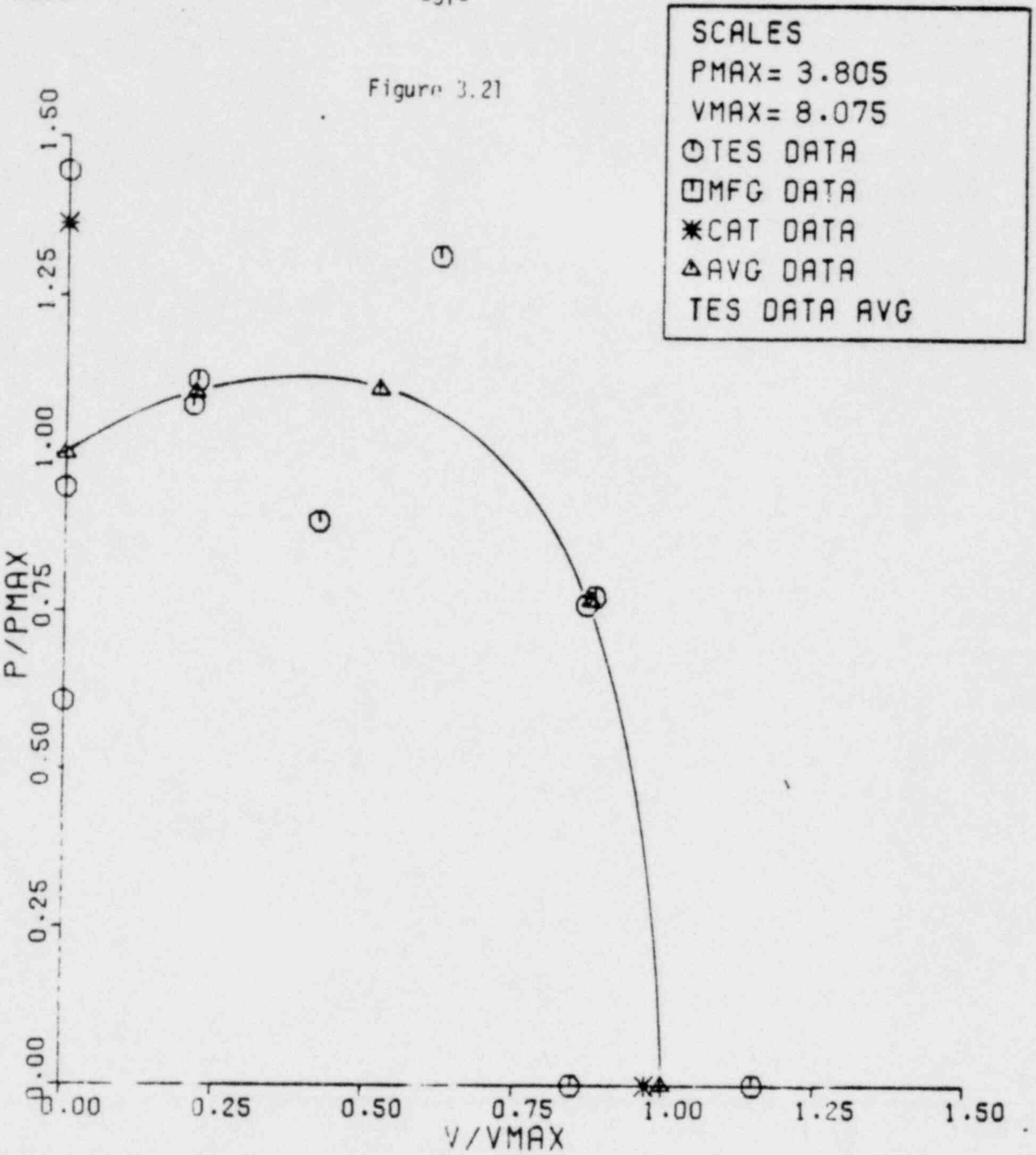
BOLT TYPE KWIK-BOLT

BOLT DIA .375

EMBEDMENT 1.625

TEST NO. 39-52.17-10.20-5.20-4.20-3.20-2

Figure 3.21



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-27-79

BOLT MFG HILTI

BOLT TYPE KWIK-BOLT

BOLT DIA .50

EMBEDMENT 2.25

TEST NO. 53.54.71-76.653.654.18-2

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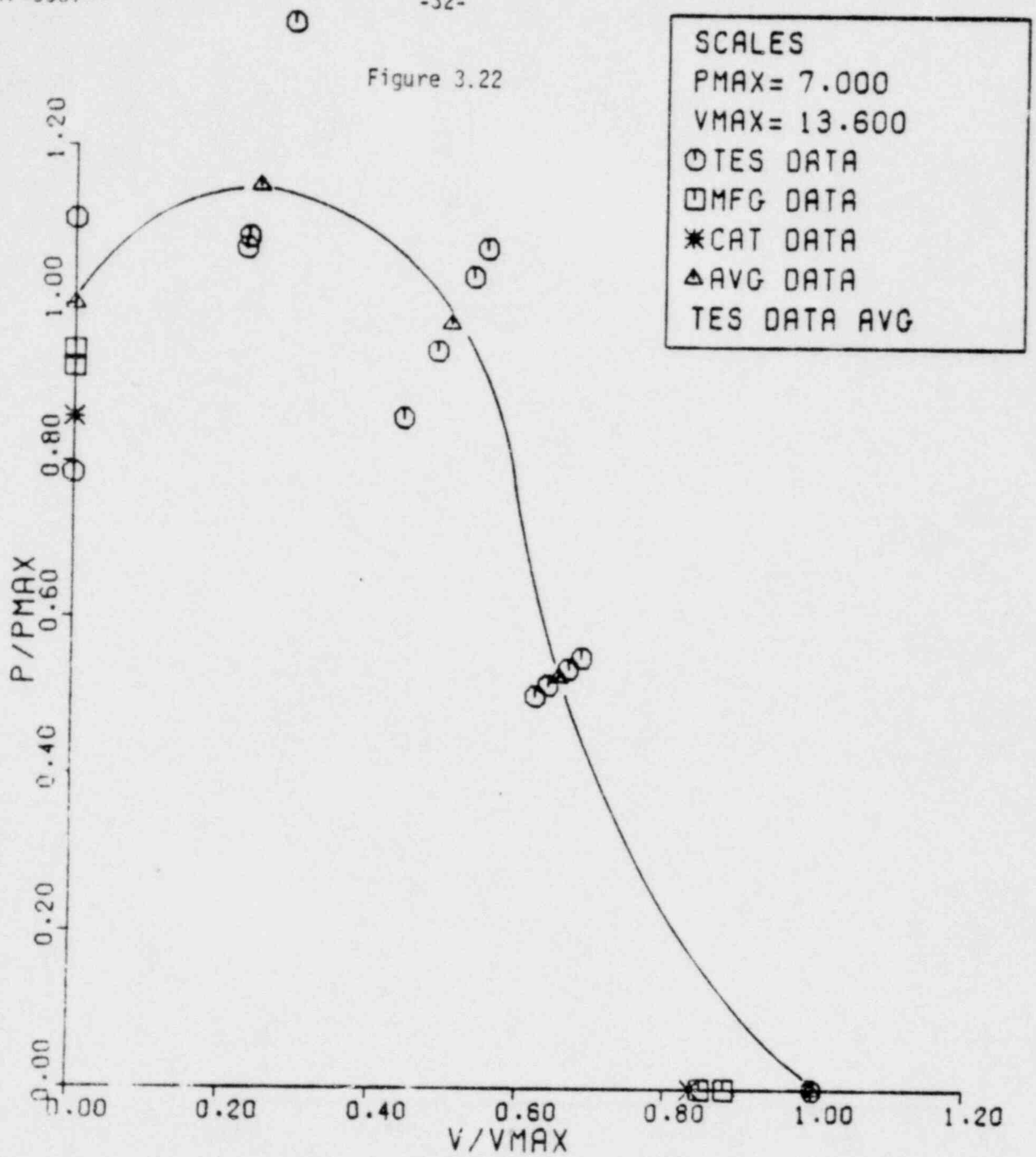
Figure 3.22



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-27-79

BOLT MFG HILTI

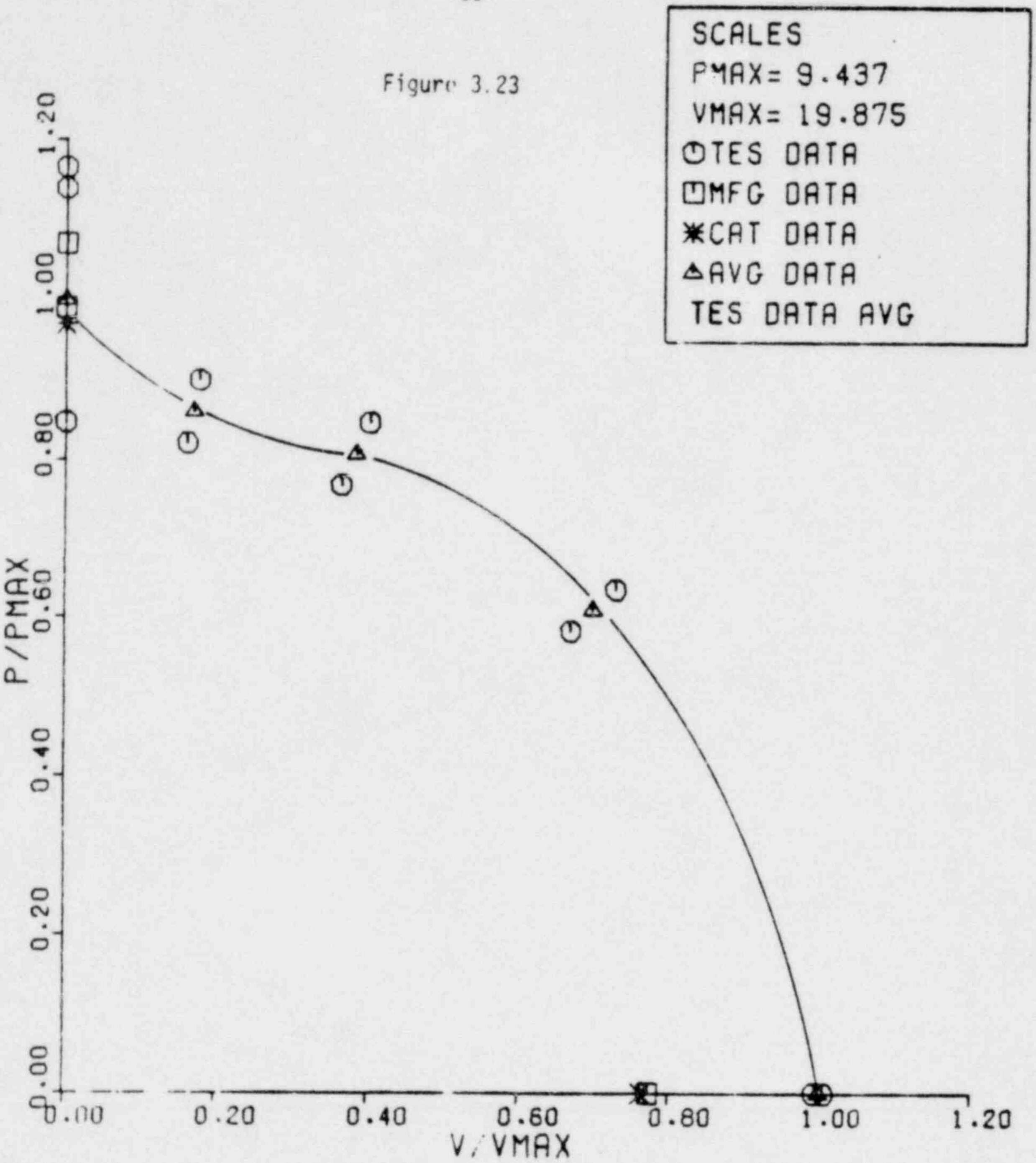
BOLT TYPE KWIK-BOLT

BOLT DIA .625

EMBEDMENT 2.75

TEST NO. SS-68.18-7.24-5

Figure 3.23



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-22-79

BOLT MFG HILTI

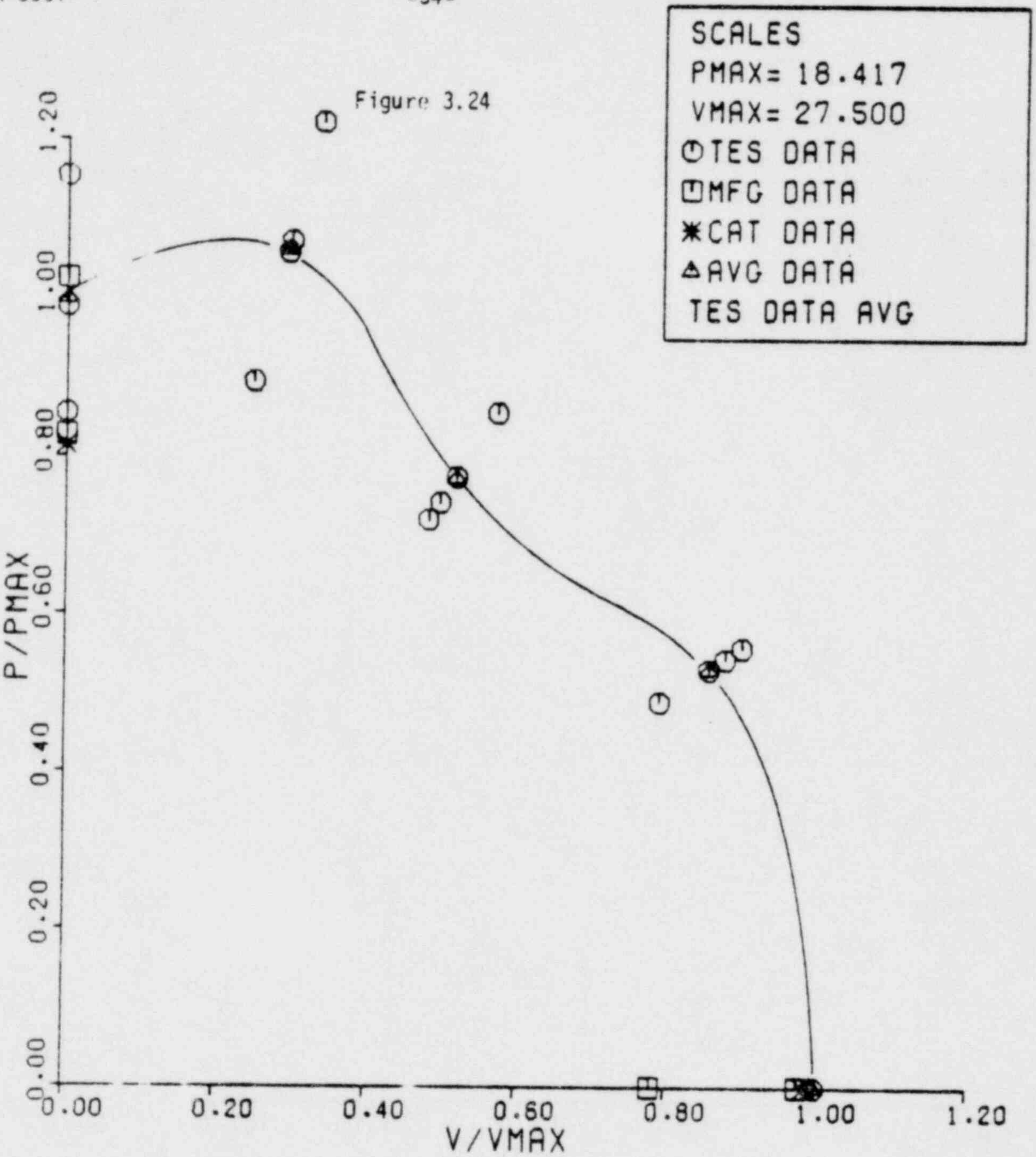
BOLT TYPE KWIK-BOLT

BOLT DIA .750

EMBEDMENT 3.250

TEST NO. 1-8.25-11

Figure 3.24



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-26-79

BOLT MFG HILTI

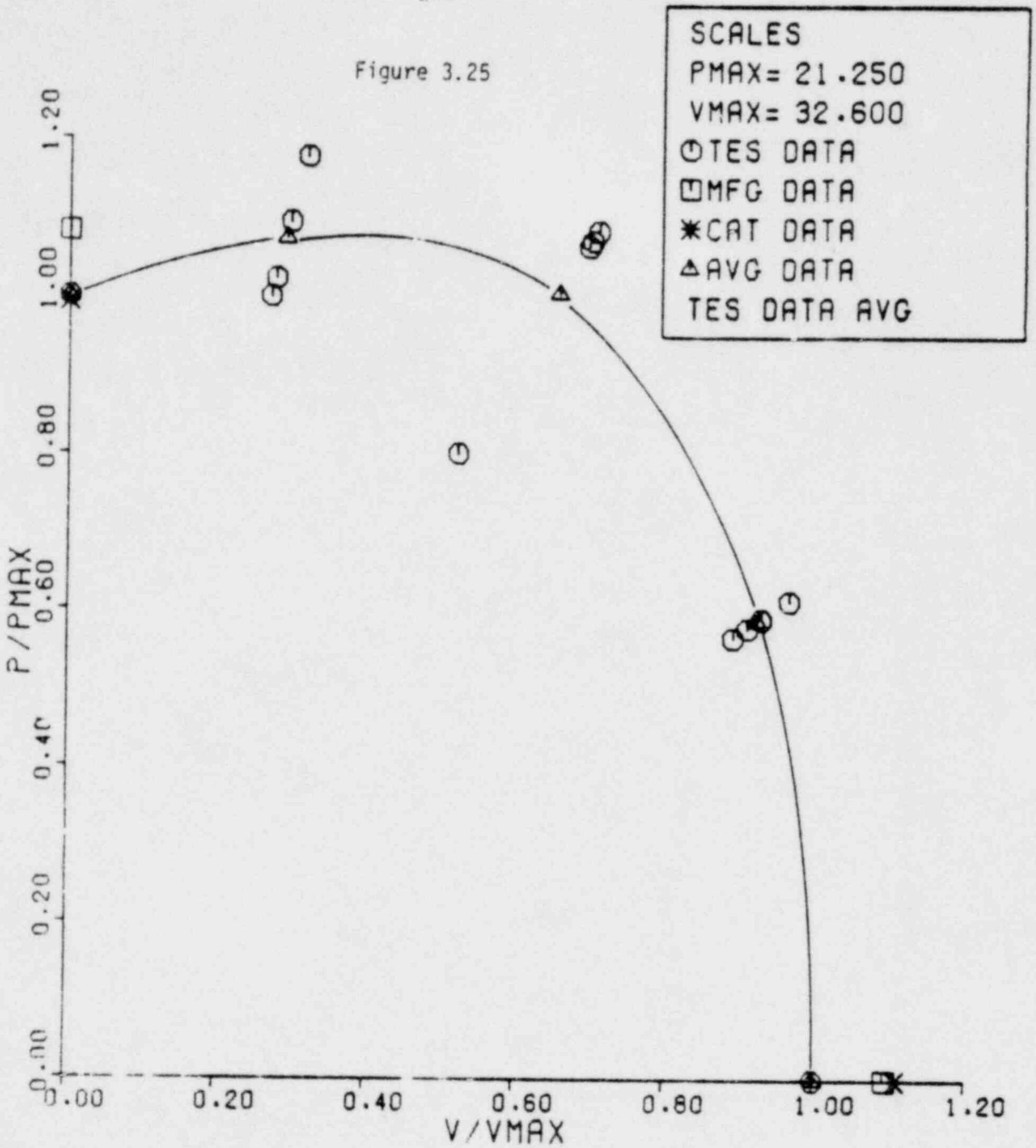
BOLT TYPE KWIK-BOLT

BOLT DIA 1.0

EMBEDMENT 5.50

TEST NO. 11-24.19-2.24-7

Figure 3.25



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-27-7

BOLT MFG HILTI

BOLT TYPE KWIK-BOLT

BOLT DIA 1.250

EMBEDMENT 5.50

TEST NO. 81-88.585-587.621-623

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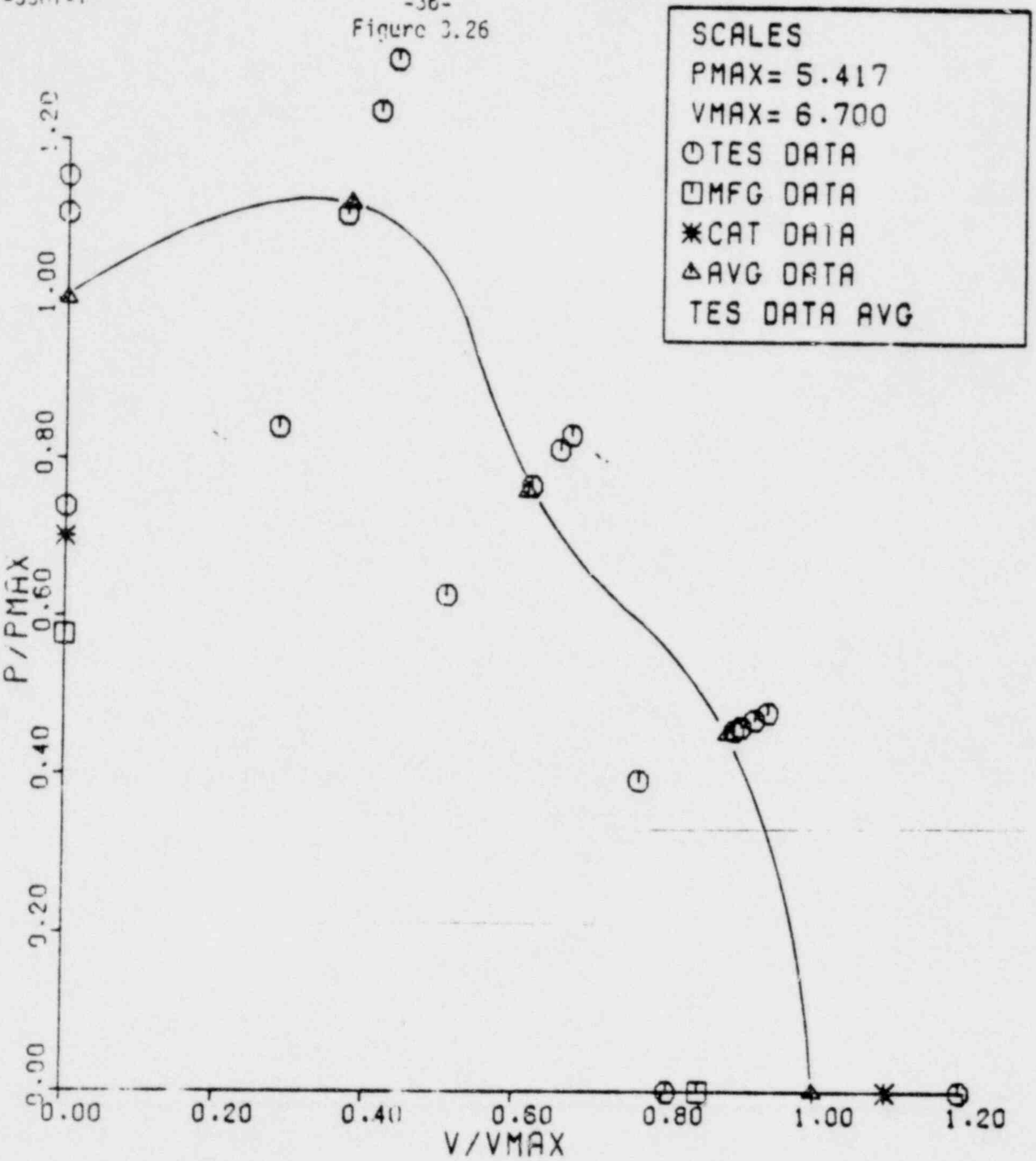
Figure 3.26



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-30-79

BOLT MFG USM-MOLLY

BOLT TYPE PARABOLT

BOLT DIA .50

EMBEDMENT 2.250

TEST NO. 202-210,215-217,646,647,651,652,18-10,18

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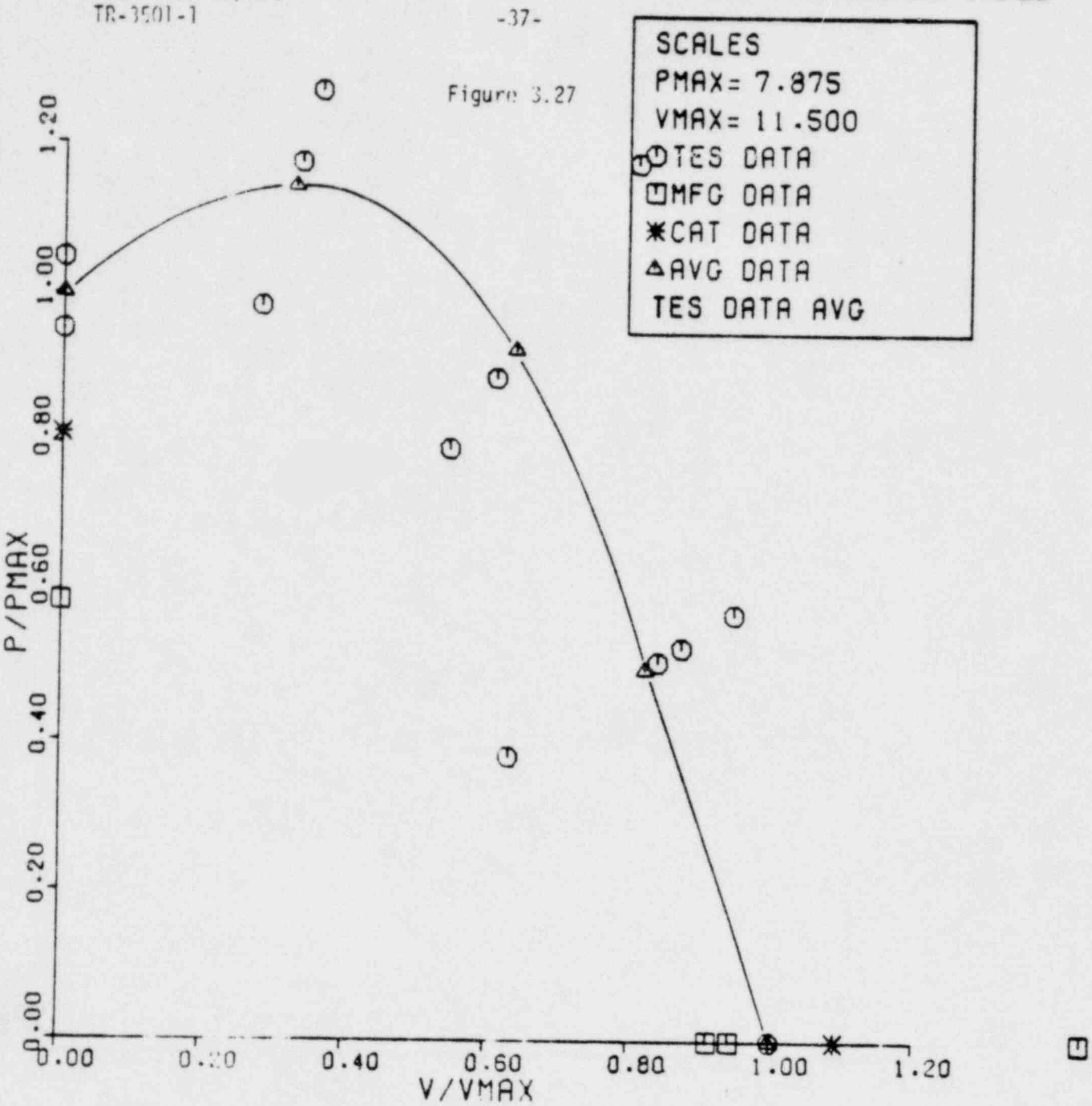
Figure 3.27



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-7-79

BOLT MFG USM-MOLLY

BOLT TYPE PARA BOLT

BOLT DIA .625

EMBEDMENT 2.75

TEST NO. 253-261.265-266.446-449.19-3

Figure 5.8

Wide Flange Column Full Model

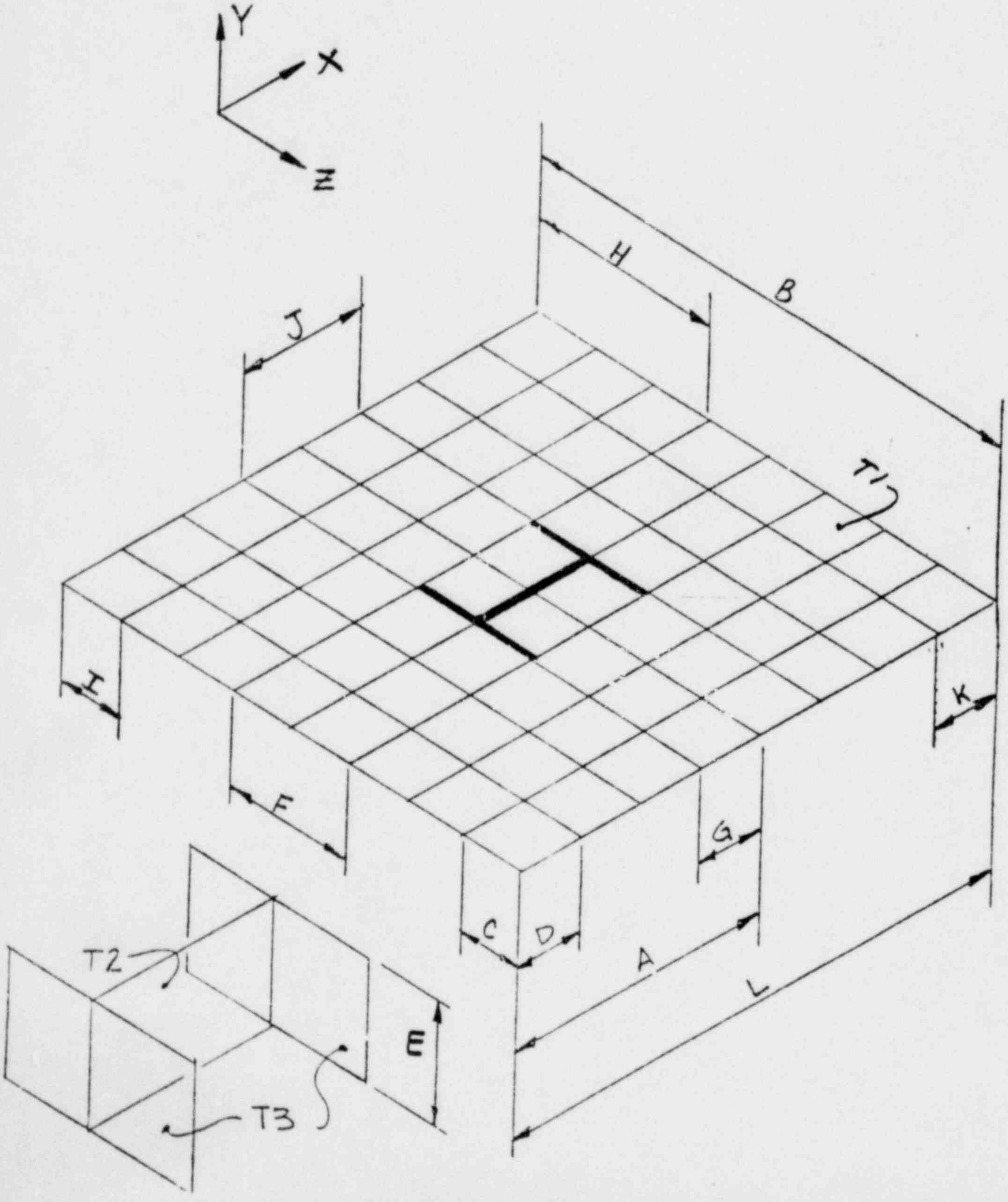
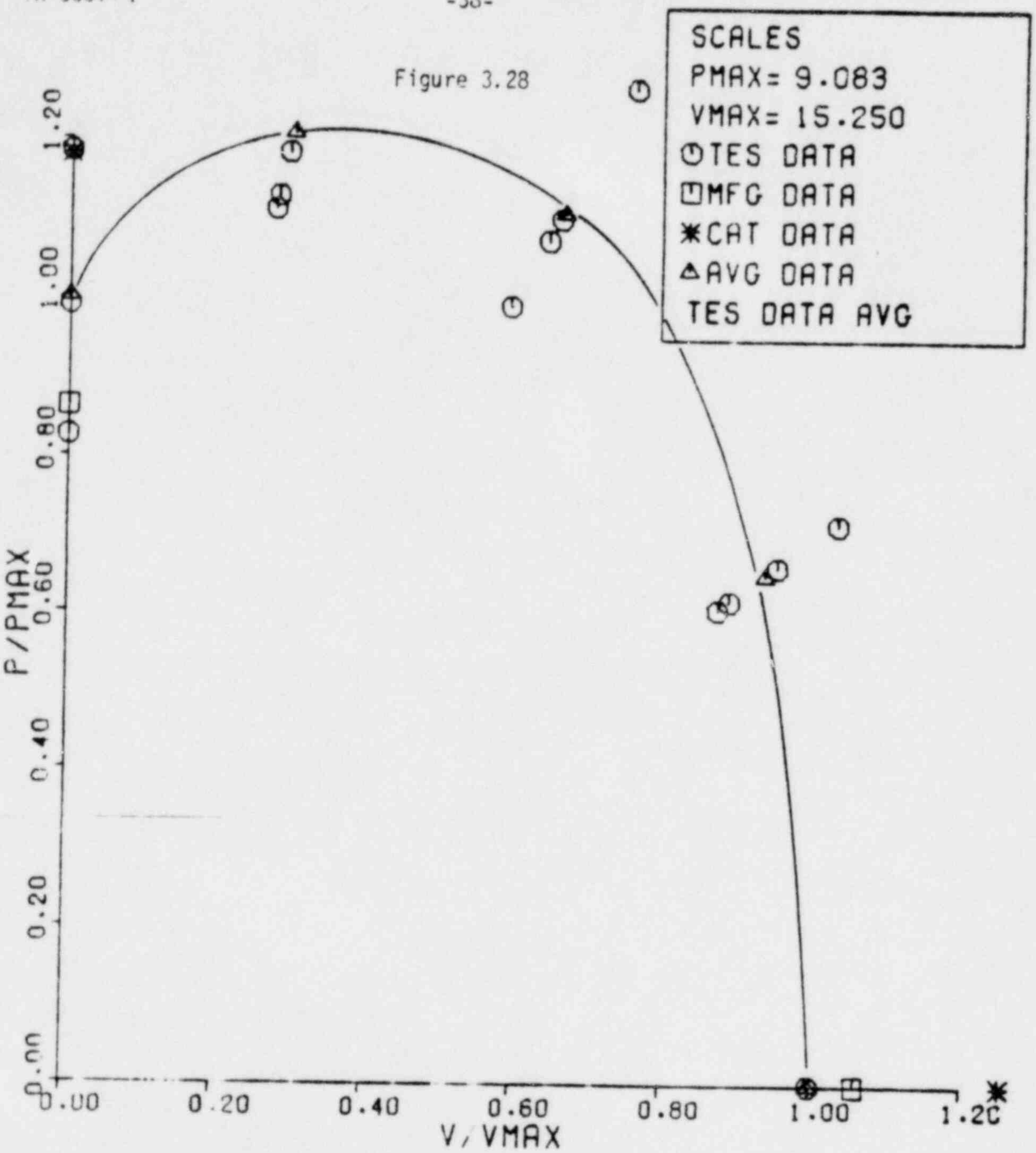


Figure 3.28



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-11-79

BOLT MFG USM-MOLLY

BOLT TYPE PARABOLT

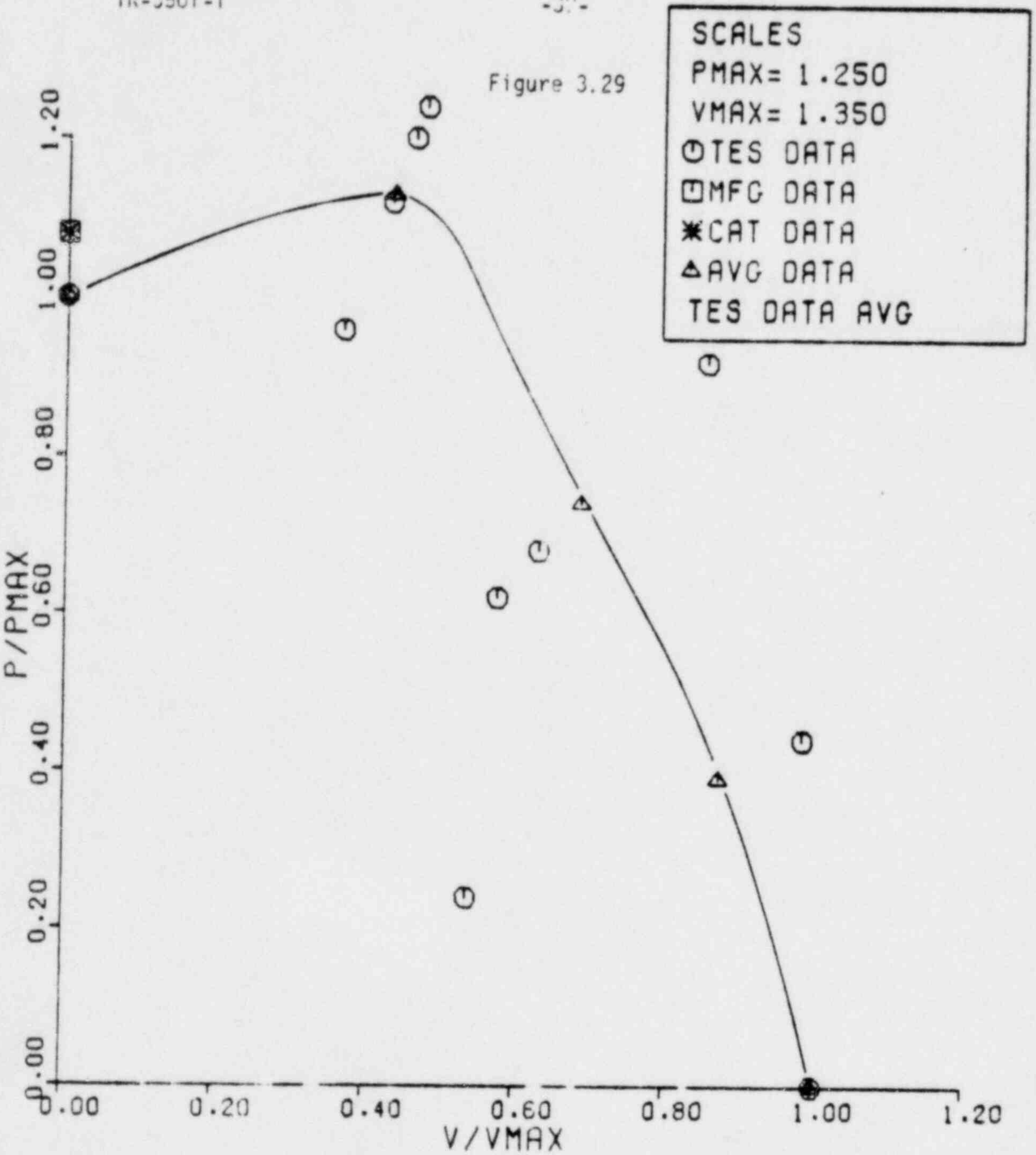
BOLT DIA .750

EMBEDMENT 3.250

TEST NO. 566-579.23-6.23-5

TELEDYNE ENGINEERING SERVICES

Figure 3.29



SHEAR TENSION INTERACTION DIAGRAM

DATE 6-29-7

BOLT MFG WEJ-IT

BOLT TYPE STUD

BOLT DIA .250

EMBEDMENT 1.125

TEST NO. 77-8).186-195

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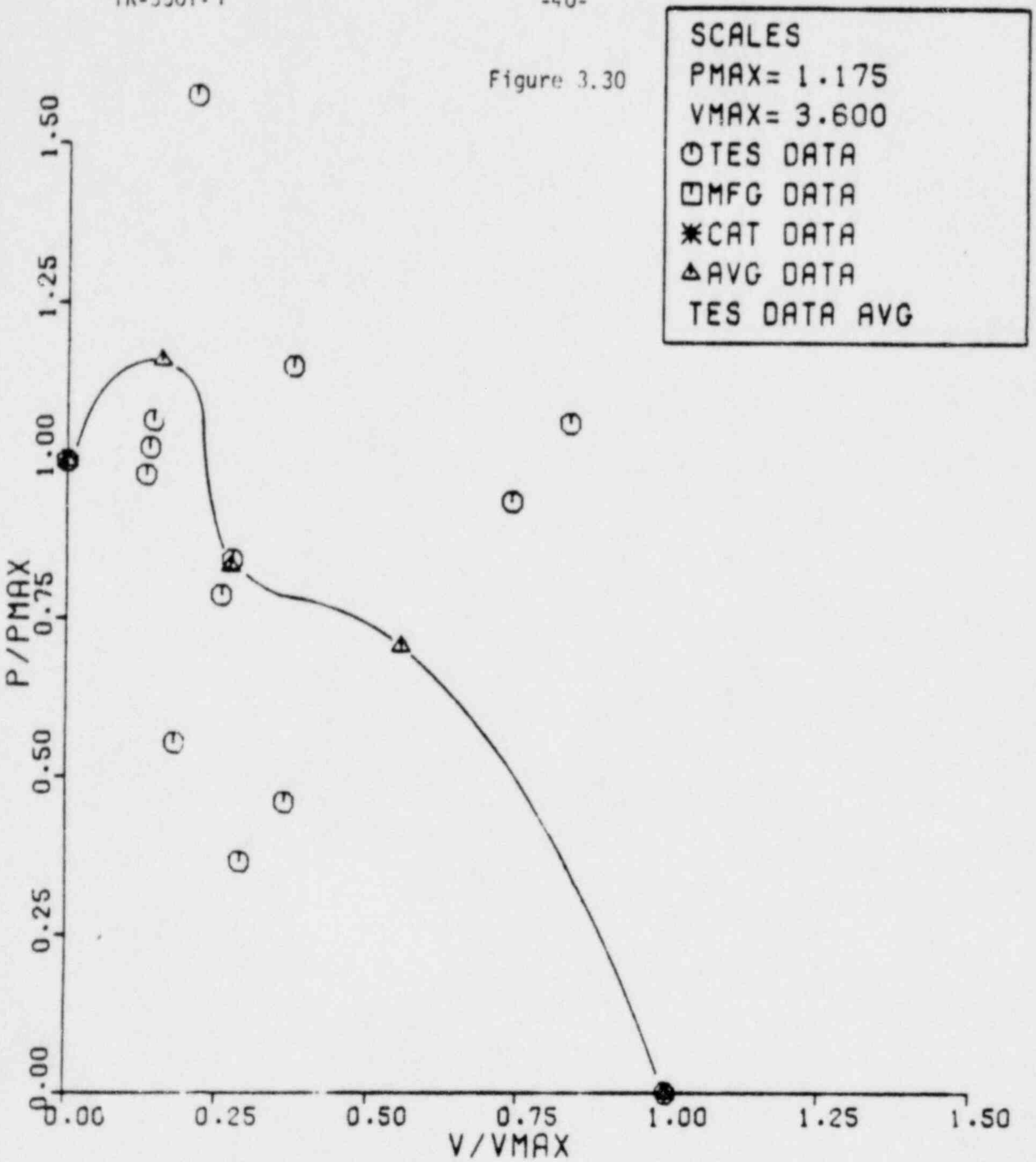
Figure 3.30



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-30-7

BOLT MFG WEJ-IT

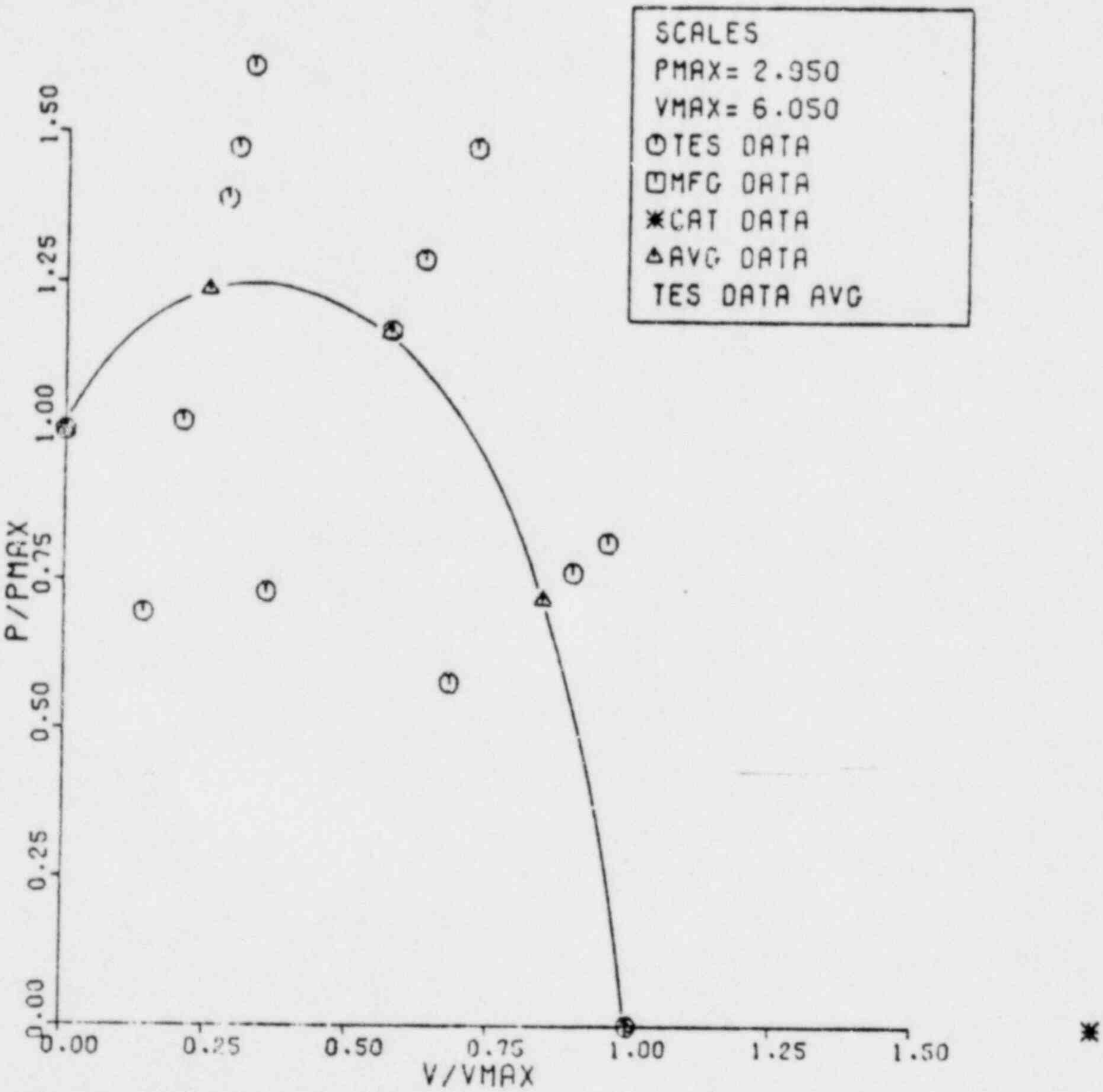
BOLT TYPE STUD

BOLT DIA .5

EMBEDMENT 2.0

TEST NO. 223-232.241.242.342.343

Figure 3.31



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-29-79

BOLT MFG WEJ-IT   BOLT TYPE STUD

BOLT DIA .625   EMBEDMENT 2.0

TEST NO. 90-99.164-167.643

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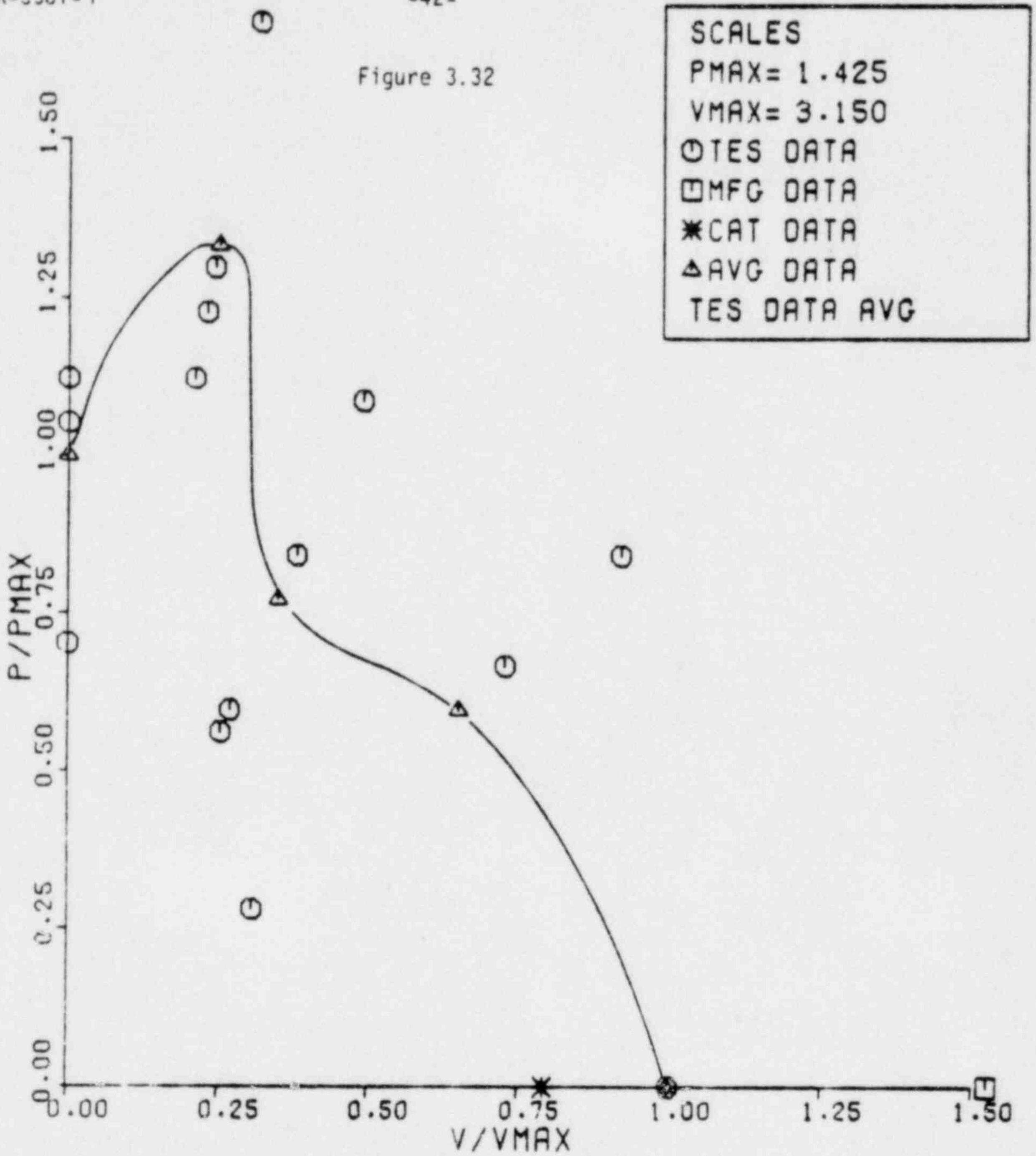
ENGINEERING SERVICES

Figure 3.32



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-29-79

BOLT MFG WEJ-IT

BOLT TYPE STUD

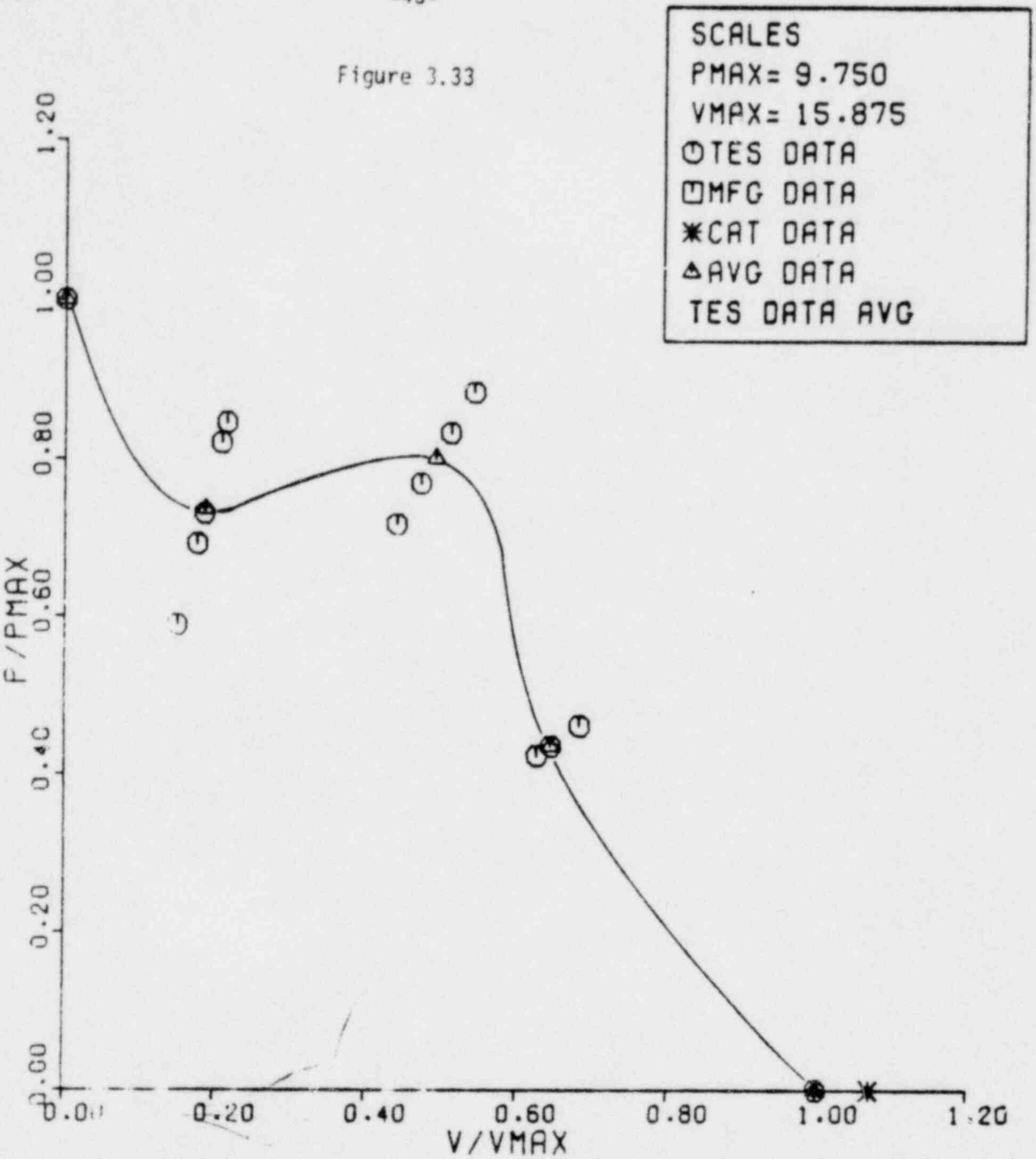
BOLT DIA .375

EMBEDMENT 1.25

TEST NO. 104-107.168-177.19-5.225.25-9

TELEDYNE ENGINEERING SERVICES

Figure 3.33



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-29-79

BOLT MFG WEJ-IT

BOLT TYPE STUD

BOLT DIA .750

EMBEDMENT 3.250

TEST NO. 9.10.69.70.142.143.178-185.626

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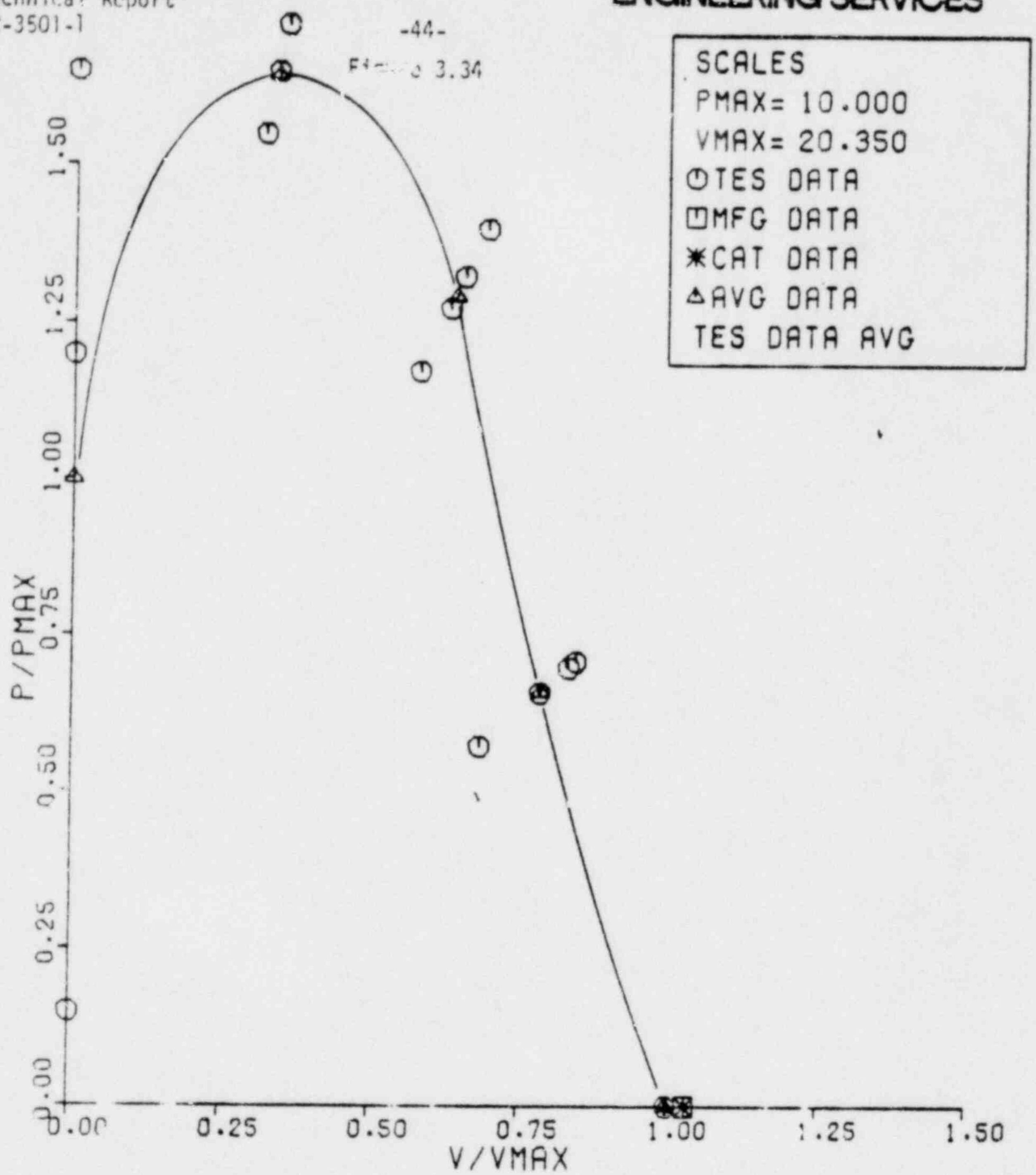
Figure 3.34



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-28-79

BOLT MFG WEJ-IT

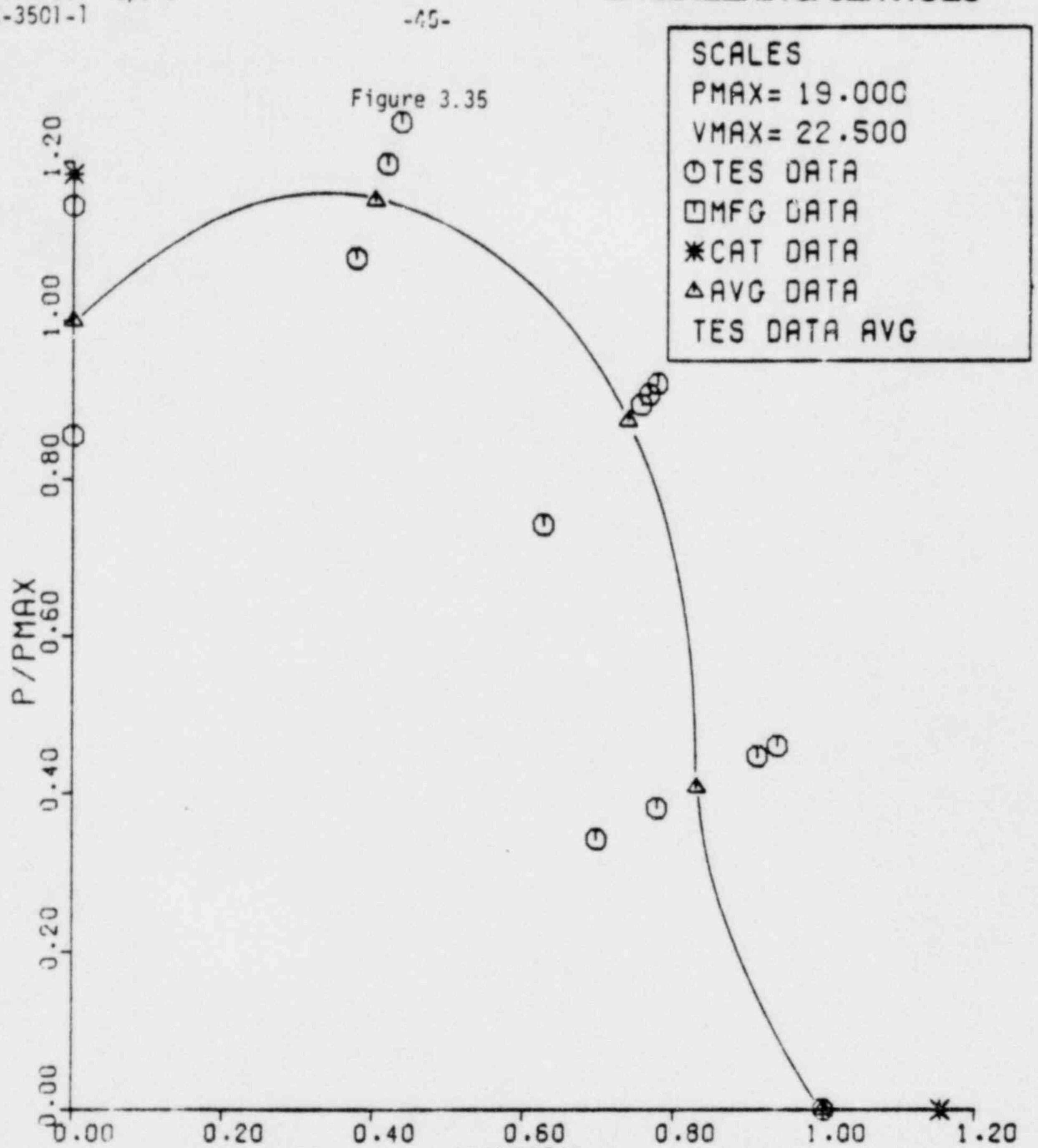
BOLT TYPE STUD

BOLT DIA .875

EMBEDMENT 4.0

TEST NO. 117.118.122-133.17-8.23-10

Figure 3.35



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-28-79

BOLT MFG WEJ-IT

BOLT TYPE STUD

BOLT DIA 1.0

EMBEDMENT 5.50

TEST NO. 108-116.119-121.606-608.24-6

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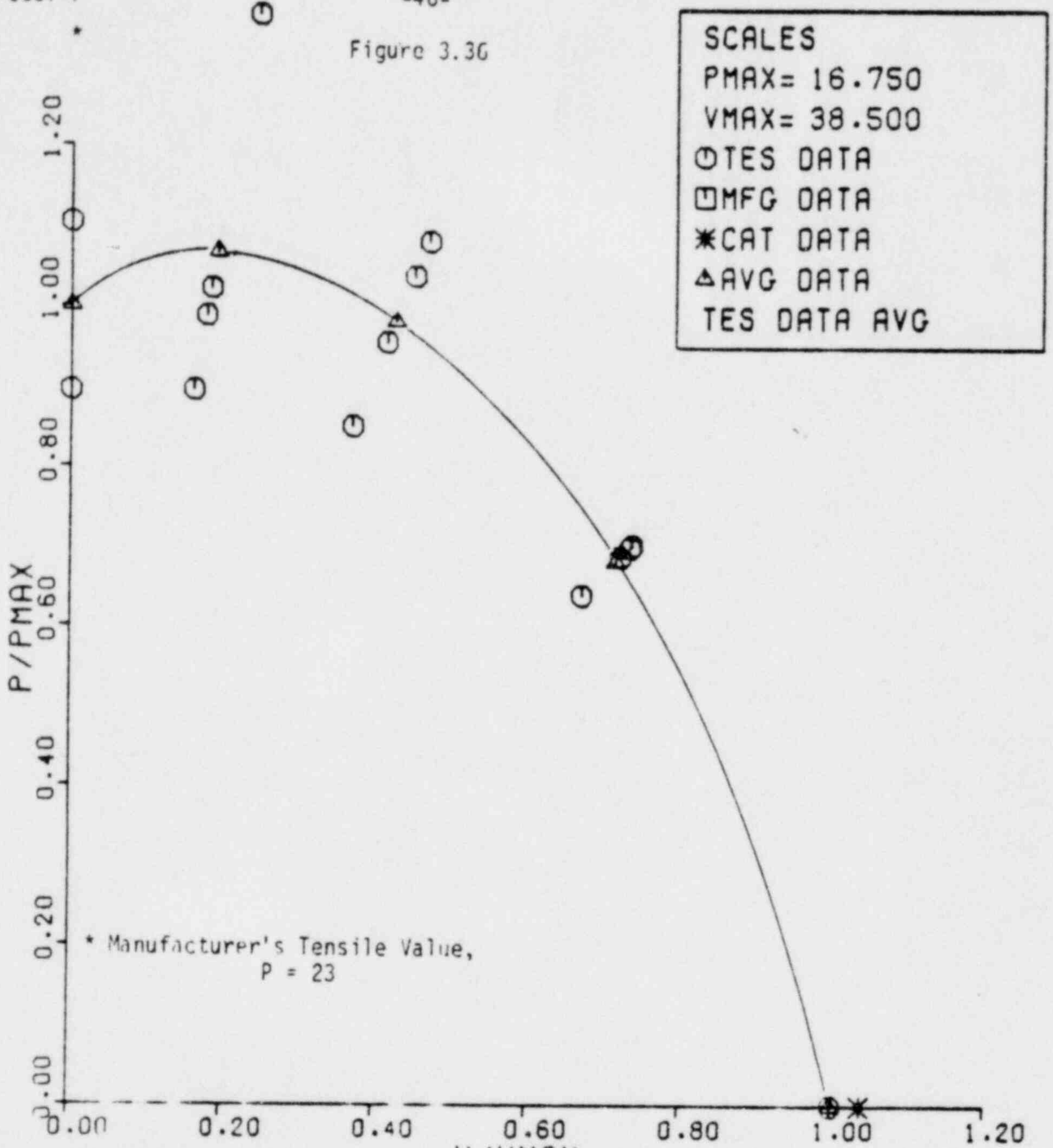
Figure 3.36



SHEAR-TENSION INTERACTION DIAGRAM

DATE 6-27-79

BOLT MFG WEJ-IT

BOLT TYPE STUD

BOLT DIA 1.250

EMBEDMENT 5.50

TEST NO. 89,100-103,442-444,474-476,596-598,19-4

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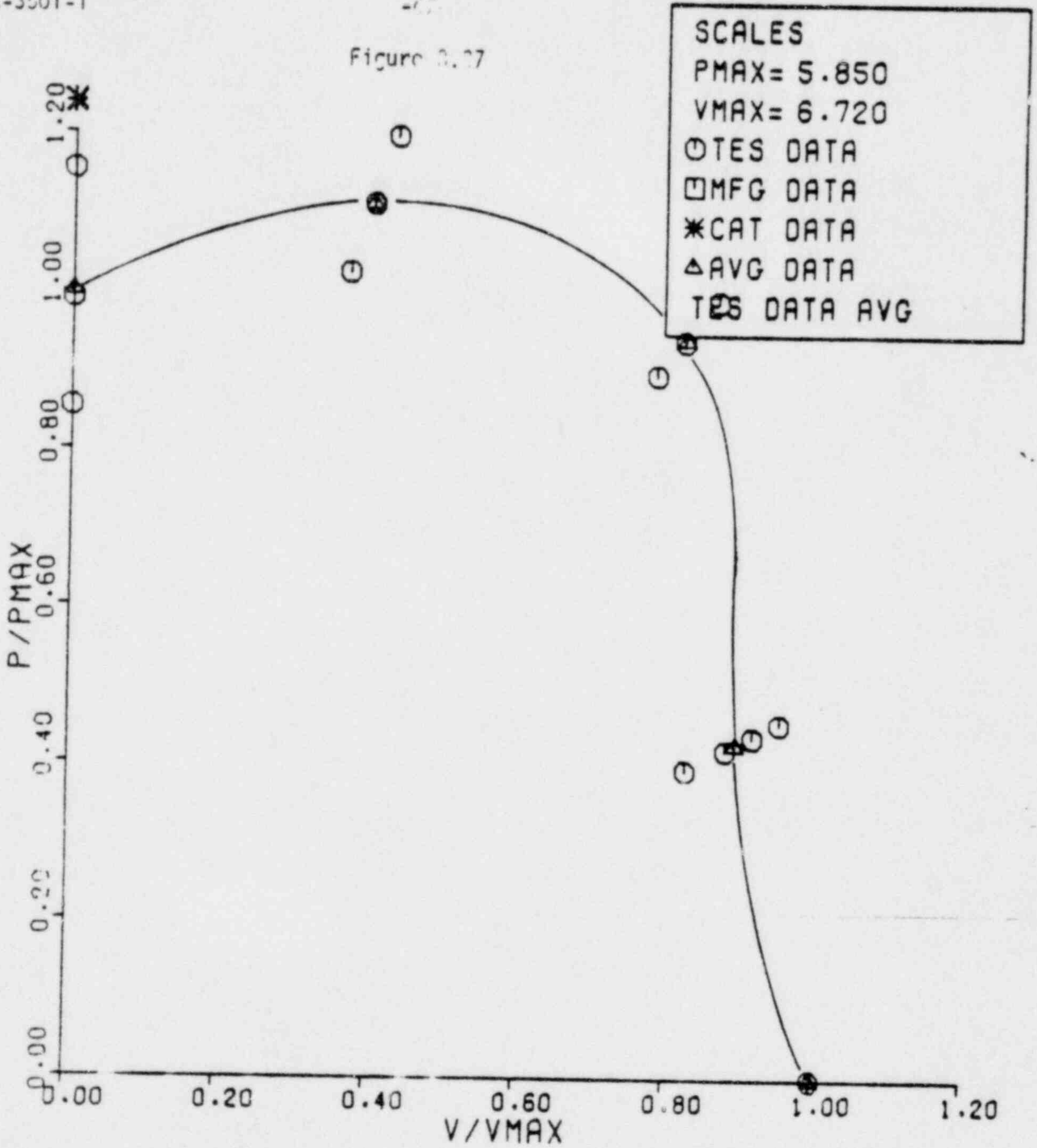
Figure 3.37



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-3-79

BOLT MFG RAWL

BOLT TYPE SELF DRILL

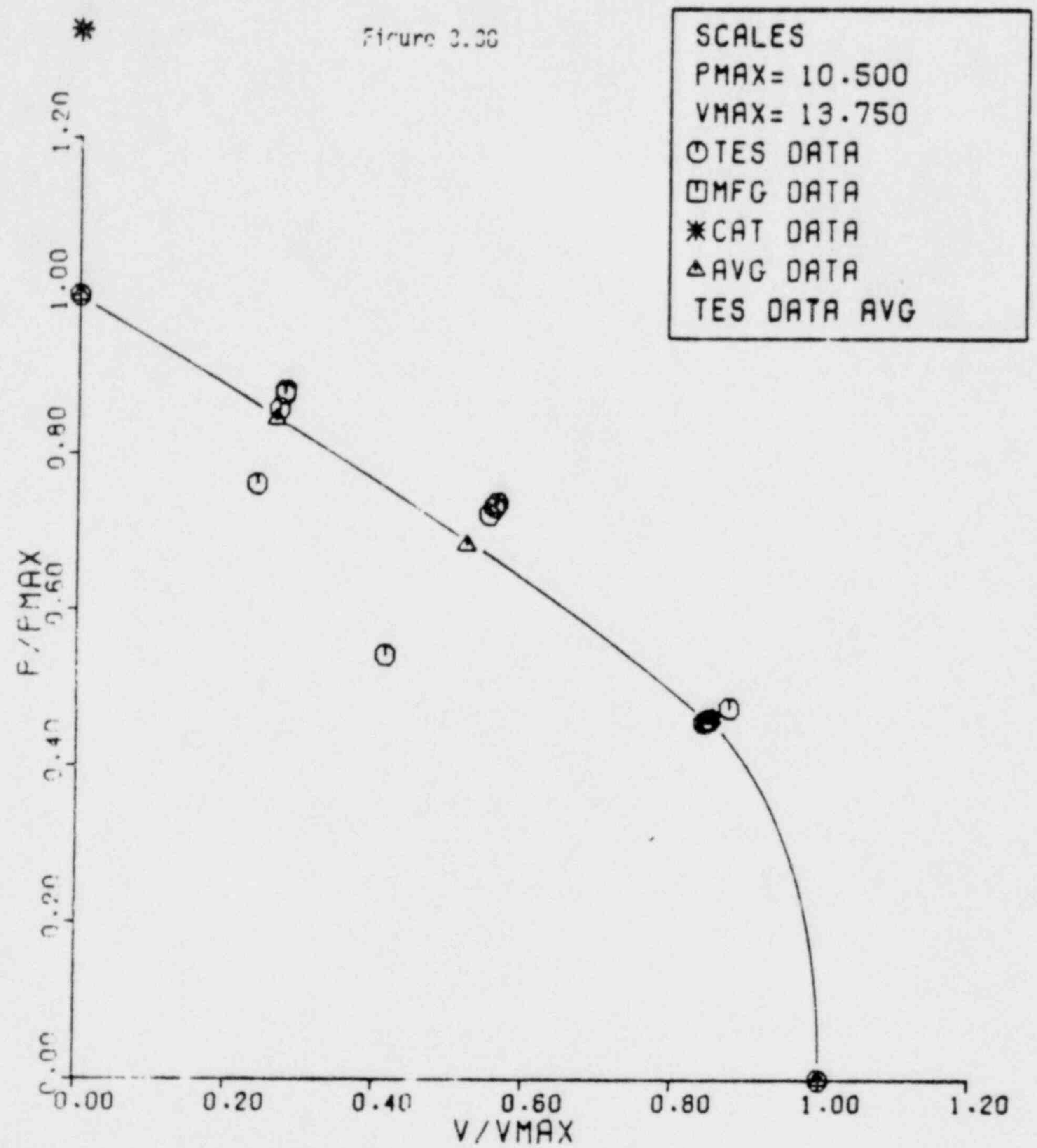
BOLT DIA .5

EMBEDMENT NOM

TEST NO. 299-307.320-323.686.24-9.24-8

TELEDYNE ENGINEERING SERVICES

Figure 3.30



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-5-79

BOLT MFG RAWL

BOLT TYPE SELF DRILL

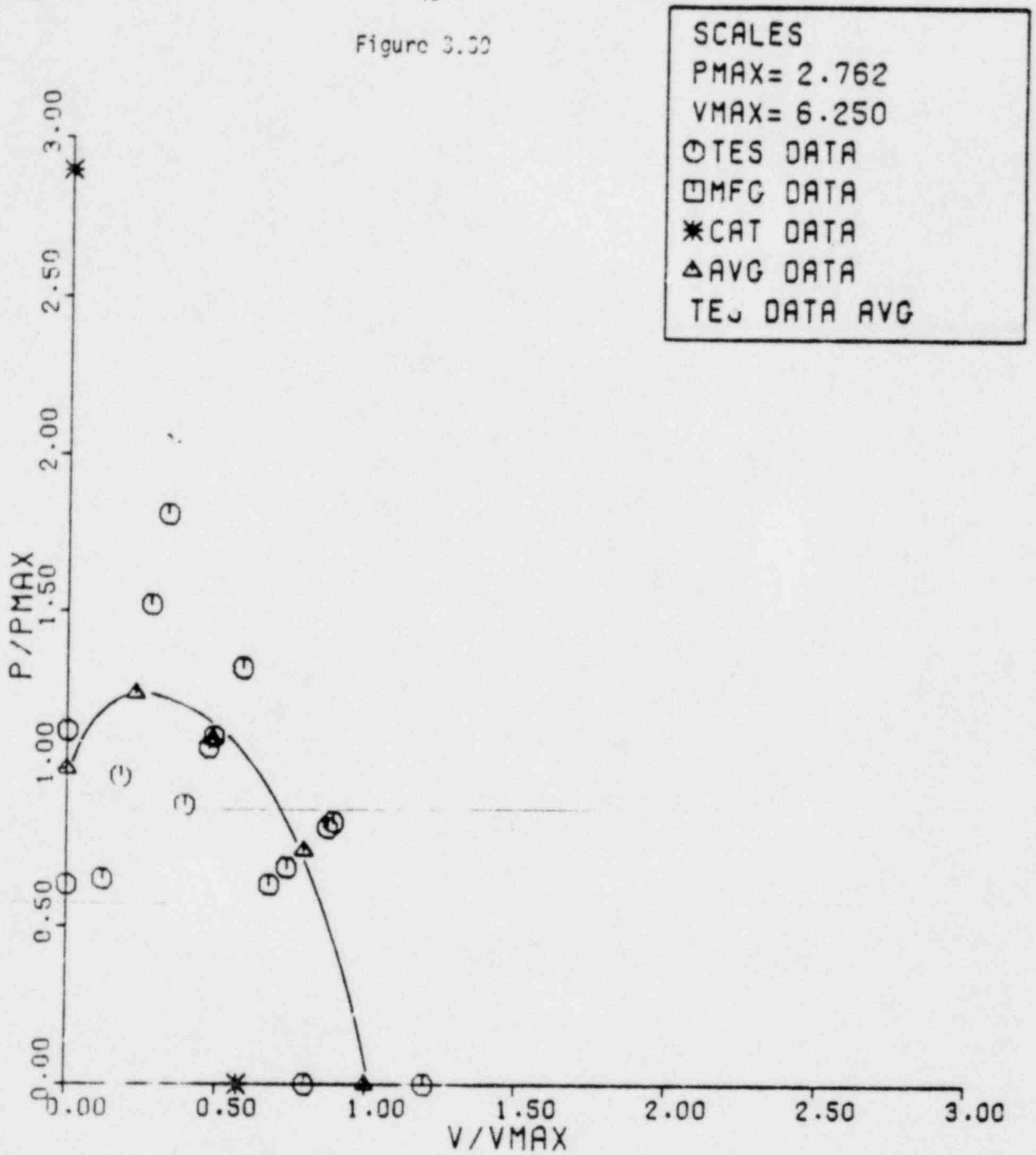
BOLT DIA .750

EMBEDMENT NOM

TEST NO. 334-341.345.347-349.649.677

TELEDYNE
ENGINEERING SERVICES

Figure 3.30



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-7-79

BOLT MFG STAR

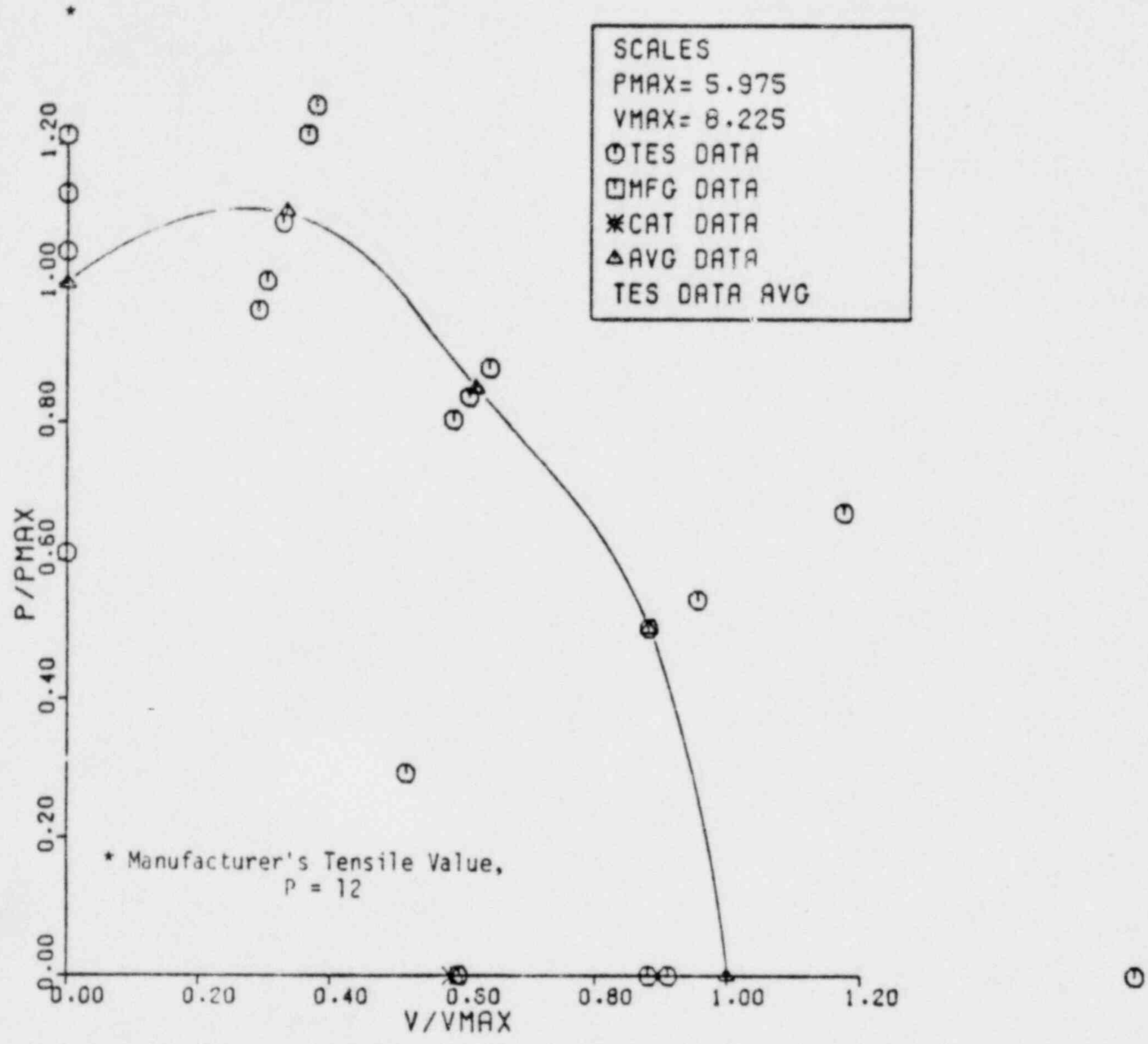
BOLT TYPE SLUG-IN

BOLT DIA .50

EMBEDMENT 1.4

TEST NO. 445,520-524,530-534,655-660,664

Figure 3.40



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-10-79

BOLT MFG STAR

BOLT TYPE SLUG-IN

BOLT DIA .625

EMBEDMENT 2.1

TEST NO. 482-486.492-496.616.665-671.675-676.687

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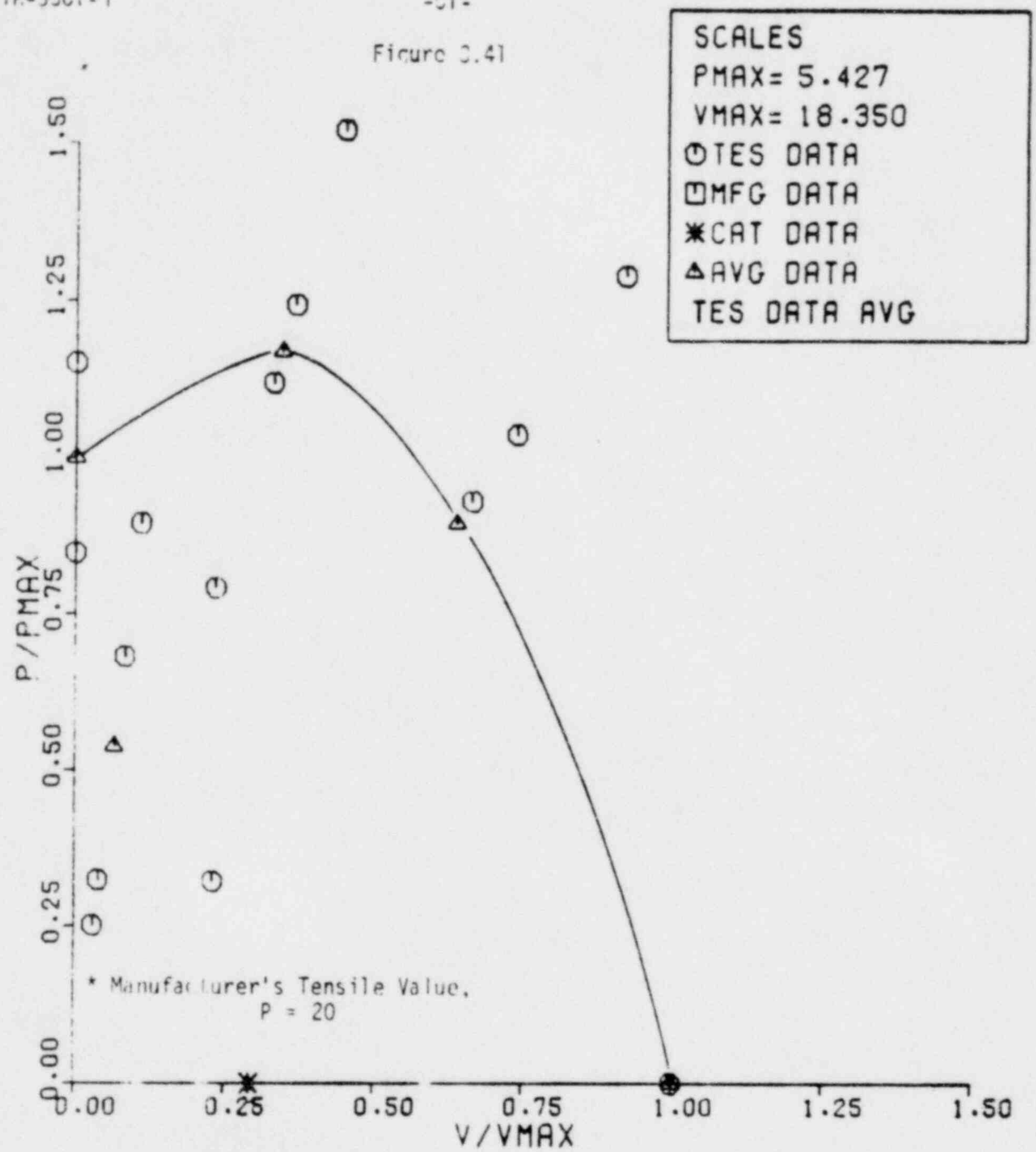
Figure 3.41



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-12-79

BOLT MFG STAR

BOLT TYPE SLUG-IN

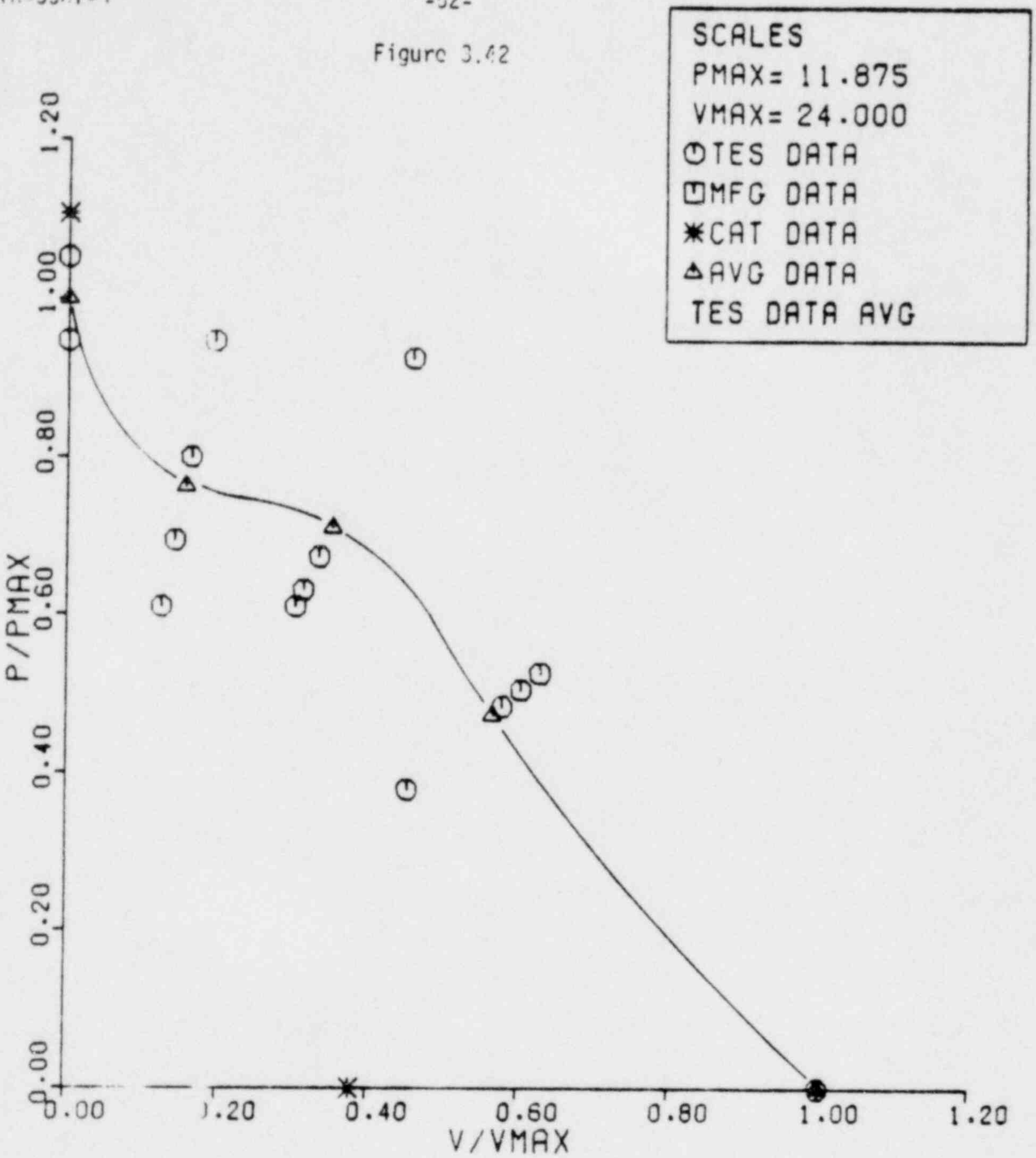
BOLT DIA .750

EMBEDMENT 2.6

TEST NO. 457-461.591-595.609-612.688

TELEDYNE ENGINEERING SERVICES

Figure 3.42



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-12-79

BOLT MFG STAR

BOLT TYPE [illegible]

BOLT DIA .875

EMBEDMENT 2.7

TEST NO. 546-550,556-559,580-584,18-14

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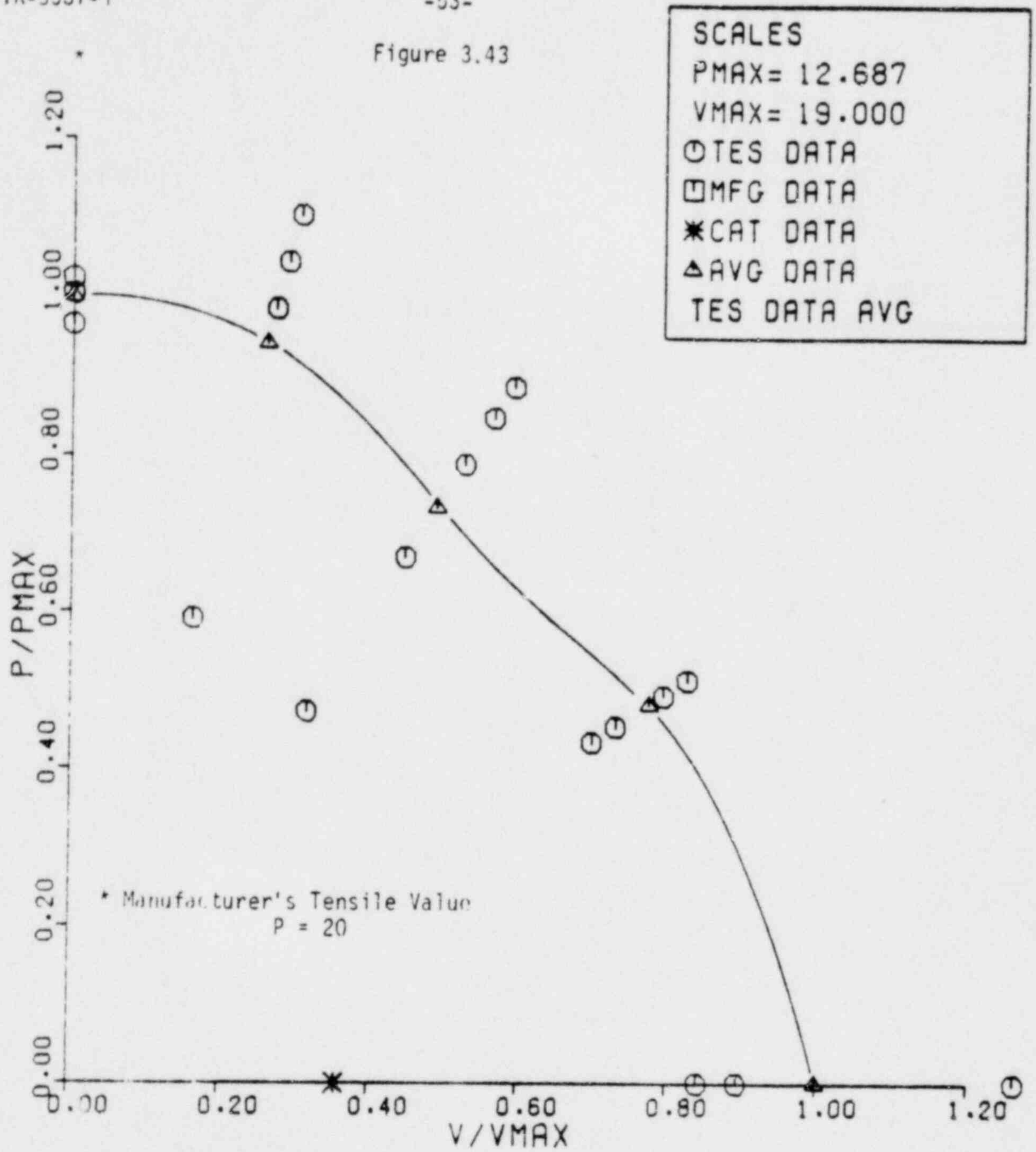
Figure 3.43



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-10-79

BOLT MFG STAR

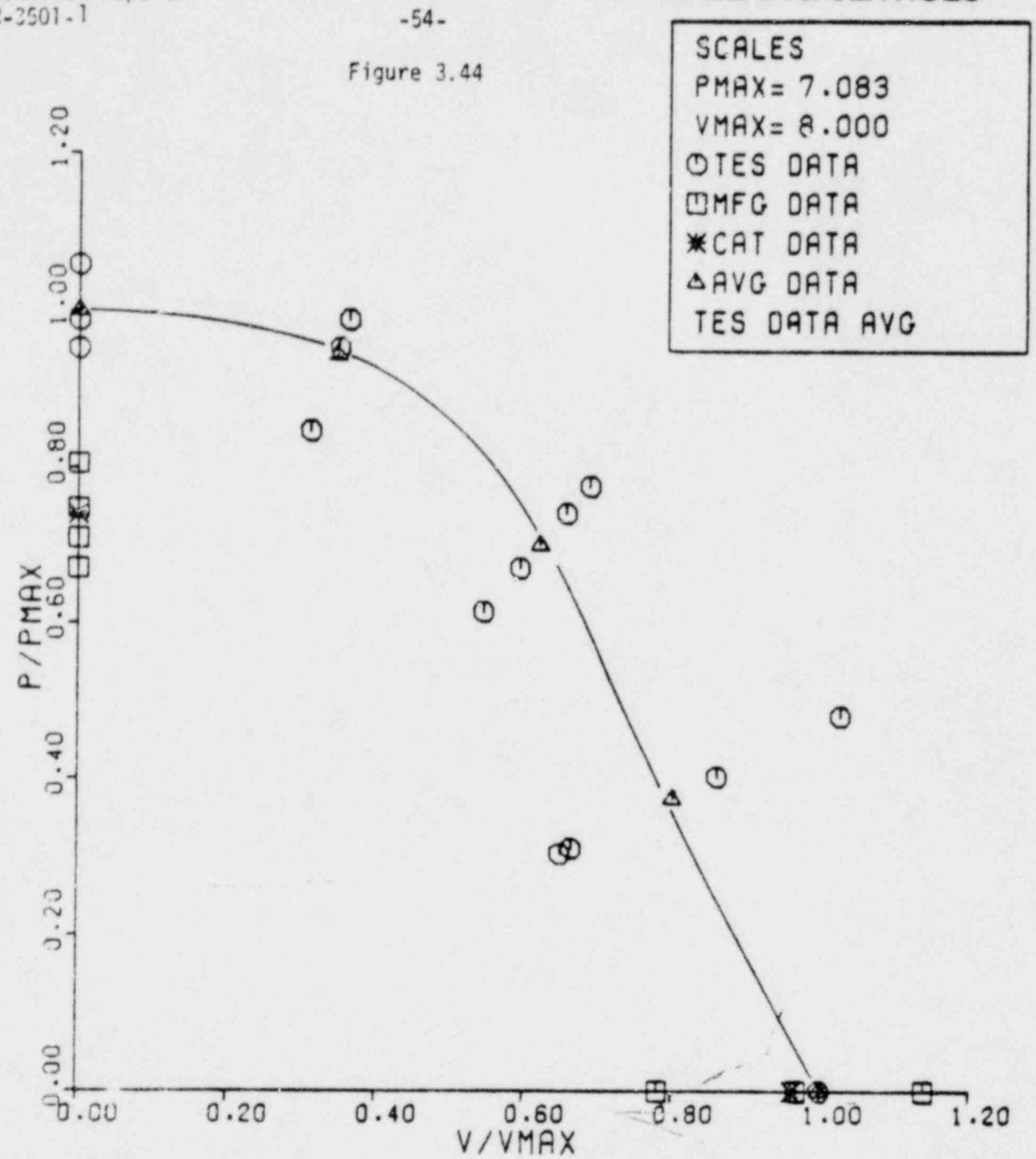
BOLT TYPE SLUG-IN

BOLT DIA 1.0

EMBEDMENT 3.50

TEST NO. 487-491.497-501.61-63.672-674.551-554.1

Figure 3.44



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-6-79

BOLT MFG RAMSET

BOLT TYPE WEDGE

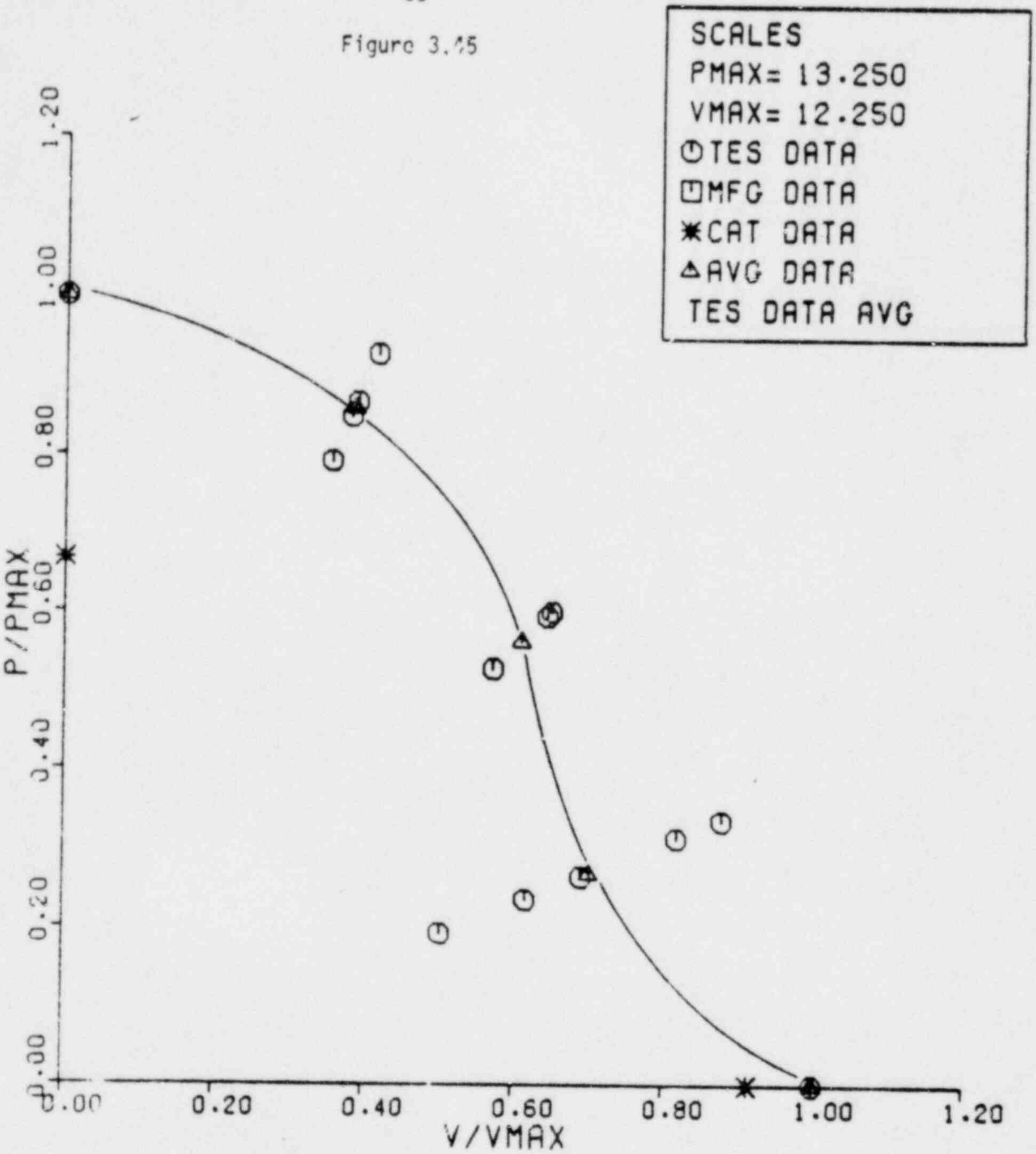
BOLT DIA .50

EMBEDMENT 2.250

TEST NO. 382-395

TELEDYNE ENGINEERING SERVICES

Figure 3.45



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-7-79

BOLT MFG RAMSET

BOLT TYPE WEDGE

BOLT DIA .625

EMBEDMENT 2.750

TEST NO. 413-417.428-434.637.645.18-12

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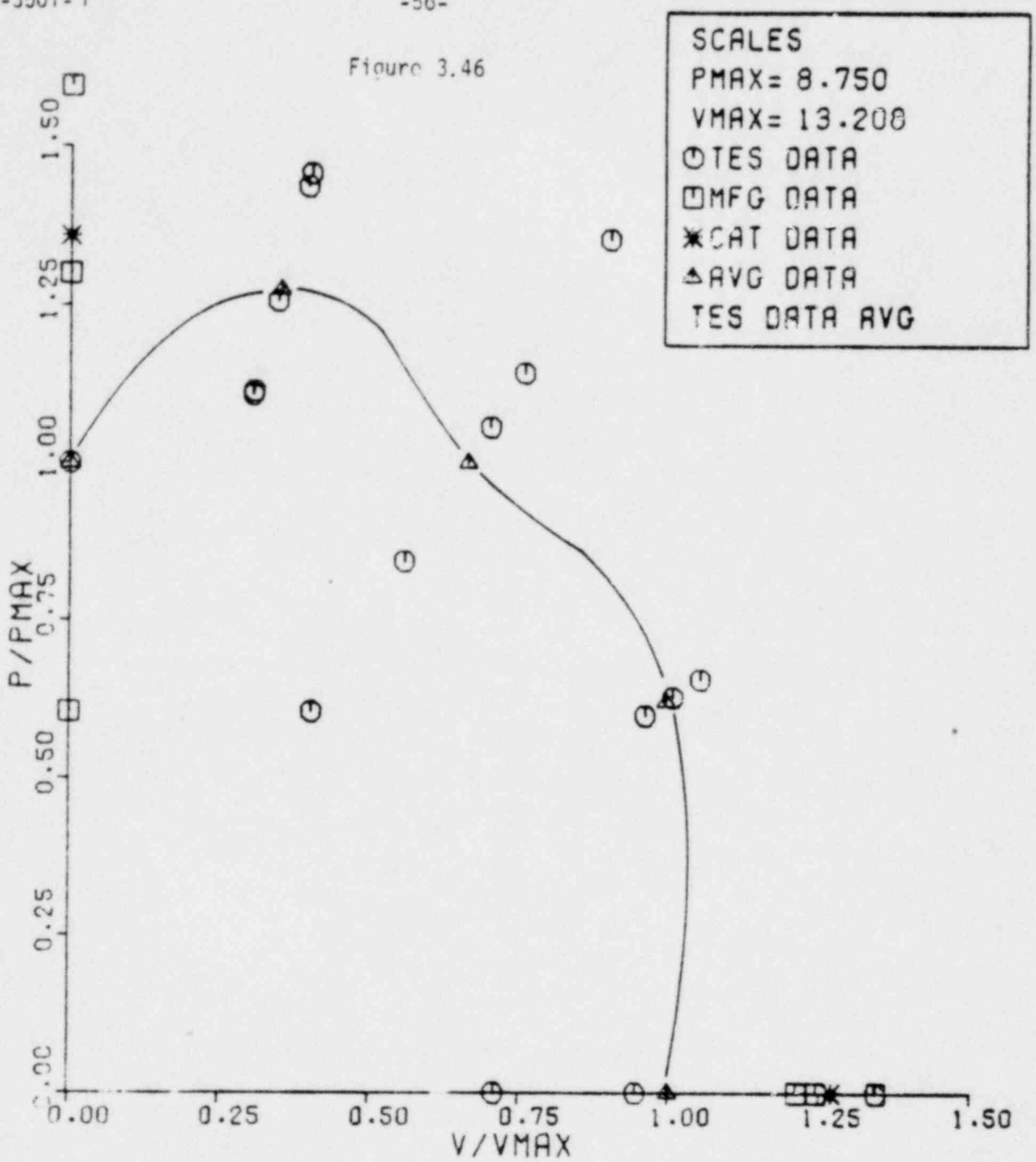
ENGINEERING SERVICES

Figure 3.46



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-7-79

BOLT MFG RAMSET

BOLT TYPE WEDGE

BOLT DIA .750

EMBEDMENT 3.25

TEST NO. 420-427, 435-441, 18-11, 18-13

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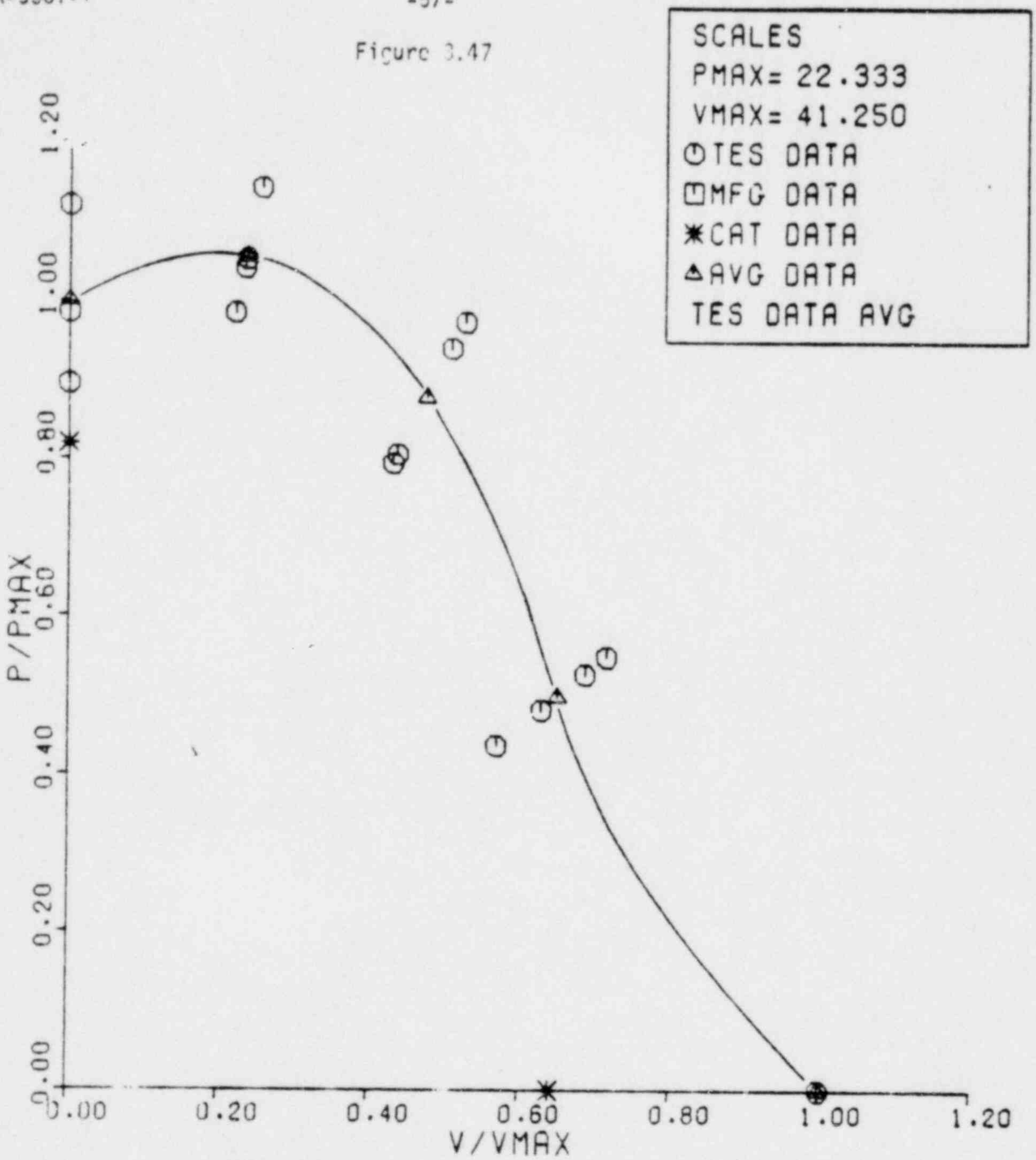
Figure 3.47



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-7-79

BOLT MFG RAMSET

BOLT TYPE WEDGE

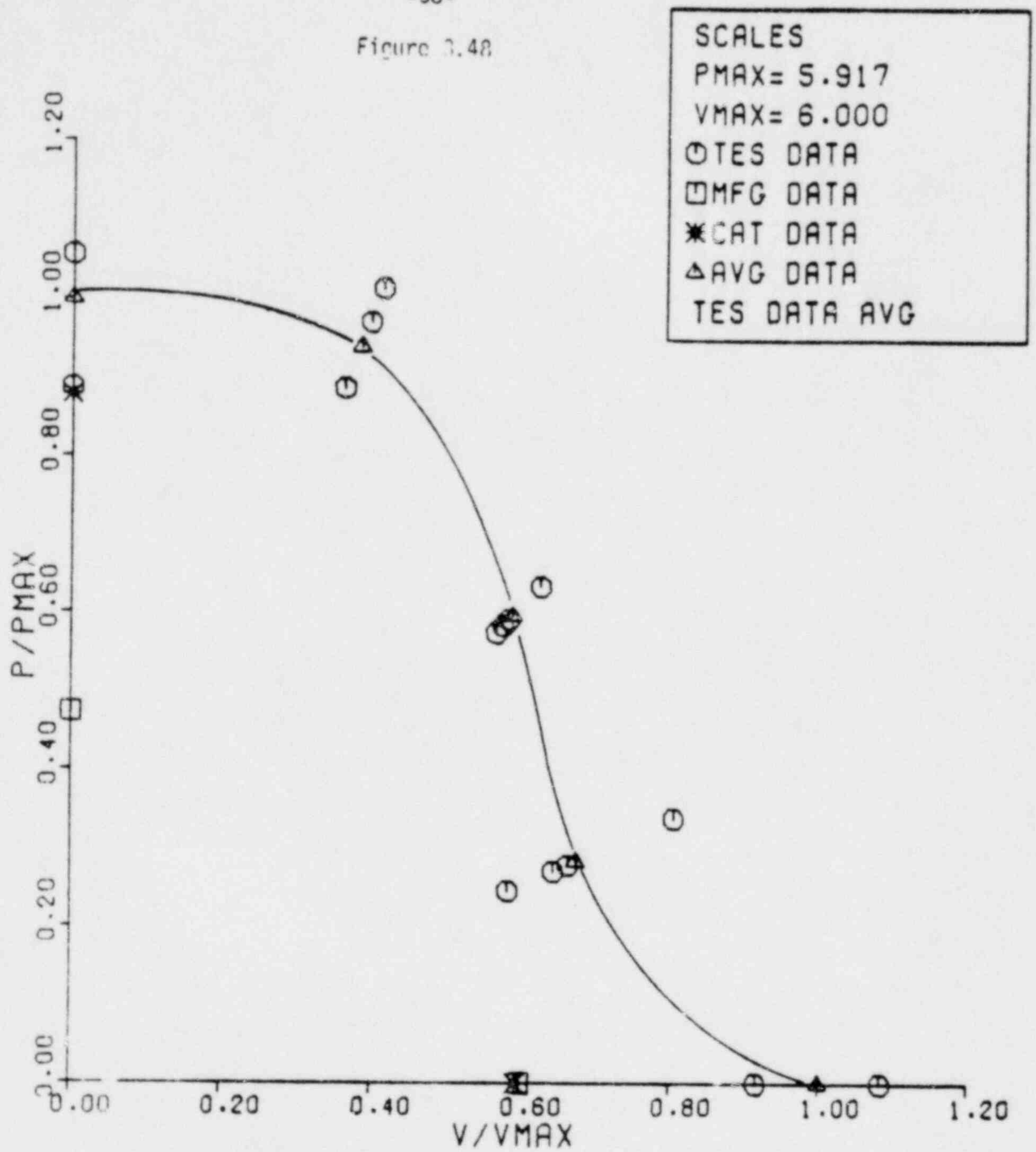
BOLT DIA 1.0

EMBEDMENT 5.50

TEST NO. 403-407.410-412.450.451.632-635.20-1

TELEDYNE ENGINEERING SERVICES

Figure 3.48



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-5-79

BOLT MFG RAMSET

BOLT TYPE SLEEVE

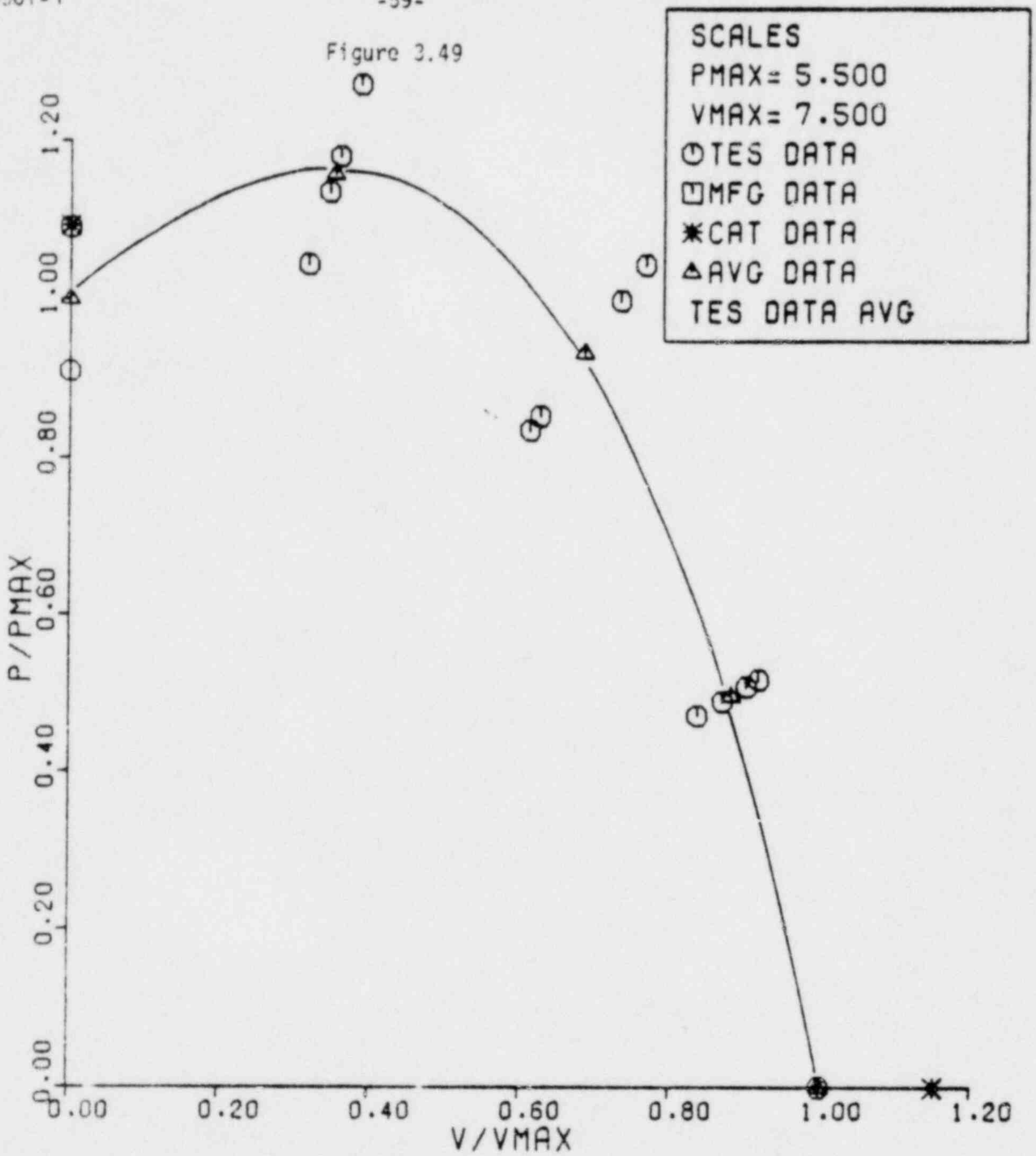
BOLT DIA .50

EMBEDMENT 2.25

TEST NO. 350-357.369-373.650.25-14

TELEDYNE ENGINEERING SERVICES

Figure 3.49



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-5-79

BOLT MFG RAMSET

BOLT TYPE SLEEVE

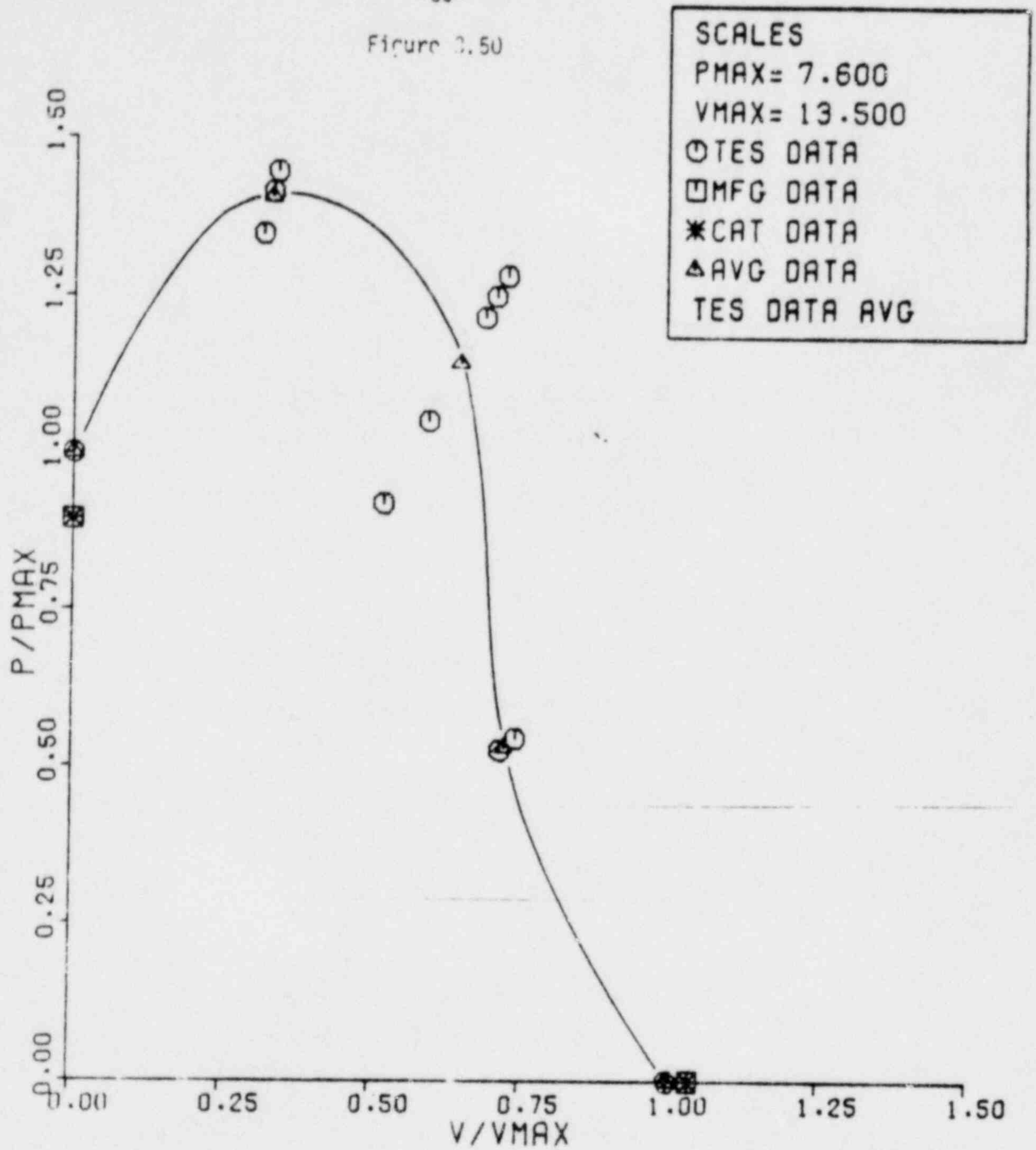
BOLT DIA .625

EMBEDMENT 2.25

TEST NO. 358-360.374-381.418.419.644.18-5

TELEDYNE ENGINEERING SERVICES

Figure 3.50



SHEAR-TENSION INTERACTION DIAGRAM

DATE 7-6-79

BOLT MFG RAMSET

BOLT TYPE SLEEVE

BOLT DIA .750

EMBEDMENT 3.25

TEST NO. 361-364.396-402.408.409.627-629

4.0 TASK 2 - CYCLIC CAPABILITY OF CONCRETE EXPANSION ANCHORS

4.1 Introduction

This section covers the cyclic testing of concrete expansion anchors, which was performed as part of the generic anchor bolt program.

4.2 Test Specimens

Each test specimen consisted of a 14 inch cube of concrete with a single anchor bolt installed in it. The concrete was specified as having a 28 day minimum compressive strength of 3000 psi. ASTM Specifications C-150-78 and C33-78 were also specified for the concrete. The maximum aggregate size was specified as 1-1/2 inches.

All anchor bolts were installed according to the manufacturers specification. All installations utilized the turn of the nut criteria rather than torque. After setting the expansion anchor, the nuts were backed off and then retightened snug tight or approximately one-quarter turn in order to demonstrate cyclic adequacy without preload.

A simulated fixture was placed under the nuts before installation in the test machine. The minimum thickness of the simulated fixture was one bolt diameter as specified in ASTM-E488. Installations of the bolts were inspected for straightness prior to testing. Bolts with an angularity between the block and bolt of 3° were rejected. The 3° criteria was necessary to allow for proper mating of the test piece and the test machine actuator.

The following Table defines the test matrix for cyclic testing.

TABLE 4.1

CYCLIC TEST MATRIX

Mfg/Type	Catalogue Design	Size 1/2	Size 3/4	Size 1
Phillips				
Snap Off	S	X	X(1)	
Wedge	WS		X	
Sleeve	HN		X	
Hilti				
Kwik Bolt	5500XXX	X	X(1)	X
USM				
Parabolt	PB		X	
Wej-It				
Stud			X	X
Rawl				
Snap Off	60XX		X	
Star				
Slug-In			X	
Ramset				
Wedge			X	
Sleeve			X(1)	

(1) Also Two Tests with a Static Shear Load Applied

4.3 Test Set-up

The cyclic tests were performed using an MTS electro hydraulic test machine. Fixturing was bolted to the stationary load cell of the test machine to provide support for the test specimens (see Figure 4.1).

Each anchor tested was a stud bolt. For the tests involving shell type anchors, a section of threaded rod was used to provide the stud required for attachment to the test machine actuator.

The MTS was set to respond to load feedback during all of the cyclic tests.

A record of load was taken at twenty minute intervals with a Visicorder oscillograph for all high cycle tests (10^6 cycles) and a single recording of load was taken for all low cycle tests (10^3 cycles).

After each cyclic test, the anchors were pulled in tension to determine the ultimate load. A pullout rate of 1/2 inch per minute was used for all anchor pullout tests.

4.4 Test Procedure

4.4.1 Scope

The purpose of this procedure is to define the methods and materials used in the cyclic testing of concrete expansion anchors.

4.4.2 Test Specimens

Each test specimen consisted of a concrete cube measuring 14 inches on a side, with a single concrete expansion anchor installed in the cube.

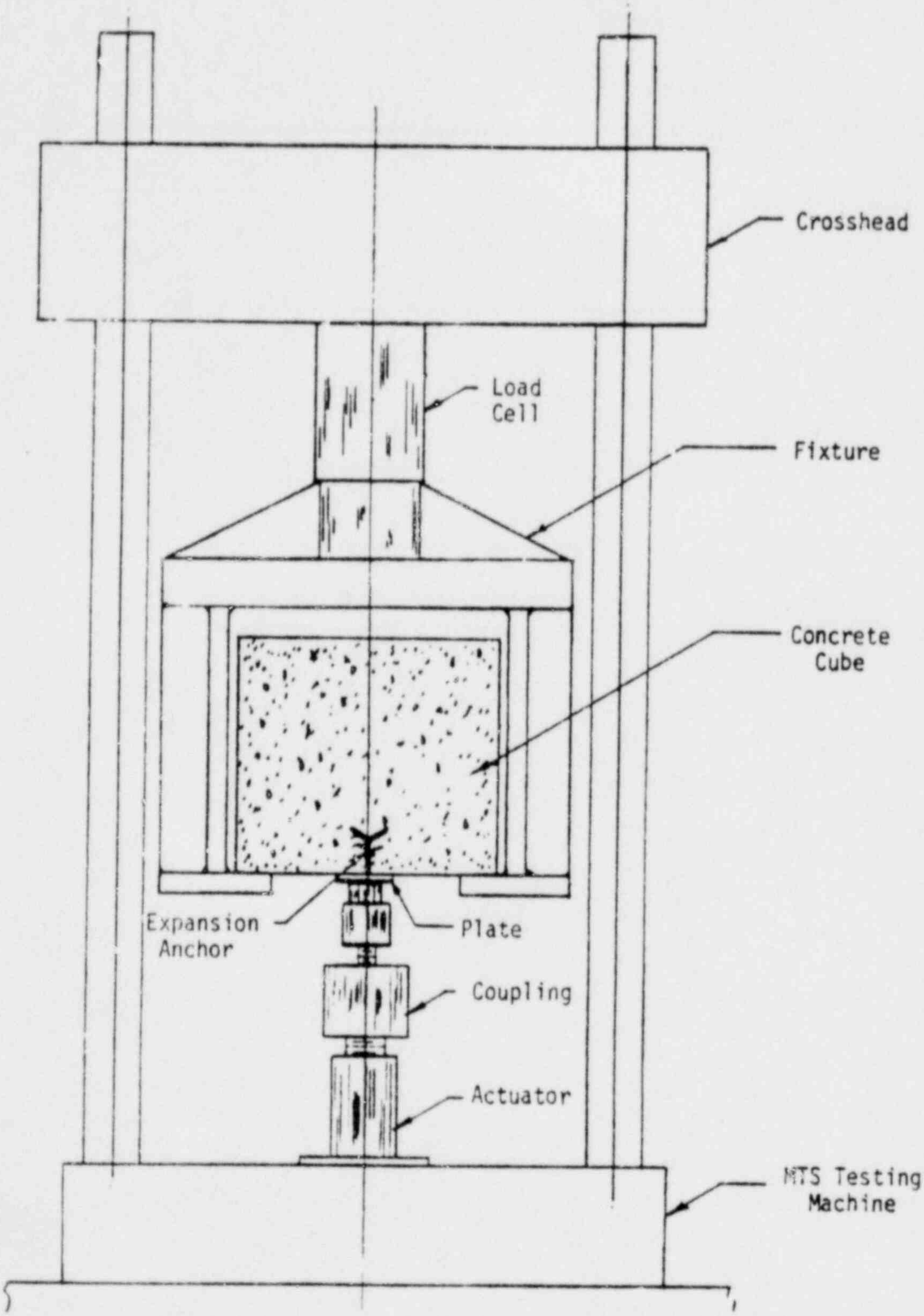


Figure 4.1 Fixture for Cyclic Test

1. Concrete Anchors

Ten types of concrete anchors were selected to be subjected to cyclic testing, as follows:

a) Phillips Red Head Snap-off
b) Phillips Wedge
c) Phillips Sleeve
d) Hilti Kwik Bolt
e) USM Parabolt
f) Wej-It Stud
g) Rawl Snap-off
h) Star
i) Ramset Wedge
j) Ramset Sleeve

All of the above mentioned bolts were tested in the 3/4 inch size. In addition, Phillips Red Head Snap-off and Hilti Kwik Bolt were tested in the 1/2 inch size and Hilti Kwik Bolt and Wej-It Stud were tested in the one inch size.

Also, two tests were performed on 3/4 inch Ramset Sleeve, Hilti Kwik Bolt and Phillips Snap-off with a static shear load applied.

2. Concrete

The test cubes are made of concrete which conforms to ASTM C94-782. Concrete conformed to the following requirements: 28 day strength 3000 psi, Portland Cement Type II per ASTM C-150-78, aggregate per ASTM C33-78 maximum size 1-1/2 inches.

3. Bolt Installation

All bolts were installed at minimum embedment according to manufacturers installation procedures.

4.4.3 Test Fixturing

The test fixture as shown in Figure 4.1 supported the anchor bolt in an inverted position in the test machine. The top part of the fixture was affixed to the stationary test machine load cell. A simulated attachment plate with a thickness of at least one bolt diameter was installed under the nut and washer on each bolt. A rigid fixture was threaded on to the stud end of each anchor bolt. All fixturing conformed to ASTM E488 with the exception that a rigid connection was used between the test machine actuator and the anchor bolt instead of the flexible one described in E488.

4.4.4 Test Machine

The cyclic tests were conducted on an MTS electro-hydraulic test machine.

1. Calibration

The test machine was calibrated in accordance with procedures set forth in the latest revision of ASTM E4. All standards used for calibration have certificates to verify traceability to NBS. All calibrations have been made within the preceeding twelve months.

4.4.5 Testing

Each anchor bolt assembly was installed in the test fixture and the bolt protruding from the cube was aligned with the test machine actuator. Bolt installation was inspected for straightness prior to testing.

After connecting the stud end of the anchor bolt to the test machine actuator, the bolt was subjected to cyclic tensile loadings. During cyclic testing, the MTS test machine was in load control mode.

Each type of anchor bolt assembly was cycled according to the following table:

Frequency	Number of Cycles	Maximum Load	Minimum Load
3 Hz	1,000	Pu/4	Pu/8
80 Hz	1,000,000	Pu/5	Pu/7.4

The shear-tension cyclic tests were performed in accordance with the following table:

Frequency	Number of Cycles	Maximum Tensile Load	Minimum Tensile Load	Static Shear Load
80 Hz	1,000,000	Pu/5	Pu/7.4	V*/4

V* = Allowable Shear Load ($V_u/4$)

Two tests were conducted on each type of bolt at each frequency and load. The load applied during each test was recorded on an oscillograph for permanent record.

Criteria for failure of a bolt is a one inch pullout during cyclic testing. After completion of a cyclic test, the amount of pullout, if any, was measured and the bolt was statically pulled to failure in tension.

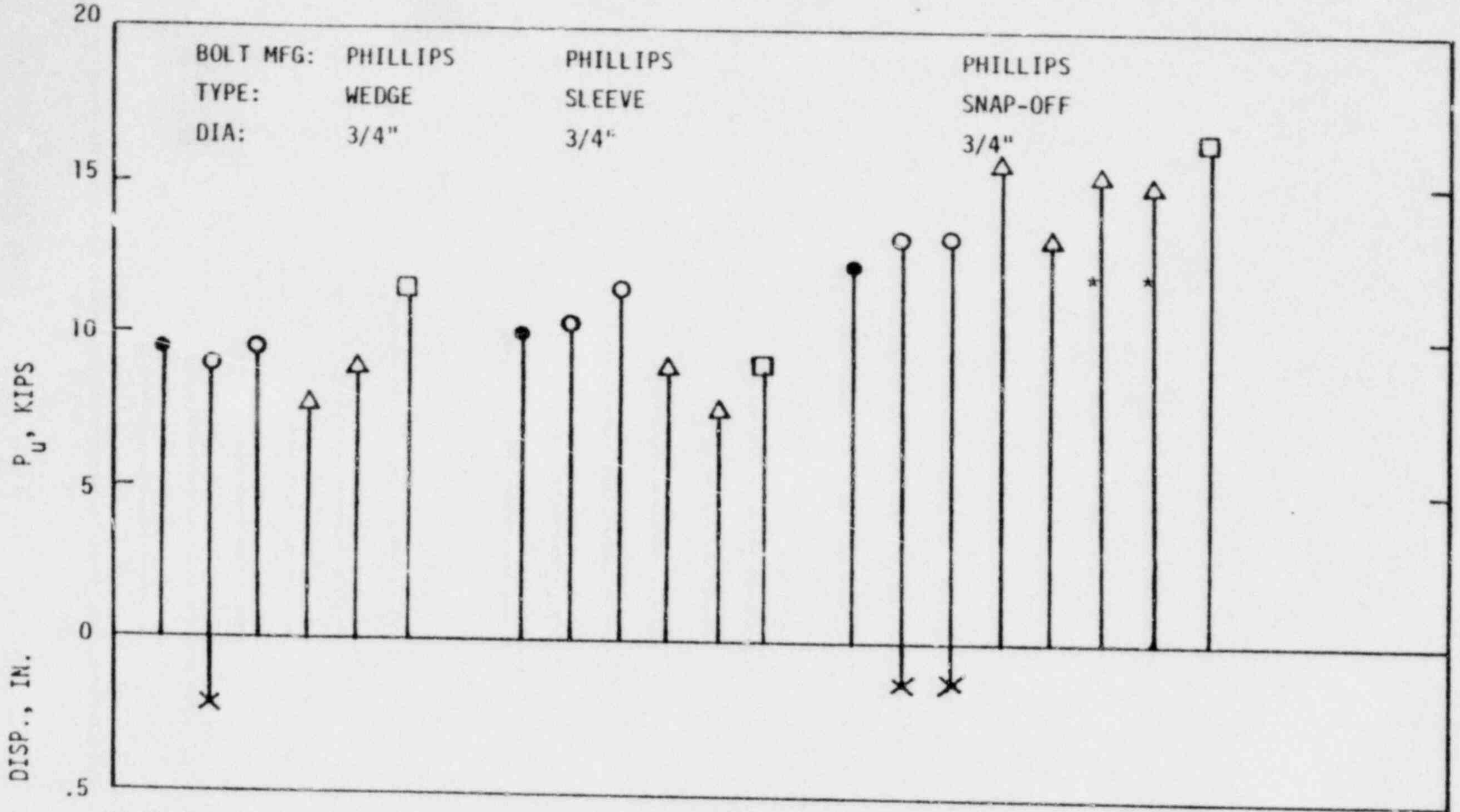
4.5 Test Results

No anchor pullout failures occurred as a result of cyclic loading. Pullout, when it did occur, occurred when the bolt was initially loaded. Maximum pullout observed was 1/4 inches. Once the initial loading was complete, no further pullout occurred as cycling progressed.

All anchors survived the cyclic testing without failure. The ultimate capacity of the anchor after cycling was comparable to that obtained in the shear-tension interaction test program.

Figures 4.2 through 4.8 graphically present the results of this test program. The results are in the form of bar charts and show ultimate strength of the expansion anchors,

1. As reported by the manufacturers catalogue (□),
2. from the TES shear-tension interaction test program (●),
3. and after completion of the cyclic testing (0 = low cycle, △ = high cycle).



Legend

- ● Pullout Strength (Average) from Shear Tension Test for Pure Tension
- O Pullout Strength after Low Cycle Test
- Δ Pullout Strength after High Cycle Test
- □ Manufacturer's Pullout Strength
- x Displacement after Cycling
- * Shear .825 kip

Figure 4.2

RESULTS OF PULLOUT TESTS AFTER CYCLING

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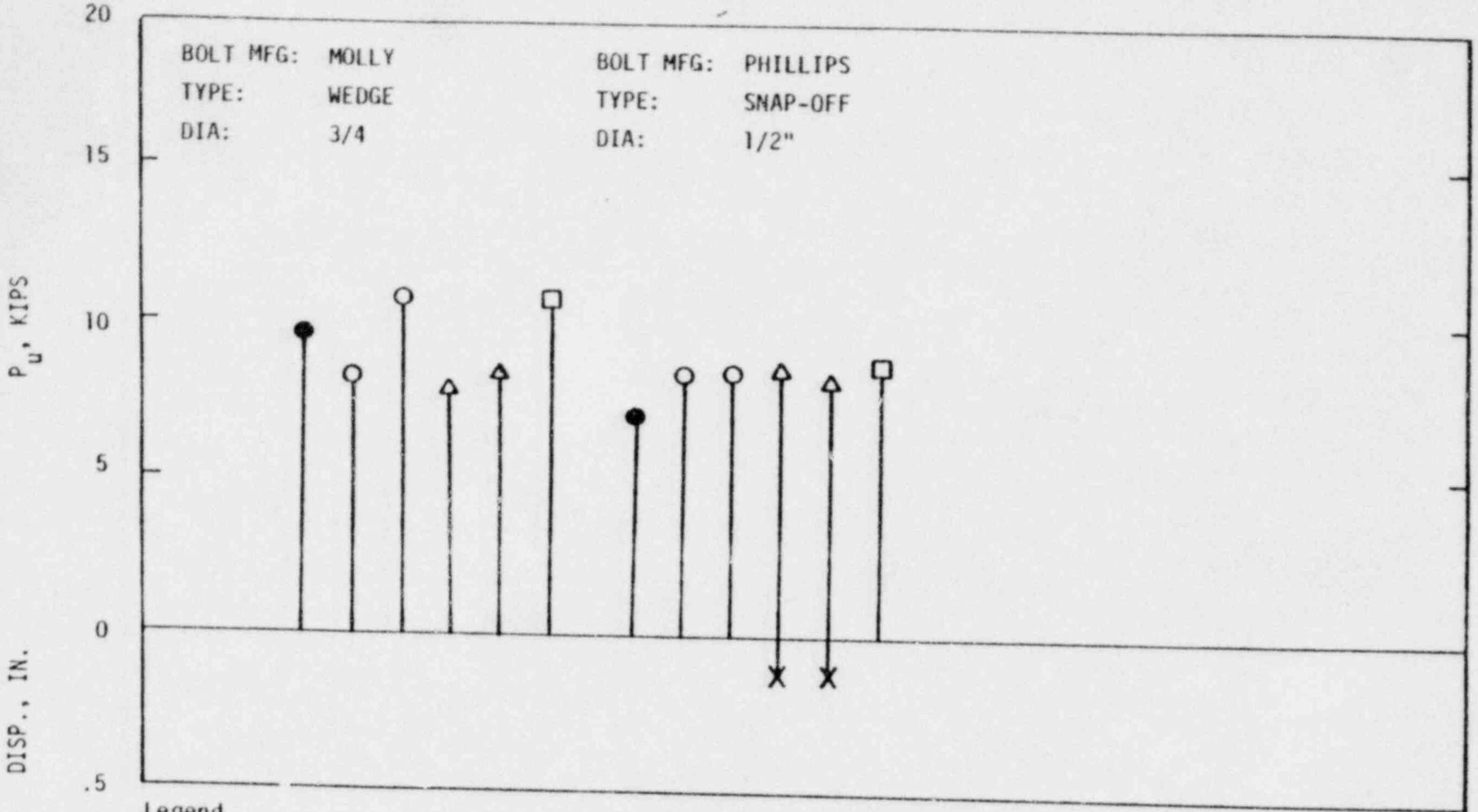
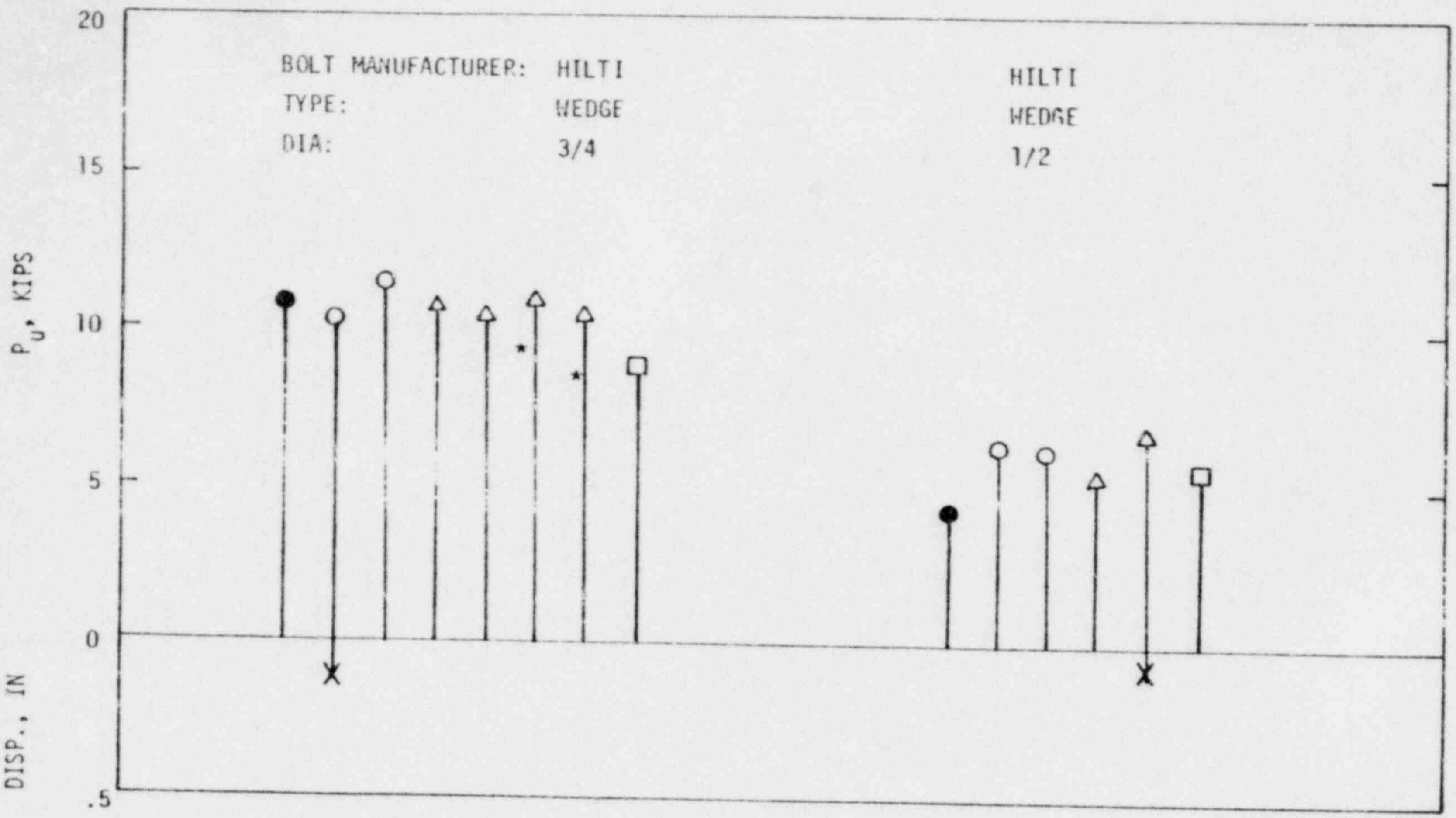


Legend

●Pullout Strength (Average) from Shear Tension Test for Pure Tension
OPullout Strength after Low Cycle Test
△Pullout Strength after High Cycle Test
□Manufacturer's Pullout Strength
xDisplacement after Cycling

Figure 4.3

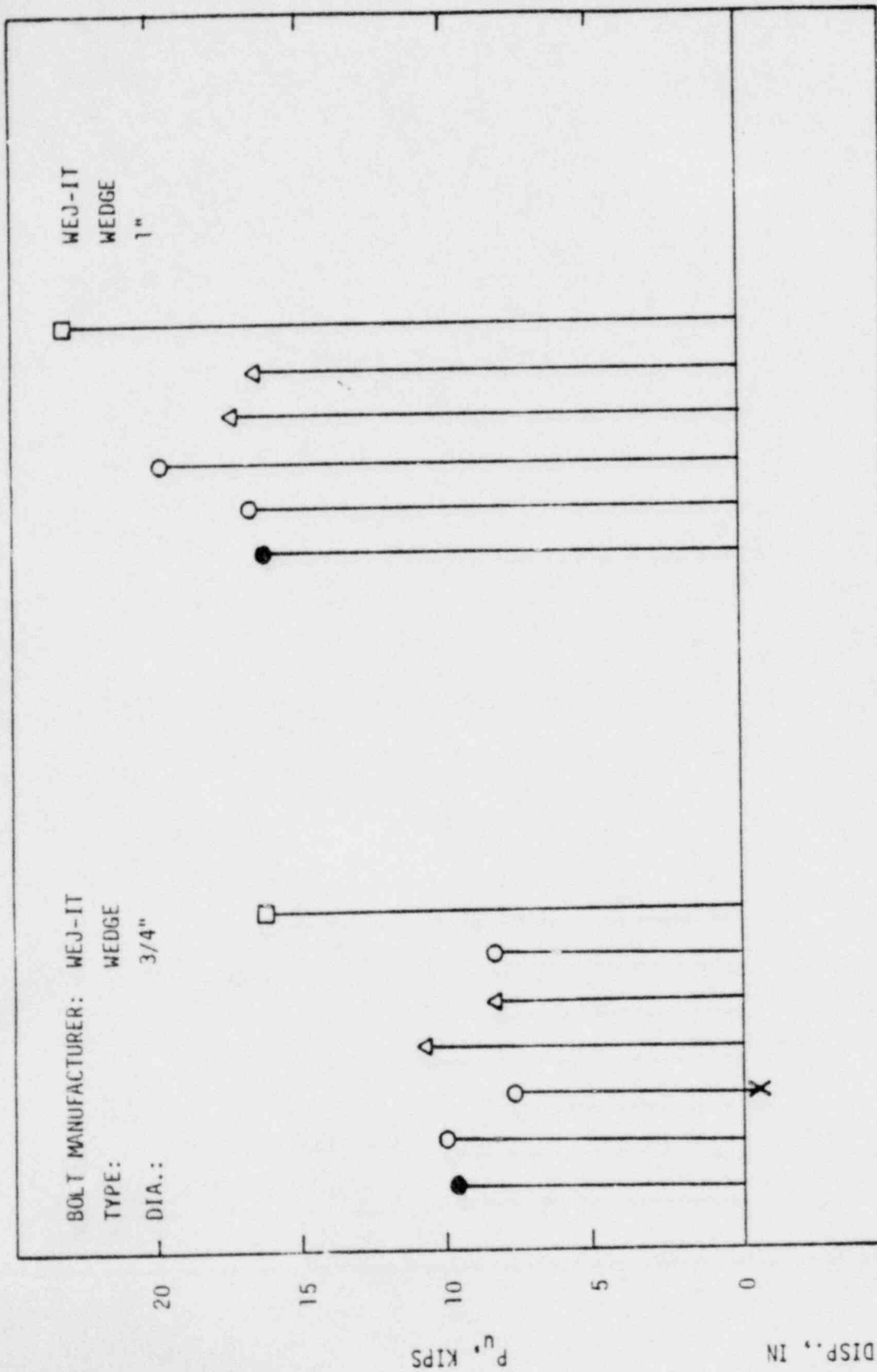
RESULTS OF PULLOUT TESTS AFTER CYCLING



LEGEND

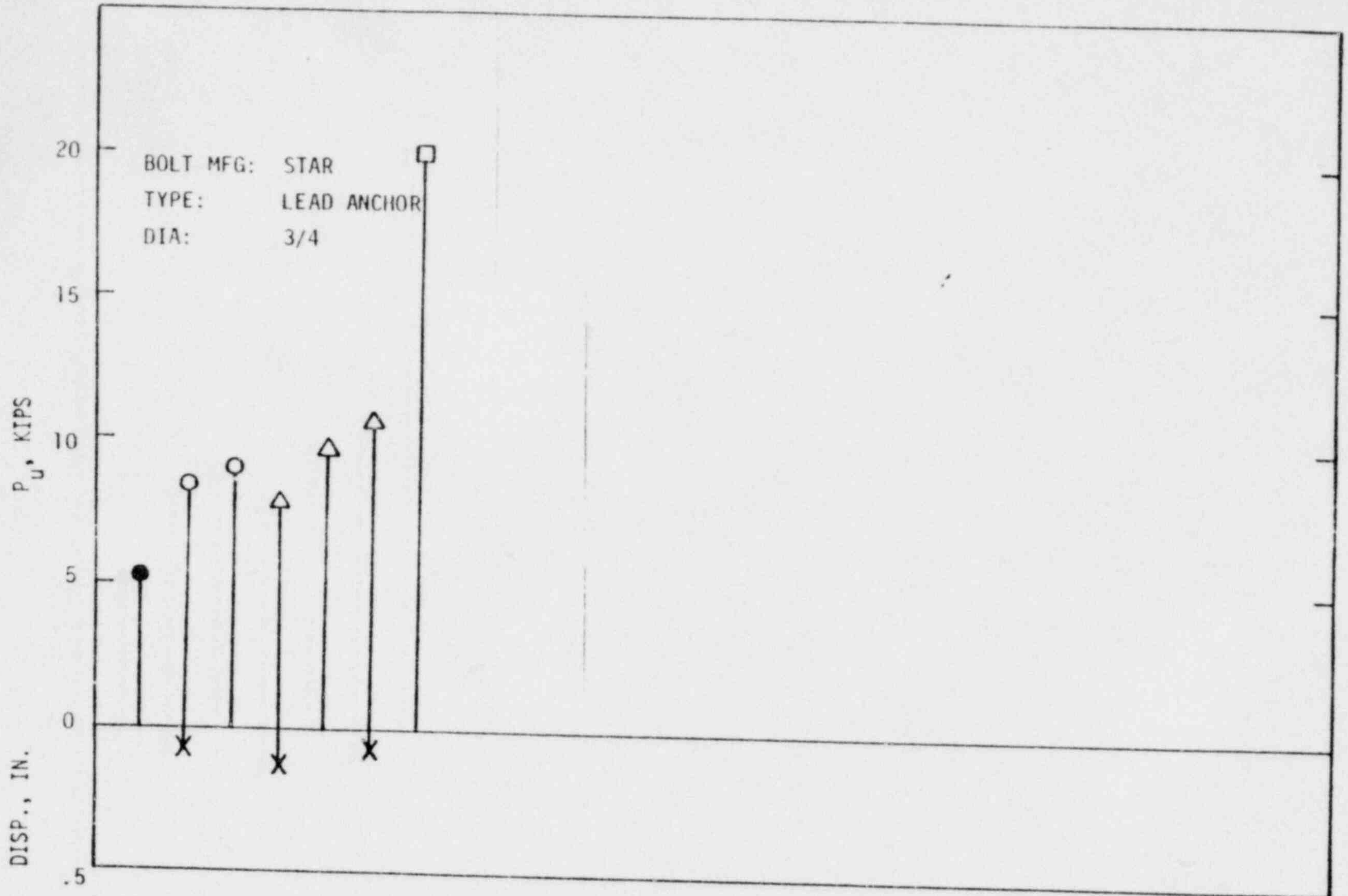
- ● Pullout Strength (Average) from Shear Tension Test for Pure Tension
- ○ Pullout Strength after Low Cycle Test
- △ Pullout Strength after High Cycle Test
- □ Manufacturer Pullout Strength
- × Displacement after Cycling
- * Shear 1.07 kips

Fig. 4.4. Results of Pullout Tests After Cycling



- ● Pullout Strength (Average) from Shear Tension Test for Pure Tension
- o Pullout Strength after Low Cycle Test
- Δ Pullout Strength after High Cycle Test
- □ Manufacturers Pullout Strength
- x Displacement after Cycling

Fig. 4.5. Results of Pullout Tests After Cycling



● Pullout Strength (Average) from Shear Tension Test for Pure Tension

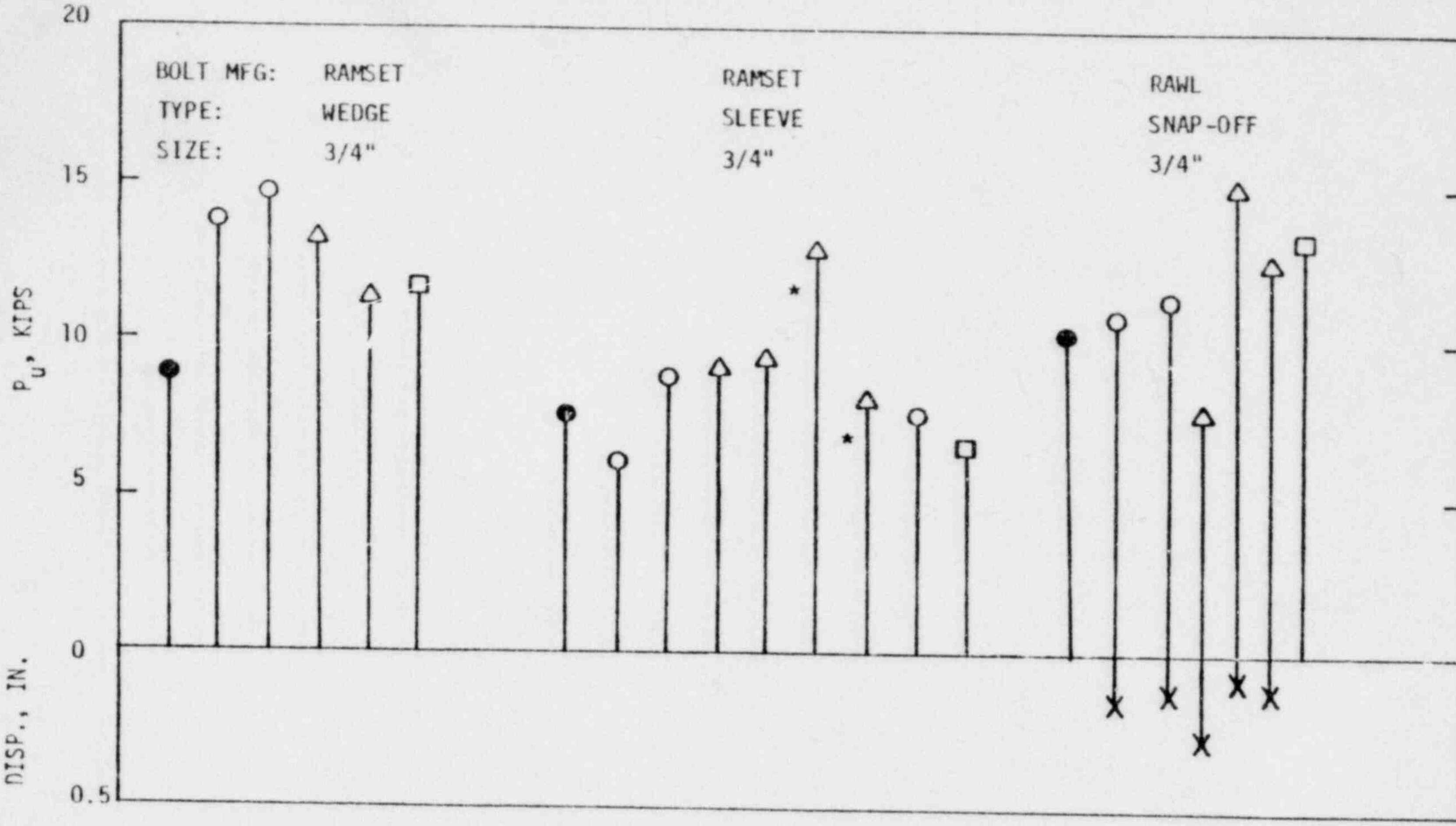
o Pullout Strength after Low Cycle Test

△ Pullout Strength after High Cycle Test

□ Manufacturer Pullout Strength

x Displacement after Cycling

Fig. 4.6. Results of Pullout Tests After Cycling



● Pullout Strength (Average) from Shear Tension Test for Pure Tension

○ Pullout Strength after Low Cycle Test

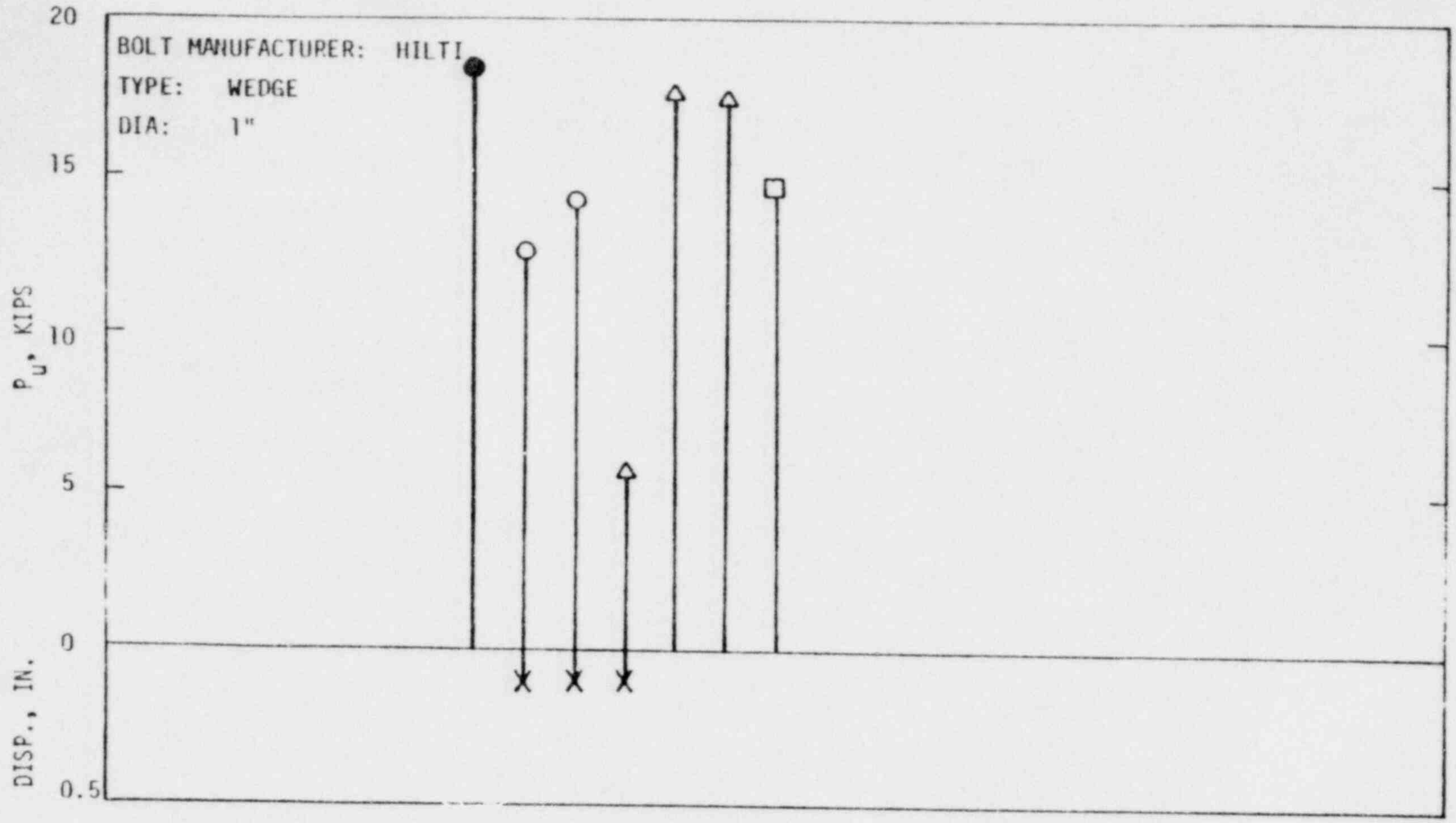
△ Pullout Strength after High Cycle Test

□ Manufacturer Pullout Strength

× Displacement after Cycling

Fig. 4.7. Results of Pullout Tests After Cycling

*Shear .856 kip



● Pullout Strength (Average) from Shear Tension Test for Pure Tension
○ Pullout Strength after Low Cycle Test
△ Pullout Strength after High Cycle Test
□ Manufacturer Pullout Strength
x Displacement after Cycling

Fig. 4.8. Results of Pullout Tests After Cycling

5.0 TASK 3 - DEVELOPMENT OF ANALYTICAL TECHNIQUE FOR BASE PLATE - ANCHOR BOLT ANALYSIS

5.1 Introduction

The lack of consistent design procedures for base plates and expansion anchor bolts has been discussed in the literature for a significant period of time. Base plate behavior, when subjected to moment and vertical load, is dependent upon several variables. As the moment increases with respect to the vertical load, the plate will bend, the tension in the anchor bolts will increase, and the compressive stress distribution in the concrete will become increasingly nonlinear.

When one reviews the common methods used to design moment resistant base plates, it becomes clear that the complexity of the behavior requires that simplifying assumptions be made. The simplest method used is to assume that the plate rotates rigidly about one edge and the maximum bolt load can then be solved by static equilibrium. This approach is reasonable only if the plate is truly rigid and rotation about an edge does occur.

A more sophisticated method involves the use of a concrete beam analogy. This approach allows the designer to consider three important variables: force in the anchor bolt, reaction force in the concrete and the location of the concrete reaction. The use of concrete beam analogy is inherently more accurate than the rigid plate assumption since it considers more variables. However, the plate stiffness is not specifically included; only the assumption that a triangular-shaped stress distribution is developed in the concrete. For biaxial bending, the common approach is to consider the bending moments independently, then sum the calculated bolt load.

5.2 Finite Element Analysis

In order to analyze flexible base plate behavior, a finite element technique was developed using the ANSYS computer program. The base plate is idealized as a mesh of plate elements connected at the corners or nodal points. The concrete is represented by spring elements attached to the nodal points and to the ground. These spring elements have the capability of resisting compressive forces in the vertical direction only. Since the element cannot resist tension, the nodal points are free to translate in the vertical up direction.

The same element type is used to represent the anchor bolts. In this case, the element will resist tension only. However, a rotational spring element may be activated by the user if moment resistance of the bolt is required.

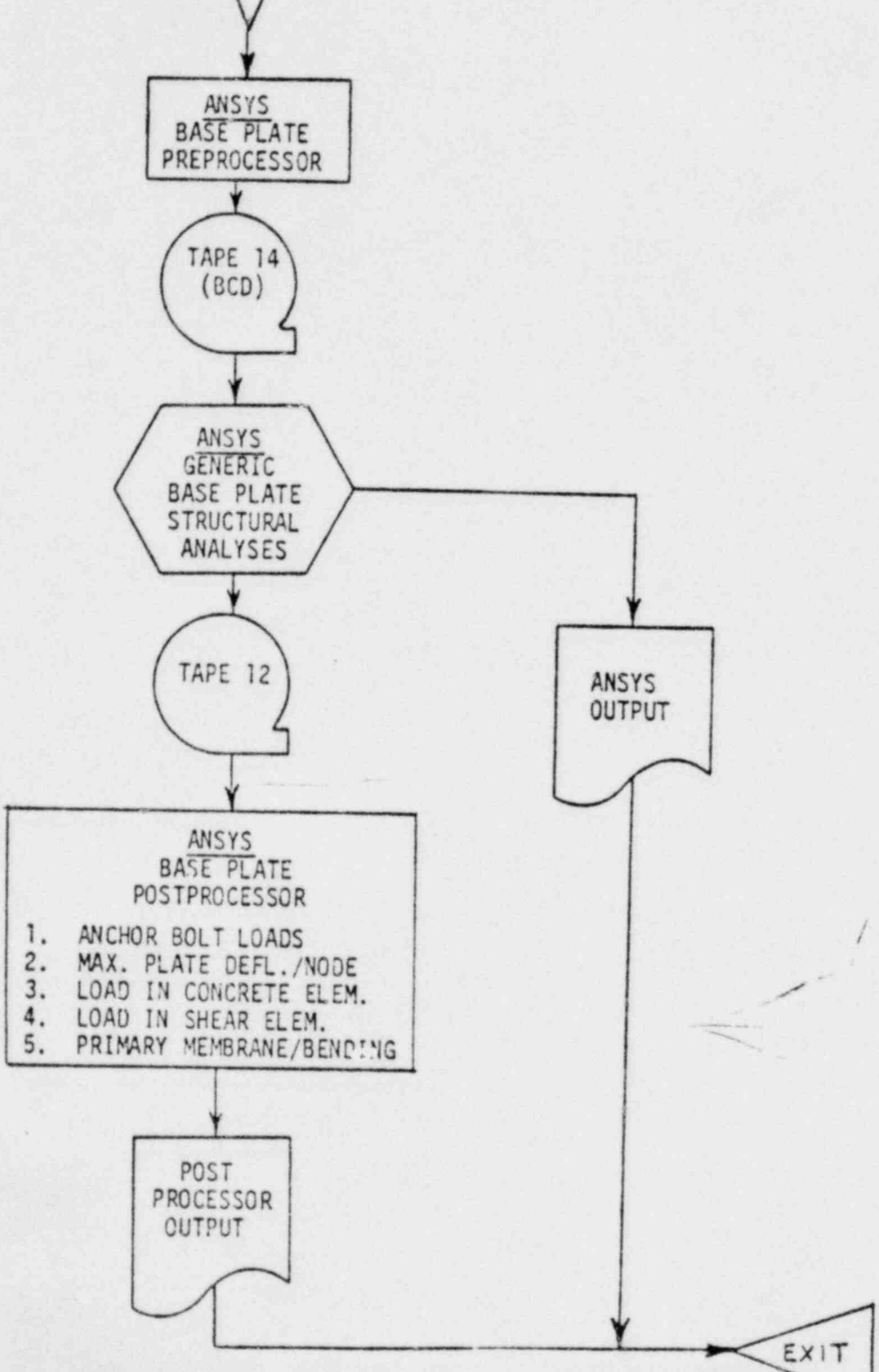
For the plate elements, flat quadrilateral shell elements are used. This element has both bending and membrane capabilities, and both in-plane and normal loads are permitted. The element can accomodate six degrees of freedom at each node.

The effect of varying the fineness of the finite element mesh was studied in order to develop a mesh size that provided a reasonable solution without requiring excessive computer time.

5.3 Generic Computer Program

Using the finite element techniques described in 5.2 above, TES developed a pre and post processor compatible with the ANSYS program to be used in evaluating loads on expansion anchors. From a minimum amount of input, the pre-processor generates the entire ANSYS input file. The post processor retrieves information from an ANSYS binary file and computes and tabulates information critical to the base plate. The flow diagram in Figure 5.1 defines the basic operational system.

Figure 5.1


ANSYS
BASE PLATE
PREPROCESSOR
TAPE 14
(BCD)
ANSYS
GENERIC
BASE PLATE
STRUCTURAL
ANALYSES
TAPE 12
ANSYS
OUTPUT
ANSYS
BASE PLATE
POSTPROCESSOR
1. ANCHOR BOLT LOADS
2. MAX. PLATE DEFL./NODE
3. LOAD IN CONCRETE ELEM.
4. LOAD IN SHEAR ELEM.
5. PRIMARY MEMBRANE/BENDING
POST
PROCESSOR
OUTPUT
EXIT

A summary of pre-processor capabilities follows:

1. Generation of ANSYS input file.

2. Plot of finite element model.

3. The ANSYS STIF63 element is used to model the base plate. It is also used to model the structural member attached. The ANSYS STIF40 element is used to model the anchor bolt (hook-tension only), the anchor bolt shear (linear), and the concrete (gap-compression only). The structural member attached (box, wide flange, angle, channel) is modeled with a single layer of elements. Typical base plate configurations are shown in Figures 5.2 through 5.15. The preprocessor input parameters are defined in Section 5.4.

4. The loading is applied to a node on the structural member's cross section located at the centroid. This cross section is modeled as a rigid body in accordance with beam theory (i.e., plane sections remain plane). Six degree-of-freedom loading is permitted. These loads (forces and moments) have the coordinate system orientation of the base plate configuration. The preprocessor will prevent execution of ANSYS if anti-symmetric loads are applied to half models.

5. The preprocessor internally divides the half model loads by two to account for symmetry.

6. Ability to add or delete anchor bolts.

7. Wave front minimization to reduce computer costs.

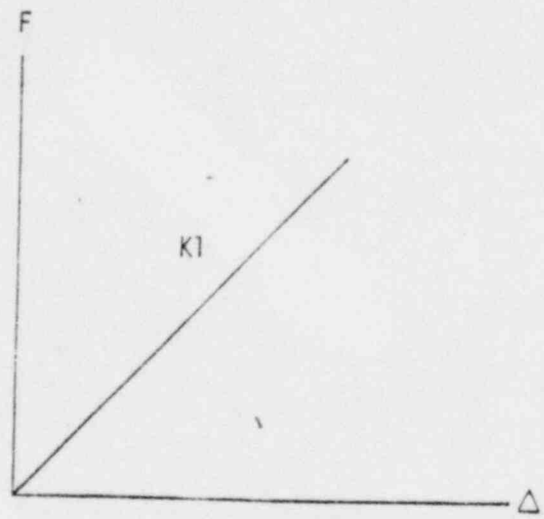
8. Capability to eliminate concrete springs.

9. Capability to move the attachment within the bolt line boundary.

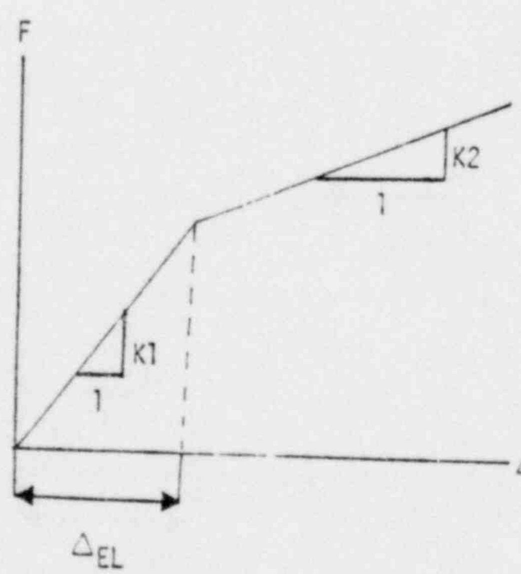
10. Capability to apply a six degree-of-freedom loading at the centroid at the attachment.

11. Linear or bilinear tension-no compression bolt properties can be considered. Anchor bolt material laws available in the pre processor are shown below.

Linear Tension-No Compression



Bilinear Tension-No Compression



12. The theory outlined below is used by the preprocessor to compute concrete spring stiffness. The following equation represents the displacement of a half space resulting from a rectangular distribution of load.

$$W_{AVE} = \frac{mP\ (1-v^2)}{E\ \sqrt{A}}$$

W_{AVE} = deflection

m = numerical factor (assumed .95) depending on the ratio of base plate side lengths

P = total load

v = Poisson's ratio

E = modulus of elasticity

A = surface area of base plate

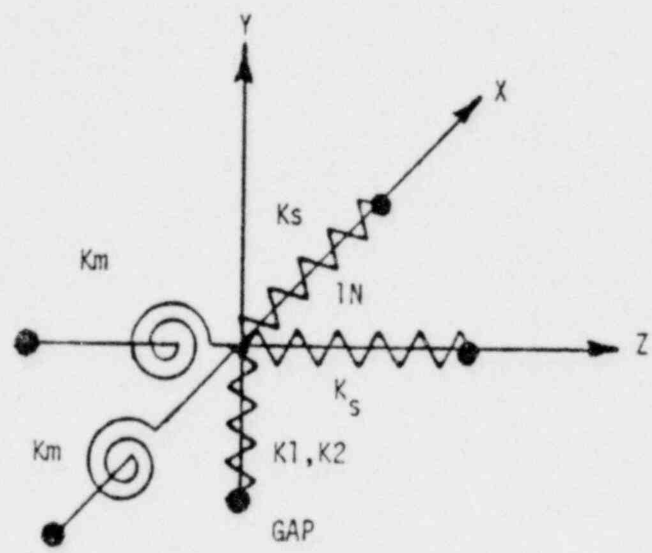
K = stiffness

The above equation is transformed to the following form of base plate total stiffness.

$$K = \frac{P}{W_{AVE}} = \frac{E\ \sqrt{A}}{m\ (1-v^2)}$$

This total stiffness is applied to the base plate by individual spring stiffness at nodes. These individual spring stiffnesses are proportioned according to their contribution area. The post processor then list each spring force as well as average concrete stress.

13. Shear and moment anchor bolt stiffnesses may also be used to represent anchor bolts.



● = supported node

Km = rotational stiffness

Ks = shear stiffness

K1 = axial stiffness (linear)

K2 = axial stiffness (bi-linear)

Figure 5.2
Box Column Half Model

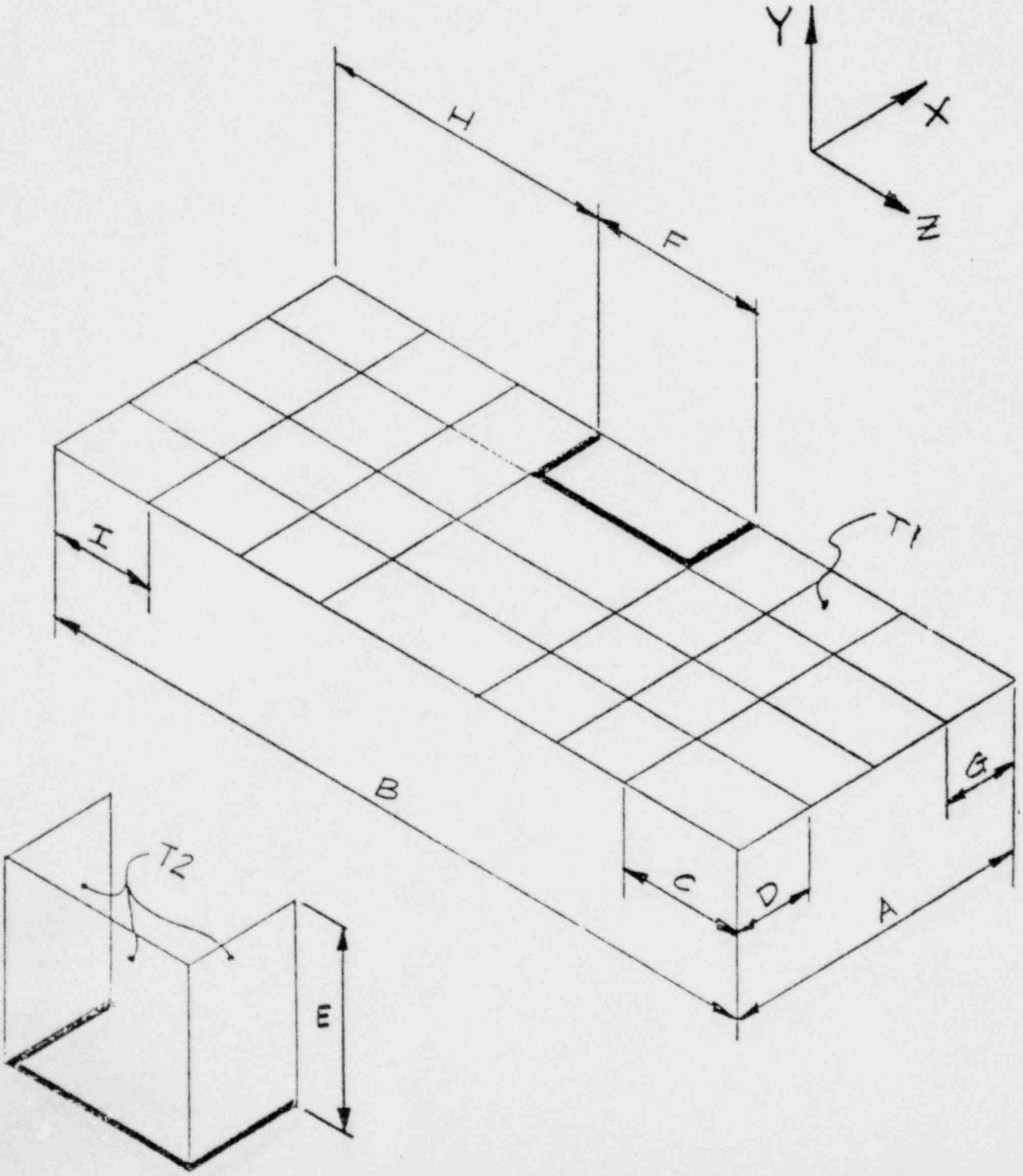


Figure 5.3 Box Column Half Model Node Numbering

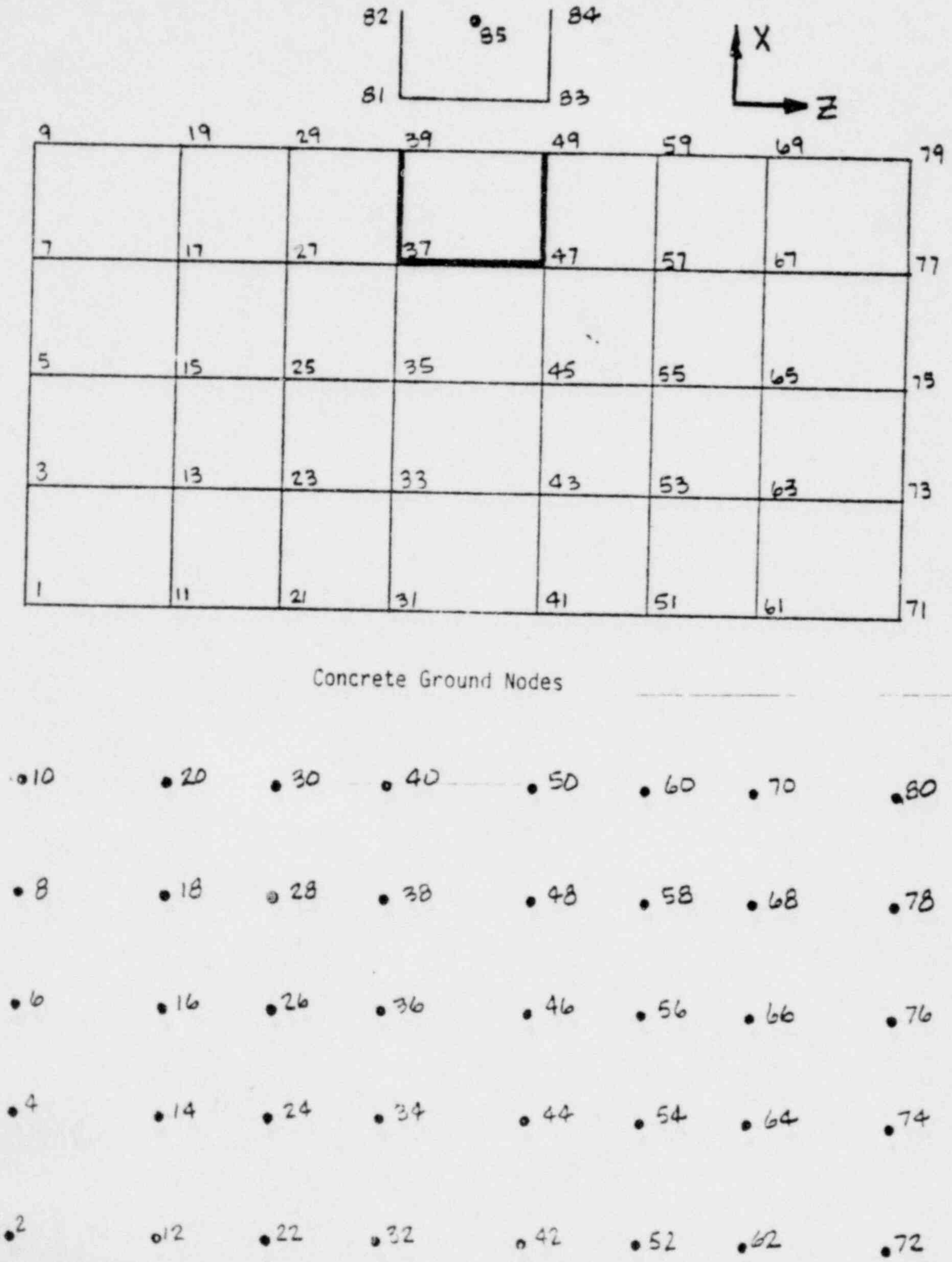


Figure 5.4

Box Column Full Model

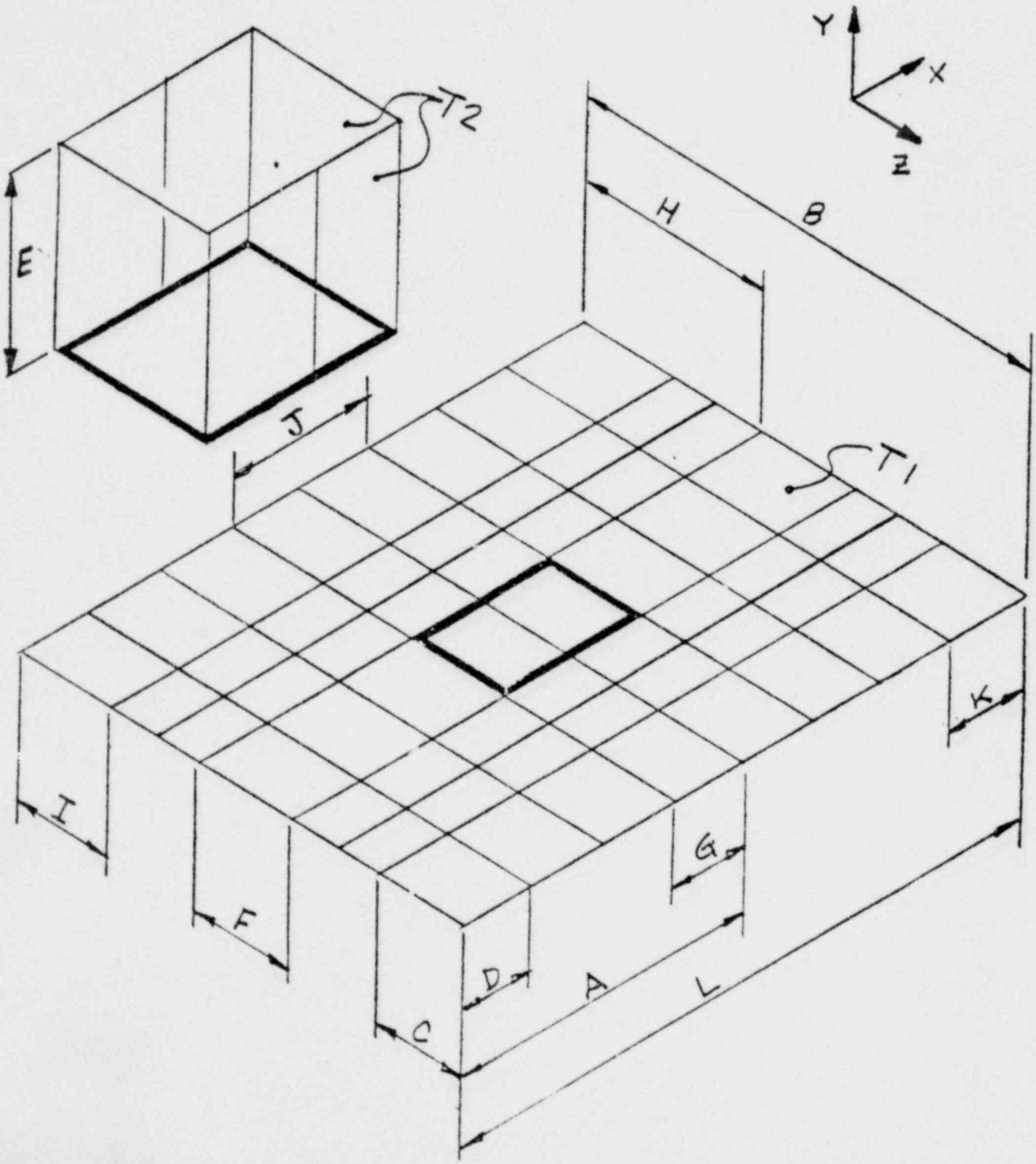


Figure 5.5 Box Column Full Model Node Numbering

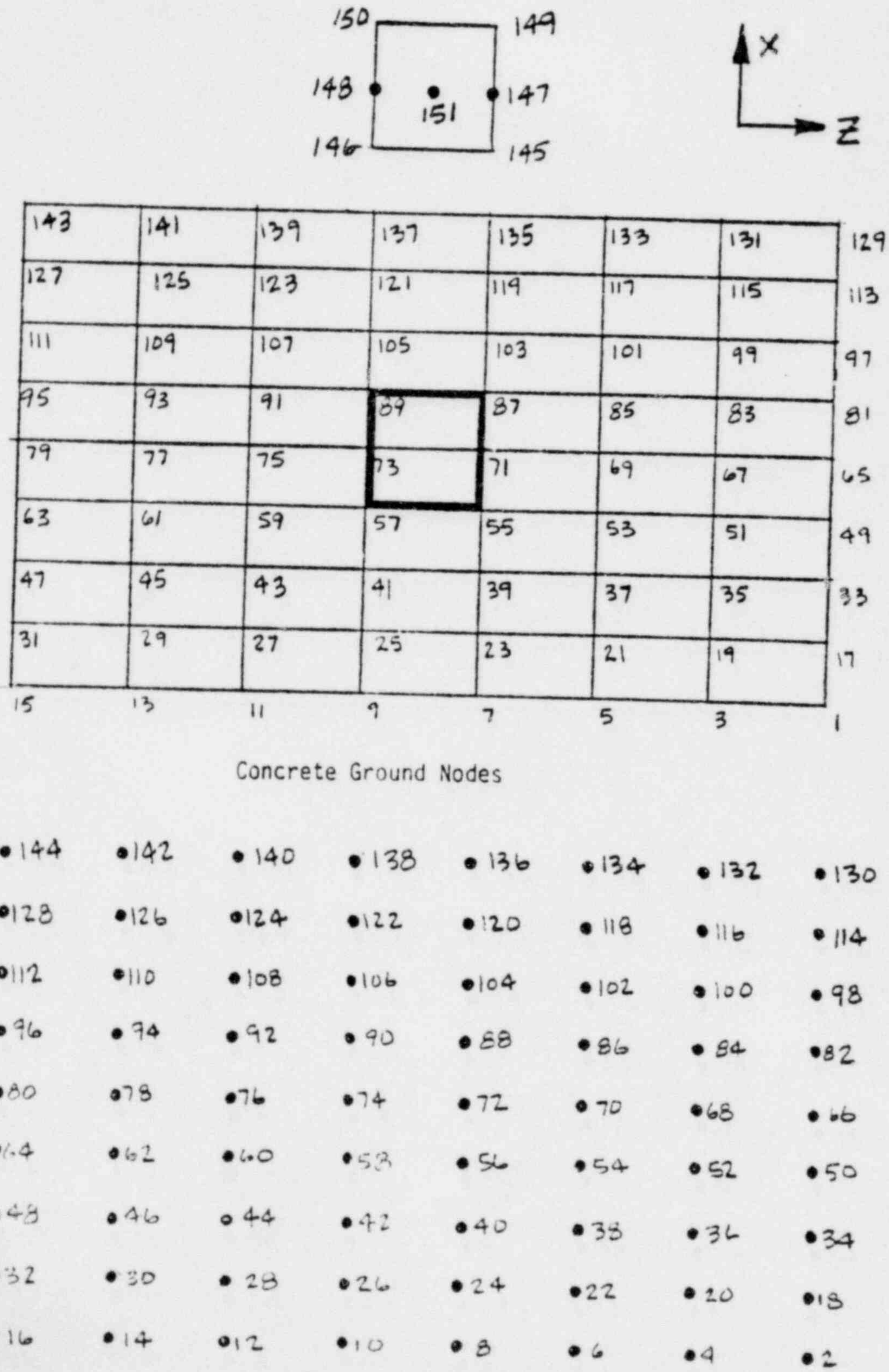


Figure 5.6

Wide Flange Half Model

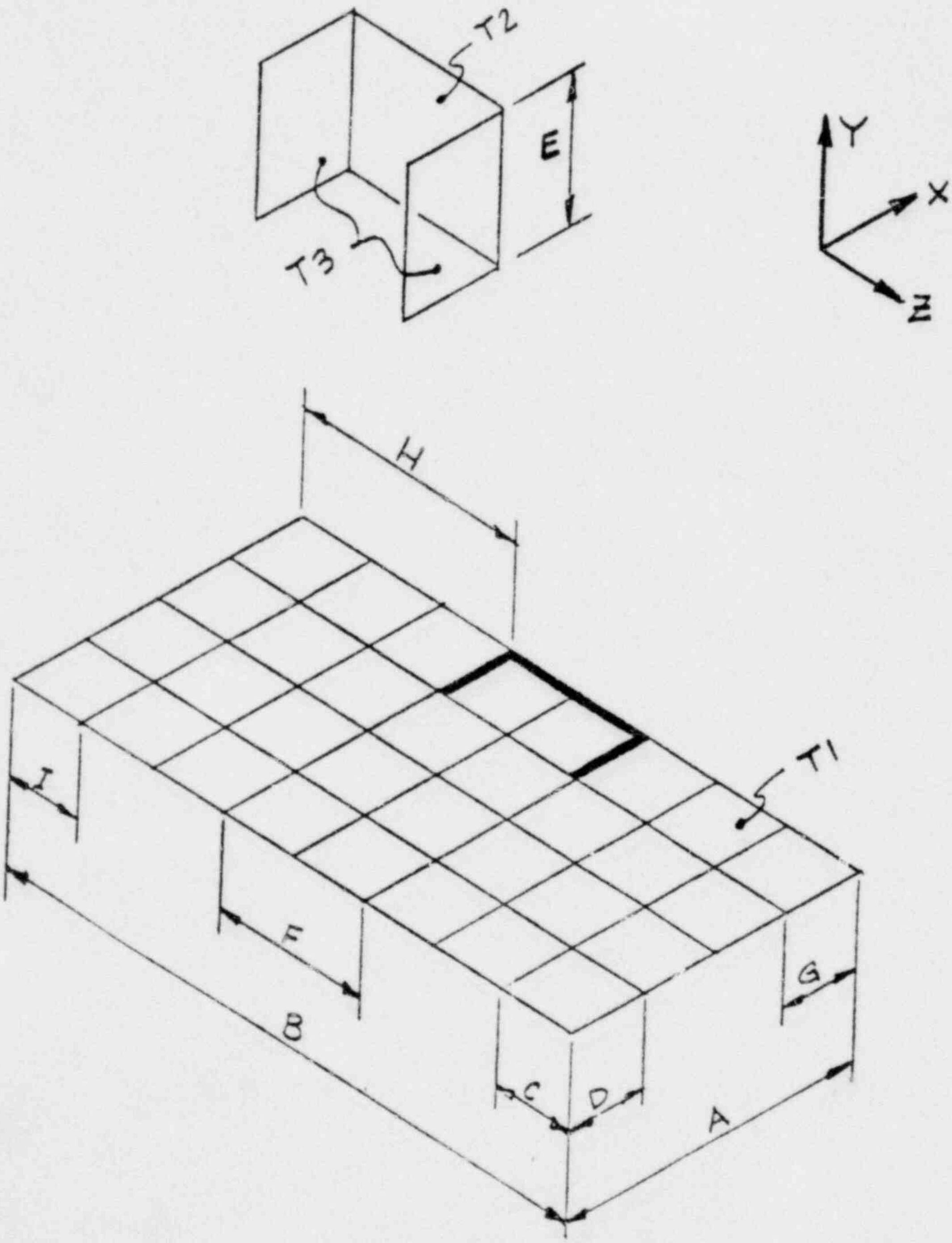


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Figure 5.7

Wide Flange Half Model Node Numbering

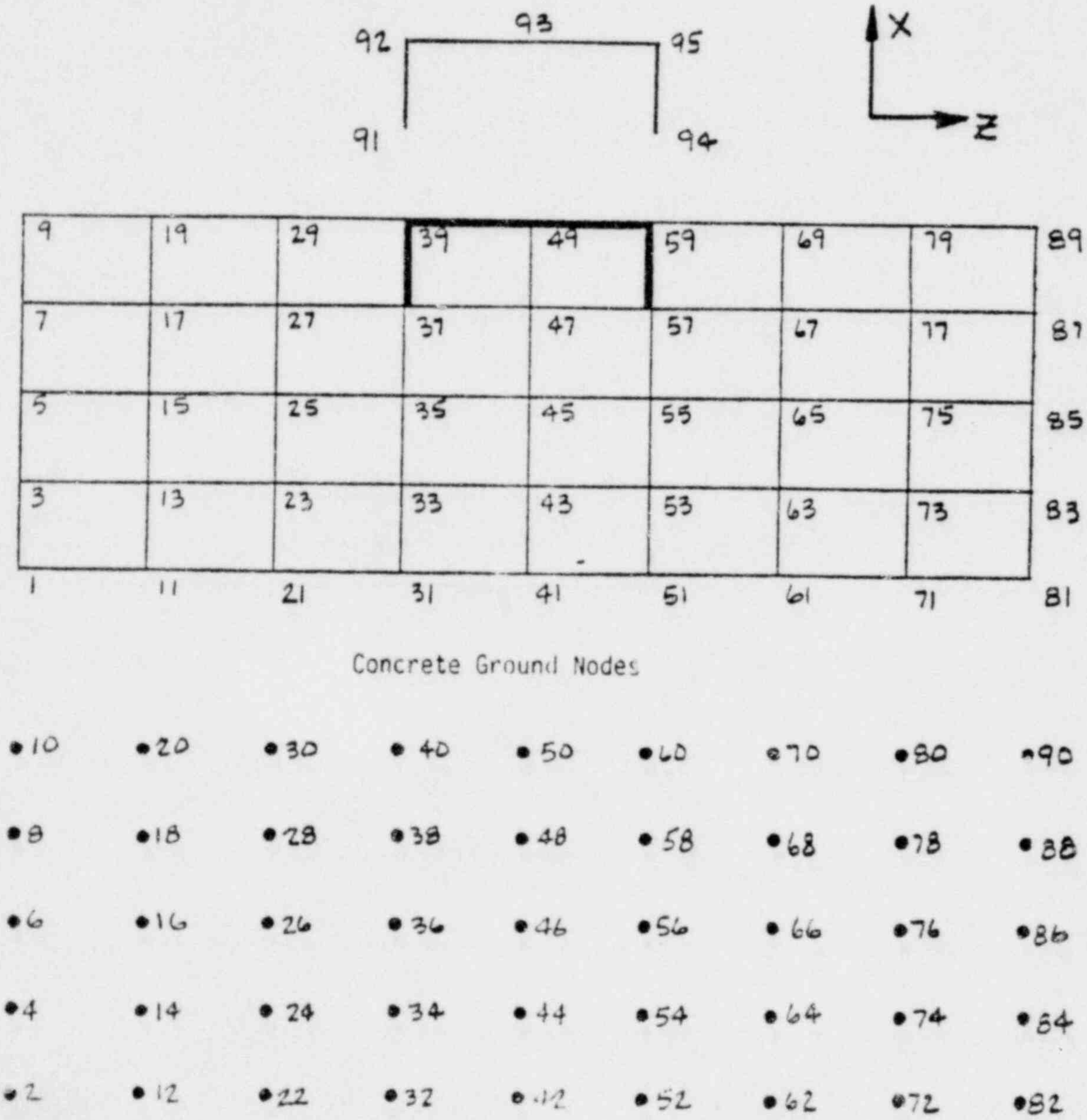


Figure 5.9
Wide Flange Column Full Model Node Numbering

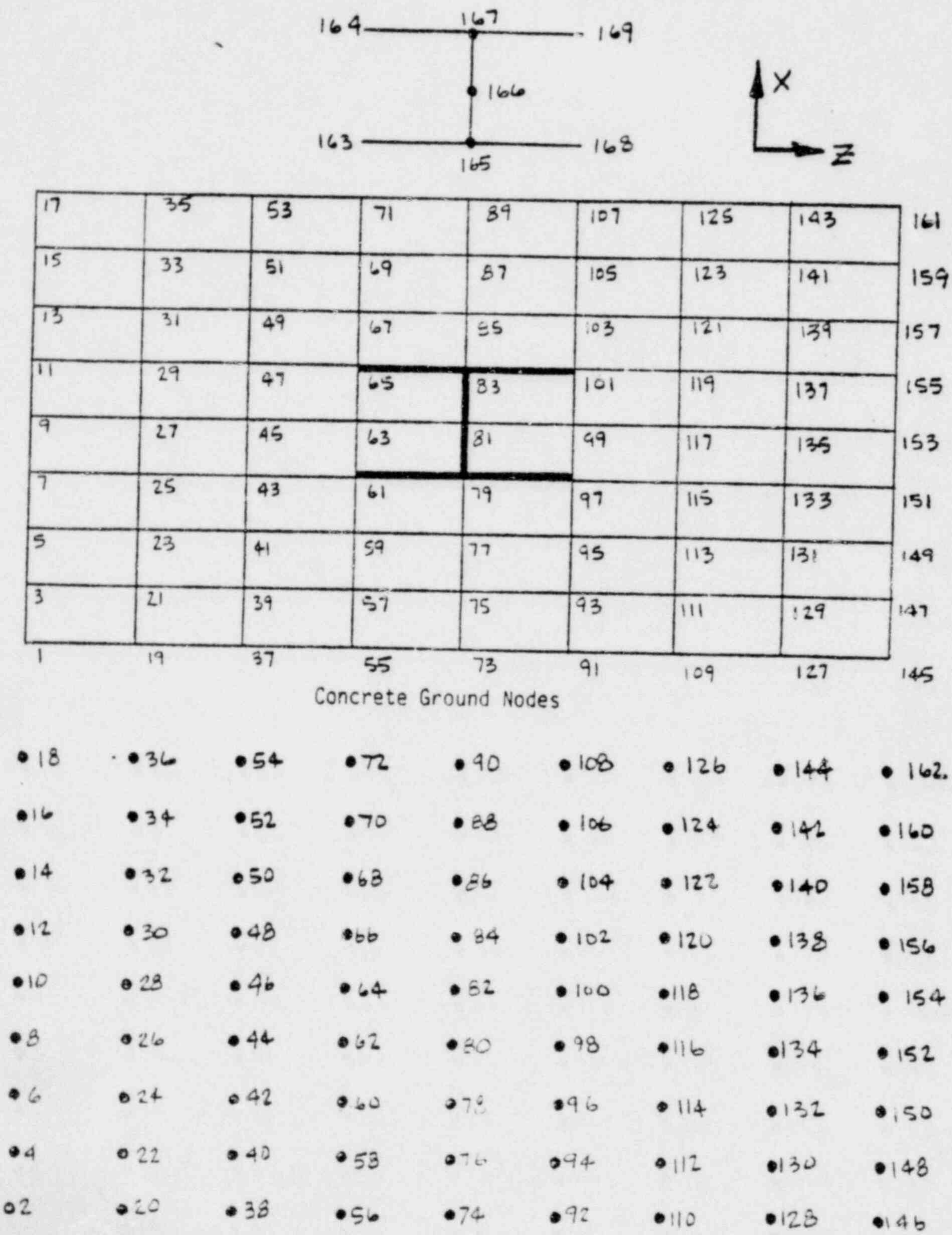
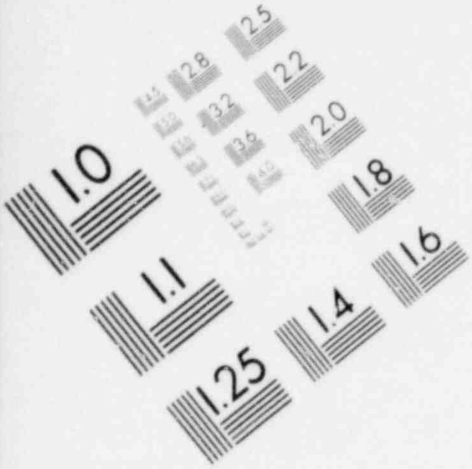


IMAGE EVALUATION TEST TARGET (MT-3)

6″



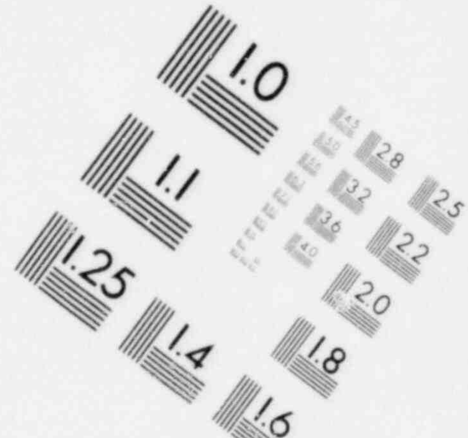
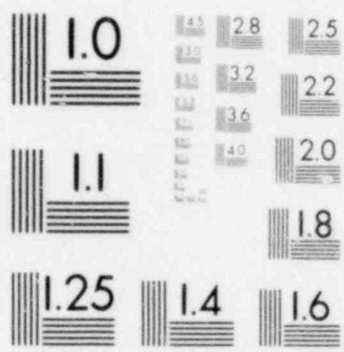
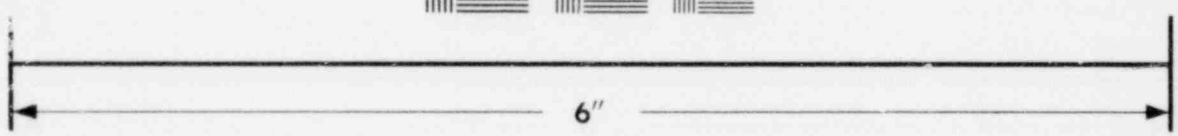
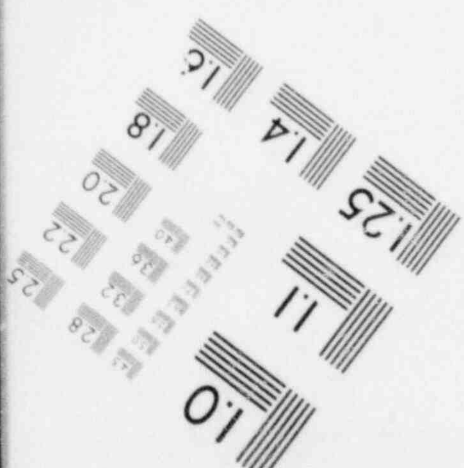


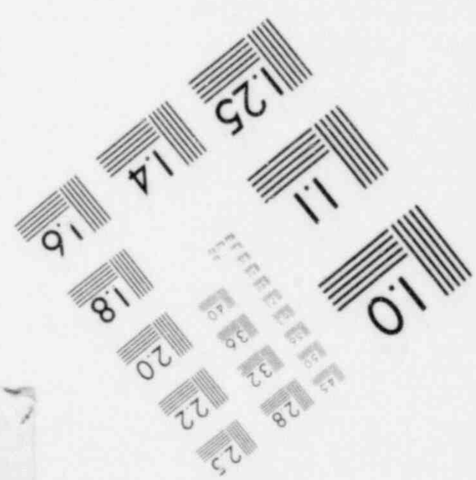
IMAGE EVALUATION TEST TARGET (MT-3)

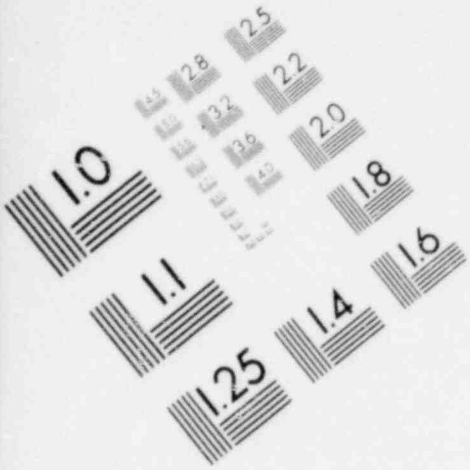




6″







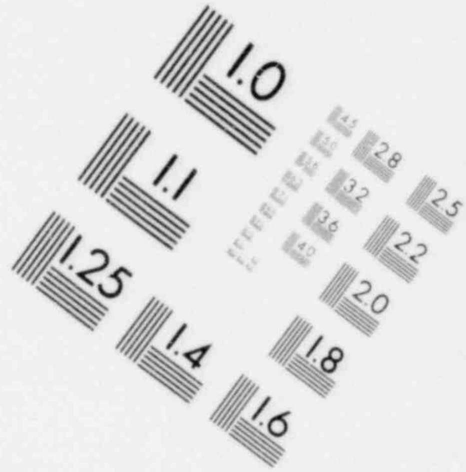
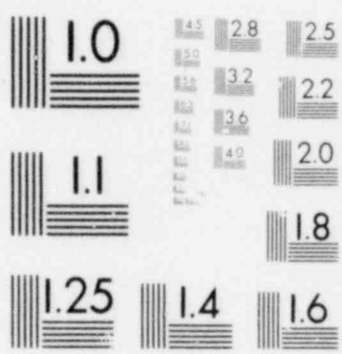
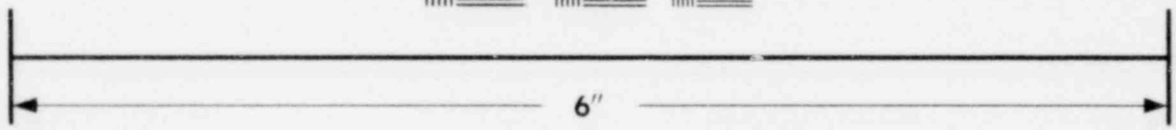
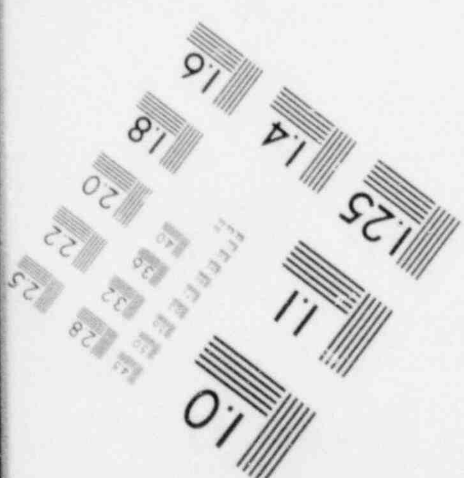


IMAGE EVALUATION TEST TARGET (MT-3)







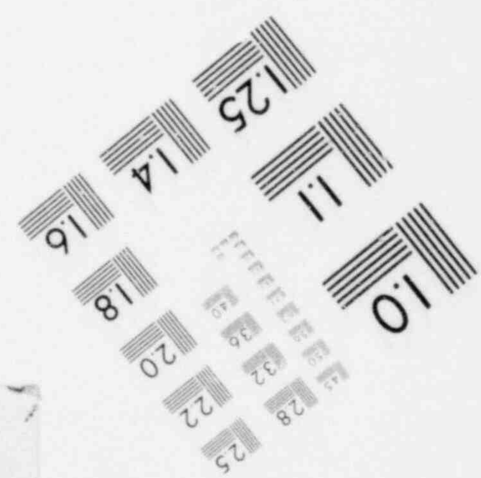


Figure 5.10

Channel Column Half Model

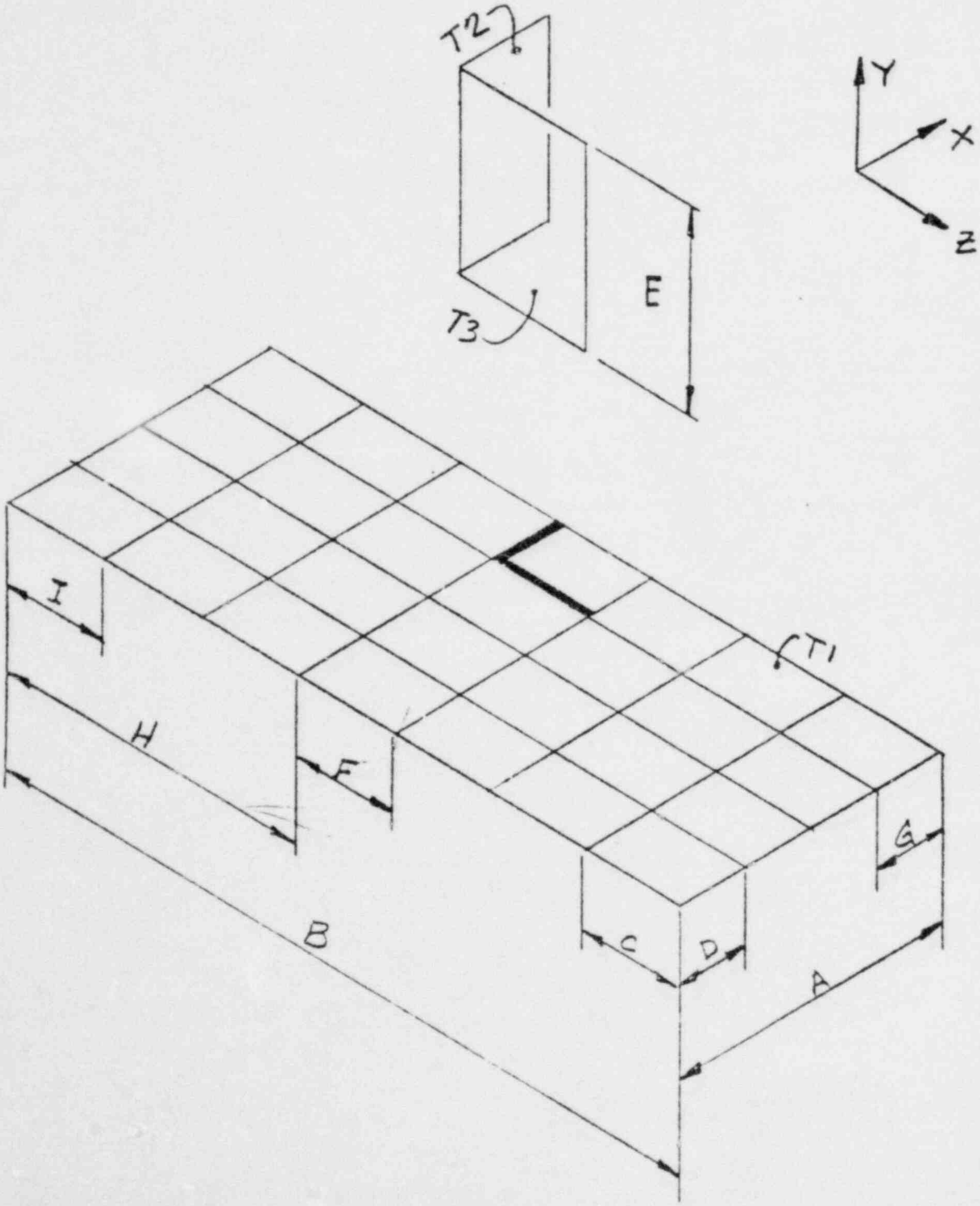


Figure 5.11

Channel Column Half Model Node Numbering

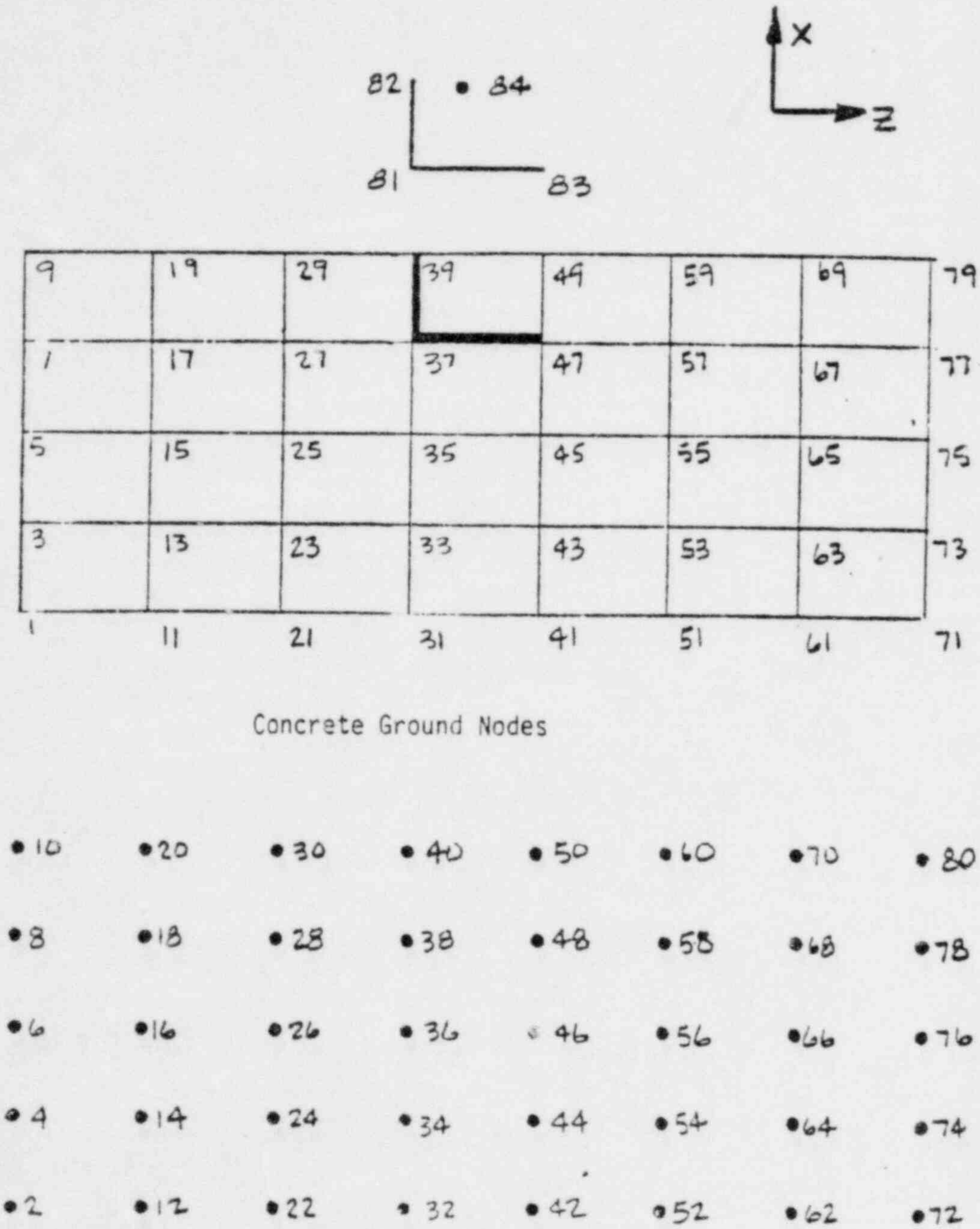


Figure 5.12

Channel Column Full Model

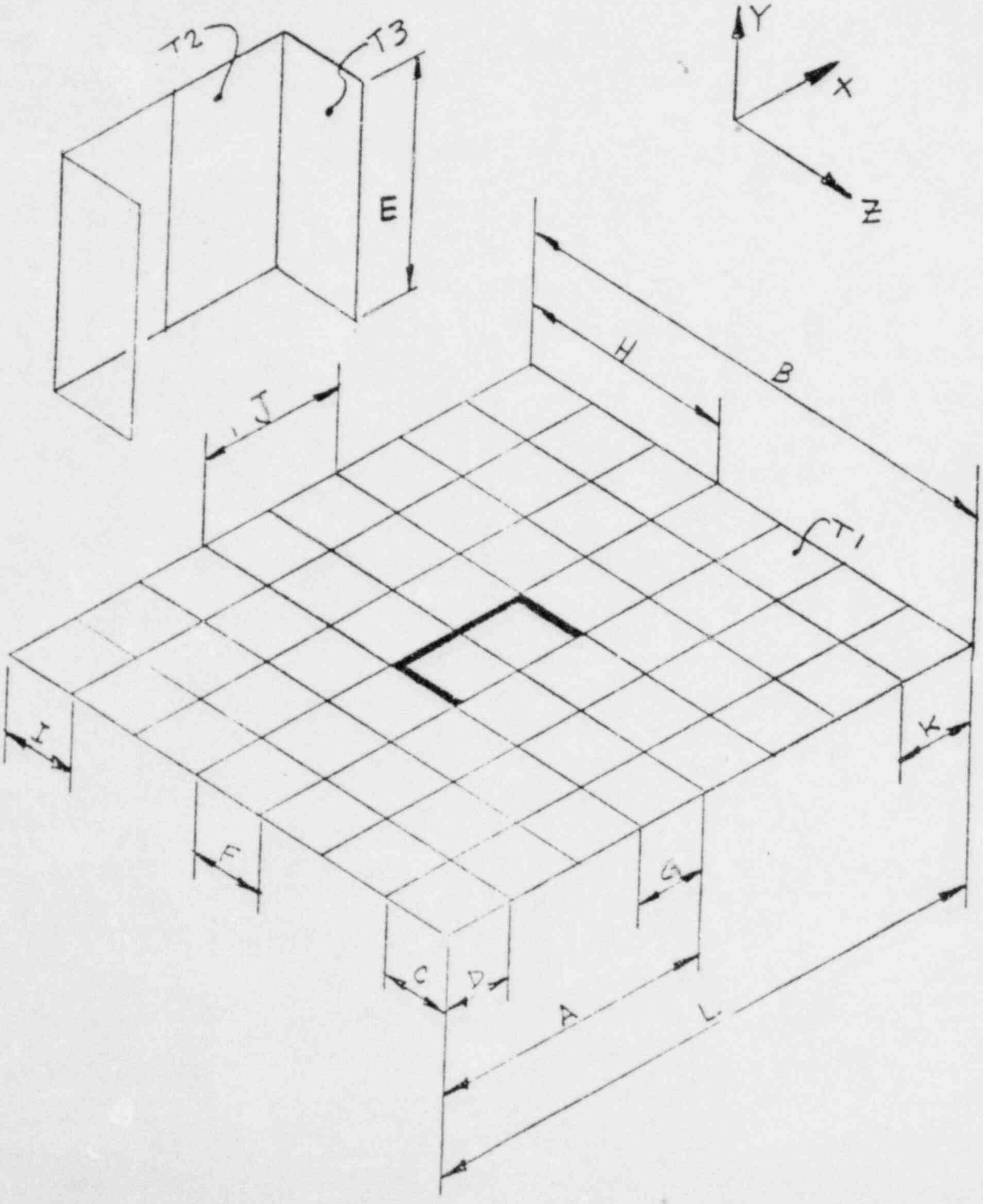


Figure 5.13

Channel Column Full Model Node Numbering

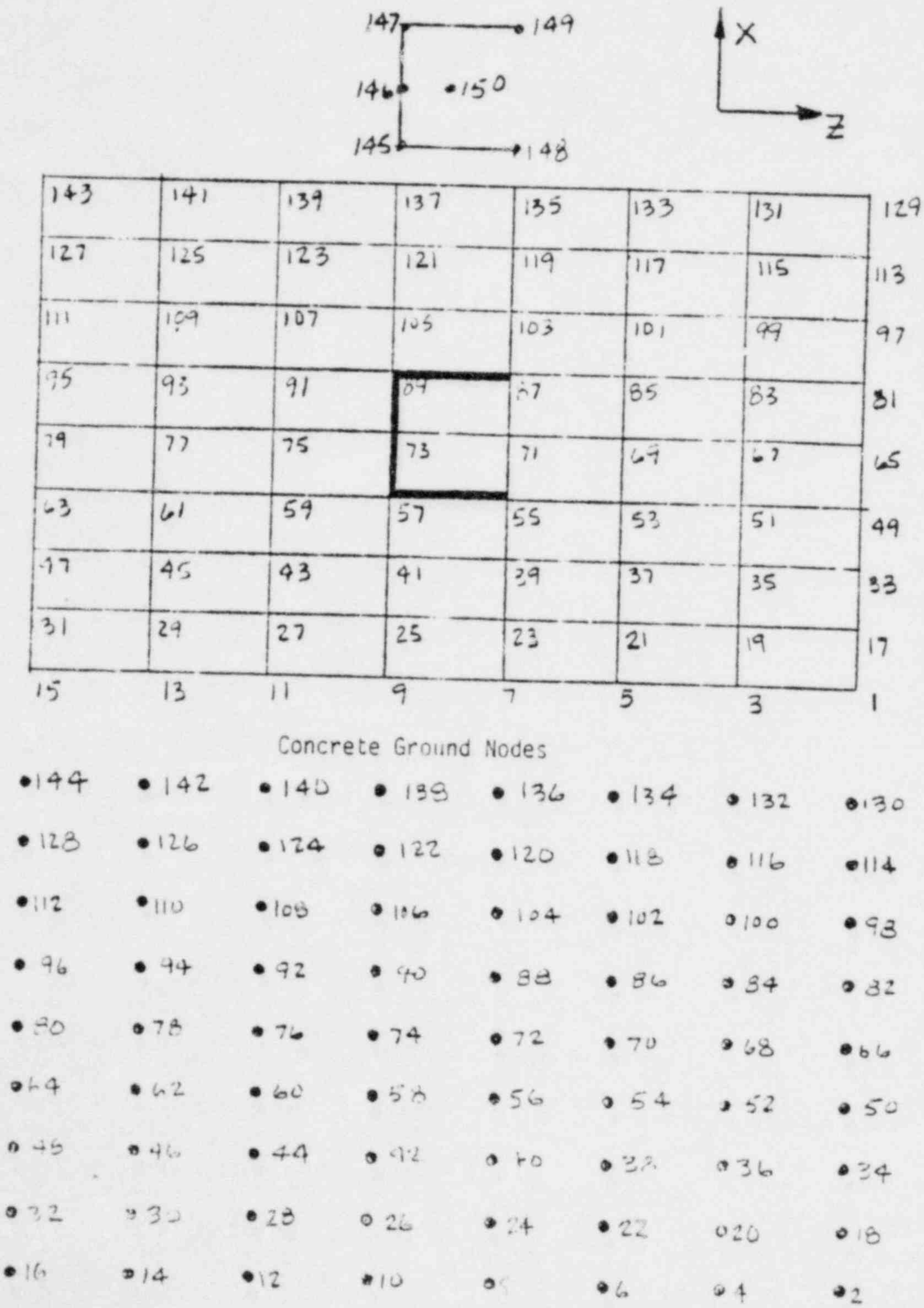


Figure 5.14
Angle Column Full Model

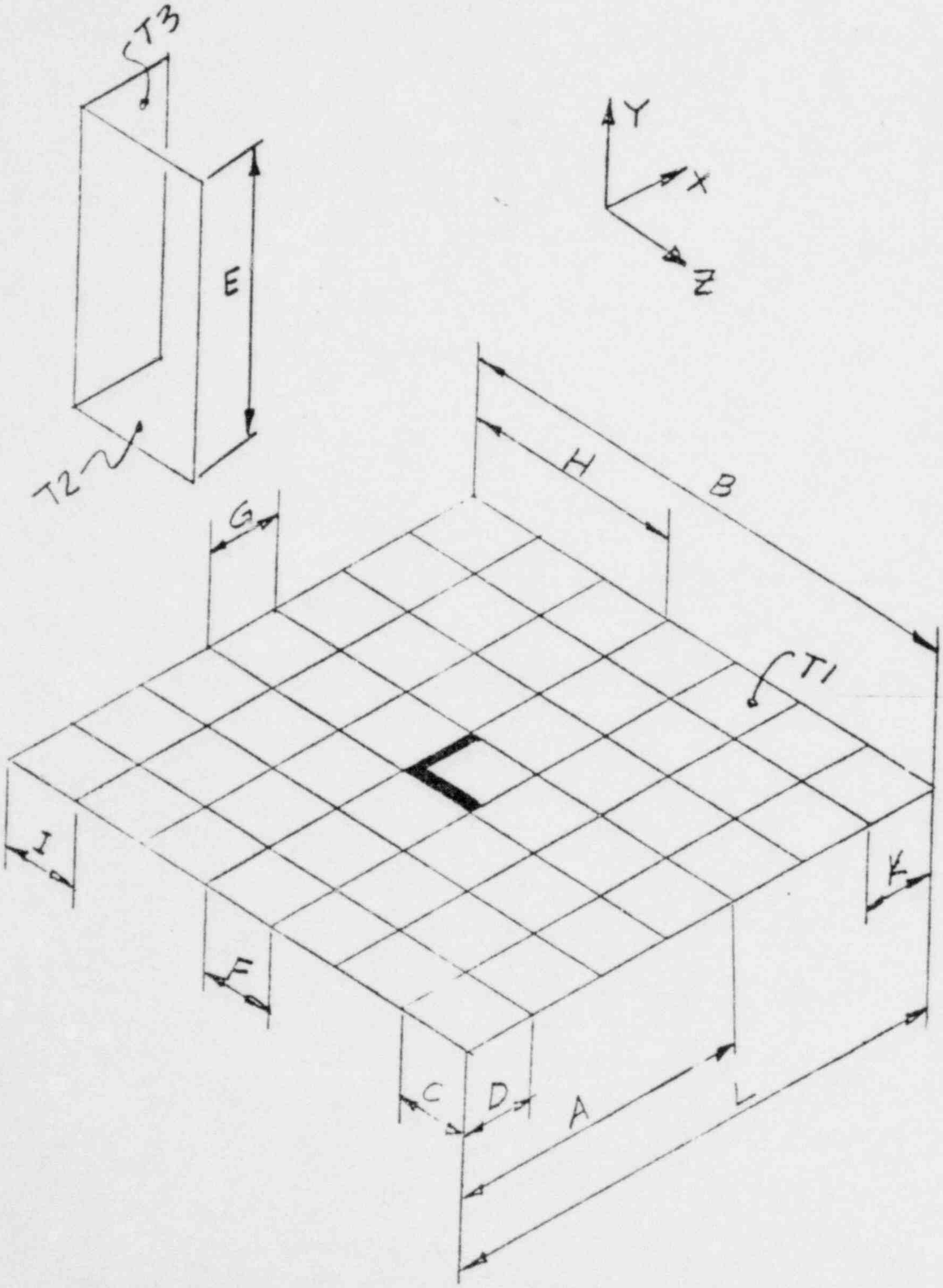
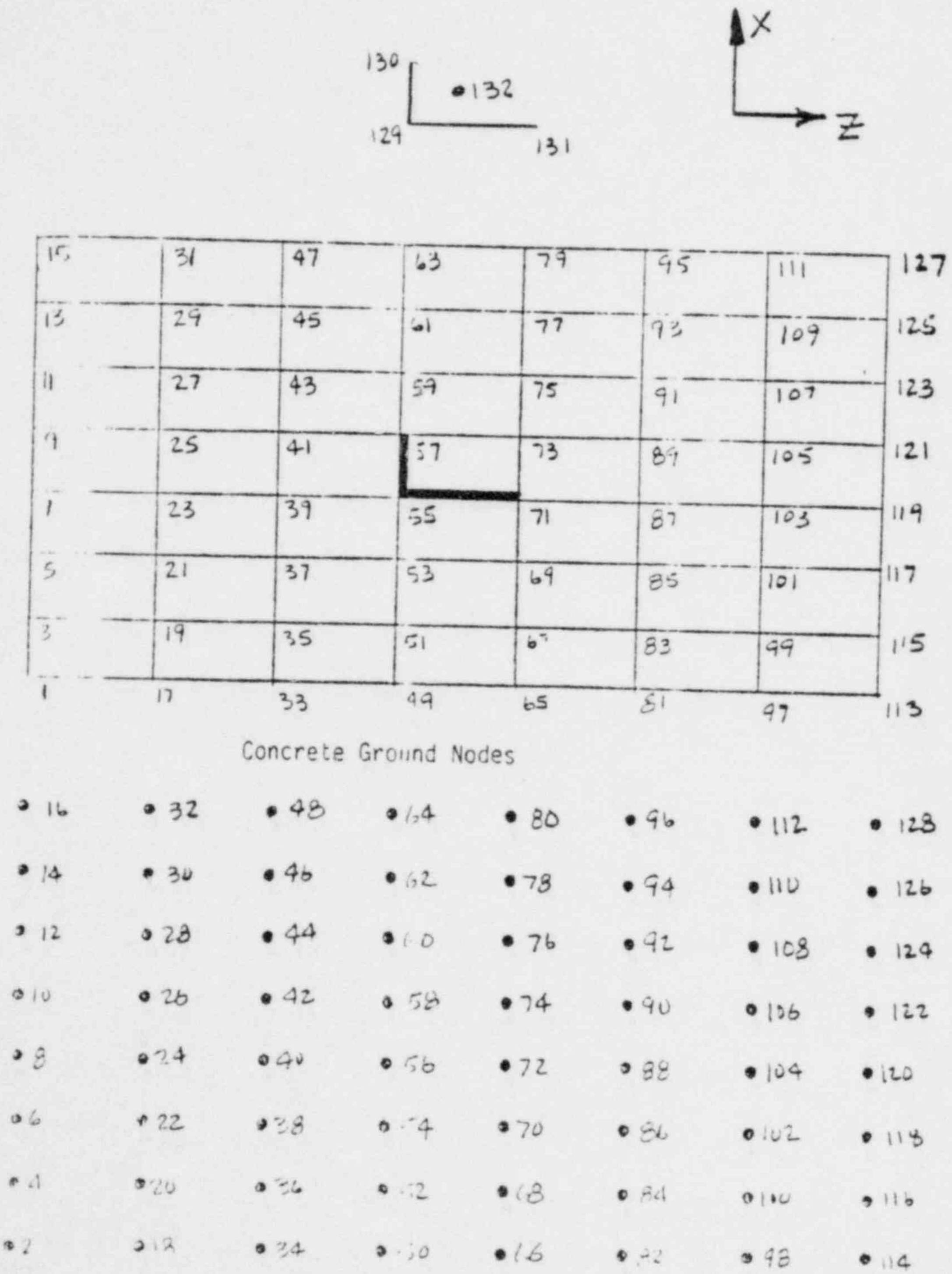


Figure 5.15

Angle Column Full Model Node Numbering



From the results of the last iteration in the ANSYS solution, certain information is required. The post processor reads an ANSYS output file and computes and tabulates anchor bolt loads, maximum plate deflection and node it occurs at, the load in the concrete and shear elements and the average bending stresses across the length and across the width of the plate. A sample problem is included below to show the post processor printout for a typical base plate.

Model Description: Channel column half model
18" x 18" base plate

Loads: MX load = 2500. in-lbs.

Stiffnesses: $K_{bolt} = 0.285 \times 10^6$ #/in

$K_{shear} = .30 \times 10^6$ #/in

$f_c' = 4000$ psi

Dimensions: A = 9.0
B = 18.0
C = 2.25
D = 2.25
E = 3.0
F = 4.5
G = 2.25
H = 6.75
I = 2.25

Thickness: T1 = 1.5 (Plate)
T2 = 0.5 (Column Web)
T3 = 1.0 (Column Flange)

```
CHANNEL COLUMN HALF MODEL MX=2500.
  5 1
  285000.                              300000.            2500.
13 63                                                      4000.
 2  4  6  8 10

     9.        18.      2,25      2,25        3.       4,5      2,25      6,75
   2,25
    1,5        .5        1.
```

```
*****************************************************************************************************
*        PRE PROCESSING FOR BASE PLATE ANALYSIS                                                     *
*        ---------------------------------------------------------------------                      *
*                                                                                                   *
*             SUMMARY OF INPUT                                                                      *
*                                                                                                   *
* CHANNEL COLUMN HALF MODEL MX=2500.                                                                *
*                                                                                                   *
*    MODEL TYPE     5      CHANNEL, HALF MODEL                                                      *
*                                                                                                   *
*                                                                                                   *
*****************************************************************************************************

** LOADING DATA **
   FX        0.
   FY        0.
   FZ        0.
   MX        2500.0
   MY        0.
   MZ        0.

** ANCHOR BOLT PARAMETERS **
   BOLT STIFFNESS K1             .28500E+06
   BOLT STIFFNESS K2             0.
   BOLT ELASTIC DISPL            0.
   BOLT SHEAR STIFFNESS          .30000E+06
   ROTATIONAL STIFFNESS          0.
   CONCRETE STRENGTH             4000.0

** BOLT LOCATIONS **
   15 63  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0

** ELIMINATED CONCRETE SPRING LOCATIONS **
    2  4  6  8 10  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
    0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
    0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0

** DIMENSIONS FOR CHANNEL HALF MODEL **
   A       9.0000
   B       18.000
   C       2.2500
   D       2.2500
   E       3.0000
   F       4.5000
   G       2.2500
   H       6.7500
   I       2.2500

** THICKNESSES **
   PLATE        1.5000
   WEB          .50000
   FLANGE       1.0000
```

```
******************************************************************************
*         POST-PROCESSING FOR BASE-PLATE ANALYSIS                            *
*       ---------------------------------------------                        *
*                                                                            *
*               SUMMARY OF RESULTS                                           *
*                                                                            *
*  CHANNEL COLUMN HALF MODEL MX=2500,                                        *
*                                                                            *
* MODEL TYPE  5       CHANNEL COLUMN, HALF MODEL                             *
*                                                                            *
*                                                                            *
******************************************************************************
```

** DISPLACEMENT SUMMARY (PLATE ONLY), **

* X-DIRECTION *

MAXIMUM

NO.	NODE	VALUE
1	37	.91304E-06
2	35	.55990E-06
3	33	.44921E-06
4	31	.41459E-06
5	23	.32498E-06

MINIMUM

NO.	NODE	VALUE
32	71	-.18878E-06
31	73	-.17757E-06
30	75	-.14723E-06
29	3	-.98038E-07
28	5	-.93096E-07

* Y-DIRECTION *

MAXIMUM

NO.	NODE	VALUE
1	9	.44359E-03
2	7	.43504E-03
3	5	.39817E-03
4	19	.38811E-03
5	17	.37967E-03

MINIMUM

NO.	NODE	VALUE
40	79	-.31387E-04
39	77	-.30460E-04
38	75	-.27095E-04
37	73	-.23710E-04
36	71	-.22554E-04

* Z-DIRECTION *

MAXIMUM

NO.	NODE	VALUE
1	47	.47053E-06
2	59	.36075E-06
3	69	.33684E-06
4	49	.33596E-06
5	57	.32576E-06

MINIMUM

NO.	NODE	VALUE

40	29	-.54159E-06
39	19	-.40713E-06
38	9	-.39779E-06
37	17	-.37449E-06
36	37	-.36628E-06

** ANCHOR BOLTS **

BOLT NO.	NODES		AXIAL FORCE	SHEAR Z	SHEAR X
1	13	14	83.087	-.41111E-02	-.31096E-01
2	63	64	0.	.41111E-02	.11793E-01

CONCRETE SPRINGS - Y DIRECTION

ELEMENT	NODES		FORCE	STRESS
5	12	11	0.	0.
7	14	13	0.	0.
12	16	15	0.	0.
14	18	17	0.	0.
16	20	19	0.	0.
17	22	21	0.	0.
19	24	23	0.	0.
21	26	25	0.	0.
23	28	27	0.	0.
25	30	29	0.	0.
26	32	31	0.	0.
28	34	33	0.	0.
30	36	35	0.	0.
32	38	37	0.	0.
37	40	39	0.	0.
38	42	41	0.	0.
40	44	43	0.	0.
42	46	45	0.	0.
44	48	47	0.	0.
46	50	49	0.	0.
47	52	51	0.	0.
49	54	53	0.	0.
51	56	55	0.	0.
53	58	57	0.	0.
55	60	59	0.	0.
56	62	61	-.37149	-.14676
58	64	63	-1.5460	-.28931
67	70	69	-5.5829	-2.8357
68	72	71	-5.8833	-4.7541
72	80	79	-6.4511	-6.7024
63	66	65	-7.2621	-1.2910
65	68	67	-11.886	-2.4859
69	74	73	-13.587	-5.0092
71	78	77	-15.190	-6.4982
70	76	75	-15.829	-5.7559

AVERAGE BENDING [illegible] GH CROSS SECTIONS OF BASE PLATE

SECTION MODULUS SXX 3.3750

Z AXIS LOCATION	MOMENT ABOUT X	BENDING STRESS
0.	0.	0.
1.13	.151E-08	.224E-09
3.44	198.	29.3
5.82	5[illegible]	87.8
9.15	-10[illegible]	-15.3
12.4	-81[illegible].	-120.
14.7	-439.	-65.1
16.9	-124.	-18.4
18.0	0.	0.

SECTION MODULUS SZZ 6.7500

X AXIS LOCATION	MOMENT ABOUT Z	BENDING STRESS
-9.00	0.	0.
-7.88	-7.04	-1.04
-5.50	63.7	9.43
-3.00	190.	28.2
-.875	283.	41.9
.875	283.	41.9
3.00	190.	28.2
5.50	63.7	9.43
7.88	-7.04	-1.04
9.00	0.	0.

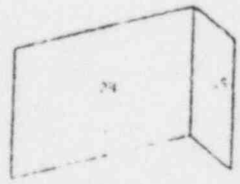
***** ANSYS TWO DIMENSIONAL PLOTS *****
***** END PLOTS *****

TELEDYNE ENGINEERING SERVICES

GEOMETRY ANSYS 1

GEOMETRY ANSYS 2

GEOMETRY ANSYS 3



GEOMETRY ANSYS 4

CHANNEL COLUMN HALF MODEL MY-2509.

5.4 Input Parameters

The following defines the input instructions for the base plate analysis program.

CARD	COLUMN	DESCRIPTION
A		Title
	1-76	Problem Title
B		Model Key and Loading
	2	0-ANSYS output 1-suppress ANSYS output
	4	Model type 1 box column, half model 2 box column, full model 3 wide flange column, half model 4 wide flange column, full model 5 channel column, half model 6 channel column, full model 7 angle column, full model
	6	Plot flag 0-no plot, run 1-plot, run 2-plot, stop
	8	Bolt property flag 0-linear tension-no compression 1-bilinear tension-no compression
	21-30	FX load
	31-40	FY load
	41-50	FZ load
	51-60	MX load
	61-70	MY load
	71-80	MZ load
C		Anchor Bolt and Concrete Parameters
	1-10	anchor bolt axial stiffness K1
	11-20	anchor bolt axial stiffness K2
	21-30	anchor bolt elastic displacement Δ_{EL}
	31-40	anchor bolt shear stiffness
	41-50	anchor bolt rotation stiffness
	51-60	concrete strength (f'c)

CARD	COLUMN	DESCRIPTION
C1	1-3 4-6 7-9 10-12, etc.	bolt locations (specify plate node numbers in sequence, smallest to largest)
C2,C3,C4	1-3 4-6 7-9 10-12, etc.	concrete springs to be eliminated (blank cards if springs are not eliminated)
D		Dimensions
	1-10	A
	11-20	B
	21-30	C
	31-40	D
	41-50	E
	51-60	F
	61-70	G
	71-80	H
D1	1-10	I
	11-20	J
	21-30	K
	31-40	L
E		Thickness
	1-10	T1, plate thickness
	11-20	T2, column thickness, web
	21-30	T3, column thickness, flange

5.5 Base Plate Verification Test

5.5.1 Introduction

As a part of the verification of the analytical techniques used in the Generic computer program, a test was performed on an actual base plate and the results compared with the analytical solution. This experimental-analytical comparison was not done to provide Design Verification in a Quality Assurance sense but rather to demonstrate the ability of the program to conservatively approximate actual results (Design Verification was performed under TES QA requirements and is on file in our Document Control center).

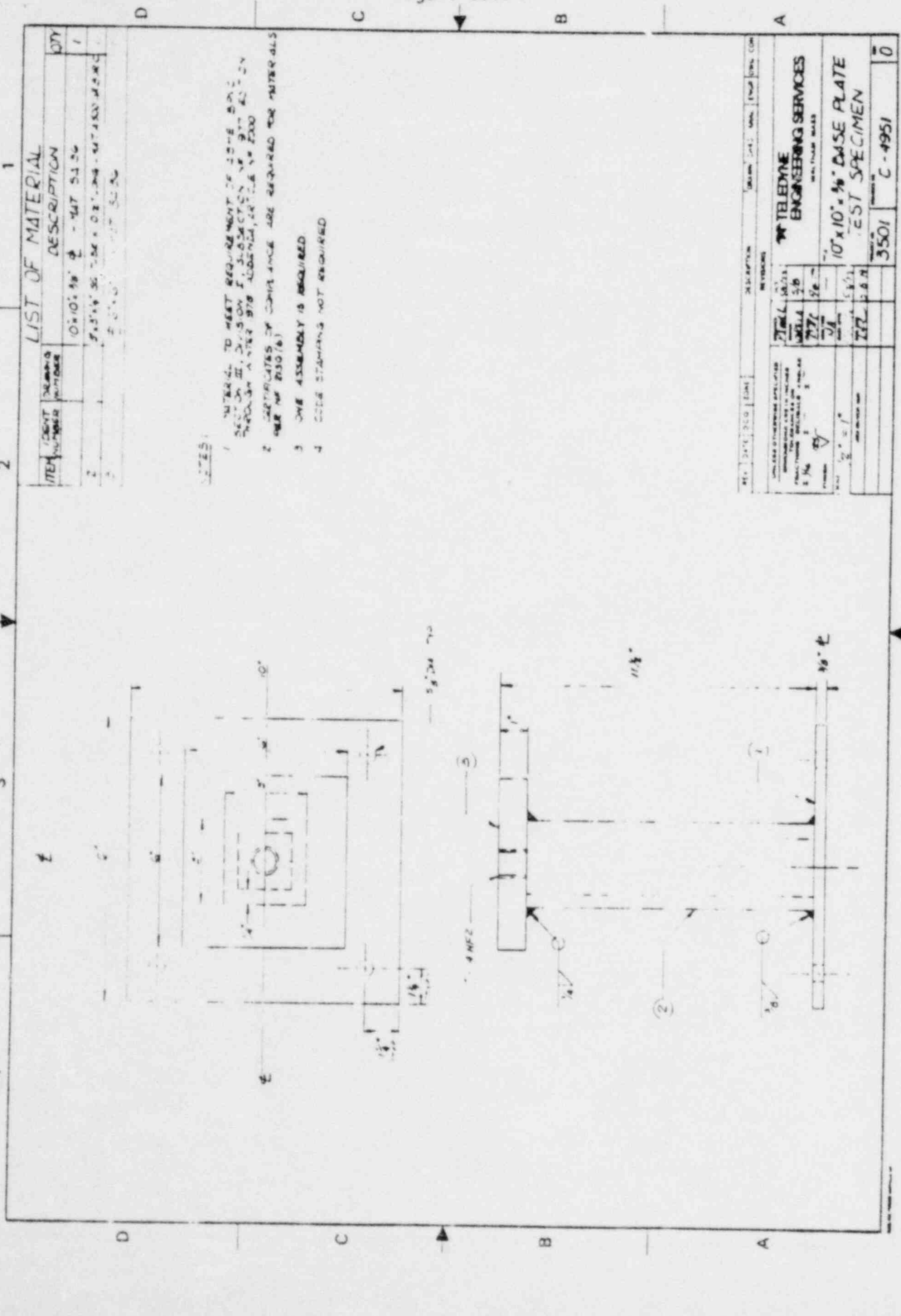
5.5.2 Scope

The following procedure defines the methods and materials used in the testing to verify the accuracy of the base plate computer solutions.

5.5.3 Test Specimen

A four-bolt base plate with a rectangular attachment was utilized to verify the accuracy of the computer base plate solution. The four bolt specimen is shown on Teledyne Engineering Services (TES) Drawing Number C-4951 (Figure 5.16). Four Phillips Red Head snap-off anchor bolts 1/2 inch in diameter were used to anchor the plate to the concrete.

Figure 5.16


LIST OF MATERIAL
ITEM
DESCRIPTION
QTY
NOTES:
ONE ASSEMBLY IS REQUIRED
TELEDYNE ENGINEERING SERVICES
10"x10"x3/8" BASE PLATE TEST SPECIMEN
3501
C-4951

5.5.4 Test Fixturing

The test frame shown in TES Drawing Number D-4953 (Figure 5.17) was anchored to the concrete test slab to provide support for the hydraulic loading jack. The hydraulic loading jack, with a capacity of 30 tons, was used to apply a vertical axial load on the specimen and a horizontal shear moment load on the specimen.

Stands assembled from 1/2 inch steel tubing were used to support dial gages at selected locations on the test piece.

Dial gages were mounted at selected locations on the plate of each test specimen and on each anchor bolt. The dial gages measure vertically up from the surface of the concrete. The dial gages were resting on the surface of the concrete as a reference surface (see Figure 5.18).

5.5.5 Test Instrumentation

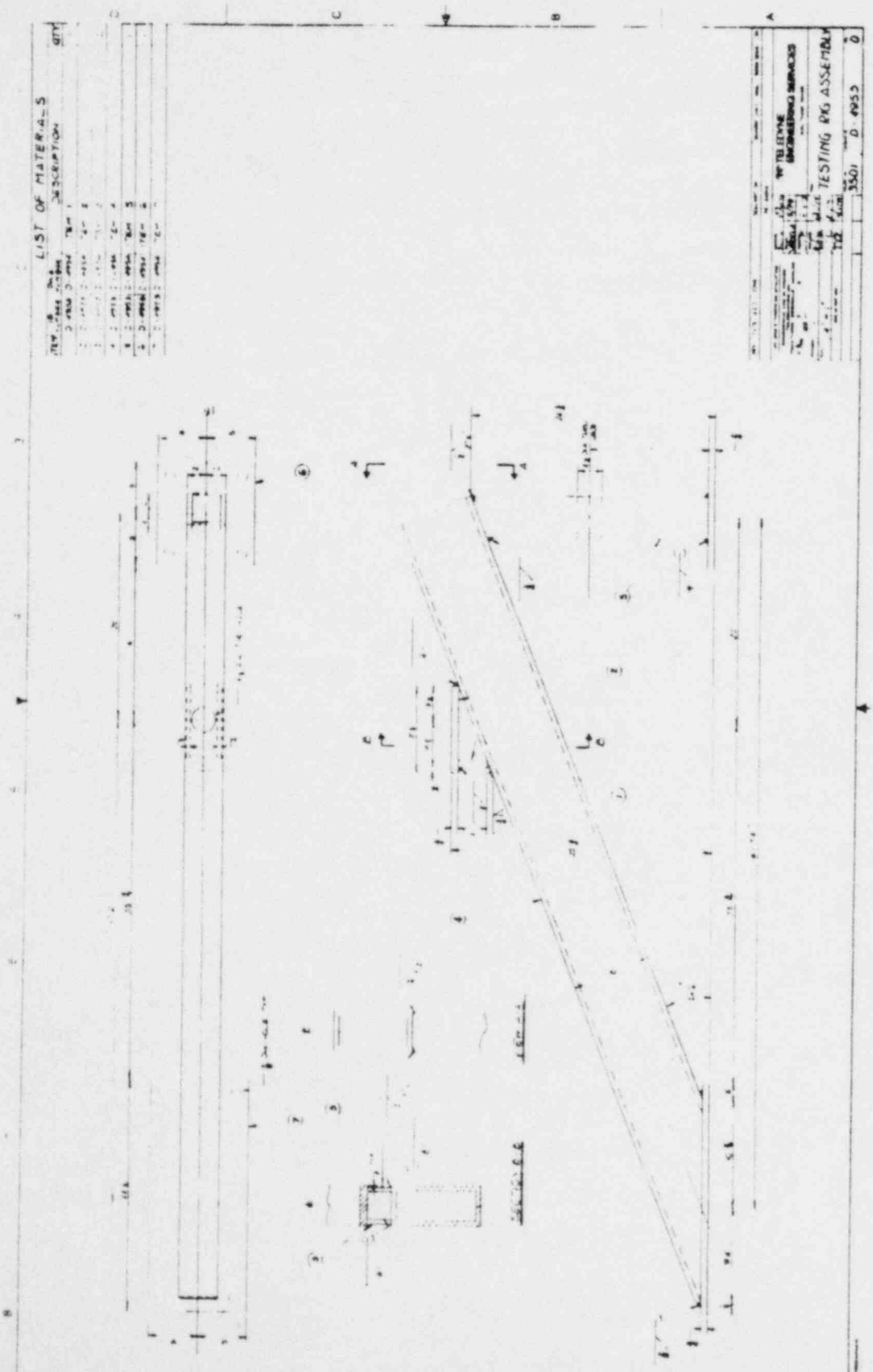
The test specimen was instrumented with strain gage rosettes to measure plate stresses. Five rosettes were applied to the base plate as shown in Figure 5.19.

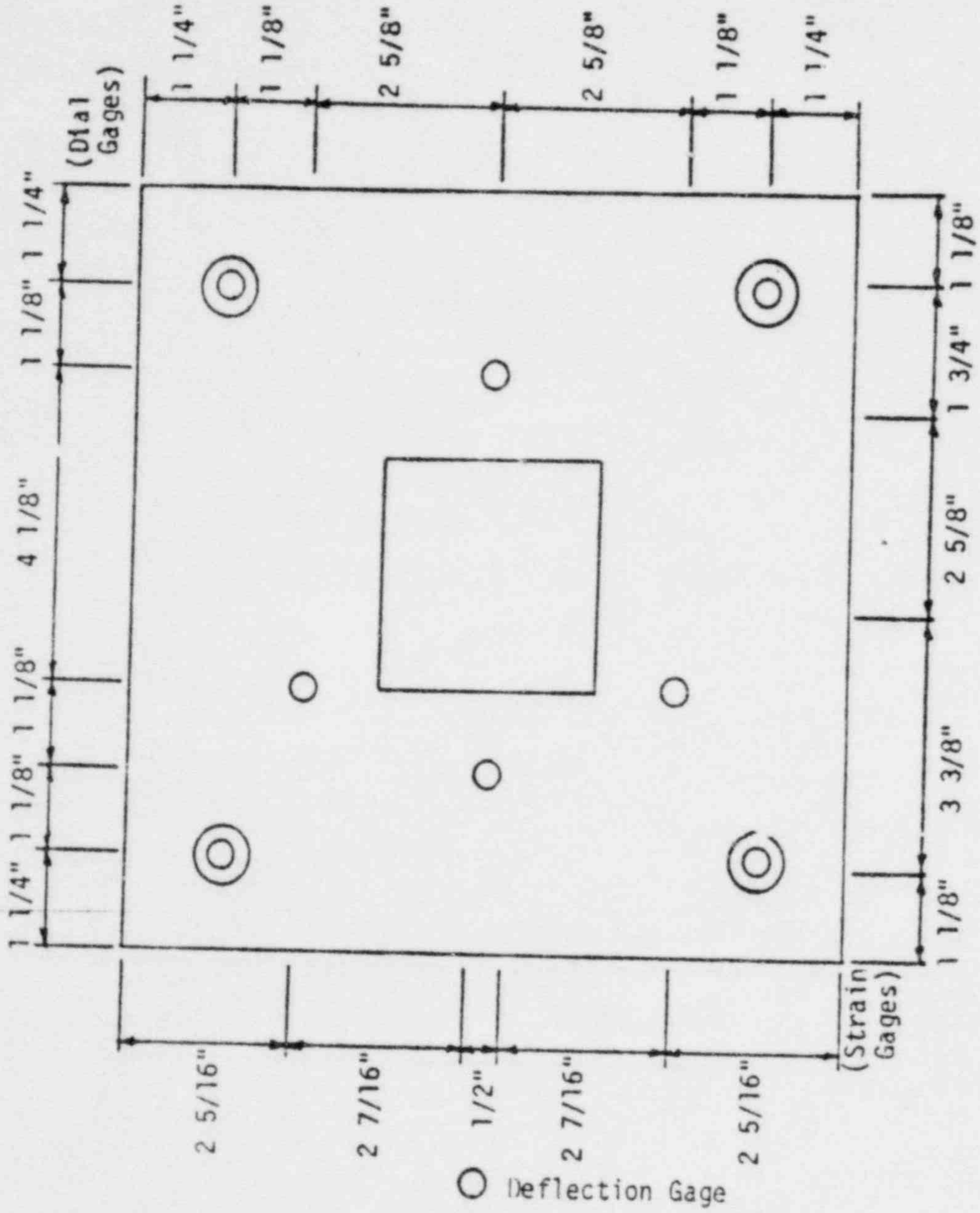
The strain gages applied to the test base plate were weldable type strain gages with a one inch gage length.

Each anchor bolt was instrumented with four strain gages.

Strain gages applied to the bolts were epoxy backed with a 1/8 inch gage length. The gages were bonded to the bolts with Eastman 910 cement.

Figure 5.17


LIST OF MATERIALS
DESCRIPTION
QTY
TELEDYNE ENGINEERING SERVICES
TESTING RIG ASSEMBLY
3501
D
4953
0



Scale: 2/5" = 1"

Figure 5.18

10" x 10" x 3/8" BASEPLATE - TEST PLATE

DIAL GAGE LOCATIONS

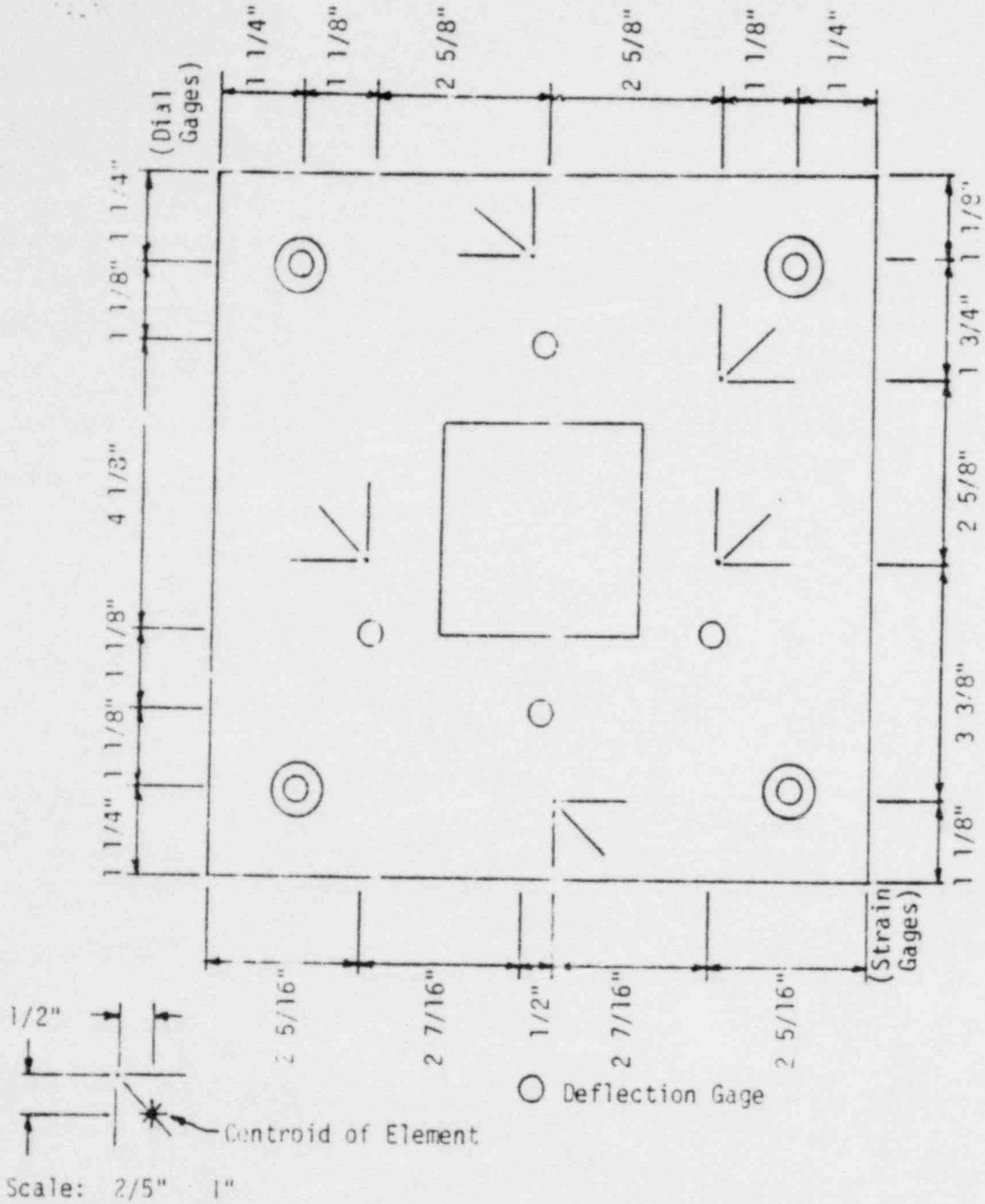


Figure 5.19

10" x 10" x 3/8" BASEPLATE

Strain Gage Locations

A three wire system was used for all strain gages to improve thermal stability.

A Strainsert tension link was used to measure the force applied to the test pieces.

All of the strain gages and the tension link were read with a Strainsert portable indicator. Calibration of the portable indicators were checked just prior to testing.

All instrument calibrations were traceable to National Bureau of Standards.

5.5.6 Base Plate Loading

Loadings applied to the four bolt base plate included axial pullout, uniaxial moment and biaxial moment.

The loading table for the test plate is as follows:

	Applied Load	
Axial (lbs)	Shear Moment 0° (in-lb)	Shear Moment 45° (in-lb)
800	7,200	7,200
2,400	14,400	14,400
4,000	20,000	20,000
5,600	21,600	21,600
6,800		

Readings from all strain gages and dial gages were taken at zero load before loading at each load step and at zero load after loading.

5.6 Comparison of Analytical and Experimental Results

An analytical solution was performed for the four bolt plate described in Section 5.5.3. The generic program was used and bolt load and plate stresses are compared.

Bolt loads from the experimental data were calculated using the following equation.

$$F_{BOLT} = AE\left(\frac{2}{GF}\right)\left(\frac{\varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \varepsilon_4}{4}\right)$$

Where: A = Bolt Area = 0.11 in^2 (at machined location)

E = Young's Modulus = 27.9×10^6

GF = Gage Factor = 2.055

ε = Measured Strain

Plate Stress were calculated from the experimental data using TES Rosette program, where:

$$\sigma_1 = \frac{E}{1 - \nu^2} (\varepsilon_1 + \nu\varepsilon_3)$$

$$\sigma_3 = \frac{E}{1 - \nu^2} (\varepsilon_3 + \nu\varepsilon_1)$$

$$\sigma_{MX}, \sigma_{MN} = \frac{\sigma_1 + \sigma_3}{2} + \sqrt{\left(\frac{\sigma_1 - \sigma_3}{2}\right)^2 + \left[\frac{(\sigma_1 - \sigma_3) \tan \emptyset}{2}\right]^2}$$

Where: $$\emptyset = \tan^{-1}\left(\frac{2\varepsilon_2 - \varepsilon_1 - \varepsilon_3}{\varepsilon_1 - \varepsilon_3}\right)$$

E, ν, gage factor, and starting and end ε values are input parameters and the program sets $\varepsilon_1, \varepsilon_2, \varepsilon_3$ equal to their respective $\Delta\varepsilon \ \frac{2}{GF}$.

5.6.1 Bolt Load Comparison

Base Plate Loading		Bolt Load (lbs)	
Condition	Bolt Number	Analytical	Experimental
Axial Load (P = 6800 lb)	1	2350	1621
	2	2350	1881
	3	2350	1962
	4	2350	2087
45° Shear/ Moment (M = 15000 in-lb)	1	2316	1658
	2	1024	*
	3	0	44
	4	978	491
0° Shear/ Moment (M = 15000 in-lb)	1	1942	1142
	2	1942	1219
	3	0	-19
	4	0	-24

* Strain Gage Malfunction

The above results indicate that the generic program conservatively predicts expansion anchor bolt loads. A review of the experimental results indicates that non-uniform loading of the bolts is occurring but in all cases, the maximum load is well below that predicted analytically. The non-uniformity of bolt loads is due to the rough surface of the slab on which the plate was tested. The plate was placed directly on the slab without grouting or surface preparation and a number of voids existed between the plate and the concrete slab.

TES performed two other analytical solutions to demonstrate the effect of voids. The first was to remove all concrete springs around the edge of the plate and the second was to remove the concrete springs at the two corners adjacent to bolts one and three. These results are shown below.

Base Plate Loading		Bolt Load (lbs)		
		Analytical		Experimental
Condition	Bolt Number	Edge Springs Removed	Corner Springs Removed	
Axial (P=6800 lb)	1	1700	1528	1621
	2	1700	2568	1881
	3	1700	1528	1962
	4	1700	2577	2087
45° Shear/ Moment (M=15000 in-lb)	1	1918	Not Analyzed	1658
	2	566		*
	3	8		44
	4	521		491
0° Shear/ Moment (M=15000 in-lb)	1	1469	Not Analyzed	1142
	2	1469		1219
	3	0		-19
	4	0		-24

* Strain Gage Malfunction

5.6.2 Plate Stress Comparison

The comments in Section 5.6.1 are applicable here. Rossette R4 was not located at the centroid of an element in the analytical solution and the analytical results are the average of two elements.

Base Plate Loading		Plate Stress (ksi)			
		Analytical		Experimental	
Condition	Rosette	σ_z	σ_x	σ_z	σ_x
Axial (P=6800 lb)	R1	18.8	8.7	15.4	8.6
	R2	2.6	17.9	1.2	15.8
	R3	18.8	8.7	16.3	8.2
	R4	6.6	2.2	7.9	2.0
	R5	2.6	17.9	2.2	20.7
45° Shear/ Moment (M=15000 in-lb)	R1	9.4	14.3	5.4	9.0
	R2	11.5	3.0	7.8	0.6
	R3	- 3.1	- 2.7	-6.1	-5.1
	R4	- 0.2	- 3.3	-7.4	-2.8
	R5	- 1.6	0.6	-2.4	0.3
0° Shear/ Moment (M=15000 in-lb)	R1	11.4	19.4	7.7	12.5
	R2	- 1.0	1.0	-5.2	- 1.3
	R3	- 3.5	- 2.1	-9.2	- 5.5
	R4	- 4.3	- 0.3	-8.8	0.6
	R5	7.7	0.8	8.4	1.6

The above results indicate that the generic program predicts the stress pattern in the plate reasonably well and, with one exception (R5 axial loading, σ_x), conservatively predicts the maximum stress. In evaluating the adequacy of a plate, the bending stress across the width and/or length of the plate (σ_x and σ_z) would be averaged to compare with an allowable value and for all cases, the analytical results would predict a higher average stress.

The results for the two other analytical solutions are as shown below.

Base Plate Loading		Plate Stress (ksi)			
		Edge Spring Removed		Corner Spring Removed	
Condition	Rosette	σ_z	σ_x	σ_z	σ_x
	R1	24.9	13.3	21.6	10.8
	R2	4.3	25.1	3.1	20.4
Axial	R3	24.9	13.3	21.6	10.8
	R4	14.1	9.0	12.9	8.2
	R5	4.3	25.1	3.1	20.4

The above results indicate what one would expect, that removing concrete-plate interface at the plate edge reduces the prying effect (which reduces bolt load, see Section 5.6.1) which increases plate bending.

.7 Curve Solution to Bolt Load

Using the generic program, TES developed a number of curves which can be used to solve for expansion anchor bolt loads (see Figures 5.20 through 5.46). The curves represent plate sizes which were common to a number of utilities in the generic program. For a fixed plate length and width and expansion anchor type and size, loads are given as a function of plate thickness and applied load. It can be seen that the curves are linear with respect to applied load so that as the applied load varies, an analyst can linearly interpolate and/or extrapolate to develop a new curve. Also, it is important to note that bolt force is sensitive to in-place anchor stiffness which is lower than stiffness of bolt alone.

6.0 SUMMARY AND CONCLUSIONS

Based on the findings of the generic program as detailed in this report, the following summary comments are provided. It is important to recognize that these comments relate only to the work performed under this program by TES and are applicable only to the bolts tested.

6.1 Shear-Tension Interaction

The results of this program indicate the following:

1. The use of linear shear-tension interaction is conservative.

2. The effect of shear load generally tends to increase the ultimate failure load particularly in smaller bolt sizes. It is felt that this occurs due to increasing the wedge force between the anchor and the concrete. Sufficient pure tension data was not obtained by TES on all bolt specimens to more precisely quantify this conclusion. This effect is not generally present in the Star slug-in type anchor because of the rigidity of the anchor itself. That is, the anchor is relatively so massive that the shear effect does not appreciably increase the wedge effect.

3. The data obtained by TES for Wej-It anchor bolts differs dramatically from the manufacturers published data. We feel this results from the fact that hole diameter is extremely critical in developing the full potential of this anchor; this has been verified in discussions with the manufacturer. Further, TES tests were performed to simulate field conditions in the utility members plants. At the time of plant construction, the Wej-It installation procedures did not indicate the criticality of hole diameter. The manufacturer's data appropriate to the vintage of the member utilities (pre 1976) indicates lower ultimate capacities than are presently advertised.

4. All failures that were bolt failure (i.e., not concrete) were examined and determined to be shear type failures.

5. It is felt that sufficient data exist to use the shear-tension interaction curves presented in this report as a design tool. | Rev 1

6.2 Cyclic Capacity

The results of this program indicate the following:

1. Cyclic loading of anchor bolts does not decay the ultimate capacity of the anchor.

2. Constant shear loading during cycling does not decay the ultimate capacity of the anchor.

3. No justification was found in these tests to apply different criteria to expansion anchors based on type. That is, shell, wedge and sleeve all exhibited full capacity after cycling.

4. No cyclic failure occurred for any bolts tested.

5. Any slip reported occurred during the initial loading.

6. Preload as high as design load is not required to develop cyclic capacity.

12 ... 1

6.3 Base Plate - Anchor Bolt Generic Computer Program

The results of this program indicate the following:

1. Base plate flexibility should be considered in determining bolt load.

2. The relative stiffness of bolt-concrete assembly and base plate is a more definitive criteria than just plate flexibility for determining the applicability of rigid plate analysis criteria. Variations of distance from attachment face to plate edge from 3t to 10t where t is plate thickness were found to be limits for flexibility effects depending on the plate size, loading and type of bolt. Bolt bending moment, which is rotation limited, is not an important factor affecting bolt performance.

3. The assumption of full face contact between plate and concrete prior to loading results conservative estimate of bolt loads.

4. The generic computer program conservatively estimates the load in expansion type concrete anchor bolts in a base plate assembly that is representative of field construction.

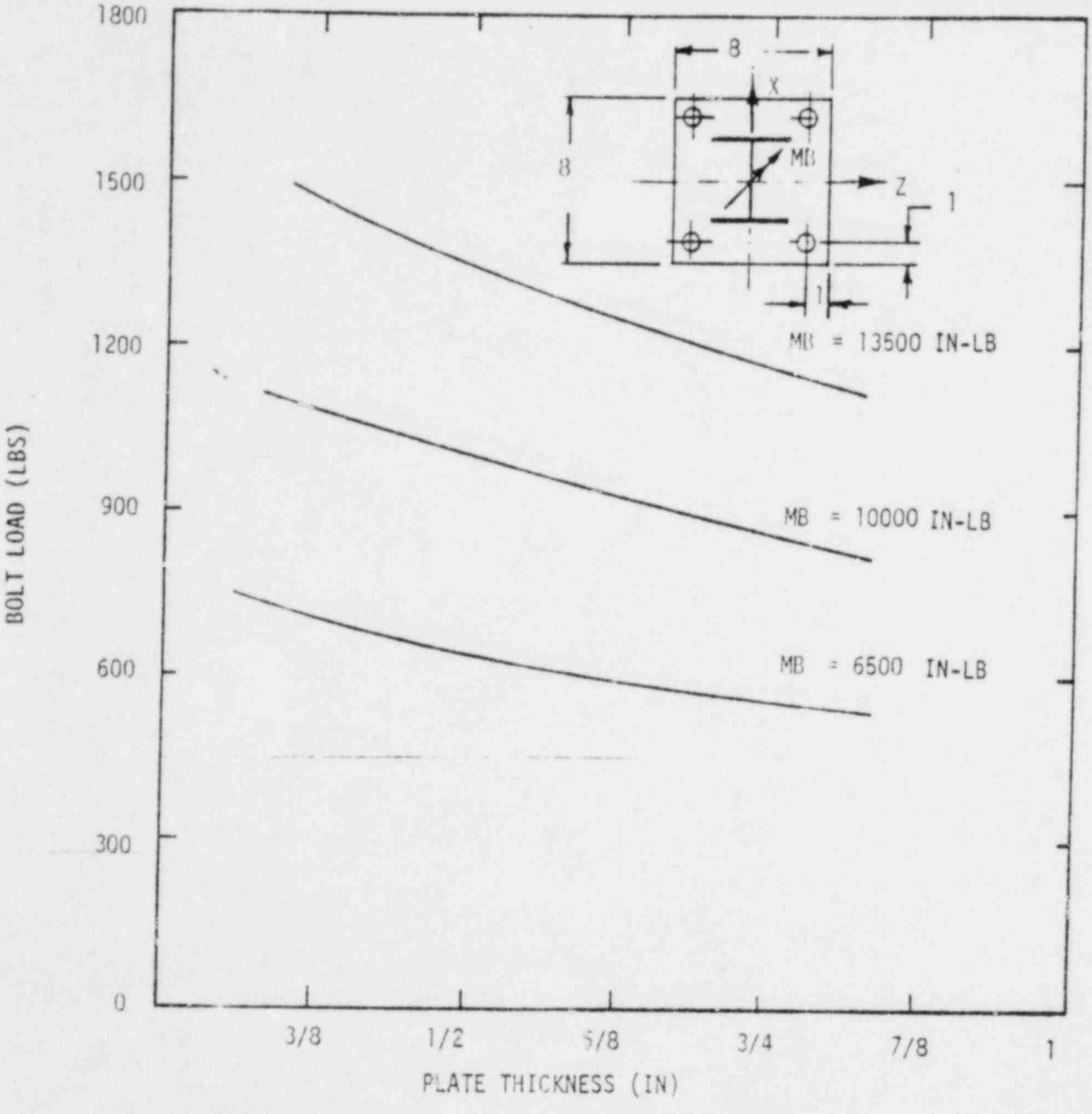


Figure 5.20 - 8" x 8" Baseplate, 1/2" Phillips Sleeve Anchor, W4 x 13 Attachment

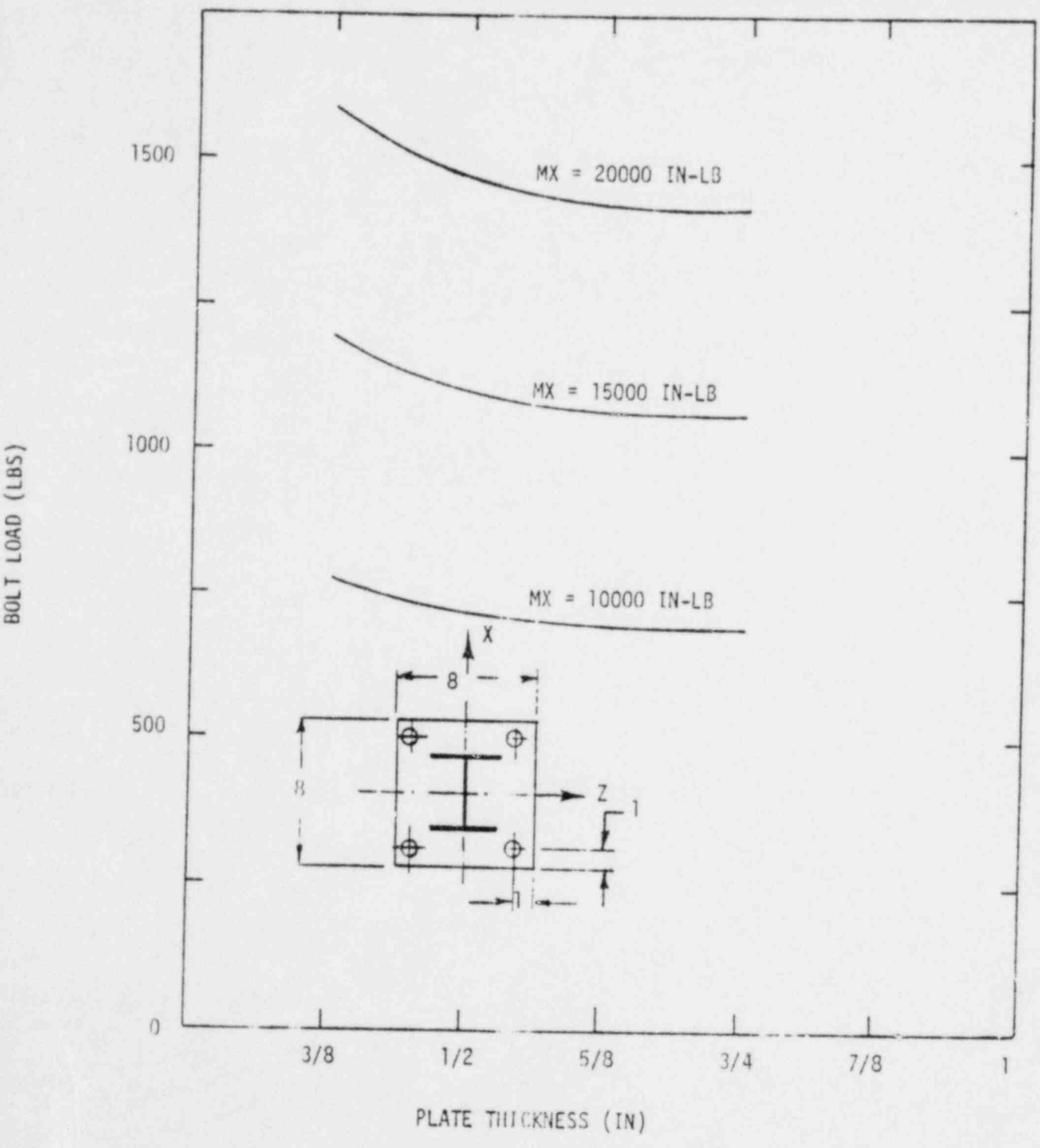


Figure 5.21 - 8" x 8" Baseplate, 1/2" Phillips Sleeve Anchor, W4 x 13 Attachment

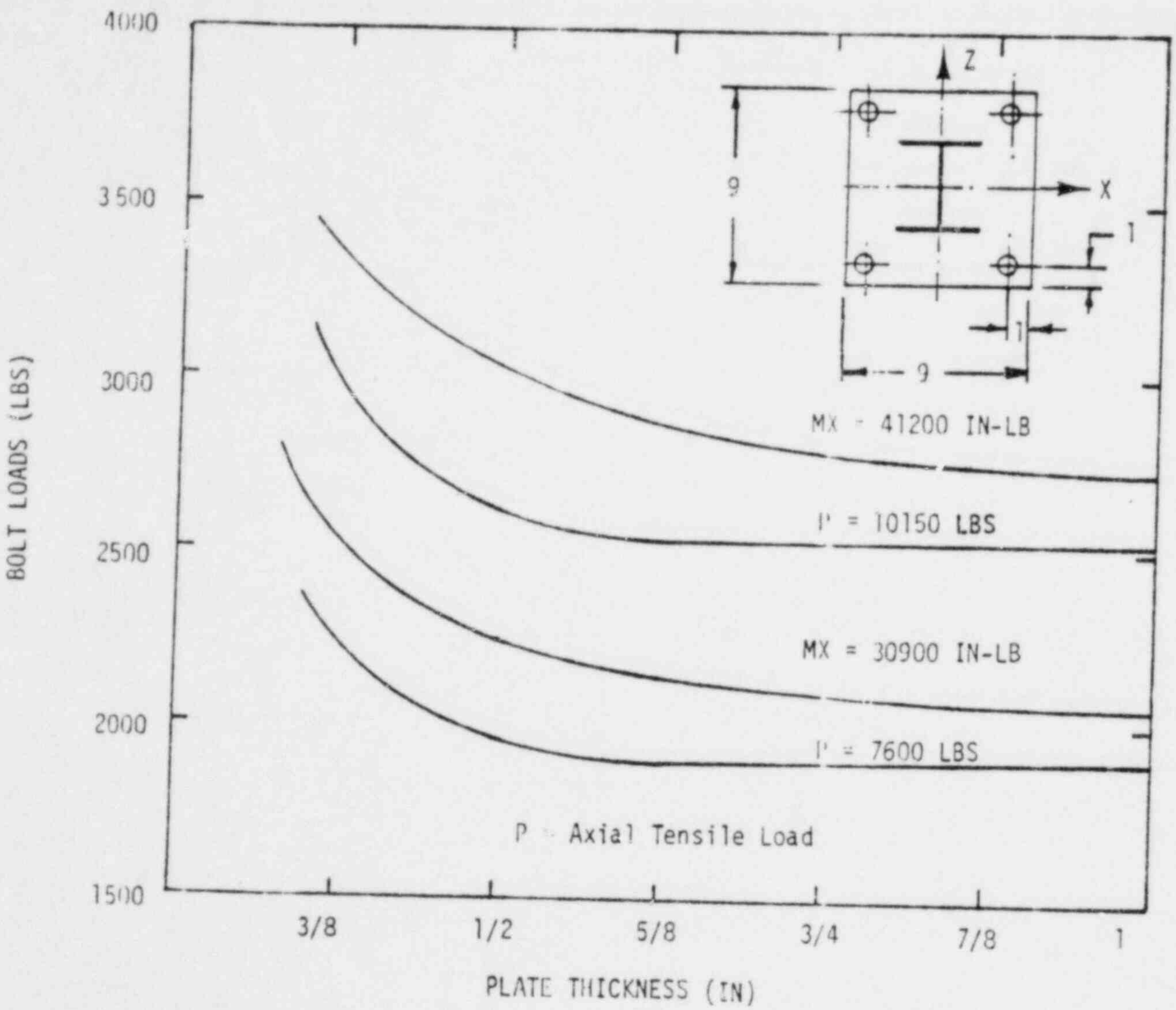


Figure 5.22 - 9" x 9" Baseplate, 3/4" Hilti Kwik-Bolt, W4 x 13 Attachment

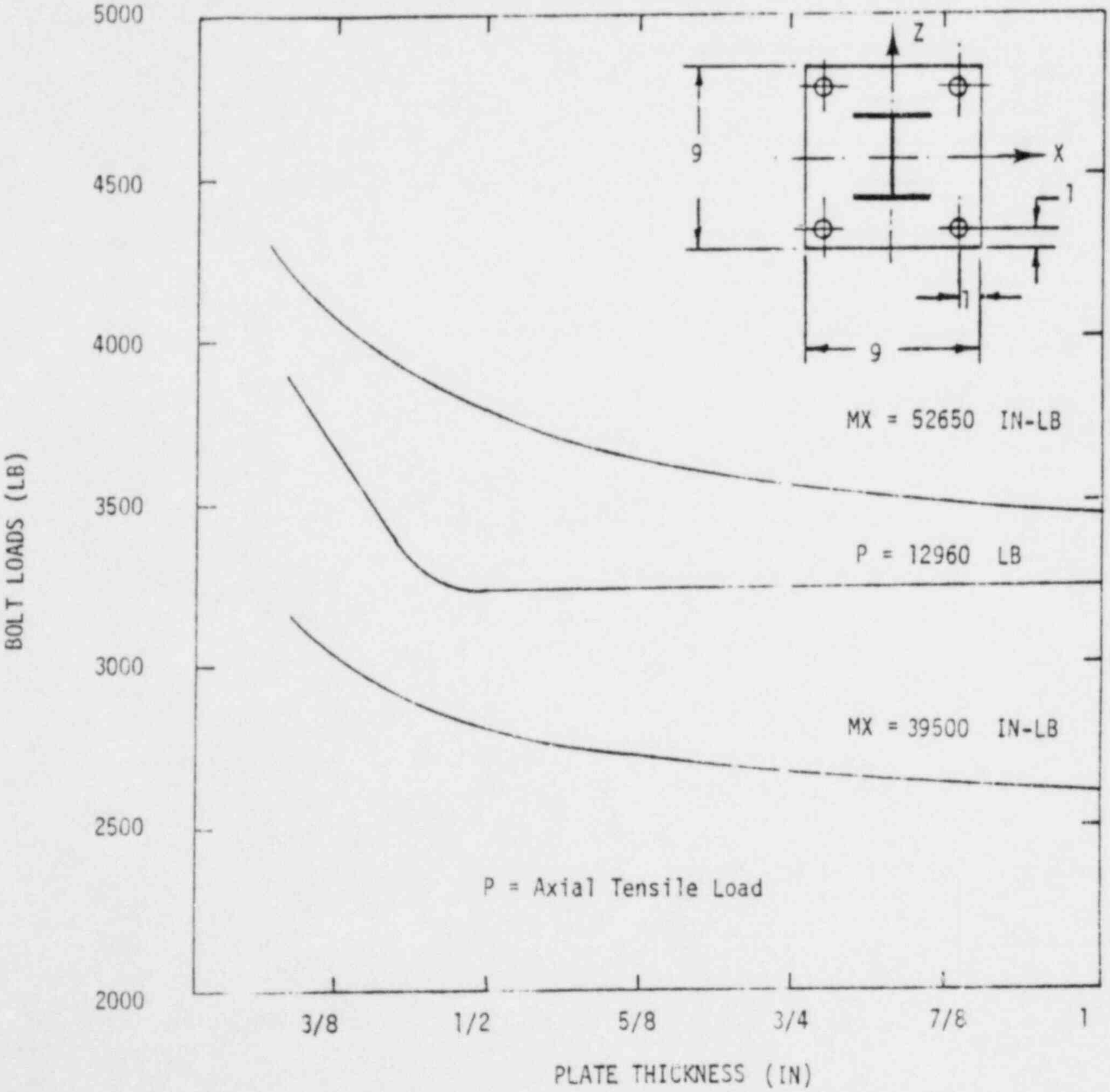


Figure 5.23 - 9" x 9" Baseplate, 3/4" Phillips Self-Drill, W4 x 13 Attachment

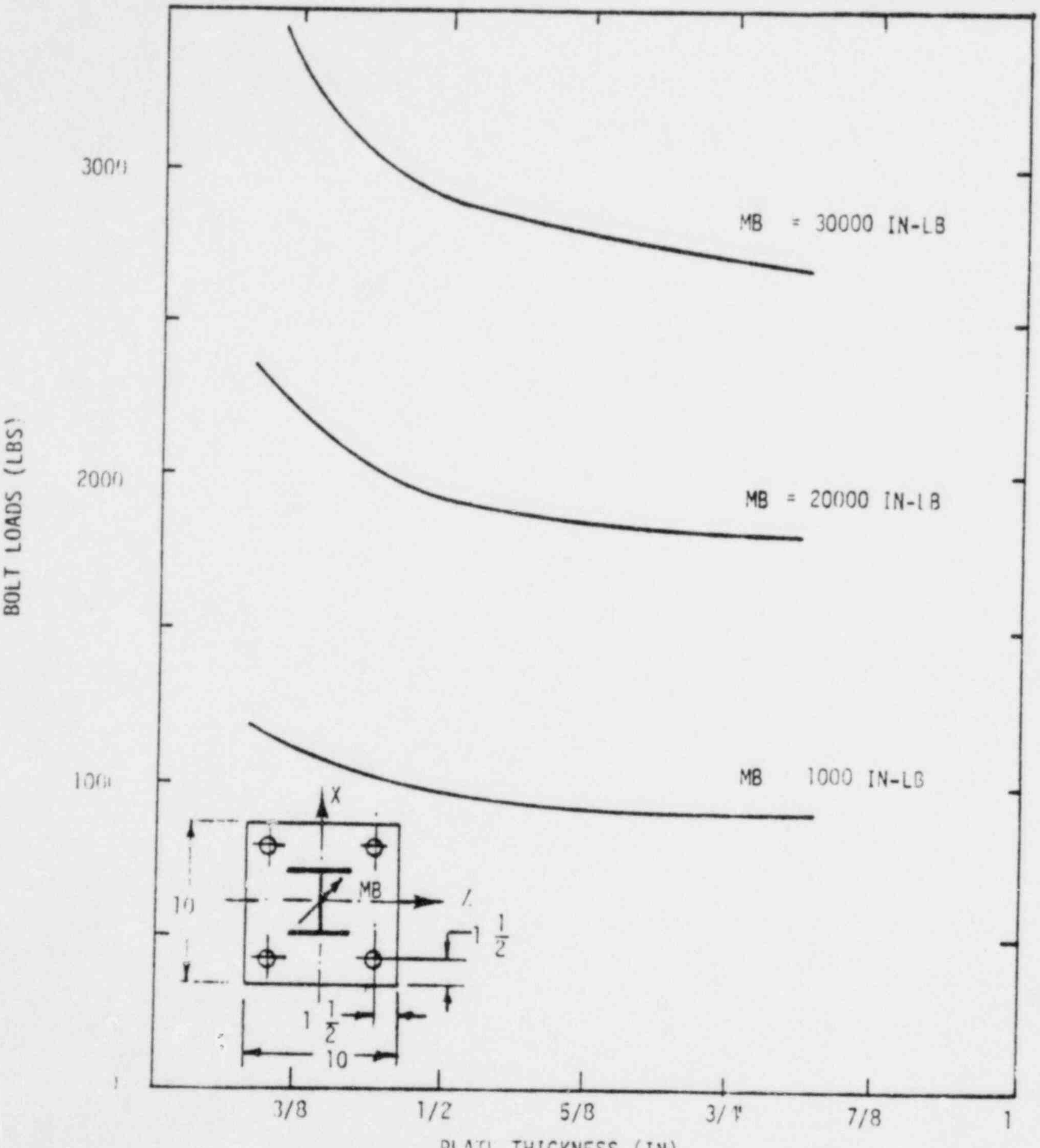


Figure 5.24 - 10" x 10" Baseplate, 3/4" Hilti Kwik-Bolt, W4 x 13 Attachment

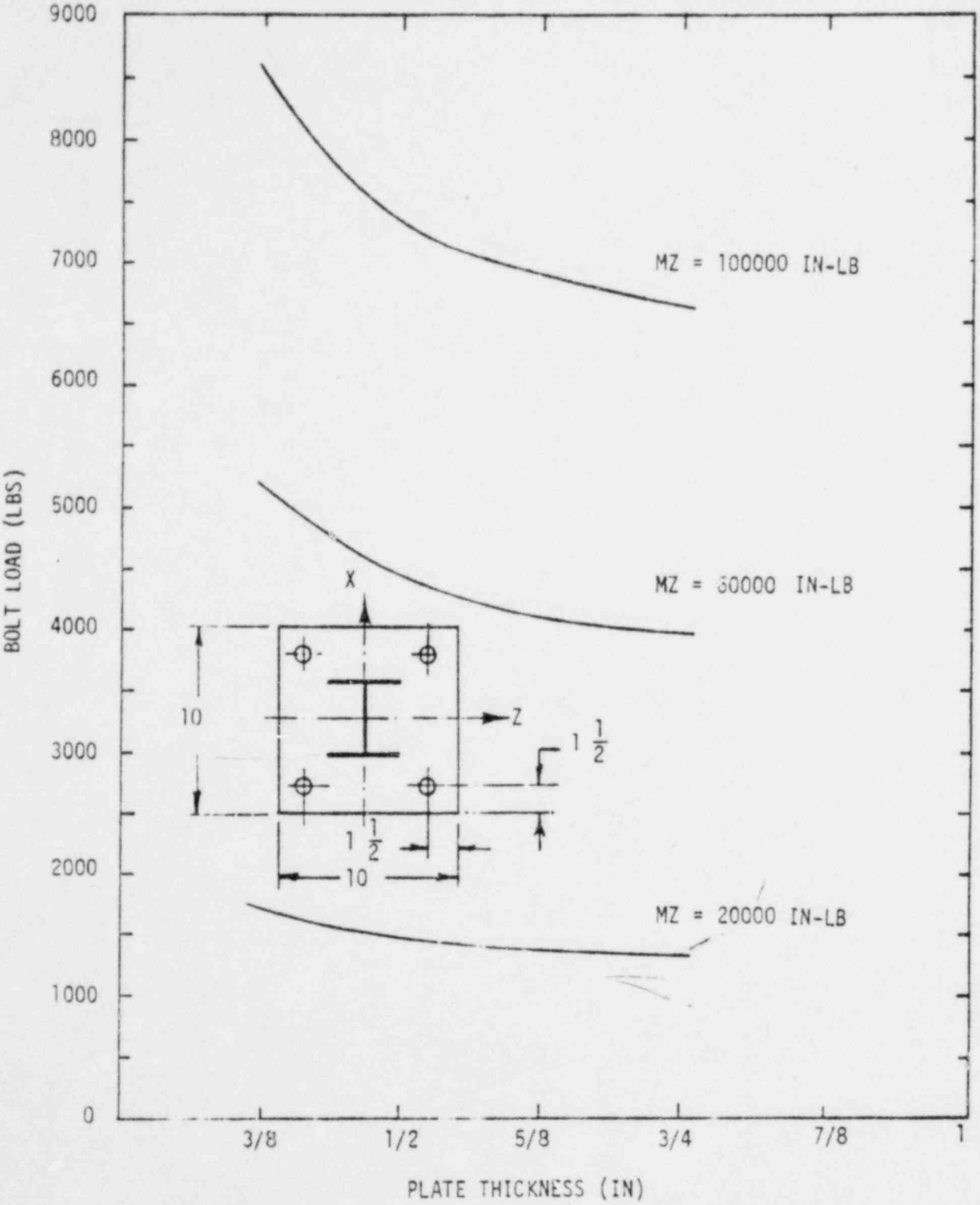


Figure 5.25 - 10" x 10" Baseplate, 3/4" Hilti Kwik-Bolt, W4 x 13 Attachment

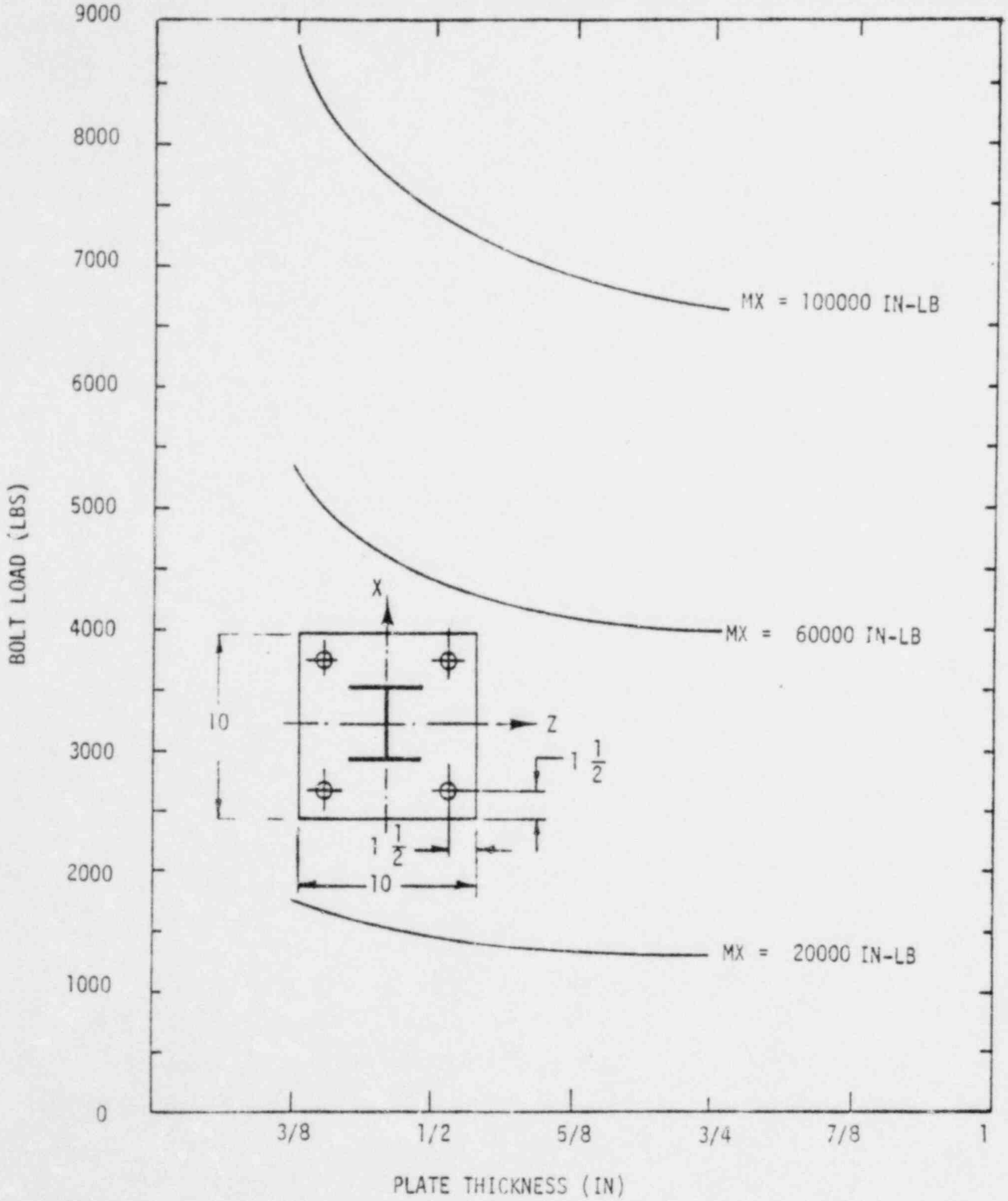


Figure 5.26 - 10" x 10" Baseplate, 3/4" Hilti Kwik-Bolt, W4 x 13 Attachment

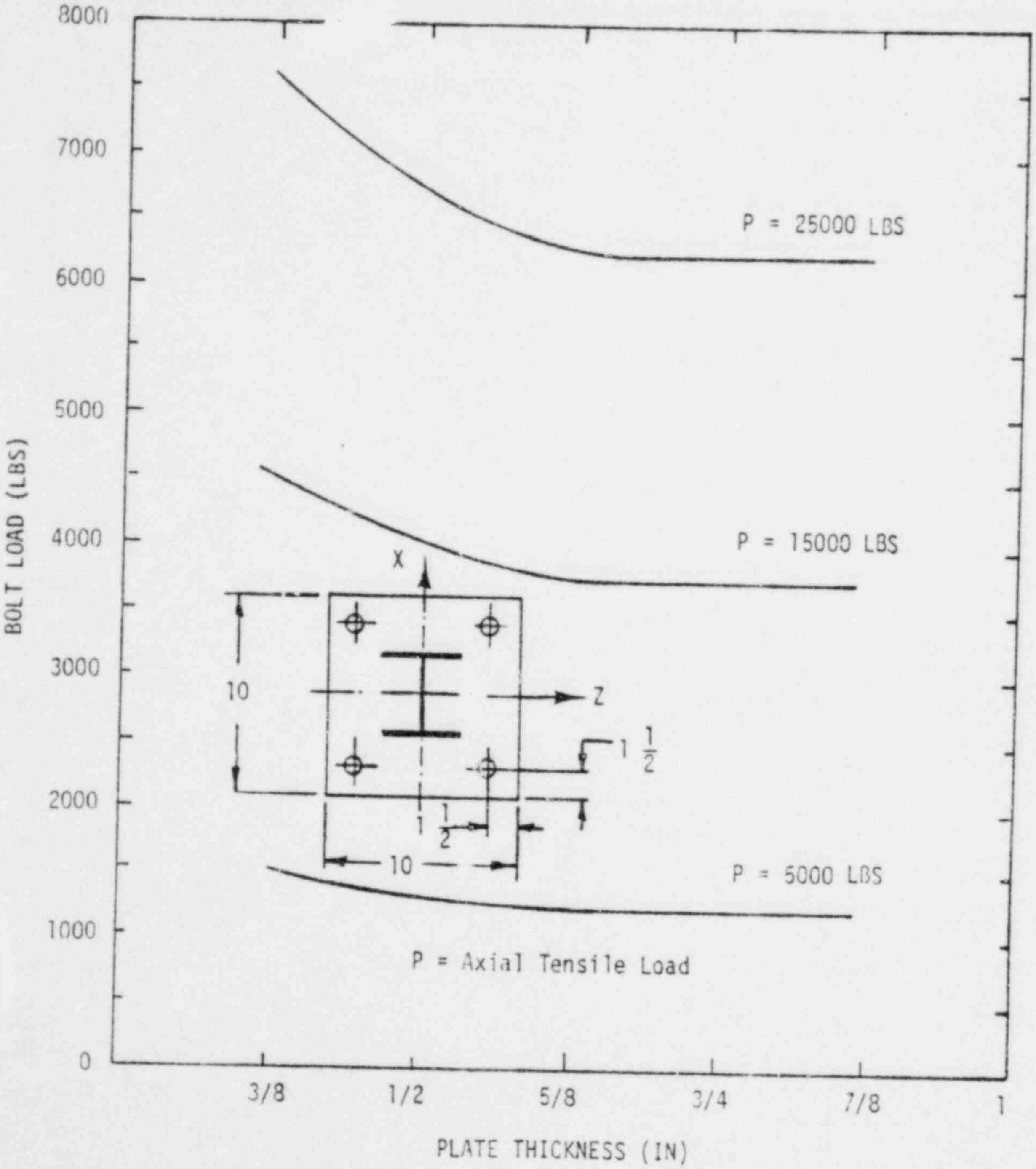


Figure 5.27 - 10" x 10" Baseplate, 3/4" Hilti Kwik-Bolt, W4 x 13 Attachment

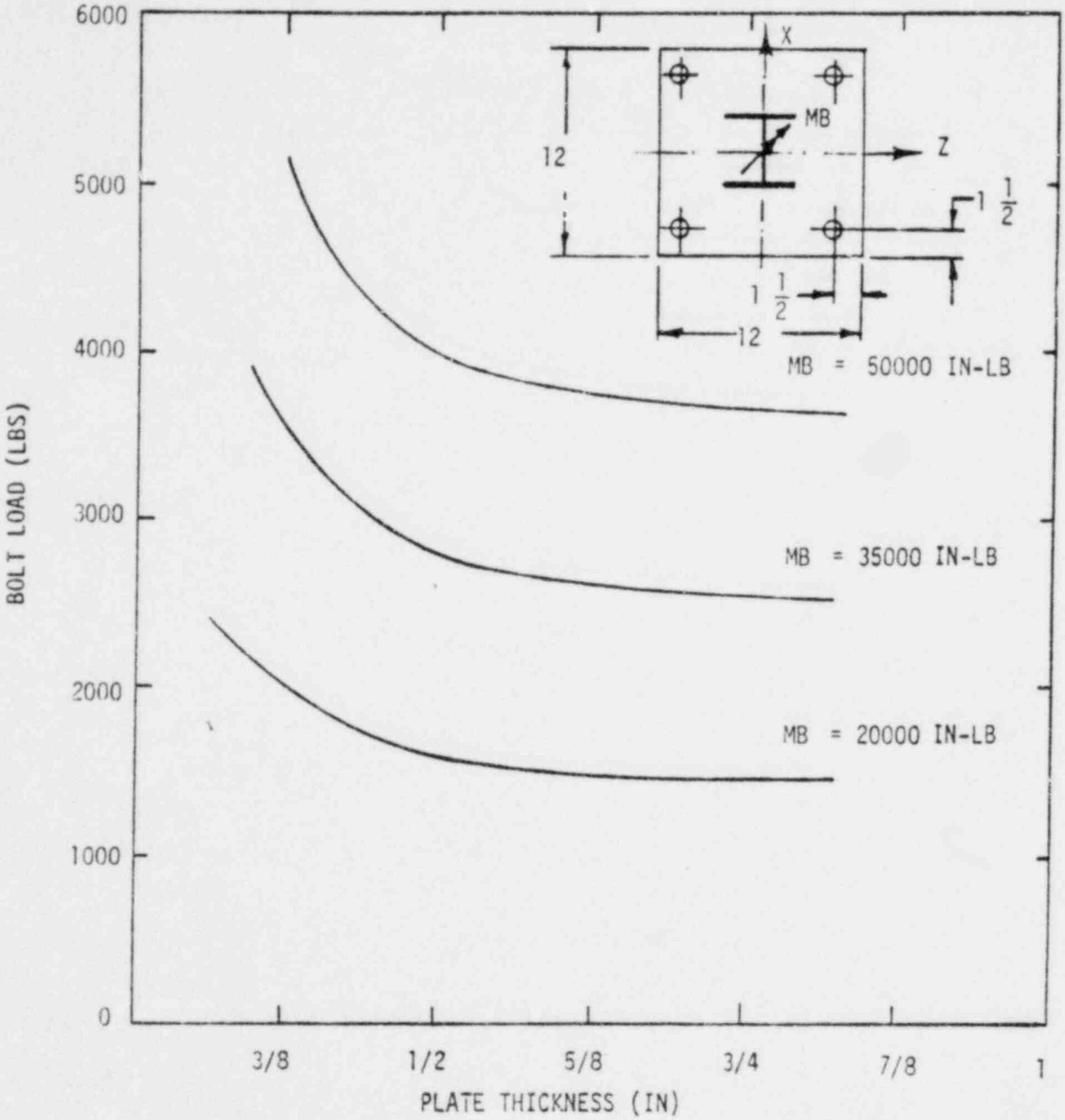


Figure 5.28 - 12" x 12" Baseplate, 3/4" Phillips Self-Drill, W4 x 13 Attachment

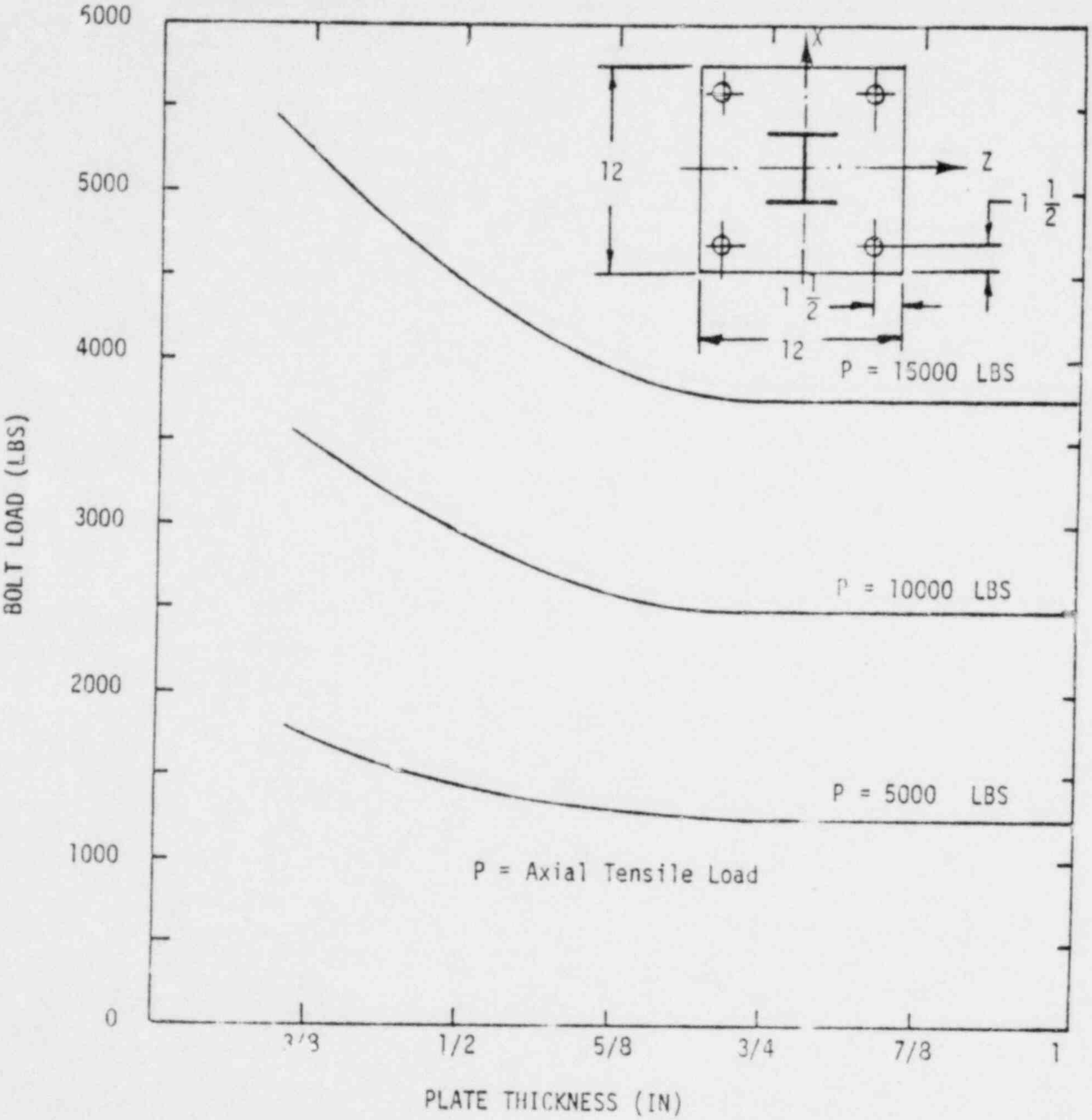


Figure 5.?9 - 12" x 12" Baseplate, 1/2" Phillips Self-Drill, W4 x 13 Attachment

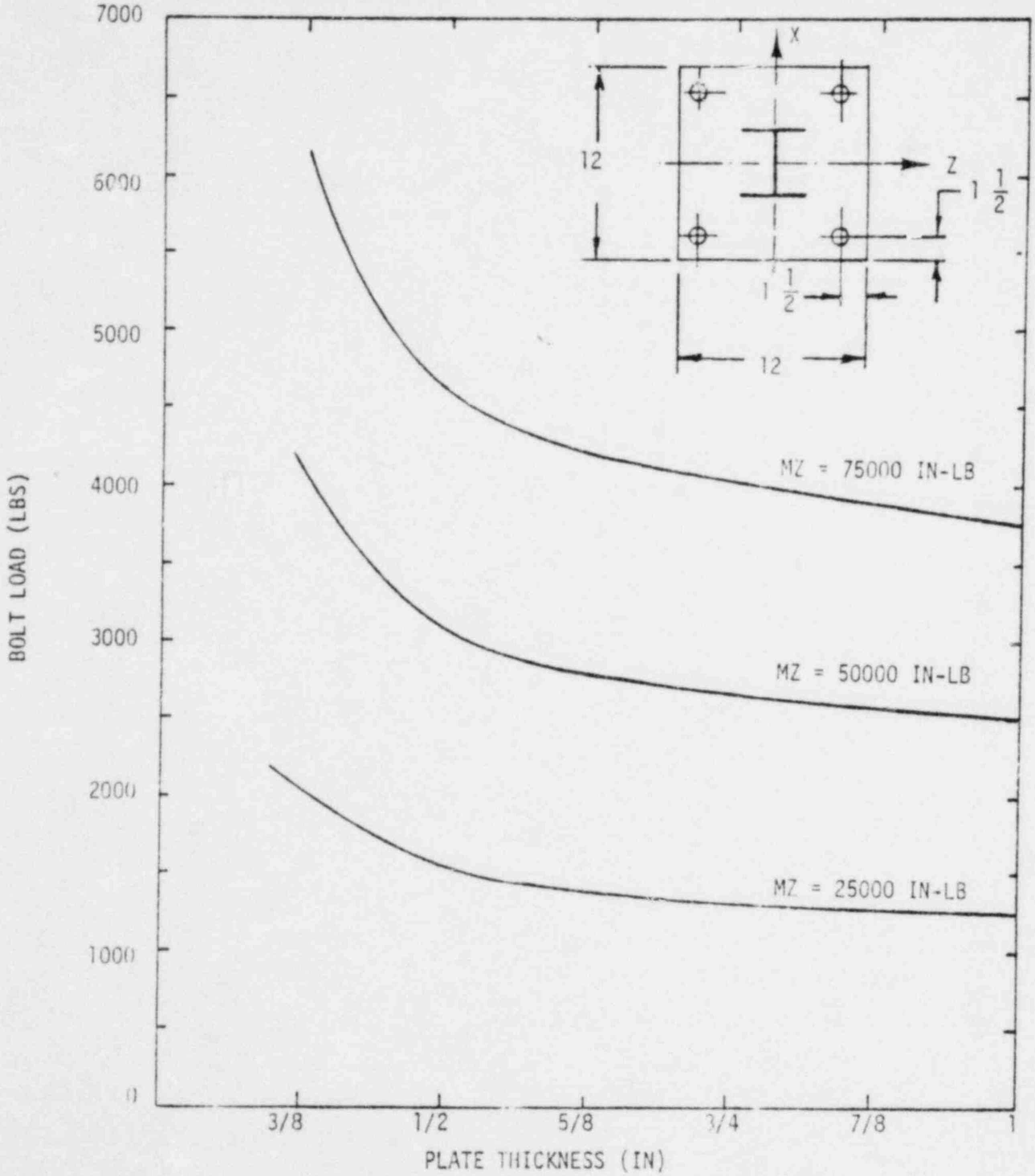


Figure 5.30 - 12" x 12" Baseplate, 1/2" Phillips Self-Drill, W4 x 13 Attachment

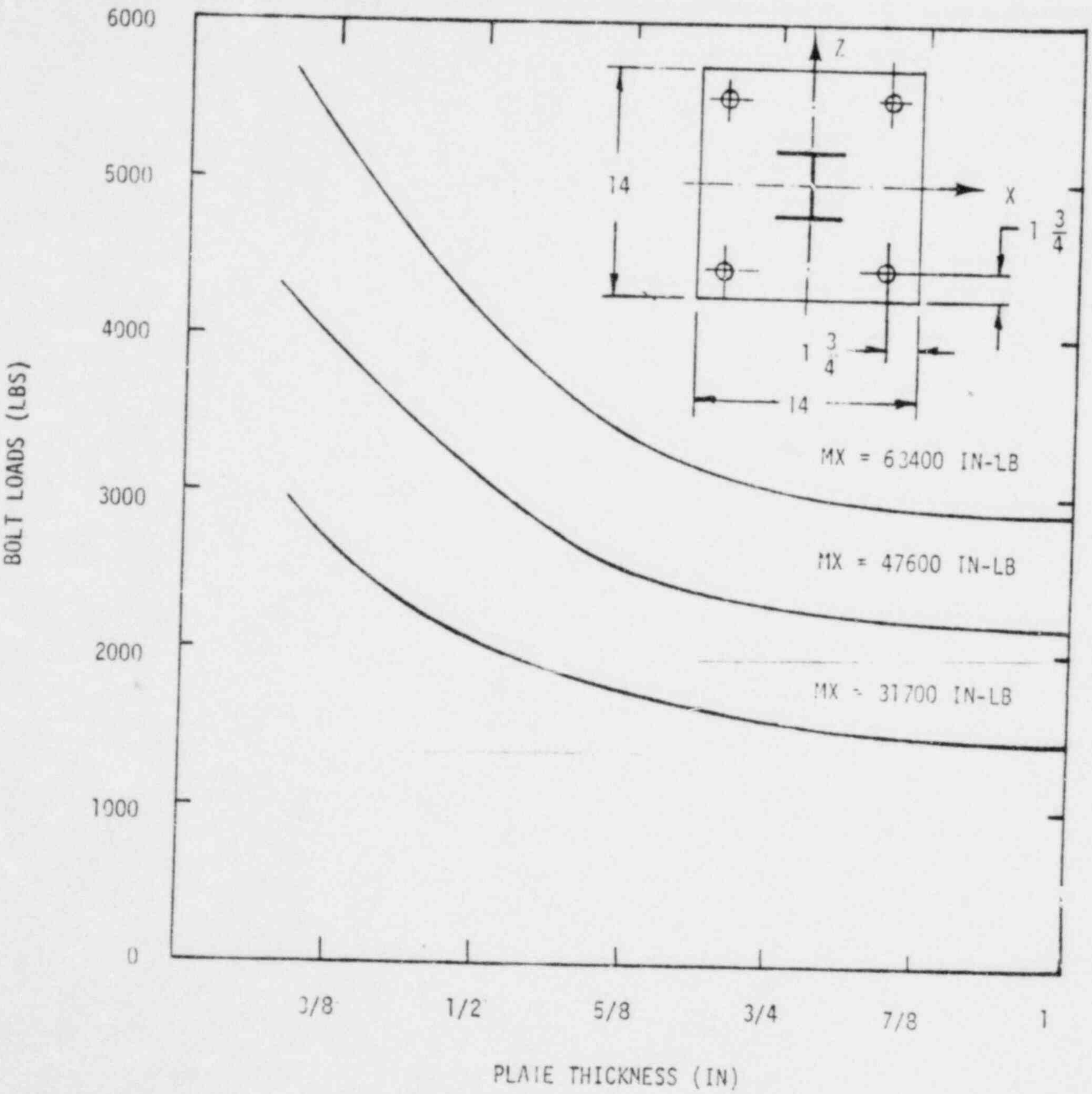


Figure 5.[illegible] - 14" x 14" Baseplate, 3/4" Hilti Kwik-Bolt, W4 x 13 Attachment

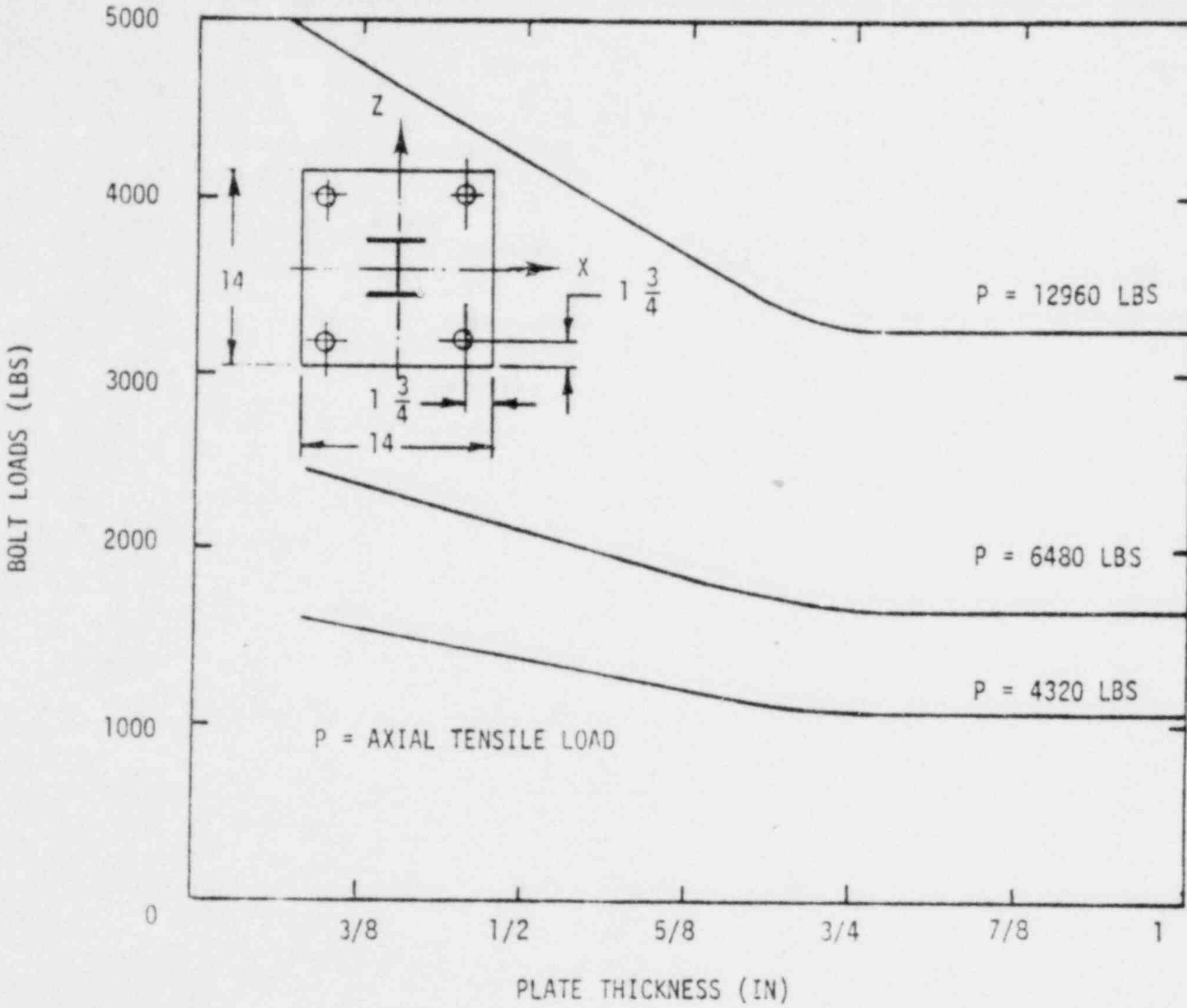


Figure 5.32 - 14" x 14" Baseplate, 3/4" Phillips Self-Drill, W4 x 13 Attachment

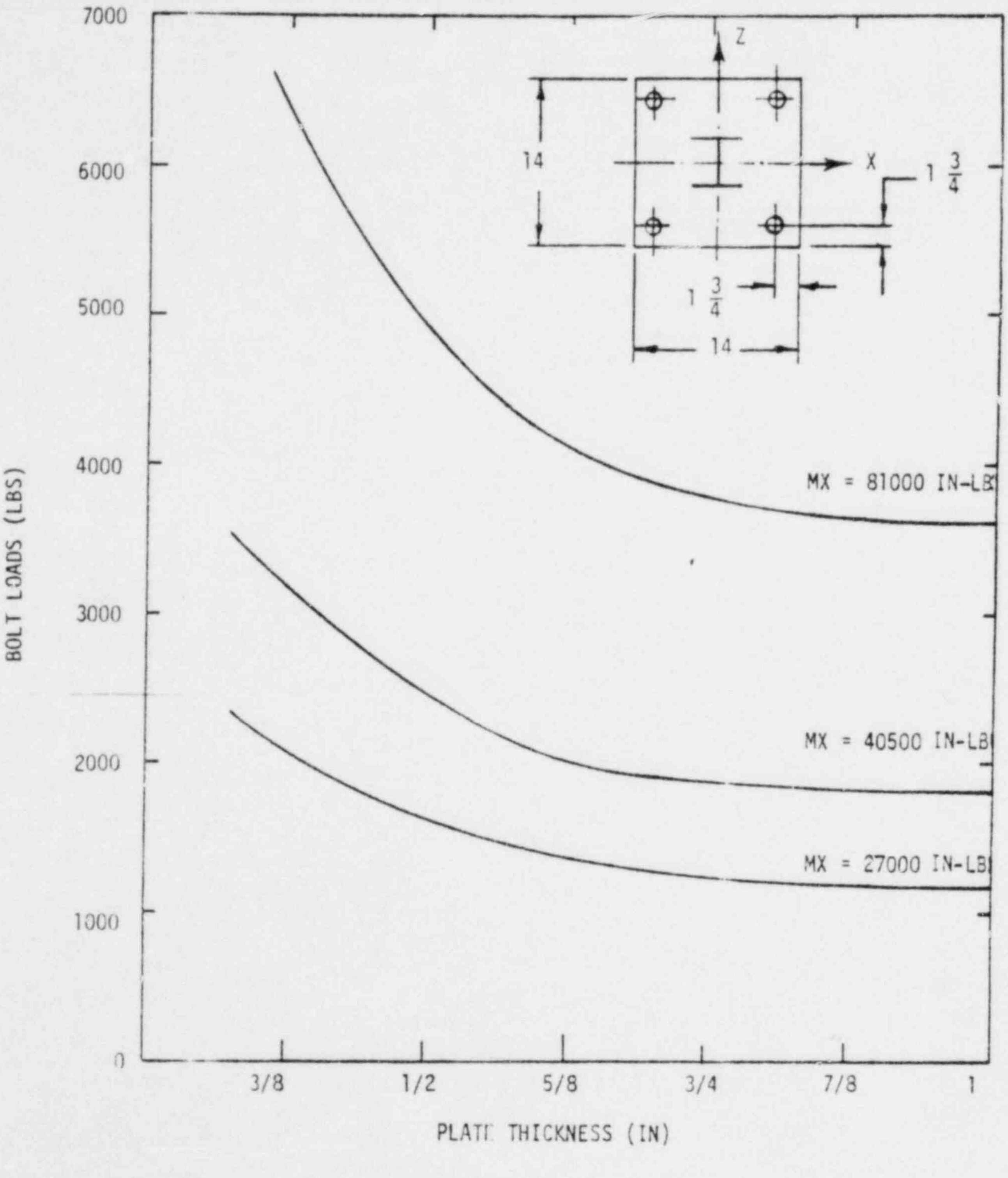


Figure 5.33 - 14" x 14" Baseplate, 3/4" Phillips Self-Drill, W4 x 13 Attachment

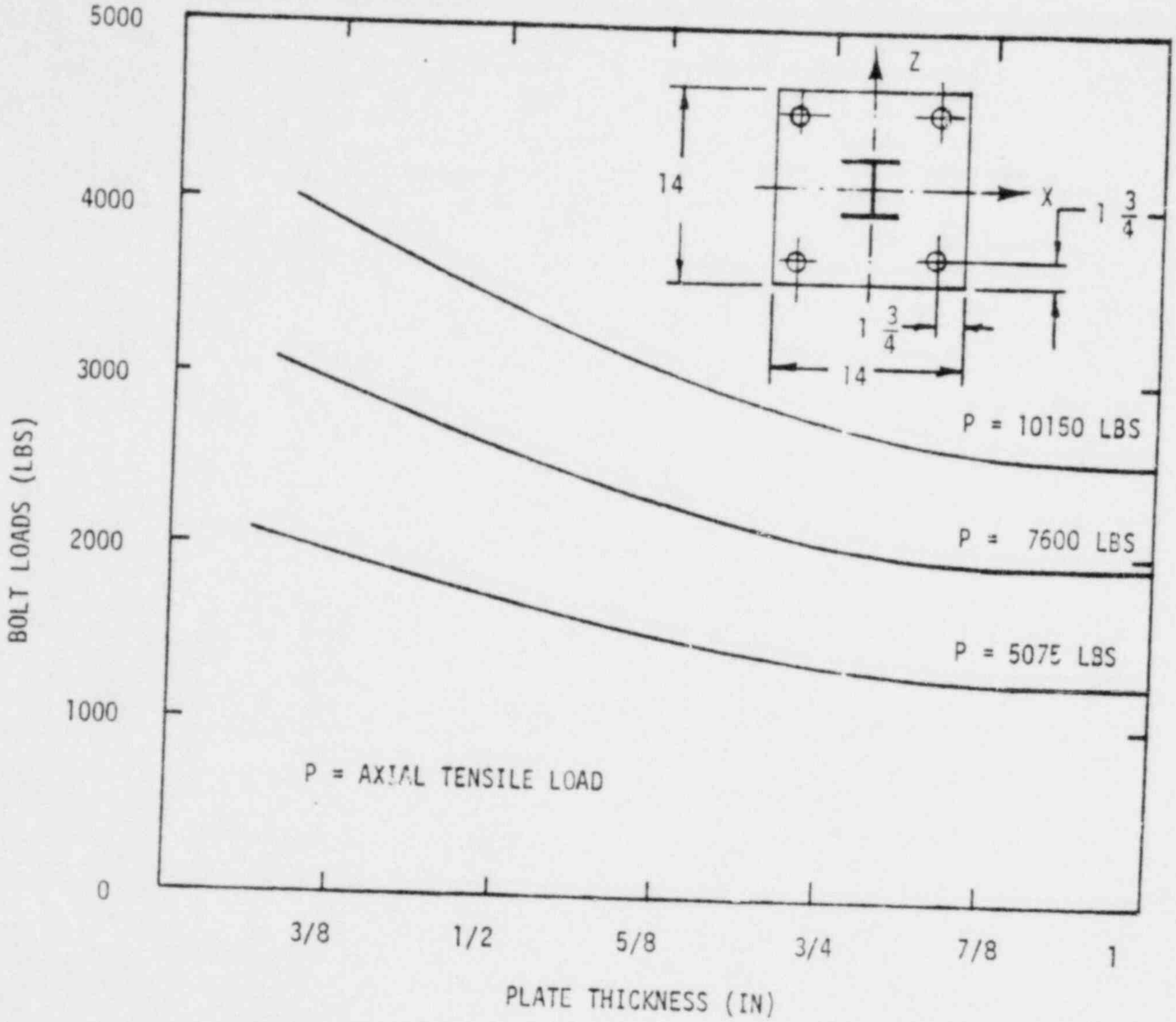


Figure 5.34 - 14" x 14" Baseplate, 3/4" Hilti Kwik-Bolt, W4 x 13 Attachment

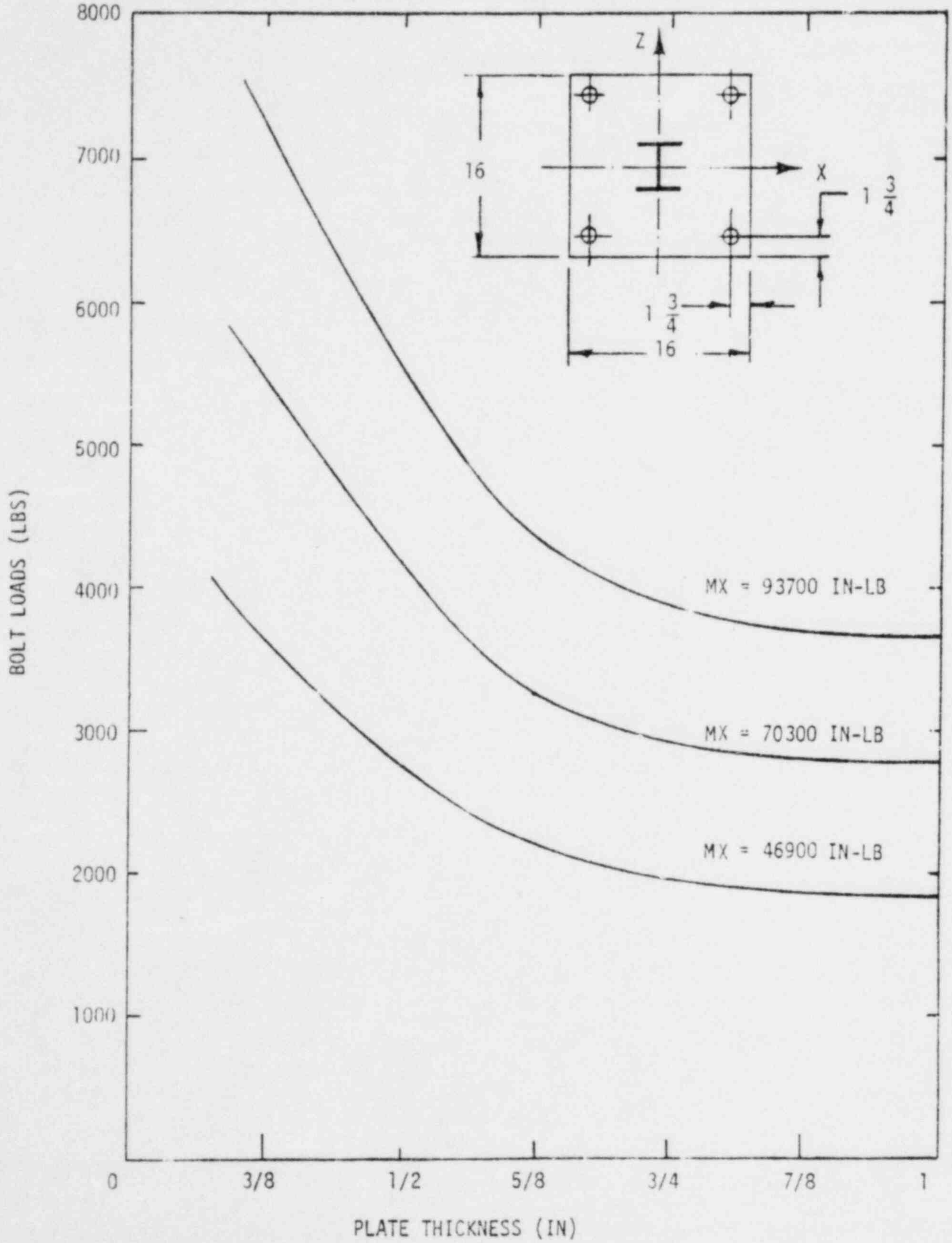


Figure 5.?5 - 16" x 16" Baseplate, 3/4" Phillips Self-Drill, W4 x 13 Attachment

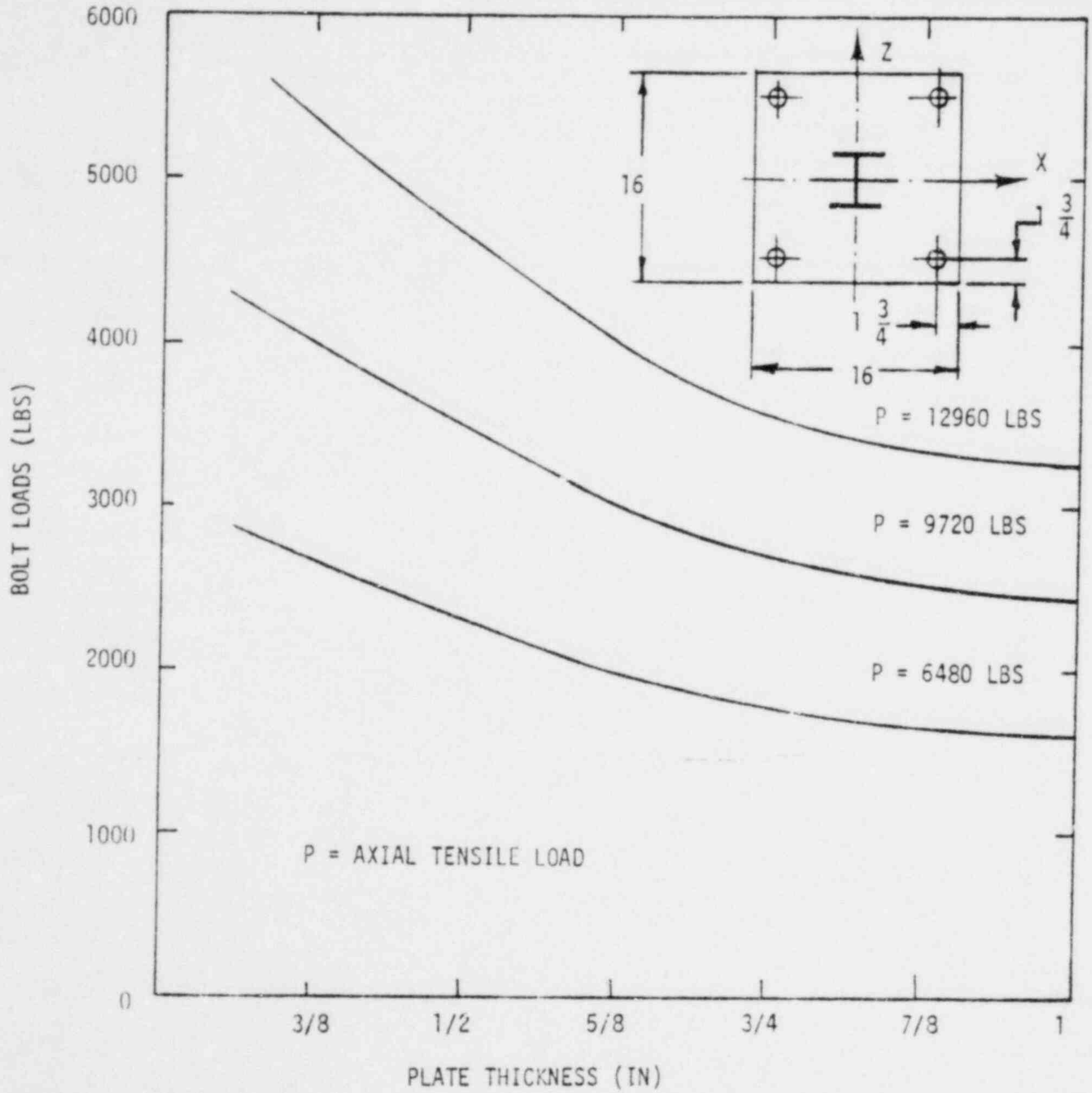


Figure 5.36 - 16" x 16" Baseplate, 3/4" Phillips Self-Drill, W4 x 13 Attachment

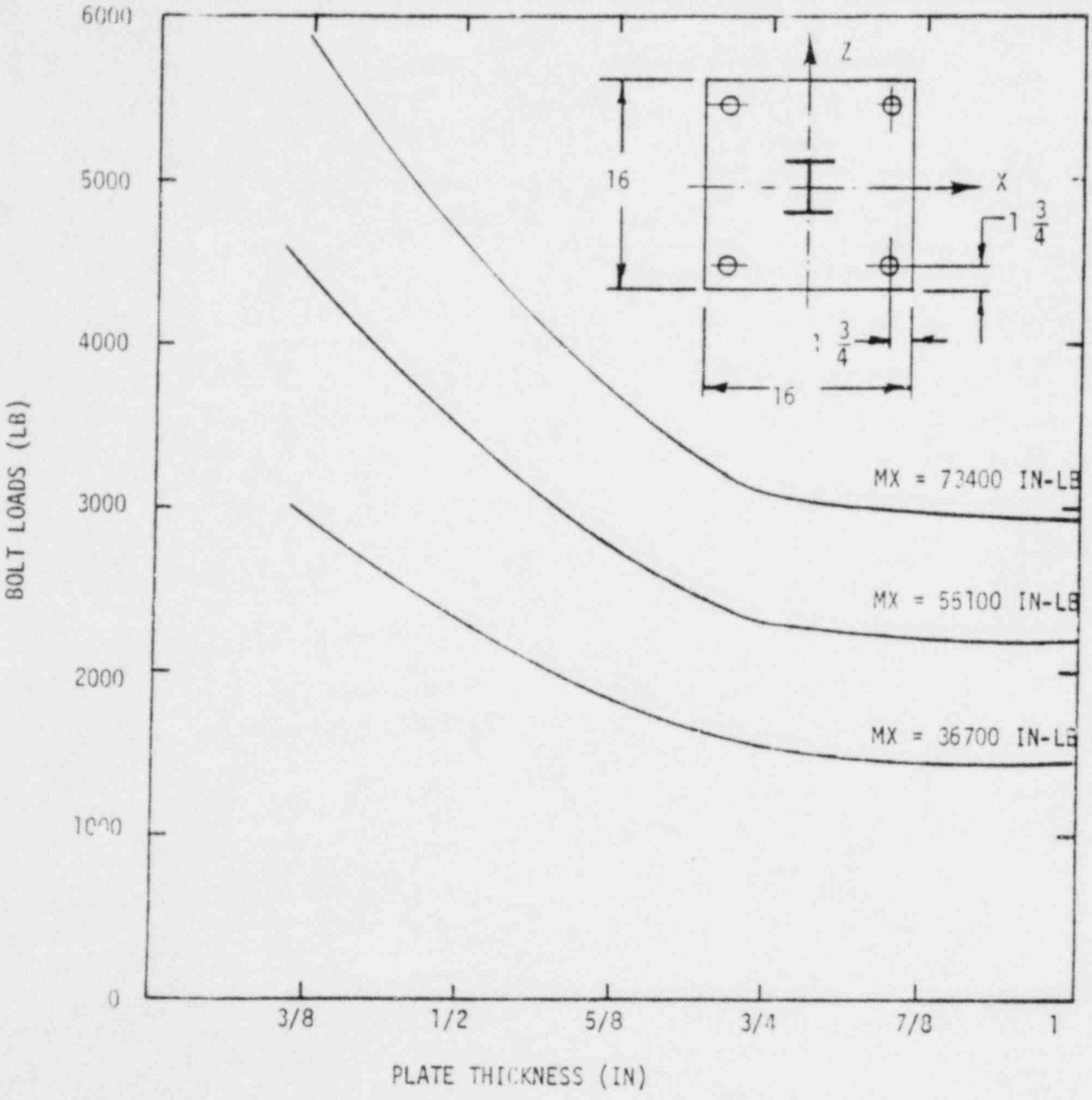


Figure 5.37 - 16" x 16" Baseplate, 3/4" Hilti Kwik-Bolt, W4 x 13 Attachment

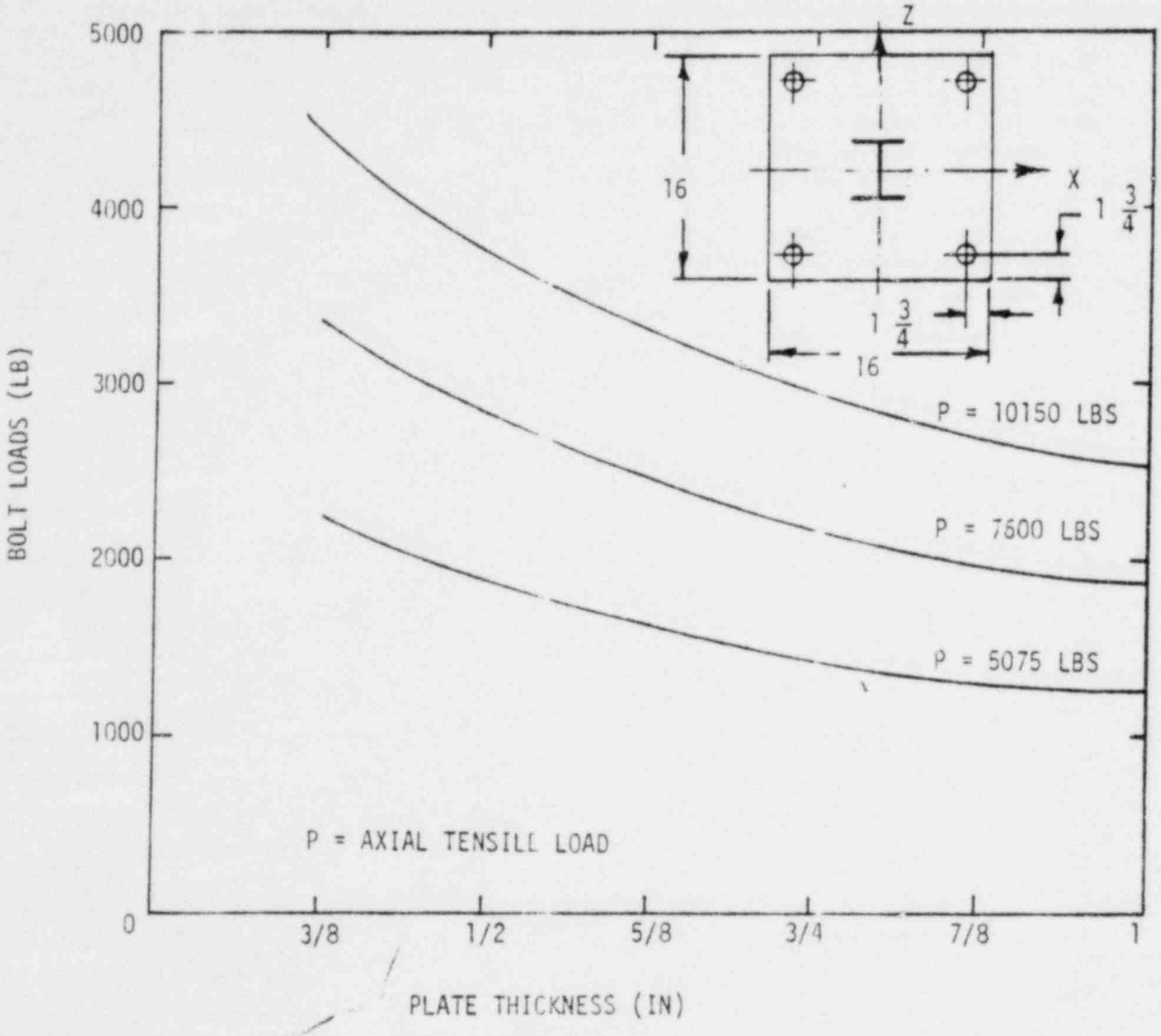


Figure 5.38 - 16" x 16" Baseplate, 3/4" Hilti Kwik-Bolt, W4 x 13 Attachment

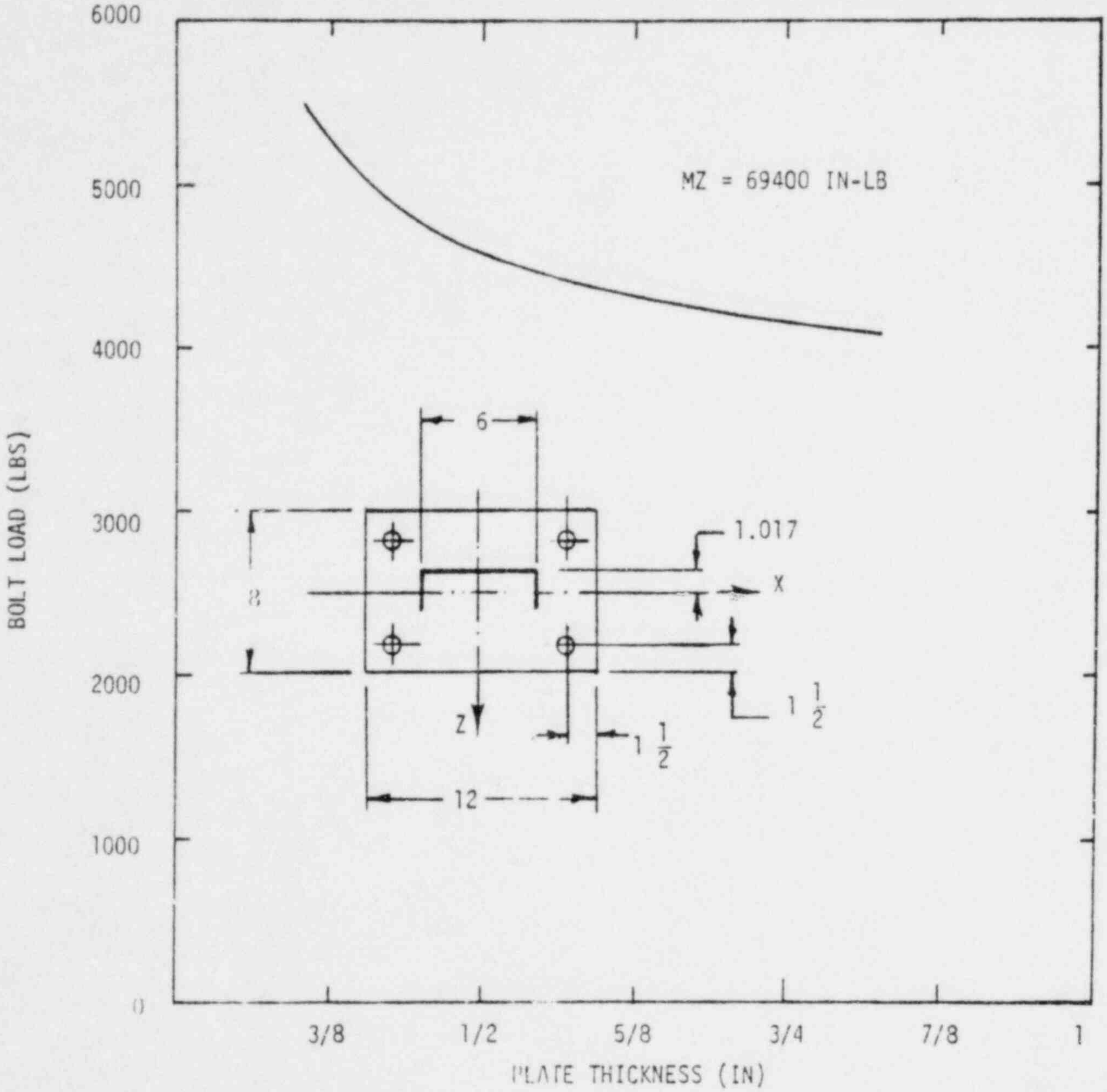


Figure 5.39 - 8" x 12" Baseplate, 3/4" Phillips Self-Drill, C6 x 10.5 Attachment

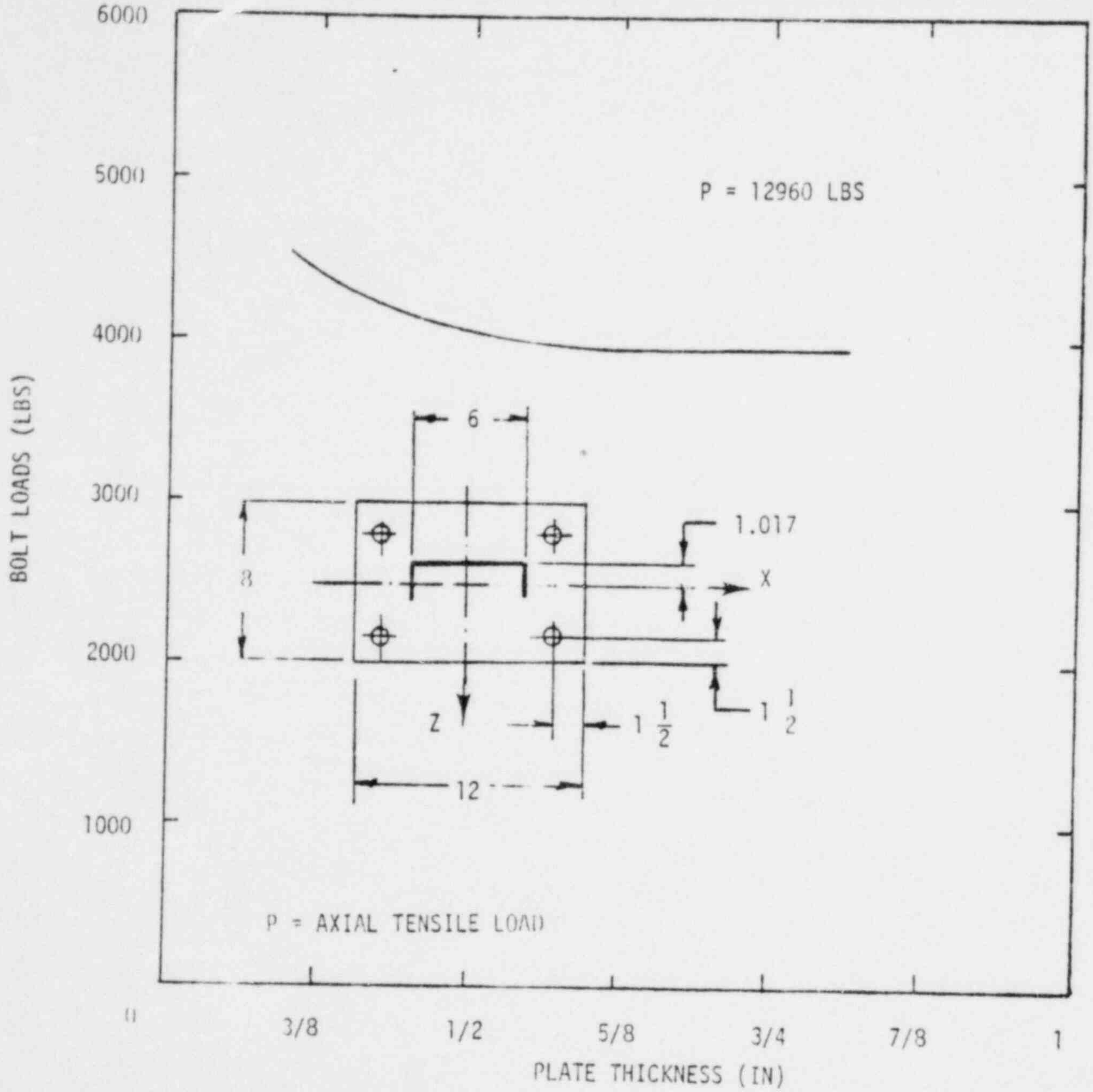


Figure 5.40 - 8" x 12" Baseplate, 3/4" Phillips Self-Drill, C6 x 10.5 Attachment

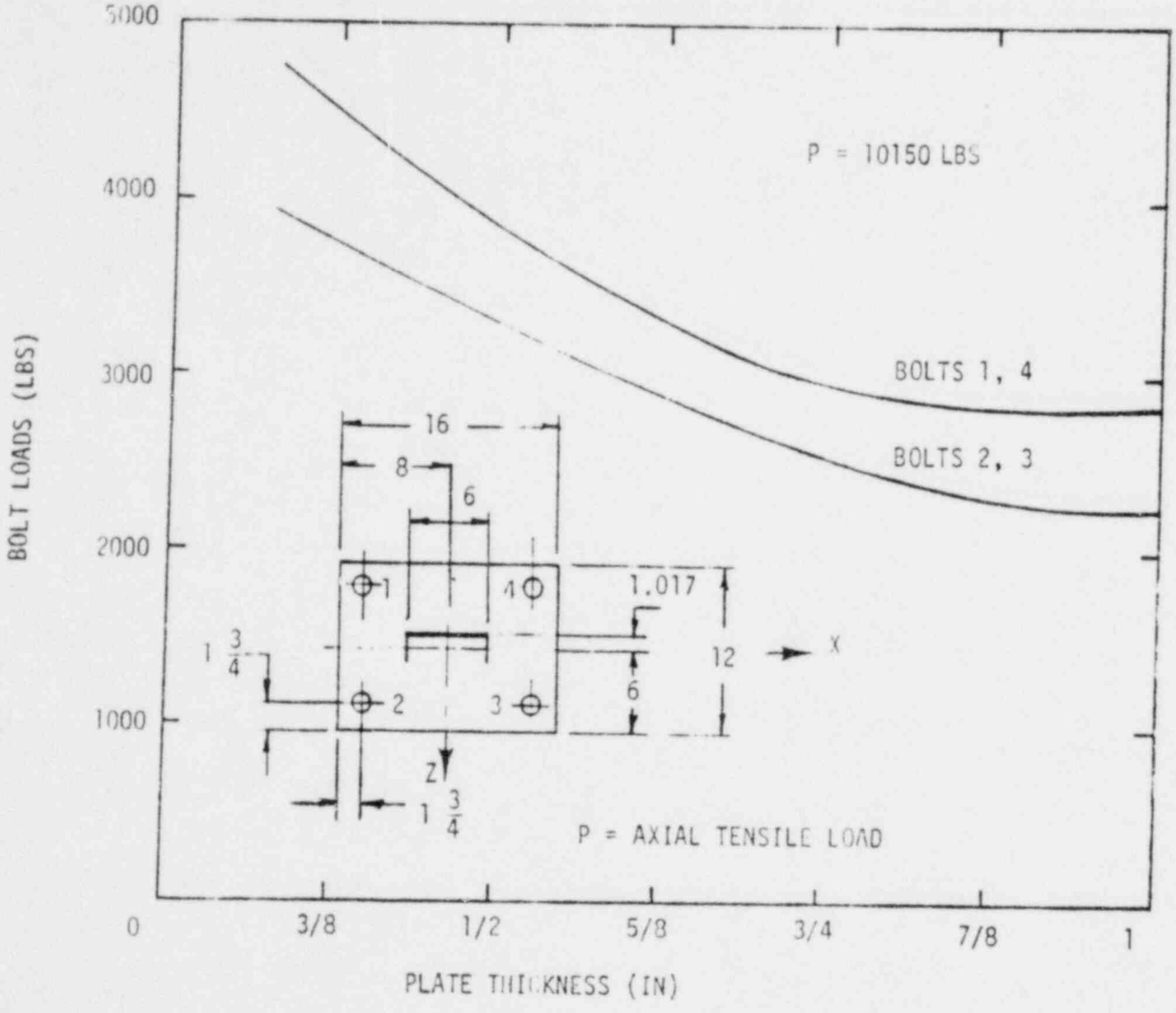


Figure 5.41 - 12" x 16" Baseplate, 3/4" Hilti Kwik-Bolt, C6 x 10.5 Attachment

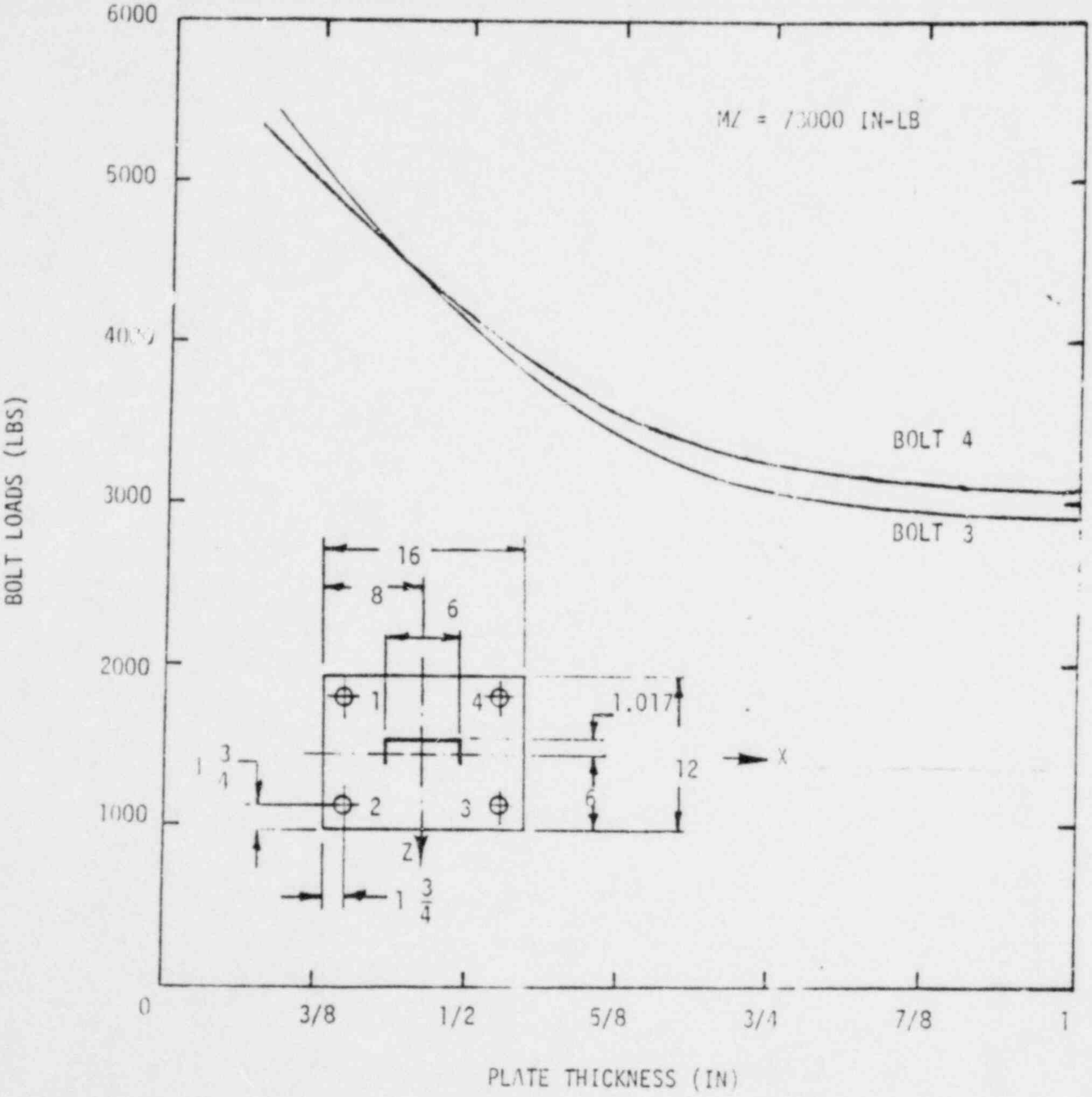


Figure 5.42 - 12" x 16" Baseplate, 3/4" Hilti Kwik-Bolt, 6 - 10.5 Attachment

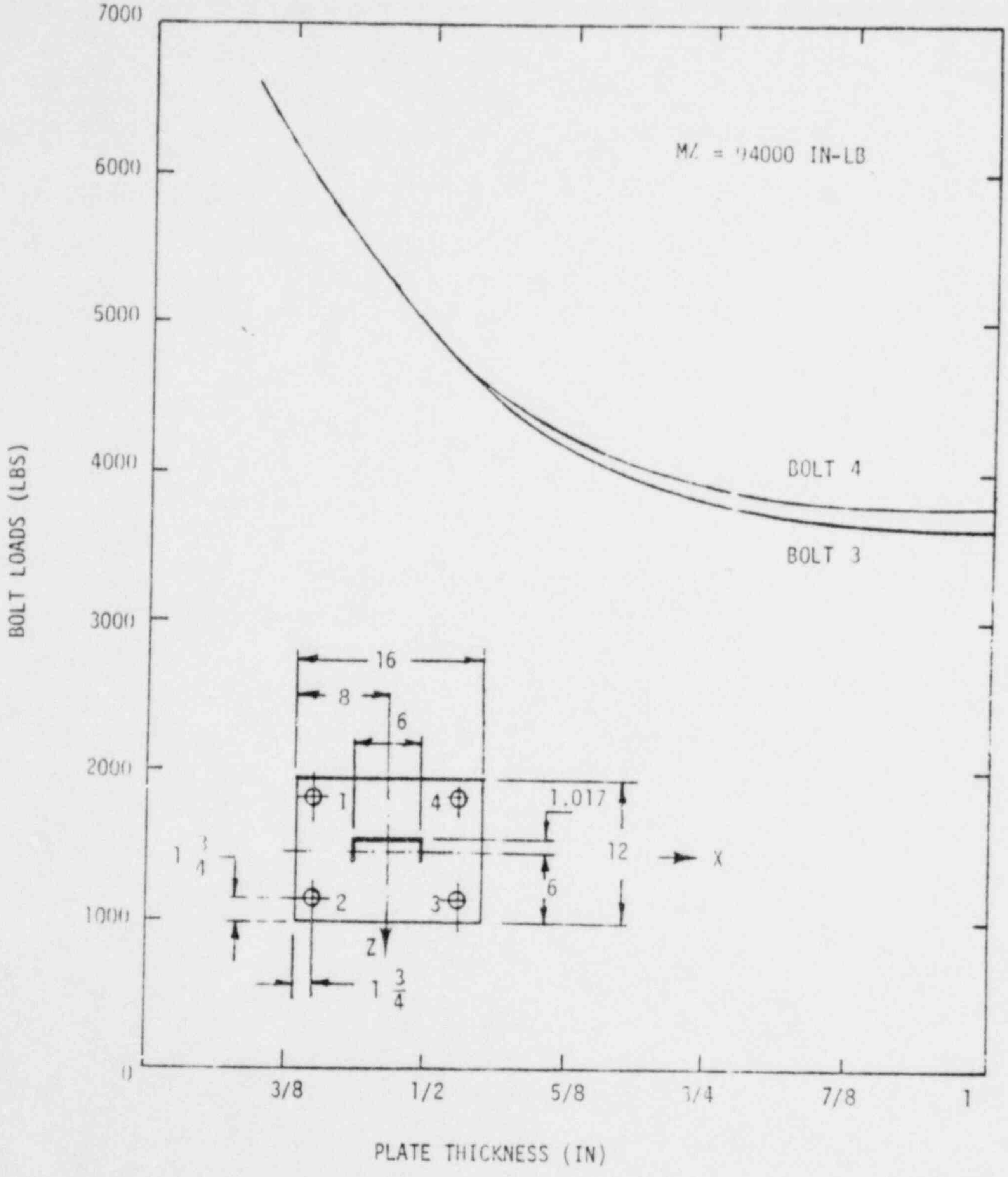


Figure 5.43 - 12" x 16" Baseplate, 3/4" Phillips Self-Drill, C6 x 10.5 Attachment

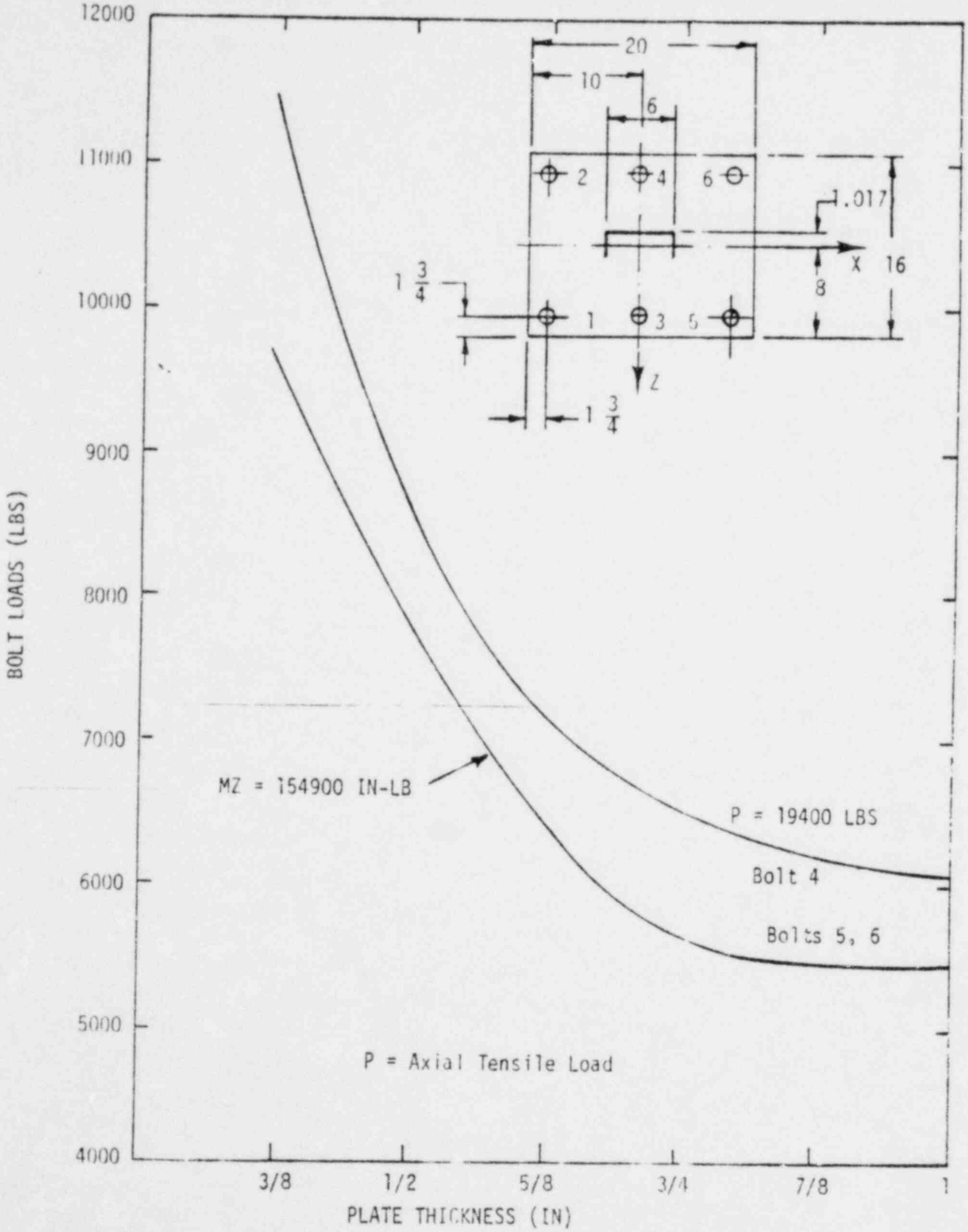


Figure 5.44 - 16" x 20" Baseplate, 3/4" Phillips Self-Drill, C6 x 10.5 Attachment

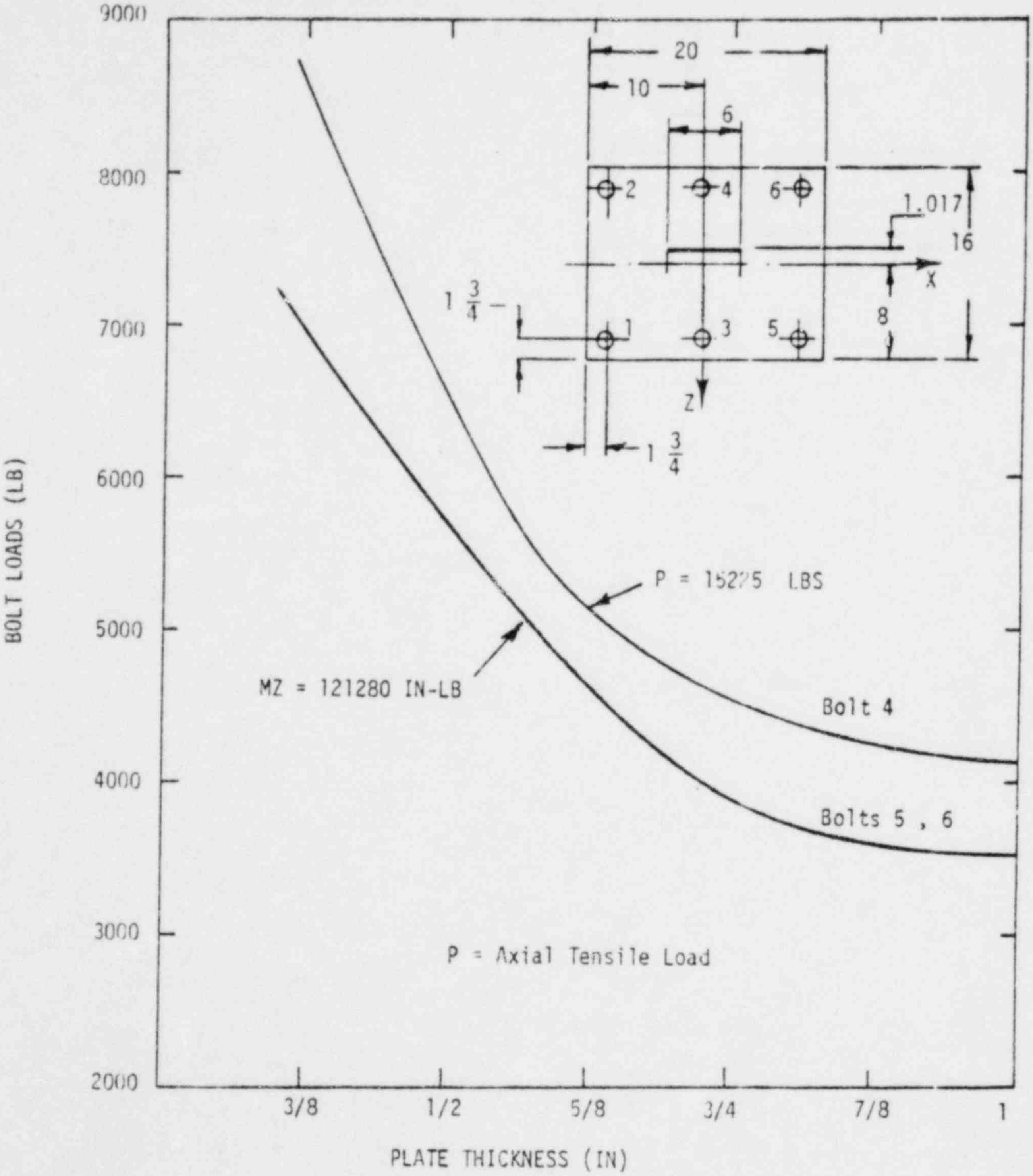


Figure 5.45 - 16" x 20" Baseplate, 3/4" Hilti Kwik-Bolt, C6 x 10.5 Attachment

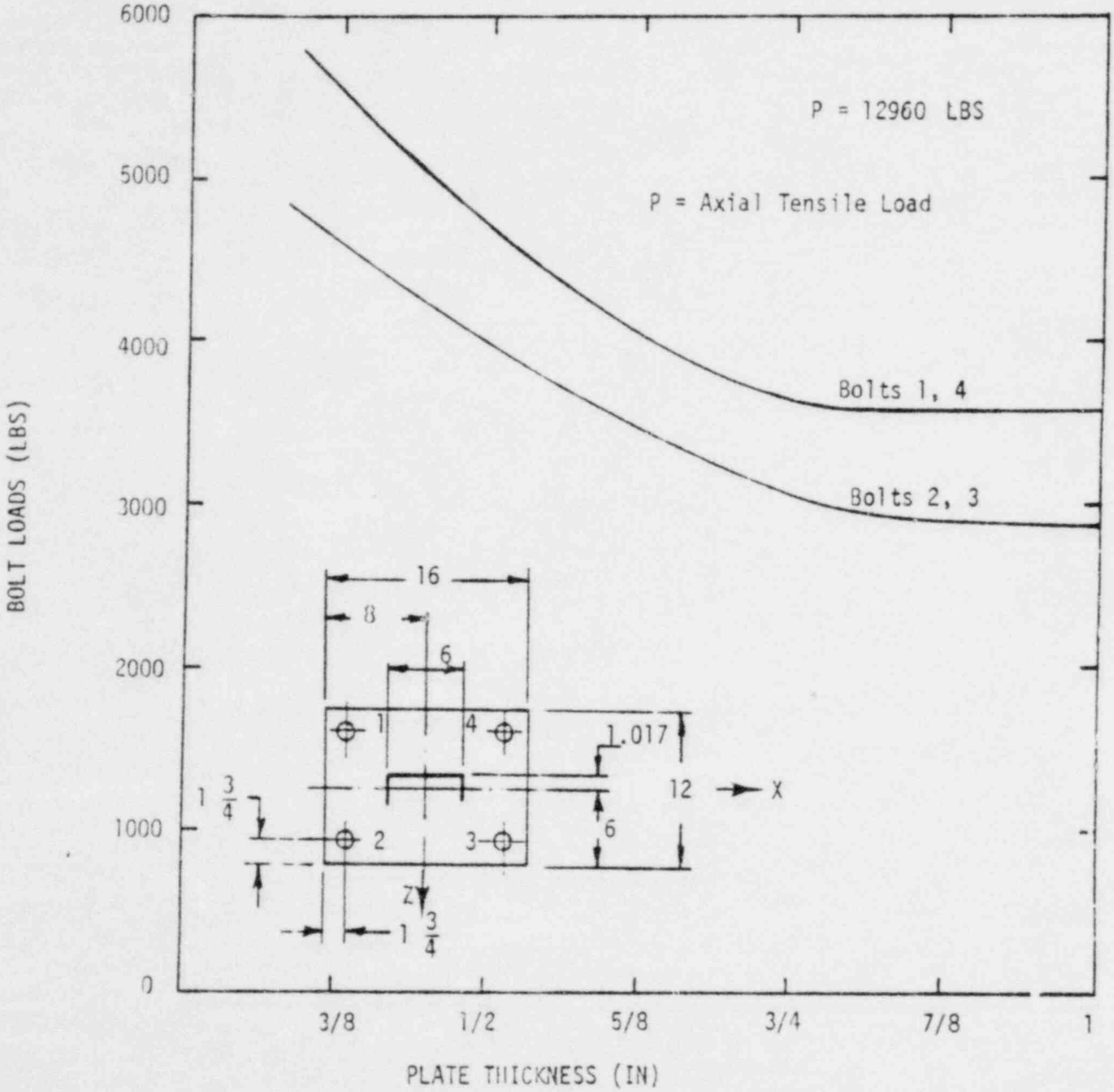


Figure 5.46 - 12" x 16" Baseplate, 3/4" Phillips Self-Drill, C6 x 10.5 Attachment