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Investigation of the stress-strain of American Standard or National Course bolts

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INVESTIGATION OF THE STRESS-STRAIN OF AMERICAN STANDARD OR NATIONAL COURSE BOLTS

BY

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A

THESIS

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Approved by ______________________

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PREFACE

The purpose of this investigation is to determine, if possible, a formula for the initial tensile load that will consider the Nominial Diameter of the bolt and the yield point of the material from which the bolt is manufactured; to determine, if possible, a torque stress relation, when tightening the bolt.

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF TABLES (cont.)

LIST OF PLATES

PART 1

INTRODUCTION

It has been the experience of the author, as well as that of many of his colleagues, that the available literature concerning torque-stress relationships in threaded bolts is very incomplete, although the subject is of vital importance in machinery fabrication. It is common knowledge that a husky mechanic with a generous wrench can overstress a bolt by incorrect tightening of the nut. Little factual information is available, however, for guiding the machanic in tightening the nut so that the bolt will perform the task for which it was designed without overstressing and possible failure.

The load-carrying capacity of highly-stressed bolts is greatly influenced by the force applied to the wrench used for tightening the bolt. Bolt size and number selected in the design of any bolted joint is generally sufficient to carry the load of the joint without overstressing and consequent failure, provided that the bolts are tightened properly. Excessive tightening of the nut on the bolt may produce such high initial stresses in the bolt that the normal design loads cannot be carried without causing bolt failure.

"A properly tightened bolt is one that is stressed with a tension load equal to or greater than the external load, yet within its own limits being stressed less than the elastic limit of the material used. When this condition is fulfilled and maintained against reasonably rigid bolted assemblies, the bolt cannot fail by fatigue because it does not experience a change in stress regardless of the fluctuating nature of the operating load.(1)

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(1) "Torquing of Nuts in Aircraft Engines" SP - 23 SAE Progress Report No. 1, Dec. 1943, p.1

It will not fail statically because, if tightened as stated, it will be capable of supporting the greatest operating load."

It is the purpose of this investigation, therefore, to try and establish some relationship between the stress-strain characteristics of the bolt and the torque-strain characteristics resulting from the tightening of the nut on the bolt to aid in the design and assembly of bolted connections. In order to do this, it was necessary to establish a correlation between the torque load applied to the nut during the tightening operation with the stress developed in the bolt.

PART 2

REVIEW OF LITERATURE

In searching for information dealing with torque-stress relationship in bolts, it is only natural to explore the technical literature in an effort to find out whet information, if any, is available on the subject in books and periodicals. Books dealing with structures and machine design were considered first.

One formula, used in many machine-design texts for calculating the initial load in a bolt due to tightening is given by the equation

$$W = 16,000\ D \qquad (1)$$

Where W = initial load in the bolt is pounds

D = bolt diameter in inches

This is an empirical relationship developed from a series of experiments conducted in the laboratories of the Sibley College of Engineering, Cornell University and used for valculating the stress produced in standard bolts when making a tight joint. (2)

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(2) Kimball, D. S. and J. H. Barr "Elements of Machine Design" 3rd. ed. John Wiley and Sons, Inc., New York 1935, p. 278

If the initial load in the bolt (W), obtained from equation (1) is divided by the cross-sectional area of the metal in the bolt at the root of the thread, the initial unit tensile stress is obtained.

The equation for the initial unit tensile stress becomes

$$S_1 = \frac{W}{A_1} = \frac{16,000\ D}{\frac{\pi D_1^2}{4}} \qquad (2)$$

Where S_1 = Initial unit stress, psi

A_1 = Cross section area of bolt at root of thread

D_1 = Diameter of bolt at root of thread

Since the root diameter of National Coarse (U.S.S.) threads is approximately 0.8 D, the equation for the initial stress, equation (2), can be simplified to the form in which it is often found in machine-design texts as follows

$$S_1 = \frac{16,000\ D}{\frac{0.64\pi D^2}{4}} = \frac{32,000}{D} \qquad (3)$$

The constant in equation (3) is given different values by various authorities, depending upon the relationship between D (the diameter of the bolt) and D_1 (the diameter of the section at the root of the thread) taken by the authority developing the equation. In every instance the equation for the initial unit tensile stress is of the form

$$S_1 = \frac{C}{D} \qquad (4)$$

Where C = a constant

A search of current technical periodicals for information about torquing of nuts on bolts, or the stress-strain characteristics of bolts, produced very little material of value. Twelve articles, published in various periodicals for the years 1930 to 1947 inclusive are listed in the Engineering Index. Of these twelve articles, only two contained information of any value in this investigation. Both articles dealt with special types of bolts.

In 1943 the War Engineering Board of the Society of Automotive Engineers saw the critical need for a uniform method of tightening nuts on aircraft engines. This board, composed of outstanding engineers connected with internal-combustion-engine-manufacturing plants, started to collect data on torquing of nuts. Their efforts produced the Report "Torquing of Nuts in Aircraft Engines" previous referred to.

J. Joyce, chief engineer of the Jo Manufacturing Company, prepared two articles (3) concerning the correct

(3) Joyce, J. Torque Wrenches, Air Tech, Reprints from Oct. 1944 issue.

use of the torque wrench and the advantages of the torque-indicating and torque-limiting wrenches. A table of "Suggested Torque Values" for fine-and course-thread series bolts and nuts was included in the article.

To establish definite torque limits for the sizes of bolts most commonly used in aircraft construction, Consolidated Vultee Aircraft Corporation conducted a series of tests based on standard AN nuts and bolts with the objective of setting standards which would satisfy design requirements and be safe with respect to the strength of the material (4).

(4) Torque Values for Standard AN Bolts and Nuts, Iron Age v. 158, n. 15, p. 59, Oct. 10, 1946

Books and technical articles discussed here contain empirical formulae for the design of bolted joints and torquing data for certain special bolting conditions (particularly in the aircraft field). Nothing was found that had a direct bearing upon the torque-stress relationship in bolts upon which this thesis is based. In view of this situation, therefore, the research work presented here is, in effect, an original approach to a problem of long standing in the machinery design and machinery fabrication field.

PART 3

DISCUSSION

A bolt that is incapable of maintaining an initial tension equal to the external load applied to the bolted joint will probably fail in severe service. Furthermore, properly-tightened bolts will sustain greater loads as the rigidity of the bolted assembly is increased or as the elesticity of the bolt is increased. There is a relatively greater percentage of failures of short bolts than of long bolts because the allowable elongation, without exceding the elastic limit of the materialm is less in short bolts. Because of this tendency for failures to predominate in short bolts, it is advised that the unit tensile stress be kept below the yield point ot eliminate the possibility of the bolt loosening thereby destroying the effectiveness of the joint and damaging the bolt.

It has been recommended in the investigation conducted by the SAE that, "The tension in the bolt when measured by the bolt stretch should be 80% of the yield strength of the bolt or 80% of the yield strength of the abutment, whichever is the weaker. The yield strength used should be that of the minimum allowable hardness of the bolt or abutment and the minimum allos-able diameter of the bolt or abutment boss, whichever is the weaker" (5).

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(5) Torquing of Nuts in Aircraft Engines, op.cit. p. iii

Since these "ecommendations would place a limiting stress upon the boltm it becomes necessary to calculate the allowable load the would produce a stress equal to 80% of the yield strength of the bolt material. This is particularly true for critically-fluctuating load, since in such cases it is imperative that the bolt stress be kept the elastic limit of the bolt material.

In tightening a nut it is far better to stress the bolt above the yield point of the material than on risk having the bolt loosen in service. Since, for adequate size bolts, the load for all practical purposes is static, there can be no harm in stressing above the yield point of the metal, providing the deformation is not so great as to reduce the static strength of the bolt. The amount of yield that can be tolerated will depend on the length of the bolt, the design of the bolt, and the characteristic of the material. Yield is concentrated at the root of the threads regardless of the length of the bolt, and since it is, little yield, as measured by elongation, can be tolerated.

The necessity for tightening above the yield point would occur only in such case as tightening a castle nut a fraction of a turn to permit installing a cotter, or where the resulting tensile load is only a few pounds above the yield strength of the bolt.

There are two problems involved in the proper loading of a bolt in service. The first is to determine the load that should be applied to the bolt on initial tightening, the second is to determine when that load has been applied. The two problems will be considered in the order stated.

Calculation of bolt loading. Determination of the load to be carried by the bolt can be made by the use of equation (2), p.4.

Since $S_1 = \frac{W_1}{A_1}$

The load becomes $W_1 = S_1 A_1 = (S_1) \left(\frac{\pi D_1^2}{4}\right)$ (5)

This equation involves the cross-sectional area of the bolt at the root of the thread. In actual engineering practice, the tendency to deal with the nominal diameter of the bolt is so great that it would be advisable to have an equation where the nominal diameter (D) could, with appropriate constants, be substituted for the root diameter (D_1). It would be a simple matter to make such a substitution if the ratio of root to bolt diameter were constant. Unfortunately, the ratio is not constant, varying from 0.769 for a 5/16-in to 0.9817 for a 3-in. diameter bolt; the range of bolt diameters analyzed. The determiniation of actual and relative ratios of root to nominal bolt diameters for bolts from 5/16 to 3-in. diameter are shown in Table 35.

Since the ratio D_1/D is not constant, and since an equation for the calculation of the initial load (W_i) that should be applied to the bolt would be most convenient if the nominal bolt diameter (D) could be employed, a study of a means for employing the nominal rather than the root diameter was undertaken.

As an approach to the problem it was assumed that the following equation

$$W_i = S_i A_1 = a D^x \tag{6}$$

could be employed, provided that the proper constants (a) and (x) could be determined. As a further aid in analyzing the possibilities of the foregoing equation, it was assumed that the initial unit stress would be the yield point value.

If S_y = Yield-point strength (psi) for the bolt material,

it was assumed that (a) in equation 6 could be replaced by an expression including (S_y) as follows:

$$a = c S_y \tag{7}$$

Where c = a constant

Since the initial stress is assumed to be the yield point value, then for this condition, and this condition only

$$S_i = S_y \tag{8}$$

Substituting equations 7 and 8 in equation 6, we obtain

$$W_i = S_y A_1 = c S_y D^x \quad (9)$$

Which simplifies to

$$A_1 = c D^x \quad (10)$$

The original assumption of the form of the equation for determining the initial load in terms of the nominal bolt diameter is true if the relationship between the cross-sectional area of the bolt at the root of the thread and the bolt diameter is correctly expressed by equation 10. Arithmetical calculations showed that equation 10 would, with proper constants for (c) and (x) express the relationship between A_1 and D; the equation, with the correct numerical constants being

$$A_1 = 0.55 D^{2.14} \quad (11)$$

The empirical relationship, equation 11, was developed as follos: the first step, in the process was to calculate the cross sectional area at the root of the thread for each USS standard bolt in the size range from 5/16 to 1-in. Following this, the relationship between the nominal bolt diameter and the area at the root of the thread was plotted on logarithmic cross-section paper, Fig. 9. Examination of this plot showed it to be a straight line. Since the data plotted as a straight line on logarithmic paper, the equation for it was of the form (6)

$$y = ax^b$$

(6) Lipka, Joseph, Graphical and Mechanical Computation John Wiled and Sons, Inc., New York, p. 128

the same as equation 10.

The slope of the line, numerically equal to (x) of equation 10, was found to be 2.14. A value for (c) was determined by substituting values in equation 10 for (A_1), (D), and (x) for a 1-in. bolt diameter. These substitutions gave

$$A_1 = c\ D^x$$

$$0.551 = (c)\ (1^{2.14})$$

For which c = 0.551

The value of o.55 was used for (c) in equation 10, a variation of less than 0.2 per cent from the vlaue calculated.

As a further check on the correctness of equation 10 test calculations were made as follows:

Bolt Diam. (Inches)	Cross-Section Actual	Area at Root of Thread Calculated by eq. 10
5/16	0.0454	0.0456
1/2	0.1257	0.1254
5/8	0.2018	0.2018
7/8	0.4193	0.414
1	0.551	0.55

Since there is a relationship between the cross-sectional area at the root of the thread and the nominal bolt diameter that can be expressed by equation 11, and since this relationship forms part of equation 9, combining the two equations results in the equation

$$W_i = 0.55\ S_y\ D^{2.14} \tag{12}$$

which is the expression for calculating the initial load imposed upon a bolt when stressed to the yield point.

If the initial load is desired when the stress is some value less than that for the yield point, all that is necessary is to multiply the right-hand side of equation 12 by the percentage of the yield-point value to which the bolt is to be stressed.

Torque testing of bolts.

It has been pointed out previously in this report that in order to properly load a bolt, it was necessary to (1) calculate the load that should be applied and (2) determine when that load has been applied. Since no information could be found concerning a satisfactory method for determining when the correct load had been applied, experimental investigations were undertaken in an attempt to produce such information.

PART 3

a

TEST EQUIPMENT

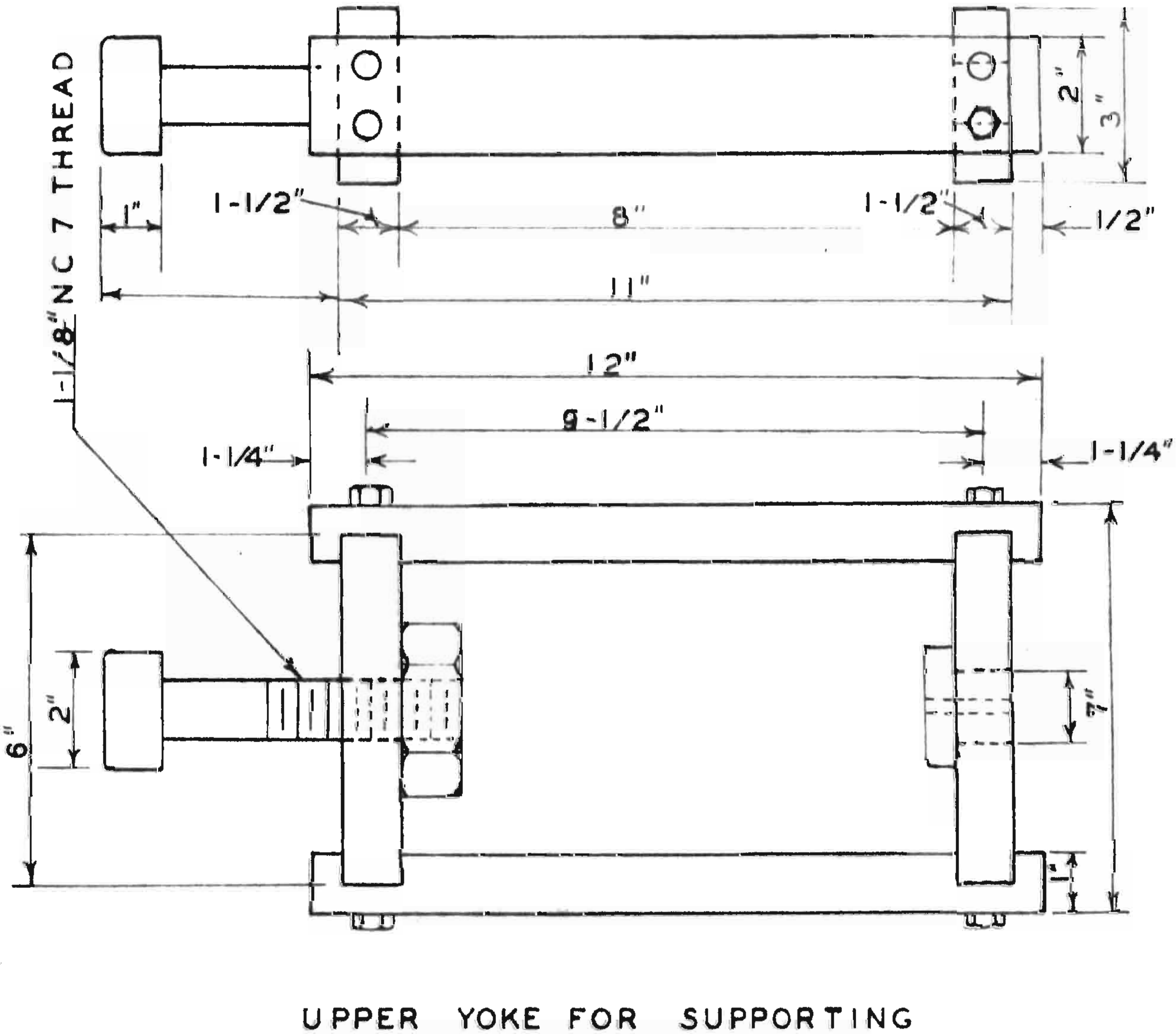
This investigation deals with the determination of the relationship between the torque applied to a nut and the resulting tensile stress produced in the bolt. A universal testing machine, Fig. 1, fitted with special yokes to facilitate the application of torque while measuring the resulting bolt stress, was used for conducting the tests.

The yokes, made of SAE 1010 steel obtained from Ryerson Steel Company, were designed to withstand the maximum load to which they would be subjected during the tests with a liberal margin of safety. Because of the limited space available for the assembled setup in the testing machine, it was necessary to make the upper yoke, Fig. 2, as short as possible yet provide space for installing mandrels, starting the upper nut on the bolt, and for connecting and operating a torque wrench. The lower yoke, Fig. 3, had to be long enough to permit installation of mandrel and starting of the lower nut on the bolt.

Each yoke was equipped with a threaded back bar to facilitate connection to the test machine centering-wedge by means of a 1-1/8-in. bolt. The bolt for the upper yoke was made long enough to accomodate a 1-1/8-in. jam nut, used to prevent turning of the upper yoke while applying torque to the nut.

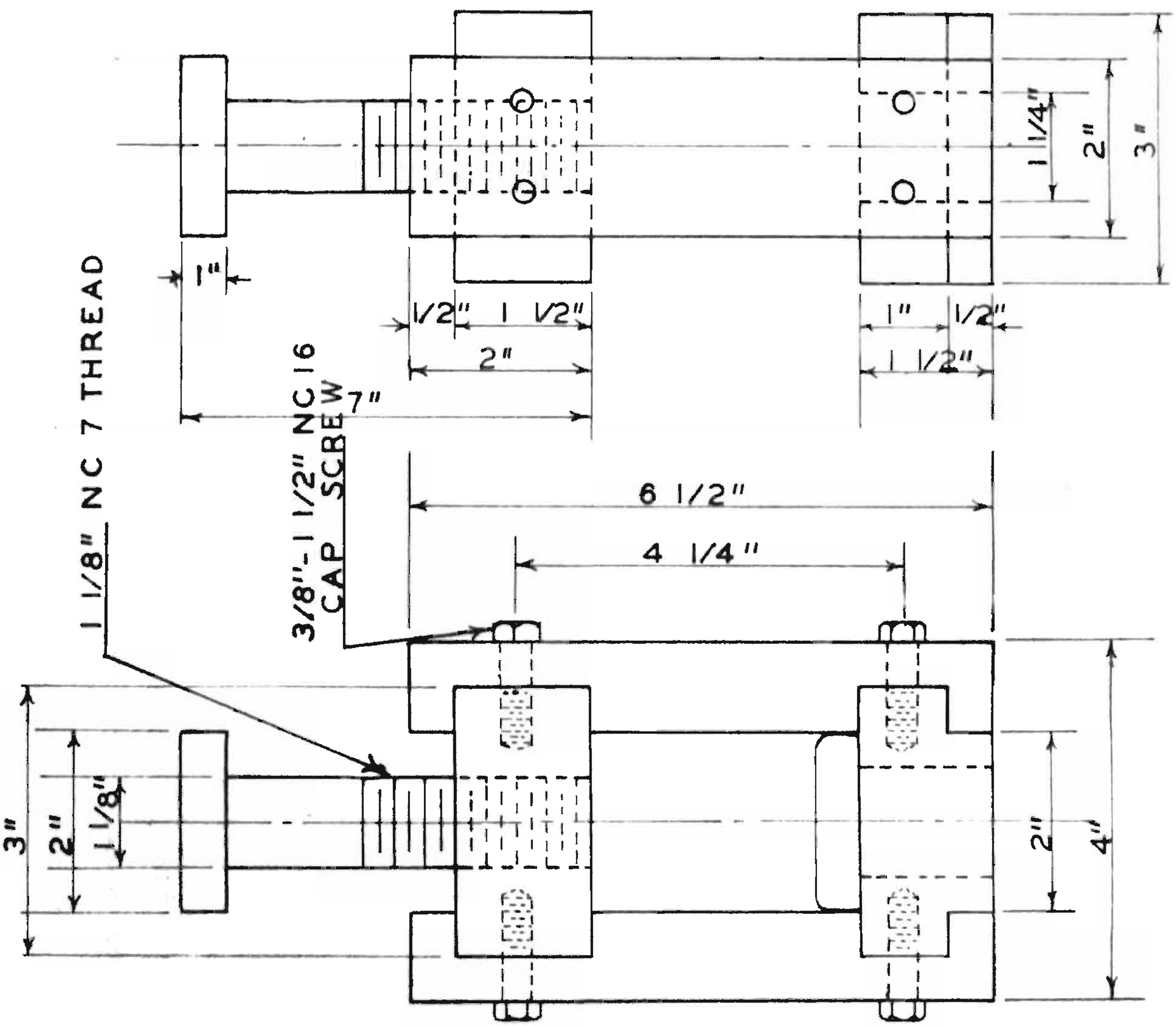
Fig. 1 Photograph of Testing Machine

FIGURE 2



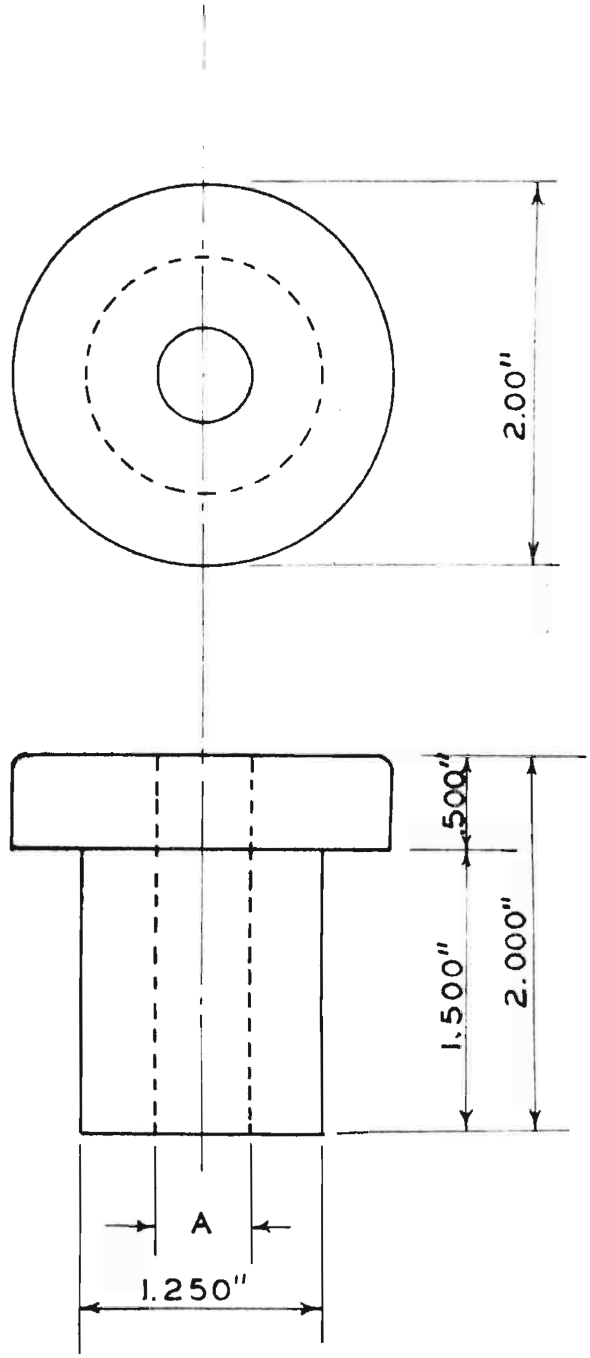
UPPER YOKE FOR SUPPORTING BOLT IN TESTING MACHINE

FIGURE 3



LOWER YOKE FOR SUPPORTING BOLT IN TESTING MACHINE

FIGURE 4



BOLT - A

3/8" - 25/64"
7/16" - 29/64"
1/2" - 33/64"
5/8" - 41/64"

MANDREL FOR HOLDING AND CENTERING BOLT IN YOKE

The bolt mandrels were made of 2 in. Rycase 1118, case hardenable material, Fig. 4, and so designed that the head had an outside diameter of 2 in. an a thickness of 1-1/2-in. The bodies of these mandrels were all 1-1/4-in. diameter by 1-1/2-in. long and all mandrels were interchangeable in top and bottom yokes. The hole through the center of each mandrel was drilled and reamed 1/64-in. greater diameter than the bolt to be used. Two mandrels were made for each size of bolt under test. These mandrels were machined finished and then case hardened in a bath of Lee Carburizing Salt for a period of 2 hours so that a penetration of approximatley 0.020-in. was obtained. Since the nut was to turn metal on metal without lubrication, it was necessary to provide the face of the mandrel with a hard and tough surface to prevent damage to it by the nut.

The test specimens were American Standard threaded bolts, sizes 3/8, 7/16, 1/2, and 5/8-in., and made of SAE 1010 cold rolled steel, obtained from Ryerson Steel Company. Each bolt was 10-in. long, completely threaded on the lathe, then sized with a new standard card die to make all bolts of a particular size the same root diameter.

The test bars were made having a test section 4-in. long and a diameter of 0.505-in. These test bars were placed in the holders with an extensometer clamped to the test section. The testing machine was then started and the test specimen loaded very slowly. Readings were taken of the applied load corresponding to elongation increments of 0.001-in. Elongation and loads were recorded until the specimen showed an increase in length of 0.100-in. over a 2-in. test length. The extensometer was then removed and the load increased until the ultimate tensile strength was reached.

The next step was to determine the elongation and stress strain data for the various bolts. A bolt was placed in the holder, Fig. 5, being centered by the mandrels. Nuts were then applied to both top and bottom and adjusted until the holders and wedges were snug and the weighing beam floated at a balance. The extensometer, Fig. 6, was then applied and zeroed. The overall length of the bolt from mandrel face to mandrel face was measured and recorded. Load increments of 100 pounds were applied and elongation

Fig. 5 Photograph of Testing Yoke in place with Bolt Set in the Holders.

Fig. 6 Photograph of Extensometer in Place.

determined for each successive load. Stress-strain data were taken for all sizes of bolts to be investigated in the manner just described.

After the stress-strain data were taken, a bolt was placed in the holders and tightened until the weight arm of the testing machine balanced at zero. The top nut was then tightened by use of the Sturtevant torque wrench, Fig. 7, until 100 inch-pounds was indicated by the wrench dial. The load thus imposed on the testing machine was measured by balancing the weighing arm. Successive increments of 50 inch-pounds were applied to the nut, Fig. 8, with the torque wrench until the bolt was broken or the capacity of the wrench (2400 inch-pounds) was reached. For each torque load applied to the bolt, the corresponding tensile load measured by the testing machine was determined.

The torque was always applied with the wrench in a horizontal plane so that binding would not produce an error in the readings of the wrench.

All test results are tabulated in the body of this Thesis, Tables 1 to 36 inclusive. Graphical plots of the data are shown on Plates 1 to 11 inclusive. These test data form the basis for the following analysis of the relationship between torque applied to the nut and the resulting load imposed in the bolt.

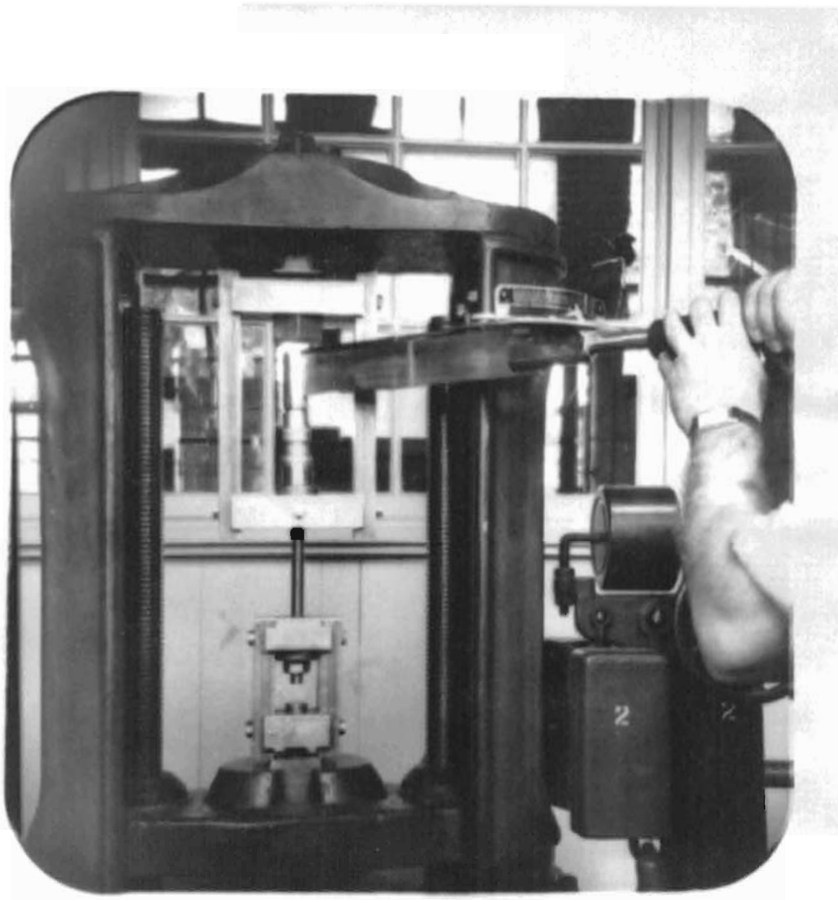


Fig. 7 Torque Wrench and Socket Assembly in place (Torque indicating dial readily visible).

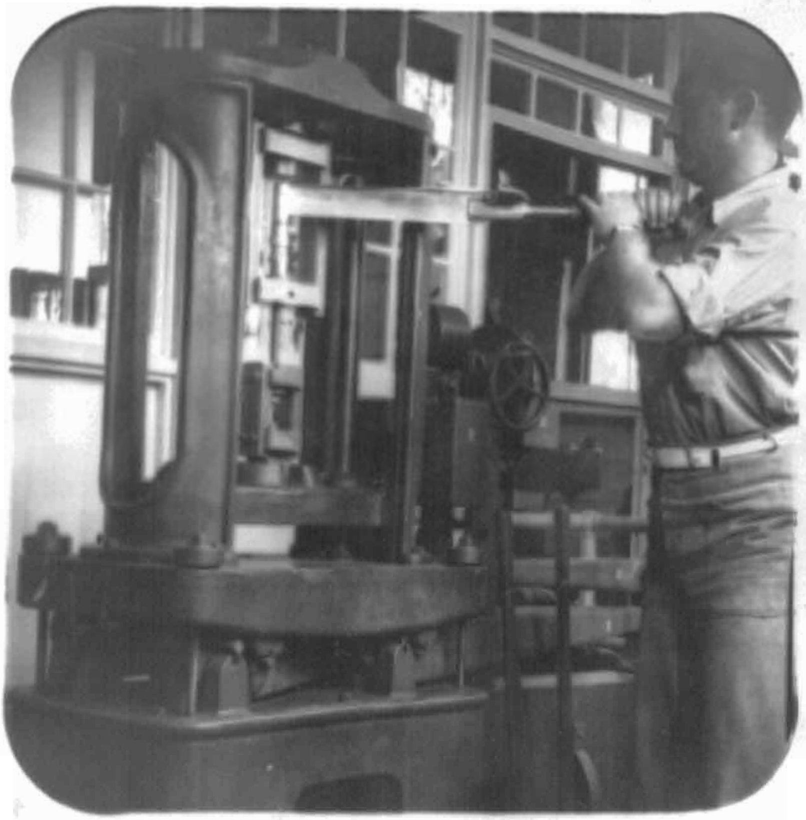


Fig. 8 Torque being applied to nut to place stress upon Bolt.

PART 3

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INTERPRETATION OF TEST RESULTS

The tensile stress-elongation data obtained from the test bars gave a yield point of 80,000 psi for the material. This yield-point figure was also obtained for the 3/8, 1/2 and 5/8-in. threaded bolts. The stock used for the 7/16 bolts supposedly of the same composition as the other specimens, had a yield point between 66,000 and 68,000 psi, a value considerably lower than that for the other bolts and the standard test specimens. In all cases the yield-point values obtained were from two to three times the value of yield point for SAE 1010 steel (28,000 psi) as given in handbooks. All investigations and analyses of the torque-tension data obtained are on the basis of a yield point of 80,000 psi for the material under test.

From the plots of torque-tension data, plates 7 to 11 inclusive, mean values of torque for 50, 60, 70, and 80 per cent of the yield point value as well as for the yield point were obtained. These values are summarized in Table 36, and plotted on Fig. 10. This plate on semi-log paper showed that the torque values vs bolt diameter for a given percentage of the yield value was approximately a straight line relationship. Values for 7/16-in. bolts did not conform to this straight-line relationship, but all other values were reasonably close to the mean line as examination of Fig. 10 will disclose. The only explanation for the failure of the 7/16-in. bolts to conform to the relationship established by the others is undoubtedly due to the difference in the yield-point value for the material of which the 7.16-in. bolts was fabricated.

Since the relationship between torque for a given percentage of the yield-point value and bolt diameter is a straight line on semi-log paper, the equation for it is the form (Fig. 11, p. 30).

$$\log T = sD + \log T_o$$

A separate equation must be developed for each load to be imposed on the bolt expressed as a percentage of the yield point. The equations for initial unit stress in the bolt equal to 100 per cent, 80 percent, and 70 per cent of the yield point value of 80,000 psi are as follows:

For 100% of yield point

$$\log T = 2.335 + 1.95\ D \qquad (13)$$

For 80% of yield point

$$\log T = 2.11 + 1.95\ D \qquad (14)$$

For 70% of yield point

$$\log T = 2.049 + 1.95\ D \qquad (15)$$

Examination of equations 13, 14, and 15 show that the only difference between them is the constant on the right hand side of the equation which is $\log T_o$. The slope is the same for all three curves, and consequently (s) had a constant value of 1.95.

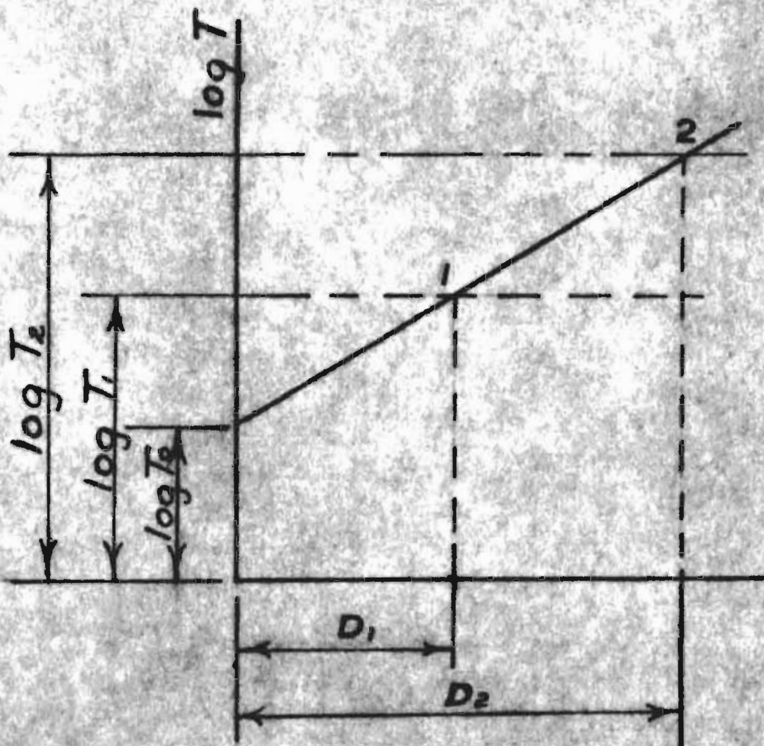


FIG 11

T = Torque in inch pounds to produce the desired load in the bolt in percent of the yield-point value.

s = Slope of the straight line = $\dfrac{\log T_2 - \log T_1}{D_2 - D_1}$

D = Bolt diameter in inches

T_o = Hypothetical torque for a bolt diameter of zero inches (Y-axis intercept).

The constants obtained in the three preceding equations were calculated by two independent methods as a check on their accuracy. One method, used in developing the constants in equation 14 will serve to illustrate the method of arriving at all constants.

$$s = \frac{\text{Log } T_2 - \log T_1}{D_2 - D_1} = \frac{\log 1220 - \log 695}{0.500 - 0.375}$$

$$= \frac{3.086 - 2.842}{0.125} = 1.95$$

Now $\log T_o = \log T_2 - sD$

Substituting known values we obtain

$$\log T_o = 3.086 - (1.95) \ (05)$$

$$= 2.11$$

The foregoing calculations are based upon the test data for 3/8 and 1/2-in. bolts when stressed to 80 per cent of the yield point as summarized in Table 36.

TABLE 1

STRESS STRAIN CHARACTERISTICS OF STEEL USED IN THIS INVESTIGATION

Diameter of Test Section 0.505 inches

Area of Test Section 0.200 sq. in.

Extensometer Set on 2 inch Test Marks

Load Pounds	Elongation Inches	Elongation Per Unit Length Inches	Unit Load Pounds
000	.000	.000	000
1840	.001	.0005	9200
2670	.0021	.00105	13350
3420	.003	.0015	17100
4200	.004	.002	21000
4930	.005	.0025	24650
5520	.006	.0030	27600
6240	.007	.0035	31200
6690	.008	.0040	33450
7290	.009	.0045	36450
7880	.010	.0050	39400
8610	.011	.0055	43050
9210	.012	.006	46050
9880	.013	.0065	49400
10530	.014	.007	52650
11200	.015	.0075	56000
11760	.016	.008	58800
12240	.017	.0085	61200
12700	.018	.009	63500
13340	.0192	.0096	66700
13800	.0202	.0101	69000
14000	.021	.0105	70000
14420	.0221	.01105	72100
14610	.023	.0115	73050
14740	.024	.012	73700
15050	.025	.0125	75250
15240	.026	.013	76200
15370	.027	.0135	76850
15550	.028	.014	77750
15670	.029	.0145	78350
15690	.030	.015	78450
16000	.032	.016	80000
16010	.033	.0165	80050
16090	.034	.017	80450
16120	.035	.0175	80600
16230	.036	.018	81150

TABLE 1 (cont.)

Load Pounds	Elongation Inches	Elongation Per Unit Length Inches	Unit Load Pounds
16330	.0375	.01875	81650
16230	.0380	.019	81150
16310	.0195	.0195	81550
16500	.0400	.02	82500
16650	.0435	.02175	83250
17040	.0494	.0247	85200
17120	.055	.0275	85600
17290	.061	.0305	86450
17610	.071	.0355	88050
17670	.091	.0455	88350
17720	.101	.0505	88600

Maximum Load 18130 x 5 = 90,650 Pounds per sq. in.

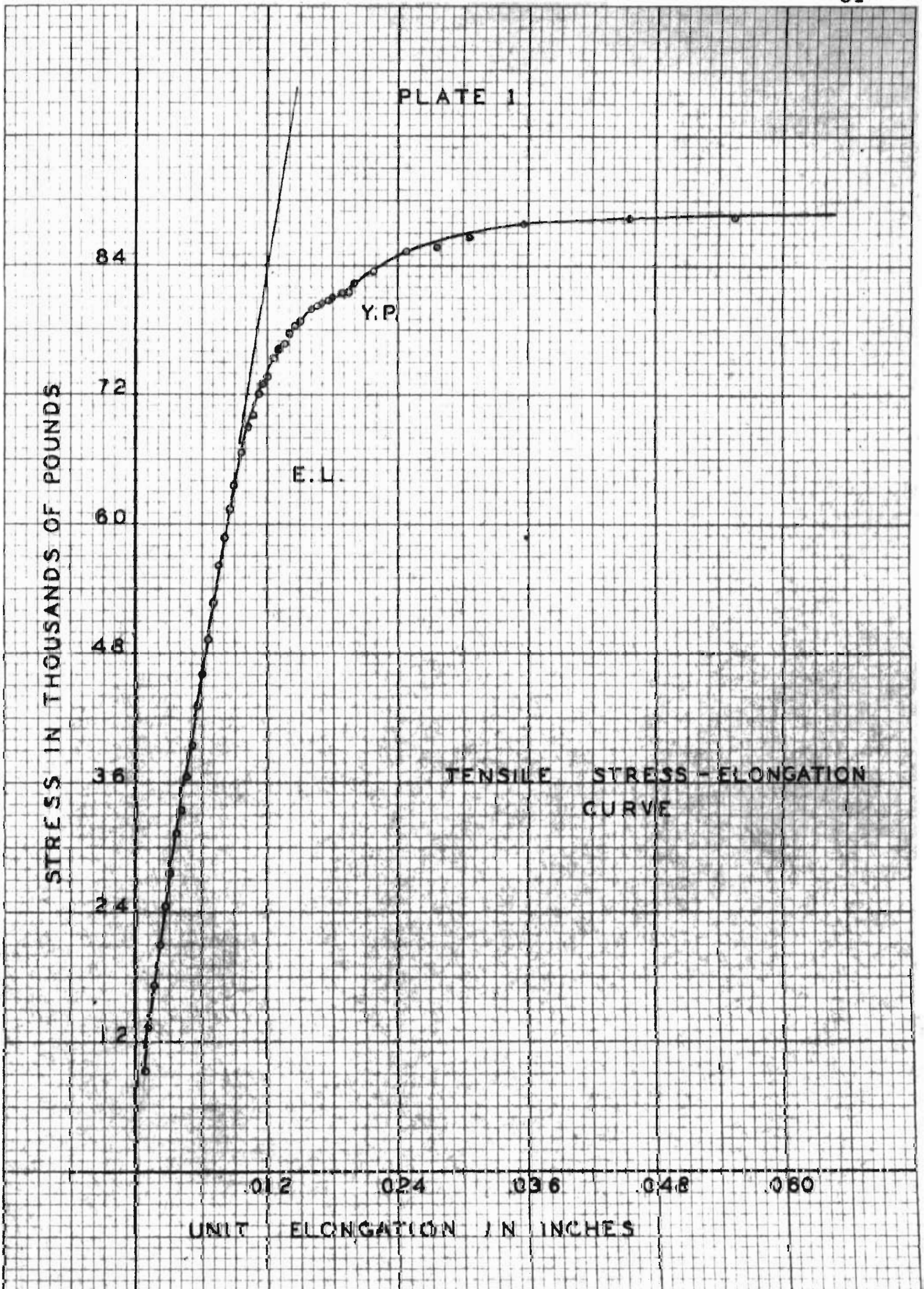


PLATE 1
Y.P.
E.L.
STRESS IN THOUSANDS OF POUNDS
84
72
60
48
36
24
12
.012
.024
.036
.048
.060
UNIT ELONGATION IN INCHES
TENSILE STRESS - ELONGATION
CURVE

TABLE 2

STRESS STRAIN CHARACTERISTICS OF STEEL USED IN THIS INVESTIGATION

Diameter of Test Section 0.505 inches

Area of Test Section 0.200 sq. in.

Extensometer Set on 2 inch Test Marks

Load Pounds	Elongation Inches	Elongation Per Unit Length Inches	Unit Load Pounds
000	.000	.000	2050
410	.001	.005	6100
1220	.002	.001	10000
2000	.003	.0015	13600
2720	.004	.002	16150
3230	.005	.0025	18750
3750	.006	.003	21700
4340	.007	.0035	23750
4750	.008	.004	26400
5280	.009	.0045	29650
5930	.0101	.00505	32500
6500	.011	.0055	34750
6950	.012	.006	37750
7550	.013	.0065	40750
8150	.014	.007	44200
8840	.015	.0075	46900
9380	.016	.008	49700
9940	.017	.0085	52450
10490	.018	.0090	55800
11160	.019	.0095	58200
11640	.020	.010	61000
12200	.021	.0105	62450
12490	.022	.011	64950
12990	.023	.0115	66900
13380	.0241	.012	68200
13640	.025	.0125	70200
14040	.0262	.0131	71800
14360	.0271	.01355	73100
14620	.0282	.0141	73800
14760	.0291	.01455	74450
14890	.030	.015	75900
15180	.031	.0155	76450
15290	.032	.016	---
---	.033	.0165	78050
15680	.035	.0175	78400
15800	.036	.018	79000
15980	.0372	.0186	79900
15980	.038	.019	79900

TABLE 2 (cont.)

Load Pounds	Elongation Inches	Elongation Per Unit Length Inches	Unit Load Pounds
16200	.040	.02	81000
16450	.045	.0225	82250
16840	.050	.025	84200
17080	.055	.0275	85400
17270	.060	.03	86350
17380	.070	.035	86900
17620	.080	.04	88100
17680	.090	.045	88400
17800	.100	.05	89000

Maximum Load 18090 x 5 = 90,450 Pounds per sq. in.

Note: Necked and broke just below the bottom punch mark for the extensometer.

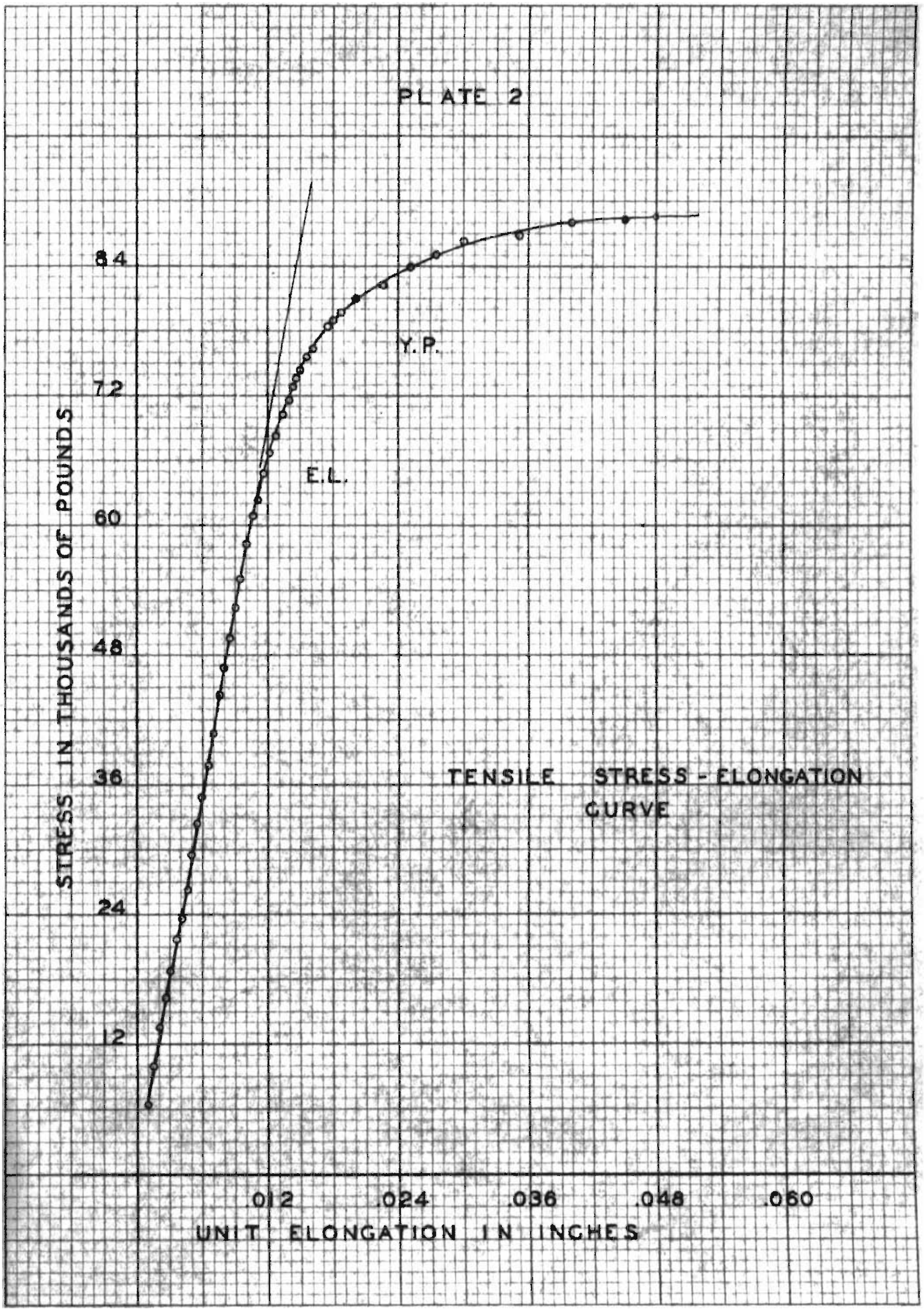


PLATE 2
84
72
60
48
36
24
12
STRESS IN THOUSANDS OF POUNDS
Y.P.
E.L.
TENSILE STRESS - ELONGATION
CURVE
.012
.024
.036
.048
.060
UNIT ELONGATION IN INCHES

TABLE 3

STRESS STRAIN DATA SHEET

3/8" Diameter Bolt	N.C. 16 threads
Minor Diameter	.2938 inches
Root Area	.0678 inches
Length	7.55 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq. in.
100	.001	.0001325	1475
200	.0025	.000331	2950
300	.005	.000662	4425
400	.007	.0009275	5900
500	.009	.001193	7375
600	.0105	.001391	8860
700	.013	.001725	10335
800	.015	.00199	11800
900	.017	.002253	13275
1000	.018	.002385	14750
1100	.019	.00252	16225
1200	.021	.00278	17720
1300	.021	.00278	19190
1400	.023	.00305	20650
1500	.0245	.003245	22100
1600	.0265	.00351	23600
1700	.028	.00371	25070
1800	.0295	.00391	26600
1900	.0305	.00404	28000
2000	.032	.00424	29530
2100	.033	.00437	30900
2200	.035	.004635	32400
2300	.0365	.004835	33900
2400	.0375	.004965	35440
2500	.0385	.005110	36850
2600	.040	.00530	38400
2700	.042	.00556	39800
2800	.043	.005699	41300
2900	.044	.00583	42800
3000	.046	.00609	44300
3100	.0475	.00629	45700
3200	.049	.00649	47200

TABLE 3 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
3300	.05	.00663	48700
3400	.051	.00676	50200
3500	.053	.007025	51600
3600	.055	.00728	53200
3700	.056	.00742	54550
3800	.058	.00768	56100
3900	.0593	.00788	57500
4000	.0605	.00802	59050
4100	.0615	.00815	60430
4200	.064	.00848	62000
4200	.065	.00862	63450
4400	.0665	.00882	64950
4500	.0675	.00895	66300
4600	.0690	.00915	67900
4700	.071	.00940	69250
4800	.0725	.00961	70900
4900	.075	.00994	72200
5000	.076	.01008	73750
5100	.079	.01049	75200
5200	.082	.01088	76750
5300	.084	.01114	77150
5400	.0875	.01160	79700
5500	.091	.01208	81100
5600	.095	.0126	82600
5700	.101	.0134	84000
5800	.107	.01419	85600
5900	.111	.0147	87000
6000	.118	.01562	88550
6100	.132	.0175	89900
6200	.143	.01895	91500
6300	.179	.02372	92800
6400	.223	.02958	94400
6530	Maximum		95800

TABLE 4

STRESS STRAIN DATA SHEET

3/8" Diameter Bolt	N. C. 16 threads
Minor Diameter	.2938 inches
Root Area	.0678 sq. in.
Length	7.474 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
100	.001	.000139	1475
200	.004	.000536	2950
300	.006	.0008035	4425
400	.051	.006835	5900
500	.053	.0071	7375
600	.055	.007365	8860
700	.056	.0075	10335
800	.057	.00764	11800
900	.058	.00777	13275
1000	.060	.00804	14750
1100	.061	.00817	16225
1200	.063	.00844	17720
1300	.064	.00857	19190
1400	.066	.00884	20650
1500	.067	.008975	22100
1600	.068	.00911	23600
1700	.070	.009375	25070
1800	.071	.0095	26600
1900	.073	.00978	28000
2000	.074	.00991	29530
2100	.075	.01005	30900
2200	.076	.01018	32400
2300	.078	.01045	33900
2400	.079	.01059	35440
2500	.081	.01085	36850
2600	.082	.0109	38400
2700	.083	.01102	39800
2800	.084	.01125	41300
2900	.086	.0115	42800
3000	.088	.01180	44300
3100	.089	.01192	45700
3200	.090	.01205	47200

TABLE 4 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
3300	.092	.01232	48700
3400	.093	.01247	50200
3500	.094	.01259	51600
3600	.096	.01285	53200
3700	.097	.01299	54550
3800	.098	.01313	56100
3900	.100	.01339	57500
4000	.101	.01352	59050
4100	.103	.0138	60430
4200	.104	.01393	62000
4300	.105	.01408	64450
4400	.107	.01433	64950
4500	.108	.01448	66300
4600	.109	.01461	67900
4700	.111	.01488	69250
4800	.113	.01513	70900
4900	.114	.01528	72200
5000	.116	.01554	73750
5100	.118	.01580	75200
5200	.120	.01609	76750
5300	.121	.01620	77150
5400	.124	.01662	79700
5500	.127	.01702	81100
5600	.130	.0174	82600
5700	.136	.01822	84000
5800	.140	.01877	85600
5900	.146	.01956	87000
6000	.153	.0205	88550
6100	.157	.02103	89900
6200	.166	.02222	91500
6300	.177	.02373	93800
6400	.202	.02705	94400
6500	.232	.0311	95800
6580	Maximum Strength		97000

TABLE 5

STRESS STRAIN DATA SHEET

3/8" Diameter Bolt	N. C. 16 threads
Minor Diameter	.2938 inches
Root Area	.0678 sq. in.
Length	7.379 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
100	.002	.000271	1475
200	.005	.000677	2950
300	.008	.001083	4425
400	.01	.001355	5900
500	.011	.001490	7375
600	.013	.001760	8860
700	.015	.00203	10335
800	.017	.002305	11800
900	.019	.002575	13275
1000	.021	.002840	14750
1100	.023	.003115	16225
1200	.024	.003250	17720
1300	.026	.003520	19190
1400	.027	.00366	20650
1500	.029	.00393	22100
1600	.030	.00406	23600
1700	.031	.00420	25070
1800	.033	.00447	26600
1900	.035	.00474	28000
2000	.037	.00501	29530
2100	.038	.00515	30900
2200	.04	.00542	32400
2300	.042	.00568	33900
2400	.043	.00582	35440
2500	.045	.00609	36850
2600	.046	.00624	38400
2700	.047	.00636	39800
2800	.048	.00650	41300
2900	.050	.00677	42800
3000	.052	.00704	44300
3100	.054	.00731	45700
3200	.055	.00745	47200
3300	.056	.00758	48700

TABLE 5 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
3400	.057	.00772	50200
3500	.058	.00785	51600
3600	.061	.00826	53200
3700	.062	.00840	54550
3800	.063	.00853	56100
3900	.064	.00866	57500
4000	.065	.00880	59050
4100	.067	.00906	60430
4200	.069	.00935	62000
4300	.07	.00947	63450
4400	.071	.00962	64950
4500	.072	.00975	66300
4600	.073	.00988	67900
4700	.074	.01000	69250
4800	.075	.01018	70900
4900	.077	.01043	72200
5000	.079	.01070	73750
5100	.081	.01097	75200
5200	.083	.01125	76750
5300	.085	.01150	77150
5400	.087	.01179	79700
5500	.090	.01220	81100
5600	.093	.01260	82600
5700	.096	.01300	84000
5800	.100	.01356	85600
5900	.103	.01395	87000
6000	.108	.01462	88500
6100	.112	.01528	89900
6200	.119	.01611	91500
6300	.129	.01745	92800
6400	.142	.01925	94400
6500	.160	.02165	95800
6600	.187	.0253	97400
6780	Maximum Strength		100000

TABLE 6

STRESS STRAIN DATA SHEET

3/8" Diameter Bolt	N. C. 16 threads
Minor Diameter	.2938 inches
Root Area	.0678 sq.in.
Length	9 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
200	.001	.00011	2950
400	.006	.00066	5900
600	.013	.001443	8860
800	.015	.001666	11800
1000	.018	.00200	14750
1200	.019	.00211	17720
1400	.021	.002241	20650
1600	.022	.002441	23600
1800	.023	.002555	26600
2000	.0245	.00272	29530
2200	.026	.002885	32400
2400	.028	.00311	35440
2600	.029	.00322	38400
2800	.030	.00333	41300
3000	.031	.00344	44300
3200	.033	.003665	47200
3400	.034	.003775	50200
3600	.036	.00400	53200
3800	.037	.00411	56100
4000	.038	.00422	59050
4200	.039	.00433	62000
4400	.0405	.004495	64950
4600	.042	.00466	67900
4800	.0435	.00483	70900
5000	.046	.00511	73750
5200	.048	.00532	76750
5400	.049	.00544	79700
5600	.0525	.00583	82600
5800	.054	.00599	85600
6000	.065	.00721	88550
6200	.072	.0080	91500
6400	.082	.0091	94400
6600	.099	.011	97400

TABLE 6 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
6800	.123	.01366	100500
7000	.156	.0173	103500
7050	.219	.0243	104100
7150	.264	.0293	105600
7200	.372	.0413	106300
7300	.436	.0484	107800

TABLE 7

STRESS STRAIN DATA SHEET

3/8" Diameter Bolt   N. C. 16 threads

Minor Diameter   .2938 inches

Root Area   .0678 sq.in.

Length   9 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq. in.
200	.000	.000000	2950
400	.002	.000296	5900
600	.004	.0005905	8860
800	.007	.001032	11800
1000	.0105	.00155	14750
1200	.0125	.001845	17720
1400	.0132	.001946	20650
1600	.0144	.002125	23600
1800	.0152	.002245	26600
2000	.0170	.002510	29530
2200	.0184	.002715	32400
2400	.0195	.00289	35440
2600	.0202	.00298	38400
2800	.0211	.003115	41300
3000	.0232	.003435	44300
3200	.0242	.003570	47200
3400	.0250	.003790	50200
3600	.0270	.003980	53200
3800	.0292	.00431	56100
4000	.0305	.00450	59050
4200	.0320	.00472	62000
4400	.0340	.00502	64950
4600	.0344	.00507	67900
4800	.0365	.00538	70900
5000	.0375	.00554	73750
5200	.040	.005905	76750
5400	.0410	.00605	79700
5600	.0435	.00642	87600
5800	.0480	.00708	85600
6000	.0502	.00740	88550
6200	.0570	.00841	91500
6400	.0665	.00981	94400

TABLE 7 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
6600	.0745	.0110	97400
6800	.0919	.0134	100500
7000	.1013	.01495	103500
7100	.1253	.0185	104850
7200	.1473	.02175	106300

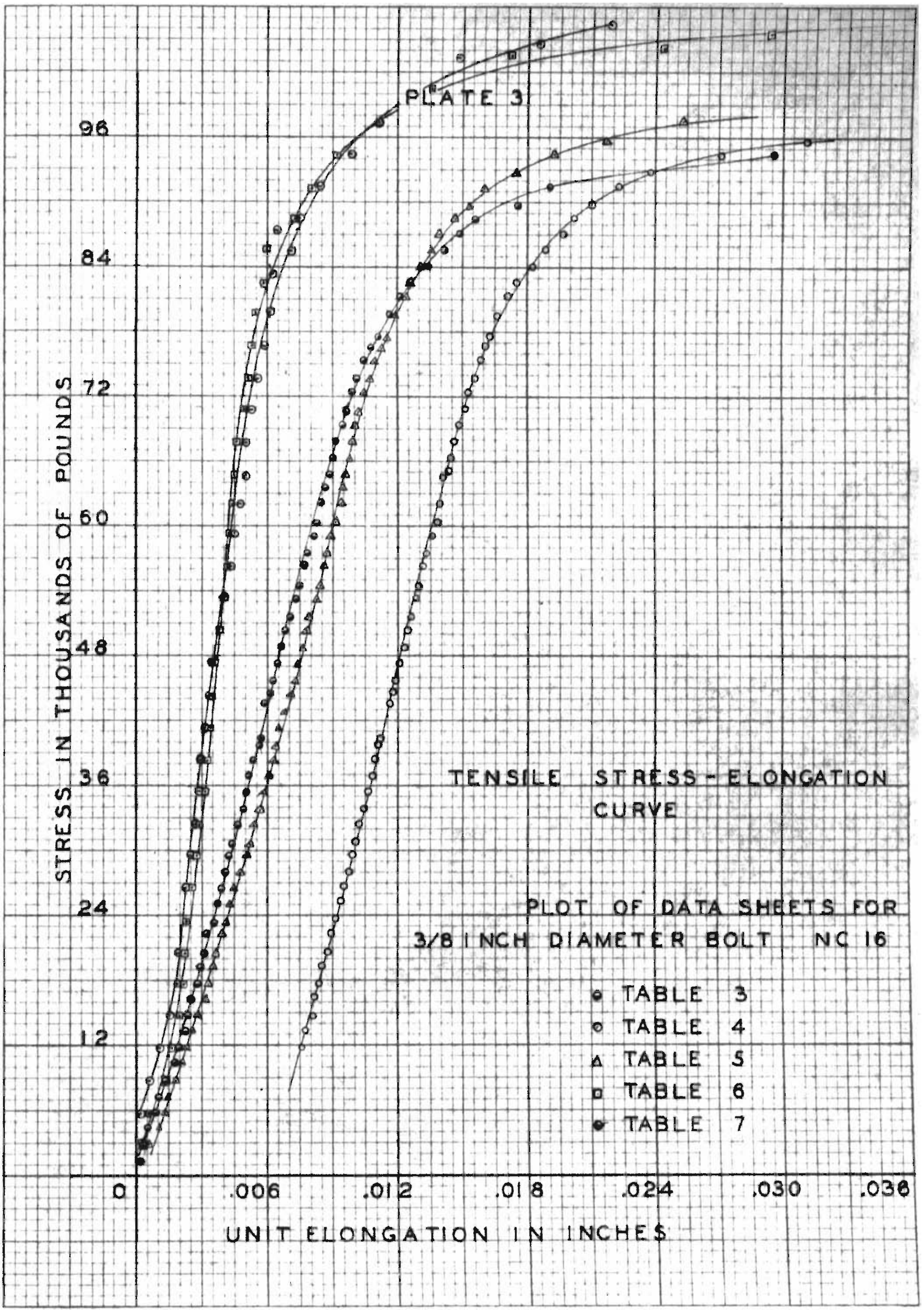


PLATE 3
STRESS IN THOUSANDS OF POUNDS
96
84
72
60
48
36
24
12
0
.006
.012
.018
.024
.030
.036
UNIT ELONGATION IN INCHES
TENSILE STRESS - ELONGATION CURVE
PLOT OF DATA SHEETS FOR 3/8 INCH DIAMETER BOLT NC 16
TABLE 3
TABLE 4
TABLE 5
TABLE 6
TABLE 7

TABLE 8

STRESS STRAIN DATA SHEET

7/16" Diameter Bolt	N. C. 14 threads
Minor Diameter	.3447 inches
Root Area	.0933 sq.in.
Length	7.274 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
200	.006	.000825	2141
400	.009	.001	4280
600	.011	.00151	6425
800	.014	.001923	8560
1000	.016	.00220	10700
1200	.020	.002746	12850
1400	.022	.00303	15000
1600	.024	.00330	17130
1800	.028	.00385	19280
2000	.030	.00412	21450
2200	.033	.00454	23550
2400	.035	.00481	25700
2600	.037	.00508	27850
2800	.039	.00536	29970
3000	.041	.00564	32100
3200	.044	.00604	34250
3400	.046	.00632	36400
3600	.048	.00660	38550
3800	.050	.00687	40700
4000	.052	.00715	42800
4200	.055	.00755	45000
4400	.057	.00783	47100
4600	.060	.00825	49300
4800	.062	.00852	51400
5000	.065	.00893	53550
5200	.067	.00920	55700
5400	.070	.00961	57800
5600	.072	.00990	50000
5800	.075	.01030	62100
6000	.077	.01058	64250
6200	.080	.01100	66400
6400	.083	.01140	68500

TABLE 8 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
6600	.087	.01196	70650
6800	.091	.01250	72800
7000	.095	.01310	75000
7200	.101	.01375	77100
7400	.108	.01485	79250
7600	.115	.01580	81400
7800	.129	.01772	83500
8000	.143	.01965	85600
8200	.174	.02390	87800
8300	.187	.02570	88800
8400	.208	.02860	90000
8500	.239	.03280	91000
8590	Maximum		92000

TABLE 9

STRESS STRAIN DATA SHEET

7/16" Diameter Bolt	N. C. 14 threads
Minor Diameter	.3447 inches
Root Area	.0933 sq. inches
Length	6.956 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress pounds/sq.in.
200	.002	.000288	2141
400	.005	.000720	4280
600	.008	.00115	6425
800	.010	.00144	8560
1000	.013	.00187	10700
1200	.015	.00216	12850
1400	.018	.00259	15000
1600	.019	.00273	17130
1800	.021	.00302	19280
2000	.023	.00331	21450
2200	.024	.00345	23550
2400	.026	.00374	26700
2600	.027	.00388	27850
2800	.029	.00417	29920
3000	.031	.00446	32100
3200	.032	.00460	34250
3400	.034	.00488	36400
3600	.036	.00518	38550
3800	.038	.00547	40700
4000	.040	.00575	42800
4200	.041	.00590	45000
4400	.043	.00618	47100
4600	.045	.00647	49300
4800	.047	.00676	51400
5000	.049	.00705	53550
5200	.051	.00734	55700
5400	.053	.00762	57800
5600	.055	.00791	60000
5800	.058	.00834	62100
6000	.060	.00863	64250
6200	.063	.00906	66400
6400	.066	.00950	68500
6600	.070	.01005	70650

TABLE 9 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
6800	.074	.01063	72800
7000	.079	.01135	75000
7200	.085	.01222	77100
7400	.093	.01365	79250
7600	.103	.01482	81400
7800	.125	.0180	83500
8000	.163	.02345	85600
8190	Maximum		87700

TABLE 10

STRESS STRAIN DATA SHEET

7/16" Diameter	N. C. 14 threads
Minor Diamter	.3447 inches
Root Area	.0933 sq. inches
Length	6.443 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
200	.002	.000311	2141
400	.005	.000776	4280
600	.007	.00109	6425
800	.011	.00171	8560
1000	.013	.00202	10700
1200	.015	.00233	12850
1400	.017	.00264	15000
1600	.019	.00295	17130
1800	.020	.00311	19280
2000	.023	.00357	21450
2200	.024	.00373	23550
2400	.026	.00404	25700
2600	.027	.00419	27850
2800	.029	.00450	29970
3000	.031	.00481	32100
3200	.032	.00497	34250
3400	.034	.00528	36400
3600	.035	.00544	38550
3800	.037	.00575	40700
4000	.039	.00606	42800
4200	.040	.00621	45000
4400	.042	.00652	47100
4600	.044	.00683	49200
4800	.046	.00714	51400
5000	.048	.00745	53550
5200	.049	.00761	55700
5400	.051	.00792	57800
5600	.053	.00824	60000
5800	.055	.00855	62100
6000	.058	.00900	64250
6200	.060	.00932	66400
6400	.063	.00978	68500
6600	.066	.01025	70650

TABLE 10 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
6800	.070	.01088	72800
7000	.074	.0115	75000
7200	.080	.01242	77100
7400	.087	.01350	79250
7600	.096	.01490	81400
7800	.111	.01725	83500
8000	.141	.02190	85600
8300	Maximum		89000

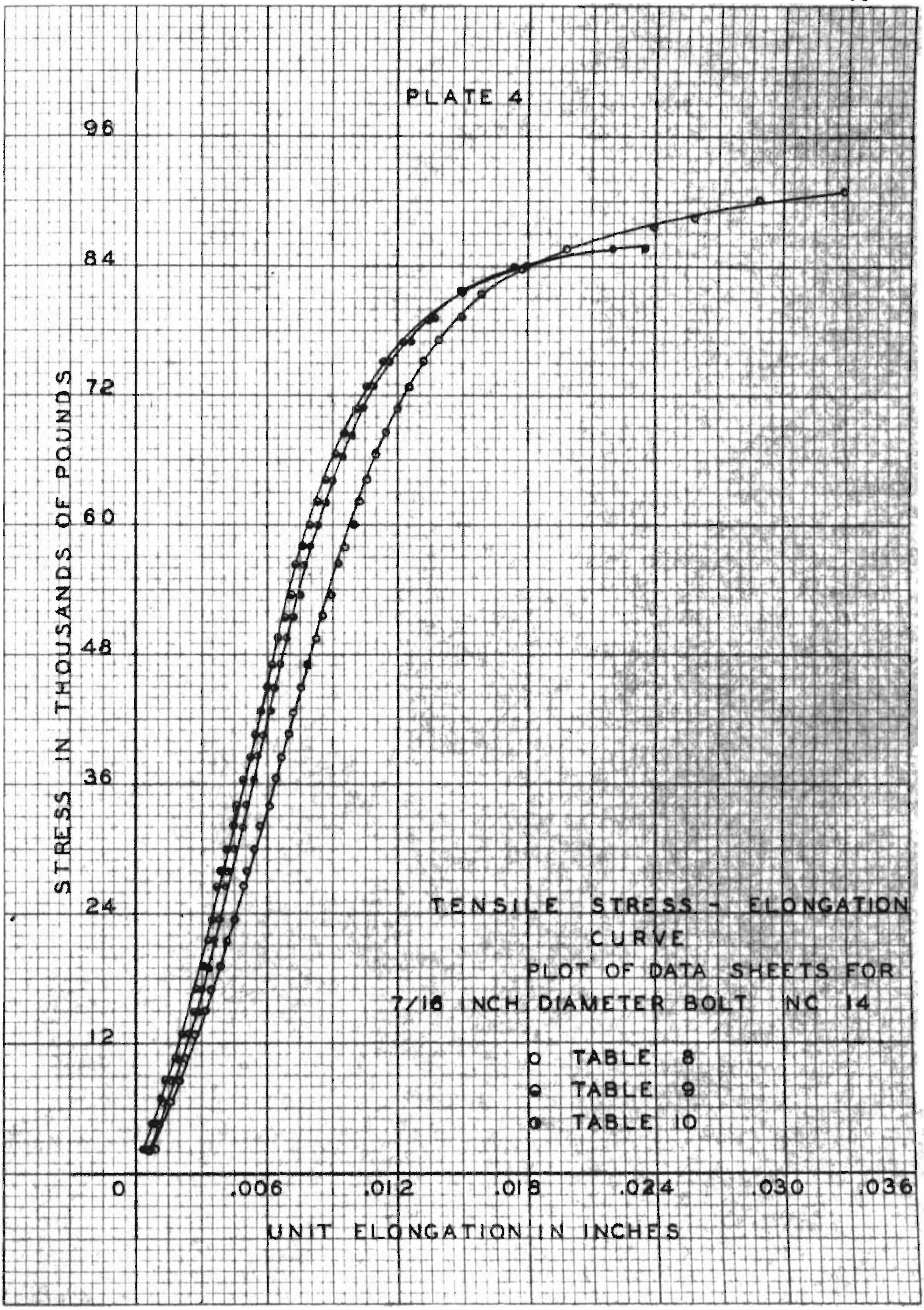


PLATE 4
96
84
72
60
48
36
24
12
0
.006
.012
.018
.024
.030
.036
STRESS IN THOUSANDS OF POUNDS
UNIT ELONGATION IN INCHES
TENSILE STRESS - ELONGATION
CURVE
PLOT OF DATA SHEETS FOR
7/16 INCH DIAMETER BOLT NC 14
TABLE 8
TABLE 9
TABLE 10

TABLE 11

STRESS STRAIN DATA SHEET

½" Diameter Bolt	N. C. 13 threads
Minor Diameter	.4001 inches
Root Area	.1257 sq. inches
Length	7.2224 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
380	.014	.00194	3020
400	.015	.00275	3180
600	.0165	.00228	4770
800	.019	.00263	6350
1000	.021	.00291	7940
1200	.025	.00346	9540
1400	.026	.00360	11120
1600	.028	.00388	12700
1800	.030	.00415	14300
2000	.032	.00443	15890
2200	.0345	.00477	17480
2400	.037	.00512	19060
2600	.0385	.00533	20620
2800	.040	.00554	22220
3000	.042	.00581	23840
3200	.044	.00608	25410
3400	.046	.00636	27000
3600	.047	.00650	28600
3800	.050	.00692	30200
4000	.058	.00802	31780
4200	.054	.00747	33300
4400	.057	.00788	34950
4600	.059	.00816	36500
4800	.060	.00830	38100
5000	.0625	.00865	39700
5200	.065	.00900	41300
5400	.067	.00927	42850
5600	.069	.00955	44500
5800	.071	.00982	46100
6000	.073	.01010	47700
6200	.075	.01038	49250
6400	.077	.01065	50800
6600	.078	.01080	52450
6800	.080	.01108	54000
7000	.081	.01108	55600

TABLE 11 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
7200	.083	.01148	57200
7400	.085	.01176	58750
7600	.087	.01203	60400
7800	.089	.01231	61900
8000	.091	.01260	63500
8200	.093	.01287	65100
8400	.095	.01315	66700
8600	.097	.01342	68250
8800	.099	.01370	69800
9000	.101	.01400	71500
9200	.104	.01440	73100
9400	.107	.01480	74600
9600	.110	.01521	76250
9800	.114	.01578	77800
10000	.118	.01633	79400
10200	.121	.01675	81000
10400	.126	.01743	82600
10600	.136	.01880	84250
10800	.140	.01936	85800
11000	.157	.02173	87400
11200	.162	.0224	89000
11400	.198	.0274	90600
11600	.220	.0304	92200
11700	.234	.0324	93000
12100	.302	.0418	96200

TABLE 12

STRESS STRAIN DATA SHEET

½" Diameter Bolt	N. C. 13 threads
Minor Diameter	.4001 inches
Root Area	.1257 sq. inches
Length	7.179 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
200			1590
400			3180
600			4770
800			6350
1000			7940
1200	.007	.000975	9540
1400	.01	.001394	11120
1600	.011	.001534	12700
1800	.014	.00195	14300
2000	.015	.00209	15890
2200	.017	.00237	17480
2400	.019	.00265	19060
2600	.02	.00279	20620
2800	.023	.00321	22220
3000	.025	.003485	23840
3200	.026	.00362	25410
3400	.028	.00390	27000
3600	.029	.00404	28600
3800	.031	.00432	30200
4000	.033	.00460	31780
4200	.036	.00502	33300
4400	.037	.00516	34950
4600	.039	.00544	36500
4800	.04	.00557	38100
5000	.048	.00669	39700
5200	.045	.00627	41300
5400	.046	.00642	42850
5600	.047	.00655	44500
5800	.05	.00696	46100
6000	.051	.00711	47700
6200	.053	.00738	49250
6400	.054	.00752	50800
6600	.056	.0078	52450

TABLE 12 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
6800	.057	.00795	54000
7000	.059	.00822	55600
7200	.060	.00836	57200
7400	.063	.00877	58750
7600	.065	.00906	60400
7800	.066	.00920	61900
8000	.067	.00934	63500
8200	.0707	.00985	65100
8400	.073	.01018	66700
8600	.075	.01045	68250
8800	.077	.01072	69800
9000	.079	.0110	71500
9200	.081	.0113	73100
9400	.084	.0117	74600
9600	.087	.01212	76250
9800	.090	.01255	77800
10000	.094	.01310	79400
10200	.098	.01365	81000
10400	.104	.0145	82600
10500	.107	.0149	83500
10600	.111	.0155	84250
10800	.116	.0162	85800
11000	.125	.0174	87400
11200	.132	.0184	89000
11400	.152	.0212	90600
11600	.170	.0237	92200
11800	.226	.0315	93600
12000	.26	.0362	95500
12200	.299	.0417	97000
12330	.347	.0497	98000
12380	Maximum		98500

TABLE 13

STRESS STRAIN DATA SHEET

½" Diameter Bolt N. C. 13 threads

Minor Diameter .4001 inches

Root Area .1257 sq. inches

Length 8.2 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
200			1590
400			3180
600	.0062	.000756	4770
800	.0103	.001257	6350
1000	.0205	.002500	7940
1200	.0310	.00378	9540
1400	.0355	.00433	11120
1600	.0408	.00498	12700
1800	.0471	.00575	14300
2000	.0437	.00583	15890
2200	.0532	.00648	17480
2400	.0545	.00666	19060
2600	.0550	.00677	20620
2800	.0565	.00689	22200
3000	.0575	.00701	23840
3200	.0585	.00714	25410
3400	.0587	.00716	27000
3600	.0594	.00725	28600
3800	.0602	.00735	30200
4000	.0605	.00737	31780
4200	.0625	.00762	33300
4400	.0633	.00772	34900
4600	.0640	.00782	36500
4800	.0653	.00796	38100
5000	.0660	.00805	39700
5200	.0667	.00814	41300
5400	.0675	.00824	42850
5600	.0692	.00844	44500
5800	.0694	.00846	46100
6000	.0695	.00847	47700
6200	.0702	.00856	49250
6400	.0705	.00860	50800

TABLE 13 (cont.)

Lead Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
6600	.0717	.00875	52450
6800	.0775	.00945	54000
7000	.0785	.00956	55600
7200	.0800	.00975	57200
7400	.0805	.00982	58750
7600	.0810	.00987	60400
7800	.0811	.00991	61900
8000	.0821	.01001	63500
8200	.0831	.01015	65100
8400	.0835	.01020	66700
8600	.0845	.01030	68250
8800	.0860	.0105	69800
9000	.0885	.0108	71500
9200	.0905	.01105	73100
9400	.0915	.01118	74600
9600	.0930	.01135	76250
9800	.0962	.01174	77800
10000	.1000	.0122	79400
10200	.1045	.01276	81000
10400	.1077	.01315	82600
10600	.1143	.01395	84250
10800	.1303	.01590	85800
11000	.1343	.01638	87400
12100	.1505	.01836	96200
12450			99100

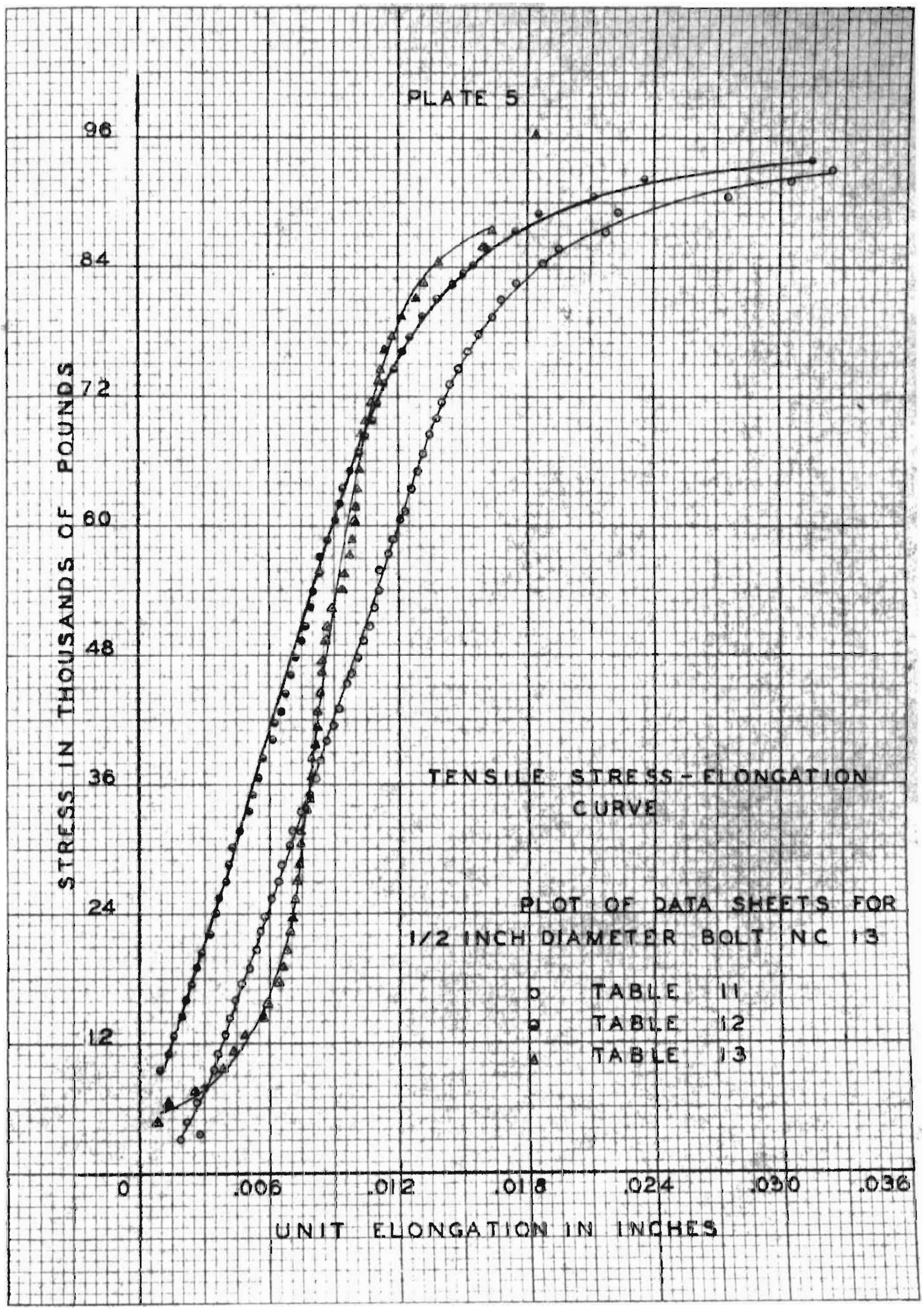


PLATE 5
STRESS IN THOUSANDS OF POUNDS
96
84
72
60
48
36
24
12
0
.006
.012
.018
.024
.030
.036
UNIT ELONGATION IN INCHES
TENSILE STRESS-ELONGATION CURVE
PLOT OF DATA SHEETS FOR 1/2 INCH DIAMETER BOLT NC 13
TABLE 11
TABLE 12
TABLE 13

TABLE 14

STRESS STRAIN DATA SHEET

5/8" Diameter Bolt	N. C. 11 threads
Minor Diameter	.506 inches
Root Area	.2018 sq. inches
Length	7.1245 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
200	.001	.0001405	993
400	.002	.000281	1982
600	.006	.000843	2975
800	.008	.001122	3965
1000	.010	.001405	4960
1200	.013	.001827	6490
1400	.015	.002105	6940
1600	.0175	.00246	7825
1800	.021	.00295	8250
2000	.024	.00337	9920
2200	.027	.00379	10900
2400	.029	.004075	11900
2600	.032	.00449	12890
2800	.034	.004775	13880
3000	.036	.00506	14870
3200	.038	.00533	15860
3400	.041	.00576	16850
3600	.0435	.00611	17840
3800	.0465	.00653	18830
4000	.049	.00688	19820
4200	.051	.00716	20810
4400	.052	.00730	21810
4600	.055	.007725	22800
4800	.058	.00815	23800
5000	.06	.00843	24790
5200	.062	.00870	25780
5400	.064	.00899	26760
5600	.0655	.00920	27750
5800	.067	.00941	28750
6000	.069	.00969	29740
6200	.071	.00997	30710
6400	.0725	.01019	31710
6600	.074	.0104	32700

TABLE 14 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
6800	.075	.01053	33700
7000	.077	.01082	34700
7200	.078	.01098	35680
7400	.08	.01125	36660
7600	.081	.01138	37670
7800	.083	.01168	38650
8000	.084	.01181	38625
8200	.085	.01194	40620
8400	.087	.01222	41610
8600	.088	.01238	42600
8800	.090	.01265	44600
9000	.092	.01293	44600
9200	.0925	.0130	45600
9400	.094	.01321	46560
9600	.096	.01350	47600
9800	.097	.01363	48600
10000	.099	.01391	49600
10200	.101	.0142	50650
10400	.103	.01448	51550
10600	.1035	.01452	52500
10800	.106	.0149	53500
11000	.1075	.0151	54500
11200	.109	.01531	55500
11400	.111	.0156	56500
11600	.1125	.0158	57500
11800	.1145	.01608	58500
12000	.117	.01642	59500
12200	.119	.01672	60470
12400	.121	.017	61470
12600	.1235	.0173	62460
12800	.126	.0177	63450
13000	.129	.01812	64450
13200	.1325	.0186	65400
13400	.136	.0191	66400
13600	.140	.01968	67400
13800	.144	.02021	68400
14000	.15	.02108	69400
14200	.156	.0219	70350
14400	.162	.02275	71350
14600	.169	.02375	72350
14800	.181	.02541	73350
15000	.200	.02810	74450
15200	.211	.02965	75500
15400	.235	.033	76400
15600	.269	.0378	77300
15800	.32	.0449	78300
16000	.367	.0516	79300

TABLE 15

STRESS STRAIN DATA SHEET

5/8" Diameter Bolt	N. C. 11 threads
Minor Diameter	.506 inches
Root Area	.2018 sq. inches
Length	7.1433 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
100	.000		
200	.011	.00154	
400	.016	.00234	1980
600	.019	.00266	2975
800	.02	.0028	3965
1000	.024	.00336	4960
1200	.027	.00278	5945
1400	.0285	.00385	6940
1600	.030	.0042	7930
1800	.032	.00447	8920
2000	.035	.00490	9910
2200	.037	.00518	10900
2400	.039	.00546	11900
2600	.041	.00574	12890
2800	.042	.00587	13880
3000	.044	.00616	14870
3200	.046	.00644	15870
3400	.048	.00672	16850
3600	.0495	.00692	17840
3800	.051	.00714	18830
4000	.053	.00742	19820
4200	.055	.0077	20800
4400	.057	.00797	21800
4600	.059	.00825	22800
4800	.060	.0084	23790
5000	.061	.00854	24780
5200	.063	.00881	25770
5400	.064	.00896	23760
5600	.066	.00924	27750
5800	.068	.00952	28740
6000	.0695	.00973	29730

TABLE 15 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
6200	.071	.00993	30720
6400	.072	.01008	31710
6600	.073	.01022	32700
6800	.076	.01063	33700
7000	.077	.01078	34690
7200	.079	.01105	35680
7400	.08	.0112	36670
7600	.082	.01147	37650
7800	.084	.01175	38640
8000	.086	.01205	39630
8200	.087	.01218	40600
8400	.088	.01231	41600
8600	.09	.01260	42600
8800	.091	.01272	43600
9000	.092	.01287	44600
9200	.095	.0133	45600
9400	.096	.01342	46600
9600	.097	.01358	67600
9800	.099	.01385	68600
10000	.100	.0140	49600
10200	.102	.01428	50600
10400	.103	.0144	51100
10600	.105	.01470	52100
10800	.107	.01496	53100
11000	.108	.01512	53500
11200	.110	.01540	54500
11400	.112	.01567	55500
11600	.115	.0161	57500
11800	.117	.01638	58500
12000	.119	.01665	59450
12200	.121	.01693	60450
12400	.125	.01750	61450
12600	.127	.01780	62450
12800	.129	.01810	63450
13000	.132	.01847	64450
13200	.136	.01905	64450
13400	.139	.01945	66450
13600	.143	.02000	67430
13800	.147	.02060	68430
14000	.155	.0217	69400
14200	.162	.02266	70400
14400	.174	.02435	71400
14600	.184	.02575	72400

TABLE 15 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
14800	.197	.02760	73400
15000	.218	.0305	74550
15200	.238	.0333	75350
15400	.253	.0354	76330
15600	.292	.0428	77300
15800	.329	.0460	78200
16000	.385	.0538	79300
16100	.452	.06325	79750

TABLE 16

STRESS STRAIN DATA SHEET

5/8" Diameter Bolt	N. C. 11 Threads
Minor Diameter	.506 inches
Root Area	.2018 sq. inches
Length	9.553 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
500			2480
1000	.0015	.000157	4955
1200	.0030	.000314	5960
1400	.0030	.000314	6950
1600	.0035	.000366	7940
1800	.0035	.000366	8930
2000	.0035	.000366	9925
2200	.0035	.000366	10900
2400	.00375	.000393	11900
2600	.0040	.000418	12870
2800	.0042	.000439	13850
3000	.0045	.000471	14850
3200	.00475	.000497	15850
3400	.0051	.000534	16850
3600	.0060	.000628	17850
3800	.0063	.000658	18830
4000	.0070	.000732	19800
4200	.0080	.000837	20800
4400	.0080	.000837	21800
4600	.0085	.000890	22790
4800	.0090	.000941	23780
5000	.0095	.000994	24780
5200	.0100	.001470	25770
5400	.0102	.001066	26760
5600	.0105	.00110	27750
5800	.0110	.00115	28730
6000	.0110	.00115	29700
6200	.0115	.00121	30700
6400	.0120	.001255	31700
6600	.0122	.00128	32690
6800	.0130	.00136	33680
7000	.0130	.00136	34770
7200	.0132	.00138	35760
7400	.0138	.00144	36750

TABLE 16 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
7600	.0142	.001487	37740
7800	.0147	.001538	38730
8000	.0150	.001570	39720
8200	.0151	.001580	40710
8400	.0153	.00160	41700
8600	.0156	.001632	42700
8800	.0160	.001674	43680
9000	.0170	.001780	34600
9200	.0173	.001810	45580
9400	.0180	.001882	46560
9600	.0180	.001882	47550
9800	.0185	.001935	48540
10000	.0187	.001957	49530
10200	.0201	.002115	50520
10400	.0205	.00214	51510
10600	.021	.00220	52500
10800	.022	.00230	53500
11100	.023	.00241	54500
11200	.0235	.00246	55500
11400	.025	.00262	56480
11600	.026	.00272	57470
11800	.027	.00282	58460
12000	.029	.00303	59450
12200	.030	.00314	60430
12400	.0317	.00332	61430
12600	.0365	.00382	62420
12800	.038	.00398	63410
13000	.0405	.00424	64400
13200	.0424	.00444	65400
13400	.0452	.00473	66380
13600	.0500	.00523	67350
13800	.055	.00575	68320
14000	.063	.00659	69300
14500	.1035	.01082	71800
15000	.161	.01685	74300
15500	.277	.02900	76750
15750	.366	.03830	78000
15825	.466	.04875	78450
15720	.571	.05975	77900
15830	.617	.06450	78500
15840	.697	.07290	78600

TABLE 17

STRESS STRAIN DATA SHEET

5/8" Diameter Bolt	N. C. 11 threads
Minor Diameter	.506 inches
Root Area	.2018 sq. inches
Length	8.69 inches

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
500	.015	.001728	2480
1000	.016	.001841	4960
1500	.0172	.001960	7440
2000	.0193	.002221	9920
2500	.0205	.00236	12400
3000	.022	.00253	14880
3500	.023	.00265	17360
4000	.0263	.00303	19820
4500	.0263	.00303	22300
5000	.0272	.00313	24800
5500	.029	.00334	27260
6000	.0295	.00340	29700
6500	.031	.00357	32300
7000	.0318	.00366	34700
7500	.033	.00380	37200
8000	.034	.00391	39600
8500	.035	.00403	42200
9000	.036	.00414	44600
9500	.037	.00426	47100
10000	.0377	.00434	49600
10200	.038	.00437	50600
10400	.0385	.00443	51600
10600	.040	.00461	52600
10800	.040	.00461	53600
11000	.0405	.00466	54500
11200	.0405	.00466	55500
11400	.0412	.00474	56500
11600	.042	.00484	57500
11800	.0425	.00489	58500
12000	.0427	.00492	59500
12200	.0432	.00497	66400
12400	.0443	.00510	61400

TABLE 17 (cont.)

Load Pounds	Elongation Inches	Unit Elongation Inches	Stress Pounds/sq.in.
12600	.0461	.00532	62400
12800	.0460	.00530	63400
13000	.0468	.00539	64400
13200	.0475	.00547	65400
13400	.0492	.00566	66400
13600	.050	.00575	67400
13800	.0512	.00590	68400
14000	.053	.00610	69400
14200	.0543	.00625	70300
14400	.0555	.00638	71300
14600	.0574	.00660	72300
14800	.0595	.00685	73300
15000	.0630	.00725	74300
15200	.0650	.00748	75300
15400	.0682	.00785	76300
15600	.072	.00828	77300
15800	.0764	.00878	78300
16000	.091	.01048	79250
16200	.097	.01115	80250
16400	.104	.01198	81250
16600	.111	.01280	82250
16800	.140	.01610	83250
17000	.173	.01992	84250
17200	.185	.0213	85200
17400	.212	.0244	86200
17600	.296	.0341	87200
18350	.392	.0452	91000
18380	.452	.0520	91100
18480	.5685	.0654	91600
18360	.671	.07725	91050
18350	.690	.0794	91000

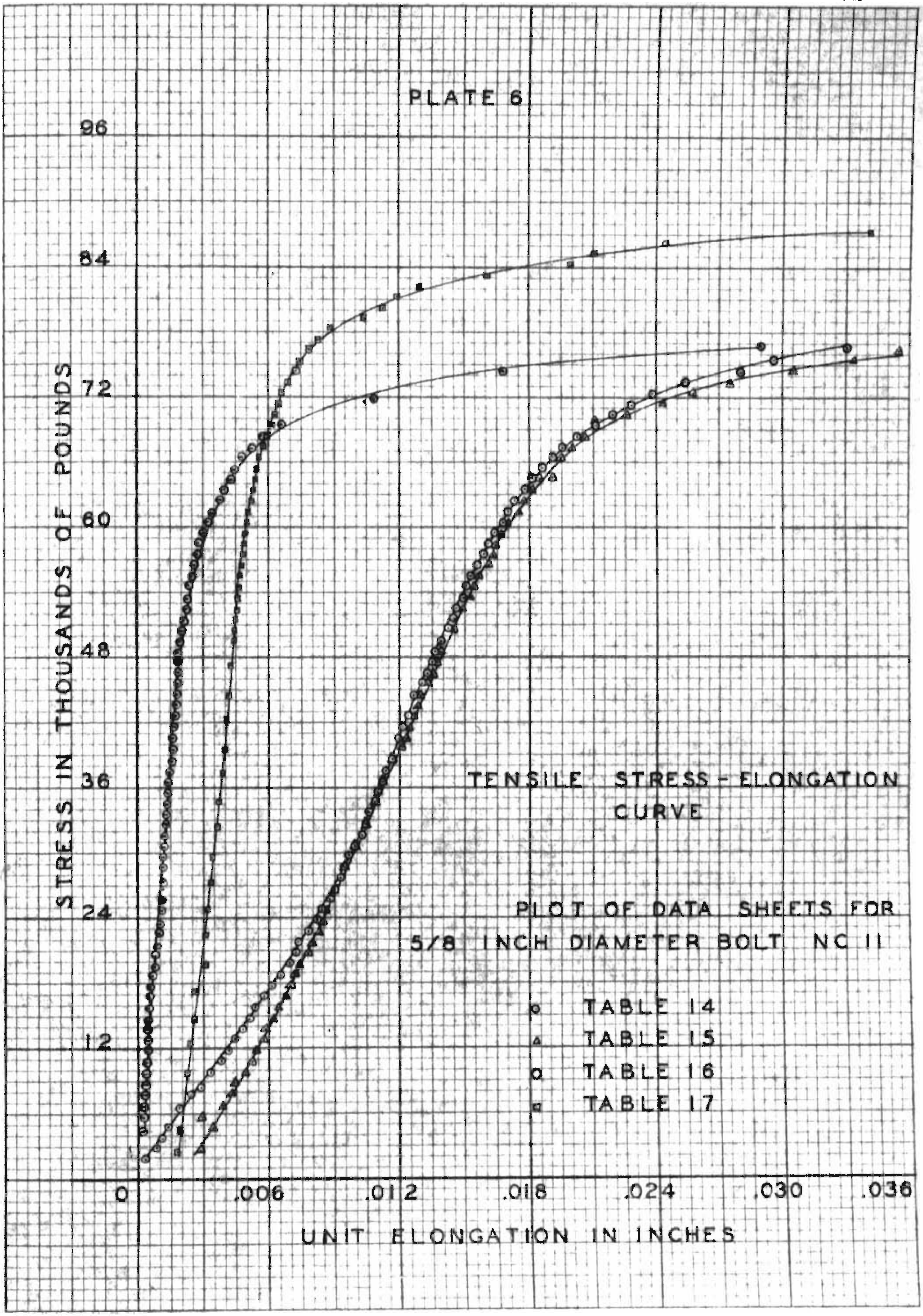


PLATE 6
STRESS IN THOUSANDS OF POUNDS
96
84
72
60
48
36
24
12
0
.006
.012
.018
.024
.030
.036
UNIT ELONGATION IN INCHES
TENSILE STRESS - ELONGATION CURVE
PLOT OF DATA SHEETS FOR 5/8 INCH DIAMETER BOLT NC 11
TABLE 14
TABLE 15
TABLE 16
TABLE 17

TABLE 18

TORQUE TENSILE DATA SHEET

3/8" Bolt	NC 16 Threads
Diameter at Thread Root	.2938 inches
Area at Thread Root	.0678 sq. inches
Length of Bolt between Hangers	7.000 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
0	100	1476
50		
100	660	9725
150	1130	16650
200	1770	26100
250	2290	33800
300	2880	42400
350	3280	48300
400	3890	57300
450	4440	65400
500	4790	70600
550	4930	72700
600	5290	77800
650	5490	80900
700	5590	82400
750	5560	82000
800	5650	83300
850	5600	82600
900	5640	83200
950	5430	80200
970	5570	82200

Specimen failed at a Torque of 970 inch pounds.

TABLE 19

TORQUE TENSILE DATA SHEET

3/8" Bolt	NC 16 Threads
Diameter at Thread Root	.2938 inches
Area at Thread Root	.0678 sq. inches
Length of Bolt between Hangers	7.000 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
0		
100		
150	1030	15200
200	1360	20050
250	1830	27000
300	2180	32150
350	2310	34100
400	2520	37150
450	2670	39400
500	2850	42000
550	2970	43800
600	3130	46200
650	3420	50500
700	4140	61000
750	4370	64500
800	4570	67400
850	4680	69100
900	4780	70500
950	4890	72100
1000	4940	72800
1050	5000	73750
1100	5180	76500
1150	5140	75700
1200	5290	78000
1250		
1300	5440	80200

Specimen failed at a Torque of

1300 inch pounds.

TABLE 20

TORQUE TENSILE DATA SHEET

3/8" Bolt	NC 16 Threads
Diameter at Thread Root	.2938 inches
Area at Thread Root	.0678 sq. inches
Length of Bolt between Hangers	7.000 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
100	480	7070
150	770	11380
200	1160	17100
250	1400	20650
300	1720	25350
350	2110	31100
400	2420	35700
450	2690	39650
500	2940	43300
550	3120	46000
600	3220	47500
650	3410	50300
700	3590	52900
750	3850	56750
800	4010	59200
850	4320	63700
900	4400	64800
950	4420	65400
1000	4820	71000
1050	4750	70000
1100	4810	70900
1150	4880	71900
1200	5070	74700
1250	5310	78300
1300	5590	82250
1350	5540	81600

Specimen failed at a Torque of
1350 inch pounds.

TABLE 21

TORQUE TENSILE DATA SHEET

3/8" Bolt	NC 16 Threads
Diameter at Thread Root	.2938 inches
Area at Thread Root	.0678 sq. inches
Length of Bolt between Hangers	7.000 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
100	380	5600
150	690	10180
200	950	14000
250	1310	19300
300	1550	22850
350	2030	30400
400	2750	40500
450	2940	43400
500	3270	48200
550	3440	50700
600	3550	52400
650	3800	56000
700	4020	59300
750	4310	63500
800	4640	68400
850	4950	73000
900	5110	75400
950	5260	72500
1000	5470	80600
1050		
1100	5580	82300
1150	5650	83250
1200	5820	86000
1250	5680	83700
1300	5750	84750
1310	5820	85700

Specimen failed at a Torque of

1310 inch pounds.

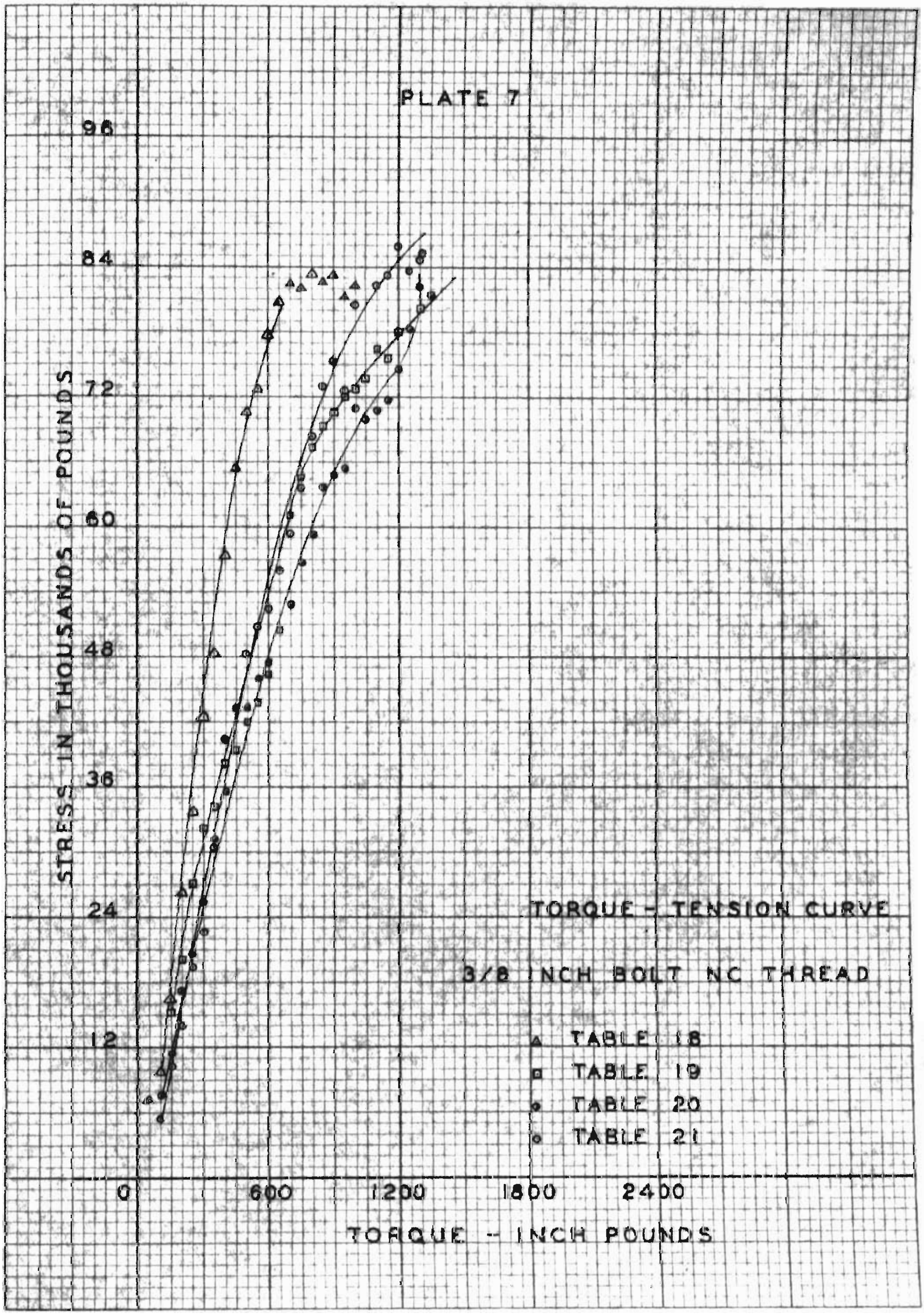


PLATE 7
STRESS IN THOUSANDS OF POUNDS
96
84
72
60
48
36
24
12
0
600
1200
1800
2400
TORQUE - INCH POUNDS
TORQUE - TENSION CURVE
3/8 INCH BOLT NC THREAD
TABLE 18
TABLE 19
TABLE 20
TABLE 21

TABLE 22

TORQUE TENSILE DATA SHEET

7/16 " Bolt	NC 14 Threads
Diameter at Thread Root	.345 inches
Area at Thread Root	.093 sq. inches
Length of Bolt between Hangers	7.000 inch

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
100	620	6670
150	1210	13000
200	1740	18700
250	2250	24200
300	2850	30650
350	2980	32050
400	3440	37000
450	3760	40400
500	4390	47200
550	4550	48900
600	4700	50500
650	4820	51700
700	5070	54500
750	5600	60200
800	5940	63800
850	6180	66400
900	6110	65750
950	6320	67900
1000	6410	68900
1050	6430	69100
1100	6580	70750
1150	6420	69000
1200	6460	69500
Maximum	8490	91250

TABLE 23

TORQUE TENSILE DATA SHEET

7/16" Bolt	NC 14 Threads
Diameter at Thread Root	.345 inches
Area at Thread Root	.093 sq. inches
Length of Bolt between Hangers	7.000 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
100	320	3440
150	760	8170
200	940	
250	1230	13230
300	1400	15050
350	1530	16450
400	2000	21500
450	2350	25300
500	2800	30100
550	3200	34400
600	3380	36300
650	3620	38900
700	3900	41900
750	4100	44100
800	4350	46750
850	4490	48200
900	4660	50200
950	5180	55800
1000	5300	57000
1050	5650	60750
1100	5820	62600
1150	6050	65100
1200	6300	67750
Maximum	7600	81700

TABLE 24

TORQUE TENSILE DATA SHEET

7/16 " Bolt	NC 14 Threads
Diameter at Thread Root	.345 inches
Area at Thread Root	.093 sq. inches
Length of Bolt between Hangers	7.000 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
100	700	7525
150	1240	13350
200	2020	21700
250	2625	28200
300	3210	34500
350	3600	38700
400	3930	42250
450	4520	48700
500	5000	53750
550	3190	55800
600	5380	57800
650	5960	64200
700	6180	66500
750	6340	68200
800	6480	69700
850	7100	76400
900	7390	79500
950	7200	77400
1000	7300	78500
Maximum	8610	92500

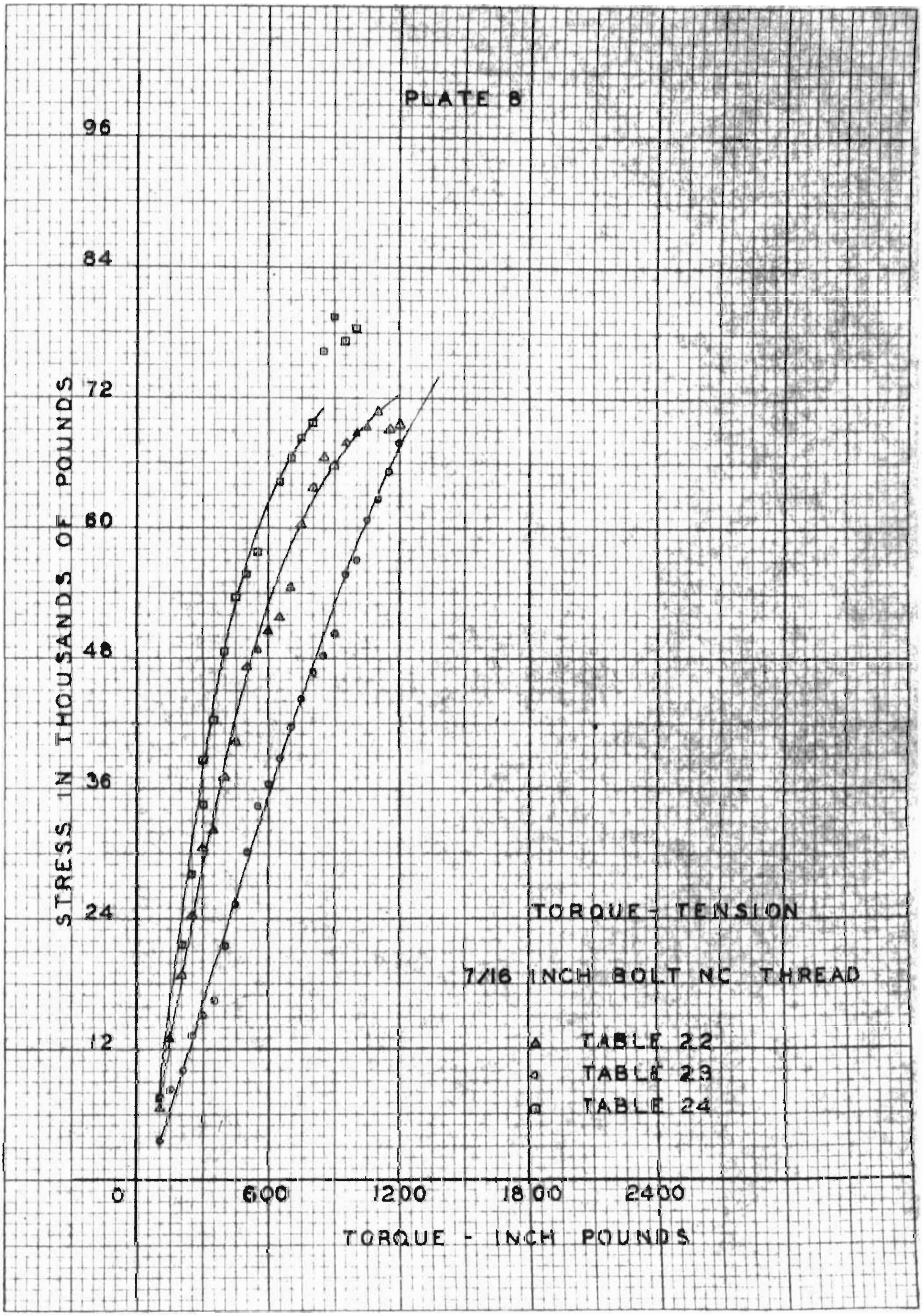


PLATE 8
STRESS IN THOUSANDS OF POUNDS
96
84
72
60
48
36
24
12
0
600
1200
1800
2400
TORQUE - INCH POUNDS
TORQUE - TENSION
7/16 INCH BOLT NC THREAD
TABLE 22
TABLE 23
TABLE 24

TABLE 25

TORQUE TENSILE DATA SHEET

½" Bolt	NC 13 Threads
Diameter at Thread Root	.4001 inches
Area at Thread Root	.1257 sq. inches
Length of Bolt between Hangers	7.000 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
100	450	3580
150	720	5720
200	1010	8025
250	1400	11130
300	1710	13600
350	1970	15650
400	2150	17100
450	2500	19880
500	2700	21420
550	2970	23600
600	3230	25700
650	3400	27050
700	3700	29400
750	4180	33200
800	4450	35400
850	4810	38300
900	5600	44500
950		
1000	5720	45400
1050	6300	50100
1100	7000	55600
1150		
1200		
1250	7740	61500
1300	7890	62700
1350	7890	62700
1400	8300	66000
1450	8880	70600
1500	9350	74300
1550	9230	73400
1600	9350	74300
1650	9600	76300
1700	9800	77900
1750	9880	78500
1800		

TABLE 25 (cont.)

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
1850	9940	78900
1900	10000	79500
2000	10200	81000
2050		
2100		
2150	10400	82600

TABLE 26

TORQUE TENSILE DATA SHEET

½" Bolt	NC. 13 Threads
Diameter at Thread Root	.4001 inches
Area at Thread Root	.1257 sq. inches
Length of Bolt between Hangers	7.000 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
100	500	3970
150	680	5410
200	1000	7950
250	1170	9300
300	1400	11130
350	1616	12850
400	2020	16060
450	2150	17100
500	2370	18830
550	2520	20000
600	2650	21060
650	3000	23850
700	3230	25700
750	3390	26950
800	3710	29500
850	3880	30810
900	4180	33200
950	4600	36600
1000	4900	38900
1050	5120	40700
1100	5280	42000
1150	5430	43200
1200	5730	45500
1250	6000	47700
1300	6200	49300
1350	6350	50500
1400	6590	52300
1450	6660	52900
1500	6810	54200
1550	6960	55300
1600	7000	55600
1650	7200	57200

TABLE 26 (cont.)

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
1700	7450	59200
1750	7610	60500
1800	8320	66150
1850	8640	68600
1900	8800	70000
1950	9000	71500
2000	9210	73250
2050	9360	74750
2100	9590	76200
2150	9500	75500
2200	9780	77100
2250	10250	81500

TABLE 27

TORQUE TENSILE DATA SHEET

½" Bolt	NC 13 Threads
Diameter at Thread Root	.4001 inches
Area at Thread Root	.1257 sq. inches
Length of Bolt between Hangers	7.000 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
100	600	4765
150	900	7150
200	1250	9925
250	1650	13120
300	1970	15670
350	2450	19480
400	2830	22500
450	3210	25500
500	3600	28600
550	3760	29900
600	4100	32600
650	4550	36200
700	4930	39400
750	5250	41700
800	5440	43200
850	5650	44900
900	5910	47000
950	6100	48500
1000	6370	50600
1050	6580	52400
1100	6860	54500
1150	7130	56600
1200	7500	59600
1250	7650	60800
1300	8000	63550
1350	8140	64600
1400	8420	66900
1450	8510	87700
1500	8900	70700
1550	9000	71500
1600	9110	72500

TABLE 27 (cont.)

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
1650	9260	73600
1700	9350	74400
1750	9420	74900
1800	9570	76100
1850	9620	76500
1900	9730	77400
1950	9940	79000
2000	10240	81400
2050		
2100		
2150		
2200	10280	81750

TABLE 28

TORQUE TENSILE DATA SHEET

½" Bolt	NC 13 Threads
Diameter at Thread Root	.4001 inches
Area at Thread Root	.1257 sq. inches
Length of Bolt between Hangers	7.000 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
100	490	3890
150	930	7390
200	1610	12800
250	2070	16450
300	2570	20420
350	2960	23500
400	3400	27000
450	3750	29800
500	4200	33400
550	4510	35800
600	5010	39850
650	5460	43400
700	5990	47600
750	6340	50400
800	6700	53300
850	7000	55600
900	7200	57200
950	7610	60500
1000	7820	62100
1050	7910	62900
1100	8050	64000
1150	8350	66400
1200	8560	68050
1250	8600	68350
1300	8760	69600
1350	8950	71200
1400	9030	71800
1450	9170	72800
1500	9370	74500
1550	9460	75250

TABLE 28 (cont.)

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
1600	9480	75400
1650	9560	76000
1700	9800	77900
1850	9930	78800
1900	10000	79500
1950		
2000	10550	83900
2050		
2100	10600	84400

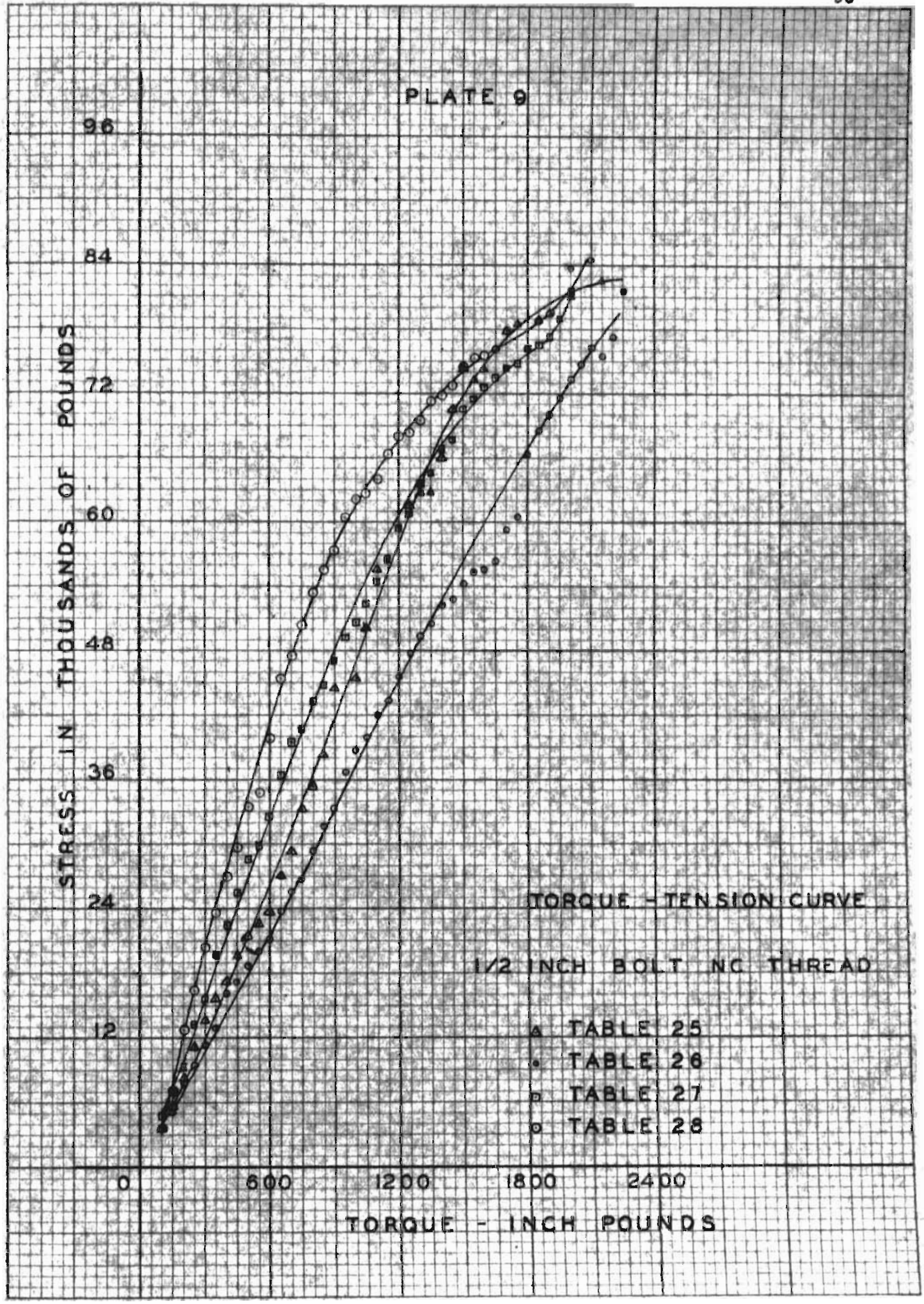


PLATE 9
96
84
72
60
48
36
24
12
0
600
1200
1800
2400
STRESS IN THOUSANDS OF POUNDS
TORQUE - INCH POUNDS
TORQUE - TENSION CURVE
1/2 INCH BOLT NC THREAD
TABLE 25
TABLE 26
TABLE 27
TABLE 28

TABLE 29

TORQUE TENSILE SATA SHEET

½" Bolt	NC 13 Threads
Diameter at Thread Root	.4005 inches
Area at Thread Root	.1258 sq. inches
Length of Bolt between Hangers	7.000 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
100	270	2147
150	550	4375
200	800	6360
250	1430	11380
300	1890	15020
350	2250	17900
400	2500	19900
450	3180	25300
500	3600	28600
550	4250	33800
600	4900	38900
650	5610	44600
700	6100	48500
750	6320	50250
800	6780	53900
850	7020	55800
900	7610	60600
950	7830	62250
1000	8200	65200
1050	8530	67800
1100	8610	68500
1150	9100	72400
1200	9200	73200
1250	9550	75900
1300	9480	75400
1350	9660	76800
1400	9860	78400
1450		
1500	9540	75800
1550	9770	77700
1600		
1700	9860	78500
1750	9530	75800

TABLE 30

TORQUE TENSILE DATA SHEET

½" Bolt	NC 13 Threads
Diameter at Thread Root	.4001 inches
Area at Thread Root	.1257 sq. inches
Length of Bolt between Hangers	7.000 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
100		
150	1270	10100
200	1560	12400
250	2070	16450
300	2430	19310
350	2860	22700
400	3330	26450
450	3860	30700
500	4170	33100
550	4880	38600
600	5370	42700
650	5870	46700
700	6540	51900
750	6900	54800
800	7480	59500
850	7550	60000
900	8000	63600
950	8310	66100
1000	8810	70600
1050	8800	70000
1100	8930	71000
1150	9300	73900
1200	9330	74250
1250	9560	76000
1300	9570	76100
1350	9730	77300
1400	10020	81100
1450	10280	81800
1500	10230	81500
1550	10230	81500
1600	10270	81700
1650	10270	81700
1700	10390	82600

TABLE 30 (cont.)

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
1750	10450	83300
1800	10600	84400
Maximum	11880	94200

TABLE 31

TORQUE TENSILE DATA SHEET

½" Bolt	NC 13 Threads
Diameter at Thread Root	.4001 inches
Area At Thread Root	.1257 sq. inches
Length of Bolt between Hangers,	7.000 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
100	480	3820
150	860	3860
200	1230	9800
250	1740	13840
300	2230	17710
350	2840	22550
400	3260	25900
450	3690	29300
500	4270	34000
550	4710	37450
600	4940	39200
650	5330	42400
700	5590	44400
750	6140	48700
800	6400	50800
850	6880	54700
900	7100	56400
950	7370	58500
1000	7420	59000
1050	7540	59800
1100	8650	68700
1150	8570	68200
1200	8790	69700
1250	8990	71400
1300	9200	73100
1350	9340	74200
1400	9410	74800
1450	9450	75200
1500	9500	75500
1550	9810	78000

TABLE 31 (cont.)

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
1600	9960	79200
1650	9980	79300
1700	10000	79550
1750	10030	79900
1800	10130	80700
1850	10140	80750
1900	10500	83500
1950	10460	83300
2000	10360	82500
2050	10480	83400
2100	10410	83000
2150	10470	83350
2200	10530	83800
Maximum	12370	98400

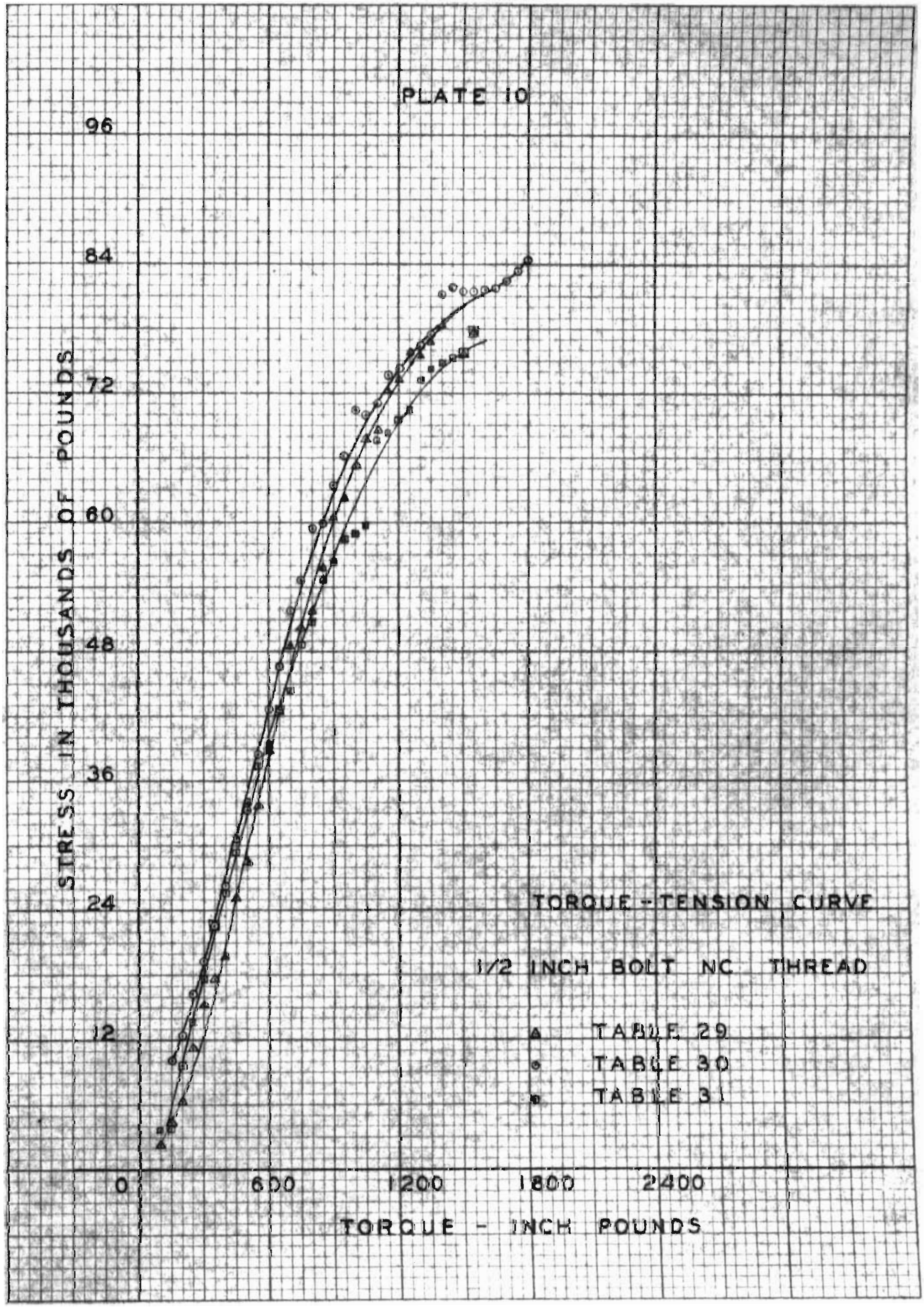


PLATE 10
STRESS IN THOUSANDS OF POUNDS
96
84
72
60
48
36
24
12
0
600
1200
1800
2400
TORQUE - INCH POUNDS
TORQUE - TENSION CURVE
1/2 INCH BOLT NC THREAD
TABLE 29
TABLE 30
TABLE 31

TABLE 32

TORQUE TENSILE DATA SHEET

5/8" Bolt	NC 11 Threads
Diameter at Thread Root	.506 inches
Area at Thread Root	.2018 sq. inches
Length of Bolt between Hangers	7 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
200	1080	5360
250	1150	5715
300	1240	6150
350	1610	8000
400	1960	9720
450	2200	10900
500	2500	12400
550	2630	13040
600	3310	16400
650	3620	17900
700	3970	19700
750	4490	22250
800	4650	23050
850	5060	26100
900	5480	27200
950	6070	30100
1000	6560	32500
1050	6850	34000
1100	6940	34400
1150	7500	37200
1200	8010	39700
1250	8310	41200
1300	8730	43300
1350	9040	44800
1400	9560	47400
1450	9830	48700
1500		
1550		
1600	10210	50700
1650	10750	53400

TABLE 32 (cont.)

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
1700		
1750	11290	56000
1800	11460	56800
1850		
1900	11910	59200
1950		
2000	12260	60800
2050	12270	60800
2100		
2150	12930	64200
2200	13530	67100
2250	13280	68300
2300		
2350	13910	69100
2400	14110	70200
Maximum	18110	90000

TABLE 33

TORQUE TENSILE DATA SHEET

5/8" Bolt	NC 11 Threads
Diameter at Thread Root	.506 inches
Area at Thread Root	.2018 sq. inches
Length of Bolt between Hangers	7 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
100		
150	880	4360
200	1740	8620
250	2180	10800
300	2190	10850
350	2200	10900
400	2660	13200
450	3000	14860
500	3360	16650
550	3670	18200
600	3960	19620
650	4430	21950
700	4870	24100
750	5120	25360
800	5250	26000
850	5690	28200
900	5900	29250
950	6070	30100
1000	6285	31150
1050	6480	32000
1100	6680	33100
1150	6770	33500
1200	7280	36100
1250	7450	36900
1300	7990	39600
1350	8065	40000
1400	8600	42600
1450	8690	43000
1500	9360	46400
1550	9650	47800

TABLE 33 (cont.)

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
1600	9940	49300
1650		
1700	10125	50200
1750	10370	51400
1800	10670	52900
1850	10730	53300
1900	11050	54700
1950	11210	55600
2000	11240	55700
2050	11165	55400
2100	11655	57750
2150	11730	58250
2200	11730	58250
2250	11800	58500
2300	11900	59000
2350	12000	59500
2400	11900	59000
Maximum	16020	79600

TABLE 34

TORQUE TENSILE DATA SHEET

5/8" Bolt	NC 11 Threads
Diameter at Thread Root	.506 inches
Area at Thread Root	.2018 sq. inches
Length of Bolt between Hangers	7 inches

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
100	380	1880
150		
200	970	4800
250	1400	6940
300	1720	8520
350	2190	10850
400	2480	12300
450	2790	13820
500	3110	15400
550	3290	16300
600	3470	17200
650	3720	18420
700	4140	20500
750	4380	21700
800	4540	22420
850	4760	23600
900	5190	25700
950	5270	26100
1000	5640	27900
1050	5870	29100
1100	5880	29150
1150	6090	30200
1200	6380	31600
1250	6580	32600
1300	6890	34100
1350	7300	36200
1400	7670	38000
1450	7920	39200
1500	7960	39450
1550	8210	40700
1600	8420	41700
1650	8690	43000

TABLE 34 (cont.)

Torque Inch Pounds	Load Pounds	Stress Pounds/sq.in.
1700	8960	44400
1750	8950	44300
1800	9220	45600
1850	9340	46250
1900	9570	47400
1950	9760	48300
2000	9770	48320
2050	9950	49300
2100	10230	50700
2150	10280	50900
2200	10430	51700
2250	10690	52900
2300	10690	52900
2350	11090	54800
2400	11140	55200
Maximum	15780	78200

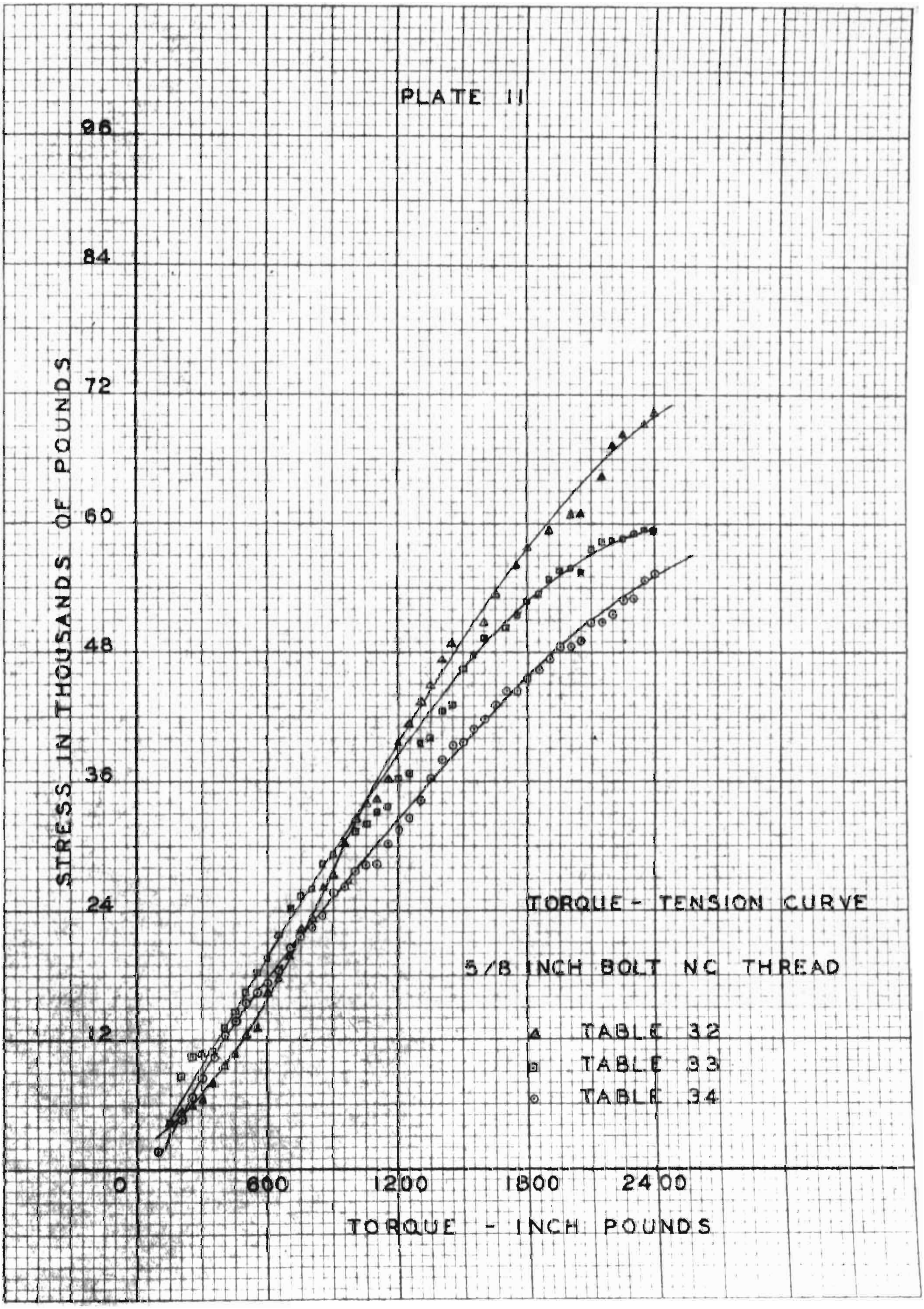


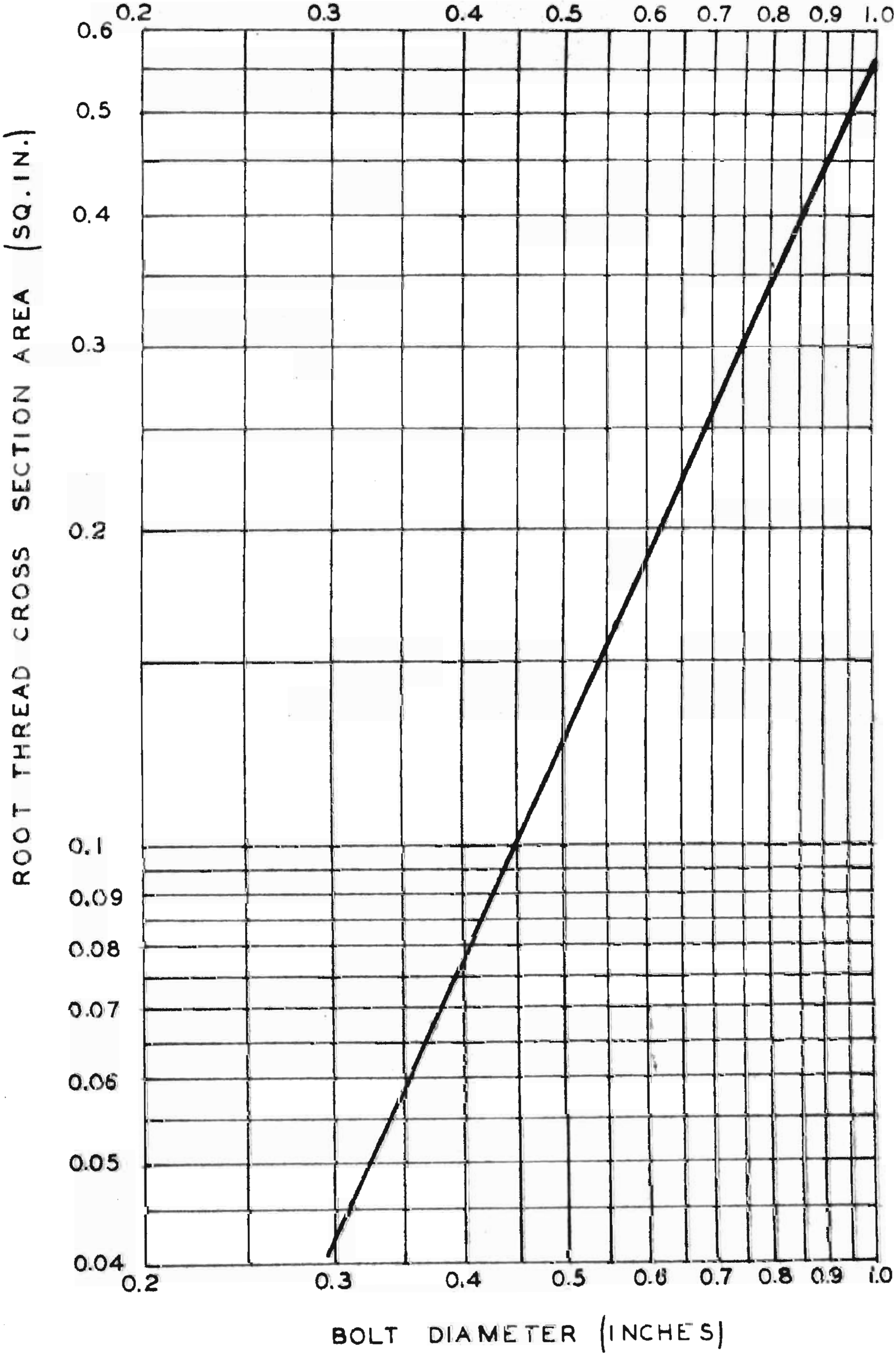
PLATE 11
96
84
72
60
48
36
24
12
0
600
1200
1800
2400
STRESS IN THOUSANDS OF POUNDS
TORQUE - INCH POUNDS
TORQUE - TENSION CURVE
5/8 INCH BOLT NC THREAD
TABLE 32
TABLE 33
TABLE 34

TABLE 35

RATIO OF BOLT ROOT DIAMETER TO NOMINAL BOLT DIAMETER

Nominal Bolt Diam. Inches		US Standard Root Diam. Inches	Ratio Root Diam. Nominal Diam.	
Fraction	Decimal		Actual	Relative
5/16	0.3125	0.2403	0.7690	0.961
3/8	0.3750	0.2938	0.7835	0.9791
7/16	0.4375	0.3447	0.7879	0.9846
1/2	0.5000	0.4001	0.8002	1.000
9/16	0.5625	0.4542	0.8075	1.009
5/8	0.6250	0.5069	0.8110	1.0135
3/4	0.7500	0.6201	0.8268	1.0333
7/8	0.8750	0.7307	0.8351	1.0436
1	1.0000	0.8376	0.8376	1.0468
2	2.0000	1.7113	0.8557	1.0693
3	3.0000	2.6752	0.8917	1.1143

FIGURE 9



ROOT OF THREAD CROSS SECTION AREA VS. BOLT DIAMETER

TABLE 36

TORQUE DIAMETER AND PERCENT YIELD POINT

OF BOLTS TESTED

Bolt size	Decimal dia.	Yield 80,000	E.L. 66,000	80% 64,000	70% 56,000	60% 48,000	50% 40,000
		650	450	450	375	325	275
3/8"	.375	1040	730	725	610	500	420
		1300	750	740	640	500	440
		1300	850	850	725	600	490
Total		4290	2780	2765	2350	1925	1625
Average		1072	695	691	587	481	406
		1090	550	650	500	385	320
7/16	.4375	1450	760	850	650	520	425
		1600	1050	1120	950	820	675
Total		4140	2360	2620	2100	1725	1420
Average		1380	787	873	700	575	473
		1500	850	920	1500	1270	1050
		1500	900	970	1160	1025	870
1/2"	.500	1875	950	1050	1080	900	750
		1930	950	1700	860	700	590
		1980	1150	1300	880	670	620
		2250	1250	1300	840	720	600
				1100	770	740	570
Total		11035	6050	8350	7290	6025	5050
Average		1839	1008	1193	1043	861	719
			1900		1750	1450	1550
5/8	.625		1600		2025	1450	1250
			1400		2500	1900	1220
Total			4900		6275	4890	4020
Average			1633	2150	2092	1620	1340

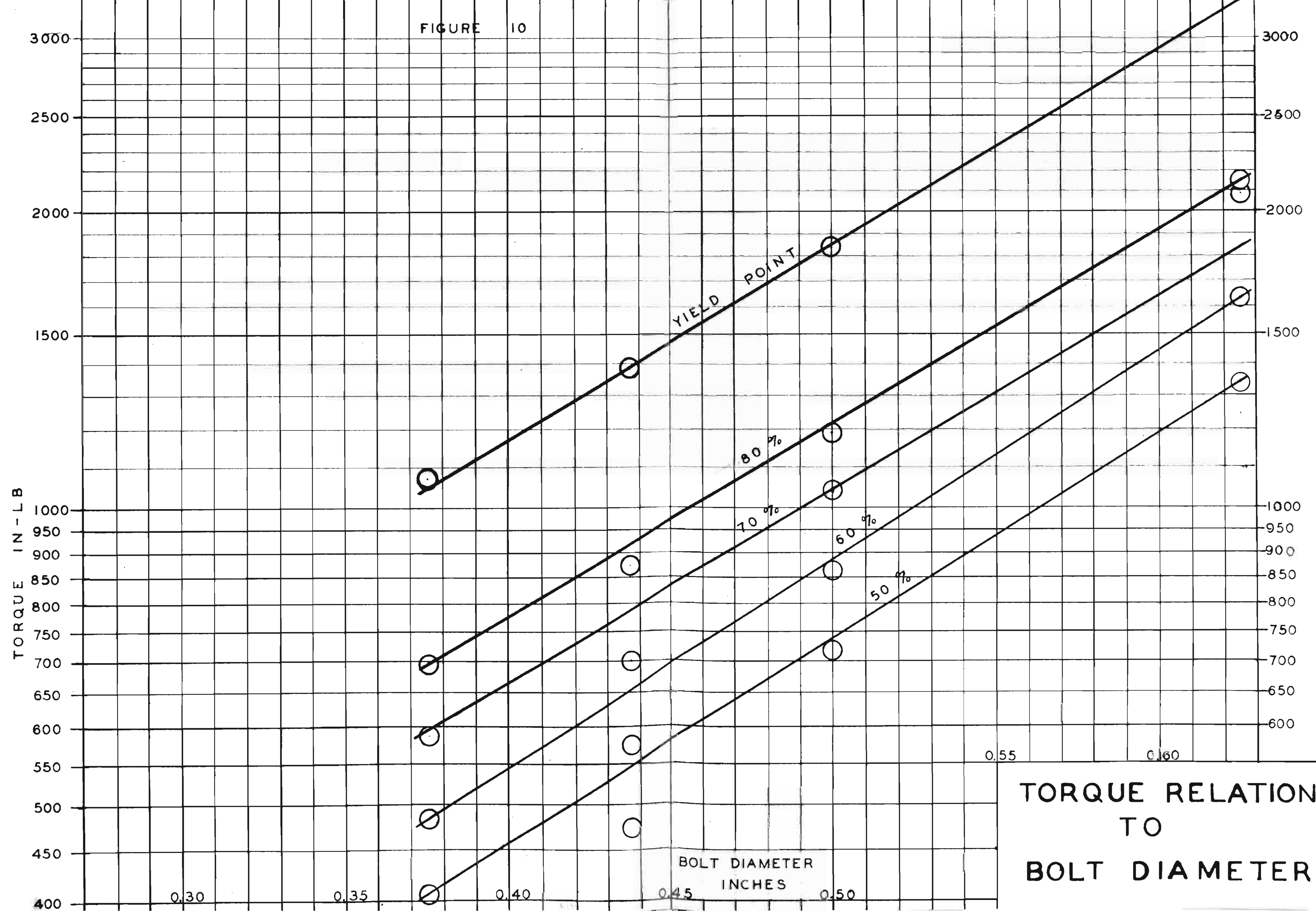


FIGURE 10
TORQUE IN-LB
3000
2500
2000
1500
1000
950
900
850
800
750
700
650
600
550
500
450
400
YIELD POINT
80 %
70 %
60 %
50 %
0.30
0.35
0.40
0.45
0.50
0.55
0.60
BOLT DIAMETER
INCHES
TORQUE RELATION
TO
BOLT DIAMETER

PART 4

CONCLUSIONS

The load that should be placed on a bolt to stress the metal at the root of the threads - the critical section - to the yield point can be calculated by means of the equation

$$W_i = 0.55\ S_y\ \ D^{2.14}$$

Where W_i = Initial load in the bolt in pounds

S_y = Yield point stress, psi

D = Nominal bolt diameter, inches

The torque that should be applied to the nut of a bolt to devlop initial stresses of 100 per cent, 80 per cent, and 70 per cent of the yield strength of 80,000 psi is calculated from the following equations.

For 100% of yield point

$$\text{Log } T = 2.335 + 1.95\ D$$

For 80% of yield point

$$\text{Log } T = 2.11 + 1.95\ D$$

For 70% of yield point

$$\text{Log } T = 2.049 + 1.95\ D$$

It is difficult to state that the torque equations developed here are entirely correct. Data taken in this investigation, with the exception of 7/16-in. bolts, conform reasonably well to the empirical equations developed. Additional data might prove that the equations developed here were entirely inadequate or that the form of the equations is not correct.

The work done in this investigation indicates clearly that additional tests should be conducted on other types of bolt material, and other diameters of bolts for USS standard threads. Tests should also be conducted on SAE thread series for various materials and different bolt diameters.

PART 5

SUMMARY

SUMMARY

A brief review is made of the solution of initial tightening of bolts set out in machine design practices, a search for any material that his investigation would duplicate.

The contruction and use of testing equipment are described. Two problems are considered, the first, to determine the load that should be applied to the bolt on initial tightening; second, to determine when that load is applied.

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VITA

The author was born July 30,1911, at Baxter Springs, Kansas. His high school education was completed in 1930 at Lamar High School in Lamar, Missouri, at which time he entered the Missouri School of Mines and Metallurgy at Rolla, Missouri. He graduated from Missouri School of Mines and Metallurgy in 1935 with a degree of B. S. in Mechanical Engineering. From the graduation in June 1935 until Nov. 1938, he was employed as assistant engineer of the Derby Oil Refining Company, Wichits, Kansas. Jan. 1939 he entered Kansas State Teachers College, Pittsburg, Kansas, where he studied Educational Courses for a certificate for teaching in High School. The school year of 1939-40 he taught in the Jane Consolidated High School of Jane, Missouri; 1940-41 he was assigned Associate professor of Electrical Engineering, John Brown University, Siloam Springs, Arkansas. August 1941 he accepted a position as assistant to the Chief Engineer for the Tide Water Oil Refinery Company, Drumright, Okla. In September 1942, he was offered a position as Instructor of Mechanical Engineering at the Missouri School of Mines and Matallurgy, Rolla, Mo., of which he accepted and has continued to date 1948. On August 30, 1944, he was called to active duty in the service of the United States, where he served as a Lieutenant in the U.S. Navy, until his release on May 5, 1946, into the U.S. Naval Reserve.