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Structural Engineering

Behavior and Modeling of A Single Plate Bearing On A Single Bolt

by
Clinton O. Rex
Research Assistant

W. Samuel Easterling, Ph.D., P.E.
Principal Investigator

Submitted to
The American Institute of Steel Construction
The American Iron and Steel Institute
The National Science Foundation
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Research Report

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TABLE OF NOMENCLATURE

a = Distance from center of plate to the caliper

A_0 = Initial cross-sectional area of tensile test specimen

A_b = Area of the bolt

A_t = True cross-sectional area of tensile test specimen

β = Steel correction factor

C_{bb} = Bolt bending stiffness coefficient

C_{bbr} = Bolt bearing stiffness coefficient

C_{bs} = Bolt shearing stiffness coefficient

C_{pbr} = Plate bearing stiffness coefficient

Δ = Plate deformation which is defined as the elongation of the hole

$\overline{\Delta}$ = Normalized plate deformation

d_b = Bolt diameter

d_h = Hole diameter

d_{m16} = Nominal diameter of a M16 bolt (16mm)

E = Modulus of elasticity for steel, 29,000 ksi

F_b = Bearing stress

F_u = Plate steel ultimate stress

F_{ub} = Ultimate stress of the bolt steel

F_y = Plate steel yield stress

G = Shear modulus for steel, 11,200 ksi

h = Height

I_b = Moment of inertia of the bolt

K = Elastic stiffness parameter for Richard Equation

K_{br} = Bearing stiffness

K_i = Initial stiffness of plate

K_p = Plastic stiffness parameter for Richard Equation

K_1 = Parameter in Richard Equation

K_b = *Bending stiffness*

K_b = Bolt stiffness

K_v = Shearing stiffness

k = Shear deformation shape correction factor, 4/3 for a circle, 1.2 for rectangle

k_b = Stiffness coefficient to account for edge and bolt spacing

k_t = Stiffness coefficient to account for plate thickness

L = Distance from the center of the plate to the face of the test rig, 1-in.

L = Length

L_0 = Initial length of tensile test specimen

L_c = Clear end distance

L_e = End distance

L_f = Final length of tensile test specimen

n = Curvature parameter for Richard Equation

P = Tensile test load

R = Load or force in plate

R_n = Nominal strength

R_o = Reference load for Richard Equation

S = Bolt spacing

t = Thickness of main plates

t' = Thickness of lap plates

t_p = Plate thickness

τ_u^p = Ultimate shear stress of the plate

ABSTRACT

One of the fundamental components of a steel connection moment-rotation behavior is the load-deformation behavior associated with high strength bolts. In the particular connections being investigated by the writer the behavior of these bolts can be approximated by the behavior of a simple lap plate connection. The lap plate connection consists of two plates held together by a bolt. The load must pass from one plate through the bolt and into the next plate. Local deformations occur in the bolt and in the plates as the load is increased.

The study presented in this report isolates the local load-deformation behavior associated with the plate and develops a method for approximating this behavior. The more general load-deformation behavior associated with the lap plate connection is the subject of a subsequent report.

1. Introduction

As part of a larger research project dealing with partially restrained composite beam-girder connections the moment-rotation behavior of partially restrained steel connections is needed. The localized load-deformation behavior associated with the bolts in the steel connection is needed to predict the moment-rotation behavior of the full steel connection. The bolt load-deformation behavior can be approximated by the load-deformation behavior of a simple single bolt lap plate connection. The lap plate connection behavior is highly influenced by the load-deformation behavior of each plate in the connection. The basic relationship between the single plate, lap plate connection, and the full steel connection is shown in Figure 1.

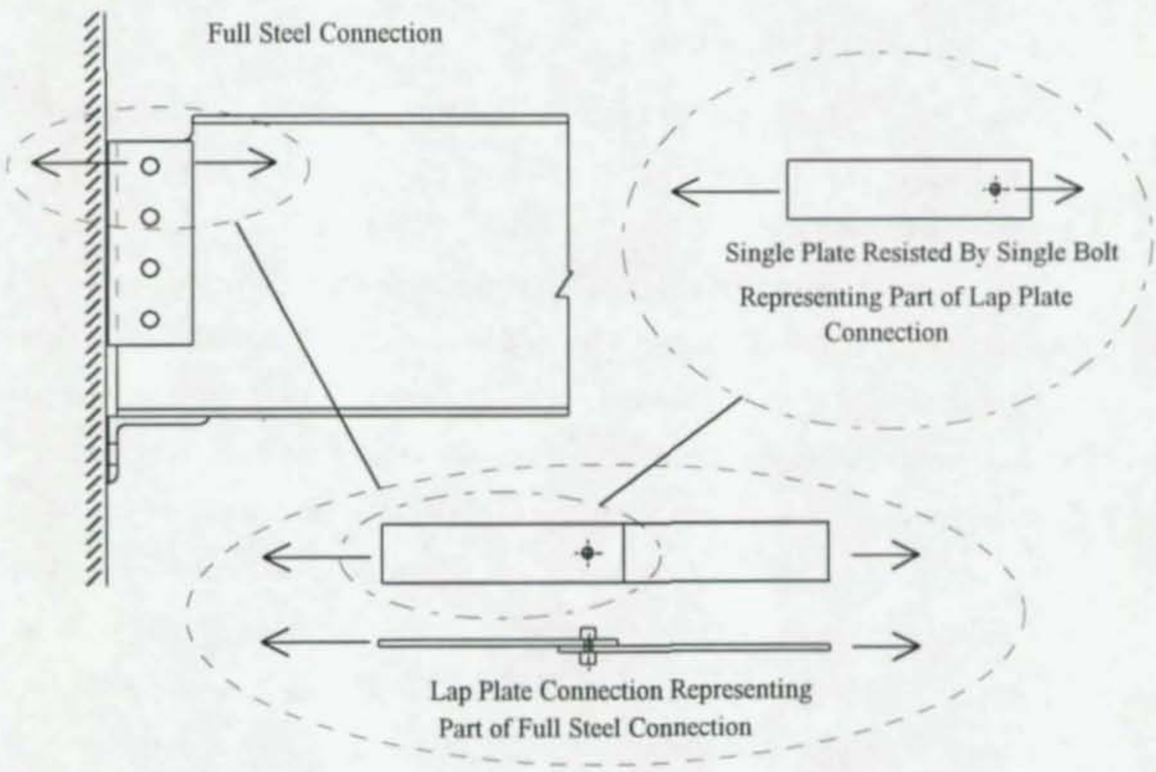

Figure 1 Relation of Single Plate Single Bolt Tests to Full Steel Connection

This report presents the development of a method to predict the load-deformation behavior of a single plate bearing against a single bolt. A combination of experimental and analytical work provide the basis for development and verification of the method.

1.1 Literature

No literature is known to be available that deals with predicting the complete load-deformation behavior of a single plate bearing against a single bolt. However, there is literature that deals with certain aspects of this behavior such as the initial stiffness and the nominal strength. A formal literature review is not presented in this part of the report. Instead, applicable literature is presented along with the development of the particular aspect of plate behavior with which the literature deals.

1.2 Focus and Objective

The focus of this report is the load-deformation behavior of a single plate bearing against a single bolt. The objective of this report is to develop a method that predicts this behavior with suitable accuracy.

Both experimental and finite element studies were conducted to provide a basis for development and verification of a method to predict the load-deformation behavior. The experimental investigation consisted of 46 single plate tests. The primary purpose of these tests was to determine the initial stiffness of the load-deformation response. However, when possible, the tests were continued until failure of the plate occurred. The specimens loaded to failure provided additional data on the basic shape of the load-deformation behavior and the upper limit of the load capacity. The finite element study consisted of over 150 finite element models of a single plate bearing against a single bolt. These models were used to consider the effect of a large range of geometric and material parameters on the initial stiffness of the load-deformation response.

Two of the most important characteristics of the load-deformation behavior are the initial stiffness and the load capacity. These two characteristics are discussed and analyzed and existing literature dealing with them is presented and evaluated. Methods for determining each of these characteristics are then developed and / or recommended.

The load-deformation behavior of a single plate bearing against a single bolt is highly non-linear. Because of this non-linearity the behavior must be represented by either a *combination of piece-wise linear segments* or by a *continuous non-linear analytical* expression. The analytical expression used here in.

There are a variety of non-linear analytical expressions available. One such expression is the Richard Equation (Richard and Elsalti, 1991). This equation is presented in Figure 2 along with a graphical interpretation of each parameter in the equation. Each parameter of the equation represents a physical aspect of the load-deformation behavior, therefore it is deemed the most logical expression to use in this study.

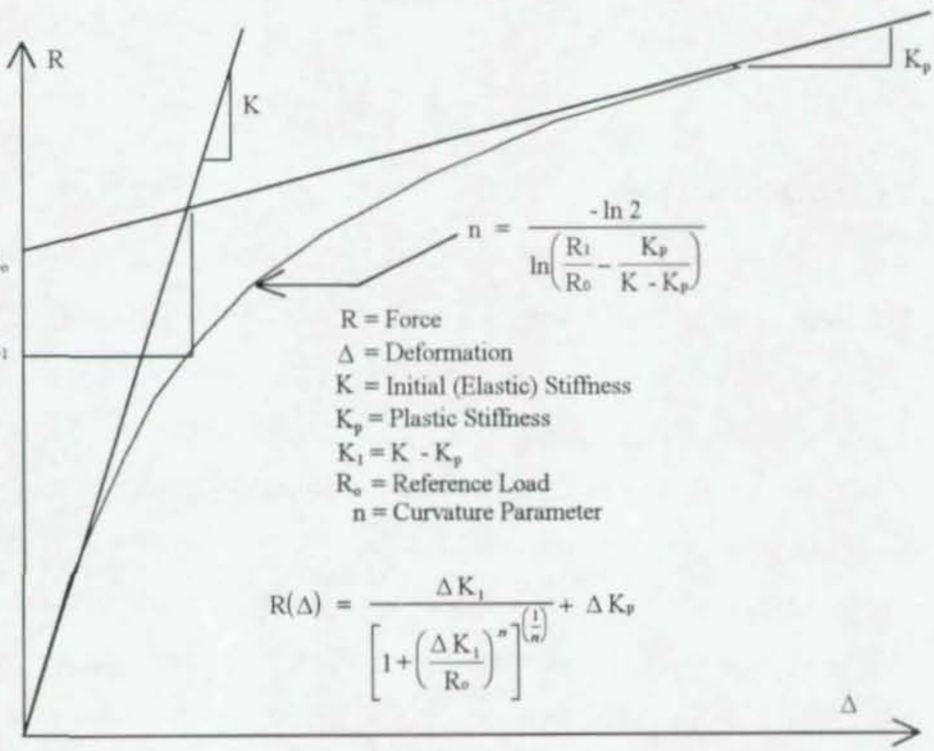

Figure 2 The Richard Equation

The following sections of this report present a development and summary of a method to predict the load-deformation behavior of a single plate bearing against a single bolt. First, a description of experimental work conducted at Virginia Tech (VT) is presented. This work provides the fundamental basis for development and verification of the method. Next, methods are developed and / or recommended for predicting the initial stiffness and load capacity. This is followed by an analysis of the basic load-deformation behavior shape and the development of proper parameters for use in the Richard Equation. Finally, the complete method for approximating the load-deformation behavior is summarized and evaluated against the experimental data.

2. Experimental Work Conducted At VT

An experimental study was conducted to provide data for the development and verification of a method for approximating the load-deformation behavior of a single plate bearing against a single bolt. The following sections describe the details and results of this study.

2.1 Test Specimens

A schematic of the typical single plate specimen is shown in Figure 3. The specimens were fabricated from two types of steel. Test specimens for Tests 1 to 28 were fabricated from 9-in. wide steel plate that had been in storage at Virginia Tech. The particular grade of this steel is unknown. Specimen widths of 3.5-in., 4.5-in., and 5.4-in. were cut from the 9-in. wide plate. The remaining tests were fabricated from 5-in. wide hot-rolled grade A36 steel plate.

All holes in the test specimens were drilled to standard sizes (d_b plus 1/16-in.). One end of the specimen had three holes to fit into the test setup. The test end had one hole. The edge of the plate at the test end of the specimen was either saw cut or shear cut.

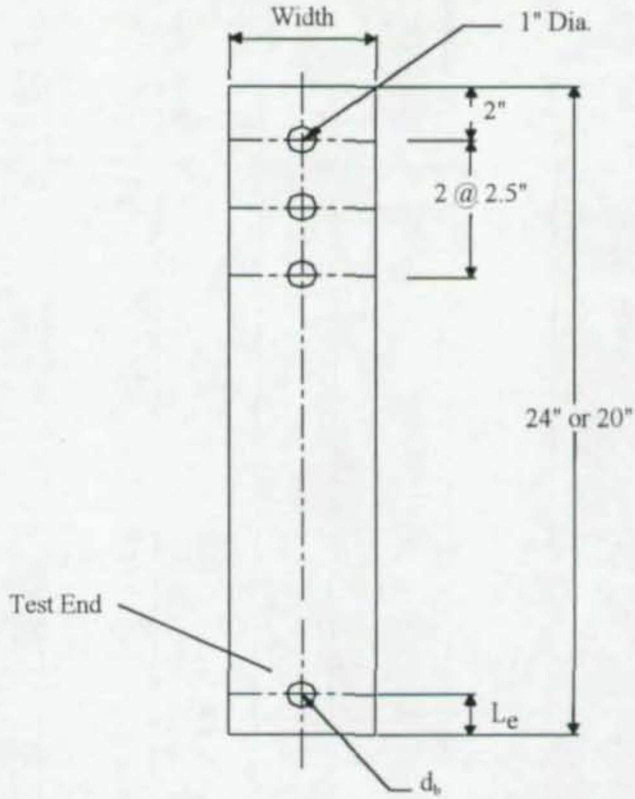

Figure 3 Test Specimen

2.2 Parameters Considered

The parameters that were systematically varied included the end distance (L_e), plate thickness (t_p), bolt diameter (d_b), edge condition (sheared or sawed), and plate width. Because of an effort to use existing materials rather than purchasing all new material the steel properties also varied among the test specimens. A summary of these parameters is presented in Table 1. A comparison of F_y and F_u values in Table 1 shows a wide variation in steel properties. The steel properties of the steel used for test specimens 1 to 28 are not typical of steels used in normal construction today. The steel used for test specimens 1 to 28 will be referred to as "high strength" and the steel used for the remaining test specimens will be referred to as "mild." The steel properties are based on the results of tensile tests which are presented in Appendix A.

Table 1 Test Specimen Parameters

Test	Bolt Diameter (in.)	Plate Thickness (in.)	Plate Width (in.)	End Distance (in.)	Edge Condition	Fy (ksi)	Fu (ksi)
1	1	0.25	4.5	1	Sawed	60	100
2	1	0.25	4.5	1	Sawed	60	100
3	1	0.25	4.5	1.5	Sawed	60	100
4	1	0.25	4.5	1.5	Sawed	60	100
5	1	0.25	4.5	2	Sawed	60	100
6	1	0.25	4.5	2	Sawed	60	100
7	1	0.25	4.5	2.5	Sawed	73.5	109
8	1	0.25	4.5	2.5	Sawed	56.5	95
9	1	0.25	4.5	3	Sawed	60	100
10	1	0.25	4.5	3	Sawed	60	100
11	1	0.25	4.5	1	Sheared	59	96.5
12	1	0.25	4.5	1	Sheared	59	96.5
13	1	0.25	4.5	2	Sheared	59	96.5
14	1	0.25	4.5	2	Sheared	59	96.5
17	1	0.25	5.4	2	Sawed	73.5	109
18	1	0.25	5.4	2	Sawed	73.5	109
19	1	0.25	3.5	2	Sawed	73.5	109
20	1	0.25	3.5	2	Sawed	73.5	109
21	0.875	0.25	4.5	2	Sawed	56.5	95
22	0.875	0.25	4.5	2	Sawed	56.5	95
23	0.75	0.25	4.5	2	Sawed	56.5	95
24	0.75	0.25	4.5	2	Sawed	56.5	95
25	0.875	0.25	4.5	1.75	Sawed	56.5	95
26	0.875	0.25	4.5	1.75	Sawed	56.5	95
27	0.75	0.25	4.5	1.5	Sawed	56.5	95
28	0.75	0.25	4.5	1.5	Sawed	60	100
29	1	0.375	5	1.5	Sheared	43.7	63.7
30	1	0.375	5	1.5	Sheared	43.7	63.7
31	1	0.5	5	1.5	Sawed	53.3	74.8
32	1	0.5	5	1.5	Sawed	51.5	74.5
33	1	0.625	5	1.3	Sawed	43.7	63.3
34	1	0.625	5	2	Sawed	43.7	63.3
35	1	0.75	5	2	Sawed	44.5	67.8
36	1	0.75	5	2	Sawed	44.5	67.8
37	1	0.375	5	1.75	Sheared	43.4	63.9
38	1	0.5	5	1.5	Sawed	51.5	74.5
39	1	0.25	5	1.5	Sawed	44.5	65.5
40	1	0.25	5	1.5	Sawed	44.5	65.5
41	1	0.25	5	1.5	Sawed	44.5	65.5
42	1	0.25	5	1	Sawed	44.5	65.5
43	1	0.25	5	1	Sawed	44.5	65.5
44	0.875	0.25	5	1	Sawed	44.5	65.5
45	0.875	0.25	5	1	Sawed	44.5	65.5
46	0.875	0.25	5	1.3125	Sawed	44.5	65.5
47	0.875	0.25	5	1.3125	Sawed	44.5	65.5
48	1	0.25	5	1	Sawed	44.5	65.5

2.3 Instrumentation

Two linear calipers were used to measure deformation on each side of the plate as shown schematically in Figure 4. The calipers have markings at each 0.001-in. By interpolating between these marks the deformations were read to the nearest 0.0001-in. +/- 0.00025-in. This instrumentation was chosen over electronic instrumentation in an attempt to improve the accuracy of displacement measurement. The accuracy of the electronic potentiometers varied from instrument to instrument but on average they were accurate to the nearest 0.001-in. +/- 0.0015-in. This resolution was believed to be insufficient for determining the initial stiffness values because the initial deformations are typically very small.

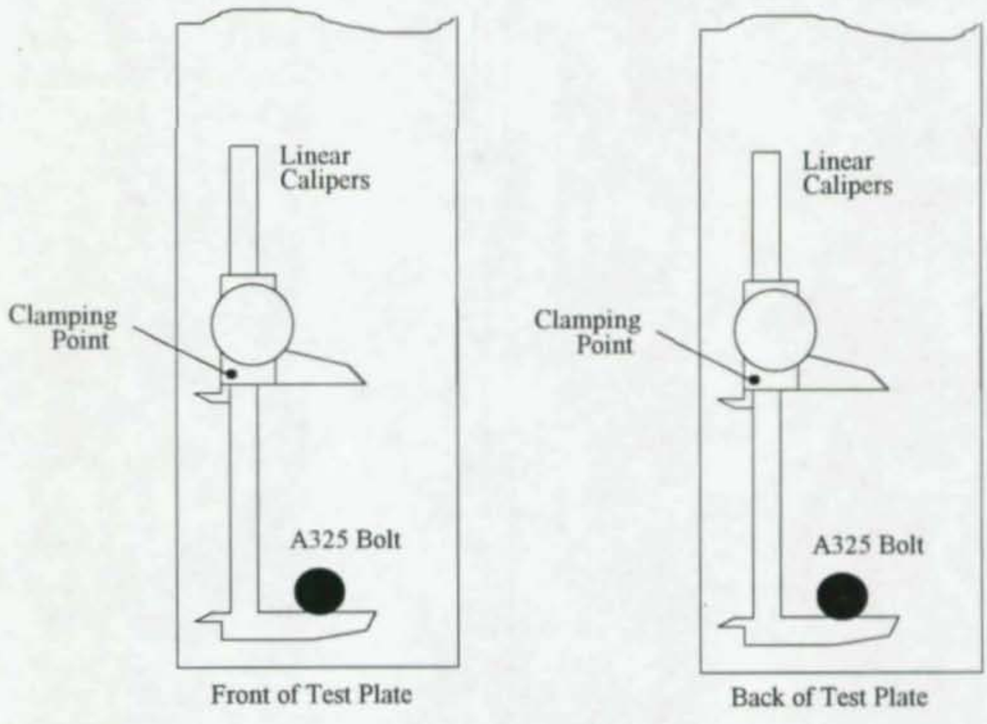

Figure 4 Displacement Instrumentation

As illustrated in Figure 4 the calipers were attached to the test plate with a small C-clamp. This fixed one edge of the caliper while the other edge was positioned so that it rested against the bottom of the bolt. The deformations determined by this setup included both elastic deformations in the plate as well as plate bearing deformations below the bolt.

Load values were based on the load cell readings taken from the universal testing machine used to test the specimens.

2.4 Test Setup

The test setup used is shown schematically in Figure 5. The top of the test plate was bolted to the test rig with two or three 1-in. diameter bolts. Spacing plates were used to center the plate in the test rig. The top and bottom of the test rig were placed in the upper and lower heads of a universal testing machine which was used to apply the load for the test. A single A325 bolt was placed through the hole in the test end of the specimen and through two holes in the bottom test rig. The 2-in. gap in the bottom test rig provided sufficient room for the plate and linear calipers.

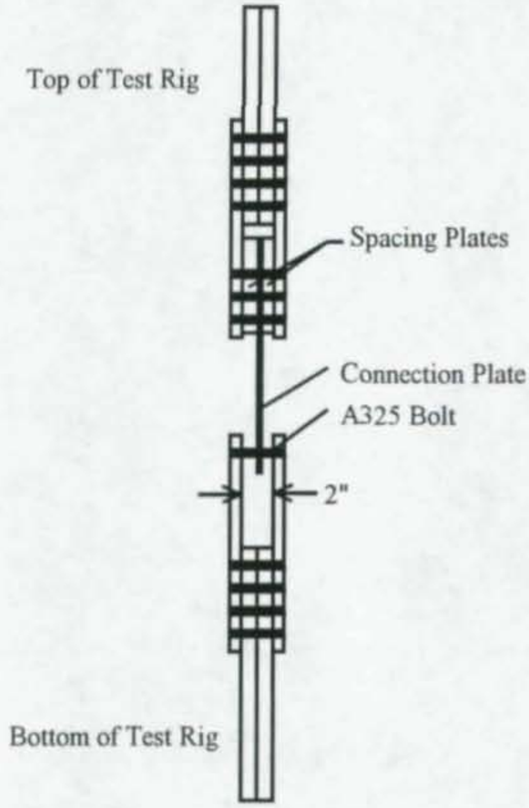

Figure 5 Test Setup

2.5 Test Procedure

Test specimens were loaded to 1 kip at a rate of 0.1-in./minute. The calipers were then checked to ensure they were bearing on the bottom of the bolt. The plates were then either loaded at a load rate of 2 kips/minute or at a displacement rate of 0.005-in./minute. The displacement controlled loading was used in lieu of the load controlled loading in the latter test specimens because it was found to provide better control over the test. Once the load deformation behavior started to soften the specimen was loaded at a rate of 0.04-in./minute. The initial deformation reading was taken when the load was between 2 and 3 kips. Subsequent deformation readings were initially taken at approximately every 2.5 kips. After the behavior started to soften load readings were taken at approximately every 0.05-in. of deformation.

Specimens were loaded until either the specimen failed or the limits of the test setup were reached. The primary characteristic of the plate load-deformation behavior that prompted these tests was the initial stiffness. As a result, the test setup was not designed to test all specimens to failure. Consequently, many specimens were not tested to failure but instead only initial stiffness data was obtained.

2.6 Results

Test summaries for each test specimen are presented in Appendix D. These test summaries consist of two pages. On the first page there is a summary of the geometric and material properties, a summary of the primary test results and test comments, and a plot showing the load deformation behavior for the specimen. On the second page the load-deformation data and a plot of the data used for determining the initial stiffness is presented.

The following sections describe the types of failure modes observed, adjustments that were made to the raw data, and the effect that plate width had on the load-deformation behavior. Aside from these topics, additional discussion of results is not presented here. Rather, the remaining results are presented and discussed in the later sections of the report as appropriate. This will allow the reader to focus on one particular characteristic of the load-deformation behavior at a time without having to constantly refer back to this results section.

2.6.1 Types of failures

As previously discussed, the maximum load that could be applied to the test specimen was limited by the test setup. In many cases this load limit was reached before any form of plate failure occurred. In some cases, however, plate failure occurred before the test setup limit was reached. In these tests there were four plate failure modes observed. These failure modes are shown schematically in Figure 6.

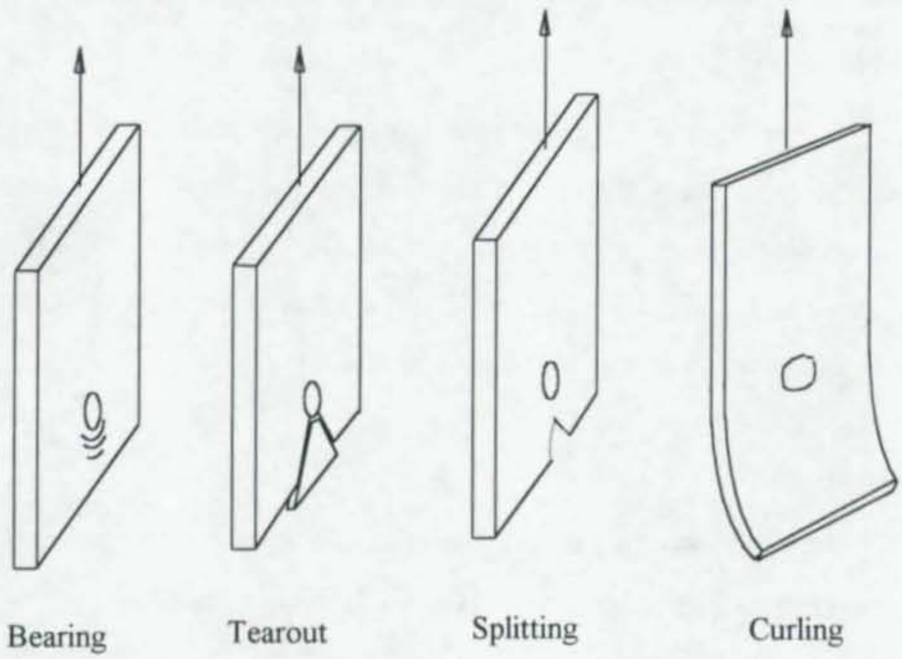

Figure 6 Typical Plate Failures

These failure modes are described as follows

- **Bearing**: Plate deformations exceeded 0.5-in. without any substantial loss in load capacity. This occurred in most of the specimens fabricated from mild steel and three of the specimens fabricated from high strength steel.

- **Tearout**: A block of steel between the bolt and the free end of the plate starts to shear out resulting in a loss in load carrying capacity. This occurred in only one test.
- **Splitting**: A split along the free end of the plate initiates and starts propagating toward the bolt hole. This occurred in all plates with sheared edges. Load capacity is usually not affected by the split until it propagates near the bolt hole. The rate at which the split propagates depends on the load stage. If the split occurs in the early load stages then the split propagates slowly; however, if the split occurs in the later load stages then it typically propagated quickly leading to fairly rapid failure.
- **Curling**: The plate below the bolt buckles out of the original plane of the plate. This occurred in almost all ¼-in. plates that had end distances greater than or equal to two-in. A loss in stiffness and eventually a loss in load capacity was associated with the plate buckling. Tests were typically stopped when the plate had deformed far enough to cause conflicts with the test setup or there was a drop in load carrying capacity.

2.6.2 Adjustments to data

Before the raw data could be used for the development and verification of load-deformation behavior prediction models there were typically three and in some cases four types of adjustments made to the data. First, estimates of elastic plate deformations and bolt deformations were removed from the raw data. Next, the new data was used to determine the initial stiffness of the specimen. The data was then shifted based on the initial stiffness such that the initial response passed through a point of zero load and zero deformation. Finally, in tests where excessive curling of the specimen occurred it was sometimes necessary to remove one of the linear calipers to prevent it from being damaged. For these tests data was adjusted for the missing caliper readings.

2.6.2.1 Removing Elastic Plate Deformations From Data

The deformations read from the calipers included not only bearing deformations in front of the bolt but also elastic deformation of the plate. Because the bearing deformations are the only deformations of interest it was necessary to estimate the elastic plate deformations so that they could be removed.

Based on the initial caliper reading and the bolt hole diameter the distance between the top of the bolt hole and the clamping point for the calipers was determined. The stress in the plate was then calculated as the plate load divided by gross area of the plate. The stress was then converted to strain assuming a modulus of elasticity of 29,000 ksi. The strain was multiplied by the distance between the top of the bolt hole and the clamping point for the calipers to estimate the elastic deformations over this length. Any deformation along the side of the bolt hole has been ignored and consequently has been lumped into the bearing deformations.

2.6.2.2 Estimating Bolt Deformations

The bolt that the test plate was bearing against had to span approximately 2-in. between the plates of the bottom test rig. Consequently it is assumed that as the test plate was loaded the load on the bolt would cause the bolt to bend. The calipers used to measure deformations rested against the bottom of the bolt at a small distance from the faces of the test plate. The vertical bolt deformation that occurs between the center of the test plate and the point where the calipers rest against the bolt would be included in the caliper measurement. This situation along with the model used for estimating the bolt deformation are shown schematically in Figure 7.

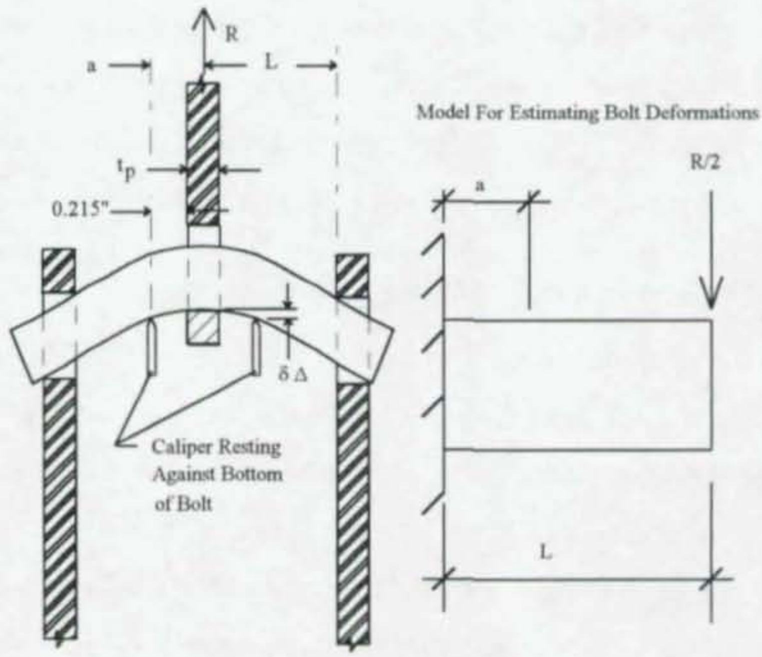

Figure 7 Vertical Bolt Deformations

Both shear and flexural deformations were included because the height to length ratio of the bolt deformation model is as high as one-half. Based on the model assumed, the change in deformation can be expressed as:

$$\delta \Delta = \frac{R}{2}\left[\frac{1}{EI_b}\left(\frac{La^2}{2} - \frac{a^3}{6}\right) + \frac{ka}{GA_b}\right] \quad \text{(Eq 1)}$$

Where:

k = Shear deformation shape correction factor, 4/3 for a circle

L = Distance from the center of the plate to the face of the test rig, 1-in.

a = Distance from center of plate to the caliper, 0.215-in. + $t_p/2$

These deformations were calculated and then subtracted from the caliper measurements.

2.6.2.3 Shifting Data Based on Initial Stiffness

Once estimated elastic plate and bolt deformations were removed from the raw data, the first few data points were used to establish the initial stiffness of the load deformation response. Based on a best fit line through these data points and the corresponding load intercept, a fictitious caliper reading for zero load was determined (fictitious because no caliper reading was taken at zero load). The data was then shifted by subtracting the fictitious caliper reading from the actual readings. This shifts the data so that the load-deformation response passes through zero load zero deformation.

2.6.2.4 Adjusting Data for Missing Caliper

If plate curling was observed one of the calipers would be removed from the plate to prevent it from being damaged before the test was over. Prior to the caliper being removed the deformation was assumed to be the average deformation from the two caliper readings. The caliper readings from the remaining caliper needed to be adjusted so that they would be consistent with the average caliper readings that were previously used. This was done by determining the typical difference between the average reading and the reading of the remaining caliper. This difference was then assumed to be constant for the remaining readings. These deformation readings based on the remaining caliper were then adjusted by this difference to estimate the deformation.

2.6.3 Effect of Plate Width on Load-Deformation Behavior

The effect of plate width on the load-deformation behavior was investigated by comparing the results from tests 5, 6, 17, 18, 19, and 20. The only variable changed in this group of tests was the plate width. Unfortunately, all the tests from this group except Test #5 failed because of plate curling. This premature failure mode prevented the tests from developing the full strength and / or deformation capacity. The load-deformation behavior for all the test from this group are plotted in Figure 8.

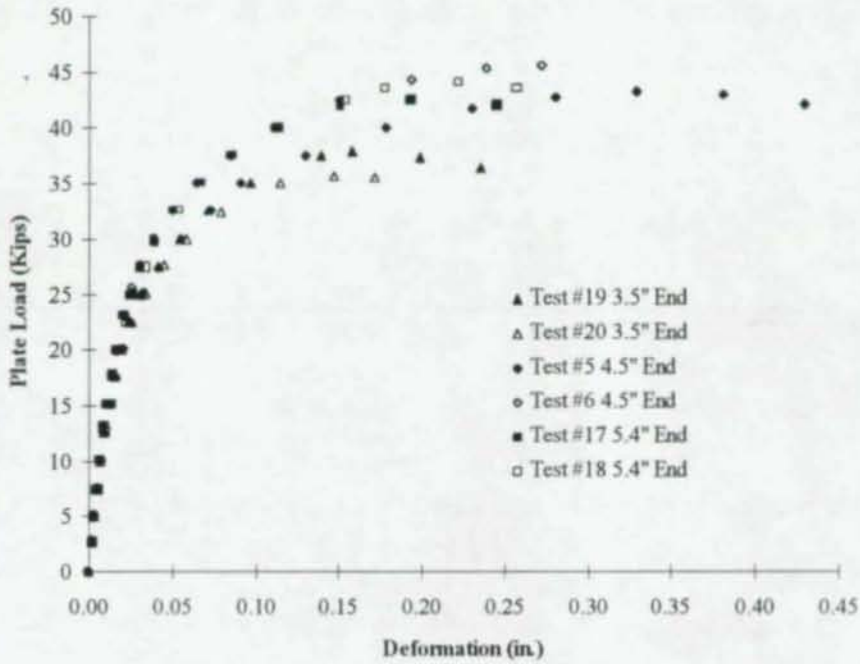

Figure 8 Effect of Plate Width on Load-Deformation Behavior

The following observations can be made by referring to Figure 8.

- Up to about 25 kips there is little if any difference between the tests.
- Beyond 25 kips the tests split into two groups. Tests 5, 19, and 20 start to soften compared to Tests 6, 17, and 18.
- Out of the group that softened Tests 19 and 20 soon become unstable and curling failure ends the test while Test 5 continues and develops the full strength and deformation capacity.
- All the other tests developed the full load but then became unstable and curling failure ended the tests before they could develop the full deformation capacity.
- The deformation at the end of the tests were between 0.15-in. and 0.25-in. for the tests that failed by curling.

The affect of plate width on the initial stiffness cannot be seen in Figure 8 because of the scale. The initial stiffness values for the test group are given in Table 2. As can be seen in Table 2 the differences between initial stiffness values are less than 5%. This variation can easily be explained when considering the average coefficient of variation for each pair of tests is 9%.

Table 2 Effect of Plate Width On Initial Stiffness

Test	Plate Width (in.)	Average Initial Stiffness (kips/in.)
19 & 20	3.5	1515
5 & 6	4.5	1525
17 & 18	5.4	1590

Based on the above observations the following conclusions may be made about the effect of plate width.

- The width of the plate may have some effect on the load capacity before the plate becomes unstable. The wider the plate the higher the load before instability.
- The width of the plate has a negligible effect on the initial stiffness.

These conclusions are based on only six tests and the minimum plate width was 3.5-in. so they should be regarded as preliminary at best.

If the plate width is less than 3.5-in. it is expected that the elastic stretching of the plate alongside the bolt hole will start to effect the initial stiffness value. In addition, as the plate width decreases the mode of failure would change from bearing type failure to a net section tension rupture.

3. Initial Stiffness

The initial stiffness of the load-deformation behavior is one of the two most important quantities needed to provide reliable predictions of this behavior. Unfortunately, it is also the hardest quantity to predict and measure. Because of the difficulty in measuring experimental initial stiffness values, it was decided that a combination of experimental and finite element work would be used to develop and evaluate predictive models.

The following sections describe how experimental and finite element values for initial stiffness were determined. Existing models for predicting the initial stiffness are presented and a new model is developed. These models are then evaluated against the experimental and finite element results. In addition, the effect of edge condition on the initial stiffness is discussed.

3.1 Data For Evaluation of Models

There are two sources of initial stiffness data used to evaluate and develop an initial stiffness prediction model. First, experimental values of the initial stiffness were determined from the experimental work previously described. Second, a finite element model was constructed and verified against the experimental data. The finite element model was then used to conduct a parameter study.

3.1.1 Initial Stiffness Values Based on Experimental Work

This section presents a discussion and summary of the initial stiffness values determined from the experimental work previously. First, the basic method for determining the initial stiffness from the test data is described. Next, the sensitivity of the initial stiffness values to the effects of loading and unloading are discussed. This is followed by a discussion of how sensitive the initial stiffness values are to the accuracy of load and deformation measurement. Finally, a summary of the initial stiffness values along with upper and lower bounds for these values based on measurement accuracy is given.

3.1.1.1 How Initial Stiffness Values Were Determined

There appears to be no indisputable method for determining the initial stiffness of test data. Each set of data has to be evaluated individually and some judgment must be used to determine which data points are appropriate for measuring the initial stiffness. For this reason it is not possible to give exact details on how the initial stiffness values were determined. However, in general the following procedure was used to determine the initial stiffness.

After subtracting elastic plate and bolt deformations from the raw experimental data the first few data points were evaluated. The initial stiffness was defined as the maximum slope of a best fit line through at least two measured data points. The data points used to determine the slope were not necessarily the first two data points. This is particularly true for the thicker plates where the stiffness appeared to increase and then decrease as load was increased. A plot showing data points chosen and the best fit line through the data is included with each test summary found in Appendix D.

3.1.1.2 Effect of Unloading and Reloading

Because of various problems with the universal testing machine used, the first measured load for some test specimens far exceeded the load range desired for determining the initial stiffness. These specimens were unloaded and the test was started again. Consequently, the initial data recorded came from the second loading of the specimen.

To determine what if any effect this loading and unloading might have on the initial stiffness three test specimens were intentionally loaded two times. Deformation data was recorded for both the first and second load sequences. The stiffness was then determined for each load sequence. These stiffness values are presented in Table 3.

Table 3 Effect of Unloading and Reloading on Initial Stiffness

Test	First Stiffness (kips/in.)	Second Stiffness (kips/in.)
25	1611	2441
26	1189	2054
28	669	1438

As can be seen in Table 3 the stiffness determined from the second load sequence was larger that that determined in the first load sequence for each test. The average increase was 821 kips/in. This represents a significant increase compared to the first stiffness. The intent of the experimental work was to determine the initial stiffness of a previously unloaded specimen. Consequently the initial stiffness values based on test data from specimens that were unintentionally loaded, unloaded, and reloaded are not considered in the remaining discussion and evaluation of results.

3.1.1.3 Sensitivity of Initial Stiffness to Instrumentation

To determine the sensitivity of the measured initial stiffness to the accuracy of the instrumentation the accuracy of the instrumentation must first be determined. The deformations were measured with linear calipers that are marked at every 0.001-in. By interpolating between the marks, measurements were made to an accuracy of 0.0001-in +/- 0.00025. Load was measured using the load cell in the universal testing machine. The accuracy of this load cell for the typical loads associated with the initial stiffness data was assumed to be +/- 100 lbs.

The first and last data points included for determining the initial stiffness were used to determine the upper and lower bounds for the initial stiffness. The variation in load and deformation was added and subtracted from the data point values. This created a box of possible load-deformation points that could have been read for each point. Upper and lower bounds on the initial stiffness were based on slopes passing from the edges of these boxes as shown in Figure 9.

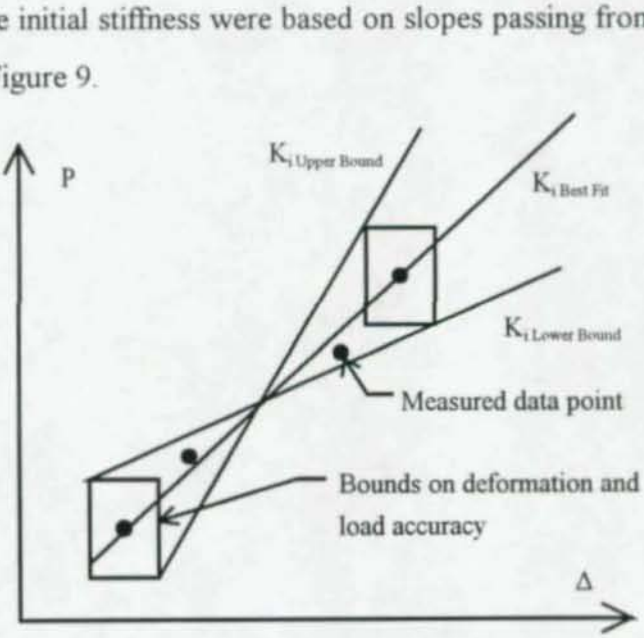

Figure 9 Upper and Lower Bounds For K_i

3.1.1.4 Test Parameters and Experimental Initial Stiffness

A summary of the test parameters that were varied and the values of the initial stiffness are presented in Table 4. Note that test specimens which were unintentionally loaded, unloaded, and reloaded have been omitted. The initial stiffness based on the best fit of the data as well as the upper and lower bounds on this stiffness are included.

Table 4 Summary of Initial Stiffness and Test Parameters

Test	Bolt Diameter (in.)	Plate Thickness (in.)	Plate Width (in.)	End Distance (in.)	Edge Condition	Fy (ksi)	Fu (ksi)	Ki Best Fit (k/in.)	Ki Upper (k/in.)	Ki Lower (k/in.)
1	1	0.25	4.5	1	Sawed	60	100	1138	1677	824
2	1	0.25	4.5	1	Sawed	60	100	1278	1958	906
3	1	0.25	4.5	1.5	Sawed	60	100	1511	1765	1336
5	1	0.25	4.5	2	Sawed	60	100	1477	1866	1217
6	1	0.25	4.5	2	Sawed	60	100	1572	1999	1277
8	1	0.25	4.5	2.5	Sawed	56.5	95	1643	2089	1332
9	1	0.25	4.5	3	Sawed	60	100	1601	2038	1303
10	1	0.25	4.5	3	Sawed	60	100	2137	2946	1646
11	1	0.25	4.5	1	Sheared	59	96.5	1258	1869	910
12	1	0.25	4.5	1	Sheared	59	96.5	1631	2995	1055
13	1	0.25	4.5	2	Sheared	59	96.5	1542	1927	1261
14	1	0.25	4.5	2	Sheared	59	96.5	2057	2783	1604
17	1	0.25	5.4	2	Sawed	73.5	109	1777	2337	1416
18	1	0.25	5.4	2	Sawed	73.5	109	1403	1743	1157
19	1	0.25	3.5	2	Sawed	73.5	109	1573	1988	1281
20	1	0.25	3.5	2	Sawed	73.5	109	1457	1821	1199
21	0.875	0.25	4.5	2	Sawed	56.5	95	1124	1336	958
22	0.875	0.25	4.5	2	Sawed	56.5	95	1172	1421	996
23	0.75	0.25	4.5	2	Sawed	56.5	95	1098	1306	941
24	0.75	0.25	4.5	2	Sawed	56.5	95	935	1087	813
25	0.875	0.25	4.5	1.75	Sawed	56.5	95	1611	2038	1314
26	0.875	0.25	4.5	1.75	Sawed	56.5	95	1189	1451	1005
28	0.75	0.25	4.5	1.5	Sawed	56.5	95	669	753	597
29	1	0.375	5	1.5	Sheared	43.7	63.7	1393	1701	1164
30	1	0.375	5	1.5	Sheared	43.7	63.7	1724	2220	1375
31	1	0.5	5	1.5	Sawed	53.3	74.8	1670	1917	1494
32	1	0.5	5	1.5	Sawed	51.5	74.5	2779	4165	2044
33	1	0.625	5	1.3	Sawed	43.7	63.3	2265	3096	1757
34	1	0.625	5	2	Sawed	43.7	63.3	2295	2852	1920
35	1	0.75	5	2	Sawed	44.5	67.8	3590	4934	2752
36	1	0.75	5	2	Sawed	44.5	67.8	3531	4861	2717
37	1	0.375	5	1.75	Sheared	43.4	63.9	1778	2335	1425
38	1	0.5	5	1.5	Sawed	51.5	74.5	1865	2390	1512
41	1	0.25	5	1.5	Sawed	44.5	65.5	1522	2894	963
42	1	0.25	5	1	Sawed	44.5	65.5	561	667	462
43	1	0.25	5	1	Sawed	44.5	65.5	1113	1484	860
44	0.875	0.25	5	1	Sawed	44.5	65.5	902	1128	760
45	0.875	0.25	5	1	Sawed	44.5	65.5	1056	1646	745
46	0.875	0.25	5	1.3125	Sawed	44.5	65.5	797	897	698
47	0.875	0.25	5	1.3125	Sawed	44.5	65.5	856	1099	695
48	1	0.25	5	1	Sawed	44.5	65.5	388	431	349

A summary of the average, minimum, maximum, and coefficient of variation of the best fit K_i is presented in Table 5 with the tests grouped by parameters. The maximum upper bound and minimum lower bound values for the test group are also given.

Table 5 Summary of Initial Stiffness Statistics

Tests	Average (k/in.)	Max (k/in.)	Min (k/in.)	COV	Upper Bound (k/in.)	Lower Bound (k/in.)
1, 2	1208	1278	1138	8%	1958	824
3	1511	-	-	-	1765	1336
5, 6	1525	1572	1477	4%	1999	1217
8	1643	-	-	-	2089	1332
9, 10	1869	2137	1601	20%	2946	1303
11, 12	1445	1631	1258	18%	2995	910
13, 14	1799	2057	1542	20%	2783	1261
17, 18	1590	1777	1403	17%	2337	1157
19, 20	1515	1573	1457	5%	1988	1199
21, 22	1148	1172	1124	3%	1421	958
23, 24	1016	1098	935	11%	1306	813
25, 26	1400	1611	1189	21%	2038	1005
28	669	-	-	-	753	597
29, 30	1558	1724	1393	15%	2220	1164
37	1778	-	-	-	2335	1425
31	1670	-	-	-	1917	1494
32,38	2322	2779	1865	28%	4165	1512
33, 34	2280	2295	2265	1%	3096	1757
35, 36	3560	3590	3531	1%	4934	2717
41	1522	-	-	-	2894	963
42, 43, 48	687	1113	388	55%	1484	349
44, 45	979	1056	902	11%	1646	745
46, 47	826	856	797	5%	1099	695

3.1.2 Initial Stiffness Data Based on Finite Element Models

The initial stiffness for a limited number and range of plate and bolt parameters were investigated experimentally. Additional data is needed to develop and / or verify a model for predicting initial stiffness. Finite element models of the single plate bearing against the single bolt were developed for this purpose. The finite element program ANSYS was used to analyze the models. The finite element model was initially verified against the experimental data. Next, the finite element model was used to carry out a parametric study.

3.1.2.1 Finite Element Mesh and Elements

Plate bearing against a bolt first appears to be a problem that can be modeled in two dimensions. However, the initial stiffness values obtained from preliminary two dimensional finite element models were in general much higher than the values determined experimentally. This was true even with very fine meshes. Consequently, a three dimensional model was constructed. As discussed later, this model compared much better with the test data. A typical three dimensional mesh is shown in Figure 10.

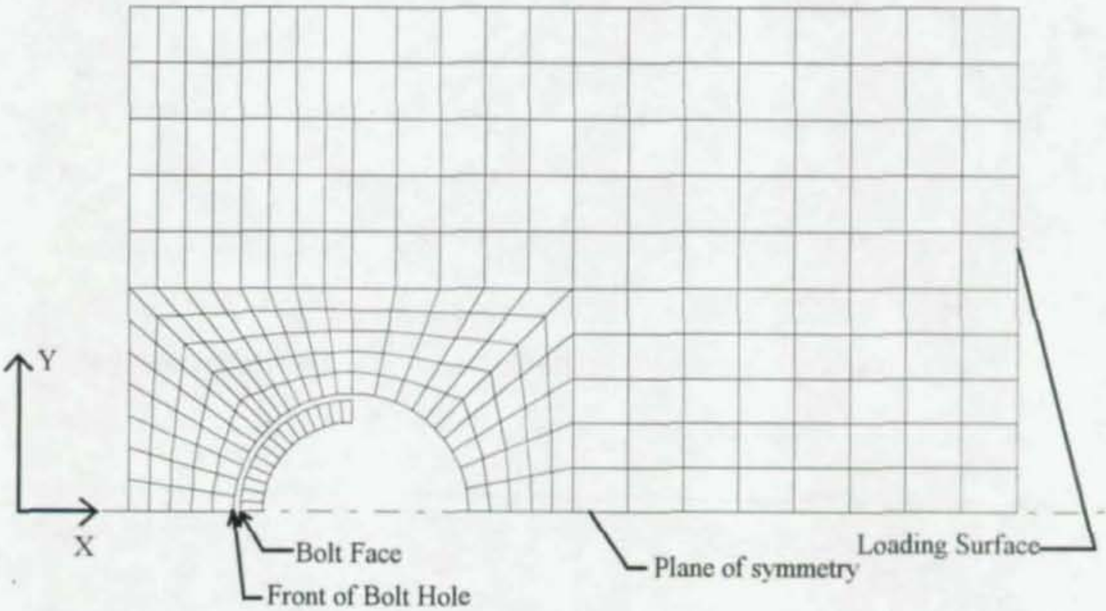

Figure 10 Typical Finite Element Mesh

ANSYS Solid 45 elements were used which are 8 node 24 dof elements. Depending on the thickness of the plate being modeled the mesh is one to four elements deep. ANSYS Contact 49 elements were used to model the contact occurring between the bolt face and the front of the bolt hole. Boundary conditions were applied to the bolt face such that it acted almost as a rigid surface. Attempts to refine the mesh density and / or use higher order elements resulted in very little if any change in initial stiffness values.

The three-dimensional plate is doubly symmetric with planes of symmetry lying parallel to the length of the plate. One plane passes through the plate mid-thickness and is parallel to the face of the plate while the other plane passes through the center of the bolt hole and is perpendicular to the face of the plate (the second plane is shown in Figure 10). Because of the symmetry, only half the thickness and half the width of the plate was actually modeled.

3.1.2.2 Stress-Strain Relationship

Piece-wise linear representations of the steel stress-strain behavior were used in the finite element models for the elements in the steel plate. The stress-strain behavior was based on tensile test data of the steel used to fabricate the experimental test plates and a statistical study of mild steel stress-strain behavior (Rex and Easterling, 1996(a)). All the stress-strain relationships used for verifying the finite element results are given in Table 6. In addition, data for a typical stress-strain plot is given. This typical behavior depends only on values of F_y and F_u. A set of example data for F_y and F_u of 50 and 70 ksi respectively is also given.

Table 6 Stress-Strain Relations Used For Finite Element Model

SC12		SC22		SC44		SC45		SC46	
ε	σ	ε	σ	ε	σ	ε	σ	ε	σ
(in./in.)	(psi)	(in./in.)	(psi)	(in./in.)	(psi)	(in./in.)	(psi)	(in./in.)	(psi)
0.001776	51500	0.0015	43500	0.001534	44500	0.001379	40000	0.001379	40000
0.02	51500	0.02	43500	0.02	44500	0.003	58000	0.002	50000
0.05	63325	0.05	54145	0.05	57630	0.02	78000	0.007	60000
0.1	70775	0.1	60515	0.1	64410	0.05	92000	0.05	85000
0.2	74500	0.2	63700	0.2	67800	0.1	100000	0.15	95000
1	74500	1	63700	1	67800	0.15	100000	1	95000
						1	100000		

SC48		SC51		Typical		Fy = 50	Fu = 70
ε	σ	ε	σ	ε	σ	ε	σ
(in./in.)	(psi)	(in./in.)	(psi)	(in./in.)	(psi)	(in./in.)	(psi)
0.00207	60000	0.001534	44500	Fy/E	Fy	0.001724	50000
0.003	74000	0.02	44500	0.02	Fy	0.02	50000
0.006	74000	0.05	55675	0.05	0.85 Fu	0.05	59500
0.04	100000	0.1	62225	0.1	0.95 Fu	0.1	66500
0.15	109000	0.2	65500	0.2	Fu	0.2	70000
1	109000	1	65500	1	Fu	1	70000

The stress-strain values in Table 6 are engineering (Lagrangian) stress-strain values. These values were converted to true stress and true or natural strain before being used in the finite element models. The definitions of true and engineering stresses and strains along with conversions from engineering to true stresses and strains are given by

$$\sigma_{eng} = P/A_0 \qquad \text{(Eq 2)}$$

$$\sigma_{true} = P/A_t = \sigma_{eng}\,(1 + \varepsilon_{eng}) \qquad \text{(Eq 3)}$$

$$\varepsilon_{eng} = \Delta L/L_0 \qquad \text{(Eq 4)}$$

$$\varepsilon_{true} = \ln\,(\,L_f/L_0\,) = \ln\,(1 + \varepsilon_{eng}) \qquad \text{(Eq 5)}$$

Where P is the tensile test load, L_0 and L_f are the initial and final lengths of the tensile test specimen, and A_0 and A_t are the initial and true cross-sectional areas of the tensile test specimen respectively. The conversions were given by the ANSYS User's Manual (1992).

The MISO option in the ANSYS finite element program was used for entering the piece-wise linear stress-strain behavior. This option uses von Mises yield criterion, an associative flow rule, and isotropic work hardening.

3.1.2.3 Analysis Procedure and Determination of Results

The finite element model was loaded by giving the loading surface (Figure 10) a fixed displacement of 0.005-in. in the positive X direction. This displacement was chosen because it was about the average deformation associated with the last data point used to determine the initial stiffness for the experimental tests. Forces developed through the contact between the bolt hole and bolt face. Displacement was defined as the hole elongation which was determined by evaluating the X displacement of the nodes on the back face of the bolt hole.

The total displacement of 0.005-in. was typically broken up into five or more steps. At each of these steps the contact forces and the displacement were determined. These force and displacement points were then plotted and a best-fit line was passed through the data to determine the initial stiffness.

3.1.2.4 Verification of Finite Element Model

Twenty finite element models were used for verification against the experimental data. These models included all the parameters that were included in the experimental tests except for edge condition which will later be shown to have no effect on the initial stiffness. Nominal values for the geometry were used. These include the plate thickness, plate width, end distance, bolt hole size, and bolt diameter. The model parameters, model results, and the corresponding experimental test results are summarized in Table 7. A graphical summary of the results is presented in Figure 11. Note that the experimental test results in Figure 11 have error bars representing the upper and lower bounds on the initial stiffness.

Table 7 Summary of Finite Element Verification Model Parameters and Results

Model	Bolt Diameter (in.)	Plate Thickness (in.)	Plate Width (in.)	End Distance (in.)	Steel Coupon $\sigma - \varepsilon$ Approx.	Model Ki (kips/in.)	Corespondin Test No.	Avg. Test Ki (kips/in.)	Upper Bound Ki (kips/in.)	Lower Bound Ki (kips/in.)
V01M3D	1	0.25	4.5	1	SC45	1175	1,2	1208	1958	824
V02M3D	1	0.25	5	1	SC51	1081	42,43,48	687	1484	349
V03M3D	1	0.25	4.5	1.5	SC45	1597	3	1511	1765	1336
V04M3D	1	0.25	5	1.5	SC51	1221	41	1522	2894	963
V05M3D	1	0.25	4.5	2	SC45	1714	5,6	1525	1999	1217
V06M3D	1	0.25	4.5	2.5	SC46	1662	8	1643	2089	1332
V07M3D	1	0.25	4.5	3	SC45	1641	9,10	1869	2946	1303
V08M3D	1	0.25	5.5	2	SC48	1947	17,18	1590	2337	1157
V09M3D	1	0.25	3.5	2	SC48	1826	19,20	1515	1988	1199
V10M3D	1	0.375	5	1.5	SC25*	1860	29,30	1558	2220	1164
V11M3D	1	0.375	5	1.75	SC22	1878	37	1778	2335	1425
V12M3D	1	0.5	5	1.5	SC12	3032	32,38	2322	4165	1512
V13M3D	1	0.625	5	1.3	SC43*	3305	33,34	2280	3096	1757
V14M3D	1	0.75	5	2	SC44	4424	35,36	3560	4934	2717
V15M3D	0.875	0.25	4	2	SC46	1533	21,22	1148	1421	958
V16M3D	0.875	0.25	4	1.75	SC46	1517	25,26	1400	2038	1005
V17M3D	0.875	0.25	5	1	SC51	1071	44,45	979	1646	745
V18M3D	0.875	0.25	5	1.3125	SC51	1112	46,47	826	1099	695
V19M3D	0.75	0.25	4	2	SC46	1422	23,24	1016	1306	813
V20M3D	0.75	0.25	4	1.5	SC46	1403	28	669	753	597

*SC25 and SC43 about same as SC22 so SC22 used instead

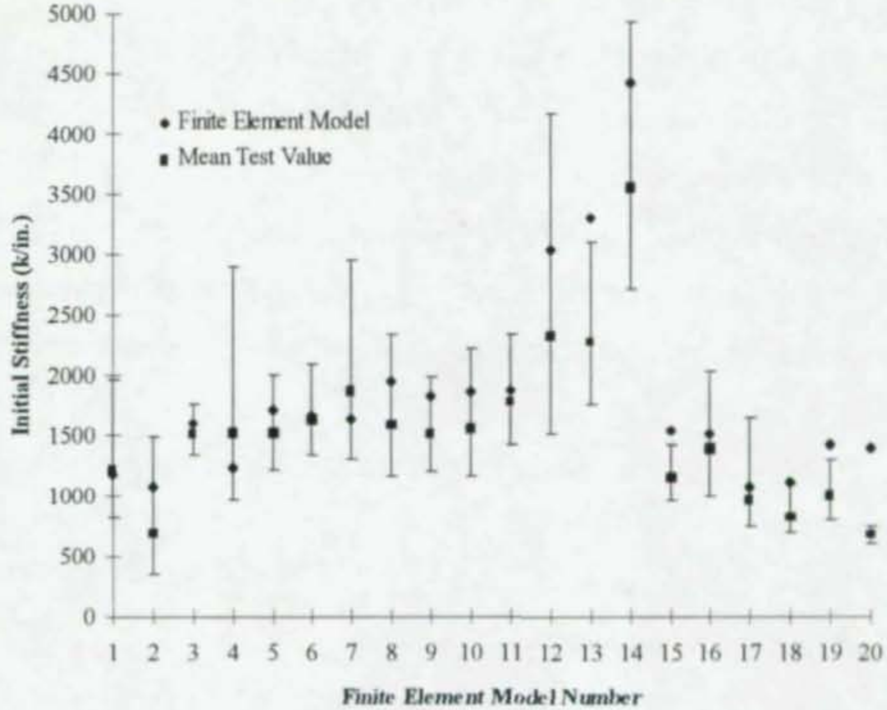

Figure 11 Finite Element Model K_i Vs. Experimental K_i

Comparison of the finite element results to the experimental test results in Figure 11 shows that all but four of the finite element results fell within the upper and lower bounds for the experimental test results. Sources of difference between finite element model and experimental test results include:

- Difference between the nominal and actual geometry
- Difficulty in experimentally measuring initial stiffness
- Variations between the actual and modeled stress-strain behavior

Overall, the agreement between the finite element results and the test results is deemed satisfactory.

3.1.2.5 Parameter Finite Element Models

Approximately 140 finite element models were analyzed to investigate the effect of changing parameters. The parameters included were

- Bolt Diameter 3/4-in., 7/8-in., and 1-in.
- Plate Thickness: 1/8-in. to 1-in. in increments of 1/8-in.
- Edge Distance: 1-in. to 3-in. in increments of 1/4-in.
- Yield Stress: 35 ksi to 60 ksi in increments of 5 ksi
- Ultimate Stress: 50 ksi to 100 ksi in increments of 10 ksi

A summary of the model parameters and results is given in Appendix C. Plate width was not included as a variable based on the experimental results discussed in Section 2.6.2.

The following observations were made based on an evaluation of the finite element models.

At large end distances:

- End distance had no effect
- K_i was linearly proportional to the thickness and the yield stress of the steel plate
- K_i was not affected by changes in the ultimate stress of the steel plate. The ultimate stress had little influence simply because the strains associated with determining the initial stiffness were typically smaller than the strains associated with significant strain hardening.
- The ratios between K_i of different bolt diameters were approximately constant. The ratio of K_i for 1-in. diameter bolts over 3/4-in. diameter bolts was on average 1.23 with other parameters constant. The ratio of 7/8-in. diameter bolts over 3/4-in. diameter bolts was on average 1.13 with other parameters constant.

At small end distances K_i is dependent on a complex inter-relationship between the plate thickness, end distance, bolt diameter, and plate yield stress. The initial stiffness values based on finite element models for a 1/4-in. plate with a yield stress of 45 ksi and varying end distance and bolt diameter are plotted in Figure 12.

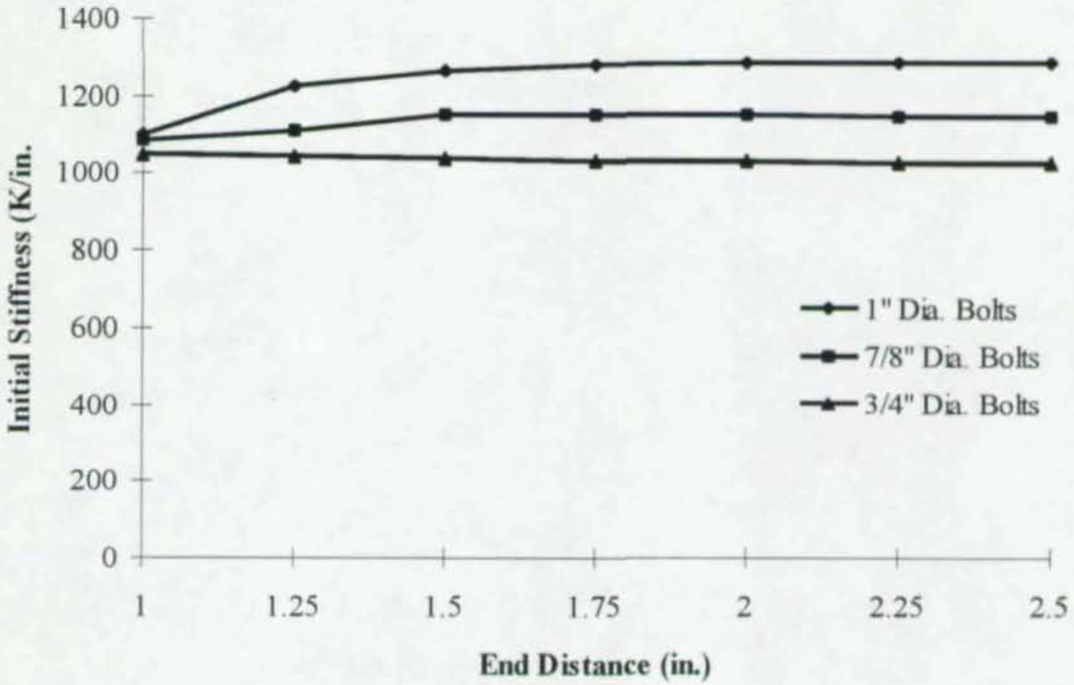

Figure 12 Relation Between Bolt Diameter, End Distance & K_i

Review of this Figure 12 shows the effect which reducing the end distance has on the initial stiffness for different bolt diameters. For the ¾-in. bolt there is little to no effect on the initial stiffness for end distances as little as 1-in. For 1-in. diameter and 7/8-in. diameter bolts the end distance has an effect on the initial stiffness starting at end distances of 1.75-in. and 1.5-in. respectively.

A relationship between end distance and F_y also exists. Finite element models for ¼-in. plates and 1-in. diameter bolts with varying end distance and F_y are plotted in Figure 13. The initial stiffness values have been normalized by the initial stiffness determined at large end distances which is termed the bearing stiffness K_{br}. Review of Figure 13 shows that as F_y increases the effect of decreasing end distance becomes larger.

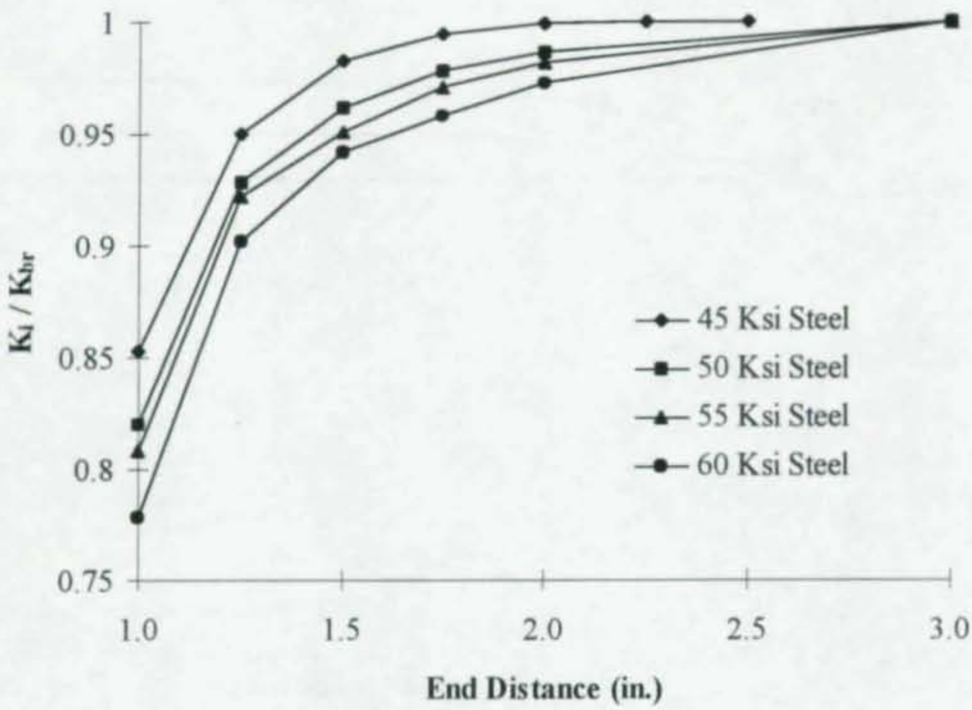

Figure 13 Relation Between Yield Stress, End Distance & K_i

3.2 Existing Prediction Models

Three models for predicting the initial stiffness of bolted joints, in which bolts are not fully tightened, were reviewed from the literature. These are described in the following paragraphs.

The first of these was given in Eurocode 3 Annex J (1994). This was developed for the purpose of determining the initial stiffness of the moment-rotation behavior of bolted joints where the bolts are in shear and not fully tightened. This initial stiffness is given by:

$$K_i = 24\, k_b\, k_t\, d_b\, F_u \qquad \text{(Eq 6)}$$

Where:

k_b = Minimum $(L_e / (4d_b) + .5 \text{ or } S / (4d_b) + .375) \leq 1.25$

$k_t = 1.5\, t_p / d_{m16} \leq 2.5$

d_{m16} = Nominal diameter of a M16 bolt (16mm)

Tate & Rosenfeld (1946) developed a method for determining the bolt load for a particular bolt in a butt joint with multiple bolts. In doing so they developed an expression for estimating the stiffness of bolts. The stiffness, K_b, is based on a combination of deformation constants associated with bolt shear (C_{bs}), bolt bending (C_{bb}), bolt bearing (C_{bbr}), and plate bearing (C_{pbr}).

$$K_b = 2 / (C_{bs} + C_{bb} + C_{bbr} + C_{pbr}) \qquad \text{(Eq 7)}$$

Where:

$$C_{bs} = \frac{t + 2t'}{3GA_b} \qquad \text{(Eq 8)}$$

$$C_{bb} = \frac{8t'^3 + 16tt'^2 + 8t't^2 + t^3}{192EI_b} \qquad \text{(Eq 9)}$$

$$C_{bbr} = \frac{(t + 2t')}{Ett'} \qquad \text{(Eq 10)}$$

$$C_{pbr} = \frac{1}{t'E} + \frac{2}{tE} \qquad \text{(Eq 11)}$$

t' = Thickness of lap plates

t = Thickness of main plates

A review of this derivation gives the estimate of the plate bearing stiffness as

$$K_i = t_p E \qquad \text{(Eq 12)}$$

Fisher (1965) reported that Vogt (1947) developed a theoretical approximation for the load deformation of riveted assemblies. The stiffness is based on bending and shear deformations in the bolt and an approximation of bearing deformations in the plates.

$$\frac{1}{K_i}=\frac{1.125t'^3+3.75tt'^2+5t't^2+2t^3}{11.78d_b^4E}+\frac{0.3(t+t')}{d_b^2E}+\frac{0.375}{d_bE}+\frac{1.3}{E}\left(\frac{1}{t'}+\frac{1}{t}\right) \quad \text{(Eq 13)}$$

A copy of Vogt's paper was not obtained, consequently it is unclear what part of the expression deals with bearing deformations of the plates. Vogt's expression will not be evaluated later; but, it has been presented here for completeness.

3.3 Proposed Model

Based on the results from the finite elements models and the experimental tests it appears that the initial stiffness depends on three primary stiffness values in the plate. The stiffness associated with bending, shearing, and bearing combine to determine the final initial stiffness. The bending and shearing occurs in the portion of the plate between the bolt and the free edge of the plate. Bearing occurs at the contact between the bolt and the plate. The model that accounts for these three stiffness values is simply three springs in series. The final stiffness is given by

$$K_i = \frac{1}{\frac{1}{K_{br}}+\frac{1}{K_b}+\frac{1}{K_v}} \quad \text{(Eq 14)}$$

Where

K_{br} = Bearing stiffness

K_b = Bending stiffness

K_v = Shearing stiffness

This simple model is consistent with the observations made from the finite element results. At large end distances the bending and shearing stiffness values would be large compared to the bearing stiffness. This means only parameters affecting the bearing stiffness would have an affect on the final stiffness. As the end distance becomes shorter the bending and shearing stiffness values start to become more comparable with the bearing stiffness and consequently start to have an affect on the final stiffness.

The three stiffness values, K_{br}, K_b, and K_v should be related to the material and geometry of the plate and bolt. The following two sections develop analytical expressions to predict these stiffness values.

3.3.1 Bearing Stiffness

At large end distances the initial stiffness is primarily controlled by bearing deformations. The physical reality of a bolt bearing on the side of a bolt hole is really a complex three dimensional problem involving material non-linearity. Some simplifications of the real problem have to be made to develop a model that relates the plate geometry and material to the bearing stiffness. Two assumptions were made to simplify the problem. First, the problem is assumed to be two dimensional; and second, the steel in contact with the bolt is assumed to be at its yield stress. With these two assumptions the basic problem becomes one of geometry.

The bolt and the bolt hole are modeled as two circles of different radii. The bolt has a radius of R_1 and the hole has a radius of R_2. Note that R_2 is always larger than R_1. Bearing deformations are represented by the portion of the bolt circle that lies outside the bolt hole circle. This basic geometry is shown in Figure 14.

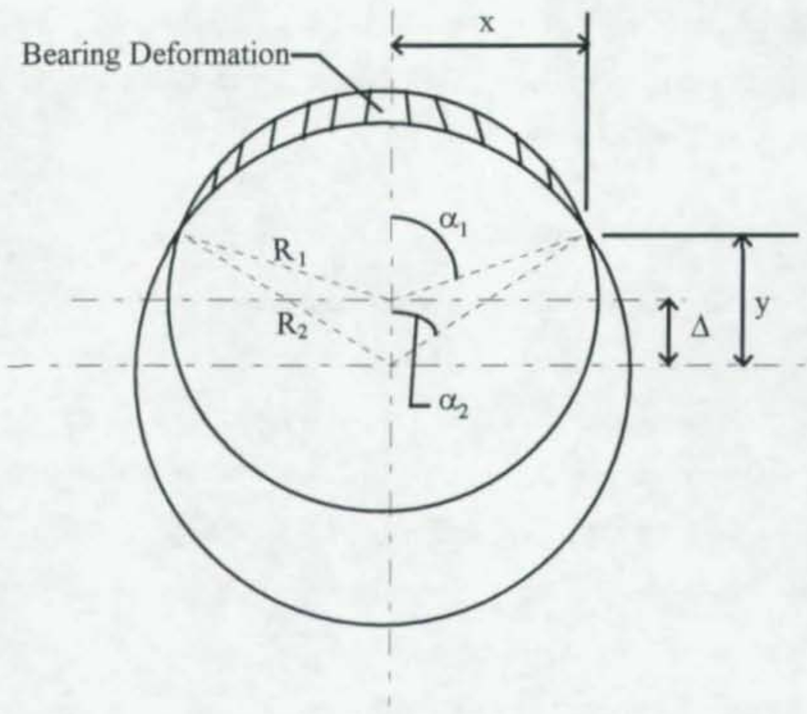

Figure 14 Bearing Stiffness Model

The bearing length will be defined as the portion of the bolt circumference that is in contact with the bolt hole. The bearing area is then defined as the bearing length times the plate thickness. Finally, the bearing force is given by the bearing area times the yield stress of the plate.

Initially (i.e. prior to load being applied), the bearing area would be zero. As load is applied the bearing area has to increase in proportion to the load. The deformation required to cause the appropriate increase in bearing area is proportional to the radii of the bolt and the bolt hole. Based on the geometric definitions given in Figure 14 the following relationships can be derived.

$$\text{Bearing Area} = 2\,\alpha_1\,R_1\,t_p \qquad \text{(Eq 15)}$$

And

$$\alpha_1 = \text{Cos}^{-1}\left[\frac{R_2^2 - R_1^2 - \Delta^2}{2\,R_1\,\Delta}\right] \qquad \text{(Eq 16)}$$

The derivation of α_1 is given in Appendix B. Note that Δ in Equation 16 is the vertical distance between the center of the bolt and the center of the hole which is equal to the maximum bearing deformation plus the difference between the bolt radius and hole radius.

The bearing force for a given bearing deformation can be determined with Equations 15 and 16. The stiffness can then be approximated as the force divided the maximum bearing deformation.

For standard holes the hole radius is 1/32-in. larger than the bolt radius. Assuming standard holes and a assuming a bearing deformation of 0.004-in. the initial stiffness based on the above model is given as

$$K_{br} = 120\ t_p\ F_y\ d_b \qquad \text{(Eq 17)}$$

The assumed bearing deformation of 0.004-in. was based on comparisons between the resulting value of K_{br} and the results of the finite element models.

Because of the simplifying assumptions made to derive Equation 17 there are some discrepancies between initial stiffness values determined using the equation and the values determined from the finite element models. Comparisons to the finite element results suggested that the relation between bolt diameter and initial stiffness was not exactly linear. To account for this difference one modification is made to Equation 17 to yield the final equation for determining the bearing stiffness.

$$K_{br} = 120\ t_p\ F_y\ d_b^{0.8} \qquad \text{(Eq 18)}$$

3.3.2 Bending And Shearing Stiffness

The bending and shearing stiffness values are similar to the bearing stiffness in that they are in reality a complex three-dimensional problem with some material non-linearity. A very simplified model of the real problem is assumed to develop an analytical expression to determine the bending and shearing stiffness. The steel in front of the bolt is modeled as an elastic fixed end beam of length L and height h. This basic concept is shown schematically in Figure 15.

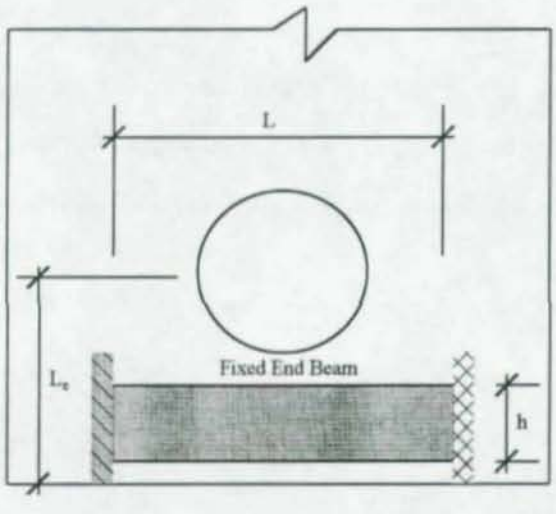

Figure 15 Bending And Shear Stiffness Model

Before bending and shearing stiffness equations can be derived for the fixed end beam the distribution of load on the beam must be assumed. In addition, the relationship between the slenderness of the beam (L/h) and the geometry of the plate must be determined. Three load distributions were considered: point load at the middle of the beam, a triangular load with the apex of the triangle at the middle of the beam, and a uniform load. Three measures of slenderness were also considered.

Shearing and bending stiffness equations were determined for each load distribution and slenderness measure. These stiffness values were then compared to the finite element model results. Based on this comparison, a uniform load distribution was chosen and the best slenderness measure was chosen. The expressions for the bending stiffness, shearing stiffness, and the inverse of the beam slenderness are given as

$$K_b = 32\ E\ t_p\ (h/L)^3 \qquad \text{(Eq 19)}$$

$$K_v = 6.67\ G\ t_p\ (h/L) \qquad \text{(Eq 20)}$$

$$h/L = L_e/d_b - 1/2 \qquad \text{(Eq 21)}$$

Equations 19 and 20 are derived in Appendix B. The value of the slenderness basically assumes the beam has a length of d_b and a height of L_e - $d_b/2$ which is a reasonable value based on the geometry shown in Figure 15.

3.4 Evaluation of Existing And Proposed Models

The proposed initial stiffness model as well as the existing models given by EC3 Annex J (1994) and Tate and Rosenfeld (1946) were evaluated against the experimental and finite element data. Initial stiffness values were determined using each of the models. The test and finite element initial stiffness values were then divided by the predicted values. The results of this evaluation are presented in Table 8.

Table 8 Evaluation of K_i Models

Model:	Proposed	EC3 Annex J	Tate & Rosenfeld
Experimental Results			
Average	0.88	1.15	0.17
COV	23%	24%	30%
Finite Element Results			
Average	1.02	1.48	0.17
COV	5%	16%	14%

The model by Tate and Rosenfeld (1946) did not compare favorably with test or finite element initial stiffness values. This was expected based the simplicity and lack of parameters in the predictive model. Considering the experimental stiffness results the proposed model and the model in EC3 Annex J (1994) were comparable. The proposed model tended to over predict the stiffness and the model in EC3 Annex J (1994) tended to under predict the stiffness. Both models had similar variation around the mean. With regard to the finite element results the proposed model compared much more favorably than the model in EC3 Annex J (1994).

The following observations are based on a qualitative comparison of the proposed model and the model given in EC3 Annex J (1994)

- When the end distance is reduced to 0.5 d_b the proposed model gives a zero stiffness while the model given in EC3 Annex J (1994) does not. In reality, when the end distance is reduced to 0.5 d_b there would only be a small sliver of steel between the edge of the bolt and the free edge of the plate. For this condition a zero stiffness seems appropriate.

- Both the proposed model and the model given in EC3 Annex J (1994) are linearly related to the plate thickness. The model given in EC3 Annex J (1994) indicates that this linear relationship ends when $t_p \geq 1.05$-in. and that subsequent increases in t_p will not increase the stiffness. The experimental and finite element results do not include any plates above 1-in. in thickness. Consequently, this particular aspect cannot be evaluated in a definitive manner; however, it is hard to believe that the initial stiffness would not increase at all with increasing plate thickness.
- Both models do account for reductions in stiffness as the end distance is reduced.
- The proposed model is linearly related to F_y while the model given in EC3 Annex J (1994) is linearly related to F_u. The results from the finite element models clearly showed a relation to the F_y and not F_u.
- Neither the modulus of elasticity or the shear modulus are parameters in the model given by EC3 Annex J (1994) while they are both parameters in the proposed model. However, EC3 (1993) is for steel structures and the general assumption would be that the given model is applicable only to steel.

Without knowing the basis for the development of the model given in EC3 Annex J (1994) a broad conclusion that the proposed model is better than the model given in EC3 Annex J (1994) is partly unjustified. The only justification for such a conclusion is the comparison to the finite element model results. However, because the finite element model is itself an approximation to the real behavior it is uncertain that this comparison is truly valid. For purposes of the current work the proposed model is used.

3.5 Effect of Plate Edge Condition

Some of the experimental tests were designed to determine the effect the plate edge condition may have on the initial stiffness. The measured initial stiffness values for these tests are presented in Table 9. The only difference between the tests in Table 9 was the end distance and edge condition. Based on these results it appears that the edge condition has no conclusive effect on the initial stiffness.

Table 9 Effect of Edge Condition On Initial Stiffness

Test	End Distance (in.)	Edge Condition	First Initial Stiffness (kips/in.)	Average Initial Stiffness (kips/in.)
1	1	Sawed	1132	1201
2	1	Sawed	1270	-
11	1	Sheared	1250	1435
12	1	Sheared	1619	-
5	2	Sawed	1467	1514
6	2	Sawed	1560	-
13	2	Sheared	1530	1530

3.6 Summary

Initial stiffness values based on the experimental tests were determined. In addition, finite element models were developed and used to analytically determine the initial stiffness for a wide range of variables. Based on the experimental and finite element results a model was developed that can be used to predict K_i. This model along with existing models were evaluated against the experimental and finite element results. In general, the proposed model compared well with these results and is consequently recommended for use.

The proposed model is based on very fundamental mechanics. However, there are four aspects of the proposed model that were based on comparisons to the experimental and finite element data. These include

- The bearing deformation of 0.004-in. used to determine the 120 constant for the bearing stiffness.
- The 0.8 power on the bolt diameter for the bearing stiffness.
- Using a uniform load distribution for the development of the bending and shearing stiffness.
- Using L_e/d_b -1/2 as a measure of the slenderness for bending and shearing stiffness.

Because these aspects of the model were somewhat dependent on the experimental and finite element results it is not recommended that the model be used outside of the range of parameters included in the experimental and finite element studies.

4. Nominal Strength

This section considers the nominal strength of the plate in front of single bolt in a standard hole (d_b + 1/16-in.). The nominal strength represents the upper boundary on the load-deformation behavior and will be limited by one of three failure modes; bearing, tearout, or splitting. Note that the curling failure mode is not considered here because it is not a common failure mode seen in typical steel connections. These failure modes were described in Section 2.6.1 of this report.

Data on the nominal strength from two experimental investigations is presented. This data is used to evaluate four existing strength models. Based on this evaluation one strength model is recommended.

4.1 Experimental Data For Evaluation of Models

There are two sources of experimental data. The first source of data is the experimental work that was conducted at VT and described in Section 2 of this report. The second source of data is the experimental work conducted at Oklahoma State University (OSU) by Lewis (1994).

4.1.1 Experimental Work Conducted at VT

As described in Section 2 of this report, 46 single bolt single plate tests were conducted. Out of those tests 20 failed by either bearing, tearout, or splitting. The results of these 20 tests are summarized in Table 10 along with the important plate parameters.

Table 10 Summary of Nominal Strength Parameters and Results

Test	tp (in.)	Le (in.)	Fu (ksi)	db (in.)	Rult (kips)	Δ @ Rult (in.)	R @ 0.25" (kips)	% Increase in R	% Increase in Δ	Failure Mode
1	0.25	1	100	1	24.3	0.2374	24.3	0%	-	Bearing
2	0.25	1	100	1	22.3	0.2498	22.3	0%	0%	Tearout
3	0.25	1.5	100	1	34.2	0.4171	33.3	3%	67%	Splitting
4	0.25	1.5	100	1	33.8	0.3857	33.0	2%	54%	Bearing
5	0.25	2	100	1	43.2	0.3291	42.1	3%	32%	Bearing
11	0.25	1	96.5	1	23.8	0.2017	23.7	0%	-	Splitting
12	0.25	1	96.5	1	22.1	0.2261	21.9	1%	-	Splitting
29	0.375	1.5	63.7	1	32.5	0.1557	-	-	-	Splitting
30	0.375	1.5	63.7	1	30.7	0.2205	30.6	0%	-	Splitting
37	0.375	1.75	63.9	1	35.4	0.2115	35.4	0%	-	Splitting
39	0.25	1.5	65.5	1	25.5	0.5068	23.9	7%	103%	Bearing
40	0.25	1.5	65.5	1	25.9	0.5072	24.1	7%	103%	Bearing
41	0.25	1.5	65.5	1	25.7	0.4996	24.1	7%	100%	Bearing
42	0.25	1	65.5	1	16.3	0.3338	16.0	2%	34%	Bearing
43	0.25	1	65.5	1	16.3	0.3807	15.6	4%	52%	Bearing
44	0.25	1	65.5	0.875	16.1	0.3833	15.8	2%	53%	Bearing
45	0.25	1	65.5	0.875	16.0	0.3210	15.8	1%	28%	Bearing
46	0.25	1.3125	65.5	0.875	22.5	0.4472	21.5	5%	79%	Bearing
47	0.25	1.3125	65.5	0.875	22.6	0.4486	21.6	4%	79%	Bearing
48	0.25	1	65.5	1	17.3	0.3734	16.9	2%	49%	Bearing

In Table 10, R_{ult} is taken as the maximum test load measured before the test ended; and, Δ @ R_{ult} is the deformation at this maximum load. If two or more load-deformation points had the same maximum load value then the first of these points was used.

Bearing failure in Table 10 means the bolt hole elongation reached 0.5-in. and the test was stopped. For later evaluation the load at 0.25-in. of hole elongation is also included in Table 10. The percentage increase of R_n compared to R @ 0.25-in. and the percentage increase in Δ @ R_n compared to 0.25-in. is also included for later evaluation.

4.1.2 Experimental Work Conducted at OSU

Lewis (1994) conducted 48 single plate single bolt tests. Variables considered in the test program included the clear distance (L_c) which was varied from 0.125 to 2.75-in., the plate thickness which varied from .25 to .75-in., and the bolt diameter which varied from .625 to 1-in. The plates were all 4-in. wide with standard holes and were fabricated from A36 steel. The clear distance is the distance from the front edge of the bolt hole to the free edge of the test plate. A summary of the variables and test results is presented in

Table 11. For comparison purposes the end distance (L_e) was calculated and is also included in Table 11.

Table 11 Test Data Reported By Lewis (1994)

Test No.	tp (in.)	Le (in.)	Lc (in.)	Fu (ksi)	Bolt Dia. (in.)	Rult (kips)	Failure Mode
1	0.26	0.678	0.272	70.9	0.75	11.3	Tearout
2	0.253	0.672	0.266	72.7	0.75	11.22	Tearout
3	0.253	1.175	0.769	72.7	0.75	22.22	Tearout
4	0.254	1.638	1.232	72.7	0.75	29.8	Tearout
5	0.252	1.884	1.478	72.7	0.75	33.45	Tearout
6	0.741	0.706	0.3	63.7	0.75	32.95	Tearout
7	0.746	0.888	0.482	63.7	0.75	44.7	Tearout
8	0.753	1.120	0.714	63.7	0.75	57.3	Tearout
9	0.746	1.536	1.13	63.7	0.75	71.25	Tearout
10	0.252	0.735	0.204	72.7	1	11.15	Tearout
11	0.25	1.281	0.75	72.7	1	23.05	Tearout
12	0.252	1.776	1.245	72.7	1	32.12	Tearout
13	0.251	2.800	2.269	72.7	1	40.79	Tearout
14	0.74	0.778	0.247	63.7	1	32.82	Tearout
15	0.744	1.285	0.754	63.7	1	63.4	Tearout
16	0.742	1.785	1.254	63.7	1	88.5	Tearout
17	0.743	0.814	0.283	62.4	1	36.25	Tearout
18	0.744	1.296	0.765	62.4	1	65.5	Tearout
19	0.743	1.767	1.236	62.4	1	90	Tearout
20	0.252	0.787	0.256	70.9	1	13.25	Tearout
21	0.25	1.297	0.766	70.9	1	23.8	Tearout
22	0.25	1.760	1.229	70.9	1	32.8	Tearout
23	0.252	2.795	2.264	70.9	1	42.25	Tearout
24	0.25	0.789	0.258	70.9	1	11.4	Tearout
25	0.25	1.192	0.786	70.9	0.75	22.75	Tearout
26	0.252	1.662	1.256	70.9	0.75	30.75	Tearout
27	0.252	1.904	1.498	70.9	0.75	33.95	Tearout
28	0.742	0.595	0.189	62.4	0.75	26.65	Tearout
29	0.744	0.873	0.467	62.4	0.75	44.9	Tearout
30	0.742	1.207	0.801	62.4	0.75	62.75	Tearout
31	0.742	1.417	1.011	62.4	0.75	74.1	Tearout
32	0.745	0.479	0.073	62.4	0.75	12.1	Tearout
33	0.251	0.646	0.302	70.9	0.625	11.3	Bearing
34	0.251	1.380	1.036	70.7	0.625	23.9	Bearing
35	0.251	2.095	1.751	70.7	0.625	28	Bearing
36	0.249	2.994	2.65	70.9	0.625	30.5	Bearing
37	0.25	2.902	2.496	70.7	0.75	32	Bearing
38	0.498	2.906	2.5	66.3	0.75	70	Bearing
39	0.5	2.946	2.54	70.5	0.75	69.5	Bearing
40	0.748	0.894	0.488	62.7	0.75	44.2	Bearing
41	0.742	1.124	0.718	62.7	0.75	56	Bearing
42	0.748	1.976	1.57	62.7	0.75	81.5	Bearing
43	0.74	2.323	1.917	62.7	0.75	90	Bearing
44	0.74	1.063	0.532	63.7	1	50.2	Bearing
45	0.745	1.273	0.742	63.7	1	60.2	Bearing
46	0.751	2.032	1.501	62.7	1	86.2	Bearing
47	0.745	3.069	2.538	63.7	1	103	Bearing
48	0.746	3.061	2.53	62.7	1	106.5	Bearing
33B	0.251	0.646	0.302	70.9	0.625	11.3	Tearout
34B	0.251	1.380	1.036	70.7	0.625	25.22	Tearout
35B	0.251	2.095	1.751	70.7	0.625	31.55	Tearout
36B	0.249	2.994	2.65	70.9	0.625	31.72	Tearout

Bearing failure in Table 11 means the bolt hole elongation reached 0.25-in. and the test was stopped. This definition of bearing failure is different from that used for the tests conducted at VT. The definition of bearing failure at 0.25-in. of hole elongation is based on the recommendation of Frank and Yura (1981).

4.1.3 Evaluation of Experimental Results

The following presents a discussion and comparison between the two sets of experimental results. The particular topics of discussion and comparison are based on conclusions made by Lewis (1994).

Lewis concluded that extreme deformations were required to cause tearout failure. The only test conducted at VT that failed by tearout was Test 2. Test 2 failed at a deformation of approximately 0.25-in. This deformation is not extreme; however, F_u was 100 ksi for steel used to fabricate Test 2. In addition, the percent elongation was only 18% which is low when compared to a more typical value of 30% for mild steel. These are the most likely reasons for the low deformation at tearout failure associated with Test 2. No other tests conducted at VT failed by tearout because the tests were ended at a hole elongation of 0.5-in. The eventual mode of failure for many of these tests would have been tearout if the tests were continued. Consequently, the tests conducted at VT do agree with the conclusion by Lewis.

Lewis concluded that increases in the clear end distance beyond 1.6-in. did not increase the strength of the test specimen significantly. The largest clear end distance associated with the tests conducted at VT which did not fail prematurely by plate curling was 1.5-in. Consequently, no agreement or disagreement with the conclusion by Lewis can be determined.

Lewis concluded if the upper limit for plate strength is set at the load when the bolt hole has reached 0.25-in. of elongation then the upper limit for the bearing stress for 5/8-in., 3/4-in., and 1-in.bolts was 3.0 F_u, 2.6 F_u, and 2.2 F_u respectively. Again, no agreement or disagreement with this conclusion can be made based on the tests conducted at VT because of the premature plate curling failures which occurred in the plates with large end distances. However, it is believed that the source of this conclusion is simply the fact that it takes more deformation for a larger bolt to come into full contact with the bolt hole which can be shown from simple geometry.

Lewis concluded that if the bolt holes were allowed to excessively elongate then there was an average increase in load capacity of 5% compared to the load capacity at a hole elongation of 0.25-in. The following conclusions were found for the tests conducted at VT. For tests fabricated from high strength steel the average increase in load capacity was 1.3% for an average increase in hole elongation of 21%. For tests fabricated from mild steel the average increase in load capacity was 3.4% for an average increase in hole elongation of 57%. These results tend to confirm the more basic conclusion that there is little to no load increase for a hole elongation beyond 0.25-in. However, the only tests included in this analysis are those that did not fail by plate curling which typically occurred at larger end distances. A comparison of tests 39 through 43 and test 48 conducted at VT shows that there is a trend for higher percentage increases in strength as the end distance becomes larger. Consequently, a general conclusion that the increase in load capacity for a hole elongation beyond 0.25-in. is small is probably unwarranted and probably ignores the behavior of larger bolts at large end distances.

4.2 Existing Prediction Models

All existing strength models treat bearing and tearout modes as one limit state. When the bolt is close to the end of the plate either a tearout failure will occur and as the bolt gets farther away from the end of the plate tearout only occurs after excessive bearing deformations (bearing failure) so an upper limit representing bearing failure is applied to each model.

The upper limit imposed on all the bearing/tearout prediction equations represents one of two things. First, it can represent a true upper limit on the bearing strength meaning that increases in the end distance do not result in increases in the strength. Second, it can represent a deformation limit imposed to keep joints from deforming excessively before the design strength is reached. It should be noted that none of the models explicitly account for splitting failures.

The most common strength model for predicting tearout failure was developed by Fisher and Struik (1974). They used a simple plate shearing model (as shown in Figure 16) to develop an equation for predicting the tearout strength of bolt.

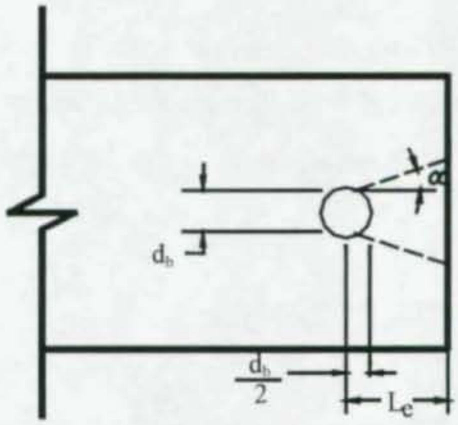

Figure 16 Bolt Tearout Model

The nominal strength R_n is assumed to be the strength developed by two shearing planes which radiate from the edges of the bolt to the end of the plate at an angle α. A lower bound on this strength is given by assuming α is zero and that the shear planes start at the point of the bolt hole closet to the end of the plate. With these assumptions the strength can be derived as follows

$$R_n = \tau_u^P \, 2t_p \left[L_e - \frac{d_b}{2} \right] \qquad \text{(Eq 22)}$$

Where

τ_u^P = Shear strength of the plate (assumed as 0.70 F_u)

Substituting and rearranging results in

$$R_n = 1.40 F_u d_b t_p \left[\frac{L_e}{d_b} - \frac{1}{2} \right] \qquad \text{(Eq 23)}$$

The bearing stress, F_b, is defined as the bearing tearout strength divided by the bearing area and is given as

$$F_b = \frac{R_n}{d_b t_p} = 1.4\,F_u\left(\frac{L_e}{d_b} - \frac{1}{2}\right) \leq 3.0\,F_u \qquad \text{(Eq 24)}$$

According to Fisher and Struik (1974) the upper limit of 3.0 F_u is associated with a change from a tearout failure mode to a failure mode associated with large bolt hole deformations. Although not explicitly stated, the data used for verifying Equation 26 did indicate that the upper limit of 3.0 F_u was also an upper limit on the bearing strength and that additional increases in end distance did not increase the strength.

In addition to Equation 24, Fisher and Struik (1974) also recommended a simpler expression.

$$F_b = F_u \frac{L_e}{d_b} \leq 3.0\,F_u \qquad \text{(Eq 25)}$$

Equation 25 was adopted by the AISC Specification (*Load and,* 1993). The specification states that for a single bolt in the line of force the bearing/tearout strength is given as

$$F_b = F_u \frac{L_e}{d_b} \leq 2.4\,F_u \qquad \text{(Eq 26)}$$

The only difference between Equation 25 and 26 is that the upper limit for bearing stress is 2.4 F_u rather than 3.0 F_u. The reduced upper limit was adopted to limit bearing deformations as suggested by Perry (1981); however, the specification does state that an upper limit of 3.0 F_u can be used instead for situations where bolt hole deformation is not a concern.

Recently, there has been a proposed change in the AISC Specification for Structural Joints Using ASTM A325 or A490 Bolts (Minutes, 1994). The proposed equation is based on the same development used by Fisher and Struik (1974) with two exceptions. First, rather than assuming the length of the shear plane is L_e - $d_b/2$ the length of the shear plane is assumed to be the clear distance (L_c) from the edge of the bolt hole to the end of the plate. Second, rather than assuming a shear strength of 0.7 F_u the shear strength is assumed as 0.6 F_u which is more consistent with all other shear failure models in the AISC Specification (*Load and*, 1993). The proposed expression is given as

$$F_b = 1.2F_u \frac{L_e}{d_b} \leq 2.4\, F_u \qquad \text{(Eq 27)}$$

Again, the upper limit of 2.4 F_u is applied to limit bolt hole deformations.

EC3 (1993) has a slightly different expression for the tearout strength.

$$F_b = 2.5\, \alpha\, F_u \qquad \text{(Eq 28)}$$

Where

α = minimum of

$L_e/3d_h$

F_{ub}/F_u

1

Considering that the bolt strength (for the most commonly used A325 and A490 grade bolts) is greater than all plate strengths that are allowed to be used in design under the AISC Specification (*Load and*, 1993), the second value for α can be ignored and the equation can be rewritten as

$$F_b = \frac{2.5}{3} F_u \frac{L_e}{d_h} \leq 2.5\, F_u \qquad \text{(Eq 29)}$$

4.3 Evaluation of Existing Models

This section evaluates the four strength models presented in Section 4.2 by comparing them to the experimental test data. Both statistical and graphical comparisons are made.

A statistical comparison of the strength models is presented in Table 12. The experimental strength R_{ult} is divided by the predicted value R_n. The average and coefficient of variation is given.

Table 12 Ratio of Test Strength To Predicted Strength

Model:	AISC (1993)	Fisher & Struik	Proposed	EC 3
Average	.998	1.155	1.446	1.227
COV	10%	25%	30%	12%

To make a graphical comparison of the models it is convenient to plot the test data and prediction models in terms of normalized bearing stress vs. L_e/d_b. Bearing stress was defined in Equation 26 and it is normalized by F_u for the steel.

It should be noted that AISC (1993) and the Fisher and Struik model can be plotted strictly as a function of the normalized variables. However, to plot the newly proposed model and the EC 3 model a couple of assumptions had to be made. First, so that the newly proposed model could be plotted an average d_b was assumed as 0.87-in.. This model is fairly insensitive to small changes in this value so using the average value seems justifiable. Second, so that the EC 3 model could be plotted an average value of L_e/d_b vs. L_e/d_h was determined as 0.93. Again, small variations in this ratio have little effect on the graphical results so using the average seems justifiable. The models along with the normalized data are presented in Figure 17.

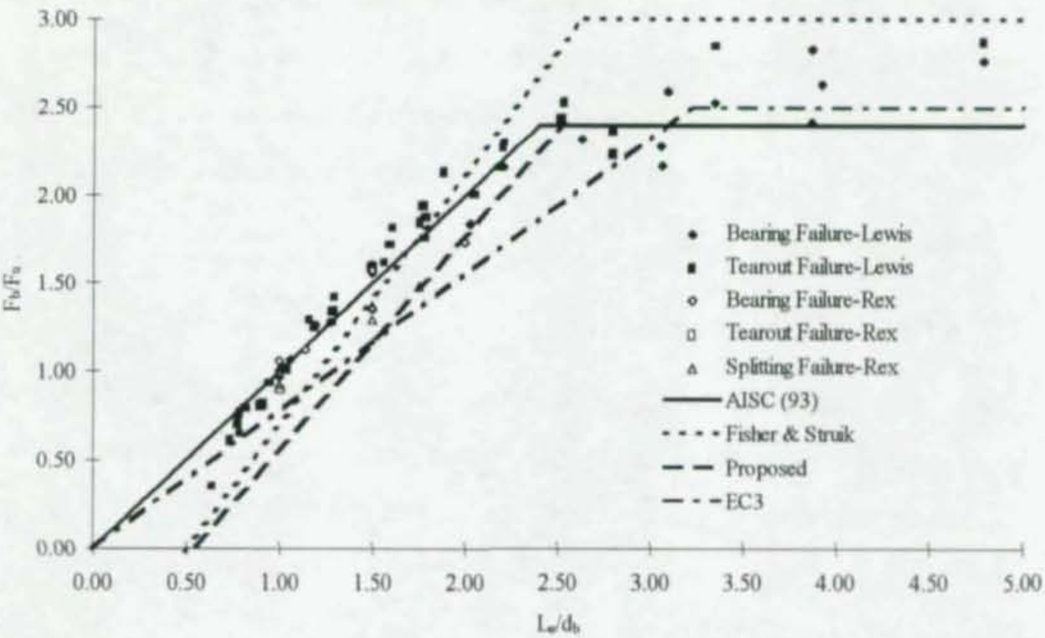

Figure 17 Normalized Bearing Stress Vs. Normalized End Distance

Review of both Table 12 and Figure 17 leads to the following observations:

- For L_e/d_b greater than 1 AISC (93) is the most accurate of all the models considered.
- At L_e/d_b of 0.5 the normalized strength predicted by AISC (93) and EC3 is approximately 0.5 while the strength predicted by the newly proposed model and Fisher and Struik is zero. The later strength is more appropriate because there would be only a sliver of steel between the edge of the bolt and the edge of the plate for this end distance. However, if the suggested edge distances given by the AISC Specification (*Load and,* 1993) are followed then the ratio of L_e/d_b would never be below a value of one which would preclude using erroneous strength values.
- Both EC3 and the proposed model are conservative and do not represent the basic trend in the experimental data.
- The Fisher and Struik model is conservative for low values of L_e/d_b (less than 2) and non-conservative for high values of L_e/d_b (greater than 2.5) and also does not represent the basic trend of the experimental data.

- Tests with low values of L_e/d_b and that failed by splitting agreed well with the AISC (1993) model. However, tests with higher values of L_e/d_b (approximately 1.5 and above) and failed by splitting had test strengths below the AISC (1993) model. It is questionable whether any of the current strength models properly predict splitting failure strengths.

4.4 Effect of Edge Condition

Plates and angles are typically either saw cut or sheared. The cut edge of a plate or angle that is saw cut is much squarer and smoother than when it is sheared. The sheared edge typically comes to a very sharp point and there are usually a number of small flaws along this edge. Sawed edges also have flaws but they usually smaller and not as severe as those found at sheared edges.

The steel between the bolt hole and the cut edge of the plate acts very much like a short deep beam. The bottom of this beam is the cut edge of the plate and in a typical loading configuration this edge is in high tension as a result of bending stresses. The small flaws along the cut edge of the plate tend to become stress risers. The increased stress at the tips of these flaws causes them to enlarge and eventually develop into a split in the steel that propagates toward the bolt hole.

The effect of the increased size and number of flaws associated with sheared edges compared to saw cut edges is not currently understood. Some of the experimental tests were designed to investigate this effect. Results of these tests are presented in Table 13.

Table 13 Effect of Edge Condition On Test Results

Test	L_e (in.)	t_p (in.)	F_u (ksi)	R_{ult} (Kips)	Δ @ R_{ult} (in.)	Edge Condition	Failure Mode
1	1	0.25	100	24.3	0.24	Saw	Bearing
2	1	0.25	100	22.3	0.25	Saw	Tearout
11	1	0.25	96.5	23.8	0.20	Sheared	Splitting
12	1	0.25	96.5	22.1	0.23	Sheared	Splitting
5	2	0.25	100	43.2	0.33	Saw	Bearing
6	2	0.25	100	45.6	0.27	Saw	Curling
13	2	0.25	96.5	41.4	0.19	Sheared	Curling
14	2	0.25	96.5	42.9	0.18	Sheared	Curling
29	1.5	0.375	63.7	32.5	0.16	Sheared	Splitting
30	1.5	0.375	63.7	30.7	0.22	Sheared	Splitting
39	1.5	0.25	65.5	25.5	0.51	Saw	Bearing
40	1.5	0.25	65.5	25.9	0.51	Saw	Bearing
41	1.5	0.25	65.5	27.7	0.50	Saw	Bearing
37	1.75	0.375	63.9	35.4	0.21	Sheared	Splitting

Two general observations are made based on Table 3.

- Of the tests shown in Table 10 all splitting failures were associated with sheared edges. Although this statistic is not included in Table 10, these splitting failures stared at an average deformation of 0.086-in. It should be noted that Test 3 which had a saw cut edge did fail by splitting but only after developing over 0.46-in. of deformation.
- All tests with sheared edges reached their maximum load at deformations less than 0.25-in.

The following are more specific observations based on comparisons of tests with similar test parameters.

- Tests 1, 2, 11, and 12 were fabricated from high strength steel and had 1-in. end distances. A comparison within this group of tests shows little difference between R_{ult} and only a slight decrease in the deformation at R_{ult} associated with the tests that had sheared edges.
- Tests 5, 6, 12, and 13 were fabricated from high strength steel and had 2-in. end distances. A comparison within this group of tests shows a reduction in both R_{ult} and

the deformation at Rult for the tests with sheared edges. However, this observation is not conclusive because tests 6, 12, and 13 failed by curling rather than by bearing or splitting.

- Tests 29 and 30 were fabricated from mild steel and had a 1.5-in end distance. There are no directly comparable tests; however, tests 39-41 differed only by plate thickness. A comparison between these two sets of tests can be made by dividing R_{ult} by t_p and F_u. A comparison of the resulting values shows a reduction in load capacity and a severe reduction (approximately 60%) in the deformation at maximum load. However, this observation is also not conclusive because of the differing plate thickness.

Unfortunately, no solid conclusions about the effect of edge condition on the strength and load-deformation behavior can be made at this time. However, it is believed that additional testing would provide the following conclusions.

- If the plate edges are shear cut rather than saw cut there is a much higher probability that splitting failure will occur.
- The effect of edge condition is negligible at short end distances. This is essentially because the load that will cause a splitting failure and the load that will cause a bearing or tearout failure will be similar for short edge distances.
- As the end distance is increased the effect of the edge condition becomes more pronounced and the full bearing or tearout strength cannot be developed because a splitting failure will develop first. In addition, the deformation at failure will be reduced and there will be no plastic plateau of the load-deformation curve.
- Once the end distance becomes large the effect of edge condition will again become negligible because of the small bending stresses induced along the edge of the plate.

4.5 Summary

Experimental strength values from two independent testing programs were summarized. Four existing strength models were also summarized and discussed. Based on a comparison of existing strength models to the experimental data, the model given in the AISC Specification (*Load and,* 1993) best represents the experimental strength values.

Although not conclusive at this time, shearing rather than sawing plates does appear to have a negative effect on the nominal strength. Existing models do not account for this effect nor do they account for splitting failure strengths. Consequently, until further research can be done it is recommended that critical edges of plates be sawed rather than sheared.

5. Richard Equation Parameters

While analytical models for determining the initial stiffness and the nominal load capacity of a single plate bearing on a single bolt have been determined, the relationship between these quantities and the four parameters that define the Richard Equation are still not known. To determine these relationships an analysis of the experimental load-deformation data was performed.

The data from each test that failed by bearing, tearout, or splitting was normalized by the maximum load for the test. Each set of data was then plotted against each other to determine if there were any noticeable differences in the basic shape of the load-deformation behavior. Any differences were then evaluated against the plate and bolt parameters to determine if there were consistent parametric relationships. Three such relationships were determined.

The first relationship determined was that as the end distance increased the load-deformation behavior softened. As illustrated in Figure 18 this trend is very subtle but can be seen by comparing Tests 1 through 5.

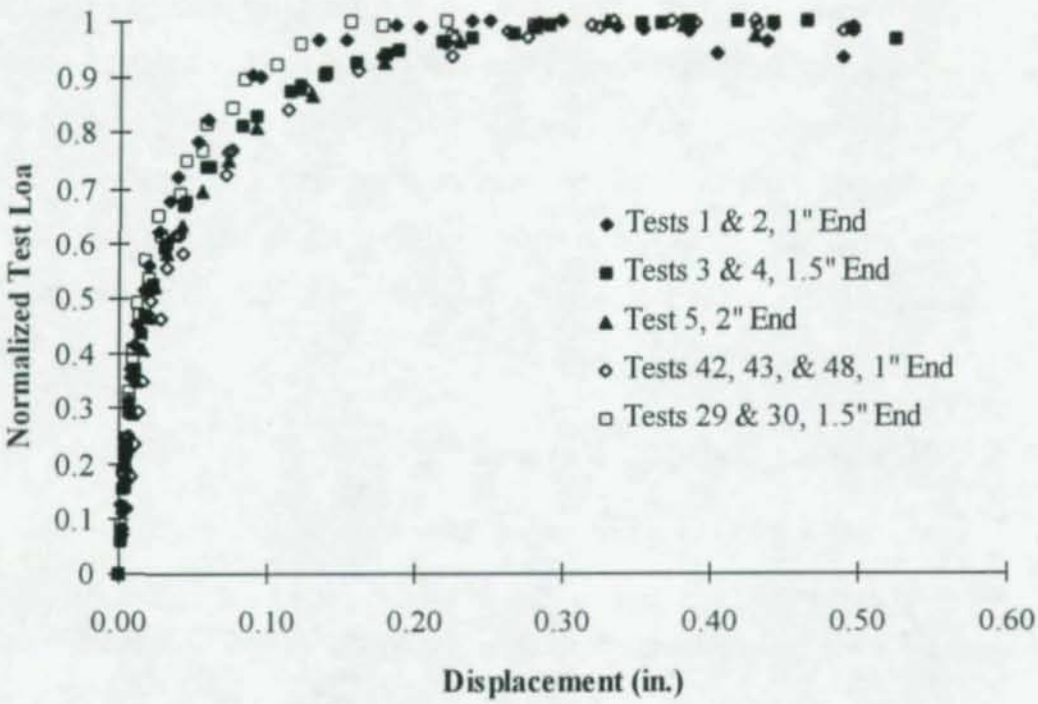

Figure 18 Effect of End Distance on Load-Deformation Behavior

Increased bearing deformation is believed to be the primary cause of the softening effect. As the end distance increases the load capacity increases until the maximum bearing capacity is reached. However, as the end distance increases the bearing deformation associated with a given load does not decrease. Consequently, when the test data with larger end distances is normalized it appears softer than the test data with shorter end distances. For example, if 12 kips is 50% of the load capacity for a 1-in. end distance then it would only be 25% of the load capacity for a 2-in. end distance however the bearing deformations would remain the same.

A variety of methods to normalize the displacement were considered in an attempt to eliminate this softening effect. The method that was finally chosen was to normalize the displacement by the ratio of the load capacity over the initial stiffness. The resulting normalized load-deformation behavior is much more consistent and is plotted in Figure 19.

Once the effect of end distance was removed a second trend was noticed in the load-deformation behavior. The normalized load-deformation behavior for the tests that were fabricated from the higher strength steel was stiffer compared to similar tests fabricated from mild steel. This relationship can be seen by comparing Tests 1 and 2 to Tests 42, 43, and 48 in Figure 19.

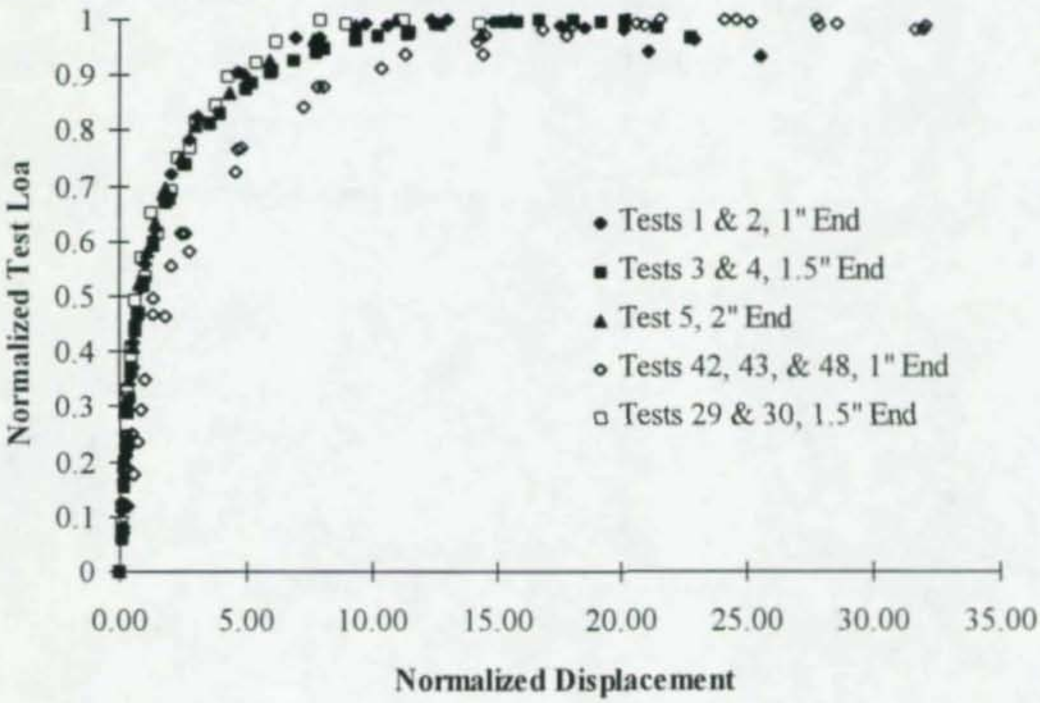

Figure 19 Effect of Steel Ductility

The cause of the difference in the load-deformation behavior between the two steels is the difference in the stress-strain behaviors for the two steels. Higher strength steels tend to reach the ultimate stress at lower strains compared to lower strength steels. A good measure of this relationship is the percent elongation of the steel. The high strength steel used in the experimental investigation had an average percent elongation of 16% while the mild steel had a percent elongation of around 30%. The difference in percent elongation is the reason for the softer behavior associated with the mild steel compared to the high strength steel. This effect can be removed by multiplying the deformations by the ratio of the percent elongation. Because mild steel is more commonly used it was decided to normalize the percent elongation with respect to mild steel. The ratio of the two percent elongation's is then 1.875. The load-deformation data for the high strength steels was multiplied by this factor. The resulting load-deformation behaviors are plotted in Figure 20.

After the effect of end distance and the effect of steel behavior had been removed the third trend in the load-deformation behavior was seen. The load-deformation data for all the tests except 29, 30, and 37 laid right on top of each other as shown in Figure 20.

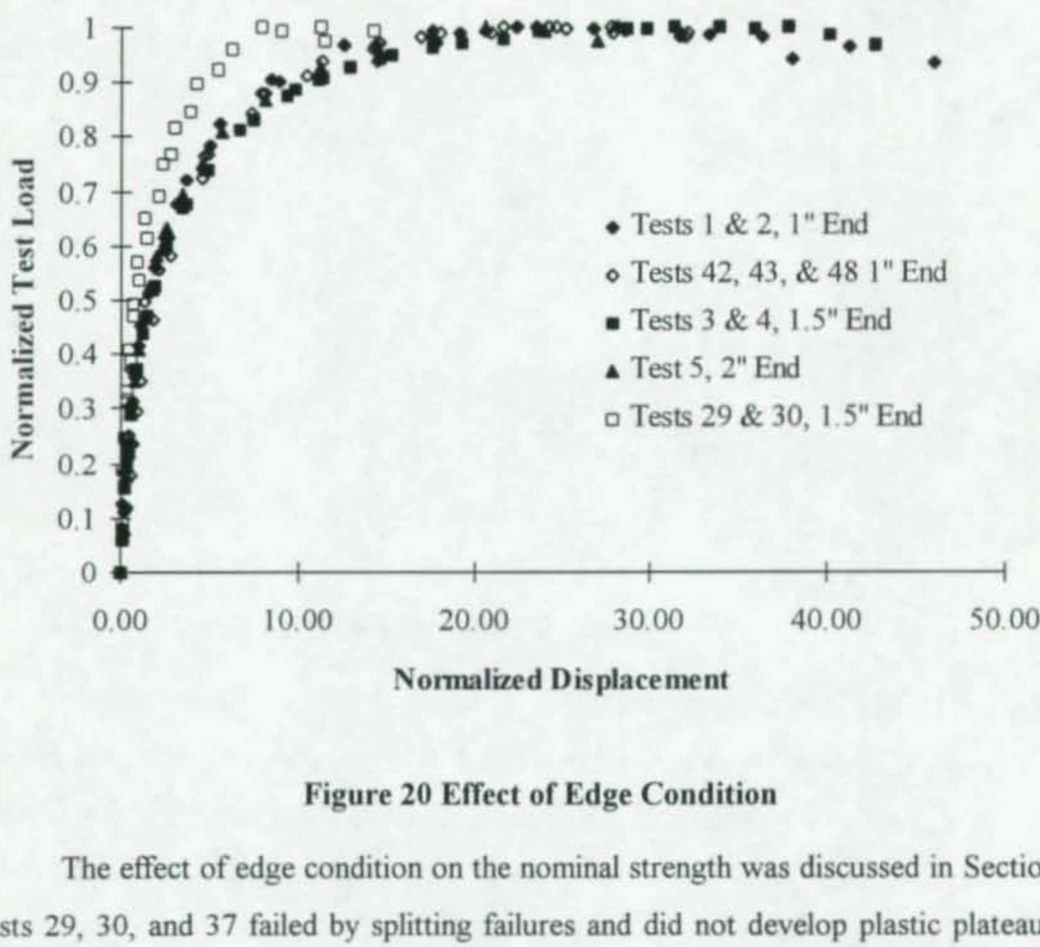

Figure 20 Effect of Edge Condition

The effect of edge condition on the nominal strength was discussed in Section 4.4. Tests 29, 30, and 37 failed by splitting failures and did not develop plastic plateaus that were typical for other tests. Each of these tests had sheared edges. If the splitting failure had not occurred, it is believed that all three of these tests would have developed higher loads and plastic plateaus. Because these tests were normalized by the individual maximum test loads they appear stiffer than the tests that developed the full bearing or tearout strength. To correct this Tests 29, 30 and 37 were re-normalized by the their respective nominal strength determined using the AISC Specification (*Load and,* 1993) strength prediction model. The resulting behavior is still slightly stiffer but much more in line with the other tests as illustrated in Figure 21.

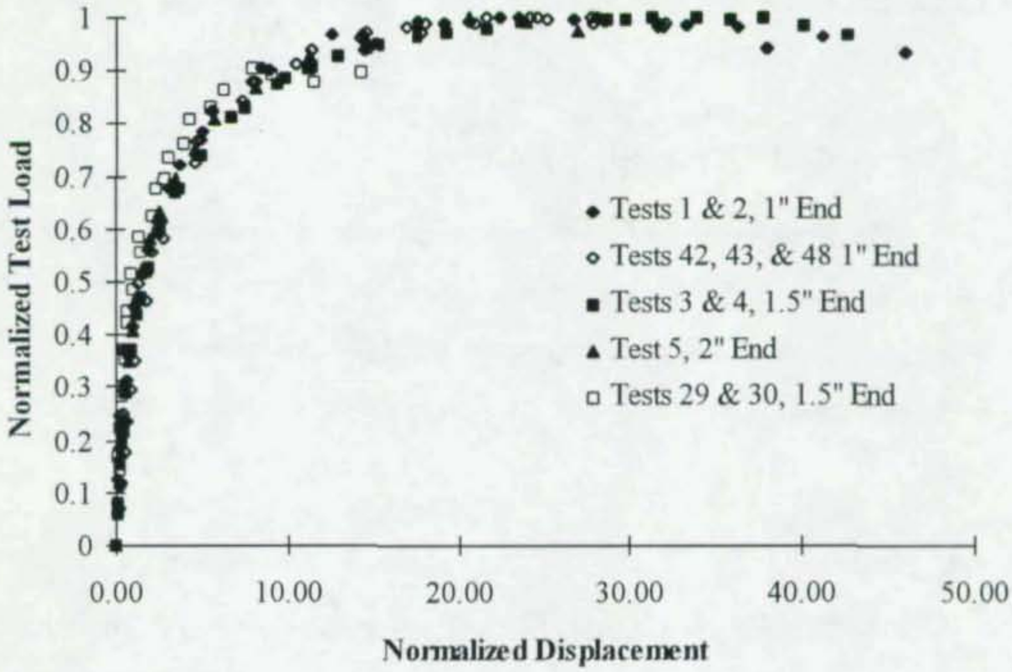

Figure 21 All Parameter Effects Removed

After all the parameter effects were removed from the normalized load-deformation data non-linear regression was used to determine appropriate values of the parameters for the Richard Equation. The non-linear regression was done using the program Sigma Plot. The resulting values are given as

$K = 1.731$

$K_p = -0.009$

$R_o = 1.74$

$n = 0.5$

By determining the load normalizing factor and the deformation normalizing factor these four parameters can be used to approximate the load-deformation behavior of the single plate bearing against the single bolt. In the above analysis the load-normalizing factor was the maximum tests load (except for Tests 29, 20, and 37). The maximum test load is approximated by the nominal strength determined in Section 4. The deformation normalizing factor was the nominal strength divided by the initial stiffness and the ratio of the percent elongations.

6. Proposed Behavior Model

The key pieces required to approximate the load-deformation behavior of a single plate bearing against a single bolt were developed in Sections 3, 4, and 5. The following section relates these key pieces and summarizes a complete method for approximating the load-deformation behavior. This method is then evaluated against the experimental results.

6.1 Model

The Richard Equation will be used to approximate the load-deformation behavior. In Section 5 normalized values for the four parameters that define the Richard Equation were determined. Substituting these values into the Richard Equation results in

$$\frac{R}{R_n} = \frac{1.74\,\overline{\Delta}}{\left(1 + \overline{\Delta}^{0.5}\right)^2} - 0.009\,\overline{\Delta} \qquad \text{(Eq 30)}$$

Where

R = Plate load

R_n = Nominal strength = $L_e\, t_p\, F_u \leq 2.4\, d_b\, t_p\, F_u$ (*Load and,* 1993)

$\overline{\Delta}$ = Normalized deformation = $\Delta\, \beta\, K_i/R_n$

Δ = Hole elongation

β = Steel correction factor = 30% / %Elongation (for typical steels taken as 1)

K_i = Initial stiffness given by

$$K_i = \cfrac{1}{\cfrac{1}{K_{br}} + \cfrac{1}{K_b} + \cfrac{1}{K_v}}$$

Where

K_{br} = Bearing stiffness = $120\ F_y\ t_p\ d_b^{0.8}$ (units are kips and inches)

K_b = Bending stiffness = $32\ E\ t_p\ (L_e/d_b - 0.5)^3$

K_v = Shearing stiffness = $6.67\ G\ t_p\ (L_e/d_b - 0.5)$

6.2 Evaluation of Model

The proposed model was used to determine load-deformation behavior for all the experimental tests described in Section 2. These predicted responses are plotted along with the experimental load-deformation data for each test summary included in Appendix D. Visual comparisons of the test data to the predicted behavior shows good correlation with tests that did not fail by curling. A more quantitative evaluation was also performed.

The load for each experimental load-deformation point was calculated using the predicted behavior. This was done for each test that did not fail by curling. Tests that only had two or three data points were also excluded. The ratio of the test load over the predicted load was then determined. The results are presented in Table 14.

Table 14 Ratio of Test Load Over Model Load

Statistic	High Strength	Mild	Combined	Tests 42, 43, 48
Average	0.88	1.06	1.006	1.02
COV	12%	19%	19%	19%
No. of Points	129	323	452	48

The results are broken into three categories: the ratio for the high strength steel specimens, mild steel specimens, and all the specimens combined. In addition, for comparison purposes, non-linear regression was used to determine the best coefficients of the Richard Equation for the test data of Tests 42, 43, and 48. These tests had identical parameters. The comparison of the resulting best fit Richard Equation load values to the test load values is included in Table 14. As can be seen in Table 14, the variation associated with the model compared to the test data is the same as the variation associated with three identical tests. Overall, this evaluation indicates an excellent correlation between test and predicted values.

7. Summary, Conclusions, and Recommendations

7.1 Summary

The objective of this study was to develop a method for approximating the load-deformation behavior of a single plate bearing against a single bolt. This behavior has a significant influence on the behavior of single bolt lap plate connection. The lap plate connection load-deformation behavior is believed to be a good approximation to the load-deformation behavior of bolts in full steel connections. This behavior is needed to evaluate the moment-rotation behavior of steel and composite partially restrained connections.

A combination of experimental and finite element results were used to develop and / or verify analytical models that predict the initial stiffness and nominal strength associated with the single plate single bolt load-deformation behavior. A qualitative analysis of the basic shape of the load-deformation behavior was conducted to determine appropriate relationships between the initial stiffness, nominal strength, steel behavior, and the four parameters required to define the Richard Equation. Normalized values for the Richard Equation parameters were then determined.

The complete proposed method for approximating the load-deformation behavior of a single plate bearing against a single bolt was summarized in Section 6.1. Evaluation of the proposed method showed good agreement with the experimental test data.

7.2 Conclusions

- The model for plate bearing stiffness given in EC 3 Annex J (1994) under predicted both experimental and finite element initial stiffness values by 15% and 48% respectively on average.

- The proposed initial stiffness model over predicted the experimental values by 12% on average and under predicted the finite element values by 2% on average.
- Based on the finite element results the initial plate stiffness is linearly related to F_y and not F_u.
- There are four basic failure modes associated with single plates bearing on single bolts. These include bearing, tearout, splitting, and curling.
- Curling failures resulted in test strengths much lower than predicted and in general should be avoided.
- Large deformations are required to develop tearout failures in mild steel. This conclusion was also given by Lewis (1994).
- Shearing plates greatly increases the chance of splitting failure occurring rather than tearout or bearing failures.
- The current strength model given in the AISC Specification (*Load and*, 1993) is based on a physical model for the tearout failure with an upper limit imposed for the bearing failure. The specification model does an excellent job of predicting the strength associated with these two failure modes.
- At small end distances the strength associated with splitting failure is similar to the strength associated with tearout failure. Consequently, the AISC Specification (*Load and*, 1993) strength model also does a good job of predicting the strength associated with splitting failures when the end distance is small.
- At larger end distances the strength associated with splitting failures appears to be less than that associated with tearout failures. Consequently, the AISC Specification (*Load and*, 1993) strength model also does not do a good job of predicting the strength associated with splitting failures when the end distance is larger.
- Changing the plate width between 3.5 and 5.4-in. had no effect on the initial stiffness of the test specimens and had an inconclusive effect on the load capacity because of curling failures.

7.3 Recommendations

- Strength models for curling and splitting failure modes are currently not available. Curling failures are not generally seen in typical connections. Consequently, there is probably little need for a strength equation for curling failure. Splitting failures are seen in typical connections and more work needs done to develop a better understanding and a strength model for splitting failures. The effect of shearing plates rather than saw cutting plates should also be considered with respect to the splitting failures.
- The load-deformation behavior for a wider range of parameters should be investigated. An improved test setup needs to be developed that allow thicker plates and smaller bolt diameters to be tested to failure. In addition, bolt hole types other than standard holes should be considered.
- The larger goal of this research is to determine the load-deformation behavior of bolts in full steel connections. Ideally, there would be a direct relationship between plate width and bolt spacing in the connection. A series of simple tests could be devised to determine if there is a direct relationship between these two parameters.

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Appendix A

Material Properties

The tensile test results from tensile coupons of the plates used in the experimental work are presented in Table A-1. The coupon designation is used in the data packs to relate the plate used in the test to a tensile coupon. The first part of the designation is the plate number and the second part is the coupon number for that plate. There were typically two coupons from each plate.

Table A-1 Steel Properties

Coupon	Width (in.)	Thickness (in.)	Elongation	Fy (ksi)	Average	Fu (ksi)	Average
1-1	1.510	0.251	31%	45.0	45.5	65.0	65.0
1-2	1.500	0.251	31%	46.0		65.0	
2-1	1.510	0.250	30%	46.0	45.8	65.5	65.5
2-2	1.510	0.250	31%	45.5		65.5	
3-1	1.500	0.625	29%	44.0	44.5	67.0	67.5
3-2	1.500	0.625	30%	45.0		68.0	
5-1	1.500	0.995	30%	43.9	43.5	70.0	70.0
5-2	1.500	0.996	29%	43.0		70.0	
6-1	1.490	0.998	30%	43.0	43.5	67.0	67.0
6-2	1.490	0.999	31%	44.0		67.0	
7-1	1.500	0.750	29%	45.0	45.0	67.0	67.0
7-2	1.500	0.750	30%	45.0		67.0	
8-1	1.500	0.750	31%	45.0	45.0	68.0	68.0
8-2	1.500	0.750	30%	45.0		68.0	
9-1	1.500	0.750	29%	45.5	45.8	69.0	69.0
9-2	1.500	0.750	30%	46.0		69.0	
10-1	1.500	0.375	32%	51.0	51.0	74.0	74.0
10-2	1.500	0.375	31%	51.0		74.0	
11-1	1.500	0.500	29%	52.5	53.3	74.5	74.8
11-2	1.500	0.500	30%	54.0		75.0	
12-1	1.500	0.500	31%	51.0	51.5	74.5	74.5
12-2	1.500	0.500	30%	52.0		74.5	
13-1	1.500	0.625	29%	47.0	46.8	70.0	70.0
13-2	1.500	0.625	31%	46.5		70.0	
15-1	1.490	0.121	32%	42.8	43.3	60.9	61.4
15-2	1.490	0.120	31%	43.8		61.8	
16-1	1.498	0.121	29%	42.6	42.9	60.7	61.1
16-2	1.497	0.119	29%	43.1		61.5	
17-1	1.497	0.120	29%	44.5	44.2	62.0	62.0
17-2	1.500	0.120	32%	43.8		62.0	
18-1	1.500	0.249	29%	47.8	47.5	66.9	66.7
18-2	1.490	0.248	29%	47.2		66.5	
19-1	1.500	0.246	29%	47.1	46.9	66.8	66.6
19-2	1.500	0.249	29%	46.7		66.4	
20-1	1.497	0.248	28%	45.9	46.1	66.4	66.2
20-2	1.498	0.250	31%	46.3		65.9	
21-1	1.490	0.367	29%	43.7	43.4	63.7	63.7
21-2	1.499	0.370	29%	43.1		63.6	
22-1	1.490	0.367	30%	44.3	43.4	63.8	63.9
22-2	1.490	0.370	29%	42.5		63.9	
23-1	1.500	0.367	29%	44.1	43.9	63.8	63.8
23-2	1.490	0.370	29%	43.6		63.8	
24-1	1.500	0.369	29%	42.9	43.3	63.7	63.7
24-2	1.500	0.367	29%	43.7		63.6	
25-1	1.500	0.371	30%	43.3	43.7	63.7	63.7
25-2	1.500	0.368	30%	44.1		63.7	

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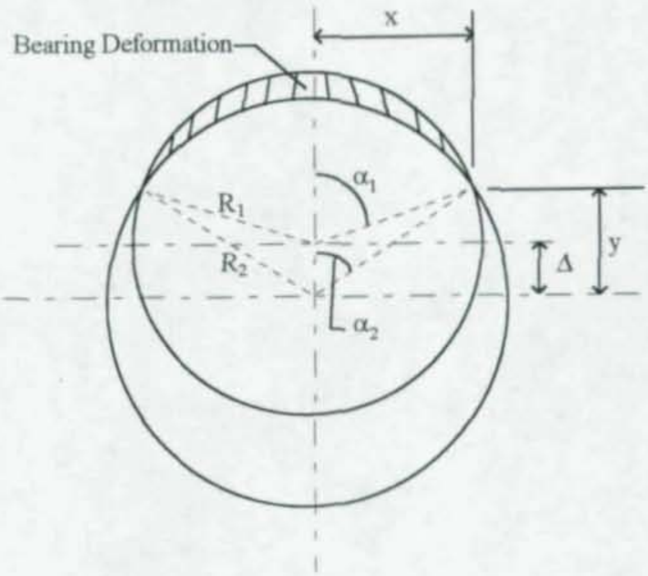
Table A-1 Steel Properties (Cont.)

Coupon	Width (in.)	Thickness (in.)	Elongation	Fy (ksi)	Average	Fu (ksi)	Average
26-1	1.490	0.500	31%	43.3	43.9	64.3	64.4
26-2	1.490	0.500	30%	44.5		64.4	
27-1	1.500	0.624	30%	45.0	44.9	68.4	68.1
27-2	1.500	0.622	29%	44.7		67.8	
27a-1	1.500	0.627	30%	45.1	45.4	68.5	68.4
27a-2	1.500	0.623	29%	45.7		68.3	
28-1	1.500	0.749	29%	44.7	44.8	68.9	69.0
28-2	1.500	0.750	31%	44.9		69.1	
29-1	1.500	0.750	29%	44.8	44.7	71.9	70.4
29-2	1.500	0.749	30%	44.5		68.9	
30-1	1.500	0.997	30%	40.1	40.4	66.3	66.4
30-2	1.500	0.998	32%	40.6		66.4	
31-1	1.500	1.000	32%	41.8	42.2	67.9	67.8
31-2	1.500	1.000	31%	42.5		67.7	
32-1	1.500	1.000	30%	41.1	41.5	67.4	67.6
32-2	1.500	1.000	31%	41.8		67.7	
33-1	1.500	0.491	28%	52.9	53.3	73.8	74.0
33-2	1.500	0.491	28%	53.7		74.1	
34-1	1.500	0.493	29%	51.4	51.8	73.3	73.9
34-2	1.500	0.493	28%	52.2		74.4	
35-1	1.500	0.486	27%	52.9	52.7	73.8	73.6
35-2	1.500	0.486	28%	52.4		73.4	
40-1	1.500	0.246	31%	47.9	47.9	66.6	67.0
40-2	1.500	0.246	30%	47.9		67.3	
41-1	1.500	0.247	31%	47.6	47.8	65.9	68.3
41-2	1.500	0.248	31%	47.9		70.6	
42-1	1.500	0.496	30%	47.1	46.8	71.1	70.8
42-2	1.500	0.495	29%	46.5		70.5	
43-1	1.500	0.627	31%	44.2	43.7	64.0	63.3
43-2	1.500	0.625	31%	43.2		62.6	
44-1	1.500	0.748	30%	44.2	44.5	67.7	67.8
44-2	1.500	0.742	31%	44.7		67.8	
45-1	1.490	0.248	18%	60.0	60.0	100.0	100.0
45-2	1.493	0.248	18%	60.0		100.0	
46-1	1.504	0.249	19%	60.0	56.5	97.0	95.0
46-2	1.500	0.250	20%	53.0		93.0	
47-1	1.496	0.248	19%	58.0	59.0	98.0	96.5
47-2	1.497	0.248	11%	60.0		95.0	
48-1	1.475	0.249	10%	74.0	73.5	111.0	109.0
48-2	1.491	0.249	15%	73.0		107.0	
50a	1.501	0.493	30%	44.8	45.1	67.1	67.5
50b	1.501	0.498	30%	45.5		67.8	
51a	1.499	0.246	28%	44.9	44.5	65.4	65.5
51b	1.500	0.246	29%	44.1		65.5	

Appendix B

Derivations

Derivation of Angle α



$$R_1 \operatorname{Sin} \alpha_1 - R_2 \operatorname{Sin} \alpha_2 = 0$$

$$-R_1 \operatorname{Cos} \alpha_1 + R_2 \operatorname{Cos} \alpha_2 = \Delta$$

$$R_2^2 = x^2 + y^2$$

$$R_1^2 = x_2 + (y - \Delta)^2$$

$$R_2^2 - R_1^2 = 2\,\Delta\, y - \Delta^2$$

$$2\,\Delta\, y = R_2^2 - R_1^2 + \Delta^2$$

$$y = \frac{R_2^2 - R_1^2 + \Delta^2}{2\,\Delta}$$

$$y - \Delta = \frac{R_2^2 - R_1^2 - \Delta^2}{2\,\Delta} = R_1 \operatorname{Cos} \alpha_1$$

$$\alpha_1 = \operatorname{Cos}^{-1}\left[\frac{R_2^2 - R_1^2 - \Delta^2}{2\,\Delta\, R_1}\right]$$

Derivation of Bending Stiffness

For a fixed end uniformly loaded beam with length L and height h the equation for the real and virtual moments at any point x along the beam are given by

$$M(x) = \frac{wLx}{2} - \frac{wL^2}{12} - \frac{wx^2}{2}$$

$$m(x) = x/2 - L/8$$

The virtual moment is based on a unit load placed at the center of the beam. Using the principle of virtual work the deflection at the center of the beam caused by bending is given by

$$\delta = \frac{2}{EI}\int_0^{\frac{L}{2}}\left(\frac{wLx}{2} - \frac{wL^2}{12} - \frac{wx^2}{2}\right)\left(\frac{x}{2} - \frac{L}{8}\right)dx$$

Carrying out the integration yields the well know deflection equation given as

$$\delta = \frac{w\,L^4}{384\,E\,I}$$

Substituting

$$w = P/L$$

$$I = t_p\,h^3 / 12$$

Yields

$$\delta = \frac{P}{32\,E\,t_p}\left(\frac{L}{h}\right)^3$$

This can be rearranged to give the stiffness as

$$K_b = 32\,E\,t_p\,(h/L)^3$$

Derivation of Shearing Stiffness

For a fixed end uniformly loaded beam with length L and height h the equation for the real and virtual moments at any point x along the beam are given by

$$V(x) = wL/2 - wx$$

$$v(x) = \tfrac{1}{2}$$

The virtual shear is based on a unit load placed at the center of the beam. Using the principle of virtual work the deflection at the center of the beam caused by shear is given by

$$\delta = \frac{2\,k}{GA}\int_0^{\frac{L}{2}}\left(\frac{wL}{2} - wx\right)\left(\frac{1}{2}\right)dx$$

Carrying out the integration yields the well know deflection equation given as

$$\delta = \frac{k}{GA}\,\frac{wL^2}{8}$$

Substituting

$k = 1.2$ for rectangular section (Boresi et al 1993)

$$w = P/L$$

$$A = t_p\,h$$

Yields

$$\delta = \frac{1.2\,P}{8\,G\,t_p}\left(\frac{L}{h}\right)$$

This can be rearranged to give the stiffness as

$$K_v = 6.67\,G\,t_p\,(h/L)$$

Appendix C

Finite Element Model Results

Table C-1 Finite Element Model Results

Model	db (in.)	tp (in.)	Le (in.)	Plate Width (in.)	Fy (ksi)	Fu (ksi)	Ki (k/in.)
D6T1E1W9	0.75	0.125	1	6	45	70	518
D6T2E1W9	0.75	0.25	1	6	45	70	1051
D6T3E1W9	0.75	0.375	1	6	45	70	1568
D6T4E1W9	0.75	0.5	1	6	45	70	2193
D6T5E1W9	0.75	0.625	1	6	45	70	2493
D6T6E1W9	0.75	0.75	1	6	45	70	3106
D6T7E1W9	0.75	0.875	1	6	45	70	3712
D6T8E1W9	0.75	1	1	6	45	70	4296
D7T1E1W9	0.875	0.125	1	6	45	70	549
D7T2E1W9	0.875	0.25	1	6	45	70	1084
D7T3E1W9	0.875	0.375	1	6	45	70	1717
D7T4E1W9	0.875	0.5	1	6	45	70	2363
D7T5E1W9	0.875	0.625	1	6	45	70	3015
D7T6E1W9	0.875	0.75	1	6	45	70	3418
D7T7E1W9	0.875	0.875	1	6	45	70	4020
D7T8E1W9	0.875	1	1	6	45	70	4465
D8T1E1W9	1	0.125	1	6	45	70	570
D8T2E1W9	1	0.25	1	6	45	70	1098
D8T3E1W9	1	0.375	1	6	45	70	1640
D8T4E1W9	1	0.5	1	6	45	70	2193
D8T5E1W9	1	0.625	1	6	45	70	2812
D8T6E1W9	1	0.75	1	6	45	70	3392
D8T7E1W9	1	0.875	1	6	45	70	3750
D8T8E1W9	1	1	1	6	45	70	4287
D6T1E3W9	0.75	0.125	1.5	6	45	70	536
D6T2E3W9	0.75	0.25	1.5	6	45	70	1038
D6T3E3W9	0.75	0.375	1.5	6	45	70	1638
D6T4E3W9	0.75	0.5	1.5	6	45	70	2311
D6T5E3W9	0.75	0.625	1.5	6	45	70	2634
D6T6E3W9	0.75	0.75	1.5	6	45	70	3280
D6T7E3W9	0.75	0.875	1.5	6	45	70	3816
D6T8E3W9	0.75	1	1.5	6	45	70	4441
D7T1E3W9	0.875	0.125	1.5	6	45	70	604
D7T2E3W9	0.875	0.25	1.5	6	45	70	1152
D7T3E3W9	0.875	0.375	1.5	6	45	70	1831
D7T4E3W9	0.875	0.5	1.5	6	45	70	2548
D7T5E3W9	0.875	0.625	1.5	6	45	70	3344
D7T6E3W9	0.875	0.75	1.5	6	45	70	3611
D7T7E3W9	0.875	0.875	1.5	6	45	70	4343
D7T8E3W9	0.875	1	1.5	6	45	70	4900
D8T1E3W9	1	0.125	1.5	6	45	70	667
D8T2E3W9	1	0.25	1.5	6	45	70	1265
D8T3E3W9	1	0.375	1.5	6	45	70	1946
D8T4E3W9	1	0.5	1.5	6	45	70	2681
D8T5E3W9	1	0.625	1.5	6	45	70	3490
D8T6E3W9	1	0.75	1.5	6	45	70	4352
D8T7E3W9	1	0.875	1.5	6	45	70	4607
D8T8E3W9	1	1	1.5	6	45	70	5317

Table C-1 Finite Element Model Results (cont.)

Model	db (in.)	tp (in.)	Le (in.)	Plate Width (in.)	Fy (ksi)	Fu (ksi)	Ki (k/in.)
D6T2E2W9	0.75	0.25	1.25	6	45	70	1041
D6T2E4W9	0.75	0.25	1.75	6	45	70	1034
D6T2E5W9	0.75	0.25	2	6	45	70	1033
D6T2E6W9	0.75	0.25	2.25	6	45	70	1029
D6T2E7W9	0.75	0.25	2.5	6	45	70	1027
D6T2E8W9	0.75	0.25	2.75	6	45	70	1024
D6T2E9W9	0.75	0.25	3	6	45	70	1024
D6T4E2W9	0.75	0.5	1.25	6	45	70	2307
D6T4E4W9	0.75	0.5	1.75	6	45	70	2304
D6T4E5W9	0.75	0.5	2	6	45	70	2298
D6T4E6W9	0.75	0.5	2.25	6	45	70	2292
D6T4E7W9	0.75	0.5	2.5	6	45	70	2286
D7T2E2W9	0.875	0.25	1.25	6	45	70	1109
D7T2E4W9	0.875	0.25	1.75	6	45	70	1151
D7T2E5W9	0.875	0.25	2	6	45	70	1150
D7T2E6W9	0.875	0.25	2.25	6	45	70	1147
D7T2E7W9	0.875	0.25	2.5	6	45	70	1145
D7T4E2W9	0.875	0.5	1.25	6	45	70	2467
D7T4E4W9	0.875	0.5	1.75	6	45	70	2565
D7T4E5W9	0.875	0.5	2	6	45	70	2568
D7T4E6W9	0.875	0.5	2.25	6	45	70	2564
D7T4E7W9	0.875	0.5	2.5	6	45	70	2560
D8T2E2W9	1	0.25	1.25	6	45	70	1223
D8T2E4W9	1	0.25	1.75	6	45	70	1280
D8T2E5W9	1	0.25	2	6	45	70	1286
D8T2E6W9	1	0.25	2.25	6	45	70	1287
D8T2E7W9	1	0.25	2.5	6	45	70	1287
D8T4E2W9	1	0.5	1.25	6	45	70	2637
D8T4E4W9	1	0.5	1.75	6	45	70	2754
D8T4E5W9	1	0.5	2	6	45	70	2760
D8T4E6W9	1	0.5	2.25	6	45	70	2776
D8T4E7W9	1	0.5	2.5	6	45	70	2779
D6T2E1F5	0.75	0.25	1	6	50	70	1151
D6T2E1F6	0.75	0.25	1	6	55	70	1246
D6T2E1F7	0.75	0.25	1	6	60	70	1335
D6T2E3F5	0.75	0.25	1.5	6	50	70	1159
D6T2E3F6	0.75	0.25	1.5	6	55	70	1274
D6T2E3F7	0.75	0.25	1.5	6	60	70	1376
D6T2E5F5	0.75	0.25	2	6	50	70	1150
D6T2E5F6	0.75	0.25	2	6	55	70	1272
D6T2E5F7	0.75	0.25	2	6	60	70	1386
D7T2E1F5	0.875	0.25	1	6	50	70	1203
D7T2E1F6	0.875	0.25	1	6	55	70	1293
D7T2E1F7	0.875	0.25	1	6	60	70	1363
D7T2E3F5	0.875	0.25	1.5	6	50	70	1274
D7T2E3F6	0.875	0.25	1.5	6	55	70	1379
D7T2E3F7	0.875	0.25	1.5	6	60	70	1482
D7T2E5F5	0.875	0.25	2	6	50	70	1281
D7T2E5F6	0.875	0.25	2	6	55	70	1403
D7T2E5F7	0.875	0.25	2	6	60	70	1518
D8T2E1F5	1	0.25	1	6	50	70	1172

Table C-1 Finite Element Model Results (cont.)

Model	db (in.)	tp (in.)	Le (in.)	Plate Width (in.)	Fy (ksi)	Fu (ksi)	Ki (k/in.)
D8T2E1F6	1	0.25	1	6	55	70	1259
D8T2E1F7	1	0.25	1	6	60	70	1312
D8T2E3F5	1	0.25	1.5	6	50	70	1375
D8T2E3F6	1	0.25	1.5	6	55	70	1481
D8T2E3F7	1	0.25	1.5	6	60	70	1587
D8T2E5F5	1	0.25	2	6	50	70	1411
D8T2E5F6	1	0.25	2	6	55	70	1529
D8T2E5F7	1	0.25	2	6	60	70	1639
P01M3D	1	0.25	1.5	4.5	35	70	953
P02M3D	1	0.25	1.5	4.5	40	70	1113
P03M3D	1	0.25	1.5	4.5	45	70	1230
P04M3D	1	0.25	1.5	4.5	50	70	1364
P05M3D	1	0.25	1.5	4.5	55	70	1480
P06M3D	1	0.25	1.5	4.5	60	70	1586
P07M3D	1	0.25	1.5	4.5	35	50	938
P08M3D	1	0.25	1.5	4.5	35	60	947
P09M3D	1	0.25	1.5	4.5	35	80	957
P10M3D	1	0.25	1.5	4.5	35	90	961
P11M3D	1	0.25	1.5	4.5	35	100	963
D7T2E9F5	0.875	0.25	3	6	50	70	1273
D7T2E9F6	0.875	0.25	3	6	55	70	1406
D7T2E9F7	0.875	0.25	3	6	60	70	1529
D8T2E9F5	1	0.25	3	6	50	70	1430
D8T2E9F6	1	0.25	3	6	55	70	1558
D8T2E9F7	1	0.25	3	6	60	70	1685
D6T2E2F7	0.75	0.25	1.25	6	60	70	1350
D7T2E2F5	0.875	0.25	1.25	6	50	70	1235
D7T2E2F6	0.875	0.25	1.25	6	55	70	1354
D7T2E2F7	0.875	0.25	1.25	6	60	70	1467
D8T2E2F5	1	0.25	1.25	6	50	70	1327
D8T2E2F6	1	0.25	1.25	6	55	70	1436
D8T2E2F7	1	0.25	1.25	6	60	70	1519
D8T2E4F5	1	0.25	1.75	6	50	70	1399
D8T2E4F6	1	0.25	1.75	6	55	70	1512
D8T2E4F7	1	0.25	1.75	6	60	70	1615
D7T6E9F4	0.875	0.75	3	6	45	70	3612
D7T6E9F5	0.875	0.75	3	6	50	70	4040
D7T8E9F4	0.875	1	3	6	45	70	4942
D7T8E9F5	0.875	1	3	6	50	70	5477
D8T6E9F4	1	0.75	3	6	45	70	4548
D8T6E9F5	1	0.75	3	6	50	70	4988
D8T8E9F4	1	1	3	6	45	70	5507

Appendix D

Data Packs

Test No. 1
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-1 Date: 12/1/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 1
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	1	-	Sawed	45

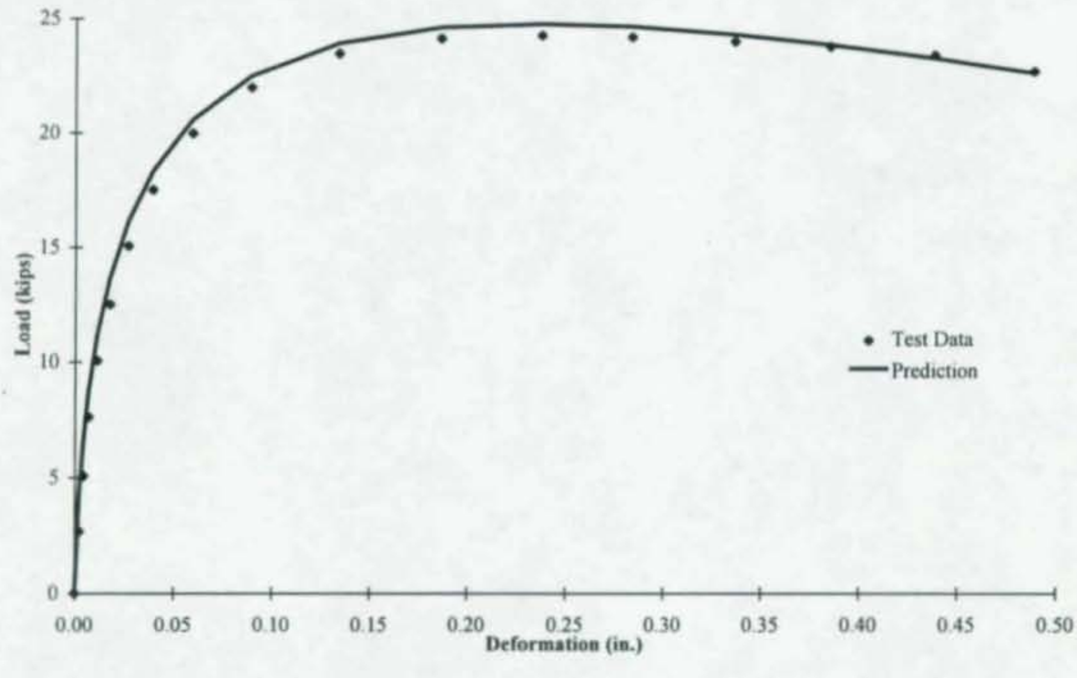
TEST RESULTS

Limit State: Bearing
Ki: 1138 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.2374	24.27
Failure:	-	-
Other:	0.250	24.25

COMMENTS

LOAD Vs. DEFORMATION CHART



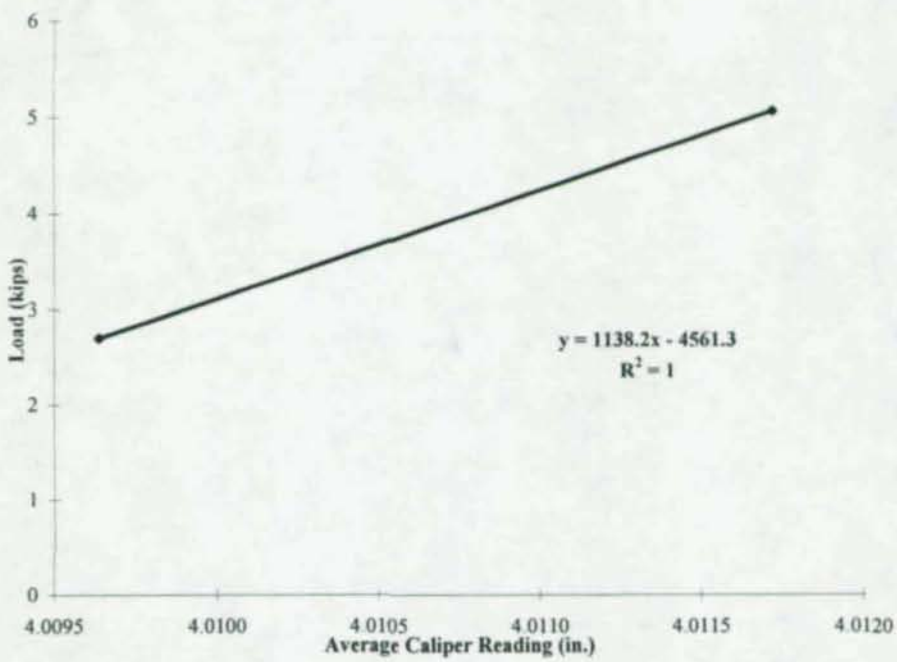
Test No. 1
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

Data Point	Load (kips)	Deflection: Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					4.0075	0.0000	0.0000
1	2.70	4.0119	4.0081	4.0100	0.0004	4.0096	0.0022	0.0022
2	5.07	4.0147	4.0101	4.0124	0.0007	4.0117	0.0043	0.0043
3	7.62	4.0179	4.0129	4.0154	0.0010	4.0144	0.0069	0.0069
4	10.06	4.0225	4.0174	4.0200	0.0013	4.0186	0.0111	0.0111
5	12.50	4.0293	4.0239	4.0266	0.0017	4.0249	0.0175	0.0175
6	15.06	4.0392	4.0333	4.0363	0.0020	4.0342	0.0268	0.0268
7	17.50	4.0520	4.0460	4.0490	0.0023	4.0467	0.0392	0.0392
8	19.96	4.0727	4.0665	4.0696	0.0027	4.0669	0.0595	0.0595
9	21.98	4.1028	4.0969	4.0999	0.0029	4.0969	0.0894	0.0894
10	23.47	4.1478	4.1414	4.1446	0.0031	4.1415	0.1340	0.1340
11	24.13	4.2000	4.1941	4.1971	0.0032	4.1938	0.1863	0.1863
12	24.27	4.2510	4.2452	4.2481	0.0033	4.2448	0.2374	0.2374
13	24.20	4.2972	4.2914	4.2943	0.0032	4.2911	0.2836	0.2836
14	24.00	4.3500	4.3440	4.3470	0.0032	4.3438	0.3363	0.3363
15	23.78	4.3990	4.3924	4.3957	0.0032	4.3925	0.3850	0.3850
16	23.40	4.4513	4.4459	4.4486	0.0031	4.4455	0.4380	0.4380
17	22.70	4.5015	4.4966	4.4991	0.0030	4.4960	0.4885	0.4885

INITIAL SLOPE



Test No. 2 **SINGLE BOLT SINGLE PLATE CONNECTION TEST**
Recorder: COR **SUMMARY SHEET**

TEST DESIGNATION

Test Designation: SBSP-2 Date: 12/1/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 1
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	1	-	Sawed	45

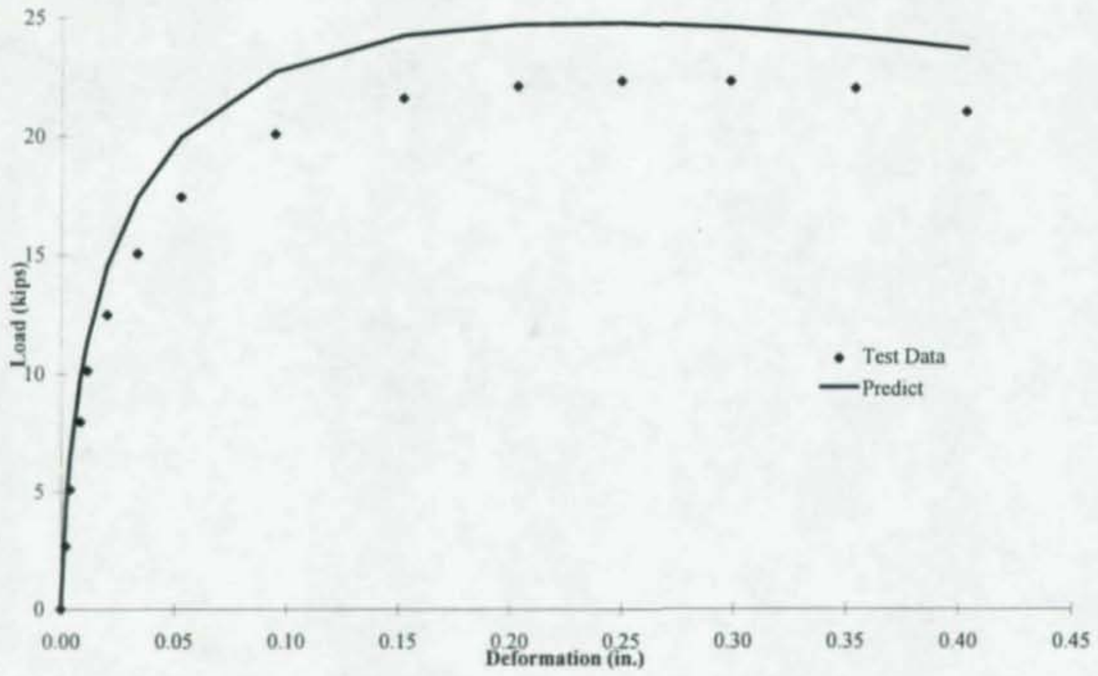
TEST RESULTS

Limit State: Tearout
Ki: 1278 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.2498	22.32
Failure:	0.4034	21.00
Other:	0.250	22.3

COMMENTS

LOAD Vs. DEFORMATION CHART



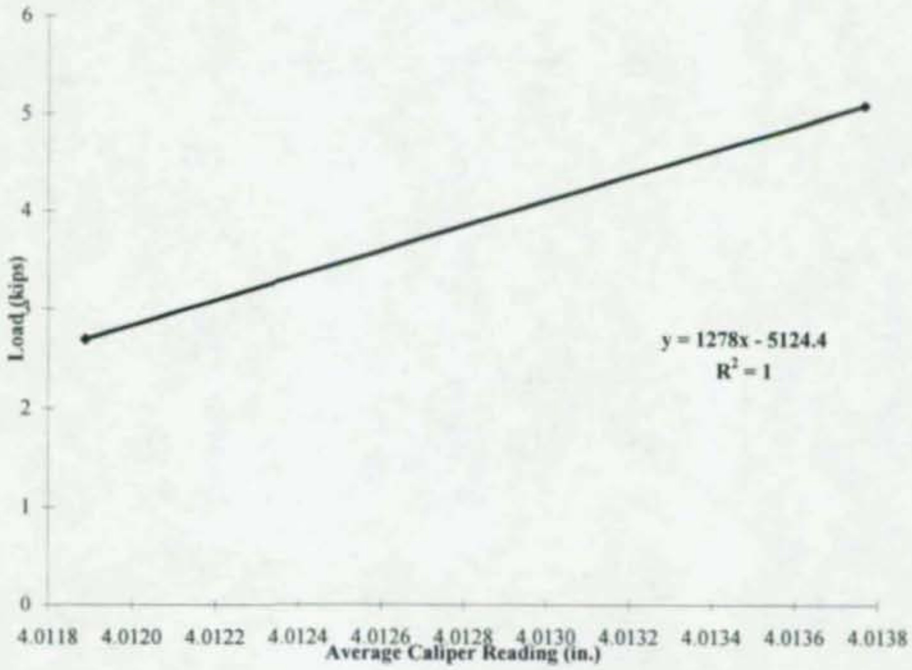
Test No. 2
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

Data Point	Load (kips)	Deflection: Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					4.0097	0.0000	0.0000
1	2.69	3.9985	4.0260	4.0123	0.0004	4.0119	0.0022	0.0022
2	5.09	4.0008	4.0281	4.0145	0.0007	4.0138	0.0041	0.0041
3	7.98	4.0060	4.0328	4.0194	0.0011	4.0183	0.0086	0.0086
4	10.13	4.0093	4.0360	4.0227	0.0014	4.0213	0.0116	0.0116
5	12.49	4.0186	4.0448	4.0317	0.0017	4.0300	0.0203	0.0203
6	15.06	4.0324	4.0583	4.0454	0.0020	4.0433	0.0336	0.0336
7	17.45	4.0520	4.0780	4.0650	0.0023	4.0627	0.0530	0.0530
8	20.08	4.0945	4.1200	4.1073	0.0027	4.1046	0.0949	0.0949
9	21.60	4.1518	4.1778	4.1648	0.0029	4.1619	0.1522	0.1522
10	22.10	4.2029	4.2288	4.2159	0.0030	4.2129	0.2032	0.2032
11	22.32	4.2496	4.2754	4.2625	0.0030	4.2595	0.2498	0.2498
12	22.30	4.2983	4.3239	4.3111	0.0030	4.3081	0.2984	0.2984
13	22.00	4.3538	4.3794	4.3666	0.0030	4.3636	0.3539	0.3539
14	21.00	4.4031	4.4288	4.4160	0.0028	4.4131	0.4034	0.4034

INITIAL SLOPE



Test No. 3
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-3 — Date: 12/1/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 — Diameter (in): 1
Bolt Hole: Std — Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	1.5	- -	Sawed	45

TEST RESULTS

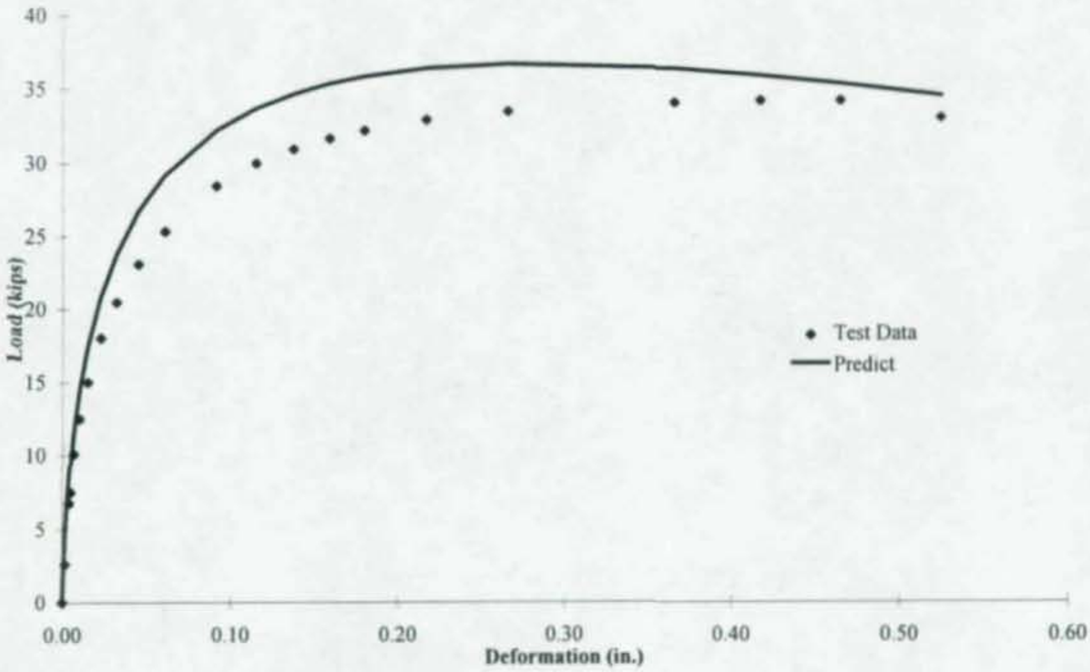
Limit State: Splitting
Ki: 1511 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.4171	34.18
Failure:	0.4649	34.18
Other:	0.250	33.3

COMMENTS

Split developed at data point 20

LOAD Vs. DEFORMATION CHART



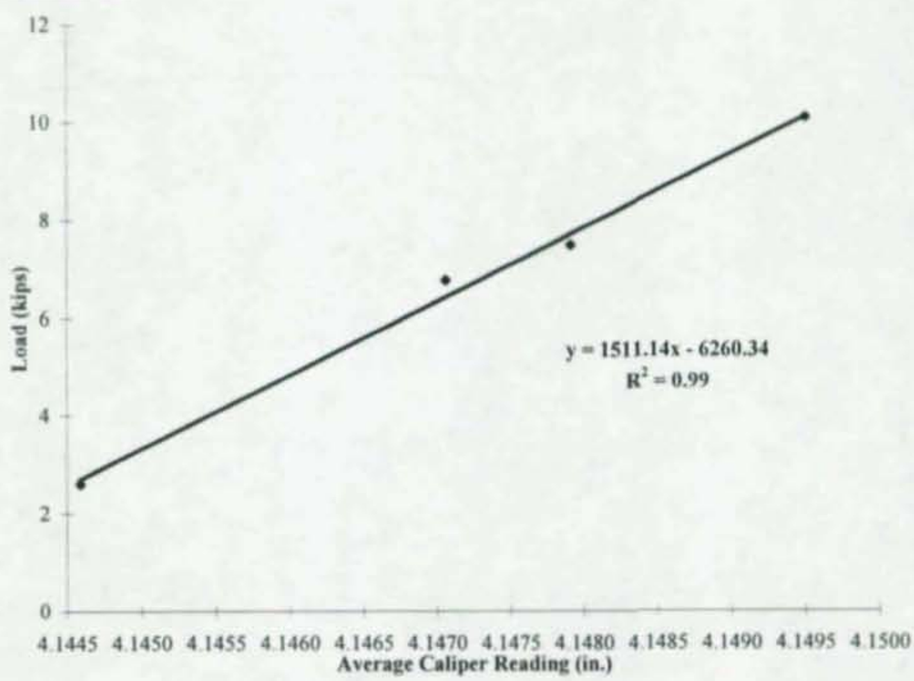
Test No. 3
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					4.1428	0.0000	0.0000
1	2.60	4.0261	4.2638	4.1450	0.0004	4.1446	0.0018	0.0018
2	6.78	4.0309	4.2651	4.1480	0.0009	4.1471	0.0043	0.0043
3	7.50	4.0319	4.2660	4.1490	0.0010	4.1479	0.0051	0.0051
4	10.10	4.0349	4.2669	4.1509	0.0014	4.1495	0.0067	0.0067
5	12.50	4.0386	4.2708	4.1547	0.0017	4.1530	0.0102	0.0102
6	15.00	4.0439	4.2760	4.1600	0.0021	4.1579	0.0151	0.0151
7	18.00	4.0521	4.2839	4.1680	0.0025	4.1655	0.0227	0.0227
8	20.45	4.0620	4.2933	4.1777	0.0028	4.1748	0.0320	0.0320
9	23.10	4.0760	4.3062	4.1911	0.0032	4.1879	0.0451	0.0451
10	25.30	4.0920	4.3224	4.2072	0.0035	4.2037	0.0609	0.0609
11	28.40	4.1235	4.3531	4.2383	0.0039	4.2344	0.0916	0.0916
12	29.95	4.1477	4.3768	4.2623	0.0041	4.2581	0.1153	0.1153
13	30.90	4.1699	4.3992	4.2846	0.0043	4.2803	0.1375	0.1375
14	31.62	4.1920	4.4208	4.3064	0.0044	4.3020	0.1592	0.1592
15	32.14	4.2129	4.4417	4.3273	0.0044	4.3229	0.1801	0.1801
16	32.88	4.2500	4.4790	4.3645	0.0045	4.3600	0.2172	0.2172
17	33.45	4.2989	4.5280	4.4135	0.0046	4.4088	0.2660	0.2660
18	34.04	4.3990	4.6275	4.5133	0.0047	4.5085	0.3658	0.3658
19	34.18	4.4501	4.6792	4.5647	0.0047	4.5599	0.4171	0.4171
20	34.18	4.4978	4.7271	4.6125	0.0047	4.6077	0.4649	0.4649
21	33.00	4.5574	4.7868	4.6721	0.0046	4.6675	0.5247	0.5247

INITIAL SLOPE



Test No. 4
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-4

Date: 12/1/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std
Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	1.5	-	Sawed	45

TEST RESULTS

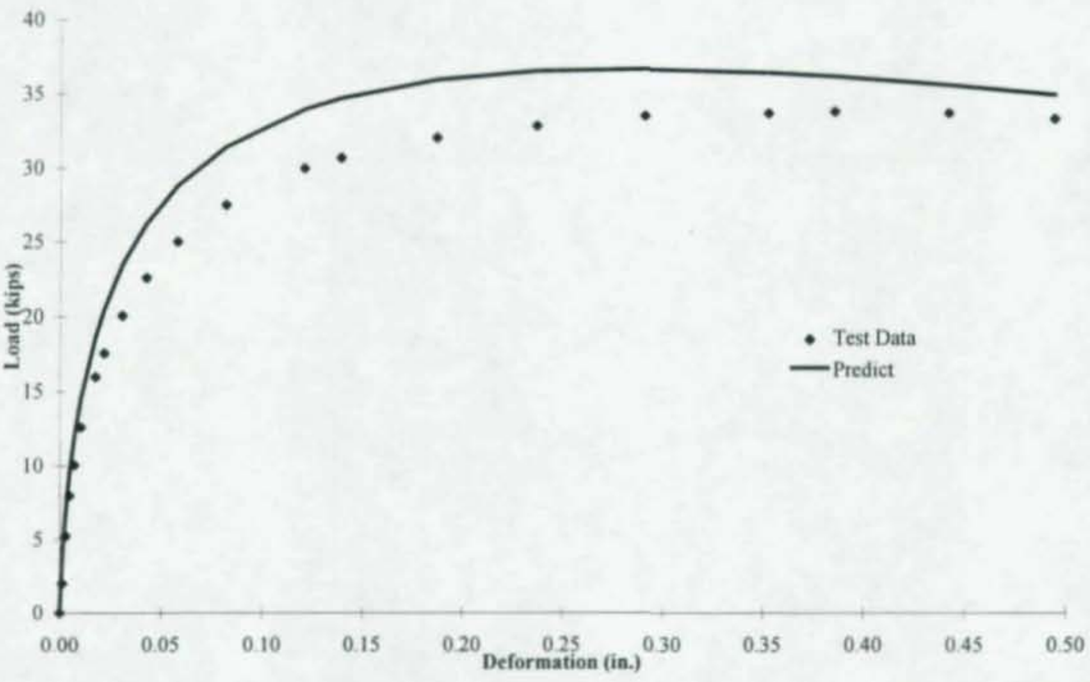
Limit State: Bearing
K_i: 1675 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.3857	33.80
Failure:	-	-
Other:	0.250	33.0

COMMENTS

Test was loaded then unloaded and reloaded at start because of test machine difficulties.

LOAD Vs. DEFORMATION CHART



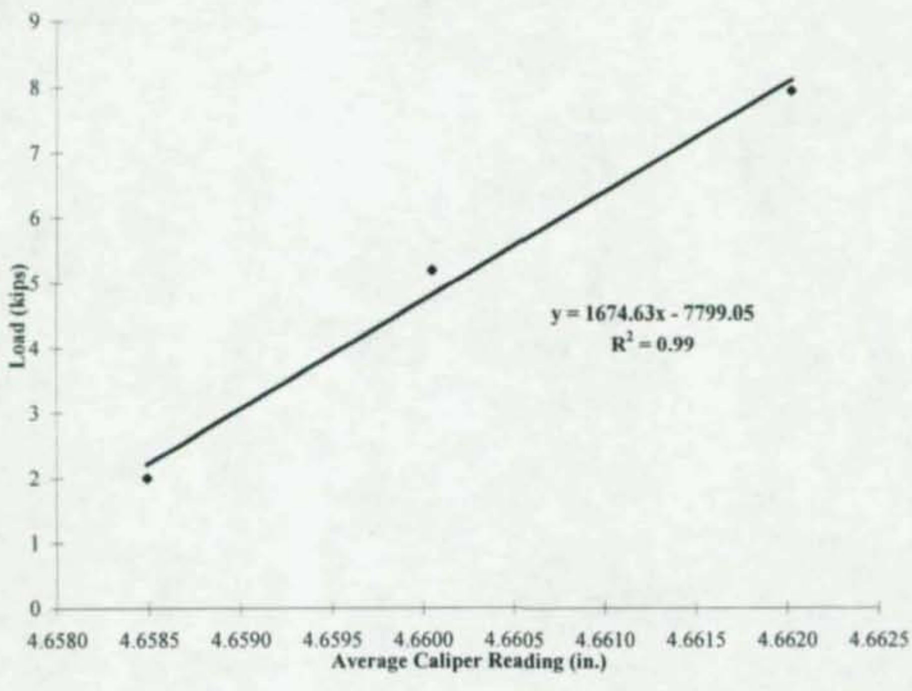
Test No. 4
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					4.6572	0.0000	0.0000
1	2.00	4.5110	4.8066	4.6588	0.0003	4.6585	0.0013	0.0013
2	5.20	4.5123	4.8094	4.6609	0.0008	4.6600	0.0029	0.0029
3	7.96	4.5142	4.8123	4.6633	0.0012	4.6620	0.0048	0.0048
4	10.04	4.5168	4.8151	4.6660	0.0015	4.6644	0.0072	0.0072
5	12.61	4.5202	4.8187	4.6695	0.0019	4.6675	0.0103	0.0103
6	15.95	4.5275	4.8267	4.6771	0.0025	4.6746	0.0175	0.0175
7	17.55	4.5321	4.8312	4.6817	0.0027	4.6789	0.0218	0.0218
8	20.06	4.5413	4.8407	4.6910	0.0031	4.6879	0.0307	0.0307
9	22.57	4.5534	4.8533	4.7034	0.0035	4.6999	0.0427	0.0427
10	25.00	4.5691	4.8692	4.7192	0.0039	4.7153	0.0581	0.0581
11	27.50	4.5934	4.8936	4.7435	0.0042	4.7393	0.0821	0.0821
12	29.98	4.6324	4.9334	4.7829	0.0046	4.7783	0.1211	0.1211
13	30.68	4.6515	4.9510	4.8013	0.0047	4.7965	0.1393	0.1393
14	32.02	4.6991	4.9996	4.8494	0.0049	4.8444	0.1872	0.1872
15	32.82	4.7490	5.0499	4.8995	0.0051	4.8944	0.2372	0.2372
16	33.50	4.7868	5.1202	4.9535	0.0052	4.9483	0.2912	0.2912
17	33.70	4.8585	5.1715	5.0150	0.0052	5.0098	0.3526	0.3526
18	33.80	4.8918	5.2043	5.0481	0.0052	5.0428	0.3857	0.3857
19	33.70	4.9483	5.2606	5.1045	0.0052	5.0993	0.4421	0.4421
20	33.30	5.0003	5.3130	5.1567	0.0051	5.1515	0.4943	0.4943

INITIAL SLOPE



Test No. 5
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-5 Date: 12/2/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 1
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	2	-	Sawed	45

TEST RESULTS

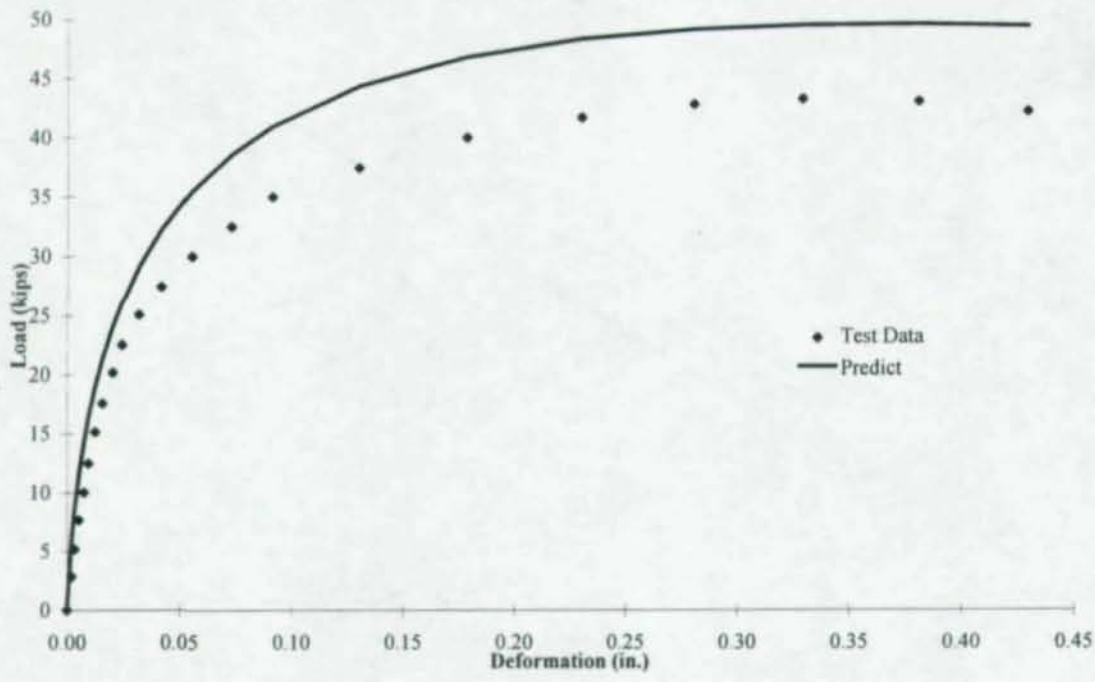
Limit State: Bearing
Ki: 1477 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.3291	43.24
Failure:	-	-
Other:	0.250	42.1

COMMENTS

Plate started curling in front of bolt around data point 20.
Tearout planes were just forming when test was ended.

LOAD Vs. DEFORMATION CHART



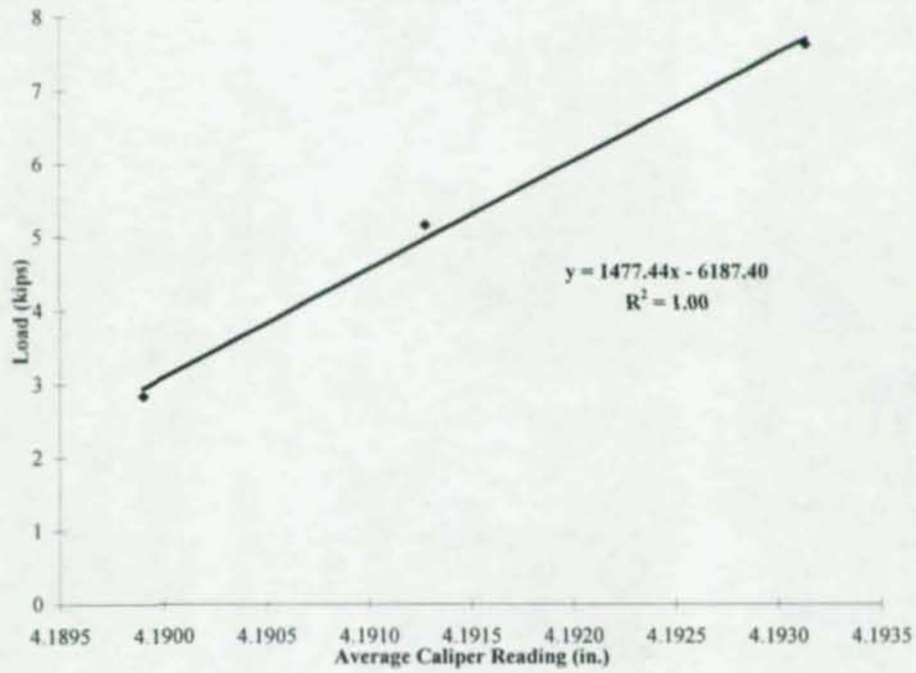
Test No. 5
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

Data Point	Load (kips)	Deflection: Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					4.1879	0.0000	0.0000
1	2.84	4.2919	4.0887	4.1903	0.0004	4.1899	0.0020	0.0020
2	5.17	4.2932	4.0908	4.1920	0.0007	4.1913	0.0034	0.0034
3	7.64	4.2951	4.0933	4.1942	0.0011	4.1931	0.0052	0.0052
4	10.03	4.2973	4.0961	4.1967	0.0014	4.1953	0.0074	0.0074
5	12.48	4.2999	4.0984	4.1992	0.0017	4.1974	0.0095	0.0095
6	15.12	4.3032	4.1019	4.2026	0.0021	4.2004	0.0125	0.0125
7	17.57	4.3067	4.1056	4.2062	0.0025	4.2037	0.0158	0.0158
8	20.18	4.3109	4.1112	4.2111	0.0028	4.2082	0.0203	0.0203
9	22.50	4.3160	4.1150	4.2155	0.0031	4.2124	0.0244	0.0244
10	25.06	4.3240	4.1231	4.2236	0.0035	4.2201	0.0321	0.0321
11	27.42	4.3339	4.1330	4.2335	0.0038	4.2296	0.0417	0.0417
12	30.00	4.3480	4.1471	4.2476	0.0042	4.2434	0.0554	0.0554
13	32.50	4.3658	4.1652	4.2655	0.0045	4.2610	0.0730	0.0730
14	35.00	4.3843	4.1840	4.2842	0.0049	4.2793	0.0913	0.0913
15	37.47	4.4239	4.2228	4.3234	0.0052	4.3181	0.1302	0.1302
16	40.00	4.4722	4.2723	4.3723	0.0056	4.3667	0.1787	0.1787
17	41.70	4.5242	4.3237	4.4240	0.0058	4.4181	0.2302	0.2302
18	42.78	4.5749	4.3741	4.4745	0.0060	4.4685	0.2806	0.2806
19	43.24	4.6236	4.4225	4.5231	0.0060	4.5170	0.3291	0.3291
20	43.00	4.6755	4.4744	4.5750	0.0060	4.5689	0.3810	0.3810
21	42.17	4.7240	4.5224	4.6232	0.0059	4.6173	0.4294	0.4294

INITIAL SLOPE



Test No. 6
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-6

Date: 12/2/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Diameter (in): 1
Bolt Hole: Std
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	2	-	Sawed	45

TEST RESULTS

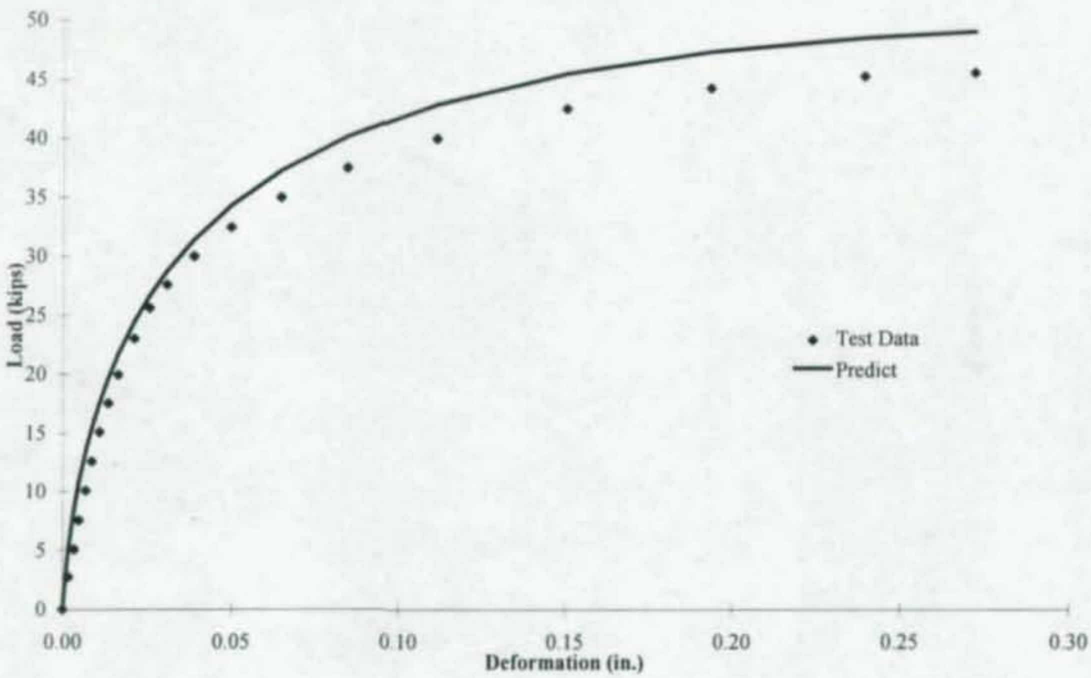
Limit State: Curling
Ki: 1572 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.2721	45.60
Failure:	-	-
Other:	0.250	45.4

COMMENTS

Plate started curling in front of bolt around data point 18.
Test was stopped to prevent damage to calipers by the plate curling.

LOAD Vs. DEFORMATION CHART



01351

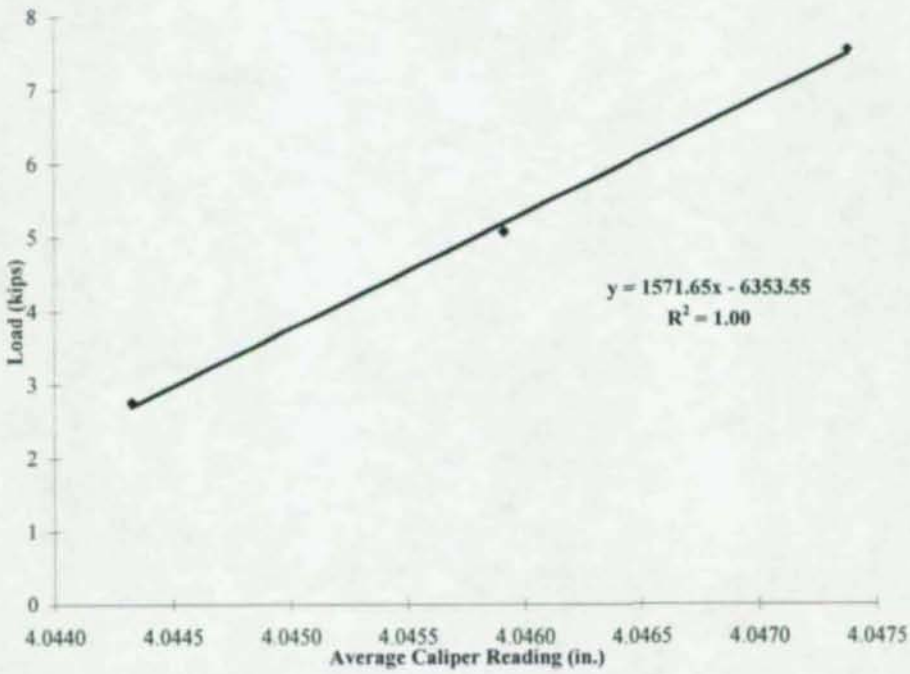
Test No. 6
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

Data Point	Load (kips)	Deflection Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					4.0426	0.0000	0.0000
1	2.76	4.0517	4.0377	4.0447	0.0004	4.0443	0.0017	0.0017
2	5.08	4.0537	4.0395	4.0466	0.0007	4.0459	0.0033	0.0033
3	7.56	4.0557	4.0411	4.0484	0.0010	4.0474	0.0048	0.0048
4	10.10	4.0579	4.0436	4.0508	0.0014	4.0494	0.0068	0.0068
5	12.60	4.0601	4.0456	4.0529	0.0017	4.0511	0.0085	0.0085
6	15.09	4.0629	4.0481	4.0555	0.0020	4.0535	0.0109	0.0109
7	17.55	4.0659	4.0509	4.0584	0.0024	4.0560	0.0134	0.0134
8	19.94	4.0692	4.0541	4.0617	0.0027	4.0590	0.0164	0.0164
9	22.99	4.0739	4.0597	4.0668	0.0031	4.0637	0.0211	0.0211
10	25.63	4.0794	4.0641	4.0718	0.0035	4.0683	0.0257	0.0257
11	27.60	4.0849	4.0695	4.0772	0.0037	4.0735	0.0309	0.0309
12	30.00	4.0934	4.0776	4.0855	0.0041	4.0814	0.0388	0.0388
13	32.50	4.1050	4.0889	4.0970	0.0044	4.0926	0.0500	0.0500
14	35.01	4.1202	4.1040	4.1121	0.0047	4.1074	0.0648	0.0648
15	37.50	4.1407	4.1240	4.1324	0.0051	4.1273	0.0847	0.0847
16	40.00	4.1679	4.1511	4.1595	0.0054	4.1541	0.1115	0.1115
17	42.55	4.2065	4.1911	4.1988	0.0058	4.1930	0.1504	0.1504
18	44.31	4.2501	4.2342	4.2422	0.0060	4.2362	0.1936	0.1936
19	45.30	4.2962	4.2801	4.2882	0.0061	4.2820	0.2394	0.2394
20	45.60	4.3288	4.3129	4.3209	0.0062	4.3147	0.2721	0.2721

INITIAL SLOPE



Test No. 7
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-7 Date: 12/2/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 1
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	2.5	-	Sawed	48

TEST RESULTS

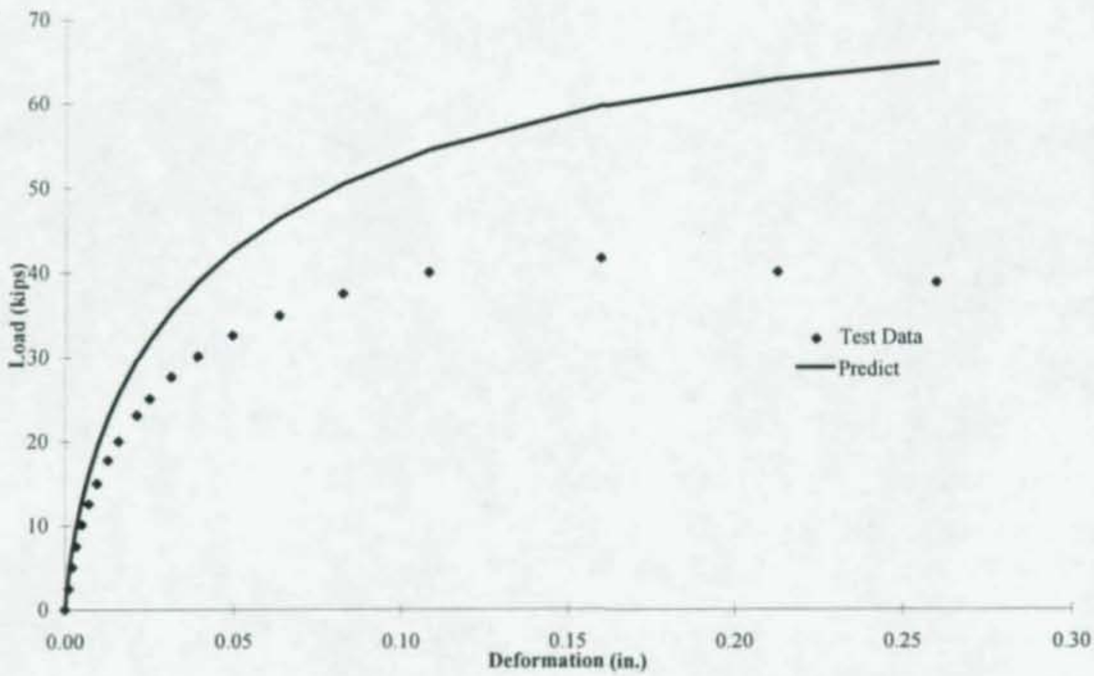
Limit State: Curling
Ki: 2271 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.1598	41.67
Failure:	-	-
Other:	0.250	39.1

COMMENTS

Test was loaded then unloaded and reloaded at start because of test machine difficulties.
Plate started curling in front of bolt around data point 14.
Removed caliper on back of plate to prevent it from being damaged.

LOAD Vs. DEFORMATION CHART



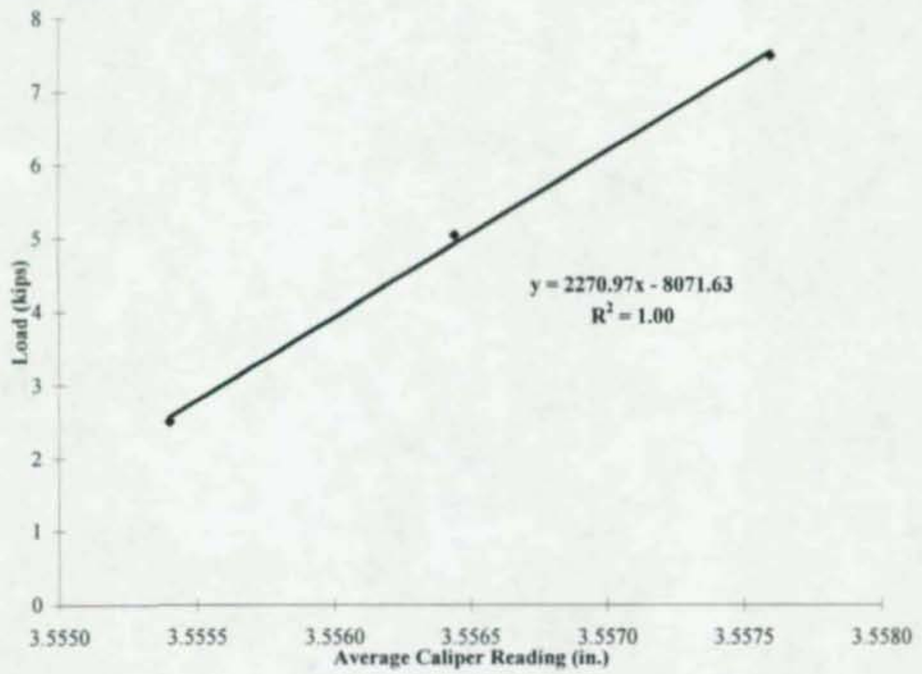
Test No. 7
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.5543	0.0000	0.0000
1	2.50	3.5843	3.5271	3.5557	0.0003	3.5554	0.0011	0.0011
2	5.05	3.5859	3.5282	3.5571	0.0006	3.5564	0.0022	0.0022
3	7.50	3.5875	3.5295	3.5585	0.0009	3.5576	0.0033	0.0033
4	10.10	3.5899	3.5310	3.5605	0.0012	3.5592	0.0050	0.0050
5	12.60	3.5925	3.5331	3.5628	0.0015	3.5613	0.0070	0.0070
6	15.00	3.5954	3.5358	3.5656	0.0018	3.5638	0.0095	0.0095
7	17.77	3.5993	3.5391	3.5692	0.0021	3.5671	0.0128	0.0128
8	20.00	3.6028	3.5424	3.5726	0.0024	3.5702	0.0159	0.0159
9	23.10	3.6089	3.5480	3.5785	0.0028	3.5757	0.0214	0.0214
10	25.05	3.6130	3.5519	3.5825	0.0030	3.5794	0.0252	0.0252
11	27.65	3.6199	3.5585	3.5892	0.0033	3.5859	0.0316	0.0316
12	30.07	3.6280	3.5663	3.5972	0.0036	3.5935	0.0393	0.0393
13	32.50	3.6385	3.5770	3.6078	0.0039	3.6038	0.0496	0.0496
14	34.90	3.6528	3.5911	3.6220	0.0042	3.6178	0.0635	0.0635
15	37.50	3.6720	3.6105	3.6413	0.0045	3.6367	0.0825	0.0825
16	40.00	3.6981	3.6365	3.6673	0.0048	3.6625	0.1082	0.1082
17	41.67	3.7494	3.6888	3.7191	0.0050	3.7141	0.1598	0.1598
18	40.05	3.8019		3.8019	0.0048	3.7971	0.2428	0.2125
19	38.80	3.8490		3.8490	0.0047	3.8443	0.2901	0.2598

INITIAL SLOPE



Test No. 8
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-8

Date: 12/2/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std
Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	2.5	-	Sawed	46

TEST RESULTS

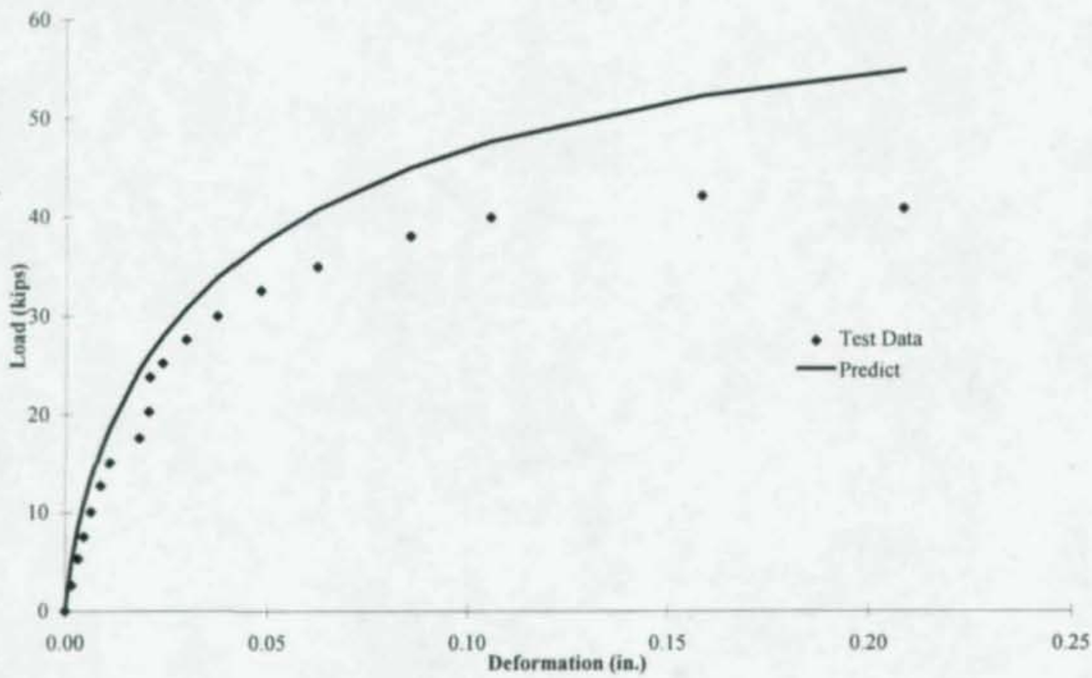
Limit State: Curling
Ki: 1643 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.1583	42.18
Failure:	-	-
Other:	-	-

COMMENTS

Plate started curling in front of bolt around data point 17.
Removed caliper on back of plate to prevent it from being damaged.

LOAD Vs. DEFORMATION CHART



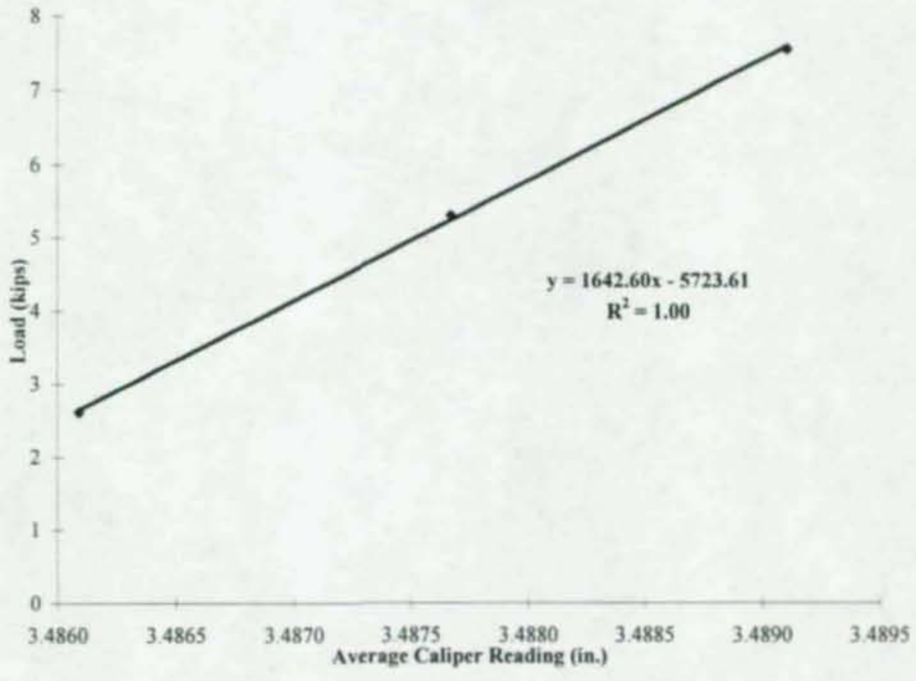
Test No. 8
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.4845	0.0000	0.0000
1	2.61	3.4421	3.5307	3.4864	0.0003	3.4861	0.0016	0.0016
2	5.31	3.4439	3.5327	3.4883	0.0006	3.4877	0.0032	0.0032
3	7.56	3.4457	3.5343	3.4900	0.0009	3.4891	0.0046	0.0046
4	10.03	3.4479	3.5361	3.4920	0.0012	3.4908	0.0063	0.0063
5	12.70	3.4505	3.5389	3.4947	0.0015	3.4932	0.0087	0.0087
6	15.00	3.4532	3.5411	3.4972	0.0018	3.4954	0.0109	0.0109
7	17.59	3.4575	3.5519	3.5047	0.0021	3.5026	0.0181	0.0181
8	20.30	3.4597	3.5551	3.5074	0.0024	3.5050	0.0205	0.0205
9	23.77	3.4619	3.5542	3.5081	0.0028	3.5052	0.0208	0.0208
10	25.18	3.4648	3.5580	3.5114	0.0030	3.5084	0.0239	0.0239
11	27.60	3.4708	3.5641	3.5175	0.0033	3.5142	0.0297	0.0297
12	30.00	3.4789	3.5721	3.5255	0.0035	3.5220	0.0375	0.0375
13	32.60	3.4899	3.5833	3.5366	0.0038	3.5328	0.0483	0.0483
14	35.00	3.5043	3.5977	3.5510	0.0041	3.5469	0.0624	0.0624
15	38.06	3.5281	3.6211	3.5746	0.0045	3.5701	0.0856	0.0856
16	40.00	3.5484	3.6413	3.5949	0.0047	3.5901	0.1056	0.1056
17	42.18	3.6011	3.6945	3.6478	0.0050	3.6428	0.1583	0.1583
18	40.90	3.6511		3.6511	0.0048	3.6463	0.1618	0.2085

INITIAL SLOPE



Test No. 9
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-9 　　Date: 12/2/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 　　Diameter (in): 1
Bolt Hole: Std 　　Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	3	-	Sawed	45

TEST RESULTS

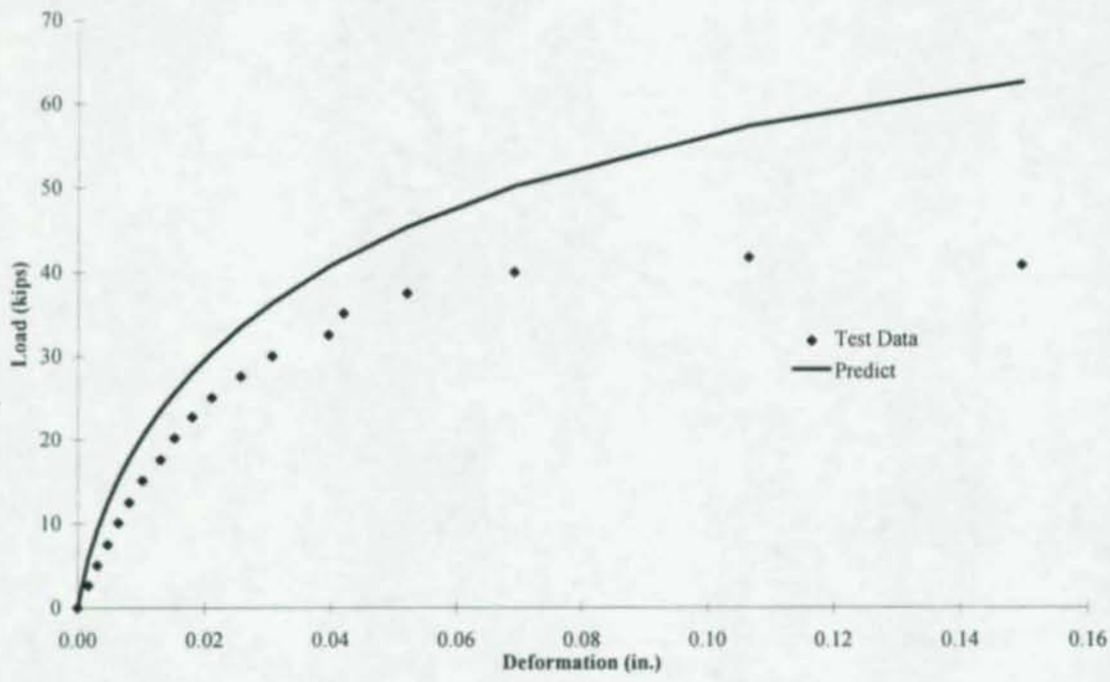
Limit State: Curling
Ki: 1601 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.1065	41.73
Failure:	-	-
Other:	-	-

COMMENTS

Plate started curling in front of bolt around data point 17.
Removed caliper on front of plate to prevent it from being damaged.

LOAD Vs. DEFORMATION CHART



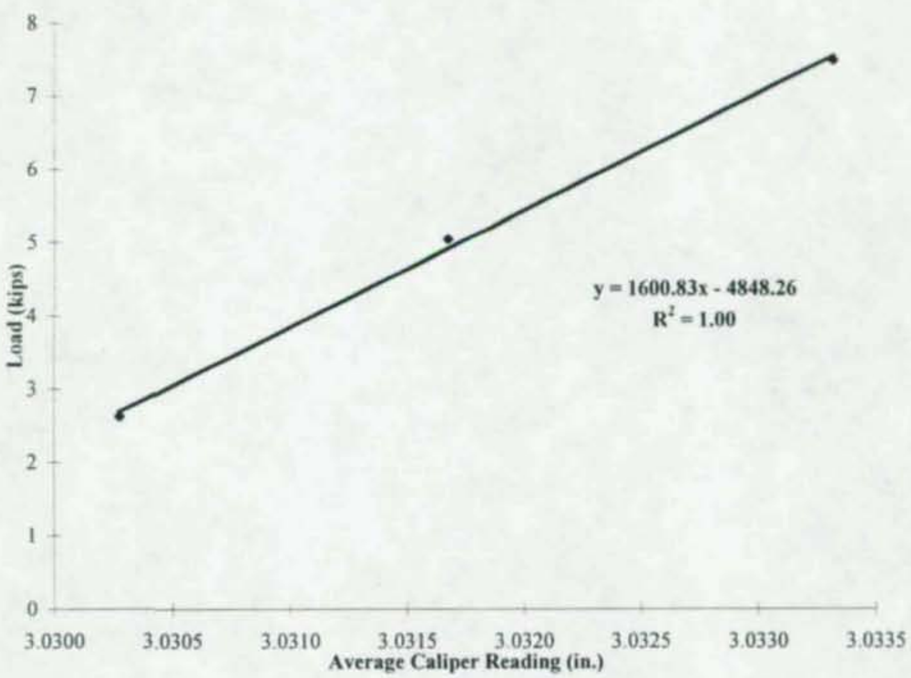
Test No. 9
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

Data Point	Load (kips)	Deflection: Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.0286	0.0000	0.0000
1	2.62	3.0271	3.0340	3.0306	0.0003	3.0303	0.0017	0.0017
2	5.05	3.0282	3.0362	3.0322	0.0005	3.0317	0.0031	0.0031
3	7.50	3.0293	3.0389	3.0341	0.0008	3.0333	0.0047	0.0047
4	10.10	3.0309	3.0412	3.0361	0.0011	3.0350	0.0064	0.0064
5	12.50	3.0325	3.0435	3.0380	0.0013	3.0367	0.0081	0.0081
6	15.10	3.0347	3.0460	3.0404	0.0016	3.0388	0.0102	0.0102
7	17.57	3.0369	3.0500	3.0435	0.0018	3.0416	0.0130	0.0130
8	20.17	3.0399	3.0519	3.0459	0.0021	3.0438	0.0152	0.0152
9	22.70	3.0429	3.0550	3.0490	0.0024	3.0466	0.0180	0.0180
10	25.05	3.0466	3.0580	3.0523	0.0026	3.0497	0.0211	0.0211
11	27.60	3.0512	3.0631	3.0572	0.0029	3.0543	0.0257	0.0257
12	30.00	3.0564	3.0683	3.0624	0.0031	3.0592	0.0306	0.0306
13	32.50	3.0681	3.0750	3.0716	0.0034	3.0682	0.0396	0.0396
14	35.10	3.0679	3.0805	3.0742	0.0037	3.0705	0.0420	0.0420
15	37.50	3.0782	3.0910	3.0846	0.0039	3.0807	0.0521	0.0521
16	40.00	3.0959	3.1080	3.1020	0.0042	3.0978	0.0692	0.0692
17	41.73	3.1338	3.1450	3.1394	0.0043	3.1351	0.1065	0.1065
18	40.80		3.1880	3.1880	0.0042	3.1838	0.1552	0.1496

INITIAL SLOPE



Test No. 10
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-10

Date: 12/2/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std
Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	3	-	Sawed	45

TEST RESULTS

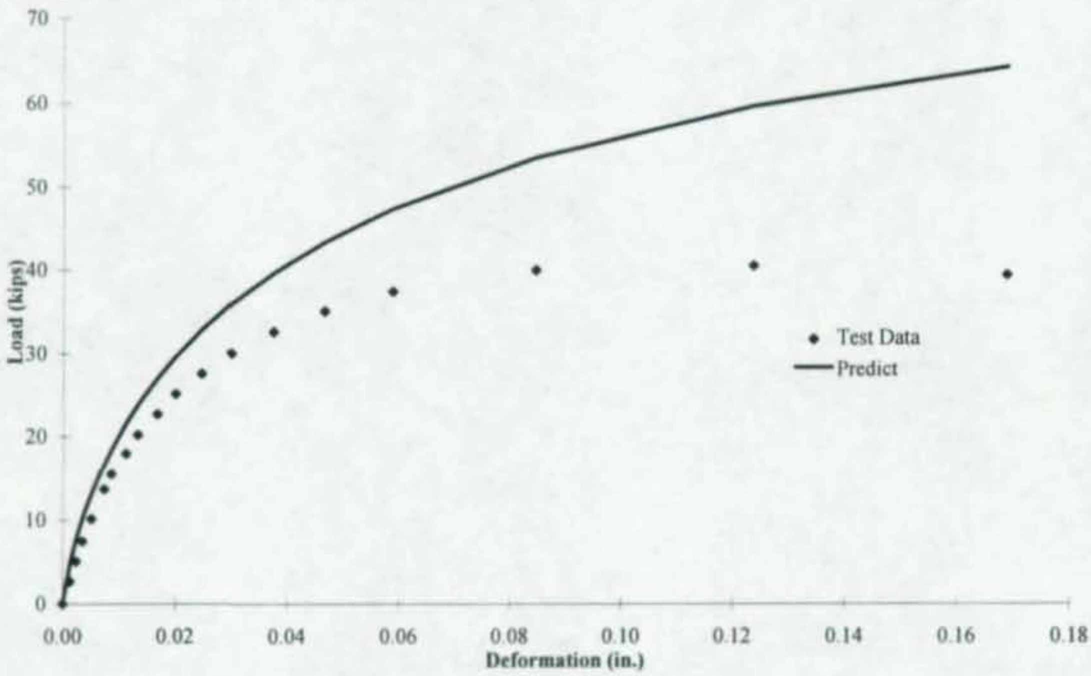
Limit State: Curling
Ki: 2137 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.1237	40.50
Failure:	-	-
Other:	-	-

COMMENTS

Plate started curling in front of bolt around data point 15.
Removed caliper on back of plate to prevent it from being damaged.

LOAD Vs. DEFORMATION CHART



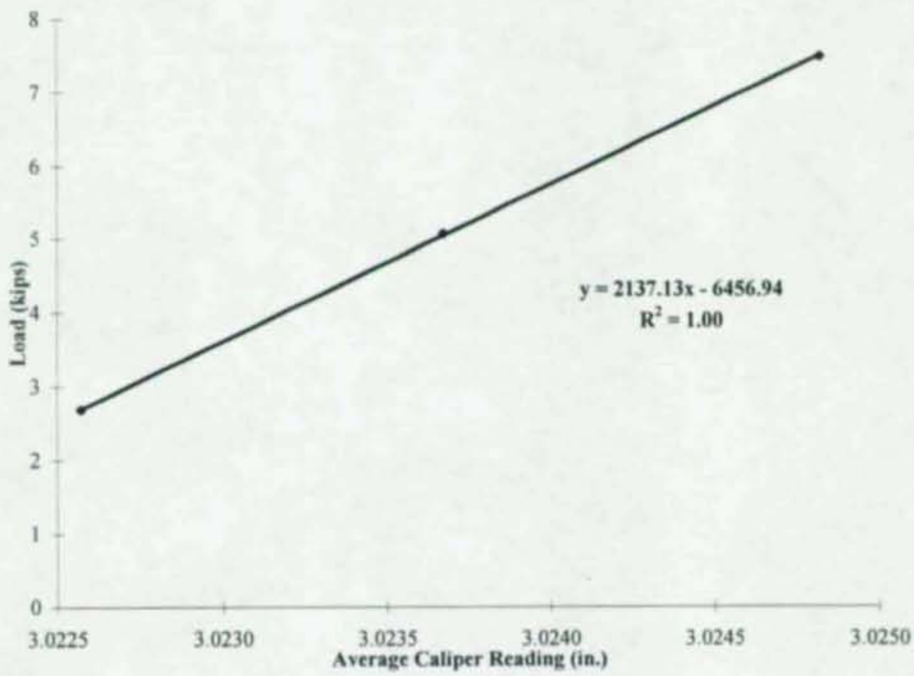
Test No. 10
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.0213	0.0000	0.0000
1	2.68	3.0351	3.0106	3.0229	0.0003	3.0226	0.0013	0.0013
2	5.07	3.0369	3.0115	3.0242	0.0005	3.0237	0.0024	0.0024
3	7.49	3.0389	3.0123	3.0256	0.0008	3.0248	0.0035	0.0035
4	10.12	3.0411	3.0138	3.0275	0.0011	3.0264	0.0051	0.0051
5	13.68	3.0442	3.0161	3.0302	0.0014	3.0287	0.0074	0.0074
6	15.54	3.0459	3.0173	3.0316	0.0016	3.0300	0.0087	0.0087
7	17.97	3.0487	3.0199	3.0343	0.0019	3.0324	0.0111	0.0111
8	20.20	3.0511	3.0222	3.0367	0.0021	3.0346	0.0132	0.0132
9	22.67	3.0549	3.0259	3.0404	0.0024	3.0380	0.0167	0.0167
10	25.08	3.0584	3.0294	3.0439	0.0026	3.0413	0.0200	0.0200
11	27.57	3.0635	3.0341	3.0488	0.0029	3.0459	0.0246	0.0246
12	30.06	3.0688	3.0400	3.0544	0.0031	3.0513	0.0300	0.0300
13	32.60	3.0772	3.0472	3.0622	0.0034	3.0588	0.0375	0.0375
14	35.07	3.0865	3.0568	3.0717	0.0036	3.0680	0.0467	0.0467
15	37.43	3.0994	3.0689	3.0842	0.0039	3.0803	0.0589	0.0589
16	40.00	3.1251	3.0951	3.1101	0.0042	3.1059	0.0846	0.0846
17	40.50	3.1642		3.1642	0.0042	3.1600	0.1387	0.1237
18	39.40	3.2093		3.2093	0.0041	3.2052	0.1839	0.1689

INITIAL SLOPE



Test No. 11
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-11

Date: 12/1/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 | Diameter (in): 1
Bolt Hole: Std | Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	1	-	Sheared	47

TEST RESULTS

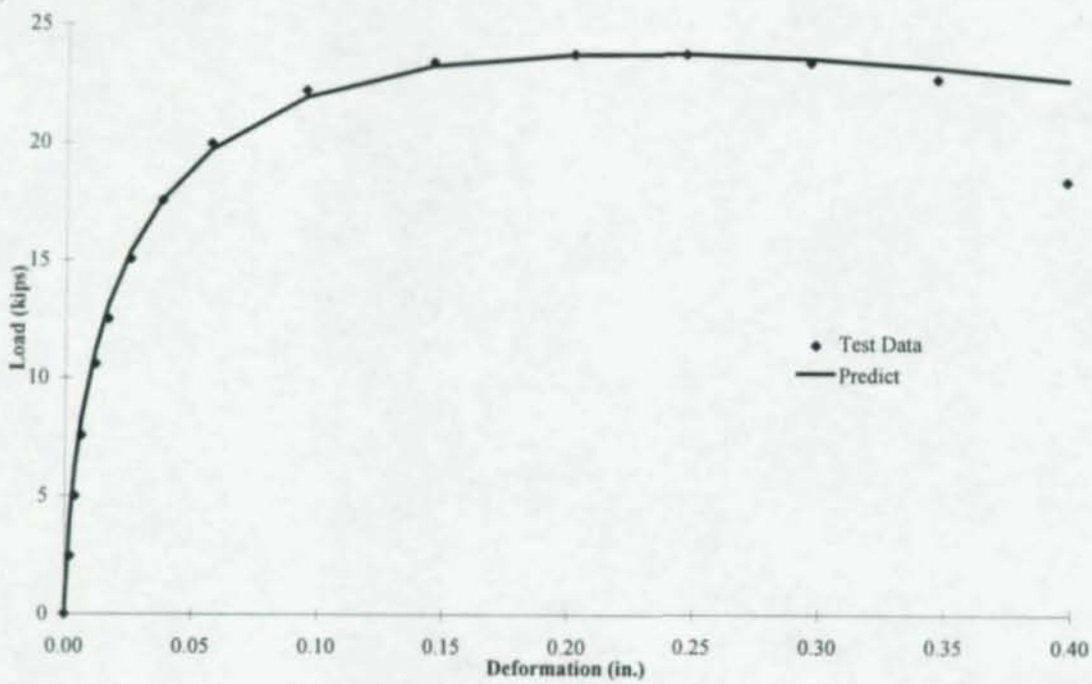
Limit State: Splitting
Ki: 1258 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.2017	23.75
Failure:	0.0948	22.20
Other:	0.250	23.7

COMMENTS

Splitting along free edge of plate noticed around data point 9.
Splitting propogated toward bolt hole.
Test stopped when load started dropping

LOAD Vs. DEFORMATION CHART



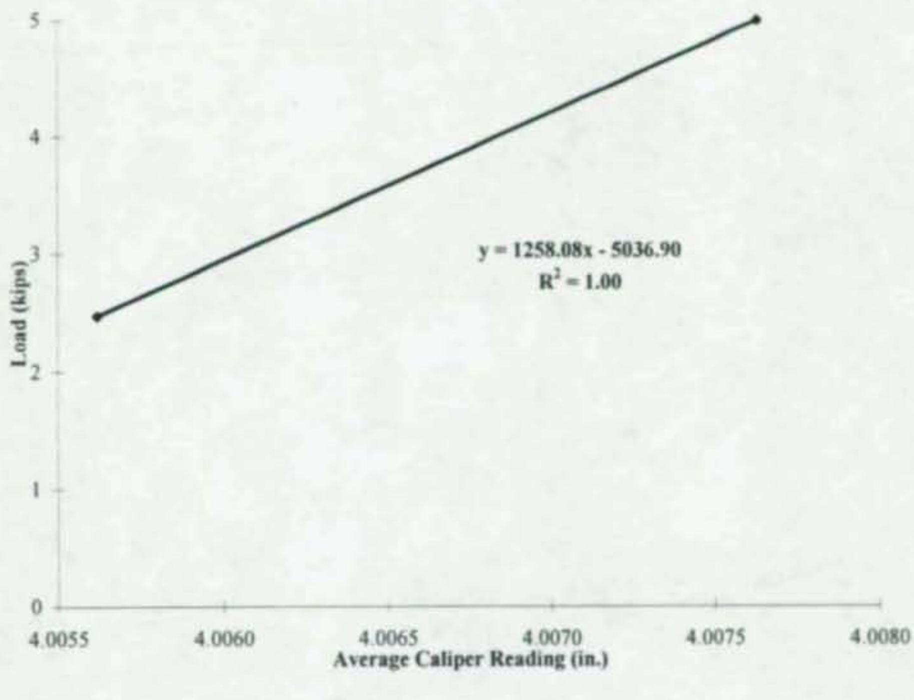
Test No. 11
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					4.0036	0.0000	0.0000
1	2.47	4.0071	4.0048	4.0060	0.0003	4.0056	0.0020	0.0020
2	5.00	4.0081	4.0085	4.0083	0.0007	4.0076	0.0040	0.0040
3	7.55	4.0102	4.0121	4.0112	0.0010	4.0101	0.0065	0.0065
4	10.58	4.0151	4.0186	4.0169	0.0014	4.0154	0.0118	0.0118
5	12.50	4.0200	4.0242	4.0221	0.0017	4.0204	0.0168	0.0168
6	15.06	4.0288	4.0334	4.0311	0.0020	4.0291	0.0254	0.0254
7	17.55	4.0411	4.0468	4.0440	0.0024	4.0416	0.0380	0.0380
8	19.96	4.0609	4.0663	4.0636	0.0027	4.0609	0.0573	0.0573
9	22.20	4.0984	4.1045	4.1015	0.0030	4.0985	0.0948	0.0948
10	23.40	4.1490	4.1557	4.1524	0.0031	4.1492	0.1456	0.1456
11	23.75	4.2050	4.2121	4.2086	0.0032	4.2054	0.2017	0.2017
12	23.75	4.2497	4.2567	4.2532	0.0032	4.2500	0.2464	0.2464
13	23.40	4.2990	4.3060	4.3025	0.0031	4.2994	0.2957	0.2957
14	22.70	4.3497	4.3561	4.3529	0.0030	4.3499	0.3462	0.3462
15	18.40	4.4008	4.4067	4.4038	0.0025	4.4013	0.3976	0.3976

INITIAL SLOPE



Test No. 12 **SINGLE BOLT SINGLE PLATE CONNECTION TEST**
Recorder: COR **SUMMARY SHEET**

TEST DESIGNATION

Test Designation: SBSP-12 Date: 12/1/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 1
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	1	-	Sheared	47

TEST RESULTS

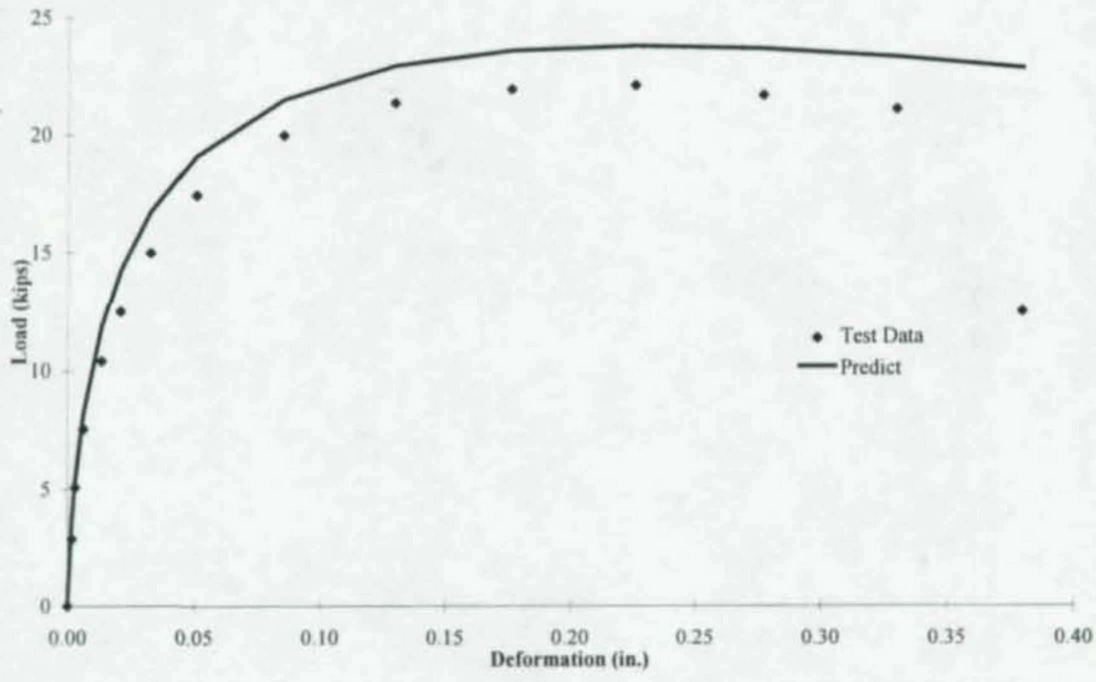
Limit State: Splitting
Ki: 1631 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.2261	22.12
Failure:	0.1300	21.38
Other:	0.250	21.9

COMMENTS

Splitting along free edge of plate noticed around data point 9.
Splitting propogated toward bolt hole.
Test stopped when load started dropping

LOAD Vs. DEFORMATION CHART



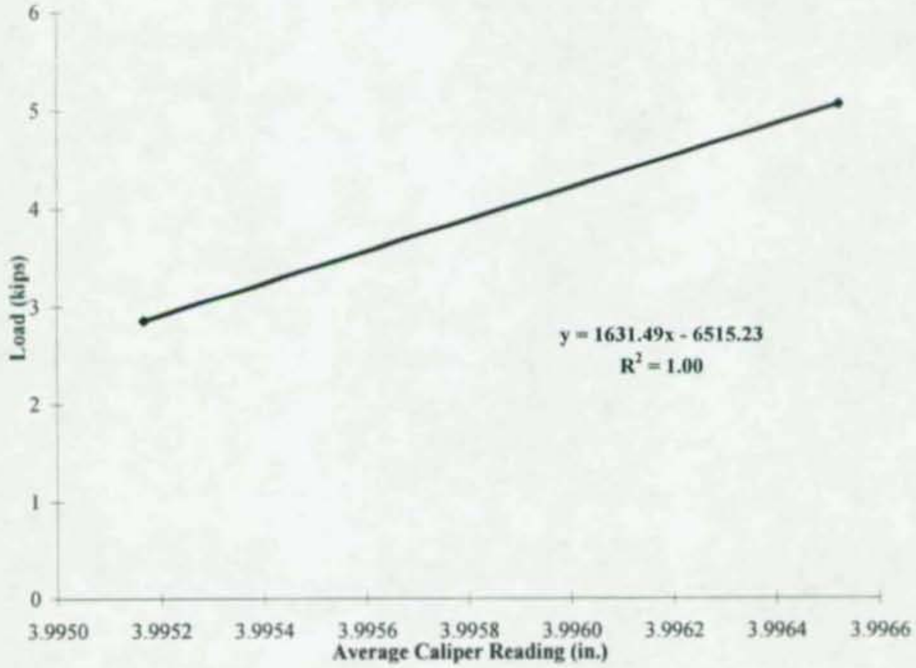
Test No. 12
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.9934	0.0000	0.0000
1	2.86	3.9720	4.0191	3.9956	0.0004	3.9952	0.0017	0.0017
2	5.07	3.9735	4.0209	3.9972	0.0007	3.9965	0.0031	0.0031
3	7.52	3.9771	4.0245	4.0008	0.0010	3.9998	0.0064	0.0064
4	10.40	3.9846	4.0319	4.0083	0.0014	4.0069	0.0134	0.0134
5	12.50	3.9928	4.0393	4.0161	0.0017	4.0144	0.0210	0.0210
6	14.98	4.0049	4.0512	4.0281	0.0020	4.0260	0.0326	0.0326
7	17.45	4.0236	4.0698	4.0467	0.0023	4.0444	0.0509	0.0509
8	19.99	4.0573	4.1060	4.0817	0.0027	4.0790	0.0856	0.0856
9	21.38	4.1020	4.1506	4.1263	0.0029	4.1234	0.1300	0.1300
10	21.95	4.1479	4.1978	4.1729	0.0029	4.1699	0.1765	0.1765
11	22.12	4.1980	4.2469	4.2225	0.0030	4.2195	0.2261	0.2261
12	21.70	4.2490	4.2978	4.2734	0.0029	4.2705	0.2771	0.2771
13	21.10	4.3021	4.3504	4.3263	0.0028	4.3234	0.3300	0.3300
14	12.50	4.3509	4.3990	4.3750	0.0017	4.3733	0.3799	0.3799

INITIAL SLOPE



Test No. 13
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-13 Date: 12/2/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 1
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	2	-	Sheared	47

TEST RESULTS

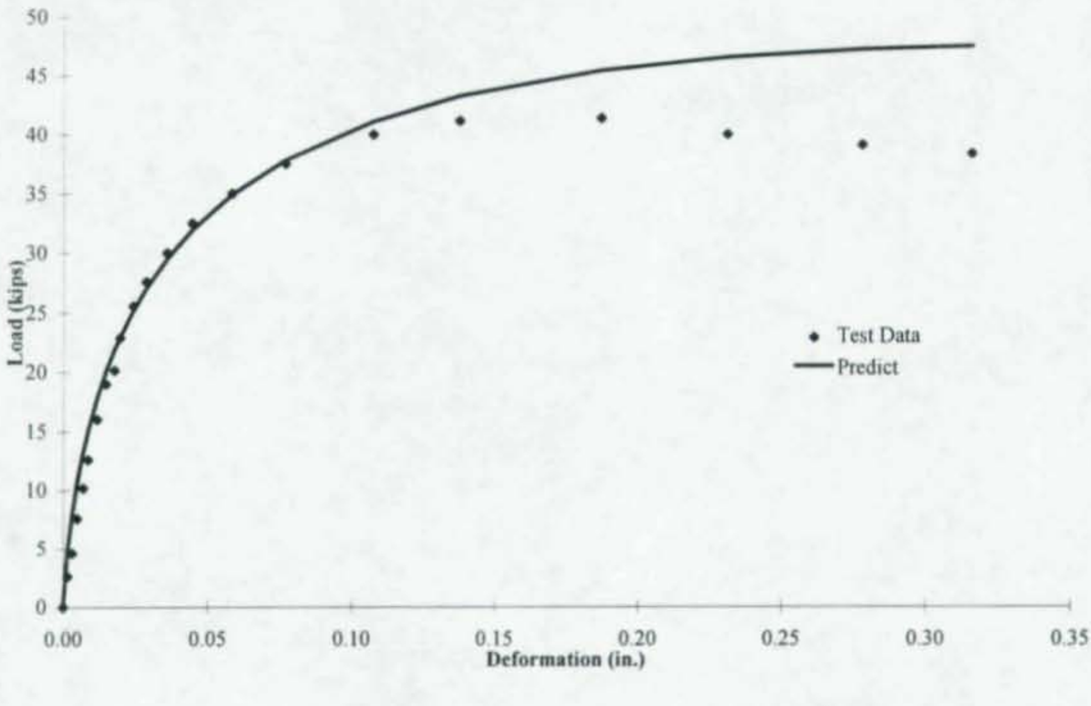
Limit State: Curling
Ki: 1542 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.1872	41.38
Failure:	-	-
Other:	0.250	39.6

COMMENTS

Plate started curling in front of bolt around data point 16.
Removed caliper on back of plate to prevent it from being damaged.
Sheared specimen may have started curling earlier than equivilent sawed specimen
because of additional curvature induced into the plate during the shearing process

LOAD Vs. DEFORMATION CHART



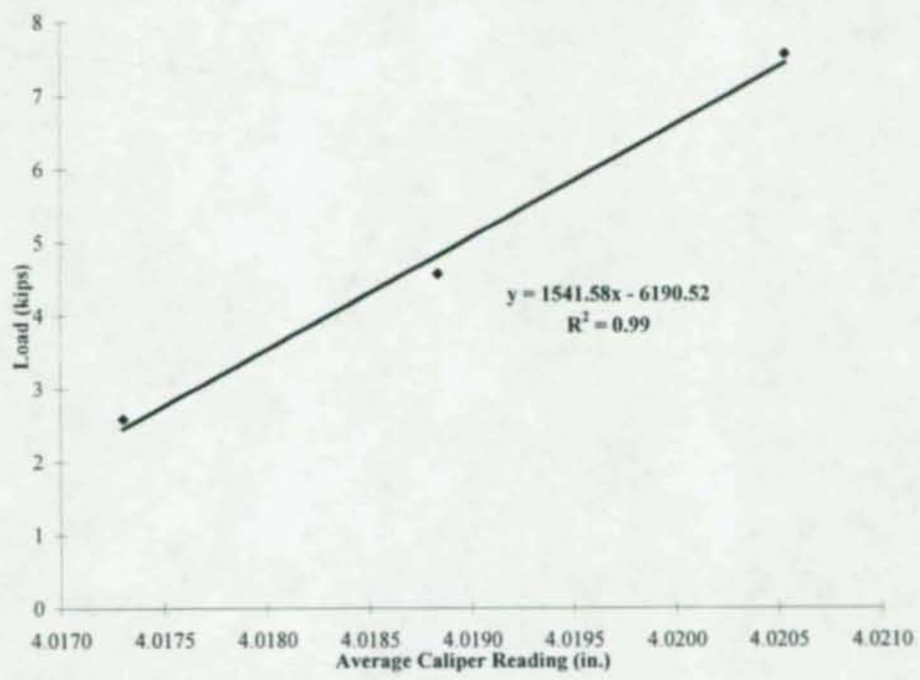
Test No. 13
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					4.0157	0.0000	0.0000
1	2.59	4.0172	4.0181	4.0177	0.0003	4.0173	0.0016	0.0016
2	4.57	4.0198	4.0191	4.0195	0.0006	4.0188	0.0031	0.0031
3	7.56	4.0222	4.0209	4.0216	0.0010	4.0205	0.0048	0.0048
4	10.16	4.0250	4.0229	4.0240	0.0014	4.0226	0.0069	0.0069
5	12.55	4.0272	4.0247	4.0260	0.0017	4.0243	0.0086	0.0086
6	16.01	4.0311	4.0280	4.0296	0.0022	4.0274	0.0117	0.0117
7	18.99	4.0349	4.0311	4.0330	0.0026	4.0304	0.0148	0.0148
8	20.15	4.0363	4.0360	4.0362	0.0027	4.0334	0.0177	0.0177
9	22.87	4.0403	4.0364	4.0384	0.0031	4.0353	0.0196	0.0196
10	25.55	4.0454	4.0411	4.0433	0.0034	4.0398	0.0241	0.0241
11	27.60	4.0501	4.0460	4.0481	0.0037	4.0443	0.0286	0.0286
12	30.00	4.0577	4.0535	4.0556	0.0040	4.0516	0.0359	0.0359
13	32.50	4.0661	4.0631	4.0646	0.0044	4.0602	0.0445	0.0445
14	35.00	4.0801	4.0773	4.0787	0.0047	4.0740	0.0583	0.0583
15	37.50	4.0990	4.0963	4.0977	0.0050	4.0926	0.0769	0.0769
16	40.00	4.1300	4.1273	4.1287	0.0054	4.1233	0.1076	0.1076
17	41.15	4.1599	4.1580	4.1590	0.0055	4.1534	0.1377	0.1377
18	41.38	4.2095		4.2095	0.0056	4.2039	0.1882	0.1872
19	40.00	4.2532		4.2532	0.0054	4.2478	0.2321	0.2311
20	39.10	4.3000		4.3000	0.0053	4.2947	0.2790	0.2780
21	38.35	4.3379		4.3379	0.0052	4.3327	0.3170	0.3160

INITIAL SLOPE



Test No. 14
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-14 Date: 12/2/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 1
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	2	-	Sheared	47

TEST RESULTS

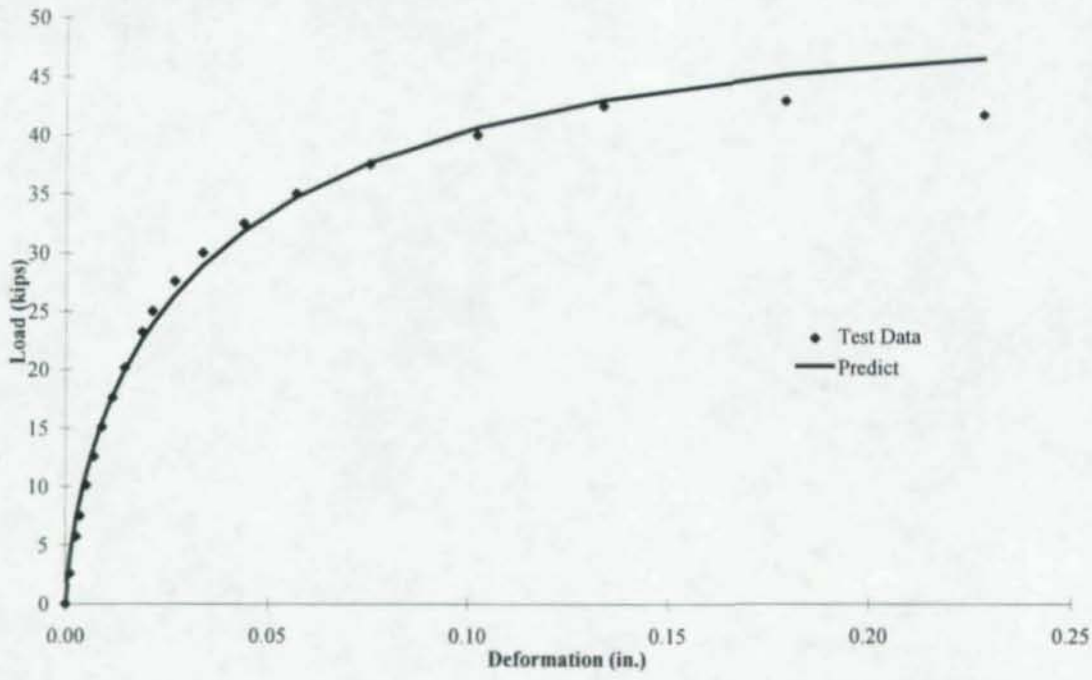
Limit State: Curling
Ki: 2057 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.1792	42.90
Failure:	-	-
Other:	-	-

COMMENTS

Plate started curling in front of bolt around data point 16.
Removed caliper on back of plate to prevent it from being damaged.

LOAD Vs. DEFORMATION CHART



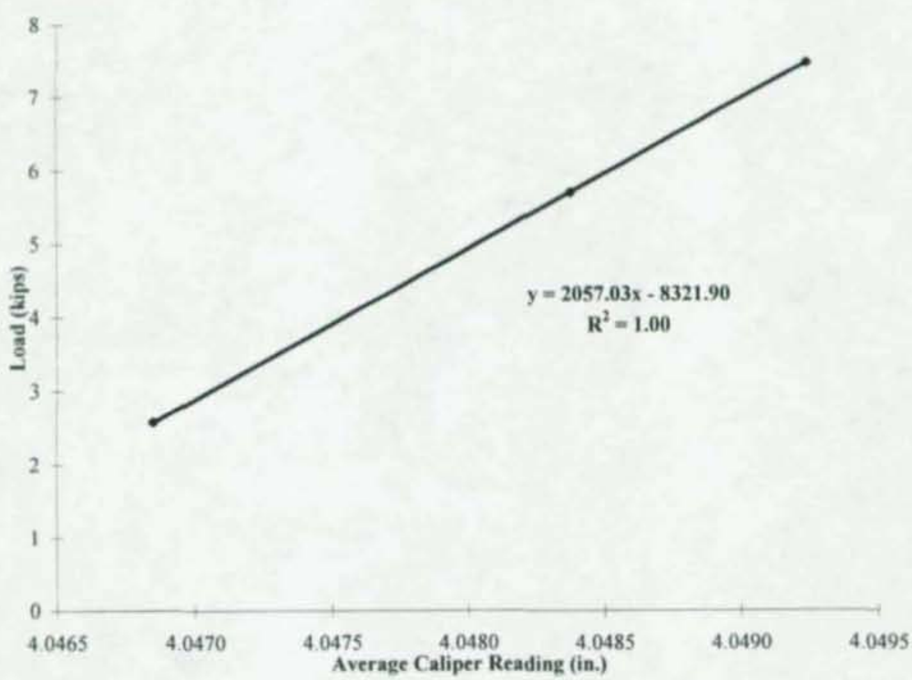
Test No. 14
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					4.0456	0.0000	0.0000
1	2.58	4.0345	4.0599	4.0472	0.0003	4.0469	0.0013	0.0013
2	5.71	4.0362	4.0621	4.0492	0.0008	4.0484	0.0028	0.0028
3	7.49	4.0374	4.0631	4.0503	0.0010	4.0492	0.0036	0.0036
4	10.12	4.0395	4.0649	4.0522	0.0014	4.0508	0.0052	0.0052
5	12.59	4.0415	4.0672	4.0544	0.0017	4.0526	0.0071	0.0071
6	15.12	4.0443	4.0691	4.0567	0.0020	4.0547	0.0091	0.0091
7	17.60	4.0473	4.0718	4.0596	0.0024	4.0572	0.0116	0.0116
8	20.14	4.0509	4.0750	4.0630	0.0027	4.0602	0.0146	0.0146
9	23.24	4.0549	4.0805	4.0677	0.0031	4.0646	0.0190	0.0190
10	25.00	4.0581	4.0828	4.0705	0.0034	4.0671	0.0215	0.0215
11	27.58	4.0640	4.0885	4.0763	0.0037	4.0725	0.0269	0.0269
12	30.00	4.0711	4.0959	4.0835	0.0041	4.0794	0.0339	0.0339
13	32.50	4.0819	4.1062	4.0941	0.0044	4.0897	0.0441	0.0441
14	35.00	4.0952	4.1196	4.1074	0.0047	4.1027	0.0571	0.0571
15	37.50	4.1142	4.1381	4.1262	0.0051	4.1211	0.0755	0.0755
16	40.00	4.1412	4.1654	4.1533	0.0054	4.1479	0.1023	0.1023
17	42.50	4.1730		4.1730	0.0057	4.1673	0.1217	0.1338
18	42.90	4.2185		4.2185	0.0058	4.2127	0.1671	0.1792
19	41.70	4.2675		4.2675	0.0056	4.2619	0.2163	0.2284

INITIAL SLOPE



Test No. 17
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-17

Date: 12/3/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std
Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	5.4	0.25	2	-	Sawed	48

TEST RESULTS

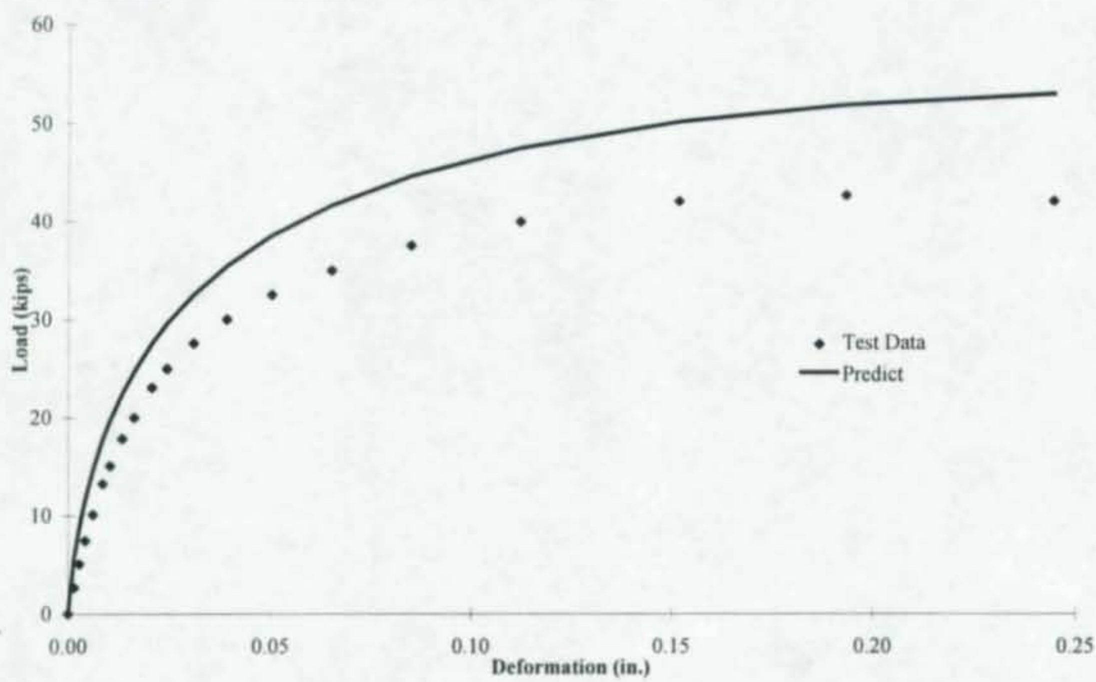
Limit State: Curling
Ki: 1777 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.1934	42.70
Failure:	-	-
Other:	-	-

COMMENTS

Plate started curling in front of bolt around data point 17.
Removed caliper on back of plate to prevent it from being damaged.

LOAD Vs. DEFORMATION CHART



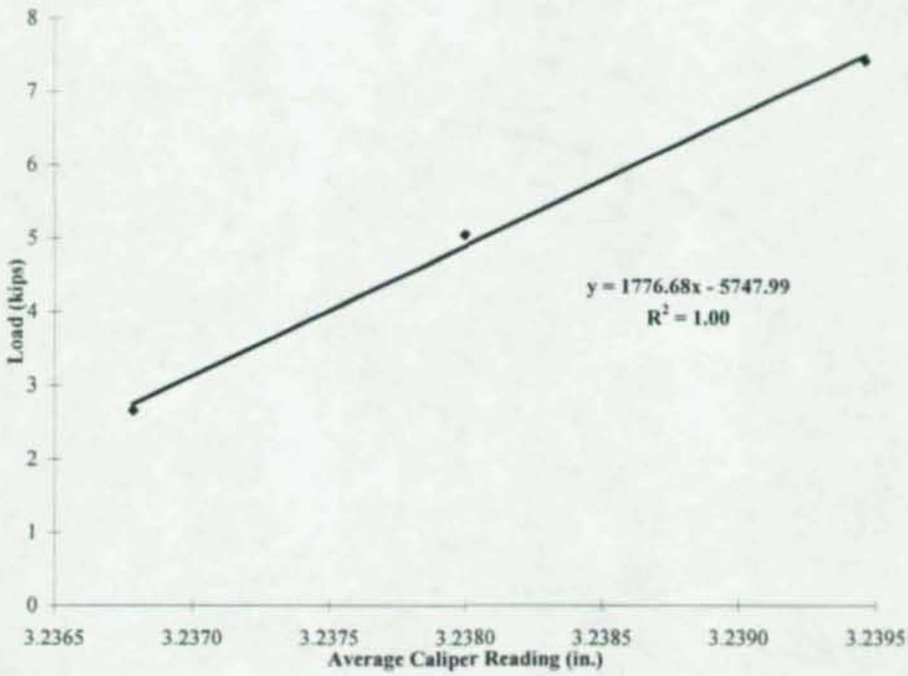
Test No. 17
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.2352	0.0000	0.0000
1	2.66	3.4480	3.0261	3.2371	0.0003	3.2368	0.0015	0.0015
2	5.06	3.4501	3.0269	3.2385	0.0005	3.2380	0.0028	0.0028
3	7.43	3.4523	3.0281	3.2402	0.0007	3.2395	0.0042	0.0042
4	10.10	3.4549	3.0298	3.2424	0.0010	3.2413	0.0061	0.0061
5	13.22	3.4581	3.0321	3.2451	0.0013	3.2438	0.0085	0.0085
6	15.06	3.4603	3.0339	3.2471	0.0015	3.2456	0.0104	0.0104
7	17.81	3.4639	3.0369	3.2504	0.0018	3.2486	0.0134	0.0134
8	20.00	3.4672	3.0398	3.2535	0.0020	3.2515	0.0163	0.0163
9	23.09	3.4723	3.0442	3.2583	0.0023	3.2560	0.0207	0.0207
10	25.00	3.4763	3.0480	3.2622	0.0025	3.2597	0.0244	0.0244
11	27.55	3.4832	3.0546	3.2689	0.0027	3.2662	0.0309	0.0309
12	30.00	3.4919	3.0629	3.2774	0.0030	3.2744	0.0392	0.0392
13	32.50	3.5035	3.0741	3.2888	0.0032	3.2856	0.0503	0.0503
14	35.00	3.5188	3.0891	3.3040	0.0035	3.3005	0.0652	0.0652
15	37.53	3.5388	3.1092	3.3240	0.0037	3.3203	0.0850	0.0850
16	40.00	3.5660	3.1371	3.3516	0.0040	3.3476	0.1123	0.1123
17	42.11	3.6053	3.1772	3.3913	0.0042	3.3871	0.1518	0.1518
18	42.70	3.6469		3.6469	0.0042	3.6427	0.4074	0.1934
19	42.10	3.6981		3.6981	0.0042	3.6939	0.4587	0.2446

INITIAL SLOPE



Test No. 18
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-18 Date: 12/4/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 1
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	5.4	0.25	2	-	Sawed	48

TEST RESULTS

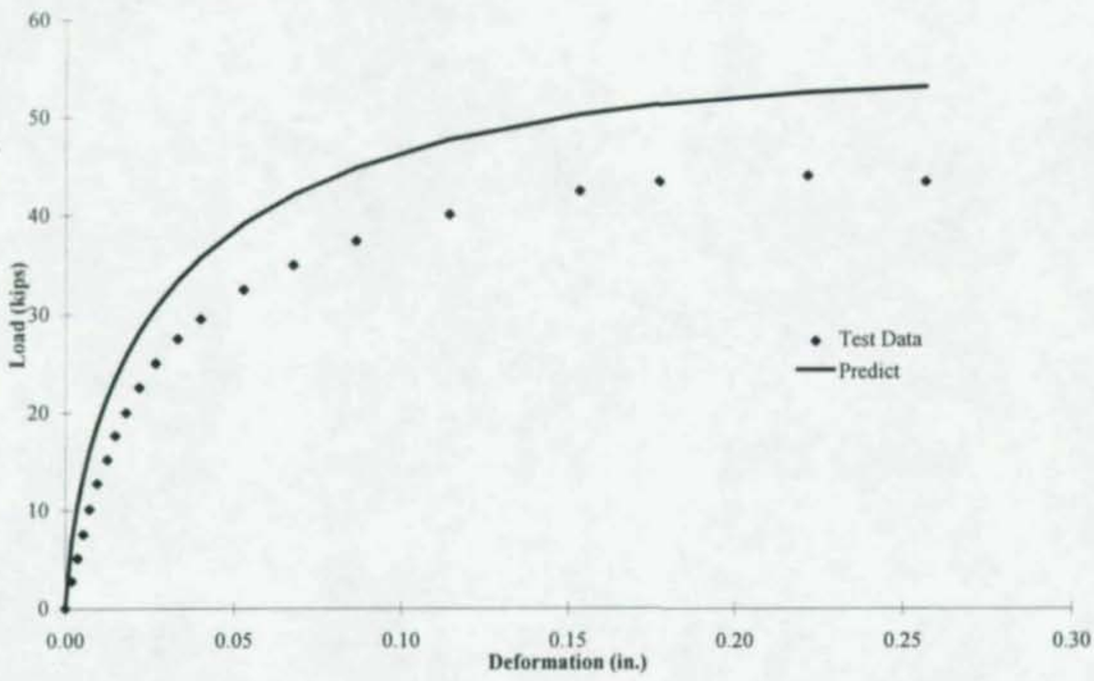
Limit State: Curling
Ki: 1403 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.2216	44.10
Failure:	-	-
Other:	0.250	43.6

COMMENTS

Plate started curling in front of bolt around data point 16.
Removed caliper on back of plate to prevent it from being damaged.

LOAD Vs. DEFORMATION CHART



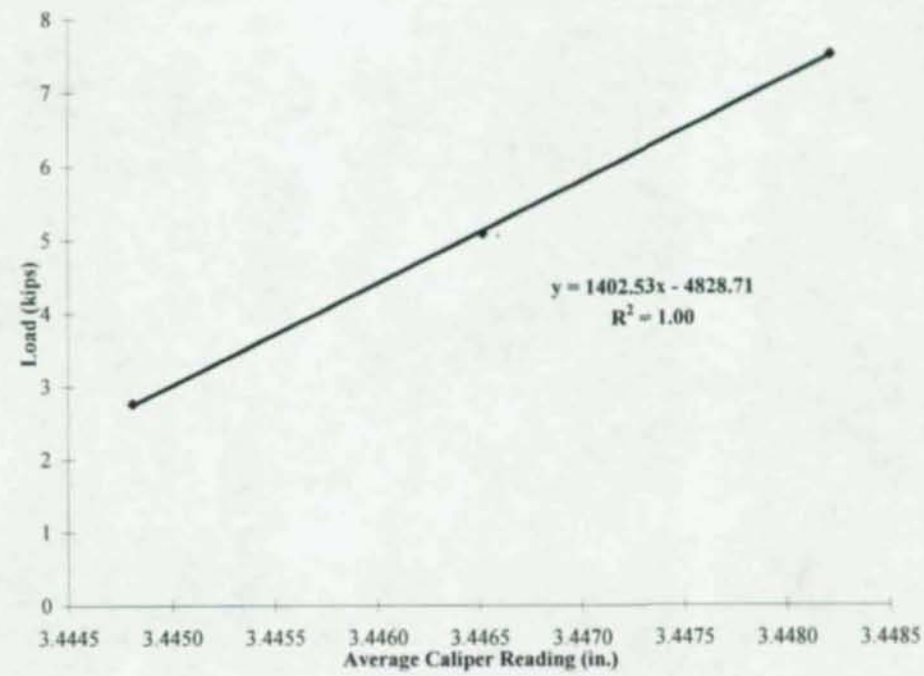
Test No. 18
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

Data Point	Load (kips)	Deflection: Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.4429	0.0000	0.0000
1	2.76	3.4513	3.4389	3.4451	0.0003	3.4448	0.0020	0.0020
2	5.10	3.4531	3.4410	3.4471	0.0005	3.4465	0.0037	0.0037
3	7.53	3.4551	3.4429	3.4490	0.0008	3.4482	0.0054	0.0054
4	10.10	3.4573	3.4449	3.4511	0.0011	3.4500	0.0072	0.0072
5	12.75	3.4600	3.4472	3.4536	0.0013	3.4523	0.0094	0.0094
6	15.17	3.4638	3.4499	3.4569	0.0016	3.4553	0.0124	0.0124
7	17.62	3.4659	3.4530	3.4595	0.0018	3.4576	0.0147	0.0147
8	20.00	3.4694	3.4563	3.4629	0.0021	3.4608	0.0179	0.0179
9	22.58	3.4738	3.4604	3.4671	0.0024	3.4647	0.0219	0.0219
10	25.07	3.4789	3.4655	3.4722	0.0026	3.4696	0.0267	0.0267
11	27.54	3.4858	3.4721	3.4790	0.0029	3.4761	0.0332	0.0332
12	29.55	3.4929	3.4791	3.4860	0.0031	3.4829	0.0401	0.0401
13	32.50	3.5061	3.4921	3.4991	0.0034	3.4957	0.0528	0.0528
14	35.00	3.5212	3.5072	3.5142	0.0037	3.5105	0.0677	0.0677
15	37.45	3.5403	3.5262	3.5333	0.0039	3.5293	0.0865	0.0865
16	40.10	3.5685	3.5545	3.5615	0.0042	3.5573	0.1144	0.1144
17	42.50	3.6076	3.5939	3.6008	0.0044	3.5963	0.1534	0.1534
18	43.50	3.6315	3.6181	3.6248	0.0046	3.6202	0.1774	0.1774
19	44.10	3.6758		3.6758	0.0046	3.6712	0.2283	0.2216
20	43.50	3.7109		3.7109	0.0046	3.7063	0.2635	0.2568

INITIAL SLOPE



Test No. 19
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-19

Date: 12/3/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Diameter (in): 1
Bolt Hole: Std
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	3.5	0.25	2	-	Sawed	48

TEST RESULTS

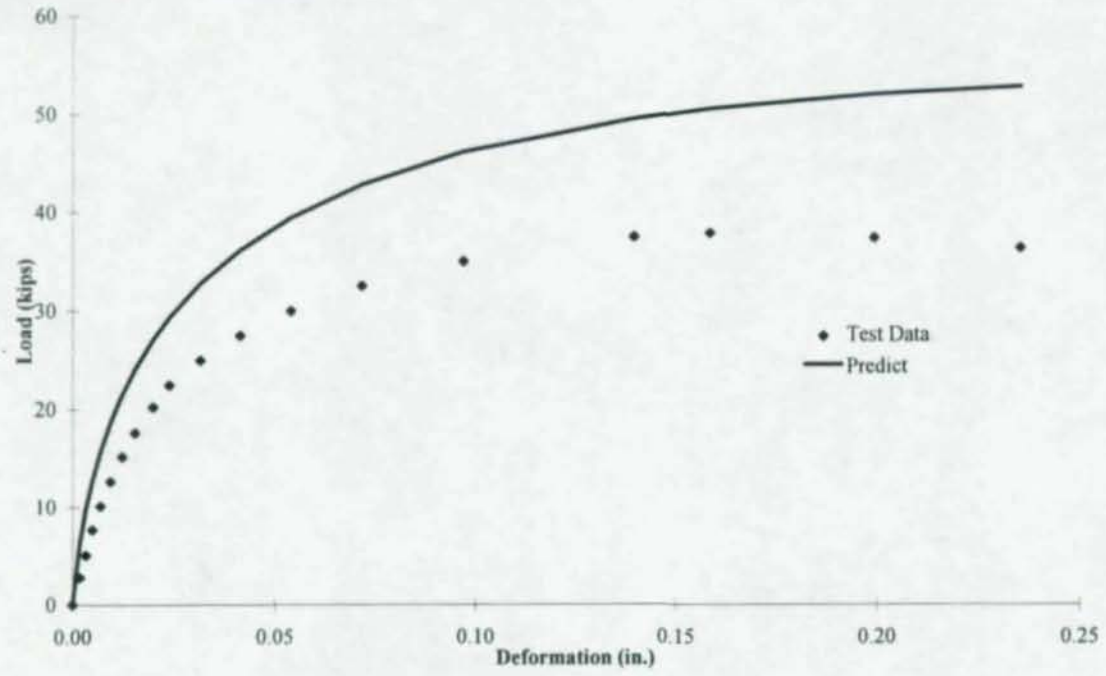
Limit State: Curling
Ki: 1573 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.1585	37.90
Failure:	-	-
Other:	-	-

COMMENTS

Plate started curling in front of bolt around data point 15.
Removed caliper on back of plate to prevent it from being damaged.

LOAD Vs. DEFORMATION CHART



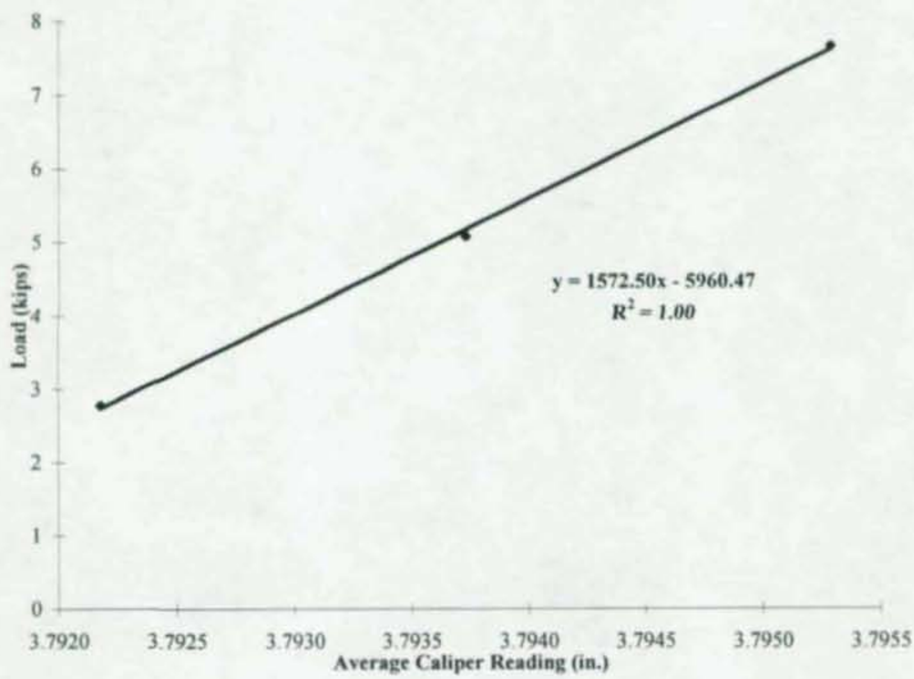
Test No. 19
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.7904	0.0000	0.0000
1	2.78	3.5050	4.0802	3.7926	0.0004	3.7922	0.0017	0.0017
2	5.09	3.5069	4.0821	3.7945	0.0008	3.7937	0.0033	0.0033
3	7.67	3.5091	4.0838	3.7965	0.0012	3.7953	0.0048	0.0048
4	10.10	3.5117	4.0859	3.7988	0.0015	3.7973	0.0068	0.0068
5	12.64	3.5148	4.0885	3.8017	0.0019	3.7997	0.0093	0.0093
6	15.16	3.5181	4.0918	3.8050	0.0023	3.8027	0.0122	0.0122
7	17.58	3.5220	4.0951	3.8086	0.0027	3.8059	0.0154	0.0154
8	20.17	3.5269	4.0999	3.8134	0.0031	3.8103	0.0199	0.0199
9	22.44	3.5308	4.1047	3.8178	0.0034	3.8144	0.0239	0.0239
10	24.98	3.5395	4.1121	3.8258	0.0038	3.8220	0.0316	0.0316
11	27.50	3.5498	4.1223	3.8361	0.0042	3.8319	0.0414	0.0414
12	30.00	3.5629	4.1351	3.8490	0.0045	3.8445	0.0540	0.0540
13	32.50	3.5810	4.1531	3.8671	0.0049	3.8621	0.0717	0.0717
14	35.00	3.6068	4.1787	3.8928	0.0053	3.8875	0.0970	0.0970
15	37.50	3.6498	4.2216	3.9357	0.0057	3.9300	0.1396	0.1396
16	37.90	3.6688	4.2406	3.9547	0.0057	3.9490	0.1585	0.1585
17	37.40	3.7095		3.7095	0.0057	3.7038	-0.0866	0.1993
18	36.40	3.7455		3.7455	0.0055	3.7400	-0.0505	0.2354

INITIAL SLOPE



Test No. 20
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-20

Date: 12/3/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std

Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	3.5	0.25	2	-	Sawed	48

TEST RESULTS

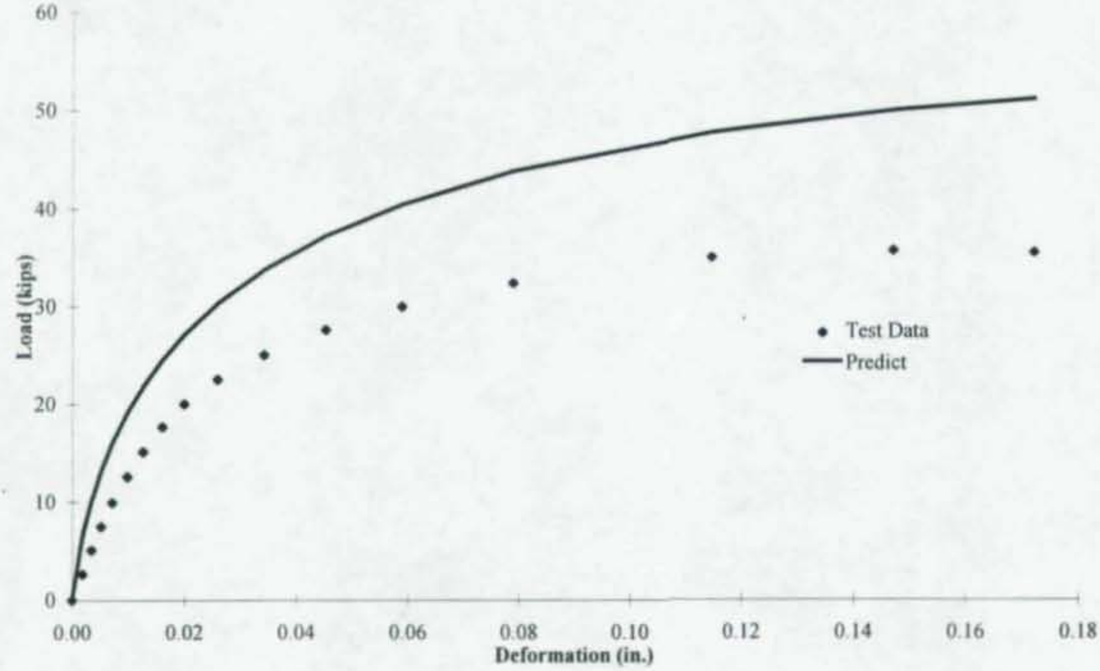
Limit State: Curling
Ki: 1457 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.1471	35.70
Failure:	-	-
Other:	-	-

COMMENTS

Test was loaded then unloaded and reloaded at start because of test machine difficulties.
Plate started curling in front of bolt around data point 14.
Removed caliper on front of plate to prevent it from being damaged.

LOAD Vs. DEFORMATION CHART



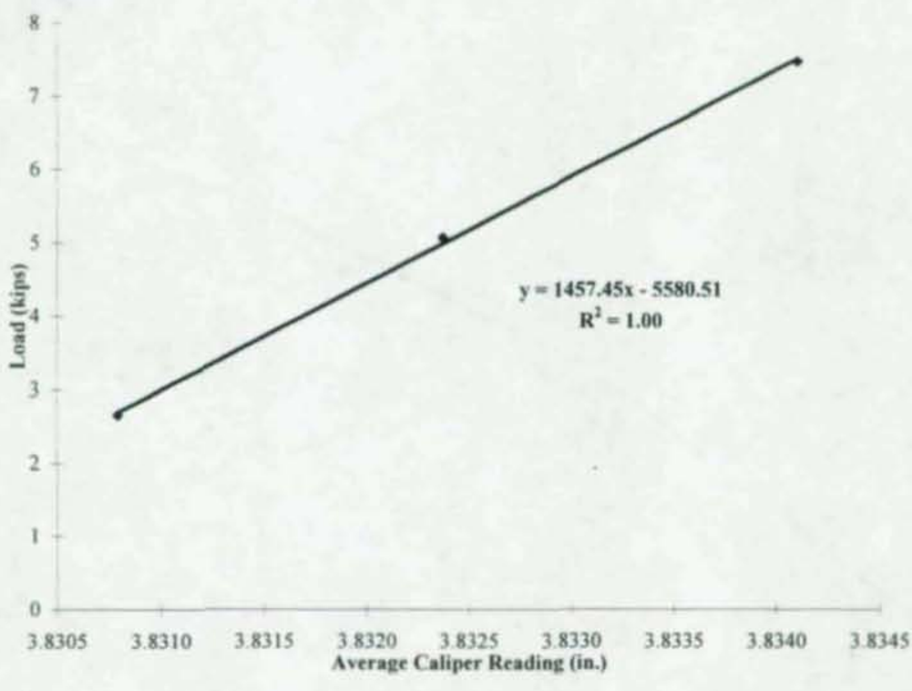
Test No. 20
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.8290	0.0000	0.0000
1	2.65	3.6435	4.0189	3.8312	0.0004	3.8308	0.0018	0.0018
2	5.07	3.6454	4.0209	3.8332	0.0008	3.8324	0.0034	0.0034
3	7.48	3.6476	4.0229	3.8353	0.0011	3.8341	0.0052	0.0052
4	9.92	3.6498	4.0254	3.8376	0.0015	3.8361	0.0071	0.0071
5	12.57	3.6527	4.0286	3.8407	0.0019	3.8387	0.0098	0.0098
6	15.12	3.6558	4.0319	3.8439	0.0023	3.8415	0.0126	0.0126
7	17.65	3.6596	4.0358	3.8477	0.0027	3.8450	0.0160	0.0160
8	20.00	3.6639	4.0400	3.8520	0.0031	3.8489	0.0199	0.0199
9	22.54	3.6701	4.0465	3.8583	0.0034	3.8549	0.0259	0.0259
10	25.06	3.6789	4.0551	3.8670	0.0038	3.8632	0.0342	0.0342
11	27.60	3.6901	4.0667	3.8784	0.0042	3.8742	0.0452	0.0452
12	30.00	3.7042	4.0807	3.8925	0.0046	3.8879	0.0589	0.0589
13	32.42	3.7248	4.1009	3.9129	0.0050	3.9079	0.0789	0.0789
14	35.00	3.7609	4.1369	3.9489	0.0054	3.9435	0.1146	0.1146
15	35.70		4.1695	4.1695	0.0055	4.1640	0.3351	0.1471
16	35.50		4.1945	4.1945	0.0054	4.1891	0.3601	0.1721

INITIAL SLOPE



Test No. 21
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-21

Date: 12/4/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std
Diameter (in): 0.875
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	2	-	Sawed	46

TEST RESULTS

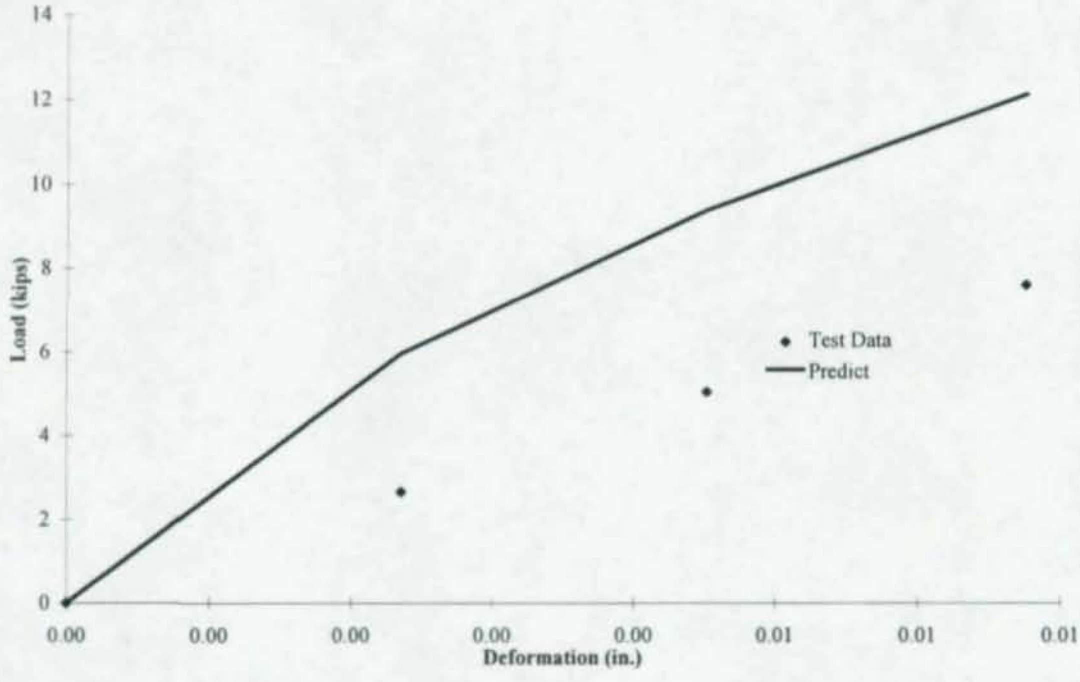
Limit State: Test Setup Limit
Ki: 1124 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.0068	7.60
Failure:	-	-
Other:	-	-

COMMENTS

Test setup limited by bolt bending.

LOAD Vs. DEFORMATION CHART



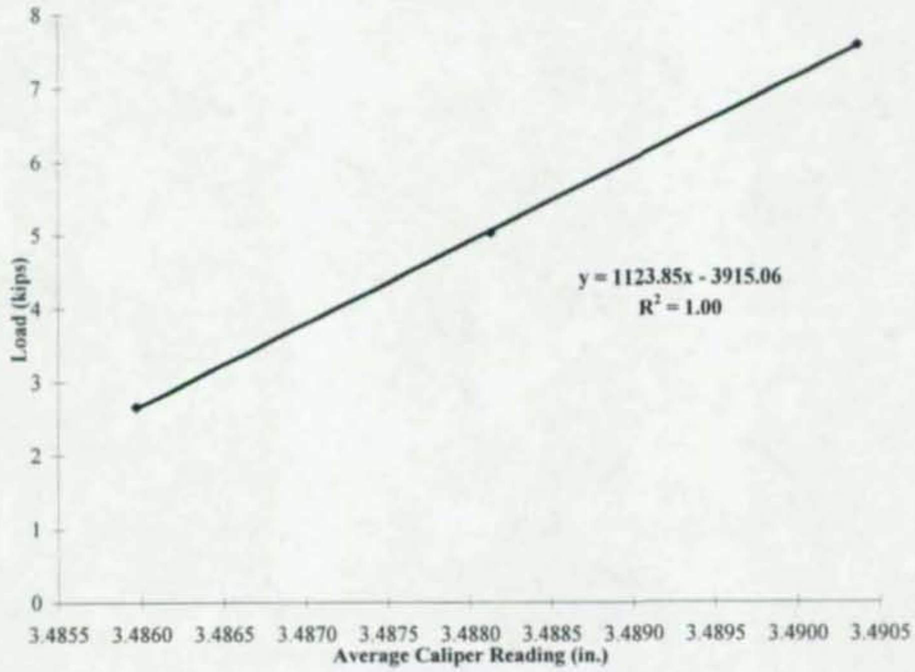
Test No. 21
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.4836	0.0000	0.0000
1	2.66	3.5608	3.4119	3.4864	0.0004	3.4860	0.0024	0.0024
2	5.04	3.5628	3.4149	3.4889	0.0007	3.4881	0.0045	0.0045
3	7.60	3.5651	3.4178	3.4915	0.0011	3.4904	0.0068	0.0068

INITIAL SLOPE



Test No. 22
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-22

Date: 12/4/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std
Diameter (in): 0.875
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	2	-	Sawed	46

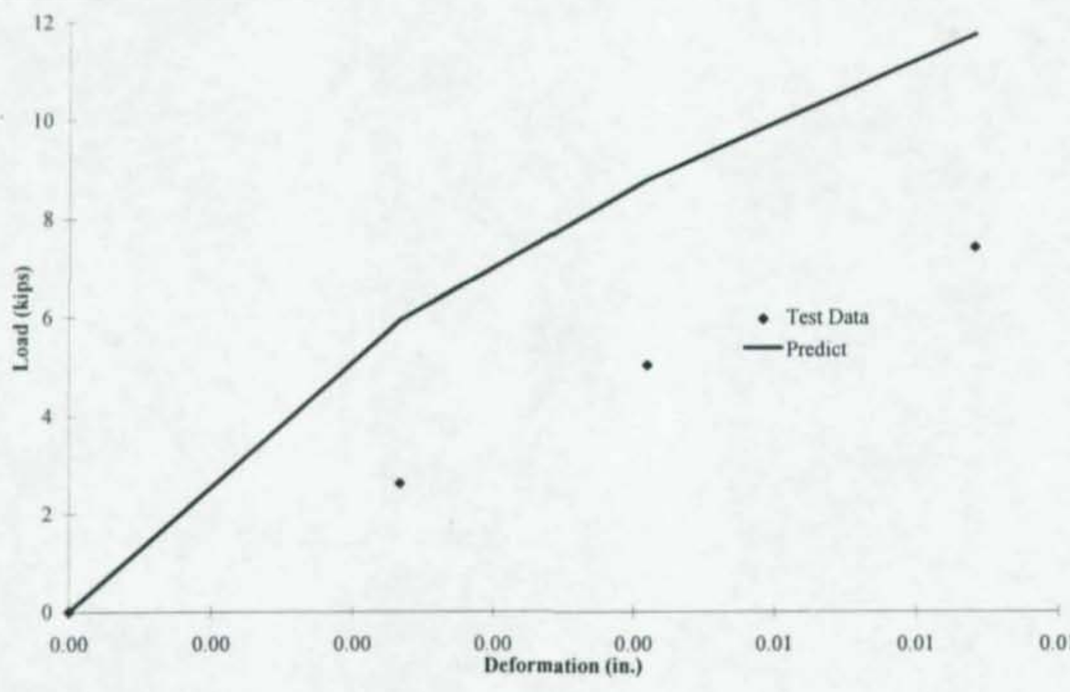
TEST RESULTS

Limit State: Test Setup Limit
Ki: 1172 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.0064	7.43
Failure:	-	-
Other:	-	-

COMMENTS
Test setup limited by bolt bending.

LOAD Vs. DEFORMATION CHART



013365

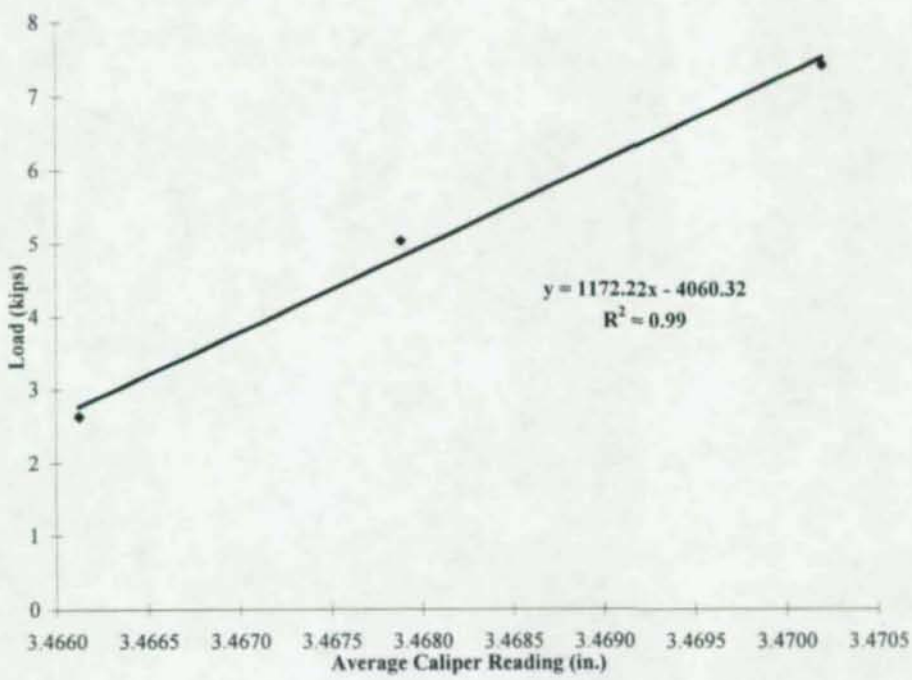
Test No. 22
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.4638	0.0000	0.0000
1	2.63	3.5310	3.4020	3.4665	0.0004	3.4661	0.0023	0.0023
2	5.04	3.5331	3.4041	3.4686	0.0007	3.4679	0.0041	0.0041
3	7.43	3.5358	3.4067	3.4713	0.0011	3.4702	0.0064	0.0064

INITIAL SLOPE



Test No. 23
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-23

Date: 12/4/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std
Diameter (in): 0.75
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	2	-	Sawed	46

TEST RESULTS

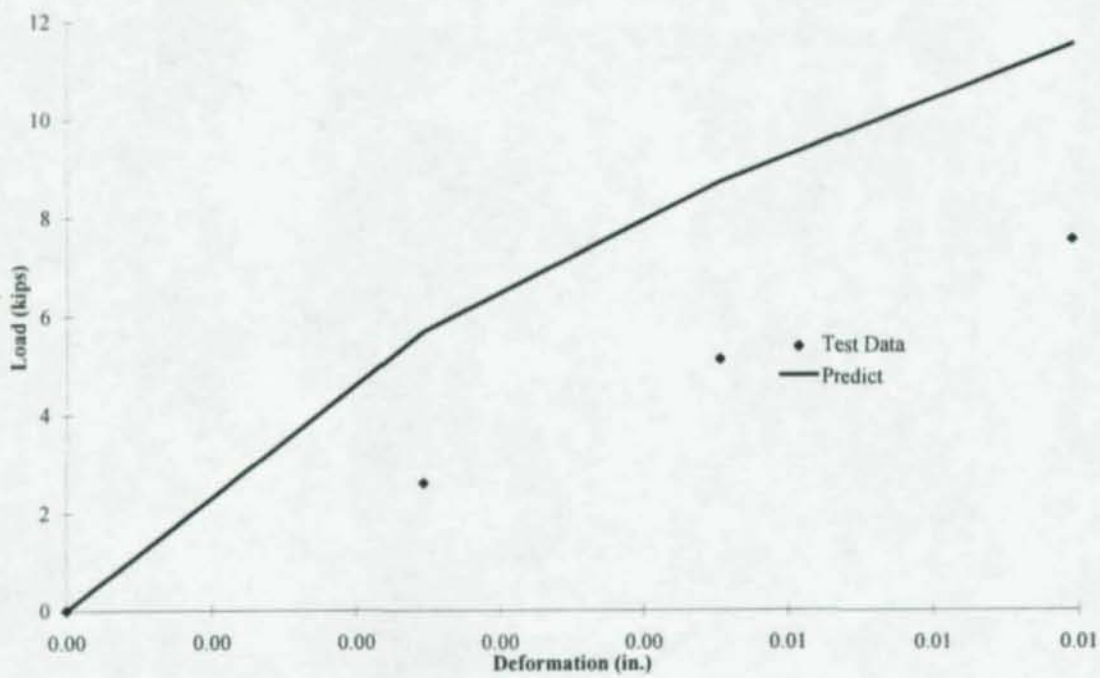
Limit State: Test Setup Limit
Ki: 1098 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.0069	7.55
Failure:	-	-
Other:	-	-

COMMENTS

Test setup limited by bolt bending.

LOAD Vs. DEFORMATION CHART



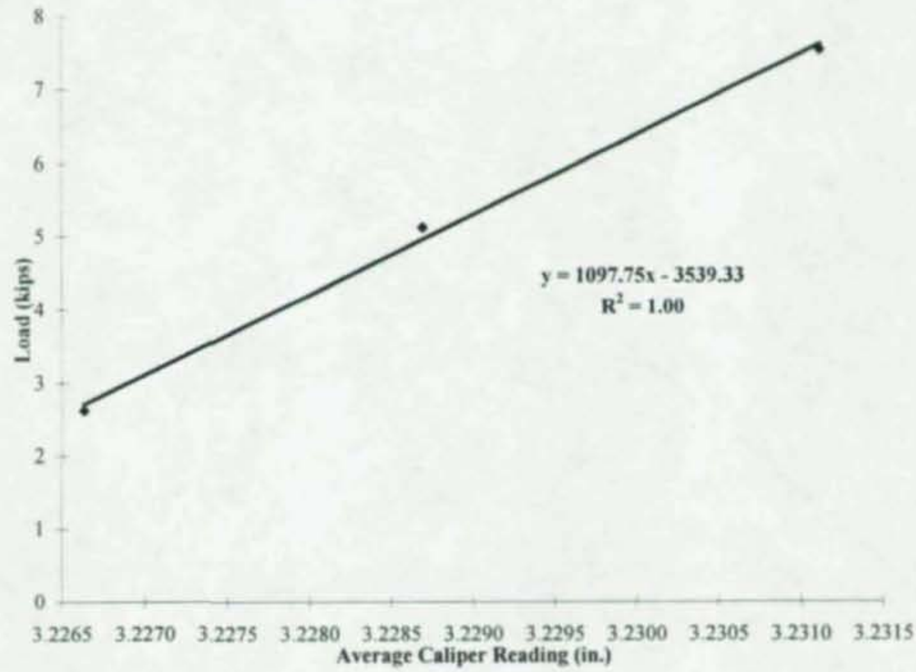
Test No. 23
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

Data Point	Load (kips)	Deflection Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.2242	0.0000	0.0000
1	2.62	3.6037	2.8505	3.2271	0.0005	3.2266	0.0025	0.0025
2	5.13	3.6061	2.8531	3.2296	0.0009	3.2287	0.0045	0.0045
3	7.55	3.6091	2.8558	3.2325	0.0013	3.2311	0.0069	0.0069

INITIAL SLOPE



Test No. 24
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-24

Date: 12/4/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std

Diameter (in): 0.75
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	2	-	Sawed	46

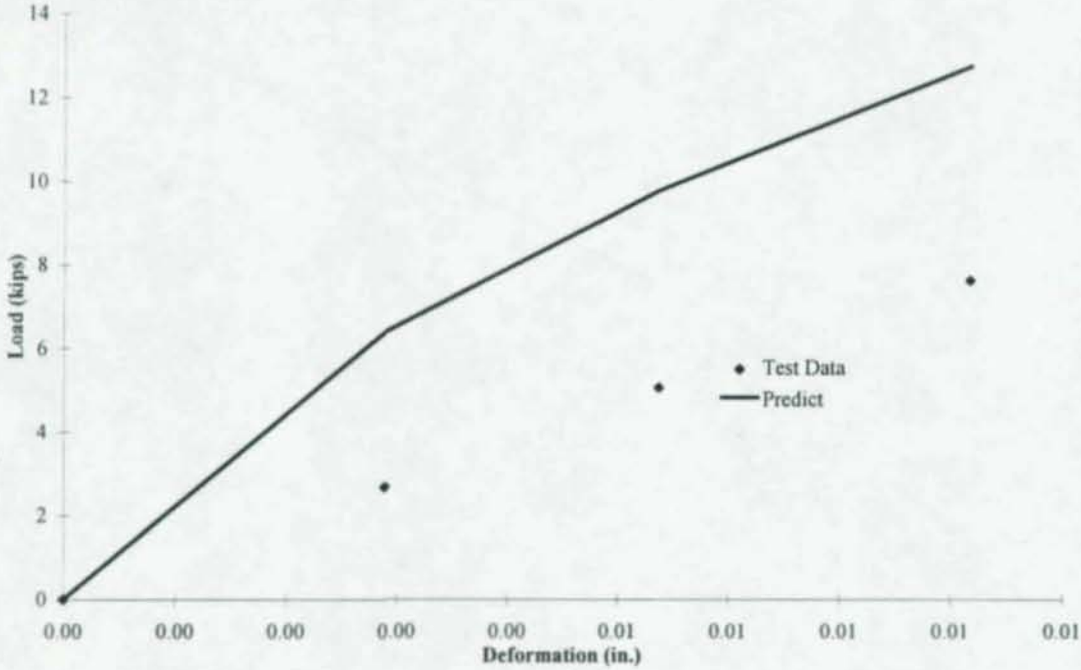
TEST RESULTS

Limit State: Test Setup Limit
Ki: 935 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.0082	7.62
Failure:	-	-
Other:	-	-

COMMENTS
Test setup limited by bolt bending.

LOAD Vs. DEFORMATION CHART



01367

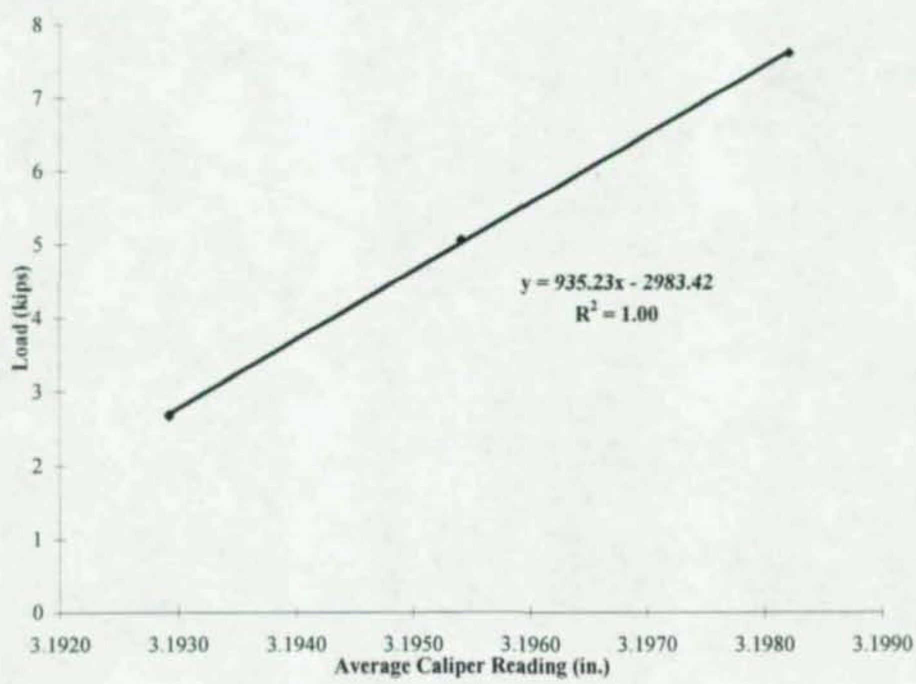
Test No. 24
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.1900	0.0000	0.0000
1	2.68	3.5293	2.8575	3.1934	0.0005	3.1929	0.0029	0.0029
2	5.06	3.5323	2.8603	3.1963	0.0009	3.1954	0.0054	0.0054
3	7.62	3.5355	2.8636	3.1996	0.0013	3.1982	0.0082	0.0082

INITIAL SLOPE



Test No. 25
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-25

Date: 12/4/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std

Diameter (in): 0.875
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	1.75	-	Sawed	46

TEST RESULTS

Limit State: Test Setup Limit

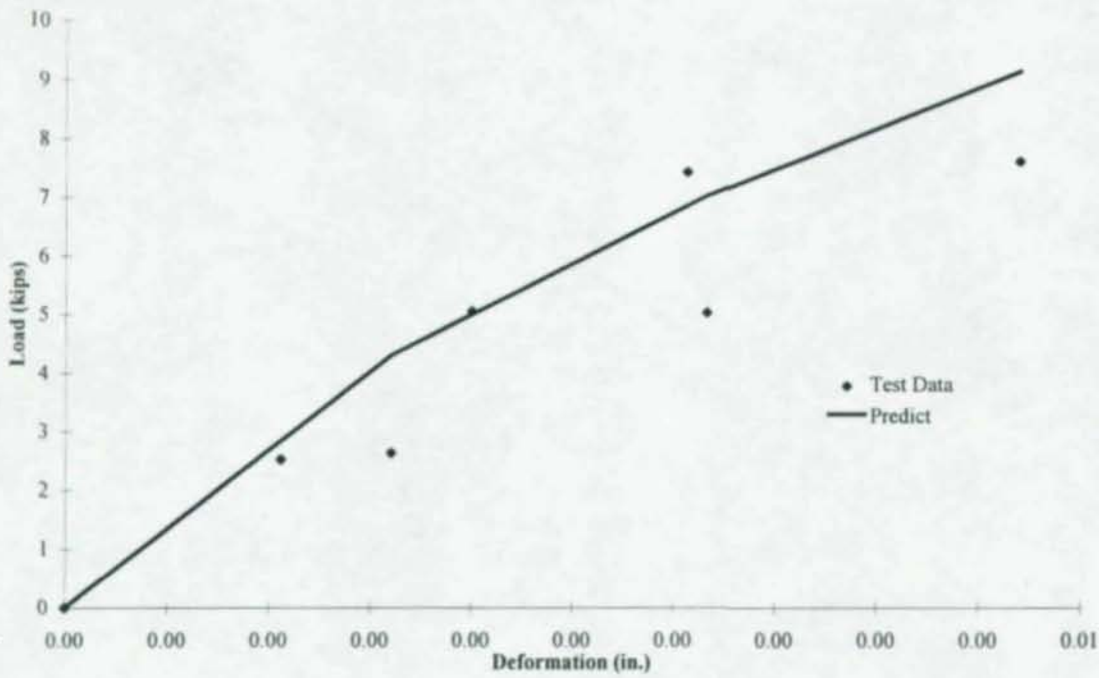
Ki(1):	1611	(kips/in.)
Ki(2):	2441	(kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.0047	7.62
Failure:	-	-
Other:	-	-

COMMENTS

Test setup limited by bolt bending.
Ran initial stiffness twice to determine the effect of loading and unloading.

LOAD Vs. DEFORMATION CHART



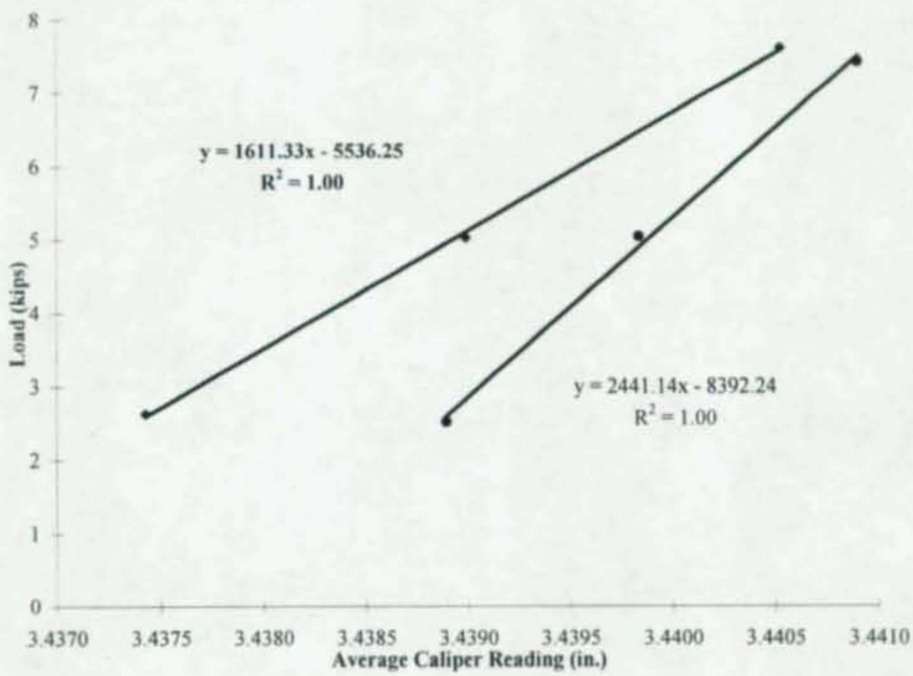
Test No. 25
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.4358	0.0000	0.0000
1	2.63	3.4421	3.4335	3.4378	0.0004	3.4374	0.0016	0.0016
2	5.03	3.4435	3.4359	3.4397	0.0007	3.4390	0.0032	0.0032
3	7.62	3.4452	3.4380	3.4416	0.0011	3.4405	0.0047	0.0047
	0.00			3.4378		3.4378		0.0000
1	2.52	3.4444	3.4341	3.4393	0.0004	3.4389	0.0011	0.0011
2	5.05	3.4450	3.4361	3.4406	0.0007	3.4398	0.0020	0.0020
3	7.43	3.4460	3.4379	3.4420	0.0010	3.4409	0.0031	0.0031

INITIAL SLOPE



Test No. 26
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-26

Date: 12/4/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std

Diameter (in): 0.875
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	1.75	-	Sawed	46

TEST RESULTS

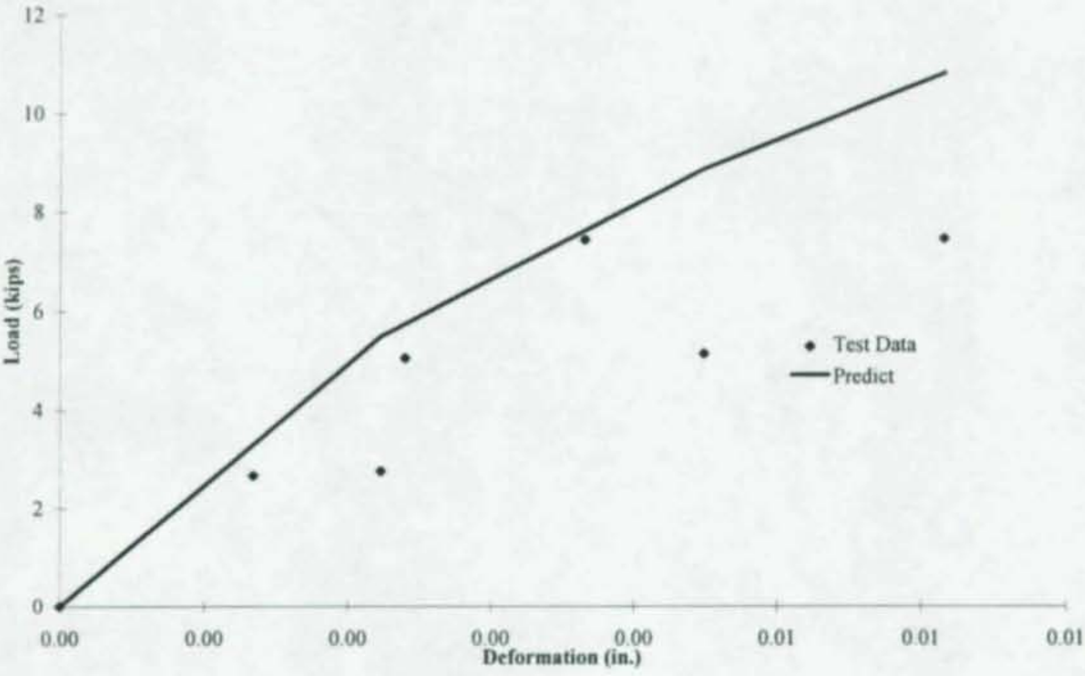
Limit State: Test Setup Limit

				Deformation (in.)	Load (kips)
Ki(1):	1189	(kips/in.)	Maximum:	0.0062	7.46
Ki(2):	2054	(kips/in.)	Failure:	-	-
			Other:	-	-

COMMENTS

Test setup limited by bolt bending.
Ran initial stiffness twice to determine the effect of loading and unloading.

LOAD Vs. DEFORMATION CHART



013 69

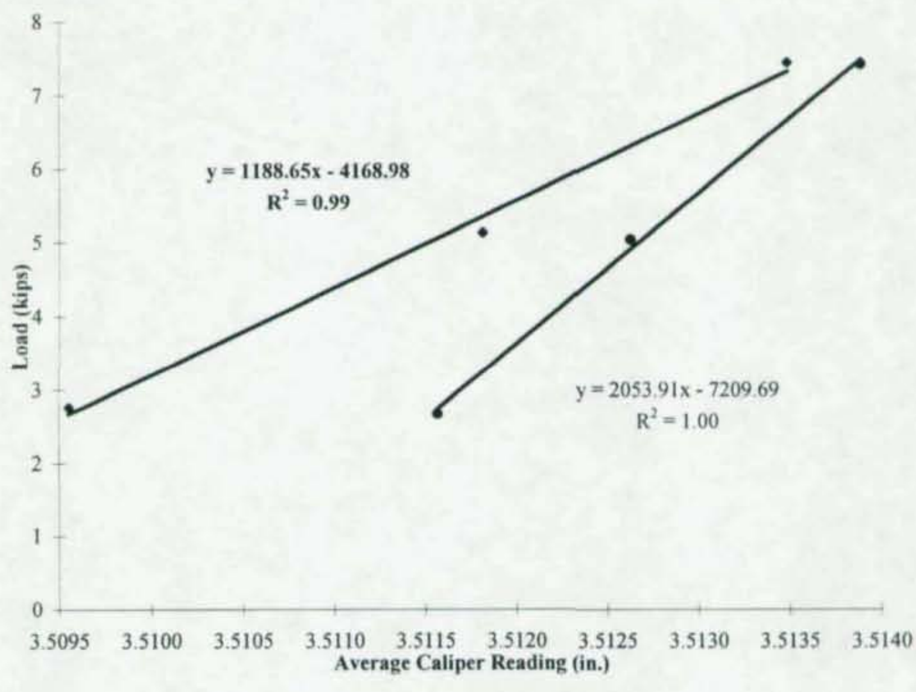
Test No. 26
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.5073	0.0000	0.0000
1	2.76	3.4691	3.5508	3.5100	0.0004	3.5096	0.0022	0.0022
2	5.14	3.4720	3.5531	3.5126	0.0007	3.5118	0.0045	0.0045
3	7.46	3.4741	3.5550	3.5146	0.0011	3.5135	0.0062	0.0062
	0.00					3.5102		0.0000
1	2.67	3.4706	3.5533	3.5120	0.0004	3.5116	0.0013	0.0013
2	5.05	3.4722	3.5545	3.5134	0.0007	3.5126	0.0024	0.0024
3	7.44	3.4740	3.5559	3.5150	0.0011	3.5139	0.0037	0.0037

INITIAL SLOPE



Test No. 27
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-27

Date: 12/4/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 | Diameter (in): 0.75
Bolt Hole: Std | Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	1.5	-	Sawed	46

TEST RESULTS

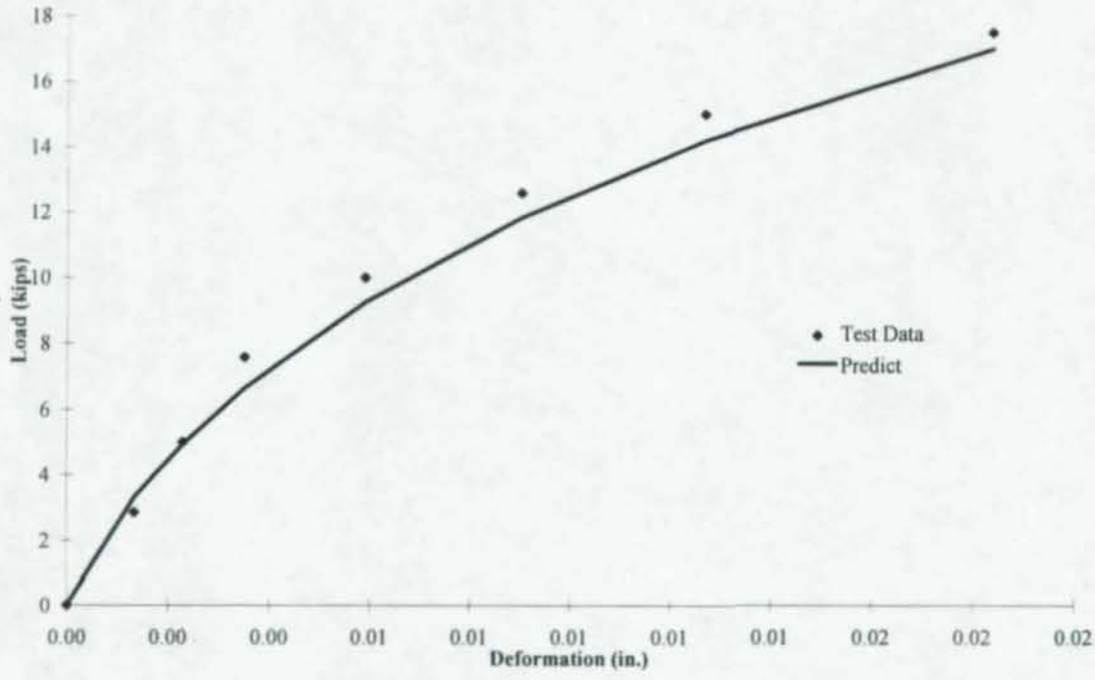
Limit State: Test Setup Limit
Ki: 2160 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.0184	17.50
Failure:	-	-
Other:	-	-

COMMENTS

Test was loaded then unloaded and reloaded at start because of test machine difficulties.
Test setup limited by bolt bending.

LOAD Vs. DEFORMATION CHART



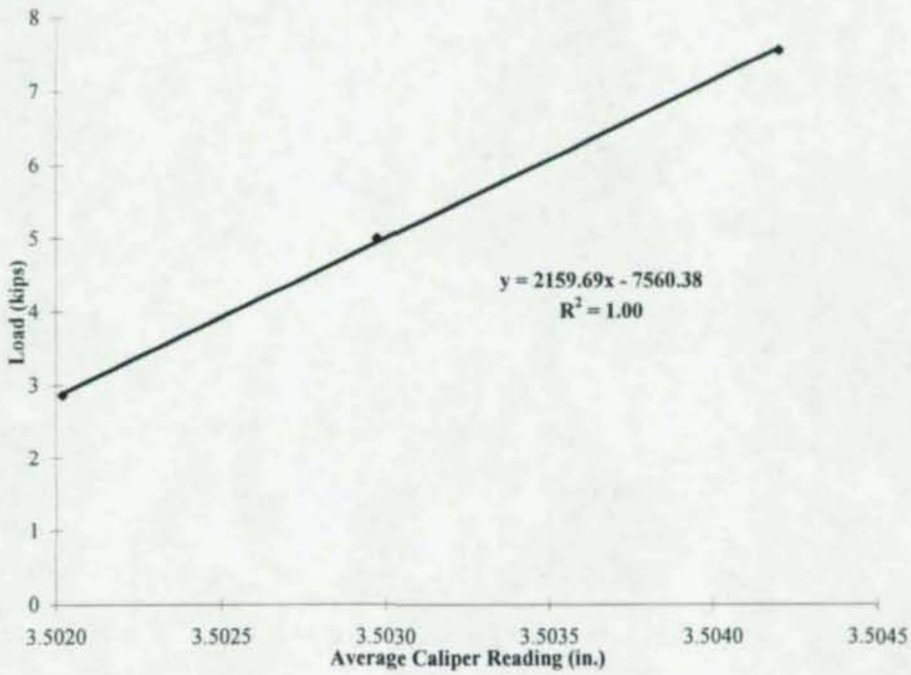
Test No. 27
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.5007	0.0000	0.0000
1	2.86	3.4943	3.5108	3.5026	0.0005	3.5020	0.0013	0.0013
2	5.00	3.4957	3.5121	3.5039	0.0009	3.5030	0.0023	0.0023
3	7.57	3.4973	3.5139	3.5056	0.0014	3.5042	0.0035	0.0035
4	10.00	3.5002	3.5167	3.5085	0.0019	3.5066	0.0059	0.0059
5	12.60	3.5040	3.5201	3.5121	0.0023	3.5097	0.0090	0.0090
6	15.00	3.5083	3.5240	3.5162	0.0028	3.5134	0.0127	0.0127
7	17.50	3.5148	3.5298	3.5223	0.0032	3.5191	0.0184	0.0184

INITIAL SLOPE



Test No. 28
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-28

Date: 12/4/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Diameter (in): 0.75
Bolt Hole: Std
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	4.5	0.25	1.5	-	Sawed	46

TEST RESULTS

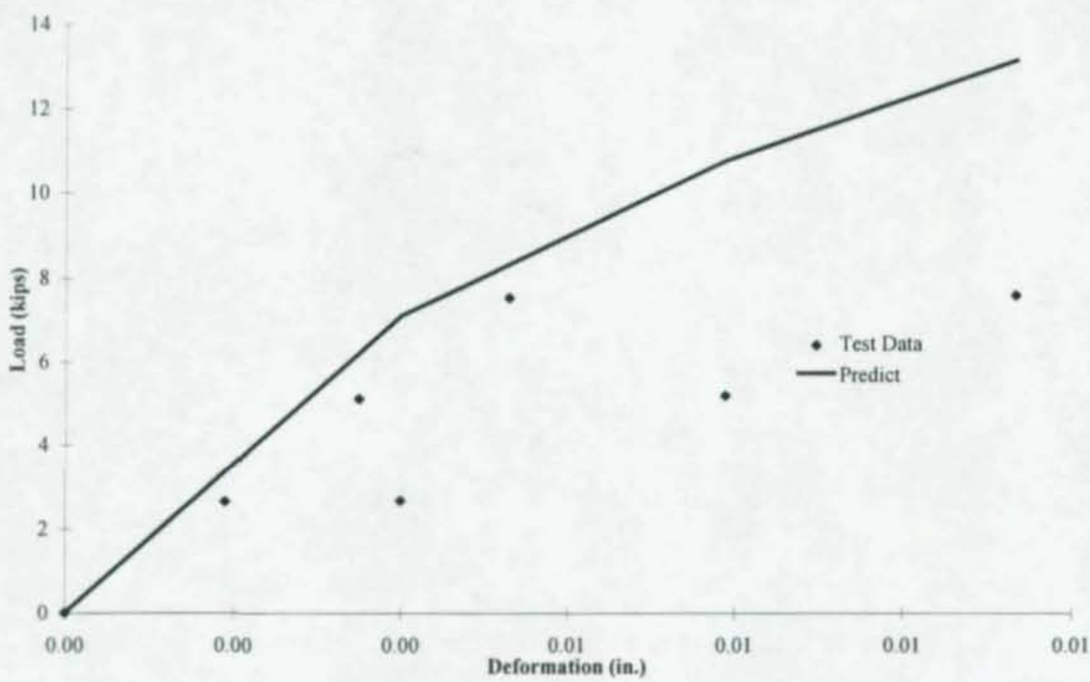
Limit State: Test Setup Limit

				Deformation (in.)	Load (kips)
Ki(1):	669	(kips/in.)	Maximum:	0.0113	7.60
Ki(2):	1438	(kips/in.)	Failure:	-	-
			Other:	-	-

COMMENTS

Test setup limited by bolt bending.
Ran initial stiffness twice to determine the effect of loading and unloading.

LOAD Vs. DEFORMATION CHART



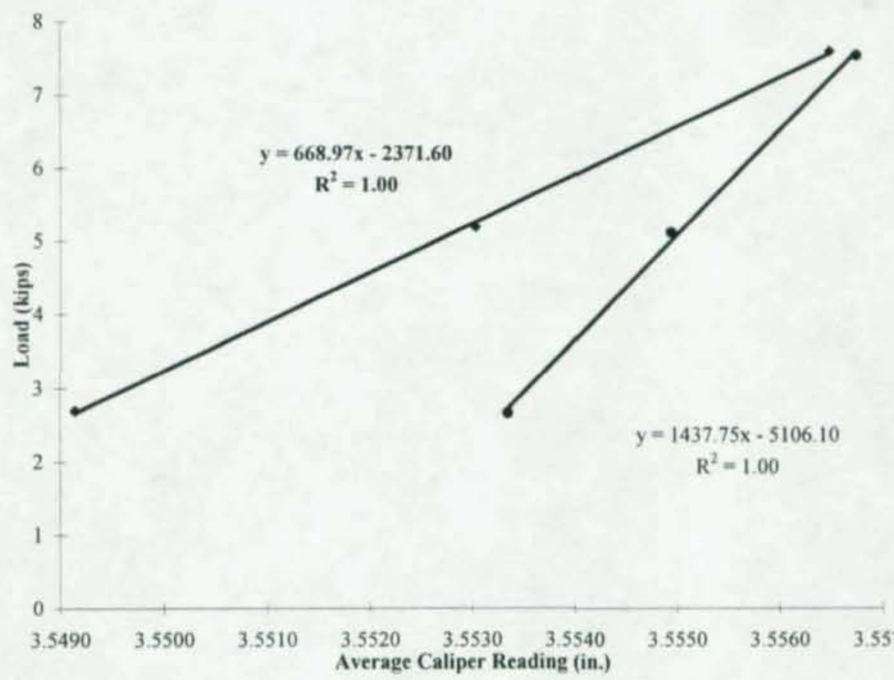
Test No. 28
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.5452	0.0000	0.0000
1	2.69	3.5522	3.5471	3.5497	0.0005	3.5491	0.0040	0.0040
2	5.19	3.5569	3.5511	3.5540	0.0010	3.5530	0.0079	0.0079
3	7.60	3.5609	3.5549	3.5579	0.0014	3.5565	0.0113	0.0113
	0.00					3.5515		0.0000
1	2.66	3.5566	3.5511	3.5539	0.0005	3.5534	0.0019	0.0019
2	5.12	3.5588	3.5530	3.5559	0.0010	3.5549	0.0035	0.0035
3	7.54	3.5611	3.5552	3.5582	0.0014	3.5567	0.0053	0.0053

INITIAL SLOPE



Test No. 29
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-29

Date: 12/5/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std
Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
S26	5	0.375	1.5	-	Sheared	25

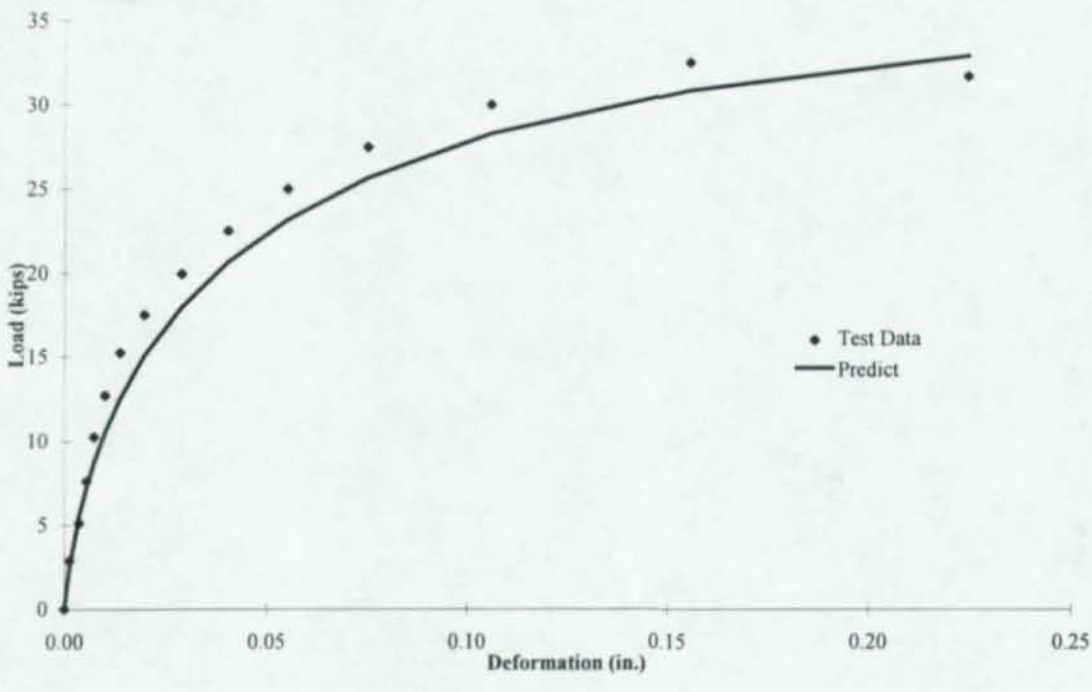
TEST RESULTS

Limit State: Splitting
Ki: 1393 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.1557	32.53
Failure:	0.106	30.00
Other:	-	-

COMMENTS
Splitting along free edge of plate noticed around data point 12.
Splitting propogated toward bolt hole.
Test stopped when load started dropping

LOAD Vs. DEFORMATION CHART



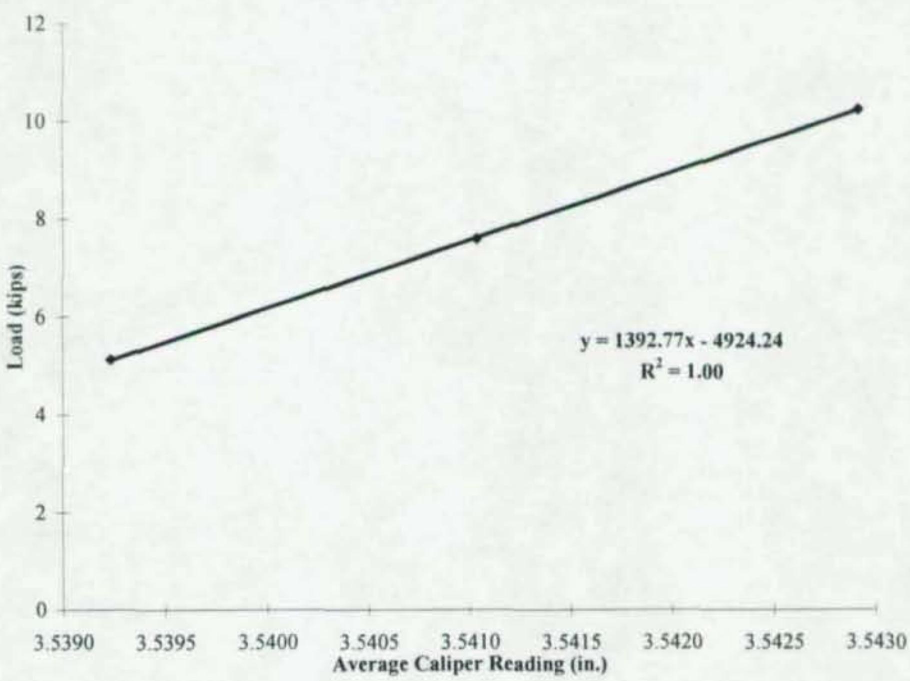
Test No. 29
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.5356	0.0000	0.0000
1	2.88	3.4980	3.5762	3.5371	0.0003	3.5368	0.0012	0.0012
2	5.12	3.5009	3.5786	3.5398	0.0005	3.5392	0.0037	0.0037
3	7.59	3.5034	3.5802	3.5418	0.0008	3.5410	0.0055	0.0055
4	10.25	3.5058	3.5821	3.5440	0.0010	3.5429	0.0073	0.0073
5	12.72	3.5089	3.5849	3.5469	0.0013	3.5456	0.0100	0.0100
6	15.25	3.5131	3.5886	3.5509	0.0015	3.5493	0.0137	0.0137
7	17.52	3.5195	3.5947	3.5571	0.0018	3.5553	0.0198	0.0198
8	19.97	3.5291	3.6039	3.5665	0.0020	3.5645	0.0289	0.0289
9	22.51	3.5411	3.6156	3.5784	0.0023	3.5761	0.0405	0.0405
10	25.00	3.5562	3.6305	3.5934	0.0025	3.5908	0.0553	0.0553
11	27.46	3.5768	3.6503	3.6136	0.0028	3.6108	0.0752	0.0752
12	30.00	3.6081	3.6812	3.6447	0.0030	3.6416	0.1061	0.1061
13	32.53	3.6580	3.7311	3.6946	0.0033	3.6913	0.1557	0.1557
14	31.70	3.7269	3.7998	3.7634	0.0032	3.7602	0.2246	0.2246

INITIAL SLOPE



Test No. 30
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-30

Date: 12/5/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std

Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
S27	5	0.375	1.5	-	Sheared	25

TEST RESULTS

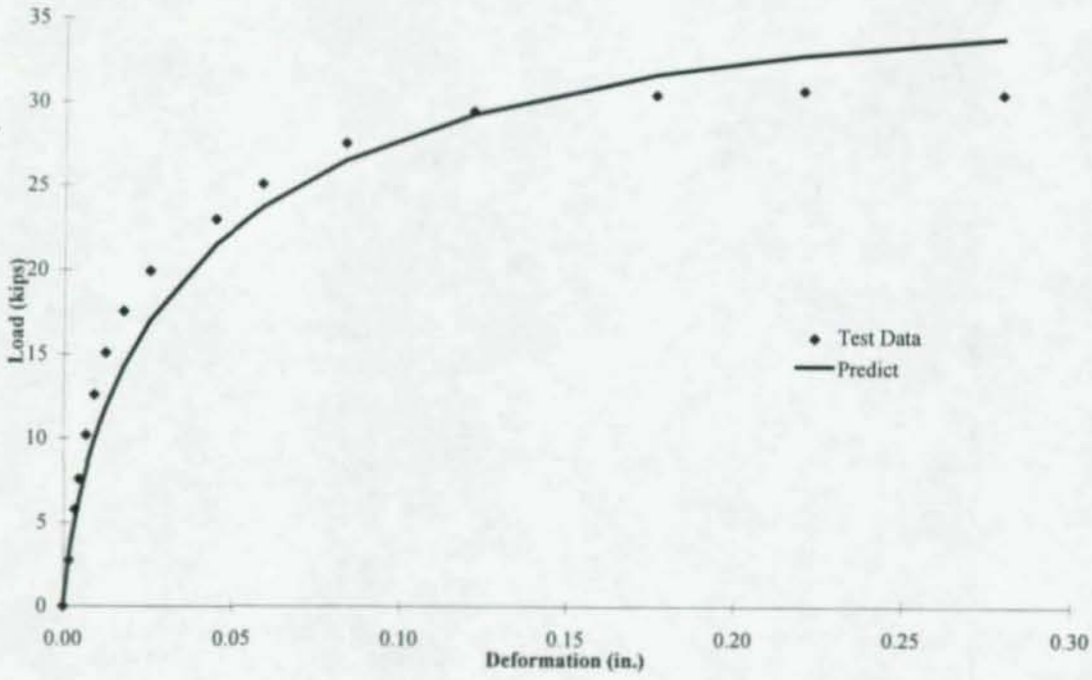
Limit State: Splitting
Ki: 1724 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.2205	30.70
Failure:	0.045	23.00
Other:	0.250	30.6

COMMENTS

Splitting along free edge of plate noticed around data point 9.
Splitting propogated toward bolt hole.
Test stopped when load started dropping

LOAD Vs. DEFORMATION CHART



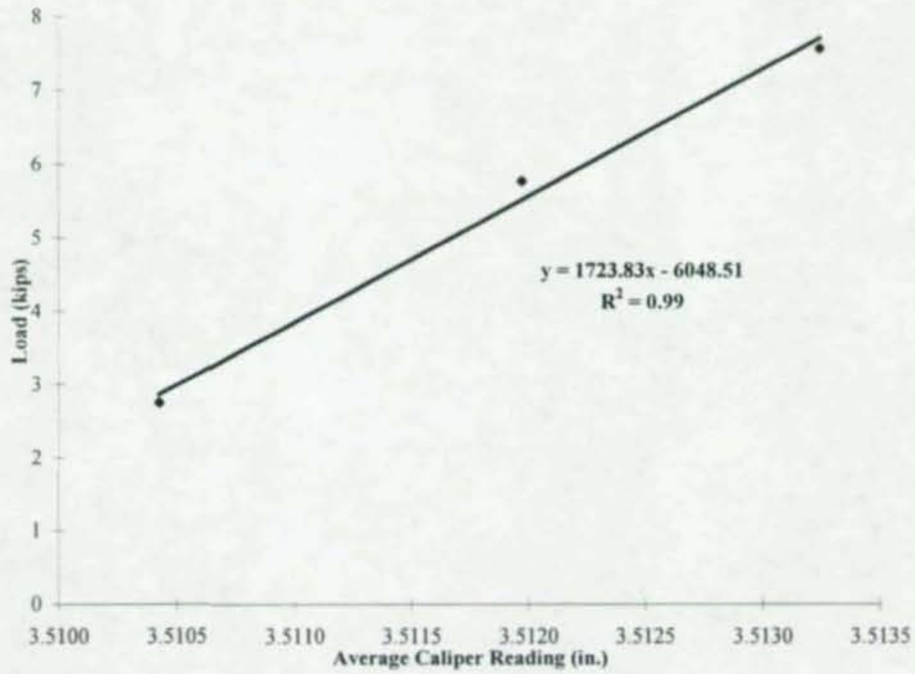
Test No. 30
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.5088	0.0000	0.0000
1	2.75	3.5569	3.4645	3.5107	0.0003	3.5104	0.0017	0.0017
2	5.78	3.5584	3.4667	3.5126	0.0006	3.5120	0.0032	0.0032
3	7.58	3.5599	3.4681	3.5140	0.0008	3.5132	0.0045	0.0045
4	10.19	3.5623	3.4706	3.5165	0.0010	3.5154	0.0067	0.0067
5	12.58	3.5650	3.4732	3.5191	0.0013	3.5178	0.0091	0.0091
6	15.07	3.5686	3.4765	3.5226	0.0015	3.5210	0.0123	0.0123
7	17.52	3.5741	3.4820	3.5281	0.0018	3.5263	0.0175	0.0175
8	19.93	3.5823	3.4900	3.5362	0.0020	3.5342	0.0254	0.0254
9	23.00	3.6023	3.5095	3.5559	0.0023	3.5536	0.0448	0.0448
10	25.06	3.6165	3.5235	3.5700	0.0025	3.5675	0.0587	0.0587
11	27.52	3.6418	3.5483	3.5951	0.0028	3.5923	0.0835	0.0835
12	29.43	3.6801	3.5869	3.6335	0.0029	3.6306	0.1218	0.1218
13	30.44	3.7350	3.6415	3.6883	0.0030	3.6852	0.1764	0.1764
14	30.70	3.7792	3.6855	3.7324	0.0031	3.7293	0.2205	0.2205
15	30.50	3.8384	3.7445	3.7915	0.0031	3.7884	0.2796	0.2796

INITIAL SLOPE



Test No. 31
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-31

Date: 12/5/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std

Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
S40	5	0.5	1.5	-	Sawed	11

TEST RESULTS

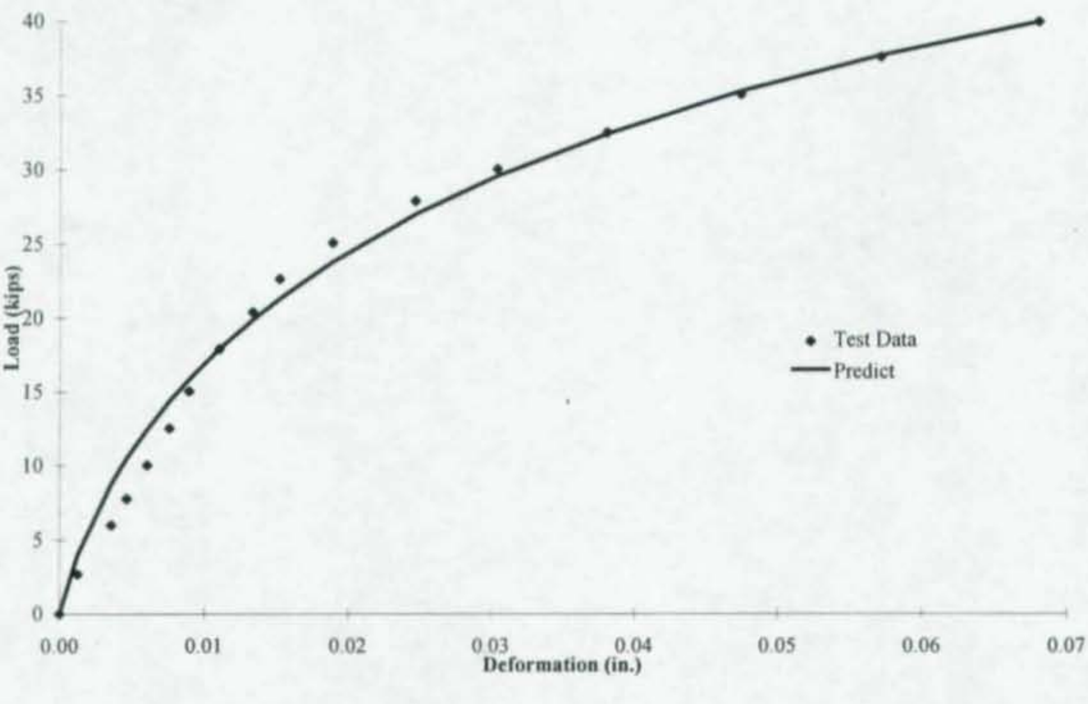
Limit State: Test Setup Limit
Ki: 1670 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.0680	39.95
Failure:	-	-
Other:	-	-

COMMENTS

Test setup limited by bolt bending.

LOAD Vs. DEFORMATION CHART



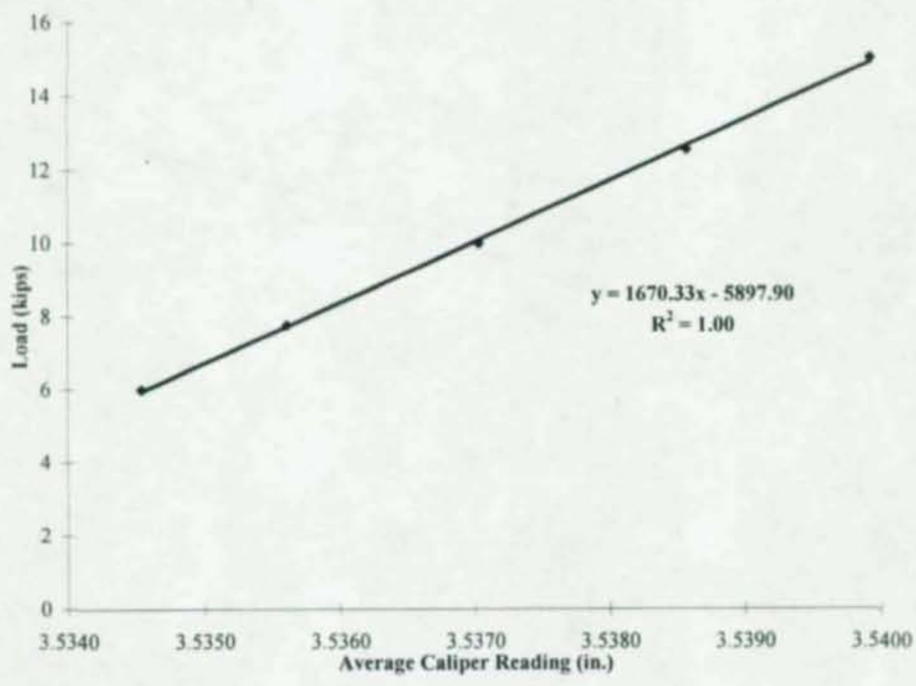
Test No. 31
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.5310	0.0000	0.0000
1	2.69	3.5499	3.5151	3.5325	0.0003	3.5322	0.0012	0.0012
2	6.00	3.5528	3.5175	3.5352	0.0006	3.5345	0.0036	0.0036
3	7.77	3.5542	3.5186	3.5364	0.0008	3.5356	0.0046	0.0046
4	10.02	3.5560	3.5201	3.5381	0.0010	3.5370	0.0061	0.0061
5	12.57	3.5578	3.5219	3.5399	0.0013	3.5386	0.0076	0.0076
6	15.06	3.5594	3.5235	3.5415	0.0015	3.5399	0.0089	0.0089
7	17.90	3.5620	3.5257	3.5439	0.0018	3.5420	0.0111	0.0111
8	20.38	3.5648	3.5280	3.5464	0.0021	3.5443	0.0134	0.0134
9	22.61	3.5670	3.5300	3.5485	0.0023	3.5462	0.0152	0.0152
10	25.05	3.5711	3.5338	3.5525	0.0025	3.5499	0.0189	0.0189
11	27.88	3.5775	3.5395	3.5585	0.0028	3.5557	0.0247	0.0247
12	30.06	3.5838	3.5451	3.5645	0.0030	3.5614	0.0304	0.0304
13	32.52	3.5918	3.5529	3.5724	0.0033	3.5691	0.0381	0.0381
14	35.08	3.6015	3.5624	3.5820	0.0036	3.5784	0.0474	0.0474
15	37.60	3.6115	3.5723	3.5919	0.0038	3.5881	0.0571	0.0571
16	39.95	3.6229	3.5832	3.6031	0.0041	3.5990	0.0680	0.0680

INITIAL SLOPE



Test No. 32
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-32

Date: 12/5/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std

Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
S41	5	0.5	1.5	-	Sawed	12

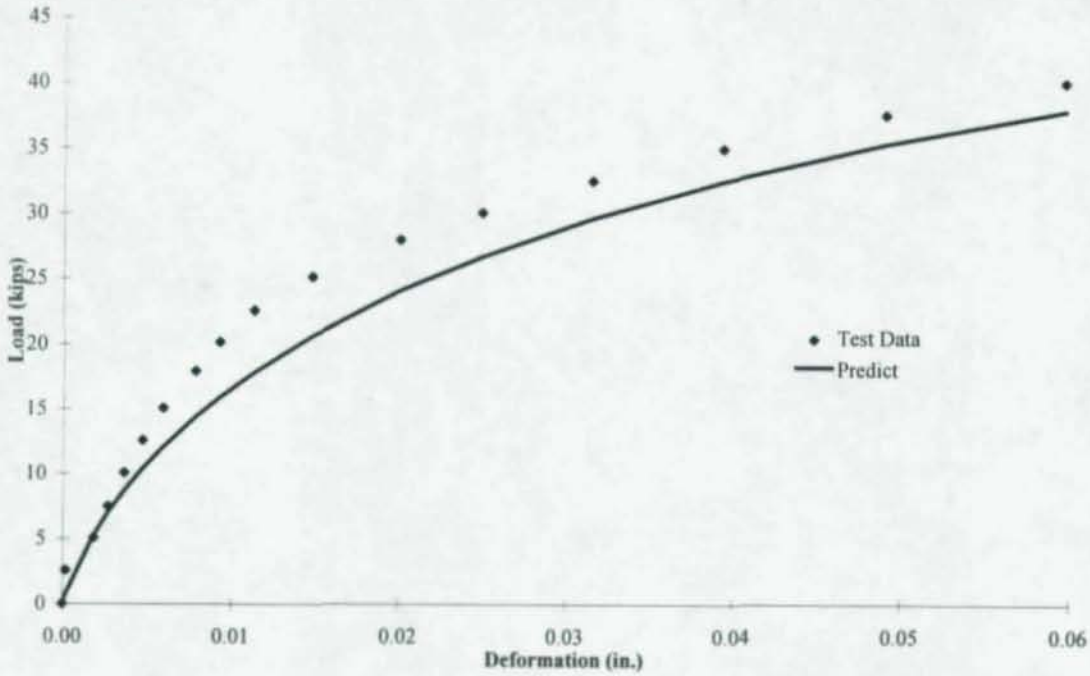
TEST RESULTS

Limit State: Test Setup Limit
Ki: 2779 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.0597	40.03
Failure:	-	-
Other:	-	-

COMMENTS
Test setup limited by bolt bending.

LOAD Vs. DEFORMATION CHART



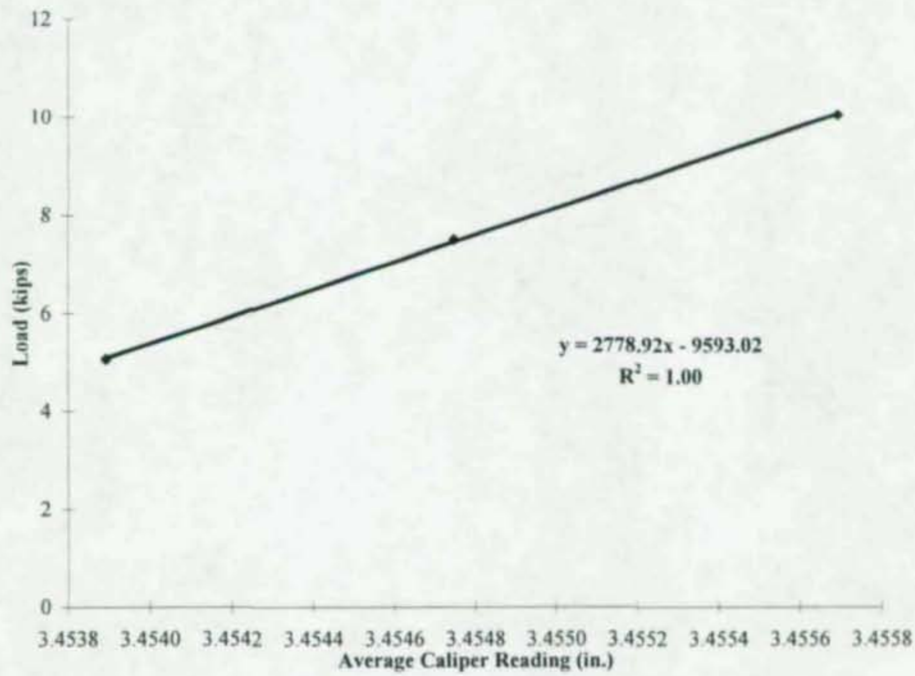
Test No. 32
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Deflection Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.4521	0.0000	0.0000
1	2.59	3.4771	3.4279	3.4525	0.0003	3.4522	0.0002	0.0002
2	5.06	3.4789	3.4299	3.4544	0.0005	3.4539	0.0018	0.0018
3	7.50	3.4799	3.4311	3.4555	0.0008	3.4547	0.0027	0.0027
4	10.06	3.4810	3.4324	3.4567	0.0010	3.4557	0.0036	0.0036
5	12.58	3.4822	3.4339	3.4581	0.0013	3.4568	0.0047	0.0047
6	15.06	3.4838	3.4352	3.4595	0.0015	3.4580	0.0059	0.0059
7	17.93	3.4859	3.4375	3.4617	0.0018	3.4599	0.0078	0.0078
8	20.15	3.4876	3.4391	3.4634	0.0020	3.4613	0.0093	0.0093
9	22.58	3.4899	3.4415	3.4657	0.0023	3.4634	0.0114	0.0114
10	25.15	3.4936	3.4452	3.4694	0.0025	3.4669	0.0148	0.0148
11	28.01	3.4990	3.4509	3.4750	0.0028	3.4721	0.0201	0.0201
12	30.09	3.5041	3.4560	3.4801	0.0030	3.4770	0.0250	0.0250
13	32.53	3.5109	3.4629	3.4869	0.0033	3.4836	0.0316	0.0316
14	34.98	3.5190	3.4709	3.4950	0.0035	3.4914	0.0394	0.0394
15	37.55	3.5289	3.4809	3.5049	0.0038	3.5011	0.0491	0.0491
16	40.03	3.5397	3.4918	3.5158	0.0040	3.5117	0.0597	0.0597

INITIAL SLOPE



Test No. 33
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-33 Date: 12/5/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 1
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
S49	5	0.625	1.3	-	Sawed	43

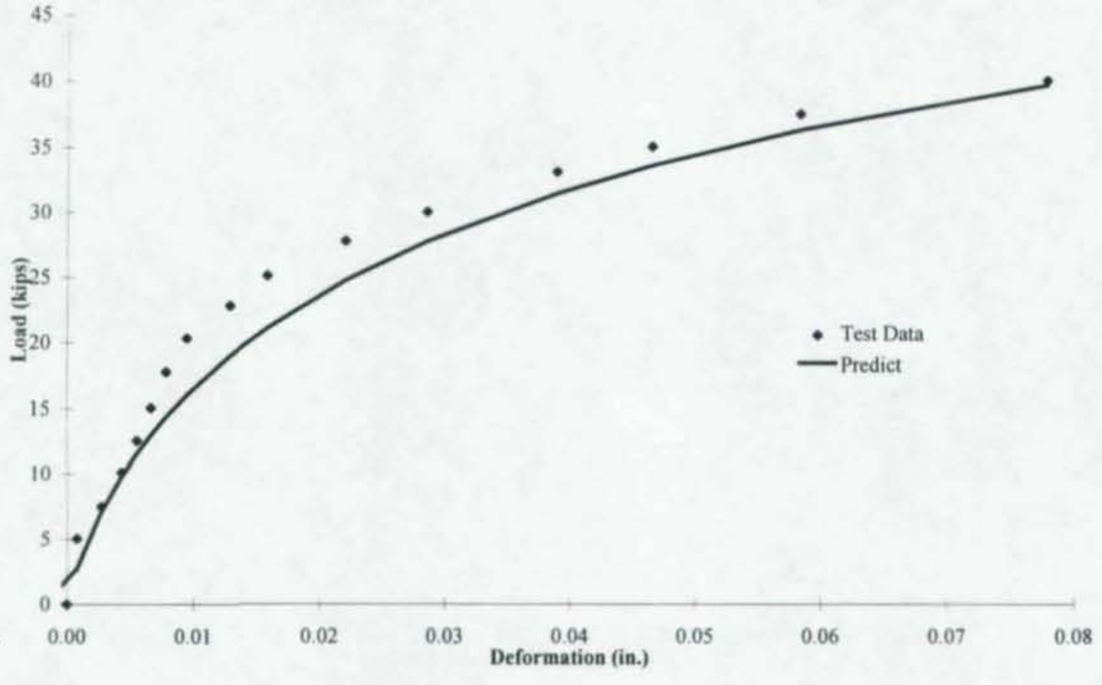
TEST RESULTS

Limit State: Test Setup Limit
Ki: 2265 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.0778	40.01
Failure:	-	-
Other:	-	-

COMMENTS
Test setup limited by bolt bending.

LOAD Vs. DEFORMATION CHART



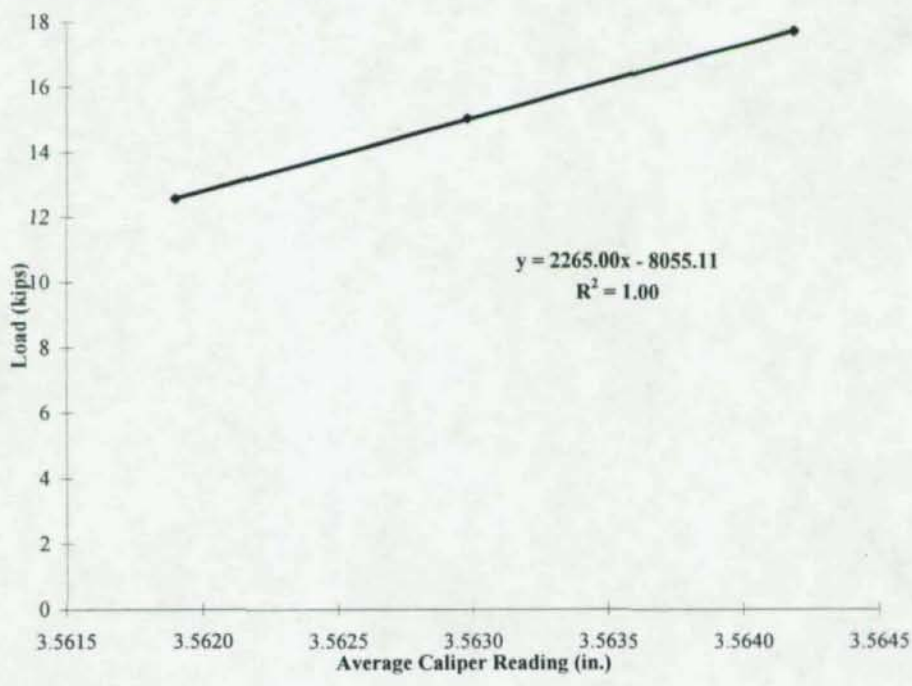
Test No. 33
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.5563	0.0000	0.0000
1	2.69	3.5909	3.5188	3.5549	0.0003	3.5546	-0.0018	-0.0018
2	5.06	3.5939	3.5214	3.5577	0.0005	3.5571	0.0008	0.0008
3	7.52	3.5961	3.5236	3.5599	0.0008	3.5590	0.0027	0.0027
4	10.10	3.5981	3.5253	3.5617	0.0011	3.5606	0.0043	0.0043
5	12.56	3.5994	3.5271	3.5633	0.0014	3.5619	0.0056	0.0056
6	15.05	3.6006	3.5286	3.5646	0.0016	3.5630	0.0066	0.0066
7	17.75	3.6019	3.5303	3.5661	0.0019	3.5642	0.0078	0.0078
8	20.33	3.6034	3.5326	3.5680	0.0022	3.5658	0.0095	0.0095
9	22.84	3.6069	3.5365	3.5717	0.0025	3.5692	0.0129	0.0129
10	25.10	3.6099	3.5399	3.5749	0.0027	3.5722	0.0159	0.0159
11	27.80	3.6161	3.5467	3.5814	0.0030	3.5784	0.0221	0.0221
12	30.03	3.6228	3.5535	3.5882	0.0032	3.5849	0.0286	0.0286
13	33.12	3.6335	3.5642	3.5989	0.0036	3.5953	0.0389	0.0389
14	35.04	3.6411	3.5722	3.6067	0.0038	3.6029	0.0465	0.0465
15	37.48	3.6532	3.5842	3.6187	0.0040	3.6147	0.0583	0.0583
16	40.01	3.6780	3.5989	3.6385	0.0043	3.6341	0.0778	0.0778

INITIAL SLOPE



Test No. 34
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: *SBSP-34* Date: *12/5/95*

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 1
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
S53	5	0.625	2	-	Sawed	43

TEST RESULTS

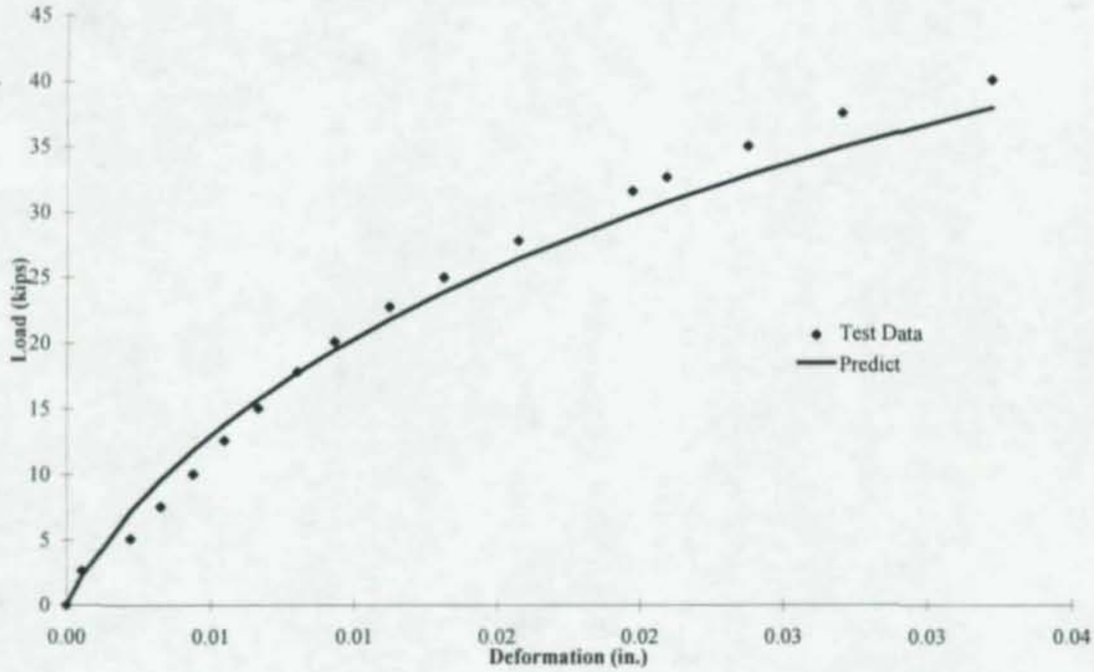
Limit State: Test Setup Limit
Ki: 2295 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.0322	40.12
Failure:	-	-
Other:	-	-

COMMENTS

Test setup limited by bolt bending.

LOAD Vs. DEFORMATION CHART



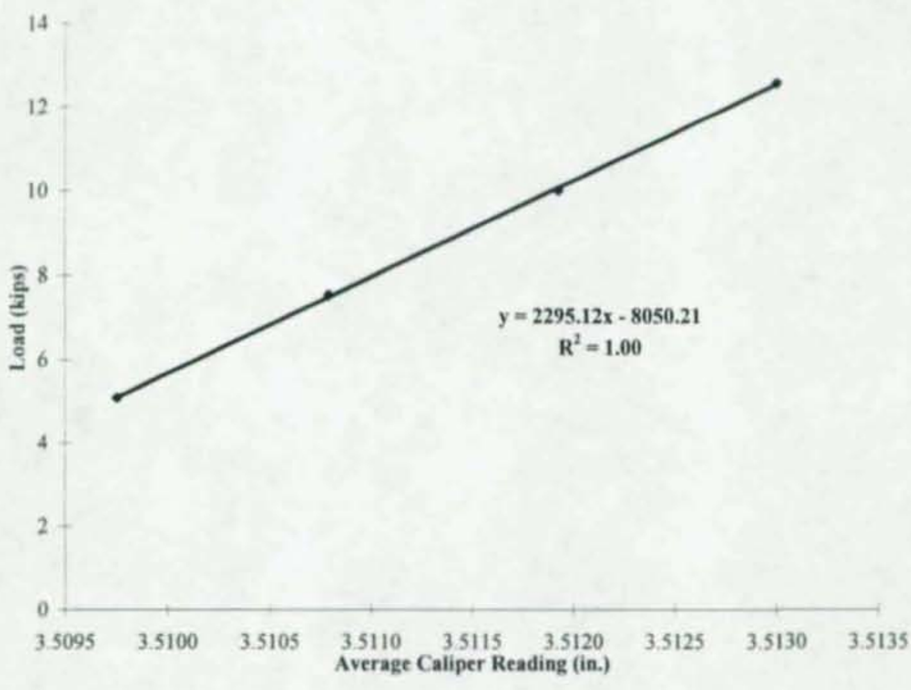
Test No. 34
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

Data Point	Load (kips)	Deflection: Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.5075	0.0000	0.0000
1	2.64	3.5035	3.5132	3.5084	0.0003	3.5081	0.0005	0.0005
2	5.09	3.5050	3.5156	3.5103	0.0005	3.5098	0.0022	0.0022
3	7.53	3.5060	3.5172	3.5116	0.0008	3.5108	0.0033	0.0033
4	10.02	3.5071	3.5189	3.5130	0.0011	3.5119	0.0044	0.0044
5	12.58	3.5083	3.5204	3.5144	0.0013	3.5130	0.0055	0.0055
6	15.05	3.5097	3.5219	3.5158	0.0016	3.5142	0.0067	0.0067
7	17.80	3.5112	3.5237	3.5175	0.0019	3.5155	0.0080	0.0080
8	20.10	3.5130	3.5250	3.5190	0.0022	3.5168	0.0093	0.0093
9	22.76	3.5151	3.5273	3.5212	0.0024	3.5188	0.0112	0.0112
10	25.02	3.5174	3.5293	3.5234	0.0027	3.5207	0.0131	0.0131
11	27.85	3.5204	3.5321	3.5263	0.0030	3.5233	0.0157	0.0157
12	31.63	3.5249	3.5364	3.5307	0.0034	3.5273	0.0197	0.0197
13	32.68	3.5261	3.5378	3.5320	0.0035	3.5284	0.0209	0.0209
14	35.06	3.5292	3.5409	3.5351	0.0038	3.5313	0.0238	0.0238
15	37.57	3.5329	3.5443	3.5386	0.0040	3.5346	0.0270	0.0270
16	40.12	3.5382	3.5499	3.5441	0.0043	3.5397	0.0322	0.0322

INITIAL SLOPE



Test No. 35
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-35

Date: 12/6/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std

Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
S70	5	0.75	2	-	Sawed	44

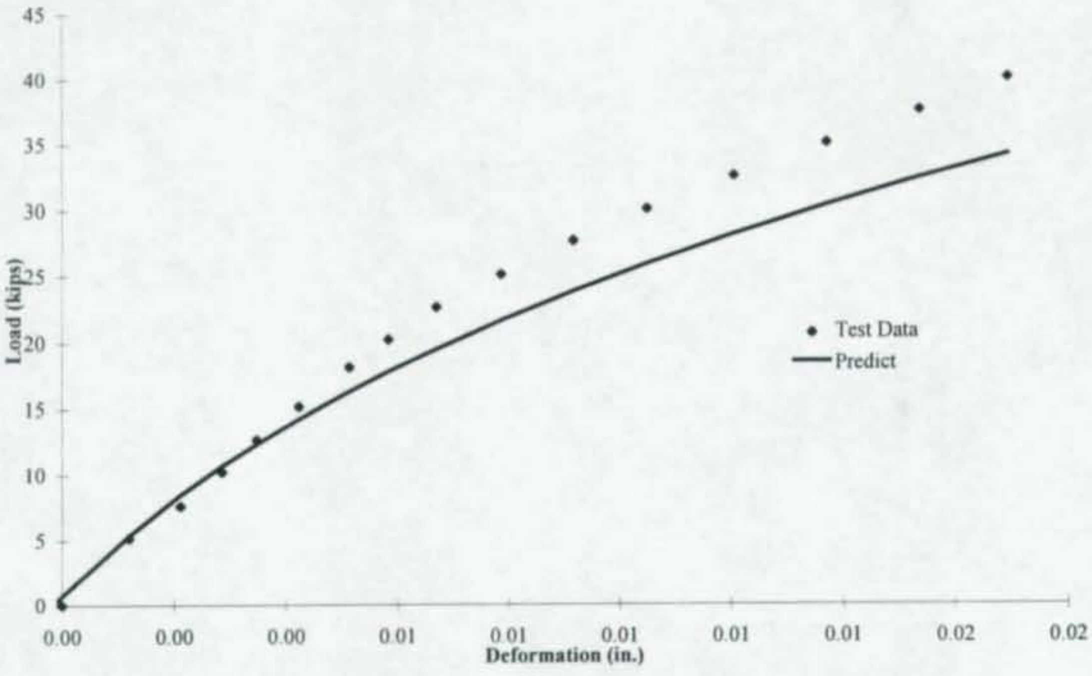
TEST RESULTS

Limit State: Test Setup Limit
Ki: 3590 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.0169	40.06
Failure:	-	-
Other:	-	-

COMMENTS
Test setup limited by bolt bending.

LOAD Vs. DEFORMATION CHART



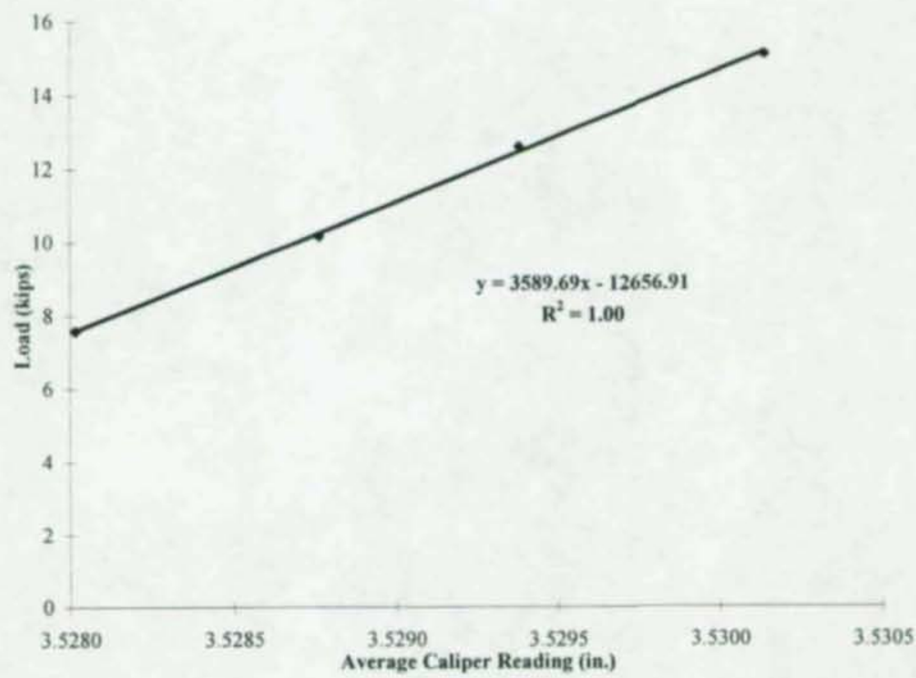
Test No. 35
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Deflection Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.5259	0.0000	0.0000
1	2.79	3.5380	3.5141	3.5261	0.0003	3.5257	-0.0002	-0.0002
2	5.14	3.5392	3.5162	3.5277	0.0006	3.5271	0.0012	0.0012
3	7.58	3.5400	3.5178	3.5289	0.0009	3.5280	0.0021	0.0021
4	10.19	3.5408	3.5191	3.5300	0.0012	3.5288	0.0029	0.0029
5	12.62	3.5413	3.5204	3.5309	0.0015	3.5294	0.0035	0.0035
6	15.13	3.5421	3.5217	3.5319	0.0018	3.5301	0.0042	0.0042
7	18.10	3.5431	3.5232	3.5332	0.0021	3.5310	0.0051	0.0051
8	20.20	3.5441	3.5241	3.5341	0.0024	3.5317	0.0058	0.0058
9	22.66	3.5451	3.5254	3.5353	0.0026	3.5326	0.0067	0.0067
10	25.11	3.5464	3.5270	3.5367	0.0029	3.5338	0.0079	0.0079
11	27.67	3.5480	3.5286	3.5383	0.0032	3.5351	0.0092	0.0092
12	30.09	3.5497	3.5301	3.5399	0.0035	3.5364	0.0105	0.0105
13	32.57	3.5515	3.5320	3.5418	0.0038	3.5380	0.0121	0.0121
14	35.08	3.5535	3.5339	3.5437	0.0041	3.5396	0.0137	0.0137
15	37.57	3.5557	3.5356	3.5457	0.0044	3.5413	0.0154	0.0154
16	40.06	3.5571	3.5379	3.5475	0.0047	3.5428	0.0169	0.0169

INITIAL SLOPE



Test No. 36
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-36 Date: 12/6/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 1
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
S71	5	0.75	2	-	Sawed	44

TEST RESULTS

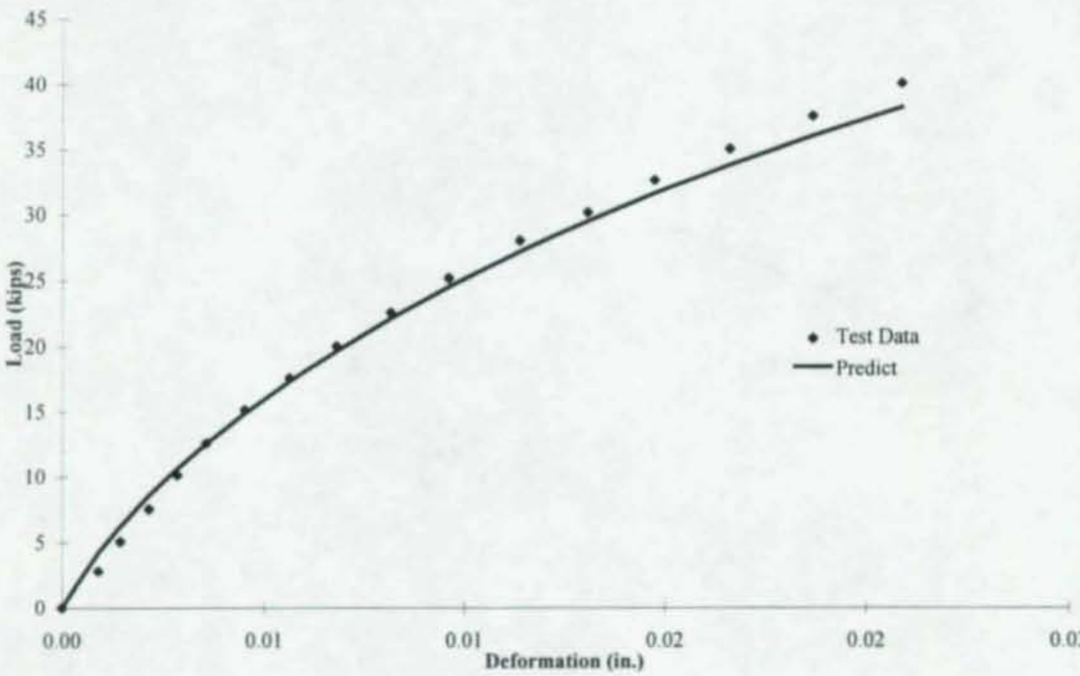
Limit State: Test Setup Limit
Ki: 3531 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.0209	40.06
Failure:	-	-
Other:	-	-

COMMENTS

Test setup limited by bolt bending.

LOAD Vs. DEFORMATION CHART



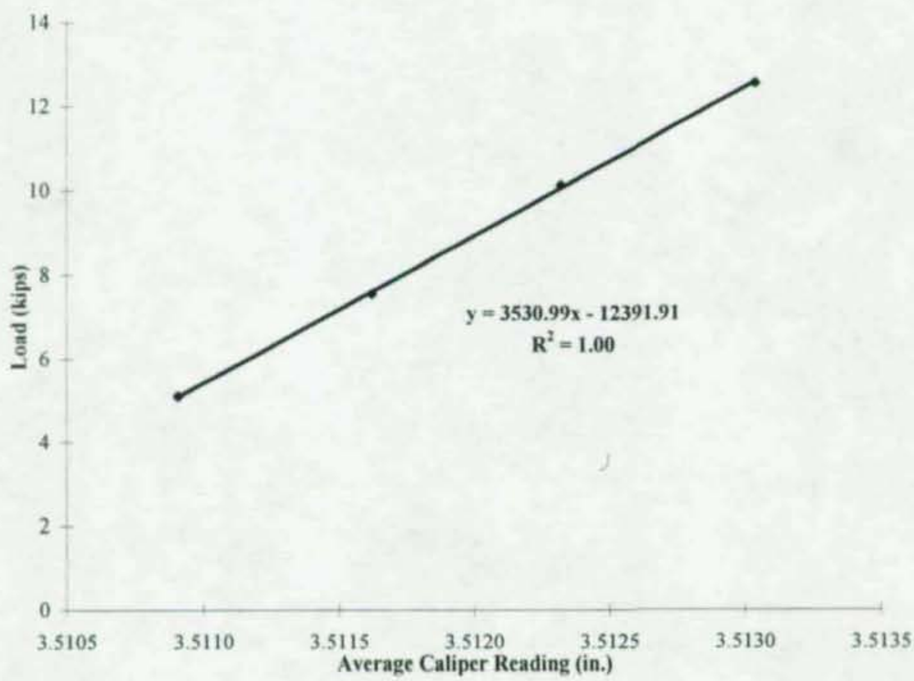
Test No. 36
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.5095	0.0000	0.0000
1	2.81	3.4975	3.5239	3.5107	0.0003	3.5104	0.0009	0.0009
2	5.09	3.4980	3.5250	3.5115	0.0006	3.5109	0.0014	0.0014
3	7.55	3.4989	3.5261	3.5125	0.0009	3.5116	0.0021	0.0021
4	10.14	3.4999	3.5271	3.5135	0.0012	3.5123	0.0028	0.0028
5	12.57	3.5009	3.5281	3.5145	0.0015	3.5130	0.0036	0.0036
6	15.14	3.5023	3.5292	3.5158	0.0018	3.5140	0.0045	0.0045
7	17.59	3.5038	3.5305	3.5172	0.0020	3.5151	0.0056	0.0056
8	20.02	3.5052	3.5320	3.5186	0.0023	3.5163	0.0068	0.0068
9	22.56	3.5070	3.5335	3.5203	0.0026	3.5176	0.0082	0.0082
10	25.18	3.5089	3.5351	3.5220	0.0029	3.5191	0.0096	0.0096
11	28.00	3.5111	3.5371	3.5241	0.0033	3.5208	0.0114	0.0114
12	30.18	3.5131	3.5390	3.5261	0.0035	3.5225	0.0131	0.0131
13	32.65	3.5151	3.5409	3.5280	0.0038	3.5242	0.0147	0.0147
14	35.04	3.5175	3.5428	3.5302	0.0041	3.5261	0.0166	0.0166
15	37.56	3.5200	3.5450	3.5325	0.0044	3.5281	0.0187	0.0187
16	40.06	3.5228	3.5472	3.5350	0.0047	3.5303	0.0209	0.0209

INITIAL SLOPE



Test No. 37
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-37 Date: 12/6/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 1
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
-	5	0.375	1.75	-	Sheared	22

TEST RESULTS

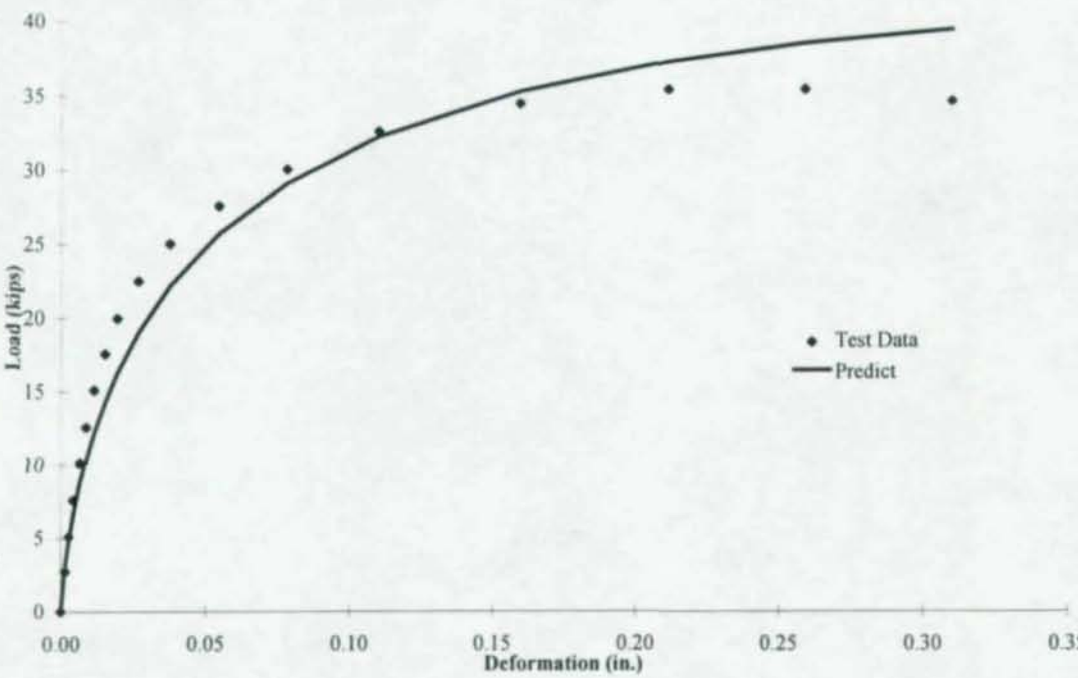
Limit State: Splitting
Ki: 1778 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.2115	35.40
Failure:	0.0546	27.54
Other:	0.250	35.4

COMMENTS

Splitting along free edge of plate noticed around data point 11.
Splitting propogated toward bolt hole.
Test stopped when load started dropping

LOAD Vs. DEFORMATION CHART



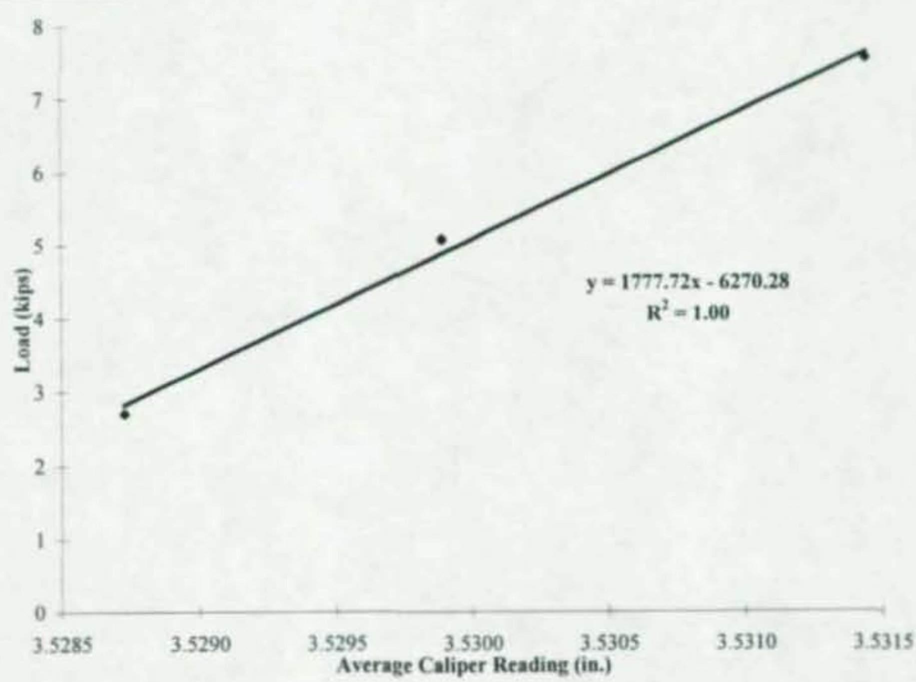
Test No. 37
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.5271	0.0000	0.0000
1	2.71	3.6091	3.4489	3.5290	0.0003	3.5287	0.0016	0.0016
2	5.08	3.6103	3.4505	3.5304	0.0005	3.5299	0.0027	0.0027
3	7.56	3.6120	3.4524	3.5322	0.0008	3.5314	0.0043	0.0043
4	10.13	3.6143	3.4549	3.5346	0.0010	3.5336	0.0064	0.0064
5	12.57	3.6169	3.4570	3.5370	0.0013	3.5357	0.0085	0.0085
6	15.07	3.6200	3.4600	3.5400	0.0015	3.5385	0.0113	0.0113
7	17.55	3.6241	3.4639	3.5440	0.0018	3.5422	0.0151	0.0151
8	19.95	3.6289	3.4681	3.5485	0.0020	3.5465	0.0193	0.0193
9	22.48	3.6364	3.4758	3.5561	0.0023	3.5538	0.0267	0.0267
10	25.00	3.6475	3.4871	3.5673	0.0025	3.5648	0.0376	0.0376
11	27.54	3.6648	3.5043	3.5846	0.0028	3.5818	0.0546	0.0546
12	30.03	3.6890	3.5281	3.6086	0.0030	3.6055	0.0784	0.0784
13	32.53	3.7215	3.5601	3.6408	0.0033	3.6375	0.1104	0.1104
14	34.43	3.7707	3.6099	3.6903	0.0035	3.6868	0.1597	0.1597
15	35.40	3.8229	3.6615	3.7422	0.0036	3.7386	0.2115	0.2115
16	35.40	3.8702	3.7093	3.7898	0.0036	3.7862	0.2590	0.2590
17	34.60	3.9210	3.7600	3.8405	0.0035	3.8370	0.3099	0.3099

INITIAL SLOPE



Test No. 38
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-38

Date: 12/6/95

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std
Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
S37	5	0.5	1.5	-	Sawed	12

TEST RESULTS

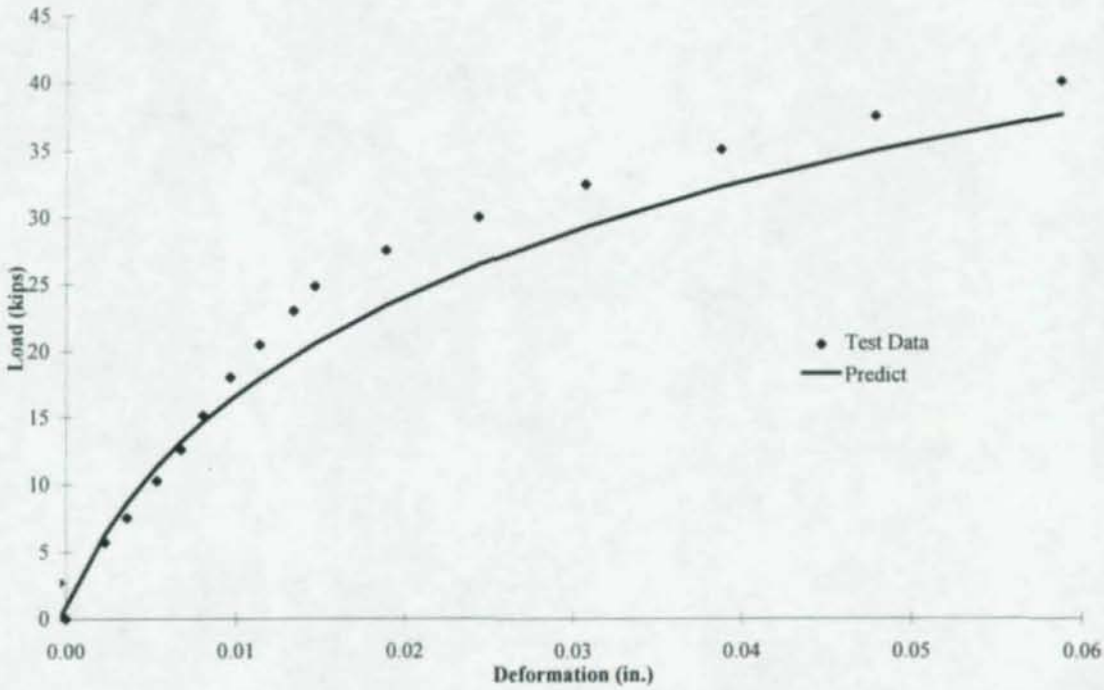
Limit State: Test Setup Limit
Ki: 1865 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	*0.0587*	*40.12*
Failure:	-	-
Other:	-	-

COMMENTS

Test setup limited by bolt bending.

LOAD Vs. DEFORMATION CHART



01381

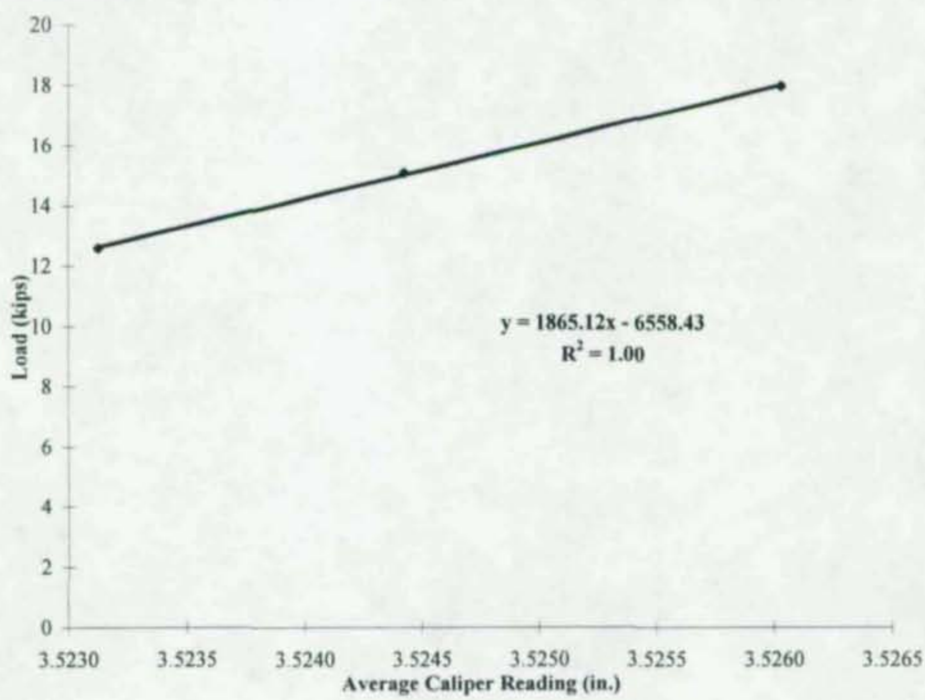
Test No. 38
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.5164	0.0000	0.0000
1	2.72	3.5031	3.5294	3.5163	0.0003	3.5160	-0.0004	-0.0004
2	5.70	3.5060	3.5325	3.5193	0.0006	3.5187	0.0023	0.0023
3	7.49	3.5074	3.5340	3.5207	0.0008	3.5199	0.0036	0.0036
4	10.24	3.5092	3.5363	3.5228	0.0010	3.5217	0.0054	0.0054
5	12.58	3.5107	3.5381	3.5244	0.0013	3.5231	0.0068	0.0068
6	15.11	3.5119	3.5400	3.5260	0.0015	3.5244	0.0081	0.0081
7	18.00	3.5133	3.5424	3.5279	0.0018	3.5260	0.0097	0.0097
8	20.46	3.5150	3.5447	3.5299	0.0021	3.5278	0.0114	0.0114
9	23.00	3.5171	3.5471	3.5321	0.0023	3.5298	0.0134	0.0134
10	24.83	3.5185	3.5486	3.5336	0.0025	3.5310	0.0147	0.0147
11	27.53	3.5229	3.5532	3.5381	0.0028	3.5353	0.0189	0.0189
12	30.00	3.5285	3.5591	3.5438	0.0030	3.5408	0.0244	0.0244
13	32.50	3.5350	3.5658	3.5504	0.0033	3.5471	0.0308	0.0308
14	35.10	3.5432	3.5741	3.5587	0.0036	3.5551	0.0387	0.0387
15	37.55	3.5523	3.5837	3.5680	0.0038	3.5642	0.0478	0.0478
16	40.12	3.5635	3.5948	3.5792	0.0041	3.5751	0.0587	0.0587

INITIAL SLOPE



Test No. 39
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-39 Date: 2/9/96

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 1
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
	5	0.25	1.5	-	Sawed	51

TEST RESULTS

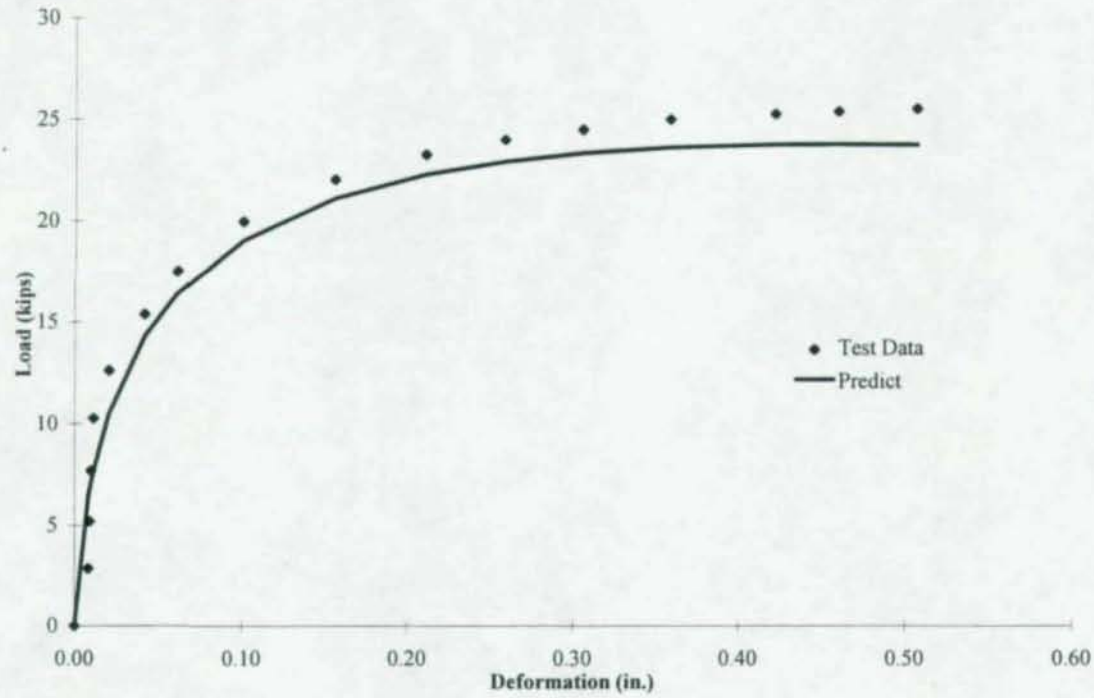
Limit State: Bearing
Ki: 1522 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.5068	25.52
Failure:	-	-
Other:	0.250	23.9

COMMENTS

Had to restart test after SATEC ran to almost 10 kips in initial loading.
Data points 1, 2 and 3 come from a second loading and are not considered for initial slope.
Data has been adjusted to test 41 @ data point 4

LOAD Vs. DEFORMATION CHART



Test No. 39
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					2.9260	0.0000	0.0000
1	2.85	3.0118	2.8572	2.9345	0.0003	2.9342	0.0082	0.0082
2	5.2	3.0130	2.8581	2.9356	0.0005	2.9351	0.0091	0.0091
3	7.68	3.0141	2.8593	2.9367	0.0007	2.9360	0.0100	0.0100
4	10.26	3.0158	2.8608	2.9383	0.0010	2.9373	0.0113	0.0113
5	12.62	3.0250	2.8708	2.9479	0.0012	2.9467	0.0207	0.0207
6	15.38	3.0462	2.8925	2.9694	0.0015	2.9679	0.0419	0.0419
7	17.52	3.0658	2.9123	2.9891	0.0017	2.9874	0.0614	0.0614
8	19.98	3.1050	2.9521	3.0286	0.0019	3.0266	0.1006	0.1006
9	22.04	3.1601	3.0079	3.0840	0.0021	3.0819	0.1559	0.1559
10	23.27	3.2152	3.0630	3.1391	0.0022	3.1369	0.2109	0.2109
11	24	3.2629	3.1111	3.1870	0.0023	3.1847	0.2587	0.2587
12	24.5	3.3100	3.1580	3.2340	0.0023	3.2317	0.3057	0.3057
13	25	3.3628	3.2110	3.2869	0.0024	3.2845	0.3585	0.3585
14	25.26	3.4263	3.2740	3.3502	0.0024	3.3477	0.4217	0.4217
15	25.4	3.4639	3.3125	3.3882	0.0024	3.3858	0.4598	0.4598
16	25.52	3.5109	3.3596	3.4353	0.0024	3.4328	0.5068	0.5068

Test No. 40
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-40

Date: 2/9/96

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std

Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
	5	0.25	1.5	-	Sawed	51

TEST RESULTS

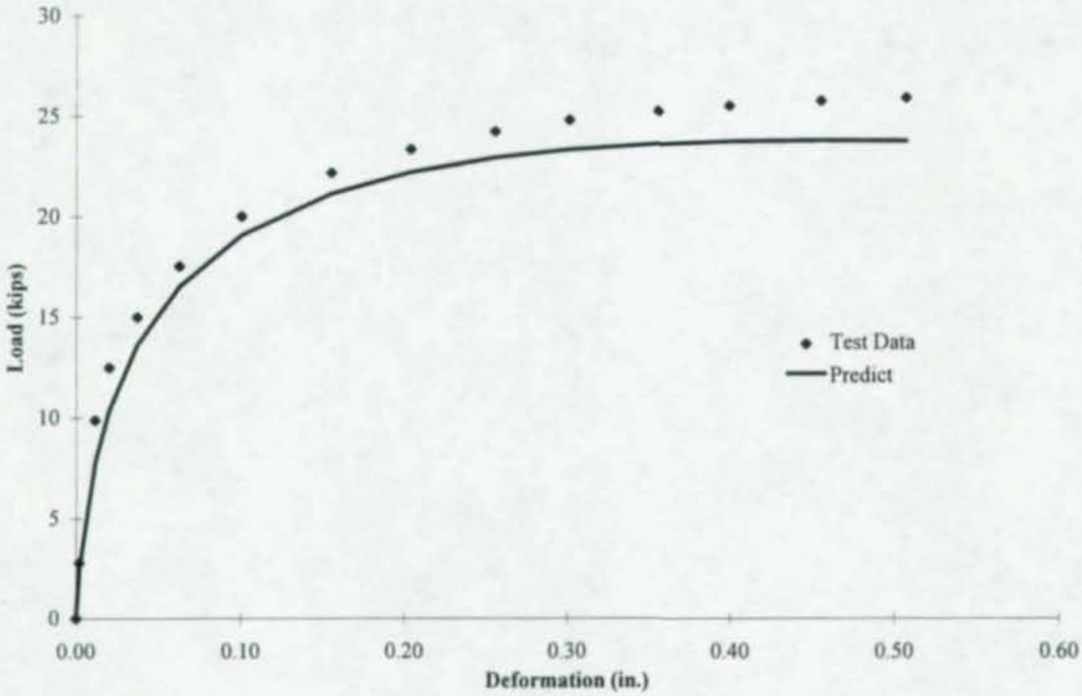
Limit State: Bearing
Ki: 1522 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.5072	25.90
Failure:	-	-
Other:	0.250	24.1

COMMENTS

SATEC shot from data point 1 to data point 2 out of control.
Insufficient data for determining initial slope.
Data has been adjusted to test 41

LOAD Vs. DEFORMATION CHART



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Test No. 40
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.0261	0.0000	0.0000
1	2.77	3.0178	3.0390	3.0284	0.0003	3.0281	0.0020	0.0020
2	9.88	3.0281	3.0492	3.0387	0.0010	3.0377	0.0115	0.0115
3	12.5	3.0371	3.0580	3.0476	0.0012	3.0463	0.0202	0.0202
4	14.98	3.0540	3.0753	3.0647	0.0015	3.0632	0.0370	0.0370
5	17.54	3.0801	3.1011	3.0906	0.0017	3.0889	0.0627	0.0627
6	*20*	*3.1186*	*3.1390*	*3.1288*	*0.0020*	*3.1268*	*0.1007*	*0.1007*
7	22.16	3.1735	3.1941	3.1838	0.0022	3.1816	0.1555	0.1555
8	23.34	3.2223	3.2429	3.2326	0.0023	3.2303	0.2042	0.2042
9	24.224	3.2741	3.2949	3.2845	0.0024	3.2821	0.2560	0.2560
10	24.8	3.3199	3.3400	3.3300	0.0024	3.3275	0.3014	0.3014
11	25.24	3.3743	3.3949	3.3846	0.0025	3.3821	0.3560	0.3560
12	25.52	3.4180	3.4379	3.4280	0.0025	3.4254	0.3993	0.3993
13	25.76	3.4740	3.4942	3.4841	0.0025	3.4816	0.4554	0.4554
14	25.9	3.5259	3.5459	3.5359	0.0025	3.5334	0.5072	0.5072

Test No. 41
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-41

Date: 2/9/96

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std

Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
	5	0.25	1.5	-	Sawed	51

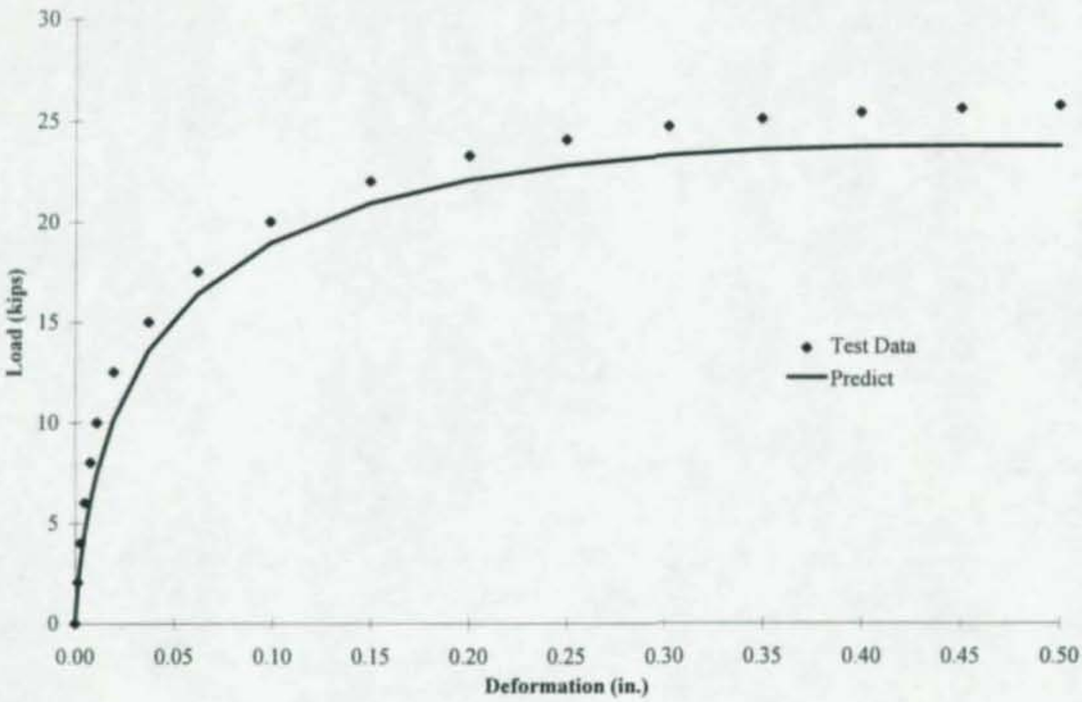
TEST RESULTS

Limit State: Bearing
Ki: 1522 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.4996	25.74
Failure:	-	-
Other:	0.250	24.1

COMMENTS

LOAD Vs. DEFORMATION CHART



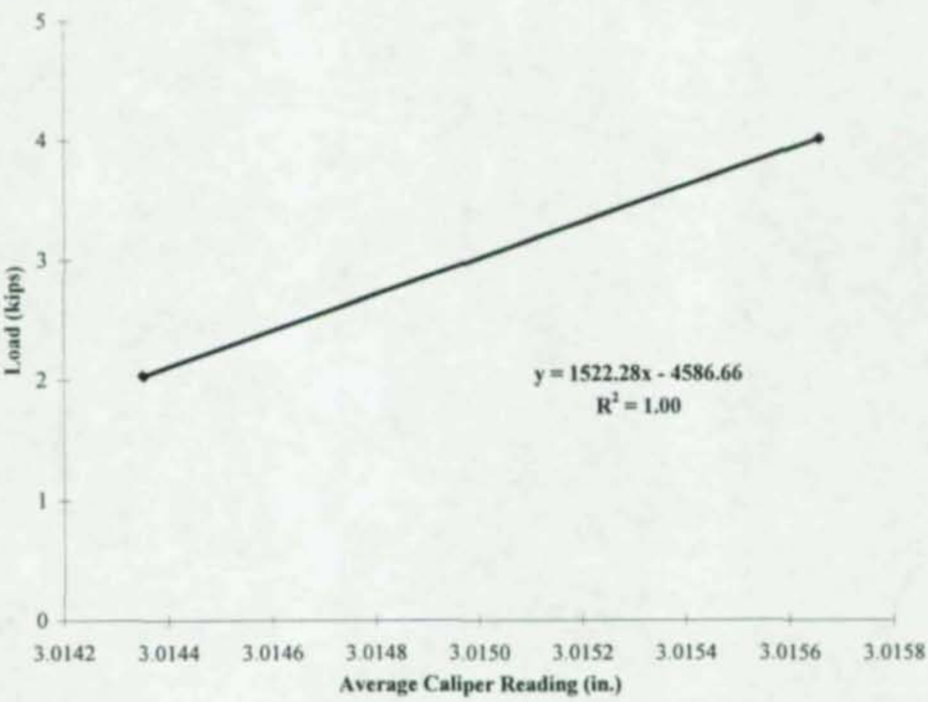
Test No. 41
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.0130	0.0000	0.0000
1	2.032	2.9611	3.0680	3.0146	0.0002	3.0144	0.0013	0.0013
2	4.02	2.9631	3.0690	3.0161	0.0004	3.0157	0.0026	0.0026
3	6.02	2.9658	3.0710	3.0184	0.0006	3.0178	0.0048	0.0048
4	8.03	2.9689	3.0740	3.0215	0.0008	3.0207	0.0076	0.0076
5	10.003	2.9725	3.0773	3.0249	0.0010	3.0239	0.0109	0.0109
6	12.51	2.9812	3.0860	3.0336	0.0012	3.0324	0.0194	0.0194
7	15.02	2.9991	3.1038	3.0515	0.0015	3.0500	0.0370	0.0370
8	17.55	3.0240	3.1287	3.0764	0.0017	3.0746	0.0616	0.0616
9	20.01	3.0610	3.1658	3.1134	0.0020	3.1114	0.0984	0.0984
10	22.03	3.1121	3.2170	3.1646	0.0022	3.1624	0.1494	0.1494
11	23.3	3.1625	3.2679	3.2152	0.0023	3.2129	0.1999	0.1999
12	24.1	3.2120	3.3178	3.2649	0.0024	3.2625	0.2495	0.2495
13	24.72	3.2640	3.3701	3.3171	0.0024	3.3146	0.3016	0.3016
14	25.09	3.3110	3.4182	3.3646	0.0024	3.3622	0.3491	0.3491
15	25.4	3.3621	3.4678	3.4150	0.0025	3.4125	0.3995	0.3995
16	25.59	3.4129	3.5185	3.4657	0.0025	3.4632	0.4502	0.4502
17	25.74	3.4622	3.5681	3.5152	0.0025	3.5126	0.4996	0.4996

INITIAL SLOPE



Test No. 42
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-42

Date: 2/9/96

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std

Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
	5	0.25	1	-	Sawed	51

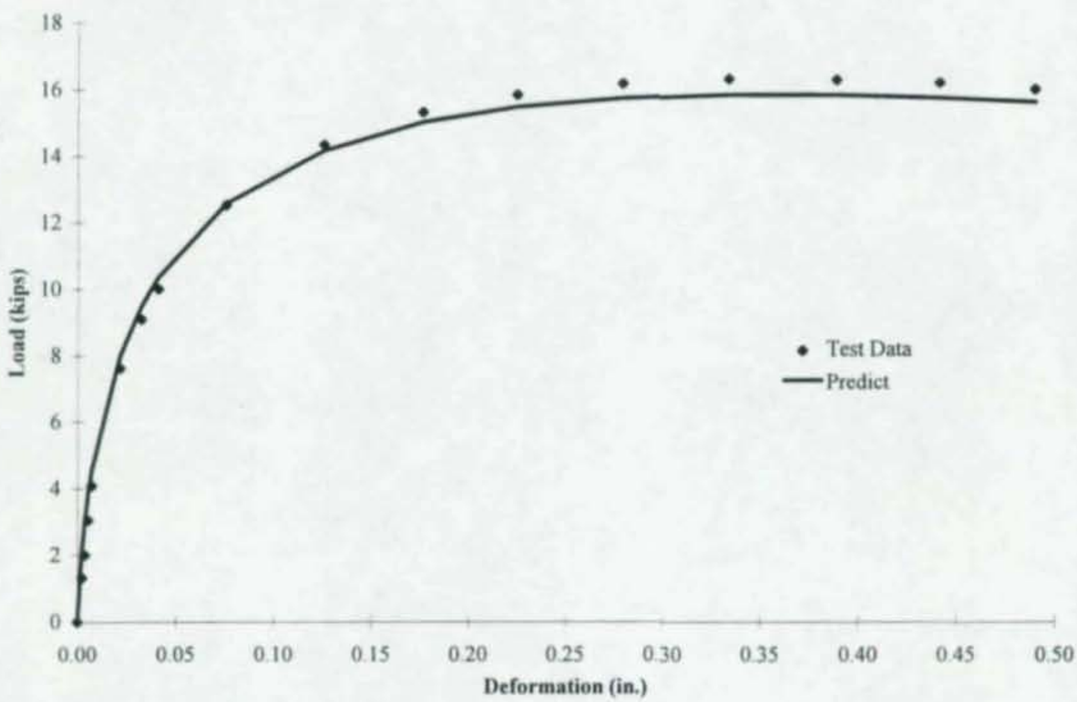
TEST RESULTS

Limit State: Bearing
Ki: 561 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.3338	16.32
Failure:	-	-
Other:	0.250	16.0

COMMENTS

LOAD Vs. DEFORMATION CHART



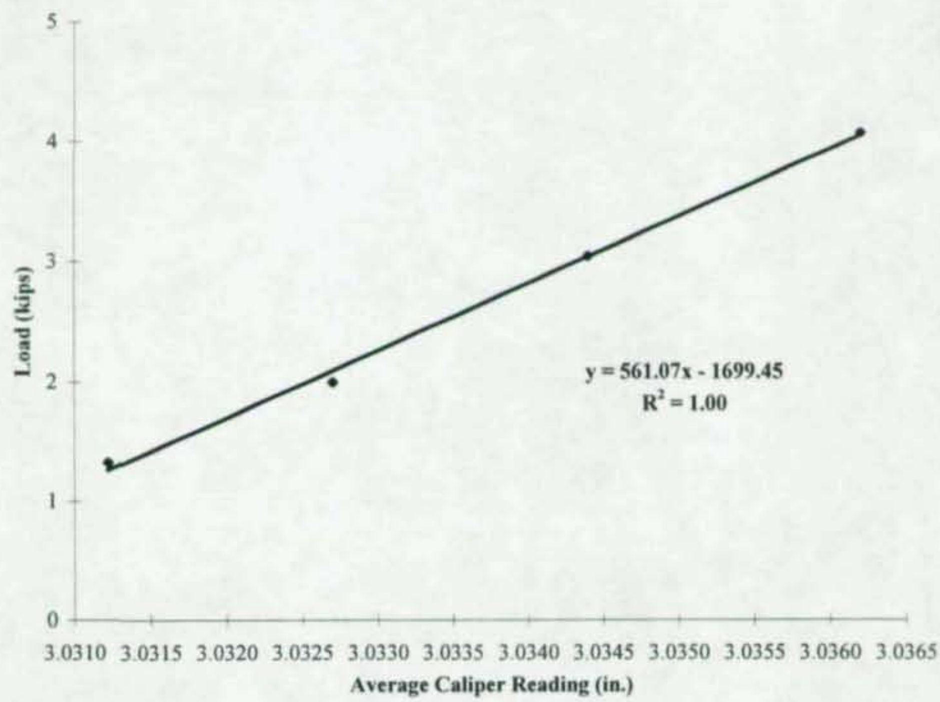
Test No. 42
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.0289	0.0000	0.0000
1	1.325	3.0278	3.0349	3.0314	0.0001	3.0312	0.0023	0.0023
2	2	3.0298	3.0360	3.0329	0.0002	3.0327	0.0038	0.0038
3	3.05	3.0313	3.0381	3.0347	0.0003	3.0344	0.0055	0.0055
4	4.08	3.0333	3.0399	3.0366	0.0004	3.0362	0.0073	0.0073
5	7.62	3.0473	3.0550	3.0512	0.0007	3.0504	0.0215	0.0215
6	9.09	3.0582	3.0661	3.0622	0.0009	3.0613	0.0323	0.0323
7	10	3.0670	3.0750	3.0710	0.0010	3.0700	0.0411	0.0411
8	12.52	3.1020	3.1098	3.1059	0.0012	3.1047	0.0757	0.0757
9	14.35	3.1520	3.1602	3.1561	0.0014	3.1547	0.1257	0.1257
10	15.32	3.2030	3.2112	3.2071	0.0015	3.2056	0.1767	0.1767
11	15.84	3.2512	3.2600	3.2556	0.0016	3.2540	0.2251	0.2251
12	16.17	3.3057	3.3141	3.3099	0.0016	3.3083	0.2794	0.2794
13	16.32	3.3600	3.3686	3.3643	0.0016	3.3627	0.3338	0.3338
14	16.29	3.4148	3.4240	3.4194	0.0016	3.4178	0.3889	0.3889
15	16.2	3.4680	3.4761	3.4721	0.0016	3.4705	0.4415	0.4415
16	16	3.5161	3.5245	3.5203	0.0016	3.5187	0.4898	0.4898

INITIAL SLOPE



Test No. 43
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-43 Date: 2/9/96

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 1
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
	5	0.25	1	-	Sawed	51

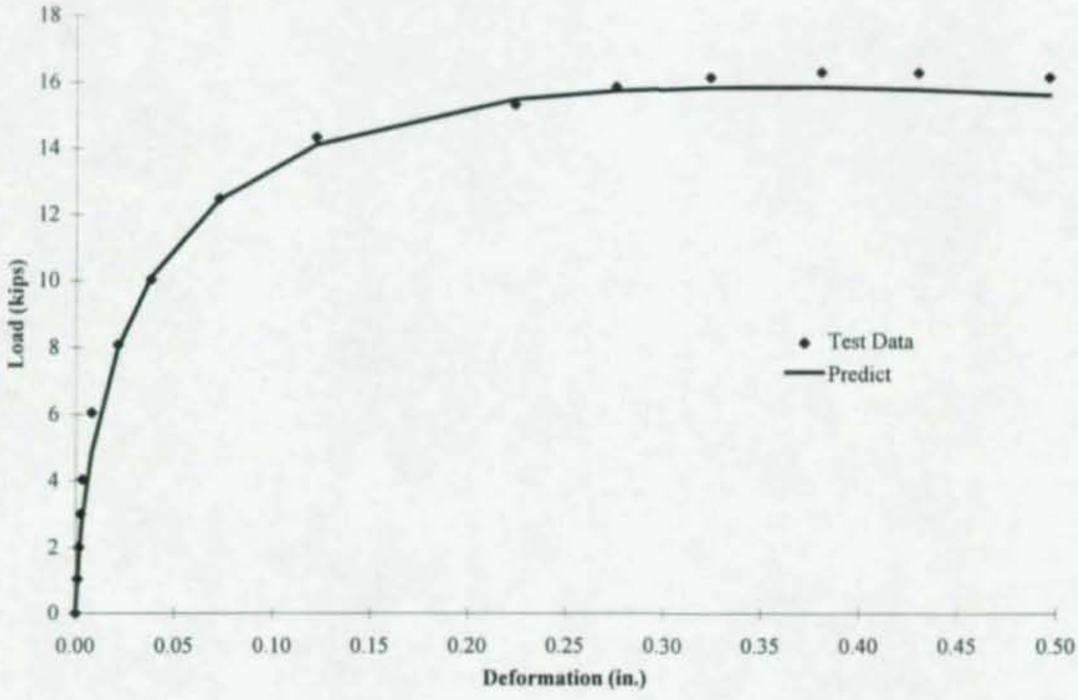
TEST RESULTS

Limit State: Bearing
Ki: 1113 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.3807	16.30
Failure:	-	-
Other:	0.250	15.6

COMMENTS

LOAD Vs. DEFORMATION CHART



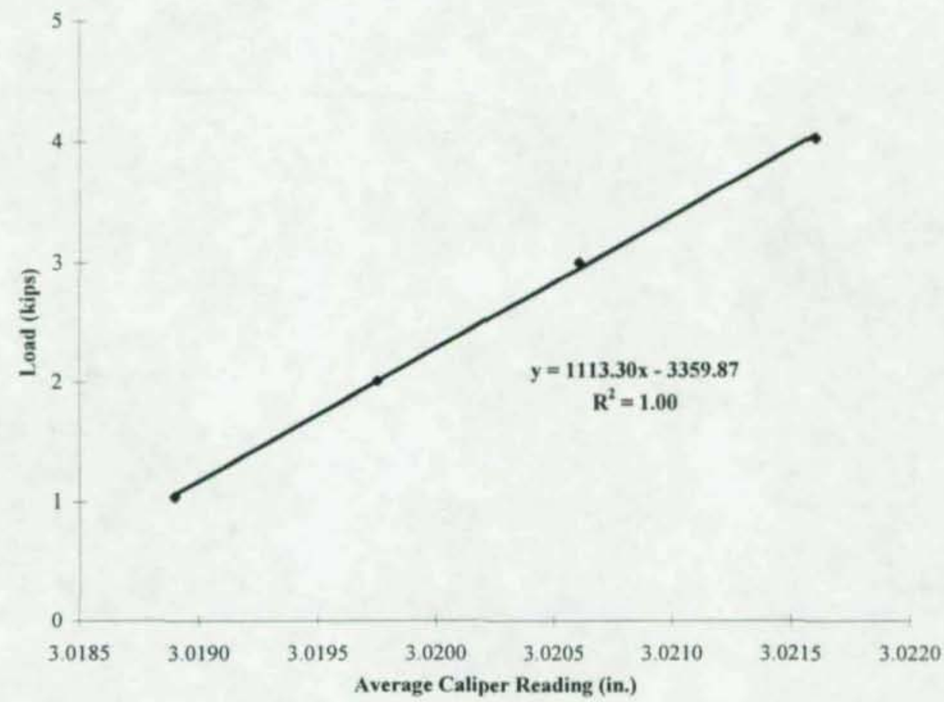
Test No. 43
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.0179	0.0000	0.0000
1	1.04	3.0316	3.0064	3.0190	0.0001	3.0189	0.0010	0.0010
2	2.01	3.0327	3.0072	3.0200	0.0002	3.0198	0.0018	0.0018
3	3.01	3.0339	3.0079	3.0209	0.0003	3.0206	0.0027	0.0027
4	4.04	3.0351	3.0089	3.0220	0.0004	3.0216	0.0037	0.0037
5	6.05	3.0400	3.0133	3.0267	0.0006	3.0261	0.0081	0.0081
6	8.08	3.0534	3.0270	3.0402	0.0008	3.0394	0.0215	0.0215
7	10.03	3.0702	3.0439	3.0571	0.0010	3.0561	0.0381	0.0381
8	12.47	3.1050	3.0788	3.0919	0.0012	3.0907	0.0727	0.0727
9	14.32	3.1548	3.1284	3.1416	0.0014	3.1402	0.1223	0.1223
10	15.31	3.2064	3.2802	3.2433	0.0015	3.2418	0.2239	0.2239
11	15.85	3.2583	3.3322	3.2953	0.0015	3.2937	0.2758	0.2758
12	*16.15*	*3.3058*	*3.3812*	*3.3435*	*0.0016*	*3.3419*	*0.3240*	*0.3240*
13	16.3	3.3625	3.4379	3.4002	0.0016	3.3986	0.3807	0.3807
14	16.28	3.4120	3.4870	3.4495	0.0016	3.4479	0.4300	0.4300
15	16.15	3.4780	3.5535	3.5158	0.0016	3.5142	0.4962	0.4962

INITIAL SLOPE



Test No. 44
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-44

Date: 2/9/96

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std

Diameter (in): 0.875
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
	5	0.25	1	-	Sawed	51

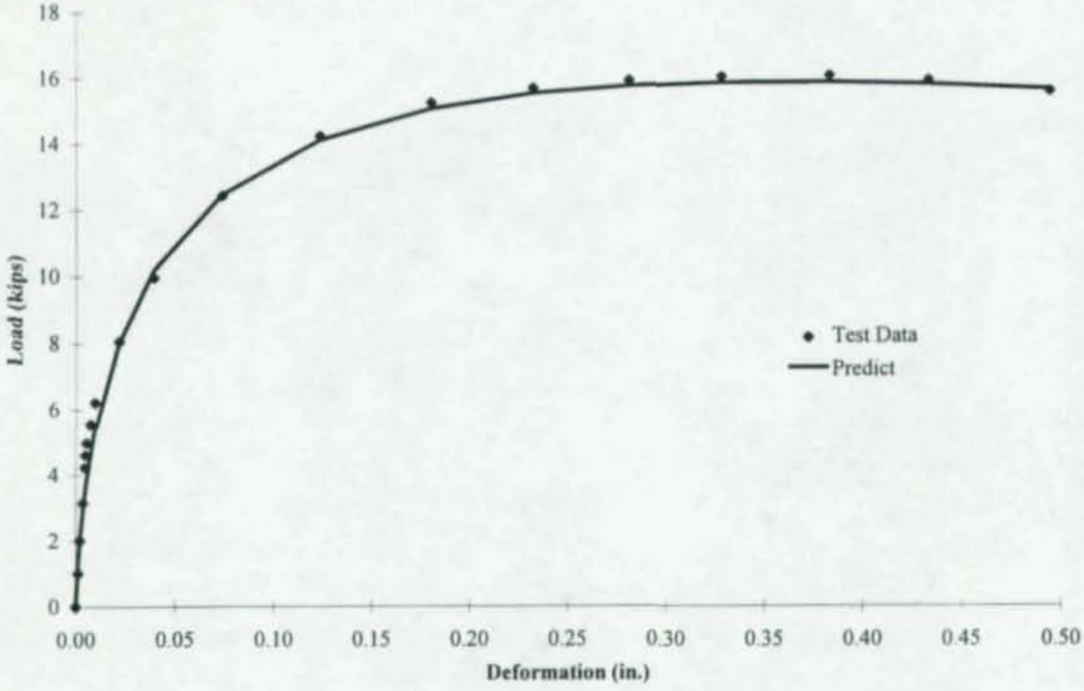
TEST RESULTS

Limit State: Bearing
Ki: 902 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.3833	16.05
Failure:	-	-
Other:	0.250	15.8

COMMENTS

LOAD Vs. DEFORMATION CHART



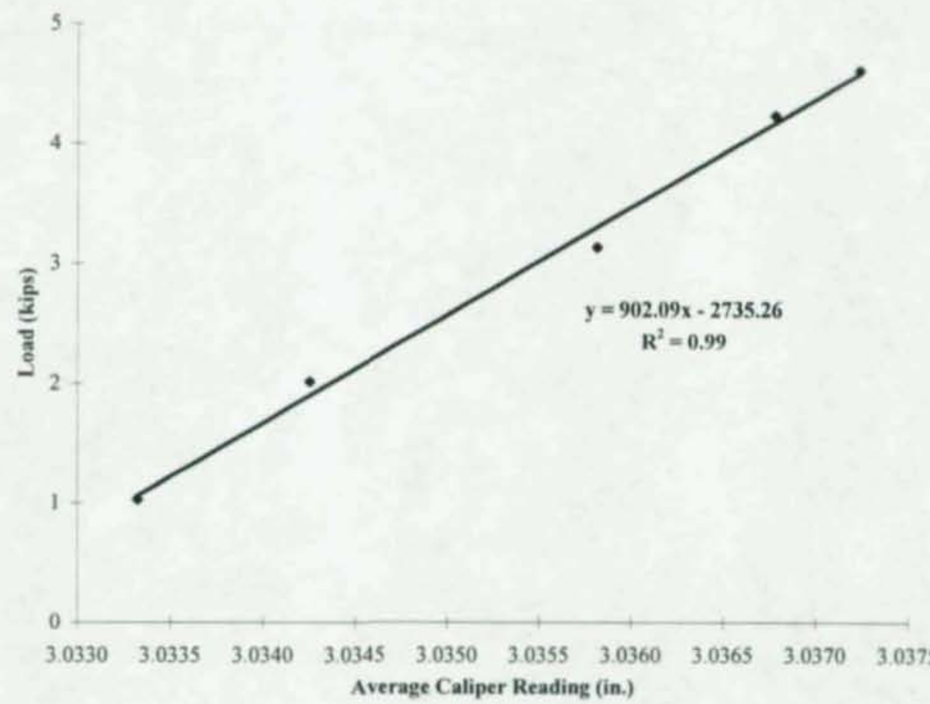
Test No. 44
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Deflection Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.0321	0.0000	0.0000
1	1.03	3.0269	3.0400	3.0335	0.0001	3.0333	0.0012	0.0012
2	2.015	3.0280	3.0410	3.0345	0.0002	3.0343	0.0021	0.0021
3	3.14	3.0295	3.0429	3.0362	0.0004	3.0358	0.0037	0.0037
5	4.24	3.0326	3.0420	3.0373	0.0005	3.0368	0.0046	0.0046
6	4.62	3.0331	3.0425	3.0378	0.0006	3.0372	0.0051	0.0051
7	4.99	3.0337	3.0431	3.0384	0.0006	3.0378	0.0057	0.0057
8	5.55	3.0351	3.0450	3.0401	0.0007	3.0394	0.0072	0.0072
9	6.2	3.0375	3.0476	3.0426	0.0008	3.0418	0.0097	0.0097
10	8.05	3.0498	3.0600	3.0549	0.0010	3.0539	0.0218	0.0218
11	9.95	3.0674	3.0779	3.0727	0.0012	3.0714	0.0393	0.0393
12	12.42	3.1025	3.1128	3.1077	0.0015	3.1061	0.0740	0.0740
13	14.22	3.1523	3.1629	3.1576	0.0017	3.1559	0.1237	0.1237
14	15.23	3.2090	3.2198	3.2144	0.0019	3.2125	0.1804	0.1804
15	15.68	3.2610	3.2720	3.2665	0.0019	3.2646	0.2324	0.2324
16	15.9	3.3100	3.3210	3.3155	0.0019	3.3136	0.2814	0.2814
17	16.02	3.3570	3.3680	3.3625	0.0020	3.3605	0.3284	0.3284
18	16.05	3.4116	3.4232	3.4174	0.0020	3.4154	0.3833	0.3833
19	15.9	3.4620	3.4728	3.4674	0.0019	3.4655	0.4333	0.4333
20	15.56	3.5230	3.5340	3.5285	0.0019	3.5266	0.4945	0.4945

INITIAL SLOPE



Test No. 45
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-45

Date: 2/9/96

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Diameter (in): 0.875
Bolt Hole: Std
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
	5	0.25	1	-	Sawed	51

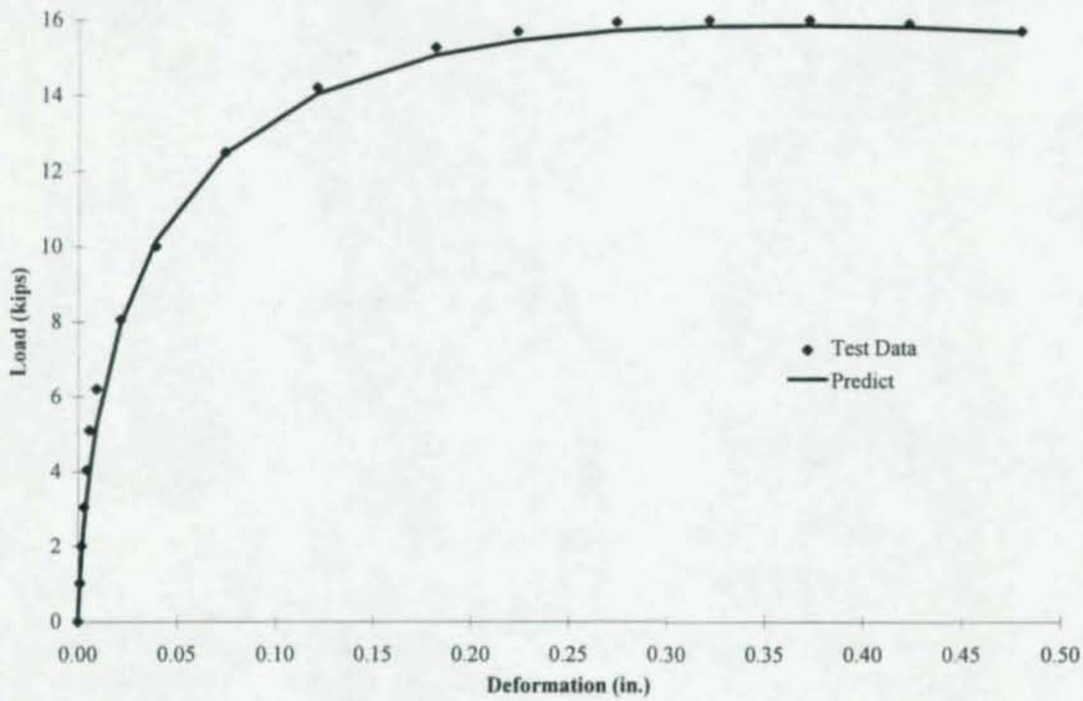
TEST RESULTS

Limit State: Bearing
Ki: 1056 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.3210	16.00
Failure:	-	-
Other:	0.250	15.8

COMMENTS

LOAD Vs. DEFORMATION CHART



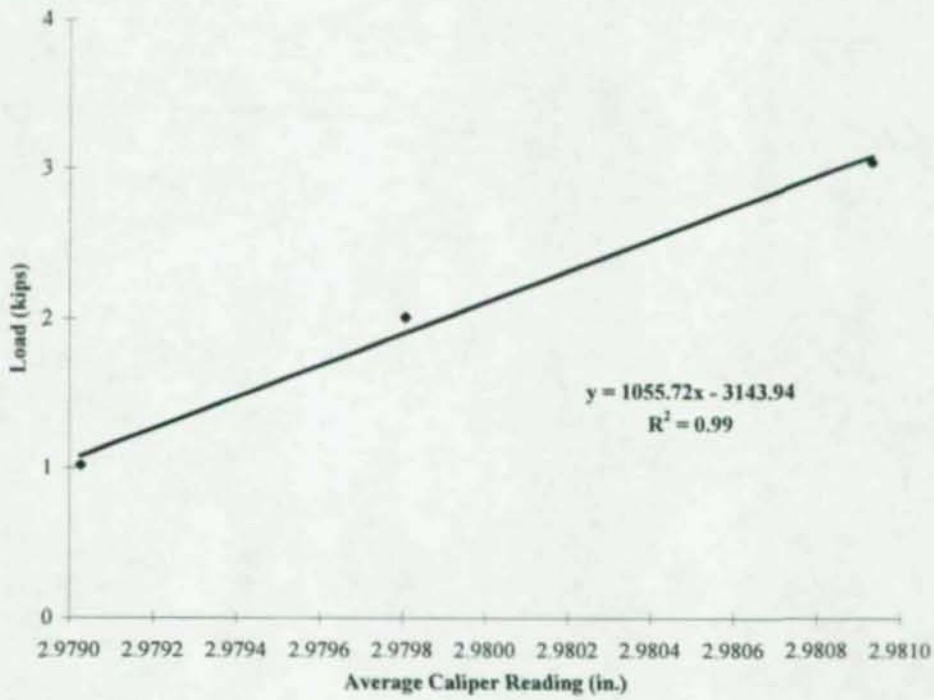
Test No. 45
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					2.9780	0.0000	0.0000
1	1.02	3.0386	2.9197	2.9792	0.0001	2.9790	0.0010	0.0010
2	2.01	3.0398	2.9203	2.9801	0.0002	2.9798	0.0018	0.0018
3	3.05	3.0412	2.9214	2.9813	0.0004	2.9809	0.0029	0.0029
4	4.04	3.0428	2.9229	2.9829	0.0005	2.9824	0.0044	0.0044
5	5.1	3.0443	2.9242	2.9843	0.0006	2.9836	0.0056	0.0056
6	6.21	3.0483	2.9279	2.9881	0.0007	2.9874	0.0093	0.0093
7	8.05	3.0607	2.9399	3.0003	0.0010	2.9993	0.0213	0.0213
8	10	3.0788	2.9578	3.0183	0.0012	3.0171	0.0391	0.0391
9	12.5	3.1141	2.9931	3.0536	0.0015	3.0521	0.0741	0.0741
10	14.21	3.1613	3.0401	3.1007	0.0017	3.0990	0.1210	0.1210
11	15.27	3.2219	3.1007	3.1613	0.0018	3.1595	0.1815	0.1815
12	15.69	3.2640	3.1425	3.2033	0.0019	3.2014	0.2234	0.2234
13	15.94	3.3145	3.1930	3.2538	0.0019	3.2518	0.2738	0.2738
14	16	3.3619	3.2400	3.3010	0.0019	3.2990	0.3210	0.3210
15	16	3.4128	3.2912	3.3520	0.0019	3.3501	0.3721	0.3721
16	15.9	3.4630	3.3420	3.4025	0.0019	3.4006	0.4226	0.4226
17	15.7	3.5195	3.3991	3.4593	0.0019	3.4574	0.4794	0.4794

INITIAL SLOPE



Test No. 46
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-46

Date: 2/9/96

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Diameter (in): 0.875
Bolt Hole: Std
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
	5	0.25	1.3125	-	Sawed	51

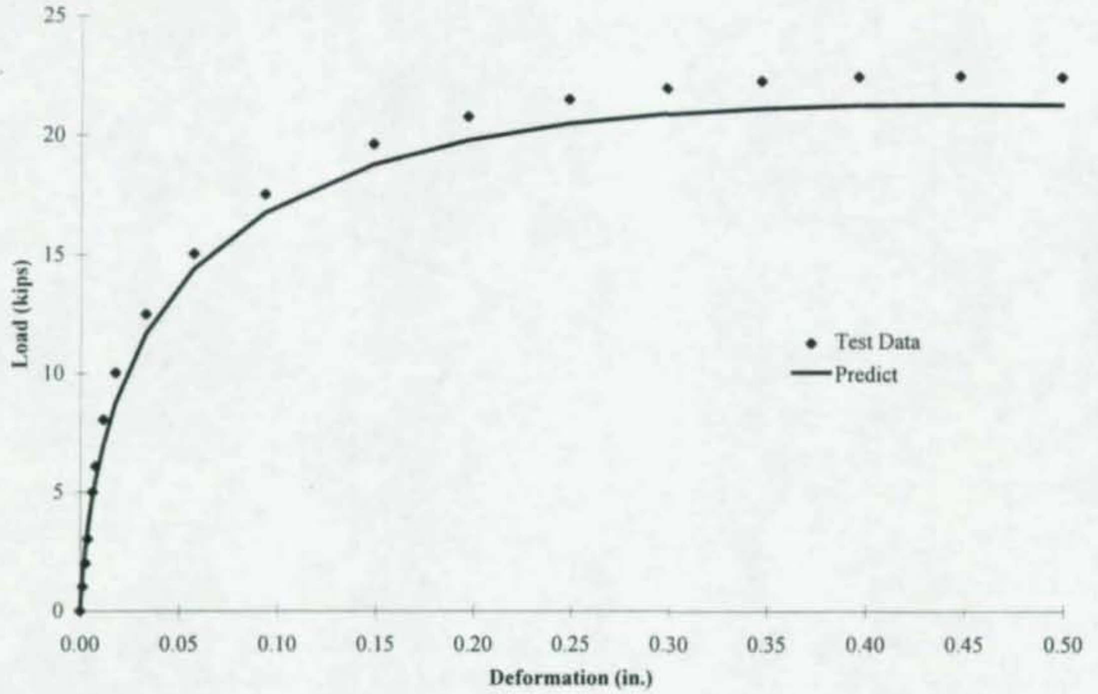
TEST RESULTS

Limit State: Bearing
Ki: 797 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.4472	22.49
Failure:	-	-
Other:	0.250	21.5

COMMENTS

LOAD Vs. DEFORMATION CHART



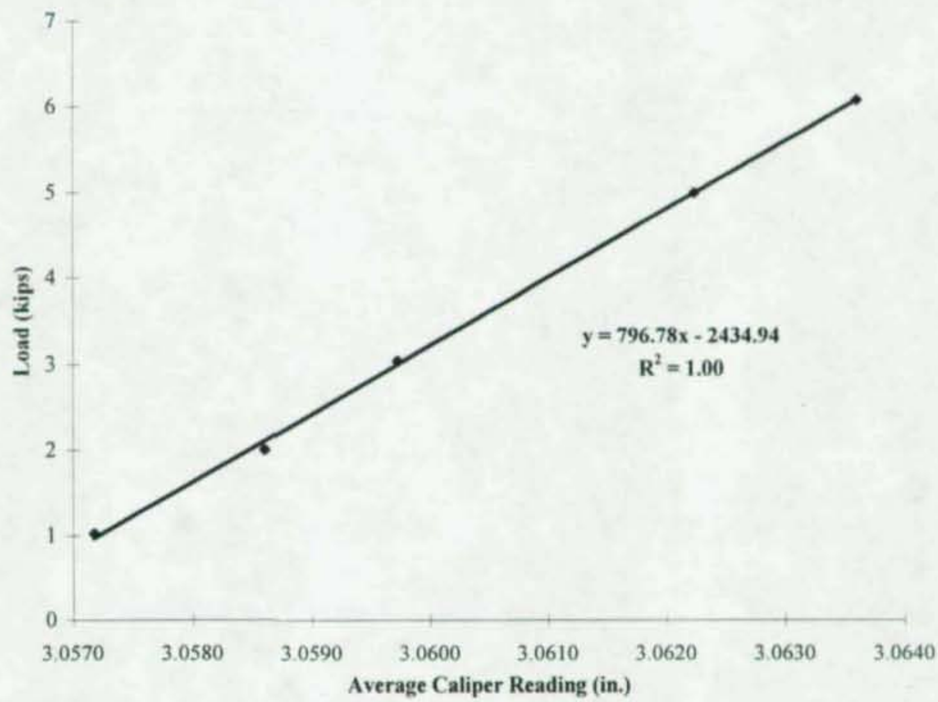
Test No. 46
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.0560	0.0000	0.0000
1	1.02	3.0644	3.0502	3.0573	0.0001	3.0572	0.0012	0.0012
2	2.005	3.0658	3.0519	3.0589	0.0002	3.0586	0.0026	0.0026
3	3.04	3.0670	3.0532	3.0601	0.0004	3.0597	0.0038	0.0038
4	5.005	3.0698	3.0559	3.0629	0.0006	3.0622	0.0063	0.0063
5	*6.09*	*3.0712*	*3.0575*	*3.0644*	*0.0007*	*3.0636*	*0.0076*	*0.0076*
6	8.06	3.0754	3.0616	3.0685	0.0010	3.0675	0.0115	0.0115
7	10.03	3.0819	3.0678	3.0749	0.0012	3.0736	0.0176	0.0176
8	12.49	3.0974	3.0835	3.0905	0.0015	3.0889	0.0329	0.0329
9	15.05	3.1221	3.1079	3.1150	0.0018	3.1132	0.0572	0.0572
10	17.52	3.1585	3.1443	3.1514	0.0022	3.1492	0.0933	0.0933
11	19.63	3.2138	3.1998	3.2068	0.0024	3.2044	0.1484	0.1484
12	20.77	3.2622	3.2484	3.2553	0.0026	3.2527	0.1968	0.1968
13	21.5	3.3139	3.3000	3.3070	0.0026	3.3043	0.2483	0.2483
14	21.97	3.3639	3.3500	3.3570	0.0027	3.3543	0.2983	0.2983
15	22.29	3.4121	3.3985	3.4053	0.0027	3.4026	0.3466	0.3466
16	22.46	3.4616	3.4475	3.4546	0.0028	3.4518	0.3958	0.3958
17	22.49	3.5129	3.4990	3.5060	0.0028	3.5032	0.4472	0.4472
18	22.43	3.5641	3.5505	3.5573	0.0028	3.5545	0.4986	0.4986

INITIAL SLOPE



Test No. 47
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-47 Date: 2/9/96

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325 Diameter (in): 0.875
Bolt Hole: Std Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
	5	0.25	1.3125	-	Sawed	51

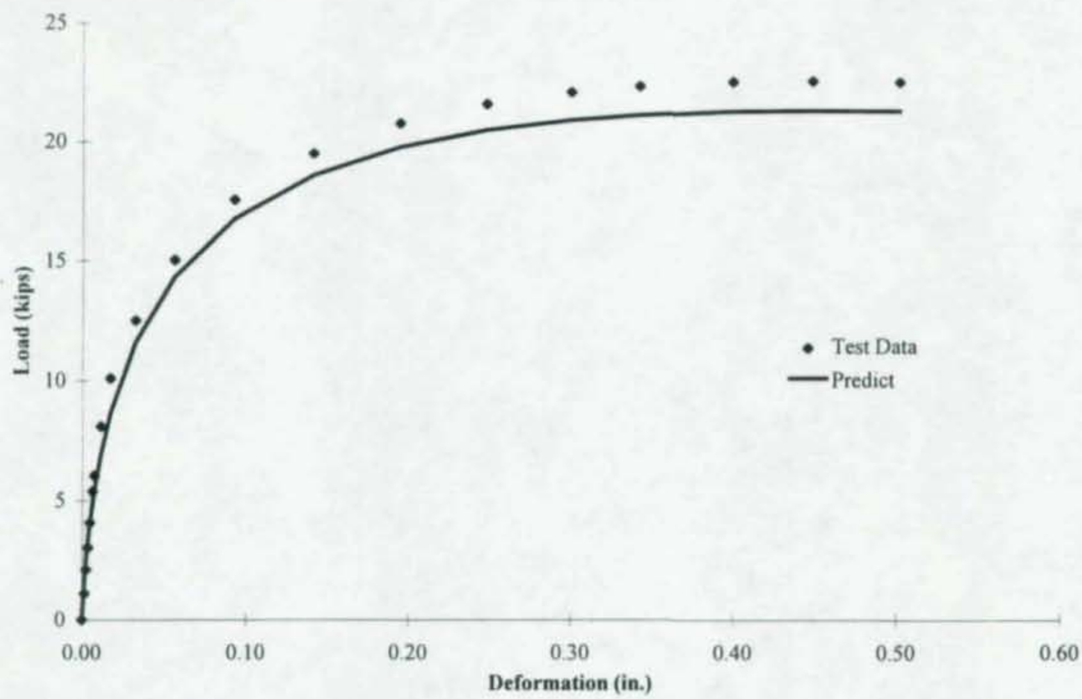
TEST RESULTS

Limit State: Bearing
Ki: 856 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.4486	22.55
Failure:	-	-
Other:	0.250	21.6

COMMENTS

LOAD Vs. DEFORMATION CHART



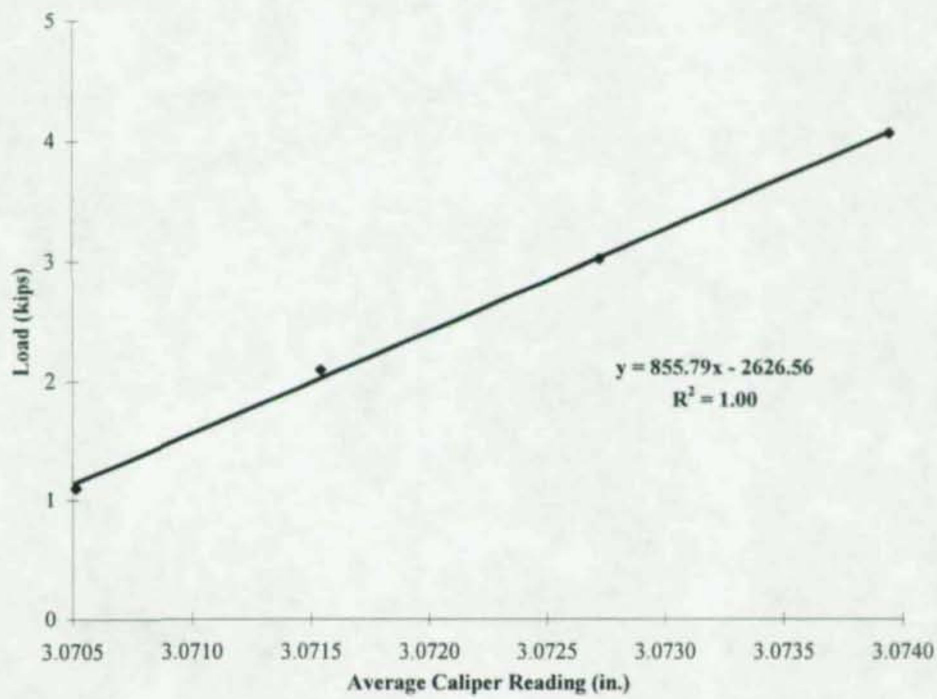
Test No. 47
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.0692	0.0000	0.0000
1	1.1	3.0615	3.0798	3.0707	0.0001	3.0705	0.0014	0.0014
2	2.092	3.0627	3.0809	3.0718	0.0003	3.0715	0.0024	0.0024
3	3.025	3.0640	3.0822	3.0731	0.0004	3.0727	0.0036	0.0036
4	4.07	3.0652	3.0837	3.0745	0.0005	3.0739	0.0048	0.0048
5	5.38	3.0671	3.0853	3.0762	0.0007	3.0755	0.0064	0.0064
6	6.031	3.0684	3.0865	3.0775	0.0007	3.0767	0.0075	0.0075
7	8.09	3.0728	3.0903	3.0816	0.0010	3.0806	0.0114	0.0114
8	10.09	3.0789	3.0963	3.0876	0.0012	3.0864	0.0172	0.0172
9	12.48	3.0942	3.1119	3.1031	0.0015	3.1015	0.0323	0.0323
10	15.03	3.1186	3.1359	3.1273	0.0019	3.1254	0.0562	0.0562
11	17.54	3.1550	3.1731	3.1641	0.0022	3.1619	0.0927	0.0927
12	19.5	3.2039	3.2219	3.2129	0.0024	3.2105	0.1413	0.1413
13	20.75	3.2570	3.2757	3.2664	0.0026	3.2638	0.1946	0.1946
14	21.56	3.3107	3.3290	3.3199	0.0027	3.3172	0.2480	0.2480
15	22.06	3.3625	3.3817	3.3721	0.0027	3.3694	0.3002	0.3002
16	22.32	3.4040	3.4242	3.4141	0.0028	3.4113	0.3422	0.3422
17	22.53	3.4620	3.4811	3.4716	0.0028	3.4688	0.3996	0.3996
18	22.55	3.5110	3.5300	3.5205	0.0028	3.5177	0.4486	0.4486
19	22.5	3.5640	3.5835	3.5738	0.0028	3.5710	0.5018	0.5018

INITIAL SLOPE



Test No. 48
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

TEST DESIGNATION

Test Designation: SBSP-48

Date: 2/9/96

GEOMETRIC AND MATERIAL PROPERTIES

BOLT

Type: A325
Bolt Hole: Std
Diameter (in): 1
Shear Plane: X

PLATES

No.	Width (in)	Thickness (in)	Le (in)	S (in.)	Edge Condition	Coupon No.
	5	0.25	1	-	Sawed	51

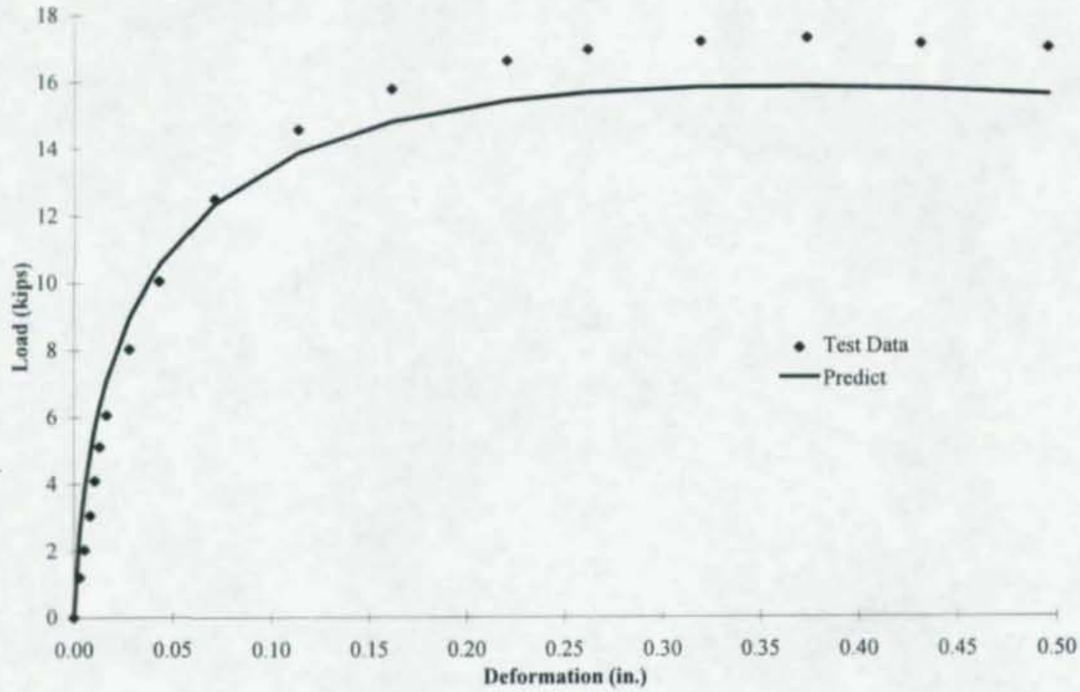
TEST RESULTS

Limit State: Bearing
Ki: 388 (kips/in.)

	Deformation (in.)	Load (kips)
Maximum:	0.3734	17.30
Failure:	-	-
Other:	0.250	16.9

COMMENTS

LOAD Vs. DEFORMATION CHART



Test No. 48
Recorder: COR

SINGLE BOLT SINGLE PLATE CONNECTION TEST
SUMMARY SHEET

DATA

		Deflection						
Data Point	Load (kips)	Front Caliper (in.)	Back Caliper (in.)	Average Caliper (in.)	Est. Bolt & Elastic Δ (in.)	Adjusted Data	Adjusted For Initial Slope	Adjusted For Missing Caliper
	0.00					3.0585	0.0000	0.0000
1	1.21	3.0693	3.0539	3.0616	0.0001	3.0615	0.0030	0.0030
2	2.035	3.0722	3.0559	3.0641	0.0002	3.0638	0.0054	0.0054
3	3.06	3.0753	3.0584	3.0669	0.0003	3.0665	0.0081	0.0081
4	4.09	3.0782	3.0609	3.0696	0.0004	3.0691	0.0107	0.0107
5	5.11	3.0810	3.0631	3.0721	0.0005	3.0715	0.0131	0.0131
6	6.05	3.0846	3.0667	3.0757	0.0006	3.0751	0.0166	0.0166
7	8.03	3.0960	3.0787	3.0874	0.0008	3.0866	0.0281	0.0281
8	10.05	3.1113	3.0942	3.1028	0.0010	3.1018	0.0433	0.0433
9	12.5	3.1391	3.1226	3.1309	0.0012	3.1296	0.0711	0.0711
10	14.59	3.1819	3.1655	3.1737	0.0014	3.1723	0.1138	0.1138
11	15.8	3.2294	3.2136	3.2215	0.0016	3.2199	0.1614	0.1614
12	16.63	3.2883	3.2725	3.2804	0.0016	3.2788	0.2203	0.2203
13	16.97	3.3295	3.3140	3.3218	0.0017	3.3201	0.2616	0.2616
14	17.2	3.3872	3.3716	3.3794	0.0017	3.3777	0.3192	0.3192
15	17.3	3.4410	3.4262	3.4336	0.0017	3.4319	0.3734	0.3734
16	17.12	3.4992	3.4836	3.4914	0.0017	3.4897	0.4312	0.4312
17	17	3.5623	3.5469	3.5546	0.0007	3.5539	0.4954	0.4954

INITIAL SLOPE