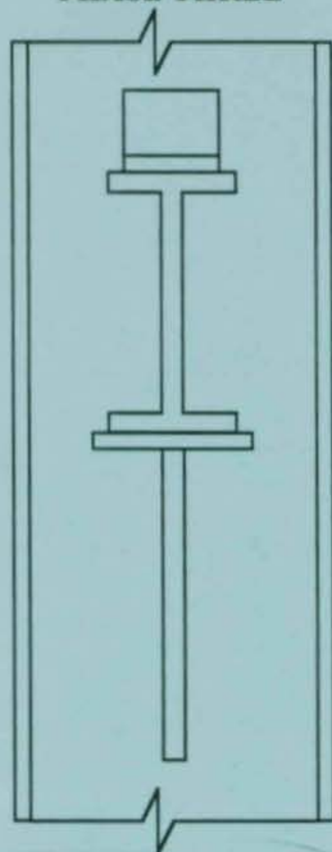
STIFFENED SEATED CONNECTIONS TO COLUMN WEBS

key words:
1- seats, beam
2- connections, shear

PHASE THREE



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UF PROJECT NO.4504429

FINAL REPORT TO THE
AMERICAN INSTITUTE OF STEEL CONSTRUCTION, INC.
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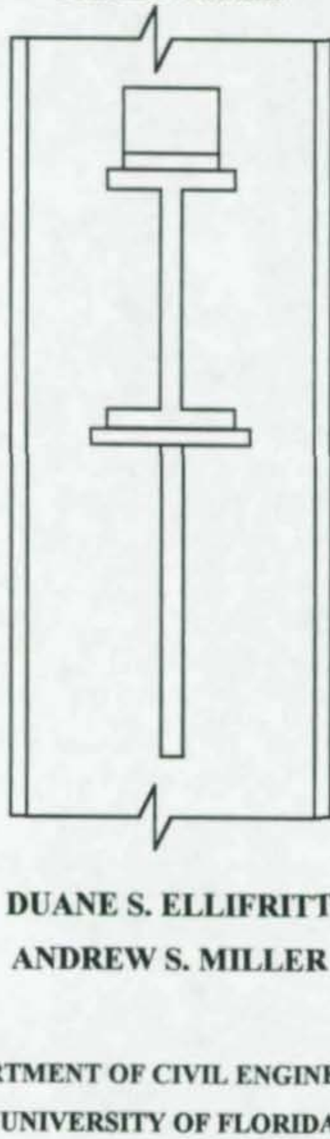

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TABLE OF CONTENTS

page

NOMENCLATURE ... iv

INTRODUCTION ... 1

PHASE THREE LABORATORY TESTING ... 3

Introduction ... 3

Part One ... 5

Part Two ... 8

Phase Three Test Results ... 9

Part One ... 9

Part Two ... 12

Calculation of Load on Stiffened Seats ... 15

Tabulated Results ... 17

Material Properties ... 21

CONCLUSION ... 21

Stiffener Buckling ... 22

Extended Seats ... 23

Welded vs Bolted Connection ... 24

Beam Web Yielding ... 24

Design Recommendations ... 24

Further Research ... 25

APPENDICES

A: Finite Element Analysis of 16 inch Stiffener 26

B: Part One Displacement v Reaction Graphs 40

C: Part Two Displacement v Reaction Graphs 55

D: Beam Web Stress and Strain Graphs 66

REFERENCES 75

NOMENCLATURE

A_W -------------------- Total weld length

B_S -------------------- Connection seat plate width

I_X -------------------- Moment of Inertia about x-axis

F_u -------------------- Ultimate stress of steel

F_y -------------------- Yield stress of steel

L_S -------------------- Length of connection stiffener

P -------------------- Applied load

P_{ASD} -------------------- ASD design load on connection

P_{FAIL} -------------------- Test failure load

P_{ULT} -------------------- Ultimate load based on weld strength

R_W -------------------- Weld allowable stress

S_X -------------------- Section modulus about x-axis

W -------------------- Stiffener width

W' -------------------- Extended seat plate length

e -------------------- Eccentricity of load

t_S -------------------- Seat plate thickness

$\overline{y}$ -------------------- Location of centroid with respect to y-axis

INTRODUCTION

This phase of the research of stiffened seated beam connections to column webs consisted of tests which were suggested by the Research Committee of AISC. These tests were performed to "fill in the holes" left by Phases One and Two, since it was felt that the previous phases of research did not deal with completely realistic seat and stiffener sizes.

Phase One (Ellifritt, Sputo, 1989) consisted of tests of four different stiffener configurations welded to the webs of four different wide flange columns. The wide flange sections used as columns during this phase, however, were actually standard beam sections. These type of sections were used for their thin webs in order to achieve large rotations of the seat. Phase One was, therefore, more of a pilot study used to see what methods of analysis and design might work well for this type of connection.

Phase Two (Ellifritt, Sputo, 1990) consisted of tests of more realistic seat configurations welded to more realistic column sections. Sixteen tests were performed in all using various means of attaching the seat to the column web and the beam to the seat.

During Phase Three, the more commonly used ratio of stiffener depth-to-width ratio of 2:1 was used, with one case tested with a stiffener depth-to-width ratio of 4:1. Also tested during this phase of research were seats using plates that extended beyond the stiffener width with erection bolts placed beyond the stiffener as well. All columns were W14x61 sections which is a typical column section.

The object of Phase Three testing was to test more realistic seated connections, which are already being used in the field, to determine if the AISC method for designing these connections is adequate and realistic. As well, Phase Three testing was to determine how the web of the beam connected to a column using a stiffened seated type connection might be affected. In other words, it was to be determined whether beam web yielding or crippling was a problem at service conditions.

Phase Three testing actually consisted of two parts. The first part of the testing took place during June and July of 1993. The second part of the testing took place in January and February of 1994. During the first part of Phase Three, the load was positioned at the quarter point of the reaction beam. With this arrangement, however, the connections did not fail, due to the oversized welds provided on our test specimens, and the limitations of our testing equipment.

For the second part of Phase Three, the load was moved as close to the seated connection as was physically possible. This means that the load was positioned at 13.5 inches from the right end of the reaction beam. The reaction beam was also raised at the right end in an attempt to simulate the same end rotation at the right end of the beam at ultimate load as in the previous tests. Two 3/4 inch plates were welded in place under the column raising the beam seat by 1½ inches

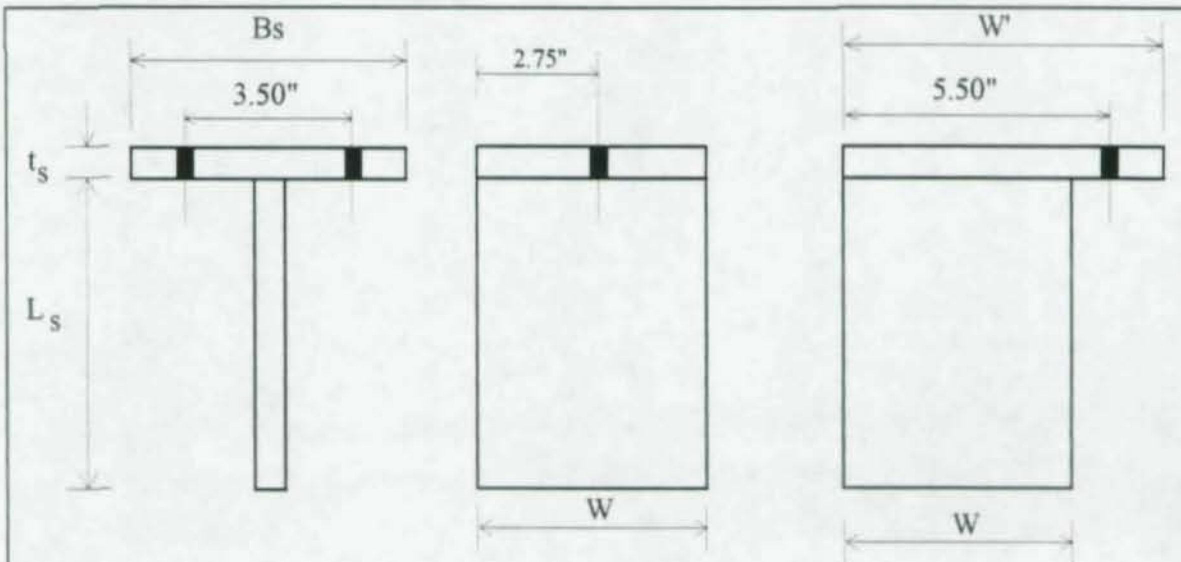
Please refer to Phases One(1989) and Two(1990) for specific results of those phases and discussions of previous studies in this area.

PHASE THREE LABORATORY TESTING

Introduction

Phase Three testing consisted of six specimens that used W14x61 column sections. Tests One, Two, and Three used beam seat plates of 3/8 in. thickness. Tests Four, Five, and Six used beam seat plate thickness of 1/2 in., 3/4 in. ,and 3/8 in. respectively. A 16 in. stiffener was used for Test Two. All other tests performed utilized 8 in. stiffeners. Tests Three, Four, and Five used beam seat plates which extended three inches beyond the stiffener width. All beam seats were six inches wide and used stiffeners that were four inches in width.

The reaction beam used in this phase of testing was the same one used in phases one and two. It was a welded girder fabricated from 70 ksi steel. The flanges were 6in.x3/4in. plates, and the web was a 14in.x1/2in. plate. High strength steel was selected in order to limit the depth of the girder, thus enabling end rotations of magnitudes typical to beams in floor systems while still providing sufficient strength for testing purposes. *Figure 1* depicts and lists the dimensions of the specimens tested, and a drawing of the load and support configuration can be seen in *Figure 2*.



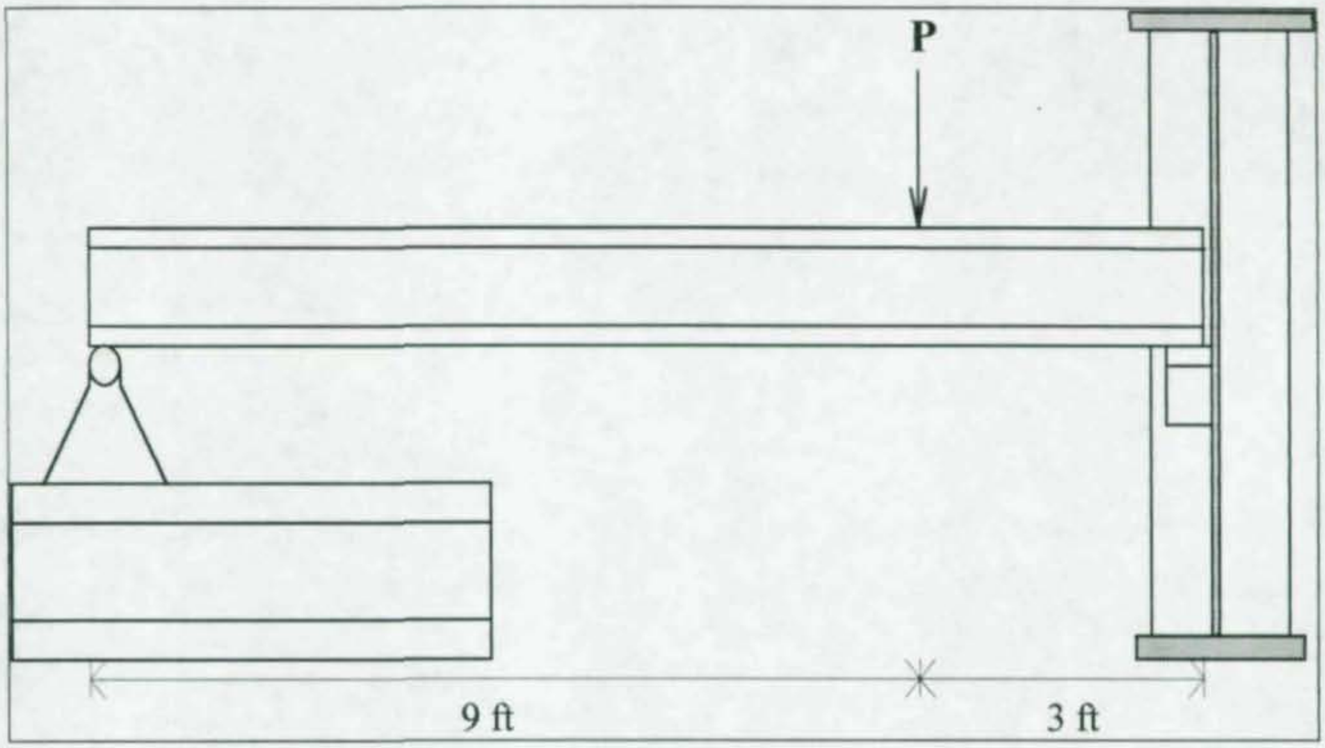
Test	W	B_s	t_s	L_s	W'
1	4"	6"	3/8"	8"	-
2	4"	6"	3/8"	16"	-
3	4"	6"	3/8"	8"	7"
4	4"	6"	1/2"	8"	7"
5	4"	6"	3/4"	8"	7"
6	4"	6"	3/8"	8"	-

All columns are W14 x 61

All stiffeners are 3/8"

Figure 1. Seat Dimensions for Phase Three

Figure 2. Load and Support Configuration

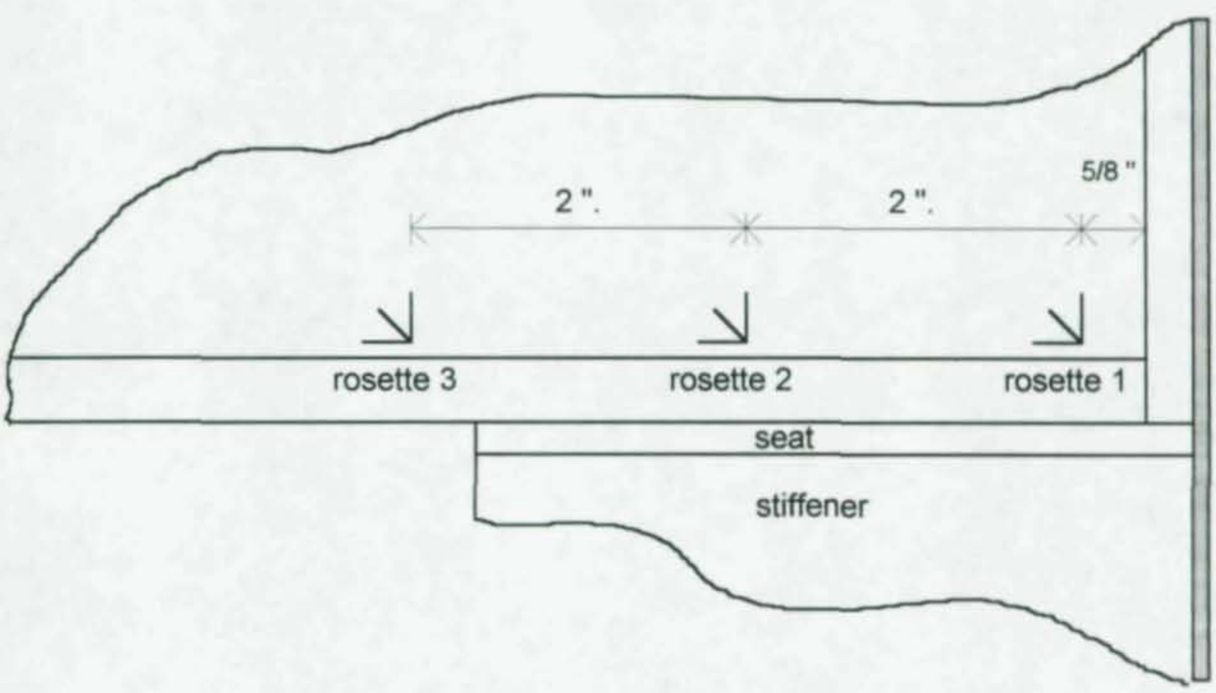


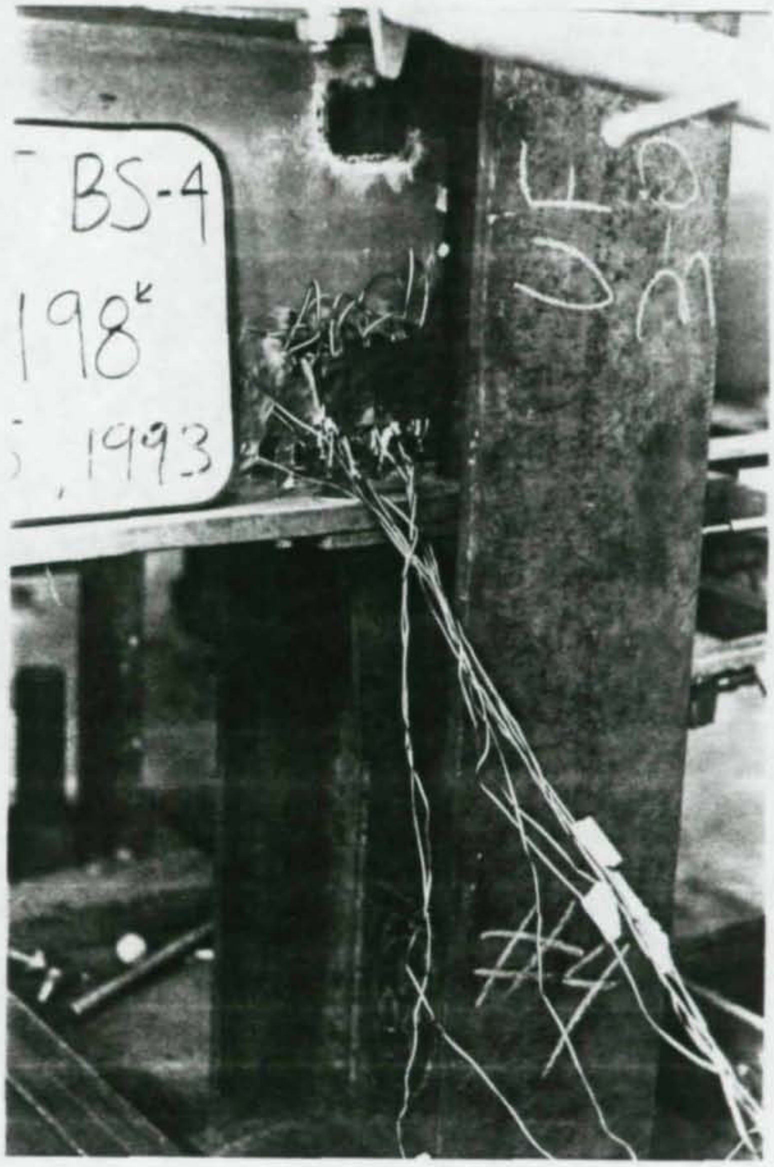
Part One

The connection of the beam to the beam seat in tests one through five was accomplished with 7/8 in. A-325 bolts only. For Test One and two the bolts were placed 2-3/4 in. out from the column face. For Test Three through five the bolts were placed a distance of 5-1/2 in. out from the column face. For Test Six, the bolts were placed a distance of 2-3/4 in. out from the column face and 1/4 in. fillet welds were made along the length of the seat on both sides of the reaction beam. The setup of Test Six was identical to Test One except for the weld along the sides of the reaction beam. During all tests a L4x4x1/4 top angle was welded at its toes to the top flange of the reaction beam and to the column web.

During this portion of Phase Three testing, the web of the reaction beam had strain gages attached to it in order to assess whether web yielding or web crippling would be a problem at service conditions. The strain gages used were weld mounted gages of type CEA-06-W250A-120 from the Micro-Measurement Division of Measurements Group, Inc. The gages were individual gages that were placed in a 45 degree rosette configuration by hand. The location of the strain gage rosettes is shown in Figure. 3. A photograph of the strain gage arrangement is also shown on the next page.

Figure 3 Strain gage rosette placement





Photograph of Strain Gage Arrangement on Beam Web for Part One

Part Two

The same test specimens, which were previously tested during Part One were used during Part Two of Phase Three. The main difference between the two parts was the location of the hydraulic ram used to apply the load as explained previously. The other difference was of course that the webs of the test columns had already yielded somewhat during the first part of Phase Three. Therefore, when looking at the load-displacement graphs in Appendix C, one must keep in mind that the total displacement of the seat and stiffener is the displacement recorded during Part Two plus any permanent deformation caused during Part One.

As mentioned previously, the column on which the seats were welded was raised 1½ inches, thus, achieving nearly the end rotation at ultimate load as in Part One. The beam curvature from Part One was calculated using the integral of the displacement formula in the ASD manual for a simply supported beam with a concentrated load at its quarter point. Any method that allows curvature calculations could have been used to achieve the same results, including the conjugate beam method. This curvature of 0.000065P rad, where P is the ultimate load from Part One, was used to find the required end displacement at the right end of the beam of 1.87 inches, using P=200 kips. Due to safety concerns and the fact that the load was still more than one foot from the end of the beam, however, the column was raised only 1.5 inches by placing two 3/4 inch plates under the column and welding them into place.

During this part of the testing, Test One and Six both used erection bolts to attach the beam to the seat. However, during Test One a top angle was not used. This caused some interesting results which can be seen in *Table 1* and *Table 2* later in this paper.

Phase Three Test Results

Part One

The test specimens were specified to have 1/4" welds attaching the stiffened seats to the column webs. The specimens were delivered having oversized welds, giving them added strength, not allowing failure using our test equipment during Part One. P_{TEST} in *Table 1* and *Table 2* refers to the maximum reaction that the seat experienced during Part One of the testing. This maximum value was a function of our testing equipment, not of the seat strength.

Before testing, the back of the column web, in the vicinity of the beam seat, was white washed along with the web of the reaction beam. The cracking of the white wash showed where yielding had occurred during testing. Yielding of the column web in the area of the beam seat and stiffener was apparent in all of the tests. Web yielding of the reaction beam was apparent in all tests as well. This, however occurred at loads well beyond the service loads of the connections.

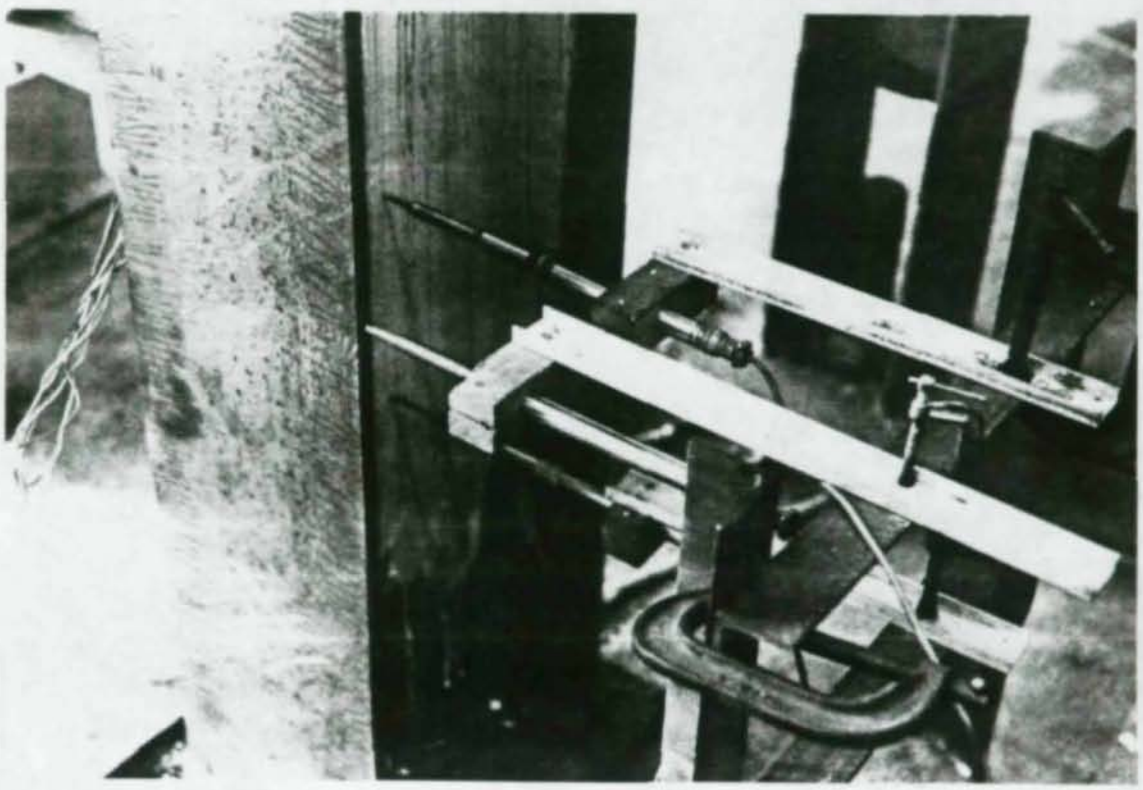
During Tests One, Two, and Five, two LVDT's were used to measure displacement of the beam seat and stiffener. They were placed in contact with the back of the column web at the elevations of the beam seat and the bottom tip of the stiffener.

The displacement (rotation) of the beam seat and stiffener may be slightly exaggerated for these tests, since, as it was later discovered, there was some rigid body rotation of the entire column. This rigid body rotation was unexpected since the column was attached at the top and bottom to the test frame. During Tests Three, Four, and Six, an additional LVDT was placed in contact with the left column flange at the elevation of the beam seat in order to monitor the rigid body motion of the column. A photograph showing the three LVDT arrangement appears on the next page

Graphs showing the LVDT displacement readings in relation to the seat reaction are located in Appendix B. LVDT 1 was located at the elevation of the seat, LVDT 2 was at the elevation of the bottom of the stiffener, and LVDT 3 was on the column flange.

Test specimen number two used a stiffener that was 16 inches in length. This was the test with the stiffener depth to length ratio of 4:1. During this test, the stiffener was observed to buckle inelastically over approximately the top 5 inches at a load applied to the reaction beam of 170^k--with the reaction at the beam seat being 127.5^k. This is seen as a problem in predicting the strength of this connection, since buckling occurs long before failure is predicted. A photograph of the buckled stiffener is included on page 11.

A simple finite element analysis was performed using SSTAN, which is a simple PC based structural analysis program created by Dr. Marc Hoit. This showed that the stresses in the top four inches of the stiffener were above the yield stresses. The input and output from the program is contained in Appendix A.



Photograph Showing Three LVDT Arrangement for Part One and Part Two

The strain gage rosettes placed on the reaction beam were most effective for the testing of specimens four and five. It was during these tests that the gages were new and unstrained. The strain data taken from these tests was plotted as principal compressive strain versus the seat reaction for each rosette location. These plots can be seen in Appendix D. A typical stress distribution is also shown in Appendix D, plotting principal stress versus position along the beam.

Part Two

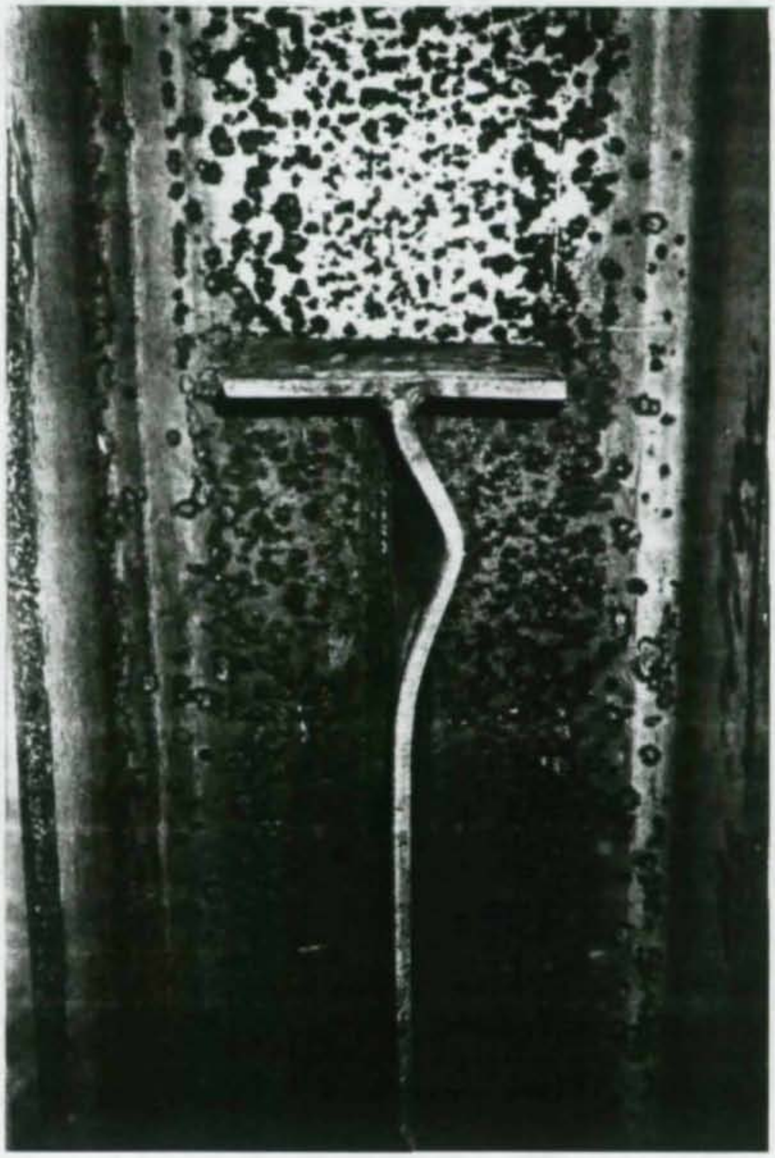
All seats were failed during the second part of testing. Graphs depicting the displacement of the seat in relation to the reaction of the seat, with the exception of one for Test Three, are available in Appendix C. The displacement data for Test Three was lost and was irretrievable when the computer reading the LVDT's crashed after testing had taken place. During this part of the testing, three LVDT's were used in the same configuration described in Part One, that is, LVDT 1 at the level of the seat, LVDT 2 at the level of the bottom of the stiffener, and LVDT 3 on the right column flange.

During Test One, which was actually the last test run, the top angle was omitted. This showed the importance of using a top angle as AISC suggests. By comparing Test One with Test Six, which was identical to Test One except for the top angle, one can see that the failure load without a top angle is approximately 20 percent less than when a top angle is used.

In fact, in four of the five tests that used top angles, failure of the seat was preceded by failure of one of the top angle's welds. It would seem that the use of a top angle not only adds stability to the connection, but adds strength as well.

During Test Two, the stiffener reached its buckling load at approximately 130^k. When this happened, the travel of the bottom of the stiffener stopped and reversed directions as buckling continued. This can be seen from the graph of displacements measured by LVDT 2 during Test Two. This graph is probably represents more of a realistic picture of the buckling event than the graph from Part One of the testing. A photograph of the buckled stiffener after Part Two testing can be seen on the following page.

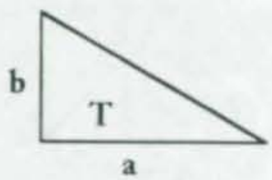
In general, failure of the seat was achieved through failure of the weld under the seat due to very large rotation of the seat. The stiffener remained attached to the column in all cases. Had loading continued, the seat and stiffener probably would have started to detach from the web even more through failure of the stiffener welds. Loading was stopped when large rotations without increase in load over three to five data retrievals were observed.



Photograph of Buckled Stiffener--Test Two, Part Two

Calculation of Load on Stiffened Seats

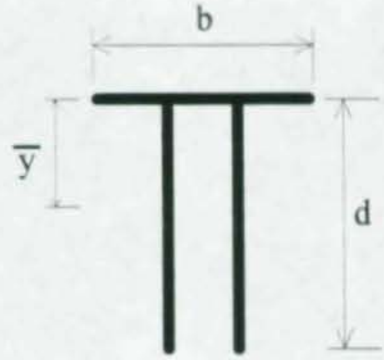
First, the following method, suggested by Omer Blodgett, was used to calculate the theoretical throat:



$$T = \frac{ab}{\sqrt{a^2 + b^2}}$$

Then, the allowable and ultimate loads on the stiffened seats tested in this phase were calculated in one of two ways for each weld size—3/8 in. x 5/16 in. or 1/4 in. x 1/4 in. The loads were calculated for *Table 1* using the AISC method and for *Table 2* using a more realistic method, referred to here as the Ellifritt, Sputo, Miller method. The main difference in the two methods is in the weld length along the width of the seat. AISC uses a value of 0.2L on each side of the stiffener. We use a weld length equal to the seat width minus the stiffener thickness. An example of the formulas used follows:

Calculation of Section Modulus of Weld:



$$\bar{y} = \frac{2d \times d/2}{2d+b} = \frac{d^2}{2d+b}$$

$$I_x = \frac{2d^3}{3} - \frac{d^4}{2d+b}$$

$$S_x = \frac{I_x}{\bar{y}} = \frac{d^2 + 2db}{3}$$

Calculation of Allowable Load on Stiffener

AISC Method,

$$R_w = \sqrt{\frac{\mathrm{P}e}{S_x} + \frac{\mathrm{P}}{2.4L}}$$

$$\mathrm{P} = \frac{2.4L^2 R_w}{\sqrt{16e^2 + L^2}}$$

Ellifritt, Sputo, Miller Method

$$R_w = \sqrt{\frac{\mathrm{P}e}{S_x} + \frac{\mathrm{P}}{A_w}}$$

$$\mathrm{P} = \frac{A_w S_x R_w}{\sqrt{A_w e^2 + S_x^2}}$$

Where $A_w = 2L_s + b - t_s$

It is felt that the Ellifritt, Sputo, Miller method of computing the allowable load on the seat based on the weld stress is a more realistic and never unconservative approach. The AISC approach, using a weld length of 0.4L under the seat, is conservative only when the width of the seat plate, B_S, is 0.8 L_S or larger. The AISC method is unconservative for cases other than mentioned above by over predicting total weld length. Although the difference in stress calculations is minimal, the use of the proper weld length does make a difference in the numbers which might confuse someone using the AISC method.

Tabulated Results

This section contains test results for both parts of Phase Three. The results are compared to calculated values of allowable and ultimate loads on the seat. The calculated values are derived as described in the previous section. For the calculations of P_{ASD} and P_{ULT} for Tests Three, Four, and Five, and eccentricity equal to 80 percent of the seat length, W′, was used instead of 80 percent of the stiffener width, W. This value for eccentricity was used because the bolts for the extended seat connections were beyond the edge of the stiffener, and it seemed more rational to base the eccentricity on the seat length in this case than on the stiffener width. Refer to *Table 1* and *Table 2* on the next two pages.

In addition to *Table 1* and *Table 2*, *Table 3* shows a comparison of the calculated values of P_{ASD} and P_{ULT} using the AISC method ad the Ellifritt, Sputo, Miller method.

Table 1. Phase Three Test Results Compared with AISC Values of P_{ASD} and P_{ULT}

actual values with 3/8 in. x 5/16 in. welds:

Test	P_{TEST}*	P_{FAIL}	P_{ASD}	P_{ULT}	P_{FAIL}/P_{ASD}	P_{FAIL}/P_{ULT}
1	149.0k	133.1k**	51.3k	102.6k	2.60	1.30
2	151.6k	177.2k	151.1k	302.2k	1.17	0.59
3	147.6k	147.6k	32.5k	65.0k	4.53	2.27
4	148.7k	148.7k	32.5k	65.0k	4.57	2.29
5	145.7k	182.5k	32.5k	65.0k	5.62	2.81
6	146.9k	166.9k	51.3k	102.6k	3.25	1.63

if 1/4in. x 1/4 in. welds were used as specified:

Test	P_{TEST}*	P_{FAIL}	P_{ASD}	P_{ULT}	P_{FAIL}/P_{ASD}	P_{FAIL}/P_{ULT}
1	149.0k	133.1k**	37.8k	75.6k	3.52	1.76
2	151.6k	177.2k	111.3k	222.6k	1.60	0.80
3	147.6k	147.6k	24.0k	48.0k	6.16	3.08
4	148.7k	148.7k	24.0k	48.0k	6.20	3.10
5	145.7k	182.5k	24.0k	48.0k	7.60	3.80
6	146.9k	166.9k	37.8k	75.6k	4.42	2.21

*Part One maximum load

**No top angle used

Table 2. Phase Three Test Results As Compared to Ellifritt, Sputo, Miller Values of P_{ASD} and P_{ULT}

actual values with 3/8 in. x 5/16 in. welds

Test	P_{TEST}*	P_{FAIL}	P_{ASD}	P_{ULT}	P_{FAIL}/P_{ASD}	P_{FAIL}/P_{ULT}
1	149.0k	133.1k**	66.5k	133.0k	2.00	1.00
2	151.6k	177.2k	146.1k	292.2k	1.21	.606
3	147.6k	147.6k	43.9k	87.8k	3.36	1.68
4	148.7k	148.7k	43.9k	87.8k	3.38	1.69
5	145.7k	182.5k	43.9k	87.8k	4.16	2.08
6	146.9k	166.9k	66.5k	133.0k	2.50	1.25

if 1/4in. x 1/4 in. welds were used as specified:

Test	P_{TEST}*	P_{FAIL}	P_{ASD}	P_{ULT}	P_{FAIL}/P_{ASD}	P_{FAIL}/P_{ULT}
1	149.0k	133.1k**	49.0 k	98.0 k	2.72	1.36
2	151.6k	177.2k	107.7 k	215.4 k	1.64	0.82
3	147.6k	147.6k	32.4 k	64.8 k	4.56	2.28
4	148.7k	148.7k	32.4 k	64.8 k	4.58	2.29
5	145.7k	182.5k	32.4 k	64.8 k	5.64	2.82
6	146.9k	166.9k	49.0 k	98.0 k	3.40	1.70

*Part One maximum load

**No top angle used.

Table 3 Comparison of Calculated Loads from AISC and Ellifritt, Sputo, Miller (ESM) Methods

actual values with 3/8 in. x 5/16 in. welds:

	AISC METHOD				ESM METHOD			
Test	P_{ASD}	P_{ULT}	P_{FAIL}/P_{ASD}	P_{FAIL}/P_{ULT}	P_{ASD}	P_{ULT}	P_{FAIL}/P_{ASD}	P_{FAIL}/P_{ULT}
1	51.3^k	102.6^k	2.60	1.30	66.5k	133.0k	2.00	1.00
2	151.1^k	302.2^k	1.17	0.59	146.1k	292.2k	1.21	.606
3	32.5^k	65.0^k	4.53	2.27	43.9k	87.8k	3.36	1.68
4	32.5^k	65.0^k	4.57	2.29	43.9k	87.8k	3.38	1.69
5	32.5^k	65.0^k	5.62	2.81	43.9k	87.8k	4.16	2.08
6	51.3^k	102.6^k	3.25	1.63	66.5k	133.0k	2.50	1.25

if 1/4in. x 1/4 in. welds were used as specified:

	AISC METHOD				ESM METHOD			
Test	P_{ASD}	P_{ULT}	P_{FAIL}/P_{ASD}	P_{FAIL}/P_{ULT}	P_{ASD}	P_{ULT}	P_{FAIL}/P_{ASD}	P_{FAIL}/P_{ULT}
1	37.8^k	75.6^k	3.52	1.76	49.0^k	98.0^k	2.72	1.36
2	111.3^k	222.6^k	1.60	0.80	107.7^k	215.4^k	1.64	0.82
3	24.0^k	48.0^k	6.16	3.08	32.4^k	64.8^k	4.56	2.28
4	24.0^k	48.0^k	6.20	3.10	32.4^k	64.8^k	4.58	2.29
5	24.0^k	48.0^k	7.60	3.80	32.4^k	64.8^k	5.64	2.82
6	37.8^k	75.6^k	4.42	2.21	49.0^k	98.0^k	3.40	1.70

Material Properties

Three tensile coupons were cut and milled from the column webs of the test specimens. These coupons were used to find the strength of the steel used in fabricating the specimens. It was assumed that the steel used to fabricate the seats and stiffeners was of the same strength as the steel used for the columns. A36 steel was specified for the columns and seats. Table 3 below shows the results of all three tensile tests and the average of all results.

Table 3. Steel Properties

Tensile Specimen	**F_y (ksi)**	**F_u (ksi)**	**$\Delta L/L$ (%)**
1	48.26	70.79	41
2	44.29	64.67	48
3	47.68	71.82	32
AVG.	46.74	69.09	40

CONCLUSION

The findings of these tests seem to show that the beam seat configurations used in this phase of testing were superior to those configurations used in Phase One and Phase Two. As stated before, however, the use of elongated stiffeners with a depth to width ratio of 4:1 or greater should be studied more closely due to the problem with buckling of the stiffener at service load.

The findings also seem to point out that the use of extended seats does not improve the overall strength of the connection. It may, in fact, decrease the strength of the connection by increasing the effective eccentricity of the reaction on the seat.

Stiffener Buckling

This buckling of the stiffener has been questioned as to whether it is a real problem since the test beam used had a web that was wider, and had a higher yield strength than the stiffener, which is not allowed by AISC specifications. The buckling of the stiffener is most likely caused by a stress concentration near the outside corner of the stiffener encountered when the beam rotates and the bearing area decreases. It is obvious that the stress concentration would still occur even if a web matching the size and yield strength of the stiffener were used. It is possible that the beam web would fail before the stiffener buckled, and it is assumed this is why AISC made this provision. It is obvious from this limited testing, however, that there is a more complex interaction between beam, stiffener, and column web when using seated connections with aspect ratios of 4:1 or greater than there is for stiffened seated connections with aspect ratios of 2:1 or smaller. Therefore, it is believed that more testing of stiffened beam seats using aspect ratios of 4:1 or larger, and possibly even 3:1, should be done using beam webs that match the stiffener thickness and yield strength. This way a rational approach to calculating the strength of stiffened seated connections using high aspect ratios can be found.

Extended Seats

It seems that the Extended seats in Tests Three, Four, and Five do not help the overall strength of the connection, and may, in fact, decrease the overall strength due to the increased eccentricity of the beam reaction on the seat. This is evident by comparing failure reaction values in Tests Three and Four to the failure reaction in Test Six. Test Five had a larger failure reaction than Tests Three, Four, and Six. However, it is felt that this is because the welds on the top angle did not fail and is probably not due to the seat configuration. It is possible that larger welds than necessary were used to attach the top angle in this case.

One may note that the ratios P_{FAIL}/P_{ASD} and P_{FAIL}/P_{ULT} are larger for Tests Three, Four, and Five than the same ratios for Test Six. This is due to the value of eccentricity used in calculating P_{ASD} for Tests Three, Four, and Five. In these cases, results were based on an eccentricity of 80 percent of the seat length W′, since AISC has not yet adopted a standard for this type of seat configuration. It is possible that using an eccentricity based on suggestions from Phase Two would give better results. In other words, an eccentricity calculated as half the distance between the end of the beam and the erection bolts plus 1/2 inch for beam clearance of the column flange might yield better results. However, more than the three tests used here would have to be completed before one could endorse such a method for computing the eccentricity of this type of connection.

Welded vs. Bolted Connection

The data seems to show that there is practically no difference in strength when using bolts or welds to attach the beam to the seat. This is evident by comparing P_{TEST} for Tests One and Six.

Beam Web Yielding

Beam web yielding does not seem to be a problem during service conditions and would not even occur for A36 beams until reactions near the ultimate capacity of the connection, P_{ULT}, were reached. This is evident by observing the graphical stress and strain data for BS4 and BS5 in Appendix D.

Design Recommendations

It is recommended that stiffened seated connections using stiffeners with a depth to width ratio of 4:1 or greater should not be used if they have been designed using weld strength as the controlling strength factor.

The Ellifritt, Sputo, Miller method of calculating the weld length for these connections seems to be a more realistic approach. It is therefore recommended that this method be used over AISC's method in order to achieve more accurate results.

It is also recommended that the code show the option of using erection bolts to connect beams to the seats in the section of the code were welded stiffened seats are used.

Further Research

Further investigation of the use of depth to width ratios of 3:1 and greater is suggested. This suggestion is made in light of the buckling incident which occurred during this phase of testing with the stiffener in Test Two. The buckling of the stiffener precedes the predicted ultimate strength, and thus, cuts into the factor of safety provided in ASD. This is seen as a greater problem when LRFD is used.

It is also recommended that research using reaction beams with web thickness and yield strength corresponding to the provisions of AISC be completed in order to achieve a more rational picture of the beam/seat interaction at failure.

Appendix A

Finite Element Analysis of 16 Inch Stiffener

As stated before, a finite element analysis was performed for test two in order to study the inelastic buckling phenomenon which occurred at a reaction of 127.5^k. The program used for the analysis was SSTAN by Dr. Marc Hoit of the Department of Civil Engineering, Structures Group, at the University of Florida. The program is designed for simple linear structural analysis and does not handle stability problems. The analysis does, however, give an idea where stress concentrations occur, which are believed to be responsible for the buckling event. A model of the stiffener showing the node numbering and a partial stress distribution is available on the following pages

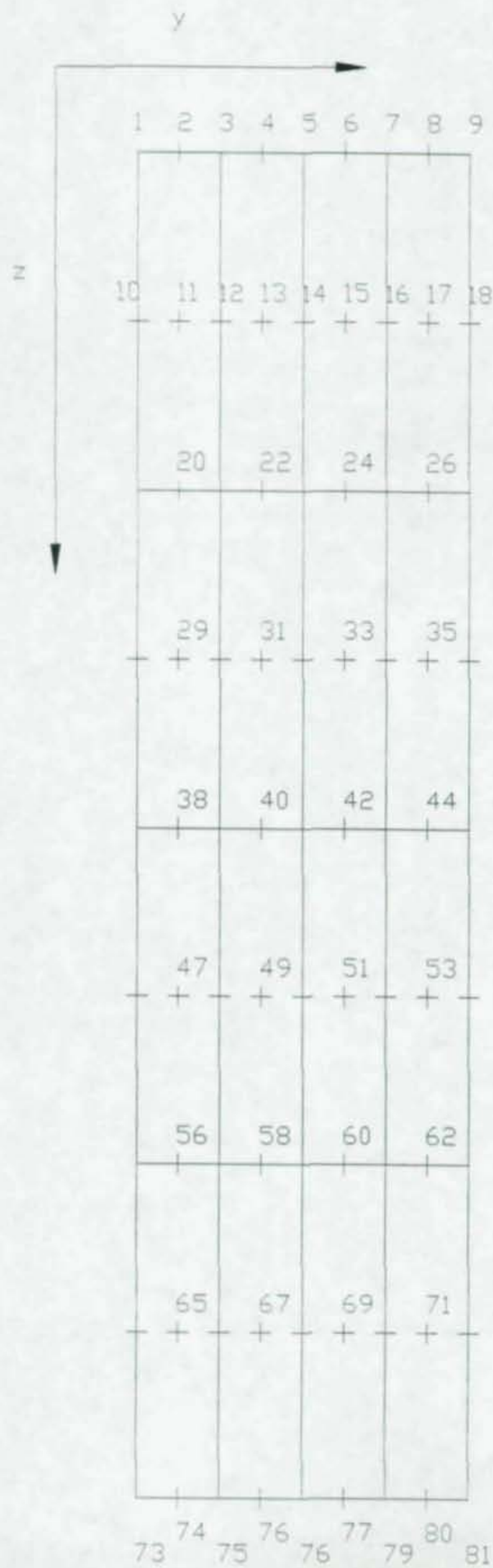
Notice that most of the stresses are above yield in the top four inches of the stiffener and they get larger nearer to the free edge, showing a concentration of compressive stress in the top right corner of the diagram. Only compressive stresses, Szz are plotted. The stresses are listed by element and node in the output from SSTAN which is included.

The load was modeled as an equivalent distributed load over the width of the stiffener, W. The stiffener was modeled using 16 nine node, plane stress, membrane elements which were fixed along the left edge. Numbering of nodes and elements is from left to right and top to bottom.

COMPRESSIVE STRESS DISTRIBUTION

S_{zz} ONLY

NODE NUMBERING



```
SSTAN study of 16 inch stiffener
C-------------------------------------------------
C  Calculation of load on each element (Pb)
C  w=127.5*(12/4)=382.5
C  Lij=1/12
C                {5}
C  Pb=wLij/30    {20}
C                {5}
C
C      {5.3125}
C  Pb={21.25}
C      {5.3125}
C-------------------------------------------------
81,1,1
COORDINATES
1    X=0     Y=0     Z=0
2            Y=.5
3            Y=1
4            Y=1.5
5            Y=2
6            Y=2.5
7            Y=3
8            Y=3.5
9            Y=4
73           Y=0     Z=16    G=1,73,9
74           Y=.5            G=2,74,9
75           Y=1             G=3,75,9
76           Y=1.5           G=4,76,9
77           Y=2             G=5,77,9
78           Y=2.5           G=6,78,9
79           Y=3             G=7,79,9
80           Y=3.5           G=8,80,9
81           Y=4             G=9,81,9
:
BOUNDARY
1,81           DOF=F,R,R,F,F,F
1,73,9         DOF=F,F,F,F,F,F
:
PLANE
16,1,0
1  E=29600 U=0.30
1  N=1,2,3,10,11,12,19,20,21,M=1  H=.375  G=4,4
:
LOADS
1  L=1  F=0,0,5.125,0,0,0
2  L=1  F=0,0,21.25,0,0,0
3  L=1  F=0,0,10.25,0,0,0
4  L=1  F=0,0,21.25,0,0,0
```

```
5   L=1   F=0,0,10.25,0,0,0
6   L=1   F=0,0,21.25,0,0,0
7   L=1   F=0,0,10.25,0,0,0
8   L=1   F=0,0,21.25,0,0,0
9   L=1   F=0,0,5.125,0,0,0
```

```
*******************************************************
**** SSTAN - Simple Structural Analysis Program ****
Copyright 1987 By Dr. Marc Hoit, University of Florida
*******************************************************
```

SSTAN study of 16 inch stiffener

NUMBER OF JOINTS = 81
NUMBER OF DIFFERENT ELEMENT TYPES = 1
NUMBER OF LOAD CONDITIONS = 1

NODE	BOUNDARY CONDITION CODES						NODAL POINT COORDINATES		
NUMBER	X	Y	Z	XX	YY	ZZ	X	Y	Z
1	F	F	F	F	F	F	.000	.000	.000
2	F	R	R	F	F	F	.000	.500	.000
3	F	R	R	F	F	F	.000	1.000	.000
4	F	R	R	F	F	F	.000	1.500	.000
5	F	R	R	F	F	F	.000	2.000	.000
6	F	R	R	F	F	F	.000	2.500	.000
7	F	R	R	F	F	F	.000	3.000	.000
8	F	R	R	F	F	F	.000	3.500	.000
9	F	R	R	F	F	F	.000	4.000	.000
10	F	F	F	F	F	F	.000	.000	2.000
11	F	R	R	F	F	F	.000	.500	2.000
12	F	R	R	F	F	F	.000	1.000	2.000
13	F	R	R	F	F	F	.000	1.500	2.000
14	F	R	R	F	F	F	.000	2.000	2.000
15	F	R	R	F	F	F	.000	2.500	2.000
16	F	R	R	F	F	F	.000	3.000	2.000
17	F	R	R	F	F	F	.000	3.500	2.000
18	F	R	R	F	F	F	.000	4.000	2.000
19	F	F	F	F	F	F	.000	.000	4.000
20	F	R	R	F	F	F	.000	.500	4.000
21	F	R	R	F	F	F	.000	1.000	4.000
22	F	R	R	F	F	F	.000	1.500	4.000
23	F	R	R	F	F	F	.000	2.000	4.000
24	F	R	R	F	F	F	.000	2.500	4.000
25	F	R	R	F	F	F	.000	3.000	4.000
26	F	R	R	F	F	F	.000	3.500	4.000
27	F	R	R	F	F	F	.000	4.000	4.000
28	F	F	F	F	F	F	.000	.000	6.000
29	F	R	R	F	F	F	.000	.500	6.000
30	F	R	R	F	F	F	.000	1.000	6.000
31	F	R	R	F	F	F	.000	1.500	6.000
32	F	R	R	F	F	F	.000	2.000	6.000
33	F	R	R	F	F	F	.000	2.500	6.000
34	F	R	R	F	F	F	.000	3.000	6.000
35	F	R	R	F	F	F	.000	3.500	6.000
36	F	R	R	F	F	F	.000	4.000	6.000
37	F	F	F	F	F	F	.000	.000	8.000
38	F	R	R	F	F	F	.000	.500	8.000
39	F	R	R	F	F	F	.000	1.000	8.000
40	F	R	R	F	F	F	.000	1.500	8.000
41	F	R	R	F	F	F	.000	2.000	8.000
42	F	R	R	F	F	F	.000	2.500	8.000
43	F	R	R	F	F	F	.000	3.000	8.000

44	F	R	R	F	F	F	.000	3.500	8.000
45	F	R	R	F	F	F	.000	4.000	8.000
46	F	F	F	F	F	F	.000	.000	10.000
47	F	R	R	F	F	F	.000	.500	10.000
48	F	R	R	F	F	F	.000	1.000	10.000
49	F	R	R	F	F	F	.000	1.500	10.000
50	F	R	R	F	F	F	.000	2.000	10.000
51	F	R	R	F	F	F	.000	2.500	10.000
52	F	R	R	F	F	F	.000	3.000	10.000
53	F	R	R	F	F	F	.000	3.500	10.000
54	F	R	R	F	F	F	.000	4.000	10.000
55	F	F	F	F	F	F	.000	.000	12.000
56	F	R	R	F	F	F	.000	.500	12.000
57	F	R	R	F	F	F	.000	1.000	12.000
58	F	R	R	F	F	F	.000	1.500	12.000
59	F	R	R	F	F	F	.000	2.000	12.000
60	F	R	R	F	F	F	.000	2.500	12.000
61	F	R	R	F	F	F	.000	3.000	12.000
62	F	R	R	F	F	F	.000	3.500	12.000
63	F	R	R	F	F	F	.000	4.000	12.000
64	F	F	F	F	F	F	.000	.000	14.000
65	F	R	R	F	F	F	.000	.500	14.000
66	F	R	R	F	F	F	.000	1.000	14.000
67	F	R	R	F	F	F	.000	1.500	14.000
68	F	R	R	F	F	F	.000	2.000	14.000
69	F	R	R	F	F	F	.000	2.500	14.000
70	F	R	R	F	F	F	.000	3.000	14.000
71	F	R	R	F	F	F	.000	3.500	14.000
72	F	R	R	F	F	F	.000	4.000	14.000
73	F	F	F	F	F	F	.000	.000	16.000
74	F	R	R	F	F	F	.000	.500	16.000
75	F	R	R	F	F	F	.000	1.000	16.000
76	F	R	R	F	F	F	.000	1.500	16.000
77	F	R	R	F	F	F	.000	2.000	16.000
78	F	R	R	F	F	F	.000	2.500	16.000
79	F	R	R	F	F	F	.000	3.000	16.000
80	F	R	R	F	F	F	.000	3.500	16.000
81	F	R	R	F	F	F	.000	4.000	16.000

EQUATION NUMBERS

N	X	Y	Z	XX	YY	ZZ
1	0	0	0	0	0	0
2	0	1	2	0	0	0
3	0	3	4	0	0	0
4	0	5	6	0	0	0
5	0	7	8	0	0	0
6	0	9	10	0	0	0
7	0	11	12	0	0	0
8	0	13	14	0	0	0
9	0	15	16	0	0	0
10	0	0	0	0	0	0
11	0	17	18	0	0	0
12	0	19	20	0	0	0
13	0	21	22	0	0	0
14	0	23	24	0	0	0
15	0	25	26	0	0	0
16	0	27	28	0	0	0
17	0	29	30	0	0	0
18	0	31	32	0	0	0
19	0	0	0	0	0	0

20	0	33	34	0	0	0
21	0	35	36	0	0	0
22	0	37	38	0	0	0
23	0	39	40	0	0	0
24	0	41	42	0	0	0
25	0	43	44	0	0	0
26	0	45	46	0	0	0
27	0	47	48	0	0	0
28	0	0	0	0	0	0
29	0	49	50	0	0	0
30	0	51	52	0	0	0
31	0	53	54	0	0	0
32	0	55	56	0	0	0
33	0	57	58	0	0	0
34	0	59	60	0	0	0
35	0	61	62	0	0	0
36	0	63	64	0	0	0
37	0	0	0	0	0	0
38	0	65	66	0	0	0
39	0	67	68	0	0	0
40	0	69	70	0	0	0
41	0	71	72	0	0	0
42	0	73	74	0	0	0
43	0	75	76	0	0	0
44	0	77	78	0	0	0
45	0	79	80	0	0	0
46	0	0	0	0	0	0
47	0	81	82	0	0	0
48	0	83	84	0	0	0
49	0	85	86	0	0	0
50	0	87	88	0	0	0
51	0	89	90	0	0	0
52	0	91	92	0	0	0
53	0	93	94	0	0	0
54	0	95	96	0	0	0
55	0	0	0	0	0	0
56	0	97	98	0	0	0
57	0	99	100	0	0	0
58	0	101	102	0	0	0
59	0	103	104	0	0	0
60	0	105	106	0	0	0
61	0	107	108	0	0	0
62	0	109	110	0	0	0
63	0	111	112	0	0	0
64	0	0	0	0	0	0
65	0	113	114	0	0	0
66	0	115	116	0	0	0
67	0	117	118	0	0	0
68	0	119	120	0	0	0
69	0	121	122	0	0	0
70	0	123	124	0	0	0
71	0	125	126	0	0	0
72	0	127	128	0	0	0
73	0	0	0	0	0	0
74	0	129	130	0	0	0
75	0	131	132	0	0	0
76	0	133	134	0	0	0
77	0	135	136	0	0	0
78	0	137	138	0	0	0
79	0	139	140	0	0	0
80	0	141	142	0	0	0

81 0 143 144 0 0 0

*** PLANE-MEMBRANE ELEMENT ***

```
********************************
   ELEMENTS ARE PLANE STRESS
********************************
```

-ELEMENT LOAD MULTIPLIERS -

LOAD	Y-GRAVITY	Z-GRAVITY
1	.000	.000

-MATERIAL PROPERTIES -

```
MATERIAL I.D. NUMBER  =      1
WEIGHT (GRAVITY LOAD) =      .0000E+00
E (YOUNGS MODULUS)    =      .2960E+05
NU (POSSIONS RATIO)   =      .3000
G (SHEAR MODULUS)     =      .1138E+05
```

-ELEMENT DEFINITIONS -

EL #	MAT	N1	N2	N3	N4	N5	N6	N7	N8	N9	THICK
1	1	1	2	3	10	11	12	19	20	21	.38
2	1	3	4	5	12	13	14	21	22	23	.38
3	1	5	6	7	14	15	16	23	24	25	.38
4	1	7	8	9	16	17	18	25	26	27	.38
5	1	19	20	21	28	29	30	37	38	39	.38
6	1	21	22	23	30	31	32	39	40	41	.38
7	1	23	24	25	32	33	34	41	42	43	.38
8	1	25	26	27	34	35	36	43	44	45	.38
9	1	37	38	39	46	47	48	55	56	57	.38
10	1	39	40	41	48	49	50	57	58	59	.38
11	1	41	42	43	50	51	52	59	60	61	.38
12	1	43	44	45	52	53	54	61	62	63	.38
13	1	55	56	57	64	65	66	73	74	75	.38
14	1	57	58	59	66	67	68	75	76	77	.38
15	1	59	60	61	68	69	70	77	78	79	.38
16	1	61	62	63	70	71	72	79	80	81	.38

THE NODE NUMBERING USED PRODUCED A HALF BANDWIDTH OF 38

```
TOTAL STORAGE REQUIRED  =     5859
TOTAL STORAGE AVAILABLE =    50000
```

*** CONCENTRATED NODAL LOADS ***

NODE	LOAD	X	Y	Z	XX	YY	ZZ
1	1	.00E+00	.00E+00	.51E+01	.00E+00	.00E+00	.00E+00
2	1	.00E+00	.00E+00	.21E+02	.00E+00	.00E+00	.00E+00

3	1	.00E+00	.00E+00	.10E+02	.00E+00	.00E+00	.00E+00
4	1	.00E+00	.00E+00	.21E+02	.00E+00	.00E+00	.00E+00
5	1	.00E+00	.00E+00	.10E+02	.00E+00	.00E+00	.00E+00
6	1	.00E+00	.00E+00	.21E+02	.00E+00	.00E+00	.00E+00
7	1	.00E+00	.00E+00	.10E+02	.00E+00	.00E+00	.00E+00
8	1	.00E+00	.00E+00	.21E+02	.00E+00	.00E+00	.00E+00
9	1	.00E+00	.00E+00	.51E+01	.00E+00	.00E+00	.00E+00

FORMATION OF STIFFNESS MATRIX

START OF SOLUTION OF EQUATIONS

*** PRINT OF FINAL DISPLACEMENTS ***

DISPLACEMENTS FOR LOAD CONDITION 1

NODE	X	Y	Z	XX	YY	ZZ
1	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
2	.00000E+00	.32054E-02	.52054E-02	.00000E+00	.00000E+00	.00000E+00
3	.00000E+00	.43859E-02	.80685E-02	.00000E+00	.00000E+00	.00000E+00
4	.00000E+00	.51495E-02	.10822E-01	.00000E+00	.00000E+00	.00000E+00
5	.00000E+00	.55781E-02	.12677E-01	.00000E+00	.00000E+00	.00000E+00
6	.00000E+00	.59152E-02	.14450E-01	.00000E+00	.00000E+00	.00000E+00
7	.00000E+00	.62435E-02	.15741E-01	.00000E+00	.00000E+00	.00000E+00
8	.00000E+00	.66082E-02	.17096E-01	.00000E+00	.00000E+00	.00000E+00
9	.00000E+00	.70046E-02	.18222E-01	.00000E+00	.00000E+00	.00000E+00
10	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
11	.00000E+00	-.55017E-03	.16245E-02	.00000E+00	.00000E+00	.00000E+00
12	.00000E+00	-.13456E-03	.40493E-02	.00000E+00	.00000E+00	.00000E+00
13	.00000E+00	.35245E-03	.59524E-02	.00000E+00	.00000E+00	.00000E+00
14	.00000E+00	.90706E-03	.77848E-02	.00000E+00	.00000E+00	.00000E+00
15	.00000E+00	.14210E-02	.92247E-02	.00000E+00	.00000E+00	.00000E+00
16	.00000E+00	.18875E-02	.10528E-01	.00000E+00	.00000E+00	.00000E+00
17	.00000E+00	.23134E-02	.11546E-01	.00000E+00	.00000E+00	.00000E+00
18	.00000E+00	.27367E-02	.12494E-01	.00000E+00	.00000E+00	.00000E+00
19	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
20	.00000E+00	.64583E-03	.17322E-02	.00000E+00	.00000E+00	.00000E+00
21	.00000E+00	.15716E-03	.23245E-02	.00000E+00	.00000E+00	.00000E+00
22	.00000E+00	-.98627E-05	.36285E-02	.00000E+00	.00000E+00	.00000E+00
23	.00000E+00	-.12213E-03	.45702E-02	.00000E+00	.00000E+00	.00000E+00
24	.00000E+00	-.84408E-04	.56532E-02	.00000E+00	.00000E+00	.00000E+00
25	.00000E+00	.60983E-04	.64053E-02	.00000E+00	.00000E+00	.00000E+00
26	.00000E+00	.28264E-03	.71031E-02	.00000E+00	.00000E+00	.00000E+00
27	.00000E+00	.55258E-03	.73853E-02	.00000E+00	.00000E+00	.00000E+00
28	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
29	.00000E+00	-.34449E-03	.73457E-03	.00000E+00	.00000E+00	.00000E+00
30	.00000E+00	-.22292E-03	.17804E-02	.00000E+00	.00000E+00	.00000E+00
31	.00000E+00	-.24139E-03	.24033E-02	.00000E+00	.00000E+00	.00000E+00
32	.00000E+00	-.20417E-03	.30955E-02	.00000E+00	.00000E+00	.00000E+00
33	.00000E+00	-.14423E-03	.35855E-02	.00000E+00	.00000E+00	.00000E+00
34	.00000E+00	-.46620E-04	.40399E-02	.00000E+00	.00000E+00	.00000E+00
35	.00000E+00	.89374E-04	.42890E-02	.00000E+00	.00000E+00	.00000E+00
36	.00000E+00	.25300E-03	.44279E-02	.00000E+00	.00000E+00	.00000E+00
37	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
38	.00000E+00	.20526E-03	.70659E-03	.00000E+00	.00000E+00	.00000E+00
39	.00000E+00	-.18385E-03	.84023E-03	.00000E+00	.00000E+00	.00000E+00
40	.00000E+00	-.16911E-03	.15216E-02	.00000E+00	.00000E+00	.00000E+00
41	.00000E+00	-.16840E-03	.18386E-02	.00000E+00	.00000E+00	.00000E+00
42	.00000E+00	-.10996E-03	.22778E-02	.00000E+00	.00000E+00	.00000E+00
43	.00000E+00	-.30326E-04	.24782E-02	.00000E+00	.00000E+00	.00000E+00

44	.00000E+00	.59334E-04	.27026E-02	.00000E+00	.00000E+00	.00000E+00
45	.00000E+00	.14270E-03	.27440E-02	.00000E+00	.00000E+00	.00000E+00
46	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
47	.00000E+00	-.13723E-03	.31135E-03	.00000E+00	.00000E+00	.00000E+00
48	.00000E+00	-.28518E-04	.78011E-03	.00000E+00	.00000E+00	.00000E+00
49	.00000E+00	-.77148E-04	.97409E-03	.00000E+00	.00000E+00	.00000E+00
50	.00000E+00	-.69348E-04	.12799E-02	.00000E+00	.00000E+00	.00000E+00
51	.00000E+00	-.51729E-04	.14481E-02	.00000E+00	.00000E+00	.00000E+00
52	.00000E+00	-.16189E-04	.16371E-02	.00000E+00	.00000E+00	.00000E+00
53	.00000E+00	.30489E-04	.17189E-02	.00000E+00	.00000E+00	.00000E+00
54	.00000E+00	.89955E-04	.17772E-02	.00000E+00	.00000E+00	.00000E+00
55	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
56	.00000E+00	.88159E-04	.31645E-03	.00000E+00	.00000E+00	.00000E+00
57	.00000E+00	-.17181E-03	.31156E-03	.00000E+00	.00000E+00	.00000E+00
58	.00000E+00	-.81675E-04	.71126E-03	.00000E+00	.00000E+00	.00000E+00
59	.00000E+00	-.65507E-04	.78942E-03	.00000E+00	.00000E+00	.00000E+00
60	.00000E+00	-.28034E-04	.10300E-02	.00000E+00	.00000E+00	.00000E+00
61	.00000E+00	.13410E-05	.10989E-02	.00000E+00	.00000E+00	.00000E+00
62	.00000E+00	.31436E-04	.12222E-02	.00000E+00	.00000E+00	.00000E+00
63	.00000E+00	.46080E-04	.12263E-02	.00000E+00	.00000E+00	.00000E+00
64	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
65	.00000E+00	-.62417E-04	.13133E-03	.00000E+00	.00000E+00	.00000E+00
66	.00000E+00	.23424E-04	.39409E-03	.00000E+00	.00000E+00	.00000E+00
67	.00000E+00	-.45322E-04	.47383E-03	.00000E+00	.00000E+00	.00000E+00
68	.00000E+00	-.62333E-04	.68976E-03	.00000E+00	.00000E+00	.00000E+00
69	.00000E+00	-.80027E-04	.78807E-03	.00000E+00	.00000E+00	.00000E+00
70	.00000E+00	-.83504E-04	.92881E-03	.00000E+00	.00000E+00	.00000E+00
71	.00000E+00	-.82419E-04	.10006E-02	.00000E+00	.00000E+00	.00000E+00
72	.00000E+00	-.72205E-04	.10818E-02	.00000E+00	.00000E+00	.00000E+00
73	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00	.00000E+00
74	.00000E+00	-.72195E-04	.18595E-03	.00000E+00	.00000E+00	.00000E+00
75	.00000E+00	-.38101E-03	.16879E-03	.00000E+00	.00000E+00	.00000E+00
76	.00000E+00	-.34375E-03	.54461E-03	.00000E+00	.00000E+00	.00000E+00
77	.00000E+00	-.38028E-03	.57469E-03	.00000E+00	.00000E+00	.00000E+00
78	.00000E+00	-.37517E-03	.78618E-03	.00000E+00	.00000E+00	.00000E+00
79	.00000E+00	-.37794E-03	.84565E-03	.00000E+00	.00000E+00	.00000E+00
80	.00000E+00	-.37231E-03	.97998E-03	.00000E+00	.00000E+00	.00000E+00
81	.00000E+00	-.38240E-03	.10441E-02	.00000E+00	.00000E+00	.00000E+00

EL#	LD#	NODE	Syy	Szz	Sxx	Syz	S(MAX)	S(MIN)	ANGLE
1	1								
		1	102.95	4.66	.00	11.73	104.33	3.28	6.71
		2	70.50	-44.76	.00	8.84	71.18	-45.43	4.36
		3	38.05	-94.17	.00	-.89	38.06	-94.18	-.39
		10	13.23	2.54	.00	72.41	80.50	-64.72	42.89
		11	15.34	-19.53	.00	69.52	69.58	-73.77	37.96
		12	17.45	-41.60	.00	59.80	54.61	-78.76	31.86
		19	-76.49	.43	.00	-5.13	.77	-76.83	-86.20
		20	-39.82	5.70	.00	-8.02	7.07	-41.19	-80.30
		21	-3.16	10.98	.00	-17.74	23.01	-15.19	-55.86
2	1								
		3	36.35	-72.17	.00	8.76	37.05	-72.88	4.58
		4	22.31	-80.69	.00	.83	22.32	-80.69	.46
		5	8.27	-89.20	.00	-6.80	8.74	-89.67	-3.97
		12	12.70	-39.86	.00	42.57	36.45	-63.61	29.16
		13	9.83	-49.58	.00	34.65	25.77	-65.51	24.69
		14	6.97	-59.30	.00	27.02	16.59	-68.92	19.60
		21	-10.95	-7.54	.00	31.70	22.50	-40.99	46.54
		22	-2.64	-18.47	.00	23.77	14.50	-35.61	35.79
		23	5.66	-29.40	.00	16.15	11.96	-35.71	21.32

3	1							
	5	9.24	-85.09	.00	5.86	9.61	-85.45	3.54
	6	4.34	-86.71	.00	-.35	4.34	-86.71	-.22
	7	-.56	-88.33	.00	-5.66	-.20	-88.69	-3.67
	14	6.64	-58.41	.00	20.75	12.70	-64.47	16.27
	15	4.10	-63.67	.00	14.54	7.09	-66.65	11.61
	16	1.56	-68.92	.00	9.23	2.75	-70.11	7.34
	23	4.04	-31.74	.00	26.20	17.88	-45.57	27.84
	24	3.86	-40.63	.00	19.98	11.52	-48.28	20.97
	25	3.68	-49.51	.00	14.68	7.46	-53.30	14.45
4	1							
	7	.51	-87.11	.00	3.94	.69	-87.28	2.57
	8	.02	-89.29	.00	-.34	.02	-89.29	-.22
	9	-.47	-91.48	.00	-3.70	-.32	-91.63	-2.32
	16	1.70	-68.15	.00	7.13	2.42	-68.87	5.77
	17	.60	-74.01	.00	2.85	.71	-74.12	2.18
	18	-.50	-79.87	.00	-.51	-.50	-79.87	-.37
	25	2.89	-49.19	.00	12.76	5.85	-52.15	13.05
	26	1.18	-58.73	.00	8.48	2.36	-59.90	7.90
	27	-.53	-68.26	.00	5.11	-.15	-68.65	4.29
5	1							
	19	11.90	-8.42	.00	.49	11.91	-8.43	1.38
	20	-4.27	-16.59	.00	-1.16	-4.16	-16.70	-5.32
	21	-20.44	-24.76	.00	-3.32	-18.64	-26.56	-28.45
	28	-7.53	-2.86	.00	31.97	26.86	-37.25	47.09
	29	-7.10	-8.98	.00	30.32	22.30	-38.37	44.11
	30	-6.67	-15.10	.00	28.16	17.59	-39.36	40.74
	37	-26.96	2.71	.00	-2.97	3.00	-27.26	-84.35
	38	-9.93	-1.36	.00	-4.61	.65	-11.94	-66.43
	39	7.11	-5.43	.00	-6.77	10.07	-8.39	-23.61
6	1							
	21	-14.08	-13.55	.00	22.91	9.10	-36.72	45.34
	22	-11.99	-22.09	.00	22.29	5.82	-39.90	38.61
	23	-9.89	-30.64	.00	20.60	2.80	-43.33	31.63
	30	-7.62	-13.25	.00	16.00	5.81	-26.68	40.02
	31	-6.26	-17.47	.00	15.39	4.51	-28.24	34.99
	32	-4.91	-21.70	.00	13.69	2.76	-29.37	29.24
	39	-1.16	-12.94	.00	12.06	6.37	-20.47	31.98
	40	-.54	-12.85	.00	11.44	6.30	-19.69	30.86
	41	.07	-12.76	.00	9.75	5.33	-18.02	28.32
7	1							
	23	-8.52	-28.66	.00	22.20	5.79	-42.97	32.80
	24	-5.58	-36.52	.00	20.01	4.24	-46.34	26.14
	25	-2.64	-44.38	.00	16.83	3.30	-50.32	19.44
	32	-4.59	-21.83	.00	13.21	2.56	-28.98	28.44
	33	-3.04	-25.77	.00	11.01	1.42	-30.23	22.04
	34	-1.48	-29.71	.00	7.83	.55	-31.74	14.51
	41	-.66	-14.99	.00	9.75	4.27	-19.92	26.84
	42	-.49	-15.01	.00	7.55	2.72	-18.23	23.05
	43	-.32	-15.03	.00	4.37	.88	-16.23	15.35
8	1							
	25	-2.41	-44.08	.00	12.73	1.17	-47.66	15.72
	26	-1.00	-49.77	.00	8.80	.55	-51.31	9.92
	27	.42	-55.47	.00	4.05	.71	-55.76	4.13
	34	-1.30	-30.00	.00	8.33	.94	-32.25	15.06
	35	-.51	-32.41	.00	4.40	.08	-33.01	7.71
	36	.27	-34.82	.00	-.35	.28	-34.83	-.57
	43	-.19	-15.93	.00	6.44	2.11	-18.23	19.65
	44	-.03	-15.05	.00	2.51	.38	-15.46	9.25
	45	.13	-14.17	.00	-2.24	.47	-14.52	-8.69
9	1							

	37	2.20	-5.43	.00	.54	2.24	-5.47	4.02
	38	-4.59	-6.81	.00	-.38	-4.53	-6.88	-9.42
	39	-11.39	-8.19	.00	-1.07	-7.87	-11.71	-73.14
	46	-3.71	-1.31	.00	13.69	11.23	-16.25	47.51
	47	-3.49	-3.60	.00	12.77	9.22	-16.31	44.87
	48	-3.27	-5.90	.00	12.08	7.57	-16.74	41.89
	55	-9.62	2.82	.00	-1.22	2.94	-9.73	-84.44
	56	-2.38	-.39	.00	-2.14	.97	-3.75	-57.46
	57	4.85	-3.61	.00	-2.83	5.71	-4.47	-16.87
10	1							
	39	-5.90	-4.12	.00	11.92	6.94	-16.97	47.14
	40	-4.20	-9.12	.00	11.70	5.29	-18.61	39.06
	41	-2.50	-14.12	.00	10.65	3.83	-20.44	30.69
	48	-3.03	-4.87	.00	6.68	2.79	-10.70	41.09
	49	-2.12	-6.58	.00	6.46	2.49	-11.18	35.48
	50	-1.20	-8.28	.00	5.41	1.72	-11.21	28.39
	57	-.16	-5.61	.00	4.59	2.45	-8.23	29.65
	58	-.03	-4.03	.00	4.36	2.77	-6.83	32.70
	59	.10	-2.45	.00	3.32	2.38	-4.73	34.51
11	1							
	41	-2.08	-11.76	.00	8.48	2.84	-16.69	30.15
	42	-1.18	-14.45	.00	7.41	2.13	-17.77	24.08
	43	-.28	-17.15	.00	5.94	1.60	-19.03	17.57
	50	-1.24	-8.29	.00	5.63	1.87	-11.41	28.98
	51	-.72	-9.36	.00	4.56	1.24	-11.32	23.27
	52	-.20	-10.43	.00	3.08	.66	-11.29	15.53
	59	-.40	-4.82	.00	4.30	2.22	-7.44	31.39
	60	-.26	-4.27	.00	3.23	1.53	-6.06	29.07
	61	-.12	-3.72	.00	1.75	.59	-4.43	22.10
12	1							
	43	-.36	-16.18	.00	4.00	.60	-17.14	13.41
	44	-.17	-17.49	.00	2.46	.17	-17.83	7.93
	45	.02	-18.79	.00	.71	.04	-18.82	2.16
	52	-.26	-10.42	.00	3.30	.72	-11.40	16.51
	53	-.10	-10.90	.00	1.76	.18	-11.18	9.02
	54	.06	-11.38	.00	.01	.06	-11.38	.05
	61	-.17	-4.67	.00	2.69	1.09	-5.93	25.07
	62	-.03	-4.32	.00	1.15	.26	-4.60	14.10
	63	.11	-3.96	.00	-.60	.20	-4.05	-8.21
13	1							
	55	2.66	-3.08	.00	.72	2.75	-3.17	7.09
	56	-.04	-2.39	.00	.37	.02	-2.45	8.86
	57	-2.75	-1.70	.00	.38	-1.58	-2.87	72.03
	64	-3.13	-.97	.00	5.79	3.84	-7.93	50.28
	65	-2.95	-1.70	.00	5.44	3.15	-7.80	48.30
	66	-2.78	-2.42	.00	5.44	2.84	-8.05	45.94
	73	-8.91	1.14	.00	-.65	1.18	-8.96	-86.29
	74	-5.87	-1.01	.00	-1.00	-.81	-6.06	-78.78
	75	-2.82	-3.15	.00	-1.00	-1.97	-4.00	-40.27
14	1							
	57	-.49	-1.10	.00	5.07	4.28	-5.87	43.27
	58	-.58	-3.63	.00	4.89	3.02	-7.23	36.34
	59	-.67	-6.16	.00	4.12	1.54	-8.37	28.18
	66	-2.23	-1.60	.00	4.00	2.09	-5.92	47.27
	67	-1.60	-1.75	.00	3.82	2.15	-5.50	44.47
	68	-.98	-1.90	.00	3.05	1.65	-4.52	40.72
	75	-3.98	-2.09	.00	.05	-2.09	-3.98	88.50
	76	-2.63	.14	.00	-.12	.15	-2.63	-87.43
	77	-1.28	2.37	.00	-.89	2.58	-1.49	-76.96
15	1							
	59	-.56	-3.56	.00	3.79	2.02	-6.13	34.21

60	-.40	-4.42	.00	3.28	1.44	-6.26	29.26	
61	-.25	-5.29	.00	2.56	.83	-6.36	22.76	
68	-1.04	-1.94	.00	2.67	1.21	-4.19	40.25	
69	-.63	-1.97	.00	2.16	.96	-3.56	36.41	
70	-.22	-2.00	.00	1.44	.58	-2.80	29.17	
77	-1.53	-.32	.00	.52	-.13	-1.72	69.79	
78	-.86	.48	.00	.01	.48	-.86	89.69	
79	-.20	1.29	.00	-.71	1.57	-.48	-68.13	
16	1							
61	-.22	-4.35	.00	1.82	.47	-5.03	20.69	
62	-.10	-4.21	.00	1.22	.24	-4.55	15.40	
63	.02	-4.07	.00	.59	.10	-4.15	8.08	
70	-.26	-2.05	.00	1.26	.39	-2.70	27.27	
71	-.10	-1.76	.00	.67	.13	-1.99	19.42	
72	.06	-1.46	.00	.04	.06	-1.46	1.32	
79	-.30	.24	.00	.55	.58	-.64	58.05	
80	-.10	.69	.00	-.05	.69	-.10	-86.63	
81	.10	1.15	.00	-.68	1.48	-.24	-63.83	

Appendix B

Part One Reaction v Displacement Graphs

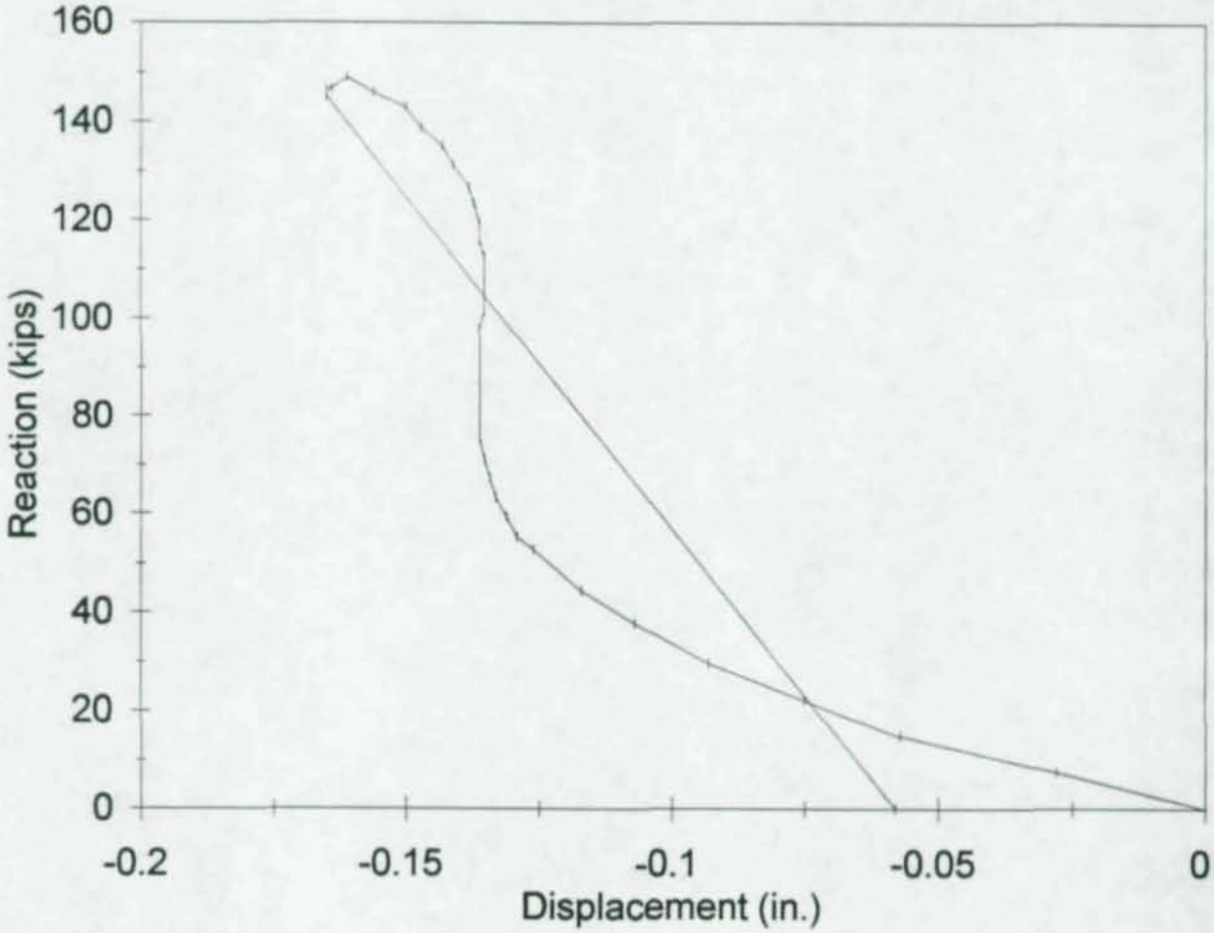
Only Specimens three, four, and six used the aforementioned third LVDT in contact with the column flange. For these specimens—all of which are denoted by BS#—the corrected values refer to the actual values read from LVDT's one and two with the value read from LVDT three subtracted from them. These three specimens, and thus, their respective graphs give the "best" load/displacement data of all tests run during part one.

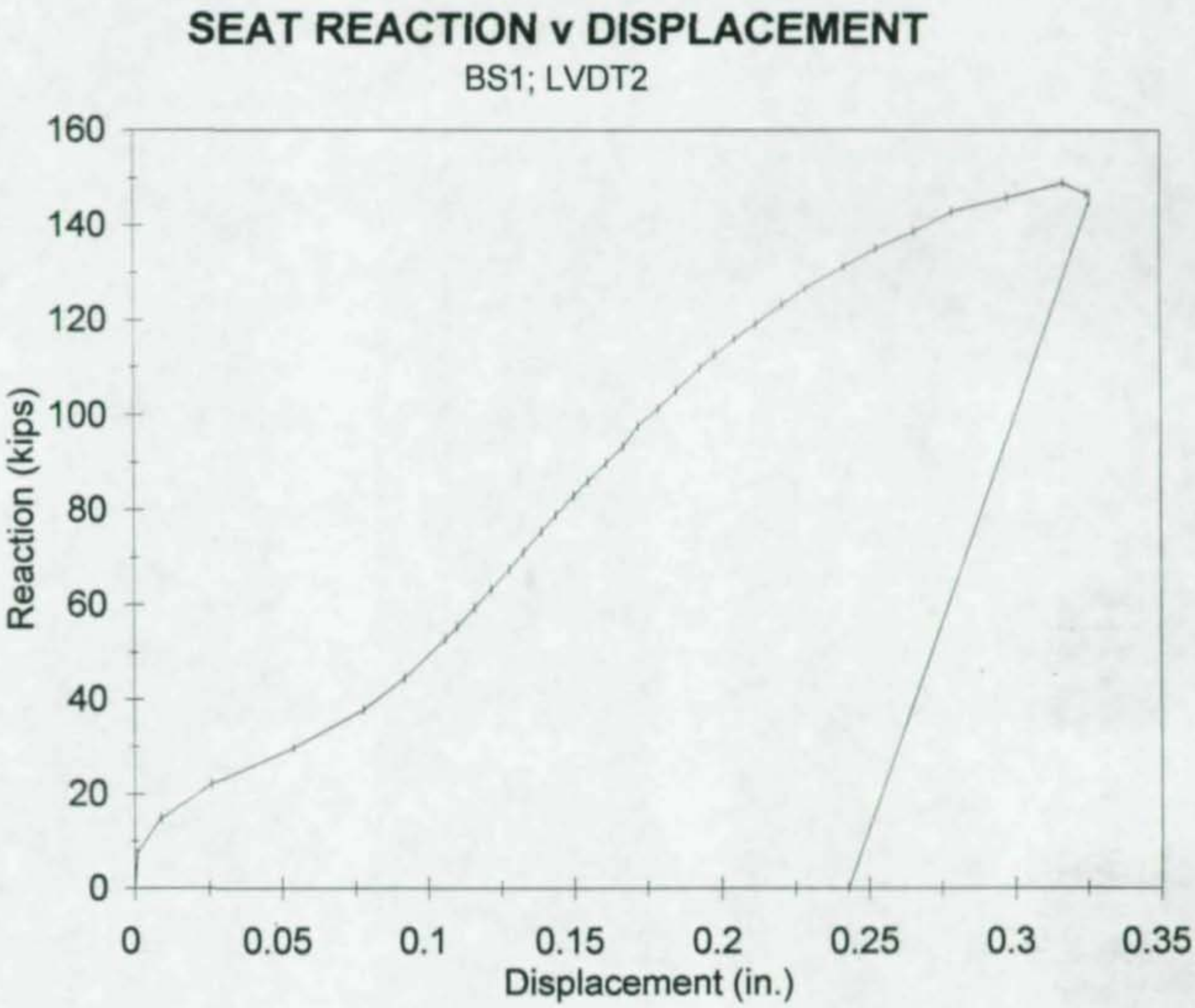
Negative displacements mean that the LVDT pin was moving out from its neutral position. Positive displacements mean the pin was being pushed inward. In other words, negative displacements correspond to the web moving away from the LVDT and positive displacements correspond to the web moving toward the LVDT.

The graphs of BS4-LVDT 1 and BS6-LVDT 1 are shown rescaled on longer axes for the purpose of comparing these graphs to their counterparts from Part Two.

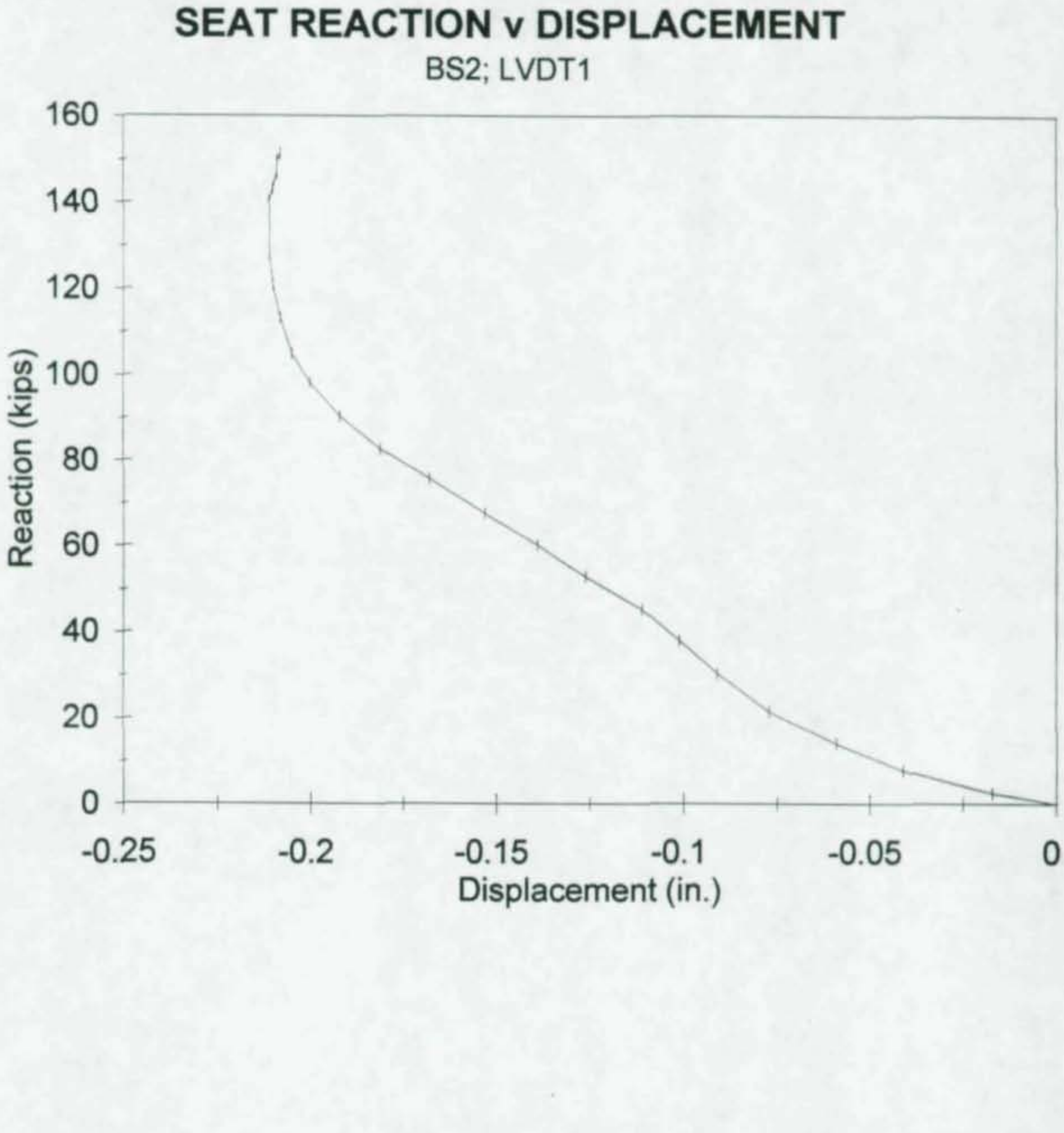
SEAT REACTION v DISPLACEMENT

BS1; LVDT1



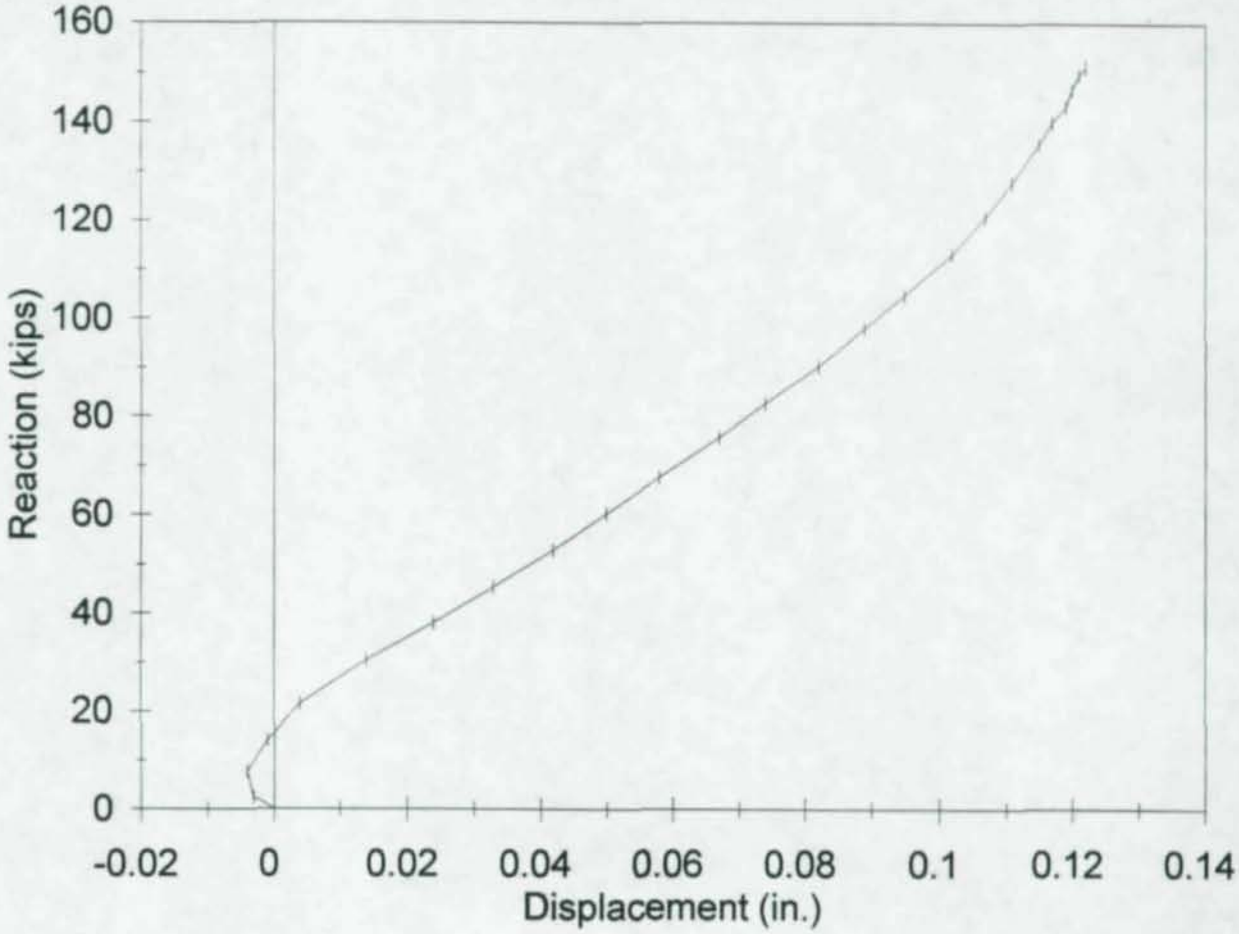


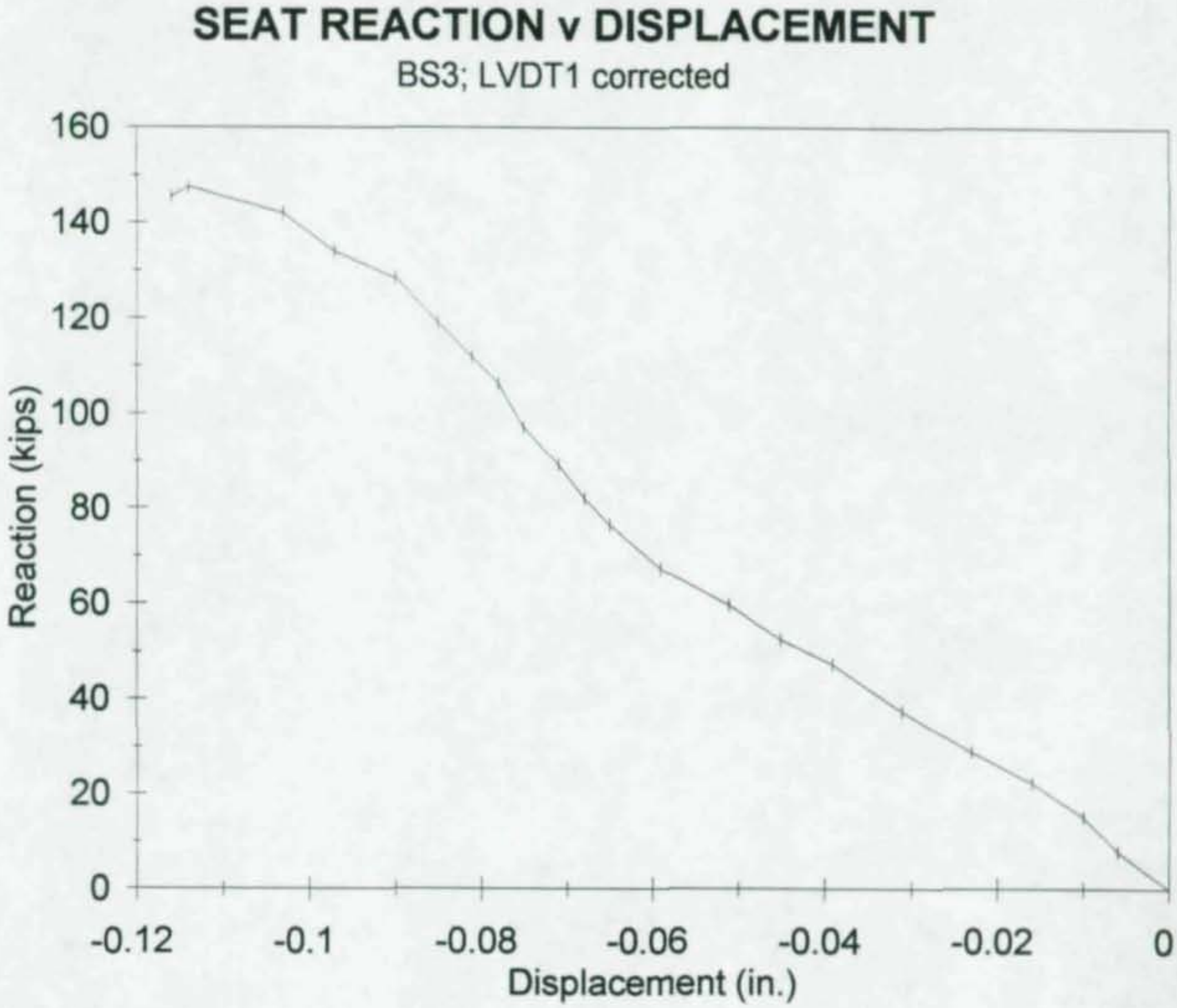
SEAT REACTION v DISPLACEMENT
BS1; LVDT2
Reaction (kips)
160
140
120
100
80
60
40
20
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Displacement (in.)

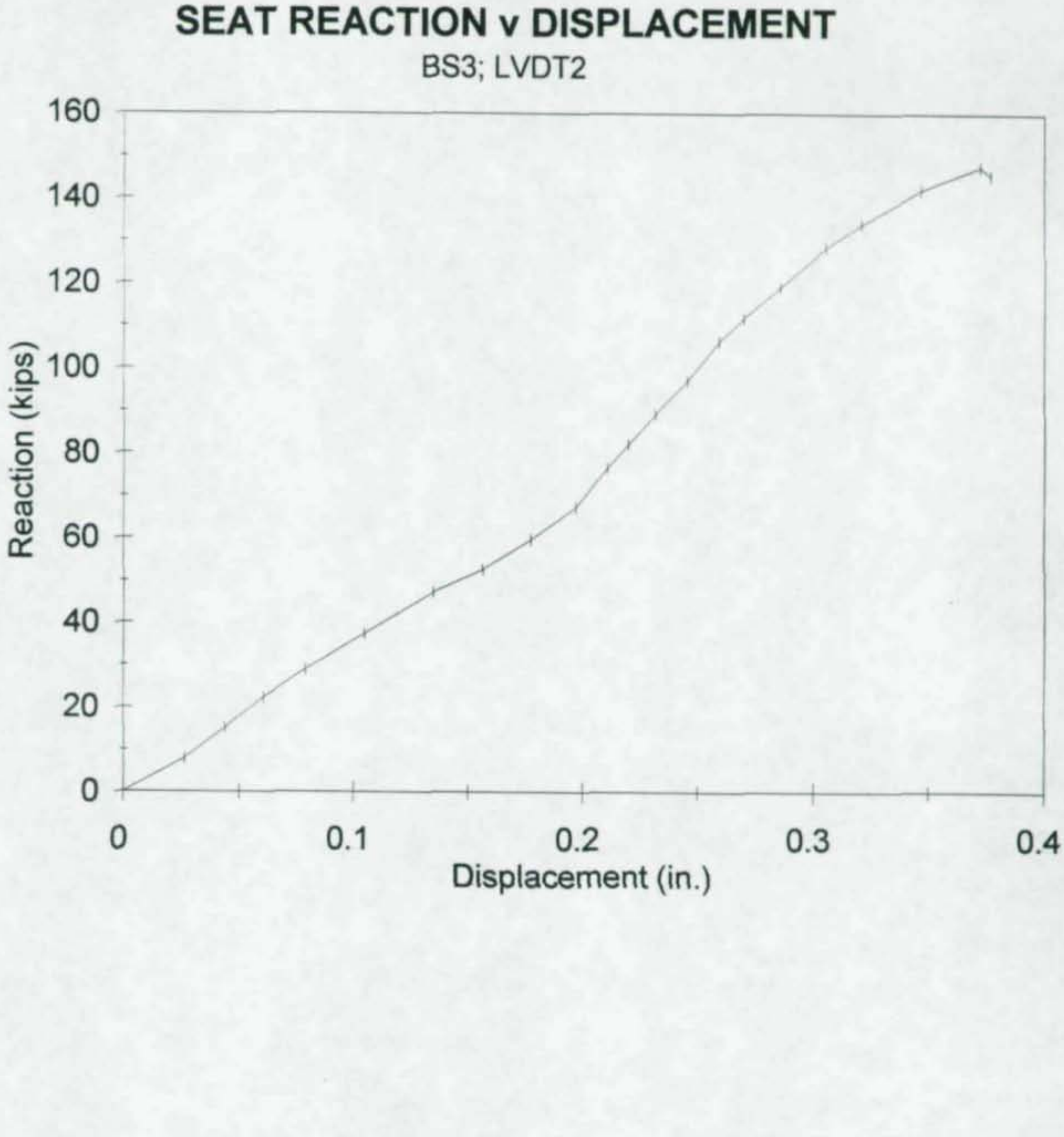

SEAT REACTION v DISPLACEMENT
BS2; LVDT1
Reaction (kips)
Displacement (in.)
160
140
120
100
80
60
40
20
0
-0.25
-0.2
-0.15
-0.1
-0.05
0

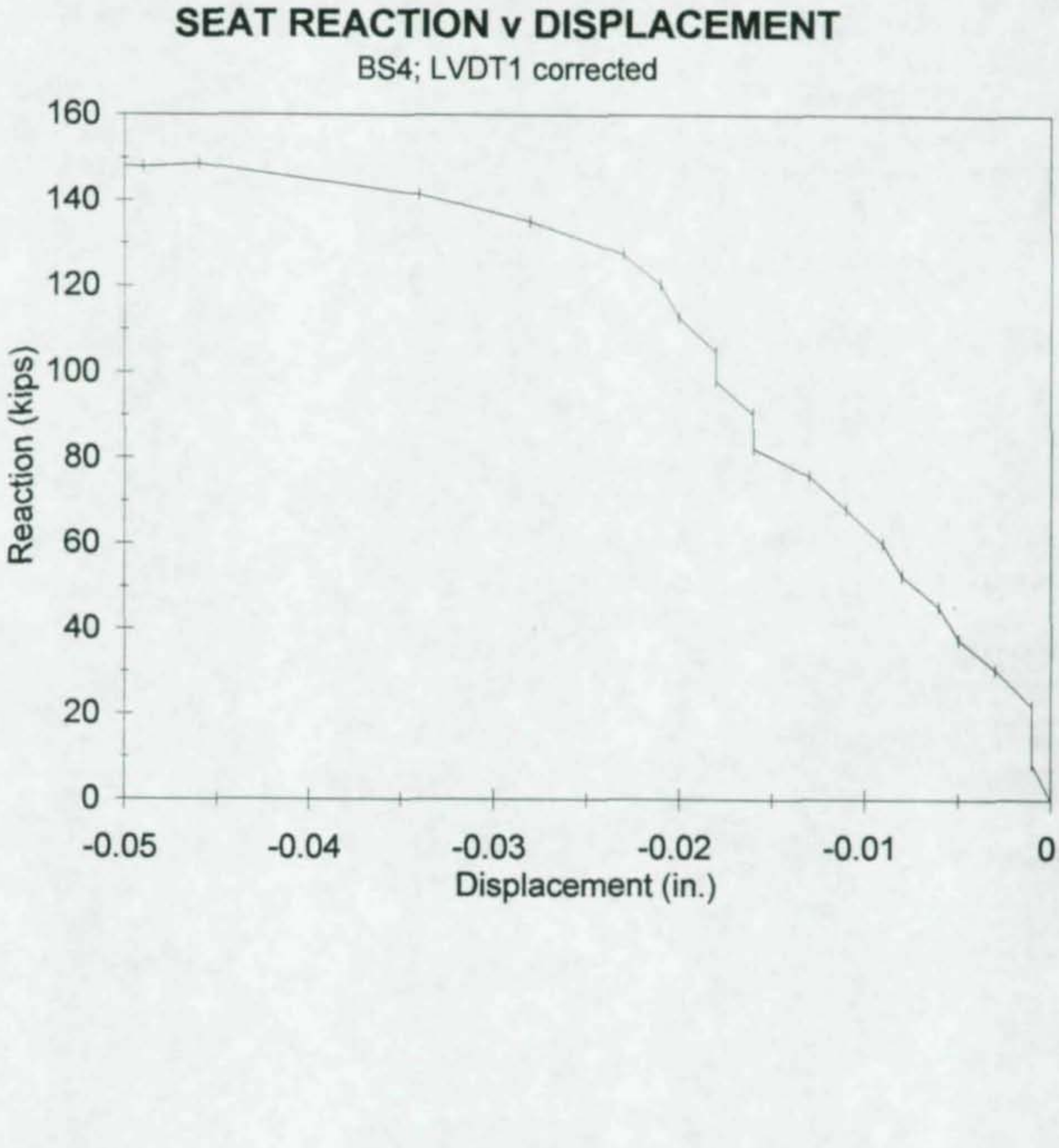
SEAT REACTION v DISPLACEMENT

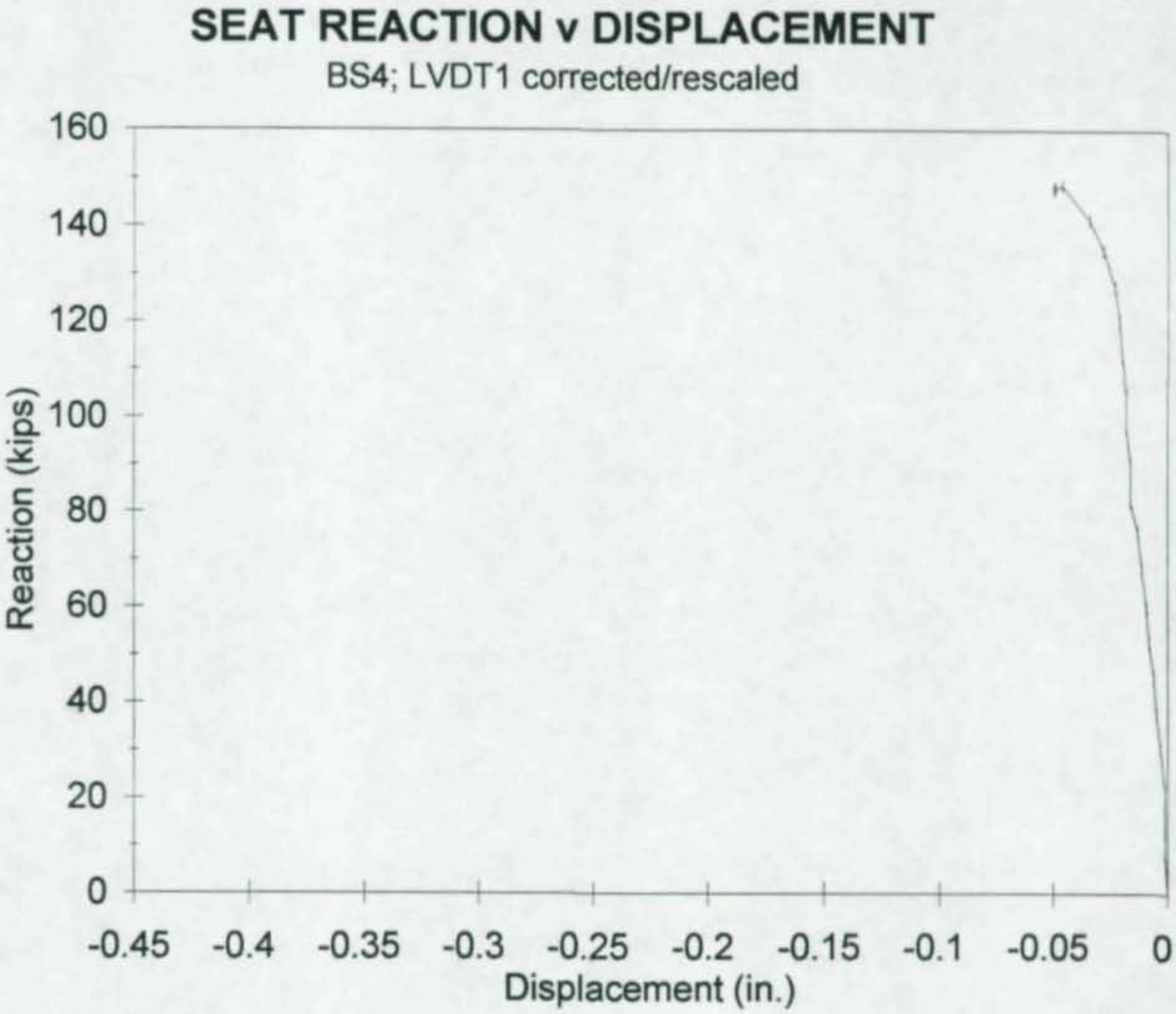
BS2; LVDT2

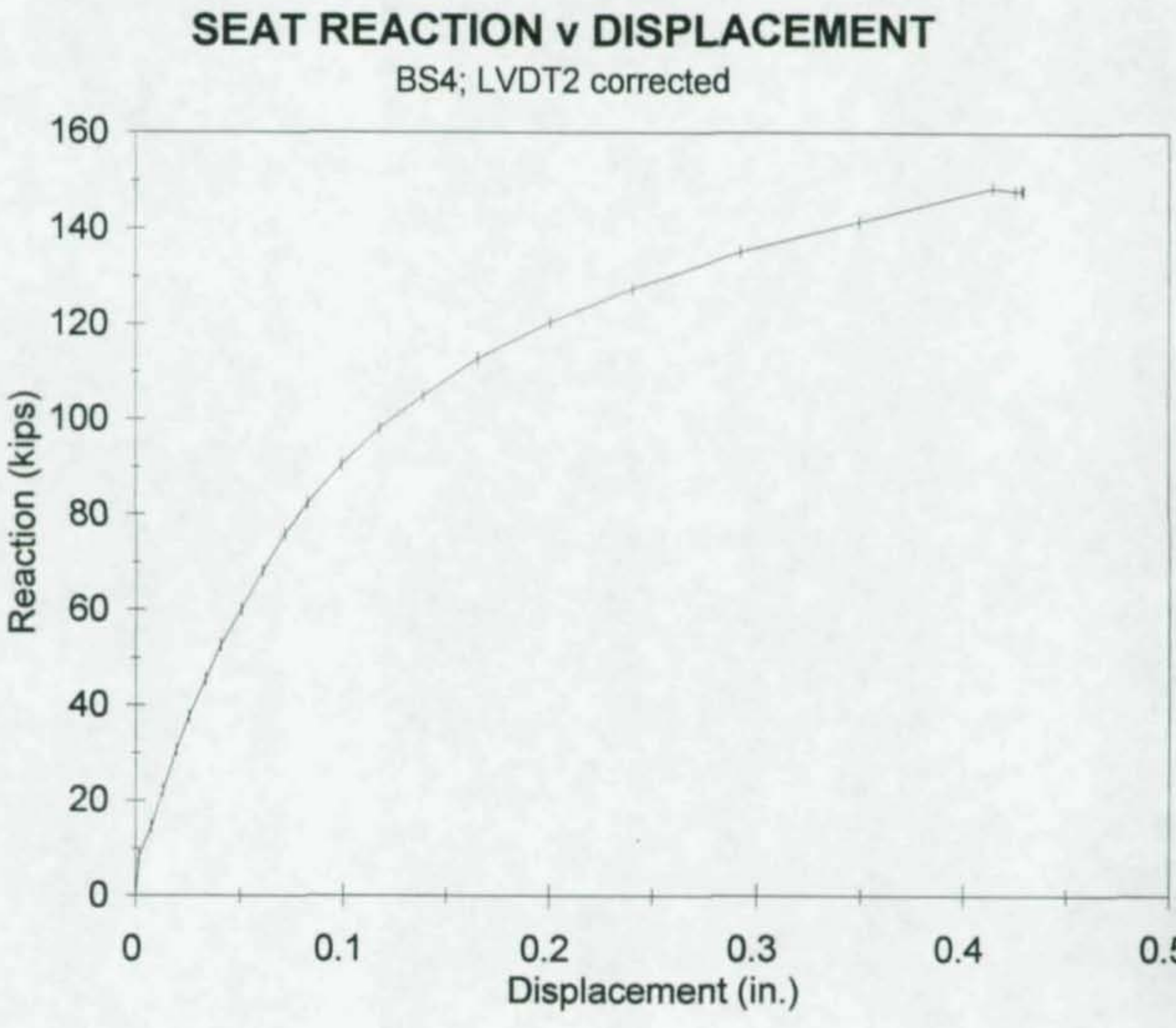


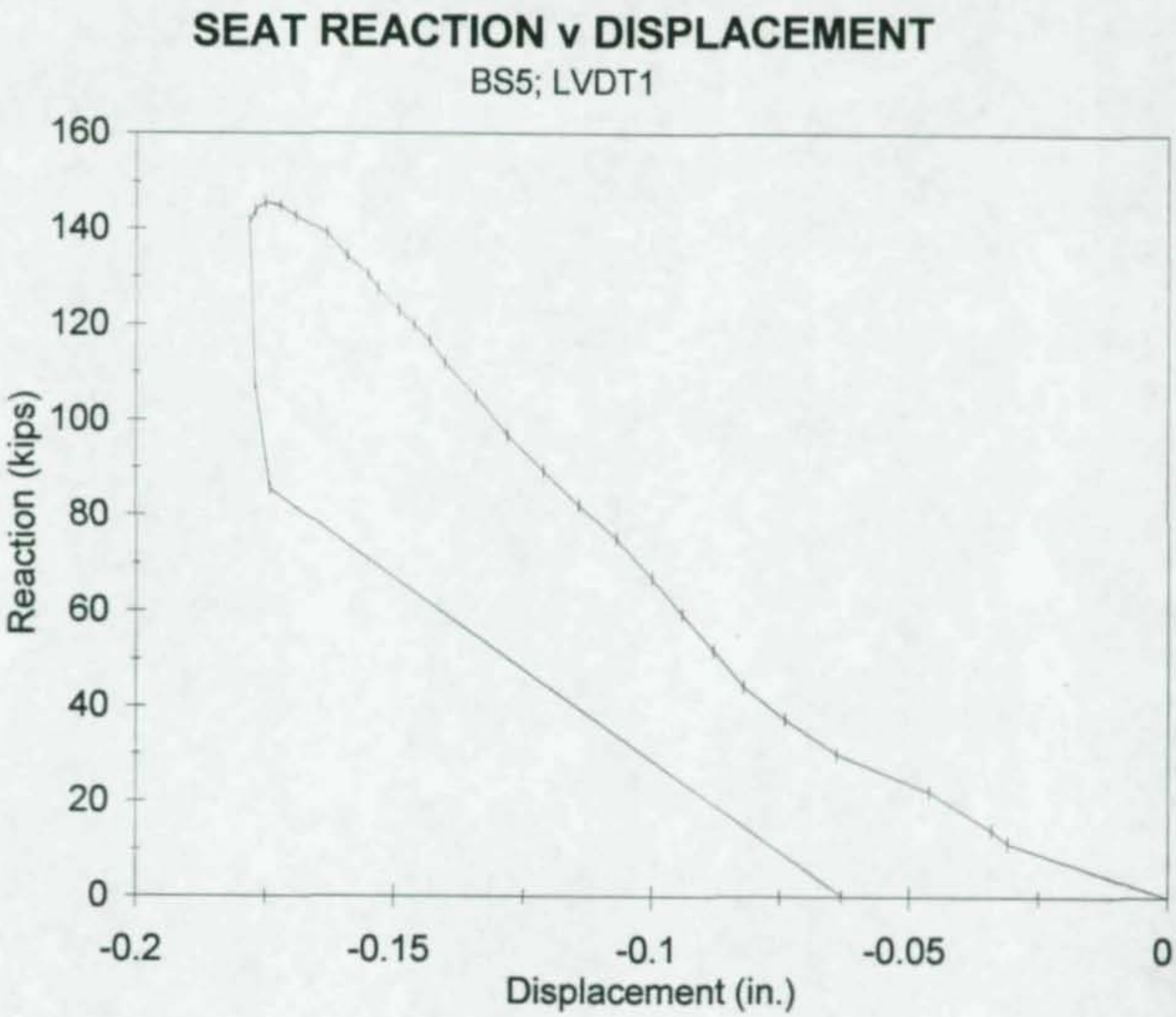

SEAT REACTION v DISPLACEMENT
BS3; LVDT1 corrected
160
140
120
100
80
60
40
20
0
Reaction (kips)
-0.12
-0.1
-0.08
-0.06
-0.04
-0.02
0
Displacement (in.)

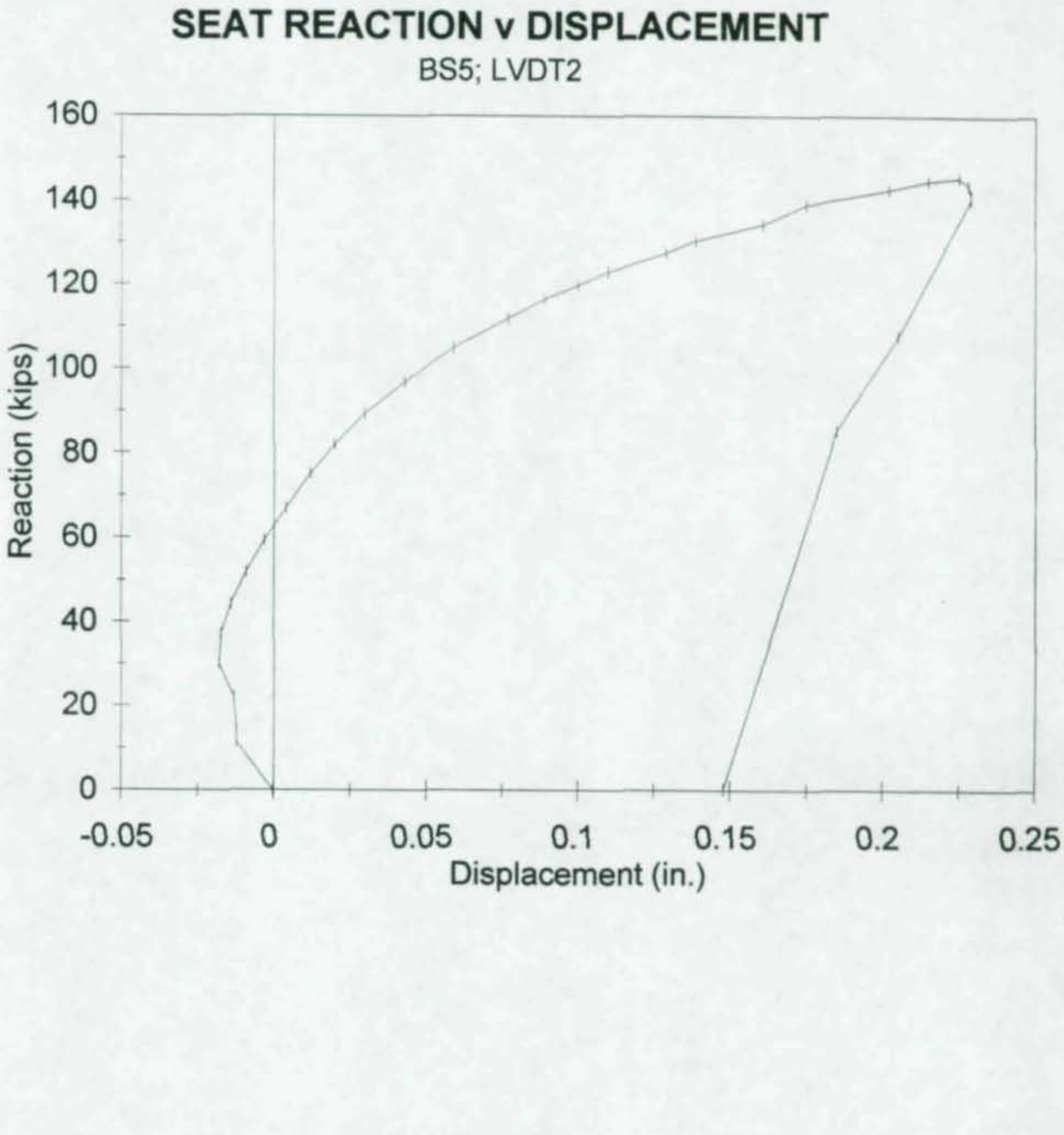

SEAT REACTION v DISPLACEMENT
BS3; LVDT2
Reaction (kips)
160
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
Displacement (in.)

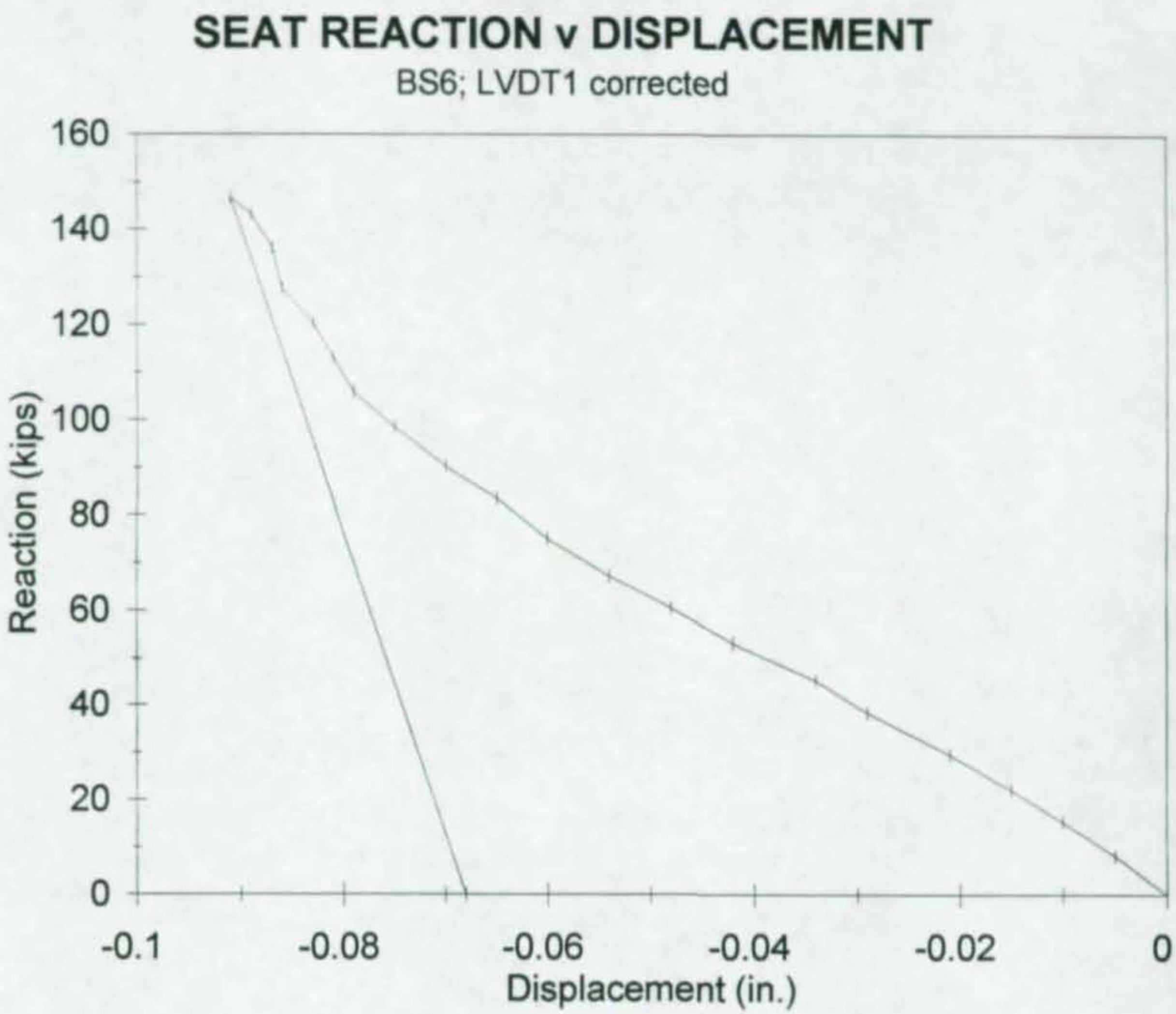

SEAT REACTION v DISPLACEMENT
BS4; LVDT1 corrected
Reaction (kips)
160
140
120
100
80
60
40
20
0
-0.05
-0.04
-0.03
-0.02
-0.01
0
Displacement (in.)

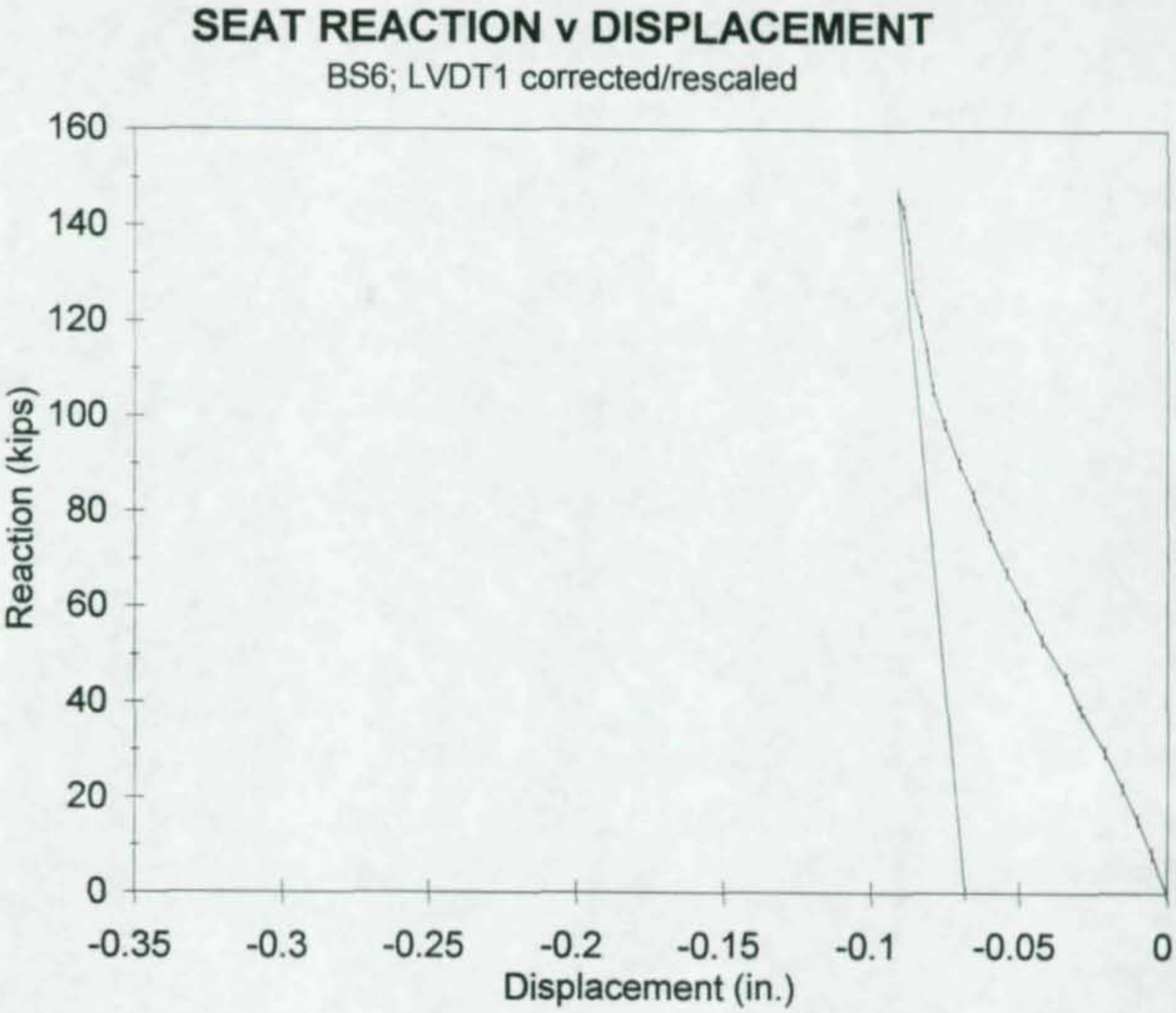

SEAT REACTION v DISPLACEMENT
BS4; LVDT1 corrected/rescaled
160
140
120
100
80
60
40
20
0
Reaction (kips)
-0.45
-0.4
-0.35
-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0
Displacement (in.)


SEAT REACTION v DISPLACEMENT
BS4; LVDT2 corrected
Reaction (kips)
Displacement (in.)
0
20
40
60
80
100
120
140
160
0
0.1
0.2
0.3
0.4
0.5


SEAT REACTION v DISPLACEMENT
BS5; LVDT1
Reaction (kips)
160
140
120
100
80
60
40
20
0
-0.2
-0.15
-0.1
-0.05
0
Displacement (in.)

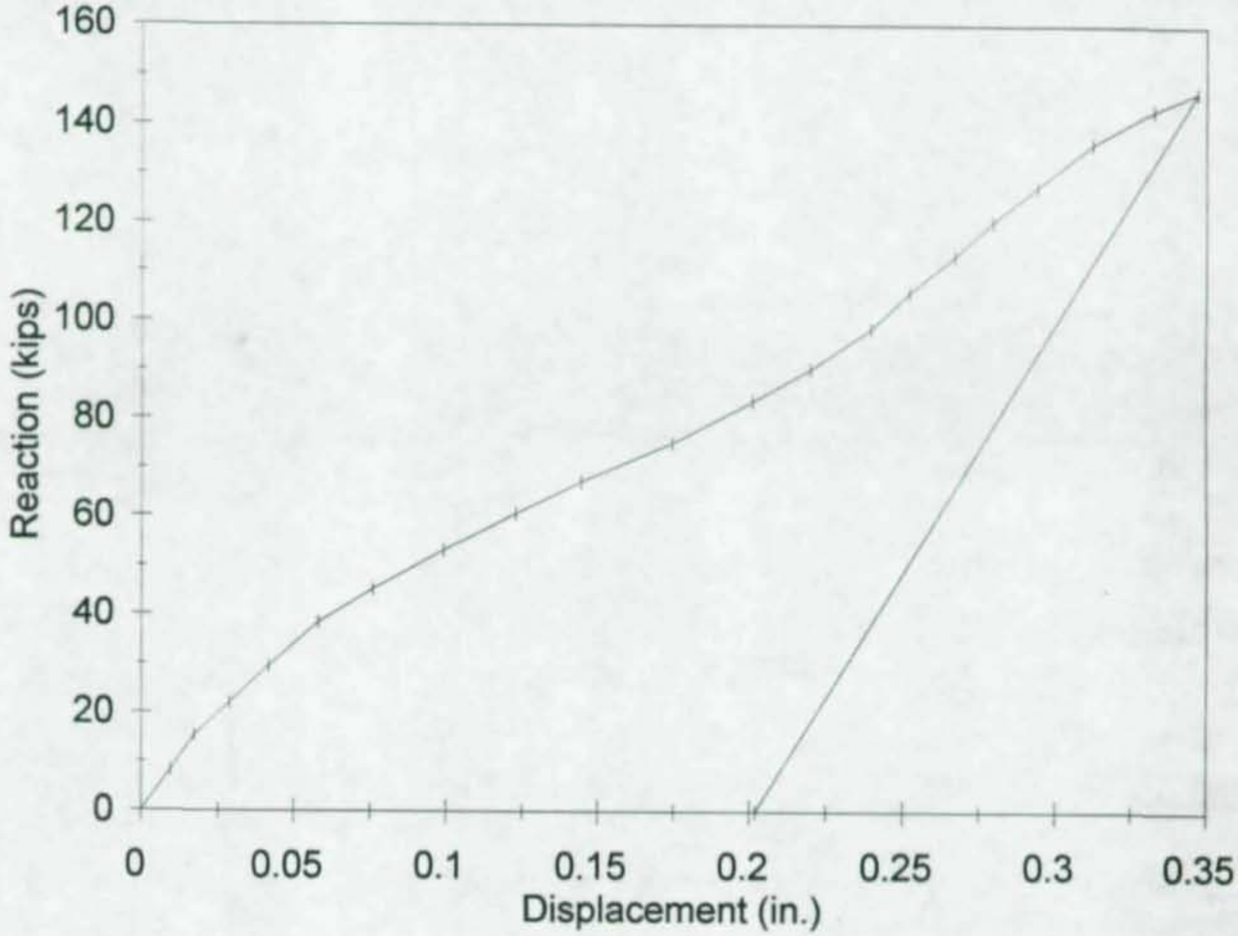

SEAT REACTION v DISPLACEMENT
BS5; LVDT2
Reaction (kips)
160
140
120
100
80
60
40
20
0
-0.05
0
0.05
0.1
0.15
0.2
0.25
Displacement (in.)


SEAT REACTION v DISPLACEMENT
BS6; LVDT1 corrected
Reaction (kips)
160
140
120
100
80
60
40
20
0
-0.1
-0.08
-0.06
-0.04
-0.02
0
Displacement (in.)


SEAT REACTION v DISPLACEMENT
BS6; LVDT1 corrected/rescaled
160
140
120
100
80
60
40
20
0
Reaction (kips)
-0.35
-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0
Displacement (in.)

SEAT REACTION v DISPLACEMENT

BS6; LVDT2 corrected



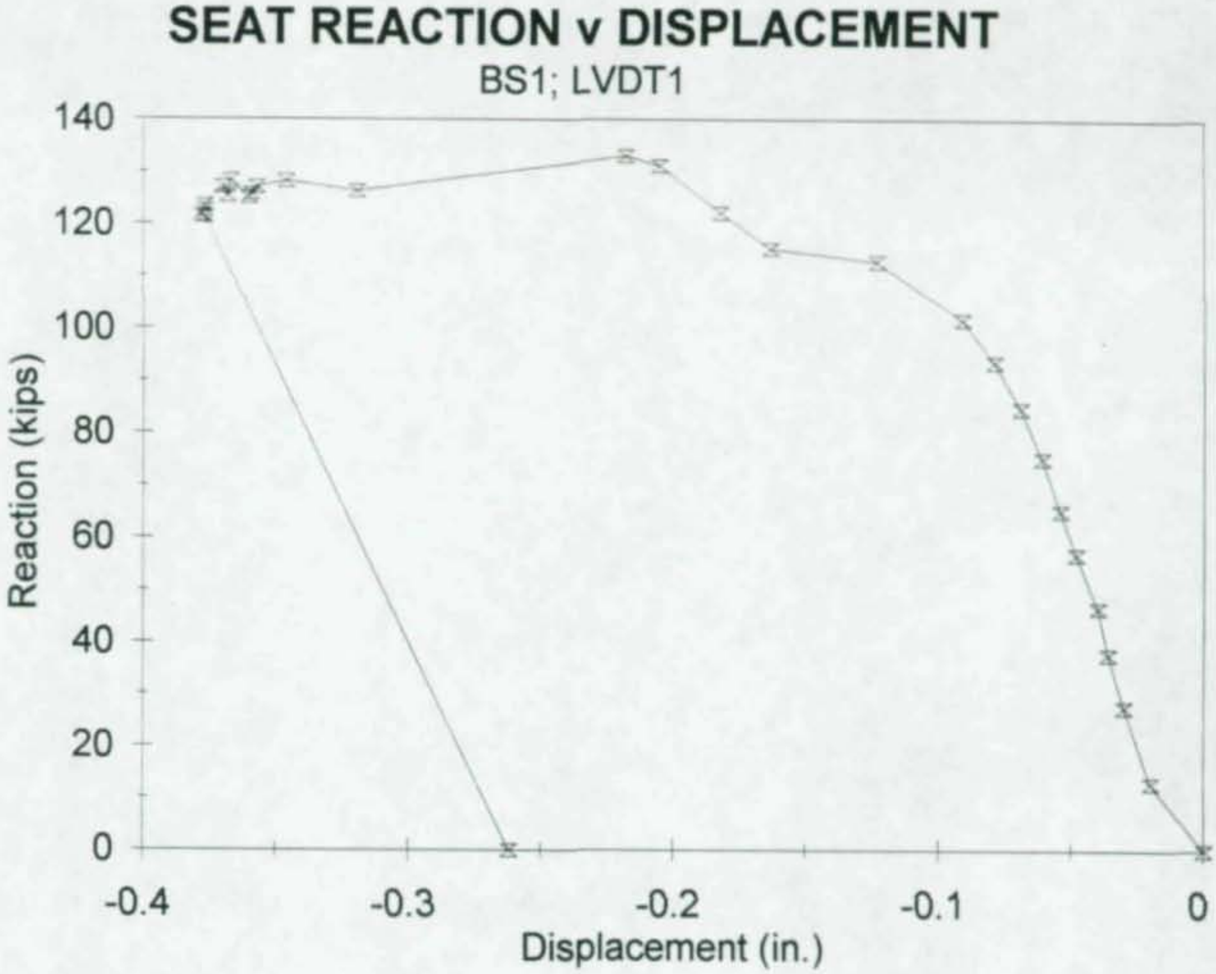
Appendix C

Part Two Reaction v Displacement Graphs

Graphs for all tests except Test Three are included here. The displacement data for Test Three was lost when the computer reading the LVDT's crashed. All tests included LVDT 3, which was placed on the left flange to measure rigid body rotation of the column. The graphs, therefore, depict only displacement of the column web and not any of the rigid body movement of the column which may have occurred, which some graphs in Part One included.

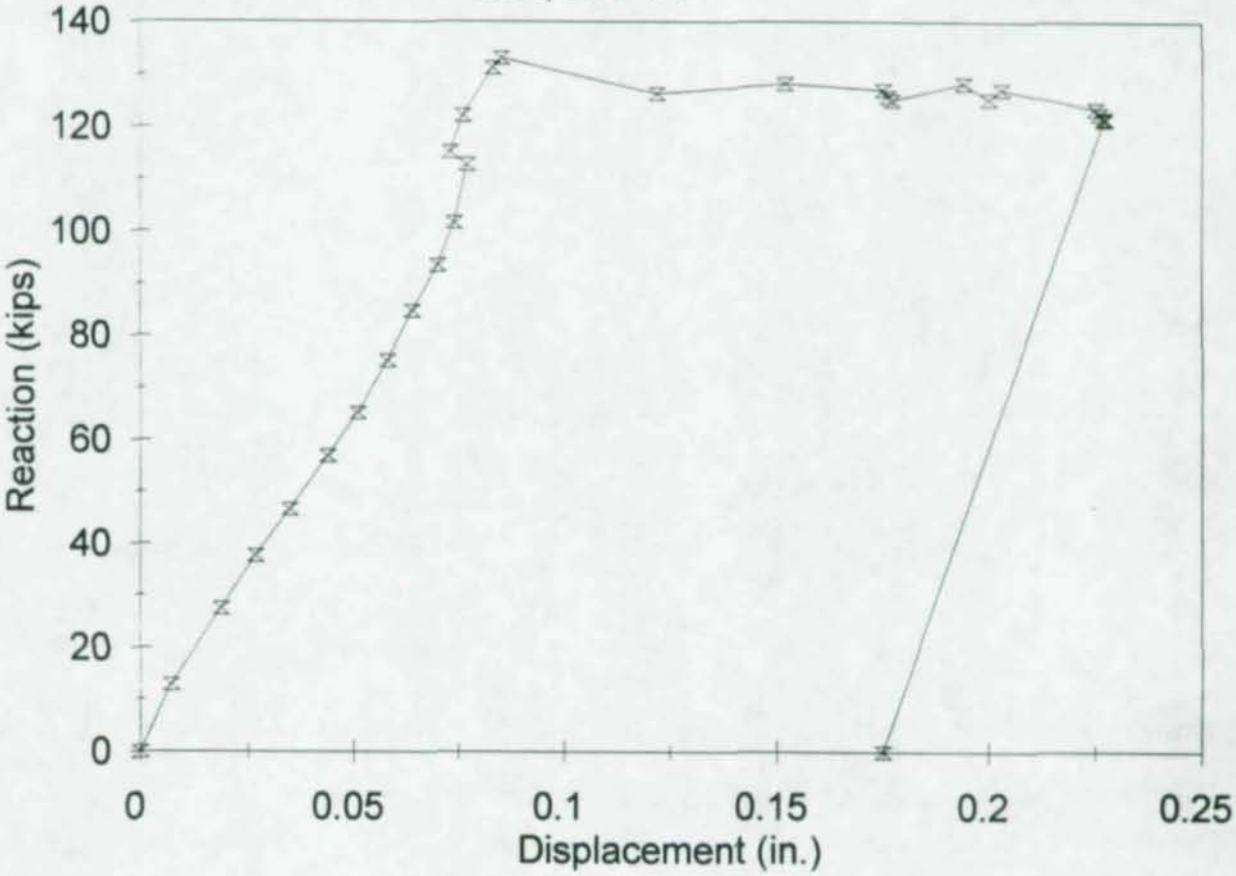
In the cases where rigid body motion was accounted for (subtracted from the total displacements in the web), the graphs of Parts One and Two match up quite well. In fact, the graphs from Part Two are a continuation of the same curve from Part One after unloading occurred.

As mentioned previously, positive displacements correspond to the portion of the web being monitored moving toward the LVDT and negative displacements correspond to the portion of the web being monitored moving away from the LVDT.

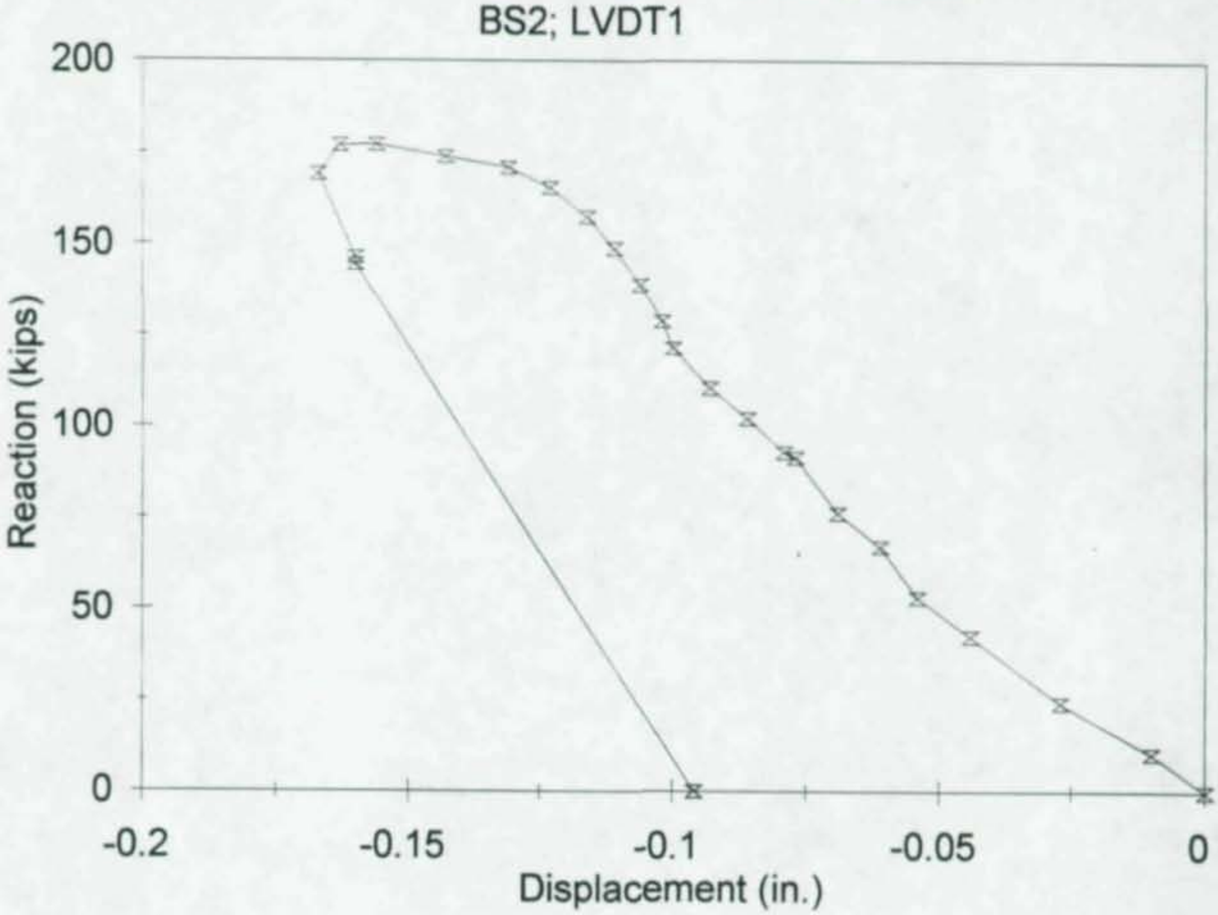

SEAT REACTION v DISPLACEMENT
BS1; LVDT1
140
120
100
80
60
40
20
0
Reaction (kips)
-0.4
-0.3
-0.2
-0.1
0
Displacement (in.)

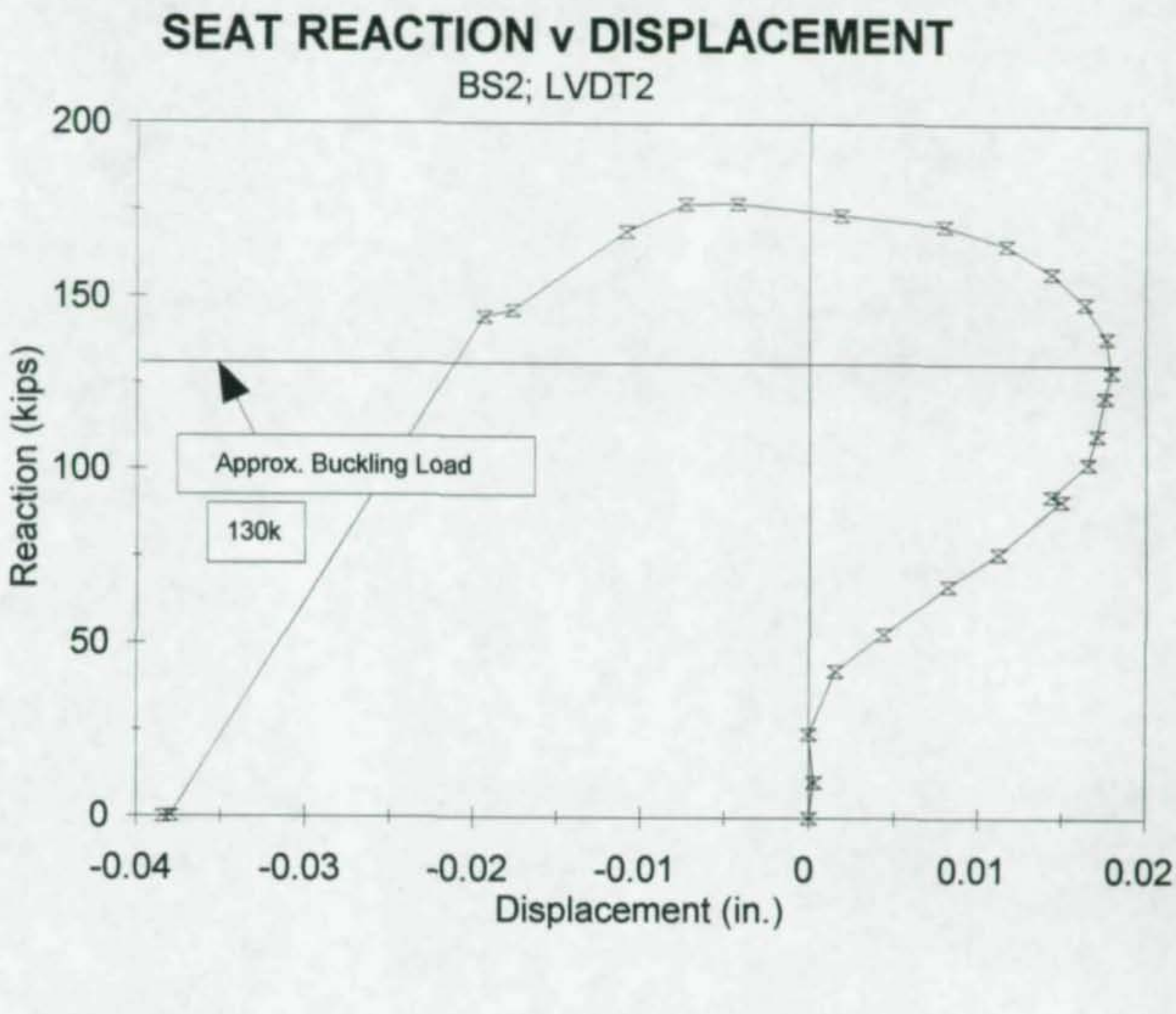
SEAT REACTION v DISPLACEMENT

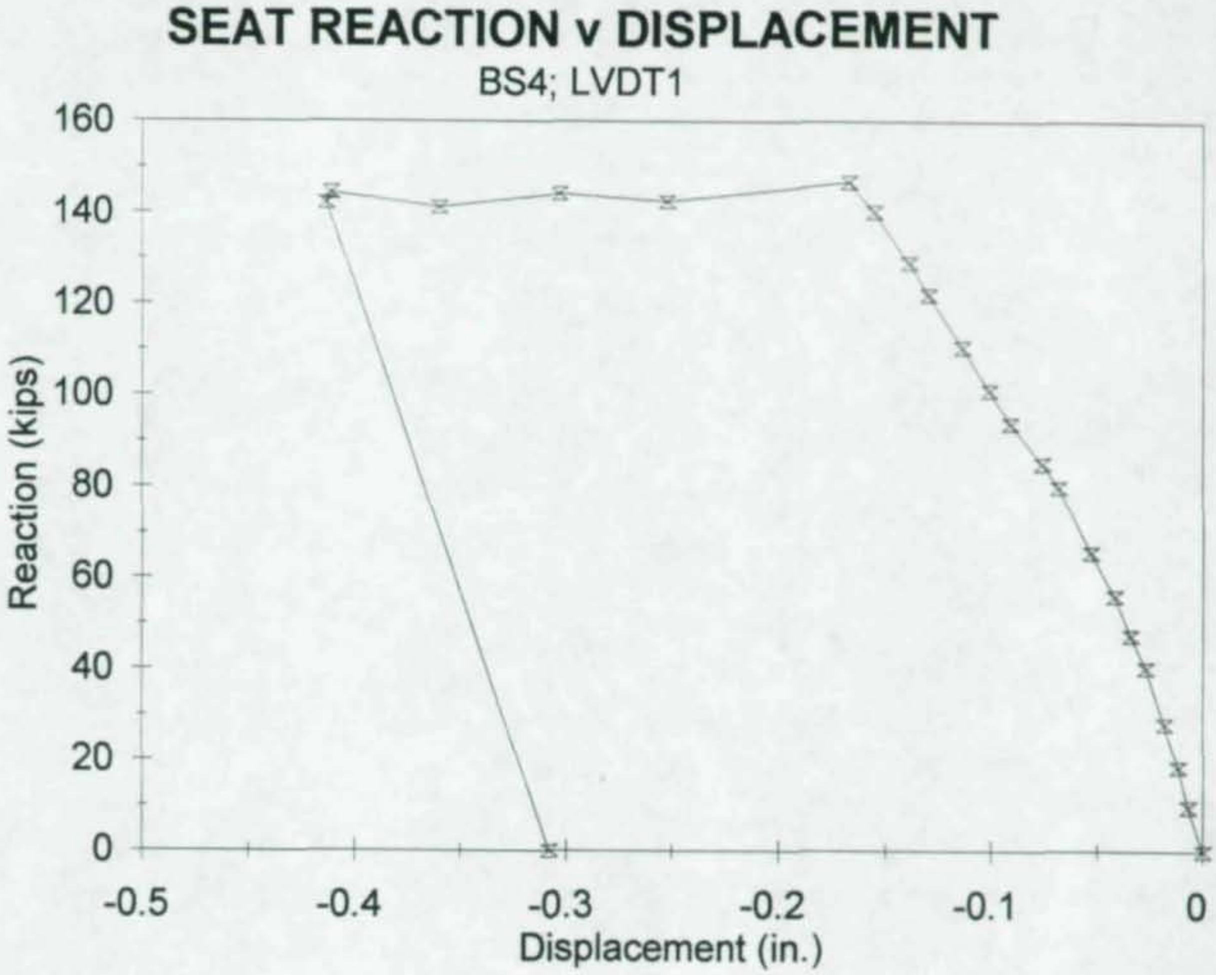
BS1; LVDT2



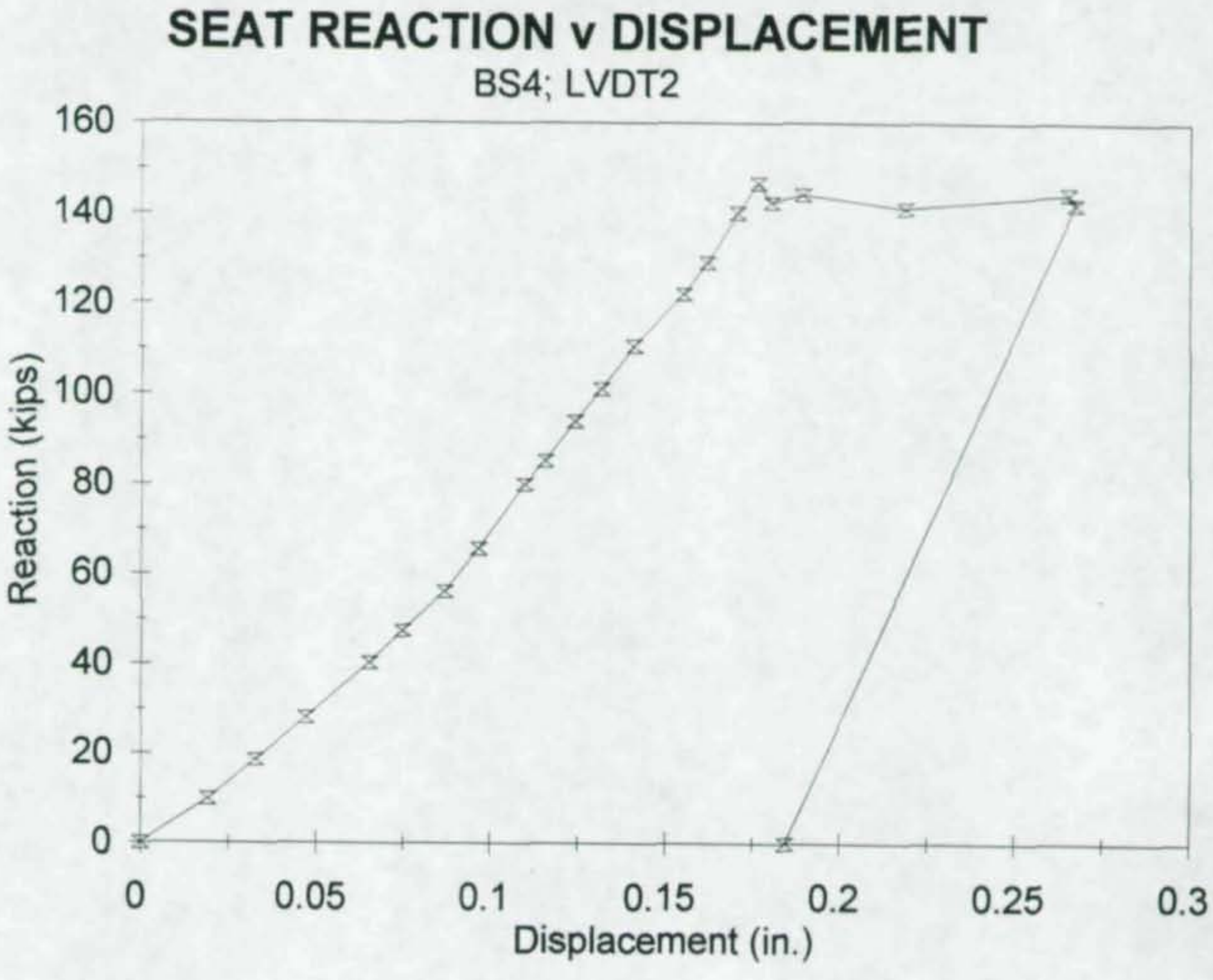
SEAT REACTION v DISPLACEMENT

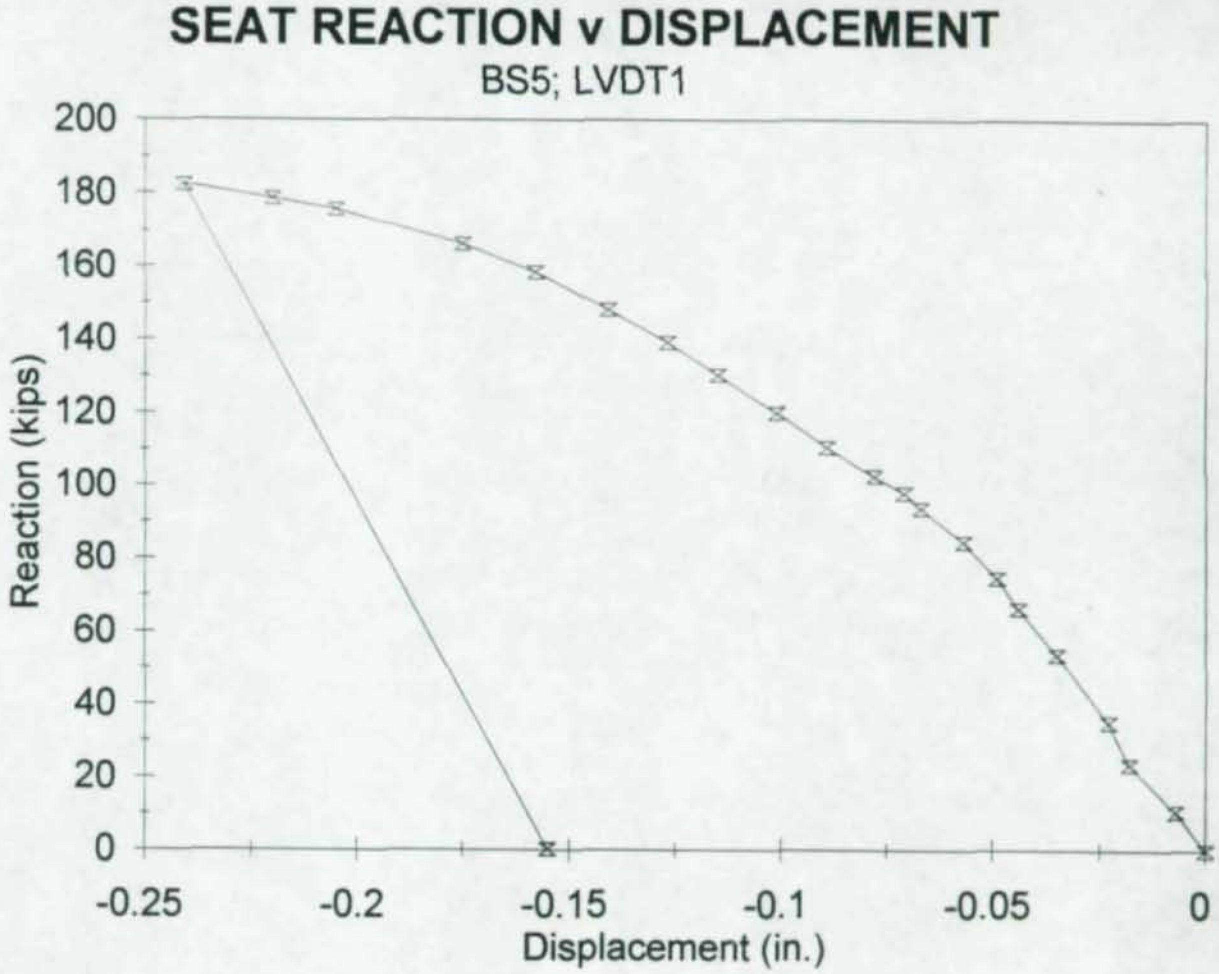


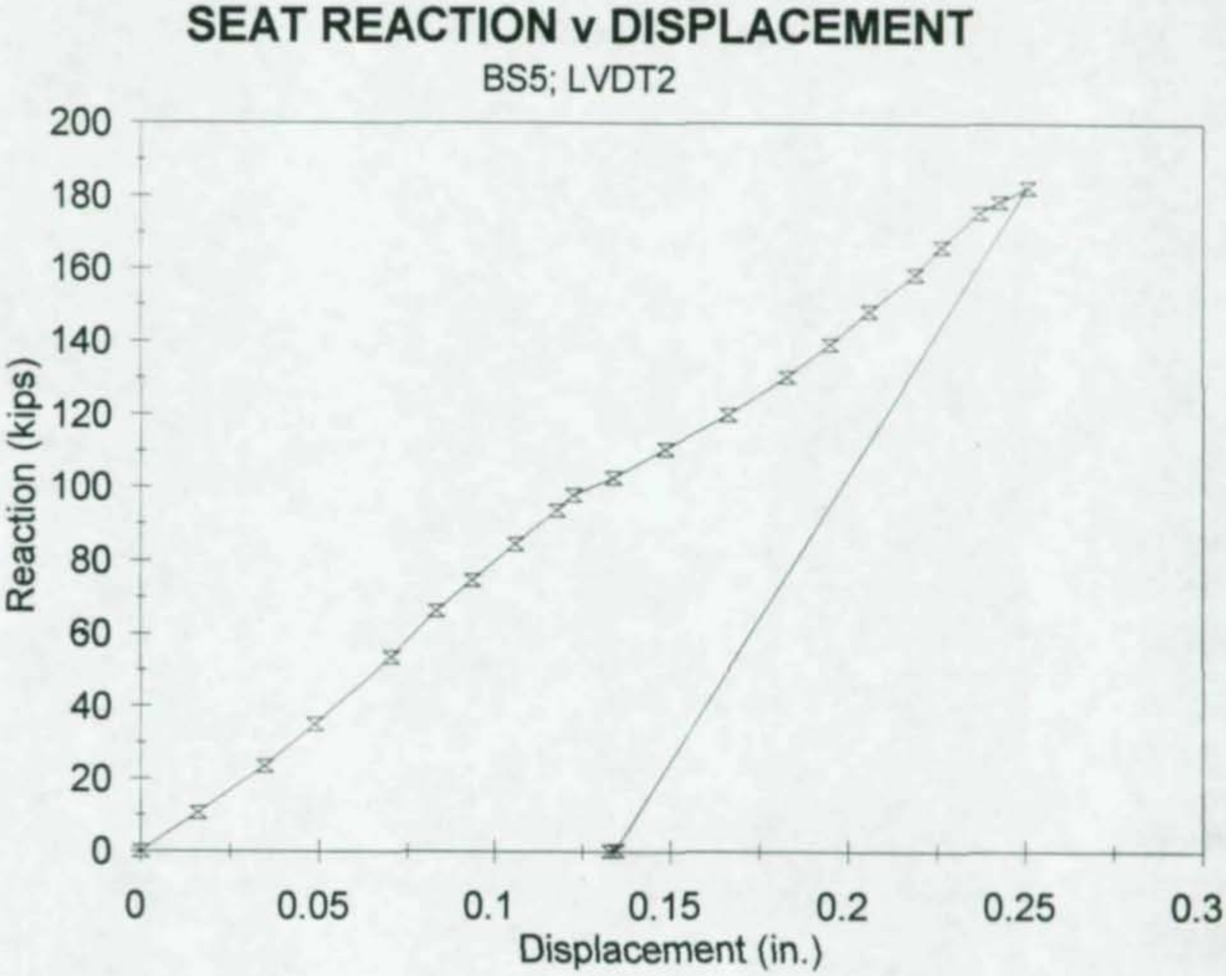

SEAT REACTION v DISPLACEMENT
BS2; LVDT2
200
150
100
50
0
Reaction (kips)
-0.04
-0.03
-0.02
-0.01
0
0.01
0.02
Displacement (in.)
Approx. Buckling Load
130k

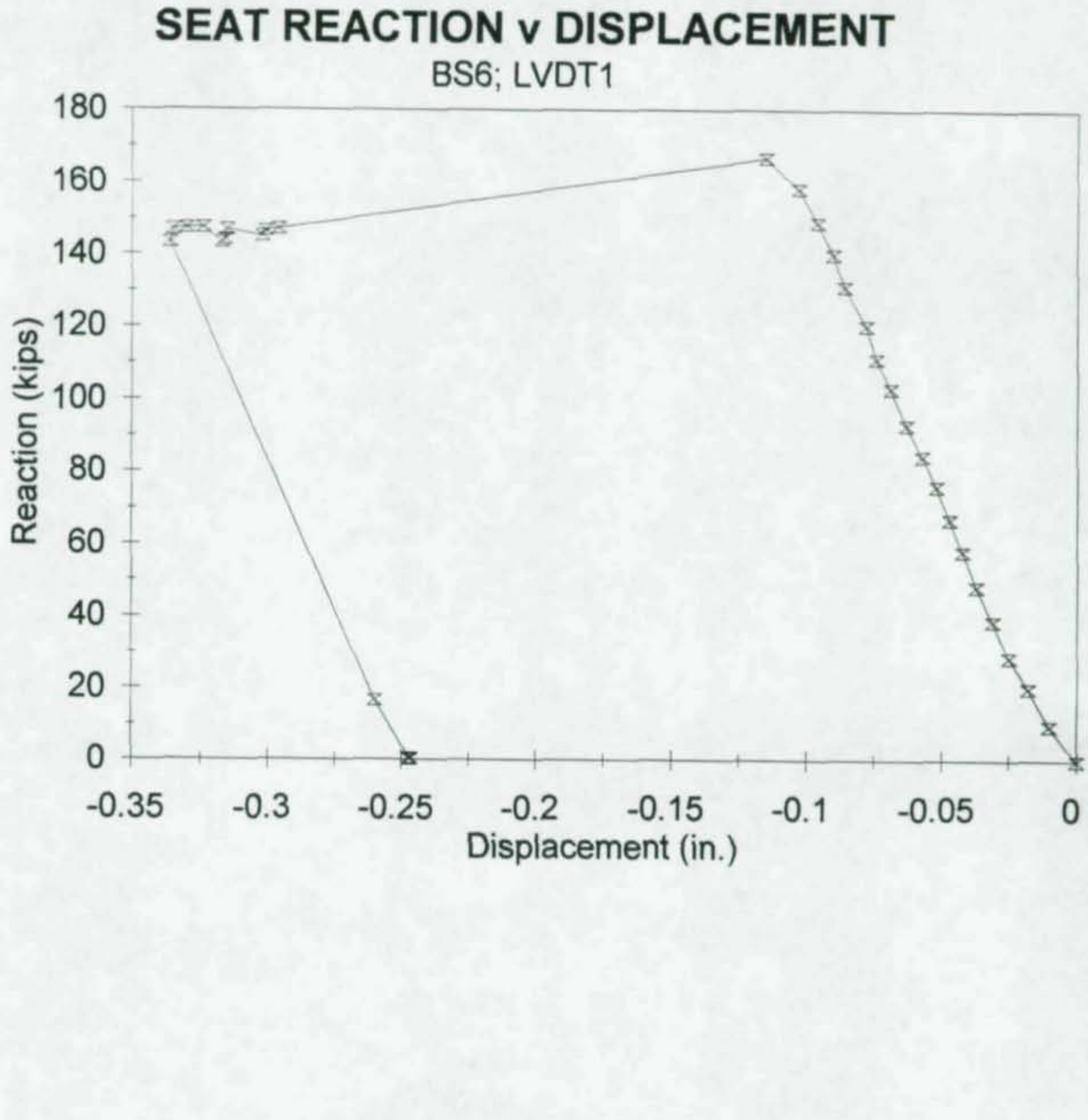


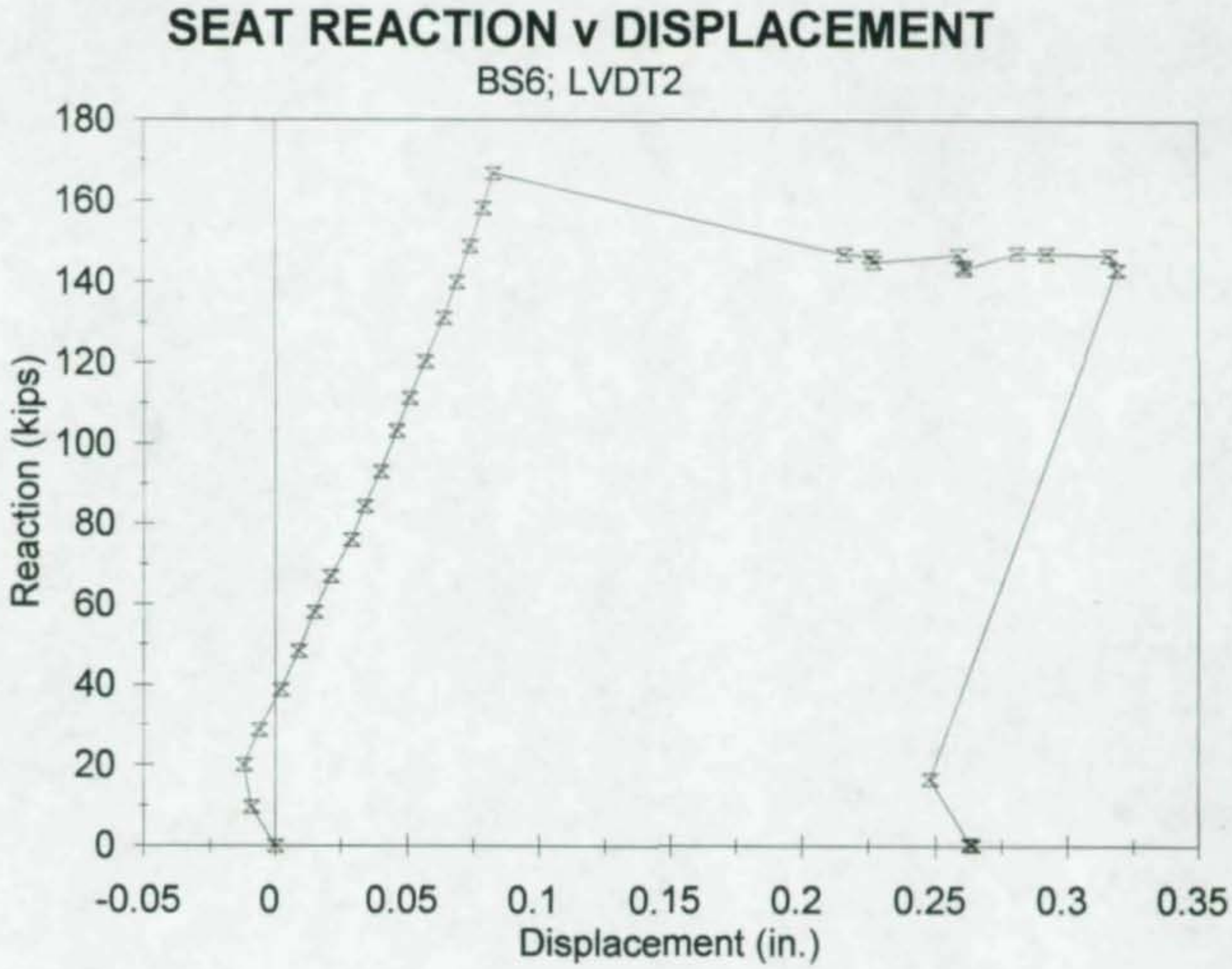
SEAT REACTION v DISPLACEMENT
BS4; LVDT1
Reaction (kips)
Displacement (in.)
160
140
120
100
80
60
40
20
0
-0.5
-0.4
-0.3
-0.2
-0.1
0


SEAT REACTION v DISPLACEMENT
BS4; LVDT2
160
140
120
100
80
60
40
20
0
Reaction (kips)
0
0.05
0.1
0.15
0.2
0.25
0.3
Displacement (in.)


SEAT REACTION v DISPLACEMENT
BS5; LVDT1
Reaction (kips)
200
180
160
140
120
100
80
60
40
20
0
-0.25
-0.2
-0.15
-0.1
-0.05
0
Displacement (in.)


SEAT REACTION v DISPLACEMENT
BS5; LVDT2
Reaction (kips)
200
180
160
140
120
100
80
60
40
20
0
0
0.05
0.1
0.15
0.2
0.25
0.3
Displacement (in.)


SEAT REACTION v DISPLACEMENT
BS6; LVDT1
Reaction (kips)
180
160
140
120
100
80
60
40
20
0
-0.35
-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0
Displacement (in.)


SEAT REACTION v DISPLACEMENT
BS6; LVDT2
Reaction (kips)
180
160
140
120
100
80
60
40
20
0
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
Displacement (in.)

Appendix D

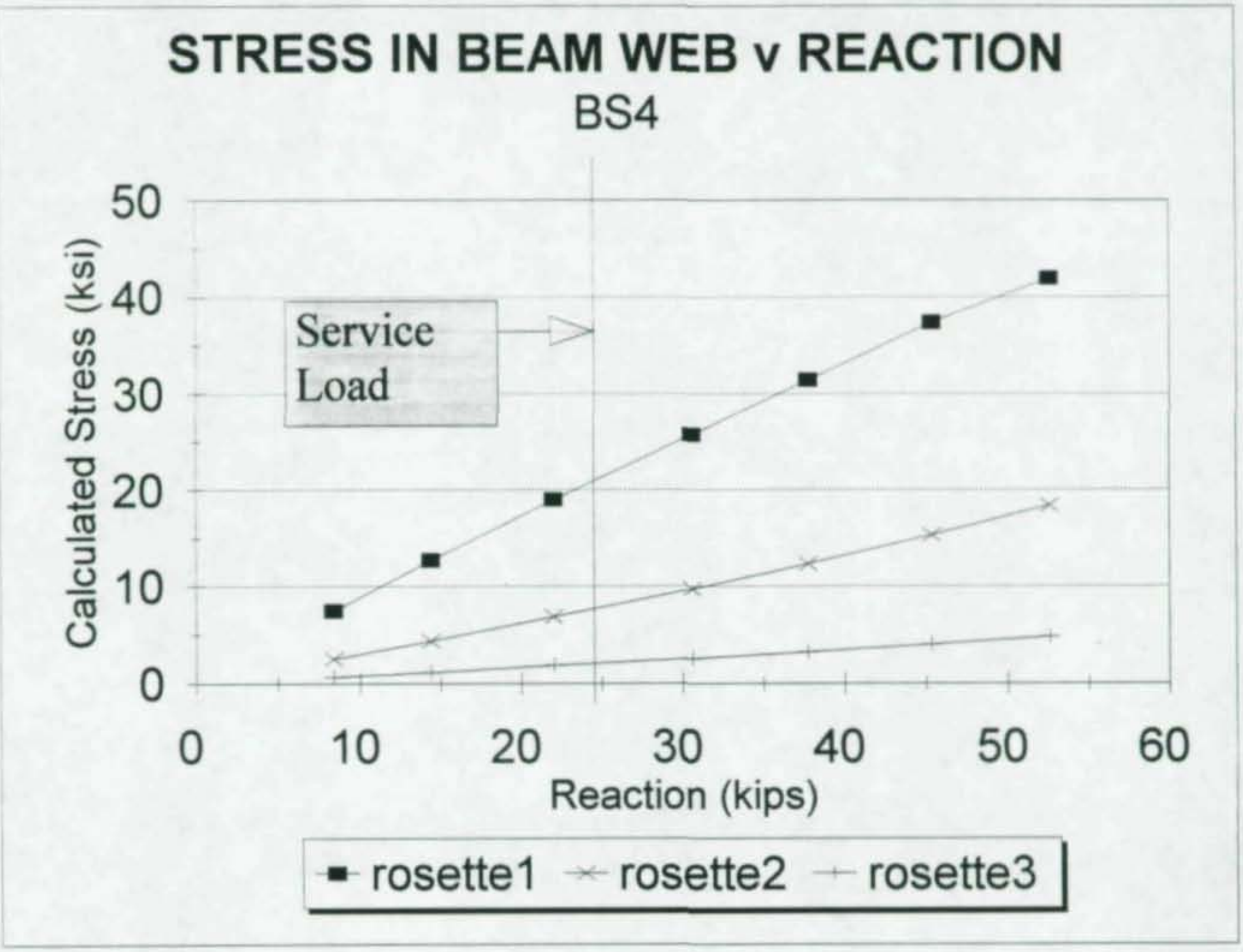
Beam Web Stress and Strain Graphs

The following graphs depict stress and strain data gathered from the strain gage rosettes mounted on the reaction beam web during Part One of this phase of testing. The data used are from Tests Four and Five. These tests gave the best strain data since in both cases the strain gages attached to the beam web were new and unstrained.

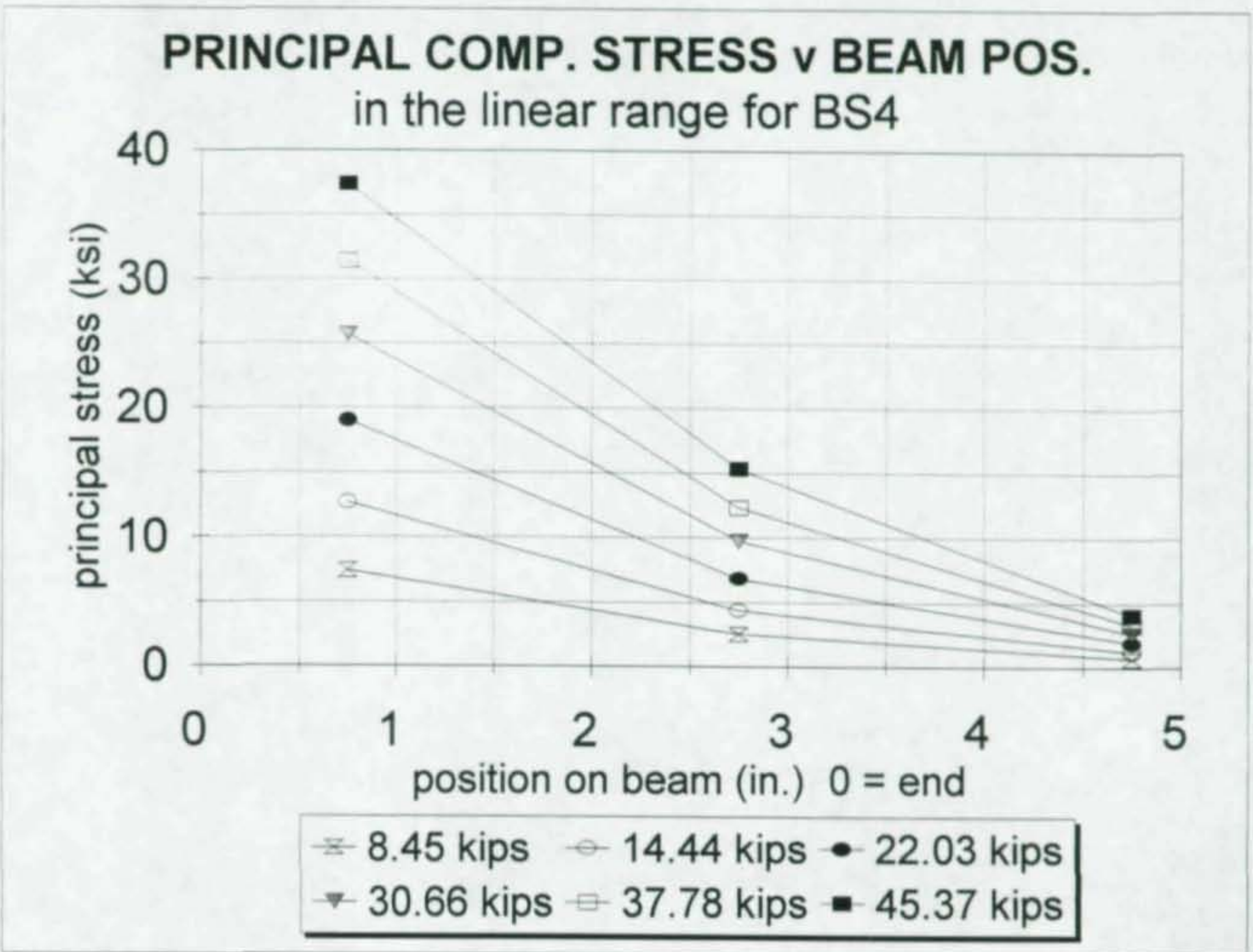
The first graph shows the compressive stress distribution in the beam web with respect to the position of the rosette on the beam. The next graph shows the stress at each rosette position as a function of the reaction at the seated connection. The stresses where computed using equations which assume linear elastic behavior from *Experimental Stress Analysis* by Dally and Riley. This is why only the points where the material is assumed to be in the linear elastic range, or very near it, where plotted for stress data.

The later graphs simply show how the beam web deformed at each rosette position as the load on the connection increased. One can relate this deformation to stress if the proper equations relating stress and strain are used.

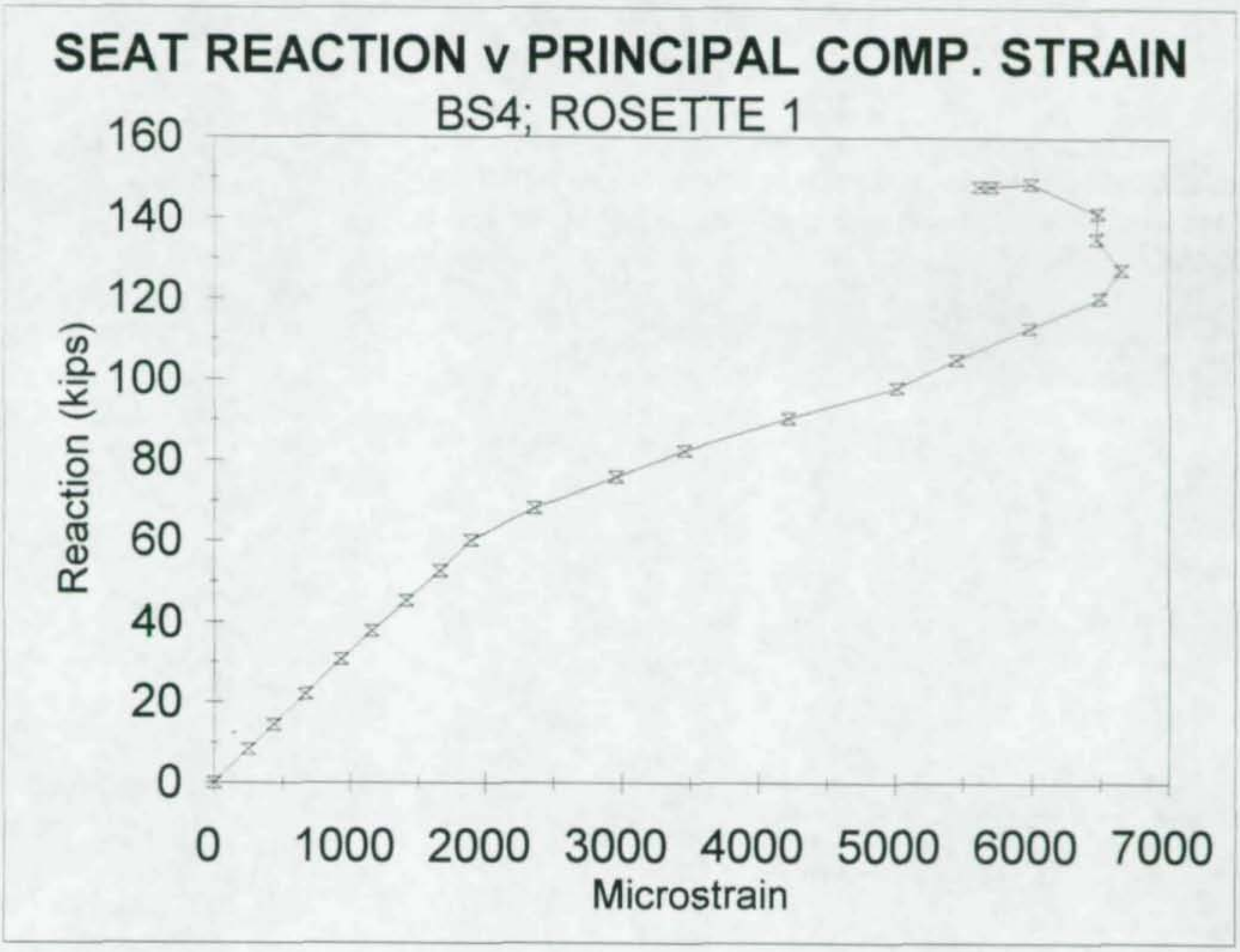
As can be seen by observing the graphs, Beam web yielding is not a problem under service conditions.

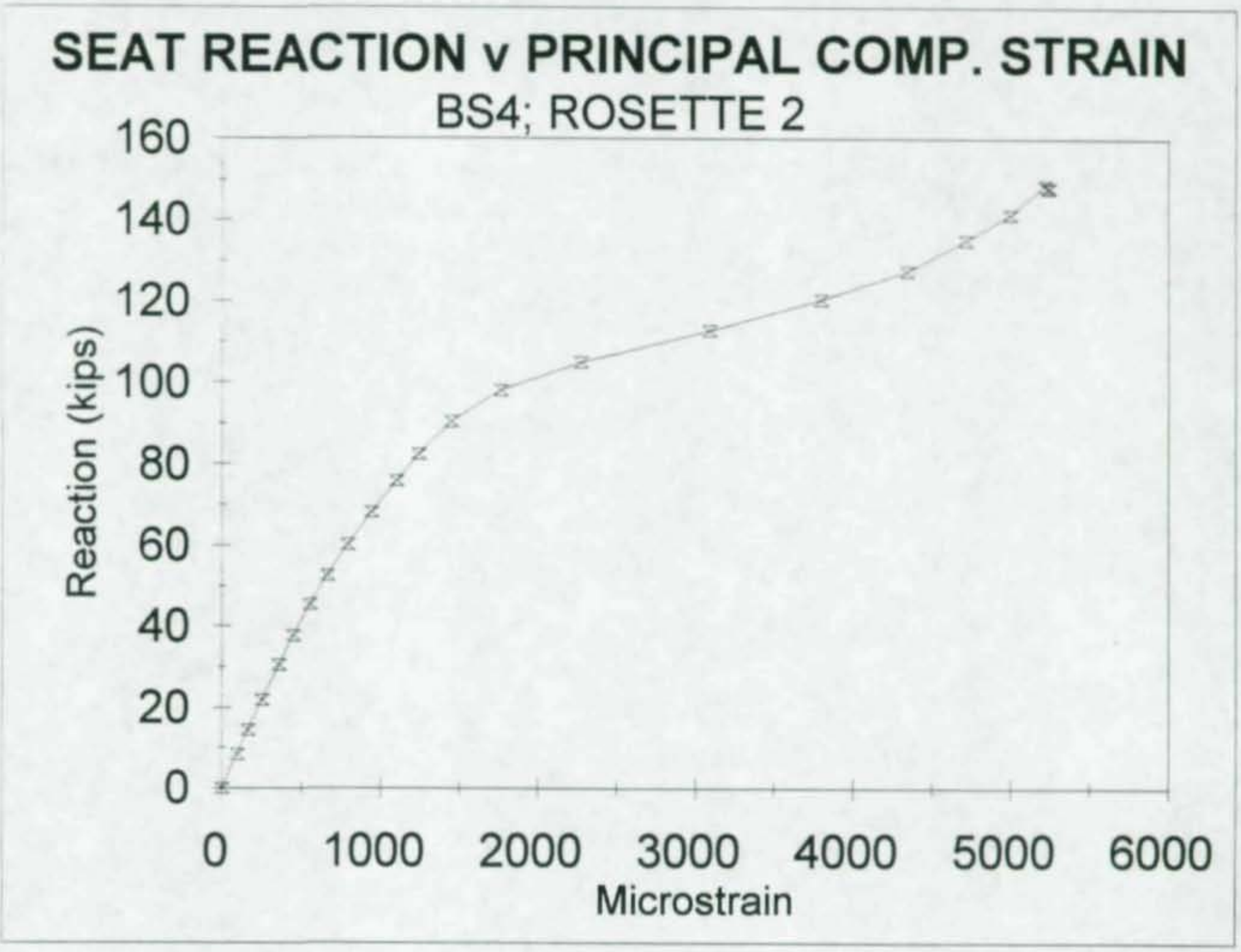


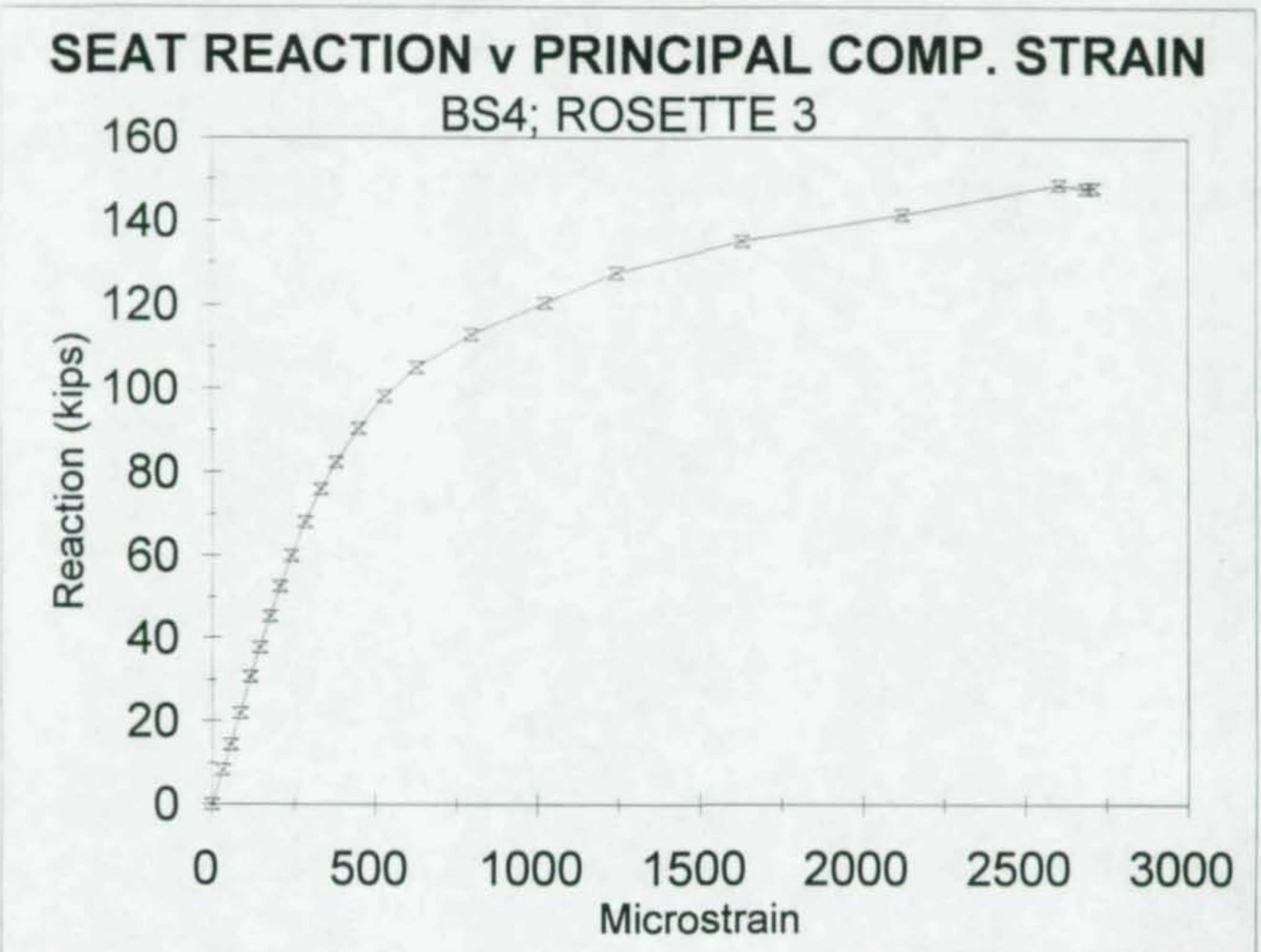
STRESS IN BEAM WEB v REACTION
BS4
Calculated Stress (ksi)
50
40
30
20
10
0
Service Load
0
10
20
30
40
50
60
Reaction (kips)
rosette1
rosette2
rosette3

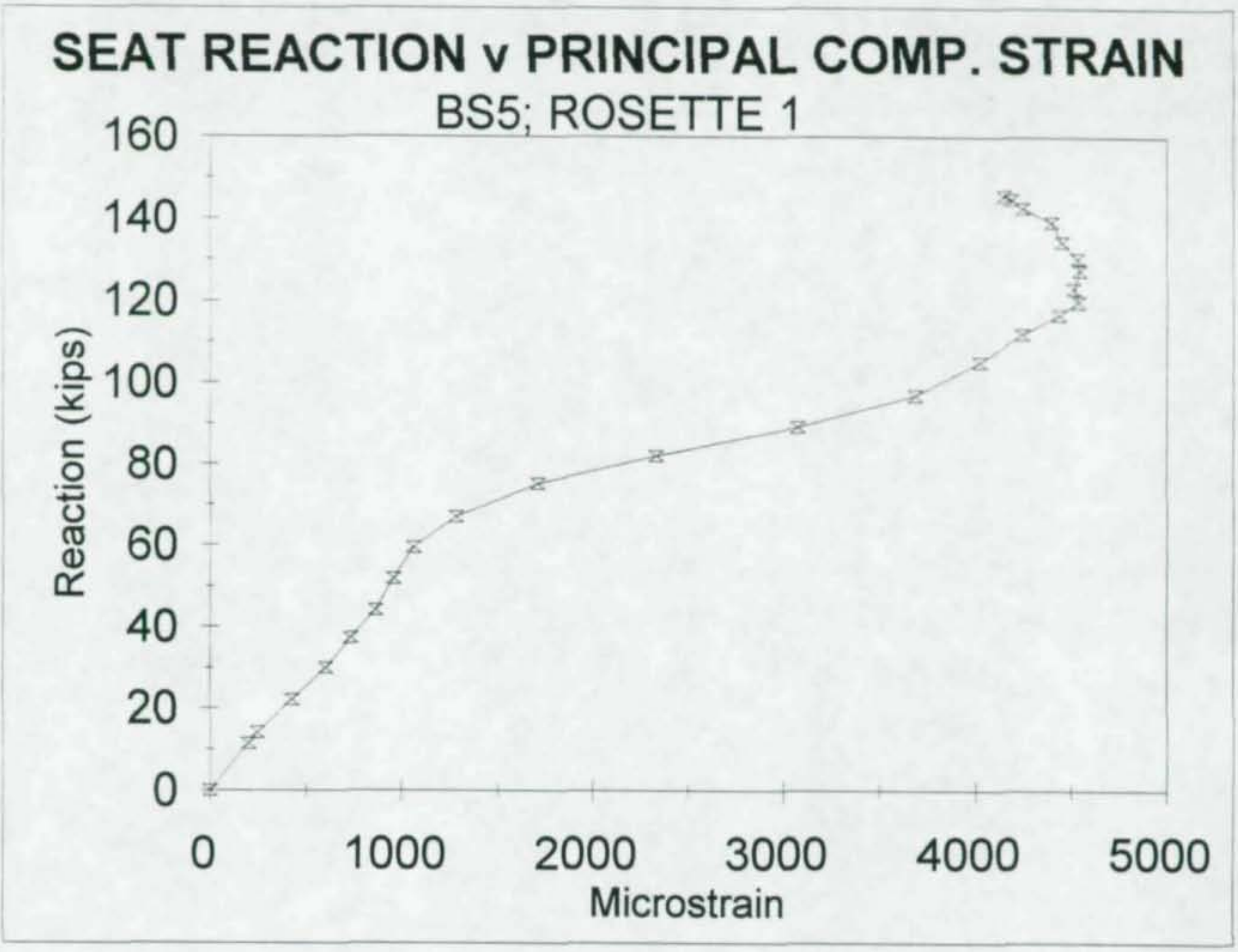


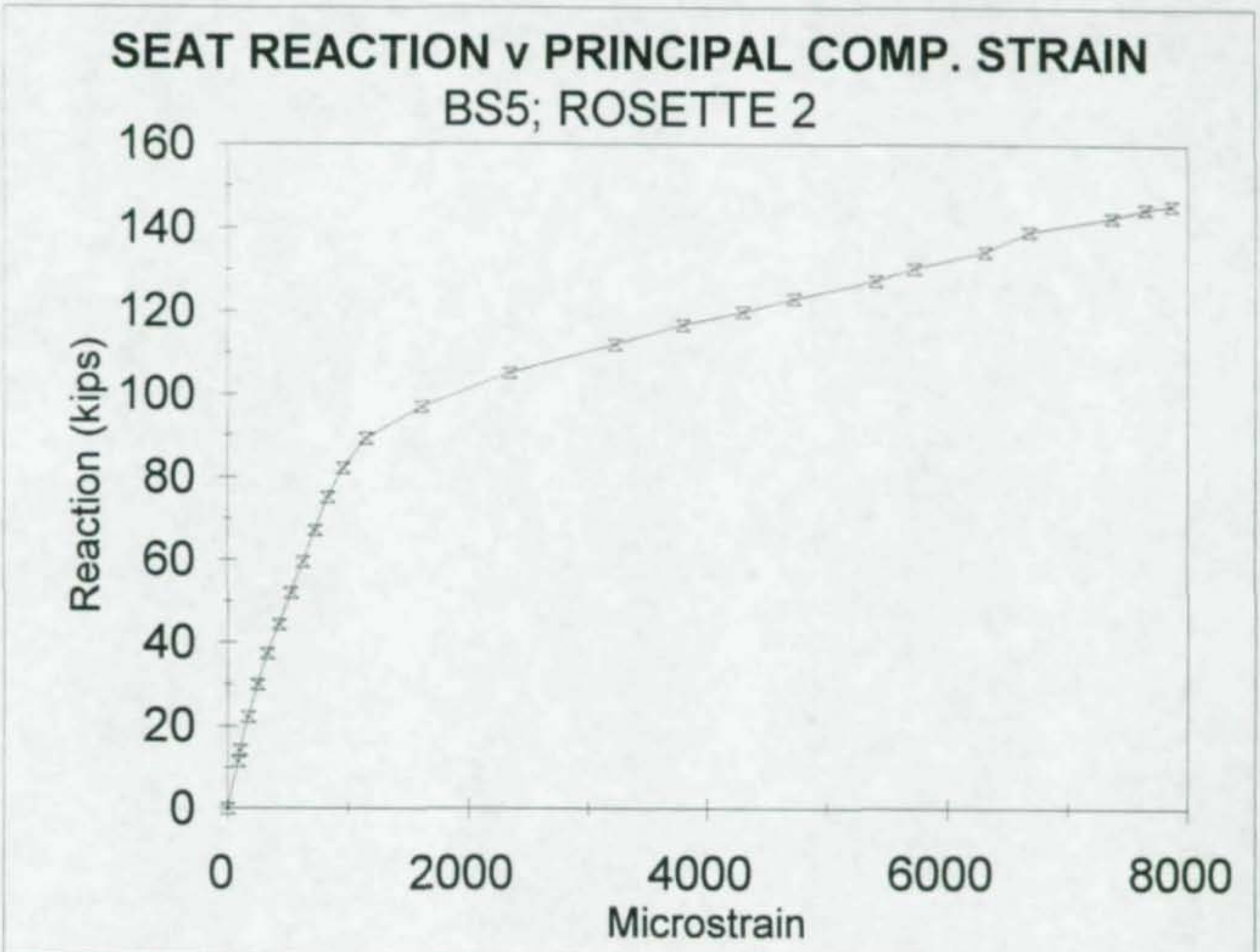
PRINCIPAL COMP. STRESS v BEAM POS.
in the linear range for BS4
principal stress (ksi)
40
30
20
10
0
0
1
2
3
4
5
position on beam (in.) 0 = end
8.45 kips
14.44 kips
22.03 kips
30.66 kips
37.78 kips
45.37 kips

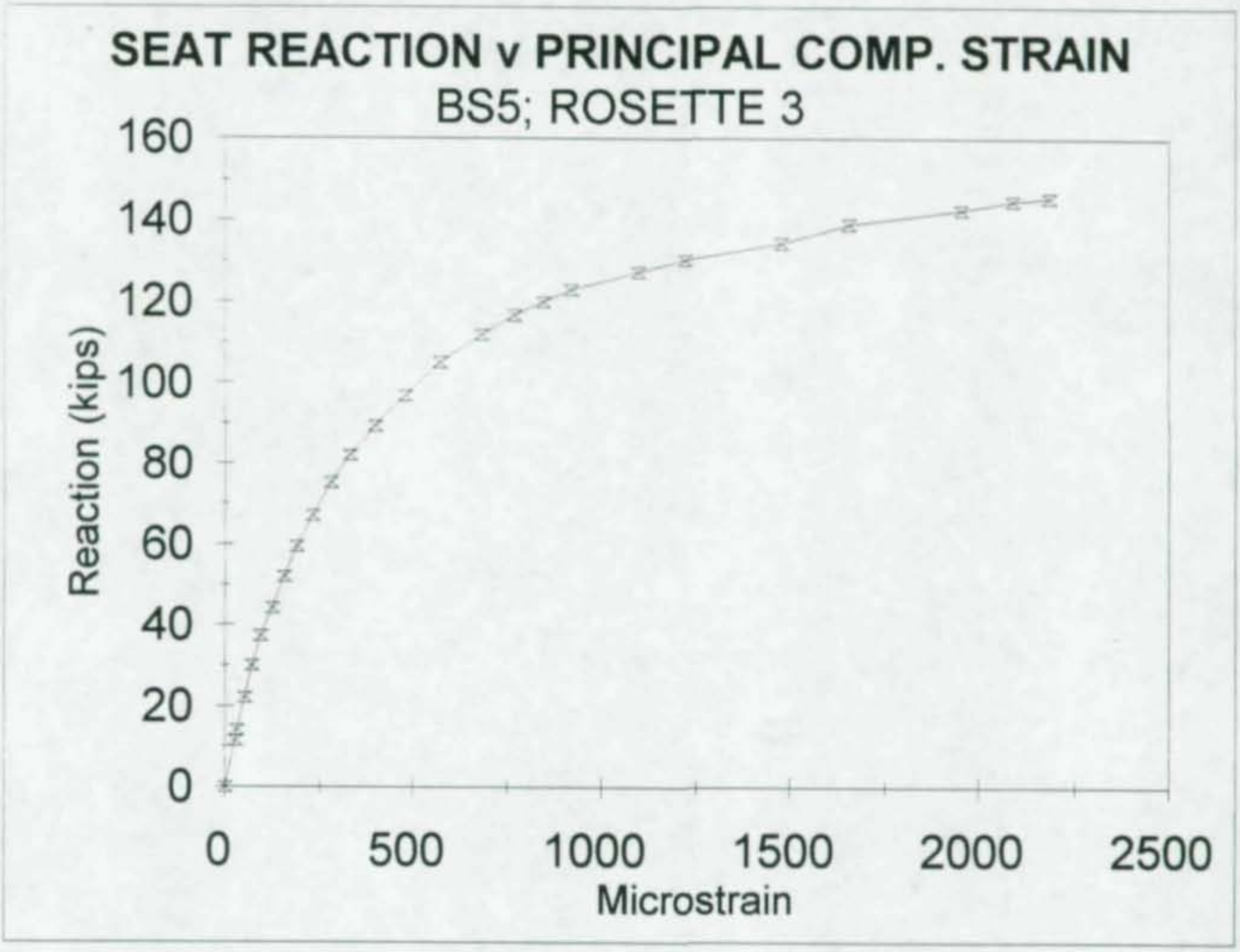

SEAT REACTION v PRINCIPAL COMP. STRAIN
BS4; ROSETTE 1
Reaction (kips)
160
140
120
100
80
60
40
20
0
0
1000
2000
3000
4000
5000
6000
7000
Microstrain


SEAT REACTION v PRINCIPAL COMP. STRAIN
BS4; ROSETTE 2
Reaction (kips)
160
140
120
100
80
60
40
20
0
0
1000
2000
3000
4000
5000
6000
Microstrain


SEAT REACTION v PRINCIPAL COMP. STRAIN
BS4; ROSETTE 3
Reaction (kips)
160
140
120
100
80
60
40
20
0
0
500
1000
1500
2000
2500
3000
Microstrain


SEAT REACTION v PRINCIPAL COMP. STRAIN
BS5; ROSETTE 1
Reaction (kips)
0
20
40
60
80
100
120
140
160
0
1000
2000
3000
4000
5000
Microstrain


SEAT REACTION v PRINCIPAL COMP. STRAIN
BS5; ROSETTE 2
160
140
120
100
80
60
40
20
0
Reaction (kips)
0
2000
4000
6000
8000
Microstrain


SEAT REACTION v PRINCIPAL COMP. STRAIN
BS5; ROSETTE 3
160
140
120
100
80
60
40
20
0
Reaction (kips)
0
500
1000
1500
2000
2500
Microstrain

REFERENCES

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2. Ellifritt, D., and T. Sputo, "Stiffened Seated Connections to Column Webs: Phase Two", University of Florida Research Report, December 1990.

3. Dally, J., and William F. Riley, Experimental Stress Analysis, McGraw-Hill, Inc., 1965.

4. Blodgett, O., Design of Welded Structures, James F. Lincoln Arc Welding Foundation, Cleveland, OH, 1966.

5. American Institute of Steel Construction, Inc., Manual of Steel Construction, Allowable Stress Design, Ninth Edition, AISC, Chicago, IL, 1989.