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by

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Report to sponsor:

American Institute of Steel Construction

JULY 1988

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF CALIFORNIA AT BERKELEY
BERKELEY, CALIFORNIA

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ABSTRACT

The behavior of tee framing connections was studied by testing nine full size beam to column assemblages. The specimens were subjected to realistic conditions that will occur under gravity loading of a beam. The effects consisted of shear and corresponding rotation. The relationship between shear and roatation was established by using inelastic program SHEAROT. The specimens were subjected to shear and roatation until failure occurred. Limit states that were established were bolt fracture, weld fracture, yielding of tee stem, fracture of net area of tee stem, and bearing yielding of bolt holes. Prior to strength tests, a ductility test was conducted on each specimen to measure its moment-rotation characteristics and ductility.

The behavior of test specimens and experimental results were analyzed and design procedures were developed and proposed. The procedures are in LRFD and ASD format and can be used with service loads or factored loads.

The predictions of the proposed methods were compared to experimental results and were shown to be close and slightly conservative. All experimental data, including variations of strength, stiffness and ductility were reported.

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The experimental data used in developing this report were collected by the second author as his CE299 report. The views and recommendations presented in this report are those of the authors, and do not necessarily represent the opinions of the University of California or the sponsor.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Tee-framing connections are one of the shear connections suggested in the AISC Manuals of Steel Construction (8,9). Tee framing connections can be welded or bolted as shown in Figure 1.1. This study is concerned with type "a" connection in the figure where tee is welded to the column flange and bolted to the beam web. Figure 1.2 shows typical applications of tee connection in beam-to-beam, beam-to-column, and beam-to-wall joints. This type of connection is normally categorized as a shear connection and is designed to transfer only the end shear reaction of the beam to the support. Like any shear connection, these connections should be designed to satisfy dual criteria of strength and ductility. The connection must have sufficient strength to transfer the end reaction and should have enough rotational ductility to accommodate the end rotation demand of the beam.

Currently, designers assume that tee framing connections behave similar to double angle connections shown in Figure 1.3, and apply procedures that are for double angles to design tee framing connections. It is assumed that tee connections behave as double angles; however, the validity of this assumption is not fully established. Differences do exist between double-angles and tee-connections. One major difference is that in tee connections flange of the tee is continuous whereas in double angle connections two outstanding legs are separate. The significance of the flange continuity is that the top portions of tee connection can develop large membrane forces relative to double angles. Also, continuous flange of tee-connections provide significant strength in in-plane bending that is not available in double-angle connections. Another difference is that when using double angles, the sum of the thicknesses of the two back-to-back legs multiplied by depth provide the area that resist shear. This area in double angles can be substantially larger than the comparable area in tee framing connections. The implication of this difference is that shear and bearing stresses in tee connections can be relatively larger than double angle connections. Also, in tee connections, bolts connecting tee stem to beam web are subjected to single shear whereas in double angles bolts are subjected to double shear.

Finally, the ductility behavior of tee connections has not been fully studied and moment-rotation characteristics can be different. Limited tests conducted on tee framing connections in the past indicates that there are differences between tee framing and double angle framing connections. To obtain more information on actual behavior of tee framing connections and to develop design procedures and recommendations, the investigation reported here was conducted. The study consisted of conducting nine full scale tests of tee framing connections with various geometric parameters and analyzing experimental results in order to develop design procedures. The design procedures are realistically based on actual behavior and failure modes of tee framing connections that were tested. The main emphasis of this research was on studying shear strength and ductility of tee connections. Shear connections in beams not only should be capable of transferring shear force but also should be ductile enough to rotate and accommodate the rotation demand of beam end. In order to test connections under more realistic conditions, a special test set-up was developed (1,2) that permits rotation of connections as shear load is applied.

In order to apply realistic shear-rotation combinations to the connections, a computer program was used (2) to analyze large number of beams. The beams were loaded up to collapse stage, to establish the shear-rotation relationship in shear connections.

The established shear-rotation relationship was simulated in the laboratory and connections were subjected to established shear-rotation combinations until failure occurred. Test results were recorded, processed and analyzed and design recommendations were formulated.

1.2 Literature Review

A survey of literature indicated that the information on the strength and ductility of this type of connection is very limited. In particular, experimental investigations of the connection behavior under realistic loading conditions are almost non-existent.

White (7) conducted four tests to study behavior of tee-framing connections in beam-to-column joints. The emphasis of the study was placed on the behavior of supporting tube columns and not the tee-connection. However, valuable information in the forms of moment-rotation curves that resulted from this study, indicated that tee framing connections may be considered flexible and designed following rules developed for double angle connections. Kennedy and Hafez studied behavior of shear end plate connections (4) shown in Figure 1.4. The study is indirectly related to present research since flange of the tee in a tee framing connections is expected to behave similar to a shear end plate. In their study, Kennedy and Hafez developed a mathematical model of moment-rotation curve that includes kinematic hardening of the plate due to membrane action under large displacements. The end plates that they studied were bolted to the column and welded to the beam which can be considered to act similar to tee connections shown as type "d" in Figure 1.1. However, the methodology that they used can be adapted to other cases as well. Further search of the literature revealed few papers relevant to this topic. These sources are given in References 3, 4, 5 and 7.

1.3 Scope of the Research

The purpose of this study was to develop design procedures for tee-framing connections. More specifically, the objectives were:

1. To provide design methods to calculate required geometry of tee element to resist a given shear force.

2. To provide methods for design of bolts connecting tee framing to the beam web.

3. To obtain experimental moment-rotation relationship for tee framing connections.

4. To provide methods that can be used to calculate capacity of a given tee framing connection.

Objectives 1 and 2 above are related to shear strength of connections and will provide information for design of connection to carry a specified shear. Objective 3 is related to rotational stiffness and ductility of connections. Objective 4 is related to analysis of a given tee framing connection.

The objectives of the study were accomplished by developing tee-connection shear and strength prediction, weld and bolt force prediction equations, and information on stiffness and ductility of connection.

Nine full scale tests of tee-connection configurations were conducted to develop and verify these analytical predictions and proposed design procedures. Figure 1.5 presents the various parameters that define the tee framing connection geometry. These geometric parameters were varied within the limits shown in Table 1.1 to develop the experimental test matrix.

In addition to design procedures, moment-rotation and shear rotation curves for all nine connections tested are reported. The information can be used to develop empirical or analytical models of rotational stiffness of connections. The models are needed in refined analysis of frames utilizing tee framing connections.

CHAPTER TWO

EXPERIMENTAL PROGRAM

2.1 General

A total of nine specimens were tested. The experiments consisted of subjecting tee-framing beam-to-column connections to a combination of shear forces, moments and rotations that would prevail in a realistic simply supported beam. The following sections explain parameters of study, test specimens, loading history and test procedures. Test results are given in Chapter 4.

2.2 Parameters of Study

The main parameters influencing the shear strength and rotational behavior were recognized to be the b/t ratio of the flange, the thickness of the tee stem, number of bolts, bolt type and length of weld. The ranges of variation of these parameters that are shown in Figure 1.5, are given in Table 1.1. The selection of parameters were done such that with the limited number of tests conducted, the most possible amount of useful data could be obtained. In addition, the parameters were selected to ensure proper presentation of real cases.

2.3 Test Specimens

A typical test specimen is shown in Figure 2.1. The specimen consisted of a W 18x35 beam connected to a W 10x77 column with tee-framing connections. Properties of tee-framing connections are given in Table 2.1. The tees used in test specimens were saw cut and welded in the laboratory.

Two types of bolts were used in the connections of test specimens. In test specimens 1 through 7, the bolts used were A325. In tests 8 and 9, the bolts used were A490. The nominal diameter in all bolts in all specimens was 7/8 inch. The bolt spacing for all specimens was 3 inches center-to-center of bolts. The edge distance of the bolts for all specimens was 1.25 inches from the top and bottom. The spacing and edge distance satisfy the requirements of current AISC Specifications (8,9).

Welds connecting tee flange to the column in all specimens were done using E7018 electrodes resulting in a nominal strength of 70 ksi for welds. The weld size was 3/16 inch for specimens 1 and 4 and 1/4 inch for all other specimens.

The column used was W 10x77 and the beam was W 18x35. These sections were selected to ensure that they will remain almost elastic during experiments and will not influence the behavior of connection as major parameters of the study. Also, 3/8" doubler plate was welded to the web of the beam so as to ensure that the web of the beam will remain elastic during the tests. The observations during the tests confirmed that indeed the column and the beam did not experience noticeable inelasticity. An exception to this was test number 7 as will be discussed later in Chapter Three.

To prevent web buckling of the beam, sufficient stiffeners were added along the line of application of concentrated loads. Lateral braces were provided at the end of the beam to prevent instability in out-of-plane direction.

2.4 Test Set-up

In a Type II connection, moment and shear are coupled. This is due to the fact that in the connections, only one element such as shear tab or tee is responsible to carry shear as well as moment. Also, added to the complexity of the problem is the presence of relatively large rotation in the connection area that causes significant inelastic strain hardening and geometric non-linearities. Therefore, even experimental study of the behavior of flexible connections through testing is a complex task. Due to high flexibility of connection, even small moments cannot be tolerated by the connection. Yet large shear forces are to be applied. These large shear forces with very small eccentricities tend to develop large enough moments to cause large unrealistic rotations.

The Type II connections must satisfy a dual criteria. The connections must have enough ductility in rotation to accommodate end rotation of the beam and, at the same time, the connection must have sufficient shear strength to transfer beam shear reaction to the support.

In order to perform a realistic test of connection, one needs to simulate the actual shear, moment and rotation values of a loaded beam as closely as possible during the experiments. Some researchers have used a typical cantilever beam specimen as shown in Figure 2.2. Although this test set-up provides valuable information on moment-rotation characteristics, it fails to measure strength of connection in shear. In this case, due to high flexibility of connection, upon application of very small shear, unrealistically large rotations take place and connection fails in bending. The results of the cantilever test specimen can only be used as a measure of bending ductility of Type II connections and not as a measure of strength.

To measure shear strength of the connection, test set-up of Figure 2.3 or similar set-ups are used by researchers. Usually in these tests, in order to fail connection before beam fails, short span beams are used. The use of short span beam in these test set-ups results in very small end rotation of the beam. Therefore, the rotation experienced by the connection during the tests will be unrealistically smaller than rotations in actual beam in a building. Consequently, since the realistic rotations are not imposed on connections, the measured shear strength at the best is an upper bound of strength and not actual strength. Particularly in welded framing connections, the rotation of connection generates large strains in the welds resulting in local cracks that can reduce direct shear strength capacity of the connection significantly.

To perform more realistic tests and to simulate combined effects of shear, moment and rotation in a Type II connection, one approach can be to fabricate an actual beam specimen with end connections as shown in Figure 2.4, and load it until failure occurs and study the behavior of connections during the testing. In this case the cost of fabricating the specimens and testing will be high; therefore, limiting the number of tests that can be performed.

To mitigate the above-mentioned difficulties, and based on extensive analytical simulations, the test set-up shown in Figure 2.5 was developed by Astaneh (1,2) which is used in this project to test tee framing connections. The set-up in Figure 2.5 can be used to test any flexible or semi-rigid connection.

The main components of the test set-up are a permanent short beam, a short column, two actuators, and support blocks. The beam which is instrumented is a W 18x35. Actuator S, which is close to the support, is force controlled and provides the bulk of shear force in the connection. Actuator R, which is displacement controlled, controls and provides the rotation of the connection. Therefore, by adjusting these two actuators, one can develop desired shear and rotation in the connection. The support blocks are concrete and steel dead weights, pre-stressed to the floor of the laboratory.

To provide lateral stability for the beam during the experiments, lateral supports are provided at the beam ends.

2.5 Loading History

As mentioned earlier, the objective in conducting the tests was to subject the tee connection to a combination of shear and rotation similar to those that prevail in a flexible connection of a beam when subjected to gravity loading. In order to obtain such variations, A. Astaneh (1) developed and used ENDROT program and further modified it to become SHEAROT program.

The program simulates loading of beam supported by flexible connections until it collapses. During loading end shear and rotations are measured. Samples of results are given in Appendix C.

By using SHEAROT program, it was found that, regardless of beam size or span, the ratio of end rotation at failure to rotation at yield is almost constant.

The computer program was used to analyze all cross sections from W16 to W33 that are listed in the AISC Manuals (8,9). In the analysis spans of 10, 30 and 50 feet were considered for all beams. The analyses indicated that variations of end shear vs. end rotation for these beams and spans are very stable and changes slightly with change of shape factor f, where f is equal to z_x/s_x. Figure 2.6 shows a plot of shear vs. rotation at the end of beams that were analyzed. As can be seen in the plot, shear vs. rotation follows an elastic path until yielding starts at midspan of the beam. At this point, rate of increase of rotation increases rapidly, causing large rotations for relatively small load increase.

In order to establish a loading history, values of end rotation when a simply supported beam approaches plastic collapse were studied. Figure 2.7 shows a plot of end rotation versus midspan maximum strain for beams that were analyzed when moment at midspan reaches 0.99 Mp, 0.999 Mp, 0.9999 Mp and 0.99999 Mp. In the analysis, the strain at midspan also was calculated. It was discovered that when midspan moment reaches 0.9999 Mp, strain at extreme fiber of midspan section reaches about 100 times yield strain which represents ultimate fracture strains for most structural shapes. Therefore reaching a moment equal to 0.999 Mp constituted failure. The end rotation corresponding to this midspan moment was consistently equal to about 2.5 yield rotation for all the beams that were analyzed. Therefore, it was decided that in order to test connections under realistic conditions, shear and rotations should be applied such that at failure of connections, the rotation be equal to 2.5 θy where θy is end rotation of a simply supported beam when midspan moment reaches yield moment.

To establish value of θy that can be used in testing, the results of computer analysis also indicated that this point is also very stable. End rotation corresponding to yielding at midspan was about 0.012 radians. Therefore, a value of θ equal to 2.5 θy resulting in 0.03 radians was selected to be targeted during the tests.

A predicted shear failure load was calculated using AISC-LRFD procedures and actual behavior of connection, considering all possible modes of failure when subjecting the tee framing connection to pure shear. Such calculations are presented and discussed in Chapter Four. Then, this value of shear strength and a rotation of 0.03 radians constituted failure point on shear vs. rotation curve. Therefore, the above two values were chosen as a target point on the shear vs. rotation graph. During strength tests, connections were subjected to monotonic shear and rotation such that the slope of shear-rotation curve was $V_{ult}/0.03$ radians as shown in Figure 2.8. For each specimen, a ductility cycle preceded strength tests. In ductility tests the specimens were subjected to rotation only by disconnecting actuator S in Figure 2.5.

To summarize, each specimen was subjected to two phases of loading. First, a ductility test was conducted by applying rotations up to 0.07 radians to the connection using a cantilever test set-up. Second, a realistic shear strength test was conducted by applying shear as well as corresponding rotation following a linear shear-rotation relationship. The load application continued until failure occurred.

2.6 Instrumentation

The instrumentation used in this series of tests is shown in Figure 2.9. The instrumentation consisted of Linear Variable Displacement Transducers (LVDT) and three Linear Potentiometers. LVDT number one was placed at the top of tee connection and was used to measure the separation between the tee flange and the column. LVDT's number 2, 3, 4 and 5 were mounted two on the top flange and two on the bottom flange of the beam. These were used to calculate the rotation of the connection. Calculation of rotation was done using the following formula:

$$\text{Rotation} = \frac{(\text{LVDT2} + \text{LVDT3} + \text{LVDT4} + \text{LVDT5})/2}{(18\ 5/16'' + 2 \times 4.5'')} \qquad (2.1)$$

The denominator in above equation is the distance from center to center of LVDT's on top and bottom flanges.

Linear potentiometer 1 was used to measure end deflections under actuator R in Figure 2.5, and linear potentiometer 2 was used to measure deflections under actuator S. Linear potentiometer 3 was used to measure the shear deformations of the tee connection in the direction of applied shear. Note that linear potentiometers 1 and 2 can be used as a backup system to calculate rotation at the connection as follows:

$$\text{Rotation} = \frac{\text{Lin.}P_o(1) - \text{Lin } P_o(2)}{54''} - \text{(elastic deflections of beam in between)} \quad (2.2)$$

Actuator R was used to control rotation at the connection and actuator S was used to control shear. Data acquisition system for the experiments consisted of an IBM-PC based system with capability of real-time recording and processing. Another IBM-PC was connected to the first PC and was used to plot shear vs. rotation to enable test conductors to monitor and follow shear-rotation history during the tests. Slides and photographs were taken to record qualitative aspects of the research.

2.7 Test Procedures

The following steps were taken in conducting each test:

1. The specimen was prepared for testing. Necessary welding of tee flange to column was done.
2. The specimen was assembled by connecting the beam to column using the type of bolts specified for the specimen. Bolts were snug tight.
3. Instrumentation was added and specimen was whitewashed. The whitewashing was done to enable the investigators to detect yielded areas.
4. The calibration of the instrumentation was checked. If a particular instrument was not exact in its reading, it was recalibrated.

5. The proper operation of the instrumentation and data acquisition systems was checked by applying a very small rotation.

6. First phase of experiments which was ductility phase began by applying rotation gradually, until rotation reached 0.07 radians. During this phase, actuator "S" in Figure 2.5 was set to neutral and only active actuator was "R" which was applying force to the end of beam as a cantilever specimen.

7. During the test, data was collected at discrete points and significant events were noted, recorded and photographed.

8. After rotation reached 0.07 during ductility test, specimen was unloaded and rotation was reversed until rotation came back to zero. This stage was the end of ductility test.

9. After completion of ductility test as in Steps 6, 7 and 8 above, second phase of experiment which was strength phase started. During this phase, by using both actuators "R" and "S", rotations and shear forces corresponding to points on load path were generated. Load path is shown in Figure 2.8. The shear-rotation loading continued until specimen failed.

CHAPTER THREE

EXPERIMENTAL RESULTS

3.1 General

This Chapter presents the quantitative and qualitative data that were collected during the experimental studies. A summary of behavior of each specimen is presented. The relevant plots of the experimental data for each specimen are given in Appendix A. A summary sheet for each test is provided in Appendix D.

3.2 Behavior of Test Specimens

As mentioned earlier, each test consisted of two phases. Phase one was a ductility cycle which consisted of rotating connection up to 0.07 radians, phase two was a strength cycle in which the shear forces coupled with proportional rotations were applied. The shears and rotations were monitored to be able to follow the realistic loading path suggested in Section 2.5.

3.2.1. Test Number One

Test specimen one had three bolts. The tee was WT4x7.5 with a stem thickness of 9/32 inch which is considered relatively thin.

Behavior of this specimen during ductility cycle was quite ductile with some minor inelasticity. When rotation reached 0.05 radians, yielding was observed adjacent to fillets at the top of the tee. When rotation reached 0.07 radians, the weld return at the top of the tee showed a hair crack. Also at this point minor yield lines were observed on the tee flange. In addition, bolt slip occurred.

During strength test, when shear reached 53 kips, yield lines were observed at bolt spacing areas of tee stem. At 76.6 kips shear, severe yielding of net area was apparent. Also, widespread yielding could be observed near the fillets of flange. The load could not be increased further beyond 76.6 kips. Therefore, the capacity was considered to be 76.6 kips shear. At maximum load, rotation of connection was 0.034 which is very close to failure target rotation of 0.03 radians.
The failure made assigned to this specimen was excessive shear yielding of net area of tee stem adjacent to bolt line connecting tee stem to beam web. Figure 3.1 shows specimen One at the end of the test. Notice severe deformation of bolt holes due to shear yielding of tee stem.

3.2.2. Test Number Two

Test specimen two had five bolts and a WT7x19 was used. Thickness of stem was 3/8. During ductility cycle when rotation reached 0.045 radians, top portion of tee yielded near weld returns and adjacent to tee fillets. When rotation reached 0.065 radians, weld returns cracked. Connection was rotated until a rotation of 0.069 radians was achieved with no further significant observations.

During strength cycle, when shear reached 116 kips, significant yielding occurred in tee stem. The nominal shear yield strength of this specimen was equal to 113 kips. At shear equal to 174 kips, failure occurred due to excessive yielding of tee stem followed by fracture of net area of tee stem. The welds or bolts did not show any sign of visible distress or yielding.

Figure 3.2 shows tee portion of the specimen after it is separated from column. The shear fracture line can be observed extending over four bolt spacing from the bottom of connection.

3.2.3. Test Number Three

Test specimen three had three bolts. The tee was WT7x19. During ductility cycle this specimen showed considerable flexibility with almost no yielding visible. When rotation approached 0.07 radians, minor yielding of top of the flange near weld return was observed. During strength test, when shear approached 45 kips, weld returns cracked. At 70 kips shear areas of flange adjacent to weld return showed more signs of yielding. At 93 kips shear, net area of tee stress showed signs of yielding and continued to yield as load was increasing. At shear equal to 107 kips, weld and stem fractured almost simultaneously.

Figure 3.3(a) shows Specimen Three at the conclusion of the test. Figure 3.3(b) shows same specimen after beam and column have been removed. Notice significant shear yielding and deformation of bolt holes. Also, shear fracture line, at the left region of the deformed bolt holes can be seen.

3.2.4. Test Number Four

Specimen in test number four was similar to test one but with five bolts. In this specimen, unlike all other specimens, unlike all other specimens, bolts were not snug tight but were tightened to develop 70% of proof load as specified in the AISC Manuals (8,9). Generally specimen showed less flexibility in rotation than all other specimens. During ductility test, at 0.025 radian rotations, yielding of flange near weld returns and close to fillets was visible. At 0.045 radians, yield lines were visible throughout the tee flange. When rotation reached 0.06 radians, weld returns cracked and immediately was followed by fracture of weld over its full length. Due to fracture of weld during ductility cycle, no strength test was conducted. Figure 3.4 shows Specimen Four at the end of test.

3.2.5. Test Number Five

The specimen for this test had five bolts and consisted of WT4x20.

During ductility test, limited yielding occurred in tee. When rotation reached 0.05 radians yielding was visible near weld returns. At 0.06 radian rotation, weld returns cracked and yield lines occurred on the middle portion of tee flange. During strength test, when shear reached 170 kips, most of the flange showed sign of yielding. At shear equal to 183 kips, fracture of net area of tee stem occurred. The bolts in this specimen were bent after the test, indicating yielding of bolts. The appearance of test specimen after conclusion of the test was similar to Specimen Two as shown in Figure 3.2.

3.2.6. Test Number Six

The specimen for this test was similar to test five but had three bolt. During ductility test, at 0.04 radians, bolt slip occurred. At 0.07 radians rotation, minor bolt bearing yielding of the stem was observed. During strength test, when shear reached 50 kips weld returns cracked and significant yielding could be observed on tee stem. At 110 kips shear, net area of tee stem fractured. Figure 3.5 shows specimen six during strength cycle.

3.2.7. Test Number Seven

The specimen for test number seven was built-up specimen fabricated by welding a 1/2 inch thick stem to a flange plate cut from WT7x19. The specimen had five bolts. The objective was to study welded tees and their behavior. During ductility cycle, specimen showed considerable ductility. At 0.05 radians rotation, tee flange showed some sign of yielding near weld returns and welds connecting stem to flange. During strength test, when shear reached 200 kips, column flange bending could be observed on tee flange. When shear force reached 232 kips, lower bolt fractured. Continued loading caused fracture of all bolts when load reached 238 kips. Figure 3.6 shows Specimen Seven after bolts that were sheared off have been removed and placed next to the connection.

3.2.8. Test Number Eight

The specimen for this test was a built-up specimen fabricated by welding 1/2 inch thick plate to a flange plate cut from

WT4x20. The specimen had three bolts. During ductility cycle, when rotation reached 0.07 radians, some minor yielding was observed on tee flange and tee stem under lower bolt. Figure 3.7 shows Specimen Eight at the end of ductility cycle with very minor yielding observed.

During strength cycle, at shear force equal to 70 kips, tee stem yielding could be observed. At shear force of 80 kips, widespread yielding was visible on tee flange. At shear force of 104 kips, weld returns cracked. Finally, when shear force reached 141 kips, weld lines connecting tee flange to the column fractured in a brittle manner.

3.2.9. Test Number Nine

The specimen for this test was built-up by welding 1/2 inch thick plate to a flange plate cut from WT4x20. The specimen had five bolts. During ductility cycle, at rotation of 0.0475 radians, tee stem compression yield lines were observed. During strength cycle, when shear load reached 113 kips, severe yielding occurred at bolt spacing. When shear force reached 209 kips, suddenly and in a brittle manner, all bolts fractured in shear similar to Specimen Seven as shown in Figure 3.6.

3.3 Experimental Data

Test results obtained from experiments are presented in the form of plots showing variation of two parameters. The variables that are plotted are shear, moment, rotation, shear displacement and location of neutral axis. The plots are given in Appendix A.

CHAPTER FOUR

ANALYSIS OF RESULTS AND DESIGN PROCEDURES

4.1 General

Failure of tee framing connections can occur due to attaining several limit states. The following failure modes were observed during the investigation. The failure modes appear to be major modes if not all possible modes of failure. Failure modes are:

1) Yielding of gross area of stem of tee.
2) Fracture of net area of stem.
3) Bearing failure of beam web as well as tee stem.
4) Fracture of welds connecting tee flange to the column.

For each failure mode, appropriate design equations and procedures were developed and proposed to be used in predicting strength of connection or in design. The predicted values based on proposed methods were compared to corresponding values obtained from the experiments. The comparison indicated that for specimens that were tested, proposed method predicts capacities with reasonable accuracy and the deviation is on the conservative side.

Design procedures that are proposed are in two formats: one is Load and Resistance Factor Design (LRFD) format and the other is Allowable Stress Design (ASD) format.

In order to develop a true reliability based procedures, one needs to accumulate a large number of statistical data on random variables involved. Due to complexity of the tee framing connection behavior and large number of variables involved, very large number of experiments should be conducted to establish characteristics and distributions of random variables. This approach is successfully used in developing LRFD equations for several major structural elements such as beams, columns, and tension members (10). In these cases relatively large number of experimental data was available. In many other cases, such as connections, the methodology in developing design equations in LRFD format has been to adapt an equation that closely relates to case under consideration. In this approach sufficient number of experiments are conducted in order to gain insight to the behavior of the elements and to establish limit states of failure. After limit states are identified, they are related to limit states that are already well known and well established. Then safety indices and reduction factors of the known limit states are adapted for the case under development. In this investigation the second approach is adapted.

As the number of experimental results increases in the future and reaches a level that can be considered statistically significant, then the reduction factors recommended here can be checked, refined and the extra margin of safety that currently exists can be removed. It is believed that by following the above-mentioned approach the knowledge and experience that is accumulated on the well known limit states are extended to the design of tee framing connections. Therefore, experiments conducted on tee framings are used to understand actual behavior of tee sections, to identify limit states and to check closeness of predictions of the proposed design procedures to actual experimental results.

Based on experimental results, it appears that the limit states of failure in tee framing connections are well defined and can be related to well known limit states of steel components. These include shear fracture of bolts, shear yielding of gross area of steel , shear fracture of net area of steel and shear fracture of welds.

The proposed LRFD and ASD procedures are given in the following sections and the predictions of these procedures are compared to experimental results in the subsequent sections.

4.2 Shear Strength of Tee Connections

This section provides proposed design equations for tee framing connections. Load and Resistance Factor Design as well as Allowable Stress Design philosophies are considered. In the proposed methods, reduction factors and factors of safety are selected to be consistent with corresponding values in AISC-LRFD Specifications (9) and AISC ASD Specifications (8).

4.2.1. Shear Yielding of Gross Area of Tee Flange

This limit state refer to a failure mode that is shown in Figure 4.1. In ordinary tee framing connections, where tees cut from wide flange shapes are used, it is unlikely that this limit state will be reached before other limit states. However, it is possible that in welded tees, a designer designs a welded tee with thin flange with relatively thick stem. In this case this limit state can be governing.

To prevent this limit state from governing one needs to ensure that tee flange thickness is equal or greater than 1/2 of the thickness of tee stem. All test specimens satisfied this rule and the shear failure of flange did not occur. By following this rule, tee stem will yield in shear before tee flange yields. Yielding of tee stem is discussed in the following subsection. Nevertheless, if one desires to check limit state of tee flange shear yielding, the following equations are suggested.

A. In LRFD Format:

$$\phi R_{n1} \geq \Sigma \gamma_i Q_{ni} \tag{4.1}$$

where,

$\phi = 0.90$

$R_{n1} = 0.60 F_y A_{vgf}$

$A_{vgf} = 2 t_f L_t$

F_y = Specified minimum yield stress of tee flange.

t_f = Thickness of tee flange.

L_t = Length of tee.

$\Sigma \gamma_i Q_{ni}$ = Governing factored reaction of the beam.

In ASD Format:

$$f_v \leq F_v \tag{4.2}$$

where,

$f_v = R / A_{vgf}$

$F_v = 0.40\ F_y$

$A_{vgf} = 2t_f\ L_t$

R= Governing service load reaction of the beam.

4.2.2. Shear Yielding of Gross Area of Stem

The experiments that were conducted, particularly tests number 1,2,3,5,6, and 8, where significant shear yielding occurred, indicated that tee stems are subjected to almost pure shear. It was observed that due to shear yielding, rotational stiffness of tee stem decreases rapidly resulting in connection moments being transferred to midspan with very small moment left in the connection to be transferred to the support. Figure 4.2 shows yielding of tee stem when this limit state is reached.

It is recommended that, in design, this limit state be the governing limit state resulting in tee stem acting as a short shear link. The recommendation, if followed, is expected to result in ductile and desirable behavior of connection. Due to shear yielding of tee stem, connection moments will be shed to midspan and connection will approach true simple connection. Also, due to large amounts of inelastic shear deformations in the connection, ample warning of imminent failure will be observed.

The suggested design equations for the limit state of yielding of gross area are:

A. In LRFD Format:

$$\phi\ R_{n2} \geq \Sigma \gamma_i\ Q_{ni} \qquad (4.3)$$

where,

$\phi = 0.90$

$R_{n2} = 0.60\ F_y\ A_{vg}$

$A_{vg} = t_w\ L_t$

F_y = Specified minimum yield stress of tee stem.

t_w = Thickness of tee stem.

L_t = Length of tee.

$\Sigma \gamma_i\ Q_{ni}$= Governing factored reaction of the beam.

In ASD Format:

$$f_v \leq F_v \tag{4.4}$$

where,

$f_v = R\ /\ A_{vg}$

$F_v = 0.40\ F_y$

R= Governing service load reaction of the beam.

4.2.3. Fracture of Net Area of Tee Stem

This limit state if reached, will result in almost total separation of beam from its support. Figure 4.3 shows typical fracture of net area in tee framing connections. Unlike fracture of net area in tension members which is brittle, shear fracture of net area was relatively ductile. In test specimens that failed due to fracture of net area, significant yielding and inelastic deformations took place before initiation and propagation of fracture crack.

In all specimens that failed due to fracture of net area, a vertical crack developed along bolt spacing midway between the centerline of the bolts and edge of the bolt holes.

The design equations for the limit state of fracture of net area are:

A. In LRFD Format:

$$\phi R_{n3} \geq \Sigma \gamma_i Q_{ni} \tag{4.5}$$

where,

$\phi = 0.75$

$R_{n3} = 0.60 F_u A_{ns}$

$A_{ns} = t_w [L_t - N (d_h)]$

F_u = Specified minimum ultimate strength of material of tee stem.

t_w = Thickness of tee stem.

L_t = Length of tee.

d_h = Diameter of bolt hole parallel to applied shear.

N = Number of bolts.

$\Sigma \gamma_i Q_{ni}$ = Governing factored reaction of the beam.

In ASD Format

$$f_{vu} \leq F_{vu} \tag{4.6}$$

where,

$f_{vu} = R / A_{ns}$

$F_{vu} = 0.30 F_u$

R= Governing service load reaction of the beam.

It must be mentioned that if a flange of connected beam is coped, it is possible that beam web will reach limit state of block shear failure. The reader is referred to AISC LRFD Specification for treatment of this limit state.

4.2.4. Bearing Failure of Tee Stem

The bearing failure of tee stem can occur when bolts tear through the edge distance or bolt spacing. This failure mode is depicted in Figure 4.4. However, some bearing yielding around the bolt holes will occur and can be tolerated. Based on test results, it is recommended that thickness and edge distance of tee stem be limited such that bearing failure will not be a governing limit state, yet, limited bearing yielding will occur. It is recommended that thickness of the tee stem be less than or equal to 1/2 of bolt diameter. The analysis indicated that this limit for bolt diameters of 3/4, 7/8 and 1 inch, will result in bearing yielding before brittle fracture of bolts occur. Also, it is recommended that vertical and horizontal edge distance of bolt holes on tee stem, be more than or equal to 2 times the diameter of bolt. The requirement is expected to prevent fracture of edge distance zone before the strength of connection is developed.

However, the following equations can be used to check limit state of bearing of tee stem.

A. In LRFD Format:

The following equations apply to standard or short slotted holes.

$$\phi R_{n4} \geq \Sigma \gamma_i Q_{ni} \qquad (4.7)$$

where,

$\phi = 0.75$

$R_{n4} = 3.0 \, d \, t \, F_u \, N$

d = Nominal diameter of bolt parallel to applied shear.

t = Thickness of connected part

N = Number of bolts

$\Sigma \gamma_i Q_{ni}$ = Governing factored reaction of the beam.

In the above equation defining value of R_{n4}, coefficient 3.0 is used. This is due to the fact that in tee framing connections that were tested elongation of bolt hole due to bearing yielding did not affect the strength but helped to increase ductility. Therefore, according to provisions of LRFD specifications (9) a value of 3.0 was adapted. For long slotted holes the reader is referred to AISC LRFD Specifications (9). In test specimens, delibrately minimum vertical edge distances were selected. The objective was to investigate current provisions regarding bearing capacity as related to edge distance. In all specimens, with the exception of 7,8 and 9 which had thick stem, the bottom edge distance showed sign of inelastic deformations and bending. Therefore, in calculating bearing capacity, the provisions of current AISC-LRFD specification(9), specifically Section J3 were followed.

4.2.5. Bearing Failure of Beam Web

In tee framing connections where bolts are used to transfer shear from beam to tee stem, it is possible that limit state of bearing failure of beam web is reached.

The design equations for this limit state are similar to case 4.2.4. above but web thicknesses should be used instead of tee stem thicknesses.

4.2.6. Shear Failure of Bolts

Specimens 7 and 9 failed in bolt shear failure mode. In both cases, bolts suddenly and in relatively brittle manner reached their limit state and fractured. Study of behavior of specimens indicated that due to significant yielding in connection, location of point of inflection of beams had moved very close to the face of column flange. A conservative location for point of inflection is suggested to be at the bolt line. This assumption will result in bolts being subjected to pure shear and weld lines being subjected to shear and a small moment due to eccentricity of shear from weld line.

The design equations for the limit state of bolt shear failure are:

A. In LRFD Format:

The following equations apply to bolts designed as bearing bolts and not as slip resistant bolts.

$$\phi R_{n6} \geq \Sigma \gamma_i Q_{ni} \qquad (4.8)$$

where,

ϕ = To be selected from Table J3.2 of AISC-LRFD Specification, (9)

$R_{n6} = A_b F_n N$

A_b = Nominal area of one bolt.

F_n = Nominal strength of bolt given in Table J3.2 of AISC-LRFD Specification (9).

N = Number of bolts

$\Sigma \gamma_i Q_{ni}$ = Governing factored reaction of the beam.

In ASD Format

$$f_{vb} \leq F_{vb} \tag{4.9}$$

where,

$f_b = R / (N A_b)$

F_{vb} = Allowable shear stress for bolts given in AISC ASD Specifications (8).

R= Governing service load reaction of the beam.

4.2.7. Weld Failure

Weld failure in tee framing connections is the most undesirable failure mode. Figure 4.4 shows this failure mode. In test specimen 4 when weld failure occurred, it was relatively brittle resulting in sudden fracture and loss of strength and stiffness of connection. In tee framing connections that were tested, when shear load increased, due to shear yielding of tee stem, connection stiffness was decreased resulting in decrease of connection moments. When ultimate strength of connections was reached, the point of inflection was between bolt line and weld line resulting in an eccentricity of less than 2.5 inches. It must be mentioned that in these experimental studies, bolts in all specimens other than one were snug tight. In fully tightened bolts, it is expected that point of inflection will be slightly further from weld line.

For tee connections with seven or less bolts an eccentricity equal to distance from centerline of bolts to weld line is recommended to be used. Using the eccentricity, one can calculate bending moment applied to the welds and welds be designed for the combined effects of bending moment and shear.

After shear and moment acting on the welds are established, it is recommended that inelastic design procedures based on the concept of "Instantaneous Center of Rotation " be used to design the welds. Tables developed based on this concept are available in AISC LRFD Manual (9) and AISC ASD Manual (8).

If column or beam, which is supporting the tee connections, is flexible then point of inflection of beam will move easily towards the welds and can be located very close to the weld line. In these cases, the welds will be subjected to almost pure shear. However, bolts will be subjected to direct shear and a small moment due to eccentricity of shear force from point of inflection of beam which is almost on the weld line. To consider this extra moment, one can design bolts for combined effects of direct shear and bending moment. Appropriate tables are provided in the AISC MAnuals (8,9) for this purpose. The tables have been developed based on the concept of "Instantaneous Center of Rotation".

4.3 Evaluating Proposed Design Methods

To verify validity of the proposed design methods, the strengths of connection specimens were calculated using the proposed procedures and were compared to test results. In these comparative studies, the nominal strength predicted by the proposed LRFD methods were considered. In all cases the predictions of the proposed LRFD methods were very close to test results and the deviations were on the conservative side.

The governing shear strength of each test specimen based on the proposed LRFD procedures was calculated and is listed in

Table 4.1. In calculating shear strengths, actual yield stress and ultimate strength of steel obtained from coupon tests were used.

Notice that application of load did not stop during testing when yielding occurred. But, loading continued until a fracture occurred. In such cases the fracture of net area always followed yielding after a very small increase of load.

From experimental studies, the following four failure modes were identified. The failure modes of beam web and supporting member (column or girder) are not included in the list.

1. Shear fracture of bolts
2. Fracture of welds
3. Shear failure of tee stem
4. Bearing failure of tee stem.

The following sections compare test results to the shear strength predicted by the proposed methods with regard to each limit state.

4.3.1. Shear Fracture of Bolts

The predicted shear strengths of specimens are given in Table 4.2 along with governing limit states. For test specimens 7 and 9 limit state of bolt shear failure was predicted by the proposed methods to be governing. In both tests, the bolts failed as predicted. In LRFD methods, the ratio of test results to predicted nominal strength were 1.10 and 1.03 for tests 7 and 9 respectively.

4.3.2. Fracture of Welds.

Weld fracture occurred in Specimens 3 and 8. In both cases the predicted nominal capacity, using the proposed procedures for welds, was less than the capacity at failure of welds in test specimens. The difference is mainly due to the fact that in the proposed method the combined effect of shear and moment in the connection is considered. Notice that in the proposed methods it was suggested that an eccentricity equal to distance between weld line and bolt line be considered in design of welds resulting in a moment acting on the weld in addition to shear. In actual testing, significant shear yielding took place in the stem before connection failed. Due to shear yielding, the connection looses a major part of its stiffness and very small elastic area of the section is left to provide rotational stiffness. This can result in reduction of rotational stiffness which in turn results in decrease of moment in the connection. Thus, the shear is transferred to the welds with very small moment.

Table 4.3 summarizes the weld capacities predicted using proposed LRFD methods along with experimental results. The weld capacities based on eccentrically loaded welds are given in columns 2 and capacities calculated based on direct shear are given in columns 3.

By studying the results, it is evident that the nominal capacity of welds predicted based on assuming only direct shear, is much closer to measured values than calculating the capacity of welds based on eccentric shear parallel to the axis of welds. Note that capacity of welds is based on size of weld which in turn is not always exact due to workmanship. Therefore, the variation in predictions in test number 3 which had a 3/16" weld may have been due to variation in mechanical properties of weld.

4.3.3. Shear Failure of Tee Stem

Tests 1, 2, 3, 5, and 6 failed due to stem failure. In all cases it was noticed that the predicted nominal capacity by proposed LRFD methods is less than the actual capacity at failure of stem. Studying test specimen after failure it was noticed that the actual line of fracture of the stem was not passing through the net area, but almost always was passing between b_{net} and b_{gross} (Refer to Figures 3.2 and 3.3b). An average value of b_{net} and b_{gross} was selected and used to calculate fracture capacity of net area of stem listed in Table 4.4.

Table 4.4 summarizes the nominal shear capacities predicted for tee stem using proposed LRFD procedures along with experimental results. Column one is the capacity of tee stem based on fracture of net area using:

$$R_n = 0.6F_u \; t_w \; L_t \qquad (4.10)$$

Column two is capacity based on refined method using following equation.

$$R_n = 0.6F_u \; t_w \; \frac{(b_{net} + b_{gross})}{2} \qquad (4.11)$$

Column three is test results at failure.

Studying the results indicated that the shear capacity of tee stem based on b_{net} is conservative by a factor of about 1.5. Also, it always is governing mode of failure, whereas in actual tests it was not. Conversely, the web capacity based on an average value of "b" gave closer results to actual capacity of specimens at failure.

4.3.4. Bearing Failure of Tee Stem

Significant bearing yielding was observed in Specimens 1,2,3,5,6 and 8. The yielding occurred in bolt hole walls resulting in bolt hole elongations. However, due to sufficiency of bolt spacings and edge distances, actual bearing failure did not occur.

4.4 Ductility of Tee-Connections

As mentioned earlier, during each test a ductility cycle preceded the strength cycle to measure rotational ductility of tee framing connection. Large rotations would be demanded from the connection when a structure is subjected to lateral loads in addition to already existing gravity load or when the connected beam approaches its collapse condition under gravity loads.

The moment-rotation and other test results obtained during ductility cycle are given in Appendix A for all test specimens. With reference to the plots of moment versus rotation of beam and moment versus rotation due to bending of tee flange, given in Appendix A, it is evident that the bending of the flange is contributing considerably to the total rotation of the connection. This contribution is a function of two factors. First, which is more important, is the width to thickness ($b_f/2t_f$) ratio of the flange and second is depth of connection. The importance of $b_f/2t_f$ ratio is due to the fact that the flange is bending in out of plane direction, thus the flexibility is a function of the $b_f/2t_f$ ratio. Therefore, the out of plane deflection of the upper part of tee-connection is a function of $b_f/2t_f$. Another factor is the length of the connection. The effect can be seen in the following equation:

$$\theta_{flange} = \frac{\text{Out of plane deflection}}{\text{Length of connection}} \qquad (4.12)$$

Since the out of plane deflection is independent of length, the total flange rotation is a function of length of connection. Table 4.5 shows comparison of the ratio of tee-flange rotation to ($b_f/2t_f$) ratio for a constant length of specimen. For a length of 8.5 inches, (3-bolt connections) the contribution of the tee-flange rotation is about 15% of the total connection rotation. Also, this contribution is independent of ($b_f/2t_f$) ratio. One exception to this is test number one in which the contribution of tee flange rotation was 36%. The reason for that may be that in the first test the bolts were not snug tight as all others but were tightened as required by AISC specifications (8,9). Bolts being tightened prevented slippage of bolts in their holes, thus demanding the flange to rotate more. For a length of 14.5 inches (5-bolt connections) the contribution of the tee-flange rotation increases with increasing ($b_f/2t_f$) ratio. For $b_f/2t_f$ = 7.22, the contribution of tee- flange rotation is about 40%, while for $b_f/2t_f$ = 6.55, the contribution of tee-flange rotation is about 33%. Test number 4 is an exception to this, and in this test the connection failed, unexpectedly, during the ductility cycle. In this test $b_f/2t_f$ ratio of flange was 6.3 which is close to $b_f/2t_f$ ratio of other tests that survived the large rotations imposed on them during ductility cycle. A likely reason for premature failure of specimen 4 could be the variation in strength of weld.

4.5 Analysis of Experimental Plots Relating Different Variables

Each experiment had two phases. The ductility phase and the ultimate shear strength phase. For each phase, seven plots were made. In the following, the results of ductility phase will be discussed first and then the discussion of the strength phase will follow.

4.5.1. Results of Ductility Phase

In the shear versus rotation plots, it is noticed that for a tee-connection with 3-bolts the shear required to rotate the connection to 0.07 radians of rotation is about half that required for the same tee-connection with 5-bolts. As number of bolts increase, the stiffness of the tee connection increases.

Considering shear force versus shear deflection under bolt line, it can be concluded that the beam and tee stem remain elastic during ductility tests and very minor yielding takes place due to bearing of bolts. The shear displacement that was recorded was equal to 1/32" in most tests. This displacement is equal to the clearance of the bolt hole.

The plots of moment versus rotation obtained during ductility cycle are given in Figure 4.5. It can be noticed that in these curves first the bolts slip thus allowing rotation with small increase in the moment, then elastic deformations take place followed by inelastic deformations, where increase in rotation causes very small increase in moment resistance.

Studying plots of moment at weld versus rotation of tee-flange provided indication of how the contribution of tee-flange rotation is affected by $b_f/2t_f$ ratio and number of bolts.

In the moment at bolt versus shear plot and moment at weld versus shear plots given in Appendix A, it can be seen that in ductility cycle there is a linear relationship due to determinacy of test set-up resulting in constant moment to shear ratio.

The plots of neutral axis position versus rotation shows that in the 3-bolt connection the neutral axis converges from infinity to the center line of the connection. While in the 5-bolt connections the neutral axis position converges to a position about 1 inch below the centroidal axis.

4.5.2. Results of Strength Phase

During strength tests, the shear versus rotation relationship suggested in Figure 2.8 was followed. It is noticed that in all specimens the ultimate capacity for shear, at 0.03 radian rotation or more, was greater than the values predicted for the connection under pure shear. This suggests that the procedure proposed to calculate the capacity of tee-connections is conservative and works well for the connection in actual loading condition where shear is coupled with rotation.

The plots of shear versus deflection under bolt line for all specimens are given in Figure 4.6. The plots indicate that the web of tee-connection undergoes significant shear plastic yielding.

In the plots of moment versus rotation of beam and moment versus rotation of tee-flange given in Appendix A, there are two items to note. The first is that the rotation in the tee-flange is larger than the total rotation of the beam. The vertical displacement of the bolts will reduce the total rotation of connection while it does not affect the tee-flange rotation. From the plots of moment versus tee-flange rotation one can see that the tee-flange has sufficient ductility. The second observation is sign of moments at bolt line and at weld line and their values. In a perfectly simple support the moment at support is zero. But in actual connection there is some resisting moment to rotation. This moment will be positive according to sign convention used in this report. As the loading increases inelasticity will develop and the end moments will be released to midspan. As a result of release of end moments point of inflection of the beam will move toward support. This movement of point of inflection can be observed in plots of moment at bolt line versus rotation of the beam given in Appendix A. In these plots, moment at the bolt line changes sign from positive to negative. The moment at the weld line also is affected by the movement of the point of inflection and decreases in value and sometimes approaches zero.

In the plots of neutral axis position versus rotation, it is observed that for 3-bolt connections the neutral axis converges faster from infinity to a position about 1.5 inches below center line of specimen, while in 5- bolt connections, neutral axis converges to a position about 3 inches below the center line of specimen as shown in Figure 4.7.

CHAPTER FIVE

CONCLUSIONS

5.1 General

The main objective of this research was to investigate the behavior of tee-framing connections and to develop design procedures. The specific findings and results have been presented in previous chapters. In this Chapter, general conclusions are provided. The conclusions are based on tests of nine tee framing connections as discussed earlier. The tees that were studied were welded to the column flange and bolted to beam web.

5.2 Conclusions

Based on test results and their analysis, the following conclusions can be made:

1. The realistic testing of tee connections indicated that considerable shear yielding occurred in the stem and flange of the tee prior to failure. The yielding caused reduction of rotational stiffness which in turn caused release of end moments to midspan of the beam. To ensure the desirable yielding, it is recommended that the steel used in tee be low yield steel such as A36 with a pronounced yield plateau. The existence of

yield plateau is important since it causes free and considerable shear yielding of the tee stem.

2. Tee connections that were studied showed some stiffness at early stages of loading but as stems yielded, the connections lost their rotational stiffness and the connections were flexible enough to be considered type II (simple) connections in common applications.

3. The limit states that were observed during the testing were: (1) bolt shear fracture, (2) tee stem yielding, (3) tee stem fracture; and (4) weld fracture. A limit states that was not observed during the tests, but can occur if the flange of the tee is too thin, is limit state of yielding of flange of tee. It appears that this limit state will be a ductile limit state and the yielding of flange will assist in reducing rotational stiffness of the connection. To avoid this limit state, the thickness of tee flange should be more than 1/2 of the thickness of tee stem. The condition is usually satisfied if tees are cut from wide flange shapes.

4. A design procedure for tee framing connections was developed and recommended in Chapter 4. The procedure is based on ensuring that shear yielding of the tee stem is the governing limit state and the capacity of connection for other limit states is greater than shear yield capacity. Following the recommended design procedure, it is expected that shear yielding occurs and rotational stiffness of connection is released thus

ensuring that connection acts as a simple connection under large forces.

5. In the proposed procedure, in order to ensure bearing yielding that will provide additional ductility, it is recommended that the thickness of the tee stem be less than or equal to 1/2 of the bolt diameter.

6. To avoid bearing fracture, the horizontal and vertical edge distance of bolt holes are recommended to be at least 2.0 times diameter of bolt. Edge distance here is defined as actual distance from the <u>edge of the bolt hole to the edge of stem.</u>

7. For each limit state, design procedures in ASD and LRFD formats are proposed. Test results indicated that proposed methods accurately predict the strength of connections that were tested.

8. Tee-connections that were tested were very ductile and could accommodate 0.07 radian rotation with minor inelastic behavior.

9. The out of plane bending of the tee-flange was one of the major factors that contribute to high ductility of the tee-connection. The out of plane bending increases with increasing $b_f/2t_f$ ratio of tee flange. It is recommended that $b_f/2t_f$ ratio of tee flange be greater than or equal to 6.5 and the material of tee be A36.

10. Neutral axis in the connection is not at mid-height of the connection. The neutral axis was located at 1.5 and 3.0 inches below centerline for 3-bolt and 5-bolt connections respectively.

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Table 1.1.-Limits of Geometric Parameters*

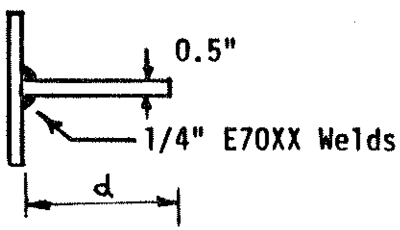
Parameters	Low	High
b_f	3-15/16"	8-1/8"
t_f	5/18"	9/10"
t_w	9/32"	1/2"
d_b	7/8"	7/8"
# of bolts	3	5
type of bolt	A 325	A 490
weld size	3/16"	1/4"
weld length	8.5"	14.5"
weld type	AWS E70XX	AWS E70XX
c-c spacing of bolts	3"	3"
edge distance	1.25"	1.25"

* Steel is A-36.

Table 2.1.-Properties of Test Specimens

	Section	b_f (in)	t_f (in)	b_f/t_f	d (in)	t_w (in)	t_f/t_w
	WT 7x19	(6.77) 6 9/16	(0.515) 1/2	(6.57) 6.56	6-14/16	(0.310) 3/8	(1.66) 1.33
	WT 4x7.5	(4.01) 3 15/16	(0.315) 5/16	(6.37) 6.3	4-1/16	(0.245) 9/32	(1.28) 1.11
	WT 4x20	(8.07) 8 1/8	(0.56) 9/16	(7.21) 7.22	4-1/8	(0.36) 3/8	(1.56) 1.5
*	Flange WT7x19 +0.5" web	(6.77) 6 9/16	(0.515) 1/2	(6.57) 6.56	6-14/16	0.5"	1
*	Flange WT4x20 +0.5" web	(8.07) 8 1/8"	(0.56) 9/16	(7.21) 7.22	4-1/8	0.5"	1.125

*



Note: values inside ( ) are from AISC Manual

Table 3.1.- Maximum Shear Forces and Rotations

Test #	DUCTILITY CYCLE AT MAXIMUM ROTATION				END OF DUCTILITY CYCLE (BACK TO NO ROTATION)				SHEAR STRENGTH CYCLE (AT FAILURE)			
	Rotation (RAD)	Moment at weld (k-in)	Moment at bolt line (k-in)	Shear (k)	Rotation (RAD)	Moment at weld (k-in)	Moment at bolt line (k-in)	Shear (k)	Rotation (RAD)	Moment at weld (k-in)	Moment at bolt line (k-in)	Shear (k)
1	0.069	223.3	214.7	3.4	0	41.7	40.3	0.55	0.034	48.5	-143.0	76.6
2	0.069	532.6	512.4	8.1	0	nr*	nr*	nr*	0.032	154.5	-280.5	174.0
3	0.069	217.6	209.6	3.2	0	- 4.2	- 4.1	-0.35	0.067	7.8	-14.4	106.8
4	0.060	412.6	401.3	5.9	0	--	--	--	--	--	--	--
5	0.070	47.9	46.2	8.2	0	- 10.4	- 9.9	-1.96	0.031	19.6	-18.5	183.1
6	0.068	226.7	216.5	4.1	0	- .04	- 1.6	-0.45	0.034	149.2	-127.8	110.8
7	0.070	682.8	642.7	9.6	0	- 17.1	- 16.7	-1.77	0.038	13.2	-36.5	238.2
8	0.070	228.0	219.5	3.4	0	- 61.9	- 56.8	-2.05	0.039	-39.8	-393.2	141.3
9	0.070	748.0	724.0	9.6	0	-181.7	-170.4	-4.52	0.033	251.8	-270.6	208.9

nr* not recorded

Table 4.1.- Comparison of Predicted Shear Strength and Test Results

Test #	WT Used	# of Bolts	Type of Bolts	Bolt Diam.	Weld Size	Weld Length	SHEAR CAPACITY*‡ KIPS						
							Shear Yield-ing*	Shear Frac-ture*	Bearing Failure	Bolt Shear	Weld Fail-ure	Test Results	Failure Mode
1	WT4x7.5	3	A-325	7/8"	3/16"	8.5"	77.8	64.1	122.1	130	64.5	77	Stem Fracture
2	WT7x19	5	A-325	7/8"	1/4"	14.5"	146.0	140.4	280.3	216	183.4	174	Stem Fracture
3	WT7x19	3	A-325	7/8"	1/4"	8.5"	85.6	81.4	155.0	130	85.9	107	Weld Fracture
4	WT4x7.5	5	A-325	7/8"	3/16"	14.5"	132.7	110.6	220.7	216	137.6	0.06 Radian **	Ductility Failure
5	WT4x20	5	A-325	7/8"	1/4"	14.5"	146.0	140.4	280.3	216	183.4	183	Stem Fracture
6	WT4x20	3	A-325	7/8"	1/4"	8.5"	85.6	81.4	155.0	130	85.9	110	Stem Fracture
7	WT7x19 +0.5" web	5	A-325	7/8"	1/4"	14.5"	194.7	187.3	373.7	216	183.4	238	Bolt Shear Fracture
8	WT4x20 +0.5" web	3	A-490	7/8"	1/4"	8.5"	114.2	108.5	206.7	162	85.9	141	Weld Fracture
9	WT4x20 +0.5" web	5	A-490	7/8"	1/4"	14.5"	194.7	187.3	373.7	*** 203	183.4	209	Bolt Shear Fracture

*Actual Fy and Fu are used.
**connection failed in ductility cycle.
***capacity of bolts in this specimen was calculated with threads included.
__ underlined values are predicted failure capacity
‡Nominal capacities (with Ø = 1.0)

Table 4.2.- Prediction of Shear Failure of Bolts

Test #	Bolt shear capacity	Test Result	Test Result / Bolt Capacity	Actual Mode of Failure
1	130^k	76.6^k	0.59	Stem Failure
2	216^k	174.0^k	0.81	Stem Failure
3	130^k	106.8^k	0.82	Weld Failure
4	216^k	--	--	Ductility Failure
5	216^k	183.1^k	0.85	Stem Failure
6	130^k	110.0^k	0.85	Stem Failure
7	216^k	238.2^k	1.10*	Bolt Failure & Partial Failure of Stem
8	162^k	141.3^k	0.87	Weld Failure
9	203^k	209.0^k	1.03*	Bolt Failure

* Expected to fail in bolt shear

Table 4.3.- Prediction of Shear Failure of Welds

Test #	Weld capacity with e=2.5"	Weld capacity (direct shear)	Test results	Test result / weld capacity with e=2.5"	Test result / weld capacity based on direct shear	Actual mode of failure
1	64.5^k	94.6^k	76.6^k	1.18*	0.81	stem failure
2	183.4^k	215.3^k	174.0^k	0.95	0.81	stem failure
3	85.9^k	126.2^k	106.8^k	1.25*	0.84	weld crack & stem failure
4	137.6^k	161.4^k	--	--	--	ductility failure
5	183.4^k	215.3^k	183.1^k	1.00*	0.85	stem failure
6	85.9^k	126.2^k	110.8^k	1.29*	0.88	stem failure
7	183.4^k	215.3^k	238.2^k	1.30*	1.11*	bolt failure & partial fail. of stem
8	85.9^k	126.2^k	141.3^k	1.65*	1.11*	weld failure
9	183.4^k	215.3^k	209.0^k	1.14*	0.97	bolt failure

* Expected to fail in weld fracture. Only specimens 3 and 8 welds failed.

Table 4.4.- Prediction of Tee Stem Failure

Test #	Stem Capacity with b_{net}	Stem Capacity based on $b_{average}$	Test Results	Test result / Stem capacity based on b_{net}	Test result / Stem capacity based on $b_{average}$	Actual mode of failure
1	64.1^k	79.9^k	76.8^k	1.20*	0.96*	stem failure
2	140.4^k	173.9^k	174.0^k	1.24*	1.00*	stem failure
3	81.4^k	101.5^k	106.8^k	1.31*	1.05*	stem fracture & web. fail.
4	110.6	137.0	--	--	--	ductility failure
5	140.4^k	173.9^k	183.1^k	1.30*	1.05*	stem failure
6	81.4^k	101.5^k	110.8^k	1.36*	1.09*	stem failure
7	187.3^k	232.0^k	238.2^k	1.27*	1.03*	bolt shear
8	108.5^k	135.3^k	141.3^k	1.30F*	1.04*	weld fracture
9	187.3^k	232.0^k	209.0^k	1.12*	0.90	bolt shear

*Expected to fail in web failure

TABLE 4.5 — CONTRIBUTION OF TEE-FLANGE ROTATION

TO DUCTILITY OF TEE-CONNECTION

Test #	Length of Specimen	bf/2tf	Rotation of Tee-Flange	Rotation of Tee-Connection	Ratio $\frac{\theta\ Flange}{\theta\ Connection}$
1	8.5	6.30	0.025	0.069	0.36
2	14.5	6.56	0.019	0.069	0.28
3	8.5	6.56	0.012	0.069	0.17
4*	14.5	6.30	0.036	0.060	0.60
5	14.5	7.22	0.026	0.070	0.37
6	8.5	7.22	0.011	0.068	0.16
7	14.5	6.56	0.025	0.070	0.36
8	8.5	7.22	0.010	0.070	0.14
9	14.5"	7.22	0.028	0.070	0.40

* Failed in ductility cycle at 0.06 rad of rotation

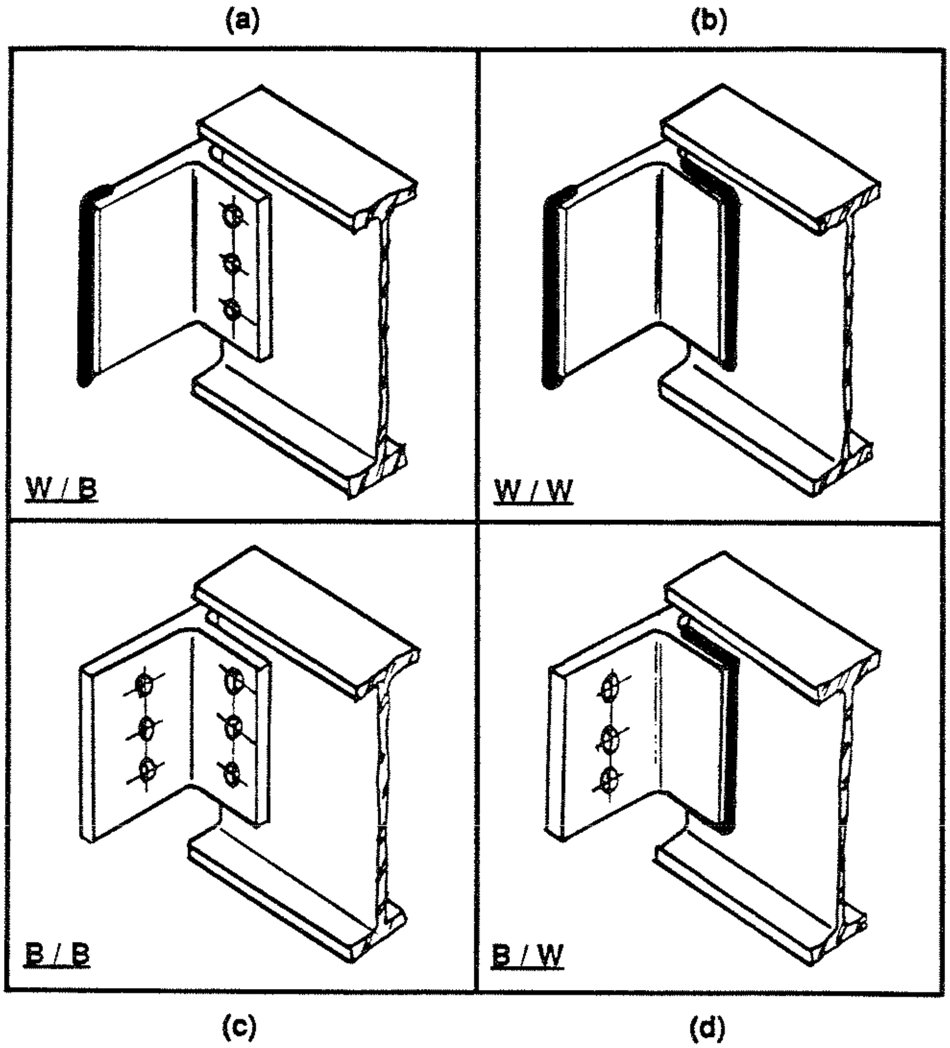


Figure 1.1. Common Types of Tee Framing Connections

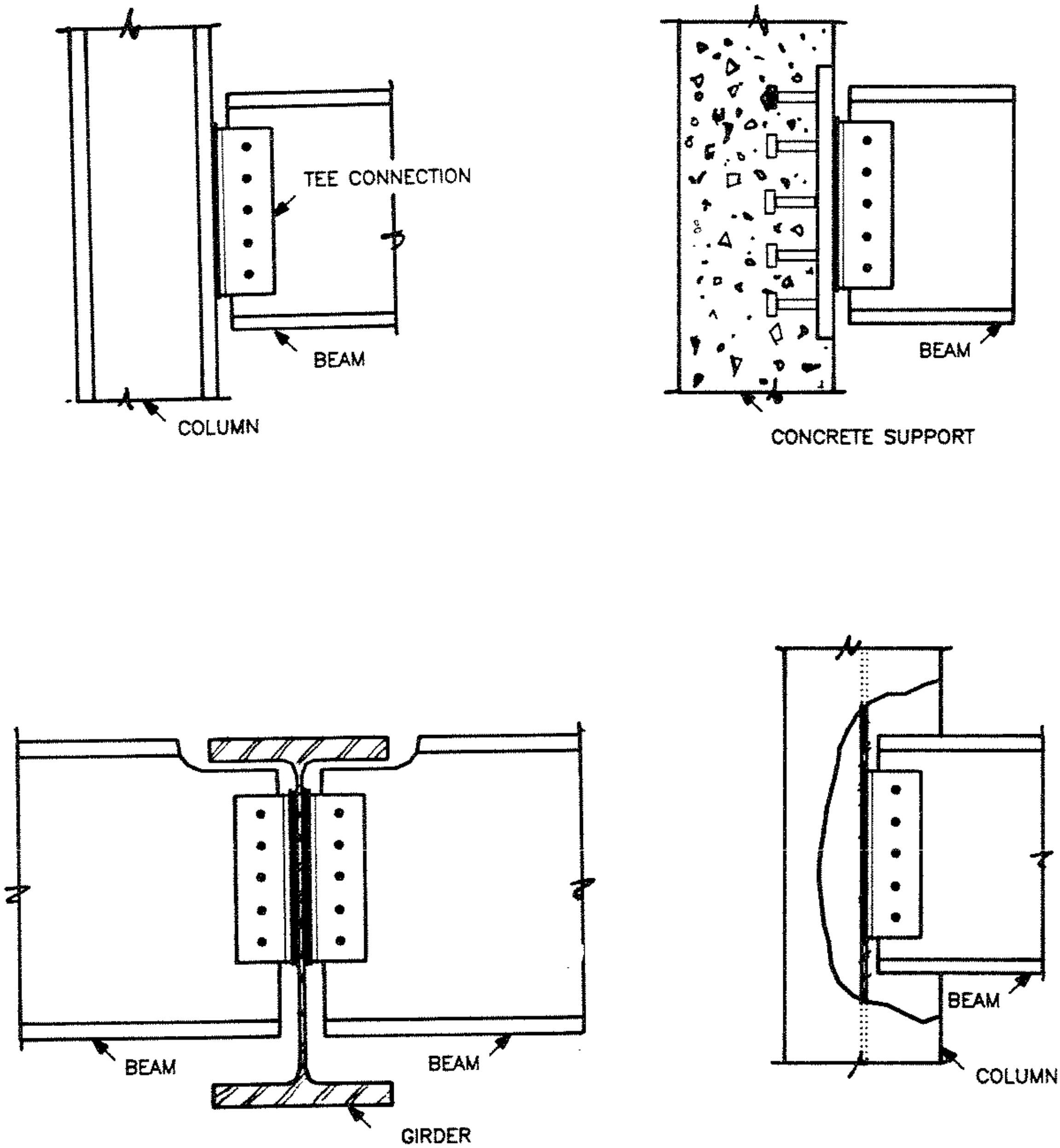


Figure 1.2. Applications of Tee-Framing Connections

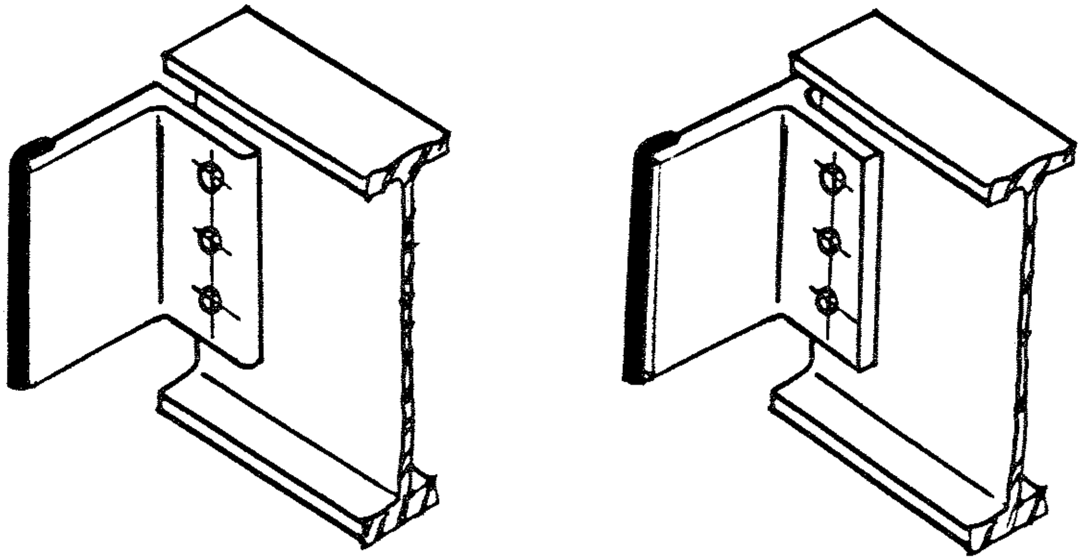


Figure 1.3. Double Angle and Tee-Framing Connection

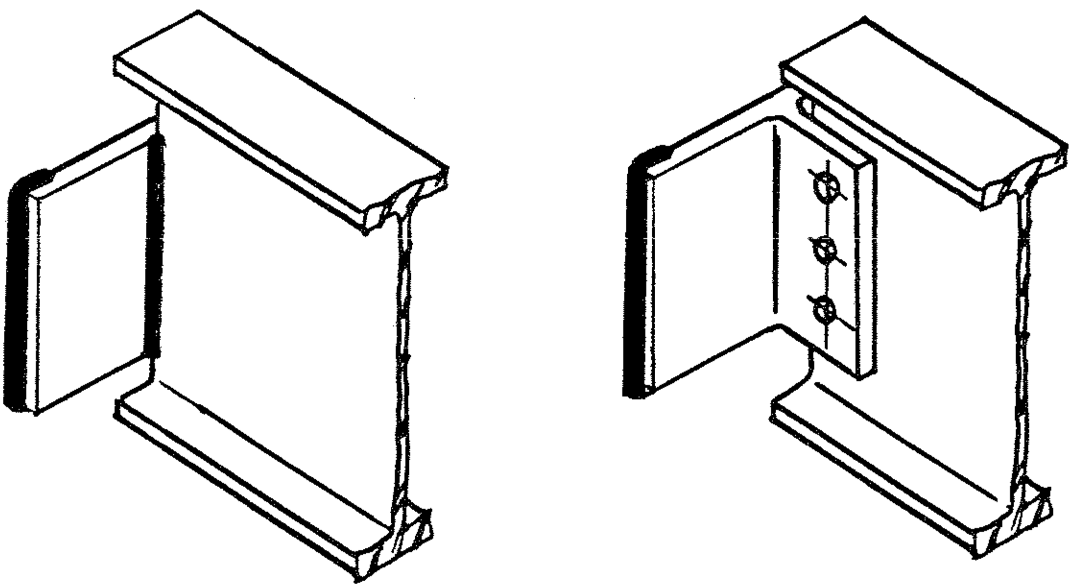


Figure 1.4. Shear End Plate and Tee Framing Connection

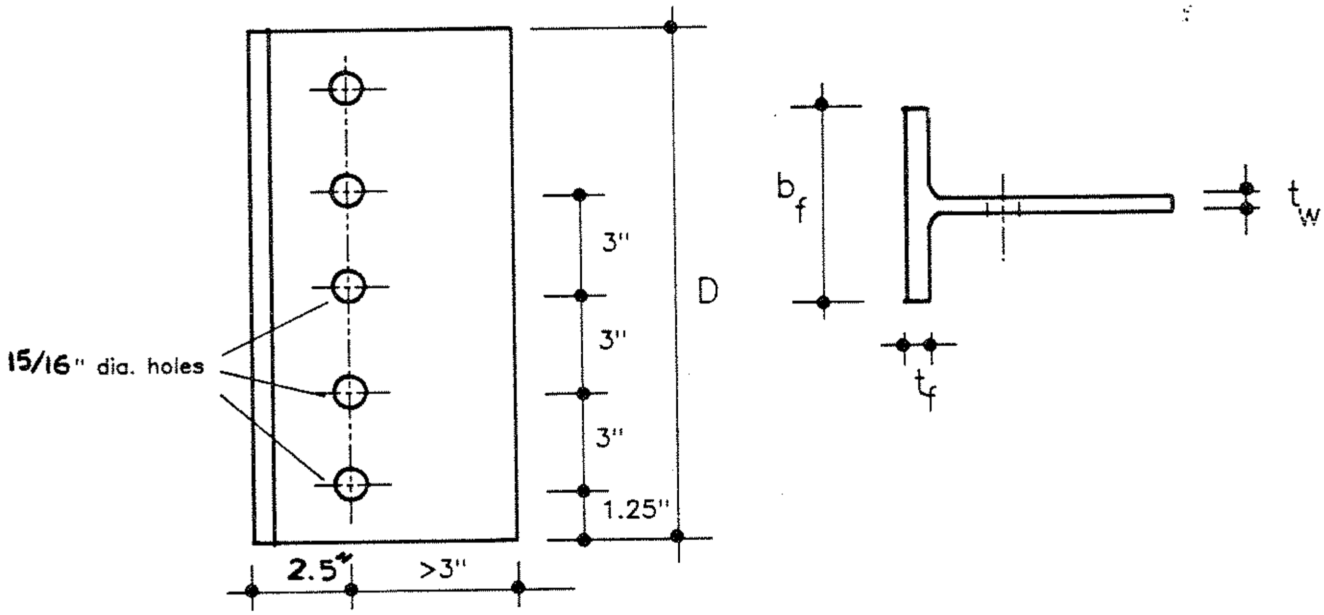


Figure 1.5. Geometric Parameters Varied in the Investigation

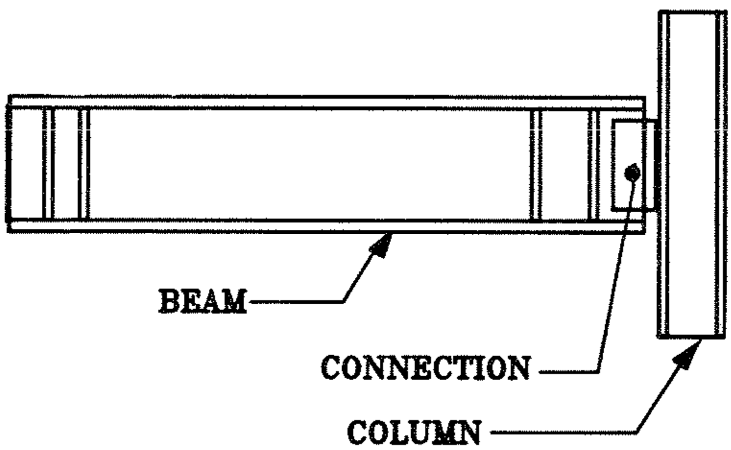


Figure 2.1. Typical Test Specimen

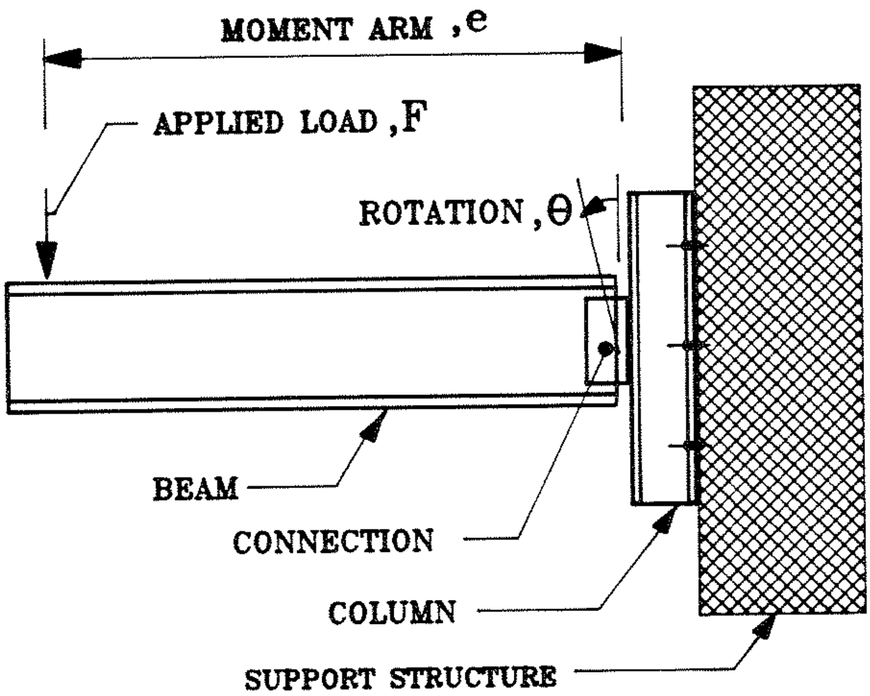


Figure 2.2. Cantilever Test Set-up Used in the Past

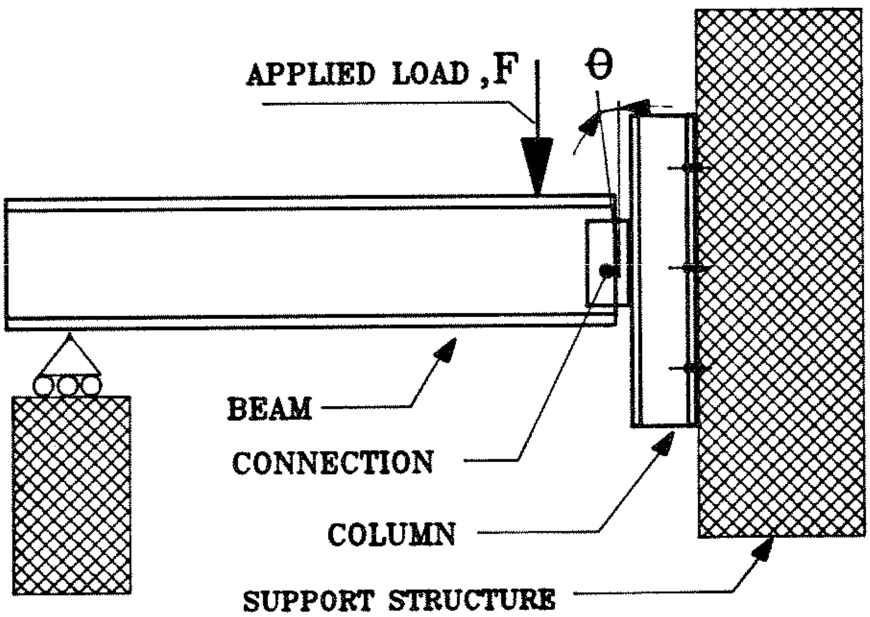


Figure 2.3. Test Set-up to Measure Direct Shear

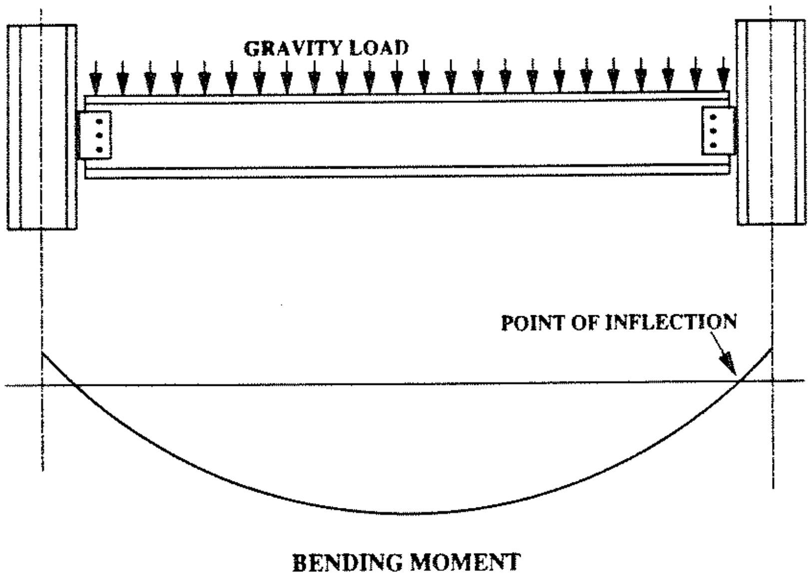


Figure 2.4. Realistic Loading of Beams

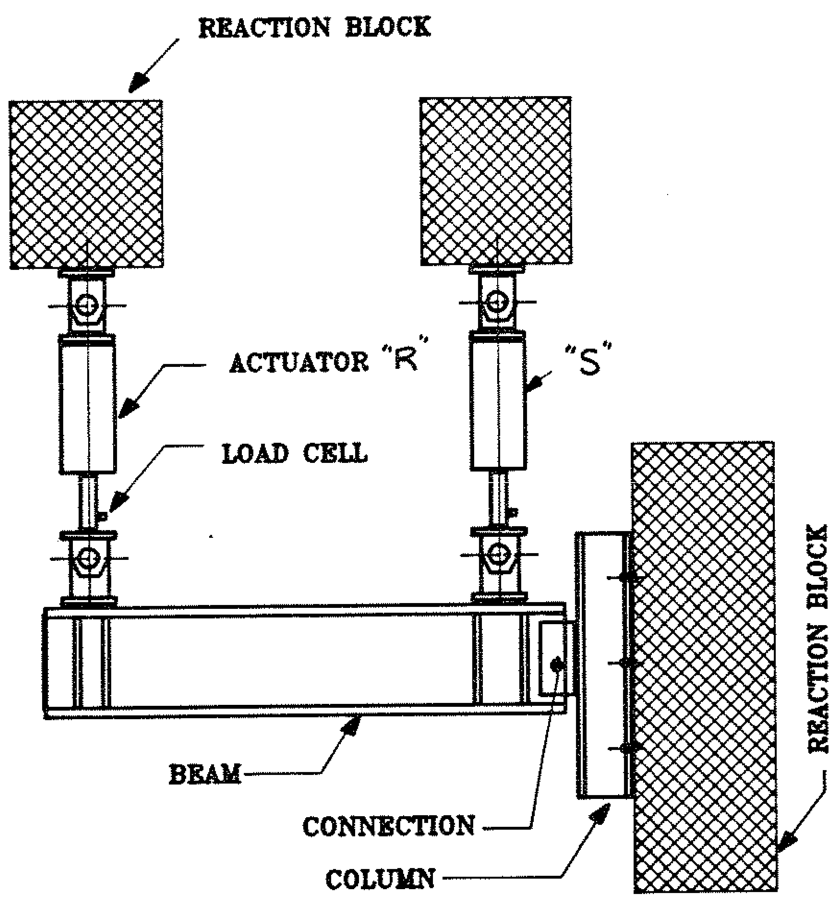


Figure 2.5 Test Set-up Used in the Investigation

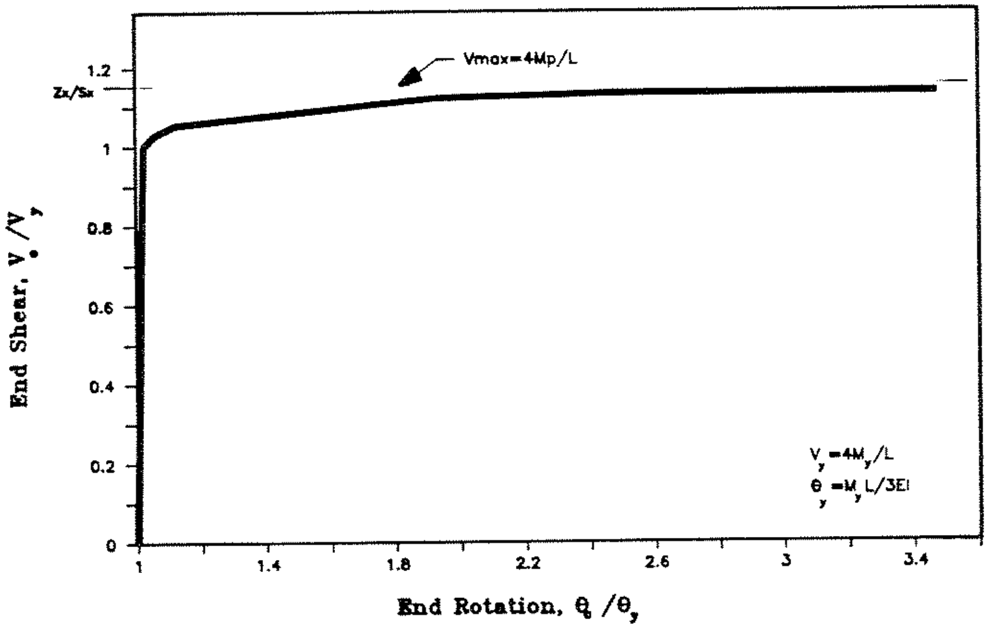


Figure 2.6. End Shear vs. End Rotation in a Simply Supported Beams

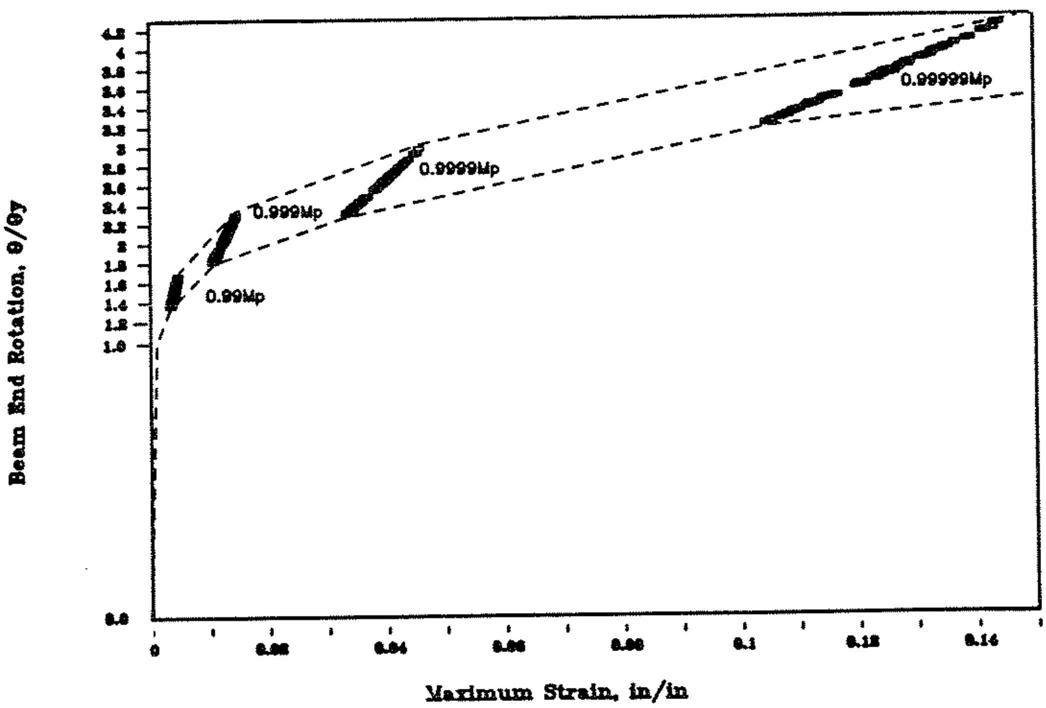


Figure 2.7. End Rotation vs. Midspan Strain in a Simply Supported Beam

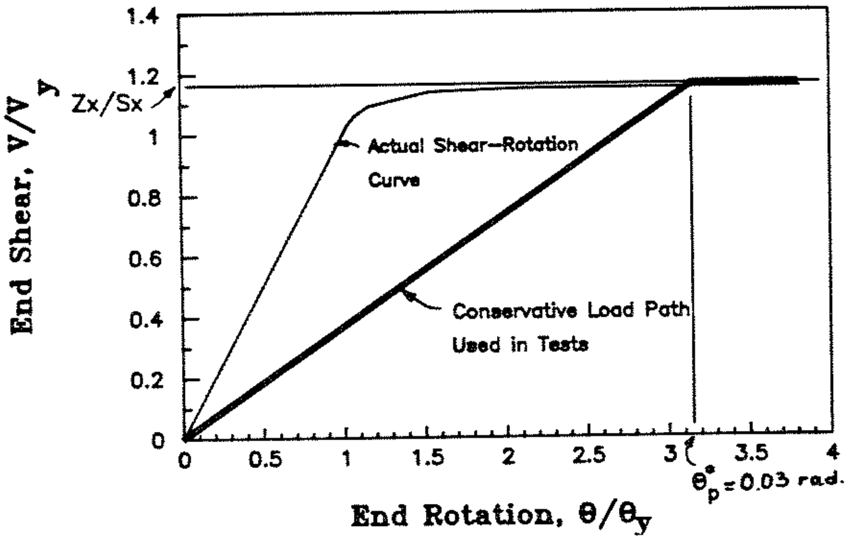


Figure 2.8. Shear-Rotation Relationship applied to Specimens

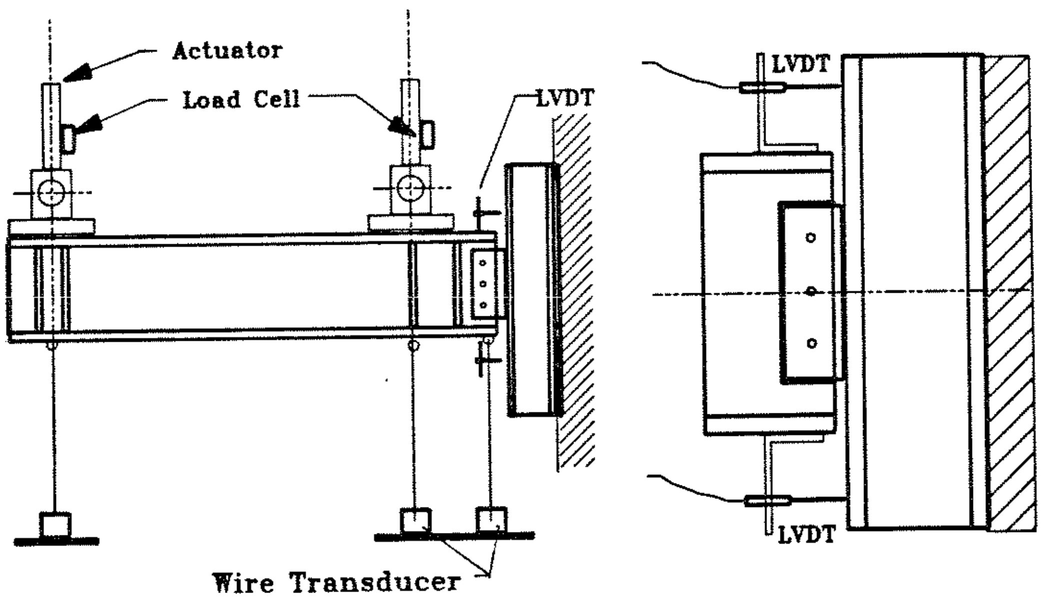


Figure 2.9. Instrumentation

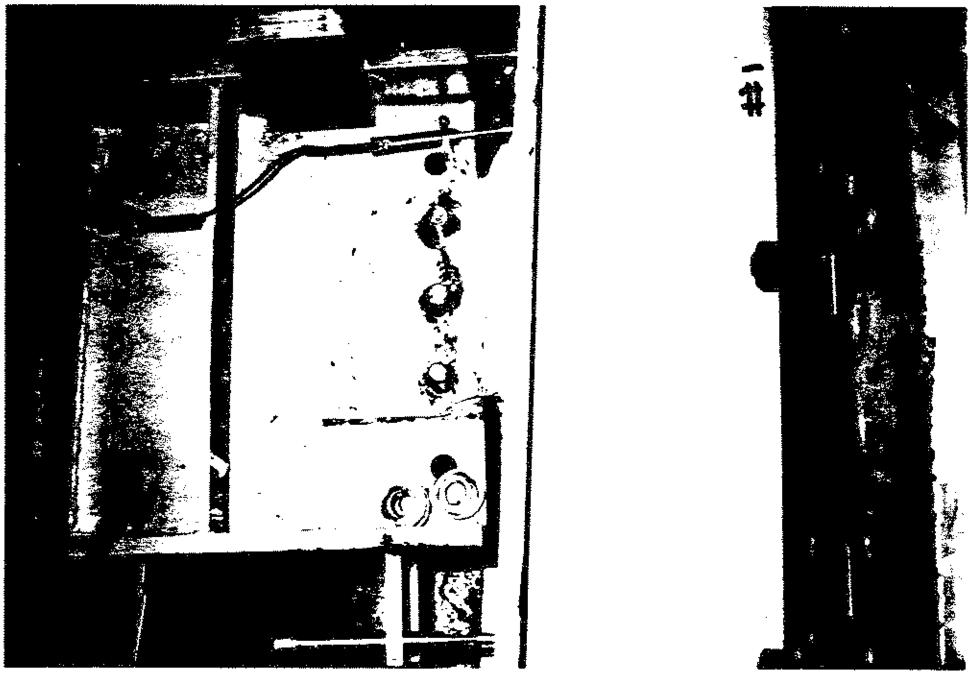


Figure 3.1. Failure of Specimen One

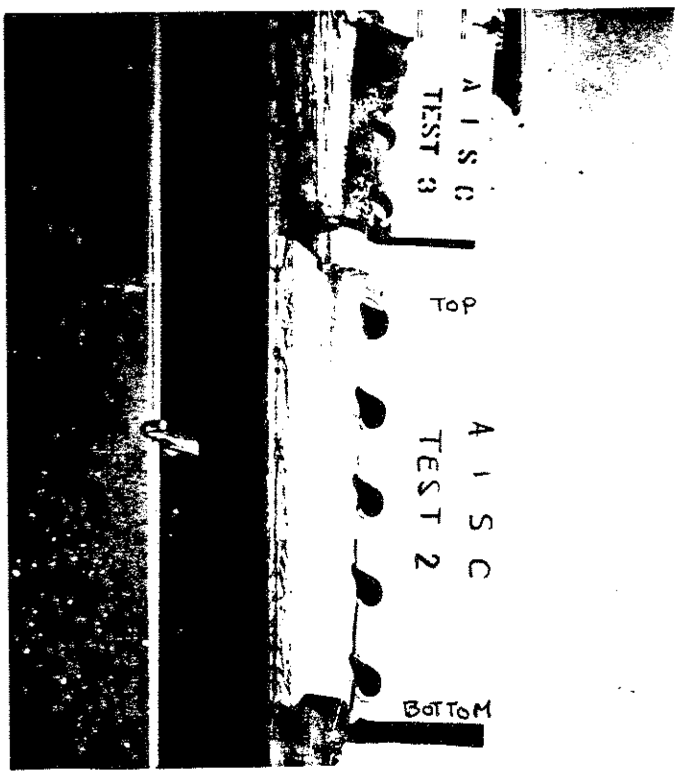
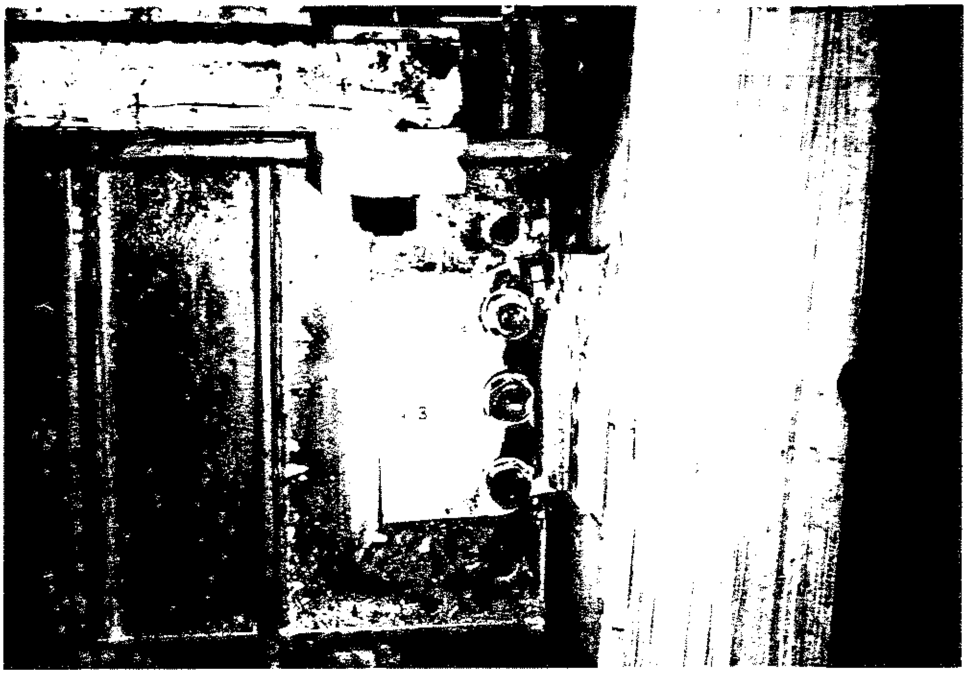
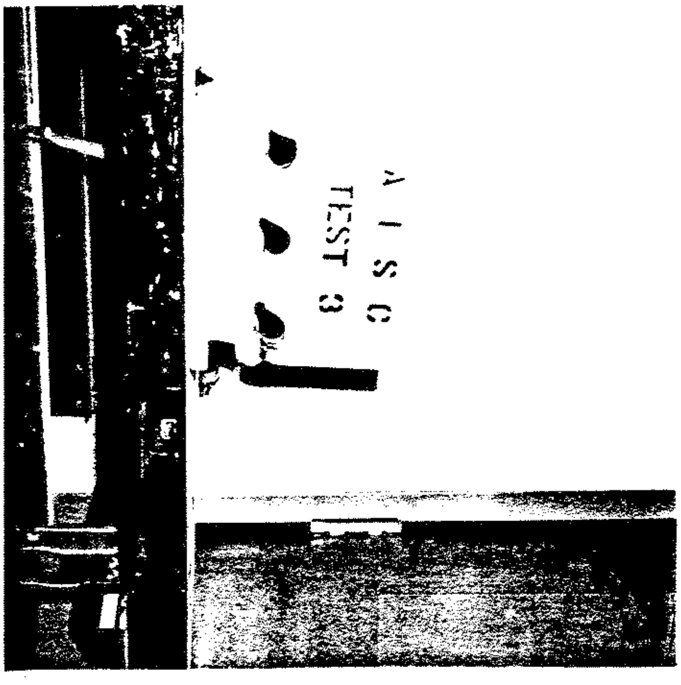


Figure 3.2. Failure of Specimen Two and Three



(a)



(b)

Figure 3.3. (a) Specimen Three Before Fracture;

(b) Specimen Three After Net Area Fracture

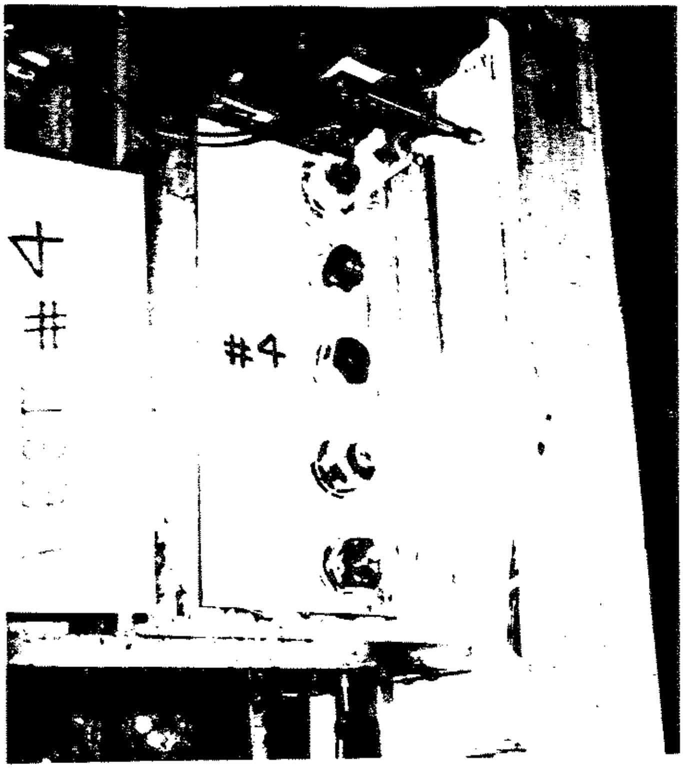


Figure 3.4. Fracture of Weld in Specimen Four

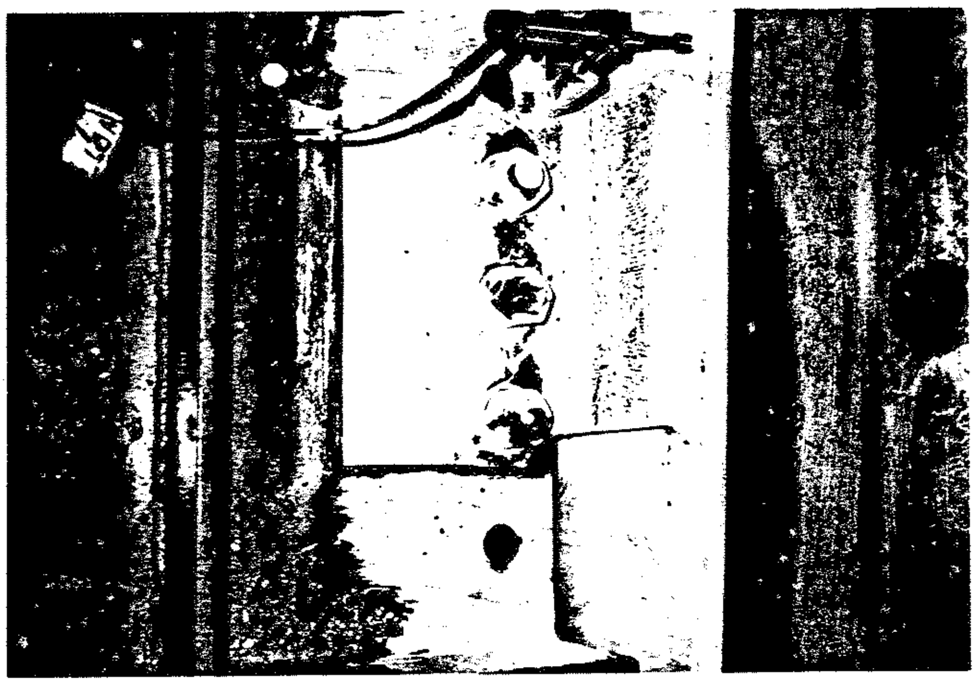


Figure 3.5. Shear Yielding of Stem in Specimen Six

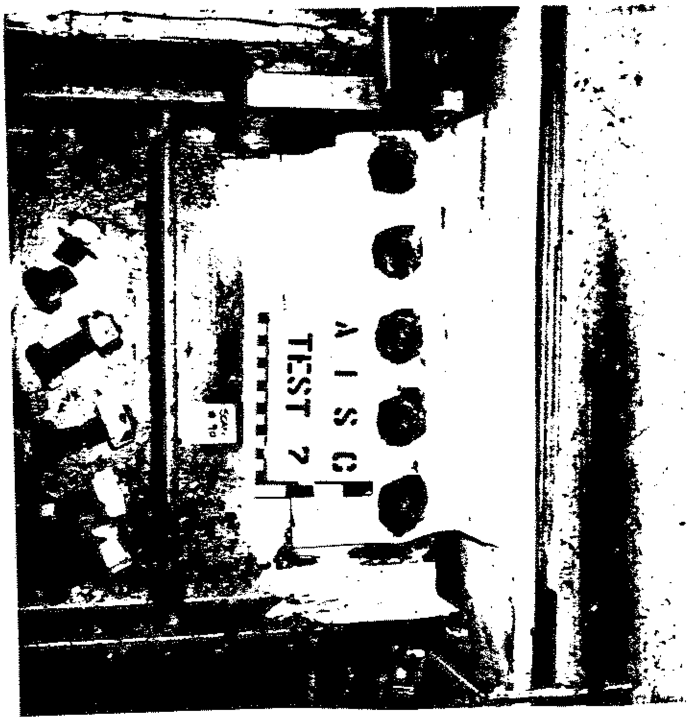


Figure 3.6. Bolt Fracture in Specimen Seven

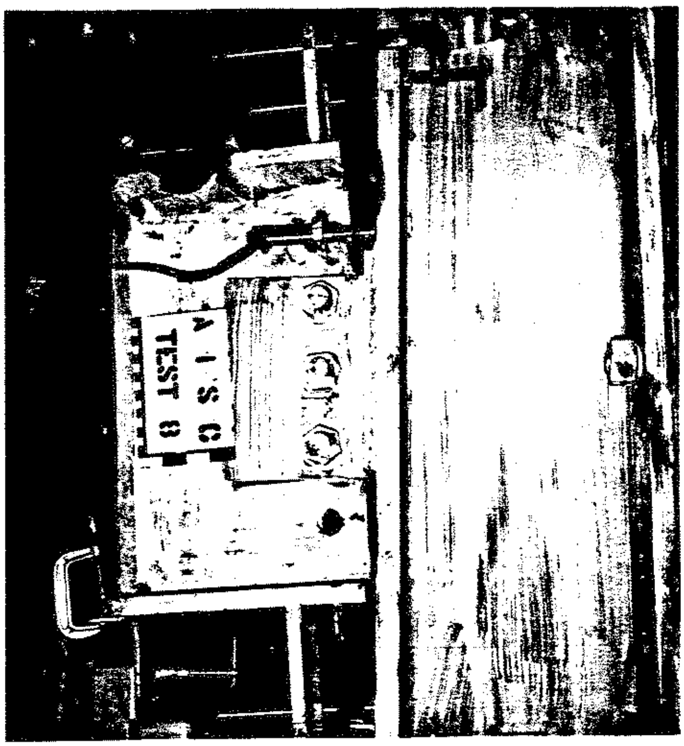


Figure 3.7. Specimen Eight During Ductility Cycle

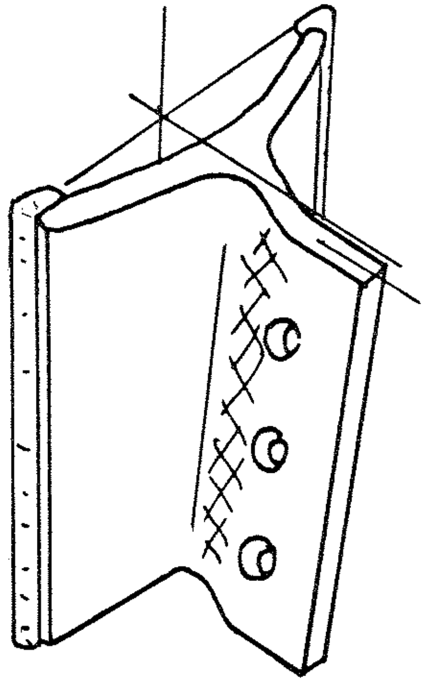


Figure 4.1. Limit State of Shear Yielding of Gross Area of Tee Stem

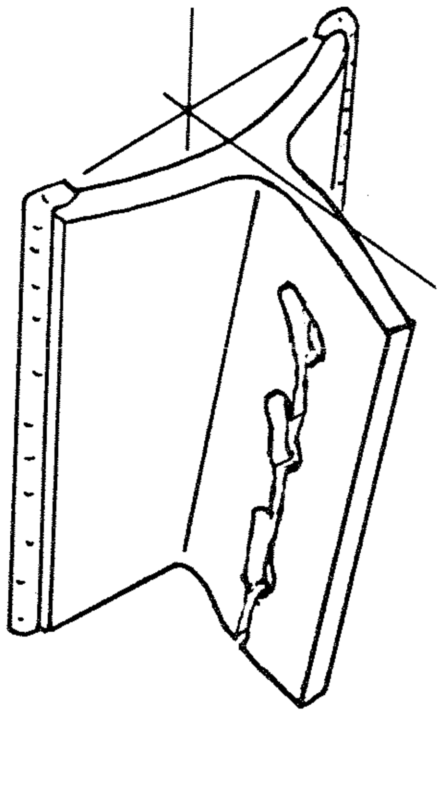


Figure 4.2. Limit State of Fracture of Net Area of Tee Stem

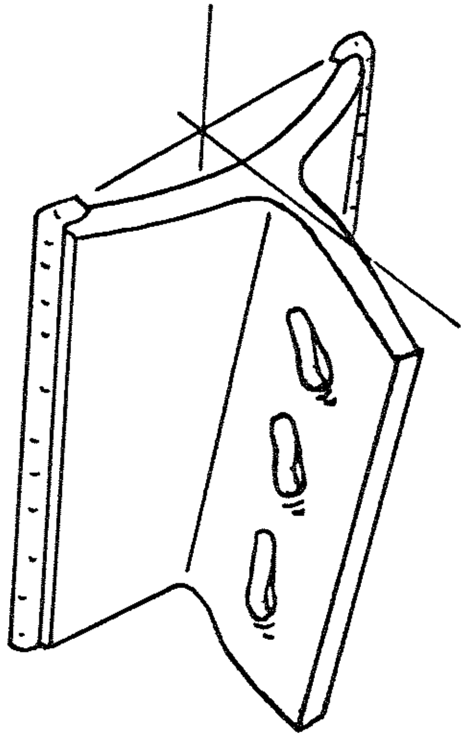


Figure 4.3. Limit State of Bearing of Tee Stem

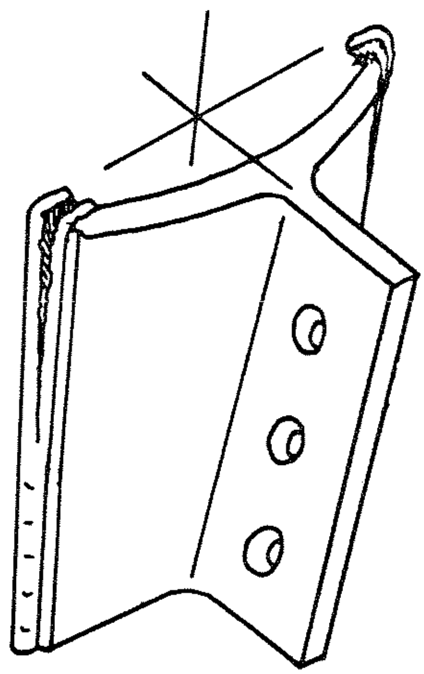


Figure 4.4. Limit State of Weld Fracture

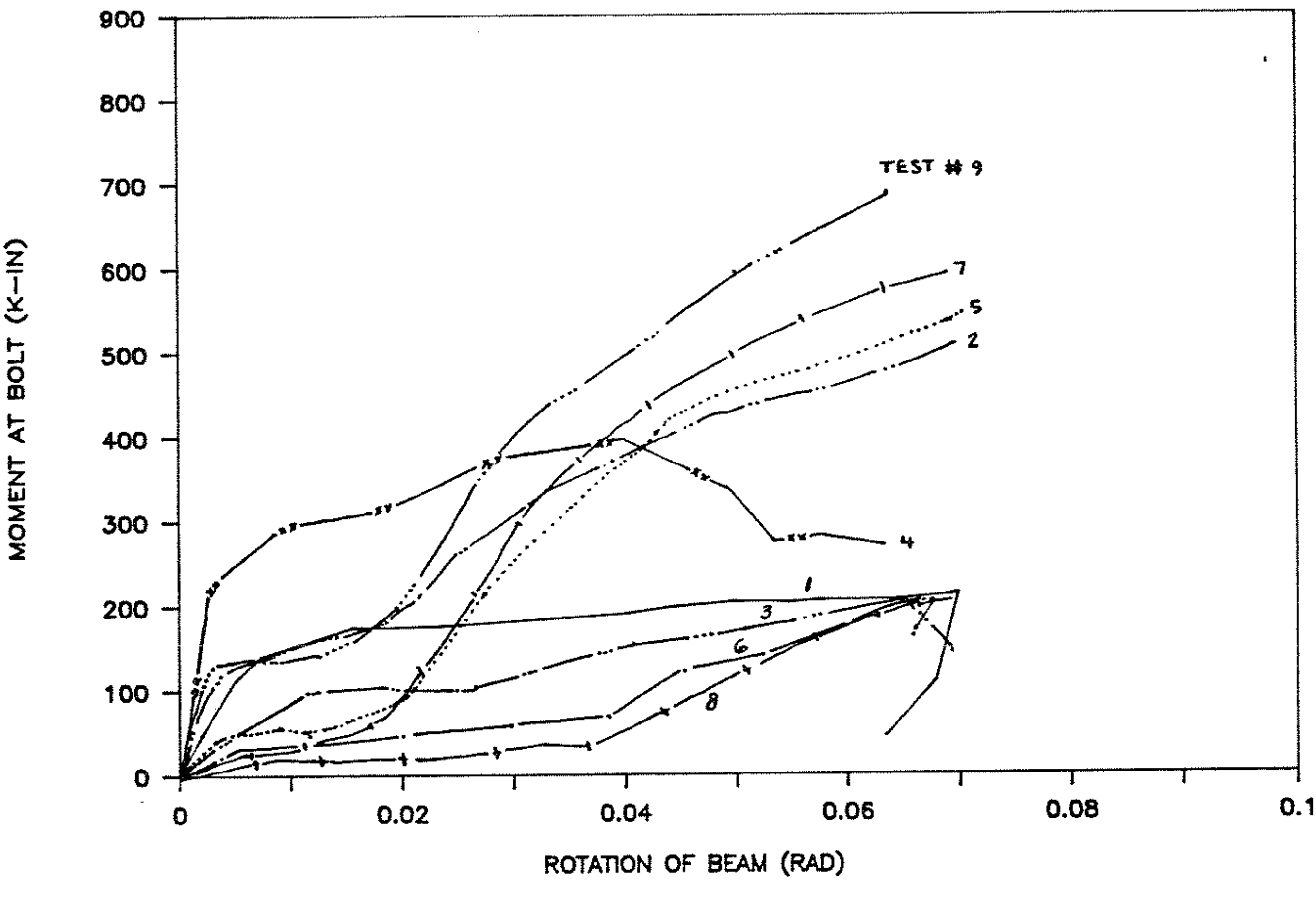


Figure 4.5. Moment versus Rotation of Connection

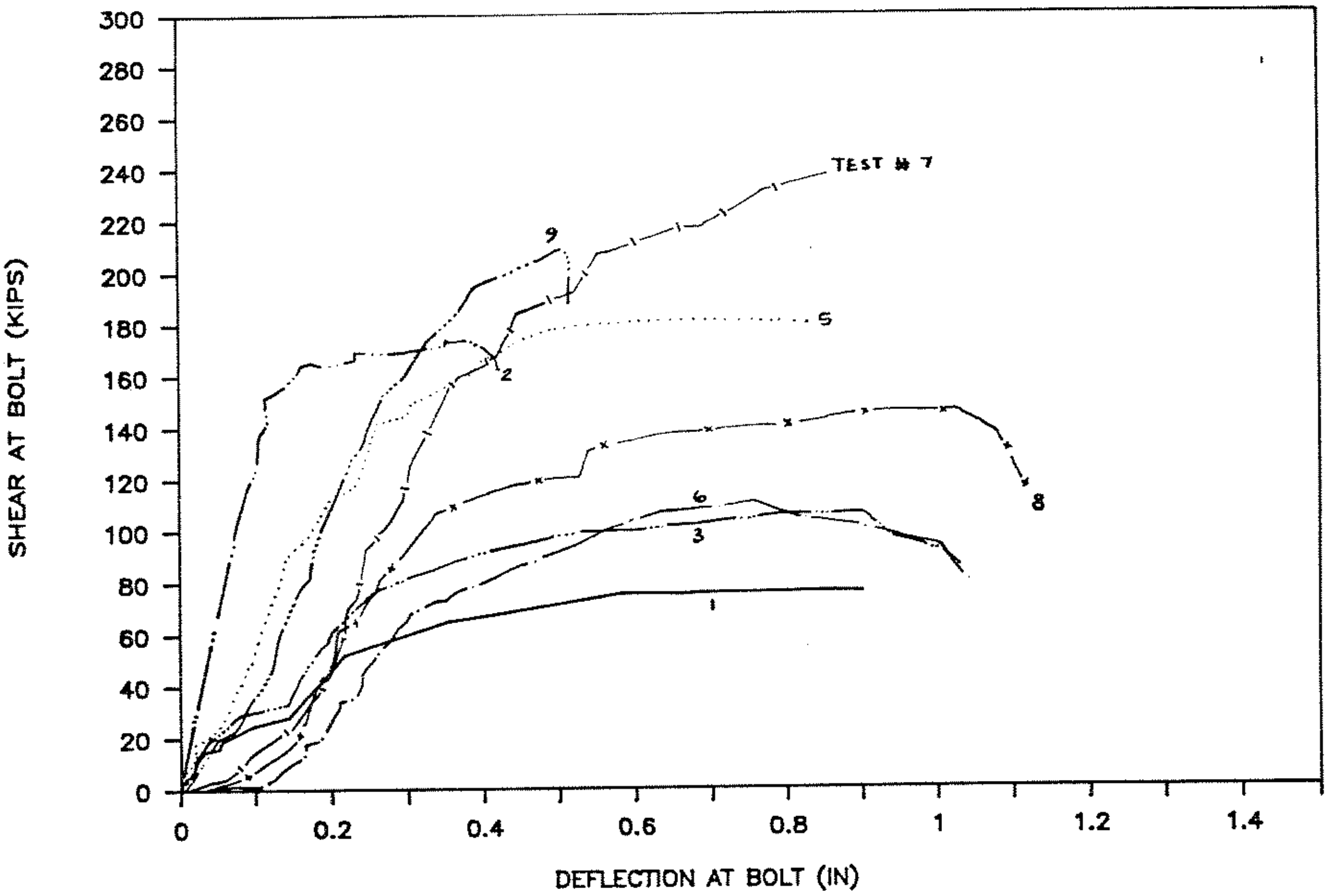


Figure 4.6. Shear versus Vertical Displacement

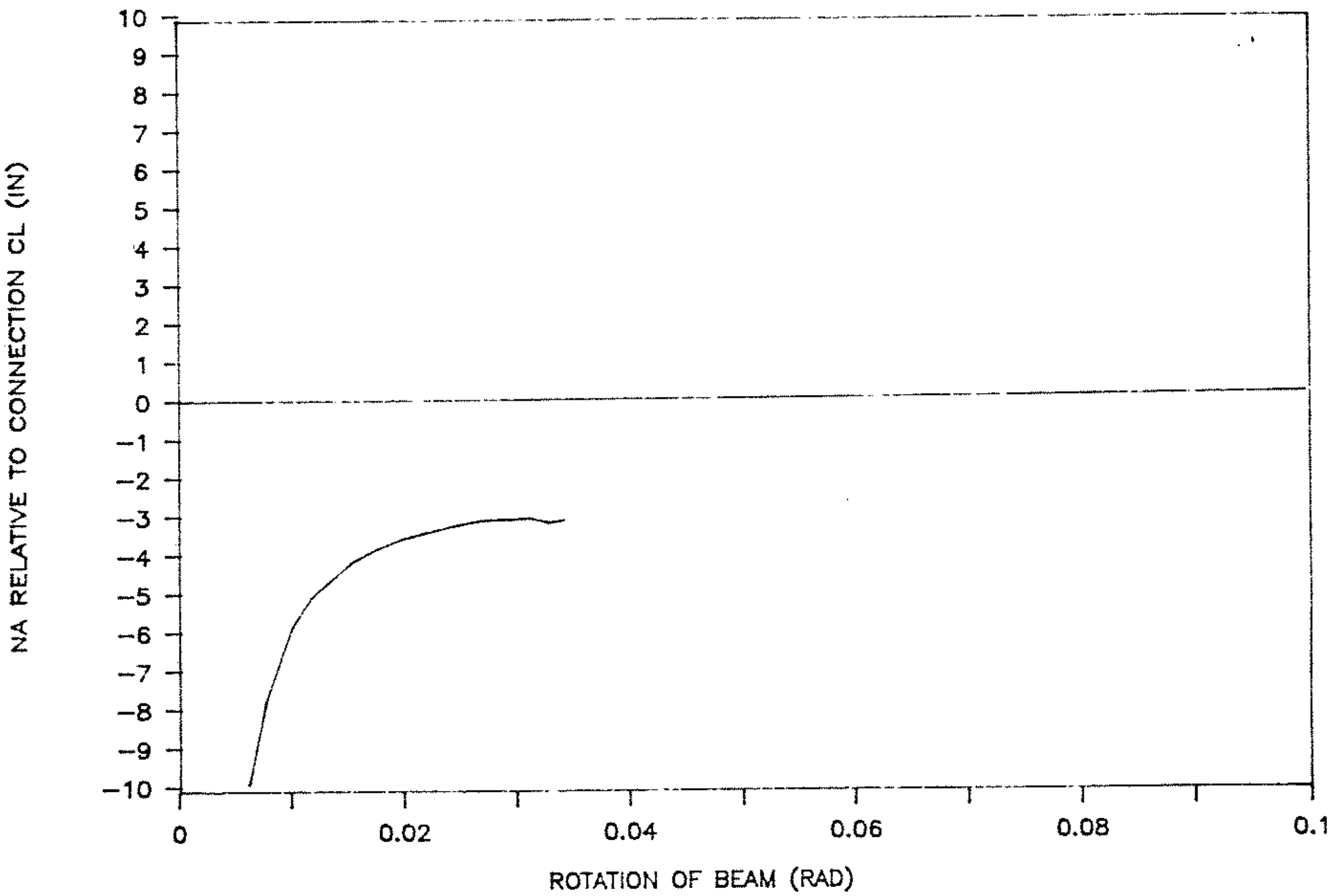


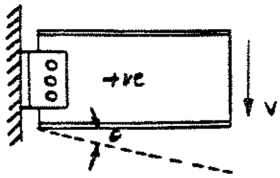
Figure 4.7. Movement of Location of Neutral Axis During Strength Test

APPENDIX A

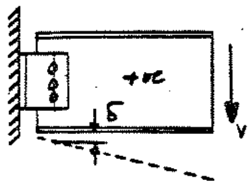
EXPERIMENTAL DATA

As indicated earlier each test had two phases, ductility and strength phases. For each phase of each test, seven plots were made. The plots for all nine tests are given in this appendix. The plots relate several parameter such as shear, moment, rotation and displacements to each other. The sign convention used in these plots is indicated in Figure A1.

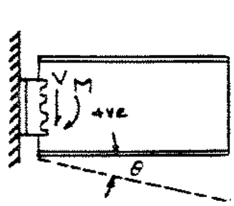
The first plot is shear at connection versus rotation of the beam end. The second plot is shear at connection versus the vertical displacement of beam at bolt line. The third plot is the moment at bolt line versus rotation of connection. The fourth plot is the moment at weld line versus the rotation due to the flange bending of tee-connection. The fifth plot is the moment at weld line versus shear at connection. The sixth plot is moment at bolt line versus shear at connection. Finally, last plot of this series is location of the neutral axis relative to the center line of connection versus rotation of the connection.



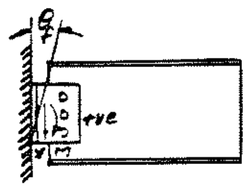
Shear versus rotation



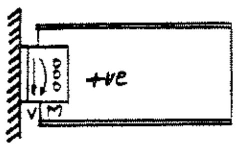
Shear versus vertical disp of connection at bolts



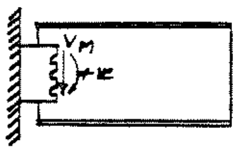
Moment at bolt line versus rotation



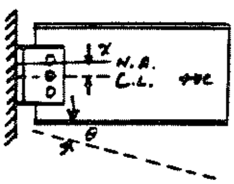
Moment at weld line versus rotation of the flange



Moment at weld line versus shear

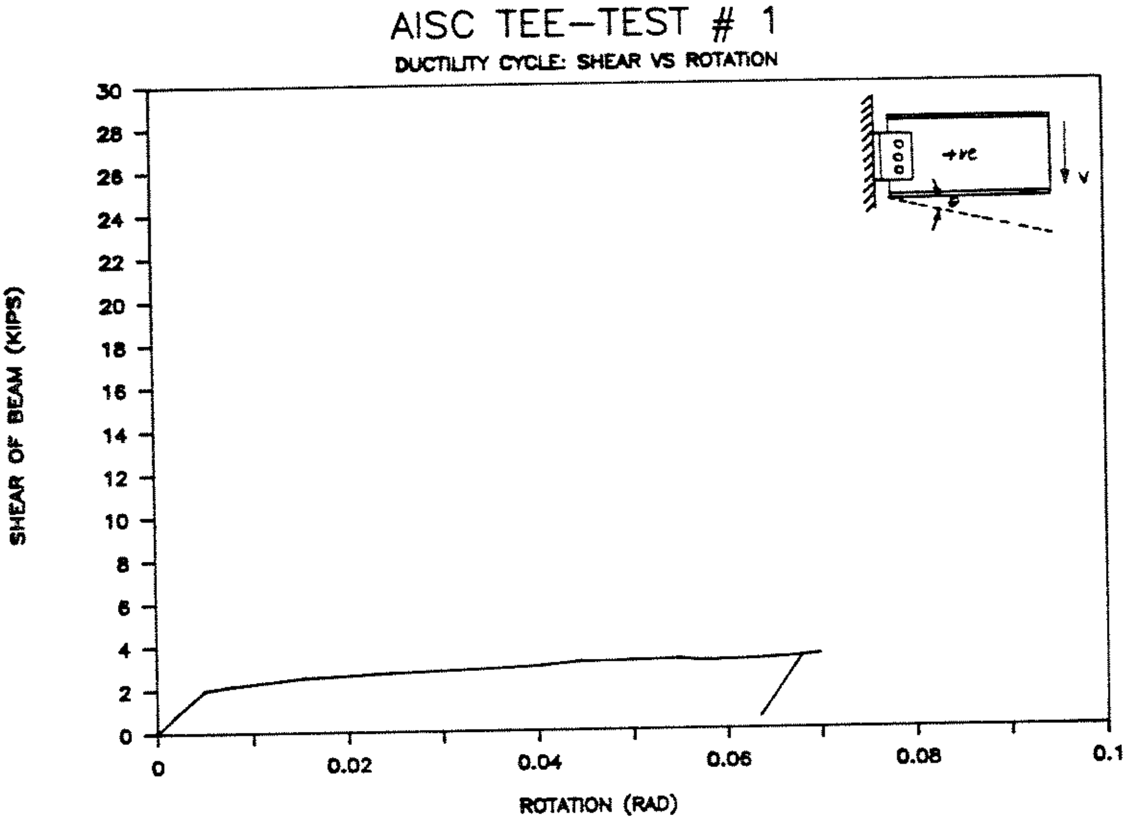


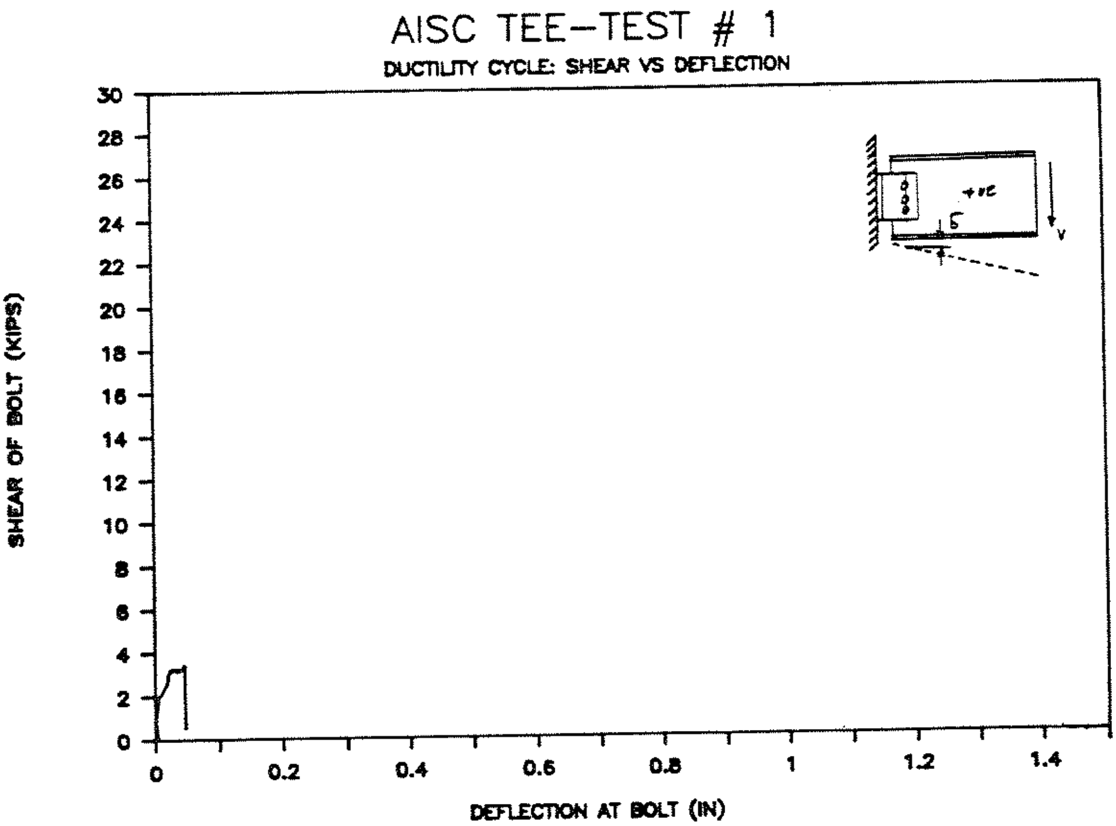
Moment at bolt line versus shear



Neutral axis position relative to center line of the tee connection versus rotation

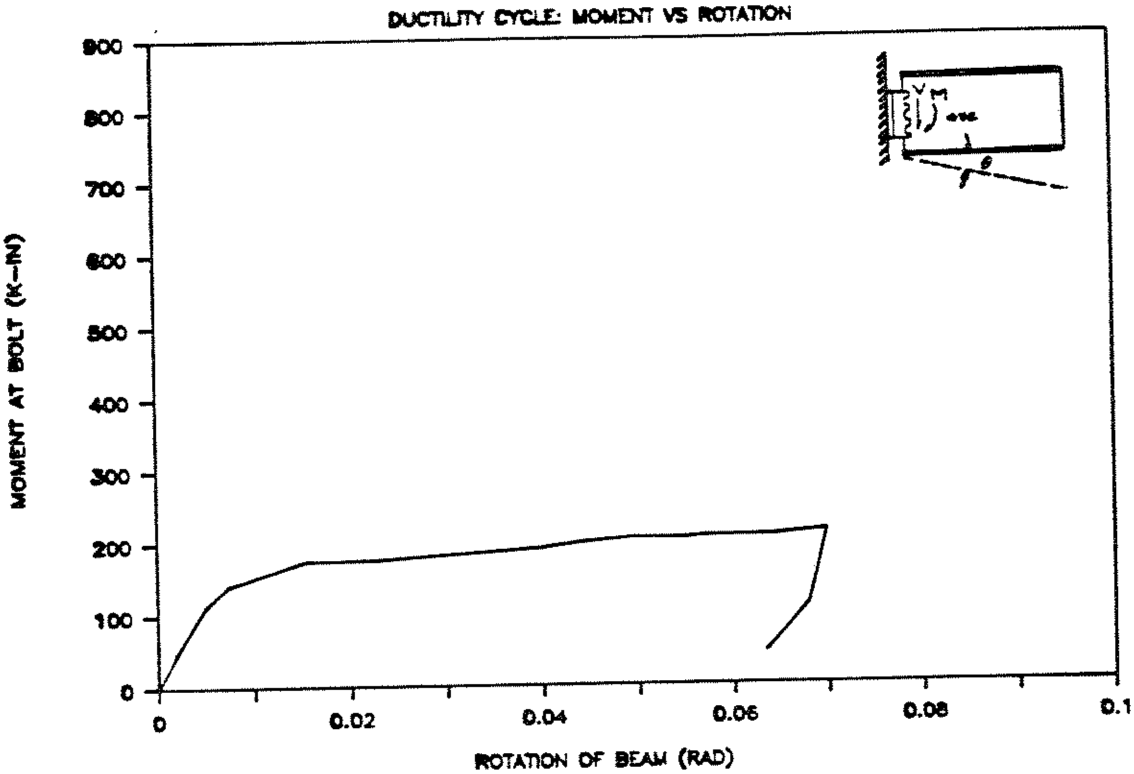
Figure A1. Sign Convention for Plots in Appendix A


AISC TEE—TEST # 1
DUCTILITY CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION (RAD)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0.02
0.04
0.06
0.08
0.1
+ve
V


AISC TEE—TEST # 1
DUCTILITY CYCLE: SHEAR VS DEFLECTION
SHEAR OF BOLT (KIPS)
DEFLECTION AT BOLT (IN)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0.2
0.4
0.6
0.8
1
1.2
1.4
+ve
V

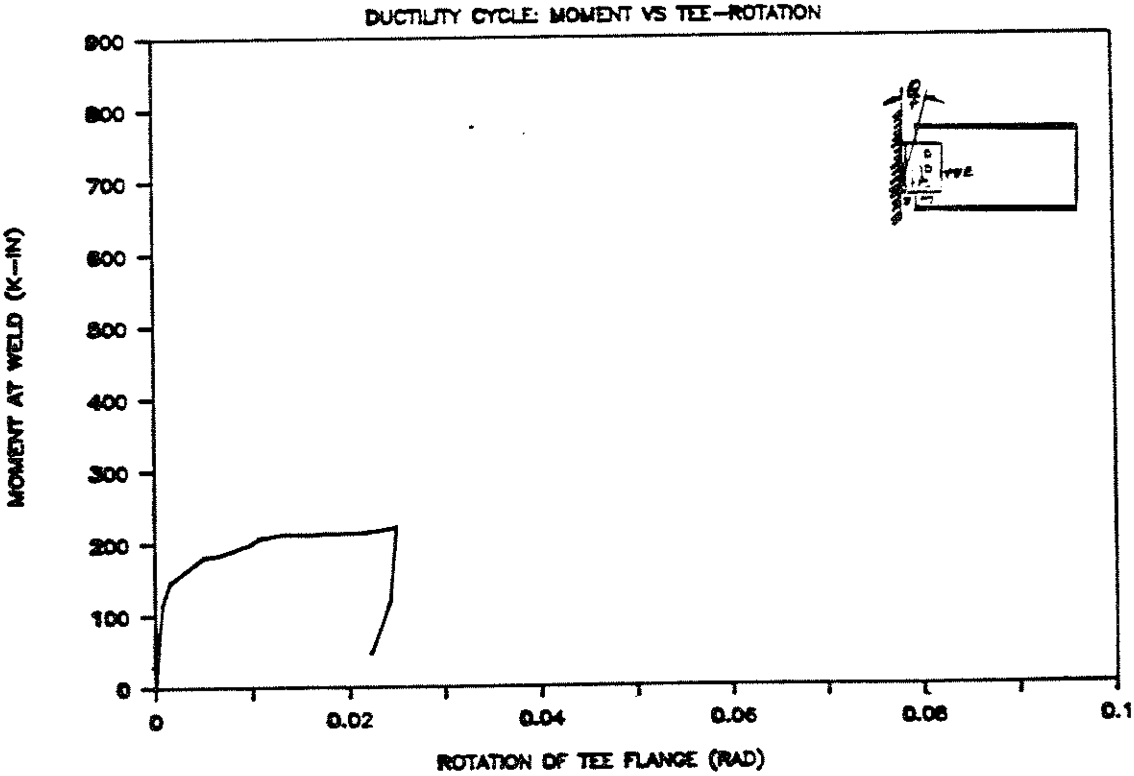
AISC TEE–TEST # 1

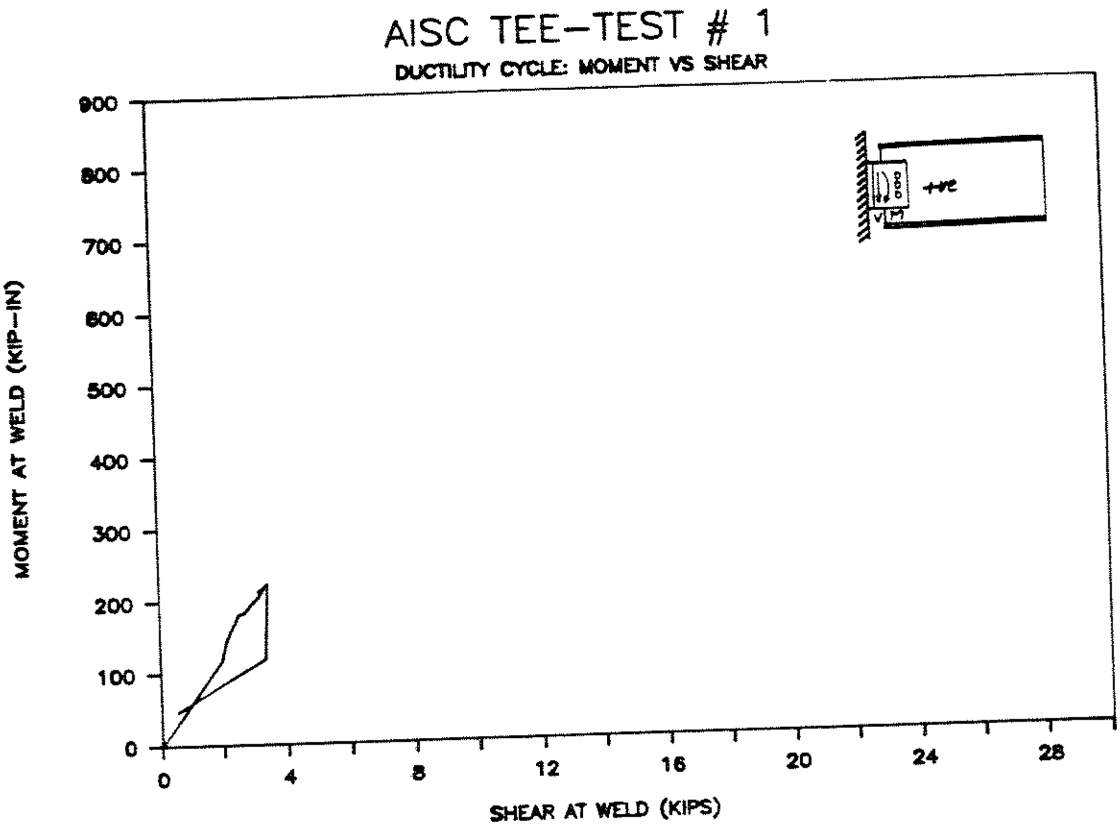
DUCTILITY CYCLE: MOMENT VS ROTATION

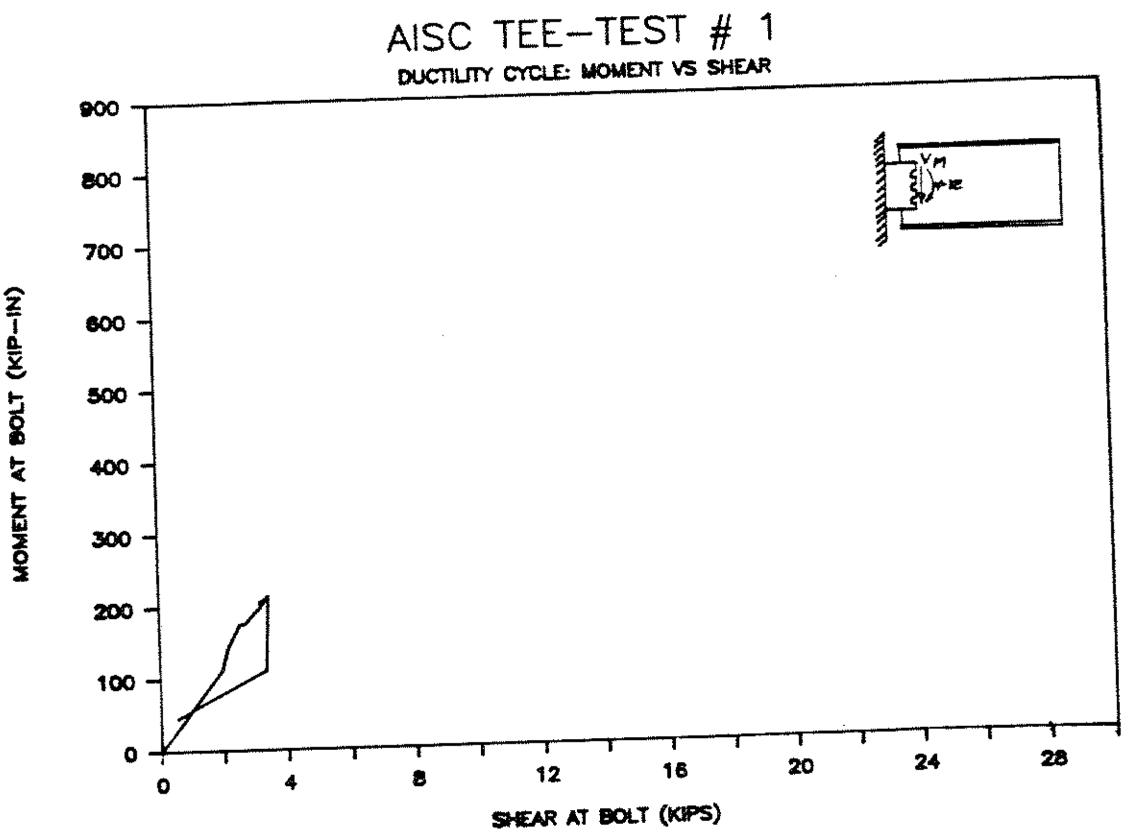


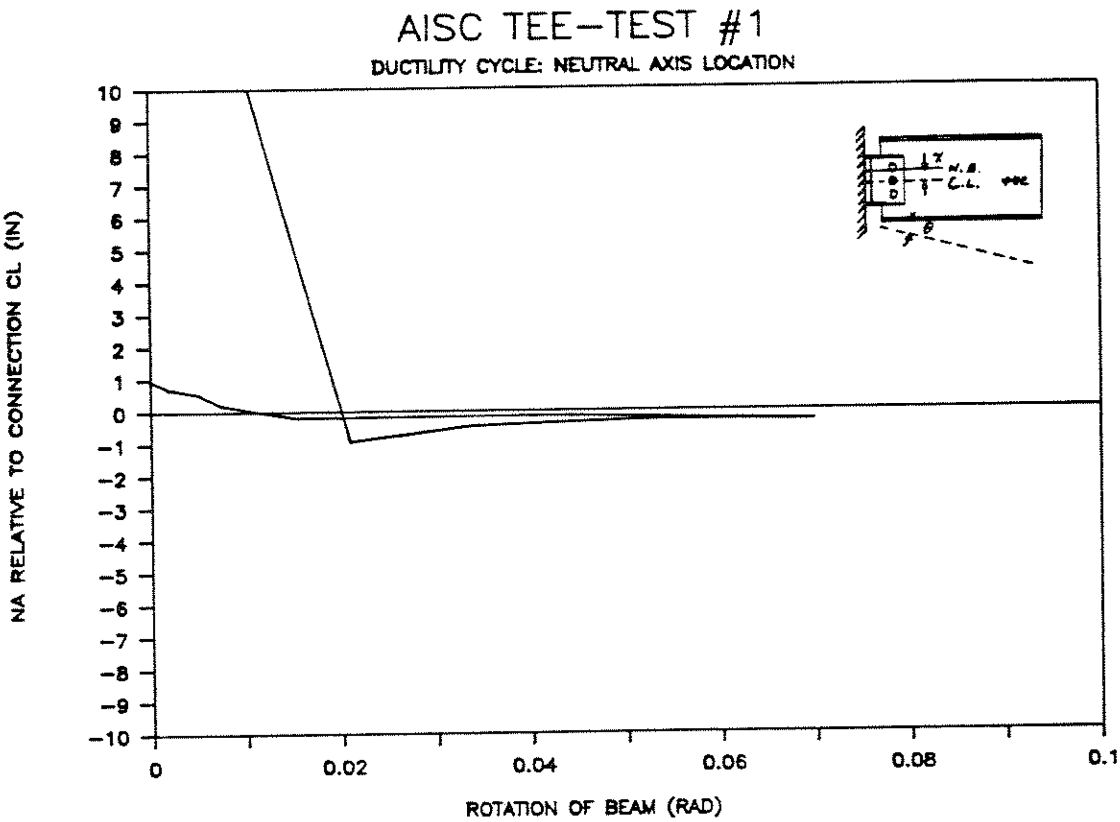
AISC TEE–TEST # 1

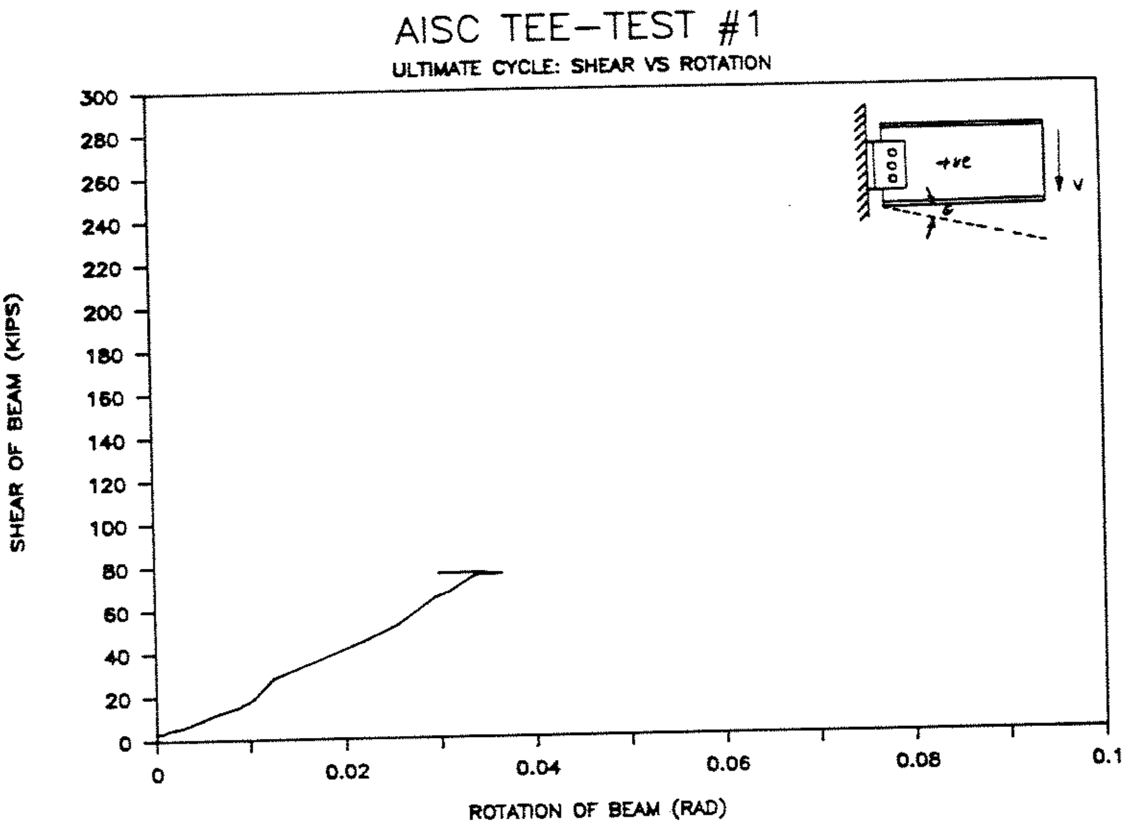
DUCTILITY CYCLE: MOMENT VS TEE–ROTATION



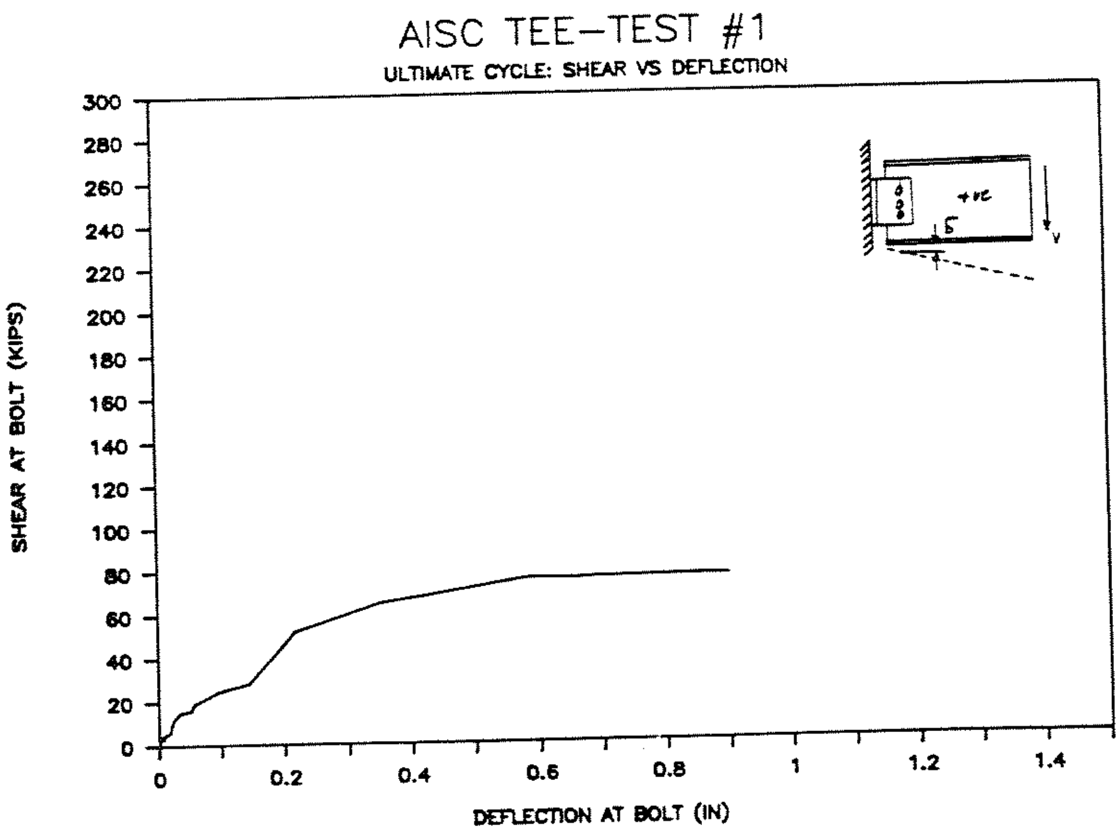

AISC TEE-TEST # 1
DUCTILITY CYCLE: MOMENT VS SHEAR
MOMENT AT WELD (KIP-IN)
SHEAR AT WELD (KIPS)
0
100
200
300
400
500
600
700
800
900
0
4
8
12
16
20
24
28
+ve


AISC TEE-TEST # 1
DUCTILITY CYCLE: MOMENT VS SHEAR
MOMENT AT BOLT (KIP-IN)
SHEAR AT BOLT (KIPS)
0
100
200
300
400
500
600
700
800
900
0
4
8
12
16
20
24
28

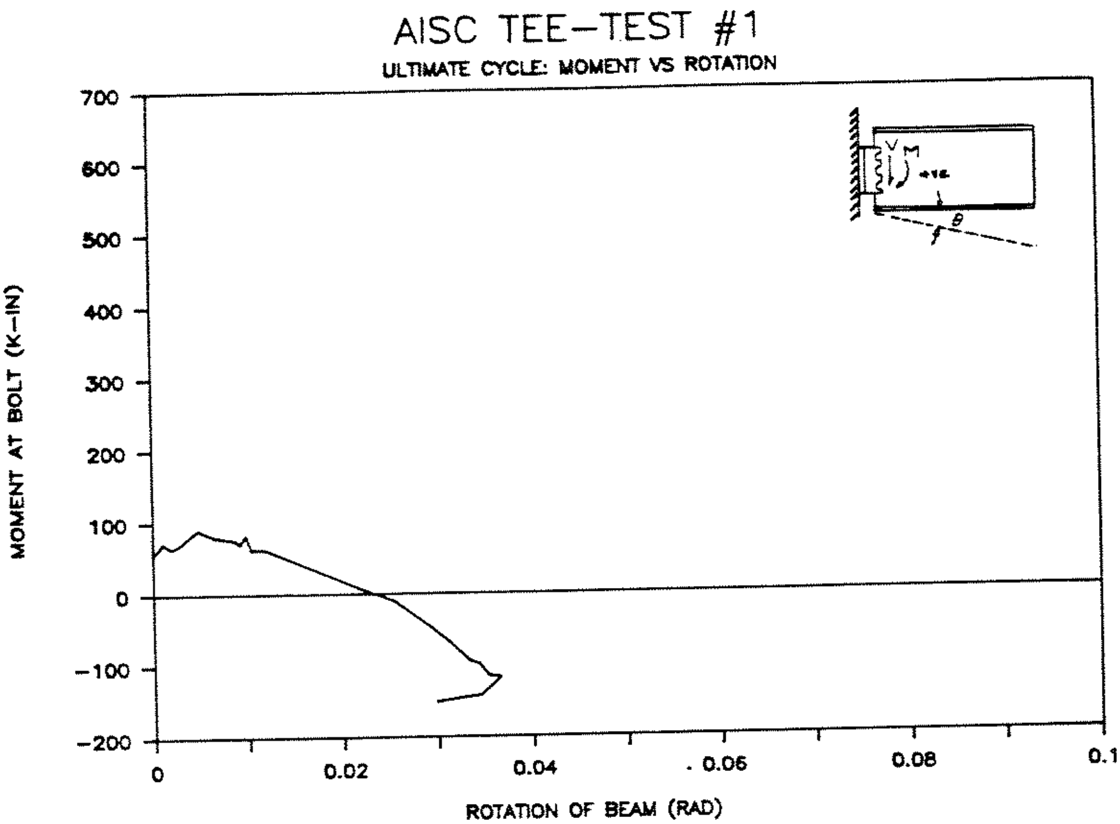

AISC TEE-TEST #1
DUCTILITY CYCLE: NEUTRAL AXIS LOCATION
NA RELATIVE TO CONNECTION CL (IN)
ROTATION OF BEAM (RAD)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
0
0.02
0.04
0.06
0.08
0.1

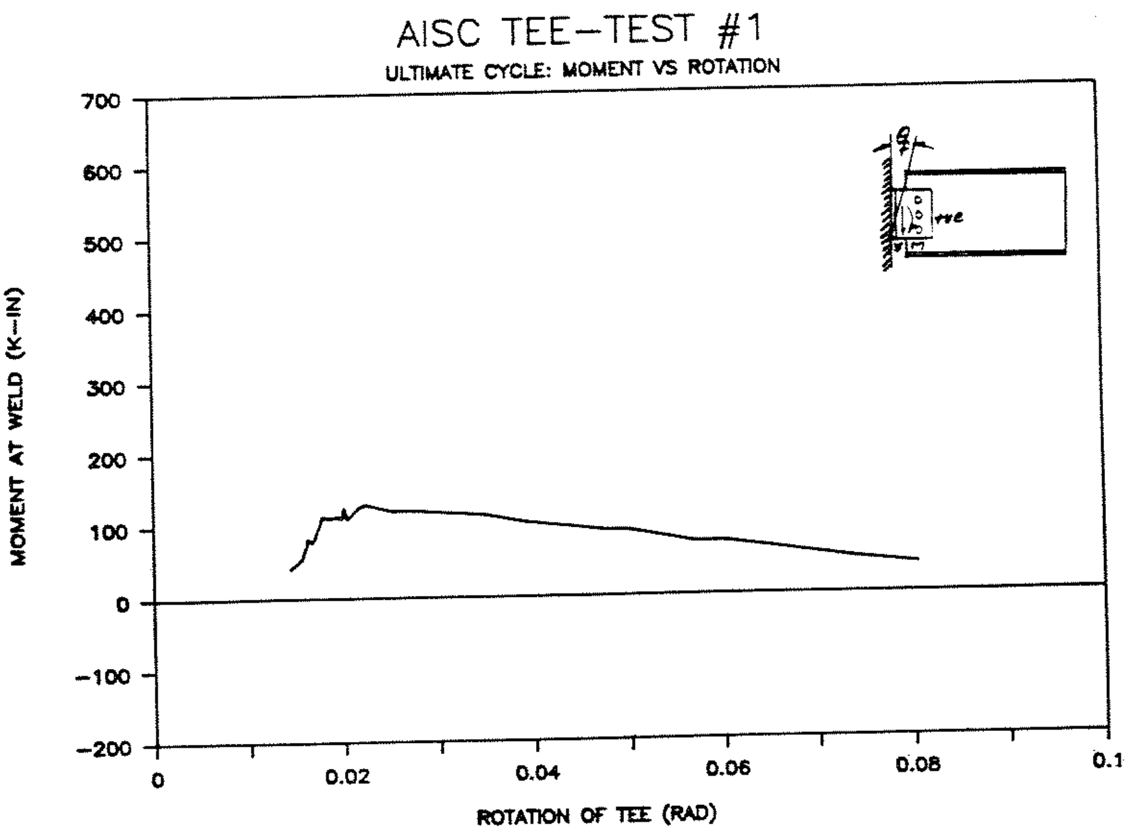


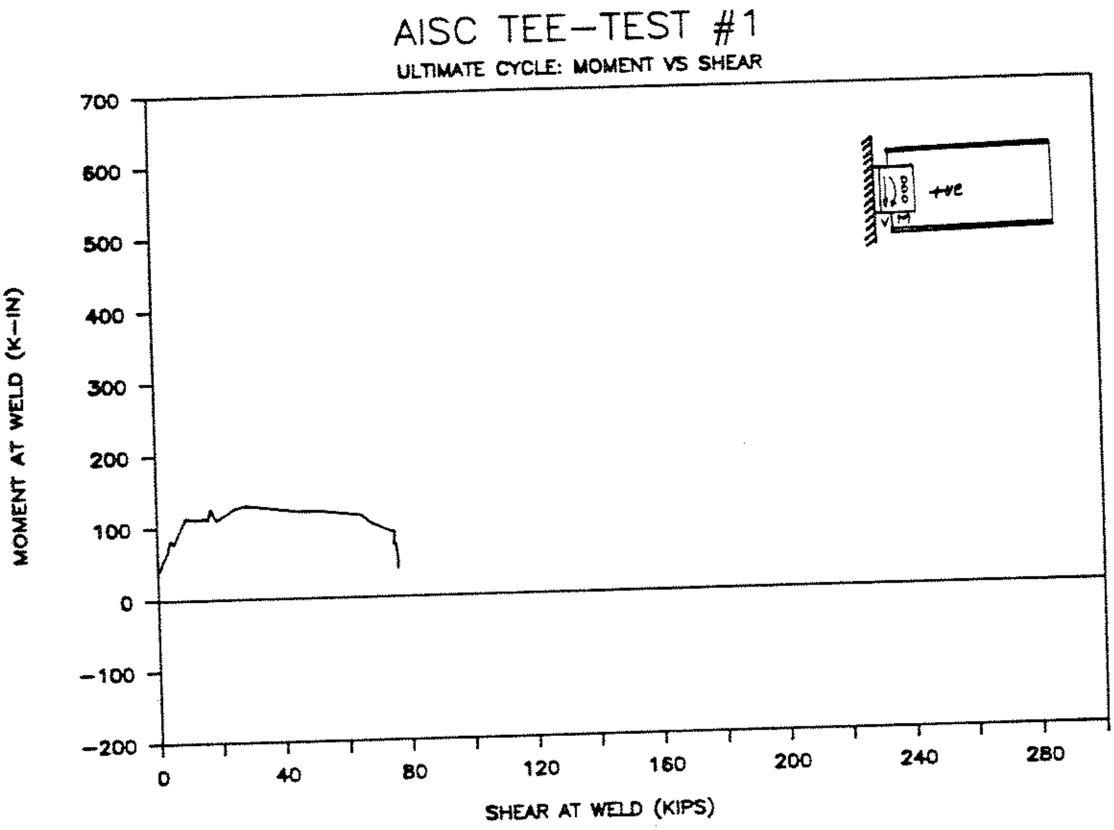
AISC TEE-TEST #1
ULTIMATE CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION OF BEAM (RAD)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
0.02
0.04
0.06
0.08
0.1
+ve
V



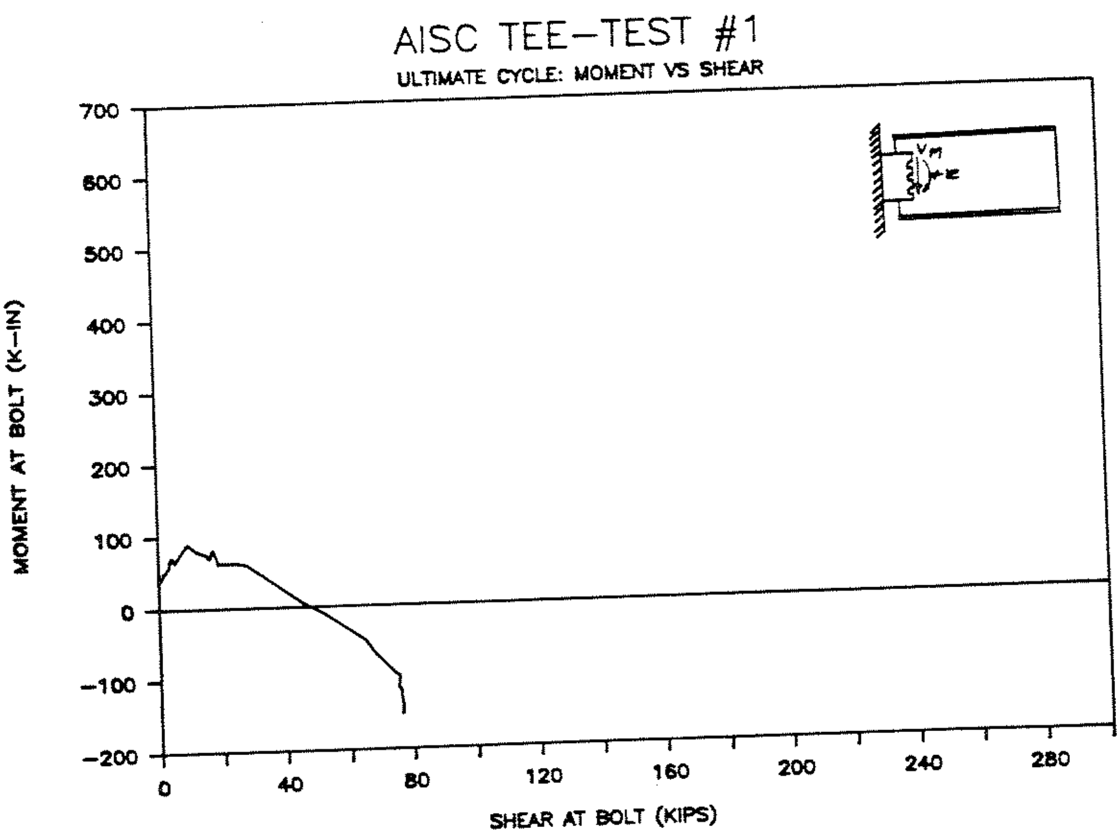
AISC TEE-TEST #1
ULTIMATE CYCLE: SHEAR VS DEFLECTION
SHEAR AT BOLT (KIPS)
DEFLECTION AT BOLT (IN)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
+ve
V


AISC TEE—TEST #1
ULTIMATE CYCLE: MOMENT VS ROTATION
MOMENT AT BOLT (K—IN)
ROTATION OF BEAM (RAD)

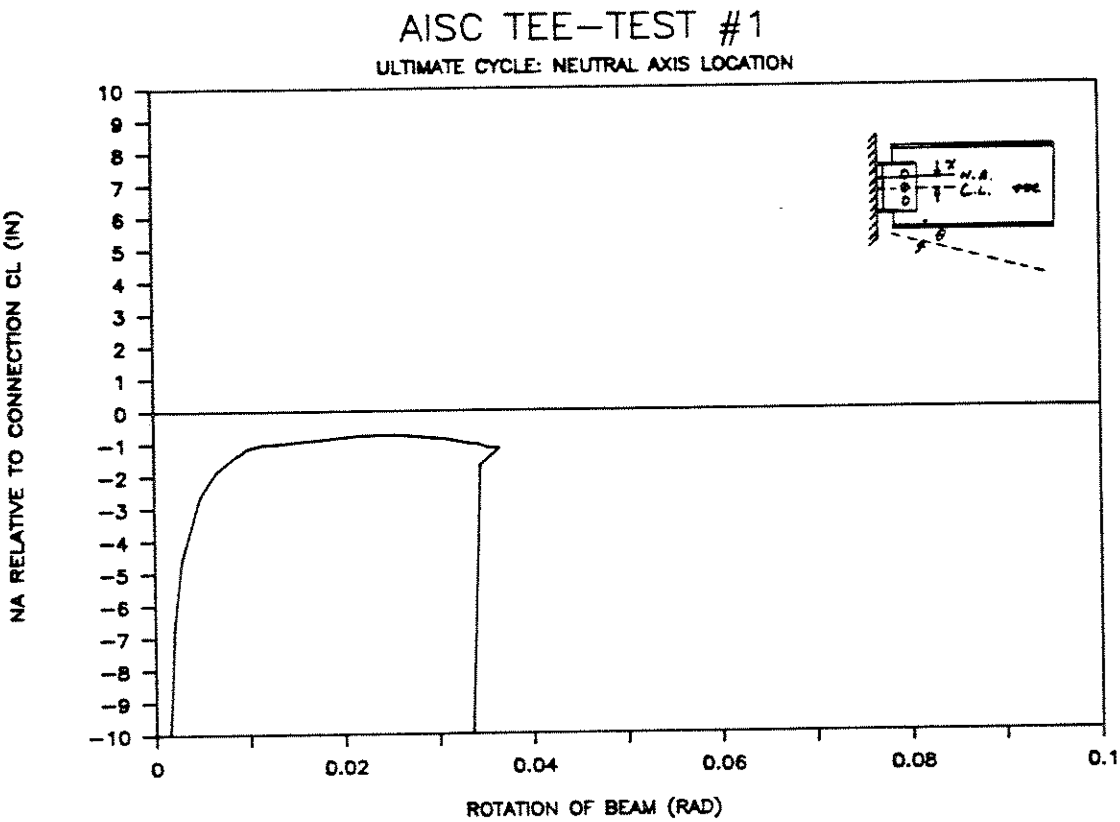

AISC TEE—TEST #1
ULTIMATE CYCLE: MOMENT VS ROTATION
MOMENT AT WELD (K—IN)
ROTATION OF TEE (RAD)

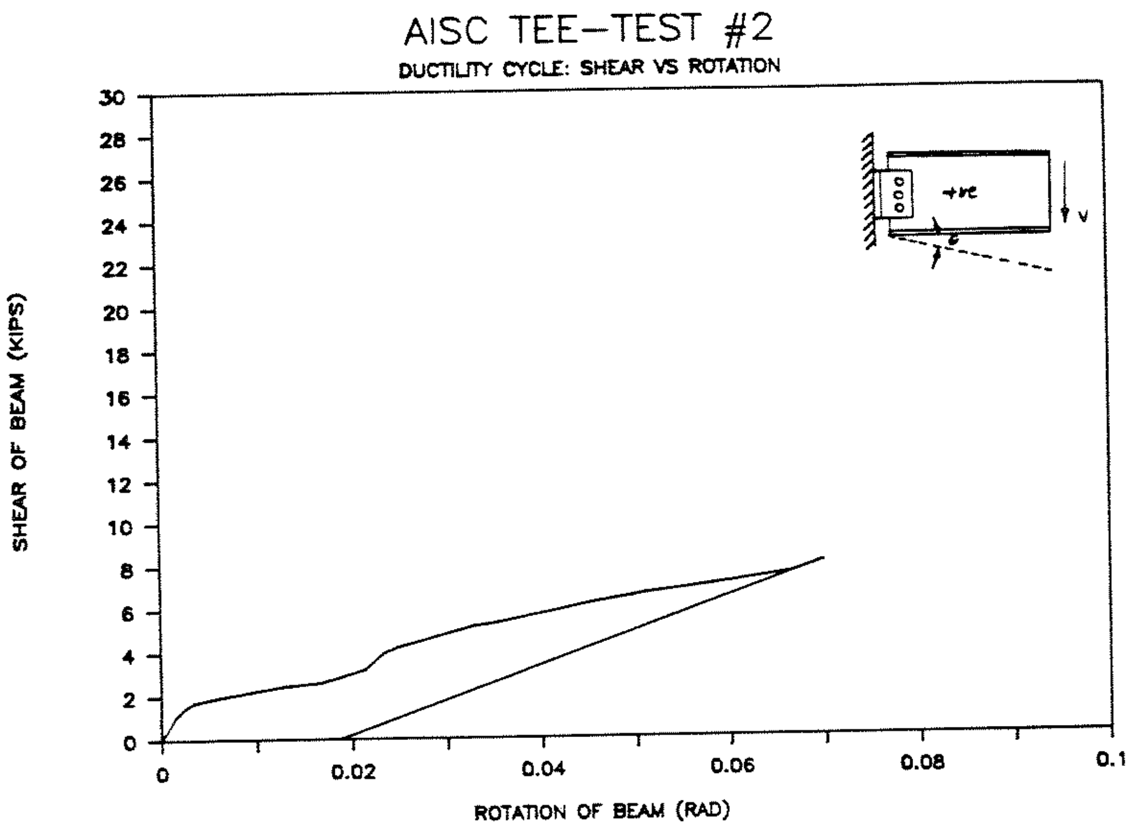


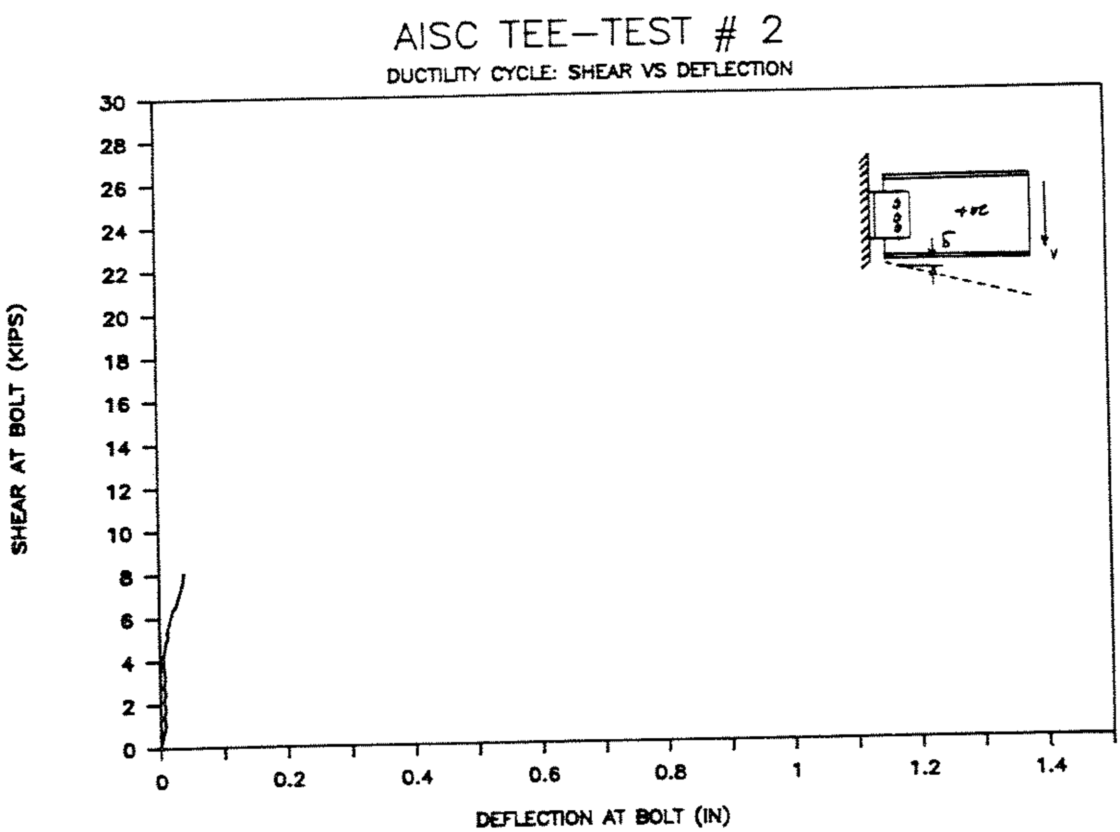
AISC TEE-TEST #1
ULTIMATE CYCLE: MOMENT VS SHEAR
MOMENT AT WELD (K-IN)
700
600
500
400
300
200
100
0
-100
-200
0
40
80
120
160
200
240
280
SHEAR AT WELD (KIPS)
+ve
V
M



AISC TEE-TEST #1
ULTIMATE CYCLE: MOMENT VS SHEAR
MOMENT AT BOLT (K-IN)
700
600
500
400
300
200
100
0
-100
-200
0
40
80
120
160
200
240
280
SHEAR AT BOLT (KIPS)

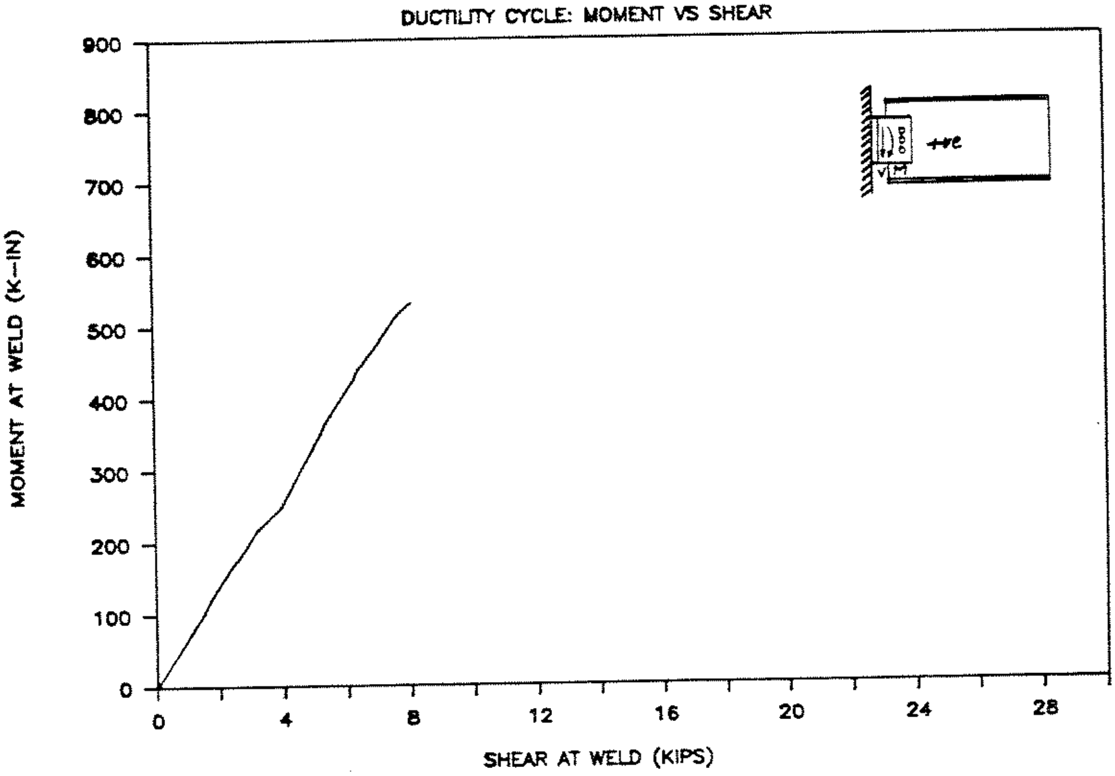

AISC TEE–TEST #1
ULTIMATE CYCLE: NEUTRAL AXIS LOCATION
NA RELATIVE TO CONNECTION CL (IN)
ROTATION OF BEAM (RAD)
10
9
8
7
6
5
4
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
0
0.02
0.04
0.06
0.08
0.1
N.A.
C.L.
θ


AISC TEE-TEST #2
DUCTILITY CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION OF BEAM (RAD)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0.02
0.04
0.06
0.08
0.1
+ve
V


AISC TEE-TEST # 2
DUCTILITY CYCLE: SHEAR VS DEFLECTION
SHEAR AT BOLT (KIPS)
DEFLECTION AT BOLT (IN)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0.2
0.4
0.6
0.8
1
1.2
1.4
+ve
V

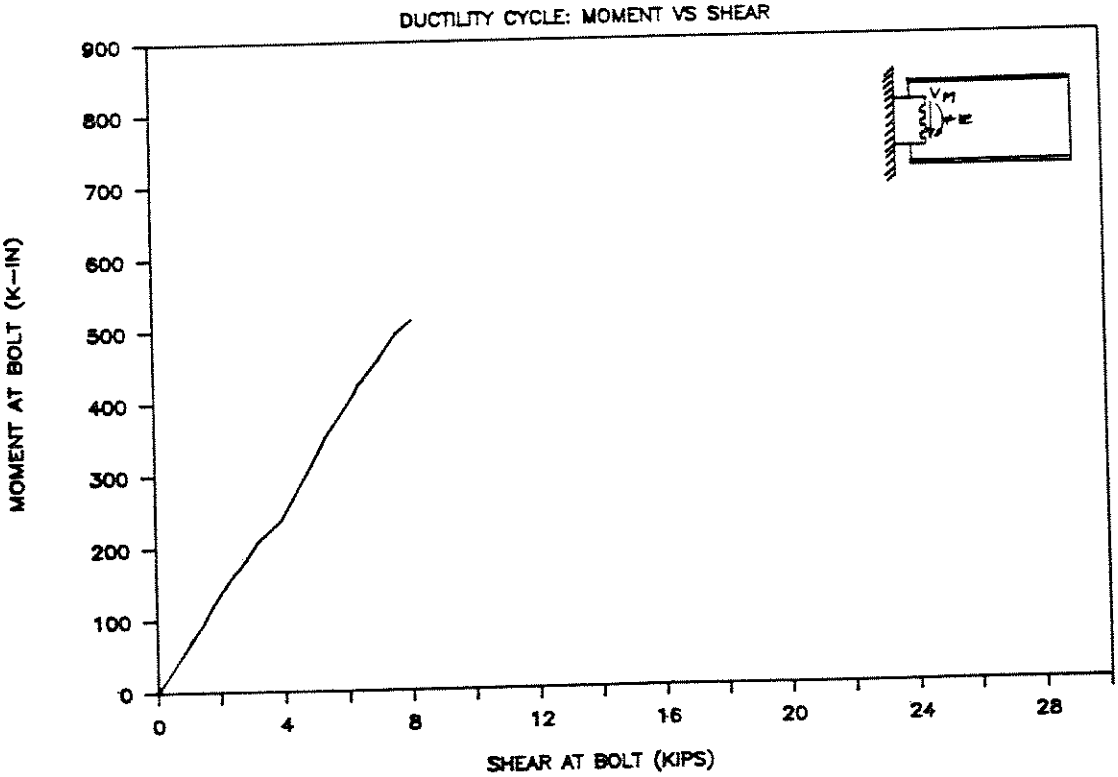
AISC TEE–TEST # 2

DUCTILITY CYCLE: MOMENT VS SHEAR

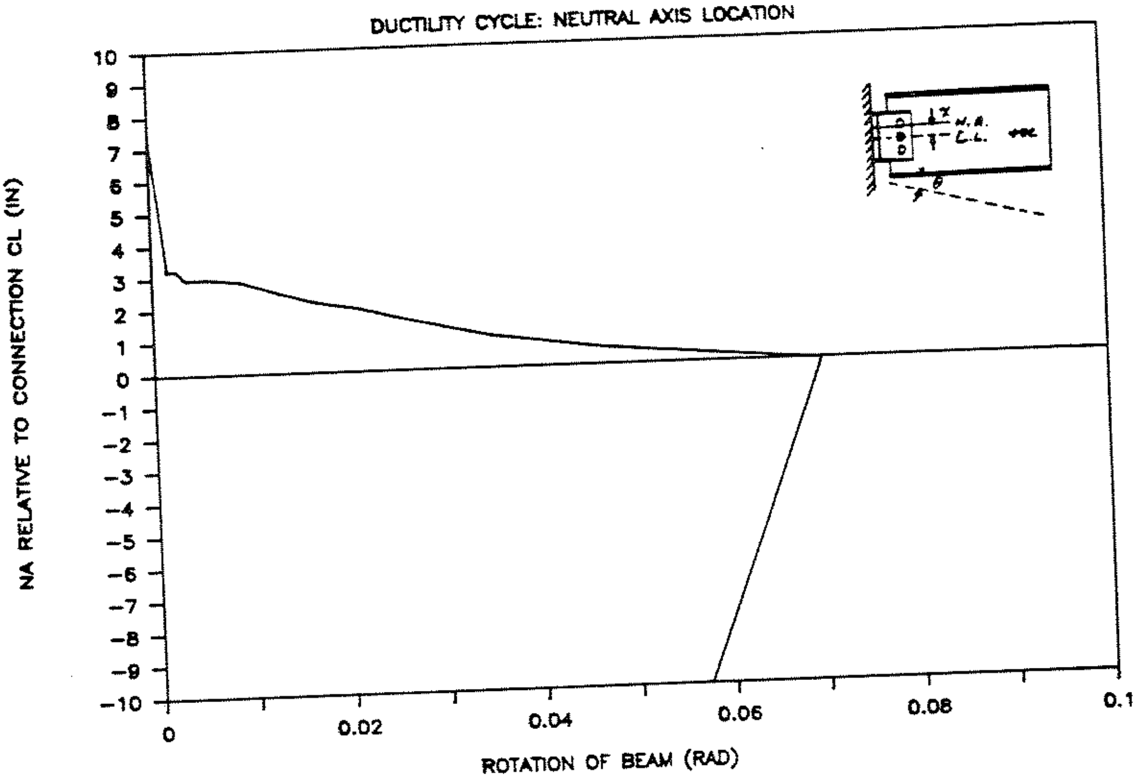


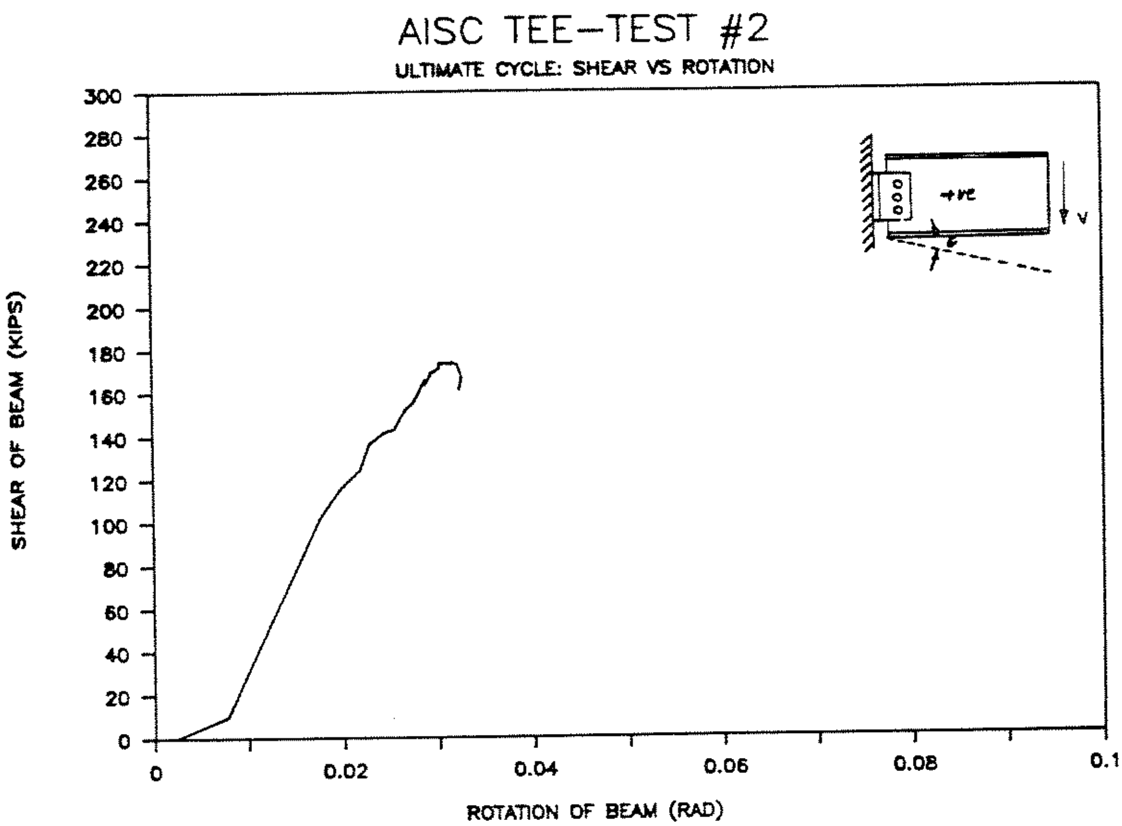
AISC TEE–TEST # 2

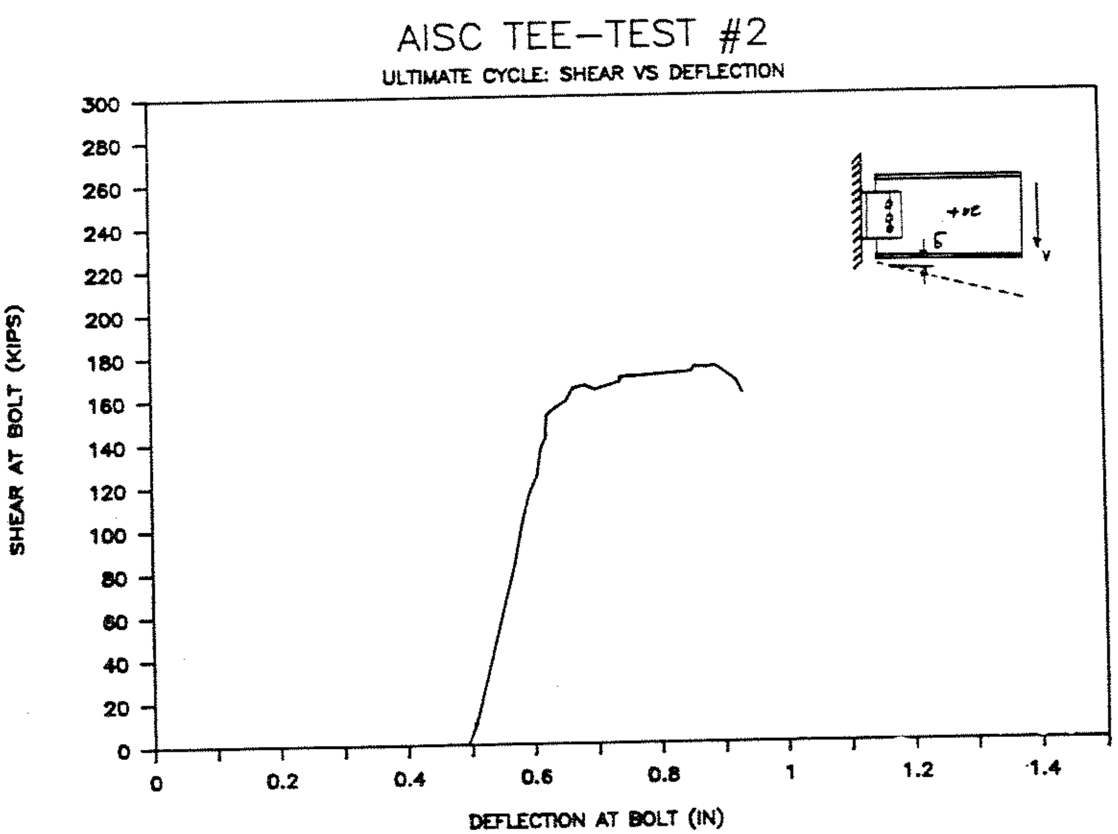
DUCTILITY CYCLE: MOMENT VS SHEAR



AISC TEE-TEST #2

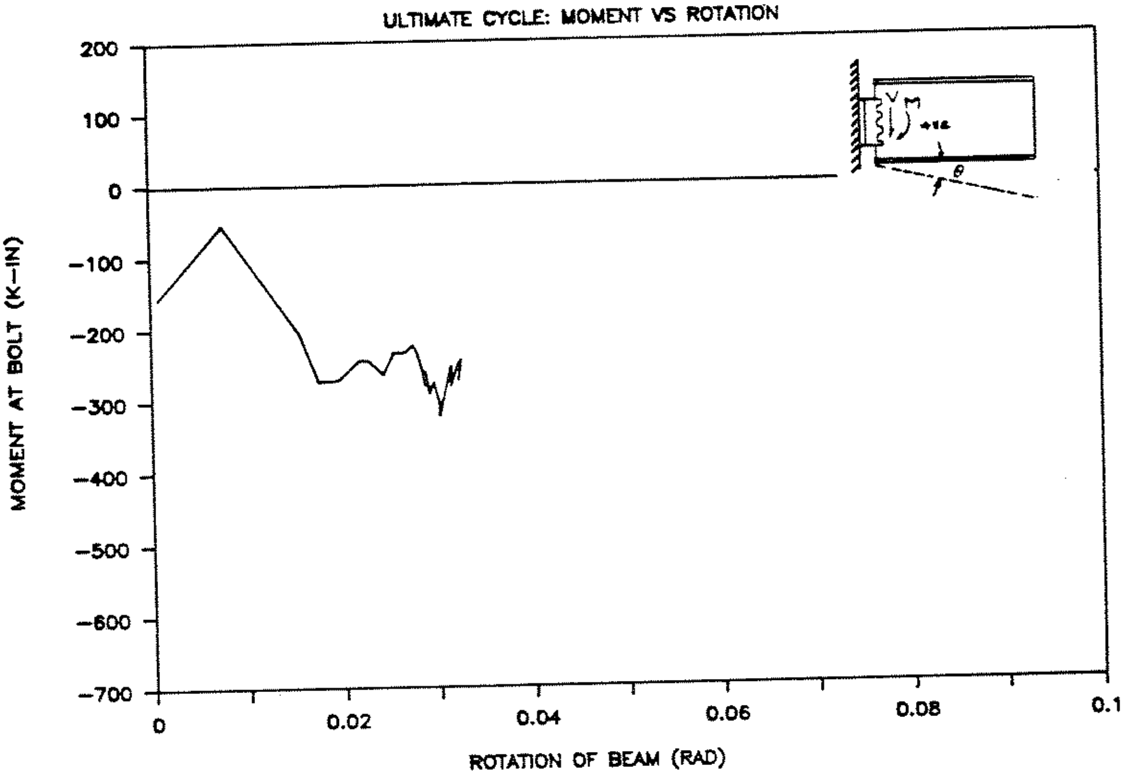



AISC TEE-TEST #2
ULTIMATE CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION OF BEAM (RAD)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
0
0.02
0.04
0.06
0.08
0.1
+ve
V


AISC TEE-TEST #2
ULTIMATE CYCLE: SHEAR VS DEFLECTION
SHEAR AT BOLT (KIPS)
DEFLECTION AT BOLT (IN)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
0
0.2
0.4
0.6
0.8
1
1.2
1.4
+ve
V

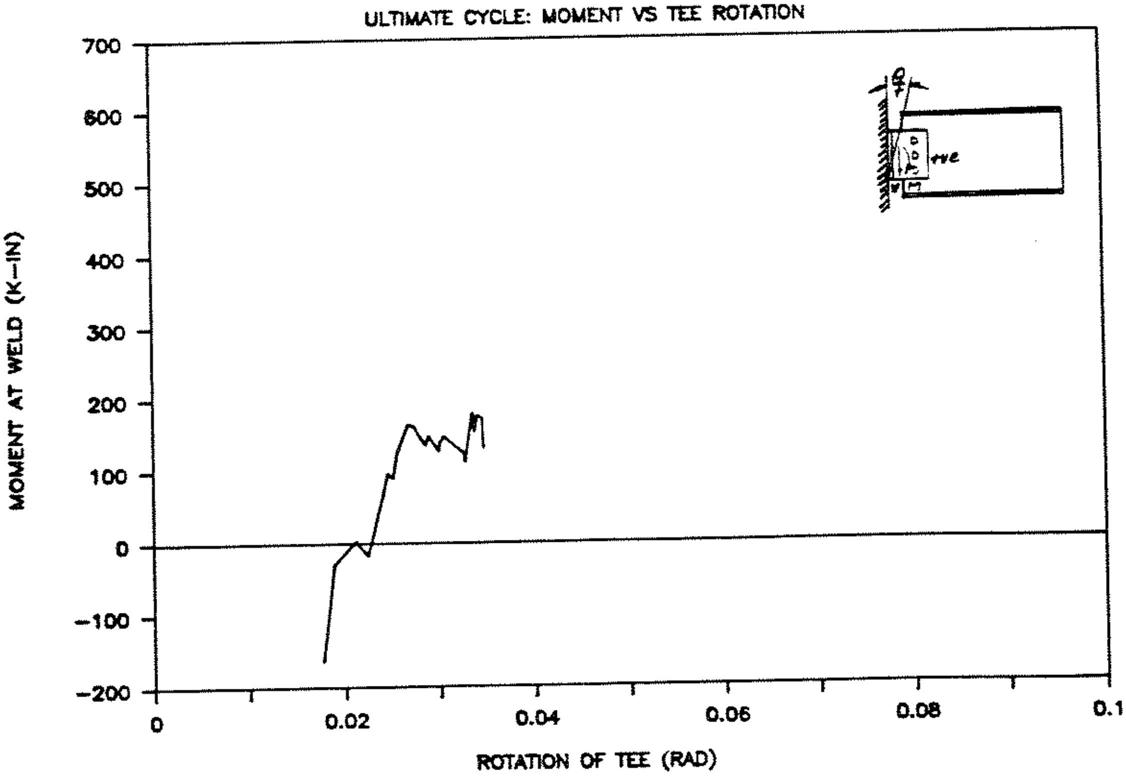
AISC TEE—TEST #2

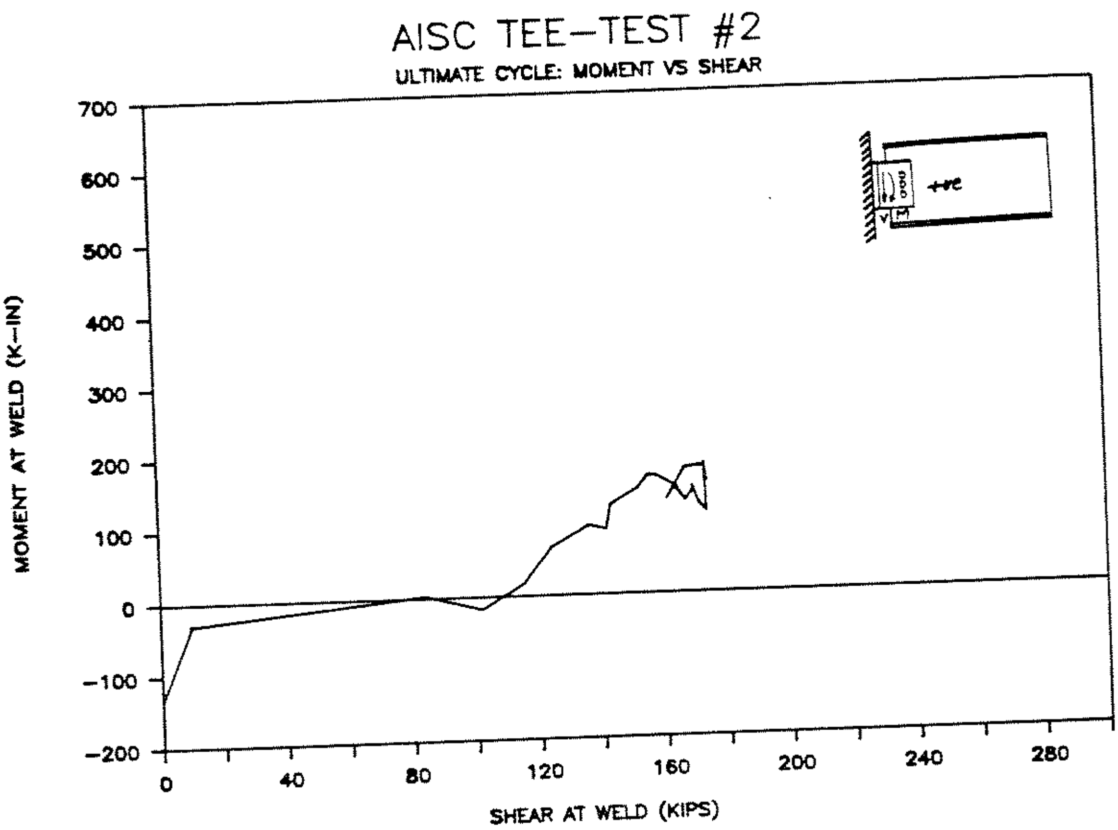
ULTIMATE CYCLE: MOMENT VS ROTATION

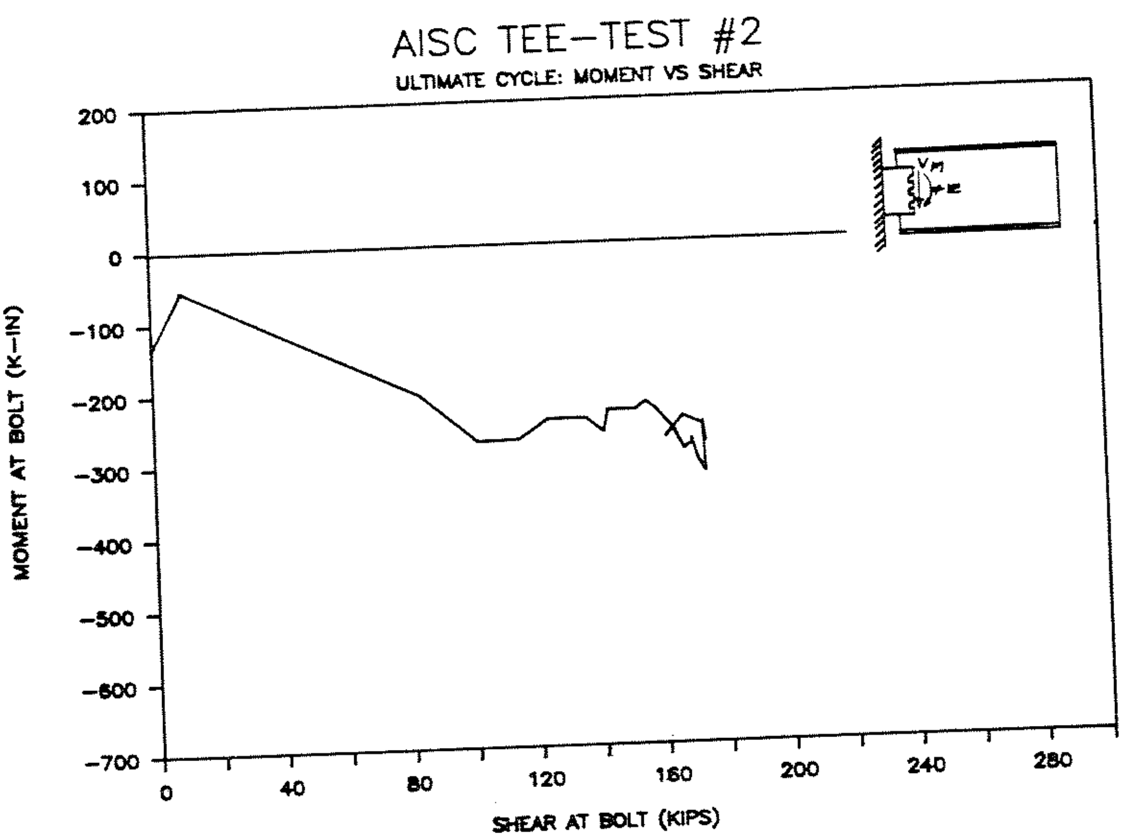


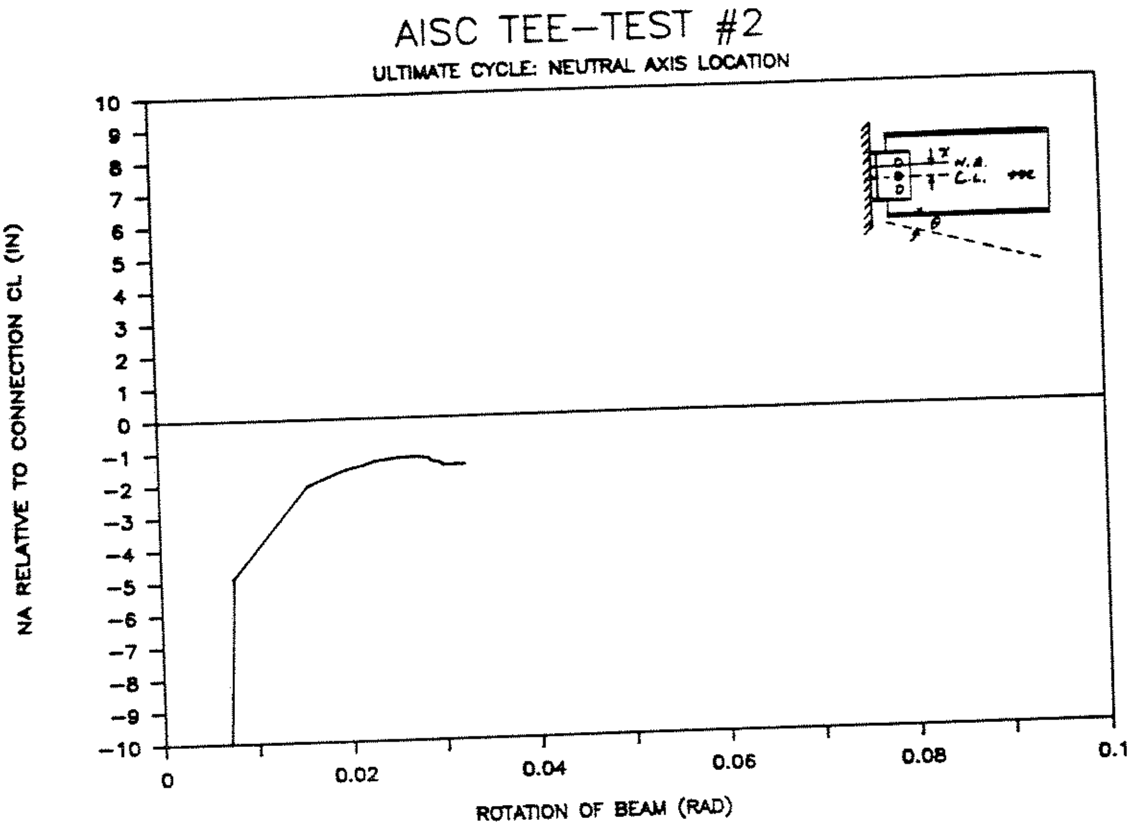
AISC TEE—TEST #2

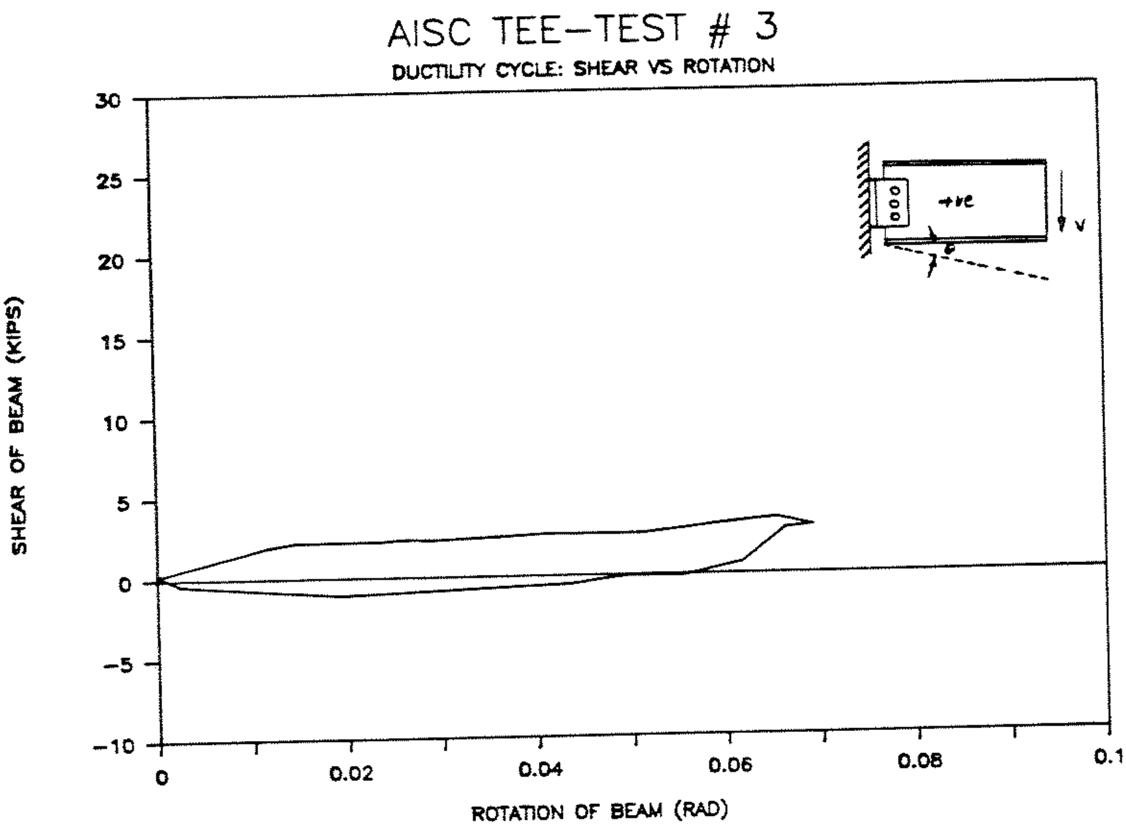
ULTIMATE CYCLE: MOMENT VS TEE ROTATION

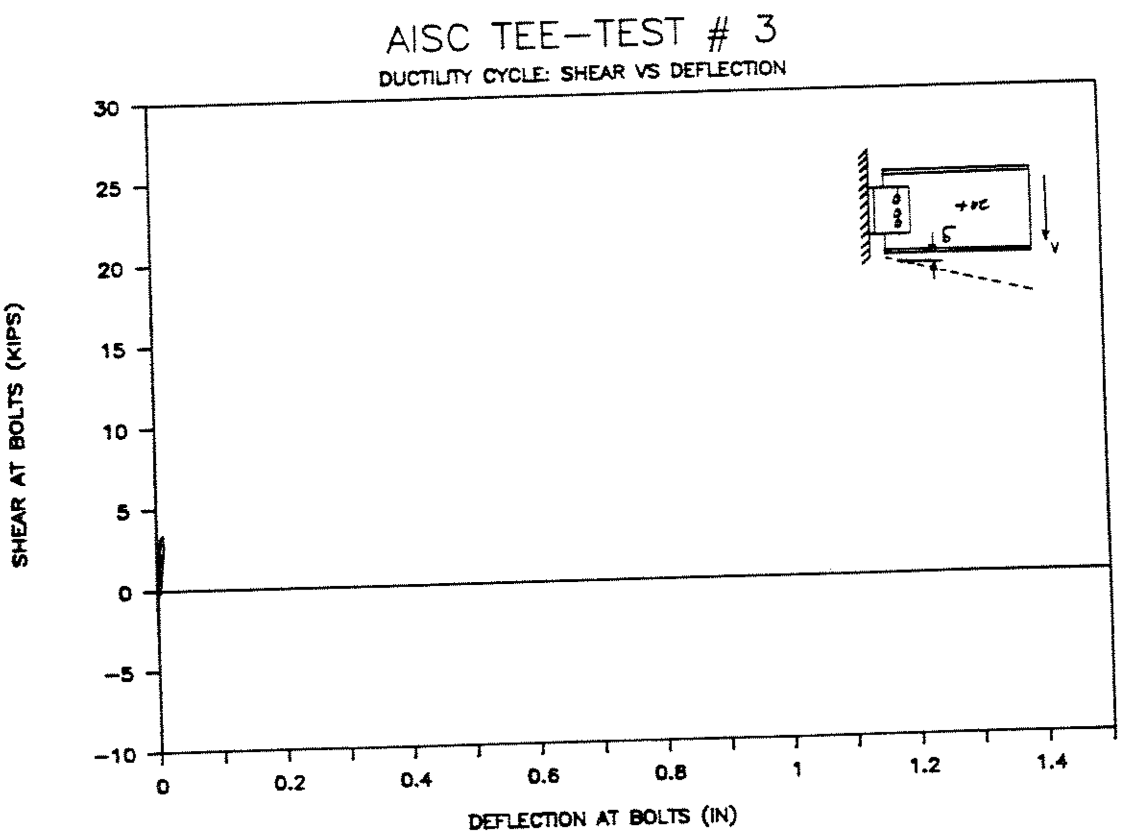


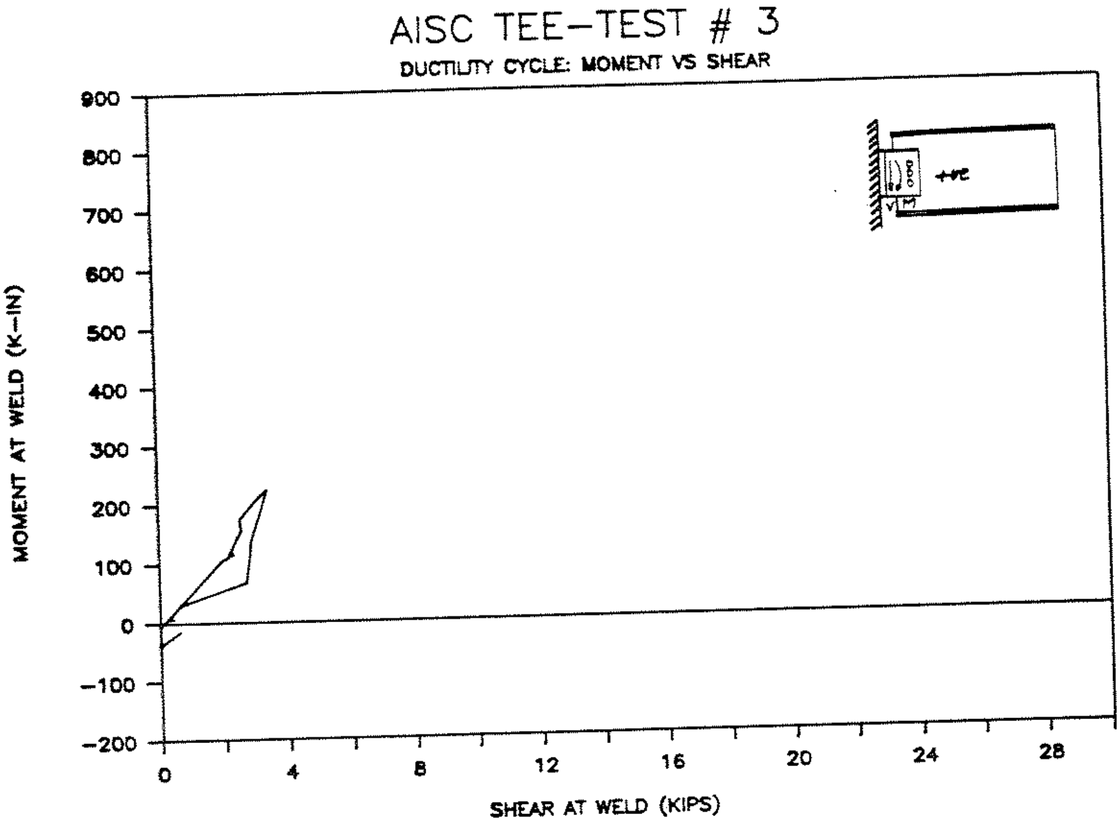

AISC TEE-TEST #2
ULTIMATE CYCLE: MOMENT VS SHEAR
MOMENT AT WELD (K-IN)
SHEAR AT WELD (KIPS)
700
600
500
400
300
200
100
0
-100
-200
0
40
80
120
160
200
240
280
+ve

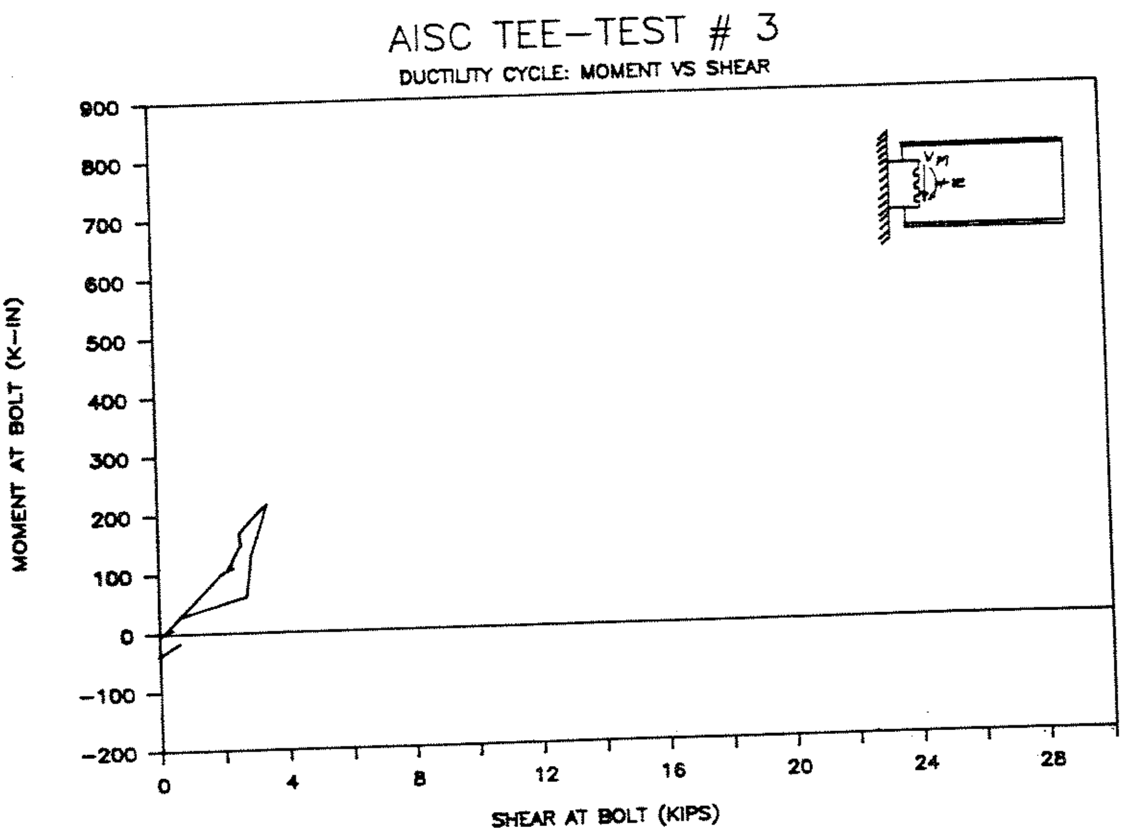

AISC TEE-TEST #2
ULTIMATE CYCLE: MOMENT VS SHEAR
MOMENT AT BOLT (K-IN)
SHEAR AT BOLT (KIPS)
200
100
0
-100
-200
-300
-400
-500
-600
-700
0
40
80
120
160
200
240
280

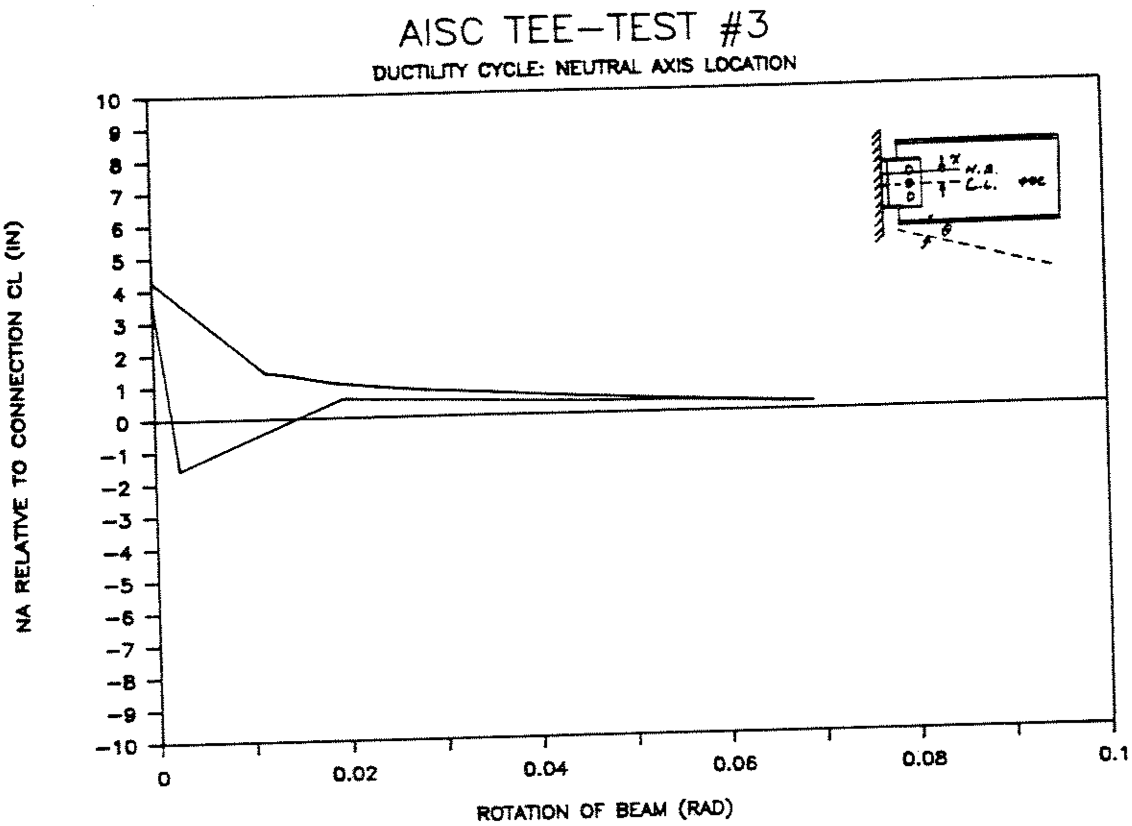

AISC TEE-TEST #2
ULTIMATE CYCLE: NEUTRAL AXIS LOCATION
NA RELATIVE TO CONNECTION CL (IN)
ROTATION OF BEAM (RAD)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
0
0.02
0.04
0.06
0.08
0.1
N.A.
C.L.


AISC TEE–TEST # 3
DUCTILITY CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION OF BEAM (RAD)
30
25
20
15
10
5
0
−5
−10
0
0.02
0.04
0.06
0.08
0.1
+ve
V


AISC TEE–TEST # 3
DUCTILITY CYCLE: SHEAR VS DEFLECTION
SHEAR AT BOLTS (KIPS)
DEFLECTION AT BOLTS (IN)
30
25
20
15
10
5
0
−5
−10
0
0.2
0.4
0.6
0.8
1
1.2
1.4
+ve
V

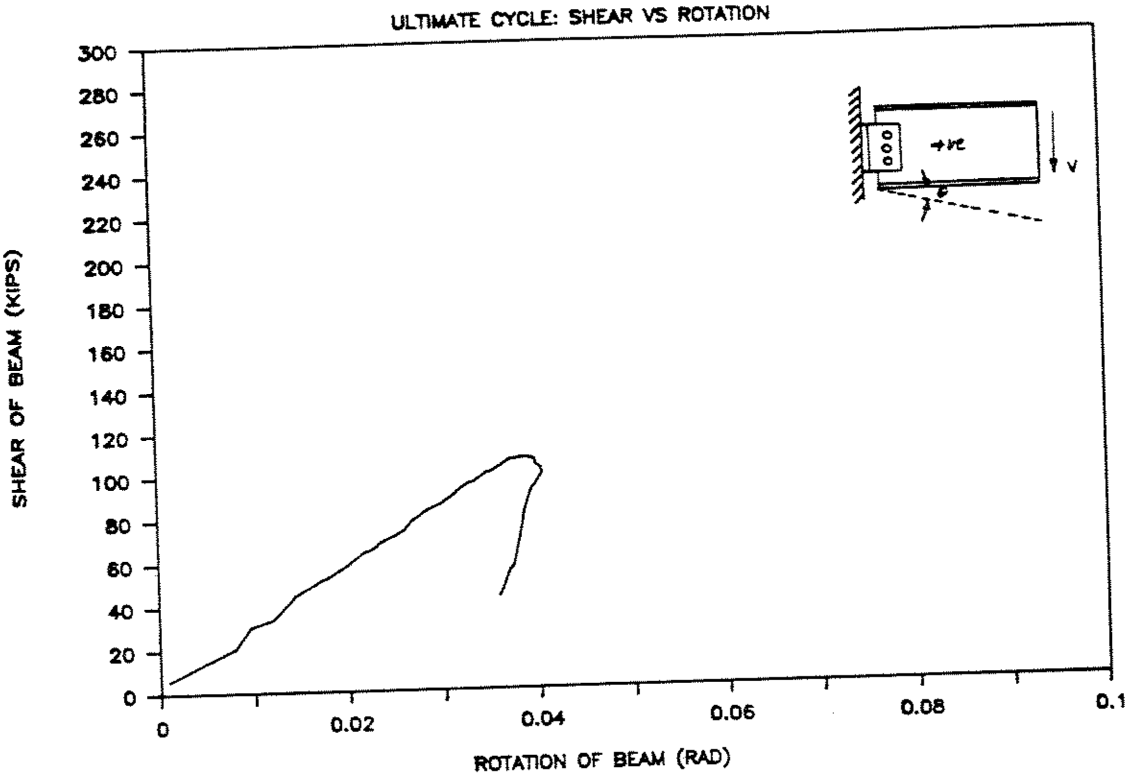

AISC TEE-TEST # 3
DUCTILITY CYCLE: MOMENT VS SHEAR
MOMENT AT WELD (K-IN)
900
800
700
600
500
400
300
200
100
0
-100
-200
0
4
8
12
16
20
24
28
SHEAR AT WELD (KIPS)


AISC TEE-TEST # 3
DUCTILITY CYCLE: MOMENT VS SHEAR
MOMENT AT BOLT (K-IN)
900
800
700
600
500
400
300
200
100
0
-100
-200
0
4
8
12
16
20
24
28
SHEAR AT BOLT (KIPS)


AISC TEE-TEST #3
DUCTILITY CYCLE: NEUTRAL AXIS LOCATION
NA RELATIVE TO CONNECTION CL (IN)
ROTATION OF BEAM (RAD)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
0
0.02
0.04
0.06
0.08
0.1
N.A.
C.L.

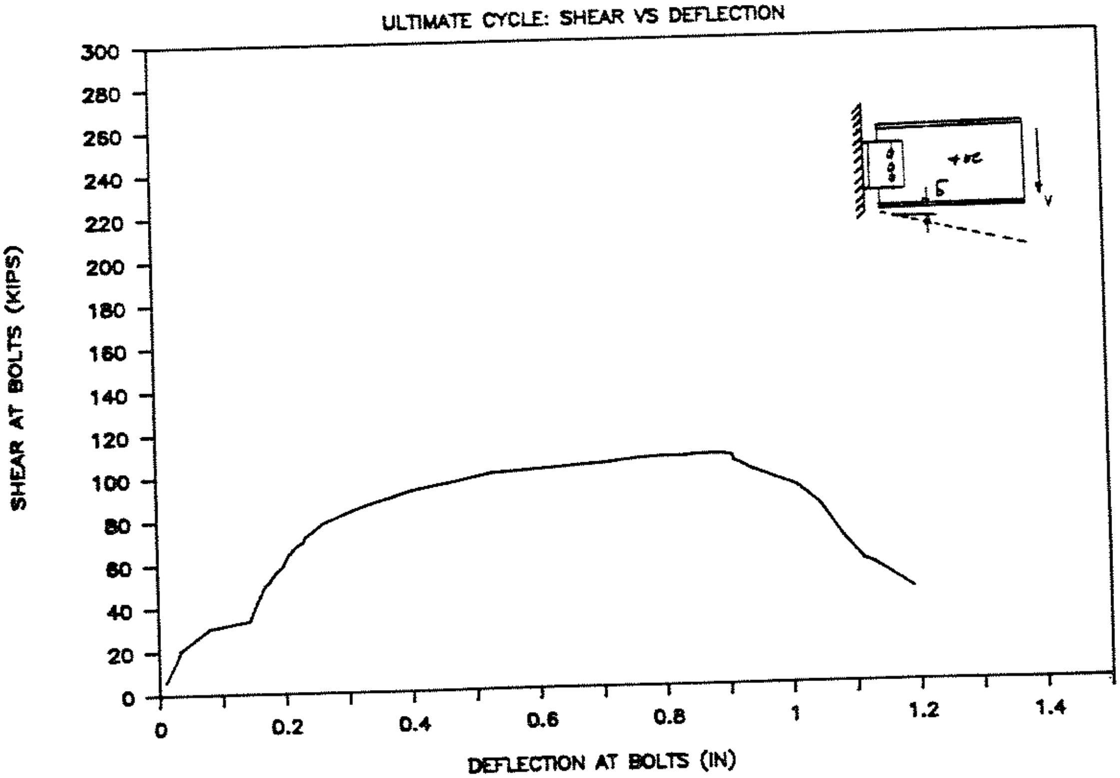
AISC TEE–TEST # 3

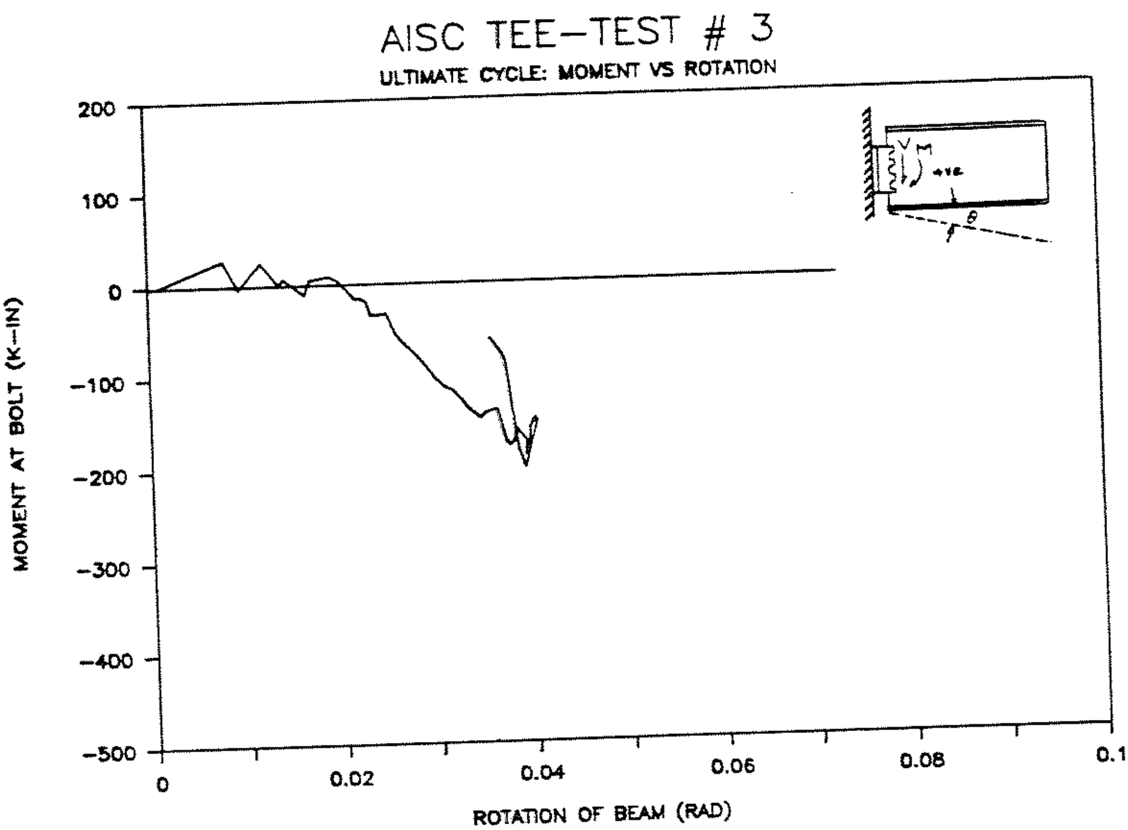
ULTIMATE CYCLE: SHEAR VS ROTATION

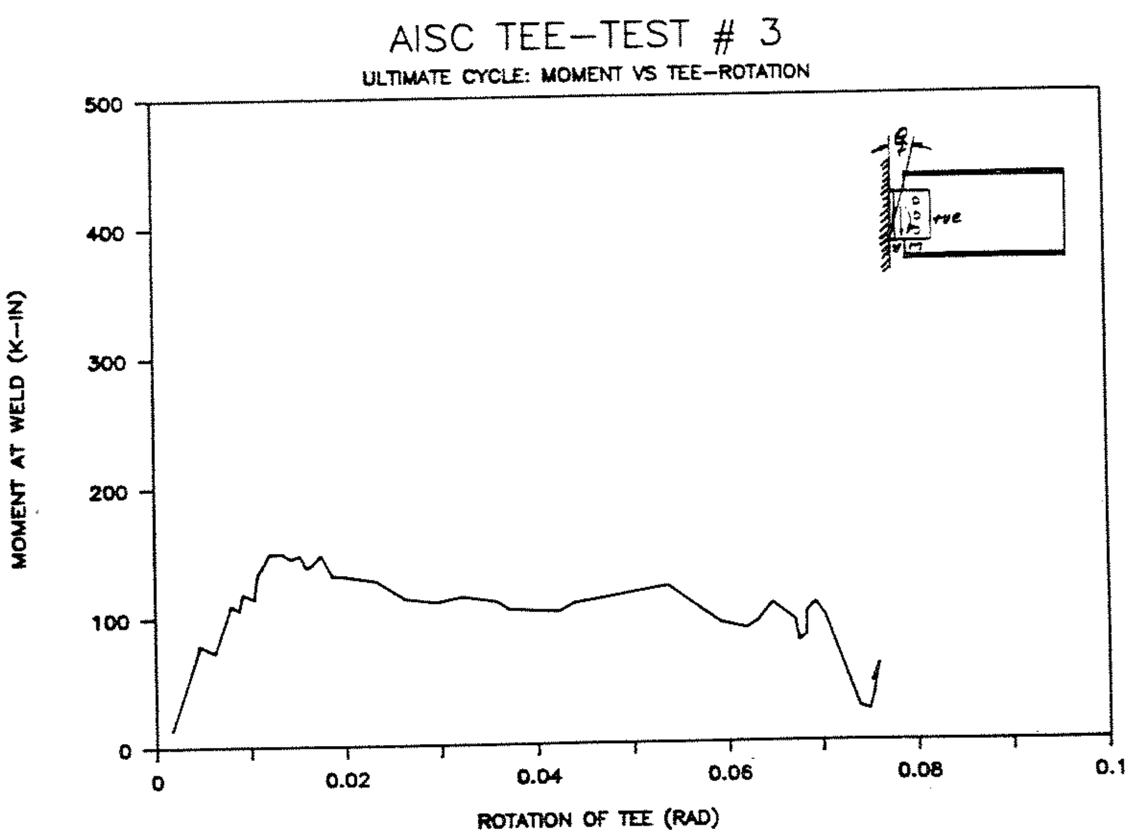


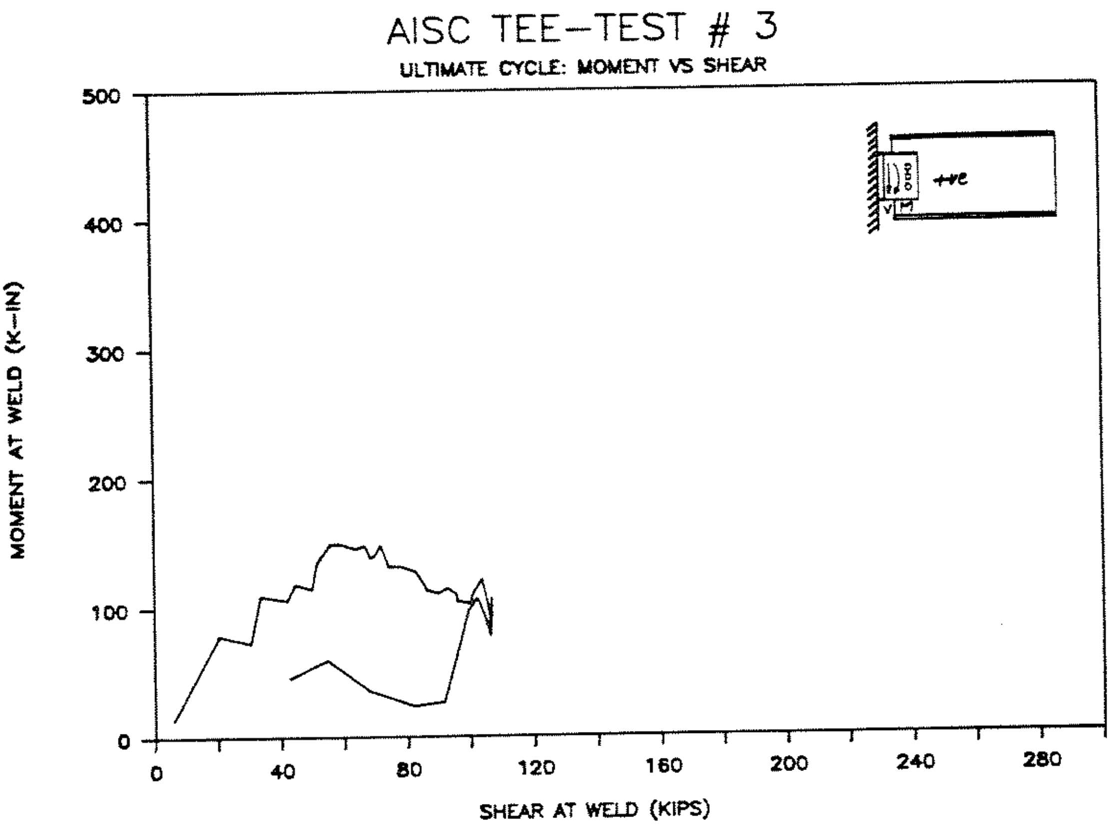
AISC TEE–TEST # 3

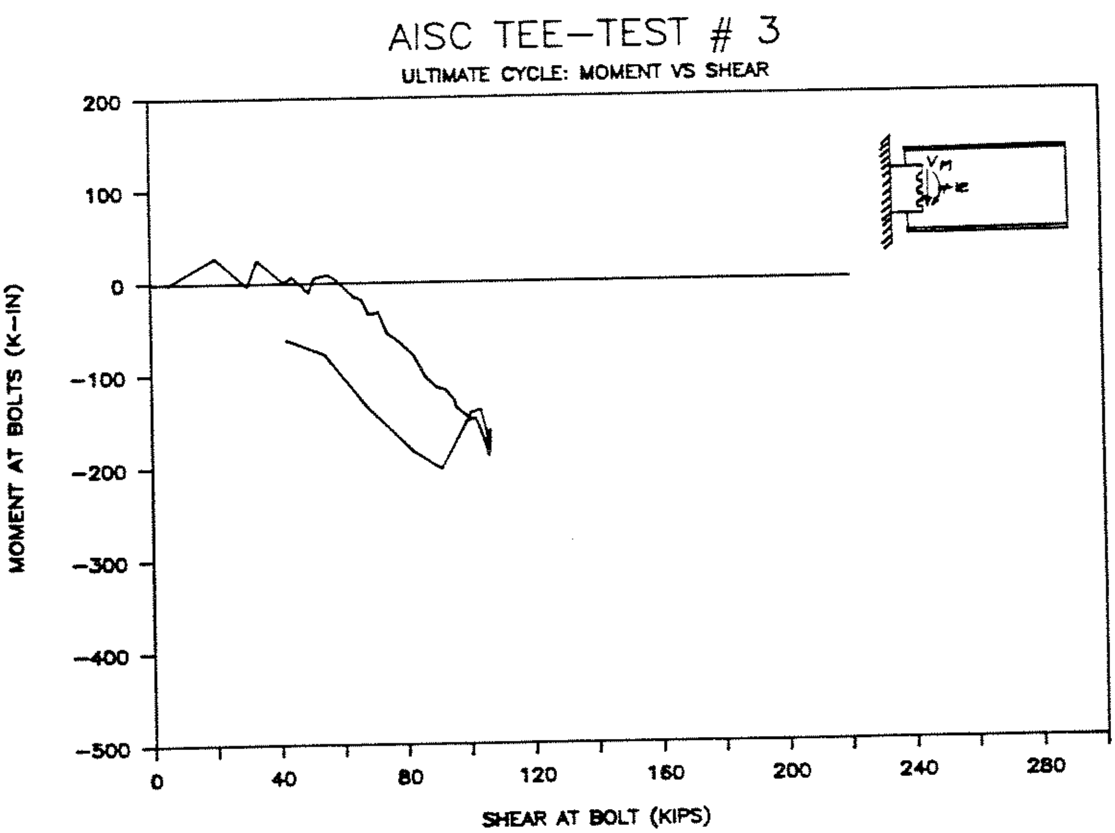
ULTIMATE CYCLE: SHEAR VS DEFLECTION

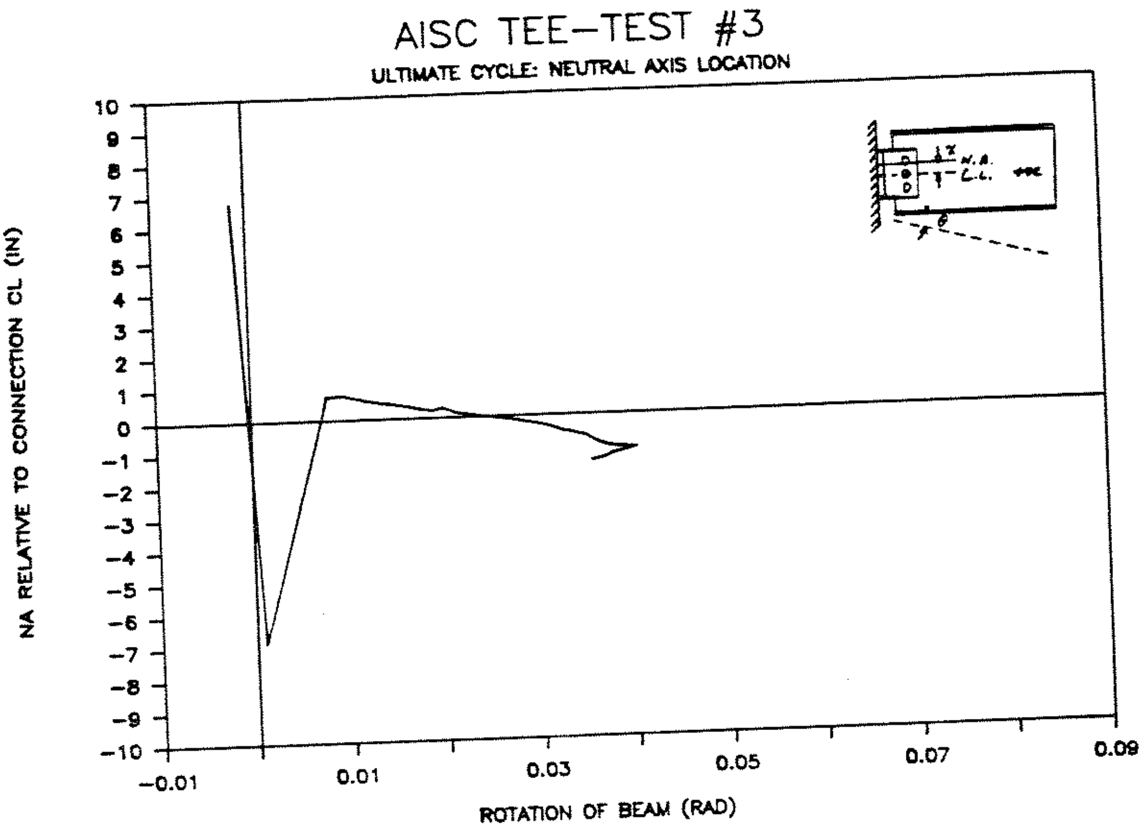



AISC TEE-TEST # 3
ULTIMATE CYCLE: MOMENT VS ROTATION
MOMENT AT BOLT (K-IN)
ROTATION OF BEAM (RAD)
200
100
0
-100
-200
-300
-400
-500
0
0.02
0.04
0.06
0.08
0.1
+ve

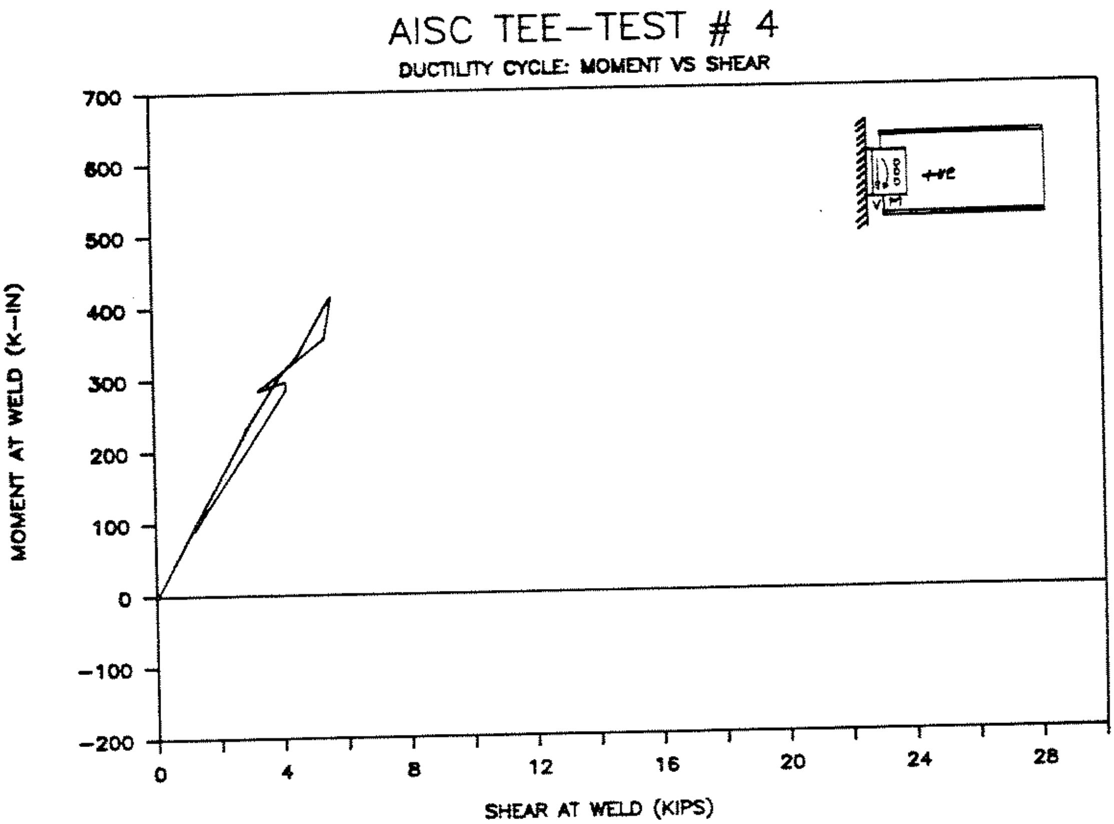

AISC TEE-TEST # 3
ULTIMATE CYCLE: MOMENT VS TEE-ROTATION
MOMENT AT WELD (K-IN)
ROTATION OF TEE (RAD)
500
400
300
200
100
0
0
0.02
0.04
0.06
0.08
0.1
+ve


AISC TEE-TEST # 3
ULTIMATE CYCLE: MOMENT VS SHEAR
MOMENT AT WELD (K-IN)
SHEAR AT WELD (KIPS)
500
400
300
200
100
0
0
40
80
120
160
200
240
280
+ve

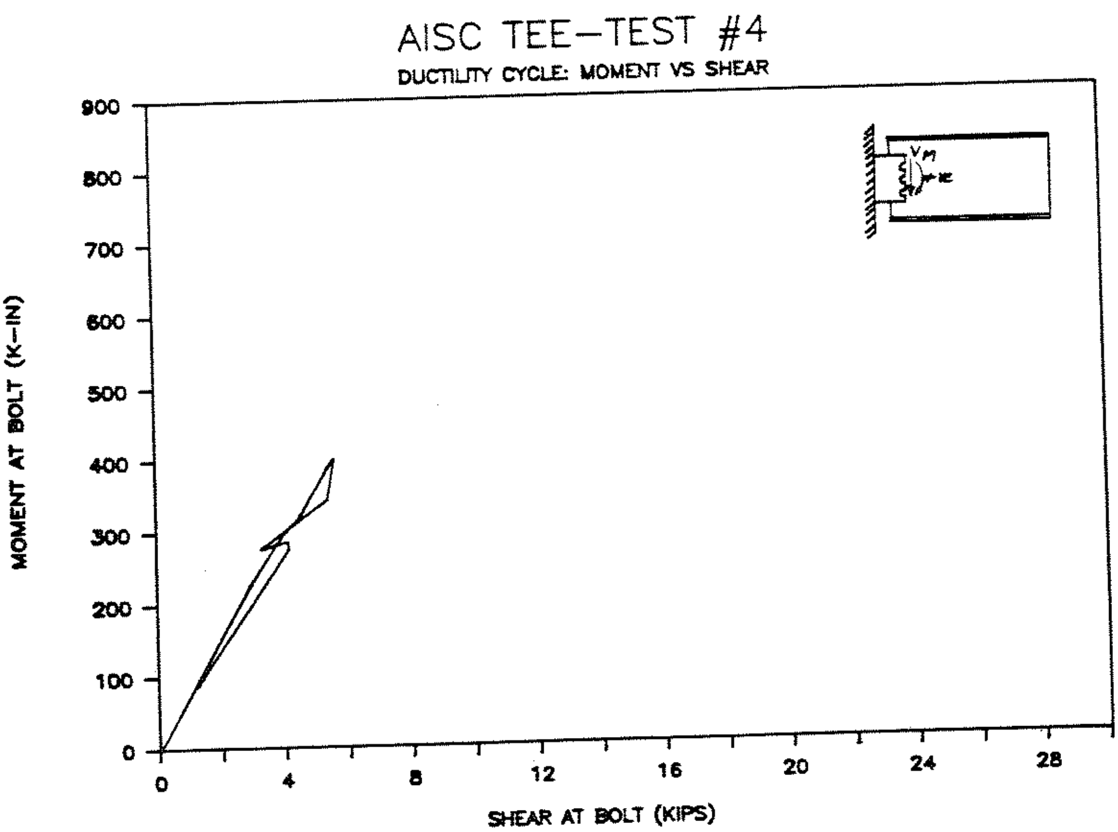

AISC TEE-TEST # 3
ULTIMATE CYCLE: MOMENT VS SHEAR
MOMENT AT BOLTS (K-IN)
SHEAR AT BOLT (KIPS)
200
100
0
-100
-200
-300
-400
-500
0
40
80
120
160
200
240
280



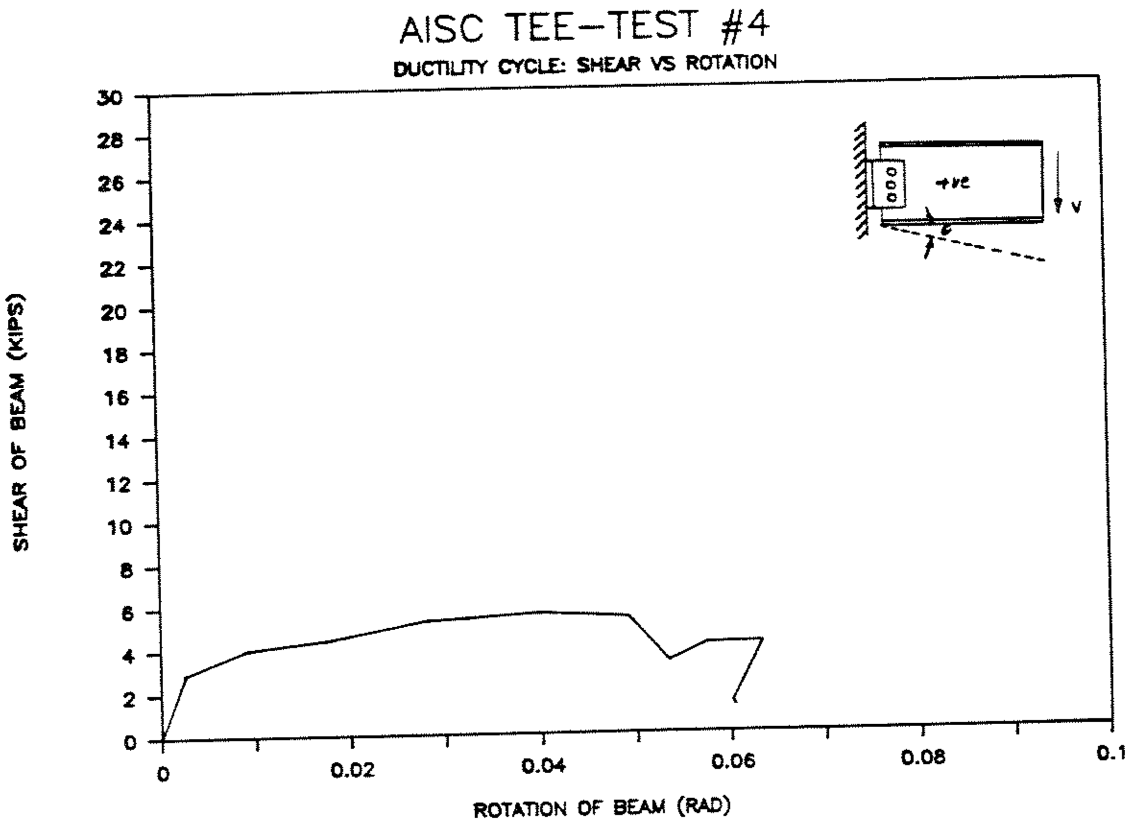
AISC TEE–TEST #3
ULTIMATE CYCLE: NEUTRAL AXIS LOCATION
NA RELATIVE TO CONNECTION CL (IN)
ROTATION OF BEAM (RAD)
10
9
8
7
6
5
4
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
−0.01
0.01
0.03
0.05
0.07
0.09
N.A.
C.L.

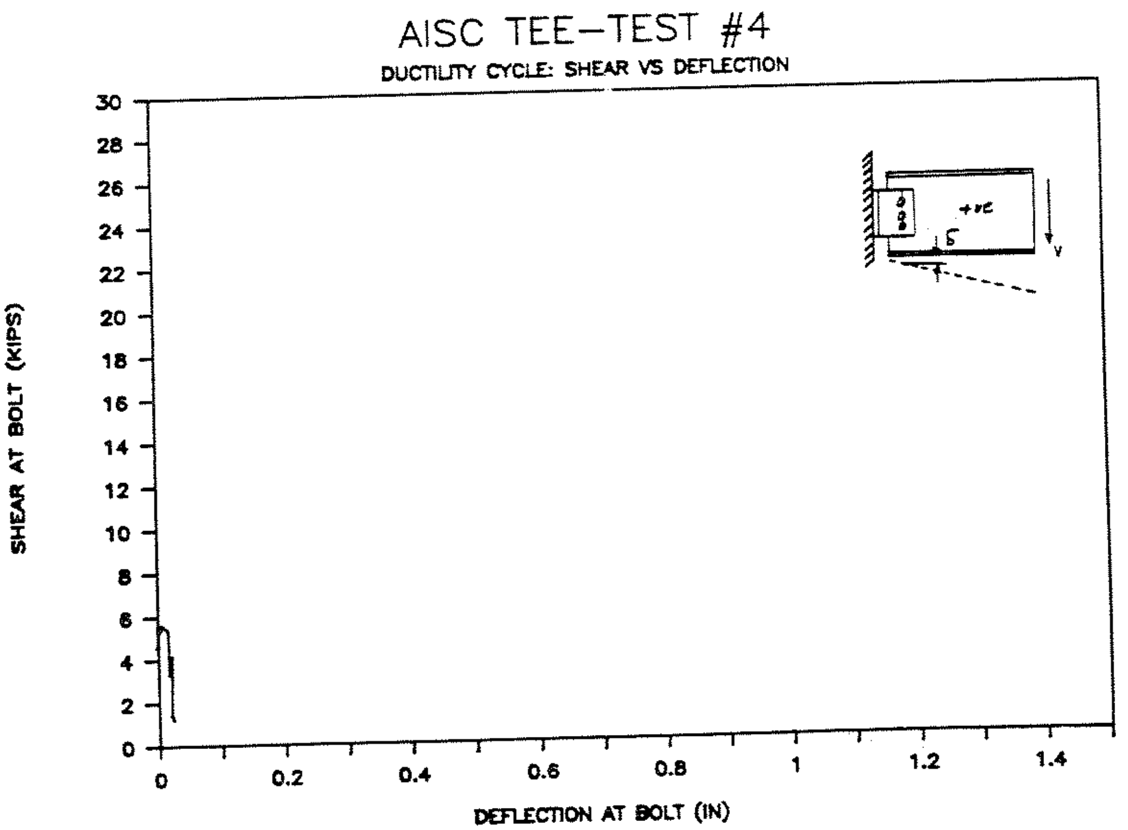


AISC TEE—TEST # 4
DUCTILITY CYCLE: MOMENT VS SHEAR
MOMENT AT WELD (K—IN)
SHEAR AT WELD (KIPS)
700
600
500
400
300
200
100
0
−100
−200
0
4
8
12
16
20
24
28

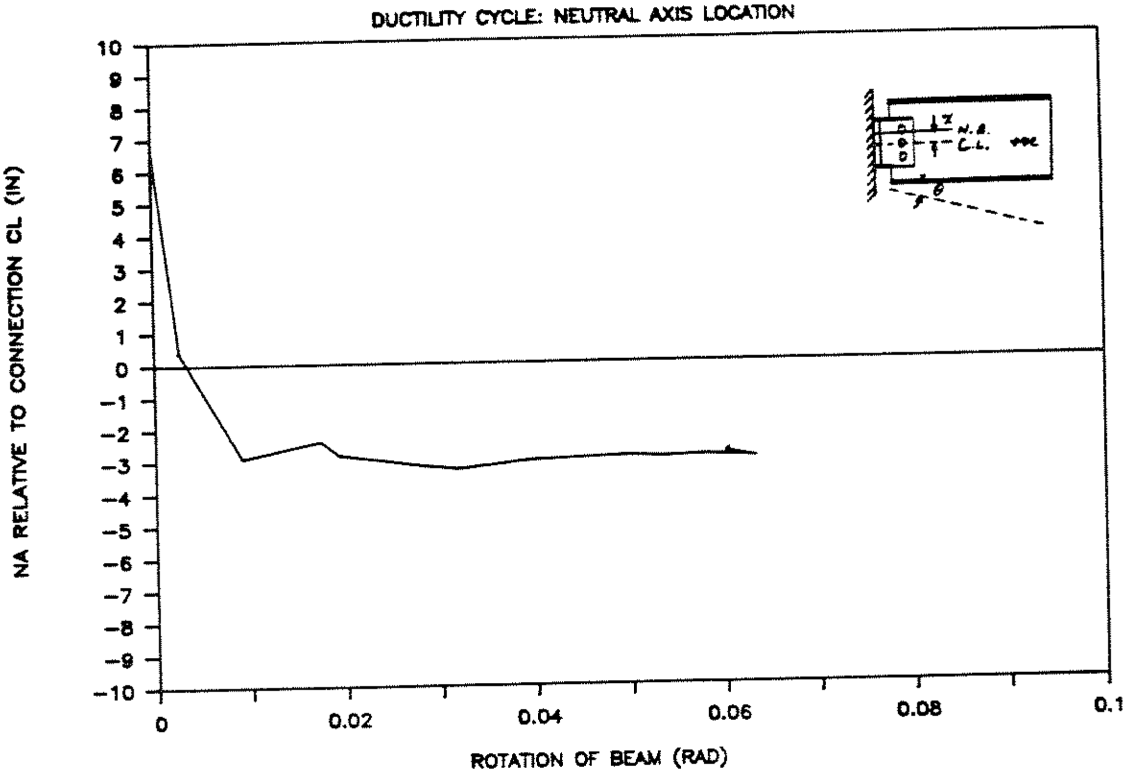


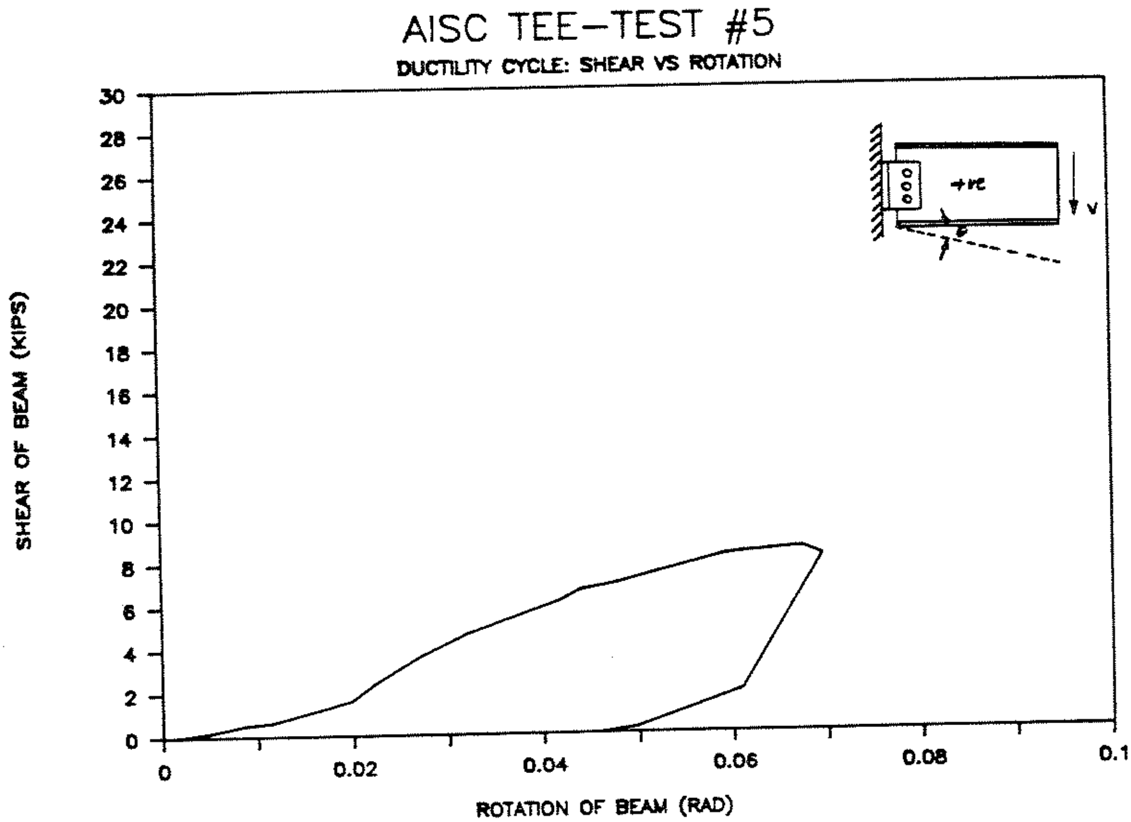
AISC TEE—TEST #4
DUCTILITY CYCLE: MOMENT VS SHEAR
MOMENT AT BOLT (K—IN)
SHEAR AT BOLT (KIPS)
900
800
700
600
500
400
300
200
100
0
0
4
8
12
16
20
24
28

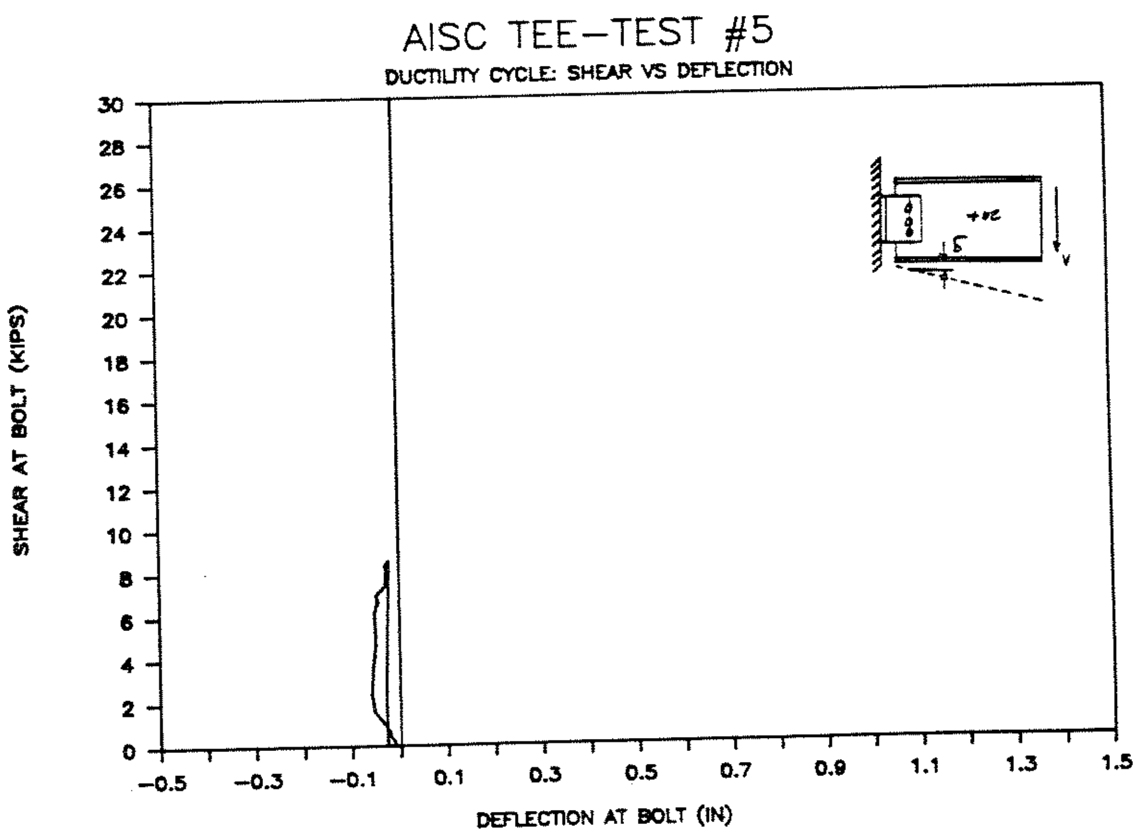

AISC TEE-TEST #4
DUCTILITY CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION OF BEAM (RAD)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0.02
0.04
0.06
0.08
0.1
+ve
V

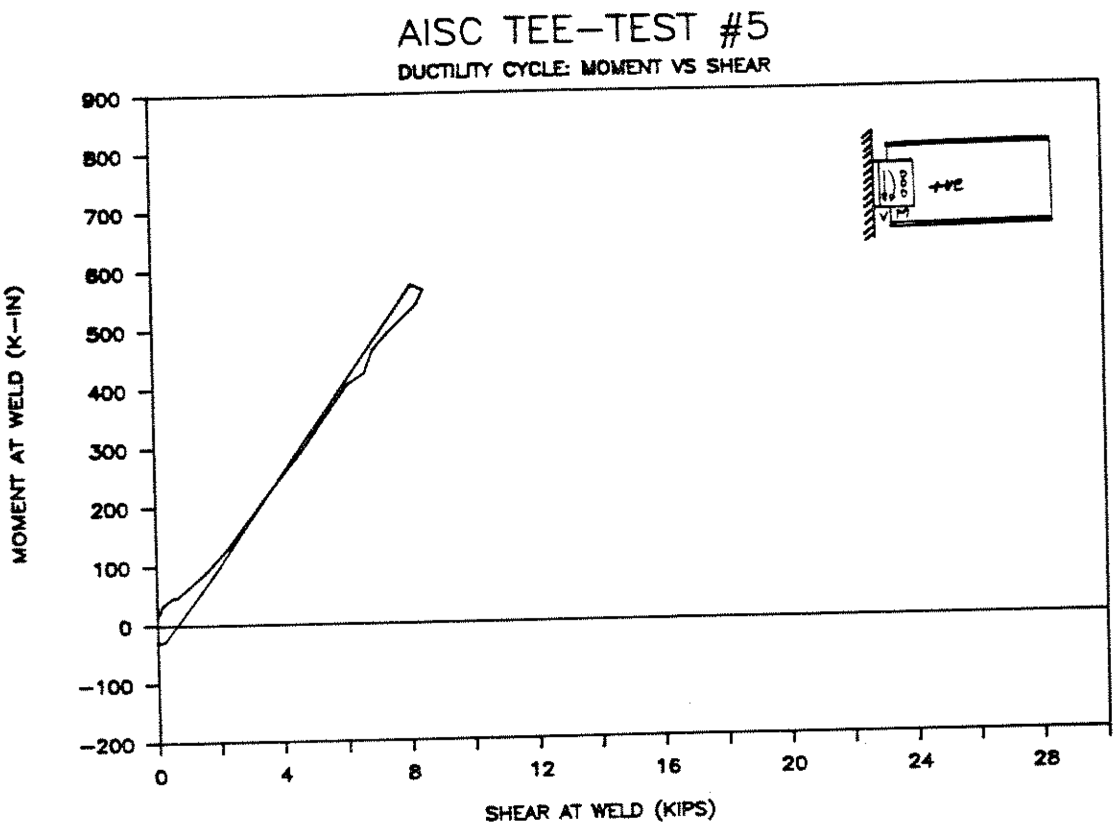

AISC TEE-TEST #4
DUCTILITY CYCLE: SHEAR VS DEFLECTION
SHEAR AT BOLT (KIPS)
DEFLECTION AT BOLT (IN)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0.2
0.4
0.6
0.8
1
1.2
1.4
+ve
V

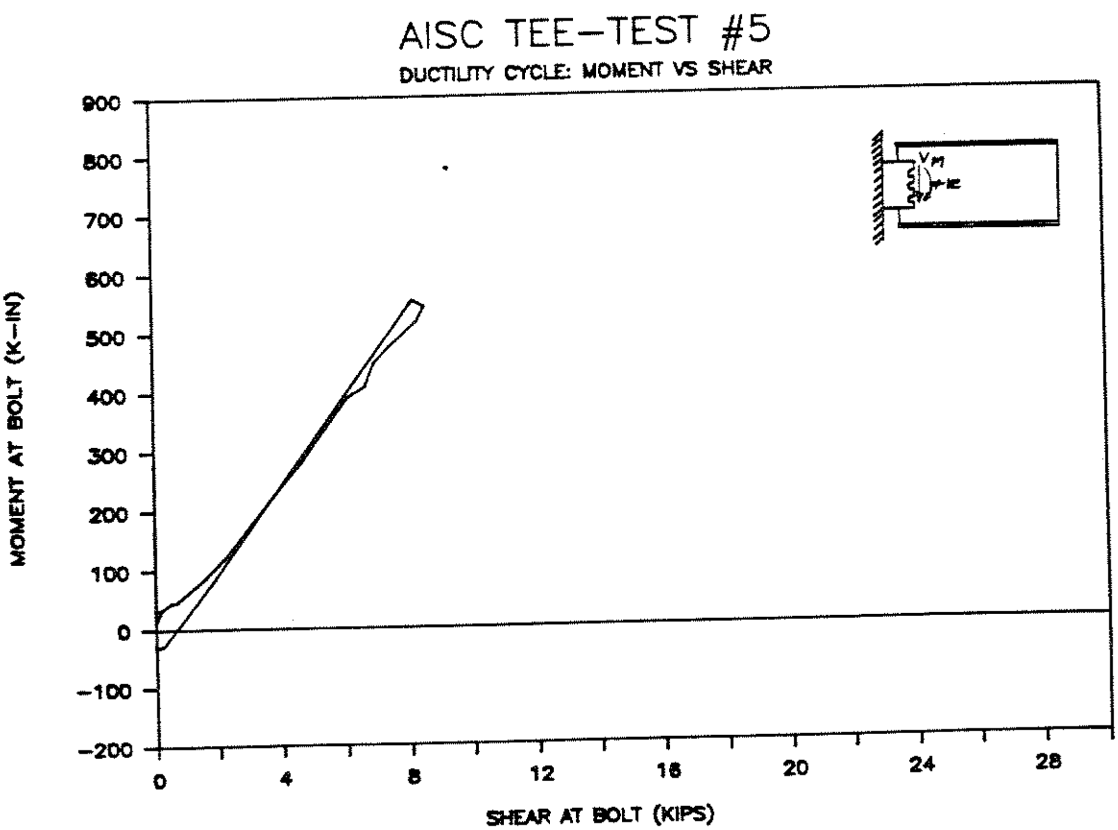
AISC TEE−TEST # 4



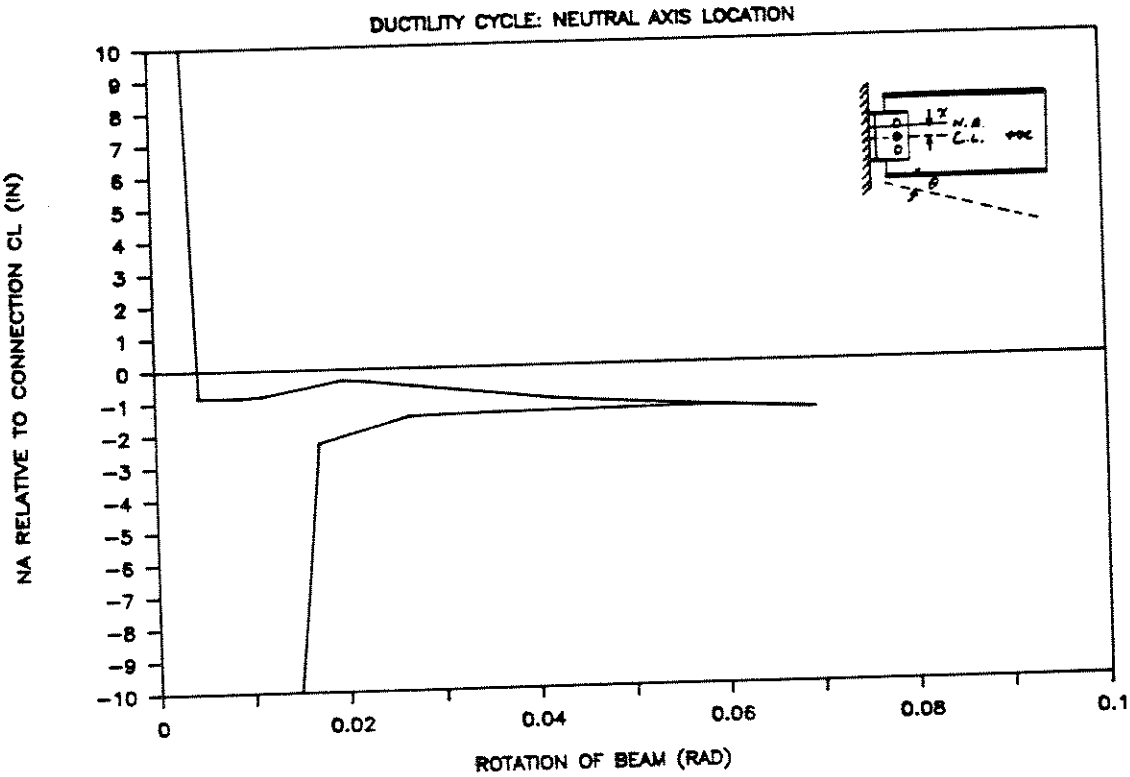

AISC TEE-TEST #5
DUCTILITY CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION OF BEAM (RAD)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0.02
0.04
0.06
0.08
0.1
+ve
V

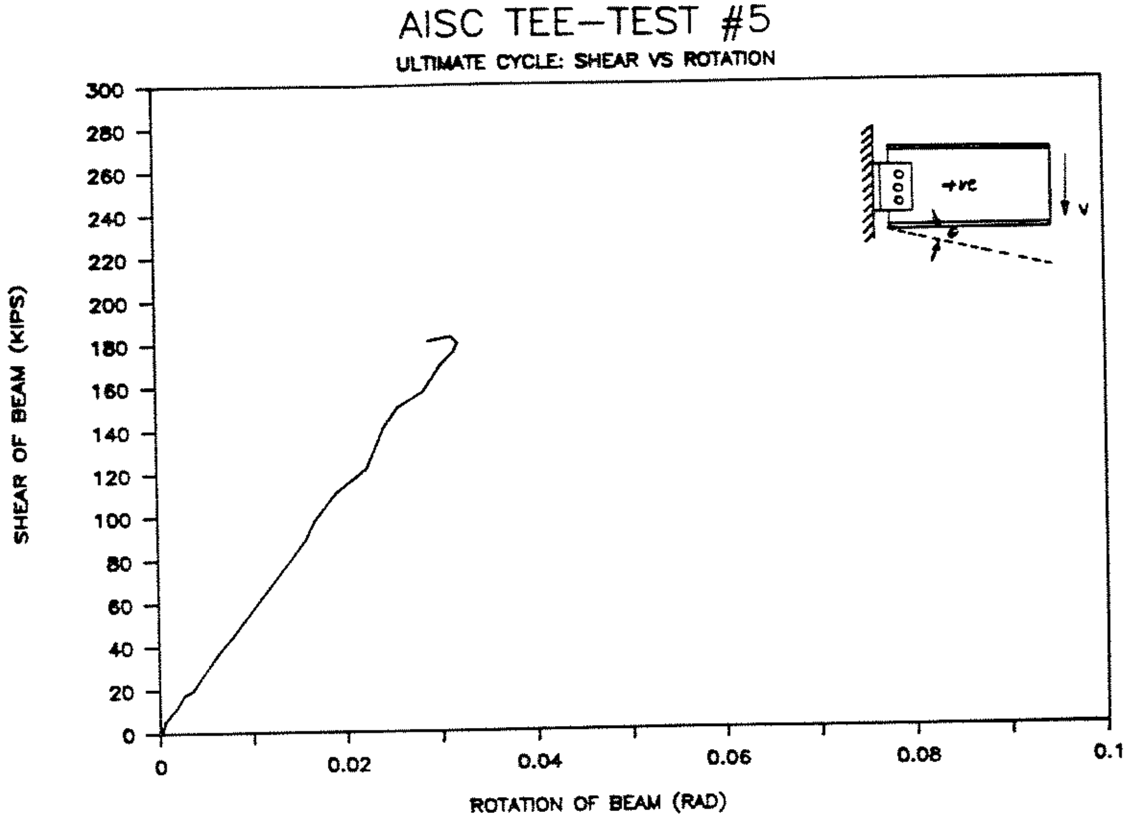

AISC TEE-TEST #5
DUCTILITY CYCLE: SHEAR VS DEFLECTION
SHEAR AT BOLT (KIPS)
DEFLECTION AT BOLT (IN)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
−0.5
−0.3
−0.1
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
+ve
V

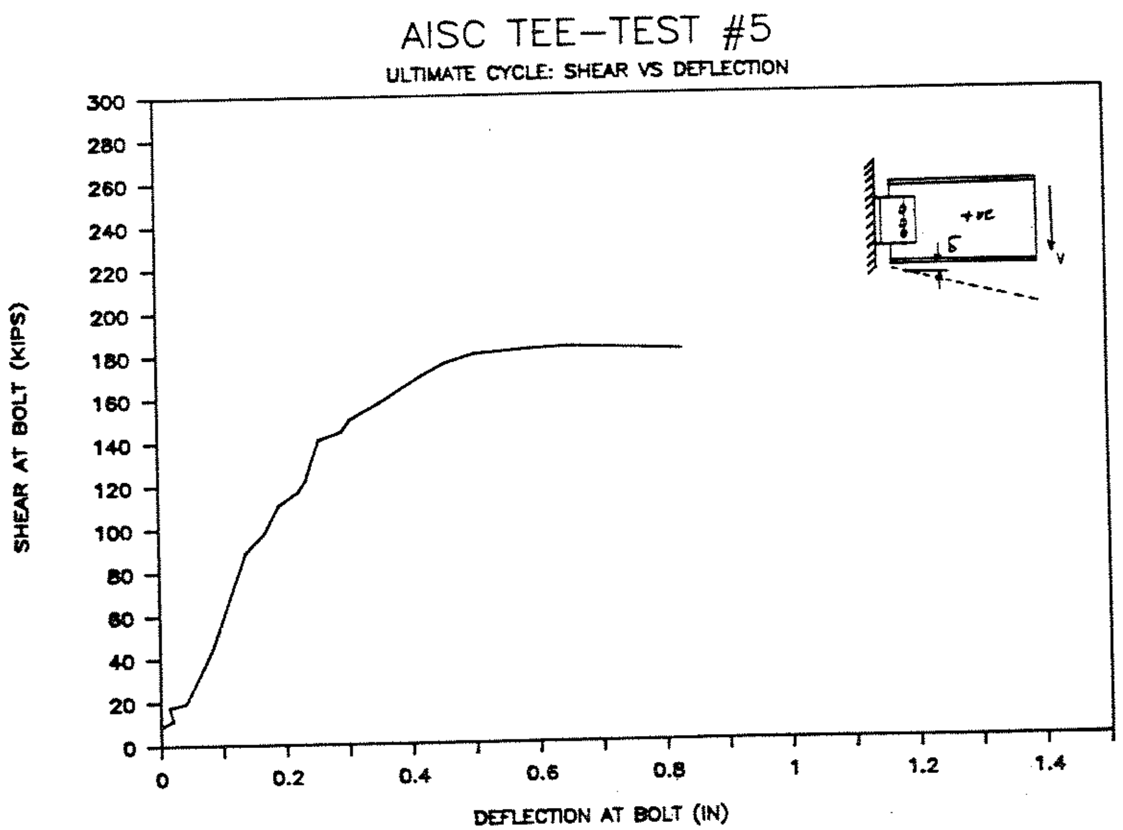

AISC TEE–TEST #5
DUCTILITY CYCLE: MOMENT VS SHEAR
MOMENT AT WELD (K–IN)
SHEAR AT WELD (KIPS)
900
800
700
600
500
400
300
200
100
0
−100
−200
0
4
8
12
16
20
24
28

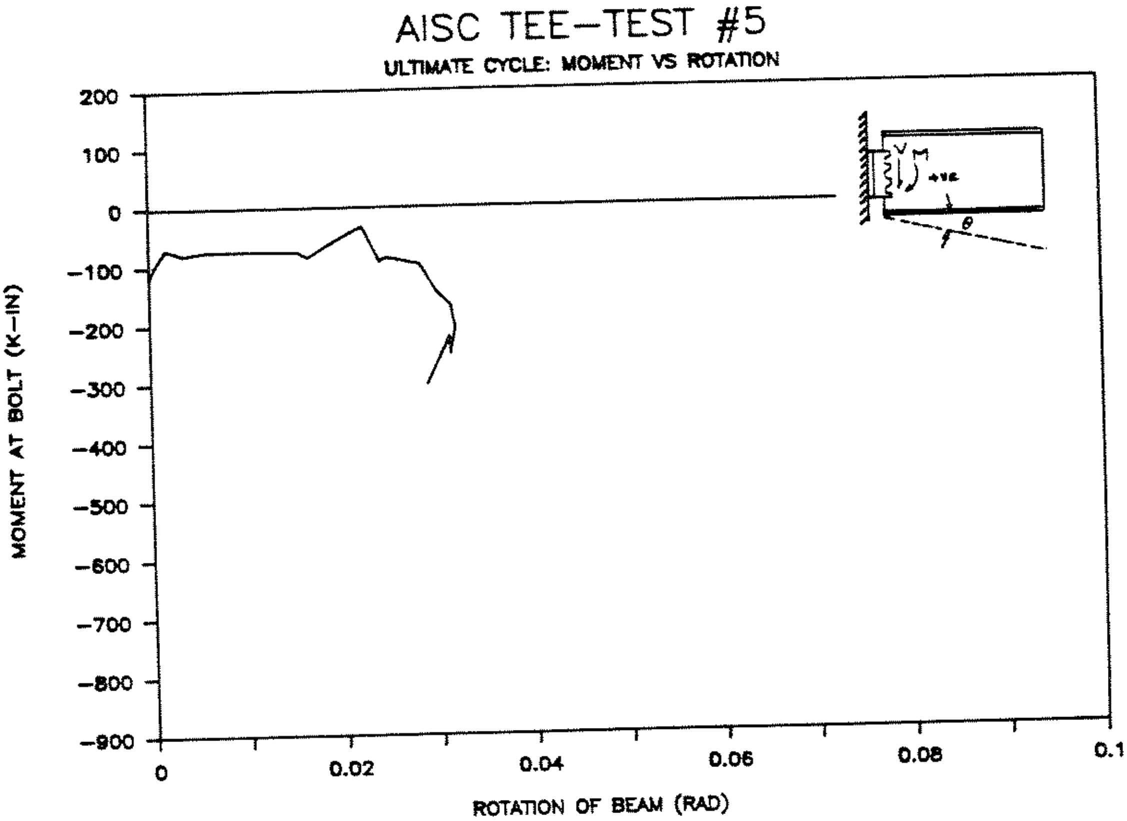

AISC TEE–TEST #5
DUCTILITY CYCLE: MOMENT VS SHEAR
MOMENT AT BOLT (K–IN)
SHEAR AT BOLT (KIPS)
900
800
700
600
500
400
300
200
100
0
−100
−200
0
4
8
12
16
20
24
28

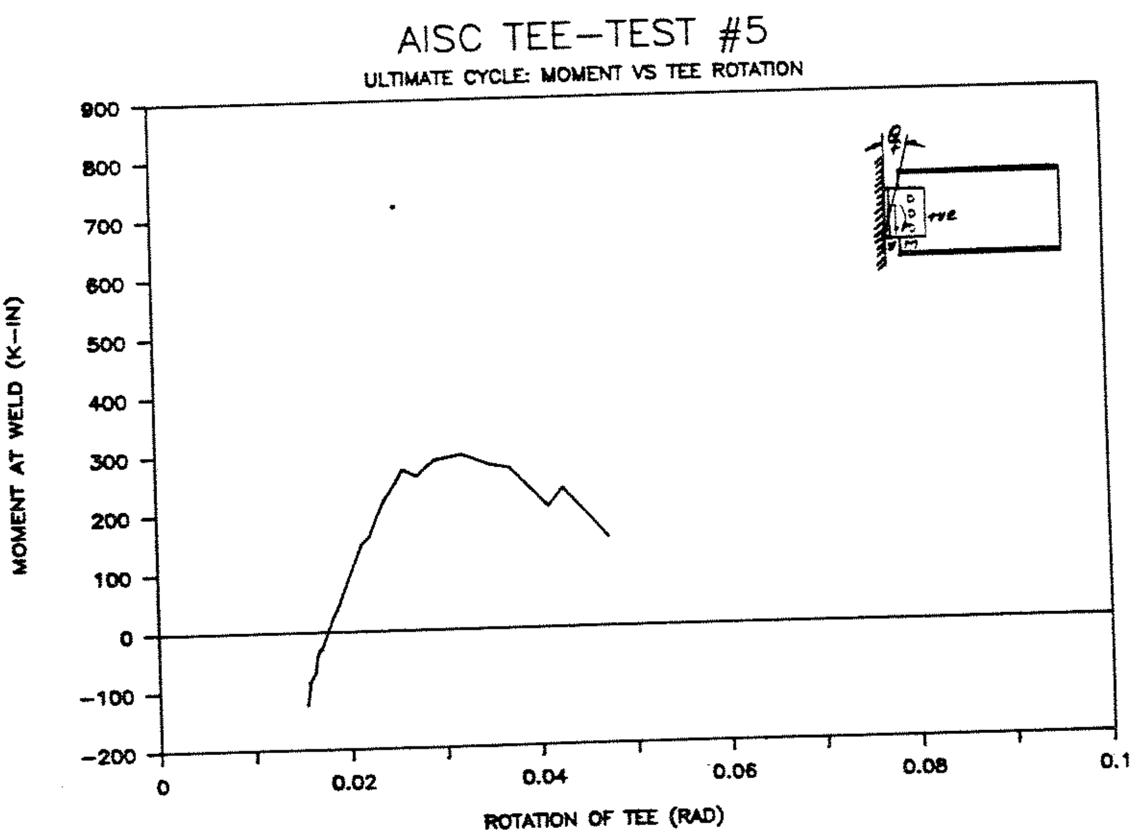
AISC TEE–TEST #5




AISC TEE-TEST #5
ULTIMATE CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION OF BEAM (RAD)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
0.02
0.04
0.06
0.08
0.1
+ve
V

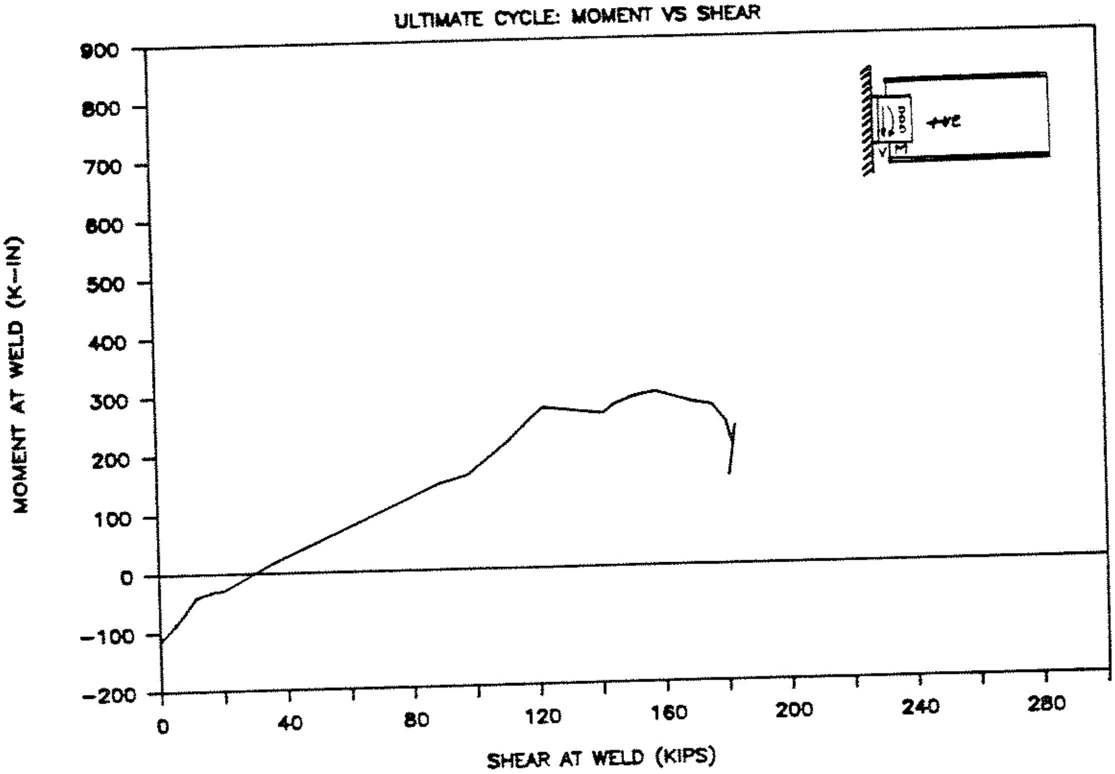

AISC TEE-TEST #5
ULTIMATE CYCLE: SHEAR VS DEFLECTION
SHEAR AT BOLT (KIPS)
DEFLECTION AT BOLT (IN)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
0.2
0.4
0.6
0.8
1
1.2
1.4
+ve
V


AISC TEE–TEST #5
ULTIMATE CYCLE: MOMENT VS ROTATION
MOMENT AT BOLT (K–IN)
ROTATION OF BEAM (RAD)
200
100
0
−100
−200
−300
−400
−500
−600
−700
−800
−900
0
0.02
0.04
0.06
0.08
0.1
V
M
+ve
θ


AISC TEE–TEST #5
ULTIMATE CYCLE: MOMENT VS TEE ROTATION
MOMENT AT WELD (K–IN)
ROTATION OF TEE (RAD)
900
800
700
600
500
400
300
200
100
0
−100
−200
0
0.02
0.04
0.06
0.08
0.1
θ
+ve
V
M

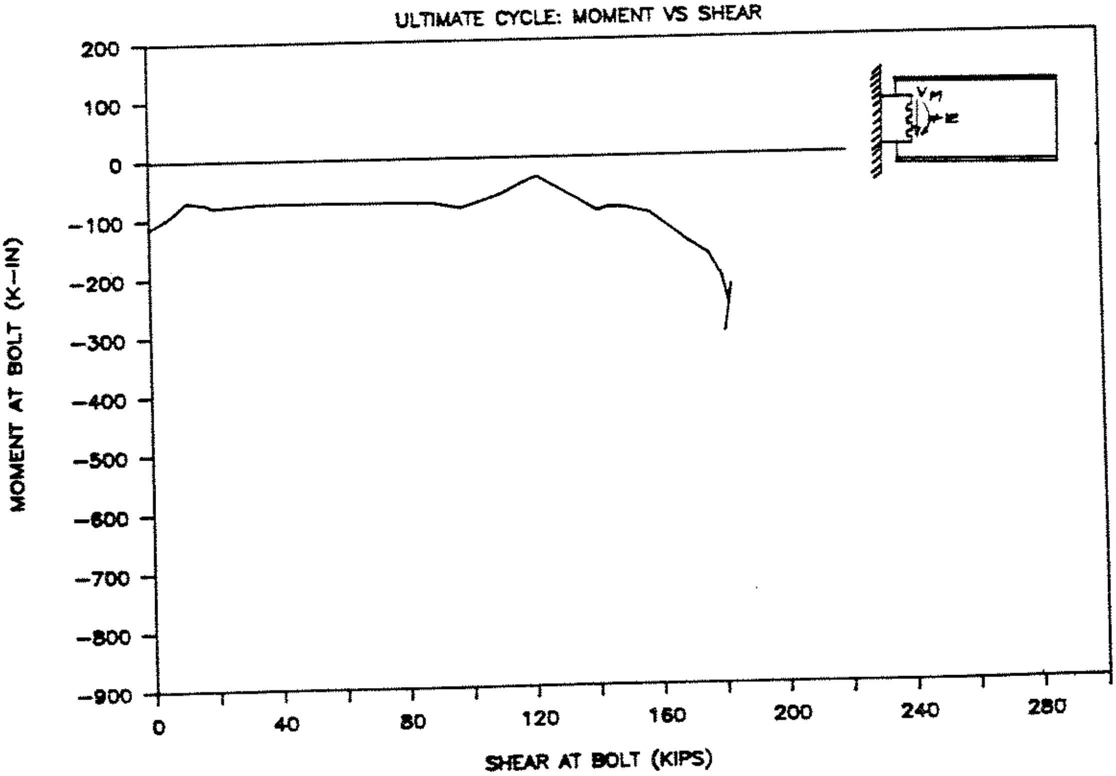
AISC TEE–TEST #5

ULTIMATE CYCLE: MOMENT VS SHEAR



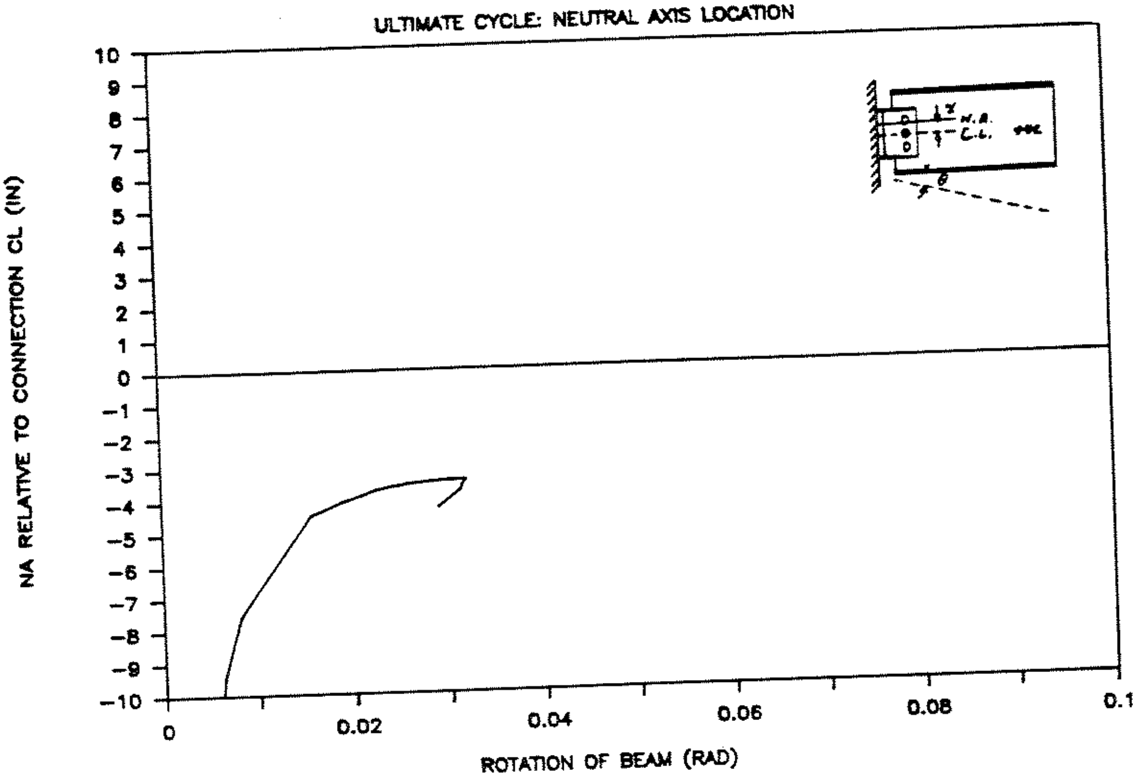
AISC TEE–TEST #5

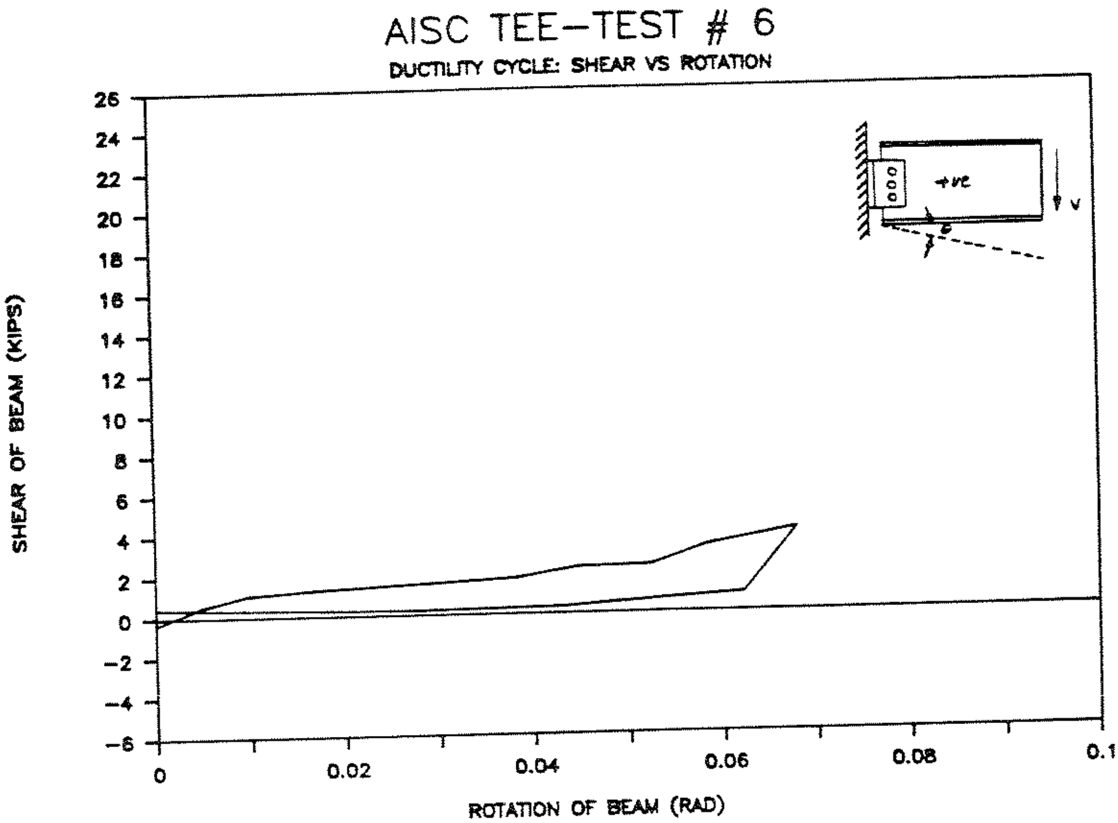
ULTIMATE CYCLE: MOMENT VS SHEAR

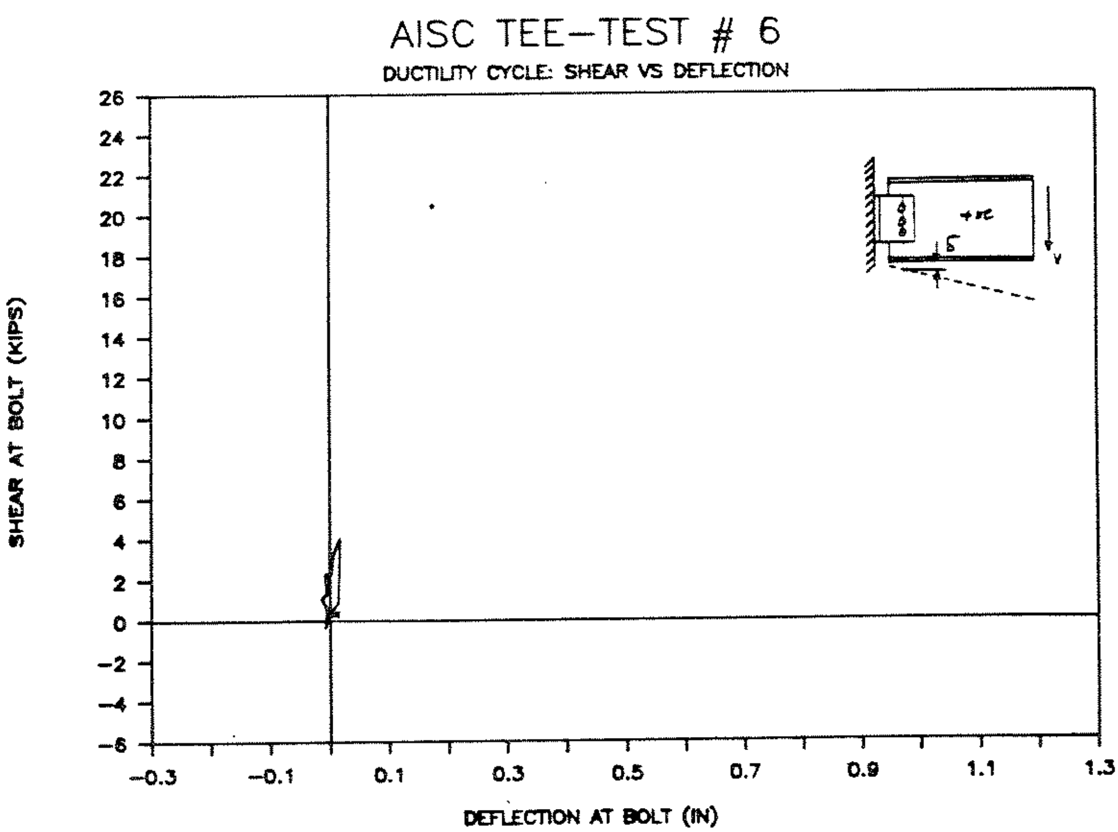


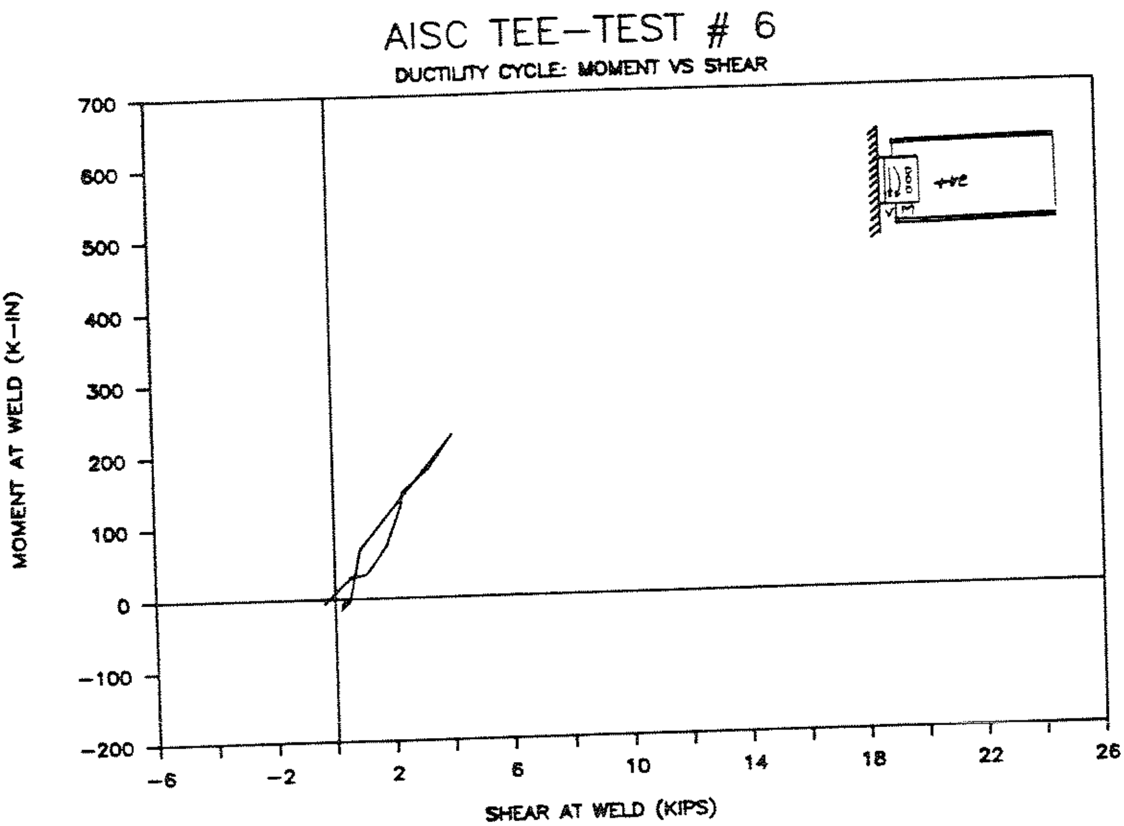
AISC TEE-TEST #5

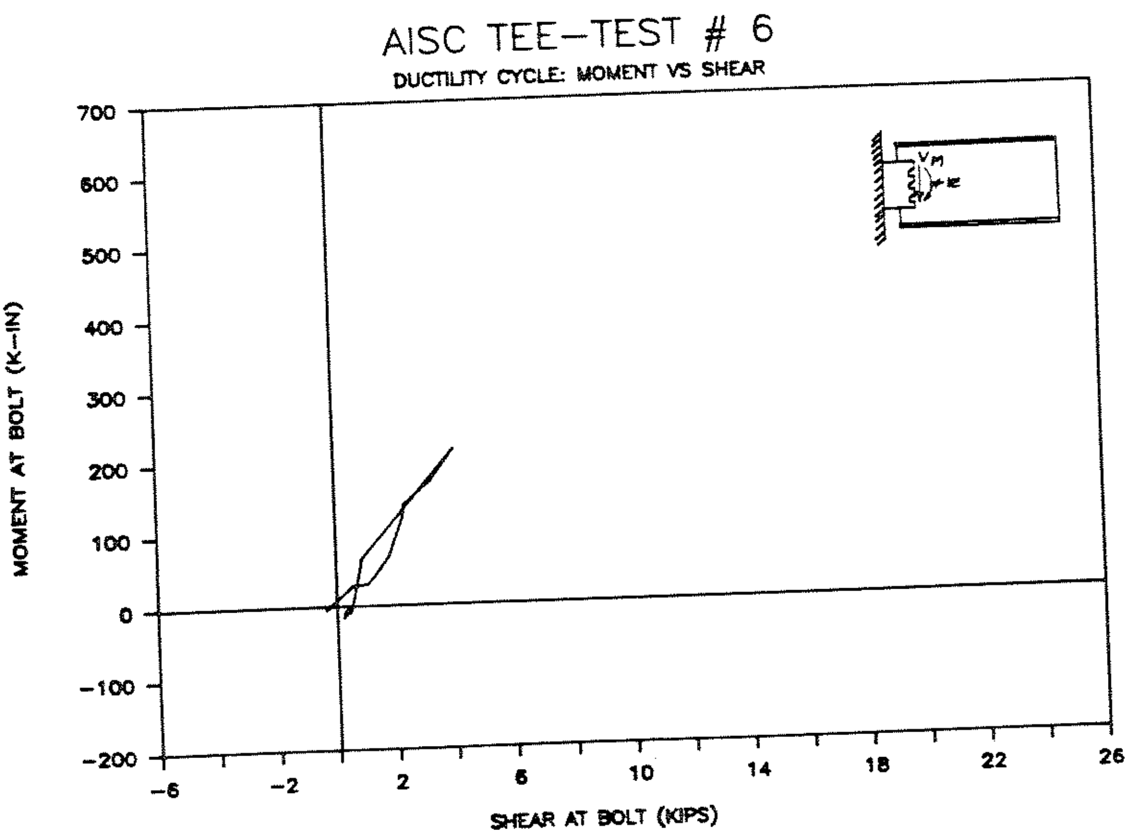
ULTIMATE CYCLE: NEUTRAL AXIS LOCATION

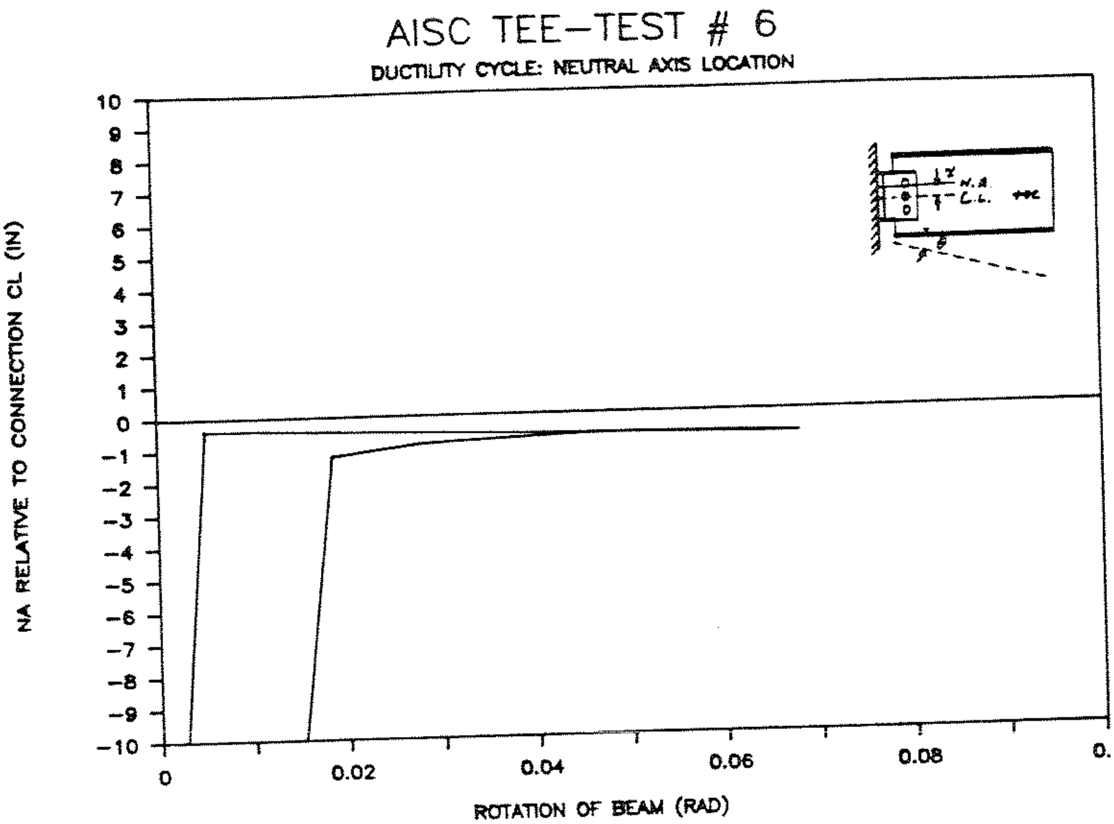



AISC TEE—TEST # 6
DUCTILITY CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION OF BEAM (RAD)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
−2
−4
−6
0
0.02
0.04
0.06
0.08
0.1
+ve
V

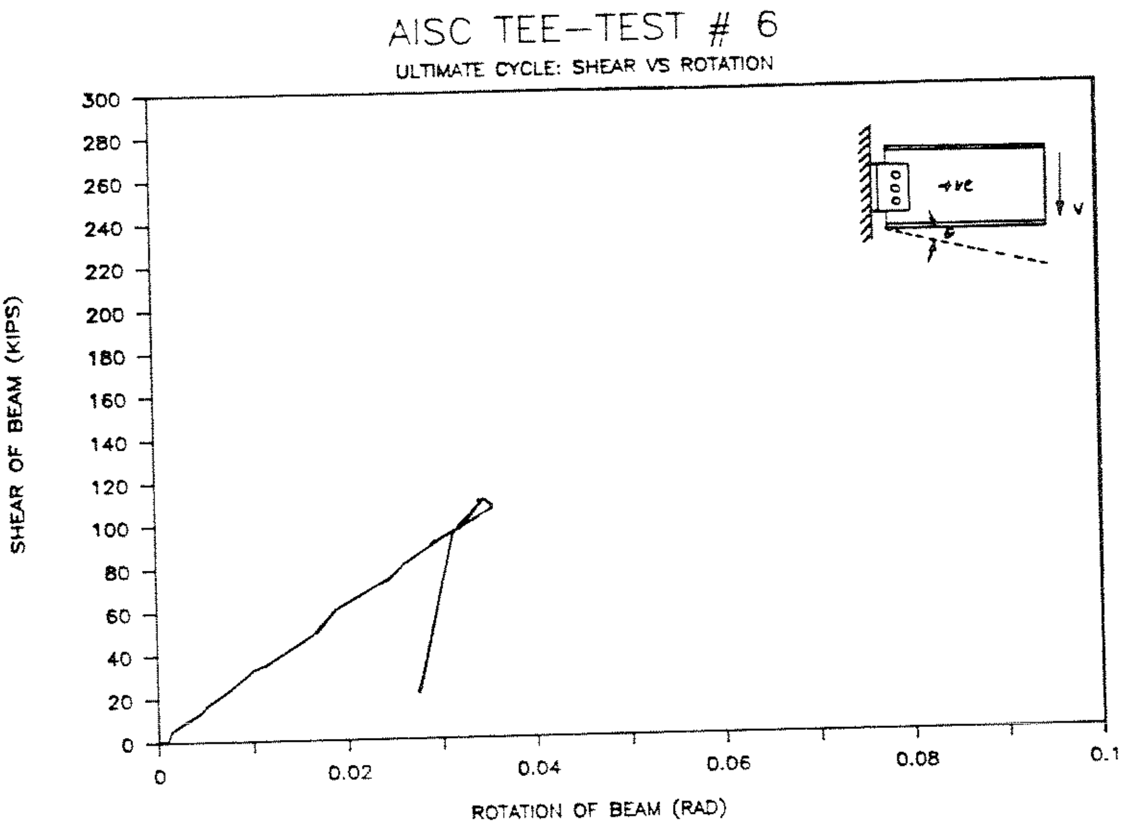

AISC TEE—TEST # 6
DUCTILITY CYCLE: SHEAR VS DEFLECTION
SHEAR AT BOLT (KIPS)
DEFLECTION AT BOLT (IN)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
−2
−4
−6
−0.3
−0.1
0.1
0.3
0.5
0.7
0.9
1.1
1.3
+ve
V

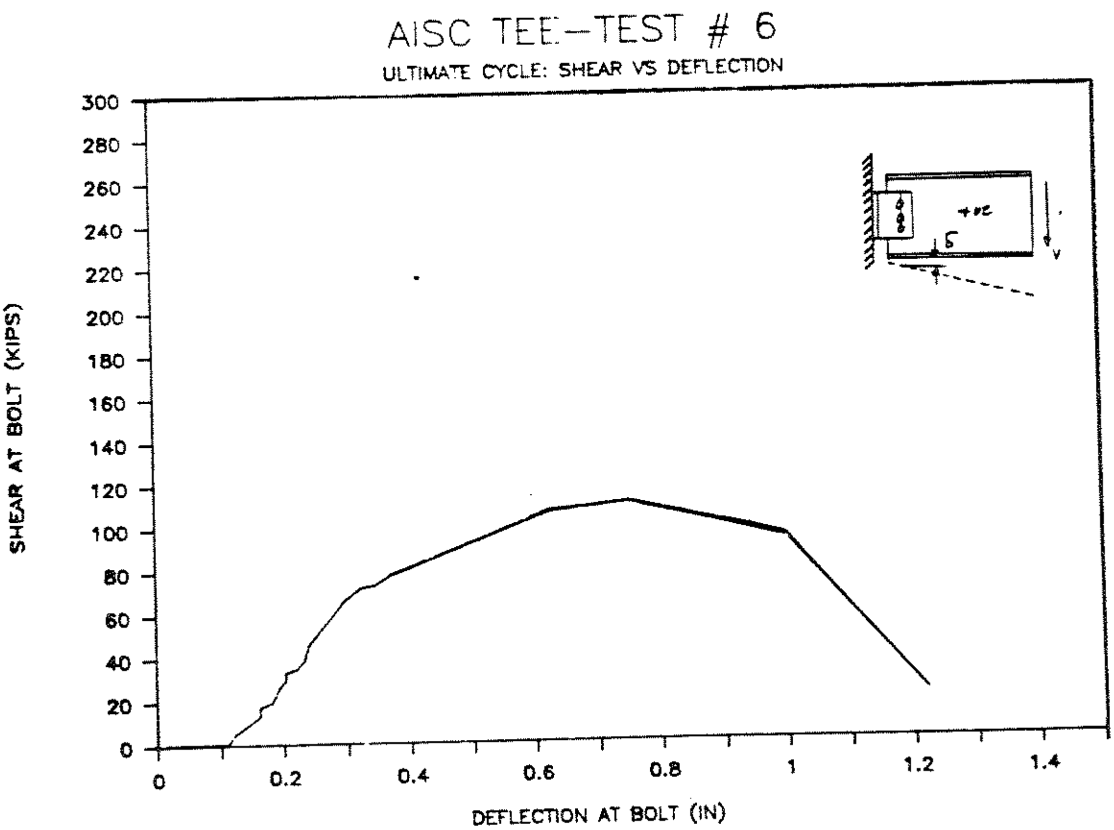

AISC TEE-TEST # 6
DUCTILITY CYCLE: MOMENT VS SHEAR
MOMENT AT WELD (K-IN)
SHEAR AT WELD (KIPS)
700
600
500
400
300
200
100
0
-100
-200
-6
-2
2
6
10
14
18
22
26
+ve

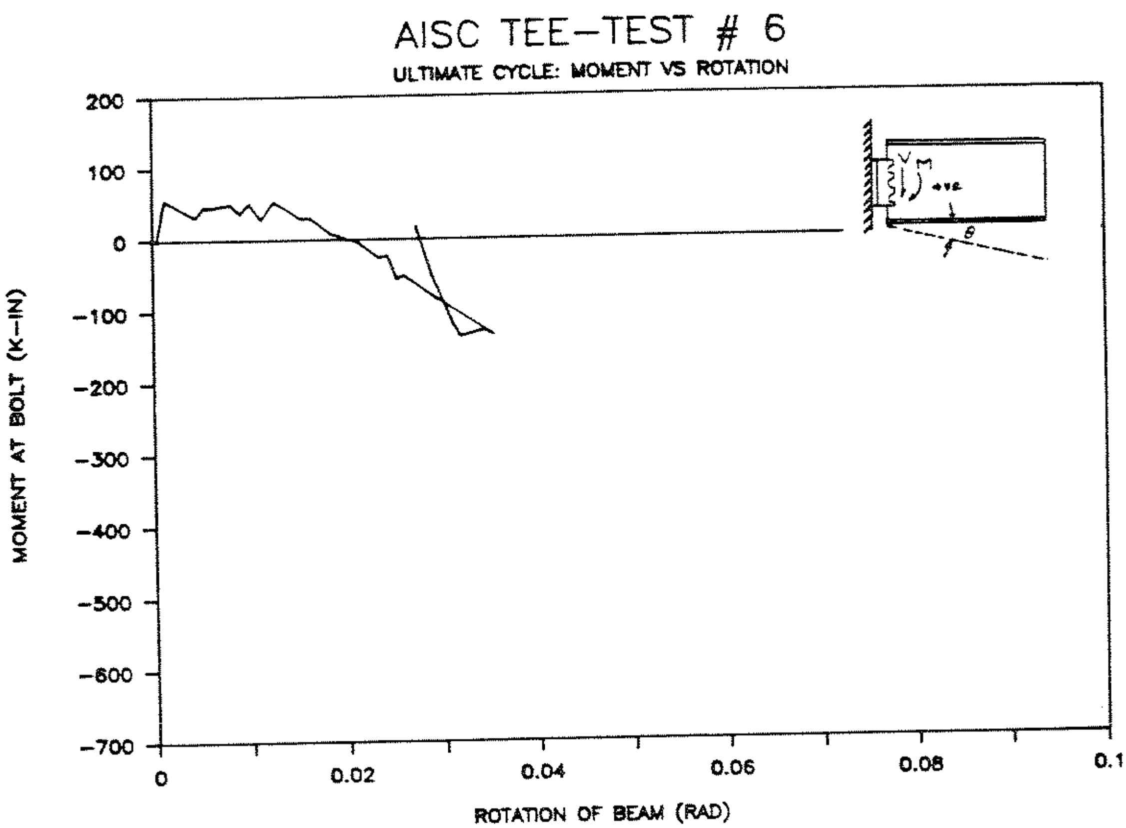

AISC TEE-TEST # 6
DUCTILITY CYCLE: MOMENT VS SHEAR
MOMENT AT BOLT (K-IN)
SHEAR AT BOLT (KIPS)
700
600
500
400
300
200
100
0
-100
-200
-6
-2
2
6
10
14
18
22
26

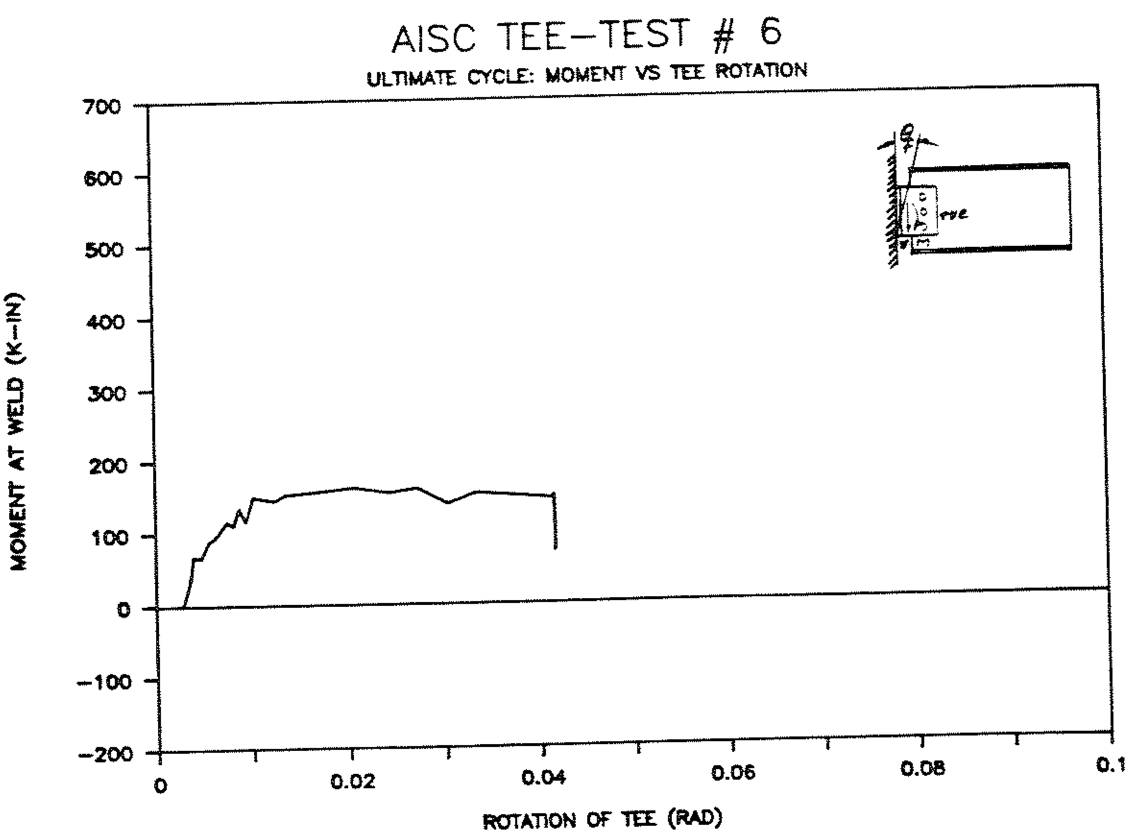


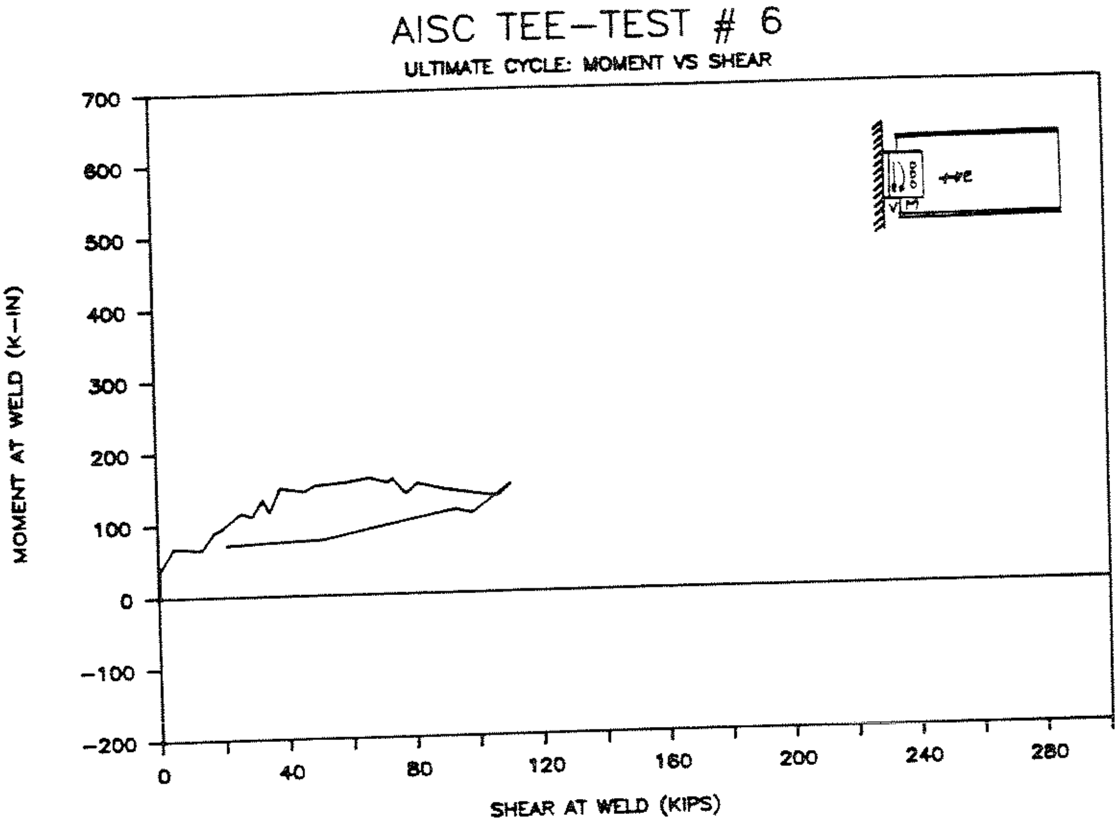
AISC TEE-TEST # 6
DUCTILITY CYCLE: NEUTRAL AXIS LOCATION
NA RELATIVE TO CONNECTION CL (IN)
ROTATION OF BEAM (RAD)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
0
0.02
0.04
0.06
0.08
0.1
N.A.
C.L.

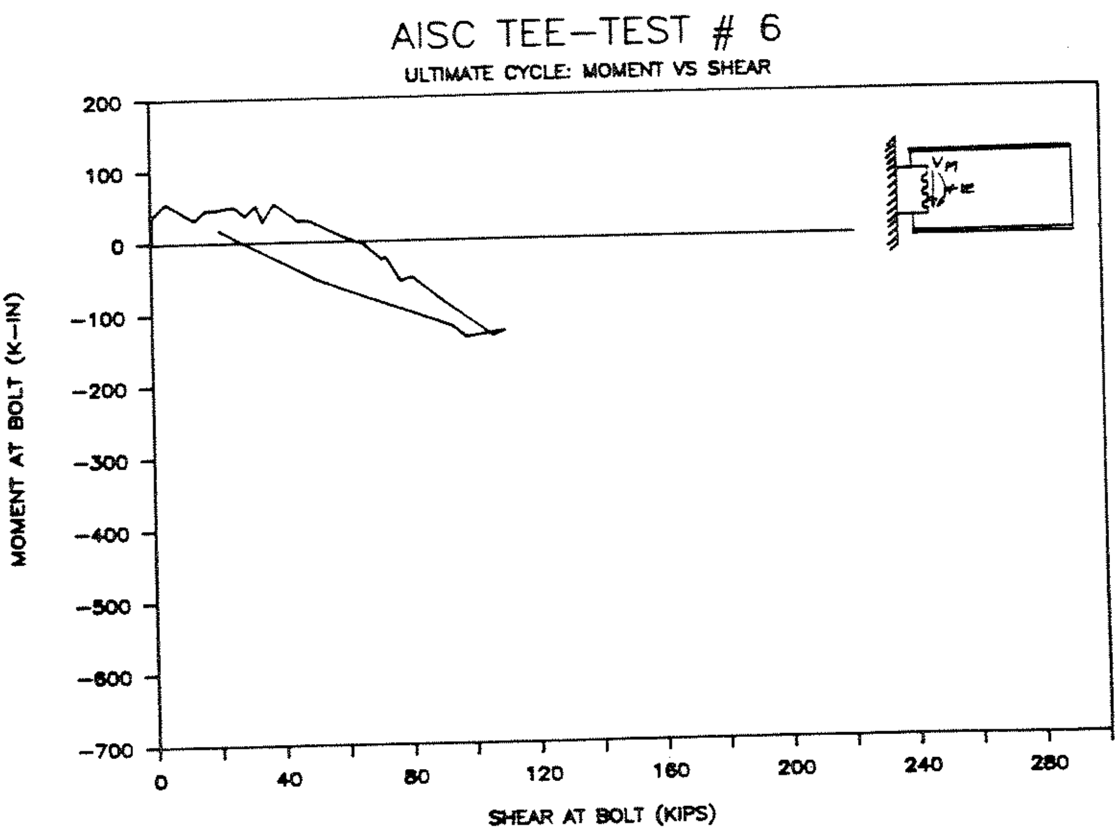

AISC TEE-TEST # 6
ULTIMATE CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION OF BEAM (RAD)
+ve
V
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
0
0.02
0.04
0.06
0.08
0.1


AISC TEE-TEST # 6
ULTIMATE CYCLE: SHEAR VS DEFLECTION
SHEAR AT BOLT (KIPS)
DEFLECTION AT BOLT (IN)
+ve
V
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
0
0.2
0.4
0.6
0.8
1
1.2
1.4

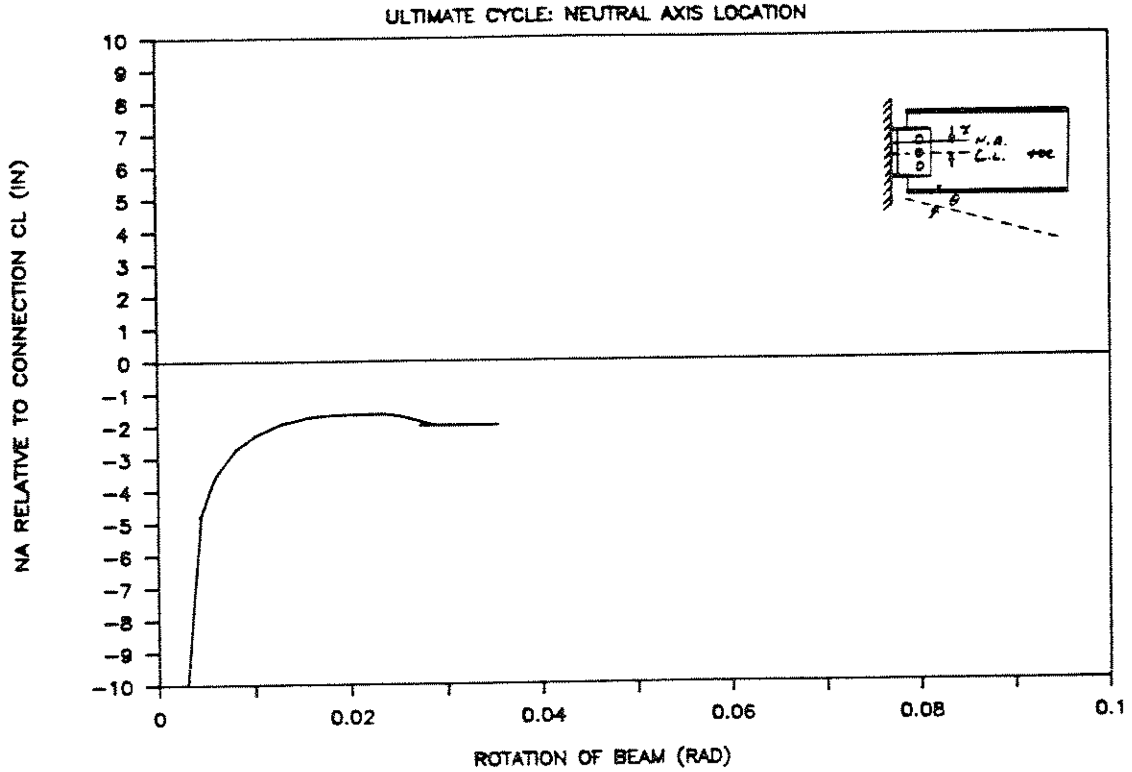

AISC TEE-TEST # 6
ULTIMATE CYCLE: MOMENT VS ROTATION
MOMENT AT BOLT (K-IN)
ROTATION OF BEAM (RAD)
200
100
0
-100
-200
-300
-400
-500
-600
-700
0
0.02
0.04
0.06
0.08
0.1

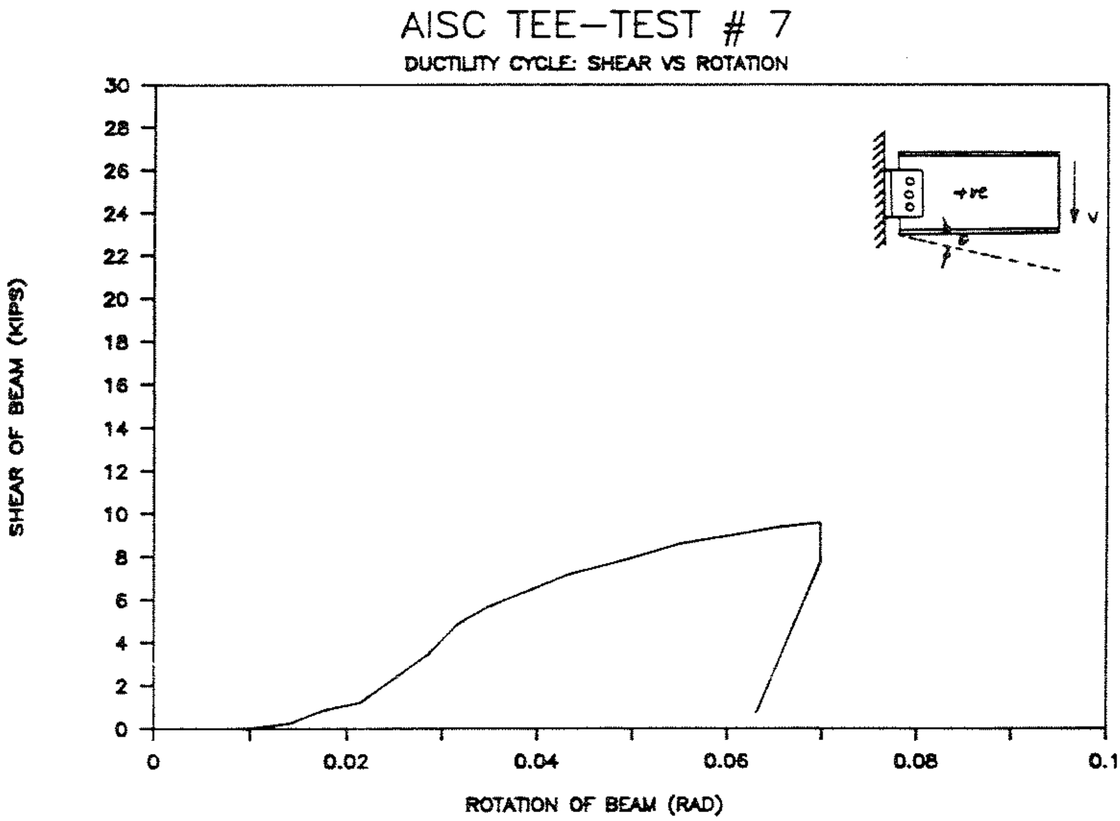

AISC TEE-TEST # 6
ULTIMATE CYCLE: MOMENT VS TEE ROTATION
MOMENT AT WELD (K-IN)
ROTATION OF TEE (RAD)
700
600
500
400
300
200
100
0
-100
-200
0
0.02
0.04
0.06
0.08
0.1

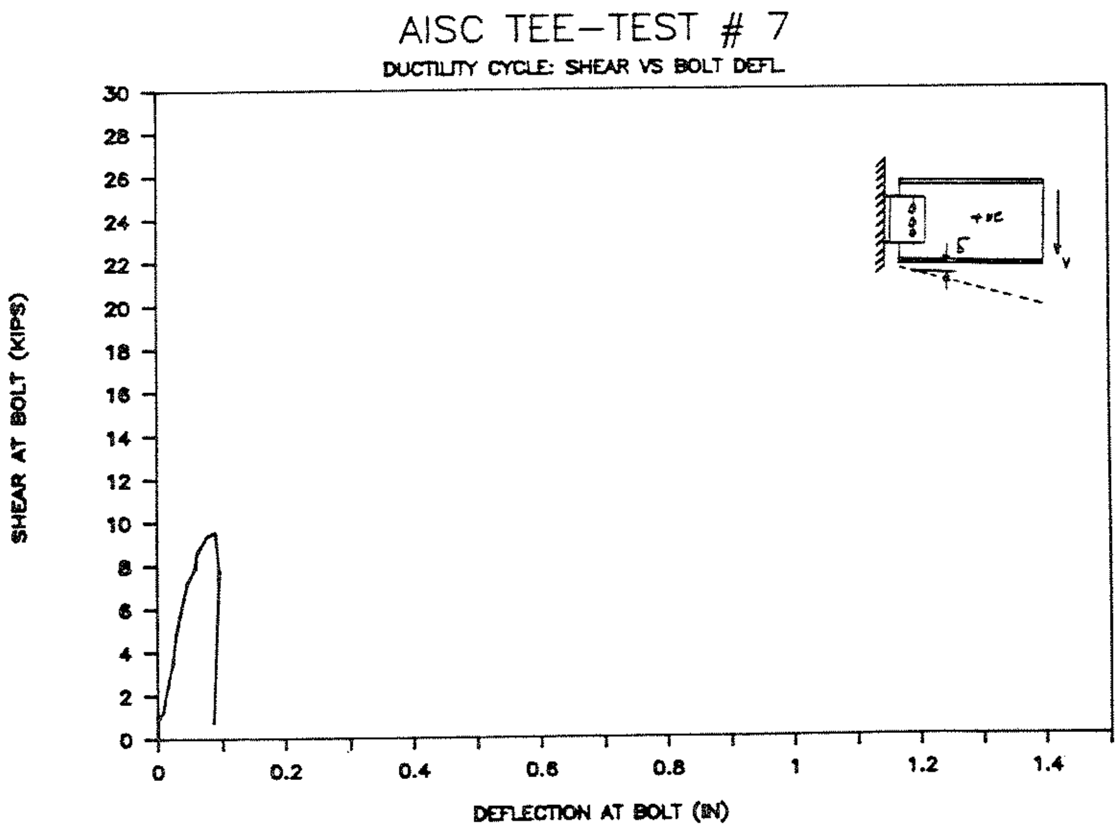

AISC TEE—TEST # 6
ULTIMATE CYCLE: MOMENT VS SHEAR
MOMENT AT WELD (K—IN)
SHEAR AT WELD (KIPS)
700
600
500
400
300
200
100
0
−100
−200
0
40
80
120
160
200
240
280

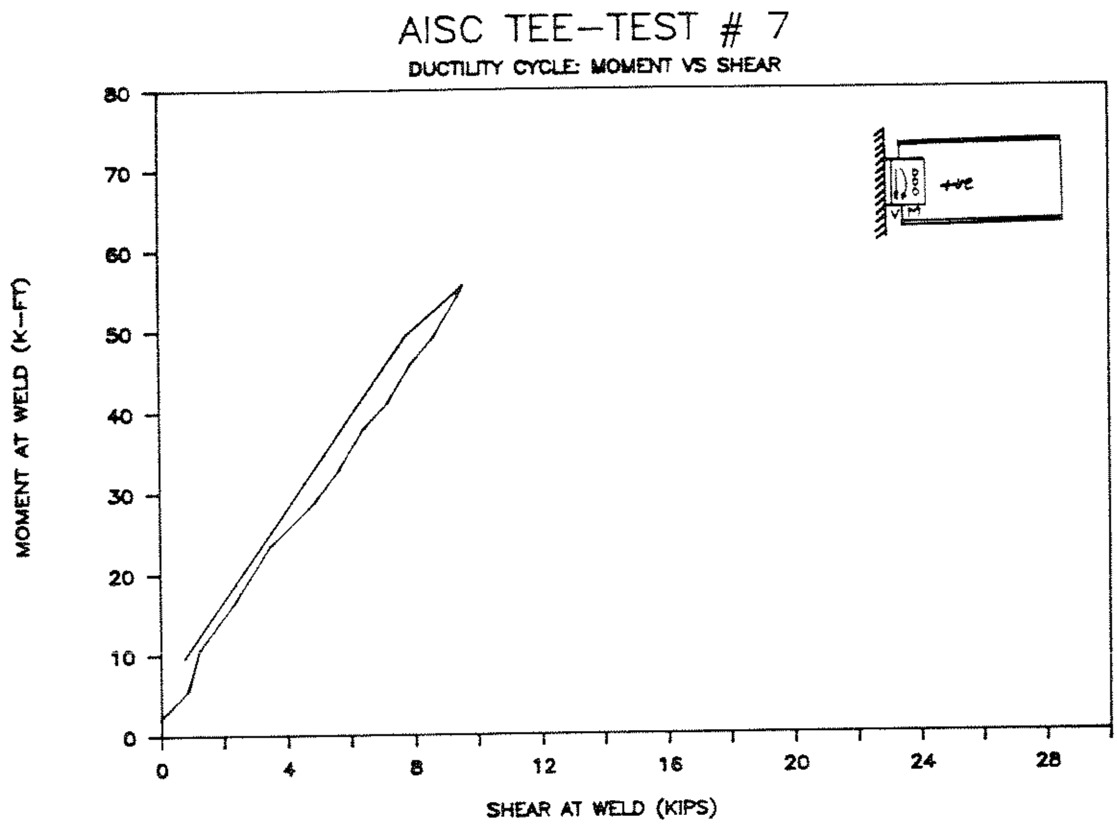

AISC TEE—TEST # 6
ULTIMATE CYCLE: MOMENT VS SHEAR
MOMENT AT BOLT (K—IN)
SHEAR AT BOLT (KIPS)
200
100
0
−100
−200
−300
−400
−500
−600
−700
0
40
80
120
160
200
240
280

AISC TEE–TEST # 6

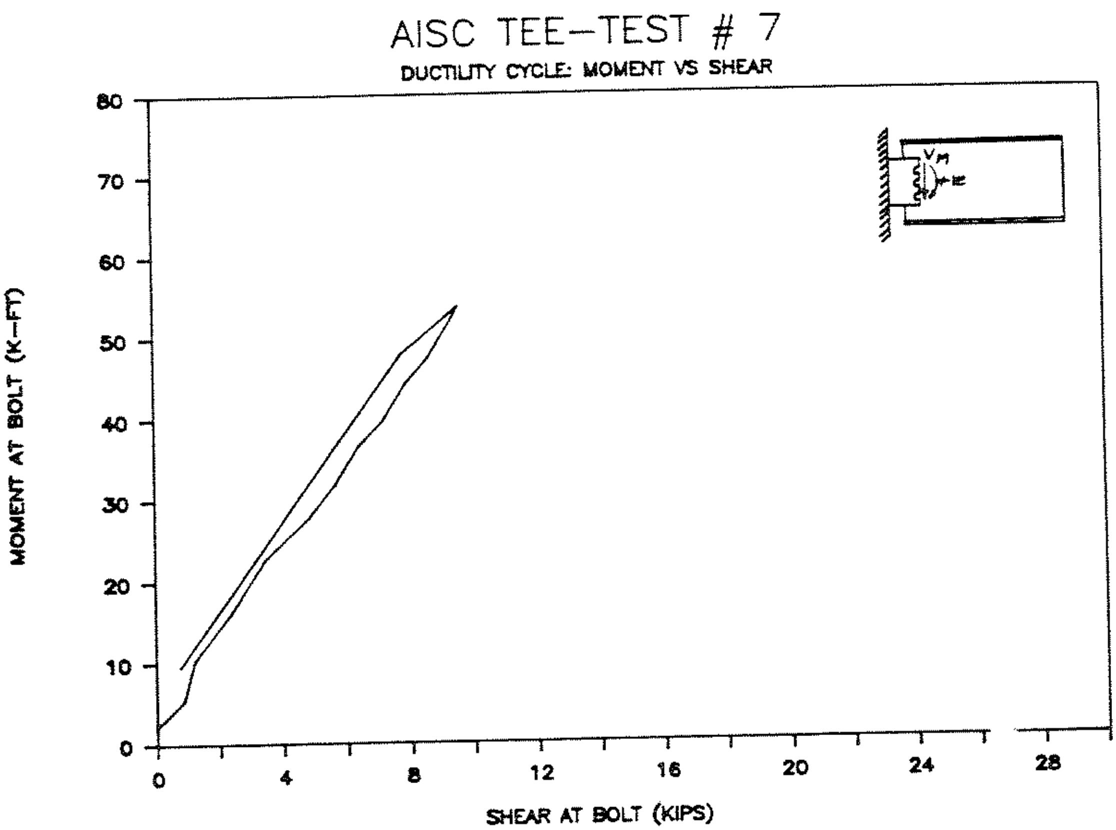



AISC TEE—TEST # 7
DUCTILITY CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION OF BEAM (RAD)
0
0.02
0.04
0.06
0.08
0.1
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
+ve
V

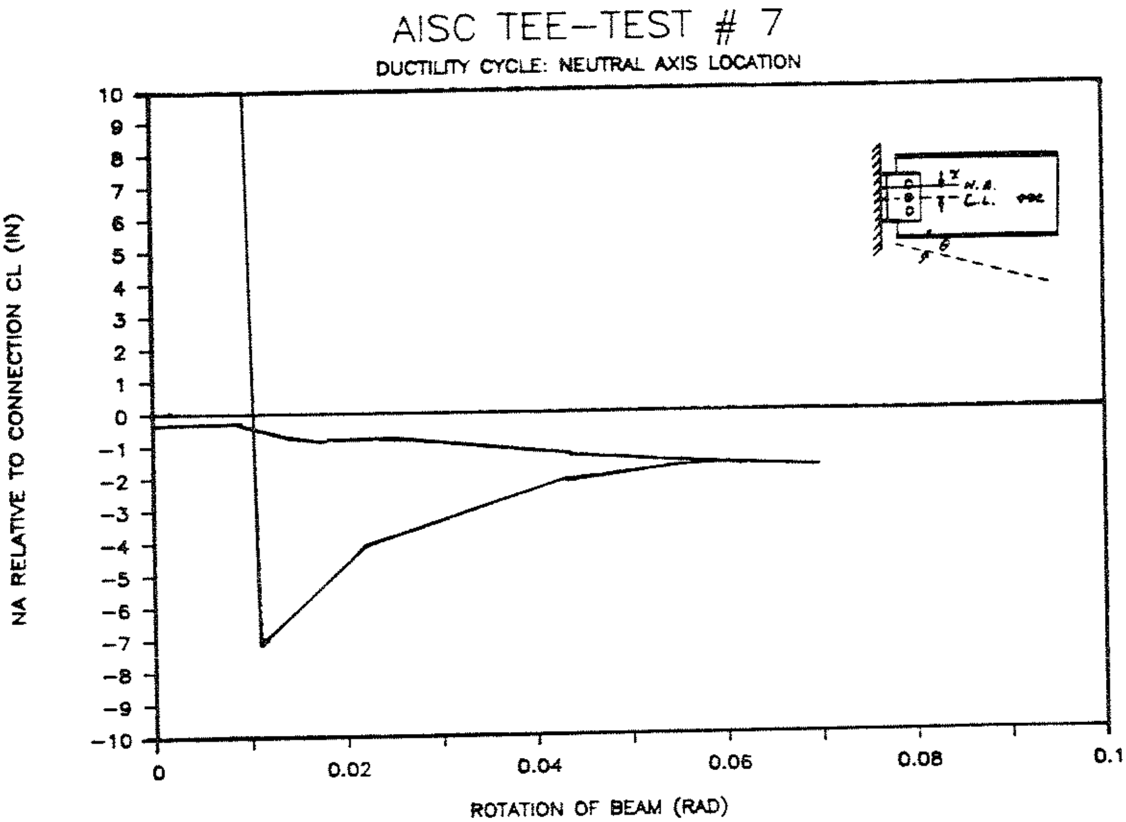

AISC TEE—TEST # 7
DUCTILITY CYCLE: SHEAR VS BOLT DEFL.
SHEAR AT BOLT (KIPS)
DEFLECTION AT BOLT (IN)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
+ve
V



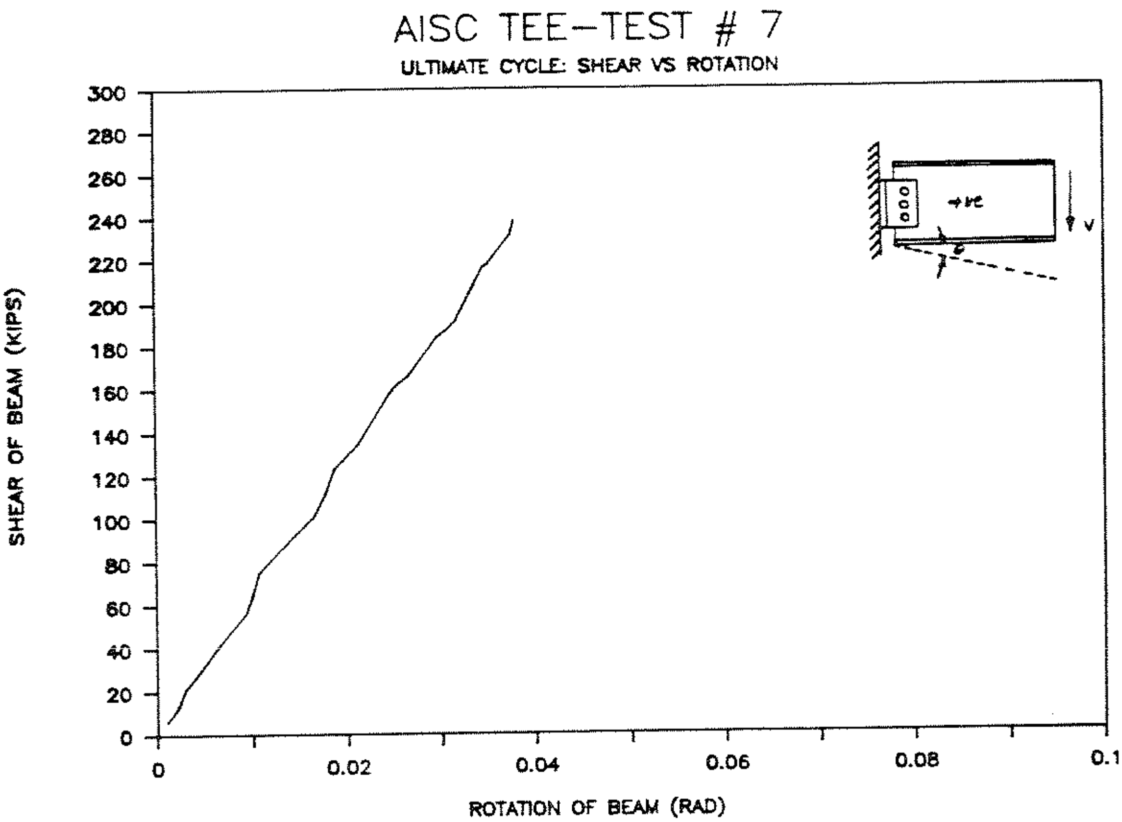
AISC TEE-TEST # 7
DUCTILITY CYCLE: MOMENT VS SHEAR
MOMENT AT WELD (K-FT)
SHEAR AT WELD (KIPS)
0
10
20
30
40
50
60
70
80
0
4
8
12
16
20
24
28
+ve
V
M

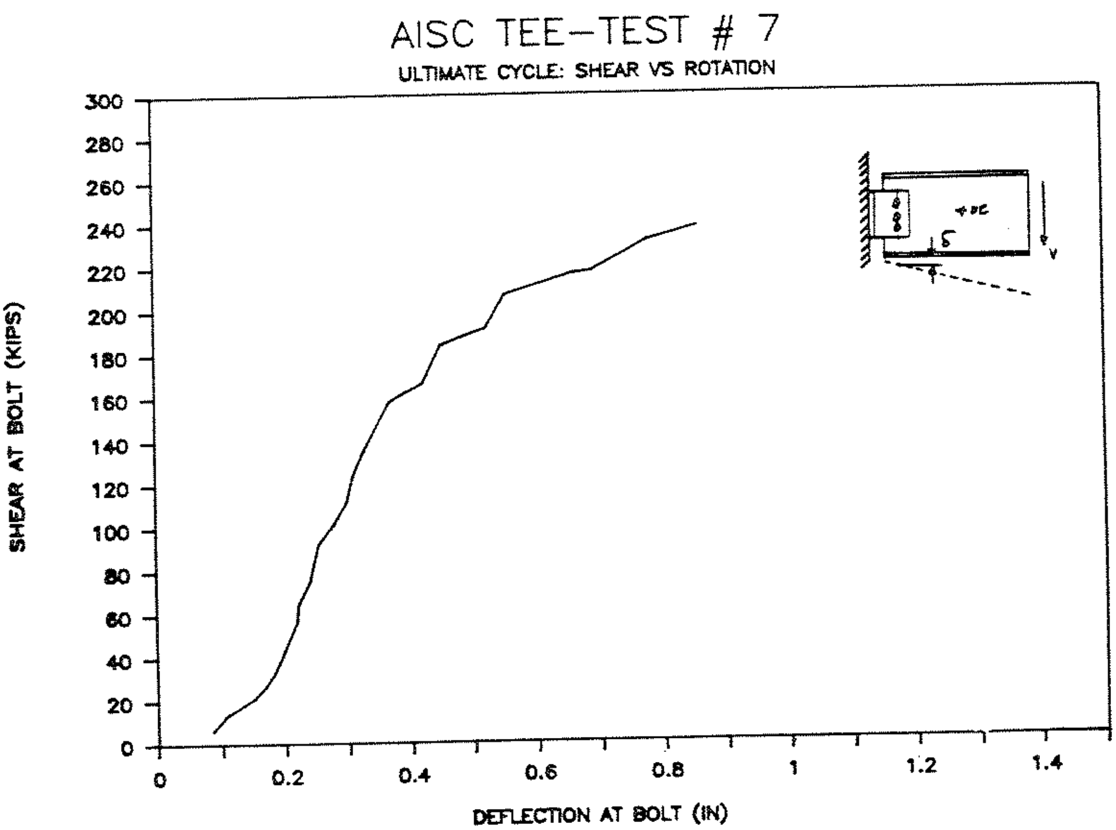


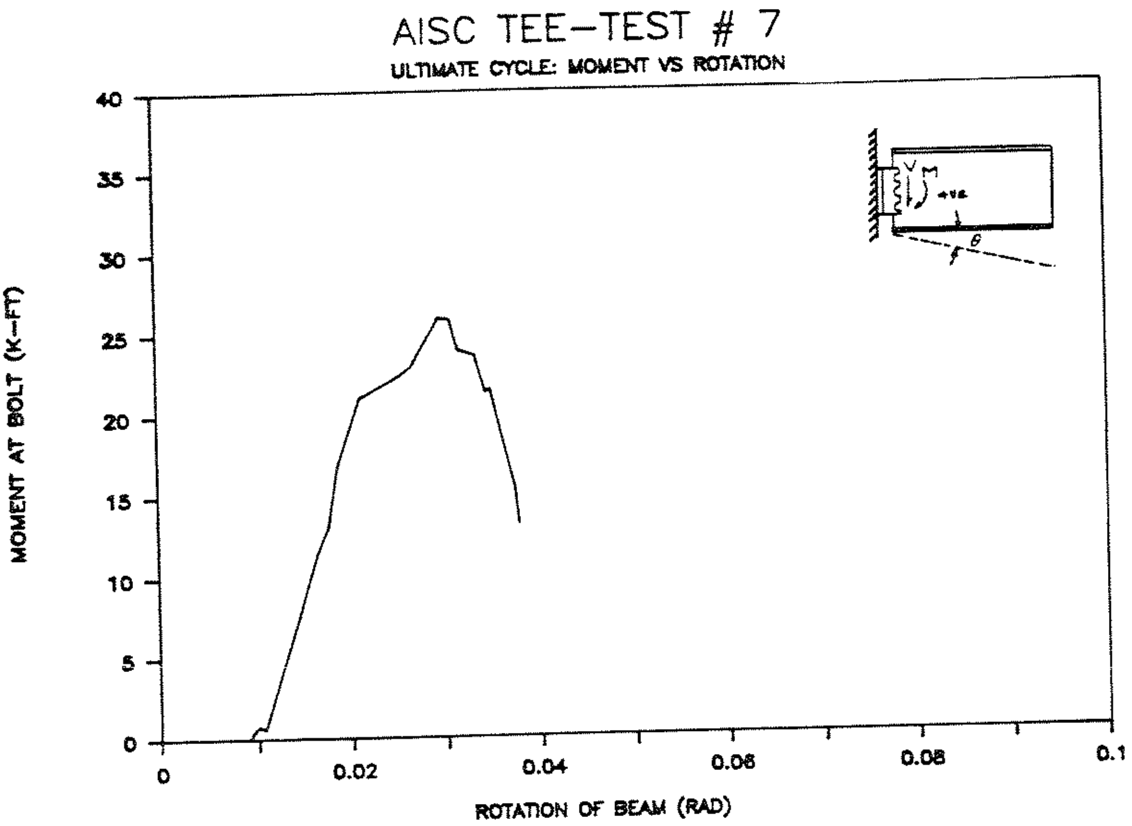
AISC TEE-TEST # 7
DUCTILITY CYCLE: MOMENT VS SHEAR
MOMENT AT BOLT (K-FT)
SHEAR AT BOLT (KIPS)
0
10
20
30
40
50
60
70
80
0
4
8
12
16
20
24
28
V
M

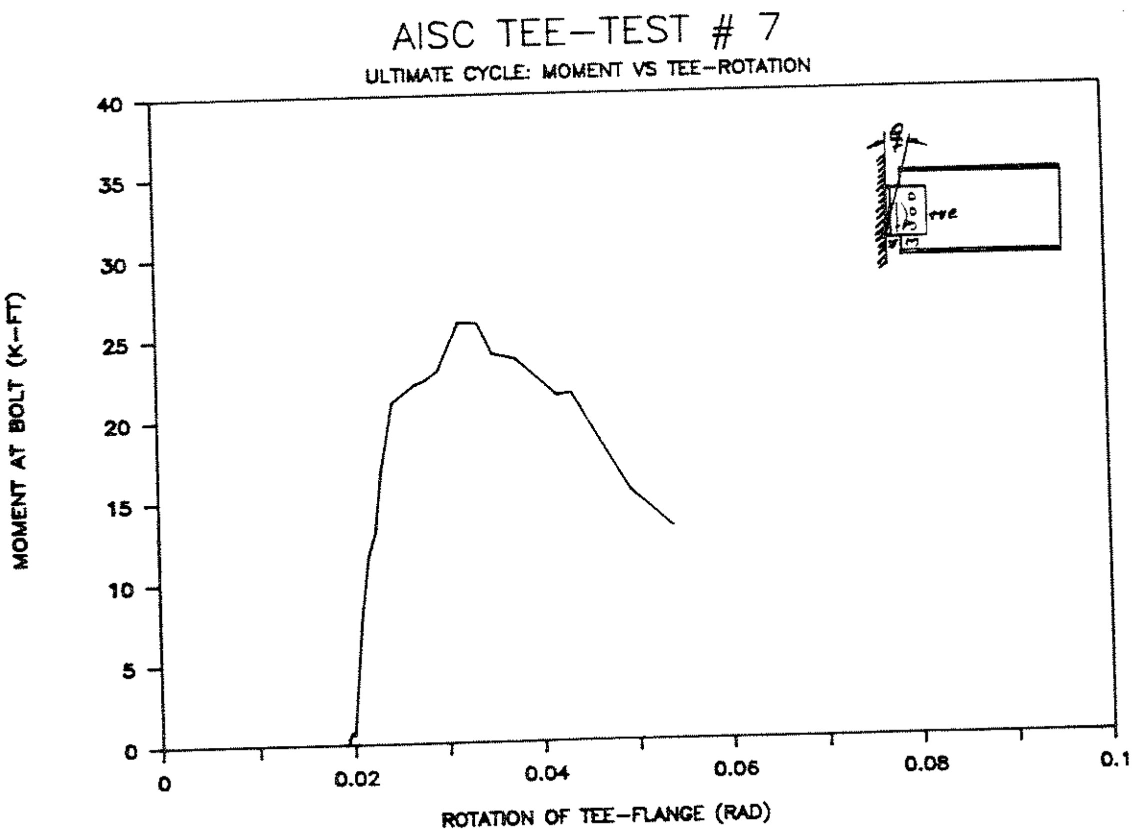


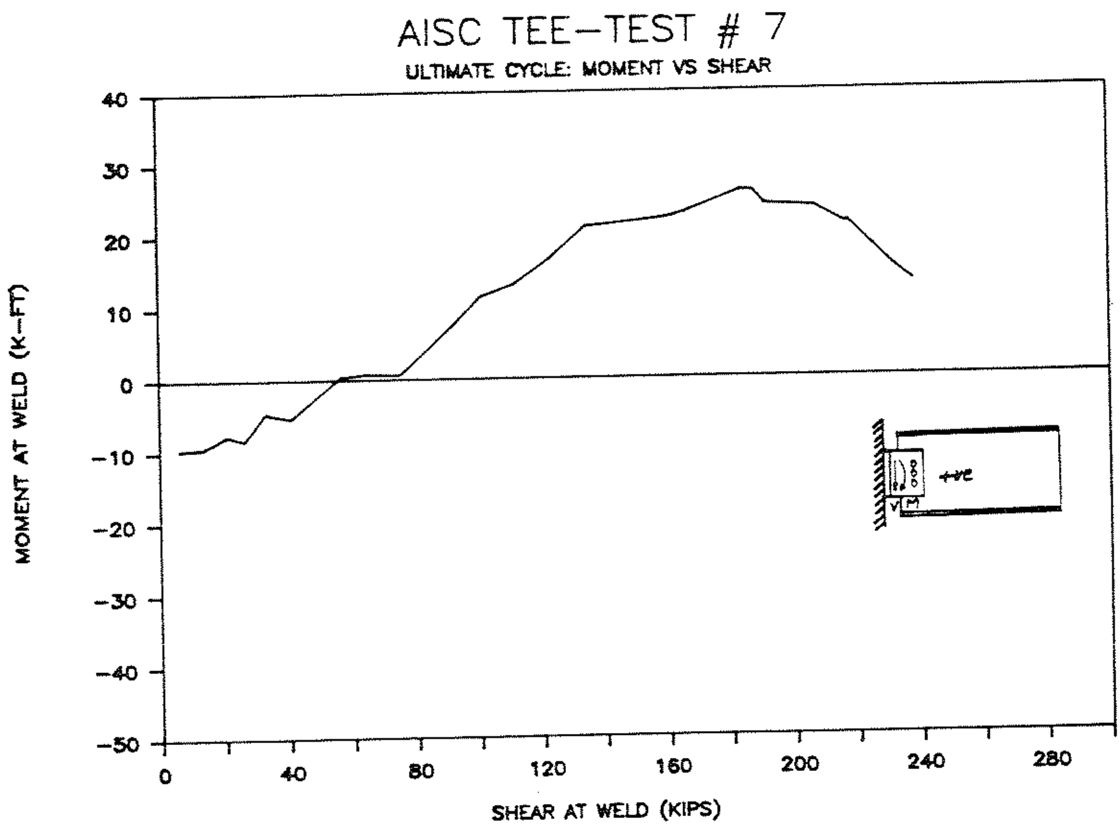
AISC TEE-TEST # 7
DUCTILITY CYCLE: NEUTRAL AXIS LOCATION
NA RELATIVE TO CONNECTION CL (IN)
ROTATION OF BEAM (RAD)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
0
0.02
0.04
0.06
0.08
0.1
N.A.
C.L.

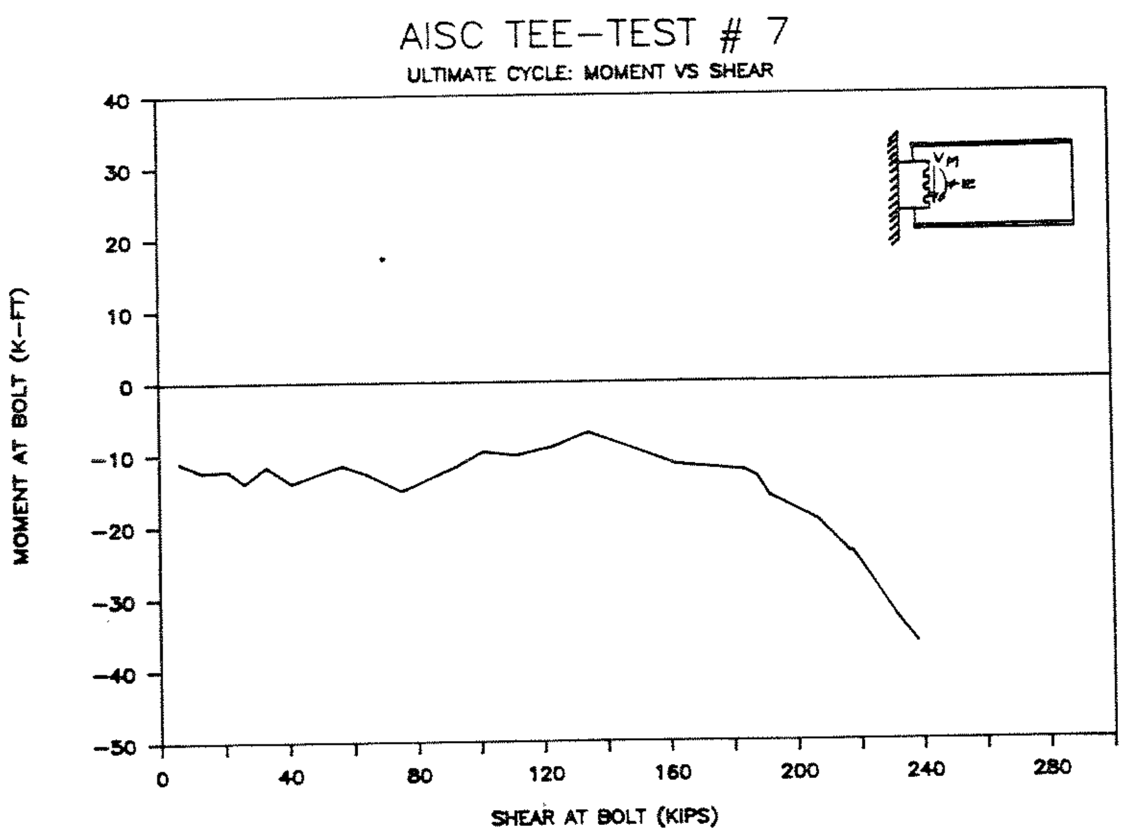

AISC TEE-TEST # 7
ULTIMATE CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION OF BEAM (RAD)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
0.02
0.04
0.06
0.08
0.1
V


AISC TEE-TEST # 7
ULTIMATE CYCLE: SHEAR VS ROTATION
SHEAR AT BOLT (KIPS)
DEFLECTION AT BOLT (IN)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
V


AISC TEE—TEST # 7
ULTIMATE CYCLE: MOMENT VS ROTATION
MOMENT AT BOLT (K—FT)
ROTATION OF BEAM (RAD)
0
5
10
15
20
25
30
35
40
0.02
0.04
0.06
0.08
0.1

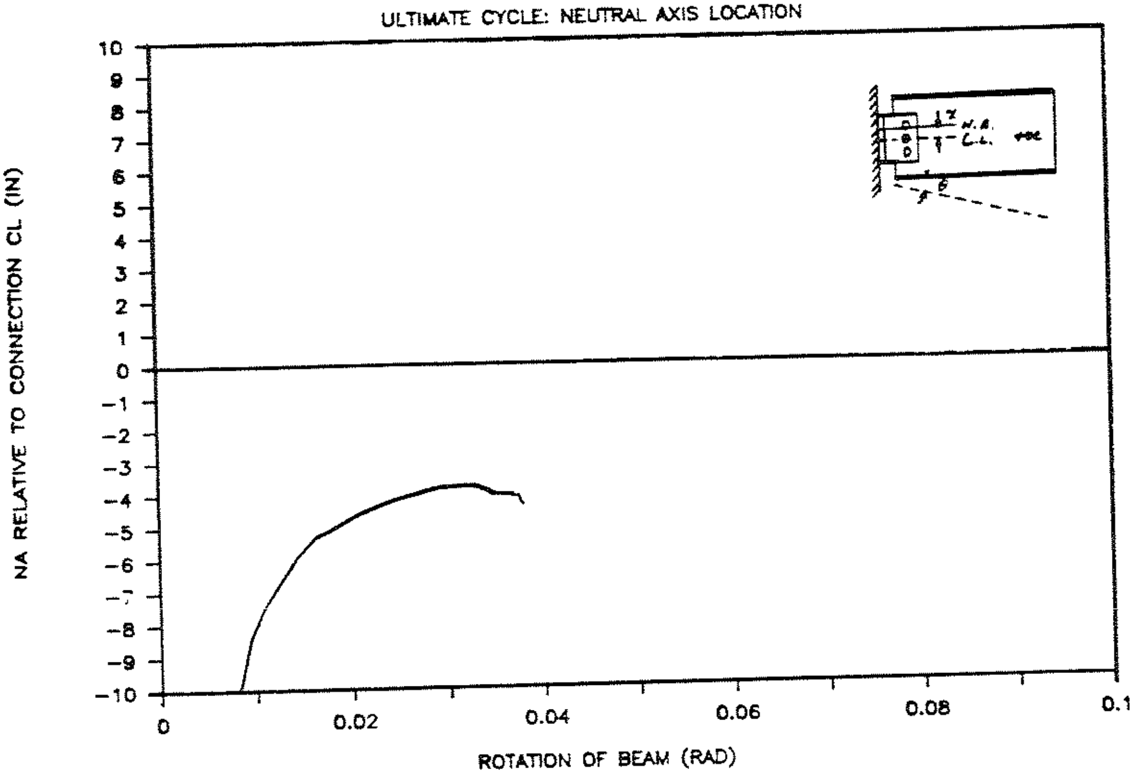

AISC TEE—TEST # 7
ULTIMATE CYCLE: MOMENT VS TEE—ROTATION
MOMENT AT BOLT (K—FT)
ROTATION OF TEE—FLANGE (RAD)
0
5
10
15
20
25
30
35
40
0.02
0.04
0.06
0.08
0.1

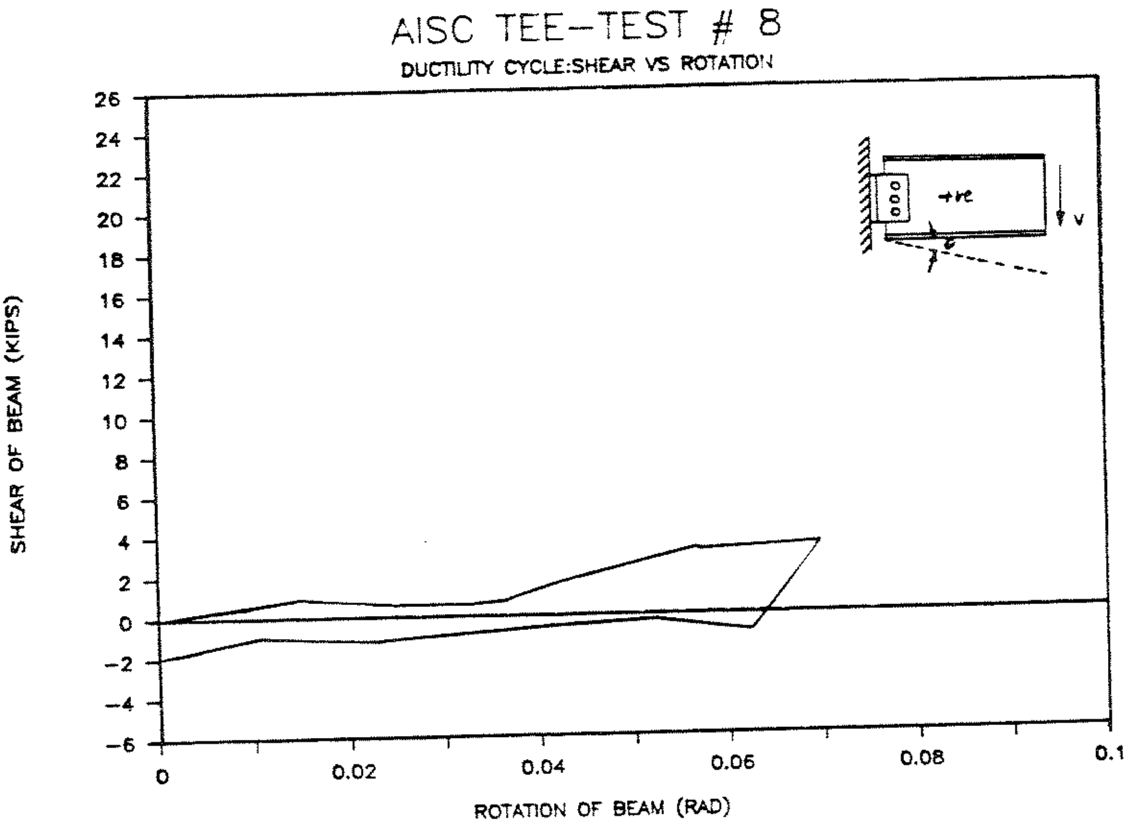

AISC TEE–TEST # 7
ULTIMATE CYCLE: MOMENT VS SHEAR
MOMENT AT WELD (K–FT)
SHEAR AT WELD (KIPS)
40
30
20
10
0
−10
−20
−30
−40
−50
0
40
80
120
160
200
240
280


AISC TEE–TEST # 7
ULTIMATE CYCLE: MOMENT VS SHEAR
MOMENT AT BOLT (K–FT)
SHEAR AT BOLT (KIPS)
40
30
20
10
0
−10
−20
−30
−40
−50
0
40
80
120
160
200
240
280

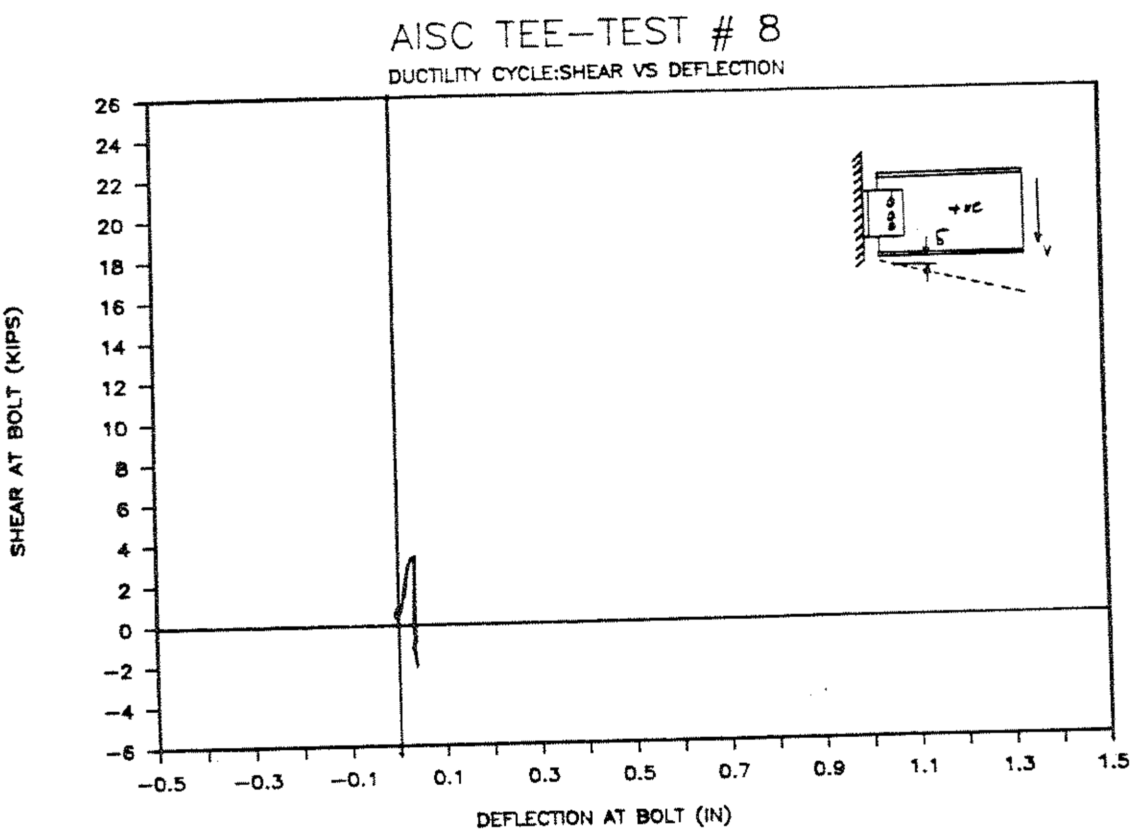
AISC TEE—TEST # 7

ULTIMATE CYCLE: NEUTRAL AXIS LOCATION

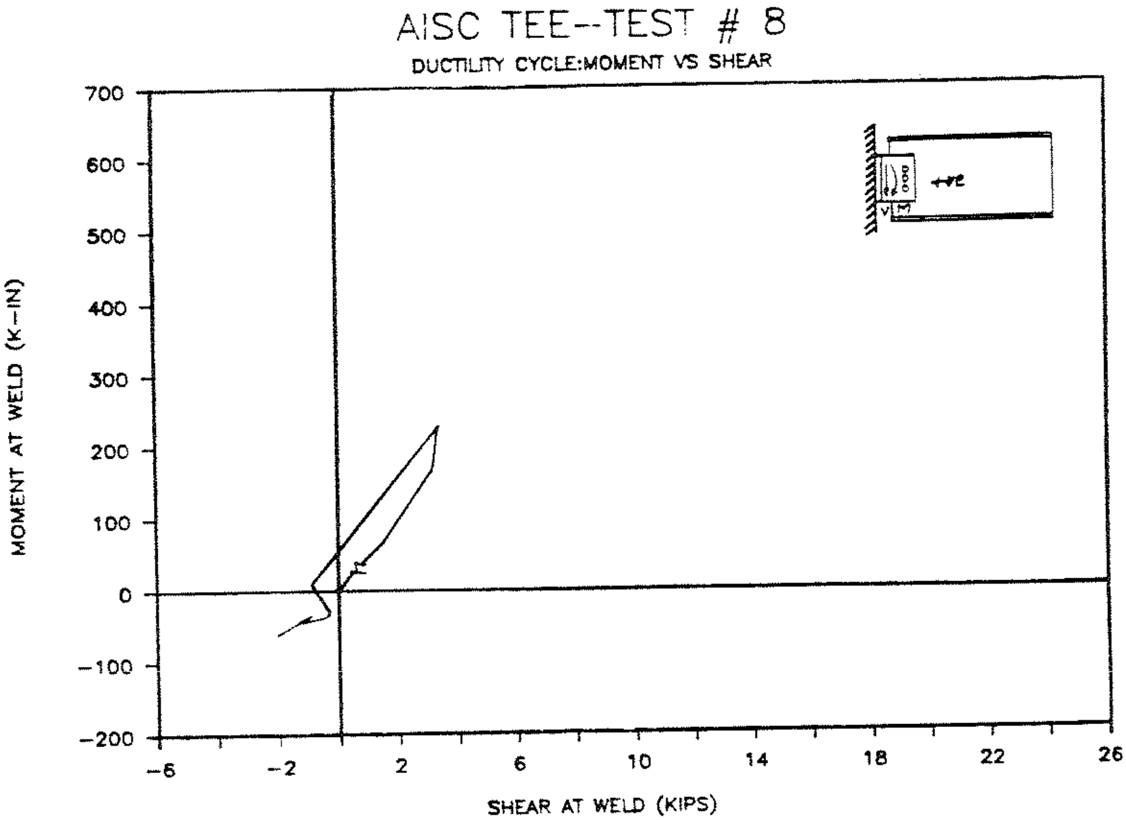


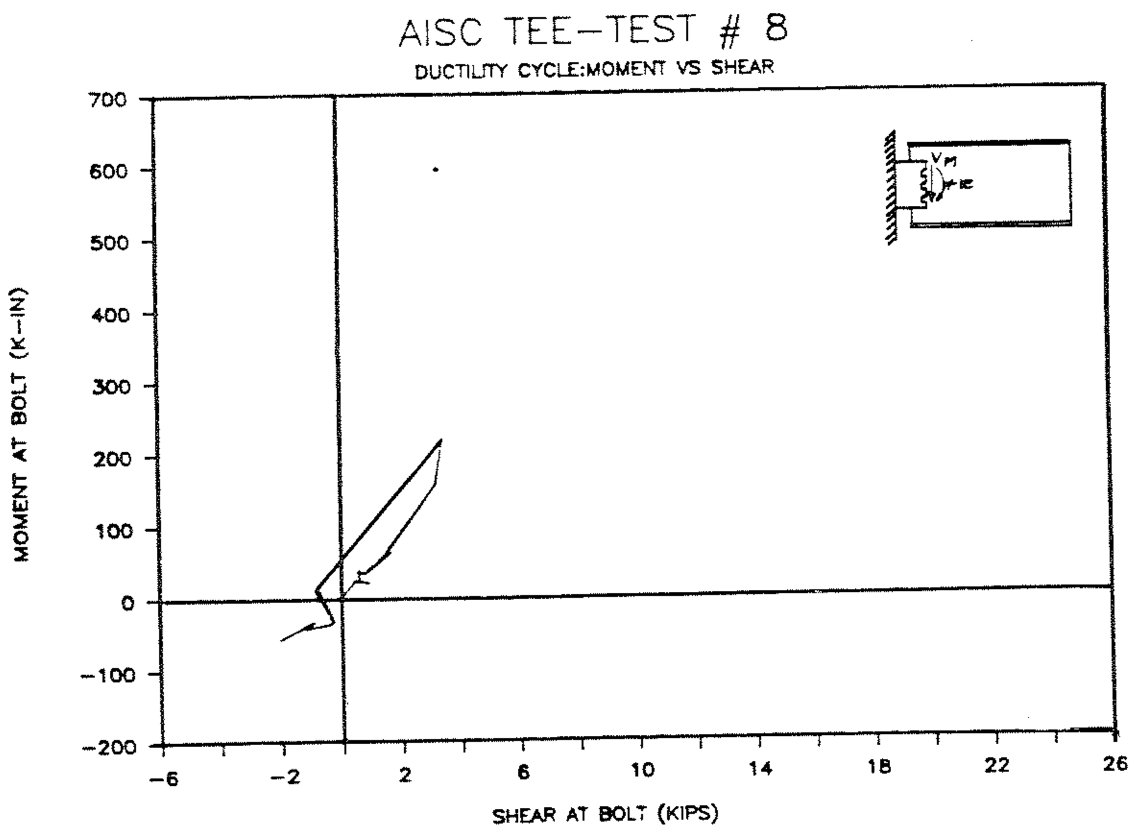


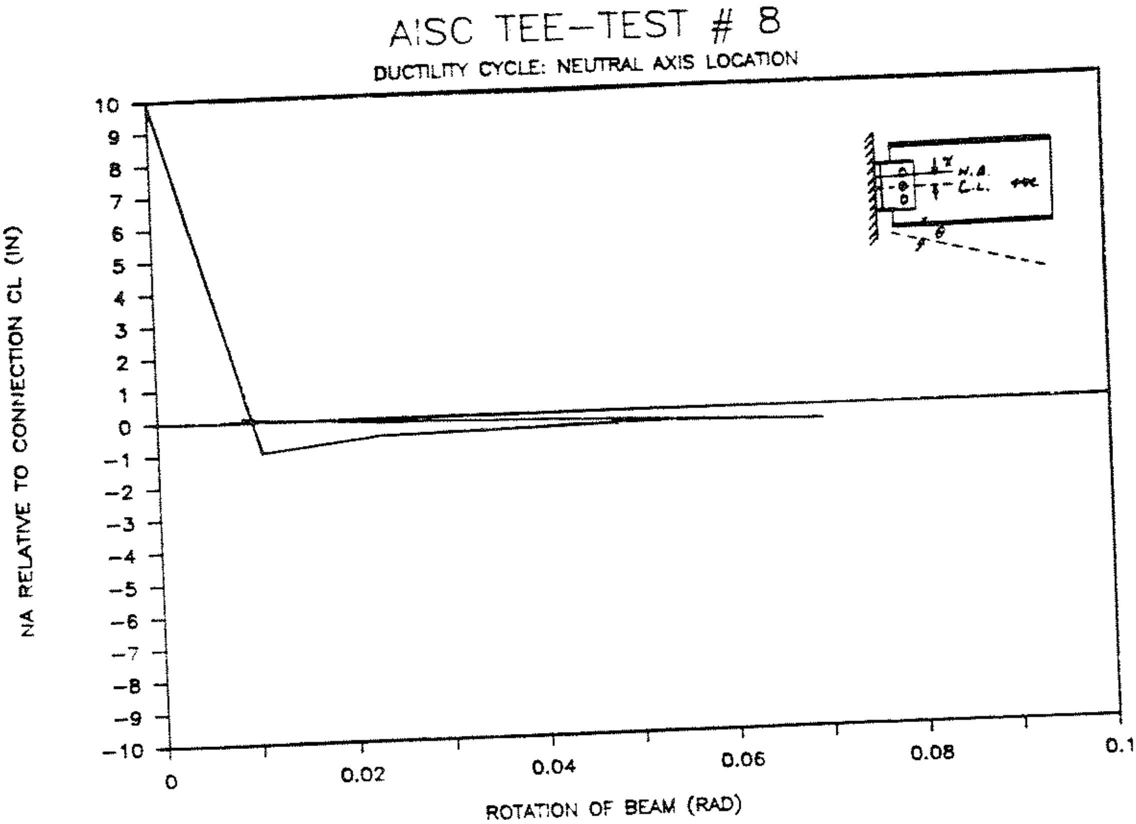
AISC TEE-TEST # 8
DUCTILITY CYCLE:SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION OF BEAM (RAD)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
0
0.02
0.04
0.06
0.08
0.1
+ve
V



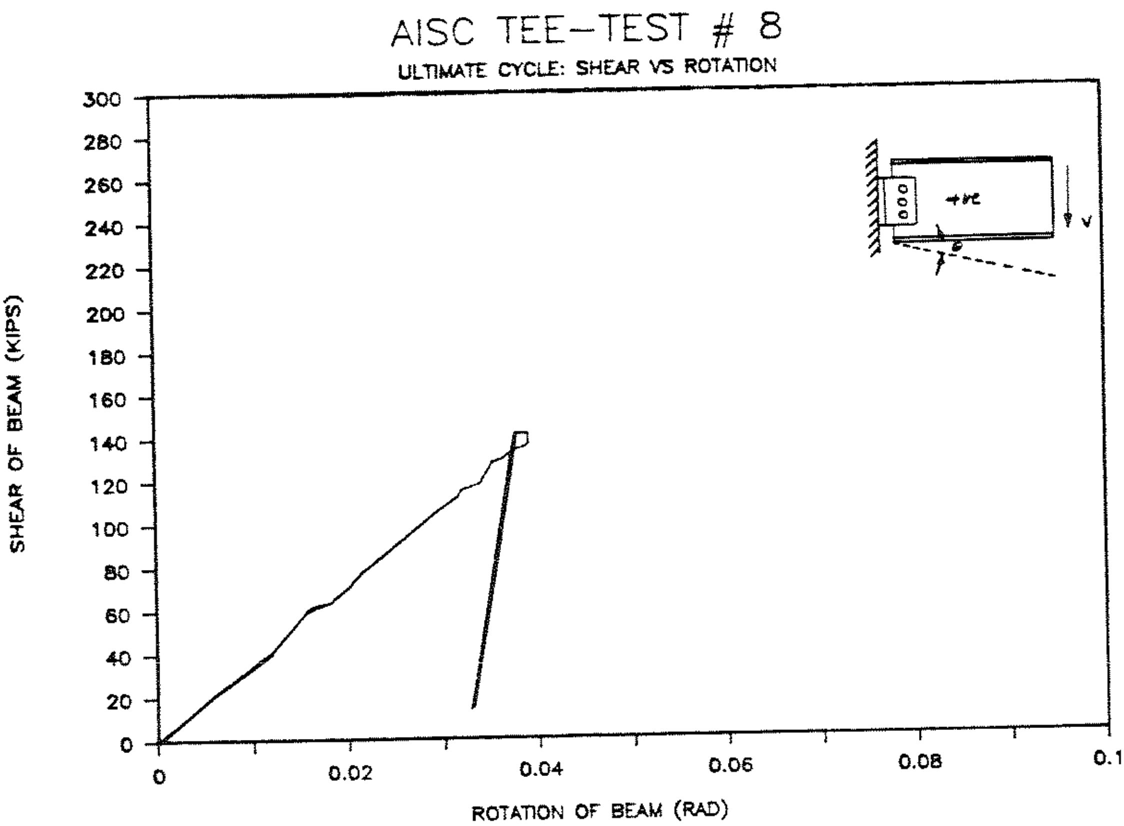
AISC TEE-TEST # 8
DUCTILITY CYCLE:SHEAR VS DEFLECTION
SHEAR AT BOLT (KIPS)
DEFLECTION AT BOLT (IN)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-0.5
-0.3
-0.1
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
+ve
V

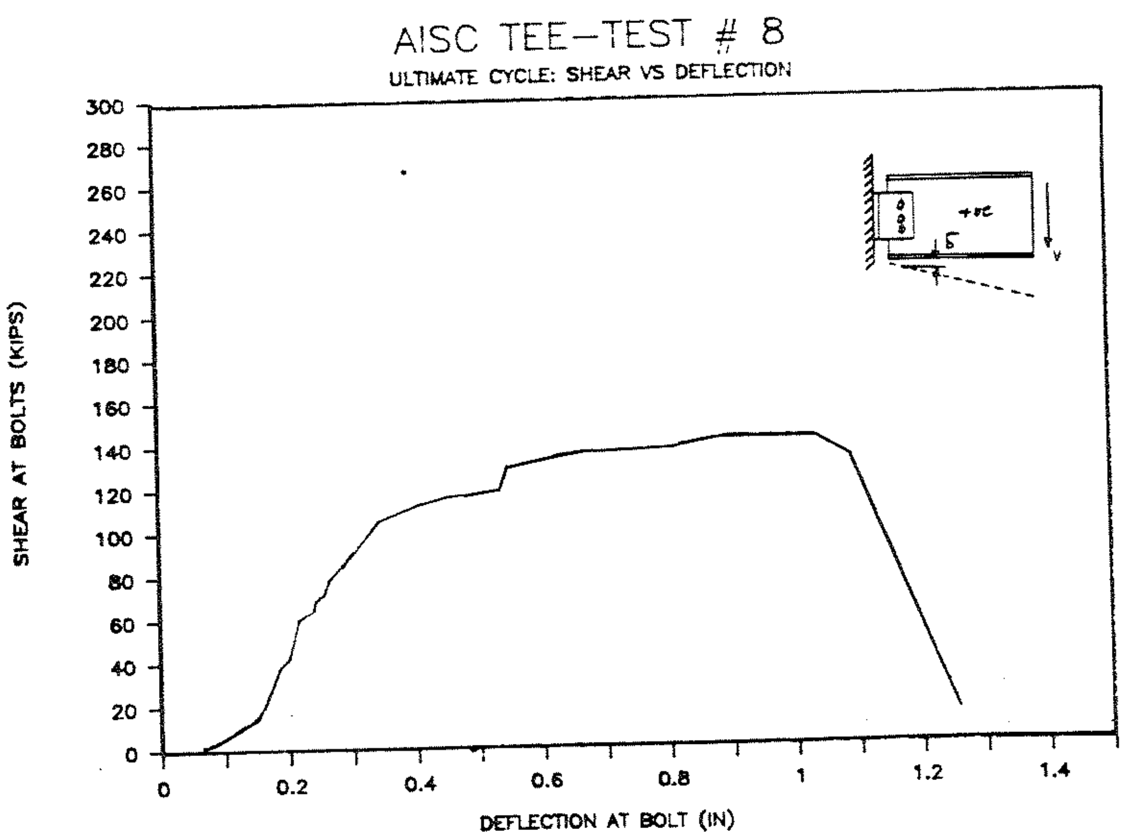

AISC TEE--TEST # 8
DUCTILITY CYCLE:MOMENT VS SHEAR
MOMENT AT WELD (K-IN)
SHEAR AT WELD (KIPS)
700
600
500
400
300
200
100
0
-100
-200
-6
-2
2
6
10
14
18
22
26

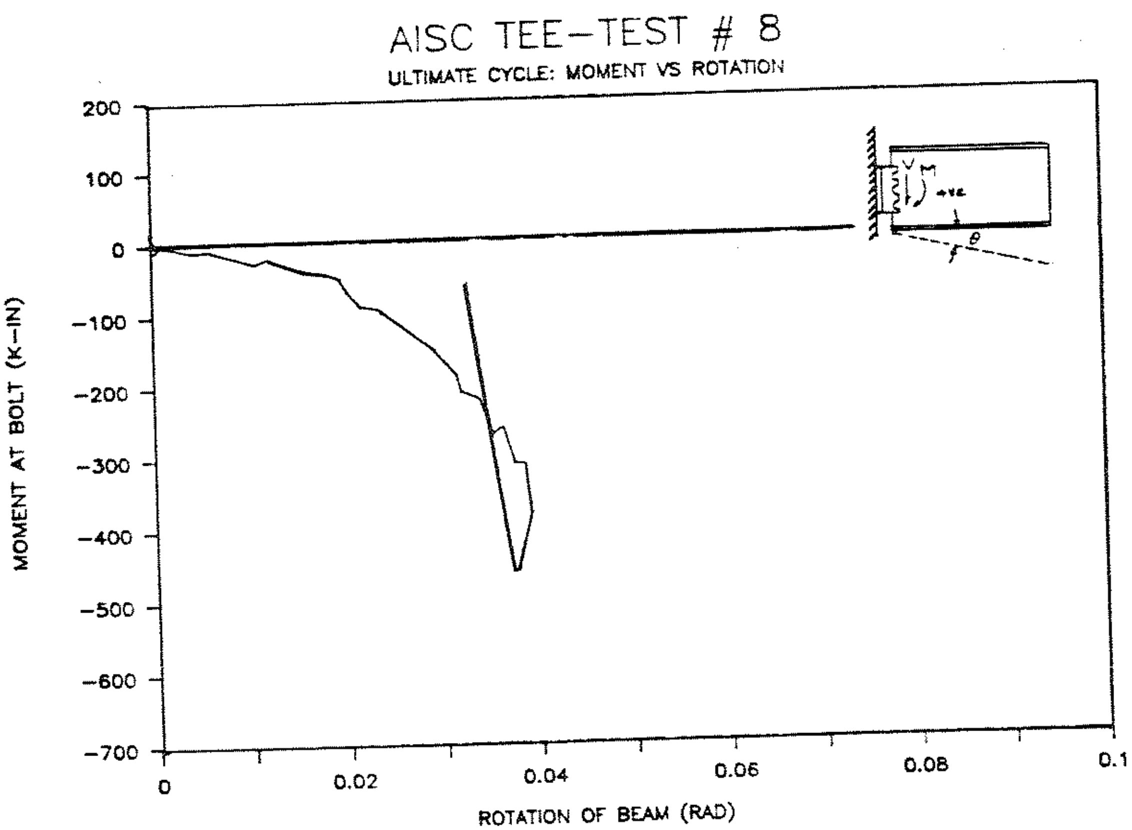

AISC TEE-TEST # 8
DUCTILITY CYCLE:MOMENT VS SHEAR
MOMENT AT BOLT (K-IN)
SHEAR AT BOLT (KIPS)
700
600
500
400
300
200
100
0
-100
-200
-6
-2
2
6
10
14
18
22
26

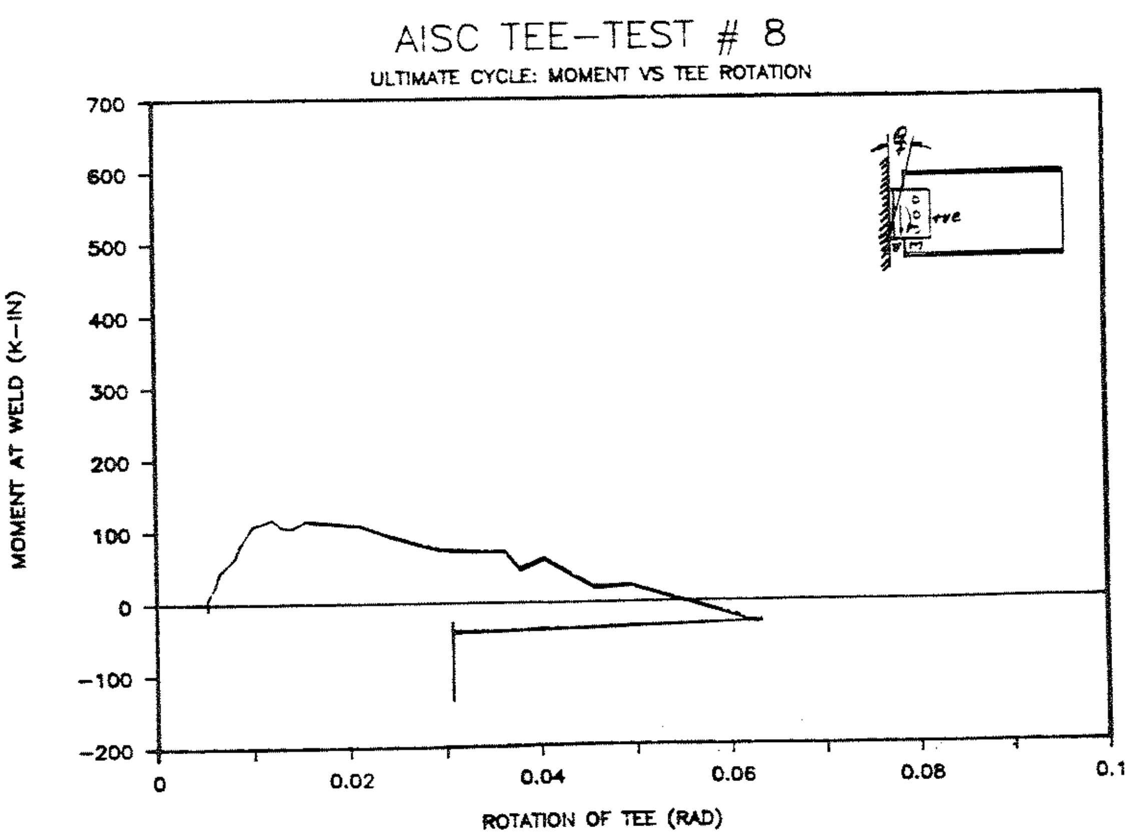


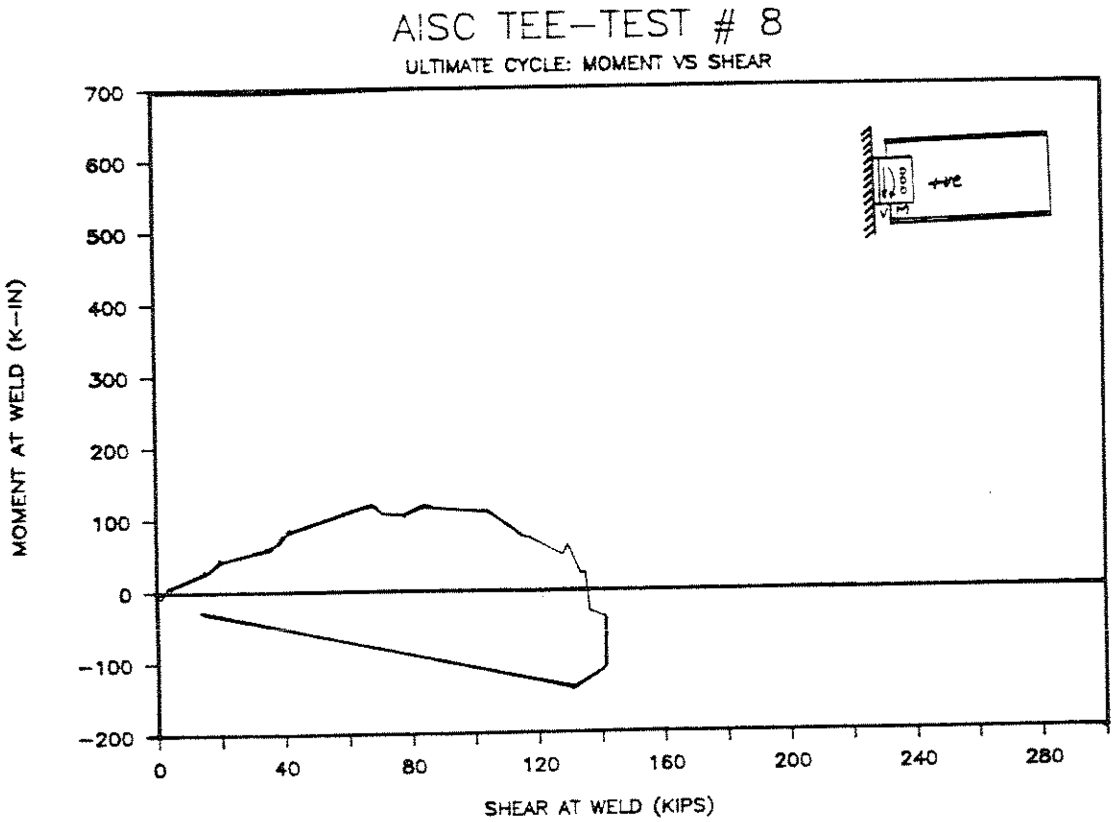
AISC TEE-TEST # 8
DUCTILITY CYCLE: NEUTRAL AXIS LOCATION
NA RELATIVE TO CONNECTION CL (IN)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
0
0.02
0.04
0.06
0.08
0.1
ROTATION OF BEAM (RAD)
N.A.
C.L.


AISC TEE-TEST # 8
ULTIMATE CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION OF BEAM (RAD)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
0.02
0.04
0.06
0.08
0.1
V

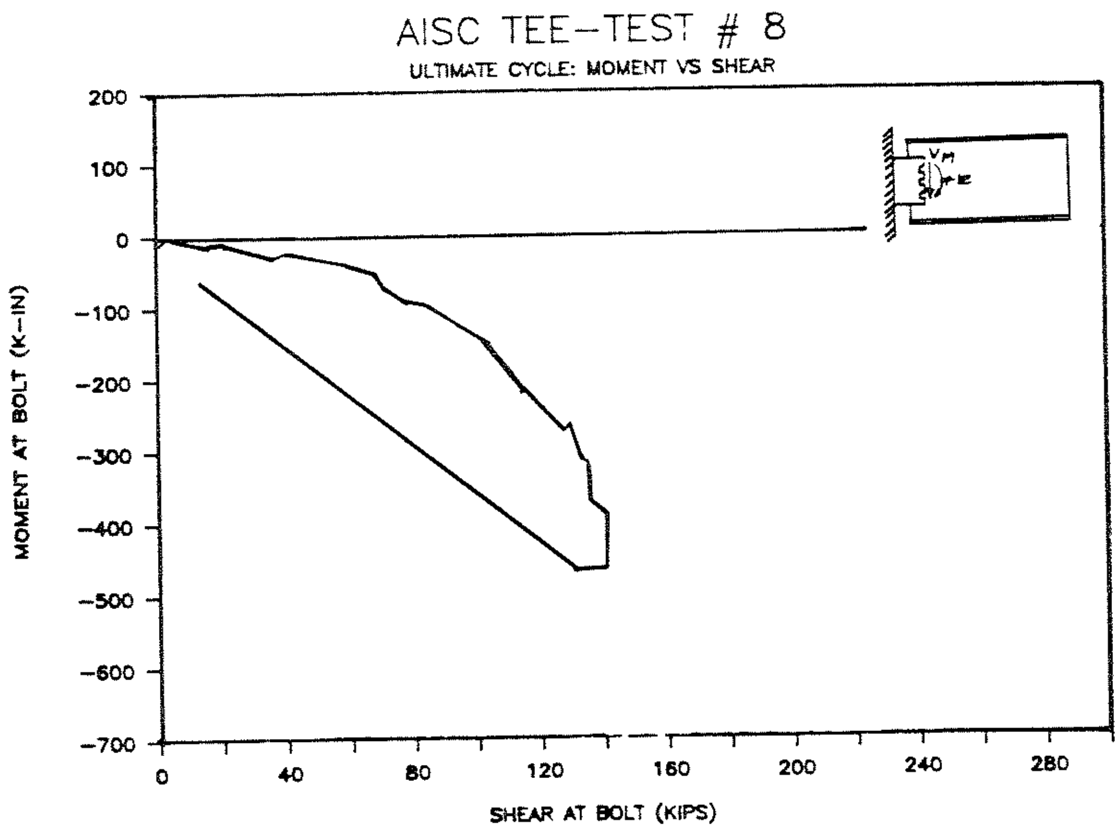

AISC TEE-TEST # 8
ULTIMATE CYCLE: SHEAR VS DEFLECTION
SHEAR AT BOLTS (KIPS)
DEFLECTION AT BOLT (IN)
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
0.2
0.4
0.6
0.8
1
1.2
1.4
V


AISC TEE-TEST # 8
ULTIMATE CYCLE: MOMENT VS ROTATION
MOMENT AT BOLT (K-IN)
200
100
0
-100
-200
-300
-400
-500
-600
-700
0
0.02
0.04
0.06
0.08
0.1
ROTATION OF BEAM (RAD)
+ve
θ


AISC TEE-TEST # 8
ULTIMATE CYCLE: MOMENT VS TEE ROTATION
MOMENT AT WELD (K-IN)
700
600
500
400
300
200
100
0
-100
-200
0
0.02
0.04
0.06
0.08
0.1
ROTATION OF TEE (RAD)
+ve



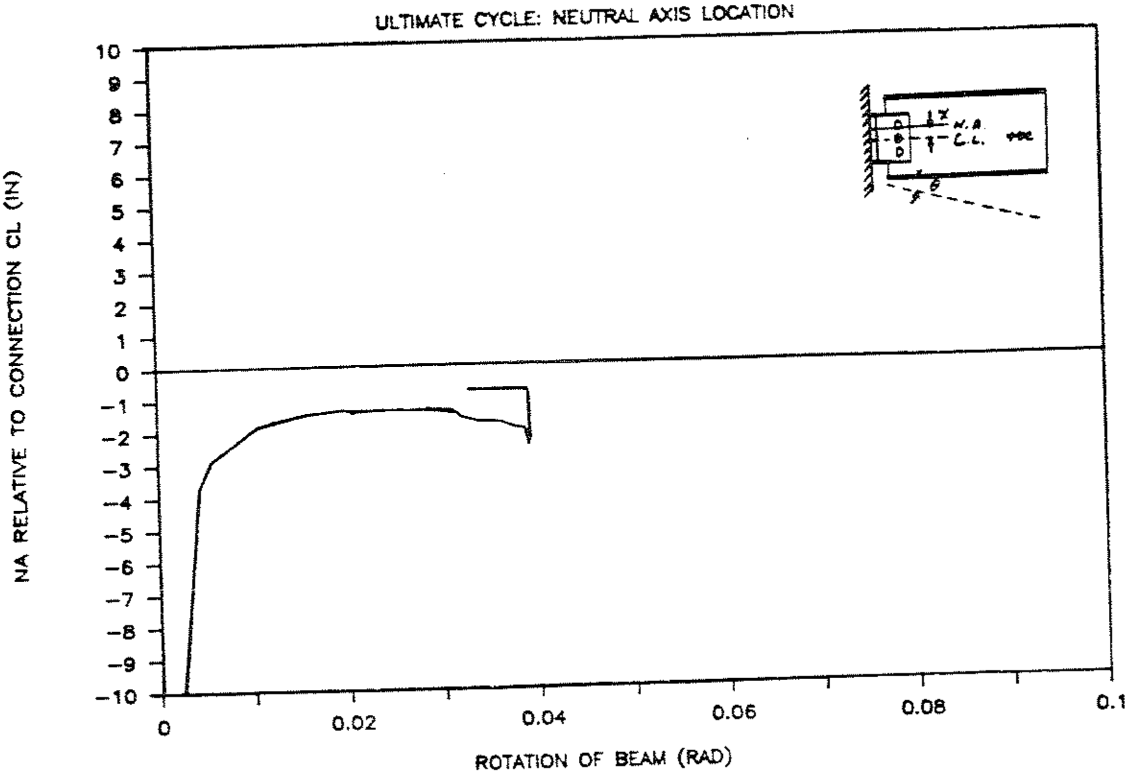
AISC TEE—TEST # 8
ULTIMATE CYCLE: MOMENT VS SHEAR
MOMENT AT WELD (K—IN)
SHEAR AT WELD (KIPS)
700
600
500
400
300
200
100
0
—100
—200
0
40
80
120
160
200
240
280
+ve

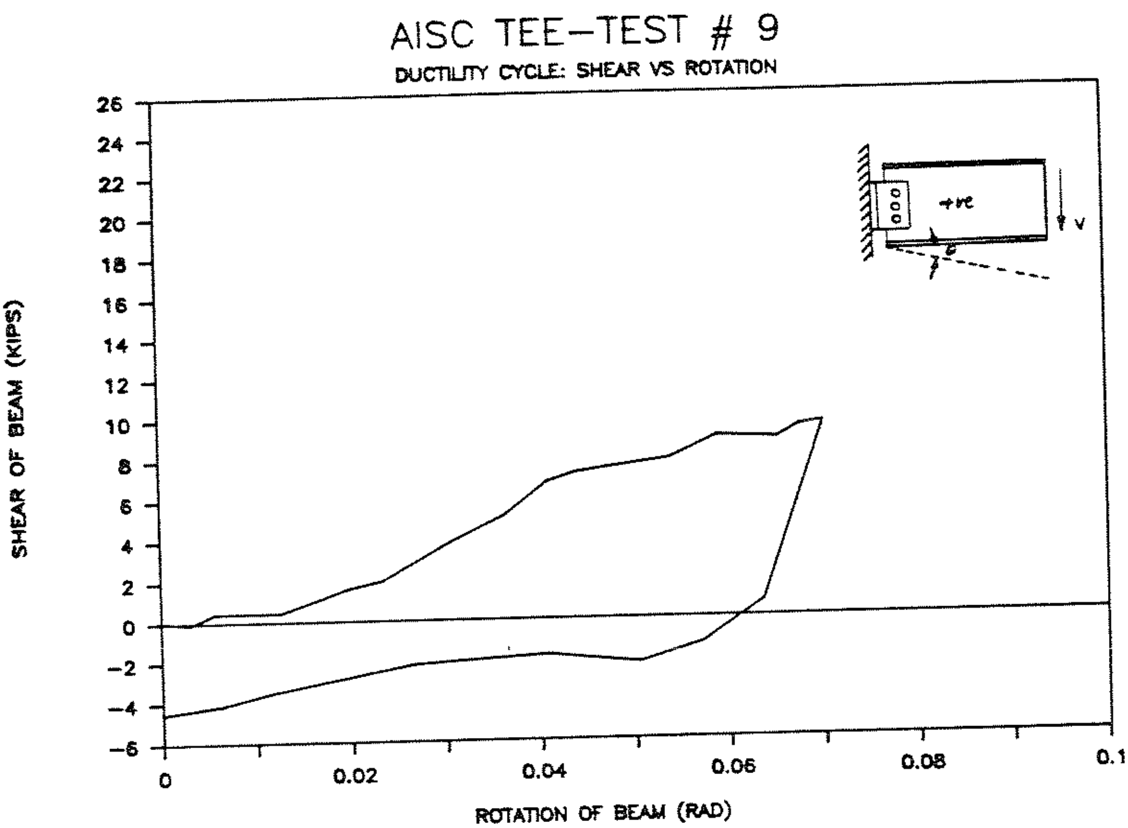


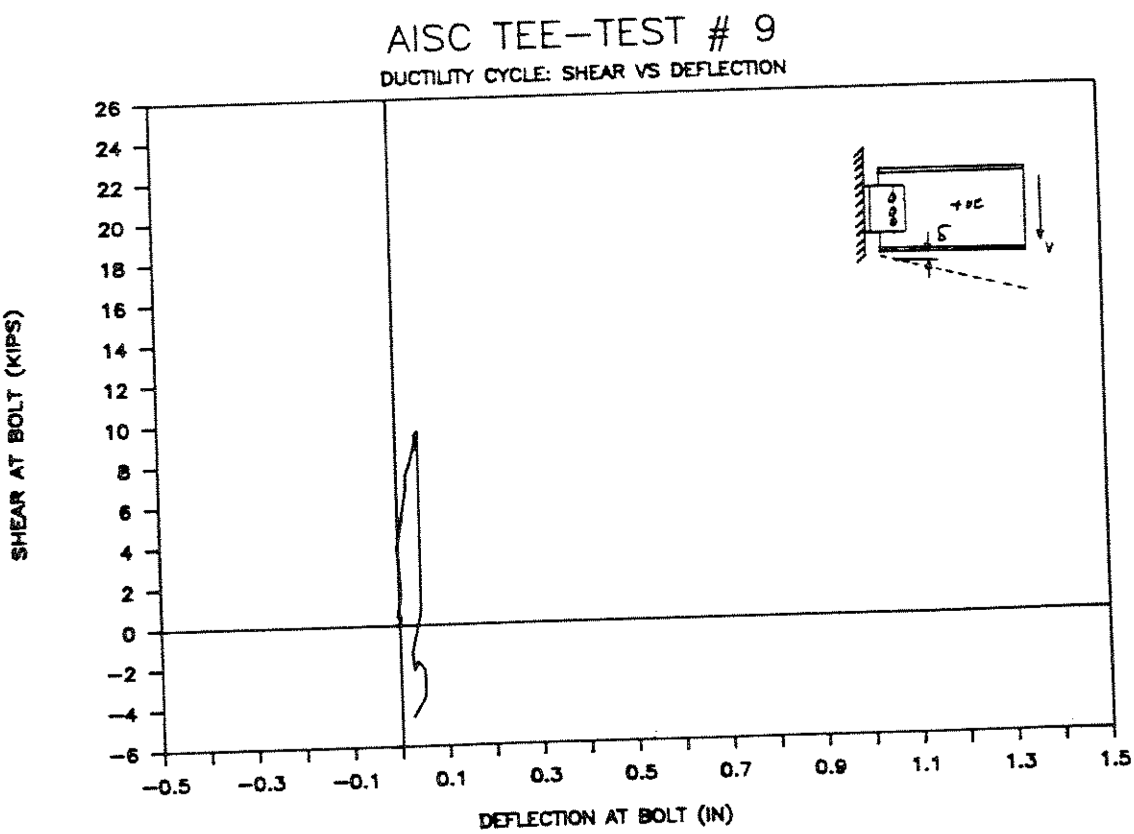
AISC TEE—TEST # 8
ULTIMATE CYCLE: MOMENT VS SHEAR
MOMENT AT BOLT (K—IN)
SHEAR AT BOLT (KIPS)
200
100
0
—100
—200
—300
—400
—500
—600
—700
0
40
80
120
160
200
240
280

AISC TEE-TEST # 8

ULTIMATE CYCLE: NEUTRAL AXIS LOCATION

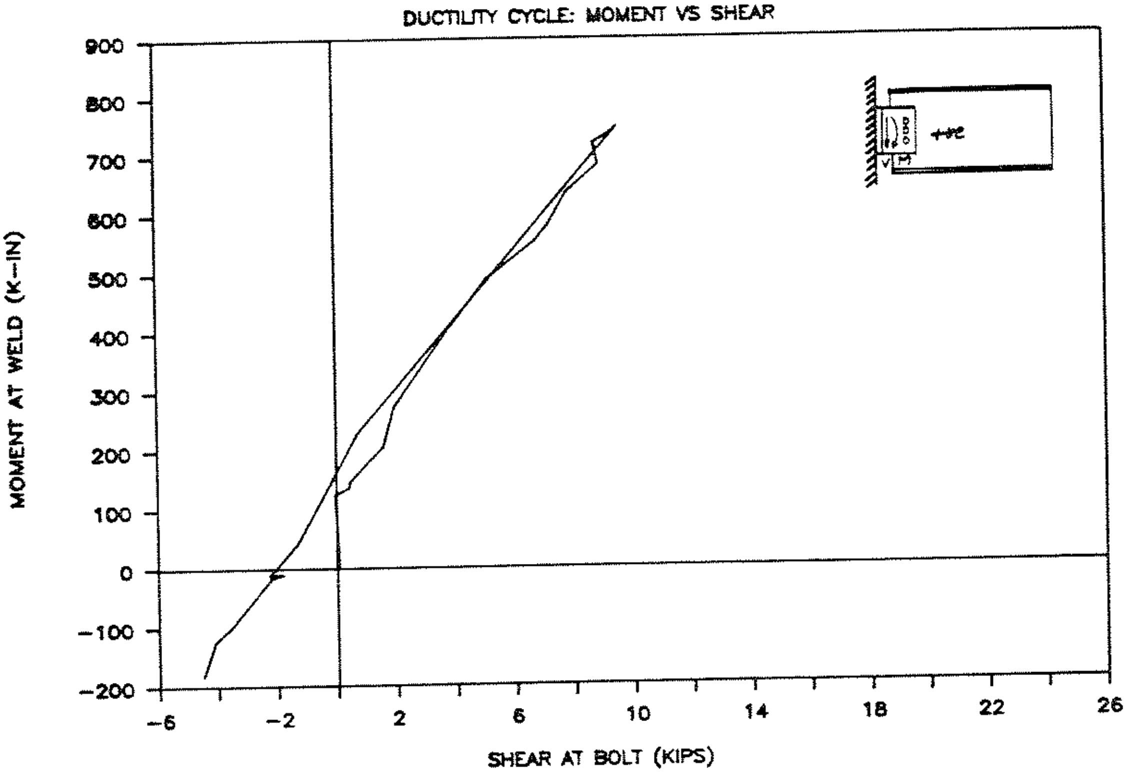



AISC TEE–TEST # 9
DUCTILITY CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
ROTATION OF BEAM (RAD)
0
0.02
0.04
0.06
0.08
0.1
26
24
22
20
18
16
14
12
10
8
6
4
2
0
−2
−4
−6
+ve
V


AISC TEE–TEST # 9
DUCTILITY CYCLE: SHEAR VS DEFLECTION
SHEAR AT BOLT (KIPS)
DEFLECTION AT BOLT (IN)
−0.5
−0.3
−0.1
0.1
0.3
0.5
0.7
0.9
1.1
1.3
1.5
26
24
22
20
18
16
14
12
10
8
6
4
2
0
−2
−4
−6
+ve
V

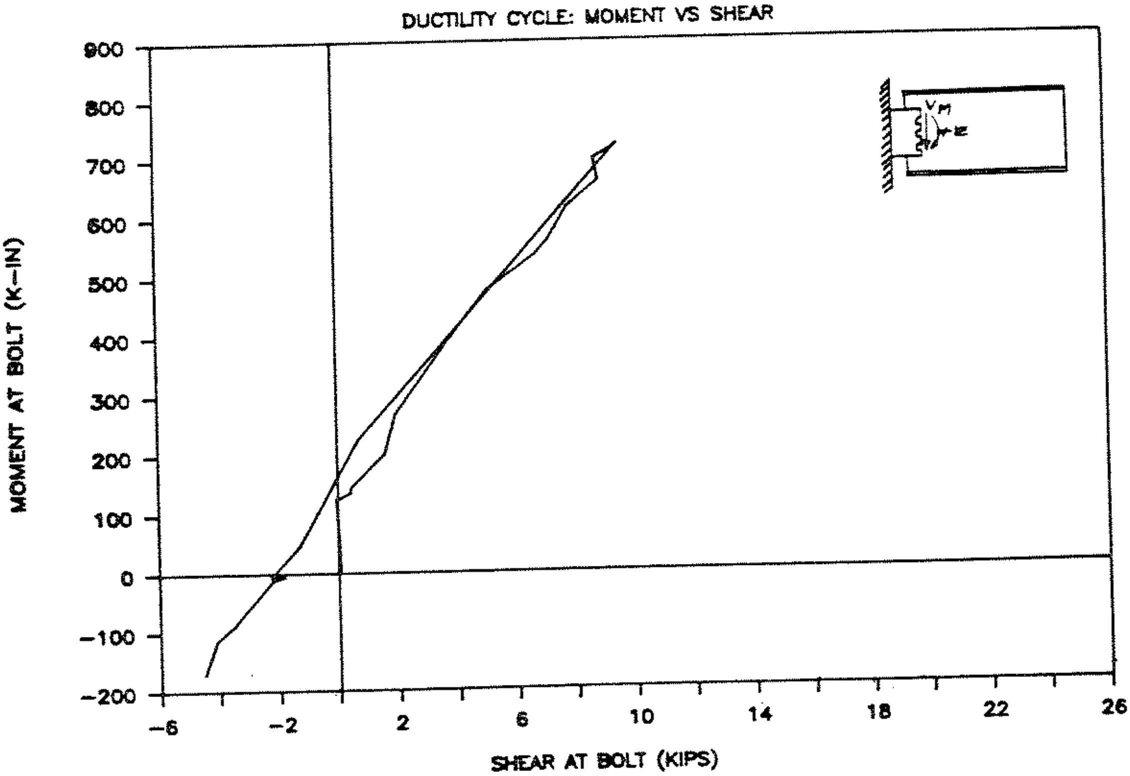
AISC TEE–TEST # 9

DUCTILITY CYCLE: MOMENT VS SHEAR

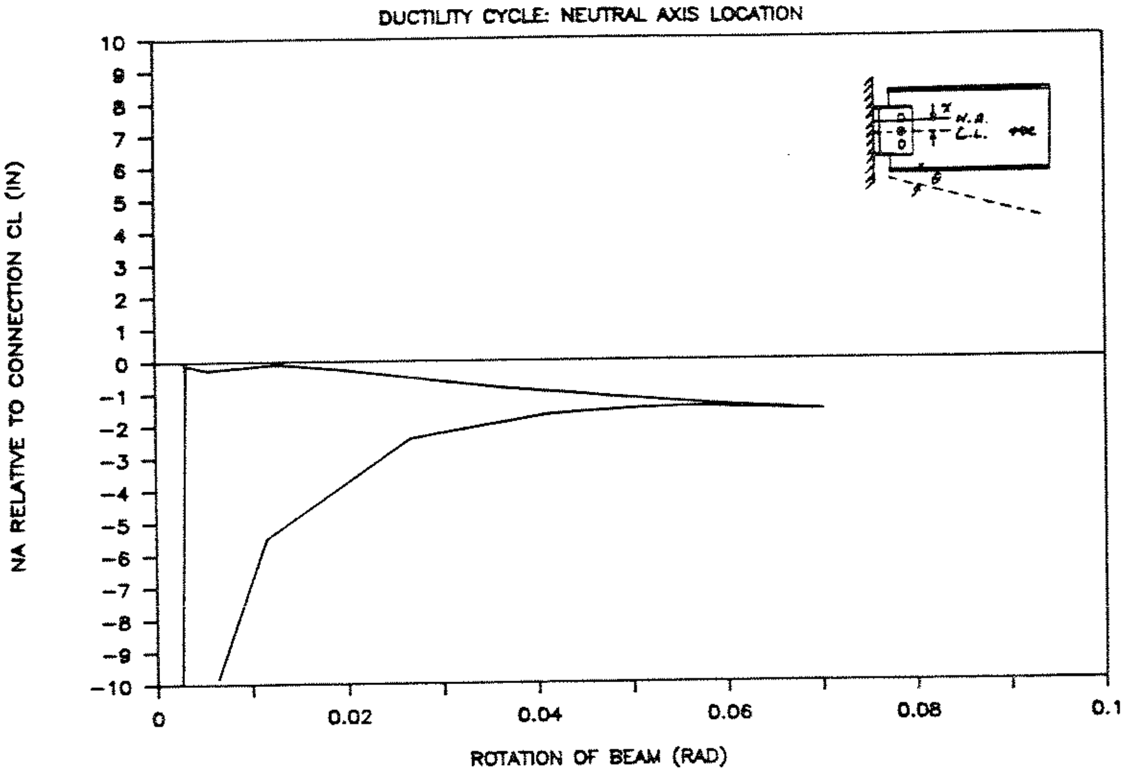


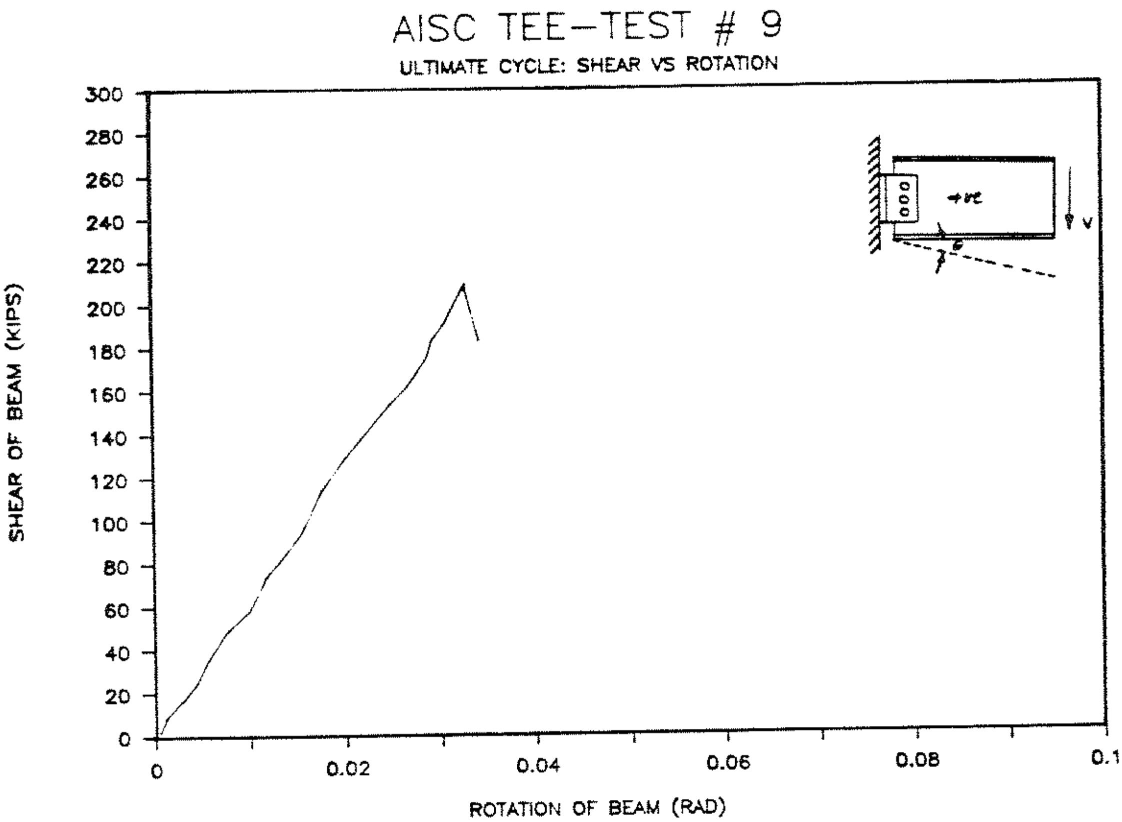
AISC TEE–TEST # 9

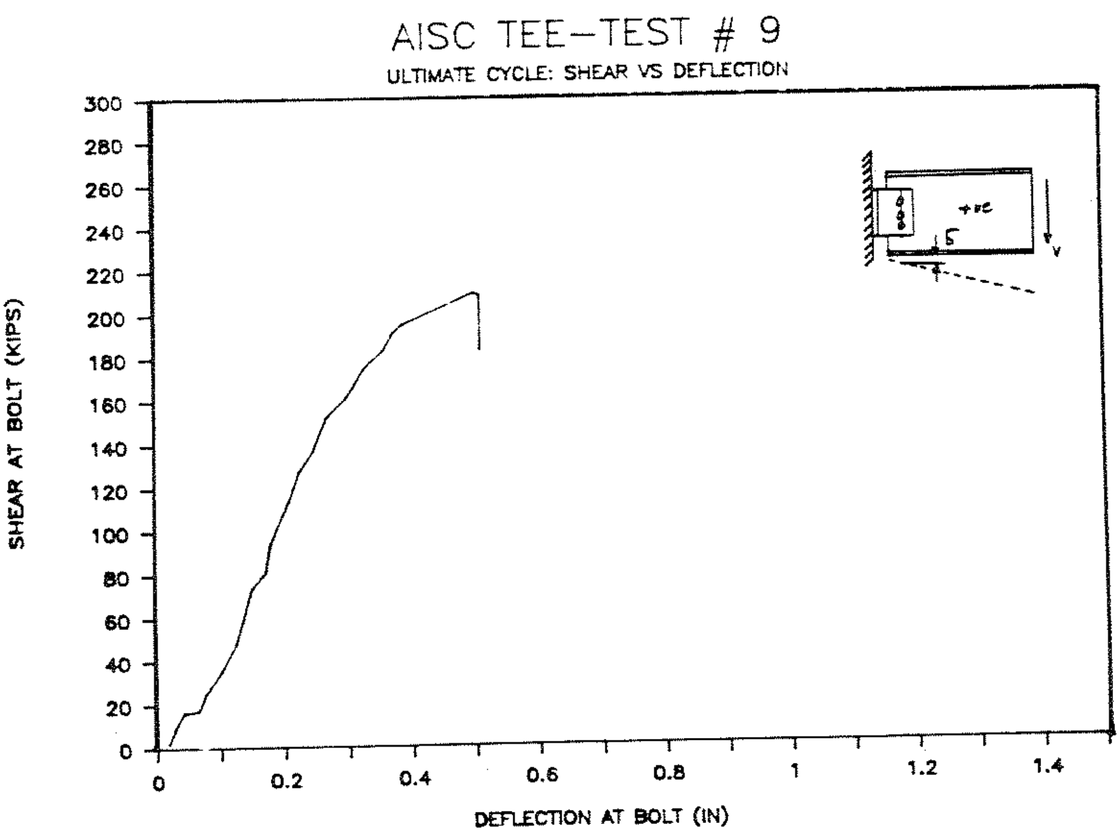
DUCTILITY CYCLE: MOMENT VS SHEAR

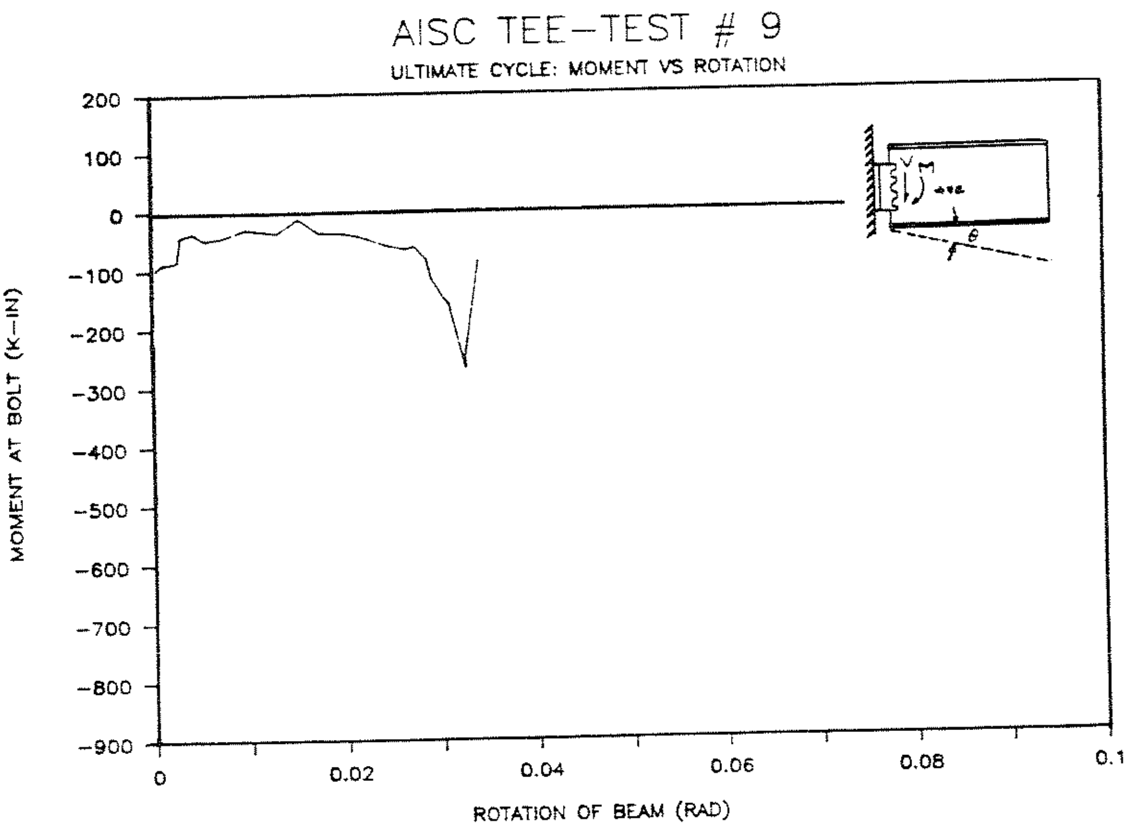


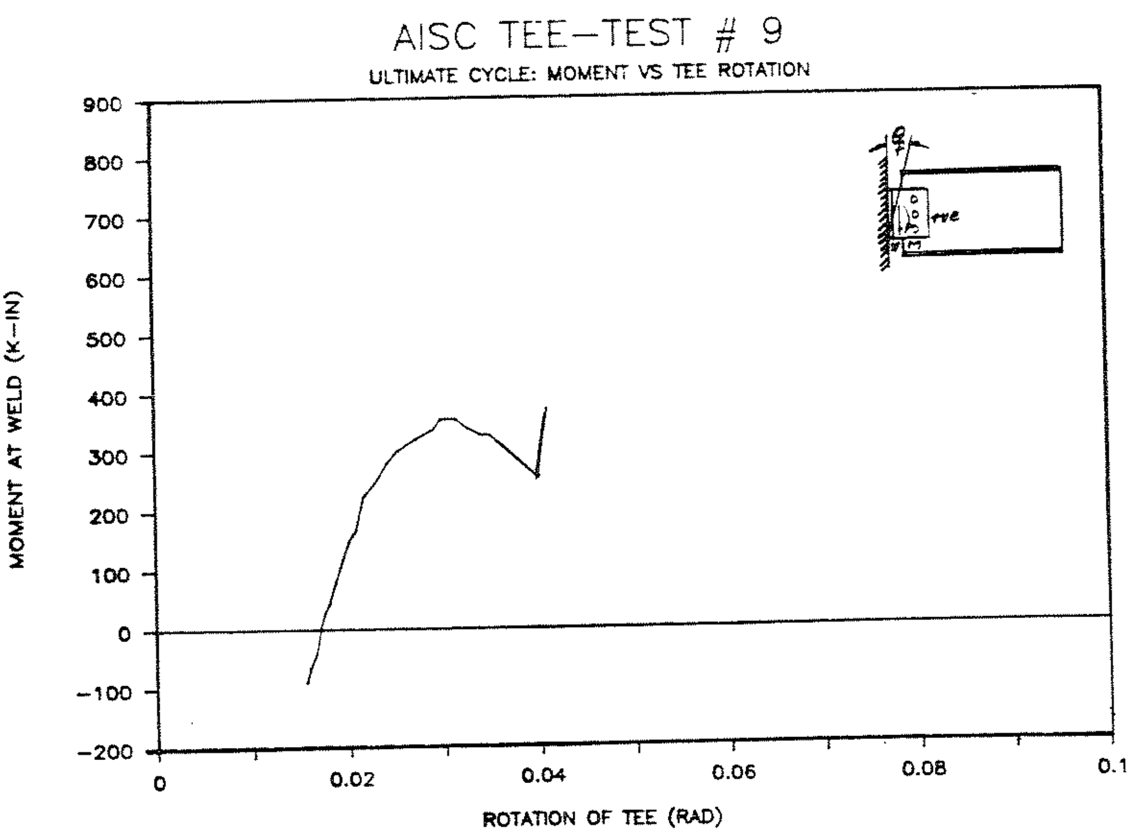
AISC TEE-TEST # 9

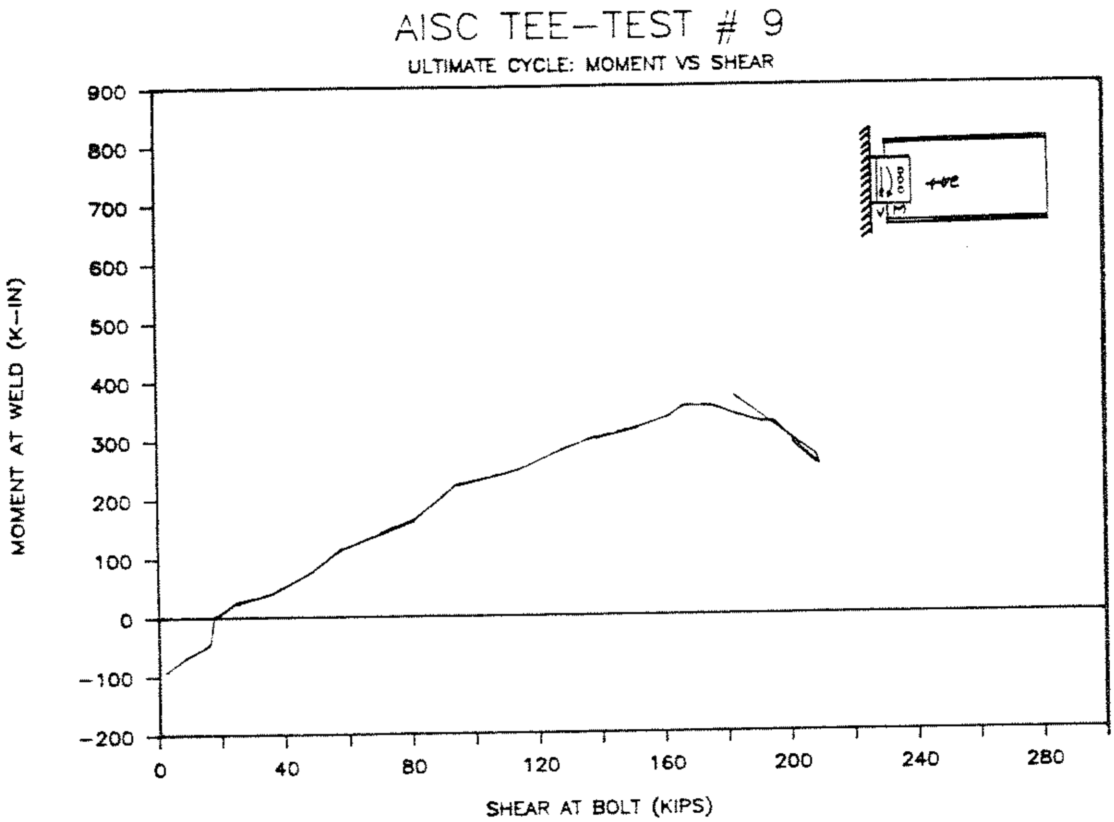



AISC TEE-TEST # 9
ULTIMATE CYCLE: SHEAR VS ROTATION
SHEAR OF BEAM (KIPS)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
0.02
0.04
0.06
0.08
0.1
ROTATION OF BEAM (RAD)
+ve
V

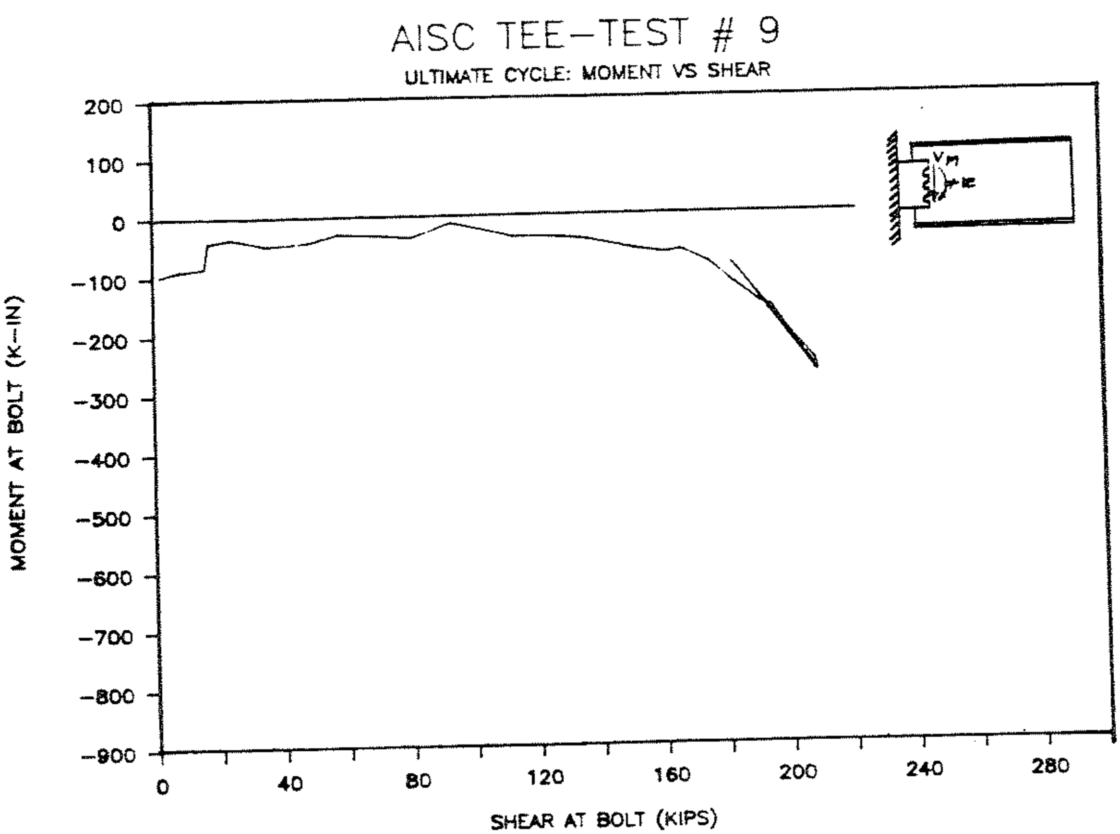

AISC TEE-TEST # 9
ULTIMATE CYCLE: SHEAR VS DEFLECTION
SHEAR AT BOLT (KIPS)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
DEFLECTION AT BOLT (IN)
+ve
V


AISC TEE-TEST # 9
ULTIMATE CYCLE: MOMENT VS ROTATION
MOMENT AT BOLT (K-IN)
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
0
0.02
0.04
0.06
0.08
0.1
ROTATION OF BEAM (RAD)

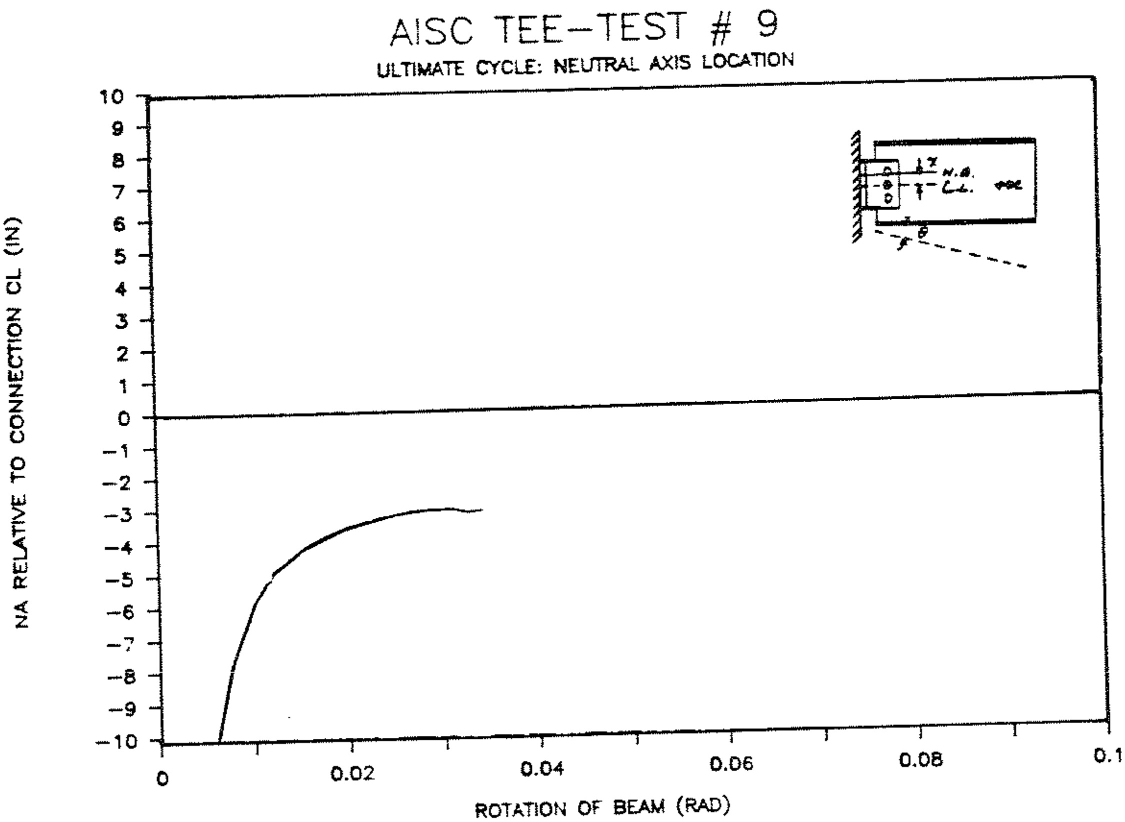

AISC TEE-TEST # 9
ULTIMATE CYCLE: MOMENT VS TEE ROTATION
MOMENT AT WELD (K-IN)
900
800
700
600
500
400
300
200
100
0
-100
-200
0
0.02
0.04
0.06
0.08
0.1
ROTATION OF TEE (RAD)



AISC TEE-TEST # 9
ULTIMATE CYCLE: MOMENT VS SHEAR
MOMENT AT WELD (K-IN)
SHEAR AT BOLT (KIPS)
900
800
700
600
500
400
300
200
100
0
-100
-200
0
40
80
120
160
200
240
280



AISC TEE-TEST # 9
ULTIMATE CYCLE: MOMENT VS SHEAR
MOMENT AT BOLT (K-IN)
SHEAR AT BOLT (KIPS)
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
0
40
80
120
160
200
240
280



AISC TEE-TEST # 9
ULTIMATE CYCLE: NEUTRAL AXIS LOCATION
NA RELATIVE TO CONNECTION CL (IN)
ROTATION OF BEAM (RAD)
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
0
0.02
0.04
0.06
0.08
0.1
N.A.
C.L.

APPENDIX B

MATERIAL TESTS

The material ordered for tee elements was A36 steel. In order to establish actual properties of material standard coupon tests were conducted. The coupons were fabricated according to ASTM Standard E8 with an eight inches long coupon that had four inches of gage length. The results of these tests are reported in this appendix. In Table B1 that follows test results regarding yield and ultimate strength of coupons are reported.

In summary, coupon tests indicated that material is A36 steel with yield point from 43.42 to 53.91 ksi and ultimate strength of 56.46 to 67.30 ksi. The degree of variation was attributed to hardening during rolling and fabrication processes.

Table B1. Results of Material Tests

Test Number	Designation	Coupon Number	Area (in2)	F_y (ksi)	F_u (ksi)	Ultimate Strain*
1	D-W	1	0.530	44.34	65.80	0.256
2	D-W	4	0.528	47.35	66.66	0.207
3	A-F	5	0.503	43.73	56.46	0.241
4	A-F	6	0.468	45.94	61.96	0.241
5	A-W	7	0.371	53.91	66.30	0.195
6	A-W	8	0.376	54.52	67.30	0.184
7	D-F	9	0.844	43.83	65.40	0.224
8	D-F	10	0.829	43.42	65.37	0.227

* Strain when maximum ultimate strength F_u reached.

Summary:

F_y=44.77 ksi and F_u= 63.61 ksi for plates thicker than 0.3"

F_y=54.22 ksi and F_u= 66.80 ksi for plates thinner than 0.3"

APPENDIX C

SAMPLES OF COMPUTER OUTPUT

In order to establish rotation demand of beam end, a computer program was developed (1,2). This appendix provides samples of output of the program.

The program was developed to study the interaction of shear and rotation in simple connections of a simply supported beam subjected to uniform load. The program applies an increasing uniformly distributed load to the beam and measures end rotation and end reaction in addition to other parameters. The program is inelastic, therefore, it continues loading until beam reaches its collapse load and collapses due to formation of a plastic mechanism. The analyses were conducted for all beams listed in the AISC Manual (9), however, only a sample of results is given in this appendix.

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-18-1988 TIME: 12:06:17

BEAM: W 16X 50 SPAN= 10 ft Fy= 36 ksi My= 243.0 k-ft Mp= 276.0 k-ft
Teta Yield= 0.00610 rad Vyweb= 222.4 kips Myfl= 252.8 k-ft Qp= 22.080 k/ft
Zx/Sx=f=1.136 qy= 19.440 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00610	0.437	516.13	0.999	0.88043	Elastic	1.000
1.02716	1.0278	0.00627	0.449	501.93	1.033	0.90435	Fl yield	0.968
1.05432	1.0634	0.00649	0.461	483.20	1.125	0.92826	Web yld.	0.889
1.08148	1.1345	0.00692	0.473	444.89	1.378	0.95217	Web yld.	0.725
1.12444	1.4603	0.00891	0.491	319.15	3.015	0.99000	Web yld.	0.332
1.13467	1.9734	0.01204	0.496	215.94	9.533	0.99900	Web yld.	0.105
1.13569	2.5209	0.01539	0.496	159.14	30.142	0.99990	Web yld.	0.033
1.13579	3.5460	0.02164	0.496	106.28	94.968	0.99999	Web yld.	0.011

BEAM: W 16X 50 SPAN= 30 ft Fy= 36 ksi My= 243.0 k-ft Mp= 276.0 k-ft
Teta Yield= 0.01831 rad Vyweb= 222.4 kips Myfl= 252.8 k-ft Qp= 2.453 k/ft
Zx/Sx=f=1.136 qy= 2.160 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01831	0.146	172.04	0.999	0.88043	Elastic	1.000
1.02716	1.0278	0.01882	0.150	167.31	1.033	0.90435	Fl yield	0.968
1.05432	1.0634	0.01947	0.154	161.07	1.125	0.92826	Web yld.	0.889
1.08148	1.1345	0.02077	0.158	148.30	1.378	0.95217	Web yld.	0.725
1.12444	1.4603	0.02674	0.164	106.38	3.015	0.99000	Web yld.	0.332
1.13467	1.9734	0.03613	0.165	71.98	9.533	0.99900	Web yld.	0.105
1.13569	2.5207	0.04615	0.165	53.05	30.126	0.99990	Web yld.	0.033
1.13579	3.5386	0.06479	0.165	35.51	94.478	0.99999	Web yld.	0.011

BEAM: W 16X 50 SPAN= 50 ft Fy= 36 ksi My= 243.0 k-ft Mp= 276.0 k-ft
Teta Yield= 0.03052 rad . Vyweb= 222.4 kips Myfl= 252.8 k-ft Qp= 0.883 k/ft
Zx/Sx=f=1.136 qy= 0.778 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.03051	0.087	103.23	0.999	0.88043	Elastic	1.000
1.02716	1.0278	0.03137	0.090	100.39	1.033	0.90435	Fl yield	0.968
1.05432	1.0634	0.03245	0.092	96.64	1.125	0.92826	Web yld.	0.889
1.08148	1.1345	0.03462	0.095	88.98	1.378	0.95217	Web yld.	0.725
1.12444	1.4603	0.04456	0.098	63.83	3.015	0.99000	Web yld.	0.332
1.13467	1.9735	0.06022	0.099	43.19	9.533	0.99900	Web yld.	0.105
1.13569	2.5207	0.07692	0.099	31.83	30.126	0.99990	Web yld.	0.033
1.13579	3.5460	0.10821	0.099	21.26	94.968	0.99999	Web yld.	0.011

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-18-1988 TIME: 12:11:36

BEAM: W 16X 36 SPAN= 10 ft Fy= 36 ksi My= 169.5 k-ft Mp= 192.0 k-ft
Teta Yield= 0.00626 rad Vyweb= 168.4 kips Myfl= 174.5 k-ft Qp= 15.360 k/ft
Zx/Sx=f=1.133 qy= 13.560 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00626	0.403	503.03	1.000	0.88281	Elastic	1.000
1.02655	1.0276	0.00644	0.413	489.20	1.036	0.90625	Fl yield	0.965
1.05310	1.0705	0.00670	0.424	466.07	1.172	0.92969	Web yld.	0.853
1.07965	1.1477	0.00719	0.435	426.32	1.436	0.95312	Web yld.	0.696
1.12142	1.4822	0.00928	0.451	304.95	3.109	0.99000	Web yld.	0.322
1.13161	2.0115	0.01260	0.456	205.59	9.831	0.99900	Web yld.	0.102
1.13263	2.5758	0.01613	0.456	151.24	31.090	0.99990	Web yld.	0.032
1.13273	3.6377	0.02278	0.456	100.66	98.316	0.99999	Web yld.	0.010

BEAM: W 16X 36 SPAN= 30 ft Fy= 36 ksi My= 169.5 k-ft Mp= 192.0 k-ft
Teta Yield= 0.01879 rad Vyweb= 168.4 kips Myfl= 174.5 k-ft Qp= 1.707 k/ft
Zx/Sx=f=1.133 qy= 1.507 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01879	0.134	167.68	1.000	0.88281	Elastic	1.000
1.02655	1.0276	0.01931	0.138	163.07	1.036	0.90625	Fl yield	0.965
1.05310	1.0705	0.02011	0.141	155.36	1.172	0.92969	Web yld.	0.853
1.07965	1.1477	0.02156	0.145	142.11	1.436	0.95313	Web yld.	0.696
1.12142	1.4822	0.02785	0.150	101.65	3.109	0.99000	Web yld.	0.322
1.13161	2.0115	0.03779	0.152	68.53	9.831	0.99900	Web yld.	0.102
1.13263	2.5758	0.04839	0.152	50.41	31.090	0.99990	Web yld.	0.032
1.13273	3.6299	0.06820	0.152	33.64	97.803	0.99999	Web yld.	0.010

BEAM: W 16X 36 SPAN= 50 ft Fy= 36 ksi My= 169.5 k-ft Mp= 192.0 k-ft
Teta Yield= 0.03131 rad Vyweb= 168.4 kips Myfl= 174.5 k-ft Qp= 0.614 k/ft
Zx/Sx=f=1.133 qy= 0.542 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.03131	0.081	100.61	1.000	0.88281	Elastic	1.000
1.02655	1.0276	0.03218	0.083	97.84	1.036	0.90625	Fl yield	0.965
1.05310	1.0705	0.03352	0.085	93.21	1.172	0.92969	Web yld.	0.853
1.07965	1.1477	0.03594	0.087	85.26	1.436	0.95313	Web yld.	0.696
1.12142	1.4822	0.04641	0.090	60.99	3.109	0.99000	Web yld.	0.322
1.13161	2.0115	0.06298	0.091	41.12	9.831	0.99900	Web yld.	0.102
1.13263	2.5758	0.08065	0.091	30.25	31.090	0.99990	Web yld.	0.032
1.13273	3.6299	0.11366	0.091	20.18	97.803	0.99999	Web yld.	0.010

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-18-1988 TIME: 11:31:26

BEAM: W 16X 100 SPAN= 10 ft Fy= 36 ksi My= 525.0 k-ft Mp= 594.0 k-ft
Teta Yield= 0.00583 rad Vyweb= 357.4 kips Myfl= 556.9 k-ft Qp= 47.520 k/ft
Zx/Sx=f=1.131 qy= 42.000 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00583	0.588	540.14	0.997	0.88384	Elastic	1.000
1.02629	1.0266	0.00599	0.603	525.95	1.026	0.90707	Fl yield	0.974
1.05257	1.0559	0.00616	0.618	510.70	1.070	0.93030	Fl yield	0.934
1.07886	1.1006	0.00642	0.634	485.95	1.231	0.95354	Web yld.	0.812
1.12011	1.3704	0.00799	0.658	362.38	2.654	0.99000	Web yld.	0.377
1.13030	1.8211	0.01062	0.664	248.93	8.392	0.99900	Web yld.	0.119
1.13132	2.3043	0.01344	0.665	184.80	26.538	0.99990	Web yld.	0.038
1.13142	3.2132	0.01874	0.665	124.08	83.876	0.99999	Web yld.	0.012

BEAM: W 16X 100 SPAN= 30 ft Fy= 36 ksi My= 525.0 k-ft Mp= 594.0 k-ft
Teta Yield= 0.01750 rad Vyweb= 357.4 kips Myfl= 556.9 k-ft Qp= 5.280 k/ft
Zx/Sx=f=1.131 qy= 4.667 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01749	0.196	180.05	0.997	0.88384	Elastic	1.000
1.02629	1.0266	0.01796	0.201	175.32	1.026	0.90707	Fl yield	0.974
1.05257	1.0559	0.01847	0.206	170.23	1.070	0.93030	Fl yield	0.934
1.07886	1.1006	0.01926	0.211	161.98	1.231	0.95354	Web yld.	0.812
1.12011	1.3704	0.02398	0.219	120.79	2.654	0.99000	Web yld.	0.377
1.13030	1.8211	0.03186	0.221	82.98	8.391	0.99900	Web yld.	0.119
1.13132	2.3042	0.04031	0.222	61.60	26.538	0.99990	Web yld.	0.038
1.13142	3.2066	0.05610	0.222	41.46	83.438	0.99999	Web yld.	0.012

BEAM: W 16X 100 SPAN= 50 ft Fy= 36 ksi My= 525.0 k-ft Mp= 594.0 k-ft
Teta Yield= 0.02916 rad Vyweb= 357.4 kips Myfl= 556.9 k-ft Qp= 1.901 k/ft
Zx/Sx=f=1.131 qy= 1.680 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02916	0.118	108.03	0.997	0.88384	Elastic	1.000
1.02629	1.0266	0.02994	0.121	105.19	1.026	0.90707	Fl yield	0.974
1.05257	1.0559	0.03079	0.124	102.14	1.070	0.93030	Fl yield	0.934
1.07886	1.1006	0.03209	0.127	97.19	1.231	0.95354	Web yld.	0.812
1.12011	1.3704	0.03996	0.132	72.48	2.654	0.99000	Web yld.	0.377
1.13030	1.8211	0.05310	0.133	49.79	8.392	0.99900	Web yld.	0.119
1.13132	2.3042	0.06719	0.133	36.96	26.538	0.99990	Web yld.	0.038
1.13142	3.2132	0.09370	0.133	24.82	83.876	0.99999	Web yld.	0.012

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-17-1988 TIME: 17:06:35

BEAM: W 24X 104 SPAN= 10 ft Fy= 36 ksi My= 774.0 k-ft Mp= 867.0 k-ft
Teta Yield= 0.00413 rad Vyweb= 433.1 kips Myfl= 799.1 k-ft Qp= 69.360 k/ft
Zx/Sx=f=1.120 qy= 61.920 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00413	0.715	762.26	1.001	0.89273	Elastic	0.999
1.02403	1.0247	0.00423	0.732	743.58	1.032	0.91419	Fl yield	0.969
1.04806	1.0591	0.00438	0.749	715.81	1.140	0.93564	Web yld.	0.877
1.07209	1.1281	0.00466	0.766	659.84	1.396	0.95709	Web yld.	0.716
1.10895	1.4175	0.00586	0.793	487.71	2.892	0.99000	Web yld.	0.346
1.11903	1.9089	0.00789	0.800	330.98	9.146	0.99900	Web yld.	0.109
1.12004	2.4331	0.01006	0.801	244.32	28.919	0.99990	Web yld.	0.035
1.12014	3.4125	0.01410	0.801	163.53	90.968	0.99999	Web yld.	0.011

BEAM: W 24X 104 SPAN= 30 ft Fy= 36 ksi My= 774.0 k-ft Mp= 867.0 k-ft
Teta Yield= 0.01240 rad Vyweb= 433.1 kips Myfl= 799.1 k-ft Qp= 7.707 k/ft
Zx/Sx=f=1.120 qy= 6.880 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01240	0.238	254.09	1.001	0.89273	Elastic	0.999
1.02403	1.0247	0.01270	0.244	247.86	1.032	0.91419	Fl yield	0.969
1.04806	1.0591	0.01313	0.250	238.60	1.140	0.93564	Web yld.	0.877
1.07209	1.1281	0.01399	0.255	219.95	1.396	0.95709	Web yld.	0.716
1.10895	1.4175	0.01757	0.264	162.57	2.892	0.99000	Web yld.	0.346
1.11903	1.9089	0.02367	0.267	110.33	9.146	0.99900	Web yld.	0.109
1.12004	2.4328	0.03016	0.267	81.45	28.904	0.99990	Web yld.	0.035
1.12014	3.4125	0.04231	0.267	54.51	90.968	0.99999	Web yld.	0.011

BEAM: W 24X 104 SPAN= 50 ft Fy= 36 ksi My= 774.0 k-ft Mp= 867.0 k-ft
Teta Yield= 0.02066 rad Vyweb= 433.1 kips Myfl= 799.1 k-ft Qp= 2.774 k/ft
Zx/Sx=f=1.120 qy= 2.477 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02066	0.143	152.45	1.001	0.89273	Elastic	0.999
1.02403	1.0247	0.02117	0.146	148.72	1.032	0.91419	Fl yield	0.969
1.04806	1.0591	0.02188	0.150	143.16	1.140	0.93564	Web yld.	0.877
1.07209	1.1281	0.02331	0.153	131.97	1.396	0.95709	Web yld.	0.716
1.10895	1.4175	0.02929	0.159	97.54	2.892	0.99000	Web yld.	0.346
1.11903	1.9089	0.03944	0.160	66.20	9.146	0.99900	Web yld.	0.109
1.12004	2.4328	0.05027	0.160	48.87	28.904	0.99990	Web yld.	0.035
1.12014	3.4125	0.07051	0.160	32.71	90.968	0.99999	Web yld.	0.011

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RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-18-1988 TIME: 11:27:57

BEAM: W 18X 40 SPAN= 10 ft Fy= 36 ksi My= 205.2 k-ft Mp= 235.2 k-ft
Teta Yield= 0.00555 rad Vyweb= 203.0 kips Myfl= 211.4 k-ft Qp= 18.816 k/ft
Zx/Sx=f=1.146 qy= 16.416 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00555	0.404	567.62	1.000	0.87245	Elastic	1.000
1.02924	1.0304	0.00572	0.416	550.45	1.040	0.89796	Fl yield	0.961
1.05848	1.0780	0.00598	0.428	521.79	1.184	0.92347	Web yld.	0.844
1.08772	1.1609	0.00644	0.440	474.97	1.450	0.94898	Web yld.	0.689
1.13474	1.5350	0.00852	0.459	330.29	3.276	0.99000	Web yld.	0.305
1.14505	2.0937	0.01162	0.463	221.75	10.360	0.99900	Web yld.	0.097
1.14608	2.6882	0.01492	0.463	162.82	32.755	0.99990	Web yld.	0.031
1.14619	3.8003	0.02109	0.463	108.40	103.152	0.99999	Web yld.	0.010

BEAM: W 18X 40 SPAN= 30 ft Fy= 36 ksi My= 205.2 k-ft Mp= 235.2 k-ft
Teta Yield= 0.01665 rad Vyweb= 203.0 kips Myfl= 211.4 k-ft Qp= 2.091 k/ft
Zx/Sx=f=1.146 qy= 1.824 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01665	0.135	189.21	1.000	0.87245	Elastic	1.000
1.02924	1.0304	0.01716	0.139	183.48	1.040	0.89796	Fl yield	0.961
1.05848	1.0780	0.01795	0.143	173.93	1.184	0.92347	Web yld.	0.844
1.08772	1.1609	0.01933	0.147	158.32	1.450	0.94898	Web yld.	0.689
1.13474	1.5350	0.02556	0.153	110.10	3.276	0.99000	Web yld.	0.305
1.14505	2.0937	0.03486	0.154	73.92	10.360	0.99900	Web yld.	0.097
1.14608	2.6879	0.04475	0.154	54.28	32.738	0.99990	Web yld.	0.031
1.14619	3.8003	0.06327	0.154	36.13	103.152	0.99999	Web yld.	0.010

BEAM: W 18X 40 SPAN= 50 ft Fy= 36 ksi My= 205.2 k-ft Mp= 235.2 k-ft
Teta Yield= 0.02775 rad Vyweb= 203.0 kips Myfl= 211.4 k-ft Qp= 0.753 k/ft
Zx/Sx=f=1.146 qy= 0.657 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02775	0.081	113.52	1.000	0.87245	Elastic	1.000
1.02924	1.0304	0.02859	0.083	110.09	1.040	0.89796	Fl yield	0.961
1.05848	1.0780	0.02991	0.086	104.36	1.184	0.92347	Web yld.	0.844
1.08772	1.1609	0.03221	0.088	94.99	1.450	0.94898	Web yld.	0.689
1.13474	1.5350	0.04259	0.092	66.06	3.276	0.99000	Web yld.	0.305
1.14505	2.0938	0.05810	0.093	44.35	10.361	0.99900	Web yld.	0.097
1.14608	2.6885	0.07460	0.093	32.56	32.772	0.99990	Web yld.	0.031
1.14619	3.8166	0.10591	0.093	21.57	104.232	0.99999	Web yld.	0.010

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-18-1988 TIME: 11:20:51

BEAM: W 18X 60 SPAN= 10 ft Fy= 36 ksi My= 324.0 k-ft Mp= 369.0 k-ft
Teta Yield= 0.00545 rad Vyweb= 272.5 kips Myfl= 337.1 k-ft Qp= 29.520 k/ft
Zx/Sx=f=1.139 qy= 25.920 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00545	0.476	578.01	1.001	0.87805	Elastic	0.999
1.02778	1.0285	0.00561	0.489	561.72	1.035	0.90244	Fl yield	0.966
1.05556	1.0654	0.00581	0.502	539.95	1.132	0.92683	Web yld.	0.884
1.08333	1.1380	0.00620	0.515	496.47	1.386	0.95122	Web yld.	0.721
1.12750	1.4731	0.00803	0.536	353.72	3.061	0.99000	Web yld.	0.327
1.13775	1.9936	0.01087	0.541	239.03	9.682	0.99900	Web yld.	0.103
1.13878	2.5489	0.01389	0.542	176.04	30.621	0.99990	Web yld.	0.033
1.13888	3.5900	0.01957	0.542	117.44	96.578	0.99999	Web yld.	0.010

BEAM: W 18X 60 SPAN= 30 ft Fy= 36 ksi My= 324.0 k-ft Mp= 369.0 k-ft
Teta Yield= 0.01635 rad Vyweb= 272.5 kips Myfl= 337.1 k-ft Qp= 3.280 k/ft
Zx/Sx=f=1.139 qy= 2.880 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01635	0.159	192.67	1.001	0.87805	Elastic	0.999
1.02778	1.0285	0.01682	0.163	187.24	1.035	0.90244	Fl yield	0.966
1.05556	1.0654	0.01742	0.167	179.98	1.132	0.92683	Web yld.	0.884
1.08333	1.1380	0.01861	0.172	165.49	1.386	0.95122	Web yld.	0.721
1.12750	1.4731	0.02408	0.179	117.91	3.061	0.99000	Web yld.	0.327
1.13775	1.9936	0.03260	0.180	79.68	9.682	0.99900	Web yld.	0.103
1.13878	2.5492	0.04168	0.181	58.67	30.637	0.99990	Web yld.	0.033
1.13888	3.5900	0.05870	0.181	39.15	96.578	0.99999	Web yld.	0.010

BEAM: W 18X 60 SPAN= 50 ft Fy= 36 ksi My= 324.0 k-ft Mp= 369.0 k-ft
Teta Yield= 0.02725 rad Vyweb= 272.5 kips Myfl= 337.1 k-ft Qp= 1.181 k/ft
Zx/Sx=f=1.139 qy= 1.037 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02725	0.095	115.60	1.001	0.87805	Elastic	0.999
1.02778	1.0285	0.02803	0.098	112.34	1.035	0.90244	Fl yield	0.966
1.05556	1.0654	0.02903	0.100	107.99	1.132	0.92683	Web yld.	0.884
1.08333	1.1380	0.03101	0.103	99.29	1.386	0.95122	Web yld.	0.721
1.12750	1.4731	0.04014	0.107	70.74	3.061	0.99000	Web yld.	0.327
1.13775	1.9936	0.05433	0.108	47.81	9.682	0.99900	Web yld.	0.103
1.13878	2.5489	0.06946	0.108	35.21	30.621	0.99990	Web yld.	0.033
1.13888	3.6054	0.09825	0.108	23.37	97.600	0.99999	Web yld.	0.010

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RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-18-1988 TIME: 11:10:01

BEAM: W 18X 106 SPAN= 10 ft Fy= 36 ksi My= 612.0 k-ft Mp= 690.0 k-ft
Teta Yield= 0.00530 rad Vyweb= 397.8 kips Myfl= 643.4 k-ft Qp= 55.200 k/ft
Zx/Sx=f=1.127 qy= 48.960 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00530	0.615	593.97	1.000	0.88696	Elastic	1.000
1.02549	1.0259	0.00544	0.631	578.79	1.030	0.90957	Fl yield	0.971
1.05098	1.0548	0.00559	0.647	562.04	1.077	0.93217	Fl yield	0.929
1.07647	1.1081	0.00588	0.662	528.46	1.288	0.95478	Web yld.	0.776
1.11618	1.3850	0.00735	0.687	392.46	2.739	0.99000	Web yld.	0.365
1.12632	1.8500	0.00981	0.693	268.29	8.662	0.99900	Web yld.	0.115
1.12734	2.3468	0.01245	0.694	198.77	27.388	0.99990	Web yld.	0.037
1.12744	3.2794	0.01739	0.694	133.30	86.426	0.99999	Web yld.	0.012

BEAM: W 18X 106 SPAN= 30 ft Fy= 36 ksi My= 612.0 k-ft Mp= 690.0 k-ft
Teta Yield= 0.01591 rad Vyweb= 397.8 kips Myfl= 643.4 k-ft Qp= 6.133 k/ft
Zx/Sx=f=1.127 qy= 5.440 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01591	0.205	197.99	1.000	0.88696	Elastic	1.000
1.02549	1.0259	0.01632	0.210	192.93	1.030	0.90957	Fl yield	0.971
1.05098	1.0548	0.01678	0.216	187.35	1.077	0.93217	Fl yield	0.929
1.07647	1.1081	0.01763	0.221	176.15	1.288	0.95478	Web yld.	0.776
1.11618	1.3850	0.02204	0.229	130.82	2.739	0.99000	Web yld.	0.365
1.12632	1.8500	0.02943	0.231	89.43	8.662	0.99900	Web yld.	0.115
1.12734	2.3468	0.03734	0.231	66.26	27.388	0.99990	Web yld.	0.037
1.12744	3.2863	0.05229	0.231	44.33	86.885	0.99999	Web yld.	0.012

BEAM: W 18X 106 SPAN= 50 ft Fy= 36 ksi My= 612.0 k-ft Mp= 690.0 k-ft
Teta Yield= 0.02652 rad Vyweb= 397.8 kips Myfl= 643.4 k-ft Qp= 2.208 k/ft
Zx/Sx=f=1.127 qy= 1.958 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02651	0.123	118.79	1.000	0.88696	Elastic	1.000
1.02549	1.0259	0.02720	0.126	115.76	1.030	0.90957	Fl yield	0.971
1.05098	1.0548	0.02797	0.129	112.41	1.077	0.93217	Fl yield	0.929
1.07647	1.1081	0.02939	0.132	105.69	1.288	0.95478	Web yld.	0.776
1.11618	1.3850	0.03673	0.137	78.49	2.739	0.99000	Web yld.	0.365
1.12632	1.8500	0.04906	0.139	53.66	8.662	0.99900	Web yld.	0.115
1.12734	2.3468	0.06223	0.139	39.75	27.388	0.99990	Web yld.	0.037
1.12744	3.2794	0.08696	0.139	26.66	86.426	0.99999	Web yld.	0.012

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-17-1988 TIME: 19:10:59

BEAM: W 21X 122 SPAN= 10 ft Fy= 36 ksi My= 819.0 k-ft Mp= 921.0 k-ft
Teta Yield= 0.00458 rad Vyweb= 468.3 kips Myfl= 856.8 k-ft Qp= 73.680 k/ft
Zx/Sx=f=1.125 qy= 65.520 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00458	0.700	687.84	1.000	0.88925	Elastic	1.000
1.02491	1.0253	0.00470	0.717	670.61	1.029	0.91140	Fl yield	0.972
1.04982	1.0535	0.00482	0.734	651.74	1.073	0.93355	Web yld.	0.932
1.07473	1.1117	0.00509	0.752	608.69	1.314	0.95570	Web yld.	0.761
1.11330	1.3902	0.00637	0.779	451.92	2.766	0.99000	Web yld.	0.362
1.12342	1.8594	0.00852	0.786	308.57	8.747	0.99900	Web yld.	0.114
1.12443	2.3613	0.01081	0.787	228.42	27.652	0.99990	Web yld.	0.036
1.12453	3.3019	0.01512	0.787	153.15	87.166	0.99999	Web yld.	0.011

BEAM: W 21X 122 SPAN= 30 ft Fy= 36 ksi My= 819.0 k-ft Mp= 921.0 k-ft
Teta Yield= 0.01374 rad Vyweb= 468.3 kips Myfl= 856.8 k-ft Qp= 8.187 k/ft
Zx/Sx=f=1.125 qy= 7.280 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01374	0.233	229.28	1.000	0.88925	Elastic	1.000
1.02491	1.0253	0.01409	0.239	223.54	1.029	0.91140	Fl yield	0.972
1.04982	1.0535	0.01447	0.245	217.25	1.073	0.93355	Web yld.	0.932
1.07473	1.1117	0.01527	0.251	202.90	1.314	0.95570	Web yld.	0.761
1.11330	1.3902	0.01910	0.260	150.64	2.766	0.99000	Web yld.	0.362
1.12342	1.8594	0.02555	0.262	102.86	8.747	0.99900	Web yld.	0.114
1.12443	2.3614	0.03244	0.262	76.14	27.652	0.99990	Web yld.	0.036
1.12453	3.3019	0.04537	0.262	51.05	87.166	0.99999	Web yld.	0.011

BEAM: W 21X 122 SPAN= 50 ft Fy= 36 ksi My= 819.0 k-ft Mp= 921.0 k-ft
Teta Yield= 0.02290 rad Vyweb= 468.3 kips Myfl= 856.8 k-ft Qp= 2.947 k/ft
Zx/Sx=f=1.125 qy= 2.621 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02290	0.140	137.57	1.000	0.88925	Elastic	1.000
1.02491	1.0253	0.02348	0.143	134.12	1.029	0.91140	Fl yield	0.972
1.04982	1.0535	0.02412	0.147	130.35	1.073	0.93355	Web yld.	0.932
1.07473	1.1117	0.02546	0.150	121.74	1.314	0.95570	Web yld.	0.761
1.11330	1.3902	0.03183	0.156	90.39	2.766	0.99000	Web yld.	0.362
1.12342	1.8594	0.04258	0.157	61.71	8.747	0.99900	Web yld.	0.114
1.12443	2.3614	0.05407	0.157	45.68	27.652	0.99990	Web yld.	0.036
1.12453	3.3019	0.07561	0.157	30.63	87.166	0.99999	Web yld.	0.011

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-18-1988 TIME: 12:09:51

BEAM: W 16X 40 SPAN= 10 ft Fy= 36 ksi My= 194.1 k-ft Mp= 218.7 k-ft
Teta Yield= 0.00620 rad Vyweb= 175.8 kips Myfl= 200.4 k-ft Qp= 17.496 k/ft
Zx/Sx=f=1.127 qy= 15.528 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00620	0.442	507.91	1.000	0.88752	Elastic	1.000
1.02535	1.0261	0.00636	0.453	494.76	1.032	0.91001	Fl yield	0.969
1.05070	1.0640	0.00660	0.464	474.32	1.151	0.93251	Web yld.	0.869
1.07604	1.1360	0.00705	0.475	436.01	1.409	0.95501	Web yld.	0.710
1.11547	1.4476	0.00898	0.493	316.87	2.989	0.99000	Web yld.	0.335
1.12561	1.9561	0.01213	0.497	214.41	9.451	0.99900	Web yld.	0.106
1.12663	2.4988	0.01550	0.498	158.00	29.893	0.99990	Web yld.	0.033
1.12673	3.5162	0.02181	0.498	105.47	94.280	0.99999	Web yld.	0.011

BEAM: W 16X 40 SPAN= 30 ft Fy= 36 ksi My= 194.1 k-ft Mp= 218.7 k-ft
Teta Yield= 0.01861 rad Vyweb= 175.8 kips Myfl= 200.4 k-ft Qp= 1.944 k/ft
Zx/Sx=f=1.127 qy= 1.725 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01860	0.147	169.30	1.000	0.88752	Elastic	1.000
1.02535	1.0261	0.01909	0.151	164.92	1.032	0.91001	Fl yield	0.969
1.05070	1.0640	0.01980	0.155	158.11	1.151	0.93251	Web yld.	0.869
1.07604	1.1360	0.02114	0.158	145.34	1.409	0.95501	Web yld.	0.710
1.11547	1.4476	0.02693	0.164	105.62	2.989	0.99000	Web yld.	0.335
1.12561	1.9561	0.03640	0.166	71.47	9.451	0.99900	Web yld.	0.106
1.12663	2.4988	0.04649	0.166	52.67	29.893	0.99990	Web yld.	0.033
1.12673	3.5162	0.06542	0.166	35.16	94.280	0.99999	Web yld.	0.011

BEAM: W 16X 40 SPAN= 50 ft Fy= 36 ksi My= 194.1 k-ft Mp= 218.7 k-ft
Teta Yield= 0.03101 rad Vyweb= 175.8 kips Myfl= 200.4 k-ft Qp= 0.700 k/ft
Zx/Sx=f=1.127 qy= 0.621 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.03101	0.088	101.58	1.000	0.88752	Elastic	1.000
1.02535	1.0261	0.03182	0.091	98.95	1.032	0.91001	Fl yield	0.969
1.05070	1.0640	0.03299	0.093	94.86	1.151	0.93251	Web yld.	0.869
1.07604	1.1360	0.03523	0.095	87.20	1.409	0.95501	Web yld.	0.710
1.11547	1.4476	0.04489	0.099	63.37	2.989	0.99000	Web yld.	0.335
1.12561	1.9561	0.06066	0.099	42.88	9.451	0.99900	Web yld.	0.106
1.12663	2.4985	0.07748	0.100	31.60	29.877	0.99990	Web yld.	0.033
1.12673	3.5162	0.10904	0.100	21.09	94.280	0.99999	Web yld.	0.011

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-18-1988 TIME: 11:35:10

BEAM: W 16X 77 SPAN= 10 ft Fy= 36 ksi My= 402.0 k-ft Mp= 450.0 k-ft
Teta Yield= 0.00599 rad Vyweb= 270.6 kips Myfl= 421.9 k-ft Qp= 36.000 k/ft
Zx/Sx=f=1.119 qy= 32.160 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00599	0.594	525.51	0.997	0.89333	Elastic	1.000
1.02388	1.0242	0.00614	0.608	512.90	1.025	0.91467	Fl yield	0.976
1.04776	1.0514	0.00630	0.623	498.87	1.071	0.93600	Fl yield	0.934
1.07164	1.0998	0.00659	0.637	471.75	1.268	0.95733	Web yld.	0.789
1.10821	1.3535	0.00811	0.659	357.12	2.619	0.99000	Web yld.	0.382
1.11828	1.7980	0.01078	0.665	245.39	8.282	0.99900	Web yld.	0.121
1.11929	2.2746	0.01364	0.665	182.20	26.191	0.99990	Web yld.	0.038
1.11939	3.1645	0.01897	0.665	122.65	82.341	0.99999	Web yld.	0.012

BEAM: W 16X 77 SPAN= 30 ft Fy= 36 ksi My= 402.0 k-ft Mp= 450.0 k-ft
Teta Yield= 0.01798 rad Vyweb= 270.6 kips Myfl= 421.9 k-ft Qp= 4.000 k/ft
Zx/Sx=f=1.119 qy= 3.573 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01798	0.198	175.17	0.997	0.89333	Elastic	1.000
1.02388	1.0242	0.01842	0.203	170.97	1.025	0.91467	Fl yield	0.976
1.04776	1.0514	0.01891	0.208	166.29	1.071	0.93600	Fl yield	0.934
1.07164	1.0998	0.01978	0.212	157.25	1.268	0.95733	Web yld.	0.789
1.10821	1.3535	0.02434	0.220	119.04	2.619	0.99000	Web yld.	0.382
1.11828	1.7980	0.03233	0.222	81.80	8.282	0.99900	Web yld.	0.121
1.11929	2.2746	0.04090	0.222	60.73	26.191	0.99990	Web yld.	0.038
1.11939	3.1711	0.05703	0.222	40.78	82.778	0.99999	Web yld.	0.012

BEAM: W 16X 77 SPAN= 50 ft Fy= 36 ksi My= 402.0 k-ft Mp= 450.0 k-ft
Teta Yield= 0.02997 rad Vyweb= 270.6 kips Myfl= 421.9 k-ft Qp= 1.440 k/ft
Zx/Sx=f=1.119 qy= 1.286 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02997	0.119	105.10	0.997	0.89333	Elastic	1.000
1.02388	1.0242	0.03070	0.122	102.58	1.025	0.91467	Fl yield	0.976
1.04776	1.0514	0.03151	0.125	99.77	1.071	0.93600	Fl yield	0.934
1.07164	1.0998	0.03296	0.127	94.35	1.268	0.95733	Web yld.	0.789
1.10821	1.3535	0.04057	0.132	71.42	2.619	0.99000	Web yld.	0.382
1.11828	1.7980	0.05389	0.133	49.08	8.282	0.99900	Web yld.	0.121
1.11929	2.2746	0.06817	0.133	36.44	26.191	0.99990	Web yld.	0.038
1.11939	3.1645	0.09485	0.133	24.53	82.341	0.99999	Web yld.	0.012

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-18-1988 TIME: 11:22:38

BEAM: W 18X 55 SPAN= 10 ft Fy= 36 ksi My= 294.9 k-ft Mp= 336.0 k-ft
Teta Yield= 0.00548 rad Vyweb= 254.3 kips Myfl= 306.2 k-ft Qp= 26.880 k/ft
Zx/Sx=f=1.139 qy= 23.592 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00548	0.464	574.38	1.000	0.87768	Elastic	1.000
1.02787	1.0287	0.00564	0.477	558.05	1.036	0.90214	Fl yield	0.966
1.05575	1.0666	0.00585	0.490	535.67	1.139	0.92661	Web yld.	0.878
1.08362	1.1405	0.00626	0.503	491.83	1.395	0.95107	Web yld.	0.717
1.12798	1.4798	0.00812	0.523	349.47	3.085	0.99000	Web yld.	0.324
1.13823	2.0056	0.01100	0.528	235.87	9.757	0.99900	Web yld.	0.102
1.13926	2.5652	0.01407	0.529	173.67	30.834	0.99990	Web yld.	0.032
1.13936	3.6084	0.01979	0.529	116.06	96.849	0.99999	Web yld.	0.010

BEAM: W 18X 55 SPAN= 30 ft Fy= 36 ksi My= 294.9 k-ft Mp= 336.0 k-ft
Teta Yield= 0.01645 rad Vyweb= 254.3 kips Myfl= 306.2 k-ft Qp= 2.987 k/ft
Zx/Sx=f=1.139 qy= 2.621 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01645	0.155	191.46	1.000	0.87768	Elastic	1.000
1.02787	1.0287	0.01693	0.159	186.02	1.036	0.90214	Fl yield	0.966
1.05575	1.0666	0.01755	0.163	178.56	1.139	0.92661	Web yld.	0.878
1.08362	1.1405	0.01877	0.168	163.94	1.395	0.95107	Web yld.	0.717
1.12798	1.4798	0.02435	0.174	116.49	3.085	0.99000	Web yld.	0.324
1.13823	2.0056	0.03300	0.176	78.62	9.757	0.99900	Web yld.	0.102
1.13926	2.5652	0.04221	0.176	57.89	30.834	0.99990	Web yld.	0.032
1.13936	3.6161	0.05950	0.176	38.59	97.352	0.99999	Web yld.	0.010

BEAM: W 18X 55 SPAN= 50 ft Fy= 36 ksi My= 294.9 k-ft Mp= 336.0 k-ft
Teta Yield= 0.02742 rad Vyweb= 254.3 kips Myfl= 306.2 k-ft Qp= 1.075 k/ft
Zx/Sx=f=1.139 qy= 0.944 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02742	0.093	114.88	1.000	0.87768	Elastic	1.000
1.02787	1.0287	0.02821	0.095	111.61	1.036	0.90214	Fl yield	0.966
1.05575	1.0666	0.02925	0.098	107.13	1.139	0.92661	Web yld.	0.878
1.08362	1.1405	0.03128	0.101	98.37	1.395	0.95107	Web yld.	0.717
1.12798	1.4798	0.04058	0.105	69.89	3.085	0.99000	Web yld.	0.324
1.13823	2.0055	0.05500	0.106	47.17	9.757	0.99900	Web yld.	0.102
1.13926	2.5652	0.07034	0.106	34.73	30.834	0.99990	Web yld.	0.032
1.13936	3.6161	0.09916	0.106	23.16	97.352	0.99999	Web yld.	0.010

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-18-1988 TIME: 11:11:52

BEAM: W 18X 97 SPAN= 10 ft Fy= 36 ksi My= 564.0 k-ft Mp= 633.0 k-ft
Teta Yield= 0.00533 rad Vyweb= 358.0 kips Myfl= 591.2 k-ft Qp= 50.640 k/ft
Zx/Sx=f=1.122 qy= 45.120 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00533	0.630	590.53	0.999	0.89100	Elastic	1.000
1.02447	1.0248	0.00547	0.646	576.02	1.027	0.91280	Fl yield	0.974
1.04894	1.0518	0.00561	0.661	560.61	1.055	0.93460	Web yld.	0.948
1.07340	1.1063	0.00590	0.676	525.94	1.292	0.95640	Web yld.	0.774
1.11112	1.3735	0.00733	0.700	393.96	2.698	0.99000	Web yld.	0.371
1.12122	1.8315	0.00977	0.706	269.76	8.533	0.99900	Web yld.	0.117
1.12223	2.3216	0.01238	0.707	199.98	26.976	0.99990	Web yld.	0.037
1.12233	3.2390	0.01728	0.707	134.32	84.945	0.99999	Web yld.	0.012

BEAM: W 18X 97 SPAN= 30 ft Fy= 36 ksi My= 564.0 k-ft Mp= 633.0 k-ft
Teta Yield= 0.01600 rad Vyweb= 358.0 kips Myfl= 591.2 k-ft Qp= 5.627 k/ft
Zx/Sx=f=1.122 qy= 5.013 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01600	0.210	196.84	0.999	0.89100	Elastic	1.000
1.02447	1.0248	0.01640	0.215	192.01	1.027	0.91280	Fl yield	0.974
1.04894	1.0518	0.01683	0.220	186.87	1.055	0.93460	Web yld.	0.948
1.07340	1.1063	0.01770	0.225	175.31	1.292	0.95640	Web yld.	0.774
1.11112	1.3735	0.02198	0.233	131.32	2.698	0.99000	Web yld.	0.371
1.12122	1.8315	0.02931	0.235	89.92	8.533	0.99900	Web yld.	0.117
1.12223	2.3216	0.03715	0.236	66.66	26.976	0.99990	Web yld.	0.037
1.12233	3.2390	0.05183	0.236	44.77	84.945	0.99999	Web yld.	0.012

BEAM: W 18X 97 SPAN= 50 ft Fy= 36 ksi My= 564.0 k-ft Mp= 633.0 k-ft
Teta Yield= 0.02667 rad Vyweb= 358.0 kips Myfl= 591.2 k-ft Qp= 2.026 k/ft
Zx/Sx=f=1.122 qy= 1.805 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02667	0.126	118.11	0.999	0.89100	Elastic	1.000
1.02447	1.0248	0.02733	0.129	115.20	1.027	0.91280	Fl yield	0.974
1.04894	1.0518	0.02805	0.132	112.12	1.055	0.93460	Web yld.	0.948
1.07340	1.1063	0.02951	0.135	105.19	1.292	0.95640	Web yld.	0.774
1.11112	1.3735	0.03663	0.140	78.79	2.698	0.99000	Web yld.	0.371
1.12122	1.8315	0.04885	0.141	53.95	8.533	0.99900	Web yld.	0.117
1.12223	2.3216	0.06192	0.141	40.00	26.976	0.99990	Web yld.	0.037
1.12233	3.2390	0.08639	0.141	26.86	84.945	0.99999	Web yld.	0.012

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RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-17-1988 TIME: 20:01:17

BEAM: W 21X 57 SPAN= 10 ft Fy= 36 ksi My= 333.0 k-ft Mp= 387.0 k-ft
Teta Yield= 0.00471 rad Vyweb= 307.1 kips Myfl= 344.9 k-ft Qp= 30.960 k/ft
Zx/Sx=f=1.162 qy= 26.640 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00471	0.434	668.69	0.999	0.86047	Elastic	1.000
1.03243	1.0339	0.00487	0.448	646.19	1.044	0.88837	Fl yield	0.958
1.06486	1.0826	0.00510	0.462	612.62	1.176	0.91628	Web yld.	0.850
1.09730	1.1691	0.00551	0.476	556.19	1.440	0.94419	Web yld.	0.694
1.15054	1.5805	0.00745	0.499	376.50	3.403	0.99000	Web yld.	0.294
1.16100	2.1616	0.01018	0.504	252.24	10.761	0.99900	Web yld.	0.093
1.16205	2.7800	0.01310	0.504	184.99	34.028	0.99990	Web yld.	0.029
1.16215	3.9312	0.01852	0.504	123.23	106.789	0.99999	Web yld.	0.009

BEAM: W 21X 57 SPAN= 30 ft Fy= 36 ksi My= 333.0 k-ft Mp= 387.0 k-ft
Teta Yield= 0.01413 rad Vyweb= 307.1 kips Myfl= 344.9 k-ft Qp= 3.440 k/ft
Zx/Sx=f=1.162 qy= 2.960 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01413	0.145	222.90	0.999	0.86047	Elastic	1.000
1.03243	1.0339	0.01461	0.149	215.40	1.044	0.88837	Fl yield	0.958
1.06486	1.0826	0.01530	0.154	204.21	1.176	0.91628	Web yld.	0.850
1.09730	1.1691	0.01652	0.159	185.40	1.440	0.94419	Web yld.	0.694
1.15054	1.5805	0.02234	0.166	125.50	3.403	0.99000	Web yld.	0.294
1.16100	2.1615	0.03055	0.168	84.08	10.761	0.99900	Web yld.	0.093
1.16205	2.7797	0.03928	0.168	61.67	34.011	0.99990	Web yld.	0.029
1.16215	3.9394	0.05567	0.168	40.98	107.333	0.99999	Web yld.	0.009

BEAM: W 21X 57 SPAN= 50 ft Fy= 36 ksi My= 333.0 k-ft Mp= 387.0 k-ft
Teta Yield= 0.02355 rad Vyweb= 307.1 kips Myfl= 344.9 k-ft Qp= 1.238 k/ft
Zx/Sx=f=1.162 qy= 1.066 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02355	0.087	133.74	0.999	0.86047	Elastic	1.000
1.03243	1.0339	0.02435	0.090	129.24	1.044	0.88837	Fl yield	0.958
1.06486	1.0826	0.02550	0.092	122.52	1.176	0.91628	Web yld.	0.850
1.09730	1.1691	0.02754	0.095	111.24	1.440	0.94419	Web yld.	0.694
1.15054	1.5805	0.03723	0.100	75.30	3.403	0.99000	Web yld.	0.294
1.16100	2.1616	0.05091	0.101	50.45	10.761	0.99900	Web yld.	0.093
1.16205	2.7800	0.06548	0.101	37.00	34.028	0.99990	Web yld.	0.029
1.16215	3.9312	0.09260	0.101	24.65	106.789	0.99999	Web yld.	0.009

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RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-17-1988 TIME: 19:52:34

BEAM: W 21X 93 SPAN= 10 ft Fy= 36 ksi My= 576.0 k-ft Mp= 663.0 k-ft
Teta Yield= 0.00461 rad Vyweb= 451.4 kips Myfl= 600.9 k-ft Qp= 53.040 k/ft
Zx/Sx=f=1.151 qy= 46.080 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00461	0.510	683.96	1.003	0.86878	Elastic	0.997
1.03021	1.0310	0.00475	0.526	663.07	1.040	0.89502	Fl yield	0.962
1.06042	1.0711	0.00493	0.541	635.33	1.143	0.92127	Web yld.	0.875
1.09063	1.1483	0.00529	0.557	581.73	1.399	0.94751	Web yld.	0.715
1.13953	1.5169	0.00699	0.582	404.43	3.206	0.99000	Web yld.	0.312
1.14989	2.0615	0.00949	0.587	272.34	10.138	0.99900	Web yld.	0.099
1.15093	2.6421	0.01217	0.587	200.22	32.068	0.99990	Web yld.	0.031
1.15103	3.7306	0.01718	0.587	133.35	101.145	0.99999	Web yld.	0.010

BEAM: W 21X 93 SPAN= 30 ft Fy= 36 ksi My= 576.0 k-ft Mp= 663.0 k-ft
Teta Yield= 0.01382 rad Vyweb= 451.4 kips Myfl= 600.9 k-ft Qp= 5.893 k/ft
Zx/Sx=f=1.151 qy= 5.120 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01382	0.170	227.99	1.003	0.86878	Elastic	0.997
1.03021	1.0310	0.01424	0.175	221.02	1.040	0.89502	Fl yield	0.962
1.06042	1.0711	0.01480	0.180	211.78	1.143	0.92127	Web yld.	0.875
1.09062	1.1483	0.01587	0.186	193.91	1.399	0.94751	Web yld.	0.715
1.13953	1.5169	0.02096	0.194	134.81	3.206	0.99000	Web yld.	0.312
1.14989	2.0615	0.02848	0.196	90.78	10.138	0.99900	Web yld.	0.099
1.15093	2.6418	0.03650	0.196	66.75	32.051	0.99990	Web yld.	0.031
1.15103	3.7385	0.05166	0.196	44.34	101.670	0.99999	Web yld.	0.010

BEAM: W 21X 93 SPAN= 50 ft Fy= 36 ksi My= 576.0 k-ft Mp= 663.0 k-ft
Teta Yield= 0.02303 rad Vyweb= 451.4 kips Myfl= 600.9 k-ft Qp= 2.122 k/ft
Zx/Sx=f=1.151 qy= 1.843 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02303	0.102	136.79	1.003	0.86878	Elastic	0.997
1.03021	1.0310	0.02374	0.105	132.61	1.040	0.89502	Fl yield	0.962
1.06042	1.0711	0.02466	0.108	127.07	1.143	0.92127	Web yld.	0.875
1.09062	1.1483	0.02644	0.111	116.35	1.399	0.94751	Web yld.	0.715
1.13953	1.5169	0.03493	0.116	80.89	3.206	0.99000	Web yld.	0.312
1.14989	2.0615	0.04747	0.117	54.47	10.138	0.99900	Web yld.	0.099
1.15093	2.6418	0.06084	0.117	40.05	32.051	0.99990	Web yld.	0.031
1.15103	3.7306	0.08591	0.117	26.67	101.145	0.99999	Web yld.	0.010

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT   PRINTING DATE: 01-17-1988   TIME: 19:07:12

BEAM: W 21X 132   SPAN= 10 ft   Fy= 36 ksi   My= 885.0 k-ft   Mp= 999.0 k-ft
Teta Yield= 0.00455 rad   Vyweb= 510.8 kips   Myfl= 928.9 k-ft   Qp= 79.920 k/ft
Zx/Sx=f=1.129   qy= 70.800 k/ft   Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00455	0.693	692.46	1.000	0.88589	Elastic	1.000
1.02576	1.0262	0.00467	0.711	674.54	1.030	0.90871	Fl yield	0.971
1.05153	1.0544	0.00480	0.729	655.84	1.064	0.93153	Web yld.	0.940
1.07729	1.1117	0.00506	0.747	613.43	1.303	0.95435	Web yld.	0.767
1.11753	1.3973	0.00636	0.774	452.47	2.784	0.99000	Web yld.	0.359
1.12768	1.8695	0.00850	0.781	308.86	8.804	0.99900	Web yld.	0.114
1.12870	2.3748	0.01080	0.782	228.58	27.840	0.99990	Web yld.	0.036
1.12880	3.3236	0.01512	0.782	153.11	87.899	0.99999	Web yld.	0.011

BEAM: W 21X 132   SPAN= 30 ft   Fy= 36 ksi   My= 885.0 k-ft   Mp= 999.0 k-ft
Teta Yield= 0.01365 rad   Vyweb= 510.8 kips   Myfl= 928.9 k-ft   Qp= 8.880 k/ft
Zx/Sx=f=1.129   qy= 7.867 k/ft   Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01365	0.231	230.82	1.000	0.88589	Elastic	1.000
1.02576	1.0262	0.01400	0.237	224.85	1.030	0.90871	Fl yield	0.971
1.05153	1.0544	0.01439	0.243	218.61	1.064	0.93153	Web yld.	0.940
1.07729	1.1117	0.01517	0.249	204.48	1.303	0.95435	Web yld.	0.767
1.11753	1.3973	0.01907	0.258	150.82	2.784	0.99000	Web yld.	0.359
1.12768	1.8695	0.02551	0.260	102.95	8.804	0.99900	Web yld.	0.114
1.12870	2.3748	0.03241	0.261	76.19	27.840	0.99990	Web yld.	0.036
1.12880	3.3307	0.04546	0.261	50.91	88.365	0.99999	Web yld.	0.011

BEAM: W 21X 132   SPAN= 50 ft   Fy= 36 ksi   My= 885.0 k-ft   Mp= 999.0 k-ft
Teta Yield= 0.02275 rad   Vyweb= 510.8 kips   Myfl= 928.9 k-ft   Qp= 3.197 k/ft
Zx/Sx=f=1.129   qy= 2.832 k/ft   Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02274	0.139	138.49	1.000	0.88589	Elastic	1.000
1.02576	1.0262	0.02334	0.142	134.91	1.030	0.90871	Fl yield	0.971
1.05153	1.0544	0.02398	0.146	131.17	1.064	0.93153	Web yld.	0.940
1.07729	1.1117	0.02529	0.149	122.69	1.303	0.95435	Web yld.	0.767
1.11753	1.3973	0.03178	0.155	90.49	2.784	0.99000	Web yld.	0.359
1.12768	1.8695	0.04252	0.156	61.77	8.804	0.99900	Web yld.	0.114
1.12870	2.3748	0.05402	0.156	45.72	27.840	0.99990	Web yld.	0.036
1.12880	3.3236	0.07560	0.156	30.62	87.899	0.99999	Web yld.	0.011

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RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-17-1988 TIME: 18:48:49

BEAM: W 24X 76 SPAN= 10 ft Fy= 36 ksi My= 528.0 k-ft Mp= 600.0 k-ft
Teta Yield= 0.00416 rad Vyweb= 378.9 kips Myfl= 540.5 k-ft Qp= 48.000 k/ft
Zx/Sx=f=1.136 qy= 42.240 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00416	0.557	756.95	1.002	0.88000	Elastic	0.998
1.02727	1.0288	0.00428	0.573	735.13	1.048	0.90400	Web yld.	0.954
1.05455	1.0796	0.00449	0.588	693.12	1.210	0.92800	Web yld.	0.827
1.08182	1.1626	0.00484	0.603	630.69	1.482	0.95200	Web yld.	0.675
1.12500	1.5194	0.00632	0.627	445.16	3.246	0.99000	Web yld.	0.308
1.13523	2.0718	0.00862	0.633	298.93	10.266	0.99900	Web yld.	0.097
1.13625	2.6598	0.01107	0.633	219.51	32.469	0.99990	Web yld.	0.031
1.13635	3.7606	0.01565	0.633	146.11	102.300	0.99999	Web yld.	0.010

BEAM: W 24X 76 SPAN= 30 ft Fy= 36 ksi My= 528.0 k-ft Mp= 600.0 k-ft
Teta Yield= 0.01248 rad Vyweb= 378.9 kips Myfl= 540.5 k-ft Qp= 5.333 k/ft
Zx/Sx=f=1.136 qy= 4.693 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01248	0.186	252.32	1.002	0.88000	Elastic	0.998
1.02727	1.0288	0.01284	0.191	245.04	1.048	0.90400	Web yld.	0.954
1.05455	1.0796	0.01348	0.196	231.04	1.210	0.92800	Web yld.	0.827
1.08182	1.1626	0.01451	0.201	210.23	1.482	0.95200	Web yld.	0.675
1.12500	1.5194	0.01897	0.209	148.39	3.246	0.99000	Web yld.	0.308
1.13523	2.0718	0.02587	0.211	99.65	10.266	0.99900	Web yld.	0.097
1.13625	2.6598	0.03321	0.211	73.17	32.469	0.99990	Web yld.	0.031
1.13635	3.7606	0.04695	0.211	48.70	102.300	0.99999	Web yld.	0.010

BEAM: W 24X 76 SPAN= 50 ft Fy= 36 ksi My= 528.0 k-ft Mp= 600.0 k-ft
Teta Yield= 0.02081 rad Vyweb= 378.9 kips Myfl= 540.5 k-ft Qp= 1.920 k/ft
Zx/Sx=f=1.136 qy= 1.690 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02081	0.111	151.39	1.002	0.88000	Elastic	0.998
1.02727	1.0288	0.02141	0.115	147.03	1.048	0.90400	Web yld.	0.954
1.05455	1.0796	0.02247	0.118	138.62	1.210	0.92800	Web yld.	0.827
1.08182	1.1626	0.02419	0.121	126.14	1.482	0.95200	Web yld.	0.675
1.12500	1.5194	0.03161	0.125	89.03	3.246	0.99000	Web yld.	0.308
1.13523	2.0718	0.04311	0.127	59.79	10.266	0.99900	Web yld.	0.097
1.13625	2.6595	0.05534	0.127	43.91	32.452	0.99990	Web yld.	0.031
1.13635	3.7606	0.07825	0.127	29.22	102.300	0.99999	Web yld.	0.010

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-17-1988 TIME: 18:59:44

BEAM: W 24X 55 SPAN= 10 ft Fy= 36 ksi My= 342.0 k-ft Mp= 402.0 k-ft
Teta Yield= 0.00419 rad Vyweb= 335.2 kips Myfl= 349.7 k-ft Qp= 32.160 k/ft
Zx/Sx=f=1.175 qy= 27.360 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta ----- Tetay	Teta (rad)	Vconn. ------ Vyweb	Span ----- Delta	Strain ------ StrainY	Mcl --- Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00419	0.408	751.26	0.995	0.85075	Elastic	1.000
1.03509	1.0390	0.00436	0.422	721.52	1.064	0.88060	Web yld.	0.940
1.07018	1.1025	0.00462	0.437	672.02	1.229	0.91045	Web yld.	0.814
1.10526	1.2006	0.00503	0.451	604.34	1.505	0.94030	Web yld.	0.665
1.16368	1.6697	0.00700	0.475	396.39	3.676	0.99000	Web yld.	0.272
1.17426	2.3011	0.00965	0.479	264.02	11.626	0.99900	Web yld.	0.086
1.17532	2.9716	0.01246	0.480	193.11	36.764	0.99990	Web yld.	0.027
1.17543	4.2299	0.01774	0.480	127.97	116.023	0.99999	Web yld.	0.009

BEAM: W 24X 55 SPAN= 30 ft Fy= 36 ksi My= 342.0 k-ft Mp= 402.0 k-ft
Teta Yield= 0.01258 rad Vyweb= 335.2 kips Myfl= 349.7 k-ft Qp= 3.573 k/ft
Zx/Sx=f=1.175 qy= 3.040 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta ----- Tetay	Teta (rad)	Vconn. ------ Vyweb	Span ----- Delta	Strain ------ StrainY	Mcl --- Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01258	0.136	250.42	0.995	0.85075	Elastic	1.000
1.03509	1.0390	0.01307	0.141	240.51	1.064	0.88060	Web yld.	0.940
1.07018	1.1025	0.01387	0.146	224.01	1.229	0.91045	Web yld.	0.814
1.10526	1.2006	0.01510	0.150	201.45	1.505	0.94030	Web yld.	0.665
1.16368	1.6697	0.02100	0.158	132.13	3.676	0.99000	Web yld.	0.272
1.17426	2.3010	0.02895	0.160	88.01	11.625	0.99900	Web yld.	0.086
1.17532	2.9716	0.03738	0.160	64.37	36.764	0.99990	Web yld.	0.027
1.17543	4.2299	0.05321	0.160	42.66	116.023	0.99999	Web yld.	0.009

BEAM: W 24X 55 SPAN= 50 ft Fy= 36 ksi My= 342.0 k-ft Mp= 402.0 k-ft
Teta Yield= 0.02097 rad Vyweb= 335.2 kips Myfl= 349.7 k-ft Qp= 1.286 k/ft
Zx/Sx=f=1.175 qy= 1.094 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta ----- Tetay	Teta (rad)	Vconn. ------ Vyweb	Span ----- Delta	Strain ------ StrainY	Mcl --- Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02096	0.082	150.25	0.995	0.85075	Elastic	1.000
1.03509	1.0390	0.02178	0.084	144.30	1.064	0.88060	Web yld.	0.940
1.07018	1.1025	0.02312	0.087	134.40	1.229	0.91045	Web yld.	0.814
1.10526	1.2006	0.02517	0.090	120.87	1.505	0.94030	Web yld.	0.665
1.16368	1.6697	0.03501	0.095	79.28	3.676	0.99000	Web yld.	0.272
1.17426	2.3010	0.04824	0.096	52.81	11.625	0.99900	Web yld.	0.086
1.17532	2.9716	0.06230	0.096	38.62	36.764	0.99990	Web yld.	0.027
1.17543	4.2212	0.08850	0.096	25.65	115.441	0.99999	Web yld.	0.009

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-17-1988 TIME: 17:02:55

BEAM: W 24X 117 SPAN= 10 ft Fy= 36 ksi My= 873.0 k-ft Mp= 981.0 k-ft
Teta Yield= 0.00408 rad Vyweb= 480.3 kips Myfl= 906.0 k-ft Qp= 78.480 k/ft
Zx/Sx=f=1.124 qy= 69.840 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00408	0.727	771.74	0.997	0.88991	Elastic	1.000
1.02474	1.0253	0.00419	0.745	752.35	1.028	0.91193	Fl yield	0.973
1.04948	1.0573	0.00432	0.763	727.02	1.114	0.93395	Web yld.	0.897
1.07423	1.1238	0.00459	0.781	672.26	1.365	0.95596	Web yld.	0.733
1.11247	1.4160	0.00578	0.809	494.97	2.864	0.99000	Web yld.	0.349
1.12259	1.9040	0.00777	0.816	336.37	9.056	0.99900	Web yld.	0.110
1.12360	2.4251	0.00990	0.817	248.43	28.634	0.99990	Web yld.	0.035
1.12370	3.4082	0.01391	0.817	165.84	90.692	0.99999	Web yld.	0.011

BEAM: W 24X 117 SPAN= 30 ft Fy= 36 ksi My= 873.0 k-ft Mp= 981.0 k-ft
Teta Yield= 0.01225 rad Vyweb= 480.3 kips Myfl= 906.0 k-ft Qp= 8.720 k/ft
Zx/Sx=f=1.124 qy= 7.760 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01224	0.242	257.25	0.997	0.88991	Elastic	1.000
1.02474	1.0253	0.01256	0.248	250.78	1.028	0.91193	Fl yield	0.973
1.04948	1.0573	0.01295	0.254	242.34	1.114	0.93395	Web yld.	0.897
1.07423	1.1238	0.01376	0.260	224.09	1.365	0.95596	Web yld.	0.733
1.11247	1.4160	0.01734	0.270	164.99	2.864	0.99000	Web yld.	0.349
1.12259	1.9040	0.02332	0.272	112.12	9.057	0.99900	Web yld.	0.110
1.12360	2.4254	0.02970	0.272	82.80	28.649	0.99990	Web yld.	0.035
1.12370	3.4009	0.04165	0.272	55.42	90.213	0.99999	Web yld.	0.011

BEAM: W 24X 117 SPAN= 50 ft Fy= 36 ksi My= 873.0 k-ft Mp= 981.0 k-ft
Teta Yield= 0.02041 rad Vyweb= 480.3 kips Myfl= 906.0 k-ft Qp= 3.139 k/ft
Zx/Sx=f=1.124 qy= 2.794 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.02041	0.145	154.35	0.997	0.88991	Elastic	1.000
1.02474	1.0253	0.02093	0.149	150.47	1.028	0.91193	Fl yield	0.973
1.04948	1.0573	0.02158	0.153	145.40	1.114	0.93394	Web yld.	0.897
1.07423	1.1238	0.02293	0.156	134.45	1.365	0.95596	Web yld.	0.733
1.11247	1.4160	0.02890	0.162	98.99	2.864	0.99000	Web yld.	0.349
1.12259	1.9039	0.03886	0.163	67.28	9.056	0.99900	Web yld.	0.110
1.12360	2.4248	0.04949	0.163	49.69	28.618	0.99990	Web yld.	0.035
1.12370	3.4009	0.06941	0.163	33.25	90.213	0.99999	Web yld.	0.011

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-17-1988 TIME: 16:52:03

BEAM: W 24X 162 SPAN= 10 ft Fy= 36 ksi My=1242.0 k-ft Mp=1404.0 k-ft
Teta Yield= 0.00398 rad Vyweb= 634.5 kips Myfl= 1304.5 k-ft Qp=112.320 k/ft
Zx/Sx=f=1.130 qy= 99.360 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00398	0.783	792.23	1.001	0.88462	Elastic	0.999
1.02609	1.0265	0.00408	0.803	771.48	1.031	0.90769	Fl yield	0.970
1.05217	1.0550	0.00419	0.824	749.90	1.066	0.93077	Web yld.	0.938
1.07826	1.1128	0.00442	0.844	701.06	1.305	0.95385	Web yld.	0.766
1.11913	1.4025	0.00558	0.876	515.37	2.804	0.99000	Web yld.	0.357
1.12930	1.8777	0.00747	0.884	351.60	8.866	0.99900	Web yld.	0.113
1.13032	2.3856	0.00949	0.885	260.20	28.012	0.99990	Web yld.	0.036
1.13042	3.3347	0.01326	0.885	174.57	88.120	0.99999	Web yld.	0.011

BEAM: W 24X 162 SPAN= 30 ft Fy= 36 ksi My=1242.0 k-ft Mp=1404.0 k-ft
Teta Yield= 0.01193 rad Vyweb= 634.5 kips Myfl= 1304.5 k-ft Qp= 12.480 k/ft
Zx/Sx=f=1.130 qy= 11.040 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01193	0.261	264.08	1.001	0.88462	Elastic	0.999
1.02609	1.0265	0.01225	0.268	257.16	1.031	0.90769	Fl yield	0.970
1.05217	1.0550	0.01258	0.275	249.97	1.066	0.93077	Web yld.	0.938
1.07826	1.1128	0.01327	0.281	233.69	1.305	0.95385	Web yld.	0.766
1.11913	1.4025	0.01673	0.292	171.79	2.804	0.99000	Web yld.	0.357
1.12930	1.8777	0.02240	0.295	117.20	8.867	0.99900	Web yld.	0.113
1.13032	2.3856	0.02846	0.295	86.73	28.012	0.99990	Web yld.	0.036
1.13042	3.3346	0.03978	0.295	58.19	88.120	0.99999	Web yld.	0.011

BEAM: W 24X 162 SPAN= 50 ft Fy= 36 ksi My=1242.0 k-ft Mp=1404.0 k-ft
Teta Yield= 0.01988 rad Vyweb= 634.5 kips Myfl= 1304.5 k-ft Qp= 4.493 k/ft
Zx/Sx=f=1.130 qy= 3.974 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01988	0.157	158.45	1.001	0.88462	Elastic	0.999
1.02609	1.0265	0.02041	0.161	154.30	1.031	0.90769	Fl yield	0.970
1.05217	1.0550	0.02097	0.165	149.98	1.066	0.93077	Web yld.	0.938
1.07826	1.1128	0.02212	0.169	140.21	1.305	0.95385	Web yld.	0.766
1.11913	1.4025	0.02788	0.175	103.07	2.804	0.99000	Web yld.	0.357
1.12930	1.8777	0.03733	0.177	70.32	8.866	0.99900	Web yld.	0.113
1.13032	2.3861	0.04744	0.177	52.03	28.042	0.99990	Web yld.	0.036
1.13042	3.3346	0.06630	0.177	34.91	88.120	0.99999	Web yld.	0.011

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-17-1988 TIME: 16:47:52

BEAM: W 27X 84 SPAN= 10 ft Fy= 36 ksi My= 639.0 k-ft Mp= 732.0 k-ft
Teta Yield= 0.00371 rad Vyweb= 442.3 kips Myfl= 654.0 k-ft Qp= 58.560 k/ft
Zx/Sx=f=1.146 qy= 51.120 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00371	0.578	848.84	0.998	0.87295	Elastic	1.000
1.02911	1.0310	0.00383	0.595	822.34	1.048	0.89836	Web yld.	0.954
1.05822	1.0846	0.00403	0.612	773.35	1.210	0.92377	Web yld.	0.826
1.08732	1.1711	0.00435	0.628	701.67	1.482	0.94918	Web yld.	0.675
1.13408	1.5548	0.00577	0.655	486.03	3.342	0.99000	Web yld.	0.299
1.14439	2.1259	0.00789	0.661	325.68	10.566	0.99900	Web yld.	0.095
1.14543	2.7337	0.01014	0.662	238.88	33.414	0.99990	Web yld.	0.030
1.14553	3.8698	0.01436	0.662	158.92	105.174	0.99999	Web yld.	0.010

BEAM: W 27X 84 SPAN= 30 ft Fy= 36 ksi My= 639.0 k-ft Mp= 732.0 k-ft
Teta Yield= 0.01113 rad Vyweb= 442.3 kips Myfl= 654.0 k-ft Qp= 6.507 k/ft
Zx/Sx=f=1.146 qy= 5.680 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01113	0.193	282.95	0.998	0.87295	Elastic	1.000
1.02911	1.0310	0.01148	0.198	274.12	1.048	0.89836	Web yld.	0.954
1.05822	1.0846	0.01208	0.204	257.78	1.210	0.92377	Web yld.	0.826
1.08732	1.1711	0.01304	0.209	233.89	1.482	0.94918	Web yld.	0.675
1.13408	1.5548	0.01731	0.218	162.01	3.342	0.99000	Web yld.	0.299
1.14439	2.1260	0.02367	0.220	108.56	10.567	0.99900	Web yld.	0.095
1.14543	2.7337	0.03043	0.221	79.63	33.414	0.99990	Web yld.	0.030
1.14553	3.8781	0.04318	0.221	52.84	105.721	0.99999	Web yld.	0.009

BEAM: W 27X 84 SPAN= 50 ft Fy= 36 ksi My= 639.0 k-ft Mp= 732.0 k-ft
Teta Yield= 0.01856 rad Vyweb= 442.3 kips Myfl= 654.0 k-ft Qp= 2.342 k/ft
Zx/Sx=f=1.146 qy= 2.045 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01855	0.116	169.77	0.998	0.87295	Elastic	1.000
1.02911	1.0310	0.01913	0.119	164.47	1.048	0.89836	Web yld.	0.954
1.05822	1.0846	0.02013	0.122	154.67	1.210	0.92377	Web yld.	0.826
1.08732	1.1711	0.02173	0.126	140.33	1.482	0.94918	Web yld.	0.675
1.13408	1.5548	0.02885	0.131	97.21	3.342	0.99000	Web yld.	0.299
1.14439	2.1260	0.03945	0.132	65.13	10.567	0.99900	Web yld.	0.095
1.14543	2.7337	0.05072	0.132	47.78	33.414	0.99990	Web yld.	0.030
1.14553	3.8781	0.07196	0.132	31.71	105.721	0.99999	Web yld.	0.009

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-17-1988 TIME: 16:44:25

BEAM: W 27X 102 SPAN= 10 ft Fy= 36 ksi My= 801.0 k-ft Mp= 915.0 k-ft
Teta Yield= 0.00366 rad Vyweb= 502.2 kips Myfl= 826.4 k-ft Qp= 73.200 k/ft
Zx/Sx=f=1.142 qy= 64.080 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00366	0.638	860.12	0.999	0.87541	Elastic	1.000
1.02846	1.0295	0.00377	0.656	834.92	1.037	0.90033	Fl yield	0.964
1.05693	1.0749	0.00394	0.674	793.53	1.174	0.92525	Web yld.	0.852
1.08539	1.1550	0.00423	0.692	724.16	1.438	0.95016	Web yld.	0.695
1.13090	1.5161	0.00555	0.721	507.89	3.210	0.99000	Web yld.	0.311
1.14118	2.0638	0.00756	0.728	341.55	10.152	0.99900	Web yld.	0.099
1.14221	2.6473	0.00970	0.729	250.95	32.108	0.99990	Web yld.	0.031
1.14231	3.7515	0.01374	0.729	166.52	101.960	0.99999	Web yld.	0.010

BEAM: W 27X 102 SPAN= 30 ft Fy= 36 ksi My= 801.0 k-ft Mp= 915.0 k-ft
Teta Yield= 0.01099 rad Vyweb= 502.2 kips Myfl= 826.4 k-ft Qp= 8.133 k/ft
Zx/Sx=f=1.142 qy= 7.120 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01099	0.213	286.71	0.999	0.87541	Elastic	1.000
1.02846	1.0295	0.01131	0.219	278.31	1.037	0.90033	Fl yield	0.964
1.05693	1.0749	0.01181	0.225	264.51	1.174	0.92525	Web yld.	0.852
1.08539	1.1550	0.01269	0.231	241.39	1.438	0.95016	Web yld.	0.695
1.13090	1.5161	0.01666	0.240	169.30	3.210	0.99000	Web yld.	0.311
1.14118	2.0638	0.02268	0.243	113.85	10.152	0.99900	Web yld.	0.099
1.14221	2.6473	0.02909	0.243	83.65	32.108	0.99990	Web yld.	0.031
1.14231	3.7435	0.04113	0.243	55.64	101.428	0.99999	Web yld.	0.010

BEAM: W 27X 102 SPAN= 50 ft Fy= 36 ksi My= 801.0 k-ft Mp= 915.0 k-ft
Teta Yield= 0.01831 rad Vyweb= 502.2 kips Myfl= 826.4 k-ft Qp= 2.928 k/ft
Zx/Sx=f=1.142 qy= 2.563 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01831	0.128	172.02	0.999	0.87541	Elastic	1.000
1.02846	1.0295	0.01885	0.131	166.98	1.037	0.90033	Fl yield	0.964
1.05693	1.0749	0.01968	0.135	158.71	1.174	0.92525	Web yld.	0.852
1.08539	1.1550	0.02115	0.138	144.83	1.438	0.95016	Web yld.	0.695
1.13090	1.5161	0.02776	0.144	101.58	3.210	0.99000	Web yld.	0.311
1.14118	2.0638	0.03779	0.146	68.31	10.152	0.99900	Web yld.	0.099
1.14221	2.6469	0.04847	0.146	50.20	32.091	0.99990	Web yld.	0.031
1.14231	3.7435	0.06855	0.146	33.39	101.428	0.99999	Web yld.	0.010

RESULTS OF ANALYSIS OF BEAM END MOMENT ROTATION RELATIONSHIP

Program:SHEAROT PRINTING DATE: 01-17-1988 TIME: 16:37:23

BEAM: W 27X 178 SPAN= 10 ft Fy= 36 ksi My=1506.0 k-ft Mp=1701.0 k-ft
Teta Yield= 0.00357 rad Vyweb= 725.8 kips Myfl= 1573.0 k-ft Qp=136.080 k/ft
Zx/Sx=f=1.129 qy= 120.480 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.00357	0.830	883.35	0.999	0.88536	Elastic	1.000
1.02590	1.0264	0.00366	0.851	860.29	1.029	0.90829	Fl yield	0.971
1.05179	1.0566	0.00377	0.873	833.98	1.093	0.93122	Web yld.	0.915
1.07769	1.1210	0.00400	0.894	773.32	1.339	0.95414	Web yld.	0.747
1.11819	1.4193	0.00506	0.928	565.70	2.867	0.99000	Web yld.	0.349
1.12835	1.9069	0.00680	0.936	384.71	9.066	0.99900	Web yld.	0.110
1.12937	2.4280	0.00866	0.937	284.20	28.674	0.99990	Web yld.	0.035
1.12947	3.4067	0.01215	0.937	190.04	90.533	0.99999	Web yld.	0.011

BEAM: W 27X 178 SPAN= 30 ft Fy= 36 ksi My=1506.0 k-ft Mp=1701.0 k-ft
Teta Yield= 0.01070 rad Vyweb= 725.8 kips Myfl= 1573.0 k-ft Qp= 15.120 k/ft
Zx/Sx=f=1.129 qy= 13.387 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01070	0.277	294.45	0.999	0.88536	Elastic	1.000
1.02590	1.0264	0.01098	0.284	286.76	1.029	0.90829	Fl yield	0.971
1.05179	1.0566	0.01130	0.291	277.99	1.093	0.93122	Web yld.	0.915
1.07769	1.1210	0.01199	0.298	257.77	1.339	0.95414	Web yld.	0.747
1.11819	1.4193	0.01518	0.309	188.57	2.867	0.99000	Web yld.	0.349
1.12835	1.9069	0.02040	0.312	128.24	9.066	0.99900	Web yld.	0.110
1.12937	2.4277	0.02597	0.312	94.75	28.659	0.99990	Web yld.	0.035
1.12947	3.4067	0.03645	0.312	63.35	90.533	0.99999	Web yld.	0.011

BEAM: W 27X 178 SPAN= 50 ft Fy= 36 ksi My=1506.0 k-ft Mp=1701.0 k-ft
Teta Yield= 0.01783 rad Vyweb= 725.8 kips Myfl= 1573.0 k-ft Qp= 5.443 k/ft
Zx/Sx=f=1.129 qy= 4.819 k/ft Strainy=Fy/E=0.0012414

Vc/Vy or q/qy	Teta / Tetay	Teta (rad)	Vconn. / Vyweb	Span / Delta	Strain / StrainY	Mcl / Mp	Beam Condition	Elastic Core
1.00000	0.9999	0.01783	0.166	176.67	0.999	0.88536	Elastic	1.000
1.02590	1.0264	0.01830	0.170	172.06	1.029	0.90829	Fl yield	0.971
1.05179	1.0566	0.01884	0.175	166.80	1.093	0.93122	Web yld.	0.915
1.07769	1.1210	0.01999	0.179	154.66	1.339	0.95414	Web yld.	0.747
1.11819	1.4193	0.02531	0.186	113.14	2.867	0.99000	Web yld.	0.349
1.12835	1.9069	0.03400	0.187	76.94	9.066	0.99900	Web yld.	0.110
1.12937	2.4280	0.04329	0.187	56.84	28.674	0.99990	Web yld.	0.035
1.12947	3.4139	0.06087	0.187	37.91	91.014	0.99999	Web yld.	0.011

APPENDIX D

SUMMARY TEST DATA

This appendix provides nine summary sheets for experiments. Each sheet summarizes properties and behavior of each specimen.

AISC TEE FRAMING CONNECTION RESEARCH

SUMMARY OF TEST NUMBER 2

OBJECTIVE: To study ductility and strength of tee-framing connections

TEST DATE: June 23, 1987

CONDUCTED BY: M.N. Nader and A. Astaneh AT: U.C. Berkeley

SPECIMEN: A-5

PROPERTIES OF TEST SPECIMEN:

TEE USED: WT 7x19

NOMINAL FLANGE WIDTH: 6-9/16" NOMINAL FLANGE THICKNESS: 1/2"

NOMINAL WEB DEPTH: 6-14/16" NOMINAL THICKNESS: 3/8"

NUMBER OF BOLTS: 5 DIAMETER OF BOLTS: 7/8" TYPE OF BOLTS: A-325

WELD SIZE: 1/4" ELECTROD USED: E70XX WELD LENGTH 14.5"

TEST RESULTS:

A. ROTATION TEST:

MAXIMUM SHEAR: 8.1 (k) MAXIMUM ROTATION: 0.069 (RAD) MAXIMUM MOMENT: 532.6 (k-in)

MAJOR OBSERVATION crack of weld return, and some yielding of flange

B. STRENGTH TEST:

MAXIMUM SHEAR: 174 k MAXIMUM ROTATION: 0.032 MAXIMUM MOMENT: 154.5 (k-in)

FAILURE MODE: combined web yield and web fracture

GENERAL COMMENTS AND DISCUSSION:

Ductility Cycle
- at 0.045 radians yielding of flange at top corners near weld returns and at tee fillet could be observed.
- at 0.065 cracking of weld return.

Strength Cycle
- at 116 kips significant yielding occurred in web due to bearing of bolts.
- at 174 kips failure occured due to yielding of web followed by web net area fracture.

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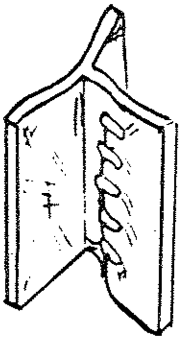


AISC TEE FRAMING CONNECTION RESEARCH

SUMMARY OF TEST NUMBER 3

OBJECTIVE: To study ductility and strength of tee-framing connections

TEST DATE: June 25, 1987

CONDUCTED BY: M.N. Nader and A. Astaneh AT: U.C. Berkeley

SPECIMEN: A-3

PROPERTIES OF TEST SPECIMEN:

TEE USED: WT 7x19

NOMINAL FLANGE WIDTH: 6-9/16" NOMINAL FLANGE THICKNESS: 1/2"

NOMINAL WEB DEPTH: 6-14/16" NOMINAL THICKNESS: 3/8"

NUMBER OF BOLTS: 3 DIAMETER OF BOLTS: 7/8" TYPE OF BOLTS: A-325

WELD SIZE: 1/4" ELECTROD USED: E70XX WELD LENGTH 8.5"

TEST RESULTS:

A. ROTATION TEST:

MAXIMUM SHEAR: 2.9$^{(k)}$ MAXIMUM ROTATION: 0.069$^{(RAD)}$ MAXIMUM MOMENT: 11.5$^{(k\text{-}in)}$

MAJOR OBSERVATION No yielding was observed

B. STRENGTH TEST:

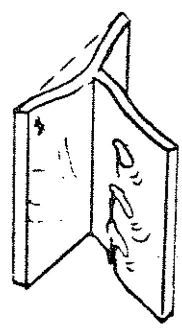
MAXIMUM SHEAR: 106.8^{k} MAXIMUM ROTATION: 0.067$^{(RAD)}$ MAXIMUM MOMENT: 7.81$^{(k\text{-}in)}$

FAILURE MODE: weld crack and initiation of web net area crack

GENERAL COMMENTS AND DISCUSSION:

Ductility Cycle
- at 0.07 radians minor yielding of top of flange near the weld return could be observed.

Strength Cycle
- at 45 kips weld end returns cracked.
- at 70 kips more yielding of flange near weld returns occurred.
- at 93 kips web net area started to yield.
- at 104 kips severe yielding occurred in the web.
- at 107 simultaneous weld crack and web fracture occurred.



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AISC TEE FRAMING CONNECTION RESEARCH

SUMMARY OF TEST NUMBER 4

OBJECTIVE: To study ductility and strength of tee-framing connections

TEST DATE: July 2, 1987

CONDUCTED BY: M.N. Nader and A. Astaneh AT: U.C. Berkeley

SPECIMEN: B-5

PROPERTIES OF TEST SPECIMEN:

TEE USED: WT 4x7.5

NOMINAL FLANGE WIDTH: 3-15/16" NOMINAL FLANGE THICKNESS: 5/16"

NOMINAL WEB DEPTH: 4-1/16" NOMINAL THICKNESS: 9/32"

NUMBER OF BOLTS: 5 DIAMETER OF BOLTS: 7/8" TYPE OF BOLTS: A-325

WELD SIZE: 3/16" ELECTROD USED: E70XX WELD LENGTH 14.5"

TEST RESULTS:

A. ROTATION TEST:

MAXIMUM SHEAR: 1.2 (k) MAXIMUM ROTATION: 0.06 (RAD) MAXIMUM MOMENT: 7.5 (k-in)

MAJOR OBSERVATION specimen failed due to weld cracking

B. STRENGTH TEST:

MAXIMUM SHEAR: — MAXIMUM ROTATION: — MAXIMUM MOMENT: —

FAILURE MODE: —

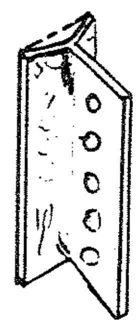
GENERAL COMMENTS AND DISCUSSION:

Ductility Cycle

- at 0.025 (radians) yielding of flange at corners near weld returns as well as shear yielding in middle of flange was apparent.
- at 0.045 radians yield lines were appearing throughout the flange. Also, we noted bearing on bottom bolt on web (compression)
- at 0.06 radians weld returns cracked and was directly followed by total weld fracture.

Strength Cycle

- due to fracture of weld during ductility cycle, the strength cycle could not be conducted.



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AISC TEE FRAMING CONNECTION RESEARCH

SUMMARY OF TEST NUMBER 5

OBJECTIVE: To study ductility and strength of tee-framing connections

TEST DATE: August 20, 1987

CONDUCTED BY: M.N. Nader and A. Astaneh AT: U.C. Berkeley

SPECIMEN: D-5

PROPERTIES OF TEST SPECIMEN:

TEE USED: WT 4.20

NOMINAL FLANGE WIDTH: 8-1/8" NOMINAL FLANGE THICKNESS: 9/16"

NOMINAL WEB DEPTH: 4-1/8" NOMINAL THICKNESS: 3/8"

NUMBER OF BOLTS: 5 DIAMETER OF BOLTS: 7/8" TYPE OF BOLTS: A-325

WELD SIZE: 1/4" ELECTROD USED: E70XX WELD LENGTH 14.5"

TEST RESULTS:

A. ROTATION TEST:

MAXIMUM SHEAR: 8.2 (k) MAXIMUM ROTATION: 0.07 (RAD) MAXIMUM MOMENT: 47.9 (k-in)

MAJOR OBSERVATION weld return crack and some flange yielding

B. STRENGTH TEST:

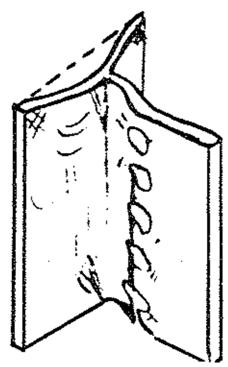
MAXIMUM SHEAR: 183.1 (k) MAXIMUM ROTATION: 0.031 RAD) MAXIMUM MOMENT: 19.63 (k-in)

FAILURE MODE: fracture of web net area combined with bolt yielding

GENERAL COMMENTS AND DISCUSSION:

Ductility Cycle
- at 0.05 radians yielding of flange corners near weld returns was noticeable.
- at 0.06 radians weld returns cracked and yield lines started to appear in middle of flange.

Strength Cycle
- at 170 kips most of the flange showed yielding as well as bolts bearing on web.
- at 183 kips fracture of web net area combined with bolt yielding (deformed) occurred.



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AISC TEE FRAMING CONNECTION RESEARCH

SUMMARY OF TEST NUMBER 6

OBJECTIVE: To study ductility and strength of tee-framing connections

TEST DATE: October 9, 1987

CONDUCTED BY: M.N. Nader and A. Astaneh AT: U.C. Berkeley

SPECIMEN: D-3

PROPERTIES OF TEST SPECIMEN:

TEE USED: WT 4.20

NOMINAL FLANGE WIDTH: 8-1/8" NOMINAL FLANGE THICKNESS: 9/16"

NOMINAL WEB DEPTH: 4-1/6" NOMINAL THICKNESS: 3/8"

NUMBER OF BOLTS: 3 DIAMETER OF BOLTS: 7/8" TYPE OF BOLTS: A-325

WELD SIZE: 1/4" ELECTROD USED: E70XX WELD LENGTH 8.5"

TEST RESULTS:

A. ROTATION TEST:

MAXIMUM SHEAR: 4.1 (k) MAXIMUM ROTATION: 0.068 (RAD) MAXIMUM MOMENT: 226.7 (k-in)

MAJOR OBSERVATION minor bearing in web due to bolt bearing on it

B. STRENGTH TEST:

MAXIMUM SHEAR: 110.8 (k) MAXIMUM ROTATION: 0.034 (RAD) MAXIMUM MOMENT: 149.2 (k-in)

FAILURE MODE: fracture of web net area

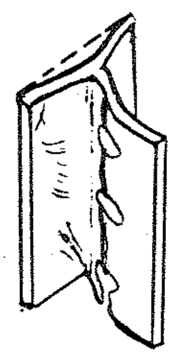
GENERAL COMMENTS AND DISCUSSION:

Ductility Cycle

- at 0.04 radians significant movement of beam relative to tee-connection due to bolt slip could be observed.
- at 0.07 radians minor bearing in web due to both bearing on it was detected.

Strength Cycle

- at 50 kips weld returns cracked and the net area of web experienced severe yielding.
- at 110 kips web net area fractured. There was a crack between 2nd and 3rd bolts.



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AISC TEE FRAMING CONNECTION RESEARCH

SUMMARY OF TEST NUMBER 7

OBJECTIVE: To study ductility and strength of tee-framing connections

TEST DATE: September 5, 1987

CONDUCTED BY: M.N. Nader and A. Astaneh AT: U.C. Berkeley

SPECIMEN: A-0.5-5

PROPERTIES OF TEST SPECIMEN:

TEE USED: flange of WT 7x19 welded to 0.5" thick plate

NOMINAL FLANGE WIDTH: 6-9/16" NOMINAL FLANGE THICKNESS: 1/2"

NOMINAL WEB DEPTH: 6-14/16" NOMINAL THICKNESS: 1/2"

NUMBER OF BOLTS: 5 DIAMETER OF BOLTS: 7/8" TYPE OF BOLTS: A-325

WELD SIZE: 1/4" ELECTROD USED: E70XX WELD LENGTH 14.5"

TEST RESULTS:

A. ROTATION TEST:

MAXIMUM SHEAR: 0.76 (k) MAXIMUM ROTATION: 0.07 (RAD) MAXIMUM MOMENT: 9.7 (k-in)

MAJOR OBSERVATION some yielding was detected in flange

B. STRENGTH TEST:

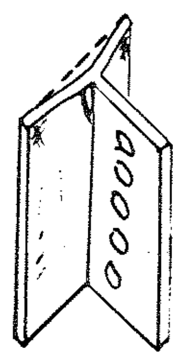
MAXIMUM SHEAR: 238 (k) MAXIMUM ROTATION: 0.038 (RAD) MAXIMUM MOMENT: 13.2 (k-in)

FAILURE MODE: very brittle bolt shear failure; also partial failure of weld is observed.

GENERAL COMMENTS AND DISCUSSION:

Ductility Cycle
- at 0.05 radians flange yielded at top corners near weld returns, also weld return cracked.
- at 0.06 radians the middle of the flange yielded (formation of 2nd plastic hinge).

Strength Cycle
- at 200 kips the column flange buckled. Also, large areas of flange of tee was yielding.
- at 232 kips the bottom bolt sheared off and the other bolts yielded. Failure took place at 238^k.



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AISC TEE FRAMING CONNECTION RESEARCH

SUMMARY OF TEST NUMBER 8

OBJECTIVE: To study ductility and strength of tee-framing connections

TEST DATE: September 22, 1987

CONDUCTED BY: M.N. Nader and A. Astaneh AT: U.C. Berkeley

SPECIMEN: D-0.5.3

PROPERTIES OF TEST SPECIMEN:

TEE USED: Flange of WT 4x20 welded to 0.5" thick plate

NOMINAL FLANGE WIDTH: 8-1/8" NOMINAL FLANGE THICKNESS: 9/16"

NOMINAL WEB DEPTH: 4-1/8" NOMINAL THICKNESS: 1/2"

NUMBER OF BOLTS: 3 DIAMETER OF BOLTS: 7/8" TYPE OF BOLTS: A-490

WELD SIZE: 1/4" ELECTROD USED: E70XX WELD LENGTH 8.5"

TEST RESULTS:

A. ROTATION TEST:

MAXIMUM SHEAR: 3.4 (k) MAXIMUM ROTATION: 0.07 (RAD) MAXIMUM MOMENT: 228 (k-in)

MAJOR OBSERVATION no yielding signs

B. STRENGTH TEST:

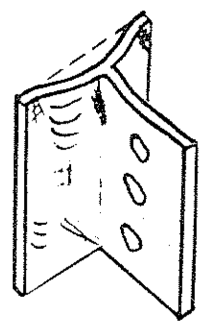
MAXIMUM SHEAR: 141.3 (k) MAXIMUM ROTATION: 0.07 (RAD) MAXIMUM MOMENT: -39.8 (k)

FAILURE MODE: weld cracked

GENERAL COMMENTS AND DISCUSSION:

Ductility Cycle
- at 0.07 radians some yielding in web was observed related to the bottom bolt bearing on it.

Strength Cycle
- at 70 kips net area of web started yielding.
- at 80 kips most of the flange was contributing in rotation (full of yield lines).
- at 104 kips weld returns cracked.
- at 118 kips strong yield lines flowing along weld of flange and web were observed.
- at 141 kips weld cracked (brittle failure).



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AISC TEE FRAMING CONNECTION RESEARCH

SUMMARY OF TEST NUMBER 9

OBJECTIVE: To study ductility and strength of tee-framing connections

TEST DATE: October 30, 1987

CONDUCTED BY: M.N. Nader and A. Astaneh AT: U.C. Berkeley

SPECIMEN: D-0.5-5

PROPERTIES OF TEST SPECIMEN:

TEE USED: Flange of WT 4x20 welded to 0.5" thick plate

NOMINAL FLANGE WIDTH: 8-1/8" NOMINAL FLANGE THICKNESS: 9/16"

NOMINAL WEB DEPTH: 4-1/8" NOMINAL THICKNESS: 1/2"

NUMBER OF BOLTS: 5 DIAMETER OF BOLTS: 7/8" TYPE OF BOLTS: A-490

WELD SIZE: 1/4" ELECTROD USED: E70XX WELD LENGTH 14.5"

TEST RESULTS:

A. ROTATION TEST:

MAXIMUM SHEAR: 9.6 (k) MAXIMUM ROTATION: 0.07 (RAD) MAXIMUM MOMENT: 748 (k-in)

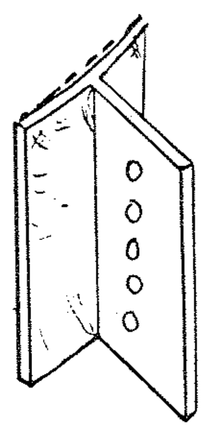
MAJOR OBSERVATION minor yield of flange

B. STRENGTH TEST:

MAXIMUM SHEAR: 208.9 (k) MAXIMUM ROTATION: 0.033 (RAD) MAXIMUM MOMENT: 251.8 (k-in)

FAILURE MODE: bolt shear failure

GENERAL COMMENTS AND DISCUSSION:



Ductility Cycle

- at 0.0475 radians compression yield of web was observed. This was due to bottom both bearing on it.
- at 0.07 radians yield lines were observed in the middle of flange (shear yield) as well as yielding of flange at corners near weld returns.

Strength Cycle

- at 113 kips yield lines developed between the bolts. Yielding of web due to compression of web was more pronounced.
- at 209 kips a sudden and very brittle failure of bolts occurred.