REPORT NO.
UCB/EERC-88/03
JANUARY 1988

EARTHQUAKE ENGINEERING RESEARCH CENTER

# CYCLIC BEHAVIOR OF STEEL DOUBLE ANGLE CONNECTIONS

by

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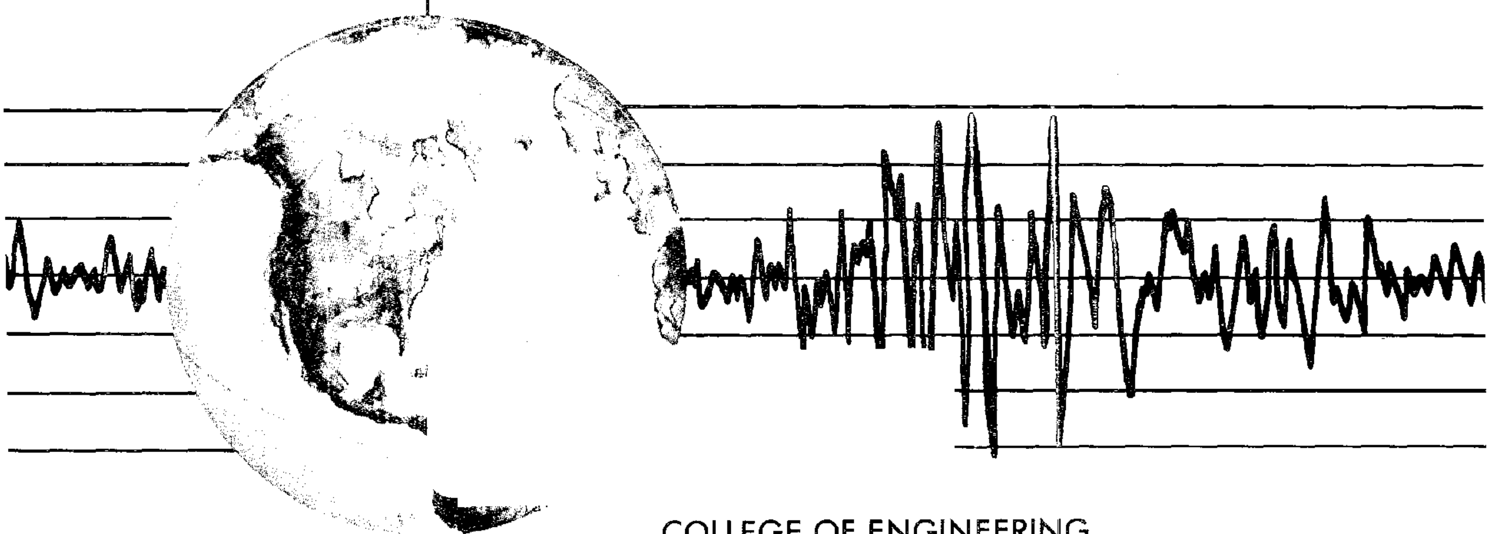
Report to URS Corporation, San Francisco



COLLEGE OF ENGINEERING
UNIVERSITY OF CALIFORNIA AT BERKELEY

50272-101

| REPORT DOCUMENTATION PAGE | 1. REPORT NO. UCB/EERC-88/03 | 2. | 3. PB91-210872 |
|---|---|---|---|

| | |
|---|---|
| 4. Title and Subtitle<br>Cyclic Behavior of Steel Double Angle Connections | 5. Report Date<br>January 1988 |
| | 6. |
| 7. Author(s)<br>A. Astaneh-Asl and M.N. Nader | 8. Performing Organization Rept. No.<br>UCB/EERC-88/03 |
| 9. Performing Organization Name and Address<br>Earthquake Engineering Research Center<br>University of California, Berkeley<br>1301 S 46th St.<br>Richmond, CA 94804 | 10. Project/Task/Work Unit No. |
| | 11. Contract(C) or Grant(G) No.<br>(C)<br>(G) |
| 12. Sponsoring Organization Name and Address<br>URS Corporation<br>100 California Street, 5th floor<br>San Francisco, CA 94111 | 13. Type of Report & Period Covered |
| | 14. |

15. Supplementary Notes

16. Abstract (Limit: 200 words)


To study the inelastic cyclic behavior of double angle steel connections, six full-scale assemblages of beam-to-column connections were subjected to severe cyclic loadings simulating the effects of strong earthquakes. The connections consisted of two equal leg angles welded to the web of the beam and bolted to the column. Steel used in the specimens was A36. The bolts were 3/4 inch A325 or A307 rib bolts. The major parameters studied were moment-rotation hysteresis behavior and variations in the bolt force. Some bolts were instrumented with strain gages, and the connection was instrumented to measure moment and rotations as well as bolt forces. The specimens were subjected to increasing levels of cyclic rotation, with each level of rotation repeated.

The results include moment-rotation cyclic hysteresis loops and cyclic bolt force variations, as well as qualitative observations. The failure modes observed were bolt tension failure, thread stripping off, and cyclic fatigue fracture of angle legs. Results of bolt pull tests and material tension coupon tests are also reported. The main conclusion was that the connections with A325 bolts tightened to 70% of proof load behaved well. Whereas, in some cases, connections with ribbed bolts were brittle and failed in early cycles through bolt thread stripping.


17. Document Analysis a. Descriptors

connections
cyclic rotation
double angle
fatigue
force
fracture

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

| 18. Availability Statement: | 19. Security Class (This Report) | 21. No. of Pages |
|---|---|---|
| Release Unlimited | unclassified | 79 |
| | 20. Security Class (This Page)<br>unclassified | 22. Price |

(See ANSI-Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

# CYCLIC BEHAVIOR OF STEEL DOUBLE ANGLE CONNECTIONS

by

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A Report on Research Sponsored by
URS Corporation, San Francisco

Report No. UCB/EERC-88/03
Earthquake Engineering Research Center
University of California
Berkeley, California

January 1988

## ABSTRACT

Double angle connections are widely used in transferring beam shear reactions to the support. Such connections are expected to undergo severe cyclic rotations during medium to large earthquakes. This report presents the findings of an experimental research program conducted at the University of California at Berkeley to study the inelastic cyclic behavior of double angle steel connections.

Six full-scale assemblages of beam-to-column connections were subjected to severe cyclic loadings simulating the effects of strong earthquakes. The connections consisted of two equal leg angles welded to the web of the beam and bolted to the column. Steel used in the specimens was A36. The bolts were 3/4 inch A325 or A307 rib bolts. The major parameters studied were moment-rotation hysteresis behavior and variations in the bolt force. Some bolts were instrumented with strain gages, and connection was instrumented to measure moment and rotations as well as bolt forces. The specimens were subjected to the increasing levels of cyclic rotation, with each level of rotation repeated.

The experimental results are reported and general conclusions are drawn on the basis of experimental behavior. The results include moment-rotation cyclic hysteresis loops and cyclic bolt force variations, as well as qualitative observations. The failure modes observed were bolt tension failure, thread stripping off, and cyclic fatigue fracture of angle legs. Results of bolt pull tests and material tension coupon tests are also reported.

The main conclusion was that the connections with A325 bolts tightened to 70% of proof load behaved well. Whereas, in some cases, connection with ribbed bolts were brittle and failed in early cycles through bolt thread stripping.

## ACKNOWLEDGEMENT

This report was submitted to URS Corporation of San Francisco as the final report of a "Service to Industry" project that was conducted at the University of California at Berkeley. The investigators wish to express their appreciation for the research grant provided by the URS Corporation. Particularly, the authors would like to thank Professor Stephen A. Mahin of the University of California and Dr. Lincoln Malik, vice president of the URS Corporation, for their support and helpful suggestions throughout the project. Thanks are also due to Dr. Said Bolourchi of URS Corporation and Thomas Conrads of Westinghouse for their contributions to the project. Cynthia Perry of URS Corporation supervised fabrication of test specimens and prepared drawings of test specimens that are used in this report. Her efforts are appreciated.

The tests were conducted in the structural engineering laboratory of the Department of Civil Engineering of the University of California at Berkeley. The assistance of the laboratory manager Roy Stephen and the laboratory staff, particularly Bill MacCracken, Mike Pitrola and Warren Matthew, is appreciated.

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# 1 . INTRODUCTION

## 1.1 General

Double angle framed beam connections are frequently used in steel structures. The main role of a double angle connection is to transfer shear from beams to the supporting elements. In many low-rise buildings, with less than four stories, these connections are used in framing systems connecting main girders to the columns. Even though these connections basically carry shear during earthquakes, it is expected that they will undergo large rotations. Thus, the behavior of the connections will have significant effect on the overall behavior and dynamic response of the structure. Therefore, for design and analysis in a severely seismic environment, it is necessary to have an in-depth understanding of the actual behavior of such connections. This report presents the results of six tests that were conducted to investigate cyclic behavior of double angle connections under simulated earthquake conditions.

Figure 1.1 shows four common types of double angle connections. The four categories are based on the type of connectors that are used to attach angles to the beam web and to the support. In this study only one type of connection shown in Figure 1.1(d), was investigated. For this type of connection, angles are welded to the beam web in the shop and bolts are placed and tightened in the field. The information available on the behavior of the four connections indicates that the connections become rotationally stiffer as one moves from type (a) to (d); type (d) is the stiffest connection. This is due to the fact that in the type (d) connection, rotational ductility is provided only by bending of the outstanding legs over a relatively short span between the bolt edges and the fillet of the back-to-back legs.

## 1.2 Literature Review

The behavior of double angle connections under monotonic loading has been investigated by several researchers. However, a survey of the literature did not produce any research done on the cyclic behavior of these connections. A brief review of research on the monotonic behavior of the double angle connections is given here in order to shed some light on the basic characteristics of behavior that not only occurs under monotonic loading but can also be observed during cyclic loading.

Birkemoe and Gilmore (2) conducted two tests of full size beams connected to the support by 4x3-1/2x3/8 inch angles. The loading in these tests was applied monotonically. Their main objective was to study effects of coping of the beam flange on the strength of the connection. One of the specimens had coping on the flange and the other identical specimen was without cope. They also conducted four component tests of the connection area to study failure modes as related to the bearing strength of the bolts. They cautioned against placing bolts too close to the end of the beams, and also indicated that a potential for tear-out failure exists for beams with top flange coping.

Sommer (10) conducted four tests of double angle connections of the type studied in this project. The study was part of a larger research project to investigate behavior of header plates and to compare the behavior of header plates with that of double angles. Kennedy (5) later reported on some of the results and concluded, among other things, that in deep connections the possibility of bolt fracture should be investigated. Sommer also proposed the use of polynomials in developing a standard moment-rotation curve for flexible connections.

Later, Frye and Morris (4) used Sommer's formulation and established standard polynomials defining moment-rotation relationships for a variety of flexible connections. They used test results from Munse et al. (9) and Sommer (10) on double angle connections to develop power values for their empirical curves. Frye and Morris then used a connection moment rotation model to perform nonlinear analysis of frames. Ang and Morris (1) further advanced the technique of nonlinear analysis of flexibly joined frames by using a Ramberg-Osgood model to represent connection behavior and to analyze three dimensional frames.

The experimental work that provides some useful information on the behavior of connections similar to those studied in this project, is the work of Kennedy (5).

Recently, a comprehensive summary of experimental and analytical work done in the area of flexible steel connections was published by the American Society of Civil Engineers (3). The document contains several papers on the state of the art of flexible connection behavior and design.

## 1.3 Background

The dynamic response of an existing building to earthquake excitations was under investigation by the URS Corporation of San Francisco. The building was a three story industrial building with steel framing. Columns and beams consisted of rolled ASTM-A7 grade steel wide flange shapes. Most connections used in the structure were double angle framed beam web connections similar to that of Figure 1.1(d).

To perform a realistic dynamic response analysis, it was necessary to model the inelastic cyclic behavior of connections as realistically as possible. A survey of the available literature indicated that information on the cyclic response of this type of connection is non-existent, and therefore, a program was developed to investigate cyclic behavior of double angle connections under severe earthquake effects. This research program consisted of conducting a sufficient number of cyclic tests of a beam-to-column assemblage and recording the hysteretic response of the connections. The focus was on welded-bolted connections of the type shown in Figure 1.1(d).

## 1.4 Objective

The main objective of the experimental program was to collect empirical data on the hysteretic behavior of double angle beam-to-column connections of the type shown in Figure 1.1 (d).

# 2 . EXPERIMENTAL PROGRAM

## 2.1 General

A total of six specimens was tested. The tests consisted of subjecting double angle beam-to-column connections to cyclic inelastic load reversals. The following sections describes the parameters studied, the test specimens, loading history and test procedures. Test results are given in Chapter 3.

## 2.2 Parameters of Study

The major objective of this research was to study the moment-rotation cyclic behavior of the connections. The main parameters influencing the cyclic behavior were recognized to be angle plastic deformations, rotational stiffness of the angles throughout the elastic and inelastic range, and bolt behavior. During the experiments, the moment-rotation hysteretic behavior of the connections was recorded. Also, bolt forces were recorded in specimens that had A325 high strength bolts.

## 2.3 Test Specimens

A typical test specimen is shown in Figure 2.1. The specimens consisted of a beam connected to a short column with double angle connections. Properties of the test specimens are given in Table 1.1. The geometry and configuration of the six connections that were tested are shown in Figures 2.2 through 2.7.

The angles used in specimen three were 3x3x5/16, and in all other five specimens, the angles were 3x3x3/8. The material used in all specimens was ASTM-A36 steel. The mechanical properties of the angles were established from standard ASTM coupon tests, the results of which are given in Chapter 4. The angles used in the test specimens were saw cut in the laboratory.

Two types of bolts were used in the connections of the test specimens. In specimens one, two and three, the bolts were old ribbed bolts removed from the connections of the existing structure. The bolts used in specimens four, five and six were all new A325 high-strength bolts. The nominal diameter of bolts in all specimens was 3/4 inch. The tensile strength of the ribbed bolts was established from pull tests, the results of which are given in Chapter 4. The bolt spacing for all specimens was 3 inches center-to-center. The edge distance of the bolts for all specimens was 1.5 inches. The spacing and edge distance satisfy the requirements of current AISC Specification (11).

Welds connecting double angles to the beam web were made using E6013 electrodes resulting in a nominal weld strength equal to 60 ksi. It was found that the E6013 electrodes closely simulate the welds in the existing structure. The weld size in all specimens was 1/4 inch.

The columns in all specimens were W10x77. This column was selected to ensure that the column would remain almost elastic during the experiments and would not add significant rotation to the overall rotation of the connection. The observations during the tests confirmed that indeed the columns did not experience any noticeable inelasticity.

The beams used in the experimental program were selected by the sponsor in consultation with the investigators to simulate realistic conditions of the existing structure. Since connections are very flexible compared to the beams, it was expected that, during the tests, the beams would remain essentially elastic. This was confirmed during the experimental program.

Test specimens were fabricated by a local steel fabricator using drawings supplied by the sponsor. The quality of workmanship was good and acceptable. The cutting of angles and welding was done by technicians in the structural engineering laboratory of the University of California at Berkeley.

## 2.4 Test Set-Up

The test set-up is shown in Figure 2.8. The set-up consisted of three major components: (1) actuator; (2) reaction block supporting the actuator; and (3) reaction block supporting the test specimens, see Figure 2.9. The actuator used in the test program was a 125-kip-capacity MTS actuator with load cell and end joints. The actuator was supported by a stub column welded to heavy steel plates prestressed to the laboratory floor. The reaction block for the test specimens was a heavy steel box also prestressed to the laboratory floor. The column for the test specimen was connected to the reaction block by means of six 1.0 inch diameter high-strength bolts. Lateral support is provided at the end of the beam, where load was applied, to prevent instability of the specimen. In actual structures such lateral support is provided by floor systems.

## 2.5 Loading History

All the cyclic rotation histories used for the specimens were similar. A typical history is shown in Figure 2.10. The specimens were subjected to symmetric and increasing cycles of rotation reversals. The rotation history was designed to simulate the effects of severe earthquakes and to cause severe inelastic activity in the connection area.

## 2.6 Instrumentation

The instrumentation used in this test series is shown schematically in Figure 2.11, and mainly consisted of Linear Variable Displacement Transducers (LVDT's) and wire transducers to measure displacements at various points on the specimens. Using the information collected by the LVDT's, the rotation of the connection was calculated in five different ways to ensure accuracy. The rotation values that were used to plot the results presented in this report are those calculated by adding the displacements measured by wire transducers on the top and bottom flanges of the beam divided by the distance between top and bottom transducers. The moment applied to the connection was calculated by multiplying force measured in the actuator by the arm. The force arm was 58.5 inches.

To measure bolt forces, special bolt gages were placed inside the holes drilled in the bolt shanks. The forces were then calculated by measuring the strain in the unthreaded part of the shank and assuming a modulus of elasticity of 29,000 ksi for the steel. During all tests, the instruments performed well and no difficulties occurred.

The data acquisition system for the experiments consisted of an IBM PC based system with capability of real time recording and processing. A videotape camera was used to record some of the highlights of the experiments. 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. Angle legs were welded to the beam web.

2. The specimen was assembled by connecting the beam to the column using the type of bolt specified for the specimen. All bolts were snug tight at this stage.

3. The specimen was placed in the test set-up and bolts were tightened to the pretensioning values that had been specified a priori. For ribbed bolts, a torque wrench was used and a maximum torque of 250 ft-lb was applied to the nuts. To prevent round headed bolts from rotating, a small tack weld was used to weld bolt heads to angles. The value of the torque, to be applied to the rib bolts, was established on the basis of field data measuring the the torque that was necessary to untighten the old rib bolts. For new ASTM-A325 bolts, the turn of nut method was used to achieve the bolt pretensioning value prescribed by the American Institute of Steel Construction Manual (11). The specified pretensioning force for 3/4 inch diameter A325 bolts is 28 kips. For the A325 bolts that had strain gages in their shanks, the bolt forces were checked continuously during tightening to ensure reaching actual pretensioning load;t these bolts had 28 kips nominal pretensioning force at the start of tests as specified by AISC Manual (11).

4. After the bolts were tightened the instrumentation was added and the specimen was whitewashed. The whitewashing was done to enable the investigators to detect yielding on the surface of the specimens.

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

6. The actual test began by applying a cyclic load and generating a rotation history of the type shown in Figure 2.10. The exact rotation history applied to each specimen is given in Chapter 3.

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

# 3 . EXPERIMENTAL RESULTS

## 3.1 General

This chapter presents the quantitative and qualitative data that were collected during the experimental studies. The observations that were made during the test are presented first, then the relevant plots of the hysteresis behavior of each specimen follow.

## 3.2 Test Number One

The specimen for this test consisted of 3 x 3 x 3/8 inch double angles with two rows of four bolts. A sketch of test specimen one is given in Figure 2.2. The bolts in one row were rib bolts and on the other row were instrumented A325 bolts tightened to a maximum torque of 250 ft-lb. Since this was the first specimen to be tested in the series, A325 strain gaged bolts were used to obtain some insight about the forces that might be generated in the bolts. The objective of these tests was to study the behavior of ribbed A307 bolts; however, because of the very short unthreaded shank length of the ribbed bolts, it was not possible to place strain gages in them. A detail of the test specimen is given in Figure 2.2.

The rotation history of the test is given in Figure 3.1. During the test, the angles in specimen one remained almost elastic with evidence of only a very limited amount of inelasticity appearing on the whitewash. Figure 3.2 shows the specimen after completion of the test. The minor black spots above the top hole and below the bottom hole are indicators of yielding.

After the second cycle, some inelasticity was observed along the bolt line of the angles indicating yielding in these areas as shown in Figure 3.3. Furthermore, bolts showed significant elongation resulting in separation of the angles from the supporting column along the bolt lines.

After six cycles, when the specimen was subjected to 0.020 radian rotation for the first time, the bolts elongated enough to release all the pretensioning force in the bolts located farthest from the center of connection. An examination of these bolts, at that time, indicated that they were completely loose and the nuts could be rotated manually. Failure of this specimen occurred when the extreme bolts stripped off the threads at the end of tenth cycle when the rotation was 0.03 radian. At this point the strength and stiffness of the connection decreased significantly.

Hysteresis loops (cyclic moment-rotation curves) for this specimen are given in Figure 3.4. Particular hysteresis loops for different cycles are given in Figures A.1 through A.5 of the Appendix. As can be seen in the figures, the hysteresis loops showed signs of "pinching" after the second cycle, which is evidence of the development of a permanent gap between the angles and the supporting columns.

## 3.3 Test Number Two

The specimen for the second test consisted of 3 x 3 x 3/8 inch double angles with two rows of six A307 rib bolts. A sketch of specimen two is given in Figure 2.3.

The rotation history of this specimen is given in Figure 3.5. The behavior of this specimen was similar to that of specimen one. The inelasticity in the angles was very limited and again, some bolts underwent permanent elongation. After the second cycle, some yielding could be observed at bolt spacings.

Failure of this specimen occurred during the fifth cycle when one of the bolts located farthest from the center of the connection stripped off the threads. Since this happened only in one direction, cyclic loading in the other direction continued for two more cycles.

Moment-rotation hysteresis loops for this specimen are given in Figure 3.6. Particular loops for each cycle are given in Figures A.6, A.7 and A.8 of the Appendix.

## 3.4 Test Number Three

The specimen for the third test consisted of 3 x 3 x 5/16 inch angles with two rows of three ribbed bolts. A sketch of specimen three is given in Figure 2.4.

The rotation history of the specimen is given in Figure 3.7. The behavior of this specimen was quite ductile and desirable. Two plastic hinges formed in angles. One plastic hinge formed along the edge of the bolt line as shown in Figure 3.8, and a second plastic hinge formed adjacent to the end of the fillet at the inert corner of the angles (Figure 3.9). In this specimen, some bolts showed some minor elongation as shown in Figure 3.10, but they were able to maintain some of their pretensioning force. Unlike specimens one and two, in specimen three the bolts did not fail. The cyclic loading of this specimen continued until connection rotation reached a value of more than 0.06 radian which was the limit attainable by the test set-up.

Moment rotation hysteresis loops for this specimen are given in Figure 3.11, in which the pinching effect is evident. More detailed loops are given in Figures A.9 through A.16 in the Appendix.

## 3.5 Test Number Four

The specimen for this test was similar to that in test number one with only one difference; namely the type of bolts that were used. In specimen number four, all bolts were A325 bolts tightened to 70% of their proof load, as specified by the AISC

Manual (11). The angles used in this specimen were 3x3x3/8 inch and the bolts were two rows of four ribbed bolts. A sketch of specimen four is given in Figure 2.5.

The cyclic rotation history of this specimen is given in Figure 3.12. The behavior of this specimen was satisfactory and ductile. Most of the yielding occurred in the angles. The bolts were initially tightened to 28 kips pretensioning load which is 70% of their proof load as specified by AISC Manual(11). After 12 cycles the angles developed fracture through the fillet area, as shown in Figure 3.13.

Moment-rotation hysteresis loops for this specimen are given in Figure 3.14. More detailed loops are given in Figures A.17 through A.22 in the Appendix.

In this specimen, all four bolts on one angle were instrumented with strain gages to measure the bolt forces. The strain measured in the bolt shank was multiplied by 29,000 to obtain the stress, from which the bolt force was calculated. Figures 3.15 through 3.18 show the time histories of the bolt forces for all four bolts.

### 3.6 Test Number Five

The specimen for this test was similar to the specimen for test number two except for the type of bolts that were used. The bolts in this specimen were all diameter A325 bolts tightened to 70% of proof load. The angles in this specimen were 3x3x3/8. A sketch of specimen five is given in Figure 2.6.

The cyclic rotation history of this specimen is shown in Figure 3.19. Unlike specimen two, the specimen in test number five behaved in a very ductile manner. Two plastic hinges formed in the angles, and the bolts did not show significant inelasticity. Failure of this specimen occurred because of fracture of the angle leg adjacent to the fillet as shown in Figure 3.20. The cracking started during the tenth cycle when the specimen had completed its 0.025 radian rotation cycle.

Moment-rotation hysteresis loops for this specimen are given in Figure 3.21. More details of the hysteresis loops for different cycles are given in Figures A.23 through A.27 in the Appendix.

In this specimen, all six bolts on one angle were instrumented with strain gages to measure bolt forces. The strain measured in the bolt shank was multiplied by 29,000 to obtain the stress, from which the bolt force was calculated. Figures 3.22 through 3.27 show the time histories of the bolt forces for all six bolts.

## 3.7 Test Number Six

The specimen for this test consisted of 3 x 3 x 3/8 double angles and two rows of five A325 bolts. Details of specimen six are given in Figure 2.7.

The cyclic rotation history of this specimen is shown in Figure 3.28. Generally, the behavior of this specimen was very similar to the behavior of specimens 4 and 5. The angles experienced considerable inelasticity, and the bolts retained about one third of their pretensioning load.

Moment-rotation hysteresis loops for this specimen are given in Figure 3.29. More detailed loops are given in Figures A.28 through A.32 in the Appendix.

In this specimen, all five bolts on one angle were instrumented with strain gages to measure bolt forces. The strain measured in the bolt shank was multiplied by 29,000 to obtain stress, from which bolt force was calculated. Figures 3.30 through 3.34 show the time histories of the bolt forces for all five bolts.

# 4 . MATERIAL TESTS

## 4.1 General

Two types of material tests were conducted during the course of this project: (1) tests of the tension capacity of ribbed bolts; and (2), tests to establish the mechanical properties of the steel used in the angles. The results of these tests are presented next.

## 4.2 Bolt Tests

As discussed in the previous chapters, in specimens one, two and three of the connection tests, rib bolts were used to connect the angles to the supporting columns. These rib bolts were actually removed from an existing building to be used in the experiments. Adequate information on the mechanical properties of such ribbed bolts was not available. The ribbed bolts were used heavily after the mid 1940's in connections of steel buildings, replacing inefficient rivets; later, the use of high strength friction and bearing bolts evolved. To obtain reliable quantitative information, a series of bolt tests were conducted; the results of five of which are reported here.

The rib bolts supplied by the sponsor were of two types. Both types had hemispherical bolt heads and ribbed shanks. Both bolts had 17 vertical ribs over the unthreaded part of their shank.

In type one, nuts and threads were similar to those of A325 bolts (5/8 inch long nut and 10 threads per inch). This type appeared to resemble closely resemble A307 bolts but with ribs on the unthreaded shank area. The average under-thread diameter of these bolts was 0.55 inch; and the outside diameter of the the threaded area was 0.7 inch. Hence the average depth of the thread was equal to 0.075 inch. The average length of the unthreaded shank was 5/8 inch.

In type two, the nuts were 7/8 inch long - 1/4 inch longer than the 3/4 inch A325 nut. These bolts had only 8 threads per inch and the depth of the thread was only 0.04 inch which is about half the A325 thread depth. The under-thread diameter of these bolts averaged about 0.62 inch and the outer diameter of the threaded part was 0.70 inch. The average length of the unthreaded shank for this type of bolt was 5/8 inch.

As mentioned above, the bolts were relatively short. In order to conduct a tension test of a bolt that also measured the strength of the nut and the stripping failure, a special set-up was devised; this is shown in Figure 4.1. The nuts were welded to the head of a one inch diameter A325 bolt. Then the bolt to be tested was placed in the set-up and tension load applied to the top and bottom end of the grips. The loading continued until failure occurred. The failure mode was very consistent for the two bolt types mentioned above. For bolts with shallow threads, failure occurred by nuts stripping off the threads on the bolts. Whereas, for type one bolts with deeper threads, failure occurred by yielding and tensile fracture of the under-thread cross section of the bolt.

Results of bolt tests are given in Figures 4.2 through 4.6.

## 4.3 Coupon Tests

A series of four coupon tests was conducted to establish the mechanical properties of the steel in the angles. The tests were conducted following standard ASTM procedures as specified in Reference (12). The gage length for the coupons was 8 inches for ultimate strain measurements and 4 inches for stress-strain curves.

Properties of the coupons are given in Table 4.1. Information on the ultimate condition of the coupons is given in Table 4.2.

The stress-strain curves are given in Figures 4.2 through 4.5. In addition, during coupon tests, the modulus of elasticity of the material was measured and recorded. Figures 4.6 through 4.10 provide information on the modulus of elasticity of steel.

# 5 . CONCLUSIONS

## 5.1 General

The main objective of this research project was to investigate, experimentally, the behavior of double angle connections subjected to cyclic rotations. The specific results have been presented in the previous chapters, particularly Chapter 3; and from these the following conclusions were drawn.

## 5.2 Conclusions

On the basis of the test results the following conclusions can be made:

1. Ribbed bolts with shallow threads do not perform satisfactorily when the connection is subjected to cyclic rotations larger than 0.025 radian. The threads can strip off in connections with two-by-four, two-by-five and two-by-six bolts with 3x3x3/8 angles.

2. The cyclic behavior of the connections with two rows of three ribbed bolts and 3x3x5/16 angles was quite satisfactory.

3. Connections with A325 bolts tightened to 70% of proof load as specified by the AISC Manual (11) perform well and show ductile behavior.

4. The high strength A325 bolts maintained about one-third of their pretensioning load as their shakedown force and did not become totally loose.

5. The neutral axis for connections with three bolts alternates between the top and bottom of the angles. For connections with two-by-four, two-by-five and two-by-six bolts, the neutral axis alternates between the top and bottom bolts.

# 6 . REFERENCES

1. Ang, K.M., and Morris, G.A., "Analysis of Three Dimensional Frames with Flexible Beam-Column Connections", *Canadian Journal of Civil Engineering,* Vol. 11, 1984.

2. Birkemoe, P.C., and Gilmore, M.I., "Behavior of Bearing Critical Double-Angle Beam Connections", *AISC, Engineering Journal*, 4th Quarter, 1978.

3. Chen, F-W, Editor, "Connection Flexibility and Steel Frames," *Proceedings* of a session sponsored by Structural Division, ASCE Convention, Detroit, October 1985.

4. Frye, J. M., and Morris, G. A., "Analysis of Flexibly Connected Steel Frames", *Canadian Journal of Civil Engineering*, Vol. 2., 1975.

5. Kennedy, D.J.L., "Moment Rotation Characteristics of Shear Connections, " *AISC, Engineering Journal*, October, 1969.

6. Lewitt, C.W., Chesson, Jr., E., and Munse, W.H., "Restraint Characteristics of Flexible and Bolted Beam-to-Column Connections",University of Illinois, Engineering Experiment Station, *Bulletin* Number 500, January 1969.

7. Lipson, S.L., "Single Angle and Single Plate Beam Framing Connections", *Canadian Structural Engineering Conference*, 1968.

8. Lipson, S.L.," Single Angle Welded-Bolted Connections", *Journal of The Structural Division,* ASCE, Vol. 193, No. ST3, March 1977.

9. Munse, W.H., Bell, W.G., and Chesson Jr., E. ,"Behavior of Beam-to- Column Connections", *Bulletin*, Department of Civil Engineering, University of Illinois, Urbana, Illinois.

10. Sommer, W.H., "Behavior of Welded Header Plate Connections, *Master of Science Thesis,* University of Toronto, Ontario, Canada, 1969.

11. --------------, *"Manual of Steel Construction",* AISC ,8th Edition, 1980.

12. --------------, "Standard Methods of Tension Testing of Metallic Materials, *ASTM Standard*, Designation E6, 1986.

Table 1.1 Properties of Test Specimens

| Test | Angles (in.xin.x.in.) | Angle Length (in.) | Weld Size (in.) | No. of Bolts | Dia. of Bolts (in.) | Bolt Type | Beam Section | Column Section |
|---|---|---|---|---|---|---|---|---|
| 1 | 3x3x3/8 | 12 | 1/4 | 2x4 | 3/4 | Rib/A325 | W16x40 | W10x77 |
| 2 | 3x3x3/8 | 18 | 1/4 | 2x6 | 3/4 | Rib | S24x80 | W10x77 |
| 3 | 3x3x5/16 | 9 | 1/4 | 2x3 | 3/4 | Rib | S12x31.8 | W10x77 |
| 4 | 3x3x3/8 | 12 | 1/4 | 2x4 | 3/4 | A325 | W16x40 | W10x77 |
| 5 | 3x3x3/8 | 18 | 1/4 | 2x6 | 3/4 | A325 | S24x80 | W10x77 |
| 6 | 3x3x3/8 | 15 | 1/4 | 2x5 | 3/4 | A325 | S24x80 | W10x77 |

Note: All welds were done with E6013 electrodes

Table 4.1 Properties of Coupons Used in Tension Tests

| Coupon | Average Thickness (in.) | Width (in.) | Area (in.$^2$) |
|---|---|---|---|
| 1 | 0.383 | 1.507 | 0.578 |
| 2 | 0.398 | 1.506 | 0.599 |
| 3 | 0.331 | 1.508 | 0.499 |
| 4 | 0.327 | 1.507 | 0.493 |

Table 4.2 Information on Ultimate Stage of Coupons

| Coupon | Initial Length (in.) | Final Length (in.) | Percent Elongation | Rupture Stress (ksi) |
|---|---|---|---|---|
| 1 | 8.03 | 9.87 | 22.914 | 36.000 |
| 2 | 8.02 | 10.01 | 24.813 | 35.000 |
| 3 | 8.02 | 10.17 | 26.808 | 28.500 |
| 4 | 8.02 | 10.15 | 26.559 | 27.000 |

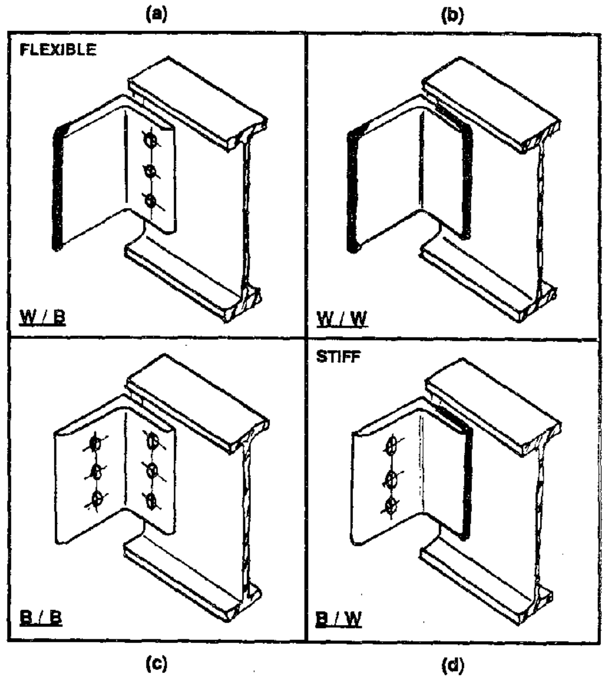


Figure 1.1 Four Common Types of Double Angle Connections

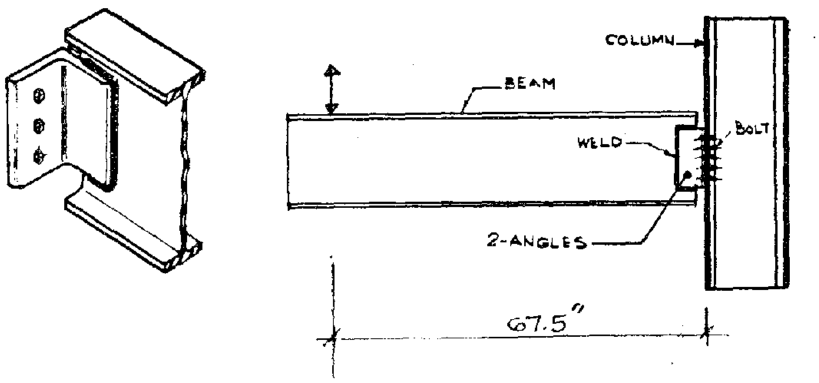


Figure 2.1 Typical Test Specimen

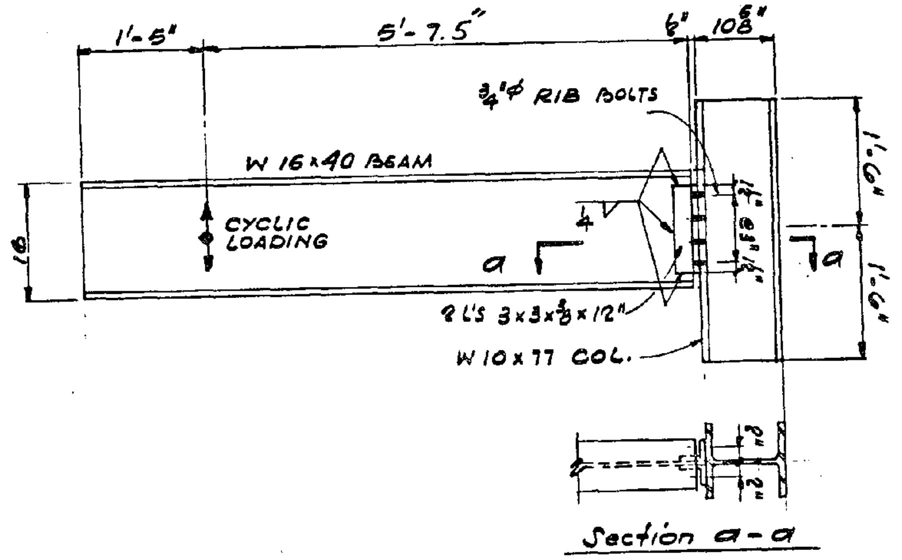


Figure 2.2 Geometry and Configuration of Specimen One

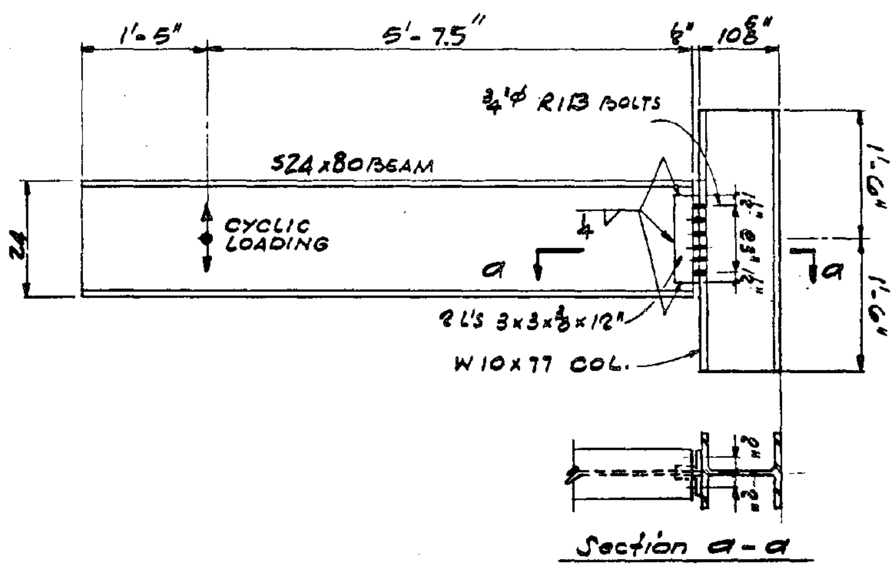


Figure 2.3 Geometry and Configuration of Specimen Two

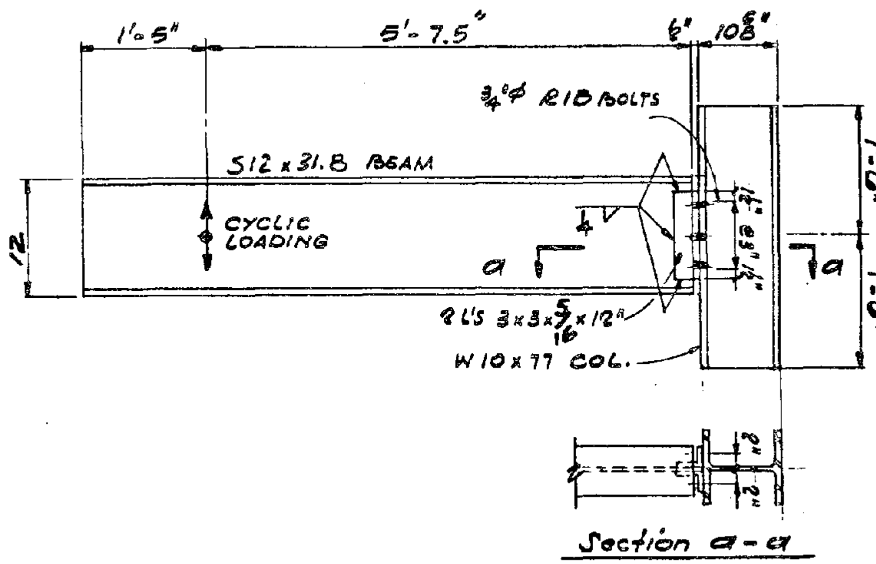


Figure 2.4 Geometry and Configuration of Specimen Three

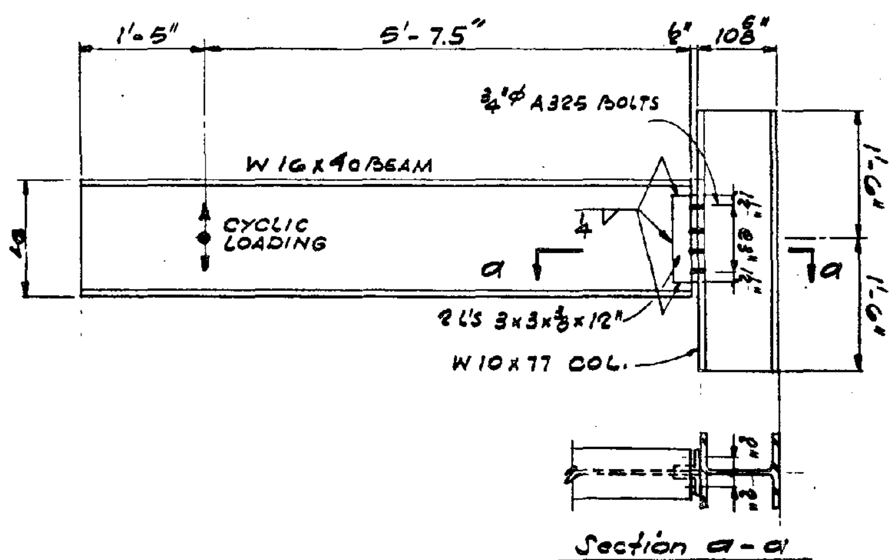


Figure 2.5 Geometry and Configuration of Specimen Four

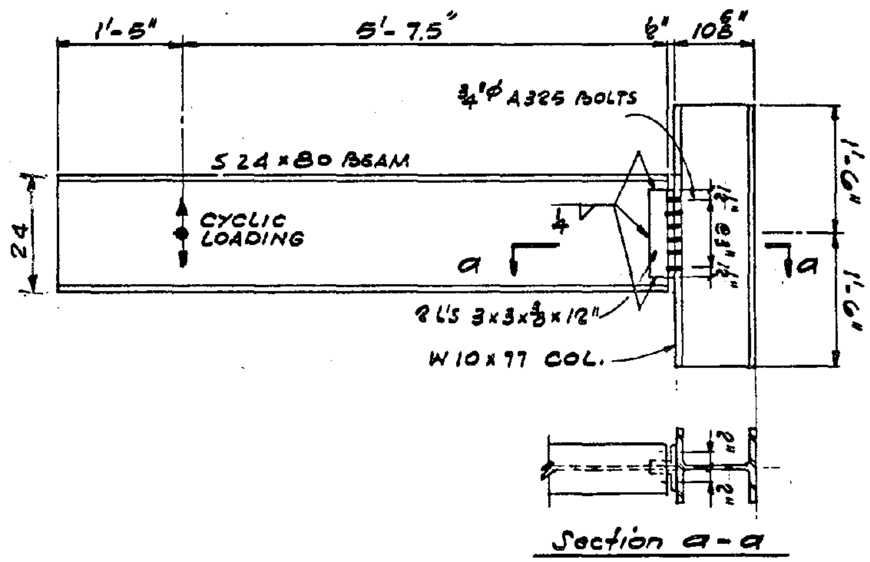


Figure 2.6 Geometry and Configuration of Specimen Five

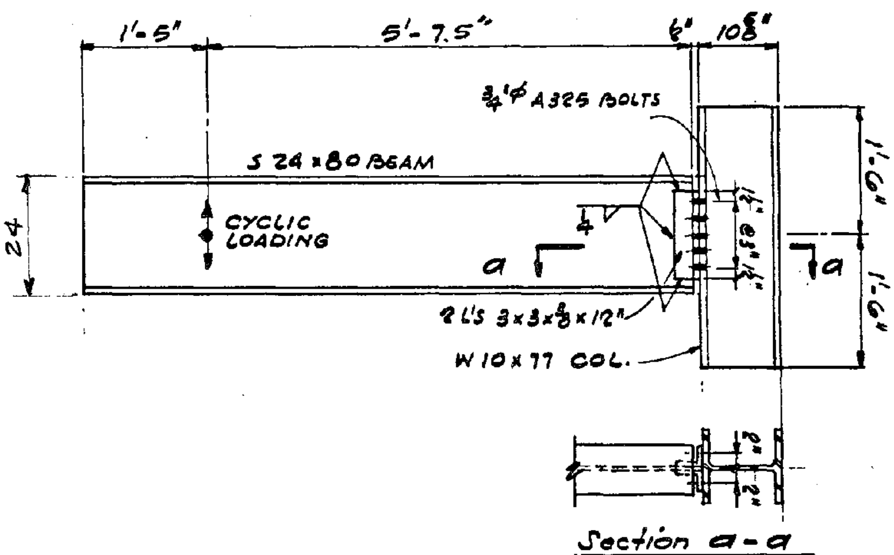


Figure 2.7 Geometry and Configuration of Specimen Six

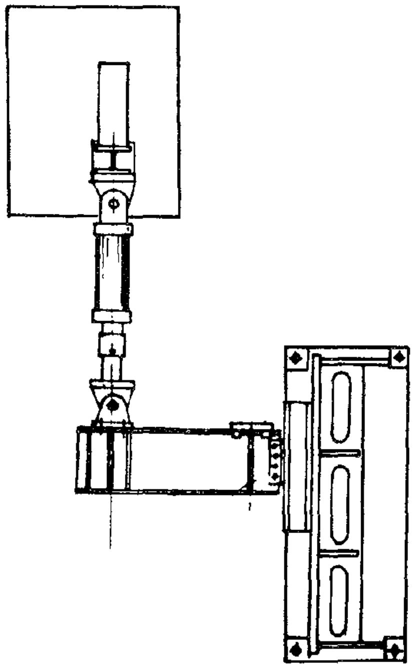

Figure 2.8 A Sketch of Test Set-Up

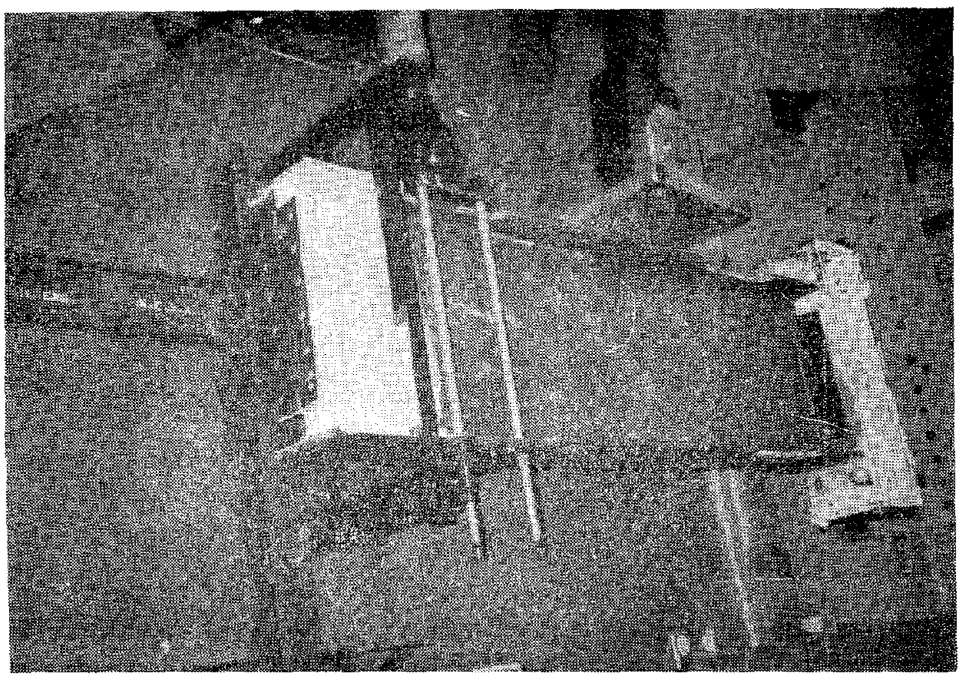

Figure 2.9 Actual Test Set-up

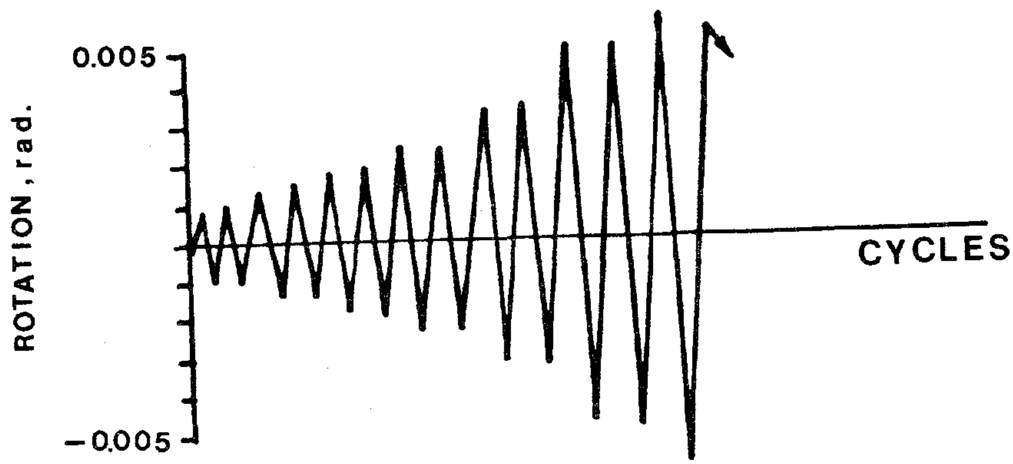


Figure 2.10 Typical Cyclic Rotation History

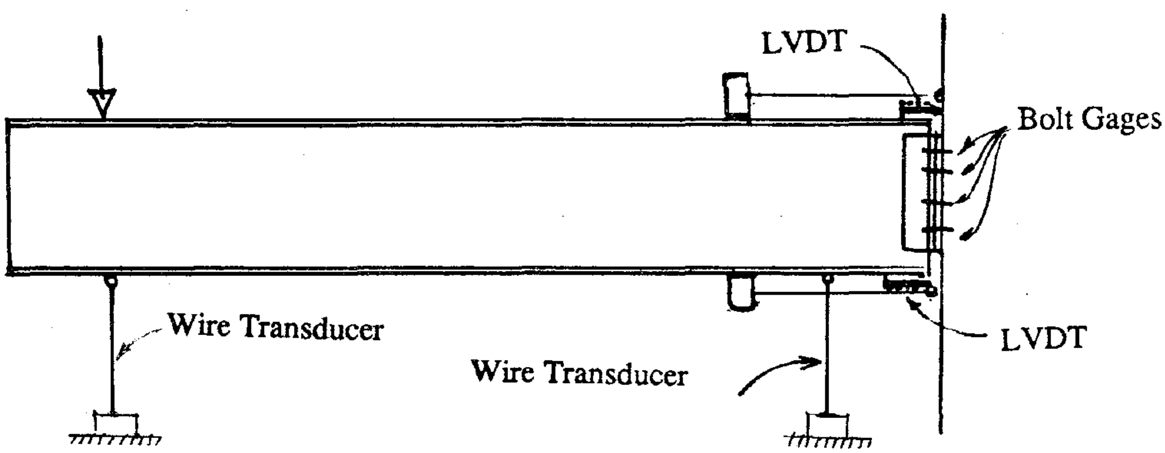


Figure 2.11 Instrumentation

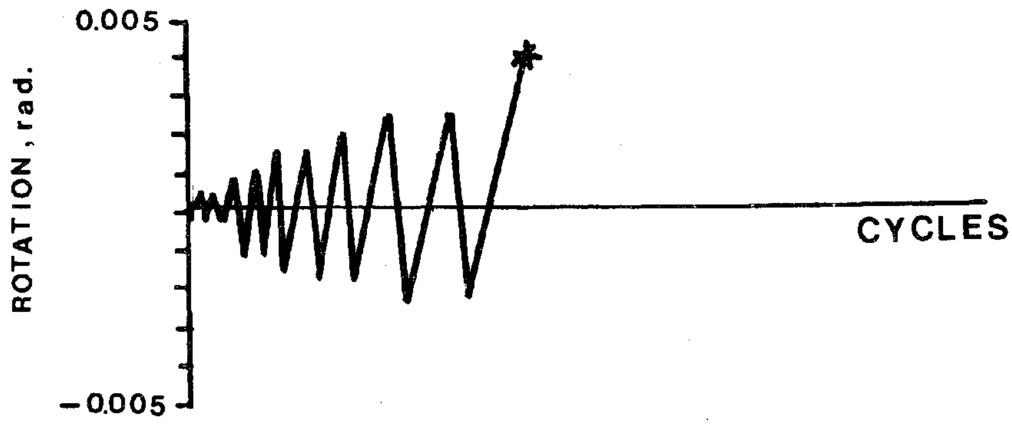


Figure 3.1 Rotation History of Specimen One

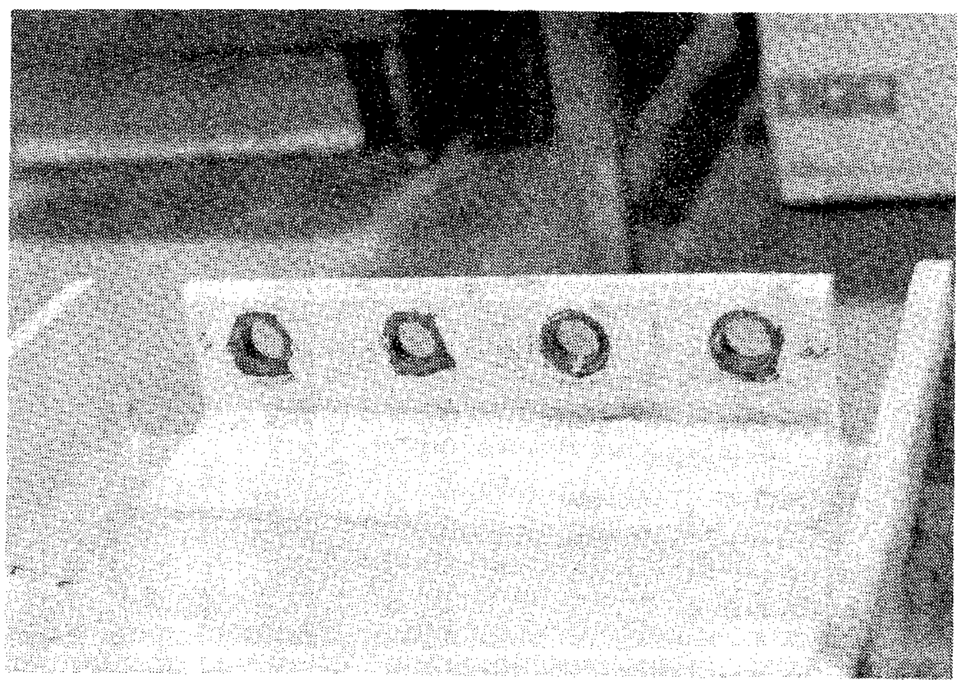

Figure 3.2 Specimen One at the End of Test

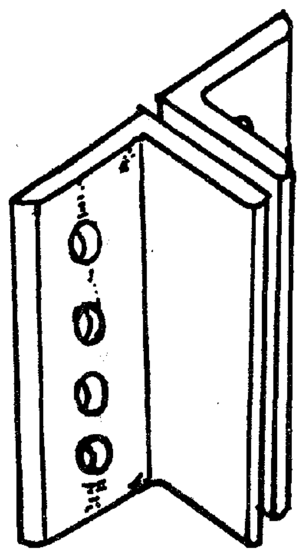

Figure 3.3 Yielding of Specimen One

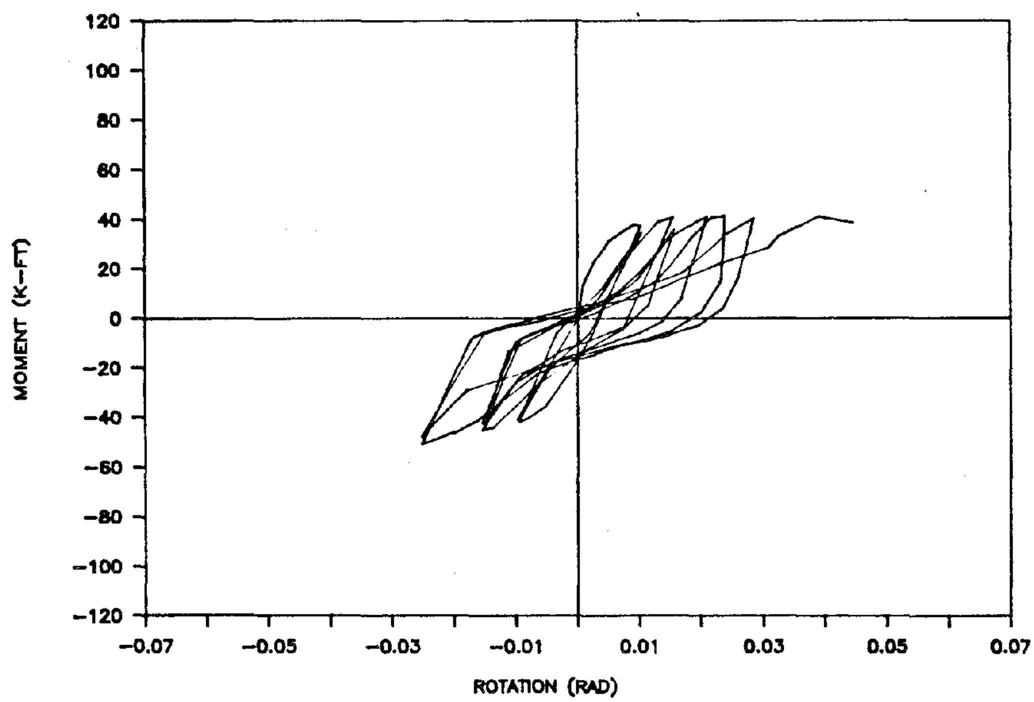


Figure 3.4 Moment-Rotation Hysteresis Loops of Specimen One

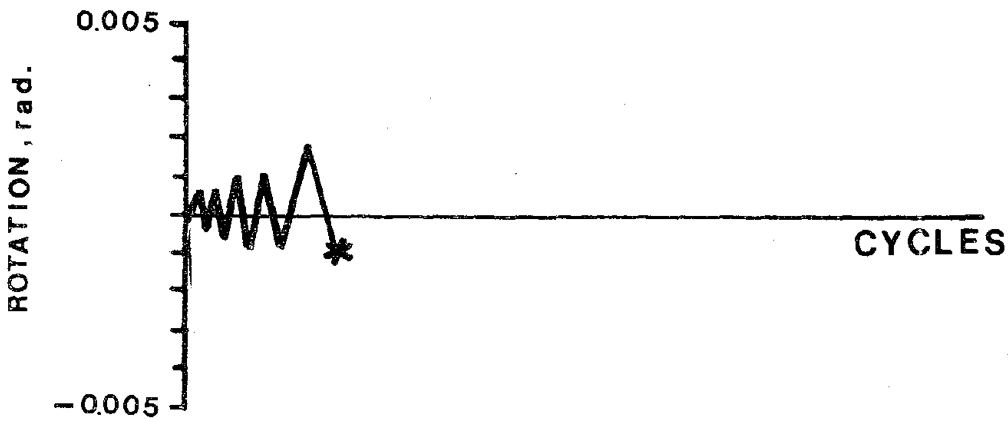


Figure 3.5 Rotation History of Specimen Two

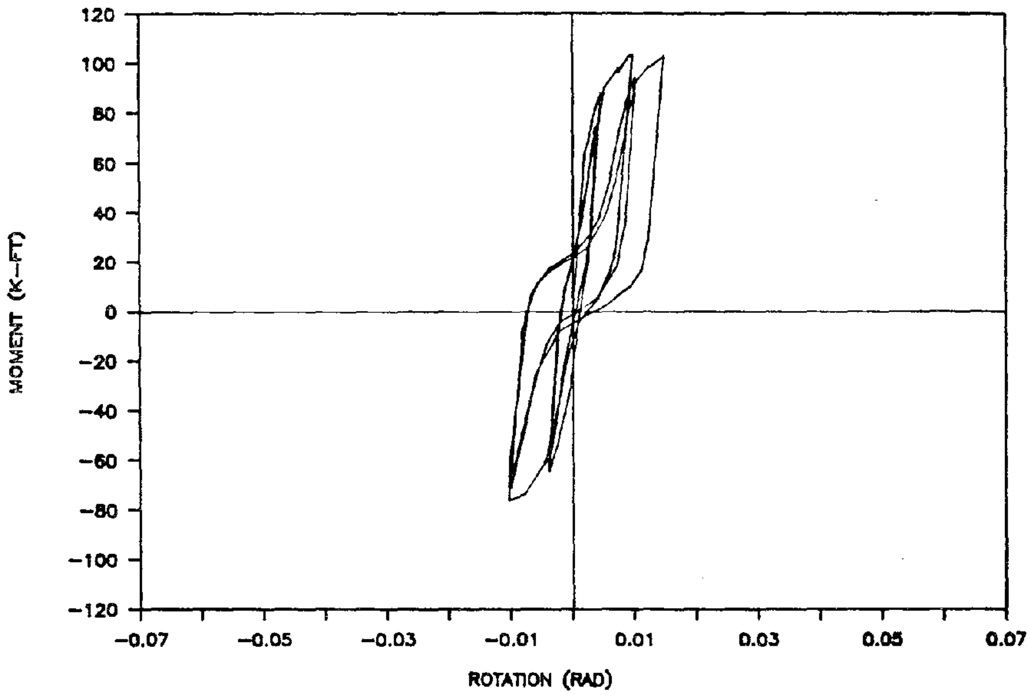


Figure 3.6 Moment-Rotation Hysteresis Loops of Specimen Two

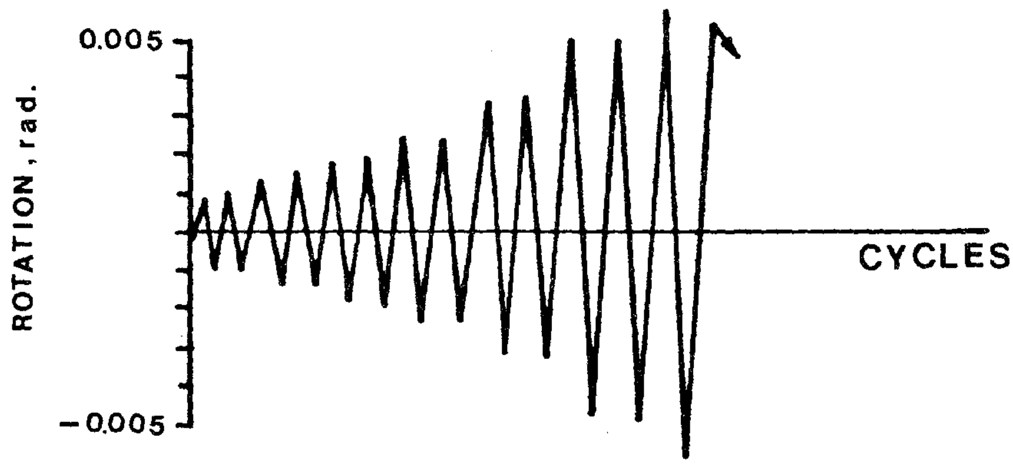


Figure 3.7 Rotation History of Specimen Three

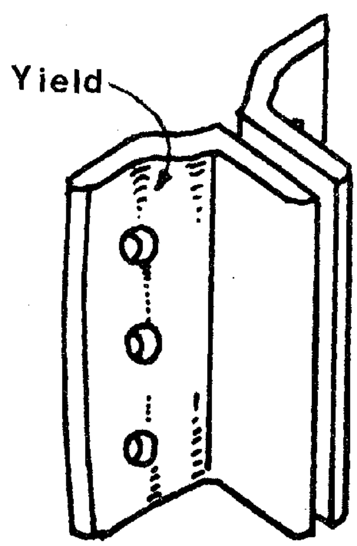


Figure 3.8 Plastic Hinge Formed in the Angles, Specimen Three

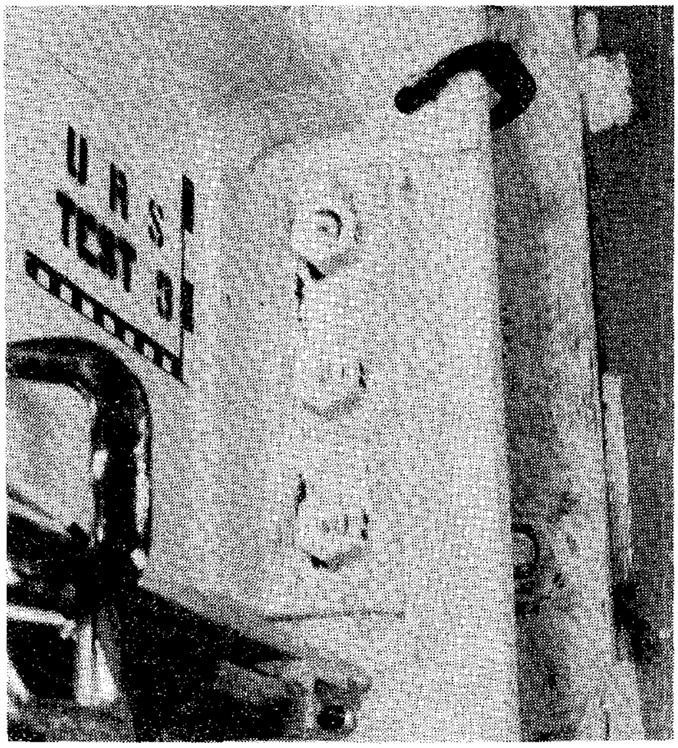


Figure 3.9 Plastic Hinges in Specimen Three

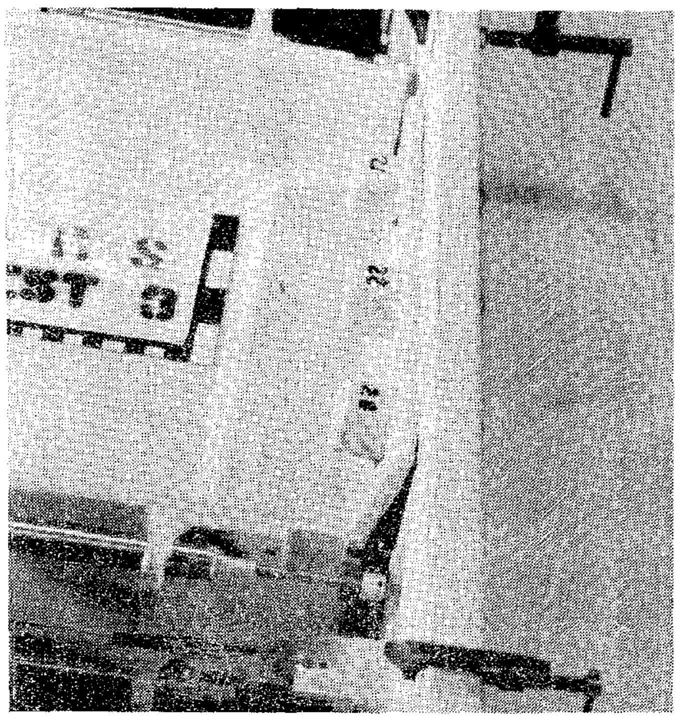

Figure 3.10 Elongation of Bolts in Specimen Three

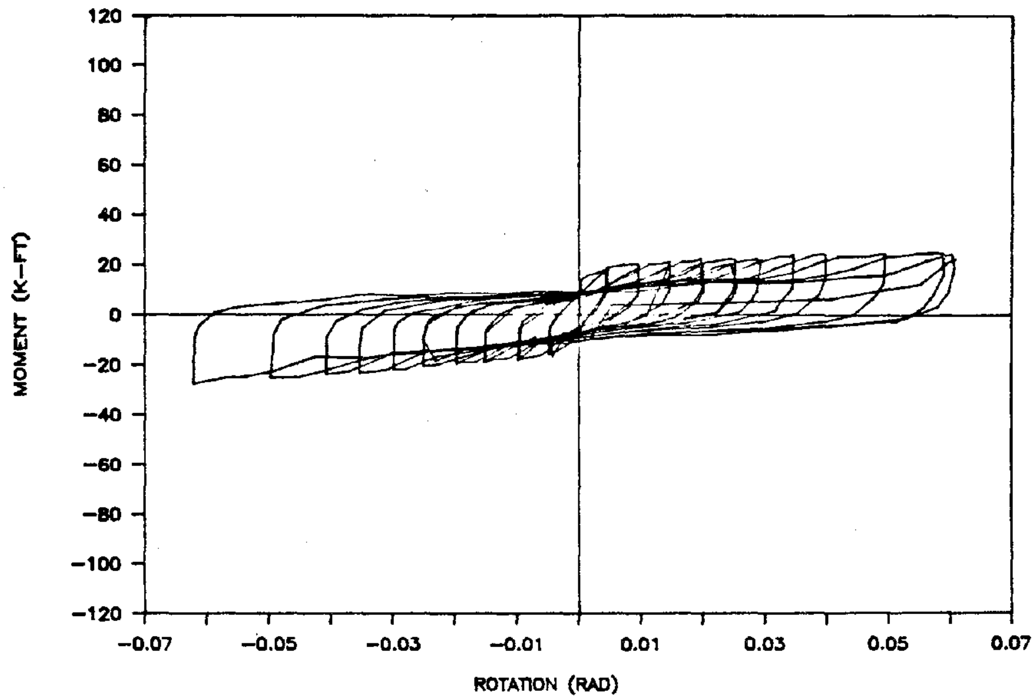


Figure 3.11 Moment-Rotation Hysteresis Loops for Specimen Three

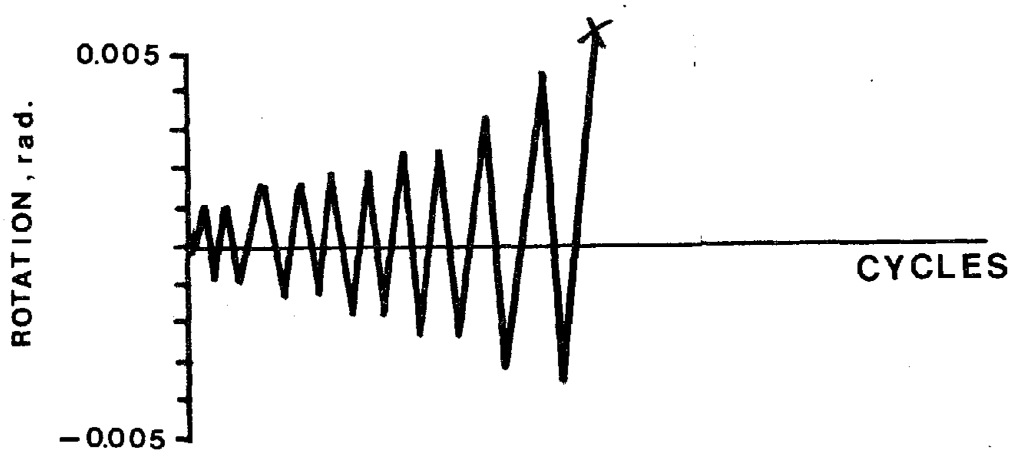


Figure 3.12 Cyclic Rotation History of Specimen Four

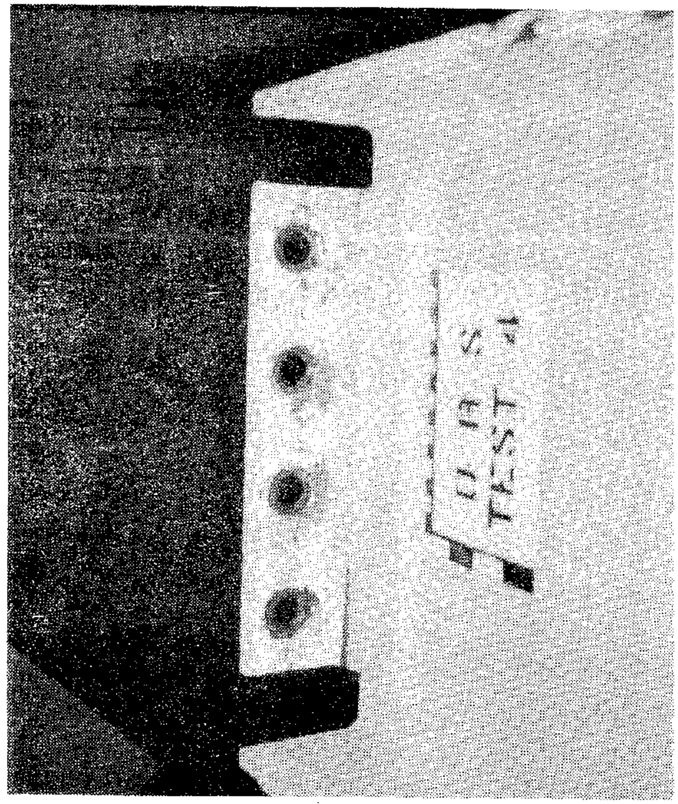

Figure 3.13 Fracture of Angles, Specimen Four

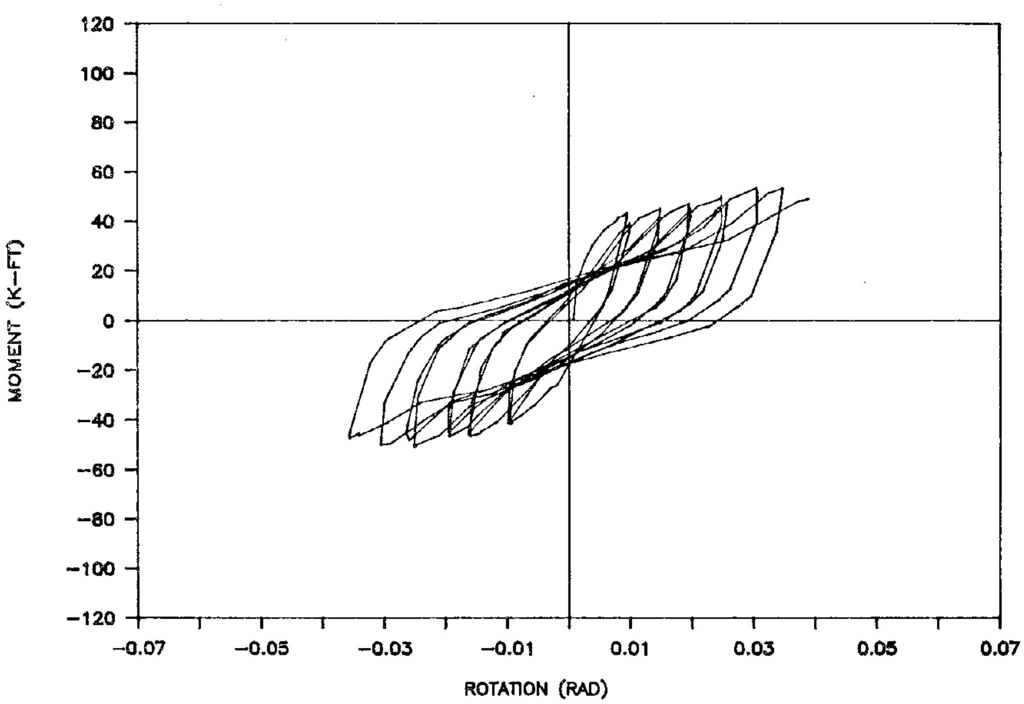


Figure 3.14 Moment-Rotation Hysteresis Loops for Specimen Four

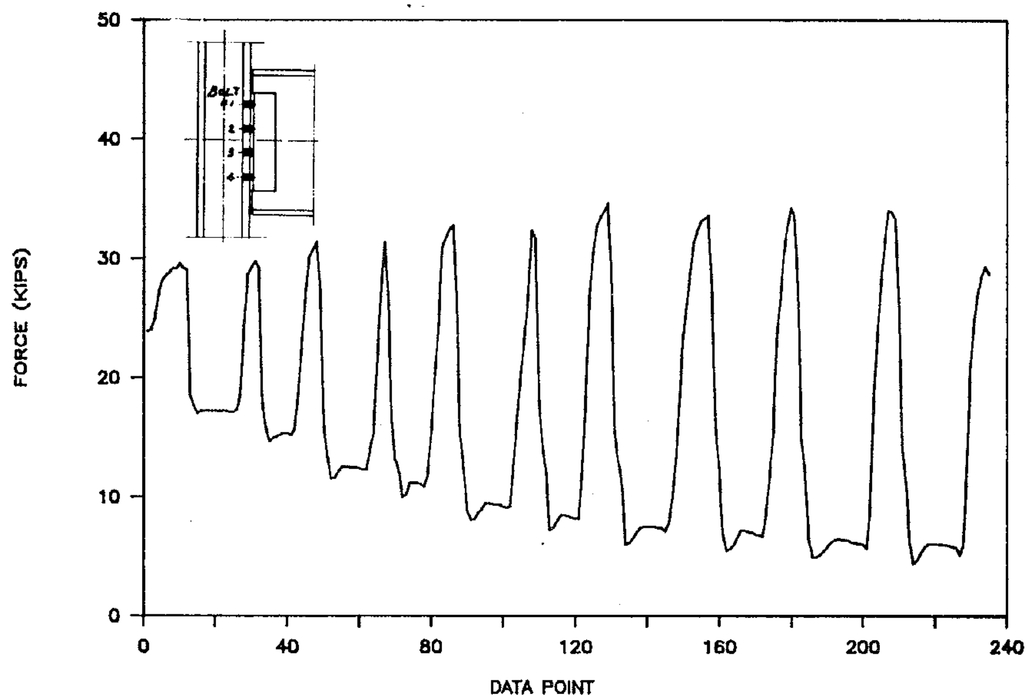


Figure 3.15 History of Bolt Force for Bolt 1, Specimen Four

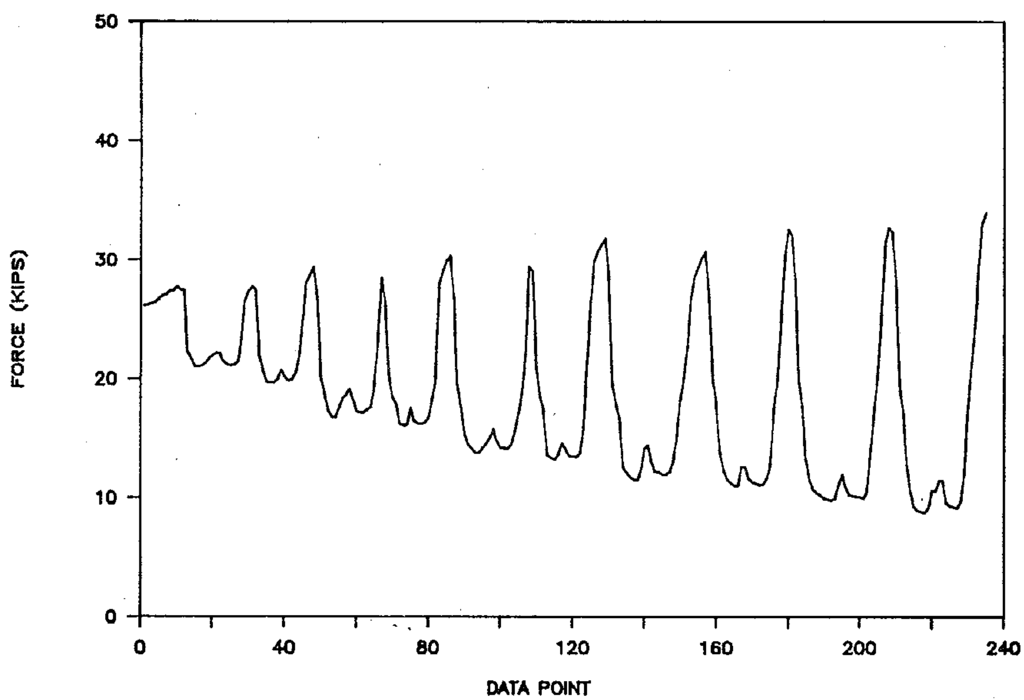


Figure 3.16 History of Bolt Force for Bolt 2, Specimen Four

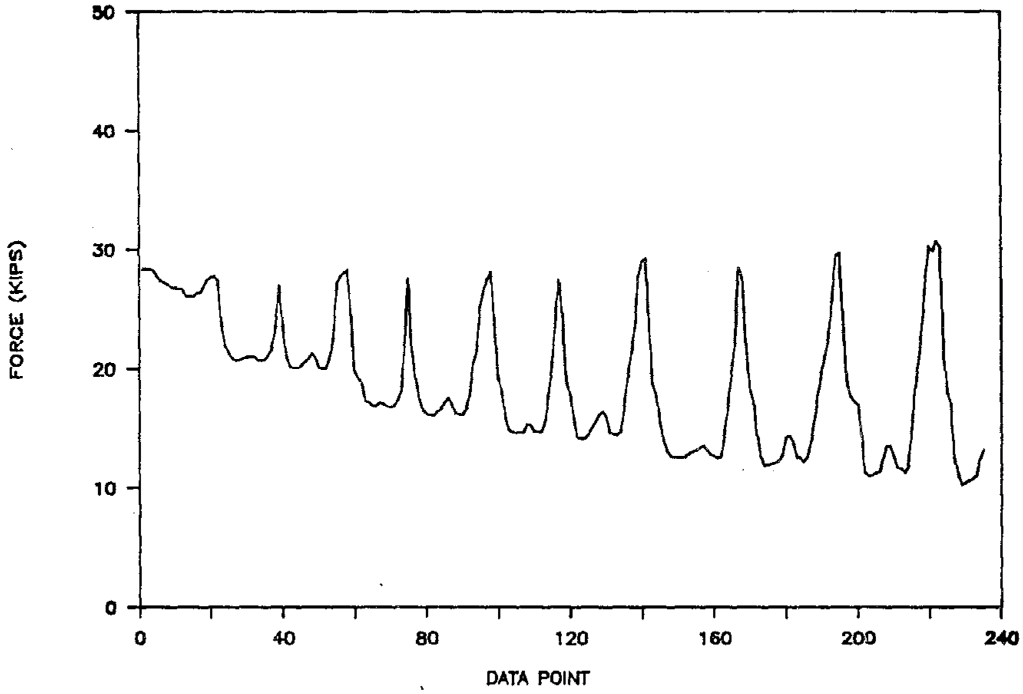


Figure 3.17 History of Bolt Force for Bolt 3, Specimen Four

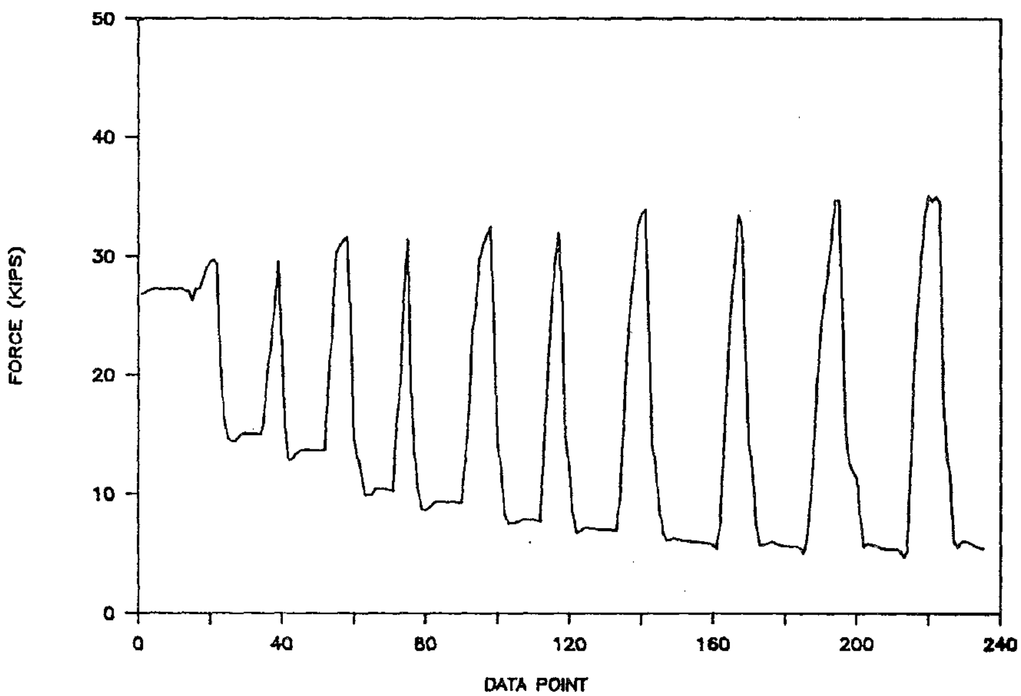


Figure 3.18 History of Bolt Force for Bolt 4, Specimen Four

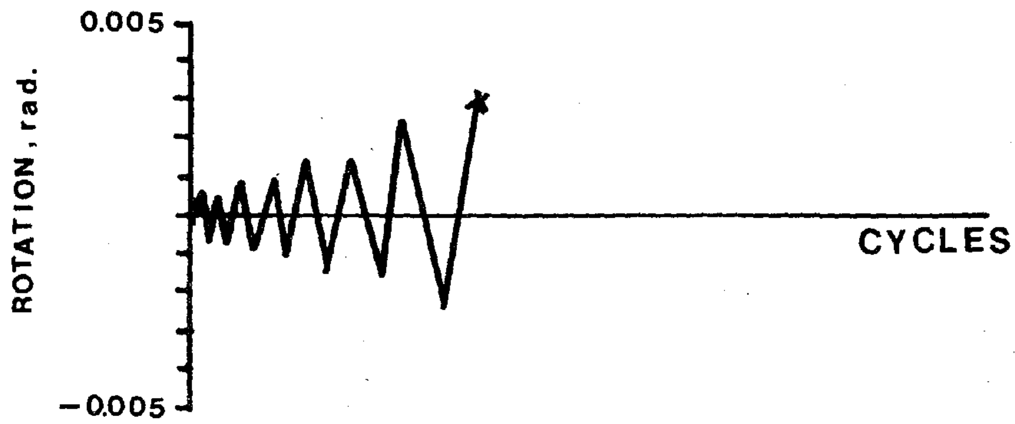


Figure 3.19 Cyclic Rotation History of Specimen Five

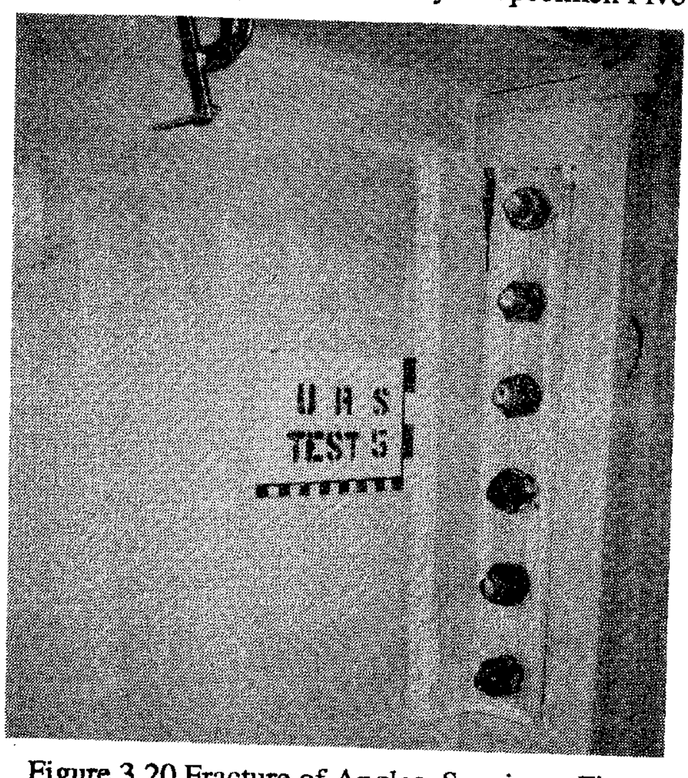


Figure 3.20 Fracture of Angles, Specimen Five

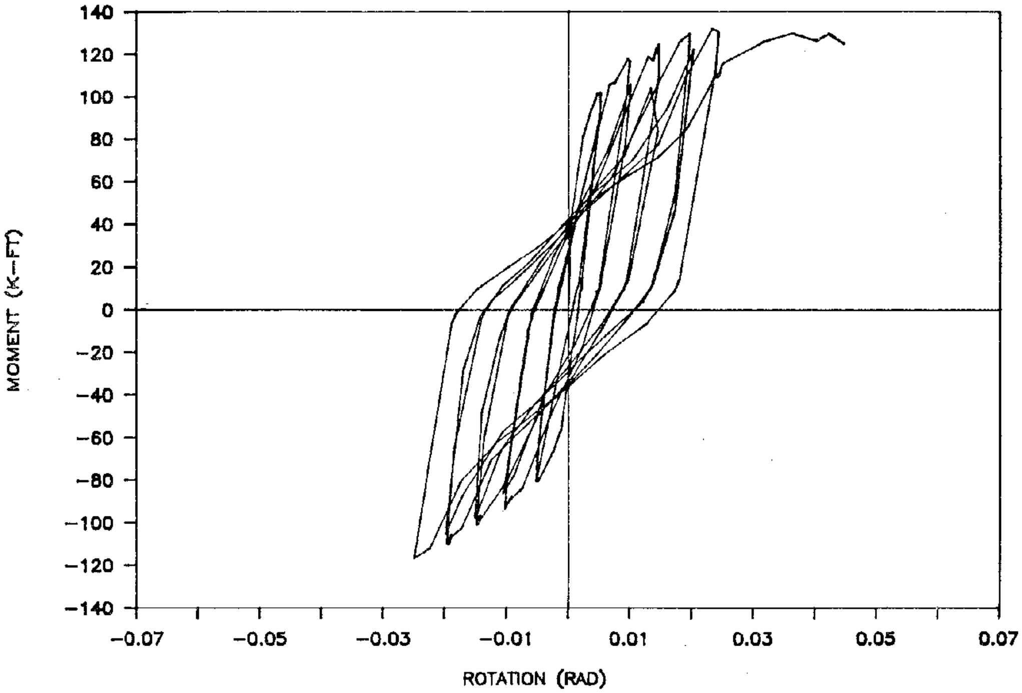


Figure 3.21 Moment-Rotation Hysteresis Loops for Specimen Five

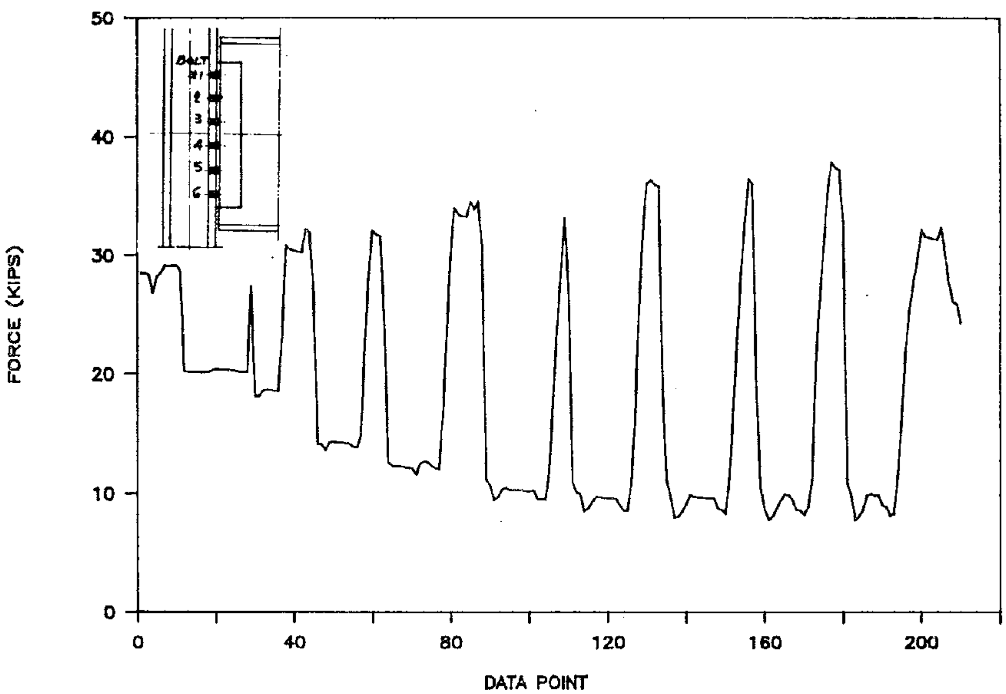


Figure 3.22 History of Bolt Force for Bolt 1, Specimen Five

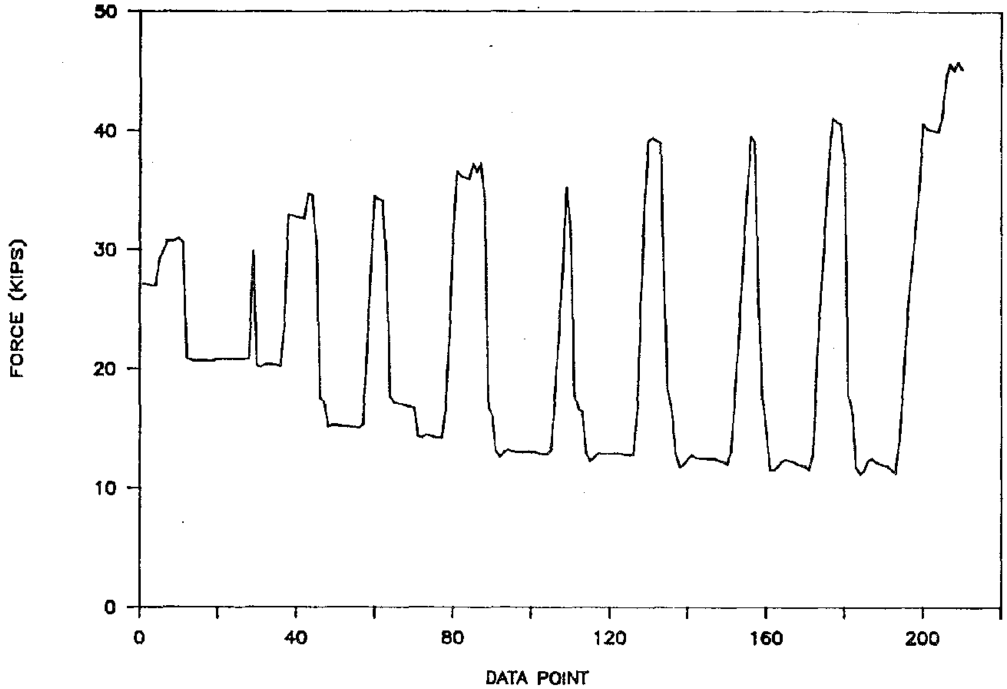


Figure 3.23 History of Bolt Force for Bolt 2, Specimen Five

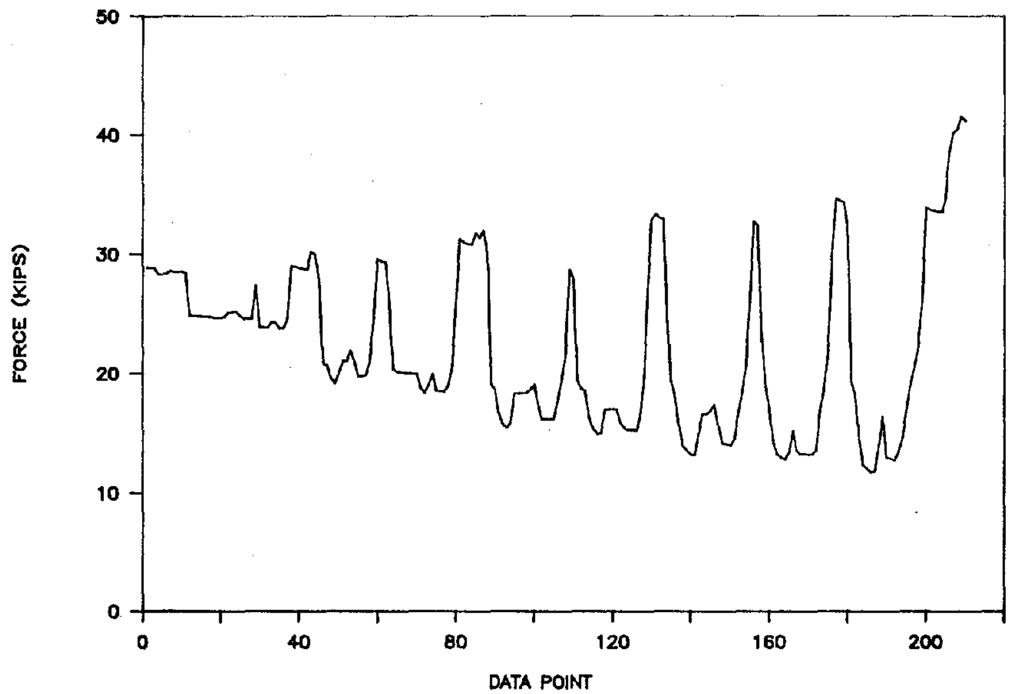


Figure 3.24 History of Bolt Force for Bolt 3, Specimen Five

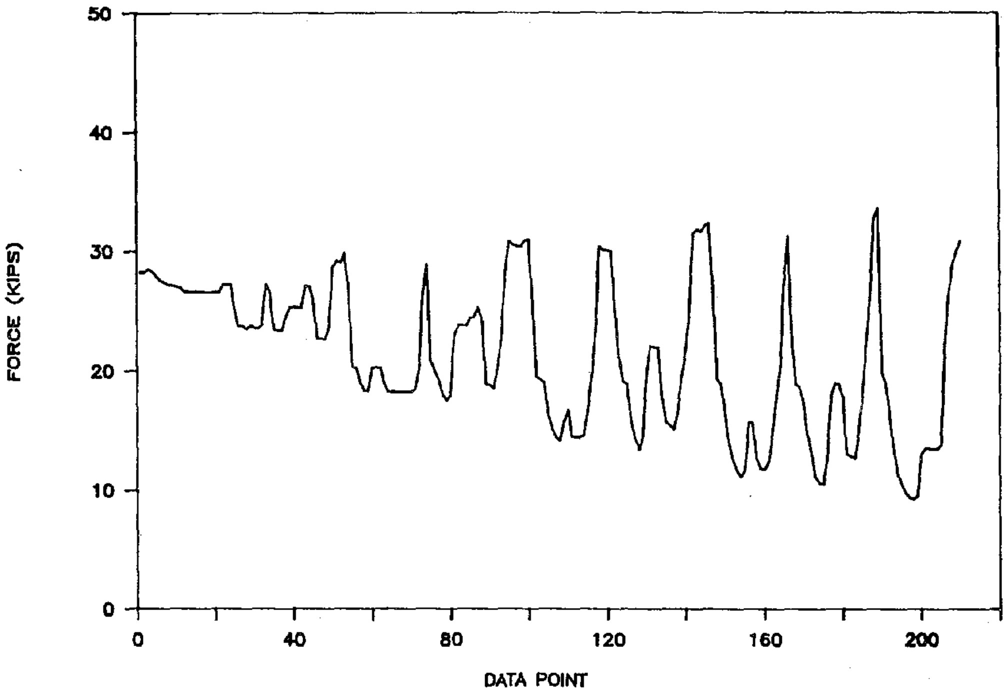


Figure 3.25 History of Bolt Force for Bolt 4, Specimen Five

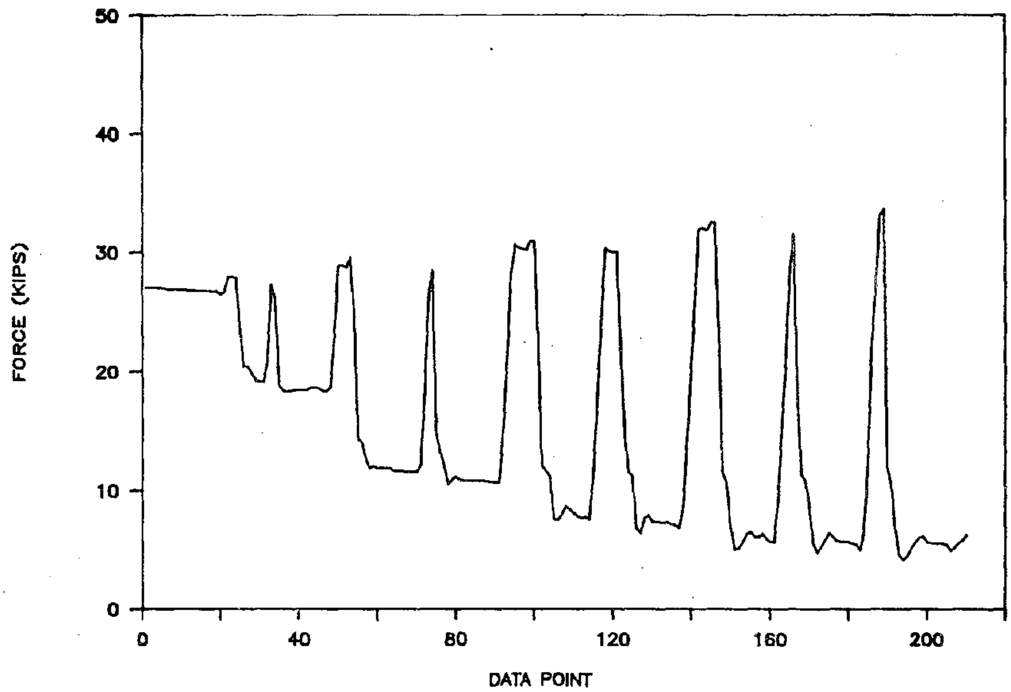


Figure 3.26 History of Bolt Force for Bolt 5, Specimen Five

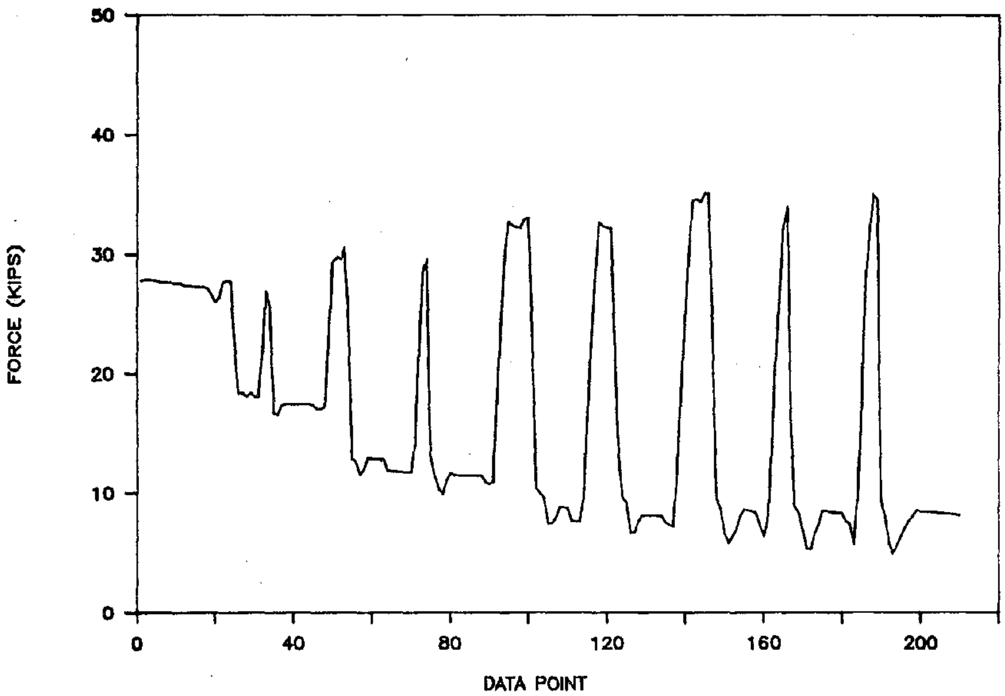


Figure 3.27 History of Bolt Force for Bolt 6, Specimen Five

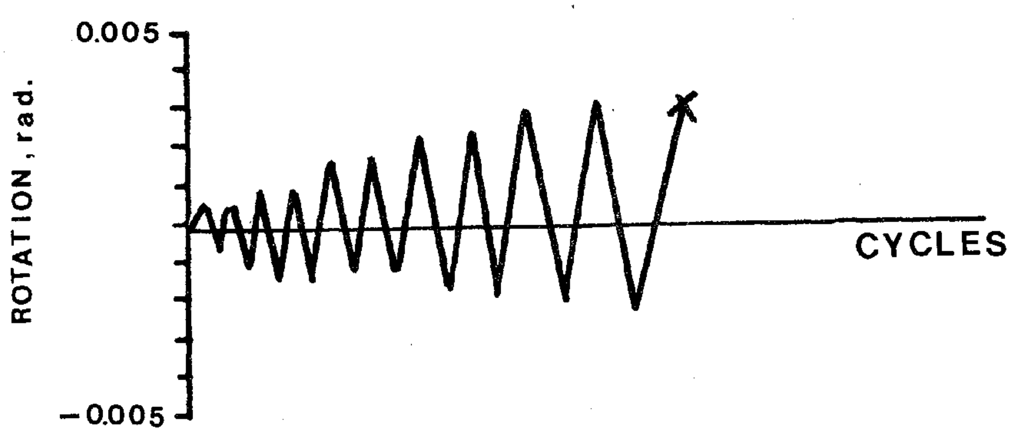


Figure 3.28 Cyclic Rotation History of Specimen Six

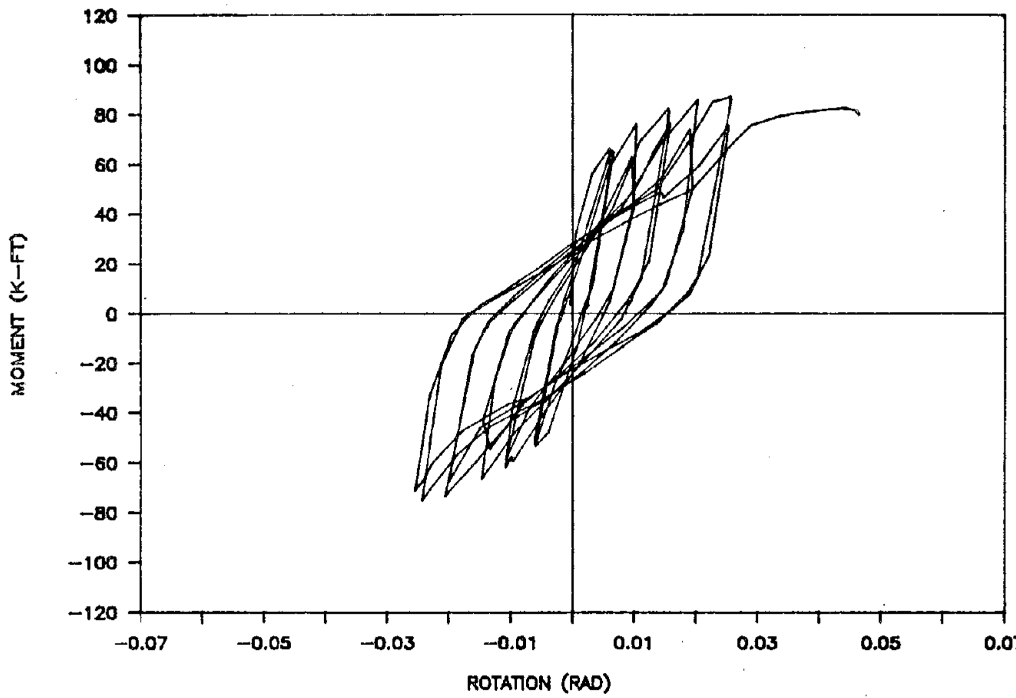


Figure 3.29 Moment-Rotation Hysteresis Loops for Specimen Six

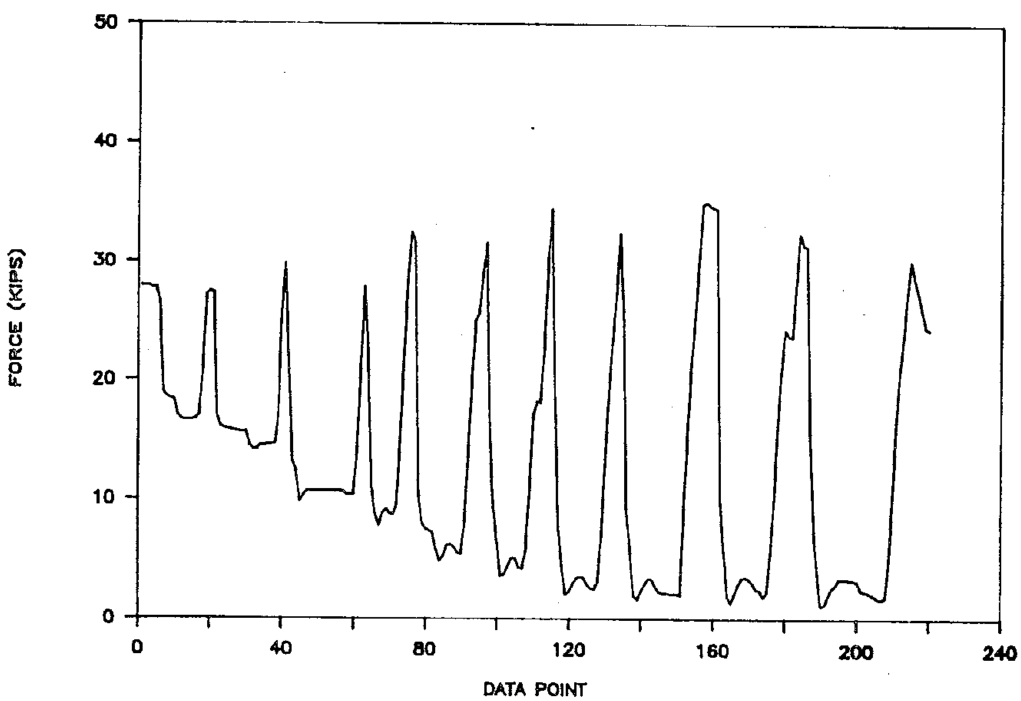


Figure 3.30 History of Bolt Force for Bolt 1, Specimen Six

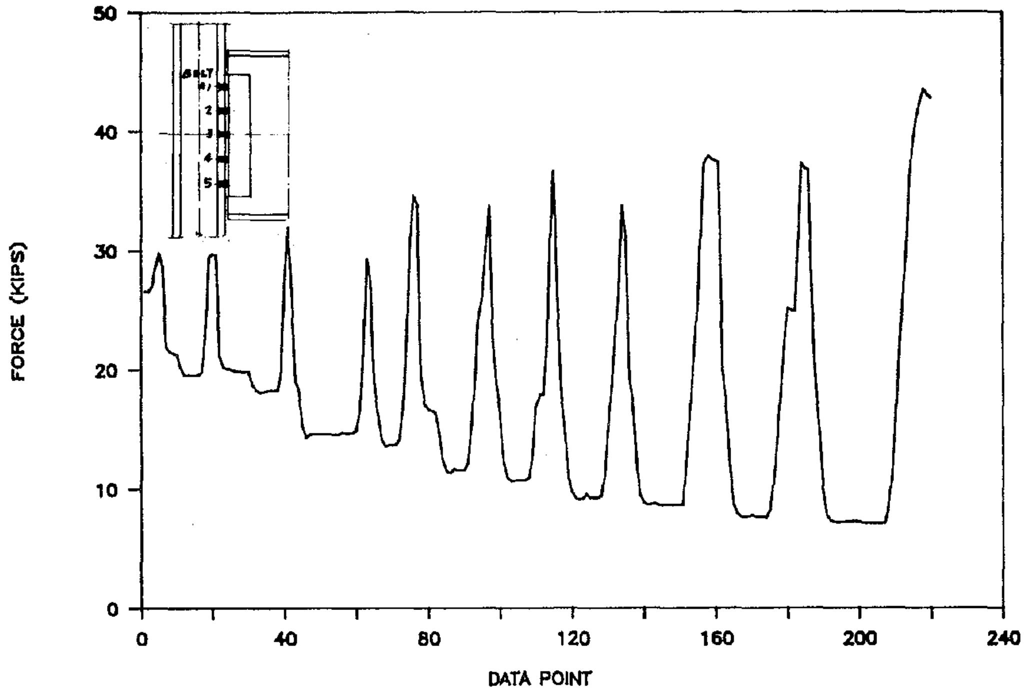


Figure 3.31 History of Bolt Force for Bolt 2, Specimen Six

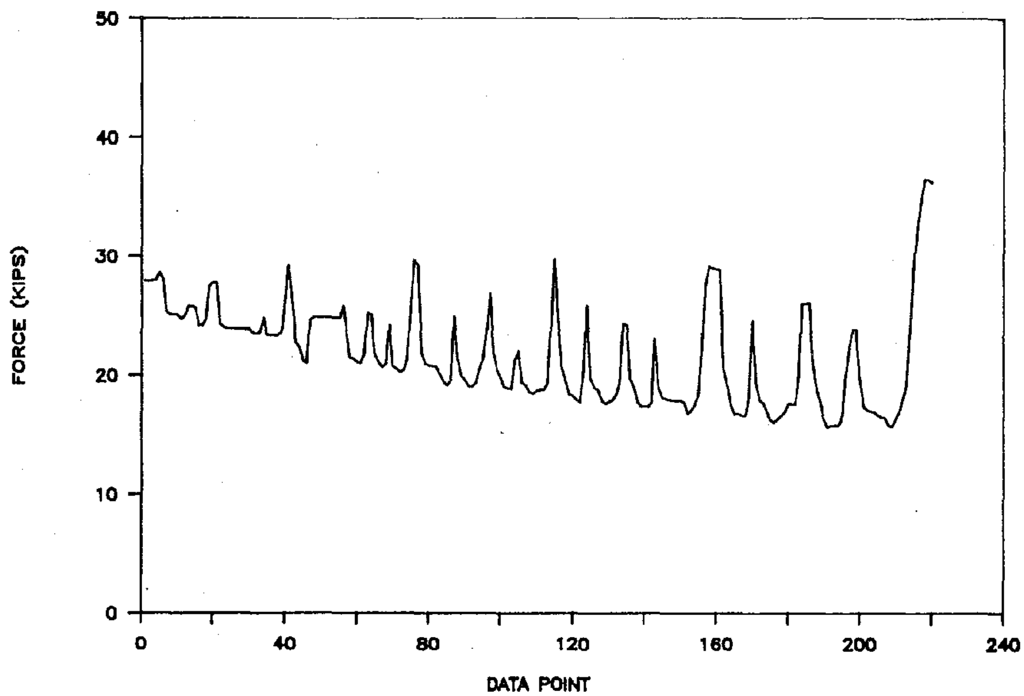


Figure 3.32 History of Bolt Force for Bolt 3, Specimen Six

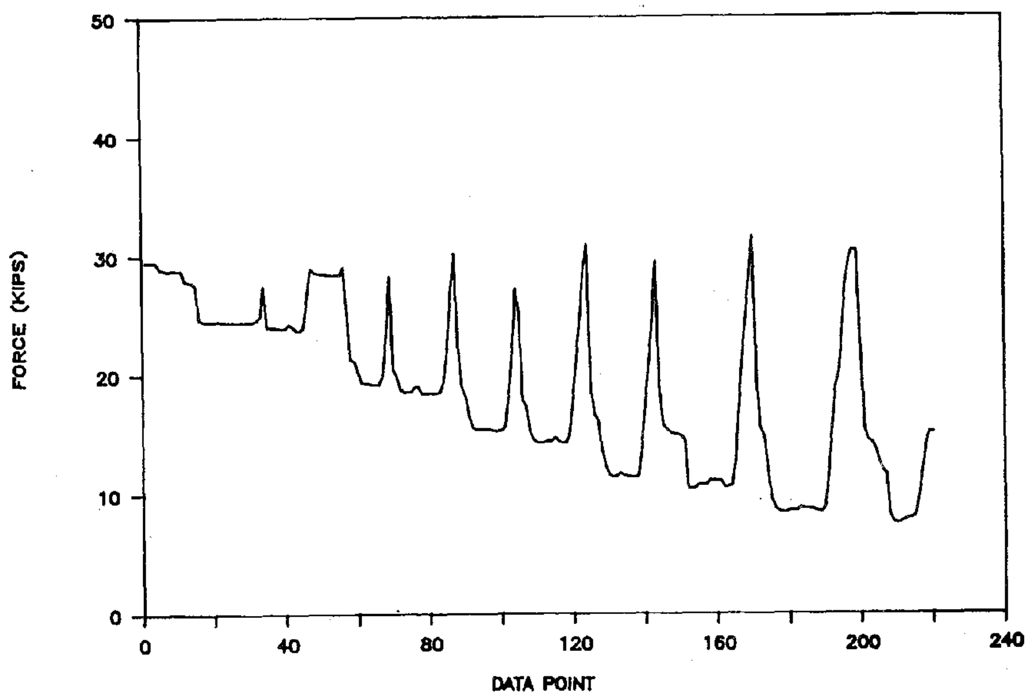


Figure 3.33 History of Bolt Force for Bolt 4, Specimen Six

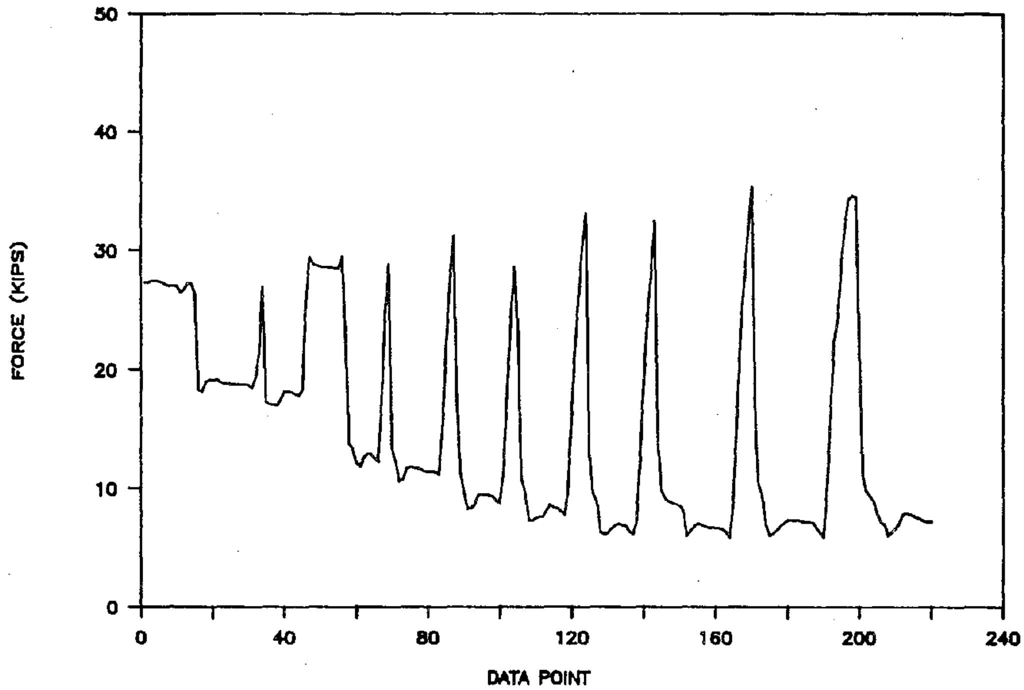


Figure 3.34 History of Bolt Force for Bolt 5, Specimen Six

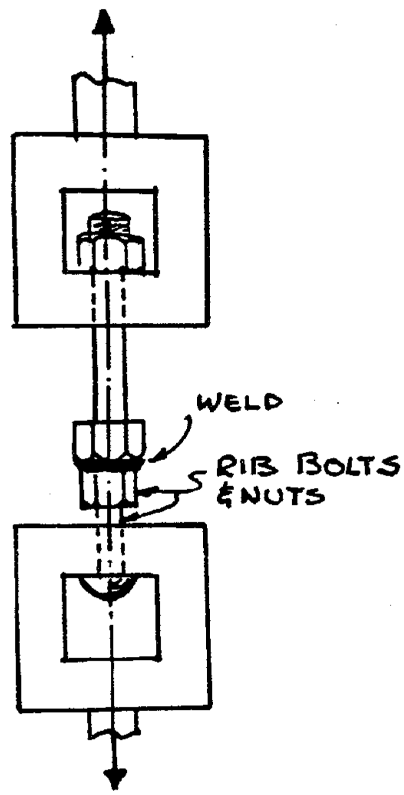


Figure 4.1 Test Fixture Used in Bolt Testing

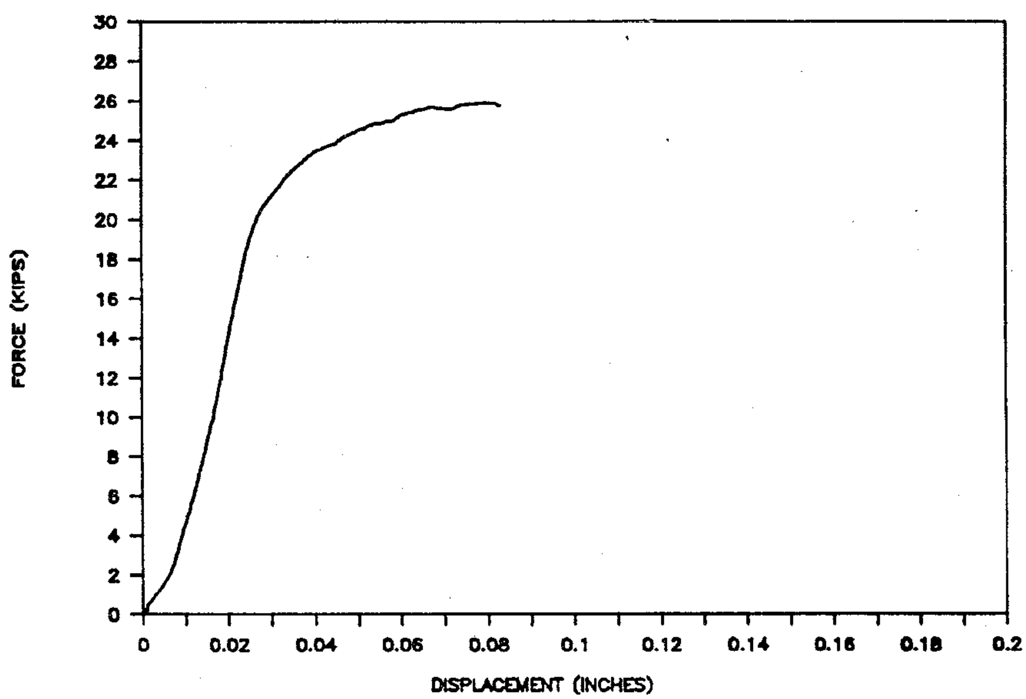


Figure 4.2 Force-Elongation Curve for Bolt # 33
(Failure Mode: Threads Stripped Off)

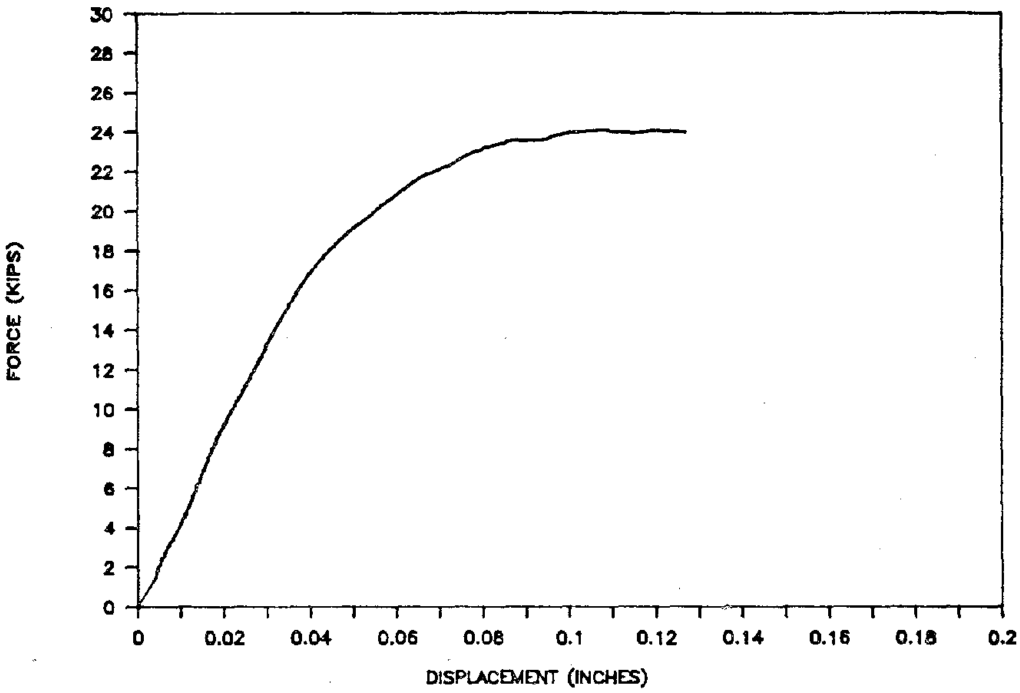


Figure 4.3 Force-Elongation Curve for Bolt # 44
(Failure Mode: Threads Stripped Off)

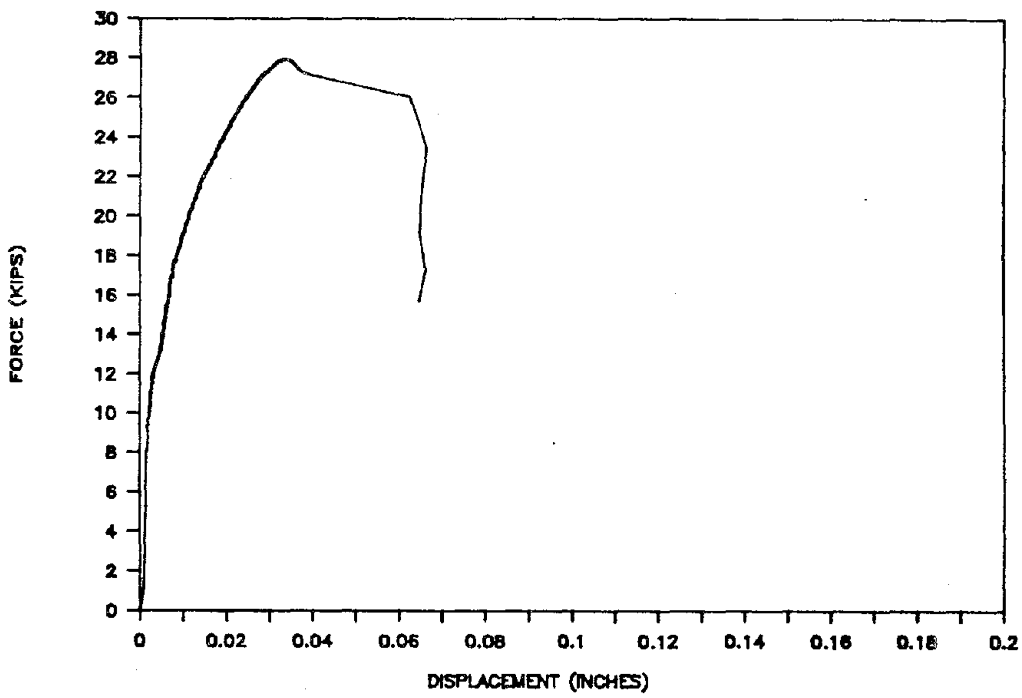


Figure 4.4 Force-Elongation Curve for Bolt # 38
(Failure Mode: Fracture of Threaded Shank)

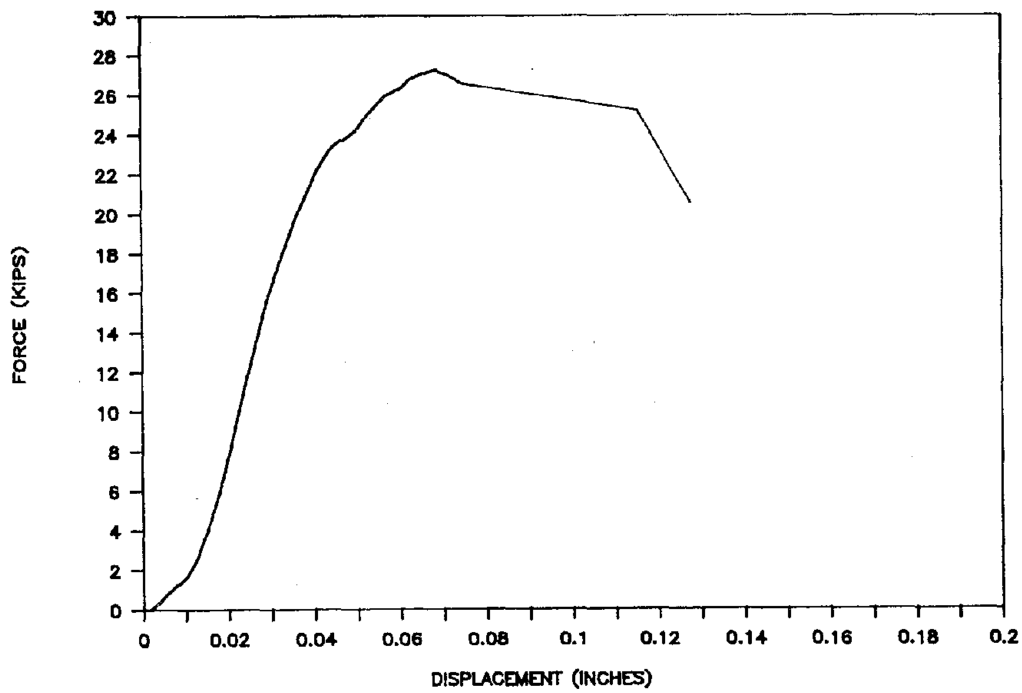


Figure 4.5 Force-Elongation Curve for Bolt # 39
(Failure Mode: Fracture of Threaded Shank)

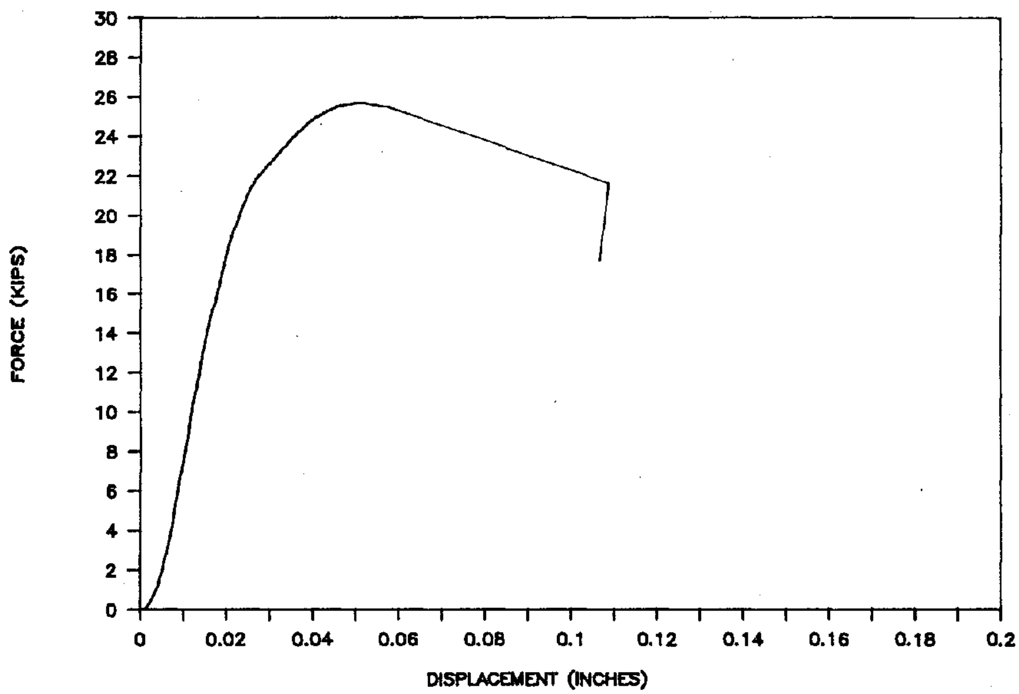


Figure 4.5 Force-Elongation Curve for Bolt # 41
(Failure Mode: Fracture of Threaded Shank)

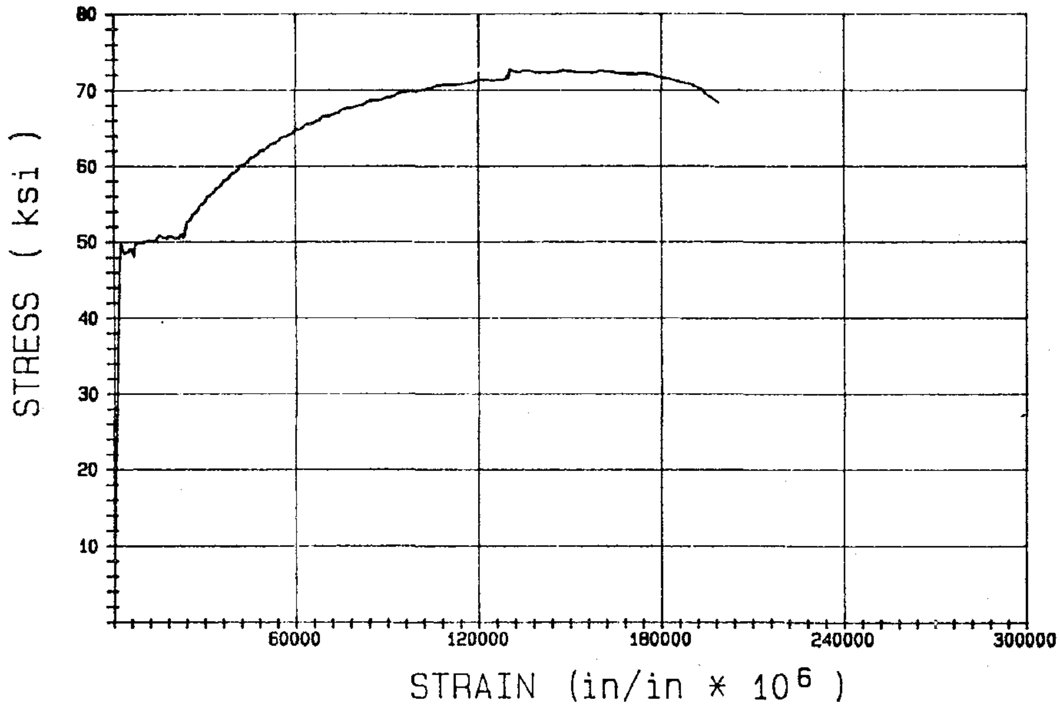


Figure 4.6 Stress-Strain Curve for Coupon # 1
Cut from 3x3x3/8 Angles

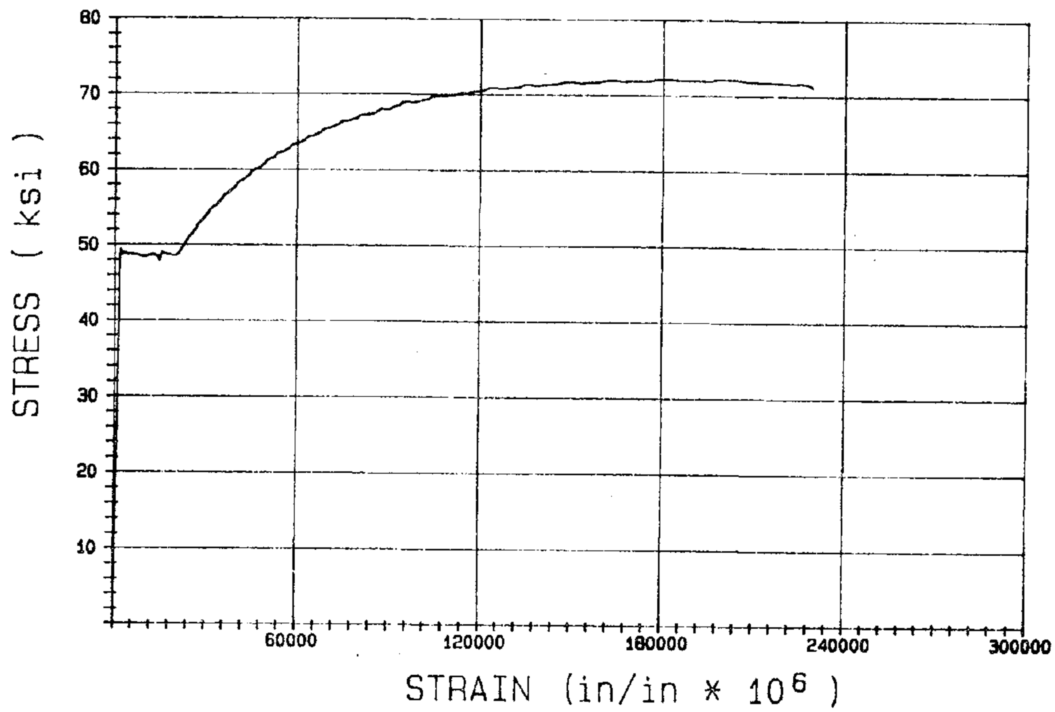


Figure 4.7 Stress-Strain Curve for Coupon # 2
Cut from 3x3x3/8 Angles

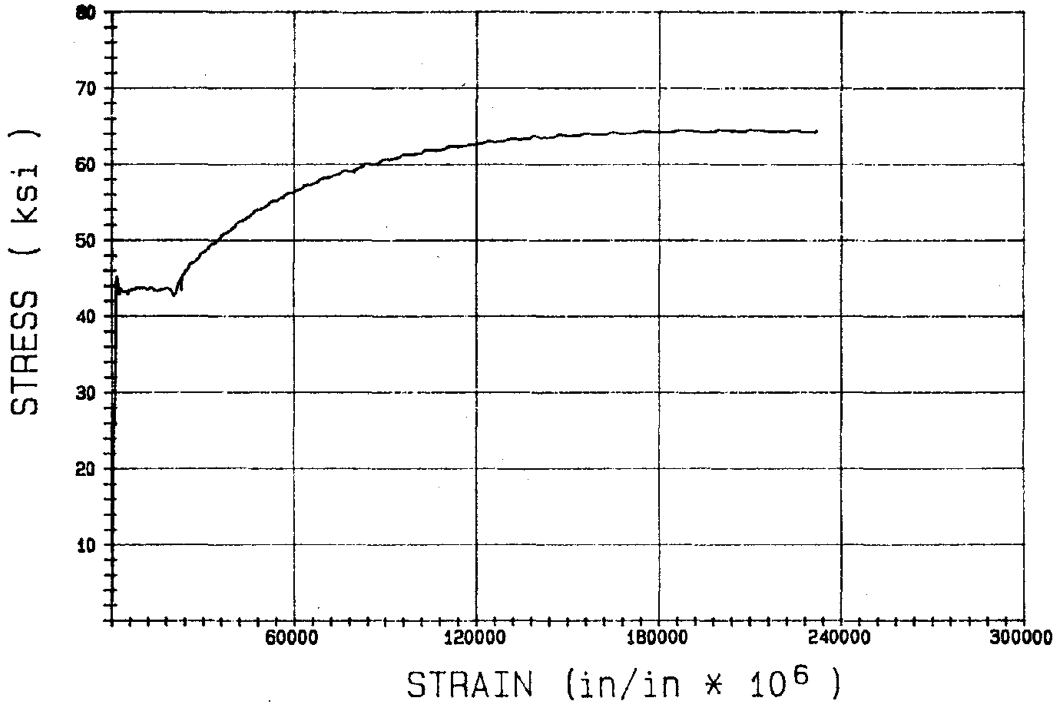


Figure 4.8 Stress-Strain Curve for Coupon # 3
Cut from 3x3x5/16 Angles

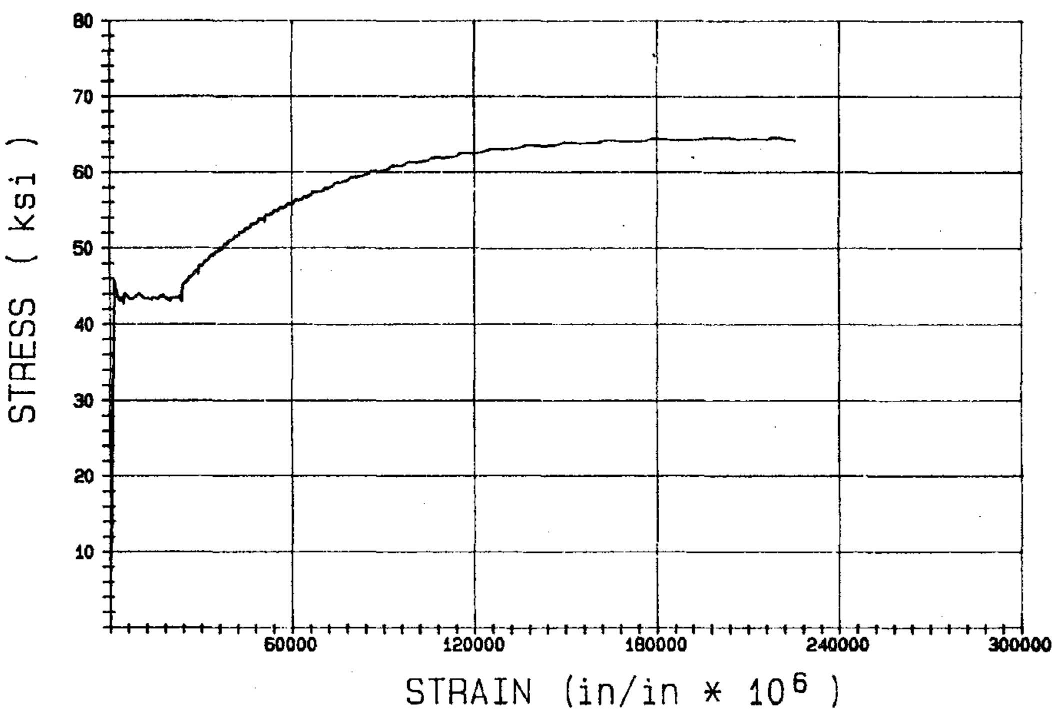


Figure 4.9 Stress-Strain Curve for Coupon # 4
Cut from 3x3x5/16 Angles

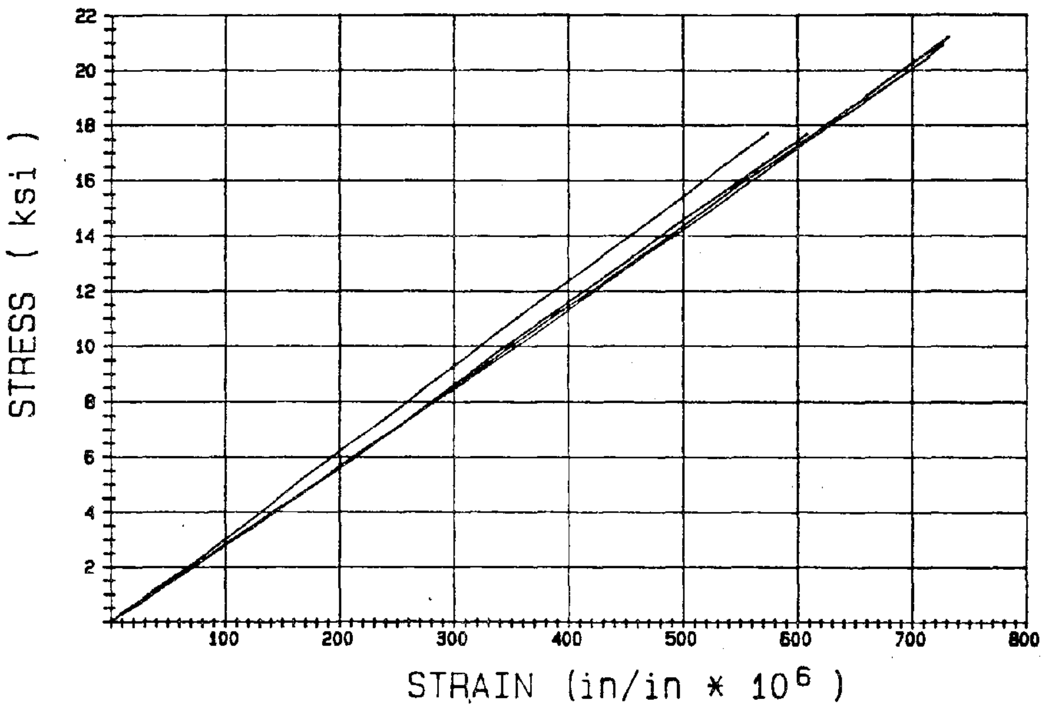


Figure 4.10 Elastic Part of Stress-Strain Curves for Measurement of Modulus of Elasticity

# APPENDIX

## A.1 General

This appendix contains more detailed plots of moment-rotation hysteresis loops. In most cases, each plot contains two curves that correspond to the same level of maximum rotation.

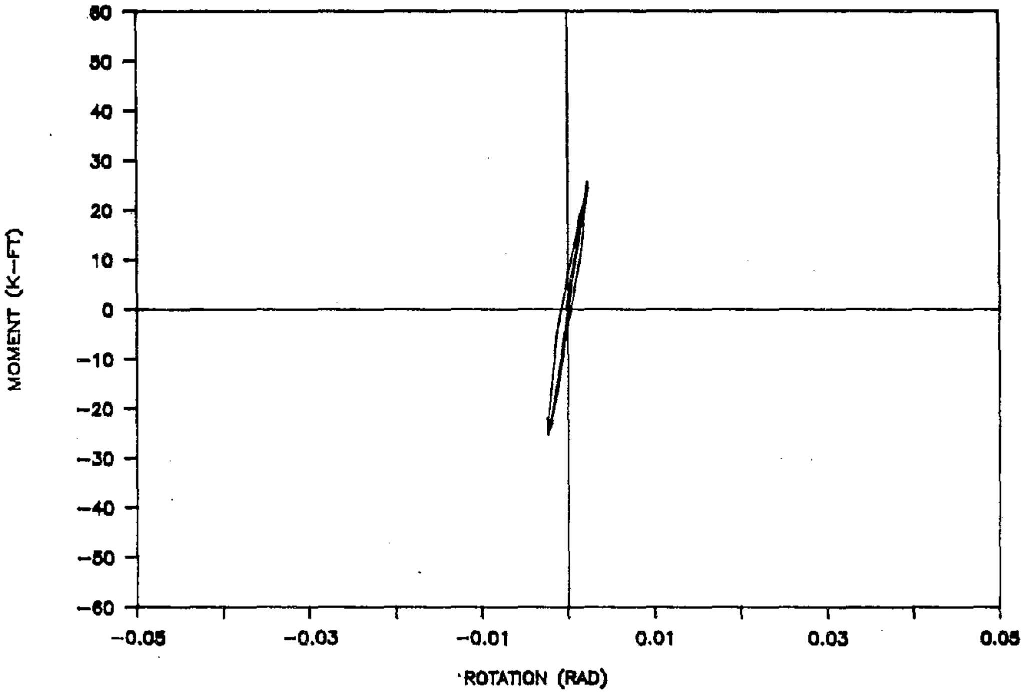


Figure A.1 Moment-Rotation Hysteresis Loops for Specimen One
First and Second Cycles

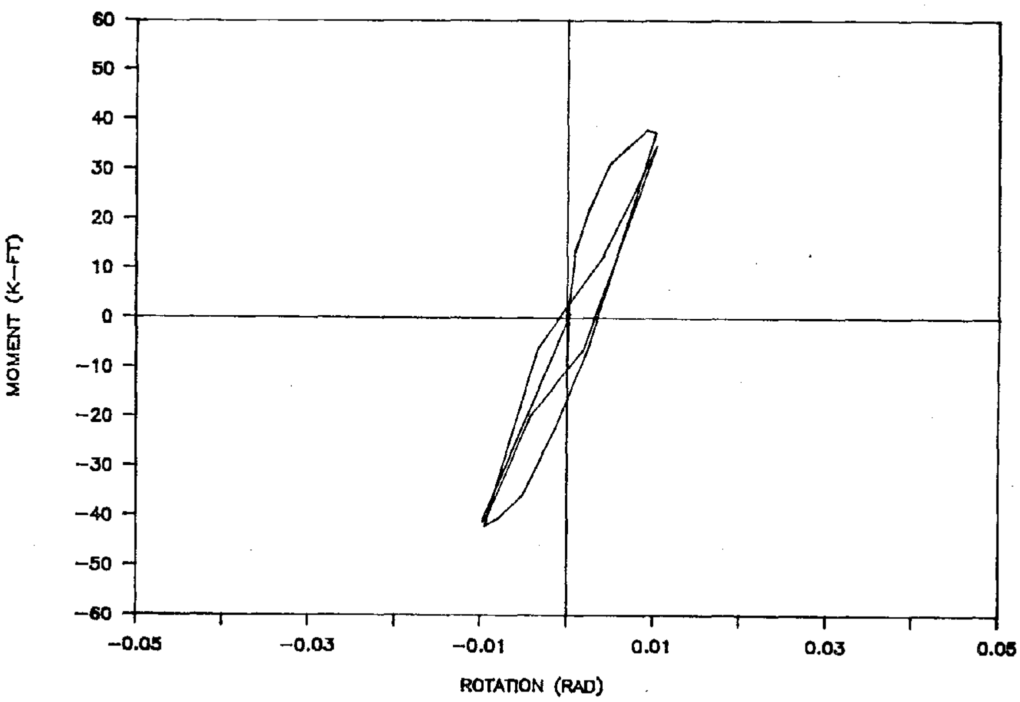


Figure A.2 Moment-Rotation Hysteresis Loops for Specimen One
Third and Fourth Cycles

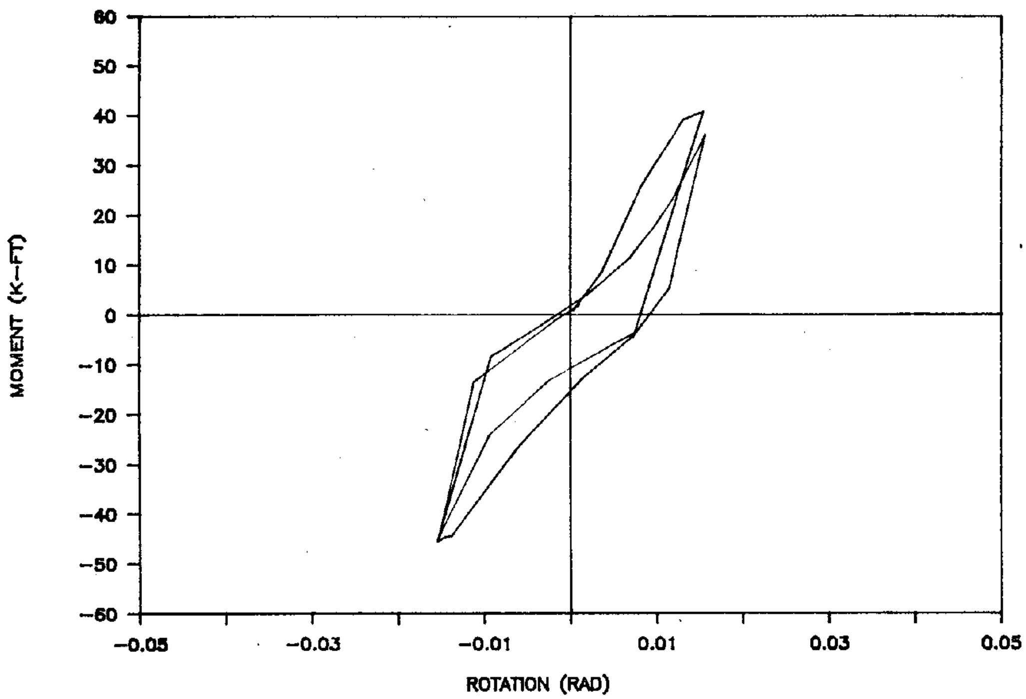


Figure A.3 Moment-Rotation Hysteresis Loops for Specimen One
Fifth and Sixth Cycles

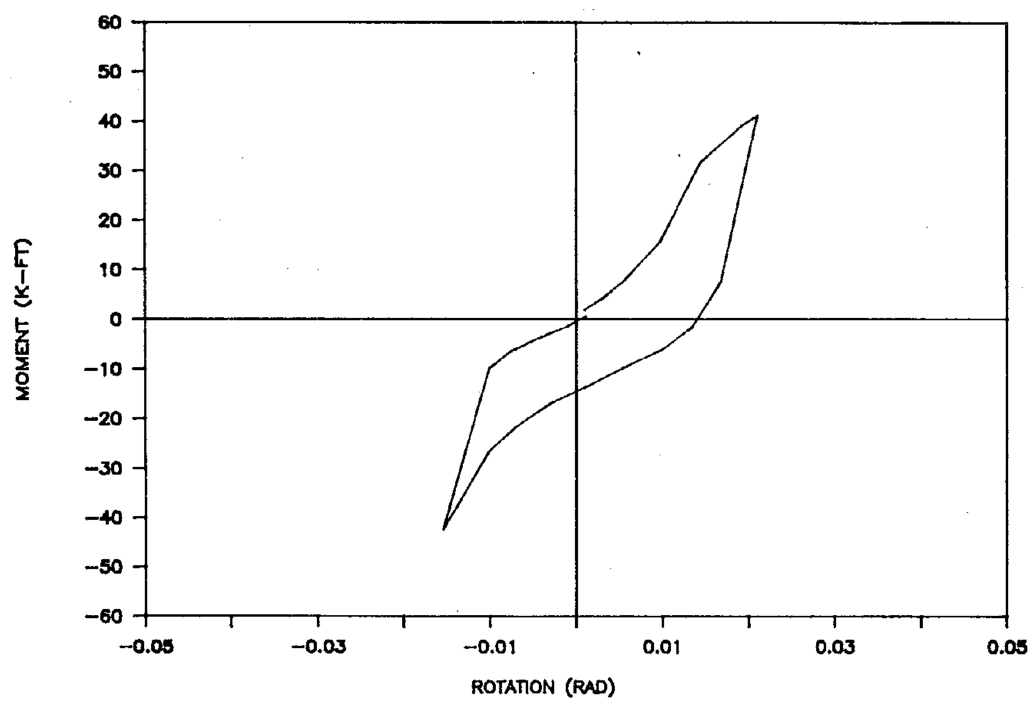


Figure A.4 Moment-Rotation Hysteresis Loops for Specimen One
Seventh Cycle

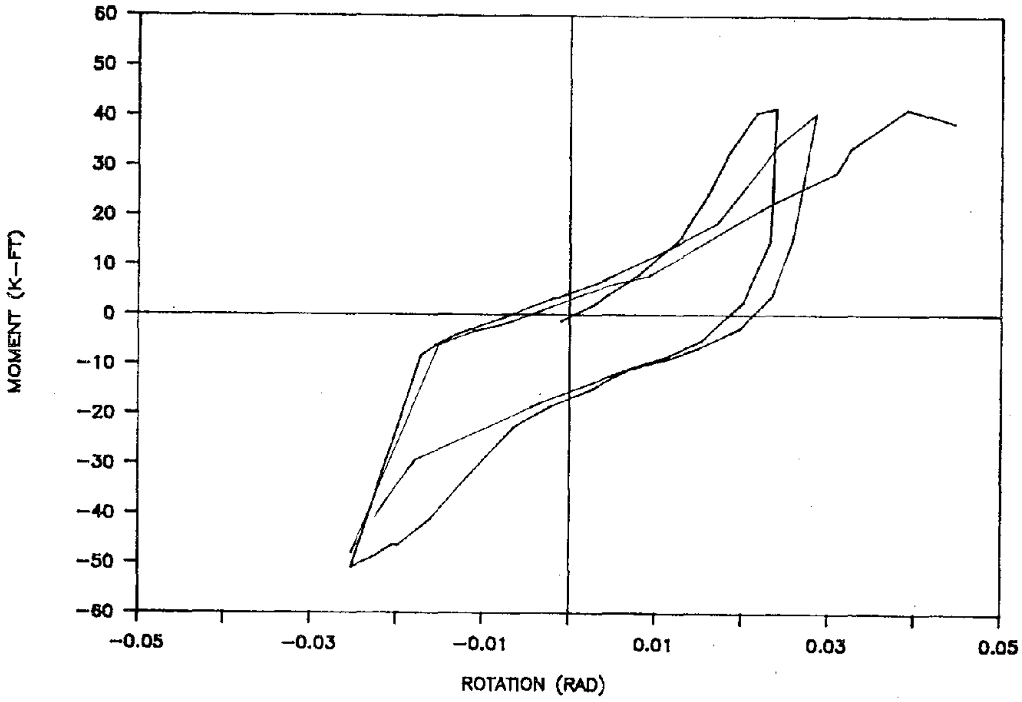


Figure A.5 Moment-Rotation Hysteresis Loops for Specimen One Eighth, Ninth and start of Tenth Cycles

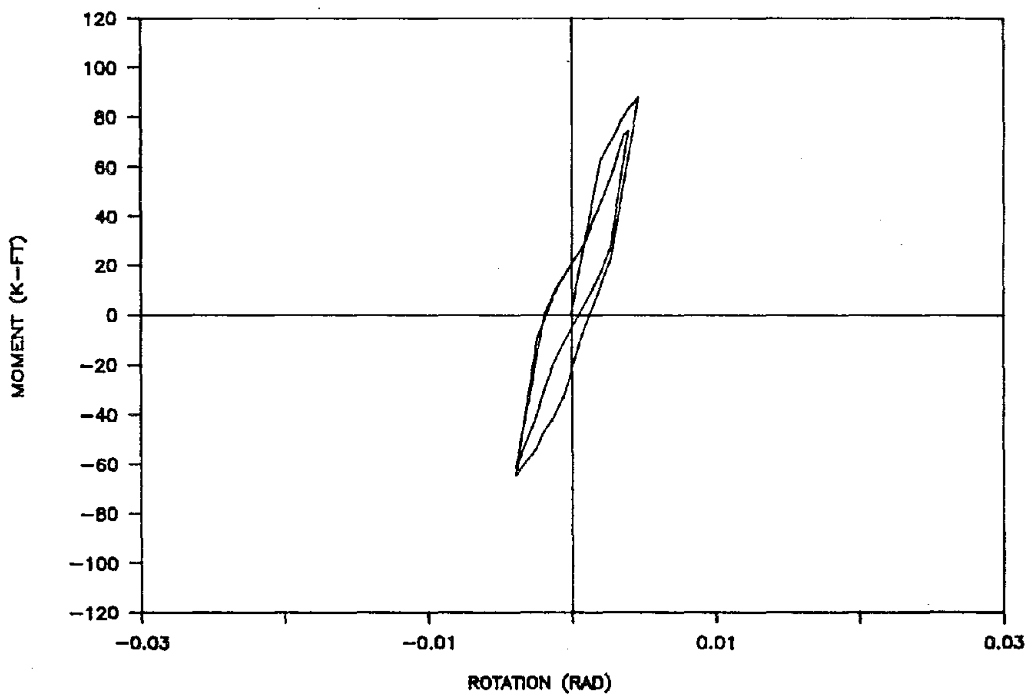


Figure A.6 Moment-Rotation Hysteresis Loops for Specimen Two First and Second Cycles

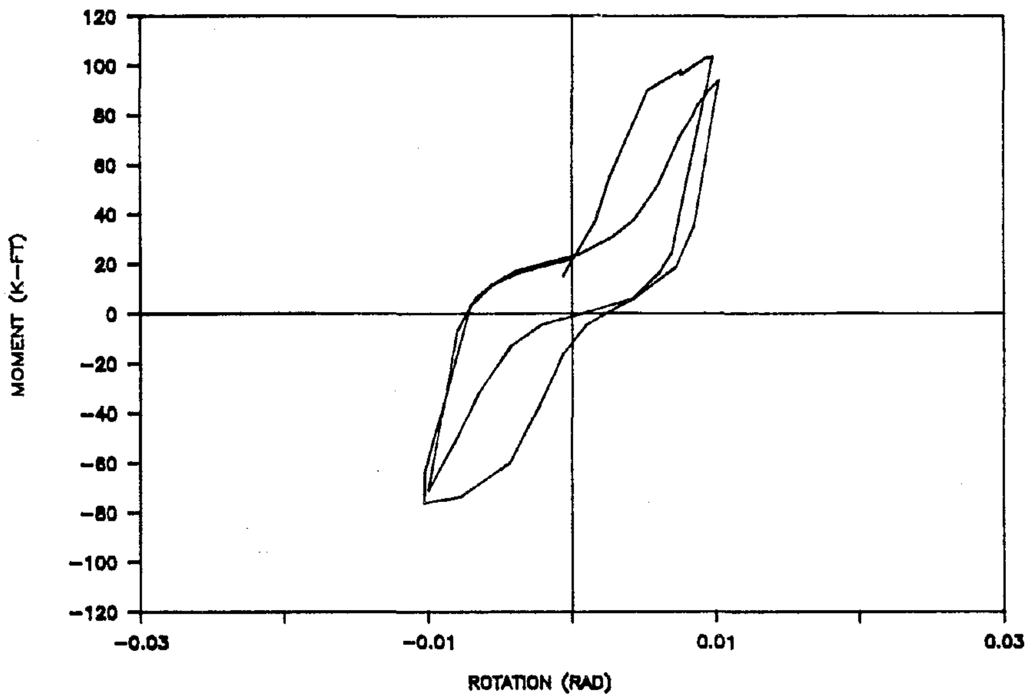


Figure A.7 Moment-Rotation Hysteresis Loops for Specimen Two
Third and Fourth Cycles

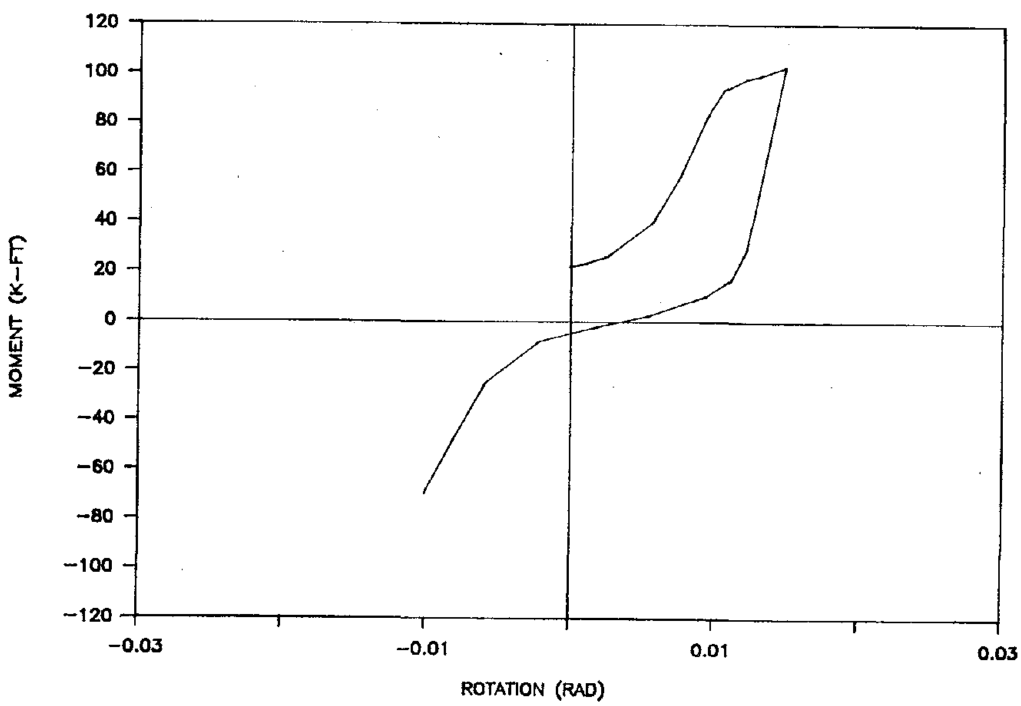


Figure A.8 Moment-Rotation Hysteresis Loops for Specimen Two
Fifth Cycle

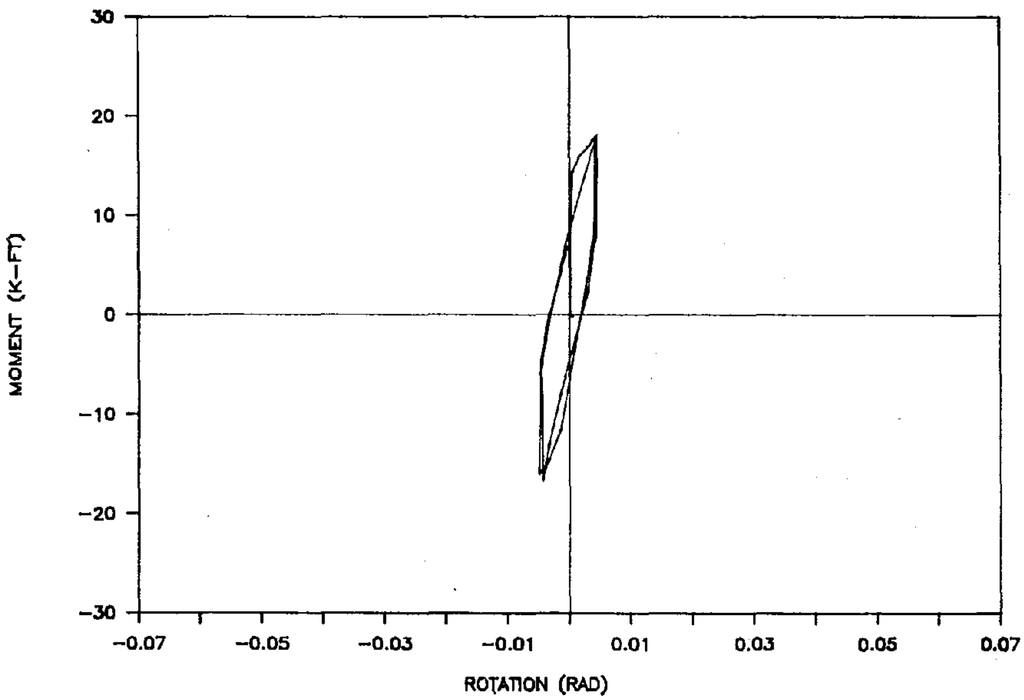


Figure A.9 Moment-Rotation Hysteresis Loops for Specimen Three
First and Second Cycles

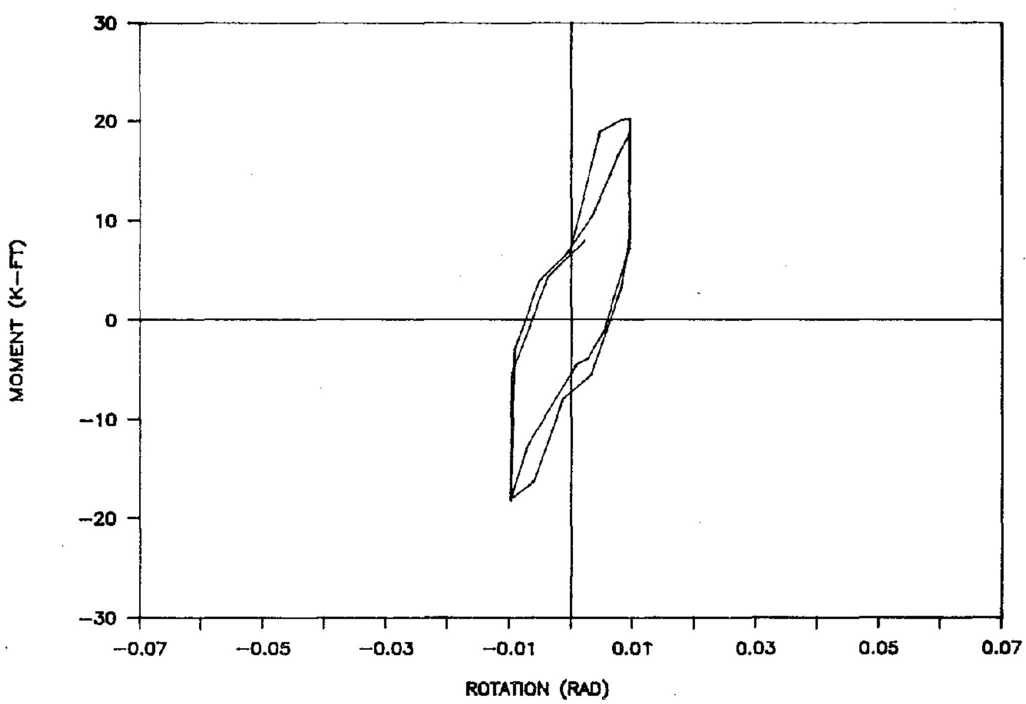


Figure A.10 Moment-Rotation Hysteresis Loops for Specimen Three
Third and Fourth Cycles

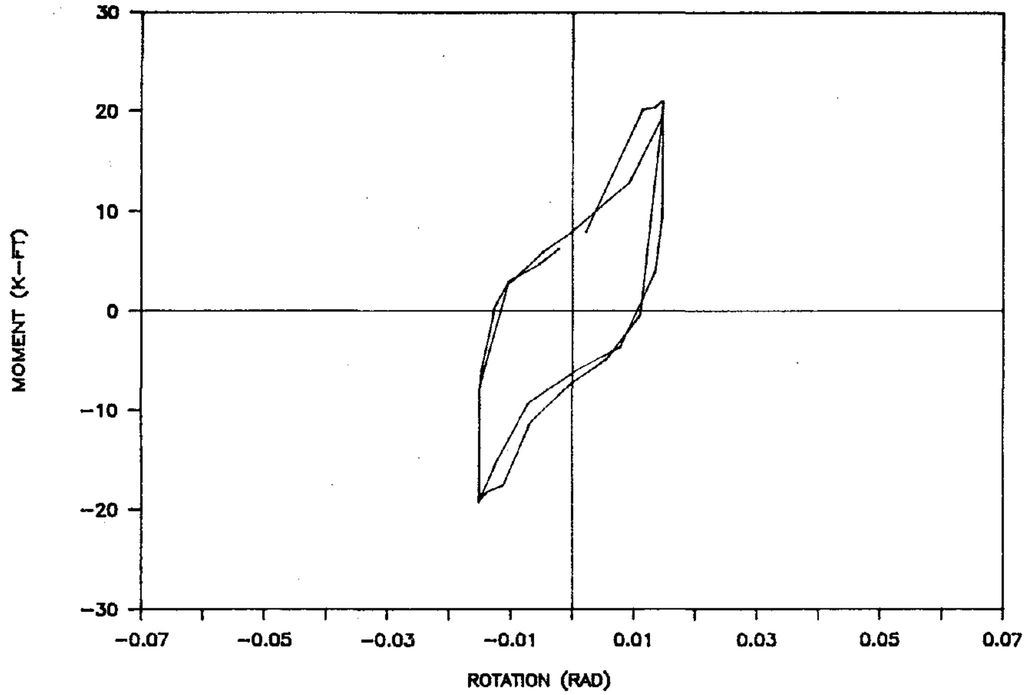


Figure A.11 Moment-Rotation Hysteresis Loops for Specimen Three Fifth and Sixth Cycles

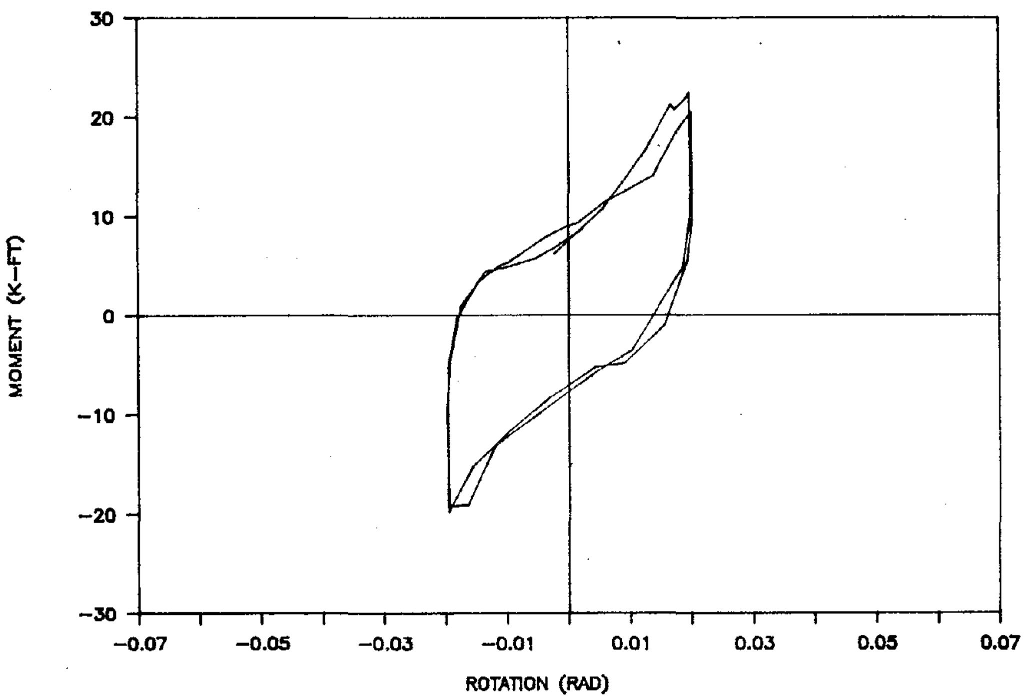


Figure A.12 Moment-Rotation Hysteresis Loops for Specimen Three Seventh and Eighth Cycles

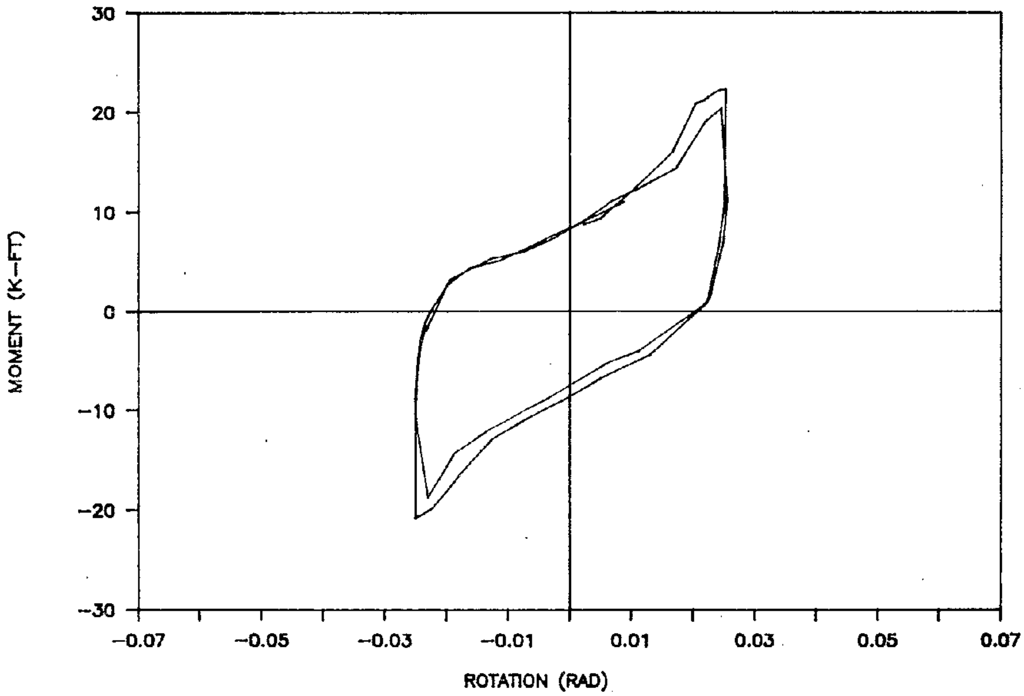


Figure A.13 Moment-Rotation Hysteresis Loops for Specimen Three Ninth and Tenth Cycles

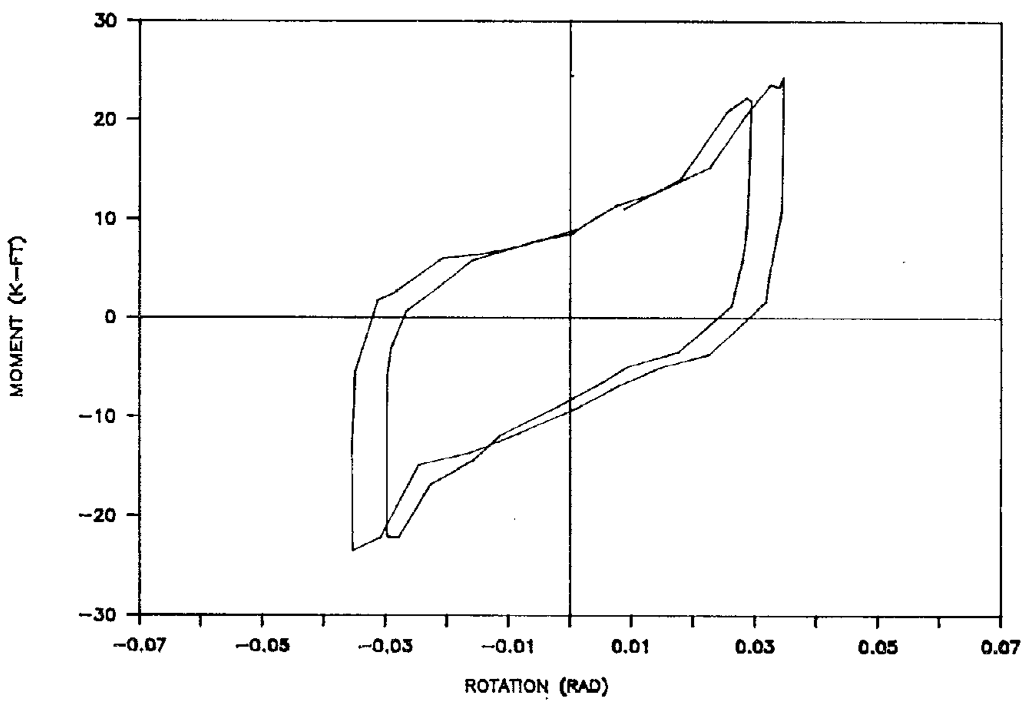


Figure A.14 Moment-Rotation Hysteresis Loops for Specimen Three Eleventh and Twelfth Cycles

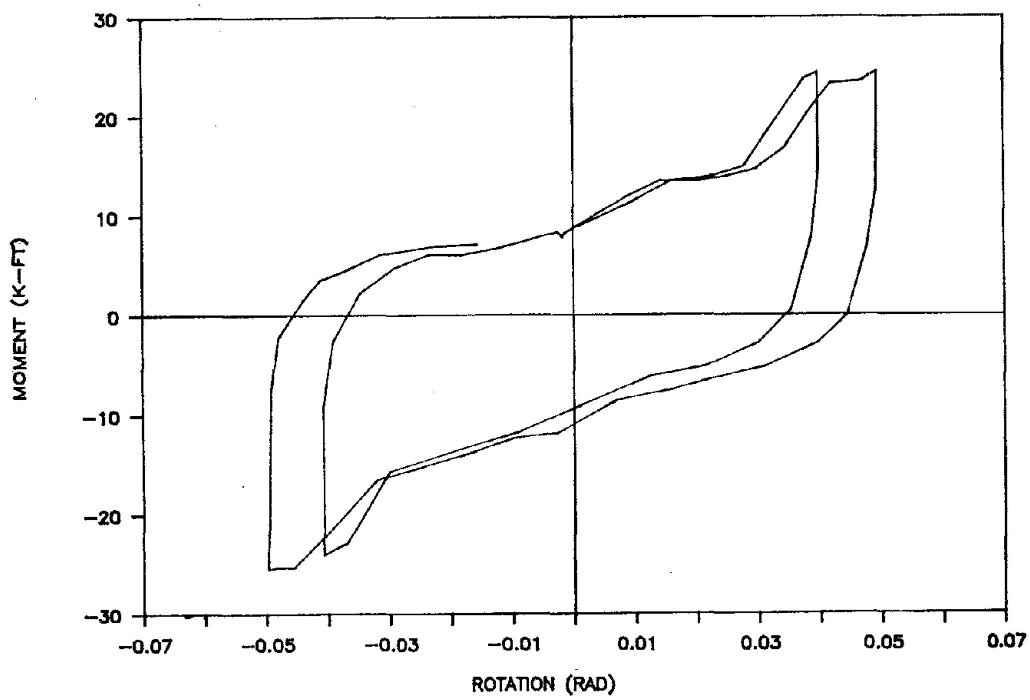


Figure A.15 Moment-Rotation Hysteresis Loops for Specimen Three
Thirteenth and Fourteenth Cycles

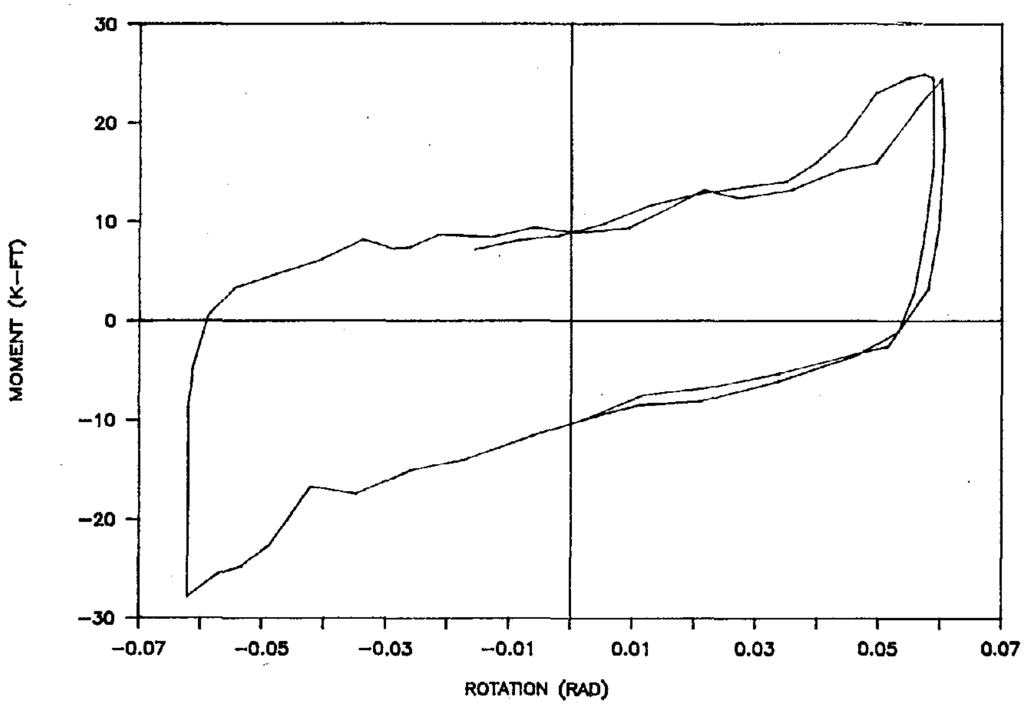


Figure A.16 Moment-Rotation Hysteresis Loops for Specimen Three
Fifteenth and Sixteenth Cycles

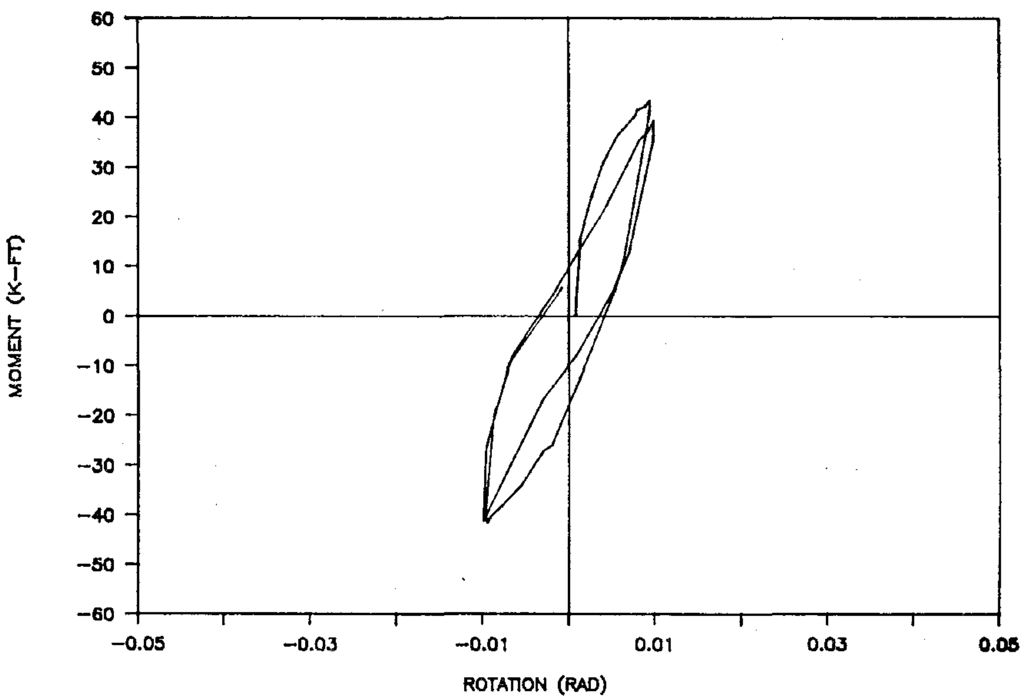


Figure A.17 Moment-Rotation Hysteresis Loops for Specimen Four
First and Second Cycles

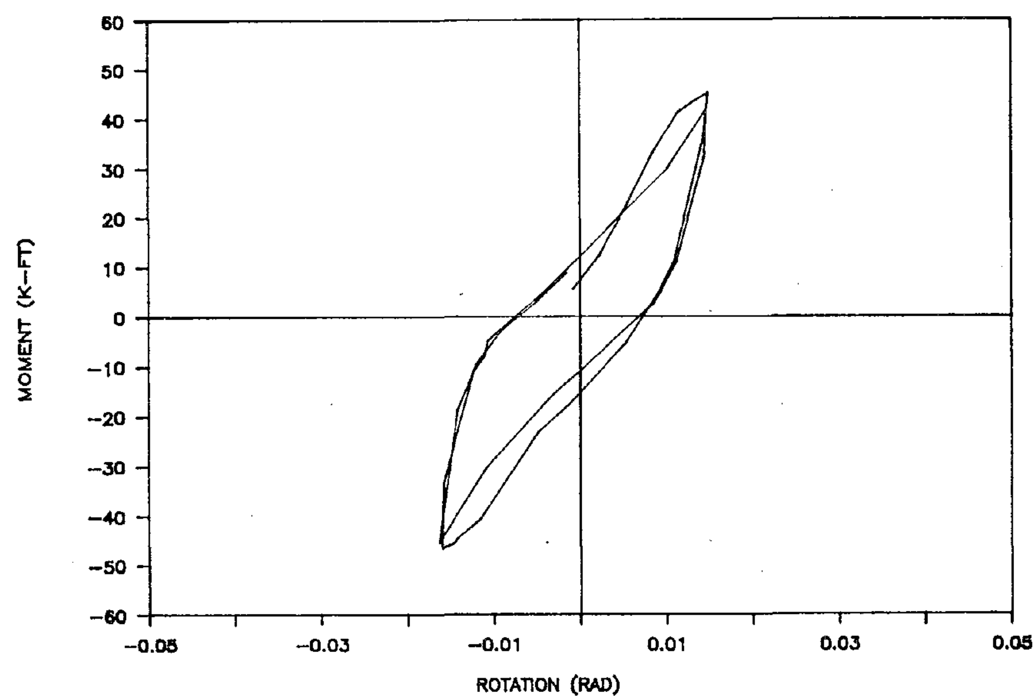


Figure A.18 Moment-Rotation Hysteresis Loops for Specimen Four
Third and Fourth Cycles

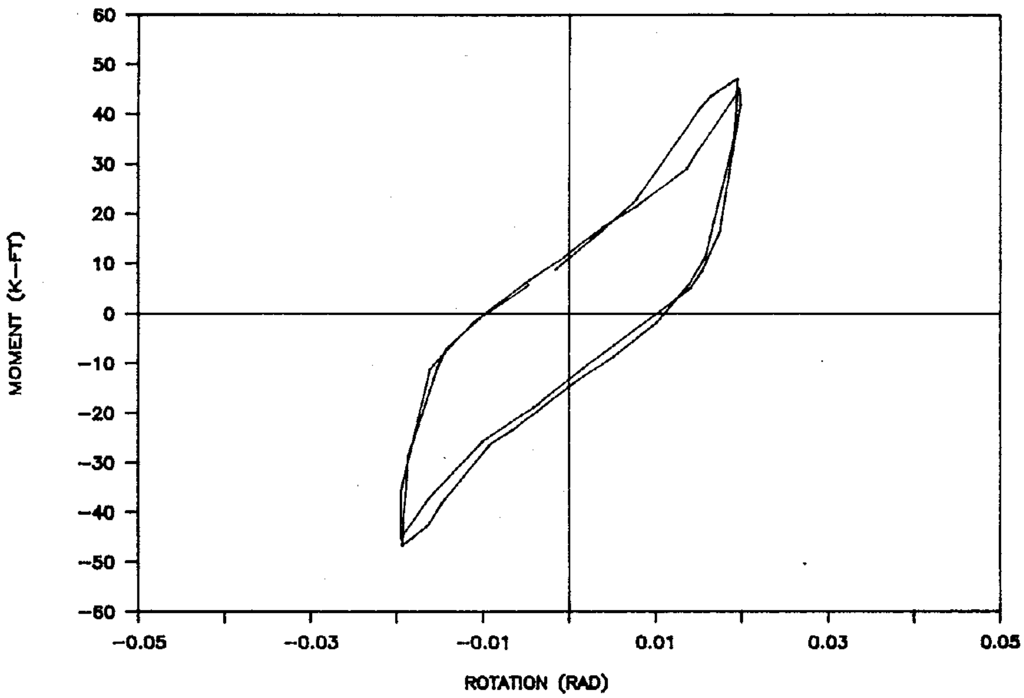


Figure A.19 Moment-Rotation Hysteresis Loops for Specimen Four
Fifth and Sixth Cycles

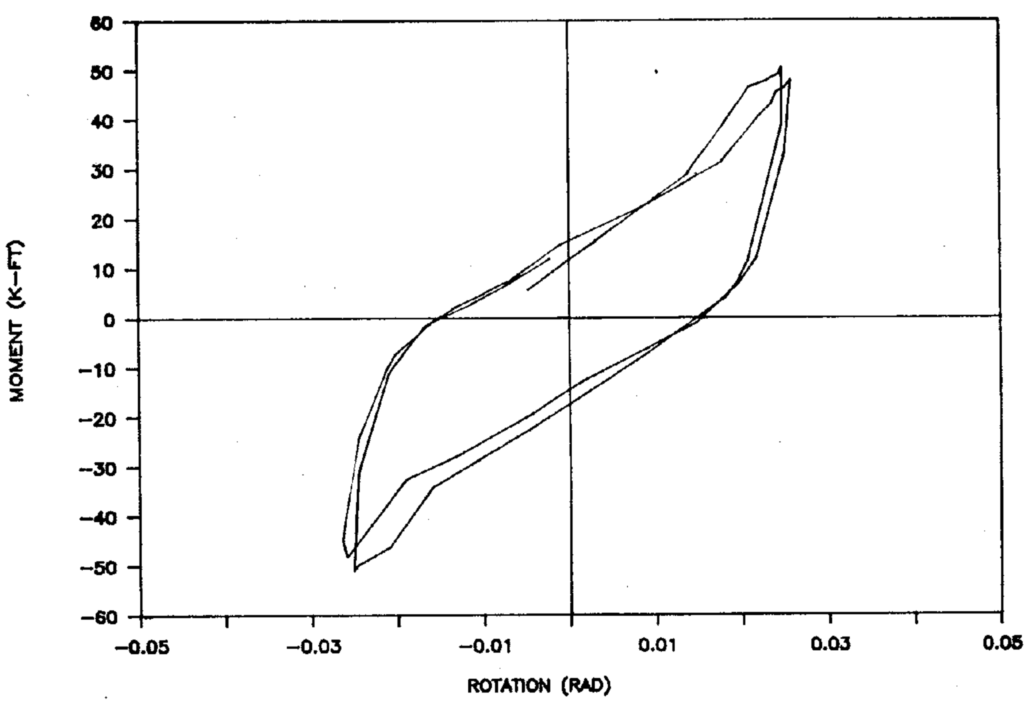


Figure A.20 Moment-Rotation Hysteresis Loops for Specimen Four
Seventh and Eighth Cycles

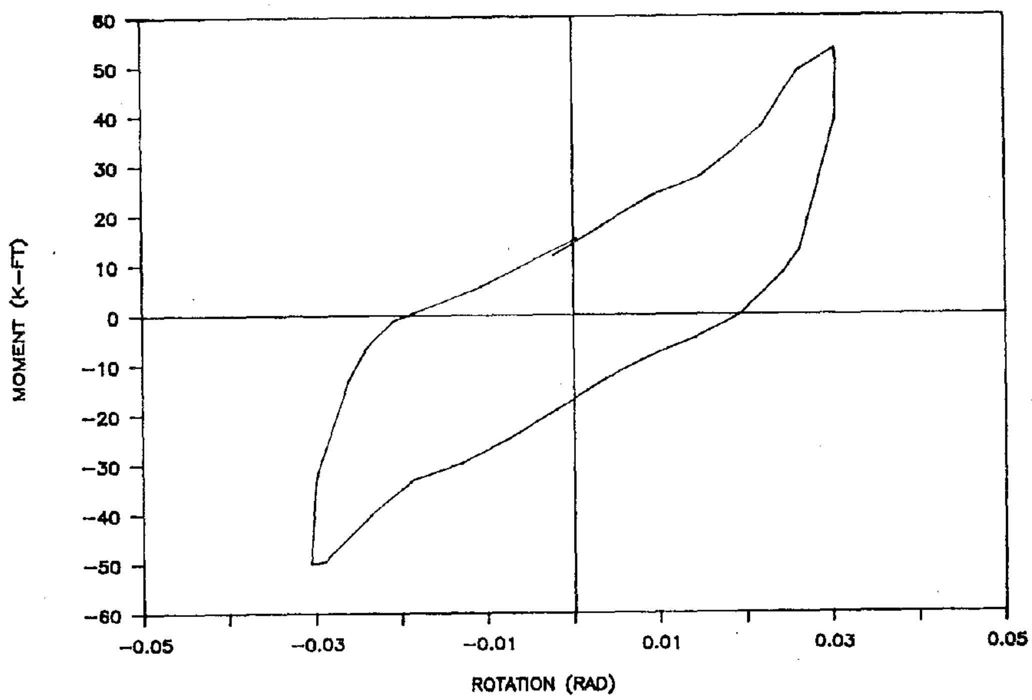


Figure A.21 Moment-Rotation Hysteresis Loops for Specimen Four Ninth Cycle

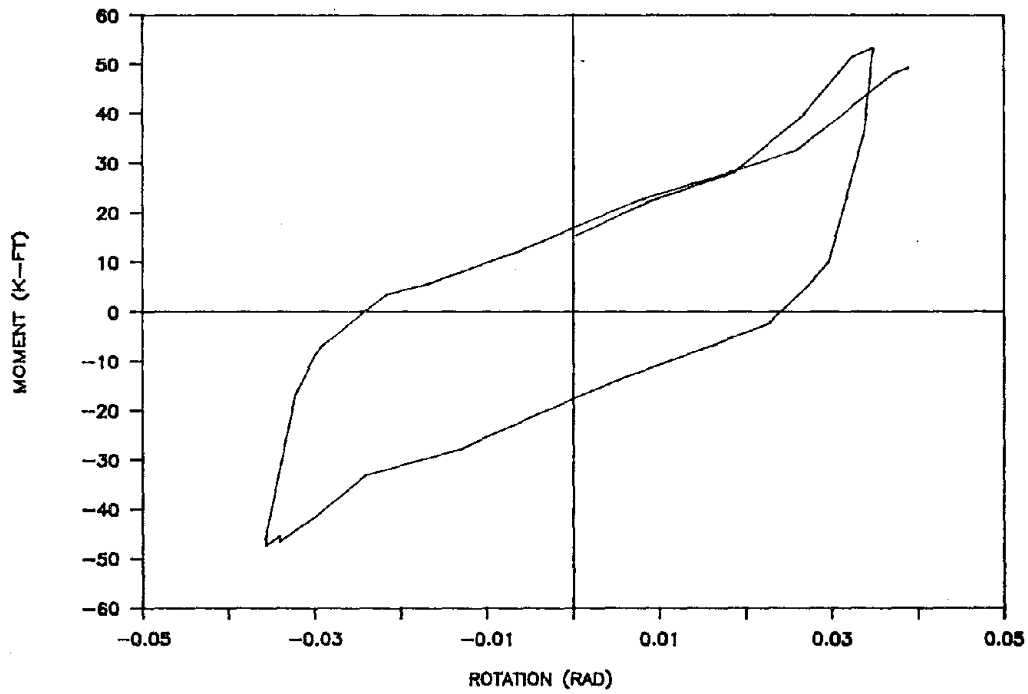


Figure A.22 Moment-Rotation Hysteresis Loops for Specimen Four Tenth Cycle

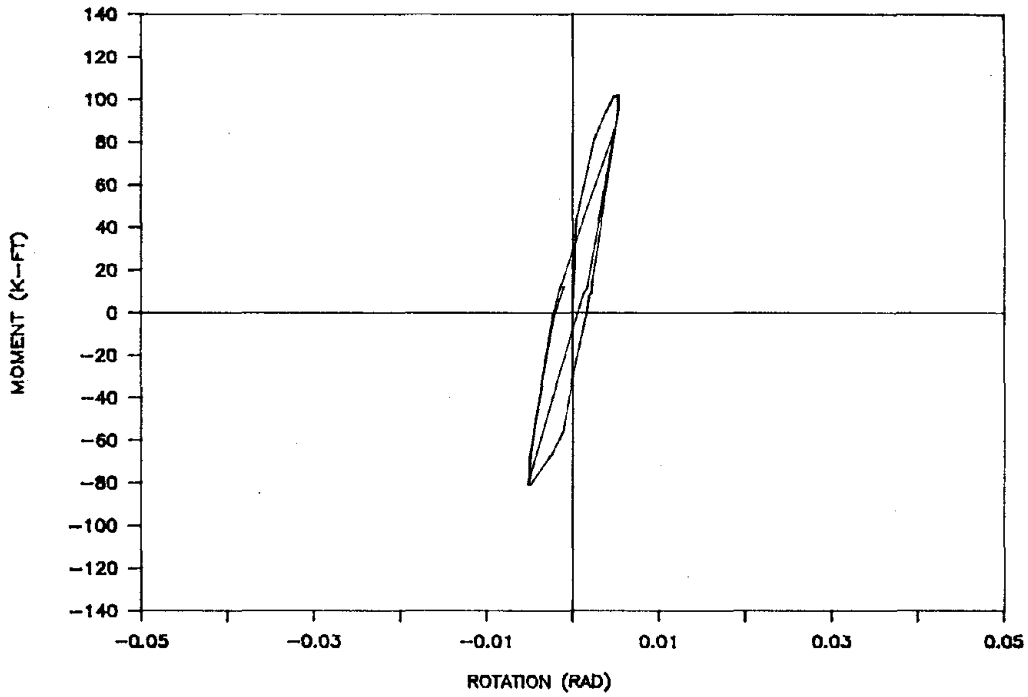


Figure A.23 Moment-Rotation Hysteresis Loops for Specimen Five
First and Second Cycles

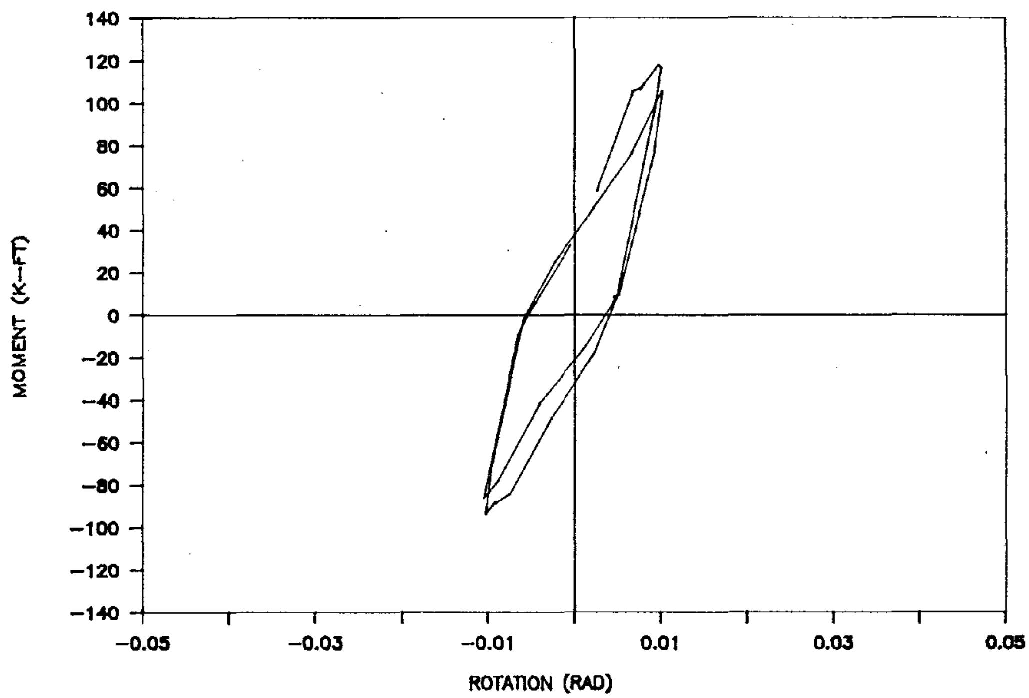


Figure A.24 Moment-Rotation Hysteresis Loops for Specimen Five
Third and Fourth Cycles

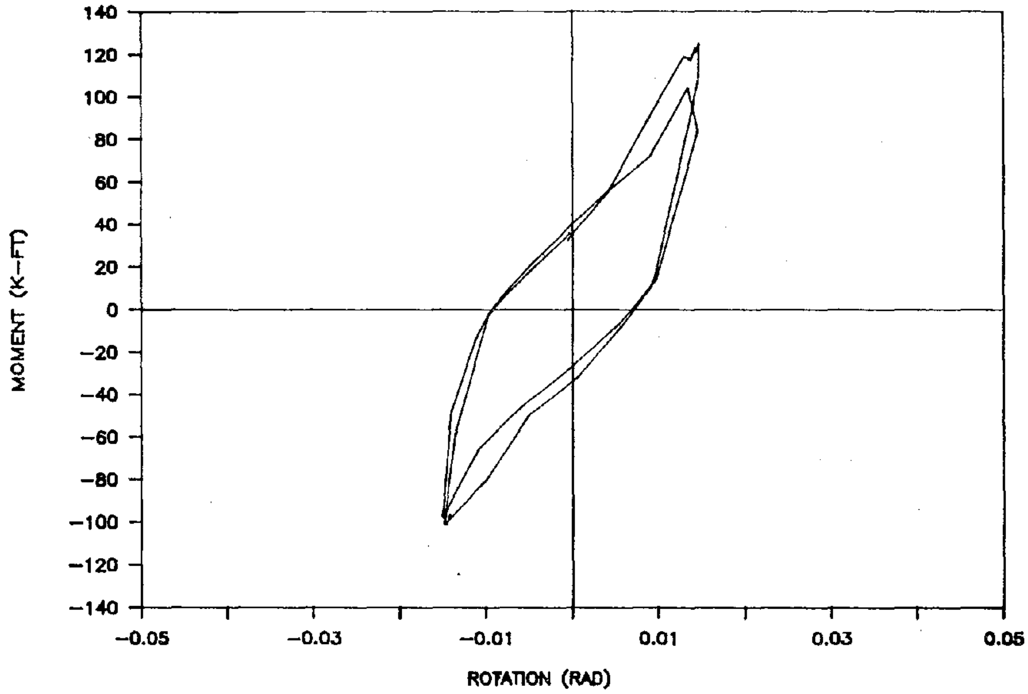


Figure A.25 Moment-Rotation Hysteresis Loops for Specimen Five
Fifth and Sixth Cycles

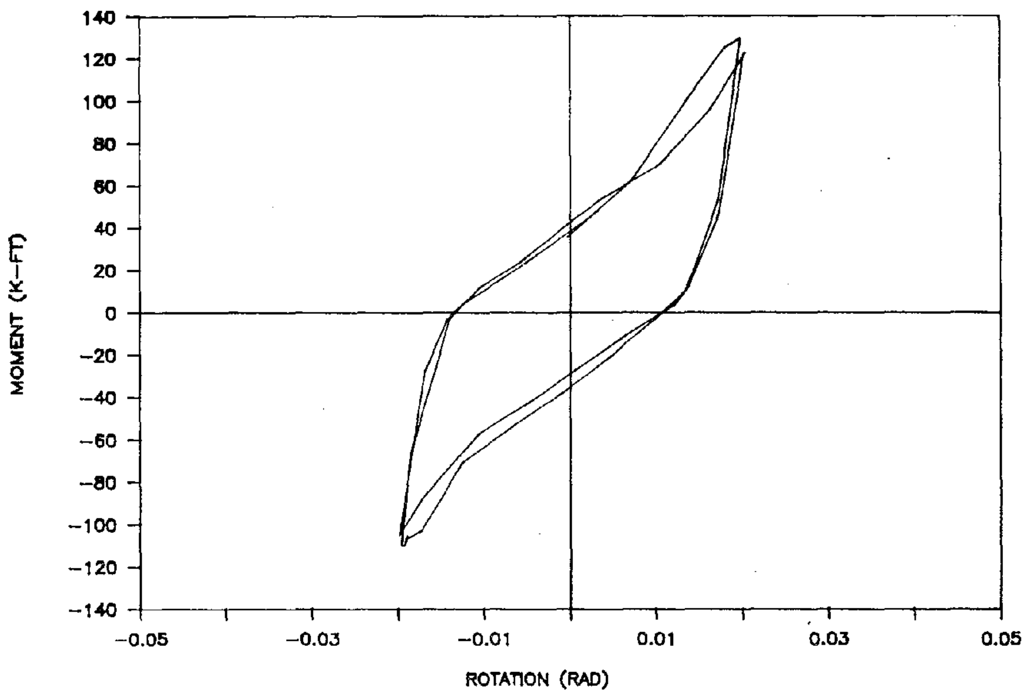


Figure A.26 Moment-Rotation Hysteresis Loops for Specimen Five
Seventh and Eighth Cycles

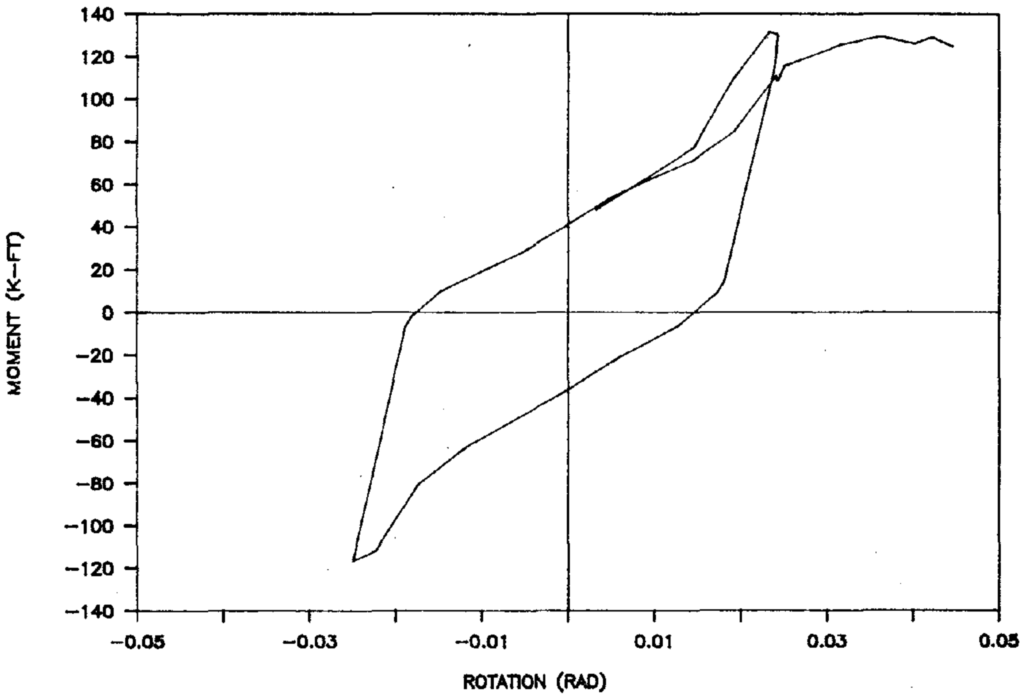


Figure A.27 Moment-Rotation Hysteresis Loops for Specimen Five
Ninth and Start of Tenth Cycles

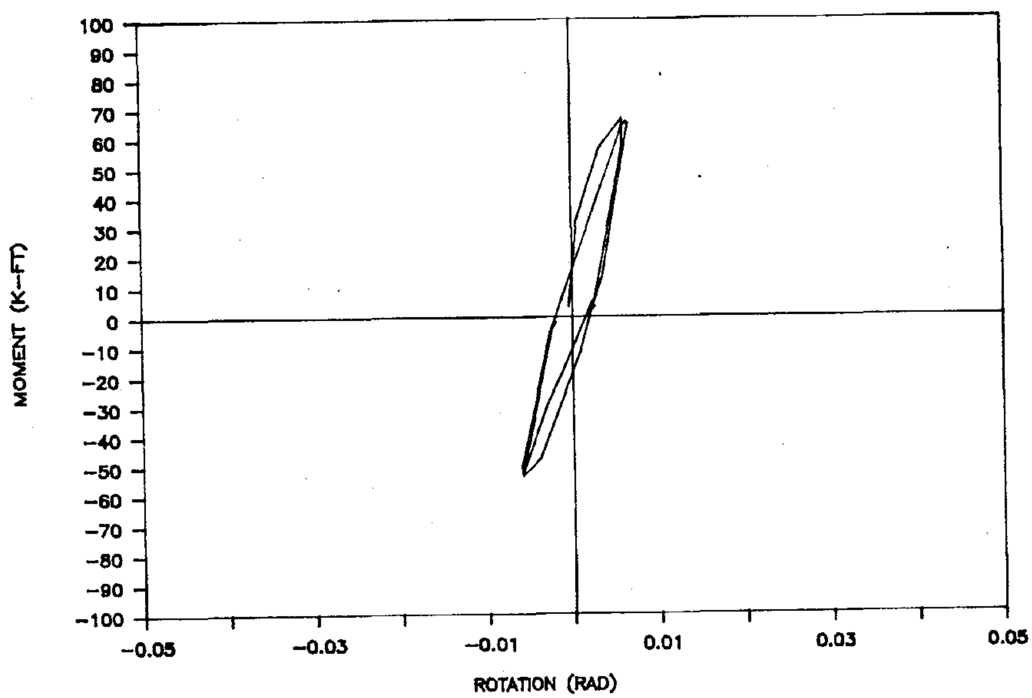


Figure A.28 Moment-Rotation Hysteresis Loops for Specimen Six
First and Second Cycles

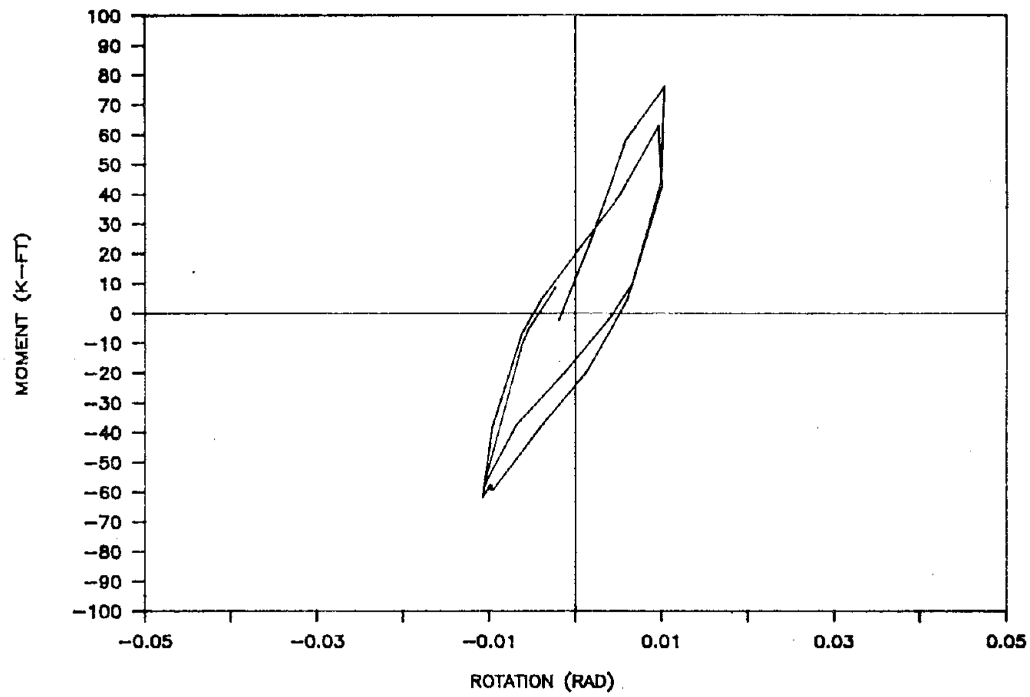


Figure A.29 Moment-Rotation Hysteresis Loops for Specimen Six
Third and Fourth Cycles

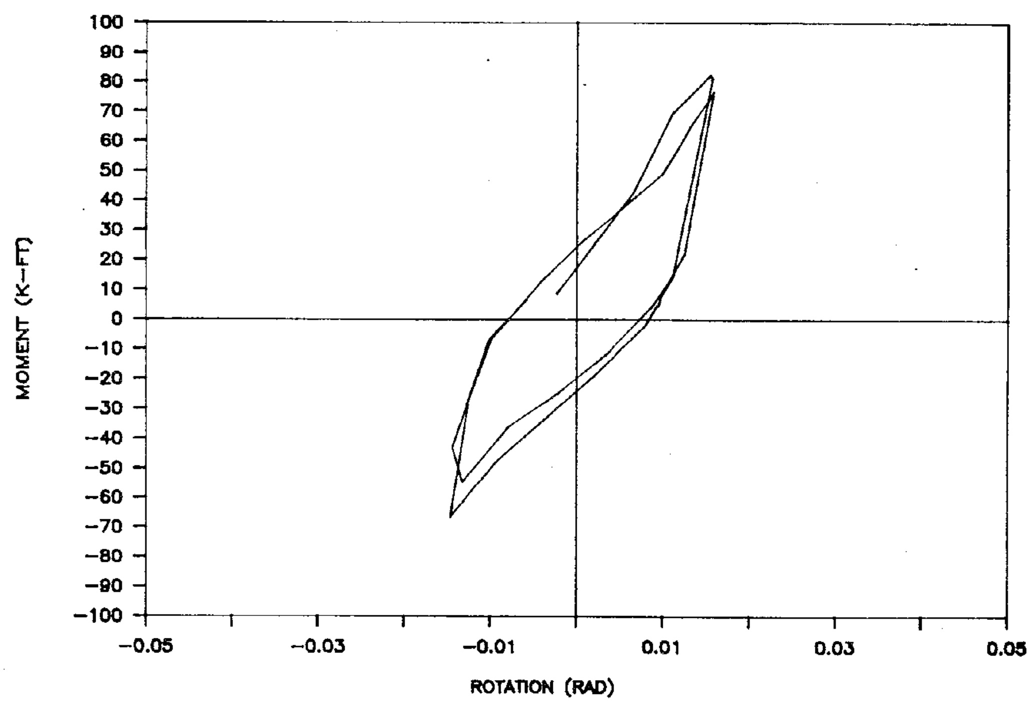


Figure A.30 Moment-Rotation Hysteresis Loops for Specimen Six
Fifth and Sixth Cycles

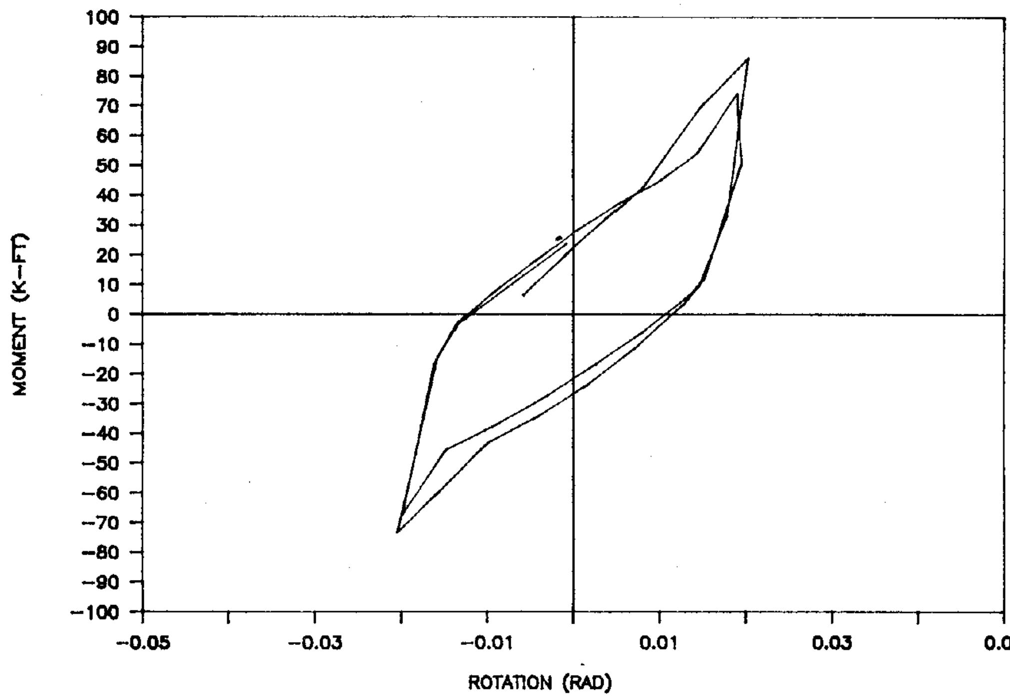


Figure A.31 Moment-Rotation Hysteresis Loops for Specimen Three Seventh and Eighth Cycles

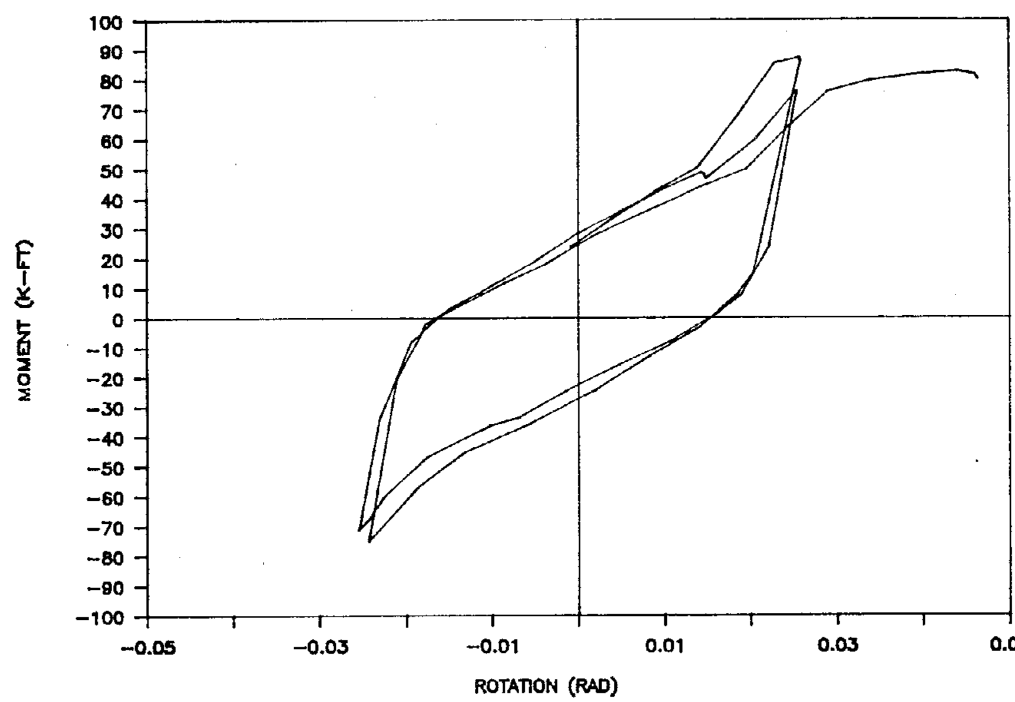


Figure A.32 Moment-Rotation Hysteresis Loops for Specimen Six Ninth, Tenth and Start of Eleventh Cycles

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