# TESTING OF THREADED MECHANICAL SPLICING SYSTEM STANDARD COUPLERS FOR ENGINEERED DEVICES CORPORATION

**Ridgefield Park, NJ**

20 May 2003
WJE No. 2002.2729

*Prepared for:*
**Engineered Devices Corporation**

*Prepared by:*
**Wiss, Janney, Elstner Associates, Inc.**

WJE

# TESTING OF THREADED MECHANICAL SPLICING SYSTEM STANDARD COUPLERS FOR ENGINEERED DEVICES CORPORATION

**Ridgefield Park, NJ**


Scott K. Graham
Project Engineer

Conrad Paulson
Project Manager


20 May 2003
WJE No. 2002.2729

*Prepared for:*
**Engineered Devices Corporation**
3 Eucker Street
Ridgefield Park, NJ 07660


*Prepared by:*
**Wiss, Janney, Elstner Associates, Inc.**
120 N. LaSalle Street, Suite 2000
Chicago, Illinois 60602
312.372.0555 tel | 312.372.0873 fax

WJE | ENGINEERS
ARCHITECTS
MATERIALS SCIENTISTS

## TABLE OF CONTENTS

WJE | ENGINEERS
ARCHITECTS
MATERIALS SCIENTISTS

# Testing of Threaded Mechanical Splicing System Standard Couplers For Engineered Devices Corporation

## INTRODUCTION

Wiss, Janney, Elstner Associates, Inc. (WJE), has conducted a series of tests on threaded mechanical splicing system standard couplers for Engineered Devices Corporation (EDC). The intent of the testing is to provide EDC with performance data for the coupler system under the requirements set forth by the New York Department of Transportation (NYDOT), New Jersey Department of Transportation (NJDOT), and Connecticut Department of Transportation (CDOT). The tests were conducted on Standard model splices in bar size Nos. 4 through 11 assembled using ASTM, A615 Grade 60 reinforcing bar. Unspliced control bar specimens were also tested. For each bar size, the control bars came from the same lots of bar that were used to make the splice specimens. The control bar tests were performed to determine the yield strength, yield strain, tensile strength and final elongation of the unspliced reinforcing bar.

## REVIEW OF TEST PROCEDURES AND ACCEPTANCE CRITERIA

WJE contacted the Department of Transportation (DOT) for the states of New Jersey, Connecticut and New York. WJE requested copies of the standard testing procedures and acceptance criteria for reinforcing bar mechanical splices from each of these three DOTs. Only New York maintains a specific procedure for testing of mechanical reinforcing bar splices. Each DOT maintains a separate standard of acceptance for reinforcing bar coupling systems. The requirements of each state are included in Appendix A, and are summarized as follows:

### New Jersey

The New Jersey Department of Transportation (NJ DOT) does not specify a particular test procedure, nor does it specify the number of specimens to be tested. The NJ DOT Standard Specification, Section 501.08-E, does specify the following criteria: "The mechanical coupler shall develop a minimum [tensile] strength of 125% of the specified yield strength of the reinforcement steel."

### Connecticut

The Connecticut Department of Transportation (CDOT) does not specify a particular test procedure, nor does it specify the number of specimens to be tested. The CDOT Standard Specification, Section M.06.01-5, does specify the following criteria: "The mechanical coupler shall develop a minimum strength of 125% of the specified yield strength of the reinforcement steel in both tension and compression."

### New York

The New York State Department of Transportation (NYDOT) maintains both a standard test procedure and acceptance criteria. The test procedure specified by NYDOT is "Test Method No. NY 709 05E", and acceptance criteria are specified in Section 709-10 of the NYDOT Standard Specification. NYDOT requires that three (3) specimens each be tested according to a three-step cyclic test procedure, and that slip across the splice be measured throughout the testing. The following are the NYDOT acceptance criteria:

- The maximum slip after 5 cycles between 5% and 50% of the specified yield strength of the reinforcing bar shall not exceed 0.254 mm (0.010 inch). At least 70% of the maximum slip shall have occurred in the first cycle.
- The maximum slip after 5 cycles between 5% and 90% of the specified yield strength of the reinforcing bar shall not exceed 0.457 mm (0.018 inch).
- The tensile strength of the splice shall be at least 90% of the specified minimum tensile strength of the reinforcing bar.

## TEST PLAN

The most stringent tensile strength requirement of the three reviewed herein is that of the NYDOT. CDOT requirements also include compressive strength. A test plan following the cyclic test procedure specified by the NYDOT will also satisfy the basic tensile testing requirements specified by CDOT and NJDOT. Compression tests are included in the test plan in order to satisfy the acceptance criteria specified by the CDOT. Control bar tests are not explicitly required by any of these three jurisdictions but are nevertheless included so that actual unspliced bar tensile properties are documented.

The test plan for each bar size is summarized as follows:

- One (1) splice specimen tested in monotonic tension
- Three (3) splice specimens tested in cyclic tension
- Three (3) splice specimens tested in monotonic compression
- One (1) unspliced control bar tested in monotonic tension

## SPECIMEN ASSEMBLY AND TEST PROCEDURES

### Specimen Authentication and Reinforcing Bar Sources

The test specimens were provided to WJE by EDC in the assembled condition. Figure 1 is taken from EDC product literature and illustrates a typical coupling sleeve along with specified sleeve dimensions for each bar size. Measurements of the same dimensions were taken by WJE on representative test specimens to verify these dimensions. The results of our measurements are summarized in Table 1. Within acceptable tolerances, the measured dimensions agree with the dimensions specified in Figure 1.

EDC indicated that all reinforcing bar is ASTM A615, Grade 60, and that all bar in any one give size came from the same lot of bar.

### Test Procedures for Control Bar Specimens

Unspliced control bar specimens were tested monotonically in axial tension in accordance with "Standard Test Methods and Definitions for Mechanical Testing of Steel Products," ASTM A370. A clip-on strain extensometer having a gage length of 2.0 inches was used to measure the elongation of each unspliced control bar test specimen. The electrical signal output from the clip-on strain gage and an electrical signal indication of the test machine load were simultaneously recorded by an analog X-Y chart recorder, or recorded digitally on a computer, or both. Force-elongation plots for all control bar specimens were produced either by the analog chart or by plotting the digital record.

Final elongation after fracture was determined by first scribing a series of gage marks onto the central length of the untested specimen at 2.0 inch intervals over a total length of at least 8.0 in. After the test, the ends of the fractured specimens were carefully fit together, and a measurement was made of the distance between two scribe points having an original gage length of 8.0 inch and approximately centered on the fracture location. The elongation was calculated as the increase in length of the gage length.

## Monotonic Tension Testing Procedures for Splice Specimens

EDC Standard Couplers were tested in monotonic tension in order to obtain splice tensile performance data that is uninfluenced by cyclic loading. Elongation (slip) of the splice was monitored by a pair of LVDTs installed in a frame having an adjustable gage length. When mounted to the specimen, the two LVDTs are located 180 degrees apart on opposite sides of the specimen. The electrical output of the LVDTs is electronically averaged to provide a single reading for slip. This slip instrumentation configuration eliminates error that could otherwise enter into the slip readings due to tensile straightening of the splice specimen. Strain in the reinforcing bar was monitored for reference purposes at a point away from the splice zone using a clip-on strain gage with a 2 inch gage length. Test machine piston position was monitored utilizing an LVDT that is internal to the test machine, and test machine load was monitored using a load cell that is also a part of the test machine. The instrumentation setup is schematically illustrated in Figure 2. A test specimen with the LVDT frame and clip-on gage attached can be seen in the photo on the cover of this report. All data were recorded digitally using a computerized data acquisition system. The digital record was used to make plots of load-elongation, load-reference strain, and load-piston movement.

Each monotonic tension test was performed using displacement control and in general accord with ASTM A 360. When the test load reached a value of approximately 120 percent of actual bar yield, the LVDT frame was removed from the specimen so that the instrument would not be damaged when the specimen failed. Similarly, the reference strain was recorded for as long into the test as was practicable. For safety purposes, the test machine was temporarily paused with displacement held constant when an instrument was removed from the specimen. After removal of the instrumentation, displacement was increased until the specimen failed. Test machine piston position was monitored by computer throughout the test, up to and including specimen failure. After fracture occurred, the peak load indicated by the test machine and the observed type of failure mode were recorded for each specimen.

## Compression Test Procedures for Splice Specimens

Compression tests were carried out in general accord with ASTM E 9, "Standard Test Methods of Compression Testing of Metallic Materials at Room Temperature". The clear length between test machine grips was kept to a minimum in order to prevent buckling of the specimen in compression. Load was applied under displacement control until the magnitude reached approximately 150 percent of the specified yield strength of the reinforcing bar. Shortening of all compression splice test specimens was obtained by monitoring piston position using an LVDT that is internal to the test machine. With the type of test machine used for these tests, piston movement is the same as crosshead movement in other types of test machines. Piston movement was taken to directly represent shortening of the compression specimens because the lengths of reinforcing bar between the ends of the coupler and the test machine grips were relatively short. The electrical signal output from the internal LVDT and an electrical signal indication of the test machine load were digitally recorded by a computer. The digital record was used to produce force-deformation plots for the compression test specimens.

## Cyclic Testing Procedures for Splice Specimens

The EDC Standard coupler specimens were tested in accordance with the following three-stage cyclic load protocol "Test Method No. NY 709 05E" as specified by the NYDOT:

| | |
|---|---|
| Stage 1 | 5 cycles between 5% and 50% of specified yield |
| Stage 2 | 5 cycles between 5% and 90% of specified yield |
| Stage 3 | Monotonic tension until specimen failure |

Elongation (slip) of the splice, reference strain in the reinforcing bar, test machine piston position and test load were all monitored using the same instrumentation setup as described herein for the monotonic tension tests. The Stage 1 and Stage 2 cyclic loads were applied under load control using a haversine waveform at a rate of 0.03 Hz. The monotonic tension test of Stage 3 was carried out using displacement control in general accord with ASTM A360. When the specimen neared failure, the instrumentation was removed in the same manner as that described in the monotonic tension tests. After removal of the instrumentation, displacement was increased until the specimen failed. Test machine piston position was monitored throughout the test, up to and including specimen failure. After fracture occurred, the peak load as indicated by the test machine and the observed type of failure mode were recorded for each specimen.

## Test Machines

All tests were carried out in a 50 kip, 100 kip or 600 kip MTS universal test machine having hydraulic grips. The current calibration certificate for each test machine is provided in Appendix B. The MTS test machines are located at the Structural Engineering Research Laboratory (SERL), University of Illinois, Urbana, Illinois.

# TEST RESULTS

The tests were carried out on the 5th through the 7th of March, 2003. All tests were directed by a licensed professional engineer who is a WJE staff member. The results of the tests are described in the following paragraphs.

## Unspliced Control Bars

One unspliced control bar was tested for each bar size. The results of the control bar tests are summarized in Table 2. Load-elongation curves for the control bars can be found in Appendix C. The tensile properties of all specimens conform to the requirements of ASTM A615 2001b.

## Splices Tested in Monotonic Tension

One splice specimen in each bar size was tested in monotonic tension. The results of the monotonic tension tests on EDC Standard Couplers are summarized in Table 3. Load-slip curves can be found in Appendix D, load-reference strain curves in Appendix E, and load-piston movement curves in Appendix F. The CDOT and the NJDOT require that a mechanical splice develop a minimum tensile strength in tension of 125% of the specified yield of the reinforcing bar, which is numerically equal to 75 ksi for splices that connect ASTM A615 Grade 60 reinforcing bars. All splice specimens met or exceeded this criterion. The NYDOT specifies that a mechanical splice develop a minimum tensile strength of 90% of the specified ultimate of the reinforcing bar, which is numerically equal to 81 ksi for splices that connect ASTM A615 Grade 60 reinforcing bars. All splice specimens except those in size Nos. 9 and 11 developed at least this strength.

## Splices Tested in Compression

Three splice specimens in each bar size were tested in monotonic compression. Results of the compression tests on EDC Standard Couplers are summarized in Table 4. Load-deformation plots for the splice specimens can be found in Appendix G. The specimens in Test Nos. 2003 and 2009 buckled at a load lower than expected. This is not an indication of inadequate splice performance but rather is a result of a large specimen clear length between the testing machine grips. Specimens that buckled were unloaded, removed from the testing machine and cut down to a shorter length as necessary to avoid further buckling. The specimens were then placed back into the testing machine and retested. The CDOT requires that a mechanical splice develop a strength in compression of at least 125% of specified yield of the reinforcing bar, which is numerically equal to 75 ksi for splices that connect ASTM A615 Grade 60 reinforcing bars. All specimens met or exceeded this strength.

## Splices Tested Cyclically

Typically, three splice specimens in each bar size were tested according to the cyclic test procedure specified by the NYDOT. In addition to the three planned specimens, one additional specimen was tested cyclically for each of bar size Nos. 9 and 11. Results of the cyclic tests on EDC Standard Couplers are summarized in Tables 5 and 6. Detailed slip gauge readings and elastic movement calculations can be found in Appendix H. Load-slip curves for the splice specimens can be found in Appendix D, load-reference strain curves in Appendix E, and load-piston movement curves in Appendix F.

A photo of a typical splice specimen after fracture is given in Figure 3. The fracture typically initiated at the root of the first thread engaged within the coupling sleeve. The fracture shown in Figure 3 is representative of specimens tested in monotonic tension and in cyclic tension.

Slip readings for each cycle of loading along with the numeric values for the NYDOT slip acceptance criteria are summarized in Table 5. Splice slip, in accordance with the NYDOT test method, has been taken as the mechanical movement of the specimen relative to the baseline reading taken at a load of 3 ksi prior to the first load cycle. The text of the NYDOT acceptance criteria is summarized on Page 2 herein. All splice specimens in each bar size successfully met the slip requirements as set forth by the NYDOT.

The breaking strengths of the splice specimens are summarized in Table 6, along with the mode of fracture for each specimen. The CDOT and the NJDOT require that a mechanical splice develop a minimum strength in tension that is 125% of the specified yield strength of the reinforcing bar, which is numerically equal to 75 ksi for splices that connect ASTM A615 Grade 60 reinforcing bars. All splice specimens summarized in Table 6 met or exceeded this criterion. The NYDOT specifies that a mechanical splice develop a minimum strength that is 90% of the specified ultimate strength of the reinforcing bar, which is numerically equal to 81 ksi for splices that connect ASTM A615 Grade 60 reinforcing bars. All splice specimens summarized in Table 6, except for two specimens in each of bar size Nos. 9 and 11, met or exceeded this criterion.

## SUMMARY

Wiss, Janney, Elstner Associates, Inc. (WJE) conducted a series of monotonic tension, monotonic compression and elastic cyclic tension tests on Standard Couplers of the reinforcing bar Threaded Mechanical Splicing System as manufactured by Engineered Devices Corporation (EDC). The specimens tested were of bar size Nos. 4 through 11 inclusive. All splices tested in compression successfully passed the requirements set forth by the Connecticut DOT. (The New York DOT and New Jersey DOT do not specify any compressive strength requirement.) All splice specimens tested in accordance with New York

DOT Test Method No. NY 709 05E survived the specified cyclic loading without any failure and also satisfied the slip requirements as specified in New York DOT standard specifications. After cycling, the specimens were loaded in monotonic tension to failure. Other splice specimens were tested in monotonic tension without any cyclic loading. All splice specimens, whether tested in monotonic tension or cyclically, successfully passed the tensile strength requirements set forth by the New Jersey DOT and the Connecticut DOT. With the exception of three specimens in each of bar size Nos. 9 and 11, all splices successfully passed the tensile strength requirements set forth by the NYDOT.

ENGINEERS
ARCHITECTS
MATERIALS SCIENTISTS

# FIGURES

| STANDARD COUPLER DATA | | | | | |
|---|---|---|---|---|---|
| Coupler Size | Thread Size | Coupler Weight (lbs.) | Coupler Length (inches) | Coupler O.D. (inches) | Flange Size (optional) |
| # 4 | ½″ - 13NC | 0.23 | 2″ | ⅞″ | 2″x2″ |
| # 5 | ⅝″ - 11NC | 0.28 | 2¼″ | 1″ | 2″x2″ |
| # 6 | ¾″ - 10NC | 0.39 | 2⅜″ | 1⅛″ | 2″x2″ |
| # 7 | ⅞″ - 9NC | 0.55 | 2¾″ | 1¼″ | 2″x2″ |
| # 8 | 1″ - 8NC | 0.99 | 3⅜″ | 1½″ | 2″x2″ |
| # 9 | 1⅛″ - 7NC | 1.66 | 3⅞″ | 1⅝″ | 2½″x2½″ |
| # 10 | 1¼″ - 7NC | 2.57 | 4⅜″ | 2″ | 2½″x2½″ |
| # 11 | 1⅜″ - 6NC | 2.60 | 4⅞″ | 2″ | 2½″x2½″ |

Standard Coupler

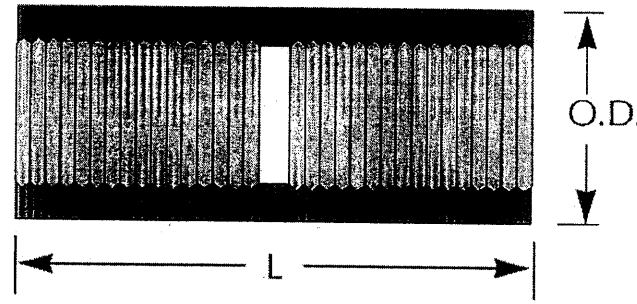


**Figure 1 - Specified Sleeve Dimensions for EDC Standard Couplers**

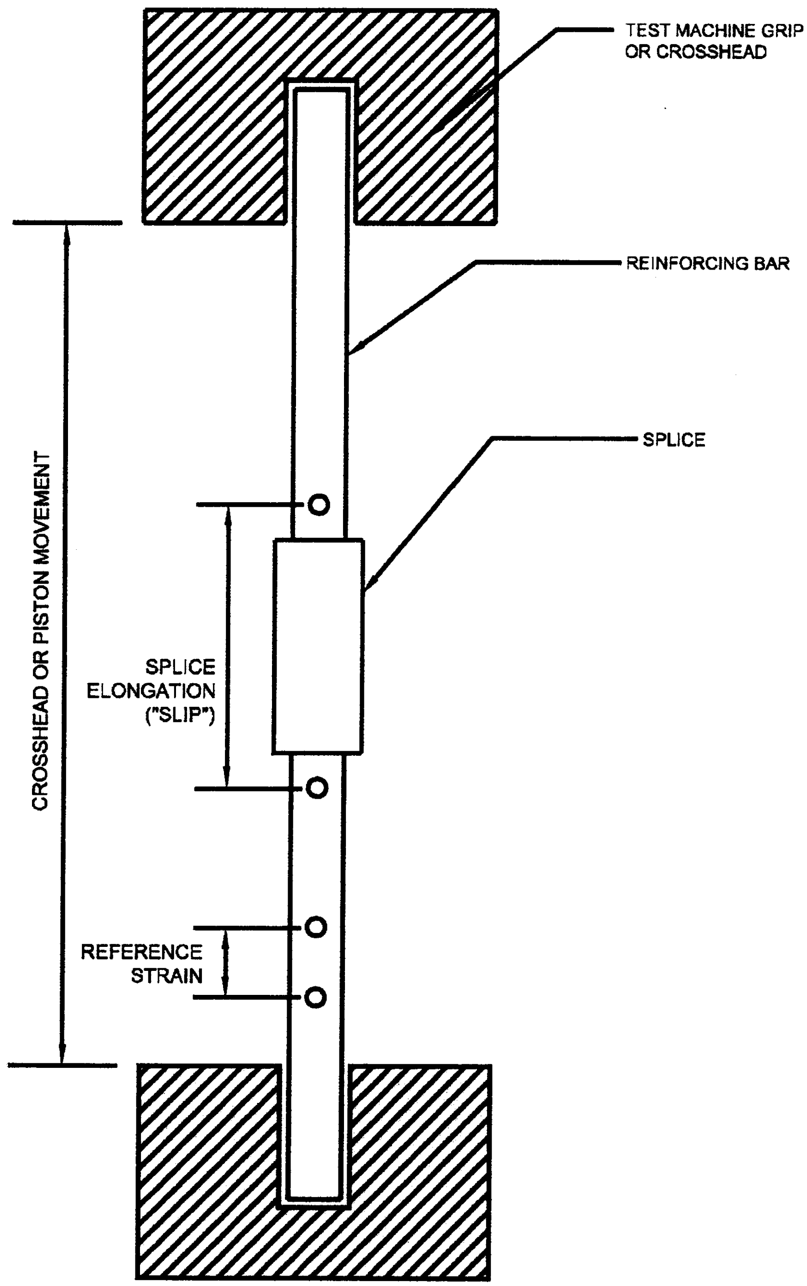


**Figure 2 - Monotonic Tension and Cyclic Tension Test Instrumentation Setup**


**Figure 3 - Representative Fracture of Spliced Bar Specimens**

# TABLES

## Table 1 - Coupling Sleeve Dimensions

| Bar Size | Lot Number | Sleeve Length (in) | Outside Diameter (in) | Male Thread Outside Diameter (in) | Threads per Inch |
|---|---|---|---|---|---|
| 4 | A - Standard | 1.989 | 0.881 | 0.504 | 13 |
| 5 | A - Standard | 2.267 | 0.998 | 0.626 | 11 |
| 6 | A - Standard | 2.376 | 1.125 | 0.752 | 10 |
| 7 | A - Standard | 2.768 | 1.250 | 0.869 | 9 |
| 8 | A - Standard | 3.361 | 1.495 | 0.999 | 8 |
| 9 | A - Standard | 3.860 | 1.637 | 1.118 | 7 |
| 10 | A - Standard | 4.366 | 2.009 | 1.254 | 7 |
| 11 | A - Standard | 4.875 | 1.998 | 1.375 | 6 |

## Table 2 - Control Bar Test Results

| Test I.D. No. | Bar Size | Bar Area ($in^2$) | Yield Strength, $f_{ya}$ | | | Yield Strain, $\varepsilon_{ya}$ | Tensile Strength, $f_{ua}$ | | | Final Elong. (percent) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | (kips) | (ksi) | ($\%f_{y=60}$) | (percent) | (kips) | (ksi) | ($\%f_{u=90}$) | |
| 1943 | 4 | 0.20 | 13.0 | 64.8 | 108% | 32.0% | 21.1 | 105.7 | 176% | 14% |
| 1944 | 5 | 0.31 | 19.6 | 63.1 | 105% | 31.0% | 31.5 | 101.5 | 169% | 15% |
| 1953 | 6 | 0.44 | 27.5 | 62.6 | 104% | 35.0% | 46.0 | 104.5 | 174% | 13% |
| 1954 | 7 | 0.60 | 41.6 | 69.3 | 116% | 31.0% | 61.9 | 103.2 | 172% | 16% |
| 1955 | 8 | 0.79 | 50.5 | 63.9 | 106% | 30.0% | 73.9 | 93.5 | 156% | 22% |
| 1965 | 9 | 1.00 | 69.0 | 69.0 | 115% | 29.0% | 101.6 | 101.6 | 169% | 18% |
| 1966 | 10 | 1.27 | 87.1 | 68.6 | 114% | 30.0% | 136.0 | 107.1 | 178% | 15% |
| 1967 | 11 | 1.56 | 104.3 | 66.9 | 111% | 30.0% | 158.3 | 101.5 | 169% | 18% |

# Table 3 - Monotonic Tension Test Results

| Test I.D. No. | Bar Size | Bar Area ($in^2$) | Tensile Strength, $f_{ya}$ | | | Final Result |
|---|---|---|---|---|---|---|
| | | | (kips) | (ksi) | ($\%f_{y=60}$) | |
| 1945 | 4 | 0.20 | 17.9 | 89.4 | 149% | Fracture at threads in bar |
| 1983 | 5 | 0.31 | 26.0 | 83.8 | 140% | Fracture at threads in bar |
| 1985 | 6 | 0.44 | 40.2 | 91.5 | 152% | Fracture at threads in bar |
| 1986 | 7 | 0.60 | 52.1 | 86.8 | 145% | Fracture at threads in bar |
| 1987 | 8 | 0.79 | 66.1 | 83.6 | 139% | Fracture at threads in bar |
| 1982 | 9 | 1.00 | 80.9 | 80.9 | 135% | Fracture at threads in bar |
| 1976 | 10 | 1.27 | 109.1 | 85.9 | 143% | Fracture at threads in bar |
| 1977 | 11 | 1.56 | 125.5 | 80.4 | 134% | Fracture at threads in bar |

## Table 4 - Compression Test Results

| Test I.D. No. | Bar Size | Bar Area (in$^2$) | Peak Load | | | Final Result |
|---|---|---|---|---|---|---|
| | | | (kips) | (ksi) | (%$f_{y=60}$) | |
| 1988 | 4 | 0.20 | 18.4 | 92.2 | 154% | No Failure |
| 1989 | 4 | 0.20 | 18.2 | 90.9 | 152% | No Failure |
| 1990 | 4 | 0.20 | 18.2 | 91.0 | 152% | No Failure |
| 1991 | 5 | 0.31 | 28.1 | 90.7 | 151% | No Failure |
| 1992 | 5 | 0.31 | 28.1 | 90.6 | 151% | No Failure |
| 1993 | 5 | 0.31 | 28.2 | 90.8 | 151% | No Failure |
| 1994 | 6 | 0.44 | 40.1 | 91.1 | 152% | No Failure |
| 1995 | 6 | 0.44 | 40.1 | 91.2 | 152% | No Failure |
| 1996 | 6 | 0.44 | 40.2 | 91.3 | 152% | No Failure |
| 1997 | 7 | 0.60 | 52.5 | 87.6 | 146% | No Failure |
| 1998 | 7 | 0.60 | 54.1 | 90.2 | 150% | No Failure |
| 1999 | 7 | 0.60 | 52.8 | 88.1 | 147% | No Failure |
| 2000 | 8 | 0.79 | 65.8 | 83.3 | 139% | No Failure |
| 2001 | 8 | 0.79 | 71.7 | 90.8 | 151% | No Failure |
| 2002 | 8 | 0.79 | 63.0 | 79.8 | 133% | No Failure |
| 2003 | 9 | 1.00 | 90.6 | 90.6 | 151% | Buckled/Retest/No Failure* |
| 2004 | 9 | 1.00 | 90.4 | 90.4 | 151% | No Failure |
| 2005 | 9 | 1.00 | 90.5 | 90.5 | 151% | No Failure |
| 2006 | 10 | 1.27 | 115.1 | 90.6 | 151% | No Failure |
| 2007 | 10 | 1.27 | 115.7 | 91.1 | 152% | No Failure |
| 2008 | 10 | 1.27 | 115.4 | 90.9 | 151% | No Failure |
| 2009 | 11 | 1.56 | 141.1 | 90.4 | 151% | Buckled/Retest/No Failure* |
| 2010 | 11 | 1.56 | 142.1 | 91.1 | 152% | No Failure |
| 2011 | 11 | 1.56 | 142.3 | 91.2 | 152% | No Failure |

* *Note - Buckling of a specimen prior to attaining 125% of the specified yield strength does not indicate inadequate splice performance. Rather, the buckling was due to excessive clear length between crossheads. Buckled specimens were removed from the testing machine, cut to a shorter clear length and retested.*

# Table 5 - Cyclic Test Results - Slip Data

| Test I.D. No. | Bar Size | Bar Area ($in^2$) | Cyclic Load Levels (Stages 1, 2) $P_{min}$ (kips) | $P_{max1}$ (kips) | $P_{max2}$ (kips) | Cycles Applied $n_1$ | $n_2$ | Slip after 1st cycle (in) | Slip after 5th cycle (in) | Slip after 10th cycle (in) | Min slip on 1st cycle (in) | Pass (Y/N) | Max Slip after 5th Cycle (in) | Pass (Y/N) | Max Slip after 10th Cycle (in) | Pass (Y/N) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1946 | 4 | 0.20 | 0.6 | 6.0 | 10.8 | 5 | 5 | 0.0024 | 0.0022 | 0.0050 | 0.0015 | Y | 0.0100 | Y | 0.0180 | Y |
| 1947 | 4 | 0.20 | 0.6 | 6.0 | 10.8 | 5 | 5 | 0.0039 | 0.0043 | 0.0016 | 0.0030 | Y | 0.0100 | Y | 0.0180 | Y |
| 1948 | 4 | 0.20 | 0.6 | 6.0 | 10.8 | 5 | 5 | 0.0018 | 0.0016 | 0.0029 | 0.0011 | Y | 0.0100 | Y | 0.0180 | Y |
| 1950 | 5 | 0.31 | 0.9 | 9.3 | 16.7 | 5 | 5 | 0.0023 | 0.0024 | 0.0049 | 0.0017 | Y | 0.0100 | Y | 0.0180 | Y |
| 1951 | 5 | 0.31 | 0.9 | 9.3 | 16.7 | 5 | 5 | 0.0027 | 0.0027 | 0.0074 | 0.0019 | Y | 0.0100 | Y | 0.0180 | Y |
| 1952 | 5 | 0.31 | 0.9 | 9.3 | 16.7 | 5 | 5 | 0.0023 | 0.0024 | 0.0036 | 0.0017 | Y | 0.0100 | Y | 0.0180 | Y |
| 1956 | 6 | 0.44 | 1.3 | 13.2 | 23.8 | 5 | 5 | 0.0052 | 0.0054 | 0.0118 | 0.0038 | Y | 0.0100 | Y | 0.0180 | Y |
| 1957 | 6 | 0.44 | 1.3 | 13.2 | 23.8 | 5 | 5 | 0.0046 | 0.0049 | 0.0123 | 0.0034 | Y | 0.0100 | Y | 0.0180 | Y |
| 1958 | 6 | 0.44 | 1.3 | 13.2 | 23.8 | 5 | 5 | 0.0068 | 0.0071 | 0.0125 | 0.0049 | Y | 0.0100 | Y | 0.0180 | Y |
| 1959 | 7 | 0.60 | 1.8 | 18.0 | 32.4 | 5 | 5 | 0.0055 | 0.0057 | 0.0077 | 0.0040 | Y | 0.0100 | Y | 0.0180 | Y |
| 1960 | 7 | 0.60 | 1.8 | 18.0 | 32.4 | 5 | 5 | 0.0040 | 0.0043 | 0.0064 | 0.0030 | Y | 0.0100 | Y | 0.0180 | Y |
| 1961 | 7 | 0.60 | 1.8 | 18.0 | 32.4 | 5 | 5 | 0.0060 | 0.0063 | 0.0087 | 0.0044 | Y | 0.0100 | Y | 0.0180 | Y |
| 1962 | 8 | 0.79 | 2.4 | 23.7 | 42.7 | 5 | 5 | 0.0047 | 0.0054 | 0.0078 | 0.0038 | Y | 0.0100 | Y | 0.0180 | Y |
| 1963 | 8 | 0.79 | 2.4 | 23.7 | 42.7 | 5 | 5 | 0.0049 | 0.0050 | 0.0072 | 0.0035 | Y | 0.0100 | Y | 0.0180 | Y |
| 1964 | 8 | 0.79 | 2.4 | 23.7 | 42.7 | 5 | 5 | 0.0060 | 0.0067 | 0.0100 | 0.0047 | Y | 0.0100 | Y | 0.0180 | Y |
| 1968 | 9 | 1.00 | 3.0 | 30.0 | 54.0 | 5 | 5 | 0.0040 | 0.0043 | 0.0060 | 0.0030 | Y | 0.0100 | Y | 0.0180 | Y |
| 1970 | 9 | 1.00 | 3.0 | 30.0 | 54.0 | 5 | 5 | 0.0059 | 0.0062 | 0.0084 | 0.0044 | Y | 0.0100 | Y | 0.0180 | Y |
| 1971 | 9 | 1.00 | 3.0 | 30.0 | 54.0 | 5 | 5 | 0.0048 | 0.0047 | 0.0063 | 0.0033 | Y | 0.0100 | Y | 0.0180 | Y |
| 1972 | 9 | 1.00 | 3.0 | 30.0 | 54.0 | 5 | 5 | 0.0045 | 0.0045 | 0.0061 | 0.0031 | Y | 0.0100 | Y | 0.0180 | Y |
| 1973 | 10 | 1.27 | 3.8 | 38.1 | 68.6 | 5 | 5 | 0.0051 | 0.0054 | 0.0073 | 0.0038 | Y | 0.0100 | Y | 0.0180 | Y |
| 1974 | 10 | 1.27 | 3.8 | 38.1 | 68.6 | 5 | 5 | 0.0055 | 0.0057 | 0.0079 | 0.0040 | Y | 0.0100 | Y | 0.0180 | Y |
| 1975 | 10 | 1.27 | 3.8 | 38.1 | 68.6 | 5 | 5 | 0.0055 | 0.0056 | 0.0074 | 0.0039 | Y | 0.0100 | Y | 0.0180 | Y |
| 1978 | 11 | 1.56 | 4.7 | 46.8 | 84.2 | 5 | 5 | 0.0053 | 0.0053 | 0.0066 | 0.0037 | Y | 0.0100 | Y | 0.0180 | Y |
| 1979 | 11 | 1.56 | 4.7 | 46.8 | 84.2 | 5 | 5 | 0.0052 | 0.0064 | 0.0089 | 0.0045 | Y | 0.0100 | Y | 0.0180 | Y |
| 1980 | 11 | 1.56 | 4.7 | 46.8 | 84.2 | 5 | 5 | 0.0039 | 0.0040 | 0.0058 | 0.0028 | Y | 0.0100 | Y | 0.0180 | Y |
| 1981 | 11 | 1.56 | 4.7 | 46.8 | 84.2 | 5 | 5 | 0.0042 | 0.0047 | 0.0070 | 0.0033 | Y | 0.0100 | Y | 0.0180 | Y |

## Table 6 - Cyclic Test Results - Strength Data

| Test I.D. No. | Bar Size | Bar Area ($in^2$) | Cyclic Load Levels (Stages 1, 2) | | | Cycles Applied | | Yield Strength | | Tensile Strength (Stage 3) | | | | Required Tensile Strength (ksi) | Pass (Y/N) | Final Result |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $P_{min}$ (kips) | $P_{max1}$ (kips) | $P_{max2}$ (kips) | $n_1$ | $n_2$ | (kips) | (ksi) | (kips) | (ksi) | ($\%f_{y=60}$) | ($\%f_{u=90}$) | | | |
| 1946 | 4 | 0.20 | 0.6 | 6.0 | 10.8 | 5 | 5 | 13.04 | 65.2 | 17.3 | 86.6 | 144% | 96% | 81.0 | Y | Bar break at thread |
| 1947 | 4 | 0.20 | 0.6 | 6.0 | 10.8 | 5 | 5 | 12.94 | 64.7 | 17.9 | 89.7 | 150% | 100% | 81.0 | Y | Bar break at thread |
| 1948 | 4 | 0.20 | 0.6 | 6.0 | 10.8 | 5 | 5 | 12.92 | 64.6 | 18.4 | 92.1 | 154% | 102% | 81.0 | Y | Bar break at thread |
| 1950 | 5 | 0.31 | 0.9 | 9.3 | 16.7 | 5 | 5 | 20.56 | 66.32 | 27.1 | 87.4 | 146% | 97% | 81.0 | Y | Bar break at thread |
| 1951 | 5 | 0.31 | 0.9 | 9.3 | 16.7 | 5 | 5 | 18.98 | 61.23 | 25.7 | 82.7 | 138% | 92% | 81.0 | Y | Bar break at thread |
| 1952 | 5 | 0.31 | 0.9 | 9.3 | 16.7 | 5 | 5 | 18.93 | 61.06 | 27.6 | 89.0 | 148% | 99% | 81.0 | Y | Bar break at thread |
| 1956 | 6 | 0.44 | 1.3 | 13.2 | 23.8 | 5 | 5 | 26.42 | 60.05 | 39.6 | 89.9 | 150% | 100% | 81.0 | Y | Bar break at thread |
| 1957 | 6 | 0.44 | 1.3 | 13.2 | 23.8 | 5 | 5 | 26.96 | 61.27 | 40.1 | 91.0 | 152% | 101% | 81.0 | Y | Bar break at thread |
| 1958 | 6 | 0.44 | 1.3 | 13.2 | 23.8 | 5 | 5 | 26.37 | 59.93 | 39.4 | 89.6 | 149% | 100% | 81.0 | Y | Bar break at thread |
| 1959 | 7 | 0.60 | 1.8 | 18.0 | 32.4 | 5 | 5 | 41.17 | 68.62 | 52.5 | 87.5 | 146% | 97% | 81.0 | Y | Bar break at thread |
| 1960 | 7 | 0.60 | 1.8 | 18.0 | 32.4 | 5 | 5 | 41.74 | 69.57 | 51.8 | 86.3 | 144% | 96% | 81.0 | Y | Bar break at thread |
| 1961 | 7 | 0.60 | 1.8 | 18.0 | 32.4 | 5 | 5 | 41.75 | 69.58 | 52.9 | 88.1 | 147% | 98% | 81.0 | Y | Bar break at thread |
| 1962 | 8 | 0.79 | 2.4 | 23.7 | 42.7 | 5 | 5 | 61.26 | 77.54 | 72.4 | 91.7 | 153% | 102% | 81.0 | Y | Bar break at thread |
| 1963 | 8 | 0.79 | 2.4 | 23.7 | 42.7 | 5 | 5 | 60.35 | 76.39 | 70.1 | 88.7 | 148% | 99% | 81.0 | Y | Bar break at thread |
| 1964 | 8 | 0.79 | 2.4 | 23.7 | 42.7 | 5 | 5 | 50.05 | 63.35 | 66.1 | 83.6 | 139% | 93% | 81.0 | Y | Bar break at thread |
| 1968 | 9 | 1.00 | 3.0 | 30.0 | 54.0 | 5 | 5 | 67.84 | 67.84 | 83.2 | 83.2 | 139% | 92% | 81.0 | Y | Bar break at thread |
| 1970 | 9 | 1.00 | 3.0 | 30.0 | 54.0 | 5 | 5 | 67.36 | 67.36 | 81.1 | 81.1 | 135% | 90% | 81.0 | Y | Bar break at thread |
| 1971 | 9 | 1.00 | 3.0 | 30.0 | 54.0 | 5 | 5 | 67.91 | 67.91 | 80.5 | 80.5 | 134% | 89% | 81.0 | N | Bar break at thread |
| 1972 | 9 | 1.00 | 3.0 | 30.0 | 54.0 | 5 | 5 | 67.54 | 67.54 | 80.8 | 80.8 | 135% | 90% | 81.0 | N | Bar break at thread |
| 1973 | 10 | 1.27 | 3.8 | 38.1 | 68.6 | 5 | 5 | 86.15 | 67.83 | 109.6 | 86.3 | 144% | 96% | 81.0 | Y | Bar break at thread |
| 1974 | 10 | 1.27 | 3.8 | 38.1 | 68.6 | 5 | 5 | 85.58 | 67.39 | 104.1 | 82.0 | 137% | 91% | 81.0 | Y | Bar break at thread |
| 1975 | 10 | 1.27 | 3.8 | 38.1 | 68.6 | 5 | 5 | 85.50 | 67.32 | 105.4 | 83.0 | 138% | 92% | 81.0 | Y | Bar break at thread |
| 1978 | 11 | 1.56 | 4.7 | 46.8 | 84.2 | 5 | 5 | 105.25 | 67.47 | 124.2 | 79.6 | 133% | 88% | 81.0 | N | Bar break at thread |
| 1979 | 11 | 1.56 | 4.7 | 46.8 | 84.2 | 5 | 5 | 105.10 | 67.37 | 128.8 | 82.6 | 138% | 92% | 81.0 | Y | Bar break at thread |
| 1980 | 11 | 1.56 | 4.7 | 46.8 | 84.2 | 5 | 5 | 105.74 | 67.78 | 118.8 | 76.2 | 127% | 85% | 81.0 | N | Bar break at thread |
| 1981 | 11 | 1.56 | 4.7 | 46.8 | 84.2 | 5 | 5 | 105.82 | 67.83 | 127.5 | 81.7 | 136% | 91% | 81.0 | Y | Bar break at thread |