Tennessee Valley Authority, Post Office Box 2000, Soddy-Daisy, Tennessee 37384-2000

May 19, 2003

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D. C. 20555

Gentlemen:

In the Matter of	)	Docket No. 50-327
Tennessee Valley Authority	)	

SEQUOYAH NUCLEAR PLANT - ACCEPTED VERSION OF TOPICAL REPORT NO. 24370-TR-C-001-A, "ALTERNATE REBAR SPLICE - BAR-LOCK MECHANICAL SPLICES"

Reference: NRC letter to TVA dated March 13, 2003, Safety Evaluation of Topical Report No. 24370-TR-C-001, "Alternate Rebar Splice - Bar-Lock Mechanical Splices" (TAC NO. MB5371)

The purpose of this submittal is to provide the accepted version of the subject topical report as requested in the reference letter. The accepted topical report now includes a copy of the reference letter, historical review information, and any original report pages that were replaced. The "-A" has been included in the topical report number to designate NRC acceptance.

There are no commitments contained in this letter. This letter is being sent in accordance with NRC RIS 2001-05. If you have any questions about this change, please telephone me at (423) 843-7170 or J. D. Smith at (423) 843-6672.

Sincerely,

Pedro Salas
Licensing and Industry Affairs Manager

Enclosure

D030

B88 030428 803

QA Record

APPROVED

This approval does not release the Contractor from any part of his responsibility for the correctness of design, details and dimensions.

Letter No. TVBEC-0393

Date: April 28, 2002

TENNESSEE VALLEY AUTHORITY

SQEP (N) BY P.G. Trudel

ALTERNATE REBAR SPLICE

BAR-LOCK MECHANICAL SPLICES

TOPICAL REPORT

PROJECT Sequoyah DISCIPLINE N
CONTRACT 99N5B-253631 UNIT 1
DESC. Topical Report - Mechanical Rebar Coupler Qual.
DWG/DOC NO. 24370-TR-C-001-A
SHEET - OF - REV. 00
DATE 04/28/03 ECN/DCN - FILE N2N-059

0	2/20/02	Issued for TVA use	SWK	DLK	JVS
REV.	DATE	REASON FOR REVISION	BY	EGS	PE
BECHTEL			JOB NO.: 24370		
			DOCUMENT NO.: 24370-TR-C-001-A		

RIMS, WTC A-K

SEQUOYAH UNIT 1

STEAM GENERATOR REPLACEMENT

ALTERNATE REBAR SPLICE –

BAR-LOCK MECHANICAL SPLICES

TOPICAL REPORT

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for Topical Report 24370-TR-C-001,

"Alternate Rebar Splice – Bar-Lock Mechanical Splices"

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

March 13, 2003

Mr. J. A. Scalice
Chief Nuclear Officer
and Executive Vice President
Tennessee Valley Authority
6A Lookout Place
1101 Market Street
Chattanooga, Tennessee 37402-2801

SUBJECT: SEQUOYAH NUCLEAR PLANT, UNIT 1, SAFETY EVALUATION OF TOPICAL REPORT NO. 24370-TR–C-001, "ALTERNATE REBAR SPLICE - BAR-LOCK MECHANICAL SPLICES" (TAC NO. MB5371)

Dear Mr. Scalice:

On March 18, 2002, the Tennessee Valley Authority (TVA, the licensee) submitted Westinghouse Topical Report No. 24370-TR–C-001, "Alternate Rebar Splice - Bar-Lock Mechanical Splices" to the staff, supplemented by a letter dated December 10, 2002.

The staff has reviewed Topical Report No. 24370-TR–C-001, "Alternate Rebar Splice - Bar-Lock Mechanical Splices" and found the Topical acceptable. The enclosed Nuclear Regulatory Commission (NRC) safety evaluation contains the staff's determination. However, this acceptance applies only to the Bar-Lock coupler assembly using American Society for Testing Maintenance A615 Grade 60 material in the #6 and #8 sizes for use on non-containment (i.e., shield building) applications at TVA's Sequoyah Units 1 and 2.

In accordance with the guidance provided on the NRC web site, we request that TVA publish an accepted version of this topical report within 3 months of receipt of this letter. The accepted version shall incorporate this letter and the enclosed safety evaluation between the title page and the abstract. It must be well indexed such that information is readily located. Also, it must contain in appendices historical review information, such as questions and accepted responses, and original report pages that were replaced. The accepted version shall include an "-A" (designated accepted) following the report identification symbol.

If the NRC's criteria or regulations change so that the conclusions in this letter are invalidated, thus making the topical report unacceptable, TVA will be expected to revise and resubmit its respective documentation, or submit justification for the continued applicability of the topical report without revision of the respective documentation.

If you have any questions concerning this matter, please contact Eva Brown at (301) 415-2315.

Sincerely,

Raj G. Anand

Raj K. Anand, Project Manager, Section 2
Project Directorate II
Division of Licensing Project Management
Office of Nuclear Reactor Regulation

Docket No. 50-327

Enclosure: Safety Evaluation

cc w/encl: See next page

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

REQUEST FOR SAFETY EVALUATION OF TOPICAL REPORT NO. 24370-TR-C-001, "ALTERNATE REBAR SPLICE - BAR-LOCK MECHANICAL SPLICES"

TENNESSEE VALLEY AUTHORITY

SEQUOYAH NUCLEAR PLANT, UNIT 1

DOCKET NO. 50-327

1.0 INTRODUCTION

In a letter dated March 18, 2002, Tennessee Valley Authority's (TVA, the licensee) Sequoyah Nuclear Plant (SQN) submitted a topical report for an alternate methodology for splicing reinforcing bars in concrete for nuclear safety-related applications at SQN. The topical report proposes that a Bar-Lock coupler system is now available for splicing reinforcing bars. Presently, the SQN licencing basis does not address the use of this type of reinforcing bar splice. This topical report describes a qualification testing program and test results for the Bar-Lock coupler system. On July 9, 2002, and October 24, 2002, meetings were held between the U.S. Nuclear Regulatory Commission staff (the staff) and TVA. Subsequently, the staff issued a request for additional information dated December 4, 2002. The licensee provided response to the additional information in a letter dated December 10, 2002.

2.0 TEST PROGRAM

Bechtel Corporation and Idaho National Engineering and Environmental Laboratory (INEEL) developed and performed a testing program for the Bar-Lock coupler system to assess its performance characteristics. TVA was heavily involved in the Bechtel/INEEL test program, and reviewed and approved the specifications, procedures and test plans associated with the procurement, testing, and installation of the Bar-Lock couplers. TVA civil engineers attended the vendor training session. TVA Engineering and Quality Assurance (QA) personnel witnessed the preparation of several test assemblies, and the testing of several specimens. TVA reviewed and approved the testing program and performance analysis, prepared by INEEL.

The reinforcing bar used in the Bar-Lock coupler assembly testing program was American Society for Testing and Maintenance (ASTM) A615 Grade 60 material in #6 and #8 sizes. The mechanical properties for the reinforcing bars were tested in according to ASTM Designation A 370-96, Standard Test Methods and Definitions for Mechanical Testing of Steel Products; and ASTM Designation E 8-99, Standard Test Methods for Tension Testing of Metallic Materials.

Enclosure

The component parts of each Bar-Lock coupler consist of a steel tube, "lock-shear" bolts, and serrated rails. The steel tube is seamless hot-rolled in conforming to ASTM A-519, with minimum tensile strength in excess of 100 kilopound per square inch (ksi). The lock-shear bolt was made from American Iron and Steel Institute (AISI) 41L40 material, and were through-hardened over the entire length and further induction-hardened at the conical bolt tip. The serrated rails were made of ASTM CD1018 material, and were machined and then carburized to a depth of 0.032 inch

The test specimen assemblies were made by steel construction workers using Bar-Lock's assembly instructions in a normal field environment. Assembly of the test specimens was monitored by Bechtel Quality Control (QC) personnel. The Bar-Lock's assemblies were tested in the same machine that had tested the mechanical properties of the reinforcing bars and in conformance with the same ASTM A 370-96 and E 8-99 standards.

Two reinforcing bar sizes (#6 and #8) of Bar-Lock coupler assemblies were statically tested. The test was conducted using forty specimens of each of the two sizes of coupler assemblies. The static test was performed according to the requirements of American Society of Mechanical Engineers (ASME) Section III, Division 2, "Code for Concrete Reactor Vessels and Containment," (the Code) Section CC-4333.2.3(a), Static Tensile Tests for Mechanical Splices. Forty specimens of each of the two sizes of the Bar-Lock coupler assemblies were tested for cyclic loadings. The cyclic test was performed according to the requirements of ASME Section III, Division 2, "Code for Concrete Reactor Vessels and Containment," Section CC-4333.2.3(b), Cyclic Tensile Tests for Mechanical Splices. The Code requires that three specimens of the bar-to-bar splice for each reinforcing bar size shall withstand 100 cycles of stress variation from 5 percent to 90 percent of the specified minimum yield strength of the reinforcing bar. In an effort to improve the cyclic durability assessment, after 100 cycles of loading required by the Code, several specimens were randomly selected to receive an additional 1000 cycles, and several other specimens were statically loaded to failure.

3.0 TECHNICAL EVALUATION

The Code requires six splice specimens for each bar size to be tensile tested statically to failure and three to be tested cyclically. The Code requires that the average tensile strength of the splices shall not be less than 90 percent of the actual tensile strength of the reinforcing bar being tested, nor less than 100 percent of the specified minimum tensile strength. Table CC-4334-1, "Tensile Requirements for Mechanical Reinforcing bar splices and Welded Joints," of the Code lists a minimum yield strength of 60 ksi and minimum tensile strength of 90 ksi for ASTM 615 Grade 60 reinforcing bars.

The INEEL report states that the average tensile strength of the 40 #6 Bar-Lock's assemblies is 106.2 ksi, which is 98.8 percent of the average #6 bar actual tensile strength. The average tensile strength of the 40 #8 Bar-Lock's assemblies is 109.0 ksi, which is 99 percent of the average #8 bar actual tensile strength. None of the 80 specimens tested cyclically failed in any manner (e.g., bar break, or bar slip within the coupler). For those specimens that received additional 1000 cycles of loading, no obvious physical degradation was observed. For those specimens that passed 100 cycles of loading and then statically loaded to tensile failure, the measured tensile strengths were essentially the same as those tested statically to failure without the 100 cycles of loading. The report also states that no practical differences were

observed in the general character of the stress-strain curve of any of the 80 specimens tested statically, and no measurable slip was detected during the cyclic tests.

The staff finds the QA/QC program for the test specimens adequate. The phenomena of no measurable slip and the similarity in the stress-strain curves of the specimens tested demonstrate that the Bar-Lock's assembly has delivered predictable results and qualifies as a viable reinforcing bar splicing system. The licensee has tested more specimens than that required by the Code, which increases the confidence level for the acceptance of the Bar-Lock's assembly. The static and cyclic test methods and results have met the requirements of the Code. The additional tests of the 1000 cycles of loading and of the tensile test to failure after the 100 cycles of loading exceed the Code requirements.

4.0 CONCLUSION

Based on the information provided by the licensee, the staff determined that the licensee has developed and performed a reasonable test program for the Bar-Lock coupler assemblies, and that the test data demonstrate the adequacy of the proposed alternate methodology for connecting (splicing) reinforcing steel bars for nuclear-safety-related applications at the Sequoyah plant.

Principal Contributor: John Ma, NRR

Date: March 13, 2003

1.0 Abstract

Original construction of nuclear power plants generally used lap splices or Cadweld splices to join concrete reinforcing steel (rebar). The Cadweld splice became the standard mechanical rebar splice for the nuclear industry, and its use is supported by years of successful installation, industry codes and standards, and regulatory acceptance. However, other mechanical splice technologies, such as the Bar-Lock coupler system, are now available.

The Bar-Lock system has achieved acceptance in commercial construction, but has not been used in domestic nuclear power applications. Presently, the Sequoyah Nuclear Plant licensing basis does not specifically address the use of this type of reinforcing bar splice. This Topical Report, which details a qualification testing program and test results, has been prepared to support use of the Bar-Lock coupler system as an acceptable alternate mechanical splice for nuclear safety-related applications at the Sequoyah plant.

2.0 Introduction

This Topical Report provides a technical justification for the use of Bar-Lock couplers in the restoration of the temporary construction openings in the Sequoyah Unit 1 reactor building as part of the steam generator replacement project (SGRP).

Mechanical splices for reinforcing steel used in nuclear safety-related concrete structures are subject to the stringent requirements of ASME Section III, Division 2/ACI-359 and ACI-318, which includes the requirement that the splice develop 125% of the minimum yield strength of the reinforcing bar. In order to demonstrate that the Bar-Lock coupler can meet these requirements, a qualification program has been performed. The qualification program included development of a testing program, performance of physical tests, and analysis and interpretation of the test results.

The Bar-Lock coupler system provides a number of installation advantages over other mechanical splice concepts that make it a candidate for the concrete restoration activities associated with the Sequoyah steam generator replacement. The Bar-Lock coupler system has specified mechanical properties that meet ASME/ACI criteria for mechanical rebar splices. The Bar-Lock coupler has achieved acceptance in commercial construction, including meeting strict Caltrans earthquake requirements. However, the Bar-Lock coupler has not yet been included (or proposed for inclusion) in NRC guidance for rebar splicing in domestic nuclear power plant applications.

3.0 Objectives

The objectives of this report are to present the necessary data supporting the use of Bar-Lock couplers in nuclear safety-related applications at Sequoyah. To achieve these objectives, the following types of information have been compiled:

- A description of the couplers is presented in sufficient detail to illustrate the advantages and benefits of this system.
- Criteria for the qualification testing of the specific Bar-Lock couplers to be used for the Sequoyah SGRP, including the 10CFR50, Appendix B requirements and a description of quality control of critical processes which were involved in the manufacture and testing of the couplers.

- A summary of previous commercial testing performed on the Bar-Lock splices.
- A description of the Bechtel / Idaho National Engineering and Environmental Laboratory (INEEL) test program and a compilation of the resulting test data, which illustrates the acceptability of the coupler system.
- Specifics of the Bar-Lock installation at Sequoyah.

4.0 Regulatory Requirements/Criteria for Mechanical Splices

Detailed below are regulatory requirements/criteria that are relevant to mechanical splices. Following each requirement/criteria is an *italicized* reference to where the requirement/criteria is addressed within this topical report.

4.1 NRC Regulatory Guide 1.136, Materials, Construction, and Testing of Concrete Containments

This regulatory guide states in part that the requirements specified in Article CC-4000 of ASME Section III, Division 2, 1980 Edition (also known as ACI 359-80), are acceptable to the NRC staff subject to the following:

- Instead of the requirements in subparagraph CC-4333.4.2, splice samples shall be production splices (cut directly from in-place reinforcement.

As discussed in Section 9.3, all splice samples will be sister splices.

4.2 ASME Section III, Division 2, Paragraph CC-4333, Mechanical Splices

This section of the ASME Code addresses the requirements for mechanical splices.

Paragraph CC-4333.2.1 requires each splice system manufacturer to conduct a series of performance tests in order to qualify his splice system for use.

The purpose of this topical report is document the performance testing performed by Bechtel/INEEL for the Bar-Lock couplers to support nuclear safety-related use of the couplers at the Sequoyah plant.

Paragraph CC-4333.2.3 specifies the type and number of performance tests to be performed. The requirements specified are summarized below:

(a) Static Tensile Tests

Six splice specimens for each bar size and splice type to be used in construction shall be tensile tested to failure using the loading rate set forth in SA-370. A tensile test on unspliced specimens from the same bar used for the spliced specimens shall be performed to establish actual tensile strength. The average tensile strength of the splices shall not be less than 90% of the actual tensile strength of the reinforcing bar being tested, nor less than 100% of the specified minimum tensile strength. The tensile strength of an individual splice system shall not be less than 125% of the specified minimum yield strength of the spliced bar. Each individual test report on both the spliced and unspliced specimens shall include at least the following information:

(1) tensile strength;

(2) total elongation;
(3) load versus extension curve to the smaller of 2% strain or the strain of 125% of the specified minimum yield strength of the reinforcing bar.

The gage length for each pair of spliced and unspliced specimens shall be the same, and equal to the length of splice sleeve, plus not less than 1 bar diameter nor more than 3 bar diameters at each end.

Section 8.5.1 provides details of the Bar-Lock static tensile testing performed and the results of the testing.

(b) Cyclic Tensile Tests

Three specimens of the bar-to-bar splice for each reinforcing bar size and splice type to be used in construction shall be subjected to a low cycle tensile test. Each specimen shall withstand 100 cycles of stress variation from 5% to 90% of the specified minimum yield strength of the reinforcing bar. One cycle is defined as an increase from the lower load to the higher load and return.

Section 8.5.2 provides details of the Bar-Lock cyclic tensile testing performed and the results of the testing.

Paragraph CC-4333.4 requires that each splicer prepare two qualification splices on the largest size bar to be used. The qualification splices shall be made using reinforcing bar identical to that to be used in the structure. The completed qualification splices shall be tensile tested using the loading rates set forth in SA-370 and the tensile results shall meet those specified in Table CC-4333-1.

Splicing crew qualification is described in Section 9.1.

Paragraph CC-4333.5.3 requires that splice samples be tensile tested.

The schedule for testing of production/sister splices at Sequoyah is described in Section 9.3.

Paragraph CC-4333.5.4 requires that splice samples be tensile tested using the loading rates set forth in SA-370 and meet the following acceptance standards:

(a) The tensile strength of each sample shall equal or exceed 125% of the specified yield strength as shown on Table CC-4333-1.
(b) The average tensile of each group of 15 consecutive samples shall equal or exceed the specified minimum strength as shown in Table CC-4333-1.

The acceptance criteria that will be used for testing of splice samples are described in Section 9.4.

4.3 ASTM A370, Standard Test Methods and Definitions for Mechanical Testing of Steel Products

Section 10 of the standard specifies the requirements for gage marks to determine the percent elongation.

A discussion of the determination of the mechanical properties of the rebar used in the coupler testing is provided in Section 8.3. This discussion includes information on the gage lengths used.

Section 13 of the standard specifies acceptable methods for determining tensile properties.

A discussion of the determination of the mechanical properties of the rebar used in the coupler testing is provided in Section 8.3. The results of the testing of the coupler assemblies are provided in Section 8.5.

4.4 ANSI N45.2.5, Supplementary Quality Assurance Requirements for Installation, Inspection, and Testing of Structural Concrete and Structural Steel During the Construction Phase of Nuclear Power Plants

ANSI N45.2.5 specifies supplementary quality assurance requirements for installation, inspection, and testing of structural concrete and structural steel for nuclear power plant construction.

Sections 6.2, 6.3, and 9.5 describe the conformance to quality requirements for the Bar-Lock couplers and installation of the couplers at Sequoyah.

5.0 Description of Bar-Lock Couplers

Bar-Lock couplers are manufactured of seamless hot-rolled steel tube conforming to ASTM A-519, with a minimum tensile strength exceeding 100 ksi. The couplers utilize a combination of lockshear bolts and heat-treated internal serrated rails to create a mechanical connection that exceeds the ASME and ACI requirements. A cutaway view of a typical Bar-Lock coupler is provided in Figure 5-1. The serrated rails extend the length of the tube to cradle and grip the rebar. As the bolts are tightened, they embed into the rebar. The serrated rails also embed into the rebar and the interior wall of the tube. The number of bolts required is dependent on the size of the rebar to be spliced. Unlike the 3 bolts shown on Figure 5-1, the Bar-Lock couplers for the #6 and #8 rebar used at Sequoyah utilize 4 and 5 bolts, respectively.

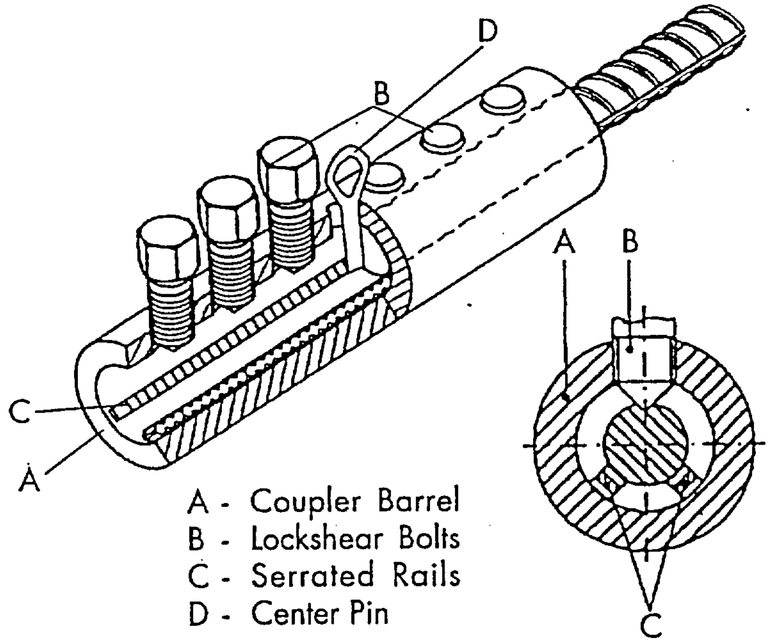

Figure 5-1 – Bar-Lock Coupler Cutaway

Installation of the Bar-Lock coupler is as follows:

- Insert the first rebar half way into the coupler to the center pin.
- Tighten the bolts to snug (finger-tight) fit.
- Insert the second piece of rebar half way into the other end of the coupler to the center pin.
- Tighten the remaining bolts to snug fit.
- Tighten all bolts in a random alternating pattern, making a minimum of two passes of tightening each bolt prior to shearing the bolt heads.

This installation process is depicted in Figure 5-2.

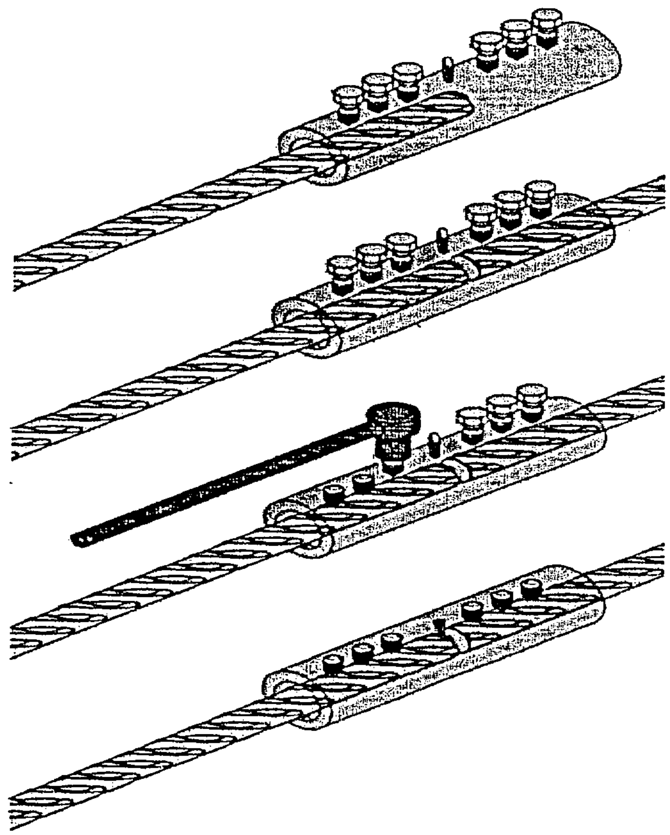

Figure 5-2 – Bar-Lock Coupler Installation

The couplers are easy to install, normally requiring no special equipment and minimal operator training, and do not require special rebar preparation. Each coupler uses lockshear bolts that require a specified minimum torque to shear the bolt heads off. Most coupler sizes can be installed with a standard impact wrench, and smaller sizes require only a manual socket wrench. No heavy crimping equipment or threading devices are required. The couplers can be used when rebar is fixed in a position (positional) as well as when the rebar is free to rotate (standard).

The susceptibility of the Bar-Lock splice bolt tip materials to stress corrosion cracking (SCC) has been considered. For SCC to occur, three elements are required: (1) a susceptible material, (2) a corrosive environment and (3) tensile stress. High hardness, low alloy steels are susceptible to stress corrosion under some circumstances. However, the alkaline environment of properly specified and placed concrete is normally not corrosive to steel. The concrete at Sequoyah is formulated to industry standards and should provide a non-corrosive environment for the reinforcing bar and other steel components. In addition, the bolts in the Bar-Lock splice are tightened against the reinforcing bar so that they are in compression, not tension. Therefore, the three necessary conditions for stress corrosion do not occur in the application of Bar-Lock splice bolt tips at Sequoyah.

6.0 Criteria for Qualification Testing

Regulatory requirements/criteria for the use and testing of mechanical splices are detailed in Section 4.

6.1 Code of Record

As indicated in Sections 3.8.1.2 and 3.8.3.2 of the Sequoyah UFSAR, the structural design of the shield building and interior concrete structures is in compliance with the American Concrete Institute (ACI) 318-63 building code working stress design requirements. The reinforcing steel conforms to the requirements of ASTM Designation A 615, Grade 60. Construction was carried out under the requirements of TVA Construction Specification G-2. UFSAR Section 3.8.1.1 states that reinforcing bars were lap spliced in accordance with ACI 318-63 requirements for Strength Design.

6.2 10CFR50 Appendix B Elements

10CFR50, Appendix B establishes quality assurance requirements for the design, construction, and operation of structures, systems, and components (SSCs) that prevent or mitigate the consequences of postulated accidents that could cause undue risk to the health and safety of the public. The pertinent requirements of 10CFR50, Appendix B apply to activities affecting the safety-related functions of those SSCs. Since the planned use of Bar-Lock couplers at Sequoyah will be to restore the safety-related shield building, 10CFR50, Appendix B requirements are applicable to the design, purchase, fabrication, handling, shipping, storage, inspection, testing, and installation of the couplers. Specifics on conformance to the Appendix B requirements relative to the use of Bar-Lock couplers is provided in the quality assurance manuals, plans, procedures, and specifications described below.

As indicated in Chapter 17 of the Sequoyah UFSAR, design and construction activities at the Sequoyah plant will be in accordance with the latest approved revision of the TVA Nuclear Quality Assurance Plan (TVA-NQA-PLN89-A). Bechtel activities related to the Unit 1 SGRP will be in accordance with the latest revision of the Bechtel Project Nuclear Quality Assurance Manual (PNQAM). INEEL work has been done in accordance with the INEEL Quality Assurance Project Plan. Bechtel witnessed and verified implementation of Bar-Lock's manufacturing quality control processes and procedures for compliance with the applicable provisions of ANSI/ASME N45.2. Reinforcing bar used in testing of the Bar-Lock couplers was procured from Consolidated Power Supply and fabricated by Birmingham Steel Corporation. Activities were performed in accordance with the QA programs in effect at the time of reinforcing bar fabrication and procurement.

Bechtel specifications issued to purchase, test, and install the reinforcing bar and Bar-Lock couplers that will be used to restore the construction opening in the Unit 1 concrete shield building include:

1. Specification 24370-C-311, "Technical Specification for Purchase of Bar-Lock Rebar Couplers", Revision 0.
2. Specification 24370-C-303, "Technical Specification for Purchase of Reinforcing Steel", Revision 0.
3. Specification 24370-C-312, "Technical Specification for Installation of Bar-Lock Rebar Splices", Revision 0.

4. Specification 24370-C-601, "Technical Specification for Qualification of Bar-Lock Coupler System for Use in Nuclear Safety-Related Applications", Revision 0.
5. Specification 24370-C-602, "Technical Specification for Qualification Testing of Bar-Lock Mechanical Rebar Splices", Revision 2.

6.3 QA Programs

6.3.1 Consolidated Power Supply

The reinforcing bar procured for use in the Bar-Lock testing was supplied by Consolidated Power Supply and fabricated by Birmingham Steel Corporation. The supplier's quality assurance program was reviewed by Bechtel and determined to meet the 10CFR50, Appendix B requirements. The supplier's QA program conforms to the provisions of ASME/ANSI N45.2, the applicable ANSI N45.2 series standards and Appendix D of Specification 24370-C-303.

The applicable technical, quality, and document submittal requirements were passed on to Birmingham Steel Corporation. Consolidated Power Supply was responsible for the quality of Birmingham Steel Corporation's work and approval of their QA program.

Reinforcing bar used for Bar-Lock coupler testing is identifiable to specific mill heat number(s) and corresponding mill test report(s) through all stages of fabrication. If an identified piece was cut, the original identification was transferred to each piece prior to cutting.

Reinforcing bar used in the test specimens is identifiable from the stage of manufacture through delivery, acceptance, and while in storage. Packaging, shipping and storage of the reinforcing bar was in accordance with ANSI N45.2.2, Level D.

6.3.2 Bar-Lock

Bar-Lock couplers are not currently manufactured as nuclear safety-related. Since the Bar-Lock couplers will be used in a nuclear safety-related application, they are subject to a commercial grade dedication program. To support this dedication, Bechtel witnessed and verified implementation of the Bar-Lock manufacturing quality control processes and procedures for compliance with the applicable provisions of ANSI/ASME N45.2. Work performed for Bar-Lock by subcontractors was also subjected to the same procedural, approval and access requirements as the Bar-Lock facility.

The following critical processes and parameters were observed and checked by Bechtel quality personnel at the manufacturing facility to verify implementation of the Bar-Lock quality program and procedures and to ensure the final product met the technical requirements.

- Critical Processes
  - Application of material traceability identification on bolt, tube and serrated rail material
  - Tapping of bolt holes
  - Induction heating of bolt tip
  - Fusion of serrated rails to tube
  - Bolt shear test
  - Heat treatment condition of serrated rails

- Critical Parameters
  - Length of tube
  - Inside diameter of tube
  - Outside diameter of tube
  - Number of bolts
  - Serrated rail location
  - Bolt spacing
  - Bolt edge distance
  - Bolt threads
  - Bolt tip hardness
  - Diameter of bolt shear plane
  - Actual bolt break-point torque values

The following records were also examined:

- Certified material test reports for tube, bolt and serrated rail material from each heat lot of couplers
- Bolt tip hardness test results
- Bolt shear test results
- Serrated rail heat treatment report
- Bolt heat treatment report

Item packaging and shipping preparation were also examined prior to the first shipment.

6.3.3 Idaho National Engineering and Environmental Laboratory (INEEL)

Work performed by INEEL has been done in accordance with INEEL's Quality Assurance Project Plan and was reviewed by Bechtel and determined to meet the applicable requirements of 10CFR50, Appendix B. The INEEL QA Project Plan conforms to the provisions of ASME/ANSI N45.2, the applicable ANSI N45.2 series standards, and Appendix C of Specification 24370-C-601.

7.0 Previous Commercial Bar-Lock Testing Information

Information on previous testing of Bar-Lock couplers is provided in Appendices A, B, C and D of this topical report and is summarized below.

7.1 Summary of Previous Tests

As detailed in Appendix A, Wiss, Janney, Elstner (WJE) Associates, Inc. conducted slip tests, tensile strength tests, and compressive strength tests on Bar-Lock S-Series reinforcing bar mechanical couplers. The primary purpose of the tests was to provide data to the International Conference of Building Officials (ICBO) Evaluation Services (ES) for acquiring an evaluation report on the S-Series version of the Bar-Lock coupler. Secondary purposes of the tests were to compare the static strength performance of the S-Series coupler with the static strength requirements for mechanical connections of reinforcing bars contained in ACI 318-95 and to evaluate slip in the coupler utilizing procedures established in Test 670, promulgated by the Department of Transportation of the State of California (Caltrans). The test results showed that the Bar-Lock S-Series couplers met the ACI 318-95 static tensile and compressive strength requirements for mechanically connected reinforcing bars.

As detailed in Appendix B, WJE conducted cyclic tests on S-Series Bar-Lock couplers using a loading protocol established by ICBO ES. This protocol subjected the mechanical connection to 20 elastic cycles below yield, and then 4 inelastic cycles at each of two different strain levels above yield, and then tested the connection to failure under increasing monotonic tension. The test results showed that the Bar-Lock S-Series couplers survived without failure the cyclic ICBO ES testing protocol, and the post-cyclic residual tensile strength of the test specimens exceeded the ACI 318-95 criteria for mechanical connections.

As detailed in Appendix C, WJE conducted tests on L-Series Bar-Lock couplers to evaluate the performance of the couplers after fatigue loading utilizing procedures established by the City of Los Angeles: 100 cycles of tensile load varying from 5% to 90% of the specified yield strength of the reinforcing steel. The couplers passed the cyclic test. The test results also showed that the coupler splices exceed the lesser of either 95% of the average actual ultimate strength or 160% of the specified yield strength of the unspliced reinforcing bar.

As detailed in Appendix D, WJE conducted monotonic compression and reversed-loading cyclic tests on L-Series Bar-Lock couplers in accordance with ICBO ES AC133. The primary purpose of these tests was to provide data to the ICBO ES for acquiring an evaluation report on the L-Series coupler system. A secondary purpose of the tests was to compare the tensile strength performance of the splice with tensile strength requirements for seismic reinforcing bar mechanical splices included in ACI 318-99. The cyclic tensile strengths and monotonic tensile strengths of the Bar-Lock L-Series couplers exceed the minimum strength requirements for a Type 2 seismic mechanical splice according to Chapter 21 of ACI 318-99.

7.2 Conclusions

According to the analyses of Wiss, Janney, Elstner Associates, Inc. the previously tested Bar-Lock S-Series and L-Series couplers have successfully met the static and cyclic strength requirements of ACI 318, the ICBO testing protocol, and the City of Los Angeles fatigue loading tests.

8.0 Bechtel/INEEL Testing Program

8.1 Overview

Bechtel Corporation and INEEL developed and performed an independent mechanical testing and analysis program to assess the mechanical performance characteristics of the Bar-Lock L-Series rebar coupler system. By design, this program provided a very rigorous test of coupler design mechanical performance, using the qualification criteria of ASME Section III, Division 2, CC-4333 as a standard of reference.

The Bechtel/INEEL test program tested and demonstrated that the mechanical properties of the L-Series Bar-Lock mechanical splices meet the existing Codes and NRC requirements and are an acceptable method of connecting reinforcing bar in nuclear power plant safety-related applications.

8.2 Test Plan

ASME Section CC-4333 specifies performance criteria to qualify rebar splicing devices for use in nuclear safety-related applications. While the strength specifications are moderately high, the quantity of test specimens required is relatively low. To achieve high statistical confidence in measured sample parameters, e.g. ultimate strength, a larger sample size (n) is required. To achieve the desired level of confidence that installation of these couplers will have the requisite performance characteristics, the quantity of verification test specimens (the sample set) was increased. For the static strength assessment, the ASME Code requires 6 specimens be tested, and all 6 must pass. In this test plan, the quantity was increased to n = 40 for each size tested. For the cyclic durability test, the ASME Code requires 3 specimens to survive the 100-cycle test. This was increased to n = 40 for each size. Increasing the statistical sample size from 6 or 3 to 40 allows a great improvement in the confidence levels (especially for the binomial distribution of the cyclic test) associated with lower bound strength and cyclic durability requirements specified in the Code.

The Bar-Lock testing was monitored by Bechtel QA/QC personnel to ensure that it was performed in accordance with the requirements in Specification 24370-C-602.

8.3 Mechanical Properties Test Results for Reinforcing Bar

Mechanical properties for the rebar material used in these tests were determined in accordance with project test procedures, incorporating relevant ASTM test standards and procedures (ASTM A 370 and ASTM E 8). Mechanical properties tests were performed on the same universal test machine, using the same measurement transducers. The same test machine, load cell, and extensometer were used in the coupler assembly tests as well. Representative stress-strain curves for both heats of re-bar are provided in Appendix E, Figures 1 and 2.

The reinforcing bar used in the Bar-Lock coupler testing program was ASTM A615 Grade 60 material in #6 (¾ in. nominal diameter) and #8 (1 in. nominal diameter) sizes. Consolidated Power Supply, the vendor of the rebar, provided certified material test reports (CMTRs). The values reported in the CMTRs are based on the results of a single tensile test. The CMTR value, while confirming the nominal material performance, is inadequate to determine "actual" material properties. The ASTM test standard recommends a minimum of three specimens be tested and the results averaged. Additional verification testing was performed as part of this test program to determine the "actual" or measured mechanical properties of the different heats of rebar employed in specimen assembly.

A common heat of rebar (CPS #5898I2899) was used in making up the #6 size coupler test assemblies. Seven #6 size plain bar sections from this heat were tested to determine actual tensile properties of this lot of material (See Appendix E, Table 1). Per ASME Section II, Division 2 requirements, the same 10 inch extensometer gage length, as was used in the #6 coupler assembly tests, was used to measure strain in the tensile properties tests. The test results are summarized in Table 8-1. Material properties obtained from the Consolidated Power Supply CMTR are provided for comparison.

Table 8-1 illustrates that the differences in yield strength value as determined by three different definitions of yield are minimal. For this type of steel, the yield point is the appropriate measurement and provides the most consistent value (smallest standard

deviation). Where "measured" or "actual" yield strength is required in the analyses, 67.7 ksi is used for the #6L coupler tests. Where "measured" or "actual" ultimate tensile strength (UTS, or F_u) is required in the analyses, 107.5 ksi is used for the #6 tests.

Table 8-1 - Mechanical Properties of Rebar Used in Test Specimens

	Yield Point (ksi)[a]	0.2%OS Yield (ksi)[b]	0.5% EUL Yield (ksi)[c]	UTS (ksi)	Elongation (%)[d]	E (Msi)[e]
#6 Average	67.7	67.9	68.2	107.5	13.2	27.8
#6 Std Dev	1.03	1.19	1.14	1.12	1.26	0.89
#6 CMTR	--	--	67.6	107.4	15	--
#8 Average	72.6	72.4	72.5	110.1	11.5	29.2
#8 Std Dev	0.45	0.57	0.47	0.74	0.98	0.46
#8 CMTR	--	--	73.1	112.0	14	--
#8 CMTR (C-series only)	--	69.0	--	112.8	16	--

A common heat of rebar (CPS #589813260) was used in making up the #8 size coupler test assemblies used in the tensile strength tests. Seven #8 size plain bar sections from this heat were tested to determine actual tensile properties of this lot of material (See Appendix E, Table 2). Per ASME requirements, the same 14.5 inch extensometer gage length was used in the tensile properties test as was used in the #8 coupler assembly tests. Test results are summarized in Table 8-1. Material properties obtained from the Consolidated Power Supply CMTR are also provided for comparison. Again, the yield point strength is selected for the material yield strength value. Where "measured" or "actual" yield strength is required in the analyses, 72.6 ksi is used for the #8 tests. Where "measured" or "actual" ultimate strength (UTS) is required in the analyses, 110.1 ksi is used for the #8 tests.

A separate heat of rebar material (CPS #123741) was used to fabricate the #8 size cyclic test coupler assemblies. There are no measured strength parameters (only specified minimums) associated with the cyclic test procedures, so no verification testing of this material was performed. The CMTR-reported values for this heat are provided at the bottom of Table 8-1 for reference.

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[a] The "upper yield point" as observed in most carbon steels.
[b] Yield strength determined using the offset method.
[c] EUL = "extension under load," the stress at a fixed strain offset from the strain point at the onset of loading.
[d] CMTR reports elongation based on the standard 8 inches gage length. By test requirements, the gage lengths used in these tests were 10.0 inches for #6 rebar and 14.5 inches for #8 rebar. There is no requirement or point of comparison in the ASME Code related to the ductility (percent uniform elongation) of the rebar material. It was measured and reported for the plain bar because it is a result of the plain bar test method data analysis of ASTM A370. The measured elongation of the plain bar is not comparable to the elongation measured in the coupler tests.
[e] Modulus of elasticity in 10^6 psi.

8.4 Description of Coupler Test Specimens

The Bar-Lock couplers used in the test and to be used at Sequoyah are Bar-Lock's "L-Series" (coupler designations 6L and 8L), which are higher strength rebar coupler for use in tension/compression, seismic and other cyclic load conditions. The specifications for these couplers are provided in Table 8-2.

Table 8-2 – Bar-Lock L-Series Coupler Specifications (Sizes #6 and #8)

Coupler Designation	For Use on Rebar Size	Coupler Specifications			Bolt Specifications		
		Outside Diameter (inch)	Length (inch)	Nominal Weight (lbs.)	Quantity per Bar	Size (inch)	Nominal Shear Torque (ft.-lb.)
6L	#6	1.9	8.0	4.5	4	1/2	80
8L	#8	2.2	12.3	9.5	5	5/8	180

The component parts of each Bar-Lock coupler consist of a steel tube, "lockshear" bolts, and serrated rails. Figure 5-1 shows a schematic diagram of the coupler design. The seamless, hot-rolled steel tube conforms to ASTM A-519, with a minimum tensile strength in excess of 100 ksi. The lockshear bolt material is AISI 41L40. The bolts are through-hardened over the entire bolt length and induction-hardened at the conical bolt tip. The serrated rails are made of ASTM CD1018 material. They are machined and then carburized to a depth of 0.032 in.

An equivalent testing program was performed for each of the two coupler/rebar sizes tested. For each size, forty test specimen assemblies were made up for tensile strength tests, and forty assemblies were made up for the cyclic durability tests. The test specimens were assembled by construction craft personnel using Bar-Lock's assembly instructions in a normal field environment. Assembly of the test specimens was monitored by Bechtel QC personnel.

8.5 Test Results

The 160 individual coupler specimens tested in this program, and the relevant specimen sample set averages and individual coupler strengths, exceeded the requirements set forth in the ASME Code, Section CC-4333.2.3(a).

Eighty tensile strength tests (forty of each size) were performed on coupler assembly specimens according to relevant sections of ASTM A 370 and E 8, and ASME CC-4333.2.3(a). A representative stress-strain curve for a coupler strength test is provided in Figure 3 in Appendix E. No practical differences were observed in the general character of the stress-strain curve of the 80 specimens tested. Test data collected included stress, strain, crosshead displacement[f], applied force, and elapsed time.

[f] Crosshead displacement refers to the relative separation between the test machine grips – the displacement of the test machine's moving crosshead relative to its fixed one.

The mechanical properties from individual specimen tests, extracted from raw test data using standard analysis methods provided in ASTM E 8, are tabulated in Table 3 in Appendix E. Representative stress-strain plots for a strength test and a cyclic test for each size are provided in Appendix E.

In addition, several specimens of each size were randomly selected to receive an initial slip test prior to the normal strength test. Virgin test specimens were installed in the test machine, and instrumented as for a normal strength test. The applied stress was increased from 0, through 3 ksi, up to 30 ksi, and then reduced to 3 ksi. The change in displacement across the coupler between the two 3 ksi stress levels was measured with an extensometer. Figure 3 in Appendix E shows the traces of applied stress and resultant displacement for the six specimens. In each case, no measurable slip was detected.[g] This was expected due to the mechanical interlocking of coupler and bar in the Bar-Lock coupler design. The observation of no bar slip within the coupler on initial loading means the coupler will develop full strength without excessive deformation upon initial loading.

8.5.1 Tensile Test Results

The ASME Code, Section CC-4333.2.3, has several criteria with which the coupler performance is compared. The two pertinent criteria for the tensile strength test results are as follows:

1. "...The *average tensile strength*[h] of the splices shall not be less than 90% of the actual tensile strength of the reinforcing bar being tested, nor less than 100% of the specified minimum tensile strength."

   As it turns out, the 90% of the actual tensile strength is the governing criteria. For the size #6 group, the specified minimum average strength value is 96.8 ksi. For the size #8 group, the specified minimum average strength value is 99.1 ksi.

   Coupler/bar size #6

   The sample set of strength data from the coupler/bar size #6 was evaluated for normal (Gaussian) probability distribution using the Wilk-Shapiro W-test and graphical analysis methods. The results show a near normal distribution, i.e. only slight departure from normality. Where necessary in the assignment of confidence limits, the assumption of normality is justified.

   The size #6 group (sample set, n = 40) average tensile strength is 106.2 ksi (98.8% of the average #6 bar actual tensile strength), with a standard deviation of only 1.87 ksi. The Code-required average strength value of 96.8 ksi (90% of actual tensile strength) is 5.0 standard deviations below the sample average. This corresponds to a probability of less than 3 in 10 million couplers would have strength less than the required 96.8 ksi minimum value. Further, a one-sided test for lower bound was also performed. This test provides a practical lower limit strength value for the 6L coupler assembly. Based upon this data set, 99% of the couplers of this

[g] The recorded slip displacements, equivalent to less than 0.001 in. over the length of the coupler, were much less than observed hysteresis error in the extensometer.

[h] This is a single average value, calculated from the entire group (sample set) of replicate test specimens, i.e. from one heat of material, in one size.

type will have a tensile strength greater than 100.13 ksi (with a 99% confidence level). This is a very strong indication that the size #6 coupler design will achieve the required minimum strength.

Coupler/bar size #8

The sample set of strength data from the coupler/bar size #8 was also evaluated for normal (Gaussian) probability distribution using the W-test and graphical analysis methods. Again, results show only slight departure from normality.

The size #8 group (sample set, n = 40) average tensile strength is 109.0 ksi (99.0% of the average #8 bar actual tensile strength), with a standard deviation of only 2.78 ksi. The required average strength value of 99.1 ksi is 3.6 standard deviations below the sample average. This corresponds to a probability of less than 2 in 10,000 couplers would have a strength less than the required 99.1 ksi minimum value. Further, a one-sided test for lower bound based upon this data set indicates that, with 99% confidence, 99% of the couplers of this type will have a tensile strength greater than 99.94 ksi. This is a very strong indication that the size #8 coupler design will achieve the required minimum strength.

To assess the general capabilities of the overall coupler design, the results from both sizes tested can be normalized by their respective bar lot (mill heat) tensile strengths and combined into one sample set. In so doing, the conclusion is that the Bar-Lock coupler design produces a splice that will achieve an average strength that is 98.9% as strong as the rebar itself. It is obvious that this greatly exceeds the ASME Code-required 90% value. The cumulative standard deviation is 2.2% of the bar strength, making the required minimum strength 4.0 standard deviations below the sample average. The equivalent likelihood is that only 3 in 100,000 would fail to achieve a strength level equivalent to the rebar ultimate strength.

2. "...The *tensile strength of an individual splice system* (test specimen)[i] shall not be less than 125% of the specified minimum yield strength of the spliced bar."

   This requirement for each individual coupler tested provides additional assurance that the occasional sample tested that may have a relatively low strength value, as compared to the sample set average, at least has an absolute minimum necessary strength for structural considerations. For the Grade 60 rebar used in this study, this required value is 75.0 ksi, and is the same for all specimens tested. All specimens tested in this test program passed this test, and by a very large margin.

   In the simplest case, the pass/fail criteria can be applied directly. For the combined sample size of 80, with no observed failures (strength below 75.0 ksi), the statement can be made that with 90% confidence, no more than 2.8% of couplers would fail this test. By the nature of this type of binomial probability distribution (pass/fail), it is difficult to state reliabilities with a higher level of confidence until many hundreds of samples are assessed. However, by normalizing the measured individual coupler strengths by the required value, an analysis of the amount of deviation on those values can provide a yet stronger comparison and corresponding statement of reliability.

[i] This is the strength value of each individual test specimen (coupler assembly) consisting of one coupler unit and two attached sections of rebar.

This distribution of normalized strengths shows that the average coupler strength is 144% of the minimum required level for individual couplers, with a standard deviation of less than 4%. Within this distribution, the probability that the strength of an individual coupler assembly would be lower than the requirement is negligible.

A comment by the NRC during a presentation on the Bar-Lock couplers on August 9, 2001 was that this minimum strength criterion for individual test specimens should be based upon the actual, measured yield strength of the bar material, rather than the specified minimum value as done above. This makes more sense from a practical view, and it removes one variable (the specified material yield strength) from the comparison. This approach does, however, apply a more stringent test of the coupler capability, since the actual yield strength will always be higher than the minimum allowable. To apply this criterion, the size #6 and size #8 specimens must be treated separately since the measured yield strengths of the two bar sizes are significantly different.

Size #6 Couplers

Using the appropriately normalized test results from the #6 test specimens, the same analysis described above was carried out. The size #6 coupler specimen tensile strengths averaged 106.2 ksi, 25.4% above the proposed strength level of 84.6 ksi (125% * 67.7 ksi) with a standard deviation of 1.86 ksi.

Size #8 Couplers

Analyzing the normalized test results from the #8 test specimens show their tensile strengths averaged 109.0, 20.1% above the proposed strength level of 90.8 ksi (125% * 72.6 ksi) with a standard deviation of 2.81 ksi.

The overall strength performance of the Bar-Lock coupler design can be summarized as excellent, based on this comprehensive test program of different size couplers. There were no failures to meet the specified or proposed strength criteria. As the various failure probability values indicate, the likelihood of an individual Type 6L or 8L coupler assembly failing to achieve the ASME required strength levels is very low.

8.5.2 Cyclic Test Results

Coupler assemblies were cyclically tested according to the requirements of ASME CC-4333.2.3(b). Forty specimens of each of the two types (6L and 8L) received 100 load cycles between 5 and 90% of specified minimum bar yield strength (60 ksi). None of the specimens failed (e.g. bar break or bar slip) within the coupler.

Applied stress and specimen extension data were digitized during the cyclic tests to provided additional insight into the coupler performance under cyclic load conditions. Appendix E, Figure 5 shows a representative plot of stress versus displacement. For clarity, only every tenth cycle is presented. It shows the accumulated slip over 100 cycles to be less than 0.0015 in. This is less than 10% of the elastic deformation that occurs during a single load cycle. The same behavior was observed in all of the tests of both coupler sizes. The couplers showed no significant deterioration (visible, or evidenced by deviations in test data) during the tests.

Based on the binomial probability function (pass/fail testing), and no observed failures in 80 tests, it can be stated with 90% confidence that less than 2.8% of the couplers would fail prior to the completion of 100 loading cycles.

Higher Count Cyclic Tests

In an effort to improve the cyclic durability performance assessment, several of the specimens in each size were selected at random to receive additional cyclic loading. Each selected specimen was subjected to an additional 1000 cycles. None of the specimens failed, and none of them showed signs of deterioration through excessive strain accumulation or physical deformation. While this does not provide a verifiable improvement in the statistical probability of failure (the confidence level is too low to be useful), it does provide an engineering indication that the cyclic durability of the couplers will far exceed 100 cycles.

Residual Strength Tests

Another test was also performed on randomly selected couplers to provide additional information regarding cyclic durability and residual strength. The selected couplers, each having been subjected to 100 loading cycles, were subsequently loaded to failure monotonically. This is the standard "tensile strength test" described in the previous section. The concept here is to determine if the prescribed cyclic loading substantially damages the integrity of the splice assembly. The eight specimens tested achieved the same nominal strength as the corresponding specimens receiving no cyclic loading. Table 4 in Appendix E summarizes these test results. These observations suggest that cyclic loading in the stress range from 3 to 54 ksi does very little, if anything, to reduce the strength capacity of a spliced joint made using the Bar-Lock L-series coupler.

8.5.3 Coupler Test Program Conclusions

The Bar-Lock coupler qualification testing program was carried out on two representative sizes – #6 and #8 – of their L-Series couplers. A total of 160 coupler assemblies were tested. Fourteen pieces of rebar were tested to determine the actual, or measured, mechanical properties of the two heats of bar material used in the test specimens.

The tensile strength tests on 80 samples exceeded the two ASME requirements by a large margin. Statistical analyses of the test results determined several important performance indicators. The overall probability of a coupler assembly (in size #6 or #8) failing to meet the minimum qualification strength criterion is less than 3 in 100,000.

There was some variation in strength between the two heats of rebar used in the strength tests. Comparing and correlating these results show that Bar-Lock L-Series coupler splices can be expected to achieve a tensile strength greater than 96% of the actual bar strength. While there are not enough different combinations of bar material and coupler size data, the combined test results from this program appear similar when normalized by the actual bar strength.

Slip tests performed on selected specimens of both sizes showed a solid mechanical connection between the coupler and the rebar. There was no tendency for the rebar to move within the coupler prior to developing full splice strength. This was expected since the conical-tipped lock bolts physically embed into the bar material providing a physical shear force transfer from bar to coupler.

Each of the 80 splice specimens that underwent the cyclic loading durability test passed the 100-cycle test, with no obvious physical degradation of the spliced joint. To provide an additional degree of assurance of adequate cyclic durability, selected specimens received 1000 cycles of loading, again with no noticeable physical degradation. Some of the specimens that passed the 100 cycle test were subsequently tested by monotonic loading to failure. The resultant measured strengths were essentially the same as the virgin strength test specimens (no cyclic loading applied). These results suggest that the design of the Bar-Lock coupler is essentially insensitive to cyclic loading to levels below 90% of the minimum bar yield strength.

The results of these tests, compared to the ASME splice system qualification requirements, indicate that the Bar-Lock coupler design for rebar splicing is entirely adequate from a strength point of view for use in nuclear safety-related construction. The additional quantity of couplers tested provides higher confidence that the couplers do meet, and indeed far exceed, those ASME-specified requirements.

9.0 Sequoyah Bar-Lock Installation

The qualification test results for the #6 and #8 L-Series Bar-Lock couplers demonstrate that, when compared to the ASME splice system qualification requirements, the Bar-Lock coupler design for rebar splicing is more than adequate from a strength point of view for use in nuclear safety-related construction. The additional couplers tested provide higher confidence that the couplers do meet, and indeed far exceed, those ASME-specified requirements. Therefore, use of Bar-Lock couplers for nuclear safety-related applications at the Sequoyah plant is considered acceptable. These #6 and #8 Bar-Lock couplers will be installed at Sequoyah consistent with the process described in Section 5.0.

9.1 Splicing Crew Qualification

At least one member of each splicing crew will be trained to install the Bar-Lock coupler. Splicing crew qualification will be demonstrated by preparing two qualification (test) splices using the largest bar size to be used. On successful inspection and testing of the qualification splices, the crew will be considered as qualified to perform production splices. Each qualified splicing crew shall be assigned an identification mark to be placed on each completed splice. Splicing crew qualification records shall be retained as permanent records.

9.2 Inspection Criteria

Inspection of splices shall be in accordance with the manufacturer's instructions and ANSI N45.2.5, except as modified by Specification 24370-C-312. Completed splices will be visually inspected for defects. In addition, it will be verified that bolt heads are either sheared off or torqued to specified values and that the Splicer Crew's identification mark is placed on each splice. Results of splice inspections will be documented and retained as permanent records.

9.3 Production/Sister Splice Testing

During the original construction, both rebar production splices and sister splices were used as samples for tensile testing. Sampling of production splices during the

restoration of the openings created during the SGR would increase the amount of concrete chipback and the potential for reinforcing bar damage. In addition to increased concrete chipback, there would be geometric constraints associated with replacing production splices taken for tensile testing.

ANSI N45.2.5-74 takes exception to taking production splice samples when the splicing sleeve is at a leak tight barrier (embedded structural steel sections or liner plate) and instead requires a representative sister splice sample to be taken.

For the Sequoyah SGRP reinforcing bar splice testing program, a similar approach will be used. Production splices will not be removed for tensile testing and sister splices shall be used exclusively. With the exception of substituting a sister splice for a production splice on a one-to-one basis, the splice tensile testing using this sampling scheme is consistent with the sampling in ANSI N45.2.5-74 when testing both sister and production splices. The proposed testing scheme also substitutes a sister splice for a production splice on a one-to-one basis for handling of substandard tensile test results. This proposed testing scheme is conservative when compared with the current edition of ASME Section III, Division 2, which requires tensile testing only one splice (sister or production) for every 100 production splices for ferrous filler metal splices.

9.4 Acceptance Criteria

Criteria for the acceptability of Bar-Lock splices used during the Sequoyah Unit 1 SGRP are detailed in Specification 24370-C-312 and are summarized below.

1. Sister splices will be tensile-tested using the loading rates set forth in ASTM Specification A-370. Testing will determine conformance to the following standards:

    a. The strength of each sample tested shall equal or exceed 125% of the minimum yield strength (i.e. 75,000 psi.)
    b. The average strength of 15 consecutive samples shall equal or exceed the minimum ultimate tensile strength (i.e. 90,000 psi.).

2. If any sample splice used for testing fails to meet the above tensile test requirements and the failure occurs in the rebar, any necessary corrective actions will be determined prior to continuing the testing frequency.

    If a sample splice used for testing fails to meet the above tensile test requirements and the failure occurs in the splice, two additional sister splices made under the same conditions and in the same position shall be produced. If either of these retests fails to achieve 90,000 psi, splicing shall be halted until the cause of the failures has been evaluated and resolved.

3. If the rate of failure does not exceed 1 in 15 consecutive samples, the sampling procedure shall be started anew.

    If the failure rate exceeds 1 in 15 consecutive samples, splicing shall be halted until the cause of the failures has been evaluated and resolved.

4. When splicing is resumed (after being halted for corrective action), the sampling procedure shall be started anew.

9.5 Quality Assurance/Quality Control

Material, installation, inspection and testing of Bar-Lock splices including qualification of installers are classified as safety-related. Safety-related work will comply with Bechtel's Quality Assurance Program for the Sequoyah Nuclear Plant - Unit 1 SGR Project and ANSI N45.2. Qualification of Inspection personnel will comply with ANSI N45.2.6.

10.0 References

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3. ASTM A 370-97a, "Standard Test Methods and Definitions for Mechanical Testing of Steel Products".
4. NRC Regulatory Guide 1.136, "Materials, Construction, and Testing of Concrete Containments", Revision 2.
5. ACI 318-63, "Building Code Requirements for Reinforced Concrete".
6. Tennessee Valley Authority Nuclear Quality Assurance Plant TVA-NQA-PLN89-A, Revision 10.
7. Bechtel Sequoyah Nuclear Power Plant Project Nuclear Quality Assurance Manual (PNQAM), Revision 1.
8. Test Program Plan for Qualification of Bar-Lock Coupler System For Use In Nuclear Safety-Related Applications, Idaho National Engineering and Environmental Laboratory.
9. TVA Construction Specification G-2, TVA General Engineering Specification – Plain and Reinforced Concrete.
10. Sequoyah Updated Final Safety Analysis Report, Amendment 16.
11. ASTM A 615, Standard Specification for Deformed and Plain Billet-Steel Bars for Reinforced Concrete.
12. 10CFR50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants.
13. Bechtel Specification 24370-C-311, Technical Specification for Purchase of Bar-Lock Rebar Couplers, Revision 0.
14. Bechtel Specification 24370-C-303, Technical Specification for Purchase of Reinforcing Steel, Revision 0.
15. Bechtel Specification 24370-C-312, Technical Specification for Installation of Bar-Lock Rebar Splices, Revision 0.
16. Bechtel Specification 24370-C-601, Technical Specification for Qualification of Bar-Lock Coupler System for Use in Nuclear Safety-Related Applications, Revision 0.
17. Bechtel Specification 24370-C-602, Technical Specification for Qualification Testing of Bar-Lock Mechanical Rebar Splices, Revision 2.
18. INEEL Quality Assurance Project Plan for Qualification of Bar-Lock Coupler System for Use in Nuclear Safety-Related Applications, Bechtel Document Number 24370-INEEL-002.
19. Bar-Lock/ Valley Machining Quality Procedures, Bechtel Document Number 24370-BAR-001.
20. Consolidated Power Corporation, Supplier Quality Program Evaluation Report, Bechtel Document Number 24370-SQP-2001-001.
21. ASTM E 8, Standard Test Methods for Tension Testing of Metallic Materials.

Appendix A

Strength Tests of S-Series Bar-Lock (MBT) Coupler

for Bar-Lock (MBT) Coupler Systems, Inc.

WJE No. 952595

May 24, 1996

STRENGTH TESTS OF
S-SERIES BAR-LOCK (MBT) COUPLER
FOR
BAR-LOCK (MBT) COUPLER SYSTEMS, INC.

WJE No. 952595

May 24, 1996

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STRENGTH TESTS OF
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FOR
BAR-LOCK (MBT) COUPLER SYSTEMS, INC.
WJE No. 952595

May 24, 1996

INTRODUCTION

Wiss, Janney, Elstner Associates, Inc. (WJE), has conducted a series of tests on reinforcing bar mechanical connectors for Bar-Lock (MBT) Coupler Systems, Inc. WJE tested the S-Series coupler, the shorter version of the Bar-Lock (MBT) coupler, in bar size Nos. 4 through 11, 14 and 18. Tests on all specimens included slip tests, tensile strength tests, and compressive strength tests.

The primary purpose of the tests reported herein is to provide data to ICBO Evaluation Service, Inc. (ICBO ES), for acquiring an ICBO ES Evaluation Report on the S-Series version of the Bar-Lock (MBT) Coupler. Secondary purposes of the tests are: to compare the static strength performance of the S-Series Bar-Lock (MBT) Coupler with the static strength requirements for mechanical connections of reinforcing bars contained in *Building Code Requirements for Reinforced Concrete (ACI 318-95)*, promulgated by the American Concrete Institute (ACI); and to evaluate slip in the coupler utilizing procedures established in Test 670, promulgated by the Department of Transportation of the State of California (Caltrans).

Unspliced control bar specimens of size Nos. 4 through 11, 14 and 18 were also tested. The control bars came from the same lots of bars as used in fabrication of the connector specimens. The control bar tests were performed to determine the yield strength and tensile strength of the unspliced reinforcing bar. The results of the control bar tests were compared to the requirements of the "Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement," ASTM Designation A615-94.

SPECIMEN ASSEMBLY AND TEST PROCEDURES

Nine S-Series couplers each for bar size Nos. 4 through 11, 14 and 18 were provided to WJE by Bar-Lock. Three couplers of each bar size were tested for slip and then tested under monotonic tension loading to failure, and three specimens were tested under monotonic compression loading. The remaining three specimens were held as spare specimens.

Mechanical Connection Identification. The mechanical splice is comprised of one S-Series Bar-Lock coupler sleeve, which is used to connect two pieces of ASTM A615 reinforcing bar. Key physical data that have been specified for the S-Series couplers by Bar Lock are summarized in Table 1.

At least one representative S-Series Bar-Lock coupler in each bar size was compared to the appropriate Bar-Lock (MBT) Coupler System's standard drawing. WJE made comparisons utilizing drawing Nos. STD-COU-001 through STD-COU-011, dated January 2, 1996. The devices tested have the same general appearance as the devices represented by the drawings. Selected measured dimensions agreed with the dimensions indicated on the standard drawings within a tolerance of 1/16 inch. During this test program, Bar-Lock revised the design of the No. 9 S-Series coupler to be the same as that of the No. 10 S-Series coupler, so that the same device would serve to couple either No. 9 or No. 10 bars. The No. 9 coupler reported herein is the revised design coupler. Bar-Lock indicated that the next revision of the standard drawings would indicate that the same coupler is used for both size Nos. 9 and 10.

Splice Assembly Procedure. Each coupler test specimen consisted of two lengths of reinforcing bar connected by the applicable size coupler. Specimens were assembled in the WJE test laboratory by Bar-Lock personnel, or by WJE personnel in accordance with written installation instructions provided by Bar-Lock.

Reinforcing Bar Sources. The reinforcing bar used in fabricating the specimens were supplied by Bar-Lock. Based on mill certification reports, the bars conform to ASTM A615, Grade 60, deformed reinforcing bar. The bar for each size tested was obtained from a single source. Mill certificates for the reinforcing bar used in fabricating the test specimens may be found in Appendix A.

Testing Procedures for Monotonically Loaded Specimens. All tension test coupler specimens, compression test coupler specimens, and unspliced reinforcing bar specimens were tested monotonically in axial tension or compression in accordance with "Standard Test Methods and Definitions for Mechanical Testing of Steel Products," ASTM A 370. All tests were directed by a licensed professional engineer who is a WJE staff member.

Monotonic tension tests on couplers, monotonic compression tests on couplers, and monotonic tension tests on unspliced control bar specimens utilized test machines as follows: specimens of size Nos. 4 through 7 were tested in a Satec universal test machine having a capacity of 120,000 lbs, and specimens of size Nos. 8 through 14 were tested in a Riehle universal test machine having a capacity of 500,000 lbs. Calibration documents for the test machines are found in Appendix B.

Elongation of tension coupler and each unspliced bar control test specimen was measured by a pair of LVDTs installed in a frame having an adjustable gage length. The electrical signal output from the LVDTs and an electrical signal indication of the test machine load were simultaneously monitored by an X-Y chart recorder, which provided force-elongation plots for all tension test specimens. Gage length of the LVDT test frame for the tension coupler tests was as follows: 8.0 in. for size Nos. 4, 5 and 6; 12.0 in. for size Nos. 7, 8, 9, 10 and 11; 24.0 in. for size No. 14, and 36.0 in. for size No. 18. Gage length for all control bar tests was 8.0 in., except for the No. 18 control bars, which utilized a clip-on extensometer with a gage length of 2.0 in.

Shortening of all compression coupler test specimens was obtained by using an LVDT that monitored test machine crosshead movement. Crosshead movement was taken to directly represent shortening of compression specimens because the projection of reinforcing bar beyond the ends of the coupler was relatively short. Approximate gage lengths between test machine crossheads at zero compressive load was 5.0, 5.8, 7.5, 9.5, 10.0, 11.0, 12.0, 13.8, 20.5 and 36.0 in. for specimens of size Nos. 4, 5, 6, 7, 8, 9, 10, 11, 14 and 18, respectively. The electrical signal output from the LVDT and an electrical signal indication of the test machine load were simultaneously monitored by an X-Y chart recorder, which provided force-deformation plots for all compression test specimens.

Procedures for Measuring Slip. As part of the monotonic tension test to failure, a slip measurement was made for each coupler specimen. The slip measurements were made with the frame-mounted LVDTs described previously, utilizing procedures established by California Department of Transportation (Caltrans) in California Test 670, "Method of Test for Steel Reinforcing Bar Mechanical Butt Splices," revised December 1995. The slip test procedure of California Test 670 may be summarized as follows. After the test specimen is installed in the test machine, but prior to application of any significant load, a reading of the LVDTs is taken. Tensile load is then applied so as to generate a nominal stress of 30 ksi in the test specimen. Next, the tensile load is decreased so as to reduce the nominal stress to 3 ksi, and a second reading of the LVDTs is taken. Slip is calculated as the difference between the second LVDT reading (at 3 ksi) and first LVDT reading (at zero load).

TEST RESULTS

Couplers Tested in Tension. Results of static tensile strength tests on S-Series Bar-Lock (MBT) couplers are summarized in Table 2. A force-elongation plot was recorded for each test; the plots are presented in Appendix C. Failure modes are also noted in Table 2. Slip measurements, made according to the slip procedures of California Test 670, are also summarized in Table 2.

ACI 318-95 gives static strength criteria for mechanical connections in reinforcing bars. Section 12.14.3 requires that "A full mechanical connection shall develop in tension or compression, as required, at least 125 percent of specified yield strength f_y of the bar." The force corresponding to this ACI strength requirement for a coupler in each bar size is also summarized in Table 2, and was calculated as $1.25 \cdot (A_s \cdot f_y)$, where A_s is the nominal bar area, as tabulated in ASTM A615, and f_y is the specified bar yield strength, taken to be 60,000 psi. The static tensile strength of all couplers summarized in Table 2 met the ACI requirement for a full mechanical connection in tension.

Couplers Tested in Compression. Results of static compressive strength tests on S-Series Bar-Lock (MBT) couplers are summarized in Table 3. A load-deformation plot was recorded for each test; the plots are presented in Appendix D. To avert the danger of a failure of a specimen due to compression buckling or compression instability, testing of compression specimens was generally halted at a load corresponding to a nominal compressive stress of approximately 90,000 psi (150 percent of specified bar yield strength, f_y).

ACI 318-95 gives the same static strength criteria for mechanical connection in compression as it does for a mechanical connection in tension, namely, 125 percent of specified yield strength, f_y, of the bar. The force corresponding to this ACI strength requirement for a coupler in each bar size is also summarized in Table 3, and was calculated as described previously for couplers in tension.

The static compressive strength of all couplers summarized in Table 3 met the ACI requirement for a full mechanical connection in compression.

Control Bar Specimens. Results of static strength tests on the unspliced control bar specimens are summarized in Table 4. A force-elongation plot was recorded for each test; the plots are presented in Appendix E. Nominal bar areas were used to calculate stresses from measured test loads. The tabulated yield strength for control bar specimens is based on a yield point observed from a pause of the load indicator, or obtained from the force-elongation plot using the load at an extension of 0.5 percent.

Tensile test requirements for unspliced bar are given in ASTM A 615. Pertinent requirements are listed in Table 4 along with the results of tests on control bar specimens. The tested yield and tensile strengths of all unspliced control bar specimens met the minimum yield strength and minimum tensile strength requirements specified by the ASTM standard for Grade 60 reinforcing bar.

SUMMARY

Monotonic tensile and compressive strength tests were carried out on the S-Series Bar-Lock (MBT) Coupler reinforcing bar mechanical connector system. The S-Series coupler system consistently demonstrated monotonic tensile strengths and monotonic compressive strengths that exceed the strength requirements for mechanically connected reinforcing bars, as stated in *Building Code Requirements for Reinforced Concrete (ACI 318-95)*, published by the American Concrete Institute.

Respectfully Submitted,

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TABLES

TABLE 1 — SPECIFIED PHYSICAL DATA FOR S-SERIES BAR-LOCK (MBT) COUPLERS

Coupler Designation	Bar Size	Tube Dimensions		Bolt Specifications		
		Outside Diameter (in.)	Length (in.)	Quantity	Size (in.)	Torque (ft-lb)
#3/10M	No. 3	1.3	3.9	4	1/2	40
#4/12M	No. 4	1.3	3.9	4	1/2	40
#5/16M	No. 5	1.7	4.5	4	1/2	80
#6/20M	No. 6	1.9	6.3	6	1/2	80
#7/22M	No. 7	1.9	8.0	8	1/2	80
#8/25M	No. 8	2.2	8.0	6	5/8	150
#9/28M	No. 9	2.9	9.0	6	3/4	295
#10/32M	No. 10	2.9	9.0	6	3/4	295
#11/35M	No. 11	3.1	11.5	8	3/4	360
#14/45M	No. 14	3.5	16.5	12	3/4	360
#18/57M	No. 18	4.3	27.9	20	3/4	475

TABLE 2 — TENSILE STRENGTH OF
S-SERIES BAR-LOCK (MBT) COUPLERS

Bar Size/ Specimen Identification	Bar Area (in^2)	Slip (in.)	Tensile Strength			Failure Mode
			(lbs)	(ksi)	(% f_y)	
04-01	0.20	.0012	20,360	101.8	170	Pull-out
04-02		.0030	20,290	101.5	169	Bar break
04-03		.0036	20,510	102.6	171	Bar break
ACI Minimum[a]		—	15,000	75.0	125	—
05-01	0.31	.0022	29,800	96.1	160	Pull-out
05-02		.0023	32,600	105.2	175	Pull-out
05-03		.0031	31,200	100.6	168	Pull-out
ACI Minimum[a]		—	23,250	75.0	125	—
06-01	0.44	.0020	43,300	98.4	164	Pull-out
06-02		.0038	39,100	88.9	148	Pull-out
06-03		.0039	42,600	96.8	161	Pull-out
ACI Minimum[a]		—	33,000	75.0	125	—
07-01	0.60	.0033	50,500	84.2	140	Pull-out
07-02		.0042	50,400	84.0	140	Pull-out
07-03		.0038	48,900	81.5	136	Pull-out
ACI Minimum[a]		—	45,000	75.0	125	—
08-01	0.79	.0049	66,200	83.8	140	Pull-out
08-02		.0047	65,200	82.5	138	Pull-out
08-03		.0044	67,400	85.3	142	Pull-out
ACI Minimum[a]		—	59,250	75.0	125	—
09-01	1.00	.0011	94,500	94.5	158	Pull-out
09-02		.0045	99,000	99.0	165	Pull-out
09-03		.0047	100,750	100.8	168	Pull-out
ACI Minimum[a]		—	75,000	75.0	125	—
10-01	1.27	.0069	111,750	88.0	147	Pull-out
10-02		.0071	109,750	86.4	144	Pull-out
10-03		.0053	109,500	86.2	144	Pull-out
ACI Minimum[a]		—	95,250	75.0	125	—
11-01	1.56	.0035	119,250	76.4	127	Pull-out
11-02		.0053	136,250	87.3	146	Pull-out
11-03		.0049	133,750	85.7	143	Pull-out
ACI Minimum[a]		—	117,000	75.0	125	—
14-01	2.25	.0061	208,750	92.8	155	Pull-out
14-02		.0066	199,750	88.8	148	Pull-out
14-03		.0064	207,500	92.2	154	Pull-out
ACI Minimum[a]		—	168,750	75.0	125	—
18-01	4.00	.0093	357,800	89.5	149	Pull-out
18-02		.0082	355,800	89.0	148	Pull-out
18-03		.0097	363,700	90.9	152	Pull-out
ACI Minimum[a]		—	300,000	75.0	125	—

Note a: Values listed in row are minimum values specified in ACI 318-95 for the indicated connector size.

TABLE 3 — COMPRESSIVE STRENGTH OF
S-SERIES BAR-LOCK (MBT) COUPLERS

Bar Size/ Specimen Identification	Bar Area (in²)	Compressive Strength			Failure Mode
		(lbs)	(ksi)	(% f_y)	
04-04	0.20	17,830	89.2	149	Bar bent
04-05		18,000	90.0	150	No failure
04-06		18,000	90.0	150	No failure
ACI Minimum[a]		15,000	75.0	125	—
05-04	0.31	28,000	90.3	151	No failure
05-05		28,000	90.3	151	No failure
05-06		28,000	90.3	151	No failure
ACI Minimum[a]		23,250	75.0	125	—
06-04	0.44	40,000	90.9	152	No failure
06-05		40,000	90.9	152	No failure
06-06		40,000	90.9	152	No failure
ACI Minimum[a]		33,000	75.0	125	—
07-04	0.60	54,000	90.0	150	No failure
07-05		54,000	90.0	150	No failure
07-06		54,000	90.0	150	No failure
ACI Minimum[a]		45,000	75.0	125	—
08-04	0.79	72,000	91.1	152	No failure
08-05		72,000	91.1	152	No failure
08-06		72,000	91.1	152	No failure
ACI Minimum[a]		59,250	75.0	125	—
09-04	1.00	90,000	90.0	150	No failure
09-05		90,000	90.0	150	No failure
09-06		90,000	90.0	150	No failure
ACI Minimum[a]		75,000	75.0	125	—
10-04	1.27	115,000	90.6	151	No failure
10-05		115,000	90.6	151	No failure
10-06		115,000	90.6	151	No failure
ACI Minimum[a]		95,250	75.0	125	—
11-04	1.56	140,400	90.0	150	No failure
11-05		140,400	90.0	150	No failure
11-06		140,400	90.0	150	No failure
ACI Minimum[a]		117,000	75.0	125	—
14-04	2.25	202,500	90.0	150	No failure
14-05		202,500	90.0	150	No failure
14-06		198,000	88.0	147	No failure
ACI Minimum[a]		168,750	75.0	125	—
18-04	4.00	360,000	90.0	150	No failure
18-05		360,000	90.0	150	No failure
18-06		360,000	90.0	150	No failure
ACI Minimum[a]		300,000	75.0	125	—

Note a: Values listed in row are minimum values specified in ACI 318-95 for the indicated connector size.

TABLE 4 – TENSILE PROPERTIES OF CONTROL BARS

Bar Size/ Specimen Identification	Bar Area (in^2)	Yield Strength			Tensile Strength		
		(lbs)	(ksi)	($\%f_y$)	(lbs)	(ksi)	($\%f_y$)
04-21	0.20	12,550	62.8	105	20,210	101.1	169
04-22		12,510	62.6	104	20,330	101.7	170
04-23		12,770	63.9	107	20,540	102.7	171
ASTM Minimum[a]		12,000	60.0	100	18,000	90.0	150
05-21	0.31	20,500	66.1	110	32,700	105.5	176
05-22		20,800	67.1	112	32,800	105.8	176
05-23		21,250	68.5	114	32,900	106.1	177
ASTM Minimum[a]		18,600	60.0	100	27,900	90.0	150
06-21	0.44	27,500	62.5	104	45,300	103.0	172
06-22		26,500	60.2	100	45,400	103.2	172
06-23		28,000	63.6	106	45,600	103.6	173
ASTM Minimum[a]		26,400	60.0	100	39,600	90.0	150
07-21	0.60	38,900	64.8	108	63,400	105.7	176
07-22		39,600	66.0	110	63,400	105.7	176
07-23		39,800	66.3	111	63,600	106.0	177
ASTM Minimum[a]		36,000	60.0	100	54,000	90.0	150
08-21	0.79	49,800	63.0	105	81,100	102.7	171
08-22		49,600	62.8	105	81,400	103.0	172
08-23		50,100	63.4	106	81,200	102.8	171
08-24		48,800	61.8	103	80,100	101.4	169
ASTM Minimum[a]		47,400	60.0	100	71,100	90.0	150
09-21	1.00	66,700	66.7	111	110,750	110.8	185
09-22		65,400	65.4	109	111,750	111.8	186
09-23		66,200	66.2	110	111,000	111.0	185
ASTM Minimum[a]		60,000	60.0	100	90,000	90.0	150
10-21	1.27	88,000	69.3	116	145,000	114.2	190
10-22		87,500	68.9	115	145,500	114.6	191
10-23		87,750	69.1	115	146,750	115.6	193
ASTM Minimum[a]		76,200	60.0	100	114,300	90.0	150
11-21	1.56	104,250	66.8	111	157,250	100.8	168
11-22		103,750	66.5	111	157,250	100.8	168
11-23		107,750	69.1	115	165,500	106.1	177
ASTM Minimum[a]		93,600	60.0	100	140,400	90.0	150
14-21	2.25	152,500	67.8	113	225,250	100.1	167
14-22		149,500	66.4	111	228,250	101.4	169
14-23		150,500	66.9	112	224,500	99.8	166
ASTM Minimum[a]		135,000	60.0	100	202,500	90.0	150
18-21	4.00	325,000	81.3	136	496,300	124.1	207
18-22		325,000	81.3	136	486,300	121.6	203
18-23		325,000	81.3	136	491,100	122.8	205
ASTM Minimum[a]		240,000	60.0	100	360,000	90.0	150

Note a: Values listed in row are minimum values specified in ASTM A615-94 for the indicated bar size

Appendix B

Cyclic Tests of S-Series Bar-Lock Couplers

for Bar-Lock (MBT) Coupler Systems, Inc.

WJE No. 952595

June 5, 1996

CYCLIC TESTS OF

S-SERIES BAR-LOCK COUPLERS

FOR

BAR-LOCK (MBT) COUPLER SYSTEMS, INC.

WJE No. 952595

June 5, 1996

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CYCLIC TESTS OF S-SERIES BAR-LOCK COUPLERS FOR BAR-LOCK (MBT) COUPLER SYSTEMS, INC.

WJE No. 952595

June 5, 1996

INTRODUCTION

Wiss, Janney, Elstner Associates, Inc. (WJE), has conducted a series of tests on reinforcing bar mechanical connectors for Bar-Lock (MBT) Coupler Systems, Inc. (Bar-Lock). WJE tested mechanical connections made from S-Series Bar-Lock couplers in bar size Nos. 4 through 11 and 14. Tests reported herein include reversed-loading cyclic tests, performed according to a loading protocol established by ICBO Evaluation Service, Inc. (ICBO ES). The ICBO ES cyclic protocol, described in detail in the next section of this report, is a multi-stage test procedure in which the mechanical connection is first subjected to 20 elastic cycles below yield, then 4 inelastic cycles at each of two different strain levels above yield, and then tested to failure under increasing monotonic tension.

Companion coupler specimens were previously tested in monotonic tension and compression, and companion unspliced control bars were tested in monotonic tension. These companion specimens were assembled from the same production lots of couplers and reinforcing bar as the specimens reported herein. The results of the tests on companion specimens are presented in "Strength Tests of S-Series Bar-Lock (MBT) Coupler for Bar-Lock Coupler Systems, Inc.", dated May 24, 1996. The companion coupler specimens met the static strength requirements for mechanical connections of reinforcing bars contained in *Building Code Requirements for Reinforced Concrete (ACI 318-95)*, promulgated by the American Concrete Institute (ACI). The companion control bars met the yield and tensile strength requirements of the "Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement," ASTM Designation A615-94.

TEST PROCEDURES

Test Specimens. The couplers utilized herein were assembled as part of the previously-cited WJE testing on S-Series Bar-Lock couplers, and had been designated as spare specimens at the time of the previous testing. Key physical data that have been specified for the S-Series couplers by Bar Lock are summarized in Table 1. Further descriptions of connector identification, specimen assembly procedures, and reinforcing bar sources may be found in the companion report.

Testing Procedures for Cyclically Loaded Specimens. Three S-Series couplers in each of size Nos. 4 through 11 and 14 were tested cyclically under reversed loading, using the following loading protocol as established by ICBO ES:

Load Stage	Tension Load	Compression Load	No. of Cycles
1	$0.95\,f_y$	$0.5\,f_y$	20
2	$2\,\epsilon_y$	$0.5\,f_y$	4
3	$5\,\epsilon_y$	$0.5\,f_y$	4
4	Load in monotonic tension to failure		

where f_y is the specified minimum yield strength of the reinforcing bar, and ϵ_y is the strain of the reinforcing bar at actual yield stress.

MTS servo-controlled universal test machines with hydraulic grips were utilized for the cyclic testing. Specimens of bar size Nos. 4 through 8 were tested in a machine with a capacity of 100,000 lbs, and larger specimens were tested in a machine with a capacity of 600,000 lbs.

Deformation (slip) of the splice during Stages 1 and 2 was measured by a pair of LVDTs installed in a frame having an adjustable gage length. Gage length of the LVDT test frame was as follows: 8.0 in. for size Nos. 4, 5 and 6; 12.0 in. for size Nos. 7, 8, 9, 10 and 11; and 24.0 in. for size No. 14. Specimen bar strain was monitored during Stages 1, 2 and 3 at a point away from the splice using a clip-on strain gage with a gage length of either 1 or 2 in.

Compression loads and tension loads were programmed into the test machine servo-controller device. The compression load in all cyclic load stages was set to $0.5 \cdot (A_s \cdot f_y)$, where A_s is nominal bar area

as listed in ASTM A615, and f_y is a specified minimum yield strength of 60,000 psi. The tension load for Stage 1 was set to $0.95 \cdot (A_s \cdot f_y)$. Tension load for Stage 2 was determined by monitoring the specimen bar strain at a point away from the splice, and then applying load to the specimen until a strain reading of 2 ϵ_y was obtained. Tension load for Stage 3 was similarly obtained using a bar strain criteria of 5 ϵ_y. The reinforcing bar strain, ϵ_y, was determined graphically from the average of the apparent yield strain results of tensile tests on unspliced control bars.

TEST RESULTS

Previous Tests on Companion Specimens. Companion coupler specimens were previously tested in monotonic tension and monotonic compression, and companion unspliced control bar specimens were previously tested in monotonic tension. A full description of the companion tests may be found in the previously-cited companion report, "Strength Tests of S-Series Bar-Lock (MBT) Coupler for Bar-Lock Coupler Systems, Inc.", by WJE and dated May 24, 1996. The companion coupler specimens met the tensile and compressive strength requirement of $1.25 \cdot (A_s \cdot f_y)$ for mechanical connections of reinforcing bars, as contained in *Building Code Requirements for Reinforced Concrete (ACI 318-95)*. The companion control bars met the yield and tensile strength requirements of the "Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement," ASTM Designation A615-94.

For ease of reference, the results of some of these previous tests are summarized again herein: the monotonic tensile tests on companion couplers are summarized in the attached Table 2, and the results of monotonic tension tests on companion unspliced control bars are summarized in the attached Table 3.

Couplers Tested Cyclically per ICBO ES Protocol. The ICBO ES cyclic test procedure includes the monitoring of slip in the coupler during cyclic load Stages 1 and 2. There is no monitoring of slip during Stage 3, but the specimen is required to survive the Stage 3 cycling without failure. The requirement for Stage 4 is that the breaking strength of the specimen is a minimum of 1.35 f_y.

Results of the cyclic tests per ICBO ES protocol are summarized in Table 4. Slip during Stages 1 and 2 are noted in the table. All specimens survived Stage 3 cycling without failure. All but two specimens demonstrated a Stage 4 tensile strength in excess of 1.35 f_y. These two specimens, Specimens 11-08 and 11-09, did exhibit a Stage 4 tensile strength in excess of 1.25 f_y, which is the strength criteria as stated in *Building Code Requirements for Reinforced Concrete (ACI 318-95)*, published by the American Concrete Institute.

SUMMARY

Cyclic tests were carried out on S-Series Bar-Lock (MBT) reinforcing bar couplers in bar size Nos. 4 through 11 and 14. The S-Series Bar-Lock couplers consistently survived without failure the cyclic testing protocol stipulated by ICBO ES, the post-cyclic residual tensile strength for all but two specimens reported herein exceeded the tensile strength criteria of 1.35 f_y established by ICBO ES. Additionally, the post-cyclic residual tensile strength for all specimens reported herein exceeded the tensile strength criteria of 1.25 f_y for mechanical connections as stated in *Building Code Requirements for Reinforced Concrete (ACI 318-95)*, published by the American Concrete Institute.

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TABLES

TABLE 1 — SPECIFIED PHYSICAL DATA FOR S-SERIES BAR-LOCK (MBT) COUPLERS

Coupler Designation	Bar Size	Tube Dimensions		Bolt Specifications		
		Outside Diameter (in.)	Length (in.)	Quantity	Size (in.)	Torque (ft-lb)
#3/10M	No. 3	1.3	3.9	4	1/2	40
#4/12M	No. 4	1.3	3.9	4	1/2	40
#5/16M	No. 5	1.7	4.5	4	1/2	80
#6/20M	No. 6	1.9	6.3	6	1/2	80
#7/22M	No. 7	1.9	8.0	8	1/2	80
#8/25M	No. 8	2.2	8.0	6	5/8	150
#9/28M	No. 9	2.9	9.0	6	3/4	295
#10/32M	No. 10	2.9	9.0	6	3/4	295
#11/35M	No. 11	3.1	11.5	8	3/4	360
#14/45M	No. 14	3.5	16.5	12	3/4	360
#18/57M	No. 18	4.3	27.9	20	3/4	475

TABLE 2 — TENSILE STRENGTH OF S-SERIES BAR-LOCK (MBT) COUPLERS

Bar Size/ Specimen Identification	Bar Area (in^2)	Slip[b] (in.)	Tensile Strength (lbs)	(ksi)	($\% f_y$)	Failure Mode
04-01	0.20	.0012	20,360	101.8	170	Pull-out
04-02		.0030	20,290	101.5	169	Bar break
04-03		.0036	20,510	102.6	171	Bar break
ACI Minimum[a]		—	15,000	75.0	125	—
05-01	0.31	.0022	29,800	96.1	160	Pull-out
05-02		.0023	32,600	105.2	175	Pull-out
05-03		.0031	31,200	100.6	168	Pull-out
ACI Minimum[a]		—	23,250	75.0	125	—
06-01	0.44	.0020	43,300	98.4	164	Pull-out
06-02		.0038	39,100	88.9	148	Pull-out
06-03		.0039	42,600	96.8	161	Pull-out
ACI Minimum[a]		—	33,000	75.0	125	—
07-01	0.60	.0033	50,500	84.2	140	Pull-out
07-02		.0042	50,400	84.0	140	Pull-out
07-03		.0038	48,900	81.5	136	Pull-out
ACI Minimum[a]		—	45,000	75.0	125	—
08-01	0.79	.0049	66,200	83.8	140	Pull-out
08-02		.0047	65,200	82.5	138	Pull-out
08-03		.0044	67,400	85.3	142	Pull-out
ACI Minimum[a]		—	59,250	75.0	125	—
09-01	1.00	.0011	94,500	94.5	158	Pull-out
09-02		.0045	99,000	99.0	165	Pull-out
09-03		.0047	100,750	100.8	168	Pull-out
ACI Minimum[a]		—	75,000	75.0	125	—
10-01	1.27	.0069	111,750	88.0	147	Pull-out
10-02		.0071	109,750	86.4	144	Pull-out
10-03		.0053	109,500	86.2	144	Pull-out
ACI Minimum[a]		—	95,250	75.0	125	—
11-01	1.56	.0035	119,250	76.4	127	Pull-out
11-02		.0053	136,250	87.3	146	Pull-out
11-03		.0049	133,750	85.7	143	Pull-out
ACI Minimum[a]		—	117,000	75.0	125	—
14-01	2.25	.0061	208,750	92.8	155	Pull-out
14-02		.0066	199,750	88.8	148	Pull-out
14-03		.0064	207,500	92.2	154	Pull-out
ACI Minimum[a]		—	168,750	75.0	125	—

Note a: Values listed in row are minimum values specified in ACI 318-95 for the indicated connector size.
Note b: Slip measurements made according to procedures of California Test 670.

TABLE 3 — TENSILE PROPERTIES OF CONTROL BARS

Bar Size/ Specimen Identification	Bar Area (in^2)	Yield Strength			Tensile Strength		
		(lbs)	(ksi)	(%f_y)	(lbs)	(ksi)	(%f_y)
04-21	0.20	12,550	62.8	105	20,210	101.1	169
04-22		12,510	62.6	104	20,330	101.7	170
04-23		12,770	63.9	107	20,540	102.7	171
ASTM Minimum[a]		12,000	60.0	100	18,000	90.0	150
05-21	0.31	20,500	66.1	110	32,700	105.5	176
05-22		20,800	67.1	112	32,800	105.8	176
05-23		21,250	68.5	114	32,900	106.1	177
ASTM Minimum[a]		18,600	60.0	100	27,900	90.0	150
06-21	0.44	27,500	62.5	104	45,300	103.0	172
06-22		26,500	60.2	100	45,400	103.2	172
06-23		28,000	63.6	106	45,600	103.6	173
ASTM Minimum[a]		26,400	60.0	100	39,600	90.0	150
07-21	0.60	38,900	64.8	108	63,400	105.7	176
07-22		39,600	66.0	110	63,400	105.7	176
07-23		39,800	66.3	111	63,600	106.0	177
ASTM Minimum[a]		36,000	60.0	100	54,000	90.0	150
08-21	0.79	49,800	63.0	105	81,100	102.7	171
08-22		49,600	62.8	105	81,400	103.0	172
08-23		50,100	63.4	106	81,200	102.8	171
08-24		48,800	61.8	103	80,100	101.4	169
ASTM Minimum[a]		47,400	60.0	100	71,100	90.0	150
09-21	1.00	66,700	66.7	111	110,750	110.8	185
09-22		65,400	65.4	109	111,750	111.8	186
09-23		66,200	66.2	110	111,000	111.0	185
ASTM Minimum[a]		60,000	60.0	100	90,000	90.0	150
10-21	1.27	88,000	69.3	116	145,000	114.2	190
10-22		87,500	68.9	115	145,500	114.6	191
10-23		87,750	69.1	115	146,750	115.6	193
ASTM Minimum[a]		76,200	60.0	100	114,300	90.0	150
11-21	1.56	104,250	66.8	111	157,250	100.8	168
11-22		103,750	66.5	111	157,250	100.8	168
11-23		107,750	69.1	115	165,500	106.1	177
ASTM Minimum[a]		93,600	60.0	100	140,400	90.0	150
14-21	2.25	152,500	67.8	113	225,250	100.1	167
14-22		149,500	66.4	111	228,250	101.4	169
14-23		150,500	66.9	112	224,500	99.8	166
ASTM Minimum[a]		135,000	60.0	100	202,500	90.0	150

Note a: Values listed in row are minimum values specified in ASTM A615-94 for the indicated bar size

TABLE 4 - RESULTS OF REVERSED-LOADING CYCLIC TESTS ON S-SERIES BAR-LOCK (MBT) COUPLERS

Bar Size/ Specimen Identification	Stage 1: Cyclic		Stage 2: Cyclic		Stage 3: Cyclic		Stage 4: Monotonic Tension		
	Cycles	Slip (in.)	Cycles	Slip (in.)	Cycles	Status[a]	Tensile Strength (lbs)	Tensile Strength (% f_y)	Failure Mode
04-07	20	0.010	4	0.023	4	NF	19,460	162	Pullout
04-08	20	0.010	4	0.029	4	NF	20,460	171	Bar break
04-09	20	0.009	4	0.021	4	NF	18,260	152	Pullout
05-07	20	0.006	4	0.016	4	NF	32,040	172	Pullout
05-08	20	0.008	4	0.017	4	NF	28,870	155	Pullout
05-09	20	0.008	4	0.024	4	NF	30,800	166	Pullout
06-07	20	0.013	4	0.023	4	NF	42,530	161	Pullout
06-08	20	0.014	4	0.025	4	NF	42,050	159	Pullout
06-09	20	0.008	4	0.019	4	NF	41,530	157	Pullout
07-07	20	0.016	4	0.046	4	NF	50,100	139	Pullout
07-08	20	0.013	4	0.044	4	NF	53,170	148	Pullout
07-09	20	0.011	4	0.038	4	NF	54,960	153	Pullout
08-07	20	0.017	4	0.033	4	NF	65,580	138	Pullout
08-08	20	0.014	4	0.045	4	NF	66,800	141	Pullout
08-09	20	0.013	4	0.028	4	NF	65,680	139	Pullout
09-07	20	0.009	4	0.024	4	NF	98,600	164	Pullout
09-08	20	0.011	4	0.023	4	NF	104,400	174	Partial slip, then bar break at first bolt
09-09	20	0.016	4	0.034	4	NF	95,400	159	Pullout
10-07	20	0.012	4	0.035	4	NF	112,800	148	Pullout
10-08	20	0.011	4	0.033	4	NF	124,200	163	Pullout
10-09	20	0.011	4	0.031	4	NF	115,900	152	Bar break at first bolt
11-07	20	0.013	4	0.042	4	NF	132,600	142	Pullout
11-08	20	0.019	4	0.047	4	NF	118,600	127	Pullout
11-09	20	0.027	4	0.058	4	NF	120,200	128	Pullout
14-07	20	0.021	4	0.053	4	NF	193,200	143	Pullout
14-08	20	0.011	4	0.044	4	NF	190,800	141	Pullout
14-09	20	0.020	4	0.057	4	NF	197,000	146	Pullout

Notes: a: NF = No failure during stage 3 cycling.

Appendix C

Cyclic Tests of L-Series Bar-Lock (MBT) Couplers

for Bar-Lock (MBT) Coupler Systems, Inc.

WJE No. 962136

October 16, 1997

CYCLIC TESTS OF L-SERIES BAR-LOCK (MBT) COUPLERS FOR BAR-LOCK (MBT) COUPLER SYSTEMS, INC.

WJE No. 962136

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CYCLIC TESTS OF L-SERIES BAR-LOCK (MBT) COUPLERS FOR BAR-LOCK (MBT) COUPLER SYSTEMS, INC.

WJE NO. 961236

October 16, 1997

INTRODUCTION

Wiss, Janney, Elstner Associates, Inc. (WJE) has conducted a series of cyclic tests on L-Series reinforcing bar mechanical connectors for Bar-Lock (MBT) Coupler Systems, Inc. Tests were conducted on three bars in each of bar size Nos. 4, 5, 6, 7, 8, 9, 10, 11 and 14. The purpose of the tests was to evaluate the performance of the couplers after fatigue loading utilizing procedures established by the City of Los Angeles: 100 cycles of tensile load varying from 5-percent to 90-percent of the specified yield strength of reinforcing steel. The tests were also compared to the requirements outlined in the 1997 Uniform Building Code (Section 1921.2.6).

Unspliced control bar specimens of size Nos. 4, 5, 6, 7, 8, 9, 10, 11, and 14 in bar Grade 60 were also tested. The control bars came from the same lots of bars as used in fabrication of the connector specimens. The control bar tests were performed to determine the yield strength and tensile strength of the unspliced reinforcing bar. The results of the control bar tests were compared to the requirements of the "Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement," ASTM Designation A615-94. It should be noted that the reinforcing bar for testing bar size No. 10 was ASTM A706-93a.

SPECIMEN ASSEMBLY AND TEST PROCEDURES

Splice Assembly Procedure - The mechanical splice is comprised of one L-Series Bar-Lock coupler sleeve, which is used to connect two pieces of reinforcing bar. Each coupler test specimen consisted of two lengths of reinforcing bar connected by the applicable size coupler. The reinforcing bars used in fabricating the specimens were supplied by Bar-Lock. Bar-Lock represents that the bar for each size tested was obtained from

a single source. Specimens were assembled by Bar-Lock personnel in accordance with their written installation instructions and then shipped to the WJE laboratories for testing.

Testing Procedures for Control Bar Specimens - Unspliced reinforcing bar specimens were tested monotonically in axial tension in accordance with "Standard Test Methods and Definitions for Mechanical Testing of Steel Products," ASTM A 370. All tests were directed by a licensed professional engineer who is a WJE staff member. A pair of LVDTs installed in a frame having an adjustable gage length measured elongation of each unspliced control bar test specimen. The electrical signal output from the LVDTs and an electrical signal indication of the test machine load were simultaneously monitored by an X-Y chart recorder, which provided force-elongation plots for all tension test specimens. Gage length of the LVDT test frame was 8.0 in.

City of Los Angeles Cyclic Test Procedure - For each bar size, three coupled specimens were loaded cyclically prior to the monotonic tension test to failure. The specimens were loaded from 5% to 90% F_y using a Haversine wave form at a rate of 0.5 cycles per second for 100 cycles. After completion of the cycles, each specimen was monotonically loaded in tension to failure. The City of Los Angeles test procedure states that the average tensile strength of the splices shall not be less than 90-percent of the average actual (tested) tensile strength of the unspliced reinforcing bar nor less than 100-percent of the specified minimum tensile strength of the bar.

1997 Uniform Building Code Test Requirements – The 1997 Uniform Building Code states in Section 1921.2.6 that mechanical connections develop in tension the lesser of 95-percent of the [average actual] ultimate tensile strength or 160-percent of the specified yield strength of the unspliced reinforcing bar.

TEST RESULTS

Control Bar Specimens - Results of static strength tests on the unspliced control bar specimens are summarized in Table 1. A force-elongation plot was recorded for each test; the plots are presented in Appendix A. Nominal bar areas were used to calculate stresses from measured test loads. The tabulated yield strength for control bar specimens is based on a yield point observed from a pause of the load indicator.

Tensile test requirements for unspliced bar are given in ASTM A615-94. Pertinent requirements are listed in Table 1 along with the results of tests on control bar specimens. The tested yield and tensile strengths

of all unspliced control bar specimens met the minimum yield strength and minimum tensile strength requirements specified by the ASTM standard for Grade 60 reinforcing bar. Size No. 10 bar meets the tensile strength criteria for both ASTM A615-94 and ASTM A706-93a.

Coupler Test Results - Results of static tensile strength tests on L-Series Bar-Lock (MBT) couplers after cyclically loaded in accordance with City of Los Angeles test procedures are summarized in Table 2. A summary comparing the average tensile strengths of couplers after cycling to 90-percent of the average tested tensile strength of the unspliced bar is shown in Table 3. The results shown in Table 3 indicate that the average coupler tensile strength for all bar sizes tested exceed both 100-percent of the specified minimum tensile strength and 90-percent of the average actual tensile strength of the unspliced reinforcing bar. Also included in Table 3 is a comparison of the average tested tensile strengths of the couplers to the UBC Section 1921.2.6 requirements. The results indicate that the couplers exceed either 95-percent of the average actual ultimate strength or 160-percent of the specified yield strength of the unspliced reinforcing bar.

SUMMARY

Strength tests were carried out on the L-Series Bar-Lock (MBT) Coupler reinforcing bar mechanical connector system after application of cyclic loads in accordance with the City of Los Angeles test procedure. The L-Series coupler system consistently demonstrated monotonic tensile strengths that exceeded the specified strength requirements after cyclic loading in all bar sizes tested herein. The L-Series coupler system also exceeded the specified strength requirements in the 1997 Uniform Building Code.

Respectfully Submitted,

WISS, JANNEY, ELSTNER ASSOCIATES, INC.

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Project Manager

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100435

TABLE 1 - TENSILE PROPERTIES OF CONTROL BARS

Bar Size/ Specimen Identification	Bar Area (in^2)	Yield Strength			Tensile Strength		
		(lbs)	(ksi)	($\%F_y$)	(lbs)	(ksi)	($\%F_y$)
04L-21	0.20	13,900	69.5	116	22,350	111.8	186
04L-22		14,380	71.9	120	22,570	112.9	188
04L-23		14,070	70.3	117	22,340	111.7	186
ASTM Minimum[a]		12,000	60.0	100	18,000	90.0	150
05L-21	0.31	19,380	62.5	104	30,600	98.7	164
05L-22		19,440	62.7	105	30,700	99.0	165
05L-23		19,480	62.8	105	30,800	99.4	166
ASTM Minimum[a]		18,600	60.0	100	27,900	90.0	150
06L-21	0.44	27,500	62.5	104	44,500	101.1	168
06L-22		27,700	62.9	105	44,700	101.6	169
06L-23		27,900	63.4	106	44,900	102.0	170
ASTM Minimum[a]		26,400	60.0	100	39,600	90.0	150
07L-21	0.60	38,000	63.3	106	62,300	103.8	173
07L-22		38,700	64.5	107	62,000	103.3	172
07L-23		38,100	63.5	106	61,500	102.5	171
ASTM Minimum[a]		36,000	60.0	100	54,000	90.0	150
08L-21	0.79	52,100	65.9	110	83,500	105.7	176
08L-22		49,100	62.1	104	81,200	102.8	171
08L-23		49,100	62.1	104	81,600	103.3	172
ASTM Minimum[a]		47,400	60.0	100	71,100	90.0	150
09L-21	1.00	65,400	65.4	109	104,500	104.5	174
09L-22		65,800	65.8	110	106,200	106.2	177
09L-23		65,600	65.6	109	106,400	106.4	177
ASTM Minimum[a]		60,000	60.0	100	90,000	90.0	150
10L-21	1.27	82,500	65.0	108	122,000	96.1	160
10L-22		82,900	65.3	109	122,300	96.3	161
10L-23		82,500	65.0	108	121,600	96.0	160
ASTM Minimum[a]		76,200	60.0	100	114,300	90.0	150
11L-21	1.56	104,600	67.1	112	152,000	97.4	162
11L-22		104,800	67.2	112	152,300	98.3	164
11L-23		104,400	66.9	111	153,100	98.1	164
ASTM Minimum[a]		93,600	60.0	100	140,400	90.0	150
14L-21	2.25	159,700	71.0	118	242,700	107.9	180
14L-22		160,500	71.3	119	242,400	107.7	180
14L-23		160,500	71.3	119	242,400	107.7	180
ASTM Minimum[a]		135,000	60.0	100	202,500	90.0	150

Note a: Values listed in row are minimum values specified in ASTM A615-94 for the indicated bar size

TABLE 2 – CYCLIC LOAD TEST RESULTS OF L-SERIES BAR-LOCK COUPLERS

Sample No.	Cyclic Load Range		Tensile Strength		
	Min = 0.05 F_y (lbs)	Max = 0.90 F_y (lbs)	(lbs)	(psi)	% F_y
04L-1			22,920	114,600	191
04L-2	600	10,800	22,740	113,700	190
04L-3			22,730	113,600	189
			Average	114,000	190
05L-1			31,250	100,800	168
05L-2	930	16,740	31,370	101,200	169
05L-3			31,480	101,500	169
			Average	101,100	169
06L-1			45,510	103,400	172
06L-2	1,320	23,760	45,570	103,600	173
06L-3			45,370	103,100	172
			Average	103,400	172
07L-1			63,300	105,500	176
07L-2	1,800	32,400	60,290	100,500	168
07L-3			61,680	102,800	171
			Average	102,900	172
08L-1			74,900	94,800	158
08L-2	2,370	42,660	82,280	104,200	174
08L-3			80,610	102,000	170
			Average	100,300	167
09L-1			96,610	96,610	161
09L-2	3,000	54,000	96,850	96,850	162
09L-3			103,800	103,800	173
			Average	99,100	165
10L-1			121,300	95,500	159
10L-2	3,810	68,600	116,200	91,500	152
10L-3			120,800	95,100	158
			Average	94,000	156
11L-1			163,700	104,900	175
11L-2	4,680	84,240	161,800	103,700	173
11L-3			158,800	101,800	170
			Average	103,500	173
14L-1			221,500	98,400	164
14L-2	6,750	121,500	234,500	104,200	174
14L-3			234,000	104,000	173
			Average	102,200	170

TABLE 3 – SUMMARY OF CYCLIC LOAD TEST RESULTS OF L-SERIES BAR-LOCK COUPLERS

		CITY OF LOS ANGELES REQUIREMENTS		UBC 1997 REQUIREMENTS	
Bar Size	Average Coupler Tensile Strength (psi)	90% of Average Tested Tensile Strength of Unspliced Bar (psi)	100% of the Specified Tensile Strength (psi)	95% of the Average Tested Tensile Strength of Unspliced Bar (psi)	160% of the Specified Yield Strength (psi)
4	114,000	100,900	90,000	106,500	96,000
5	101,100	89,100	90,000	94,100	96,000
6	103,400	91,400	90,000	96,500	96,000
7	102,900	92,900	90,000	98,000	96,000
8	100,300	93,500	90,000	98,700	96,000
9	99,100	95,100	90,000	100,400	96,000
10	94,000	86,500	90,000	91,300	96,000
11	103,500	88,100	90,000	93,000	96,000
14	102,200	97,000	90,000	102,400	96,000

Appendix D

ICBO ES Cyclic Tests on L-Series MBT Couplers

for Bar-Lock Coupler Systems

WJE No. 982850-A

October 27, 1999

Wiss, Janney, Elstner Associates, Inc.

ICBO ES CYCLIC TESTS ON L-SERIES MBT COUPLERS FOR BAR-LOCK COUPLER SYSTEMS

WJE No. 982850-A

October 27, 1999

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ICBO ES CYCLIC TESTS ON
L-SERIES MBT COUPLERS
FOR BAR-LOCK COUPLER SYSTEMS
WJE No. 982850-A

October 27, 1999

INTRODUCTION

Wiss, Janney, Elstner Associates, Inc. (WJE), has conducted a series of monotonic compression and reversed-loading cyclic tests on reinforcing bar mechanical splices for Bar-Lock Coupler Systems (Bar-Lock). The tests were conducted on L-Series MBT mechanical splices in bar size Nos. 4 through 11 and 14. The test procedures were in general accordance with "Acceptance Criteria for Mechanical Connectors for Steel Bar Reinforcement," AC133, January 1998, issued by ICBO Evaluation Services (ICBO ES). A copy of this document can be found in Appendix A.

The primary purpose of the tests reported herein is to provide data to ICBO ES for acquiring an evaluation report on the L-Series MBT coupler system. A secondary purpose of the tests is to compare the tensile strength performance of this splice with tensile strength requirements for seismic reinforcing bar mechanical splices included in *Building Code Requirements for Reinforced Concrete (ACI 318-99)*, promulgated by the American Concrete Institute (ACI).

Unspliced control bar specimens were also tested. For each bar size, the control bars came from the same lot of bar used to make the splice specimens, which were assembled using ASTM A615, Grade 60 reinforcing bar. The control bar tests were performed to determine the yield strength, yield strain, tensile strength and final elongation of the unspliced reinforcing bar. The results of the control bar tests were compared to the requirements of the "Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement," ASTM Designation A615-96b.

SPECIMEN ASSEMBLY AND TEST PROCEDURES

Connector Identification. Assembled splice specimens were provided to WJE by Bar-Lock. WJE witnessed assembly of select splice specimens, and observed that assembly was in accord with Bar-Lock procedures. Figure 1 schematically illustrates the typical Bar-Lock L-Series MBT coupler. Specified dimensions for L-Series MBT couplers are summarized in Table 1. Representative couplers in each size were compared to Bar-Lock standard drawing No. L-SUM, with revisions dated September 1999, and other related Bar-Lock standard drawings for the L-Series MBT couplers. The devices tested have the same appearance as the devices represented by the drawings. Selected dimensions were measured and were found to agree with the dimensions indicated in Table 1 and on the standard drawing L-SUM, with tolerances as stated on the standard drawings.

Control Bar Specimens and Reinforcing Bar Sources. Bar-Lock provided to WJE the unspliced control bar specimens. Bar-Lock represents that all pieces of reinforcing bar in each size, whether a control bar specimen or in an assembled splice specimen, came from the same lot of reinforcing steel. Bar-Lock also indicated the reinforcing bar is ASTM A615, Grade 60. Mill marks found on the reinforcing bar confirm the bar type and grade.

Test Procedures for Monotonic Tension Tests. Unspliced control bar specimens and certain selected spliced 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 pair of LVDTs installed in a frame having an adjustable gage length measured elongation of each unspliced control bar test specimen. The electrical signal output from the LVDTs and an electrical signal indication of the test machine load were simultaneously recorded by an analog X-Y chart recorder, or were digitally recorded on a computer. Force-elongation plots for all control bar specimens were produced either by the analog chart or by plotting the digital record. Gage length of the LVDT test frame was 8.0 in. for the unspliced bar specimens. This same instrumentation was also utilized on spliced bar

specimens tested in monotonic tension. Gage lengths for the spliced bar specimens are given later in this report.

For unspliced bar specimens, 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 in. and approximately centered on the fracture location. The elongation was calculated as the increase in length of the gage length. Final elongation was not determined for spliced bar specimens.

Compression Tests on Splice Specimens. Shortening of all compression sleeve splice test specimens was obtained by using an electrical output from an LVDT, internal to the test machine, that monitored test machine piston position. For this type of test machine, piston movement is the same as crosshead movement in other types of test machines. Piston movement was taken to directly represent shortening of compression specimens because the clear length of reinforcing bar between the ends of the coupler and the test machine grip was 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.

The clear length between test machine grips was kept to a minimum in order to prevent buckling of the specimen in compression. Approximate clear gage length between test machine grips at zero compressive load was 8.3, 9.0, 10.0, 11.8, 12.1, 13.8, 14.5, 19.0, and 22.0 inches for specimens in bar size Nos. 4, 5, 6, 7, 8, 9, 10, 11 and 14, respectively. These distances are approximately equal to the length of the splice plus one bar diameter at each end of the splice.

Testing Procedures for Cyclically Loaded Specimens. Reversed-load cyclic tests utilized the following loading protocol, as established by ICBO ES in the AC133 document:

Load Stage	Tension Load.	Compression Load	No. of Cycles
1	$0.95 f_y$	$0.5 f_y$	20
2	$2 \varepsilon_y$	$0.5 f_y$	4
3	$5 \varepsilon_y$	$0.5 f_y$	4
4	Load in monotonic tension to failure		

where f_y is the specified minimum yield strength of the reinforcing bar, and ε_y is the strain of the reinforcing bar at [actual] yield stress.

Elongation (slip) of the splice during Stages 1, 2 and 3 was monitored by a pair of LVDTs installed in a frame having a gage length of 8, 8, 10, 12, 12, 15, 16, 19 and 24 in. for specimens in bar size Nos. 4, 5, 6, 7, 8, 9, 10, 11 and 14, respectively. Strain in the reinforcing bar was monitored for reference purposes during Stages 1, 2, 3 and 4 at a point away from the splice zone using a clip-on strain gage with a gage length of 2 in. Test machine piston position was also monitored. The instrumentation setup is schematically illustrated in Fig. 2.

Compression loads and tension loads for Stages 1, 2 and 3 were programmed into the test machine controller, which was operated under load control for the cycling. The compression load in all cyclic load stages was set to $0.5 \cdot (A_s \cdot f_y)$, where A_s is nominal bar area as listed in ASTM A615, and f_y is a specified minimum yield strength of 60 ksi. The tension load for Stage 1 was set to $0.95 \cdot (A_s \cdot f_y)$. Tension load for Stage 2 was determined by applying strain to the splice specimen until the bar reference strain reached the value of $2 \varepsilon_y$; the load in the test machine at that strain value was then recorded and subsequently utilized as the Stage 2 maximum load. Maximum tension load for Stage 3 was similarly obtained using a target value of $5 \varepsilon_y$ for the bar reference strain. The bar yield strain, ε_y, was determined in advance from the apparent yield strain values obtained graphically from the load-elongation curves for the unspliced control bars.

After the Stage 1, 2 and 3 cyclic loading, each splice specimen was monotonically loaded in tension to failure. The Stage 4 tests were carried out in accordance with "Standard Test Methods and Definitions for Mechanical Testing of Steel Products," ASTM A370. The test machine was operated in

displacement control during Stage 4. The LVDT frame instrument remained on the specimen and the elongation (slip) across the splice was recorded during the initial portion of the Stage 4 test to failure. 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 fractured. After removal of the instrumentation, displacement was increased until the specimen fractured. Test machine crosshead movement (i.e., piston position) was monitored by computer throughout the test, up to and including specimen fracture. The peak load indicated by the test machine and the observed type of fracture were recorded for each specimen.

Test Machines. Some unspliced control bar tests were carried out in either a 120 kip Satec universal testing machine or a 500 kip Riehle universal test machine, located at the WJE laboratory facility in Norhbrook, Illinois. All cyclic tests, all compression tests and all tension tests on spliced bar specimens, and some tension tests on control bar specimens, were carried out in either a 600 kip, 100 kip or 50 kip MTS universal test machine having hydraulic grips. The current calibration certificates for all test machines are provided in Appendix B.

The MTS test machine is located at the Structural Engineering Research Laboratory (SERL), University of Illinois, Urbana, Illinois. WJE has reviewed the competence and compliance of SERL with the portions of ICBO ES document AC89 relevant to the services provided by SERL to WJE, and WJE finds SERL acceptable. Details of the WJE review are provided in Appendix C.

TEST RESULTS

The tests were carried out at various times during the period of February to August, 1999. 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. Unspliced control bars were tested for each bar size. The results of the tests on the unspliced control bars are summarized in Table 2. For the No. 10 control bars, Test 0593 is the control for the No. 10 compression test specimens, and Tests 0681 and 0682 are both controls for

the No. 10 cyclic and monotonic tension tests. The tensile properties of all control bar specimens conform to the requirements of ASTM *A615-96b*. Load-elongation curves for the control bars can be found in Appendix D.

Connectors Tested in Compression. Five splice specimens were tested in compression for each bar size. Results of the compression tests are summarized in Table 3. A force-deformation plot was recorded for each test; the plots are presented in Appendix E. To avert the failure of a specimen due to compression buckling or compression instability, testing of all compression specimens was halted at a load corresponding to a nominal compressive stress of approximately 90 ksi (150 percent of specified bar yield strength f_y).

Loading on the group of compression specimens in size No. 10 was initially halted at a compressive load that was less than the compressive strength requirement of AC133. These specimens were subsequently loaded to a compressive load in excess of the strength requirement. For each No. 10 compression test specimen, the force-deformation curves for both the initial loading and the subsequent re-loading are shown on the same plot in Appendix E. It is our opinion that this multiple loading sequence neither beneficially nor adversely influenced the results of the compression tests.

The AC133 acceptance criteria requires that a mechanical connection develop in compression a strength of 125 percent of specified yield strength f_y of the bar. This corresponds to a value of 75 ksi for a specified yield strength of 60 ksi. The UBC 1997 and *ACI 318-99* have the same compressive strength requirement. The compressive strength of all couplers summarized in Table 3 meet the AC133, *UBC* and *ACI 318* requirements for a mechanical connection in compression.

Some tests listed in Table 3 are noted to have ended with buckling of the specimen. This was a buckle of the bar-and-splice assembly, not a buckle of the coupling sleeve. The buckling occurred because the clear length of the bar-and-splice test specimen was relatively long for the applied loads. The buckling does not represent inadequate performance of the coupling sleeve. These are valid tests

because the compressive loads sustained by specimens that buckled exceeded the previously-summarized compressive strength requirements.

Splices Tested Cyclically per ICBO ES AC133 Protocol. Results of the cyclic tests per ICBO ES protocol are summarized in Table 4. Five specimens were tested in each bar size. Load-elongation (load-slip) curves for the splice specimens can be found in Appendix F. Load-strain curves for the reference strain in the reinforcing bar on the cyclically loaded splice specimens can be found in Appendix G. Load-crosshead movement (load-piston movement) curves, which trace overall specimen lengthening through to the occurrence of fracture, can be found in Appendix H. Minimum and maximum loads for the cycling of Stages 1, 2 and 3 are noted in Table 4, as are the numbers of cycles accomplished during each stage of cycling. The Stage 4 breaking strengths of the specimens are also noted in Table 4, along with the mode of fracture for the specimens.

The ICBO ES AC133 cyclic test procedure requires the recording of load-elongation (load-slip) curves for the splice specimens during the cyclic testing. While AC133 has no numeric criteria for slip, each splice specimen is required to survive the cyclic loading of Stages 1, 2 and 3 without breaking. All specimens summarized in Table 3 survived the prescribed number of cycles for Stages 1, 2 and 3 without breaking.

Three modes of fracture were observed: fracture of the reinforcing bar away from the splice; pull out of the reinforcing bar from the sleeve; and fracture of the bar within the splice.

The first specimen in size No. 4 (Test 0537) buckled during Stage 3 cycling. The length of this test specimen was shortened and testing resumed. It is our opinion that the remounting and continued testing of this specimen did not beneficially influence the results of this particular test, and that the test is valid. During the resumed test, data were inadvertently not recorded electronically. The buckling does not represent inadequate performance of the splice, but rather occurred because the clear length of the test specimen was too long. The subsequent No. 4 specimens were tested with shorter lengths and therefore did not buckle.

The AC133 strength requirement for Stage 4 loading in tension is that the mechanical splice specimen develop the lesser of 95 percent of the [actual] ultimate tensile strength of the bar or 160 percent of the specified yield strength, f_y, of the bar. This is the same as the requirement found in the 1997 edition of the *Uniform Building Code (UBC)*, Section 1921.2.6.1.2, for a Type 2 mechanical splice, which is permitted for use in the plastic hinge regions of reinforced concrete structures designed for earthquake loading. The strength requirement for each size of splice is summarized in Table 5. It can be seen in Table 5 that the final strength requirement for splices in size Nos. 4 though 11 is 96.0 ksi, and the requirement for size No. 14 is 92.5 ksi.

The Stage 4 strength of all couplers summarized in Table 4, except for one specimen in size No. 10 (Test 0684) and one specimen in size No. 11 (Test 0638), meet the strength requirement of AC133 and *UBC* 1997. It is our opinion that the result of Test 0638 in size No. 11 does not deviate significantly (deviation is less than 1 percent) from the tabulated strength requirement, particularly when variability and tolerances inherent with laboratory testing are considered. Consequently, Test 0638 should be taken as meeting the stipulated strength requirement.

The result of test No. 0684 in size No. 10, however, does deviate somewhat from the requirement. Therefore, five supplemental monotonic tensile tests were carried out on spliced bar specimens in size No. 10. The results are summarized in Table 6, and data plots for these tests are included in Appendices F, G and H. The results of all of the supplemental tests meet the strength requirement stipulated by AC133 and UBC 1997.

The Chapter 21 seismic provisions of *ACI 318-99* includes a Type 2 mechanical splice, which is permitted for use in sections of concrete members where yielding of reinforcement is likely to occur as a result of inelastic lateral displacements under earthquake loading. Section 21.2.6.1 of *ACI 318-99* states that a Type 2 splice shall develop in tension the specified tensile strength of the spliced bar. For each size of coupler, the minimum strength according to *ACI 318-99* is also summarized in Table 5. The

tensile strength of all splice specimens summarized in Tables 4 and 6 exceed the *ACI 318* minimum strength requirement for a Type 2 seismic mechanical splice.

SUMMARY

Wiss, Janney, Elstner Associates, Inc. conducted a series of monotonic compression and reversed-loading cyclic tests on the L-Series MBT mechanical coupler produced by Bar-Lock Coupler Systems. All splice specimens that were loaded in compression had compressive strengths that exceeded the compressive strength requirements of ICBO ES AC133, *UBC* 1997 and *ACI 318-99*. No failures occurred when splice specimens were cyclically loaded as prescribed by AC133. These specimens were then loaded in monotonic tension to fracture. Supplemental monotonic tensile strength tests were also conducted on splice specimens of a select size. The testing demonstrated compliance of the MBT L-Series couplers with acceptance criteria for a Type 2 seismic mechanical splice according to provisions of ICBO ES AC133 (January 1998) and *UBC* 1997. The cyclic tensile strengths and monotonic tensile strengths also exceeded the minimum strength requirements for a Type 2 seismic mechanical splice according to Chapter 21 of *ACI 318-99*.

Respectfully Submitted,
WISS, JANNEY, ELSTNER ASSOCIATES, INC.

Conrad Paulson, P.E., S.E.
Project Manager

CP/cp

FIGURES

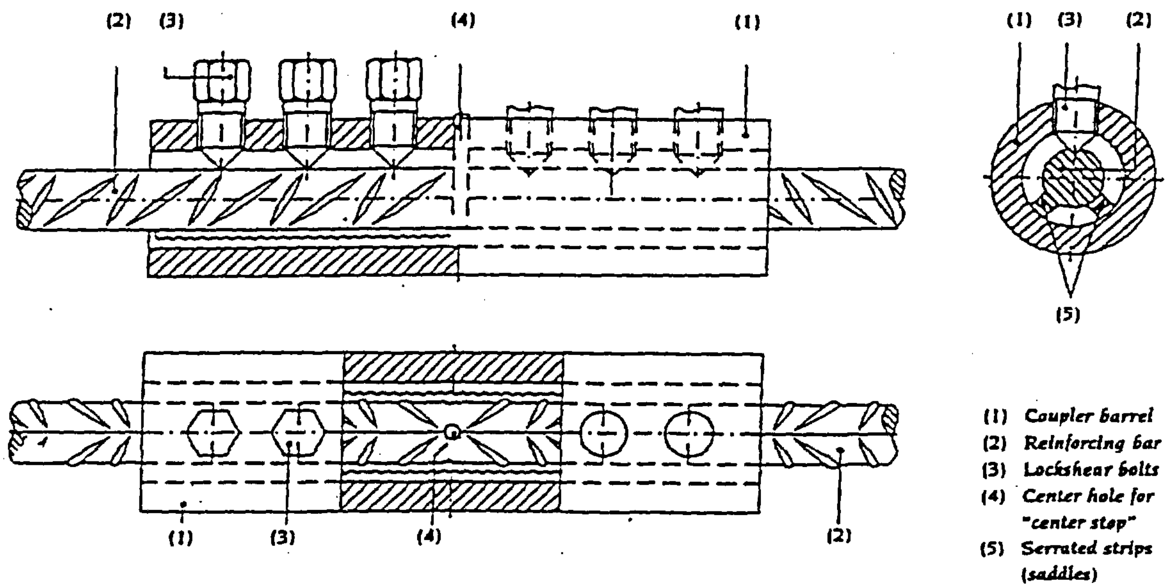

Figure 1 - Schematic illustration of Bar-Lock MBT coupler

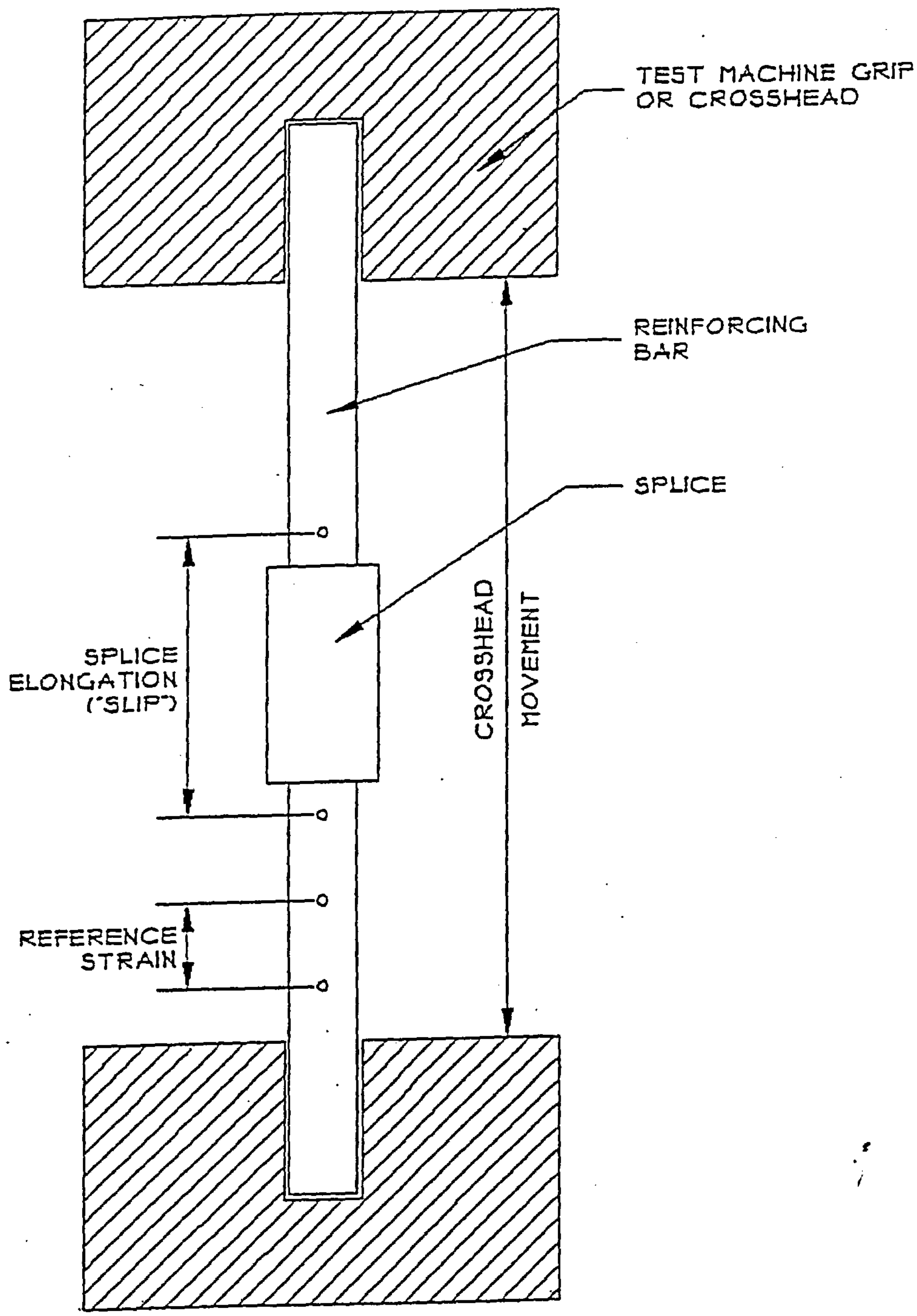

Figure 2 - Test Istrumentation Setup

TABLES

TABLE 1 – SPECIFIED DIMENSIONS FOR L-SERIES MBT COUPLERS

Designation	Length (mm)	Outside Diameter (mm)	Inside Diameter (mm)	Number of Bolts	Bolt Size (diam., mm)
#4/13M	100	33.4	20.7	4	M10
#5/16M	140	33.4	20.7	6	M10
#6/19M	204	48.3	31.3	8	M12
#7/22M	248	48.3	31.3	10	M12
#8/25M	258	57.0	38.0	8	M16
#9/29M	292	73.6	45.6	8	M20
#10/32M	356	73.6	45.6	10	M20
#11/36M	420	79.2	51.2	12	M20
#14/43M	484	88.9	60.9	14	M20

TABLE 2 –TESTS ON UNSPLICED CONTROL BARS

Test I.D. No.	Bar Size	Bar Area (in^2)	Yield Strength, f_{ya}			Yield Strength, ε_{ya} (percent)	Tensile Strength, f_{ua}			Final Elong. (percent)
			(kips)	(ksi)	($\%f_{y-60}$)		(kips)	(ksi)	($\%f_{y-60}$)	
0498	4	0.20	13.8	69.0	115%	0.25%	22.1	110.6	184%	13%
0499	5	0.31	20.0	64.5	108%	0.25%	32.8	105.6	176%	13%
0500	6	0.44	28.3	64.3	107%	0.20%	46.9	106.7	178%	17%
0501	7	0.60	37.9	63.2	105%	0.20%	61.7	102.8	171%	16%
0502	8	0.79	50.9	64.4	107%	0.24%	85.0	107.6	179%	19%
0503	9	1.00	66.8	66.8	111%	0.25%	110.9	110.9	185%	17%
0593[a]	10	1.27	87.0	68.5	114%	0.25%	131.6	103.6	173%	20%
0681[a]	10	1.27	84.0	66.1	110%	0.24%	134.8	106.1	177%	16%
0682[a]	10	1.27	84.0	66.1	110%	0.24%	134.9	106.2	177%	15%
0637	11	1.56	98.0	62.8	105%	0.24%	158.0	101.3	169%	16%
0595	14	2.25	147.0	65.3	109%	0.25%	219.0	97.3	162%	21%

Note a: Test No. 0593 is the control bar for No. 10 compression test Nos. 0621 to 0625, and test Nos. 0681 and 0682 are both control bars for No. 10 cyclic test Nos. 0683 to 0687 and also No. 10 monotonic test Nos. 0688 to 0692.

TABLE 3 – COMPRESSION TESTS ON L-SERIES MBT COUPLER SPECIMENS

Test I.D. No.	Bar Size	Bar Area (in²)	Peak Load (kips)	Peak Load (ksi)	Peak Load ($\%f_{y-60}$)	Final Result
0537	4	0.20	18.3	91.7	153%	No failure
0538	4	0.20	18.4	92.1	153%	No failure
0539	4	0.20	17.2	85.9	143%	Bar Buckled
0540	4	0.20	18.1	90.4	151%	No failure
0541	4	0.20	18.1	90.4	151%	No failure
0588	5	0.31	28.3	91.3	152%	No failure
0589	5	0.31	28.3	91.3	152%	No failure
0590	5	0.31	27.5	88.8	148%	Bar Buckled
0591	5	0.31	27.4	88.4	147%	Bar Buckled
0592	5	0.31	26.0	83.7	140%	Bar Buckled
0558	6	0.44	41.6	94.5	158%	No failure
0559	6	0.44	40.6	92.3	154%	No failure
0560	6	0.44	40.2	91.4	152%	No failure
0561	6	0.44	40.6	92.3	154%	No failure
0562	6	0.44	40.6	92.3	154%	No failure
0563	7	0.60	54.1	90.2	150%	No failure
0564	7	0.60	54.2	90.3	151%	No failure
0565	7	0.60	55.0	91.7	153%	No failure
0566	7	0.60	55.1	91.8	153%	No failure
0567	7	0.60	53.5	89.2	149%	Bar Buckled
0568	8	0.79	71.3	90.3	150%	No failure
0569	8	0.79	71.8	90.9	151%	No failure
0570	8	0.79	71.9	91.0	152%	No failure
0571	8	0.79	72.1	91.3	152%	No failure
0572	8	0.79	71.7	90.8	151%	No failure
0573	9	1.00	91.6	91.6	153%	No failure
0574	9	1.00	91.7	91.7	153%	No failure
0575	9	1.00	92.5	92.5	154%	No failure
0576	9	1.00	91.6	91.6	153%	No failure
0577	9	1.00	92.3	92.3	154%	No failure
0621	10	1.27	115.4	90.9	151%	No failure
0622	10	1.27	115.8	91.2	152%	No failure
0623	10	1.27	116.4	91.7	153%	No failure
0624	10	1.27	115.5	90.9	152%	No failure
0625	10	1.27	115.7	91.1	152%	No failure
0643	11	1.56	143.5	92.0	153%	No failure
0644	11	1.56	142.7	91.5	152%	No failure
0645	11	1.56	142.5	91.3	152%	No failure
0646	11	1.56	142.1	91.1	152%	No failure
0647	11	1.56	141.7	90.8	151%	No failure
0616	14	2.25	204.4	90.8	151%	No failure
0617	14	2.25	204.3	90.8	151%	No failure
0618	14	2.25	204.1	90.7	151%	No failure
0619	14	2.25	203.7	90.5	151%	No failure
0620	14	2.25	204.6	90.9	152%	No failure

TABLE 4 – AC133 CYCLIC TESTS ON L-SERIES MBT COUPLER SPECIMENS

Test I.D. No.	Bar Size	Bar Area (in^2)	Cyclic Load Levels (Stages 1, 2, 3)				Cycles Applied			Tensile Strength (Stage 4)			Final R[illegible]lt
			P_{min} (kips)	P_{max1} (kips)	P_{max2} (kips)	P_{max3} (kips)	n_1	n_2	n_3	(kips)	(ksi)	($\%f_{y=60}$)	
0532	4	0.20	-6.0	11.4	12.3	13.6	20	4	2	20.9	104.3	174%	Bar Break
0533	4	0.20	-6.0	11.4	13.4	15.2	20	4	4	21.6	108.2	180%	Bar Break
0534	4	0.20	-6.0	11.4	12.3	13.7	20	4	4	21.1	105.4	176%	Bar Break
0535	4	0.20	-6.0	11.4	12.5	14.2	20	4	4	21.1	105.4	176%	Bar Break
0536	4	0.20	-6.0	11.4	12.0	13.7	20	4	4	20.7	103.4	172%	Bar Break
Average										21.1	105.3	176%	
0527	5	0.31	-9.3	17.7	18.7	21.7	20	4	4	32.5	104.8	175%	Bar Break
0528	5	0.31	-9.3	17.7	19.7	21.9	20	4	4	32.6	105.1	175%	Bar Break
0529	5	0.31	-9.3	17.7	20.1	22.7	20	4	4	32.8	105.7	176%	Bar Break
0530	5	0.31	-9.3	17.7	19.7	21.7	20	4	4	32.6	105.2	175%	Bar Break
0531	5	0.31	-9.3	17.7	19.5	21.7	20	4	4	32.5	104.7	175%	Bar Break
Average										32.6	105.1	175%	
0543	6	0.44	-13.2	25.1	28.0	30.4	20	4	4	47.3	107.5	179%	Bar Break
0544	6	0.44	-13.2	25.1	27.3	29.7	20	4	4	47.1	107.0	178%	Bar Break
0545	6	0.44	-13.2	25.1	27.8	30.2	20	4	4	47.2	107.3	179%	Bar Break
0546	6	0.44	-13.2	25.1	27.5	30.0	20	4	4	47.0	106.9	178%	Bar Break
0547	6	0.44	-13.2	25.1	27.8	30.0	20	4	4	47.2	107.2	179%	Bar Break
Average			Min -30ksi			Max 69 ksi				47.2	107.2	179%	
0548	7	0.60	-18.0	34.2	35.5	38.9	20	4	4	60.1	100.2	167%	Pullout
0549	7	0.60	-18.0	34.2	35.8	39.0	20	4	4	60.9	101.5	169%	Pullout
0550	7	0.60	-18.0	34.2	36.0	39.5	20	4	4	61.3	102.1	170%	At B[illegible]
0551	7	0.60	-18.0	34.2	37.1	41.3	20	4	4	61.2	101.9	170%	Pullou[illegible]
0552	7	0.60	-18.0	34.2	37.3	40.9	20	4	4	60.5	100.9	168%	Pullout
Average										60.8	101.3	169%	
0553	8	0.79	-23.7	45.0	49.4	55.8	20	4	4	84.5	106.9	178%	Pullout
0554	8	0.79	-23.7	45.0	49.4	56.9	20	4	4	81.7	103.4	172%	Pullout
0555	8	0.79	-23.7	45.0	50.2	57.5	20	4	4	84.1	106.5	177%	Pullout
0556	8	0.79	-23.7	45.0	49.7	56.9	20	4	4	82.6	104.6	174%	Pullout
0557	8	0.79	-23.7	45.0	49.6	57.1	20	4	4	82.6	104.6	174%	Pullout
Average			-30 ksi			72.8 ksi				83.1	105.2	175%	
0522	9	1.00	-30.0	57.0	66.0	76.0	20	4	4	110.1	110.1	184%	Pullout
0523	9	1.00	-30.0	57.0	65.7	74.0	20	4	4	110.0	110.0	183%	Pullout
0524	9	1.00	-30.0	57.0	65.7	75.6	20	4	4	108.1	108.1	180%	At Bolt
0525	9	1.00	-30.0	57.0	65.7	75.8	20	4	4	109.8	109.8	183%	Pullout
0526	9	1.00	-30.0	57.0	65.0	74.4	20	4	4	109.9	109.9	183%	Pullout
Average										109.6	109.6	183%	
0683	10	1.27	-38.1	72.4	82.9	92.9	20	4	4	127.1	100.1	167%	At Bolt
0684	10	1.27	-38.1	72.4	82.7	94.1	20	4	4	117.0	92.1	154%	At Bolt
0685	10	1.27	-38.1	72.4	82.5	93.3	20	4	4	129.6	102.0	170%	Pullout
0686	10	1.27	-38.1	72.4	82.3	92.1	20	4	4	129.0	101.6	169%	Pullout
0687	10	1.27	-38.1	72.4	82.3	92.1	20	4	4	124.0	97.6	163%	Pullout
Average										125.3	98.7	164%	

TABLE 4 (CONCLUDED)– AC133 CYCLIC TESTS ON L-SERIES MBT COUPLER SPECIMENS

Test I.D. No.	Bar Size	Bar Area (in^2)	Cyclic Load Levels (Stages 1, 2, 3)				Cycles Applied			Tensile Strength (Stage 4)			Final Resul.
			P_{min} (kips)	P_{max1} (kips)	P_{max2} (kips)	P_{max3} (kips)	n_1	n_2	n_3	(kips)	(ksi)	($\%f_{y=60}$)	
0638	11	1.56	-46.8	88.9	92.8	104.8	20	4	4	148.4	95.1	159%	At Bolt
0639	11	1.56	-46.8	88.9	95.4	108.8	20	4	4	154.3	98.9	165%	At Bolt
0640	11	1.56	-46.8	88.9	95.4	108.8	20	4	4	149.3	95.7	160%	At 2nd Bolt
0641	11	1.56	-46.8	88.9	95.4	108.8	20	4	4	159.9	102.5	171%	Bar Break
0642	11	1.56	-46.8	88.9	94.4	106.6	20	4	4	154.8	99.2	165%	At Bolt
Average										153.3	98.3	164%	
0604	14	2.25	-67.5	128.3	132.7	153.3	20	4	4	211.4	94.0	157%	Pullout
0605	14	2.25	-67.5	128.3	137.3	153.3	20	4	4	219.1	97.4	162%	Pullout
0606	14	2.25	-67.5	128.3	137.3	153.0	20	4	4	217.8	96.8	161%	Pullout
0607	14	2.25	-67.5	128.3	133.7	153.6	20	4	4	216.2	96.1	160%	Pullout
0608	14	2.25	-67.5	128.3	133.7	151.9	20	4	4	214.4	95.3	159%	Bar Break
Average										215.8	95.9	160%	
										Note: For size No. 14 specimens, strength acceptance criteria is 92.5 ksi or 154% f_y; as summarized in Table 5.			

TABLE 5 – SPLICE ACCEPTANCE CRITERIA

Bar Data		Bar Strength				Type 2 "Seismic" Splice Strength Criteria					
						ICBO ES AC133 (1998) / UBC (1997)				ACI 318-99 Chapter 21	
Bar Size	Bar Area (in^2)	Specified		Actual		Compression	Tension			Compression	Tension
		f_{yo} (ksi)	f_{uo} (ksi)	f_{ya} (ksi)	f_{ua} (ksi)	125% f_{yo} (ksi)	160% f_{yo} (ksi)	95% f_{ua} (ksi)	Lesser of (ksi)	125% f_{yo} (ksi)	100% f_{uo} (ksi)
4	0.20	60.0	90.0	69.0	110.6	75.0	96.0	105.1	96.0	75.0	90.0
5	0.31	60.0	90.0	64.5	105.6	75.0	96.0	100.4	96.0	75.0	90.0
6	0.44	60.0	90.0	64.3	106.7	75.0	96.0	101.3	96.0	75.0	90.0
7	0.60	60.0	90.0	63.2	102.8	75.0	96.0	97.7	96.0	75.0	90.0
8	0.79	60.0	90.0	64.4	107.6	75.0	96.0	102.2	96.0	75.0	90.0
9	1.00	60.0	90.0	66.8	110.9	75.0	96.0	105.4	96.0	75.0	90.0
10	1.27	60.0	90.0	68.5	103.6	75.0	96.0	98.4	96.0	75.0	90.0
10	1.27	60.0	90.0	66.1	106.1	75.0	96.0	100.8	96.0	75.0	90.0
10	1.27	60.0	90.0	66.1	106.2	75.0	96.0	100.9	96.0	75.0	90.0
11	1.56	60.0	90.0	62.8	101.3	75.0	96.0	96.2	96.0	75.0	90.0
14	2.25	60.0	90.0	65.3	97.3	75.0	96.0	92.5	92.5	75.0	90.0

f_{yo} = Specified yield strength
f_{uo} = Specified tensile strength
f_{ya} = Actual yield strength
f_{ua} = Actual tensile strength

TABLE 6 - MONOTONIC TENSION TESTS ON L-SERIES MBT COUPLERS

Test I.D. No.	Bar Size	Bar Area (in^2)	Tensile Strength (kips)	(ksi)	($\%f_{y=60}$)	Final Result
0688	10	1.27	129.1	101.7	169%	At Bolt
0689	10	1.27	125.9	99.1	165%	Pullout
0690	10	1.27	133.3	105.0	175%	At Bolt
0691	10	1.27	127.0	100.0	167%	Pullout
0692	10	1.27	129.2	101.7	170%	Pullout
Average			128.9	101.5	169%	

Appendix E

Tabulated Mechanical Test Results and Example Raw Data

Bechtel/INEEL Tests

December 2001

Table 1 – Tensile Properties for #6 Rebar Heat ID: 5898I2899

Specimen ID	HOF Yield (ksi)	UTS (ksi)	ε_f (%)	E (Msi)
U6-2	67.7	106.9	14.0	28.7
U6-5	66.8	106.6	13.5	27.4
U6-9	67.0	107.0	12.9	28.1
U6-11	67.6	107.8	14.2	28.6
U6-12	69.9	109.7	10.6	27.3
U6-14	67.9	107.9	12.9	28.3
U6-18	67.3	106.5	14.1	26.2
Averages	67.7	107.5	13.2	27.8

Table 2 – Tensile Properties for #8 Rebar (Heat ID: 5898I3260)

Specimen ID	HOF Yield (ksi)	UTS (ksi)	ε_f (%)	E (Msi)
U8-11	72.5	110.3	12.9	30.1
U8-12	72.4	108.8	11.2	28.7
U8-13	71.7	109.5	12.2	29.3
U8-14	73.0	111.0	9.8	28.8
U8-16	72.8	110.2	11.0	29.1
U8-18	72.5	110.4	11.7	29.2
U8-20	73.0	110.6	11.5	29.1
Averages	72.6	110.1	11.5	29.2

Table 3 – Splice Specimen Strength Test Results

Specimen ID (#6)	Failure Type[j]	Final Strain (%)	UTS (ksi)	Specimen ID (#8)	Failure Type	Final Strain (%)	UTS (ksi)
Average	--	NA[k]	106.2	Average	--	NA[b]	109.0
S6-01	O	3.8	107.9	S8-01	O	3.7	109.6
S6-02	P	15.2	108.0	S8-02	T	1.4	96.8
S6-03	P	14.4	98.9	S8-03	O	4.9	109.8
S6-04	P	15.2	106.4	S8-04	O	3.7	110.1
S6-05	O	4.9	107.3	S8-05	P	10.4	108.4
S6-06	O	4.1	107.8	S8-06	T	4.9	109.7
S6-07	O	4.2	107.6	S8-07	T	4.4	110.4
S6-08	P	13.1	106.9	S8-08	T	3.6	109.4
S6-09	T	2.7	103.2	S8-09	O	3.6	110.5
S6-10	O	4.6	107.6	S8-10	T	1.8	102.1
S6-11	P	13.0	107.3	S8-11	T	2.1	106.0
S6-12	O	4.4	105.6	S8-12	*	3.8	108.0
S6-13	T	2.7	103.4	S8-13	O	3.4	110.5
S6-14	P	10.8	105.8	S8-14	T	3.2	110.1
S6-15	P	12.3	104.0	S8-15	*	3.7	106.7
S6-16	O	3.8	108.0	S8-16	T	4.0	111.0
S6-17	P	9.8	103.7	S8-17	T	2.1	104.5
S6-18	P	11.5	106.3	S8-18	T	4.5	109.3
S6-19	P	19.1	106.1	S8-19	T	4.0	109.4
S6-20	P	15.4	107.6	S8-20	O	4.6	110.1
S6-21	P	11.0	106.0	S8-21	T	3.5	109.7
S6-22	P	11.6	105.0	S8-22	T	4.3	109.4
S6-23	T	2.7	103.1	S8-23	T	3.8	109.8
S6-24	O	4.1	107.8	S8-24	T	3.3	108.5
S6-25	P	11.5	105.1	S8-25	P	10.4	110.0
S6-26	P	11.3	107.9	S8-26	T	4.2	109.9

[j] B = bar break outside coupler but within extensometer gage length, O = bar break outside coupler and outside extensometer gage length, T = bar break at tip of first lock bolt, P = bar pulled out of coupler without breaking, * = bar break in interior of coupler

[k] The final strain is dependent on several factors, including mode of failure. An average value for all tests has no significance. For example, in a pull-out failure the final strain is determined by the length of time the operator chooses to continue the test once pull-out is observed.

Specimen ID (#6)	Failure Type[j]	Final Strain (%)	UTS (ksi)	Specimen ID (#8)	Failure Type	Final Strain (%)	UTS (ksi)
Average	--	NA[k]	106.2	Average	--	NA[b]	109.0
S6-27	P	12.2	106.4	S8-27	*P	7.0	109.7
S6-28	O	3.9	107.8	S8-28	T	4.1	109.0
S6-29	B	4.8	107.0	S8-29	O	3.8	109.7
S6-30	O	4.3	107.6	S8-30	O	3.5	110.3
S6-31	O	4.4	107.4	S8-31	T	3.9	110.5
S6-32	T	3.8	107.2	S8-32	T	2.5	109.0
S6-33	T	2.9	105.7	S8-33	O	4.4	110.3
S6-34	P	12.6	105.7	S8-34	T	3.5	109.7
S6-35	T	4.4	107.2	S8-35	T	2.5	105.4
S6-36	T	2.8	104.2	S8-36	T	4.1	110.5
S6-37	O	3.8	107.2	S8-37	*	5.0	110.2
S6-38	P	11.5	107.4	S8-38	P	10.3	109.9
S6-39	P	12.9	107.0	S8-39	T	3.9	111.2
S6-40	P	11.3	106.3	S8-40	P	10.2	113.6

Table 4 – Results of Residual Strength Tests on Load-Cycled Specimens

Specimen ID (#6)	Failure Type	Final Strain (%)	UTS (ksi)	Specimen ID (#8)	Failure Type	Final Strain (%)	UTS (ksi)
Average	--	NA	104.9	Average	--	NA	106.7
C6-2	P	3.8	104.3	C8-15			106.6
C6-3	P	3.7	106.3	C8-21			106.0
C6-7	P	5.0	106.2	C8-27			107.6
C6-14	P	7.0	103.3				
C6-15	P	3.7	104.5				

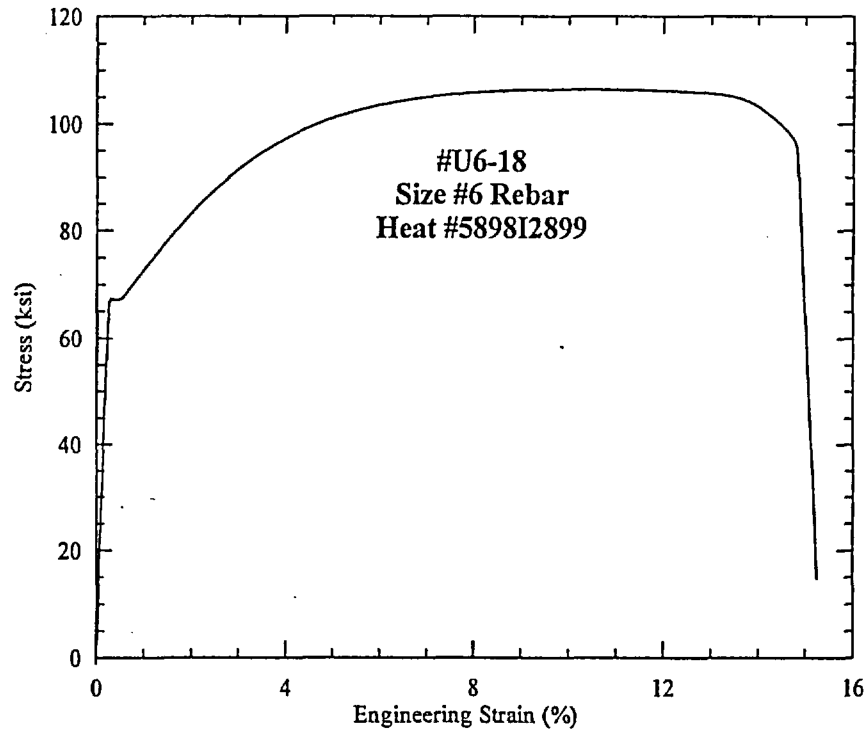

Figure 1 – Representative Stress-Strain Curve from #6 Rebar Material

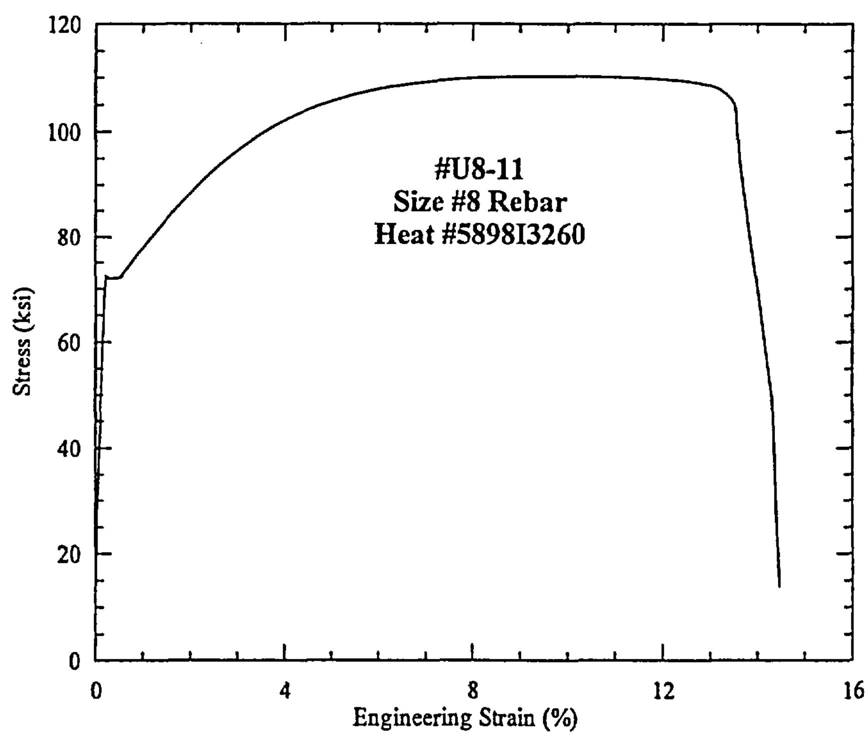

Figure 2 – Representative Stress-Strain Curve from #8 Rebar Material

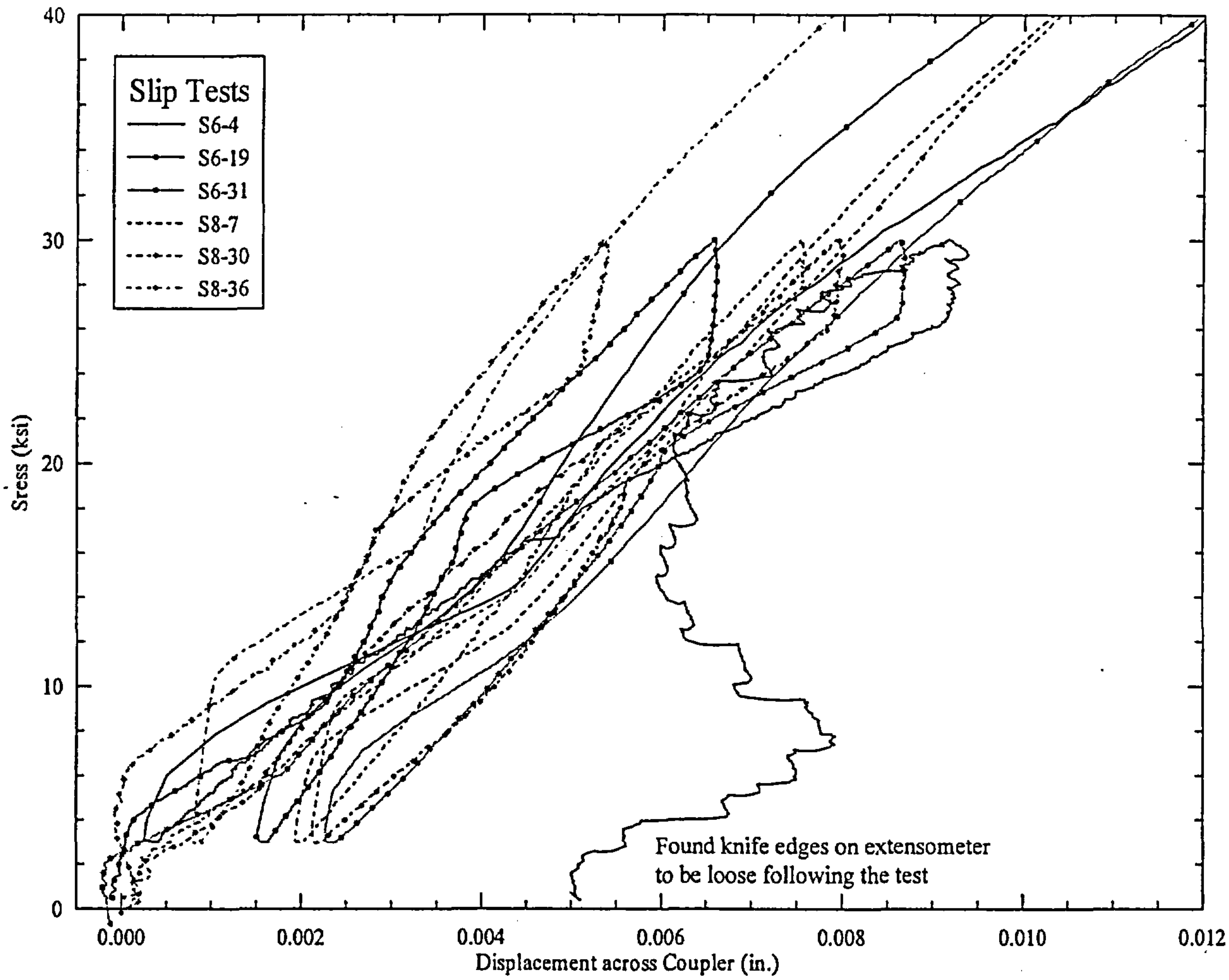

Figure 3 – Data Curves Showing Load-Unload Cycle to Assess Bar Slip in Couplers

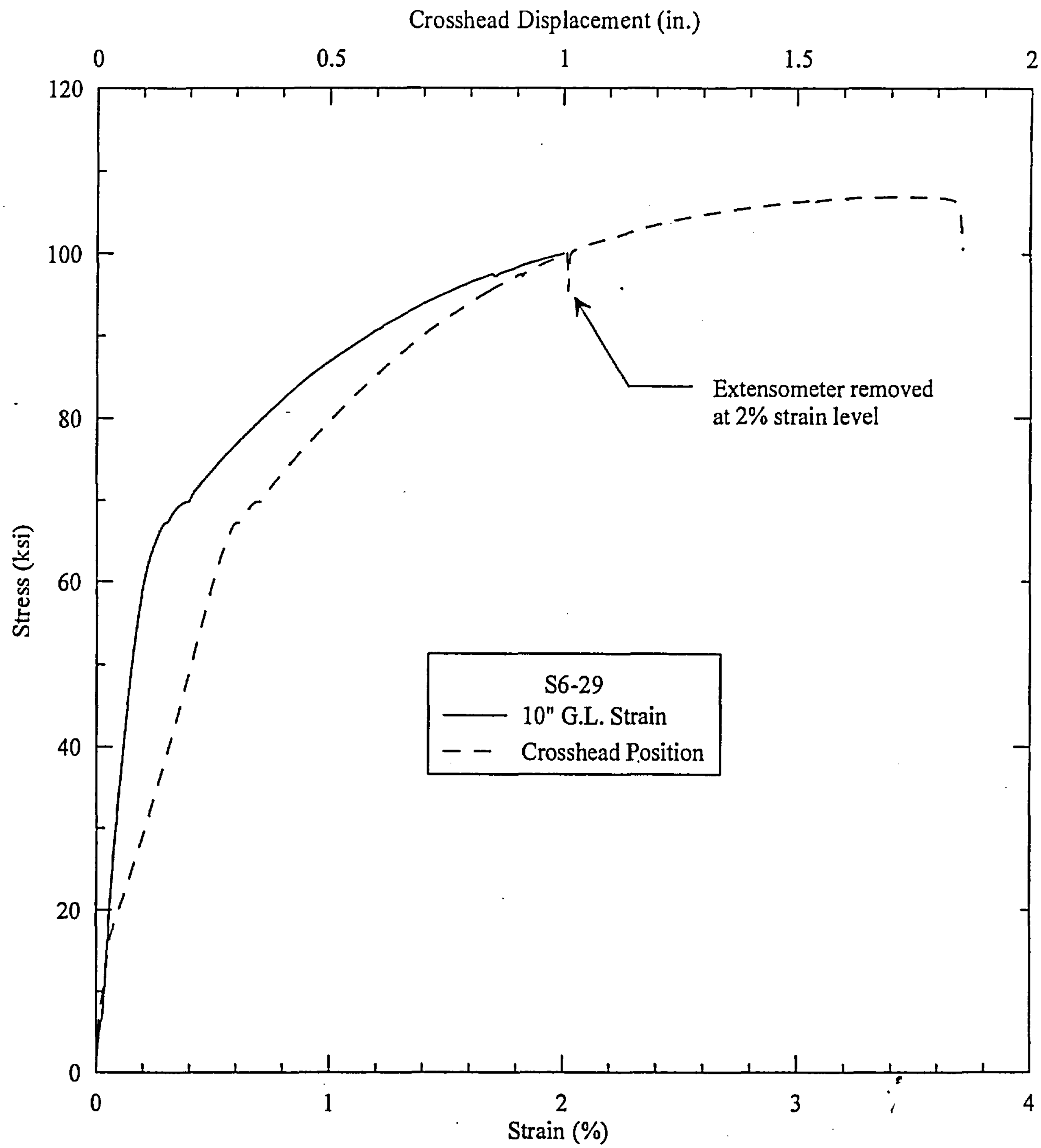

Figure 4 – Representative Stress, Strain, and Displacement Data from a Coupler Assembly Strength Test

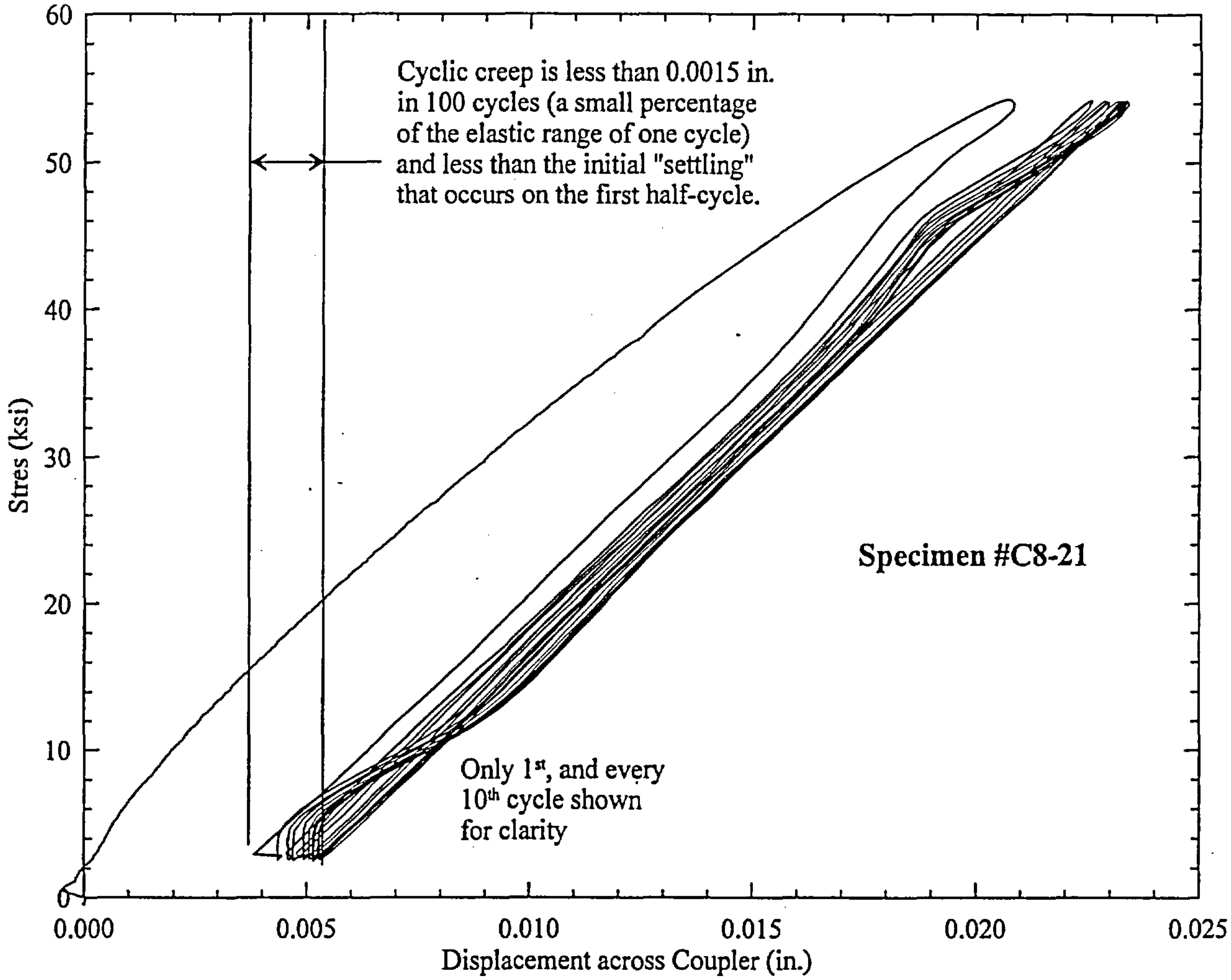

Figure 5 – Cyclic Stress-Displacement History for a Typical Test

Appendix F
No Significant Hazards Consideration Determination

I. DESCRIPTION OF THE PROPOSED CHANGE

The four steam generators of the Sequoyah Nuclear Plant Unit 1 will be replaced during the spring of 2003. To support the replacement of the old steam generators (OSGs) with the replacement steam generators (RSGs), temporary construction openings will be cut through the concrete shield building, steel containment vessel, and concrete steam generator compartment roofs. Restoration of the temporary concrete construction openings may be accomplished by splicing new reinforcing steel (rebar) to the existing rebar and pouring new concrete.

Original construction at the Sequoyah plant used lap splices to join rebar. Generally, Cadweld splices have been used in the nuclear industry when safety-related concrete repairs involve removal and replacement of a portion of the rebar. The Cadweld splice has become the standard mechanical rebar splice for the nuclear industry, and its use is supported by years of successful installation, industry codes and standards, and regulatory acceptance. However, the Sequoyah plant proposes to use the Bar-Lock coupler system to restore the temporary concrete construction openings following installation of the new Unit 1 steam generators.

To support use of the Bar-Lock coupler system at the Sequoyah plant, a qualification testing program was undertaken. Details of this testing program and the test results are documented in Topical Report 24370-TR-C-001.

II. REASON FOR THE PROPOSED CHANGE

The Bar-Lock coupler system provides a number of installation advantages over other mechanical splice concepts that make it a candidate for the concrete restoration activities associated with the Sequoyah steam generator replacement. The Bar-Lock coupler system has specified mechanical properties that meet ASME/ACI criteria for mechanical rebar splices.

III. SAFETY ANALYSIS

Mechanical splices for reinforcing steel used in nuclear safety-related concrete structures are subject to the stringent requirements of ASME Section III, Division 2/ACI-359 and ACI-318, which includes the requirement that the splice develop 125% of the minimum yield strength of the reinforcing bar. In order to demonstrate that the Bar-Lock coupler can meet these requirements, a qualification program has been performed. The qualification program included development of a testing program, performance of physical tests, and analysis and interpretation of the test results.

The Bar-Lock coupler qualification testing program was carried out on two representative sizes – #6 and #8 – of their L-Series couplers. A total of 160 coupler assemblies were tested. Fourteen pieces of rebar were tested to determine the actual, or measured, mechanical properties of the two heats of bar material used to fabricate the test specimens.

The tensile strength tests on each of the 80 samples exceeded the two ASME requirements by a large margin. Statistical analyses of the test results determined several important performance indicators. Based on the observed data distribution, the probability of a coupler assembly (in size #6 or #8) failing to meet the minimum qualification strength criterion is less than 3 in 100,000.

There was some variation in strength between the two heats of rebar used in the strength tests. Comparing and correlating these results show that Bar-Lock L-Series coupler splices can be expected to achieve a tensile strength greater than 96% of the actual bar strength. While there are not enough different combinations of bar material and coupler size data, the combined test results from this program appear similar when normalized by the actual bar strength. So, it is likely these test results are representative of the performance of other sizes of Bar-Lock L-Series couplers. In other words, the mechanical design of the Bar-Lock L-Series coupler is such that spliced joints can be expected to develop over 96% of the actual bar strength.

Slip tests performed on selected specimens of both sizes showed a solid mechanical connection between the coupler and the rebar. There was no tendency for the rebar to move within the coupler prior to developing full splice strength. This was expected since the conical-tipped lock bolts physically embed into the bar material providing a physical shear force transfer from bar to coupler.

Each of the 80 splice specimens that underwent the cyclic loading durability test passed the 100-cycle test, with no obvious physical degradation of the spliced joint. To provide an additional degree of assurance of adequate cyclic durability, selected specimens received 1000 cycles of loading, again with no noticeable physical degradation. Some of the specimens that passed the 100 cycle test were subsequently tested by monotonic loading to failure. The resultant measured strengths were essentially the same as the virgin strength test specimens (no cyclic loading applied). These results suggest that the design of the Bar-Lock coupler is essentially insensitive to cyclic loading to levels below 90% of the minimum bar yield strength.

The results of these tests, compared to the ASME splice system qualification requirements, indicate that the Bar-Lock coupler design for rebar splicing is entirely adequate from a strength point of view for use in nuclear safety-related construction. The additional quantity of couplers tested provides higher confidence that the couplers do meet, and indeed far exceed, those ASME-specified requirements.

IV. NO SIGNIFICANT HAZARDS CONSIDERATION DETERMINATION

TVA has concluded that operation of SQN Unit 1, in accordance with the proposed use of Bar-Lock L-Series couplers in the restoration of the temporary concrete construction openings, does not involve a significant hazards consideration. TVA's conclusion is based on its evaluation, in accordance with 10 CFR 50.91(a)(1), of the three standards set forth in 10 CFR 50.92(c).

A. The proposed amendment does not involve a significant increase in the probability or consequences of an accident previously evaluated.

No changes in event classification as discussed in UFSAR Chapter 15 will occur due to use of the Bar-Lock couplers.

The restoration of the temporary concrete construction openings in the shield building and steam generator compartments may utilize Bar-Lock couplers to splice new rebar to the existing rebar. These structures limit the release of radioactivity following an accident, direct the steam released due to a pipe break inside containment through the ice condenser, and protect the SSCs inside containment from external events. The accidents of interest here are those that rely on the shield building to limit the release of radioactivity to the environment, those that rely on the divider barrier inside containment to direct the steam released due to a pipe break through the ice condenser, and those that result from some external event. The design of the shield building and steam generator compartments is such that they are not postulated to fail and initiate an accident described in the UFSAR.

The Bar-Lock coupler qualification tests detailed in Topical Report 24370-TR-C-001 demonstrated that the Bar-Lock coupler meets the ASME strength requirements and is, therefore, acceptable for use in nuclear safety-related applications. Based on these test results, it is concluded that use of the Bar-Lock couplers in restoring the temporary concrete construction openings will not reduce the structural capability of the repaired structures. They will, therefore, continue to perform their functions as described in the Sequoyah UFSAR.

Therefore, the proposed use of the Bar-Lock couplers will not significantly increase the probability or consequences of an accident previously evaluated.

B. The proposed amendment does not create the possibility of a new or different kind of accident from any accident previously evaluated.

As indicated in the response to Question IV.A above, the design of the shield building and steam generator compartments is such that they are not postulated to fail and initiate an accident described in the UFSAR. The Bar-Lock couplers are passive devices and as such will not initiate or cause an accident.

The restoration of the temporary concrete construction openings in the shield building and steam generator compartments may utilize Bar-Lock couplers to splice new rebar to the existing rebar. The Bar-Lock coupler qualification tests detailed in Topical Report 24370-TR-C-001 demonstrated that the Bar-Lock coupler meets the ASME strength requirements and is, therefore, acceptable for use in nuclear safety-related applications. Based on these test results, it is concluded that use of the Bar-Lock couplers in restoring the temporary concrete construction openings will not reduce the structural capability of the repaired structures. This will restore these structures to their design capability. The shield building and steam generator compartments will, therefore, continue to perform their functions as described in the Sequoyah UFSAR.

Therefore, the possibility of a new or different accident situation occurring as a result of this condition is not created.

C. The proposed amendment does not involve a significant reduction in a margin of safety.

As indicated in Sections 3.8.1.2 and 3.8.3.2 of the Sequoyah UFSAR, the structural design of the shield building and interior concrete structures is in

compliance with the American Concrete Institute (ACI) 318-63 building code working stress design requirements. The reinforcing steel conforms to the requirements of ASTM A 615, Grade 60. UFSAR Section 3.8.1.1 states that reinforcing bars were lap spliced in accordance with ACI 318-63 requirements for Strength Design.

The restoration of the temporary concrete construction openings in the shield building and steam generator compartments may utilize Bar-Lock couplers to splice new rebar to the existing rebar. The restoration of the construction openings, including use of the Bar-Lock couplers, will conform to the requirements of ACI 318. Therefore, following completion of the restoration of these structures, they will still comply with ACI 318 requirements.

In addition to conforming to ACI 318 requirements, the Bar-Lock coupler qualification tests detailed in Topical Report 24370-TR-C-001 demonstrated that the Bar-Lock coupler meets the ASME strength requirements.

Therefore, a significant reduction in the margin to safety is not created by this modification.

V. ENVIRONMENTAL IMPACT CONSIDERATION

The proposed change does not involve a significant hazards consideration, a significant change in the types of or significant increase in the amounts of any effluents that may be released offsite, or a significant increase in individual or cumulative occupational radiation exposure. Therefore, the proposed change meets the eligibility criteria for categorical exclusion set forth in 10 CFR 51.22(c)(9). Therefore, pursuant to 10 CFR 51.22(b), an environmental assessment of the proposed change is not required.

Appendix G

Responses to NRC Request for Additional Information

S64 021210 800

Tennessee Valley Authority, Post Office Box 2000, Soddy-Daisy, Tennessee 37384-2000

December 10, 2002

10 CFR 50.4

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D. C. 20555

Gentlemen:

In the Matter of	)	Docket Nos. 50-327
Tennessee Valley Authority	)	

SEQUOYAH NUCLEAR PLANT (SQN) - STEAM GENERATOR REPLACEMENT PROJECT - TOPICAL REPORT NO. 24370-TR-C-001, "ALTERNATE REBAR SPLICE - BAR-LOCK MECHANICAL SPLICES," RESPONSE TO NRC REQUEST FOR ADDITIONAL INFORMATION

Reference: NRC letter to TVA dated December 4, 2002, "Sequoyah Nuclear Plant, Units 1 and 2 - Request for Additional Information Concerning Unit 1 Steam Generator Replacement Topical Reports and Associated Technical Specification Amendment (TAC NOS. MB5370, MB5371, MB5387)"

The purpose of this submittal is to provide additional information in response to the staff's referenced letter. Based on discussion with the staff during a meeting between TVA, Bechtel, and NRC on October 24, 2002, TVA understands that the additional information will allow the staff to complete their review of the subject topical report. The approval of the topical report supports SQN's Unit 1 steam generator replacement outage that is scheduled to begin in March 2003.

Enclosed is the additional information that supports Topical Report No. 24370-TR-C-001. The additional information requested for Topical Report Nos. 24370-TR-C-002 and 24370-TR-C-003 will be submitted by separate letters.

This letter is being sent in accordance with NRC RIS 2001-05. There are no commitments contained in this letter.

If you have any questions about this change, please telephone me at (423) 843-7170 or J. D. Smith at (423) 843-6672.

Sincerely,

Original signed by

Pedro Salas
Licensing and Industry Affairs Manager

Enclosure

JDS:DVG:SJM
Enclosure
cc (Enclosure):
R. J. Adney, LP 6A-C
J. L. Beasley, OPS 4A-SQN
M. J. Burzynski, BR 4X-C
M. H. Dunn, ET 10A-K
D. L. Koehl, POB 2B-SQN
J. E. Maddox, LP 6A-C
NSRB Support, LP 5M-C
R. T. Purcell, OPS 4A-SQN
J. A. Scalice, LP 6A-C
K. W. Singer, LP 6A-C
WBN Site Licensing Files, ADM 1L-WBN
EDMS, WTC A-K

I:License/steam generator replacement/topical reports/RAI response for Bar-Lock.doc

ENCLOSURE

TENNESSEE VALLEY AUTHORITY
SEQUOYAH NUCLEAR PLANT (SQN)
UNIT 1
DOCKET NO. 327

ADDITIONAL INFORMATION FOR TOPICAL REPORT NO. 24370-TR-C-001, "ALTERNATE REBAR SPLICE - BAR-LOCK MECHANICAL SPLICE"

NRC Question No. 1

Provide a copy of the Bechtel/Idaho National Engineering and Environmental Laboratory (INEEL) test report for the Bar-Lock Mechanical Splices. The report should include information on who performed the splice tests, their qualifications, and how the tests were performed.

TVA Response

A copy of the Bar-Lock test report prepared by INEEL is provided as Attachment 1. This report summarizes the test plan, results of rebar material testing, couplers tested, and results of the tensile and cyclic testing of the couplers.

Based on the INEEL test plan, Bechtel developed a specification that defined the testing requirements. These test requirements were incorporated into the work plan and inspection record (WPIR) for controlling the Satec test machine setup, preparation of the Bar-Lock test specimens, and performance of the testing.

Bechtel personnel performed testing of the Bar-Lock couplers at the SQN site using a Satec 600VTL test machine. These personnel were trained by Instron/Satec in the use of the test machine.

Calibration of the test machine was performed prior to its use and after completion of the Bar-Lock testing. Bechtel Quality Control (QC) personnel reviewed the calibration documentation for acceptability.

Rebar and coupler test specimens were prepared in accordance with Bar-Lock guidelines and the requirements of the Bechtel specification by personnel trained either by a Bar-Lock representative or by Bechtel personnel certified by Bar-Lock. TVA and Bechtel Quality Assurance (QA) QC personnel periodically monitored the preparation and testing of the test specimens.

An INEEL representative was present during the initial setup of the Satec machine, programming of the test software, and witnessed the coupler testing.

NRC Question No. 2

Describe TVA's involvement, if any, in the Bechtel/INEEL test program.

TVA Response

TVA was heavily involved in the Bechtel/INEEL test program

- TVA reviewed and approved the following specifications, procedures and test plans associated with the procurement, testing, and installation of the Bar-Lock couplers.
  - 24370-C-311, "Technical Specification for Purchase of Bar-Lock Couplers"
  - 24370-C-312, "Technical Specification for Installation of Bar-Lock Rebar Splices"
  - 24370-C-602, "Technical Specification for Qualification Testing of Bar-Lock Mechanical Rebar Splices"
  - Construction Procedure CP-C-13, "Bar-Lock Rebar Splices"
  - "Test Program Plan for Qualification of Bar-Lock Coupler System for Use in Nuclear Safety-Related Applications," prepared by Idaho National Engineering and Environmental Laboratory
  -
- TVA Civil Engineers attended the vendor training session conducted at SQN on August 21, 2001.
- TVA Engineering and QA personnel witnessed the preparation of several test assemblies on August 21-22, 2001.
- TVA Engineering and QA personnel also witnessed testing of several specimens throughout the duration of the test program from October 11, 2001 to October 19, 2001.
- TVA reviewed and approved the Mechanical Testing Program and Performance Analysis, prepared by INEEL.

NRC Question No. 3

Clarify whether TVA has evaluated and determined that the Quality Assurance (QA) programs of the reinforcing bar supplier (Consolidated Power Supply), the reinforcing bar fabricator (Birmingham Steel Corporation), the manufacturer of the Bar-Lock coupler (including lockshear bolt, and serrated rail), and the contractors who performed the tests (Bechtel/INEEL), meet the Title 10, *Code of Federal Regulations* (10 CFR) Part 50, Appendix B requirements? Provide the results of TVA's evaluations of theses QA programs.

TVA Response

TVA has reviewed and approved Bechtel's Sequoyah Steam Generator Replacement (SGR) Project Nuclear Quality Assurance Manual. The policies in this manual correspond to each of the 18 criteria of 10 CFR 50, Appendix B and meet the requirements of ANSI N45.2 and N45.2 series standards and QA-related NRC regulatory guides.

Bechtel, in its role as a contractor to TVA, imposed the applicable 10 CFR 50 Appendix B requirements along with the technical and document submittal requirements on the subcontractors involved in the material supply, fabrication, and testing of the rebar and Bar-Lock couplers. Bechtel reviewed the quality programs for the rebar supplier (Consolidated Power Supply), the manufacturer of the Bar-Lock coupler (Valley Machining), and INEEL, and where appropriate, required changes to these programs to bring them into compliance with the requirements of 10 CFR 50, Appendix B. Bechtel specifications required their subcontractors to extend the specification requirements to their contractors.

NRC Question No. 4

On page 10 the report states that Bechtel witnessed and verified implementation of Bar-Lock's manufacturing quality control processes and procedures for compliance with the applicable provisions of American National Standards Institute/ American Society of Mechanical Engineers (ANSI/ASME) N45.2. Identify and submit for staff's review the applicable provisions of ANSI/ASME N45.2 that were considered. Discuss how the Bar-Lock's manufacturing quality control processes and procedures comply with the 10 CFR Part 50, Appendix B requirements.

TVA Response

The provisions/requirements of ANSI/ASME N45.2-77 that were considered applicable to the manufacturer of the Bar-Lock couplers (Valley Machining) are:

2. Quality Assurance Program
3. Organization
5. Procurement Document Control
6. Instructions, Procedures, and Drawings
7. Document Control
8. Control of Purchased Material, Equipment, and Services
9. Identification and Control of Materials, Parts, and Components
10. Control of Special Processes
11. Inspection
12. Test Control
13. Control of Measuring and Test Equipment
14. Handling, Storage, and Shipping
15. Inspection, Test, and Operating Status
16. Nonconforming Items
17. Corrective Action
18. Quality Assurance Records
19. Audits

Review of the Bar-Lock manufacturing processes along with the provisions of the specification for the purchase of the Bar-Lock couplers as described below assures that the corresponding requirements of 10 CFR 50, Appendix B are also met.

A specification, written for the purchase of the Bar-Lock couplers, identified the technical requirements the Bar-Lock manufacturer was required to meet. These requirements covered applicable codes and standards, quality, shipping, handling, storage, critical processes and parameters, and documentation. Bechtel QA personnel performed surveillances during the manufacturing of the Bar-Lock couplers to verify that the manufacturing process was performed in a manner that was consistent with the specification. The critical processes identified in the specification and the results of the Bechtel QA surveillances are summarized below:

a. Application of material traceability identification on bolt, tube, and saddle material

The material traceability of each heat lot of material for the tubing, hex stock for bolting, and square stock for the saddles was verified by review of the mill tag affixed to each bundle of material and visual

verification of the physical markings on the stock. The material test reports were reviewed to verify material composition and strength were as required by the specification.

b. Tapping of bolt hole

The drilling and tapping of bolt holes was performed in one machine operation. The hole locations were checked initially by the machinist and by the inspector when the machine was set up. Set up pieces were identified as such and were not included as part of the production run. When the production run began, the finished holes were checked on a random basis by the machinist and by the roving inspector using a calibrated go/no go plug gauge. In addition, 100 percent of the threaded holes were verified as completely drilled and tapped since each coupler is fully assembled with the bolts installed at final assembly and inspection. This process was monitored by Bechtel QA and Bar-Lock personnel throughout the drilling and tapping process. No deviations from the design drawing were noted.

c. Induction heating of bolt tip

The induction heating process was monitored on a periodic basis by Bechtel QA personnel and by the operator and QC inspector. Six samples were taken by the operator and verified by the QC inspector at approximately four-hour intervals during the induction hardening process. The tested bolts all fell within the specified hardness range.

d. Fusion of saddles to tube

The weld of the saddle to the tube is critical only to the extent that it needs to hold the saddles in position until the bar is inserted and the bolts set. There is no credit taken for the weld in the ability of the coupler to withstand the required tensile and cyclic performance criteria. The weld is tested on a random basis by the QC inspector by dropping the coupler from a height of 5 feet onto concrete. If there is no weld failure, the weld is considered acceptable. There were no failures noted during these tests.

e. Bolt shear testing

Each shear value bolt test was witnessed by Bechtel QA personnel. Unique heat lot numbers were assigned to

each batch of bolts sent to the heat treatment facility. After heat treating and quench, the bolts were tested at the heat treatment facility for hardness to determine the amount of time and temperature required in the draw furnace. After final treatment the bolts were again checked for hardness to verify conformance with the required hardness. The shear testing for each lot resulted in satisfactory results. Each bolt was stamped during the machining operation with the letters VMC to help assure that no other bolts would be co-mingled with those produced for Sequoyah.

f. Heat treatment condition of saddles

After machining, the saddles were heat treated and case hardened. Bechtel QA personnel witnessed the furnace load time and verified the furnace temperature. Fifty-three saddles of each size were tested to verify that the required minimum case hardening depth and hardness were achieved. The results were satisfactory.

The critical parameters identified in the specification were:

a. Length of tube
b. Inside diameter of tube
c. Outside diameter of tube
d. Number of bolts
e. Saddle location
f. Bolt spacing
g. Bolt edge distance
h. Bolt threads
i. Bolt tip hardness
j. Diameter of bolt shear plane
k. Actual bolt break-point torque values.

The critical parameters listed above were verified by Valley Machining machine operators and QC personnel. Bechtel QA personnel verified each of these parameters during regular monitoring throughout the manufacturing process.

All measurements were made using equipment calibrated under a controlled calibration program with standards of calibration being traceable to NIST or another nationally recognized standard. Calibration records were reviewed by Bechtel QA personnel.

The supplier procurement documents from Bar-Lock to Valley Machining were reviewed by Bechtel QA personnel for the coupler design for nuclear safety-related applications. In addition, the procurement documents for the tube material, hex

stock for bolts, and square stock for the saddles were reviewed.

Bechtel QA personnel examined a completed container of couplers for shipping preparation and container identification. The preparation was found to comply with the requirements of ANSI N45.2.2, Level C, as required by the specification.

NRC Question No. 5

On page 11 of the report it states that, "Since the Bar-Lock couplers will be used in a nuclear safety-related application, they are subject to a commercial grade dedication program." Describe and submit the commercial grade dedication program for staff's review.

TVA Response

The TVA dedication program for procurement and use of commercial grade items in safety-related applications is based on guidelines contained in Electric Power Research Institute (EPRI) Report No. NP-5652, "Guideline for the Utilization of Commercial Grade Items in Nuclear Safety-Related Applications." TVA procedures require the use of one (or any combination of) the methods described in the report for dedication of commercial grade items. Based on the nature of the Bar-Lock coupler procurement (i.e., an infrequent procurement of a specialized component), the "source verification" method described in Section 3.3 of the EPRI report was used. Under this dedication process, a component-specific specification was developed (as discussed in the response to Question 4) which established the Codes, Standards and quality assurance requirements for fabrication of the couplers. The specification established minimum material and tensile strength requirements based upon the safety function performed by the coupler and identified the critical processes and parameters requiring verification to ensure compliance with the established functional requirements.

To verify conformance with the requirements of the specification, source surveillance of the manufacturer's facility and fabrication activities was performed prior to and during component manufacture. The scope of the surveillance activities verified compliance with the quality assurance and critical parameter requirements of the specification. The results of the inspections, tests, and certifications performed during source surveillance activities were documented in a material fabrication report compiled by the manufacturer. This documentation was reviewed by TVA as part of the component receipt inspection and was confirmed to be adequate to establish the component critical

characteristics under the "source verification" dedication method outlined in EPRI Report No. NP-5652.

NRC Question No. 6

On page 12 of the report it states that the records of bolt shear test results were examined. Describe how the bolt shear test was conducted and submit a typical bolt shear test result, including the relationship between applied shear force and recorded shear deformation of a test bolt.

TVA Response

The bolt shear-torque test was conducted. The shear-torque was tested by gripping the end of the bolt to secure it, and then torquing the bolt until the head sheared off. The torque wrench used for the test had a memory device capable of recording shear-torque of the bolt head. The bolts were inspected and tested to meet the Bar-Lock Bolt Specifications. The major diameter, pitch, fit, and length were inspected and recorded. The shear-torque (ft-lbs) value at bolt head break was also recorded. These values were recorded for each sample set on Valley Machining Form POP-05 #3. Typical inspection and testing record sheets are provided as Attachment 2.

The shear deformation at the bolt head was not specifically tested. Any deformation that occurs due to the shear-torque test will be localized, occurring in the shear plane of the bolt head break. The bolt head break is located outside the active area of the coupler and would therefore have no impact on the strength, reliability, and function of the coupler.

NRC Question No. 7

The Bar-Lock coupler system relies on the clamping force generated on the rebars between the lockshear bolts and serrated rails. Provide the magnitude of the compressive stress and force on the tip of a lockshear bolt and the strain in the bolt after the bolt installation. Provide the stress relaxation characteristic of the lockshear bolt (relaxation is defined as the loss of its compressive stress under strain for a period of time). Provide evidence that the clamping force generated by the lockshear bolt would not be reduced, as a result of the relaxation phenomenon, to a point that would degrade the proper function of the Bar-Lock coupler system during the life of the plant.

TVA Response

The Bar-Lock bolt tips are hardened to a level that exceed the hardness of the rebar, ensuring no plastic deformation of the bolt tips. The results of the testing performed at SQN confirmed this design, in that where the splice failure mode was rebar pull-out, the rebar had been damaged by the bolt tips, while no bolt tip failures were experienced. Note that the splice failure occurred well after the design load was reached. To show that the design properly accounts for the stress and strain is evidenced in the reliability of the couplers tested in this qualification process.

Stress relaxation is associated with materials within or very near their creep temperature ranges. For carbon and low alloy steel bolting, stress relaxation is not considered a concern at ambient temperatures. Under these conditions the stress in the Bar-Lock coupler is not time dependent.

ATTACHMENT 1

Idaho National Engineering and Environmental Laboratory (INEEL) Test Report

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INEEL/EXT-02-01387

Qualification of the Bar-Lock Rebar Coupler For Use in Nuclear Safety-Related Applications: Mechanical Testing Program and Performance Analysis

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Idaho National Engineering and Environmental Laboratory
Materials Department
Idaho Falls, Idaho 83415-2218

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Summary

Bechtel Corporation and INEEL developed and performed an independent mechanical testing and analysis program to assess the mechanical performance characteristics of the Bar-Lock L-Series rebar coupler system. A test plan that exceeded the assessment requirements given in ASME Section CC-4333 was developed. To achieve high statistical confidence in measured sample parameters, e.g. ultimate strength, the number of specimens tested was increased to forty (40) from the ASME Code-required quantity of six (6). Bechtel QA/QC personnel monitored the testing program to ensure that it was performed in accordance with the requirements in Specification 24370-C-602.

Static strength tests of two sizes, #6 and #8, of Bar-Lock coupler assemblies showed that they exceeded the ASME-specified minimum strength levels by large margins. Statistical analysis of the results showed a 99.998% probability that the average strength of a group of coupler assemblies would exceed the ASME static strength requirement of 90% of the joined rebar tensile strength. Assessing the performance of individual coupler assemblies against the ASME-specified minimum strength (75 ksi for the Grade 60 rebar used in the tests) for individual assemblies showed that the average strength of an individual assembly was more than 8 standard deviations above the specified minimum. This corresponds to the probability that essentially 100% of all coupler assemblies would exceed the specified minimum strength.

Forty specimens of each of the two sizes (6L and 8L) of coupler/rebar assembly were tested to determine their cyclic loading durability. The test procedure cycled each assembly between 5 and 90% of specified minimum bar yield strength (60 ksi) 100 times. None of the specimens failed in any manner, e.g. bar break, or bar slip within the coupler.

In an effort to improve the cyclic durability performance assessment, several randomly selected specimens received additional cyclic loading. Each selected specimen had an additional 1000 loading cycles imposed. None of the specimens failed, and none of them showed signs of deterioration through excessive strain accumulation or physical deformation. This provides an empirical indication that the cyclic durability of the couplers will far exceed 100 cycles.

Further, some coupler assemblies randomly selected from those already receiving 100 loading cycles were subsequently loaded to failure monotonically (static strength test). This test determined if the prescribed cyclic loading substantially damages the integrity or strength of the coupler splice assembly. The eight specimens tested all achieved the same nominal strength as like specimens receiving no cyclic loading.

The Bechtel/INEEL test program tested and demonstrated that the mechanical properties of the L-Series Bar-Lock mechanical splices meet the existing Codes and NRC requirements and are an acceptable method of connecting reinforcing bar in nuclear power plant safety-related applications. The large quantity of couplers tested provides a higher confidence that the couplers do meet, and indeed far exceed, those ASME-specified requirements.

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Qualification of the Bar-Lock Rebar Coupler for Use in Nuclear Safety-Related Applications: Mechanical Testing Program and Performance Analysis

1. OVERVIEW

Bechtel Corporation and INEEL developed and performed an independent mechanical testing and analysis program to assess the mechanical performance characteristics of the Bar-Lock L-Series rebar coupler system. By design, this program provided a very rigorous test of coupler design mechanical performance, using the qualification criteria of **ASME Section III, Division 2, CC-4333** as a standard of reference.

The Bechtel/INEEL test program tested and demonstrated that the mechanical properties of the L-Series Bar-Lock mechanical splices meet the existing Codes and NRC requirements and are an acceptable method of connecting reinforcing bar in nuclear power plant safety-related applications.

2. TEST PLAN

ASME Section CC-4333 specifies performance criteria to qualify rebar splicing devices for use in nuclear safety-related applications. While the strength specifications are moderately high, the quantity of test specimens required is relatively low. To achieve high statistical confidence in measured sample parameters, e.g. ultimate strength, a larger sample size (n) is required. To achieve the desired level of confidence that any installation of these couplers will have the requisite performance characteristics, the quantity of verification test specimens (the sample set) was increased. For the static strength assessment, the ASME Code requires six specimens be tested, and all six must pass. In this test plan, the quantity was increased to n = 40 for each size tested. For the cyclic durability test, the ASME Code requires three specimens to survive the 100-cycle test. This was increased to n = 40 for each size. Increasing the statistical sample size from six or three to 40 allows a great improvement in the confidence levels (especially for the binomial distribution of the cyclic test) associated with lower bound strength and cyclic durability requirements specified in the Code.

The Bar-Lock testing was monitored by Bechtel QA/QC personnel to ensure that it was performed in accordance with the requirements in **Specification 24370-C-602**.

3. REINFORCING BAR MECHANICAL PROPERTIES TESTS

Mechanical properties for the rebar material used in these tests were determined in accordance with project test procedures, incorporating relevant American Society for Testing and Materials (ASTM) test standards and procedures (**ASTM Designation A 370-96, Standard Test Methods and Definitions for Mechanical Testing of Steel Products**; and **ASTM Designation E 8-99, Standard Test Methods for Tension Testing of Metallic Materials**). All mechanical properties tests were performed on the same universal test machine, using the same measurement transducers. The same test machine, load cell, and extensometer were used in all of the coupler assembly tests as well. Bechtel Quality Assurance Department retains all calibration certification and records for this equipment and these devices.

The reinforcing bar used in the Bar-Lock coupler testing program was ASTM A615 Grade 60 material in #6 (¾ in. nominal diameter) and #8 (1 in. nominal diameter) sizes. Consolidated Power Supply, the vendor of the rebar, provided certified material test reports (CMTRs). The values reported in the CMTRs are based on the results of a single tensile test. The CMTR value, while confirming the nominal material performance, is inadequate to determine "actual" material properties. The ASTM test standard recommends a minimum of three specimens be tested and the results averaged. Additional verification testing was performed as part of this test program to determine the "actual" or measured mechanical properties of the different heats of rebar employed in specimen assembly. Figures 1 and 2 show representative stress-strain curves for both heats of re-bar used in this test program.

3.1 #6 Re-Bar Material

A common heat of rebar (CPS #5898I2899) was used in making up all #6-size coupler test assemblies. Per ASME Section II, Division 2 requirements, the same 10 inch extensometer gage length, as would be used in the #6 coupler assembly tests, was used to measure strain in the tensile properties tests. Seven #6-size plain bar sections from this heat were tested to determine actual tensile properties of this lot of material. Table 1 summarizes the test results. Material properties obtained from Consolidated Power Supply CMTR are provided for comparison.

It is apparent that the differences in yield strength as determined by three different definitions are minimal. For this type of steel, the yield point is the appropriate measurement and provides the most consistent value (smallest standard deviation). Where "measured" or "actual" yield strength is required in the analyses, 67.7 ksi is used for the #6L coupler tests. Where "measured" or "actual" ultimate tensile strength (UTS, or F_u) is required in the analyses, 107.5 ksi is used for the #6 tests.

Table 1. Mechanical Properties of Rebar Used in Test Specimens

	Yield Point (ksi)	0.2%OS Yield (ksi)	0.5% EUL Yield (ksi)	UTS (ksi)	Elongation (%)	E (Msi)
#6 Average	67.7	67.9	68.2	107.5	13.2	27.8
#6 Std Dev	1.03	1.19	1.14	1.12	1.26	0.89
#6 CMTR	--	--	67.6	107.4	15	--
#8 Average	72.6	72.4	72.5	110.1	11.5	29.2
#8 Std Dev	0.45	0.57	0.47	0.74	0.98	0.46
#8 CMTR	--	--	73.1	112.0	14	--
#8 CMTR (C-series only)	--	69.0	--	112.8	16	--

3.2 #8 Re-Bar Material

A common heat of rebar (CPS #5898I3260) was used in making up all of the #8-size coupler test assemblies used in the tensile strength tests. Per ASME requirements, the same 14.5 inch extensometer

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gage length was used in the tensile properties test as would be used in the #8 coupler assembly tests. Seven #8-size plain bar sections from this heat were tested to determine actual tensile properties of this lot of material. Table 1 summarizes the results of those tests. Material properties obtained from Consolidated Power Supply CMTR are also provided for comparison. Again, the yield point strength is selected for the material yield strength value. Where "measured" or "actual" yield strength is required in the analyses, 72.6 ksi is used for the #8 tests. Where "measured" or "actual" ultimate strength (UTS) is required in the analyses, 110.1 ksi is used for the #8 tests.

3.3 Material for #8 Coupler Size Cyclic Durability Tests

A separate heat of rebar material (CPS #123741) was used to fabricate the size #8 cyclic test coupler assemblies. There are no measured strength parameters (only specified minimums) associated with the cyclic test procedures, so no verification testing of this material was performed. The CMTR-reported values for this heat are provided at the bottom of Table 1 for reference.

4. DESCRIPTION OF COUPLER TEST SPECIMENS

The Bar-Lock couplers used are Bar-Lock's "L-Series" (coupler designations 6L and 8L), which are higher strength rebar couplers for use in tension/compression, seismic and other cyclic load conditions. The specifications for these couplers are provided in Table 2.

Table 2. Bar-Lock L-Series Coupler Specifications (Sizes #6 and #8)

Coupler Designation	For Use on Rebar Size	Coupler Specifications			Bolt Specifications		
		Outside Diameter (inch)	Length (inch)	Nominal Weight (lbs.)	Quantity per Bar	Size (inch)	Nominal Shear Torque (ft.-lb.)
6L	#6	1.9	8.0	.4.5	4	1/2	80
8L	#8	2.2	12.3	9.5	5	5/8	180

The component parts of each Bar-Lock coupler consist of a steel tube, "lock-shear" bolts, and serrated rails. Figure 3 shows a schematic diagram of the coupler design. The seamless, hot-rolled steel tube conforms to ASTM A-519, with a minimum tensile strength in excess of 100 ksi. The lockshear bolt material is AISI 41L40. The bolts are through-hardened over the entire bolt length and further induction-hardened at the conical bolt tip. The serrated rails are made of ASTM CD1018. They are machined and then carburized to a depth of 0.032 in.

An equivalent testing program was performed for each of the two coupler/rebar sizes tested. For each size, forty test specimen assemblies were made up for tensile strength tests, and forty assemblies were made up for the cyclic durability tests. The test specimen assemblies were made up by steel construction workers using Bar-Lock's assembly instructions in a normal field environment. Assembly of the test specimens was monitored by Bechtel QC personnel.

5. TEST RESULTS

All of the 160 individual coupler specimens tested in this program, and all relevant specimen sample set averages and individual coupler strengths, exceeded the requirements set forth in the ASME Code, Section CC-4333.2.3(a).

Eighty tensile strength tests (forty of each size) were performed on coupler assembly specimens according to relevant sections of ASTM A 370 and E 8, and ASME CC-4333.2.3(a). A representative stress-strain curve for a coupler strength test is provided in Figure 4. No practical differences were observed in the general character of the stress-strain curve of any of the 80 specimens tested. All test data collected included stress, strain, crosshead displacement, applied force, and elapsed time. The actual individual test specimen results obtained through standard analysis methods provided in ASTM E 8 are tabulated in Tables 3 and 4. A representative stress-strain plot for a cyclic test is provided in Figure 5.

Table 3. Tensile Properties for #6 Rebar (Heat ID: 5898I2899)

Specimen ID	HOF Yield (ksi)	UTS (ksi)	ε_f (%)	E (Msi)
U6-2	67.7	106.9	14.0	28.7
U6-5	66.8	106.6	13.5	27.4
U6-9	67.0	107.0	12.9	28.1
U6-11	67.6	107.8	14.2	28.6
U6-12	69.9	109.7	10.6	27.3
U6-14	67.9	107.9	12.9	28.3
U6-18	67.3	106.5	14.1	26.2
Averages	67.7	107.5	13.2	27.8

Table 4. Tensile Properties for #6 Rebar Heat ID: 5898I2899

Specimen ID	HOF Yield (ksi)	UTS (ksi)	ε_f (%)	E (Msi)
U8-11	72.5	110.3	12.9	30.1
U8-12	72.4	108.8	11.2	28.7
U8-13	71.7	109.5	12.2	29.3
U8-14	73.0	111.0	9.8	28.8
U8-16	72.8	110.2	11.0	29.1
U8-18	72,5	110.4	11.7	29.2
U8-20	73.0	110.6	11.5	29.1
Averages	72.6	110.1	11.5	29.2

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In addition, several specimens of each size were randomly selected to receive an initial slip test prior to the normal strength test. A statistically-legitimate random selection process, using a random number generation algorithm on a computer, was applied to make the selections. Virgin test specimens were installed in the test machine, and instrumented as for a normal strength test. The applied stress was increased from 0, through 3 ksi, up to 30 ksi, and then reduced to 3 ksi. The change in displacement across the coupler between the two 3 ksi stress levels was measured with an extensometer. Figure 5 shows the traces of applied stress and resultant displacement for the six specimens. In all cases, no measurable slip was detected.[1] The observation of no bar slip within the coupler on initial loading means the coupler will develop full strength without excessive deformation upon initial loading.

5.1 Tensile Test Results

The ASME Code, Section CC-4333.2.3, has several criteria with which coupler performance is compared. The two pertinent criteria for the tensile strength test results are:

1. "...The *average tensile strength*[2] of the splices shall not be less than 90% of the actual tensile strength of the reinforcing bar being tested, nor less than 100% of the specified minimum tensile strength."

2. "...The *tensile strength of an individual splice system* (test specimen)[3] shall not be less than 125% of the specified minimum yield strength of the spliced bar."

The coupler assembly performance for both sizes evaluated exceeded both of these criteria. Table 5 tabulates the results of the individual strength tests. Discussion of the comparisons of test results to ASME specified minimum values follow:

5.1.1 Minimum Average Tensile Strength Comparison

For the lots of rebar tested, the "90% of the actual tensile strength" is the governing criteria. For the size #6 group, the specified minimum average strength value is 96.8 ksi. For the size #8 group, the specified minimum average strength value is 99.1 ksi.

5.1.1.1 Coupler/bar size #6

The sample set of strength data from the coupler/bar size #6 was evaluated for normal (Gaussian) probability distribution using the Wilk-Shapiro W-test and graphical analysis methods. The results show a near normal distribution, i.e. only slight departure from normality. Where necessary in the assignment of confidence limits, the assumption of normality is justified.

The size #6 group (sample set, n = 40) average tensile strength is 106.2 ksi (98.8% of the average #6 bar actual tensile strength), with a standard deviation of only 1.87 ksi. The Code-

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[1] the measured slip displacements, equivalent to less than 0.001 in. over the length of the coupler, were much less than observed hysteresis error in the extensometer.

[2] This is a single average value, calculated from the entire group (sample set) of replicate test specimens, i.e. from one heat of material, in one size.

[3] This is the strength value of each individual test specimen (coupler assembly) consisting of one coupler unit and two attached sections of rebar.

required average strength value of 96.8 ksi (90% of actual tensile strength) is 5.0 standard deviations below the sample average. This corresponds to a probability of less than 3 in 10 million couplers would have strength less than the required 96.8 ksi minimum value. Further, a one-sided test for lower bound was also performed. This test provides a practical lower limit strength value for any #6L coupler assembly. Based upon this data set 99% of all couplers of this type will have a tensile strength greater than 100.13 ksi (with a 99% confidence level). This is a very strong indication that the size #6 coupler design will achieve the required minimum strength. These results are confirmed in a letter report (see Appendix F) from INEEL statistician J.J. Einerson. Mr. Einerson reviewed the statistical analyses of the mechanical test data.

5.1.1.2 Coupler/bar size #8

The sample set of strength data from the coupler/bar size #8 was also evaluated for normal (Gaussian) probability distribution using the W-test and graphical analysis methods. Again, results show only slight departure from normality.

The size #8 group (sample set, n = 40) average tensile strength is 109.0 ksi (99.0% of the average #8 bar actual tensile strength), with a standard deviation of only 2.78 ksi. The required average strength value of 99.1 ksi is 3.6 standard deviations below the sample average. This corresponds to a probability of less than 2 in 10,000 couplers would have a strength less than the required 99.1 ksi minimum value. Further, the one-sided test for lower bound (described above) based upon this data set indicates that, with 99% confidence, 99% of all couplers of this type will have a tensile strength greater than 99.94 ksi (see letter report included in the Appendix). This is a very strong indication that the size #8 coupler design will achieve the required minimum strength.

To assess the general capabilities of the overall coupler design, the results from both sizes tested can be normalized by their respective bar lot (mill heat) tensile strengths and combined into one sample set. In so doing, the conclusion is that the Bar-Lock coupler design produces a splice that will achieve an average strength that is 98.9% as strong as the rebar itself. It is obvious that this greatly exceeds the ASME Code-required 90% value. The cumulative standard deviation is 2.2% of the bar strength, making the required minimum strength 4.0 standard deviations below the sample average. The equivalent likelihood is that only 3 in 100,000 would fail to achieve a strength level equivalent to 90% of the bar ultimate strength.

5.1.2 Minimum Tensile Strength of Individual Specimens

This requirement for each individual coupler tested provides additional assurance that the occasional sample tested that may have a relatively low strength value, as compared to the sample set average, at least has an absolute minimum necessary strength for structural considerations. For the Grade 60 rebar used in this study, this required value is 75.0 ksi, and is the same for all specimens tested. All specimens tested in this test program passed this test, and by a very large margin.

5.1.2.1 Binomial (Pass/Fail) Assessment

In the simplest case, the pass/fail criteria can be applied directly. For the combined sample size of 80, with no observed failures (strength below 75.0 ksi), the statement can be made that with 90% confidence, no more than 2.8% of couplers would fail this test. By the nature of this type of binomial probability distribution (pass/fail), it is difficult to state reliabilities with

a higher level of confidence without assessing many hundreds of samples. However, by normalizing the measured individual coupler strengths by the required value, an analysis of the amount of deviation on those values can provide a yet stronger comparison and corresponding statement of reliability.

5.1.2.2 Assessment Using Normalized Coupler Strength Distribution

This distribution of normalized strengths shows that the average coupler strength is 144% of the minimum required level for individual couplers, with a standard deviation of less than 4%. So the required strength value is 11 standard deviations below the sample average. The probability tables do not show probabilities below 8 standard deviations from the mean, but at that value, the probability is less than 2x10-15 that the strength of an individual assembly would be lower than the requirement, i.e. practically impossible.

5.1.2.3 Assessment Using Alternative Strength Criterion

A comment by the US Nuclear Regulatory Commission (USNRC), during a presentation on the Bar-Lock couplers on August 9, 2001, was that the minimum strength criterion for individual test specimens should be based upon the actual, measured yield strength of the bar material, rather than the specified minimum value (as done above, per the ASME qualification specification). This makes more sense from a practical view, and it removes one variable (the specified material yield strength) from the comparison. However, this approach does apply a more stringent test of the coupler capability, since the actual yield strength will always be higher than the minimum allowable. To apply this criterion, the size #6 and size #8 specimens must be treated separately since the measured yield strengths of the two bar sizes are significantly different.

Size #6 Couplers

Using the appropriately normalized test results from the #6 test specimens, the same analysis described above was carried out. The size #6 coupler specimen tensile strengths averaged 106.2 ksi, 25.4% above the USNRC-proposed strength level of 84.6 ksi (125% * 67.7 ksi) with a standard deviation of 1.86 ksi. The proposed minimum strength here is still more than 11 standard deviations above the proposed minimum level, with the probability being essentially zero that any coupler would fail to achieve this strength level.

Size #8 Couplers

Analyzing the normalized test results from the #8 test specimens show their tensile strengths averaged 109.0, 20.1% above the USNRC-proposed strength level of 90.8 ksi (125% * 72.6 ksi) with a standard deviation of 2.81 ksi. The proposed minimum strength here is still 6.5 standard deviations above the proposed minimum level. The resultant failure probability is still less than 1x10-10.

5.1.3 Tensile Strength Performance Exceeds Requirements

The overall strength performance of the Bar-Lock coupler design can be summarized as excellent, based on this comprehensive test program of different size couplers. There were no failures to meet any of the specified or proposed strength criteria in any case. As the various failure probability values indicate, the likelihood of any individual Type 6L or 8L coupler assembly failing to achieve the ASME required strength levels is very low.

Table 5. Re-Bar Splice Assemblies Strength Test Results

Specimen ID (#6)	Failure Type[4]	Final Strain (%)	UTS (ksi)	Specimen ID (#8)	Failure Type	Final Strain (%)	UTS (ksi)
Average	--	NA[5]	106.2	Average	--	NA[b]	109.0
S6-01	O	3.8	107.9	S8-01	O	3.7	109.6
S6-02	P	15.2	108.0	S8-02	T	1.4	96.8
S6-03	P	14.4	98.9	S8-03	O	4.9	109.8
S6-04	P	15.2	106.4	S8-04	O	3.7	110.1
S6-05	O	4.9	107.3	S8-05	P	10.4	108.4
S6-06	O	4.1	107.8	S8-06	T	4.9	109.7
S6-07	O	4.2	107.6	S8-07	T	4.4	110.4
S6-08	P	13.1	106.9	S8-08	T	3.6	109.4
S6-09	T	2.7	103.2	S8-09	O	3.6	110.5
S6-10	O	4.6	107.6	S8-10	T	1.8	102.1
S6-11	P	13.0	107.3	S8-11	T	2.1	106.0
S6-12	O	4.4	105.6	S8-12	*	3.8	108.0
S6-13	T	2.7	103.4	S8-13	O	3.4	110.5
S6-14	P	10.8	105.8	S8-14	T	3.2	110.1
S6-15	P	12.3	104.0	S8-15	*	3.7	106.7
S6-16	O	3.8	108.0	S8-16	T	4.0	111.0
S6-17	P	9.8	103.7	S8-17	T	2.1	104.5
S6-18	P	11.5	106.3	S8-18	T	4.5	109.3
S6-19	P	19.1	106.1	S8-19	T	4.0	109.4
S6-20	P	15.4	107.6	S8-20	O	4.6	110.1
S6-21	P	11.0	106.0	S8-21	T	3.5	109.7
S6-22	P	11.6	105.0	S8-22	T	4.3	109.4
S6-23	T	2.7	103.1	S8-23	T	3.8	109.8
S6-24	O	4.1	107.8	S8-24	T	3.3	108.5

[4] B = bar break outside coupler but within extensometer gage length, O = bar break outside coupler and outside extensometer gage length, T = bar break at tip of first lock bolt, P = bar pulled out of coupler without breaking, * = bar break in interior of coupler

[5] The final strain is dependent on several factors, including mode of failure. An average value for all tests has no significance. For example, in a pull-out failure the final strain is determined by the length of time the operator chooses to continue the test once pull-out is observed.

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Specimen ID (#6)	Failure Type[4]	Final Strain (%)	UTS (ksi)	Specimen ID (#8)	Failure Type	Final Strain (%)	UTS (ksi)
Average	--	NA[5]	106.2	Average	--	NA[b]	109.0
S6-25	P	11.5	105.1	S8-25	P	10.4	110.0
S6-26	P	11.3	107.9	S8-26	T	4.2	109.9
S6-27	P	12.2	106.4	S8-27	*P	7.0	109.7
S6-28	O	3.9	107.8	S8-28	T	4.1	109.0
S6-29	B	4.8	107.0	S8-29	O	3.8	109.7
S6-30	O	4.3	107.6	S8-30	O	3.5	110.3
S6-31	O	4.4	107.4	S8-31	T	3.9	110.5
S6-32	T	3.8	107.2	S8-32	T	2.5	109.0
S6-33	T	2.9	105.7	S8-33	O	4.4	110.3
S6-34	P	12.6	105.7	S8-34	T	3.5	109.7
S6-35	T	4.4	107.2	S8-35	T	2.5	105.4
S6-36	T	2.8	104.2	S8-36	T	4.1	110.5
S6-37	O	3.8	107.2	S8-37	*	5.0	110.2
S6-38	P	11.5	107.4	S8-38	P	10.3	109.9
S6-39	P	12.9	107.0	S8-39	T	3.9	111.2
S6-40	P	11.3	106.3	S8-40	P	10.2	113.6

5.2 Cyclic Test Results

Coupler assemblies were cyclically tested according to the requirements of ASME CC-4333.2.3(b). Forty specimens of each of the two types (6L and 8L) received 100 load cycles between 5 and 90% of specified minimum bar yield strength (60 ksi). None of the specimens failed in any manner, e.g. bar break, or bar slip within the coupler.

Applied stress and specimen extension data were digitized during the cyclic tests to provided additional insight into the coupler performance under cyclic load conditions. Figure 6 shows a representative plot of stress versus displacement. For clarity, only every tenth cycle is presented. It shows the accumulated slip over 100 cycles to be less than 0.0015 in. This is less than 10% of the elastic deformation that occurs during a single load cycle. The same behavior was observed in all of the tests of both coupler sizes. The couplers showed no significant deterioration (visible, or evidenced by deviation is test data) during the tests.

Based on the binomial probability function (pass/fail testing), and no observed failures in 80 tests, it can be stated with 90% confidence that less than 2.8% of all couplers would fail prior to the completion of 100 loading cycles.

5.2.1 Higher Count Cyclic Tests

In an effort to improve the cyclic durability performance assessment, several of the specimens in each size were selected at random to receive additional cyclic loading. Each selected specimen was subjected to an additional 1000 cycles. None of the specimens failed, and none of them showed signs of deterioration through excessive strain accumulation or physical deformation. While this does not provide a verifiable improvement in the statistical probability of failure (the confidence level is too low to be useful), it does provide an engineering indication that the cyclic durability of the couplers will far exceed 100 cycles.

5.2.2 Residual Strength Tests

Another test was also performed on randomly selected couplers to provide additional information regarding cyclic durability and residual strength. The selected couplers, all having been subjected to 100 loading cycles, were subsequently loaded to failure monotonically. This is the standard "tensile strength test" described in the previous section. The concept here is to determine if the prescribed cyclic loading substantially damages the integrity of the splice assembly. The eight specimens tested all achieved the same nominal strength as the corresponding specimens receiving no cyclic loading. Table 6 summarizes these test results. These observations suggest that cyclic loading in the stress range from 3 to 54 ksi does very little, if anything, to reduce the strength capacity of a spliced joint made using the Bar-Lock L-series coupler.

Table 6. Results of Residual Strength Tests on Load-Cycled Specimen Assemblies

Specimen ID (#6)	Failure Type	Final Strain (%)	UTS (ksi)	Specimen ID (#8)	Failure Type	Final Strain (%)	UTS (ksi)
Average	--	NA	104.9	Average	--	NA	106.7
C6-2	P	3.8	104.3	C8-15			106.6
C6-3	P	3.7	106.3	C8-21			106.0
C6-7	P	5.0	106.2	C8-27			107.6
C6-14	P	7.0	103.3				
C6-15	P	3.7	104.5				

6. COUPLER TEST PROGRAM CONCLUSIONS

The Bar-Lock coupler qualification testing program was carried out on two representative sizes – #6 and #8 – of their L-Series couplers. One hundred-sixty (160) coupler assemblies were tested. Fourteen (14) pieces of plain rebar were tested to determine the actual, or measured, mechanical properties of the two heats of bar material used in the test specimens.

6.1 Tensile Strength

The tensile strength tests on 80 samples from each of the two sizes all exceeded the two ASME requirements by a large margin. Statistical analyses of the test results determined several important performance indicators, all of which suggested that any given coupler assembly would far exceed the

ASME-specified strength requirements. *The overall probability of any coupler assembly (in size #6 or #8) failing to meet the minimum qualification strength criterion is less than* 3 in 100,000.

There was some variation in strength between the two heats of rebar used in the strength tests. Comparing and correlating these results show that Bar-Lock L-Series coupler splices can be expected to achieve a tensile strength greater than 96% of the actual strength of the bar material that is connected using the coupler device. While there are not enough different combinations of bar material and coupler size data to make this statement with high probabilistic certainty, the combined test results from this program appear similar when normalized by the actual bar strength. Therefore, it is likely these test results are representative of the performance of other sizes of Bar-Lock L-Series couplers. In other words, the mechanical design of the Bar-Lock L-Series coupler is such that spliced joints can be expected to develop over 96% of the actual bar strength.

6.2 Mechanical Slippage in the Couplers

Slip tests performed on selected specimens of both sizes showed a solid mechanical connection between the coupler and the rebar. There was no tendency for the rebar to move within the coupler prior to developing full splice strength. This was expected since the conical-tipped lock bolts physically embed into the bar material providing a physical shear force transfer from bar to coupler.

6.3 Cyclic Loading Durability

All 80 splice specimens that underwent the cyclic loading durability test passed the 100-cycle test, with no obvious physical degradation of the spliced joint. To provide an additional degree of assurance of adequate cyclic durability, selected specimens received 1000 cycles of loading, again with no noticeable physical degradation. Some of the specimens that passed the 100 cycle test were subsequently tested by monotonic loading to failure. The resultant measured strengths were essentially the same as the virgin strength test specimens (no cyclic loading applied). These results suggest that the design of the Bar-Lock coupler is essentially insensitive to cyclic loading to levels below 90% of the minimum bar yield strength.

6.4 Overall Coupler Performance

All of these test results, compared to the ASME splice system qualification requirements, indicate that the Bar-Lock coupler design for rebar splicing is entirely adequate from a strength point of view for use in nuclear safety-related construction. The large quantity of couplers tested provides higher confidence that the couplers do meet, and indeed far exceed, those ASME-specified requirement.

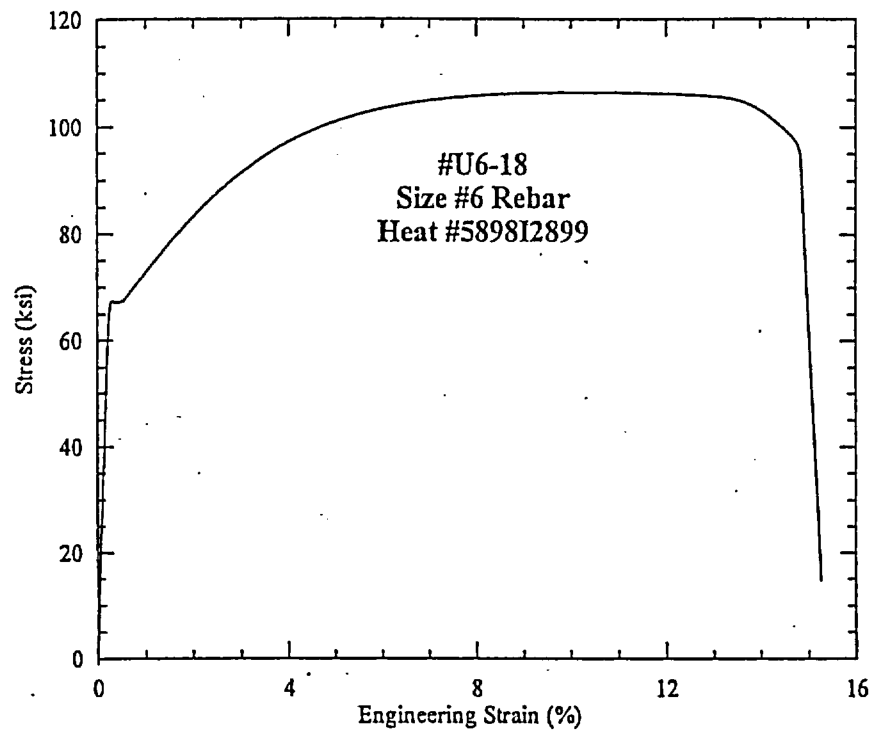

Figure 1. Representative Stress-Strain Curve from #6 Rebar Material

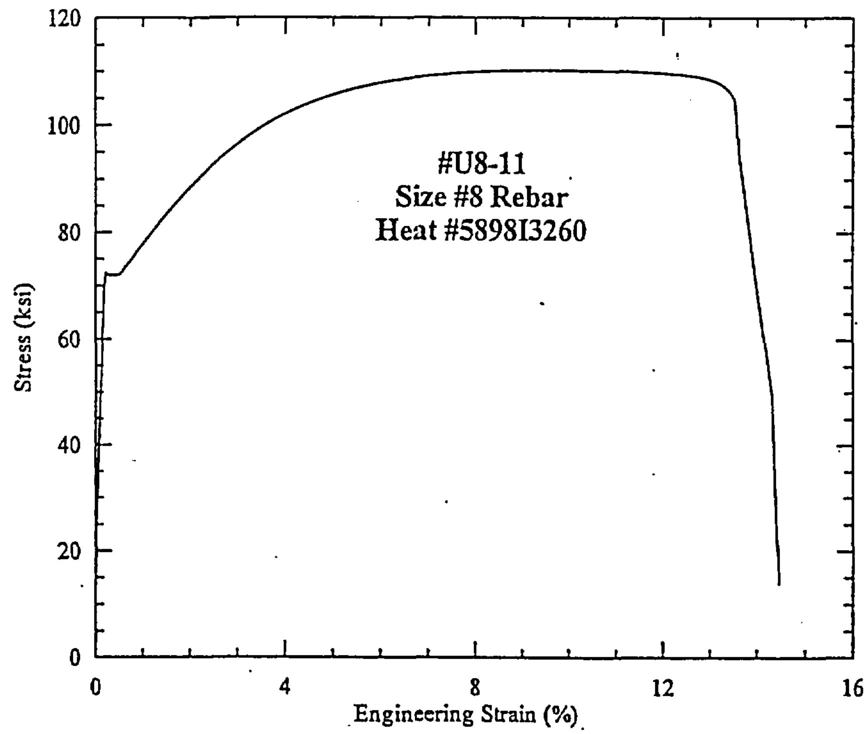

Figure 2. Representative Stress-Strain Curve from #8 Rebar Material

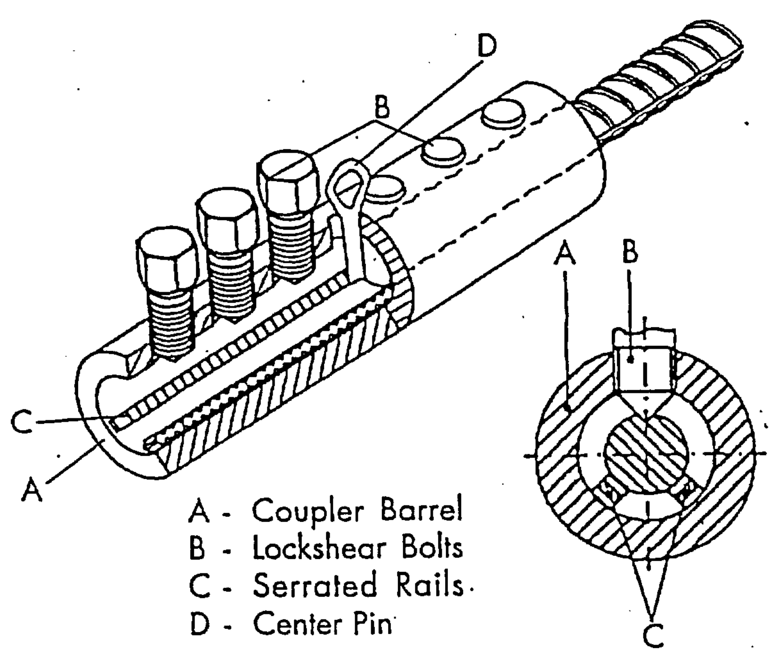

Figure 3. Bar-Lock Coupler Cutaway View Showing Internal Details

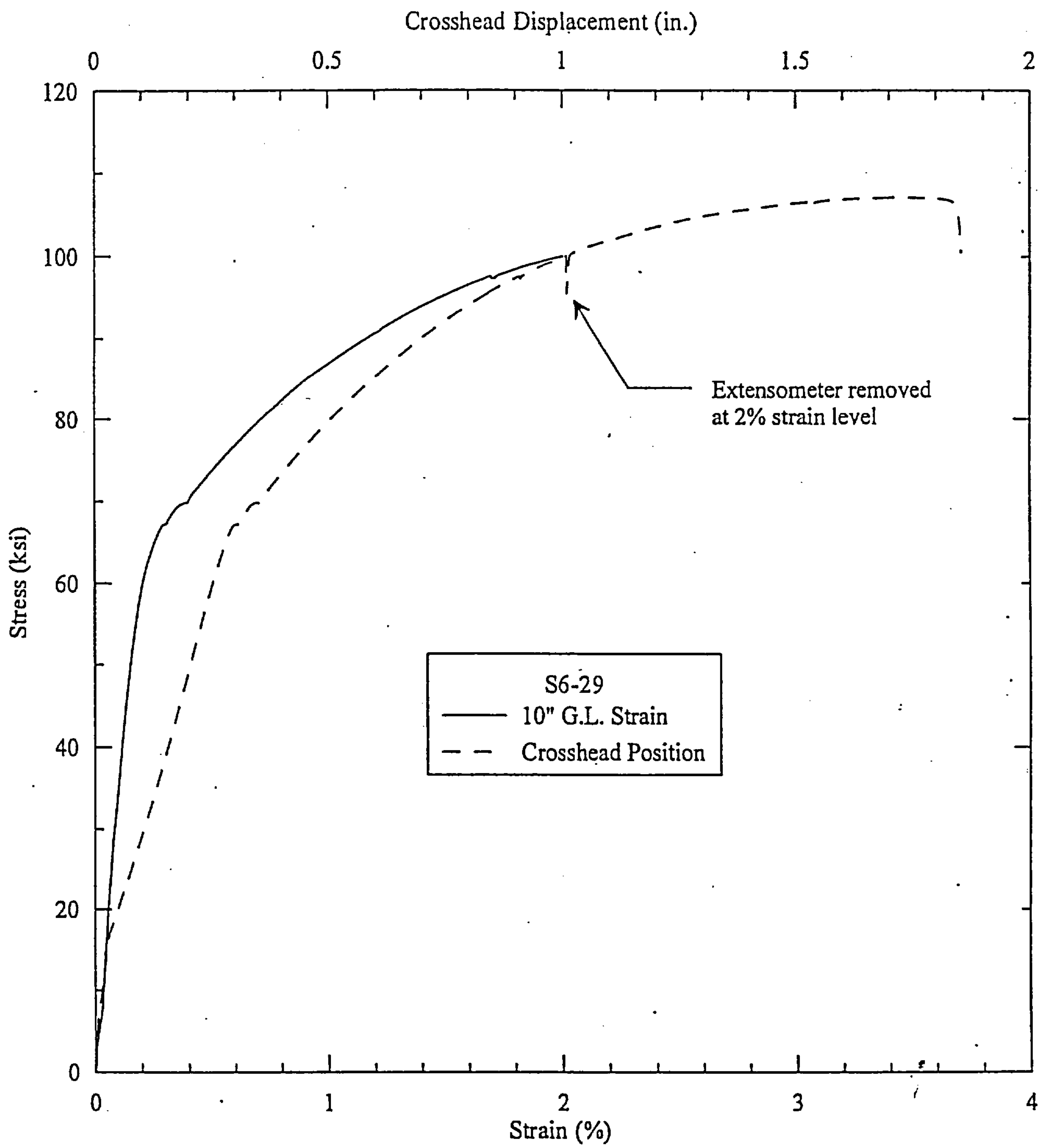

Figure 4. Representative Test Data from a Coupler Assembly Strength Test

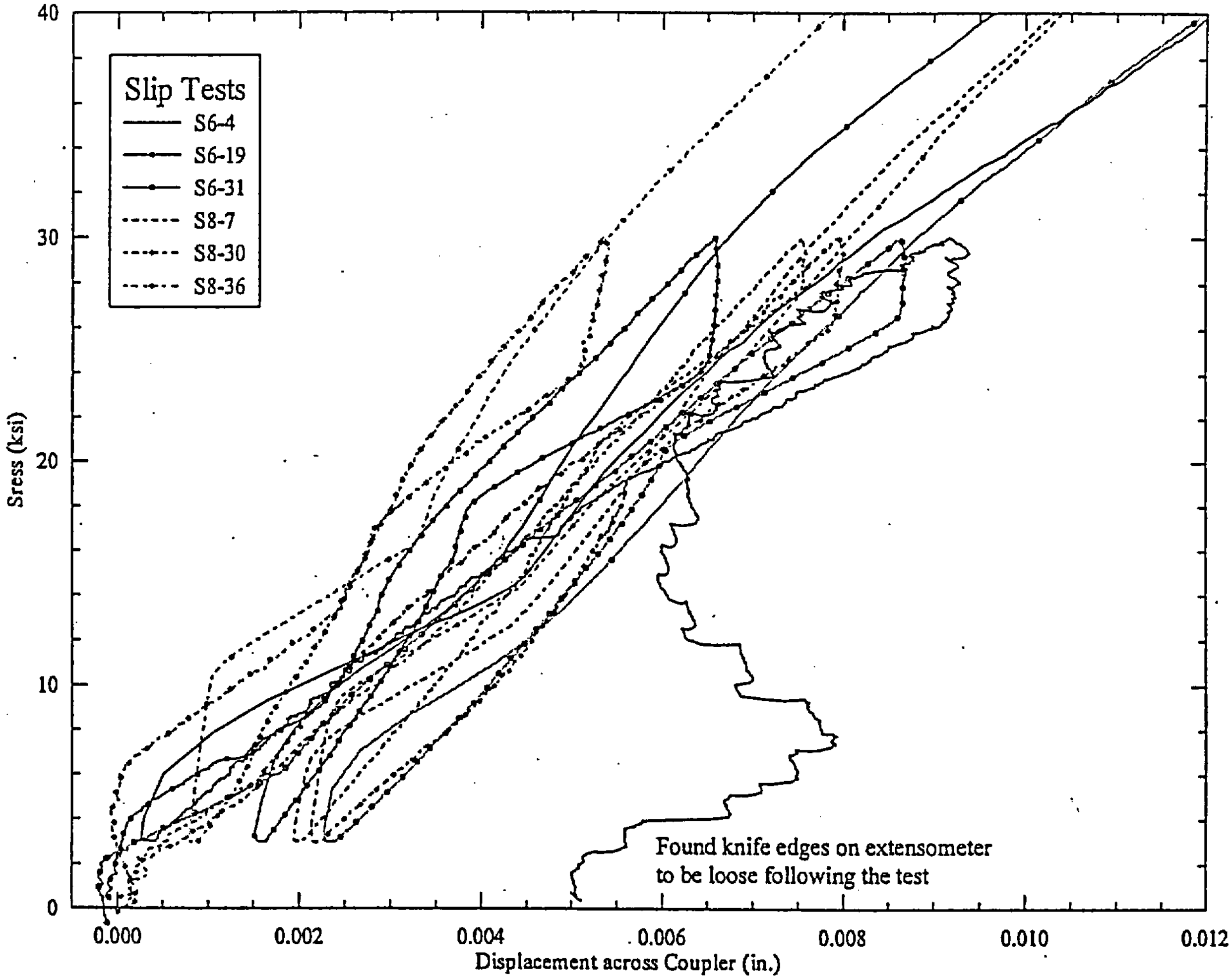

Figure 5. Data Curves Showing Load-Unload Cycle to Assess Bar Slip in Couplers

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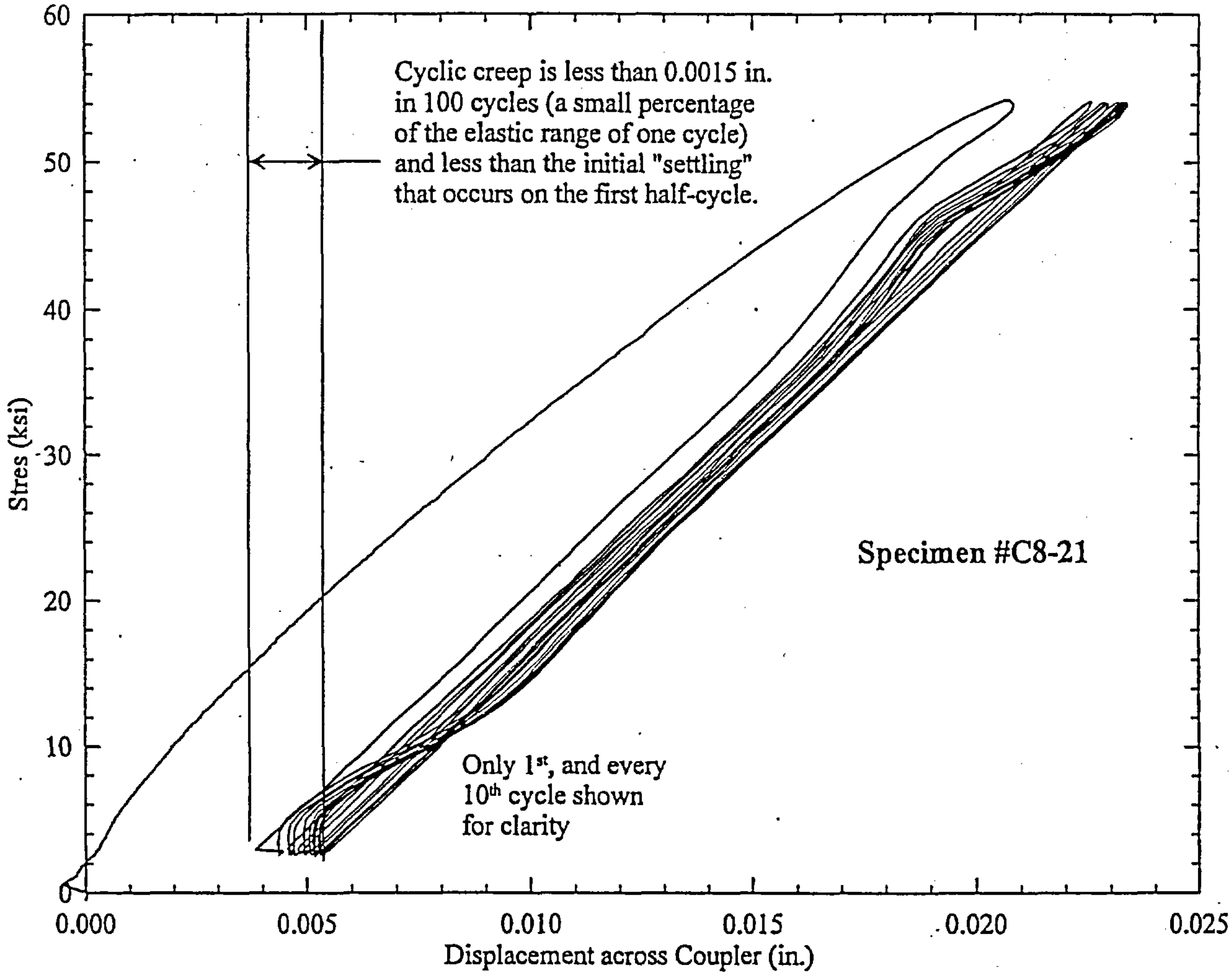


Figure 6. Cyclic Stress-Displacement History for a Typical Test

ATTACHMENT 2

Valley Machining
(Typical Inspection and Testing Record Sheets)

32a-i

Valley Machining Co
1250 22nd Avenue
PO Box 155
Rock Valley, IA 51247

Bolt Size:	M16B-N	Revision:	3-V2	Lot Qty:	4,474
				Ship Qty:	
Date of Test:	5/25/01	Bolt Lot #:	L17R2	Ship Date:	

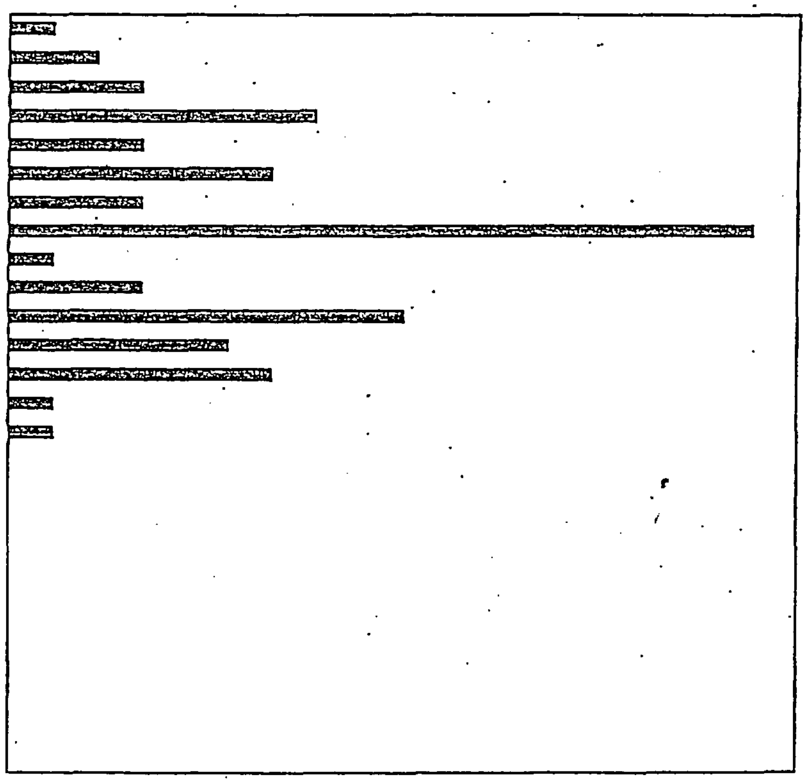
sample size	68

Nuclear App. Bolt

Test Parameter	Specification	Sample One Qty Pass	Sample One Qty Fail	Sample Two Qty Pass	Sample Two Qty Fail
Major Diameter (max/min)	.618 .628	68			
Pitch	2.00	68			
Fit	6g	68			
Length "E" (dim. +/-.010)	0.984	68			
Shear (ft-Lbs) Torque	180 205	68			
In-process Test Results		**High**	**Low**	**Accept**	**Reject**
Ind-Hard	*54/64*	64	62		

Shear Torque Data	Quantity
180	1
181	2
182	3
183	7
184	3
185	6
186	3
187	17
188	1
189	3
190	9
191	5
192	6
193	1
194	1
195	
196	
197	
198	
199	
200	
201	
202	
203	
204	
205	

HISTOGRAM



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NOTES:

LOT ACCEPTED ____________ VMC REVIEW OK Will Schader
5/25/01

Valley Machining Co

1250 22nd Avenue
PO Box 155
Rock Valley, IA 51247

Bolt Size:	M12-N	Revision:	3	Lot Qty:	4,843
				Ship Qty:	
Date of Test:	5/24/01	Bolt Lot #:	L19R2	Ship Date:	

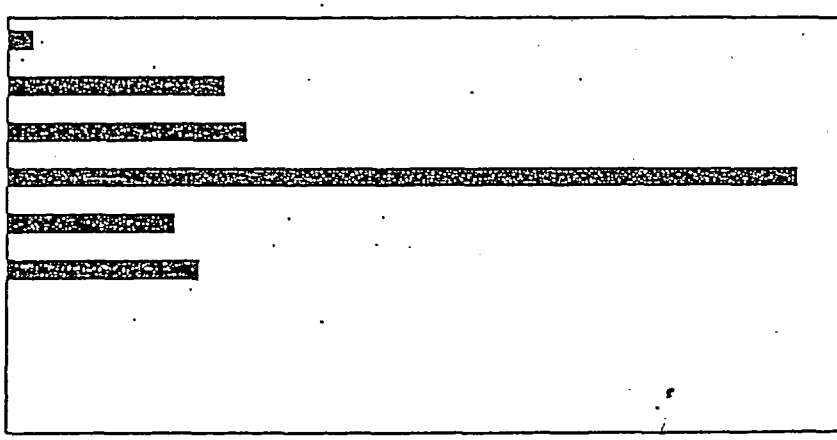
sample size	68

Nuclear App. Bolt

Test Parameter	Specification	Sample One Qty Pass	Sample One Qty Fail	Sample Two Qty Pass	Sample Two Qty Fail
Major Diameter (max/min)	.461 .471	68			
Pitch	1.75	68			
Fit	6g	68			
Length "E" (dim. +/-.010)	0.837	68			
Shear (ft-Lbs) Torque	80 88	68			
In-process Test Results		High	Low	Accept	Reject
Ind-Hard	*54/64*	63	61		

Shear Torque Data	Quantity
80	1
81	9
82	10
83	33
84	7
85	8
86	
87	
88	

HISTOGRAM



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LOT ACCEPTED ______________ VMC REVIEW OK Will Schader 5/25/01

prepared by: Will Schader
Quality Control Engineer

Form POP-05#3 10/10/00

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