BECHTEL
LOS ANGELES POWER DIVISION

DEFICIENCY EVALUATION REPORT
10 CFR 50.55(e)
AND/OR
10 CFR PART 21

1. REPORT NO. 81-14
REV. NO. -0-
DATE May 15, 1981
PAGE 1 OF 1

2. PROJECT - NAME/JOB NUMBER	3. UNIT	4. Q CLASS	5. REFERENCE DOCUMENTS
PVNGS/10407	3	Q	NCR C-C-2643

6. SEISMIC CATEGORY	7. HOW DISCOVERED
1	Containment Installation

8. REQUIREMENT

Specification 13-(-131

9. DESCRIPTION OF CONDITION

Two (2) ASTM A354BD bolts 1½" Ø x 2'-9" have cracked and separated during normal handling in the field.

- Bolts are supplied by Marathon Steel and used for pipe restraint anchor bolts.
- Each bolt is cracked 5½" from the end in the 9" long threaded portion.
- Examination of the crack shows light corrosion on the crack for 60-70% thru the bolt and balance of separation was subsequent propagation resulting in complete separation.

10. REPORT INITIATOR

J. E. Pfunder

11. QA VALIDATION OF BLOCKS 1-10

D R. Hawkins 5/15/81 12:30pm
DATE TIME

12. QA ~~RELEASE~~ notification OF DER TO:

	DATE	TIME
R. Stiens (PROJ ENG)	5/14/81	1:45PM
J. Houchen (PROJ MGR)	5/14/81	2:00PM
D. Krisha (QA SUPERVISOR)	5/14/81	1:20PM

13. PRELIMINARY EVALUATION

POTENTIALLY REPORTABLE YES ☒ NO ☐

W. G. Bingham 5/29/81 (PROJ ENG/DATE) W H Wilson 5/29/81 (PROJ MGR/DATE)

DATE CLIENT NOTIFIED 5/29/81 (B. S. Kaplan)

14. FINAL EVALUATION

REPORTABLE 10CFR 50.55(e) YES ☒ NO ☐
REPORTABLE 10CFR21 YES ☒ NO ☐
10CFR21 REPORT BY Bechtel Power

for W. G. Bingham 12/3/82 (PROJ ENG/DATE) W H Wilson 12/3/82 (PROJ MGR/DATE) D C LaVella (QA CONCURRENCE) 12/3/82 (DATE)

15. VERIFICATION OR CORRECTIVE ACTION

QA ______ DATE ______ ☐ ACCEPTED

TRANSFERRED TO NCR/CAR ☐ NO. ______

16. DISTRIBUTION LIST

			OTHERS
		☒ EVALUATION COMMITTEE	
☒ PROJ. MGR.	☒ PROJ. ENGR.	☒ CLIENT	☒ A. K. Priest
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☒ QA SUPERVISOR	☒ PROJ. PROC. MGR.	☒ MGR. OF QA	☐

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PROJECT FILE D.4.33

BECHTEL LOS ANGELES POWER DIVISION	PALO VERDE NUCLEAR GENERATING STATION PROJECT EVALUATION – DEFICIENCY EVALUATION REPORT JOB NO. 10407	REPORT NO. 81-14 REV./DATE 0 10-28-82 PAGE 1 OF 6

PREPARED BY		Q. CLASS	UNIT	REFERENCE DOCUMENTS
K. M. Schechter (NAME)	12-3-82 (DATE)	Q	1,2,3	Purchase Order Specification 13-CM-131

KMS

PART 21 REPORTABILITY: IF THE ANSWER TO ANY OF THESE CRITERIA (SEE PQPM 16.2 FOR DEFINITIONS) ARE NO THEN THE CONDITION IS NOT REPORTABLE UNDER PART 21.

1. DOES THE DEFECT EXIST IN A BASIC COMPONENT? ☒ YES ☐ NO
2. DOES THE DEFECT PRESENT A SUBSTANTIAL SAFETY HAZARD? ☒ YES ☐ NO
3. HAS THE COMPONENT BEEN DELIVERED OR OFFERED FOR ACCEPTANCE? ☒ YES ☐ NO

PROJECT EVALUATION ☐ INTERIM REPORT ☒ 50.55(e) FINAL REPORT ☒ PART 21 REPORT

I. DESCRIPTION CONDITION

The Palo Verde Project purchases anchor studs and bolts from Marathon Steel Company, Phoenix, Arizona, who in turn uses several subtier suppliers as sources of the fasteners to them.

Four (4) A354 Grade BD 1-1/2 inch diameter studs, used as anchor studs for the pipe whip restraints in the containment building, cracked and separated during normal handling. One of these studs was then lab tested for chemical and mechanical properties in accordance with ASTM A354. The stud met the ASTM specification requirements for yield strength, tensile strength, reduction of area, and chemical composition, but failed to meet the 14% elongation requirement (13% actual) and had a hardness far outside the HRC 33 to 38 range (HRC 48 on the edge of the cross section). Subsequently, a representative sample consisting of five percent (80) of the remaining A354 Grade BD bolts to be installed in Unit 3 were tested for the hardness requirement. The results showed that 29% (23 out of 80) of these bolts failed with 9 high and 14 low. Of the 14 that tested low, only one achieved the minimum ultimate tensile strength requirement.

Hardness testing of all the accessible completed installations has shown that fasteners, with hardness values both above and below the ASTM specification requirements, have been installed. Only 32% of the installed fasteners are currently planned for use; the remainder are associated with embedded plates which are not currently used.

The cause of this deficiency is attributed to inadequate heat treatment control by the various bolt manufacturers. This may be caused in part by the relatively small sampling requirement currently imposed by the ASTM Standard.

Bechtel quality assurance issued Corrective Action Requests S-81-69 and S-81-70 to obtain corrective action plans from Marathon Steel in regard to control of purchased material. As a result, corrective actions included audits and

IDENTIFY CALCULATION OR OTHER DESIGN DOCUMENT WHICH WILL BE INITIATED OR REVISED TO SUPPORT THIS EVALUATION
Attachment: Engineering Evaluation of Nonconforming ASTM A354 Grade BD Studs and Bolts
DOCUMENT TITLE, NUMBER, AND REVISION AND FORECAST COMPLETION DATE

SAR IMPACT ☐ YES ☒ NO
P. Bowler 12-3-82
NGS DATE

PEM EVALUATION AND REPORTABILITY RECOMMENDATION
W. G. Bingham 12/3/82
PEM DATE
☒ REPORTABLE
☐ NOT REPORTABLE

PF-3186 (10407) 10/80

re-audits of the subtier bolting material suppliers to assure that quality assurance programs were continually implemented and acceptable so that only conforming material is supplied to the project.

II. ANALYSIS OF SAFETY IMPLICATIONS

This condition is evaluated as reportable under the requirements of 10CFR 50.55(e) and Part 21. Although this extensive evaluation has determined that a safety significant condition does not currently exist, the potential for defective installations is evident. To date, only two pipe whip restraint designs require modifications as a result of nonconforming studs. The deficiency is also reportable as a breakdown in the quality assurance program in that inadequate surveillance and control resulted in an extensive number of non-conforming fasteners being delivered to the jobsite.

III. CORRECTIVE ACTION

a. Since February 19, 1982, Bechtel Construction has implemented a program whereby all quality class Q ASTM A354 Grade BD bolting material is tested for hardness prior to installations. This will remain in effect for the remainder of the construction phase.

b. Bechtel Engineering has prepared the attached report, "Engineering Evaluation of Nonconforming ASTM A354 Grade BD Studs and Bolts". This report utilizes the recommendations of Bechtel's Material and Quality Services Department and Teledyne Engineering Services (TES) to establish an acceptance criteria based upon Rockwell "C" scale hardness; additionally, these results were independently reviewed and accepted by Battelle Pacific Northwest Laboratories. As shown on page 5, the TES Recommended Acceptance Criteria with limitations specified by Bechtel, places a maximum acceptable hardness value of HRC41 and requires a down rating of design capacity for fasteners with hardness values less than HRC32.

c. All embedded fasteners which are accessible, have been hardness tested and the results documented. Bechtel Engineering has performed a recheck of all design calculations and drawings issued prior to February 19, 1982 to verify the adequacy of the connections affected by the above criteria. All embedded studs used after February 19, 1982 shall be evaluated using the documented hardness data and observing the established acceptance criteria. A note to preclude inadvertent and improper future use of the remaining studs and studs not accessible for testing has been added to all applicable Engineering Design Drawings. Long term stress levels (i.e., initial preload) for pipe whip restraint and jet impingement barrier studs will be controlled by either double-nut method or reduction of installation torque.

d. Of the 288 polar crane girder hold-down bolts installed in Units 1 and 2, 32 bolts, randomly selected, have been hardness tested (64 of 576 = 11%). None of the bolts have hardness exceeding HRC41. A revision to the calculations has been prepared to demonstrate that the design can accommodate down rating of all bolts (including those released for installation in Unit 3) to the allowable stresses of the "softest" installed bolt.

e. Bechtel quality assurance conducted a follow-up verification review at Marathon on 10-8-82 to evaluate the current status of corrective actions taken to resolve subtier suppliers' deficiencies. It was concluded that Marathon's corrective actions are satisfactory and that objective evidence is on file.

f. The following Nonconformance Reports (NCRs) will be dispositioned Use-As-Is/Rework.

Unit 1	Unit 2	Unit 3
C-C-2797	C-C-2825	C-C-2881
C-C-3163	C-C-2887	C-C-3743
C-C-3456	C-C-3182	C-C-3745
C-C-3592	C-C-3486	C-C-3594
	C-C-3593	

All studs with hardness value exceeding HRC 43 ($L > 669$) shall be removed by saw cutting. All studs with hardness value less than HRC 32 ($L < 582$) and values HRC 42 and HRC 43 ($654 \leq L \leq 669$) shall be identified by installing a tag, as shown on page 6, and securing with a hand-tight nut.

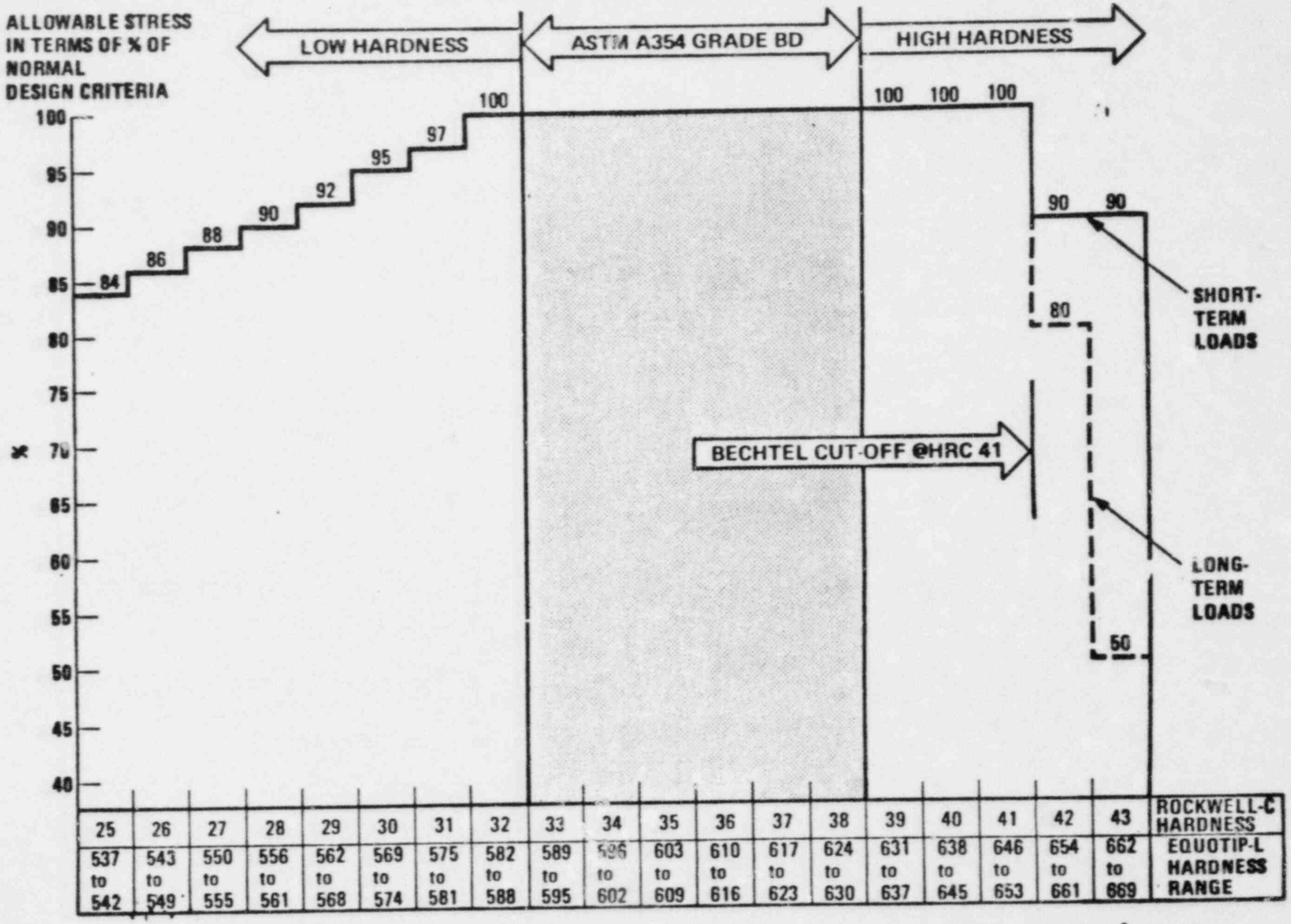
IV. AFFECTED MANUFACTURERS

The bolting material manufacturers which have supplied this material to Marathon Steel are identified but not necessarily limited by the following list since according to Appendix C, Figure 1 (page C-8), 424 studs were not identifiable. These studs either had no identifying symbol or the marked end was not exposed.

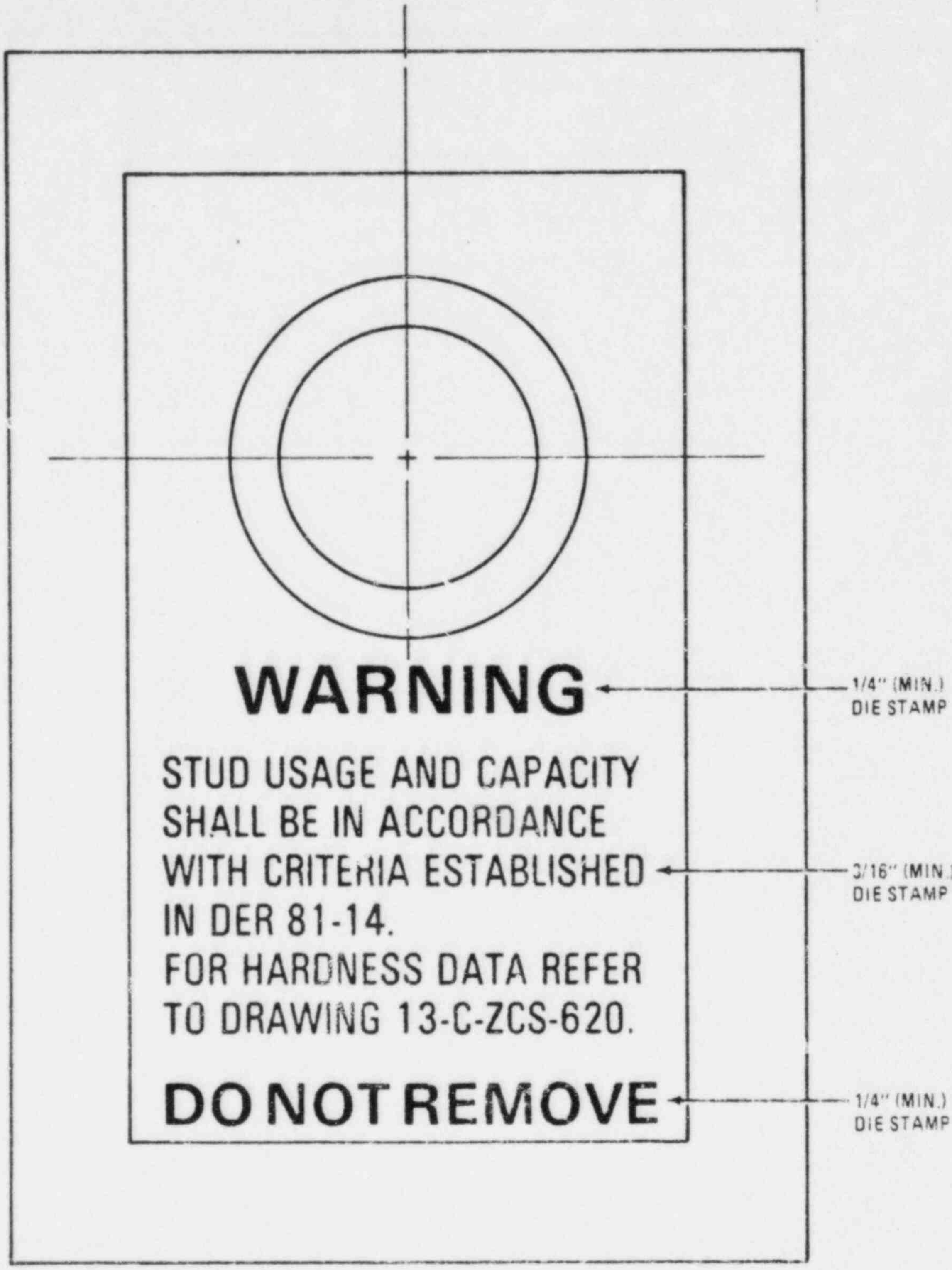
Manufacturer	Supplier Identification Symbol
Bosco Fastening Service Center Phoenix, AZ	B
Custom Bolt Phoenix, AZ	CB
Copper State Bolt & Nut Co. Phoenix, AZ	CS
Joseph B. Dyson & Sons Painesville, OH	JBD
Sullivan Bolt Commerce, CA	S
Cal Pacific Fabricating Santa Fe Springs, CA	None

This report satisfies the reporting requirements of 10CFR21.21(b) (3) with the exception of sub-part (vi) which requires the number and location (customers and/or facilities) of other possible defective material.

TES RECOMMENDED ACCEPTANCE CRITERIA



IDENTIFICATION TAG DETAILS



FOR 1" TO 1-1/2" STUDS : 3-1/2" x 6" 24 GA. S.S. WITH 1-5/8" DIA. HOLE
FOR 2" STUDS : 5" x 7-1/2" 24 GA. S.S. WITH 2-1/8" DIA. HOLE

Note: Text shall not be obscured by the fastening nut.

DEFICIENCY EVALUATION REPORT NO. 81-14

ENGINEERING EVALUATION OF NONCONFORMING ASTM A354 GRADE BD STUDS AND BOLTS

PALO VERDE NUCLEAR GENERATING STATION

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JOB NUMBER 10407
BECHTEL POWER CORPORATION
NORWALK, CALIFORNIA
SEPTEMBER 1982

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FIGURES

1 PROBLEM IDENTIFICATION

1.1 BACKGROUND

Palo Verde Nuclear Generating Station (PVNGS) specifies ASTM A354 Grade BD material for applications where high strength threaded fasteners are required with diameters greater than 1-1/2 inches or with special length and threading requirements for concrete embedment.

All structural steel and bolts, as well as other materials and testing methods, are specified for PVNGS using ASTM Standards, as is the industry wide practice. ASTM A490, a widely used specification for high strength bolts for structural steel joints, specifically refers the user to A354 Grade BD for applications, such as those described above, where similar mechanical properties are desired.

1.2 DISCOVERY OF PROBLEM

During May and June, 1981, four 1 1/2-inch diameter by 2 feet 9 inches long ASTM A354 Grade BD studs cracked and separated during normal handling in the field; all four studs cracked approximately four to six inches from one end, within the threaded portion of the studs. The studs were components of embed plate assemblies which are used to anchor pipe whip restraints to the containment internal concrete structure. At the time of the discoveries, all of the Unit 1 and Unit 2 studs and bolts had already been installed and some of the Unit 3 studs were already installed. No subsequent failures of ASTM A354 Grade BD fasteners have been experienced at PVNGS.

1.3 PROBLEM CONTRIBUTORS

1.3.1 EXCESSIVE HARDNESS

The failure mechanism of the examined studs has been established as Stress Corrosion Cracking (SCC) which propagated to the point where brittle fracture occurred. The SCC was the result of stud hardnesses around 49 on the Rockwell C-Scale (HRC 49) which drastically exceeds the ASTM Specification requirements (HRC 33 to 38).

1.3.2 SMALL TEST SAMPLING QUANTITIES

A review of material certificates has shown that proper documentation was provided with all of the received materials; however, it is clearly evident that nonconforming materials passed, undetected, due to the small test sampling percentage required by the ASTM Specification. Additional testing was not considered when ASTM A354 Grade BD material was specified since there was no reason to suspect that testing beyond the ASTM requirement was necessary.

1.4 IMMEDIATL ENGINEERING ACTION TAKEN

Upon discovery of the stud failures, the following measures were immediately implemented as part of the evaluation and resolution plan.

1.4.1 CONCRETE PLACEMENT STOP WORK

Stop Work Notice No. 81-SW-4 was issued to stop all concrete placements which contained embedded ASTM A354 Grade BD studs.

1.4.2 FIELD USER TEST FOR HARDNESS

Since hardness was the only nonconforming parameter, Work Plan Procedure/ Quality Control Instruction No. 68.0 was established to perform a field user's test for hardness on all ASTM A354 Grade BD fasteners prior to their installation. Bechtel purchased an EQUOTIP hardness tester to perform the tests at PVNGS. Only those fasteners with hardness values within a tentative acceptance range were painted white on the end and released for use in Unit 3; unacceptable fasteners were painted red on the end and have been placed in warehouse quarantine.

1.4.3 LIFTING OF STOP WORK NOTICE

Stop Work Notice No. 81-SW-4 was lifted when the user's test program for measuring hardness of all ASTM A354 Grade BD fasteners was implemented. This permitted containment internal concrete construction to resume using only fasteners with hardness within the tentative acceptance range.

1.4.4 OTHER FASTENER MATERIALS

Investigations into samples of ASTM A194, A540, A307, A325, A490, and A563 fasteners received at the jobsite were made and no nonconformances were discovered.

1.5 IDENTIFICATION OF ALL ASTM A354 GRADE BD FASTENER APPLICATIONS

The Engineering Drawings have been reviewed to locate all ASTM A354 Grade BD fasteners. The applications fall into four categories. These are depicted in figures 1 through 9 and described below

1.5.1 PIPE WHIP RESTRAINT EMBEDS AND JET IMPINGEMENT BARRIER EMBEDS (FIGURES 1 THROUGH 6)

The majority of the studs are used to anchor embed plate assemblies to the walls and slabs of the containment internal concrete structure. These embed plates are used to anchor pipe whip restraints and jet impingement barriers. These embed plates were added to the drawings at an early stage of the project when the exact number and locations of postulated high-energy line breaks had not yet been finalized. Consequently, only about 25% of the embeds are to be utilized for pipe whip restraint and jet impingement barrier attachments. The utilized embedded studs sustain only attachment dead loads during the normal operating condition.

1.5.2 COLUMN HOLD-DOWN STUDS (FIGURE 7)

Two of the structural steel columns in each containment building utilize ASTM A354 Grade BD anchor studs to secure the column base to the top of a concrete wall. These columns are approximately four feet long and the studs are designed to resist uplift loads during postulated accident pressure conditions. During normal operating conditions the studs are subjected to only their initial preload.

1.5.3 POLAR CRANE GIRDER HOLD-DOWN BOLTS (FIGURE 8)

The containment building is equipped with a polar crane which travels on a circular rail supported by 36 equal chord girders. The girders are supported by embedded brackets which cantilever inward from the containment shell. The hold-down bolts maintain girder alignment for normal operation and resist overturning and uplift during a seismic event. One end of the girders is bolted snug tight with slotted holes to allow for thermal expansion.

1.5.4 AUXILIARY FEEDWATER PUMP ANCHOR STUDS (FIGURE 9)

The only application of ASTM A354 Grade BD studs outside of the containment building is to secure the turbine-driven auxiliary feedwater pump in the basement of the main steam support structure. The critical load conditions for these studs are accident or SSE.

2 DISCUSSION

2.1 INITIAL LABORATORY ANALYSIS

The first stud which cracked and separated was discarded by the crafts. The second stud which cracked and separated and three additional randomly selected studs of the same type were sent to Engineering Testing Laboratories, Phoenix, Arizona, for chemical and mechanical analyses. The three randomly selected studs were found to be within the Specification requirements for yield strength, tensile strength, chemical content, and hardness.

2.2 BECHTEL M&QS FAILURE ANALYSIS

The second stud, described above, and the third and fourth studs which cracked and separated were taken to Bechtel, San Francisco, Materials and Quality Services (M&QS) Department for extensive testing: The examination procedures included visual and liquid penetrant examination, mechanical testing, emission spectrographic and electron microscopic analyses, and heat treatment study.

2.3 SAMPLING OF WAREHOUSE STUDS

A sampling of eighty studs representing five different diameters was released from the jobsite warehouse for hardness testing. This represented approximately 5% of the remaining studs required for Unit 3 installations. The results showed that a significant number of studs had a hardness above and below the ASTM specified limits. It was recognized at this point that the investigation into the hardness problem should include all sizes of ASTM A354 Grade BD fasteners.

2.4 FURTHER TESTING OF WAREHOUSE STUDS

The same sample of eighty stud specimens underwent further testing initiated by Bechtel as follows:

A. Thirteen of the studs with low hardness were destructively tested to measure yield and tensile strength. Twelve of the thirteen studs failed to achieve the minimum specified tensile strength.

B. Sixty-three studs were EQUOTIP hardness tested in order to develop a correlation curve to convert EQUOTIP L-value to a HRC value. The limits of ASTM A354 Grade BD (HRC 33 minimum to HRC 38 maximum) corresponded to EQUOTIP L-value of 570 to 620 respectively based upon a least squares straight line fit for the sixty-three data points. This tentative acceptance criteria was used to establish the Work Plan Procedure described in paragraph 1.4.2, and to rescind the Stop Work Notice as explained in paragraph 1.4.3.

2.5 HARDNESS TESTING OF ALL ASTM A354 FASTENERS

All installed ASTM A354 Grade BD fasteners, approximately 4500 fasteners, have been EQUOTIP hardness tested with the exceptions listed below. The data has been recorded in a field data log and the nonconforming fasteners identified on Nonconformance Reports (NCR's). See figures 10, 11, and 12.

2.5.1 INACCESSIBLE EMBEDDED STUDS

Eighty fasteners are inaccessible for testing due to mechanical, electrical, or other installations which obstruct surface preparation or the EQUOTIP impact device. None of these studs are presently being used.

2.5.2 UNIT 1 AND UNIT 2 POLAR CRANE GIRDER HOLD-DOWN BOLTS

Of the two hundred eighty-eight bolts installed in each unit, thirty-two bolts, randomly selected, have been tested.

2.6 OTHER FASTENER MATERIALS

In addition to ASTM A354 Grade BD, Bechtel has investigated the fastener materials listed below to verify that the codes and standards are being met. Bechtel has not discovered any other fastener material where deficiencies have surfaced.

2.6.1 ASTM A194 GRADE 2H NUTS

Fifty nuts taken from the embed plate assemblies have been tested for hardness and/or proof load tests. All fifty nuts, covering five different diameters, met the Specification requirements.

2.6.2 ASTM A540 NUCLEAR STEAM SUPPLY SYSTEM (NSSS) SUPPORTS

Most of the ASTM A540 bolts have been installed in all three units. In one instance thirty-two reactor coolant pump lateral support studs were shortened by saw cutting due to excessive projection. Thirty of these 3-inch diameter specimens were tested for hardness and all thirty met the Specification requirements.

2.6.3 ASTM A307, A325, AND A490 BOLTS AND ASTM A194, A325, AND A563 GRADE C NUTS

Samples of each available lot of fasteners from Marathon's sub-tier supplier were laboratory tested and all were found to be within the limits of their respective Specifications.

2.6.4 TENSION INSPECTION PROGRAM

An inspection program which follows the intent of Subsection 6(d)5 of the AISC Specification for Structural Joints Using ASTM A325 or A490 Bolts, dated April 26, 1978, has been implemented for all such bolted connections. A minimum of one bolt per connection is being tested.

3 EVALUATION OF DATA AND RECOMMENDATIONS

3.1 RESULTS OF INITIAL LABORATORY ANALYSIS

The second fractured stud (the first one to be tested) met the Specification requirements for yield strength, tensile strength, reduction of area, and chemical composition, but failed to meet the 14% elongation requirement (13% actual) and had a hardness far outside the HRC 33 to 38 range (HRC 48 on the edge of the cross section).

3.2 RESULTS OF M&QS FAILURE ANALYSIS

A copy of the Bechtel M&QS analysis report, "Failure Analysis - ASTM A354 BD Bolting For Concrete Embed Assemblies," dated October 2, 1981, is included in appendix A of this evaluation. The report concludes that the failure was a result of progressive stress corrosion cracking, caused by improper heat treatment of the stud material, which ultimately led to overload failure. M&QS recommends that A354 Grade BD fasteners with a surface hardness in excess of HRC 41 be disallowed.

3.3 REVIEW BY TELEDYNE

Teledyne Engineering Services (TES), Waltham, Massachusetts, has reviewed all of the data which was compiled as of their contract date of January 5, 1982. A copy of their report, "Acceptability for Service of Low Alloy, Quenched and Tempered Support Studs and Bolts," dated September 16, 1982, is included in appendix B of this evaluation. There are two basic conclusions in their report. They are jointly summarized in figure 13 and described as follows:

A. Guidelines are given for short term and long term stress allowables for fasteners with hardness outside the Specification limits.

B. TES verifies that EQUOTIP is an acceptable hardness testing method and that a valid correlation between EQUOTIP L-value and Rockwell C-Scale can be made. Rockwell standard calibration blocks were used to demonstrate that the EQUOTIP "Conversion Table for Steel and Cast Steel" is appropriate for ASTM A354 Grade BD.

3.4 INDEPENDENT REVIEW BY BATTELLE

Due to the potential severity of the problem and the related safety implications, it was felt that an additional independent review to substantiate the Bechtel and TES positions would be prudent.

This independent evaluation of the data and the TES report has been conducted by Dr. S. H. Bush and Dr. F. A. Simonen of Battelle Pacific Northwest Laboratories (Battelle Northwest, BNW), Richland, Washington. BNW's evaluation is actually based upon Revision 0 of the TES report dated September 1, 1982. However the changes incorporated in Revision 1 of the TES report are of an editorial nature only. A copy of their report, "A Review of Arizona Nuclear Power Project Bolting Failures," dated September 22, 1982 is included in appendix C of this evaluation. BNW is in agreement with TES in the concepts of establishing an upper bound cutoff for acceptability of "hard" fasteners due to their susceptibility to stress corrosion cracking and/or brittle fracture, and down rating of "soft" fasteners due to their decrease in strength. They also agree that limitations on preload (long term stress) would minimize the susceptibility to inter-granular stress corrosion cracking.

3.5 HARDNESS TEST DATA

Hardness test data for the embedded ASTM A354 Grade BD fasteners, including those tests performed after the initiation of the M&QS, TES, and BNW studies, are compiled in appendix D of this evaluation. Also included in appendix D are figures D-1 through figure D-19 which uniquely locate and identify all embedded stud assemblies.

4 SUMMARY AND CONCLUSIONS

4.1 EQUOTIP HARDNESS TEST VERIFICATION

Based upon TES verification and recommendations, the conversion table for "Steel and Cast Steel (E-modul 210000 N/mm^2)" published in the "EQUOTIP Hardness Tester Conversion Tables" shall be used. See figure 14. The EQUOTIP table converts to HRC values approximately HRC 1.7 lower than the data fit curve described in paragraph 2.4 item B.

4.2 ACCEPTANCE CRITERIA FOR SHORT TERM LOADS

The TES criteria for allowable stresses for short term loads shall be adopted for PVNGS; however, a more conservative upper bound cutoff value of HRC 41 will be chosen, per recommendations by BNW and Bechtel M&QS.

4.2.1 PIPE WHIP RESTRAINT AND JET IMPINGEMENT BARRIER STUDS

64% of the installed studs are within the ASTM specification limits. Per M&QS, TES, and BNW recommendations to accept hardnesses of HRC 32, 39, 40, and 41 without reductions, the total is increased to 84% acceptable. Only 2% of the installed studs are rejectable due to hardness greater than HRC 41. 12% of the installed studs require a down rating in strength due to hardness below HRC 32. The remaining 2% are inaccessible for testing and shall not be used without further engineering assessment. See figures 15 through 18.

4.2.2 COLUMN HOLD-DOWN STUDS

Hardness test results are shown in figure 19. These studs are acceptable since all of the studs tested in Unit 1 and Unit 2 and those released for installation in Unit 3 have hardness less than HRC 41. A revision to the calculations has been prepared to demonstrate that the design for short term loads can accommodate the down rating of installed "soft" studs.

4.2.3 POLAR CRANE GIRDER HOLD-DOWN BOLTS

The 11% sample (32 of 288 per unit) tested in Unit 1 and Unit 2 shall be used as a basis for acceptance of these bolts. None of the bolts have hardness greater than HRC 41. All 445 bolts in stock for Unit 3 have been tested and none have hardness greater than HRC 41. See figures 20 and 21. A revision to the calculations has been prepared to demonstrate that the design for short term loads can accommodate down rating of all bolts to the allowable stresses of the "softest" installed bolt.

4.2.4 TURBINE-DRIVEN AUXILIARY FEEDWATER PUMP ANCHOR STUDS

Three studs are inaccessible in Unit 1 due to interference with the installed pump. The other eleven studs in Unit 1 as well as fourteen studs in Unit 2 and Unit 3 have been tested. None of the studs have hardness greater than HRC 41 nor less than HRC 33 therefore the design is not affected and the studs are acceptable. See figure 22.

4.3 LONG TERM STRESS LIMITATIONS

4.3.1 PIPE WHIP RESTRAINT AND JET IMPINGEMENT BARRIER STUDS

PVNGS shall adopt long term stress allowable limits much more conservative than the TES recommendations for high hardness studs used for restraint attachments as described in paragraph 1.5.1. These studs shall be either; (A) double nutted with the first nut snug tight and held in place with a wrench while the second nut is tightened to 25 foot pounds; or, (B) torqued to produce tensile stress less than 12 ksi which corresponds to approximately 11% of the normal criteria. Normal criteria for initial preload of high strength bolts is 70% of the minimum specified tensile strength, which is 105 ksi in this case.

4.3.2 OTHER ASTM A354 GRADE BD FASTENERS

For the already installed column hold-down studs, polar crane girder hold-down bolts, and auxiliary feedwater pump studs described in paragraphs 1.5.2, 1.5.3, and 1.5.4, the normal criteria shall be used since none of the tested fasteners have hardness higher than HRC 41.

4.4 INACCESSIBLE AND UNUSED STUDS

For the remainder of the embedded pipe whip restraint and jet impingement barrier studs described in paragraph 1.5.1 which are not currently being used, the following action has been taken.

4.4.1 CONTROL OF STUD USAGE PRIOR TO CUTOFF DATE

The following note has been added to all applicable Engineering Design Drawings:

"Use of embeds detailed on drawing 13-C-ZCS-619 is restricted to pipe whip restraints issued prior to February 19, 1982. Any subsequent use must comply with the final evaluation of DER 81-14."

All of the calculations and drawings issued prior to this date have been checked using the acceptance criteria established herein and found to be satisfactory with no modifications required.

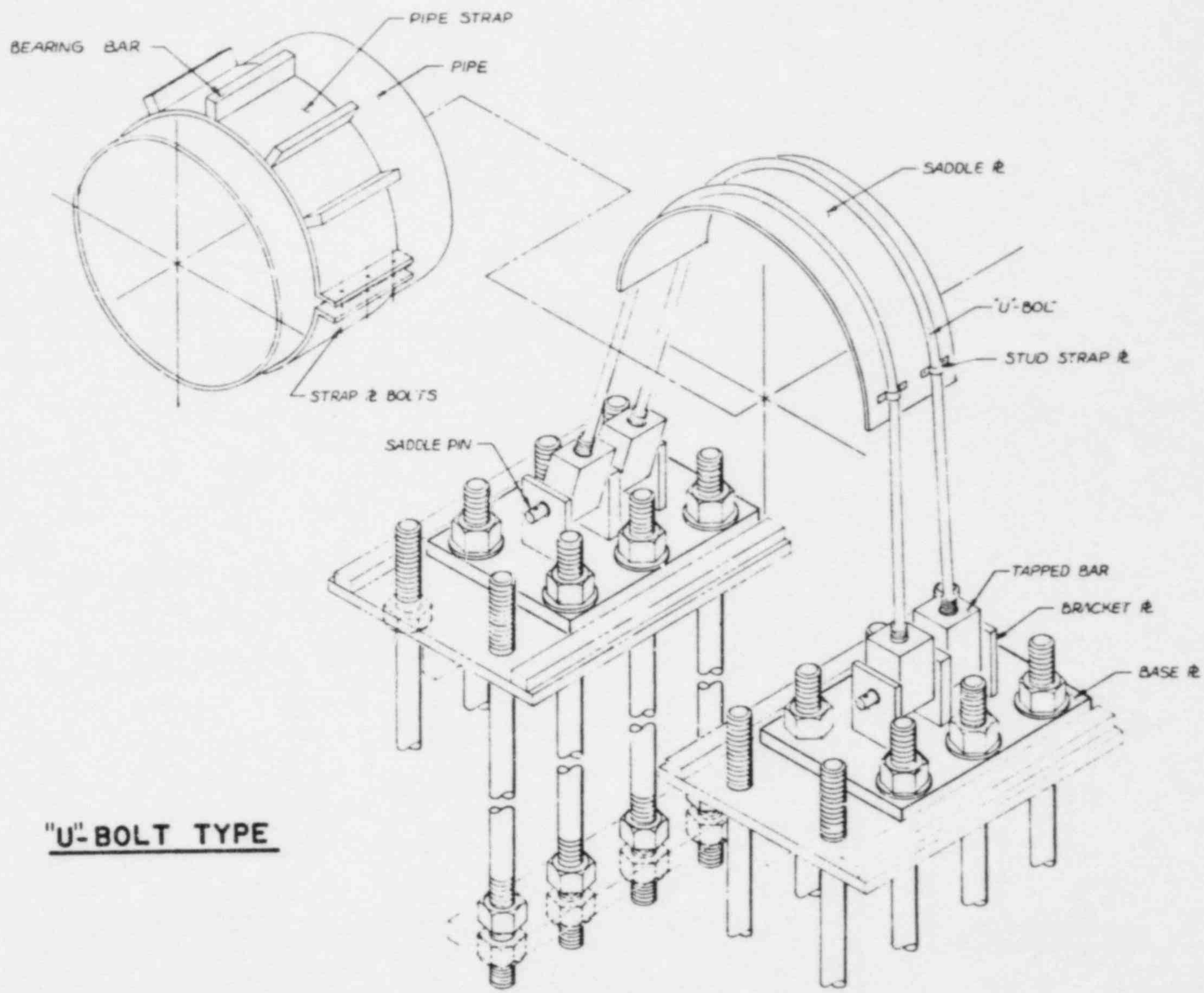
4.4.2 EVALUATION OF STUD USAGE AFTER CUTOFF DATE

The data compiled in Appendix D serves as a permanent record of the as-installed locations and EQUOTIP hardness measurements of the studs. This data shall be used to evaluate acceptability and capacity of studs issued for use after February 19, 1982.

4.5 DISPOSITION OF NONCONFORMANCE REPORTS

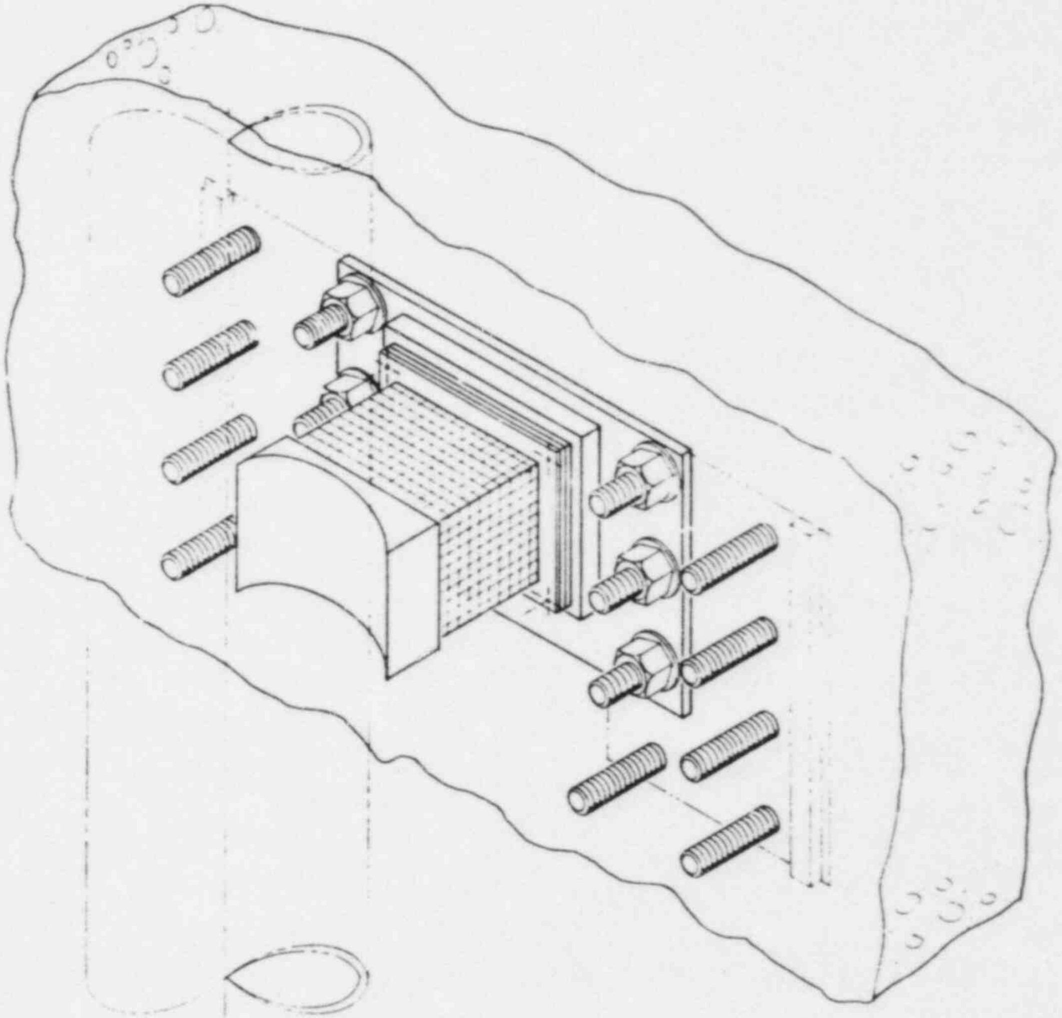
All applicable NCR's involving installed fasteners shall be dispositioned "Use As Is/Rework." Based upon the summary and conclusions of this DER No. 81-14, the structural integrity of components which utilize ASTM A354 Grade BD fasteners, issued prior to February 19, 1982, has not been impaired. All studs with hardness value exceeding HRC 43 ($L > 669$) shall be removed by saw cutting. All studs with hardness value less than HRC 32 ($L < 582$) and values HRC 42 and HRC 43 ($654 \leq L < 669$) shall be identified by installing a tag, as shown in figure 23, and securing with a hand-tight nut. Engineering shall perform a review of all design calculations utilizing these fasteners issued after February 19, 1982, in light of the established acceptance criteria, and issue revisions to Engineering Calculations and Design Drawings as required. All such revisions to Engineering Design Drawings shall be issued through Design Change Packages.

2nd Draft



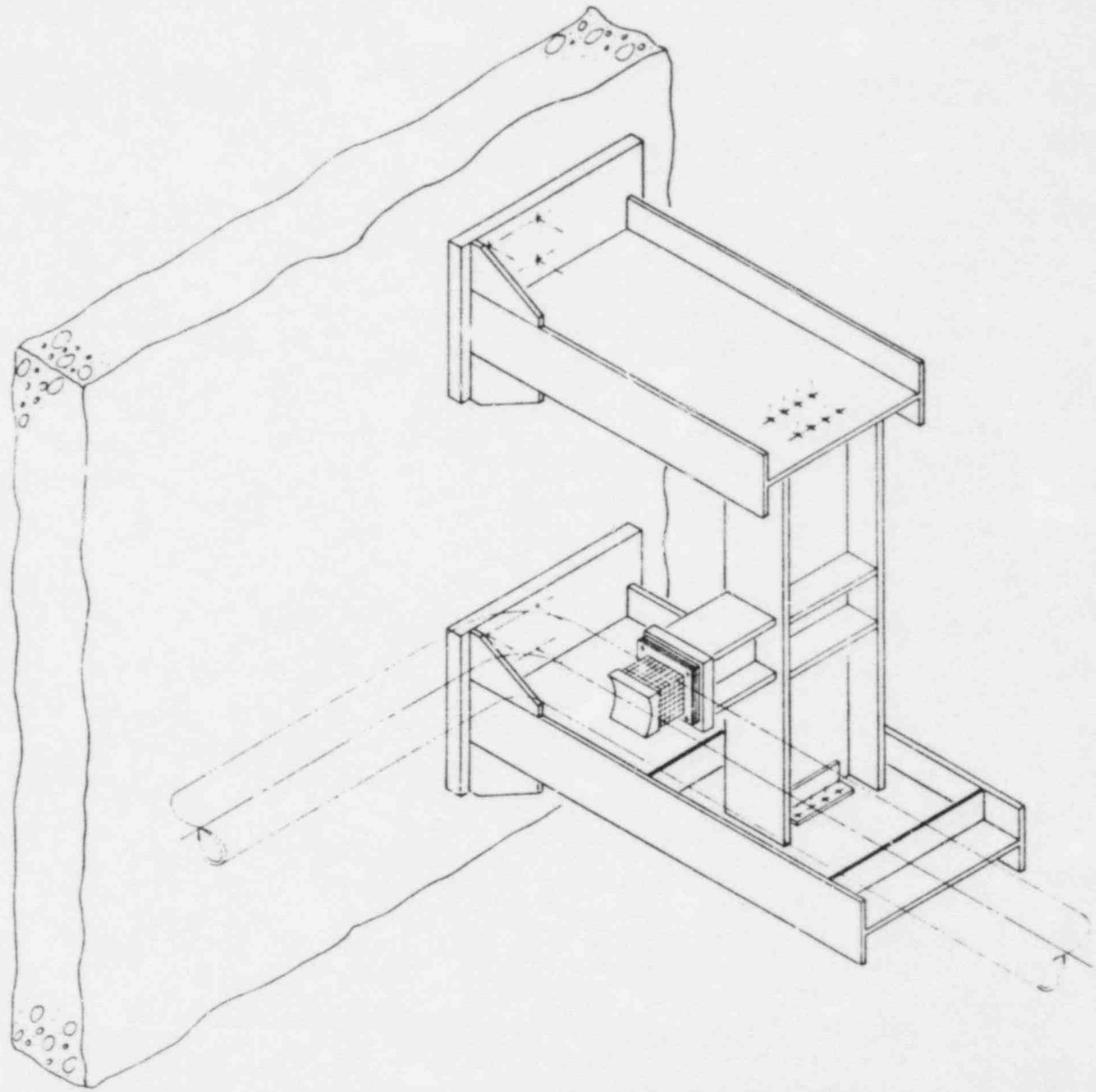
"U"-BOLT TYPE

FIGURE 1



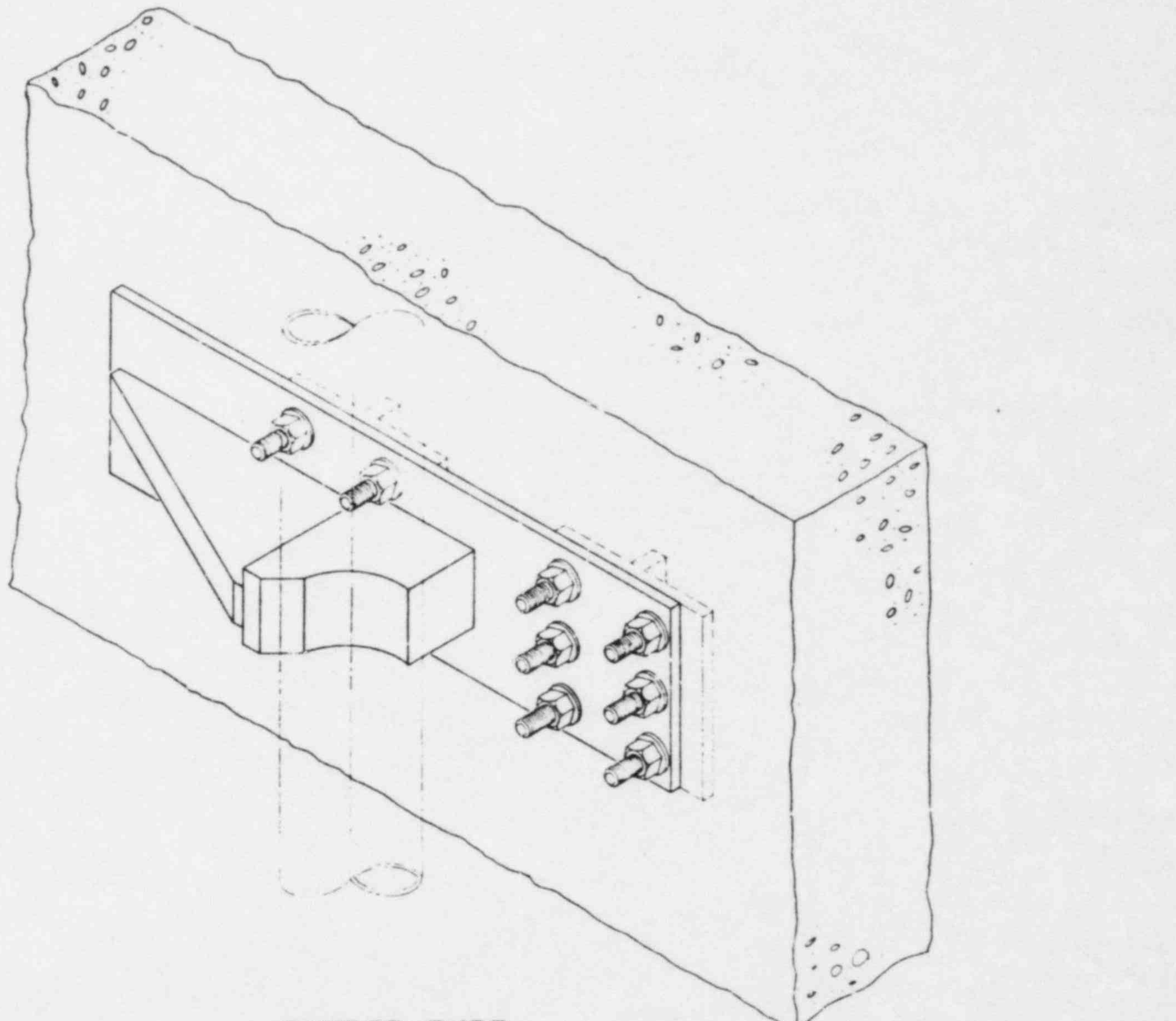
ENERGY ABSORBING MATERIAL

FIGURE 2



FRAME & E.A.M. TYPE

FIGURE 3



BUMPER TYPE

FIGURE 4

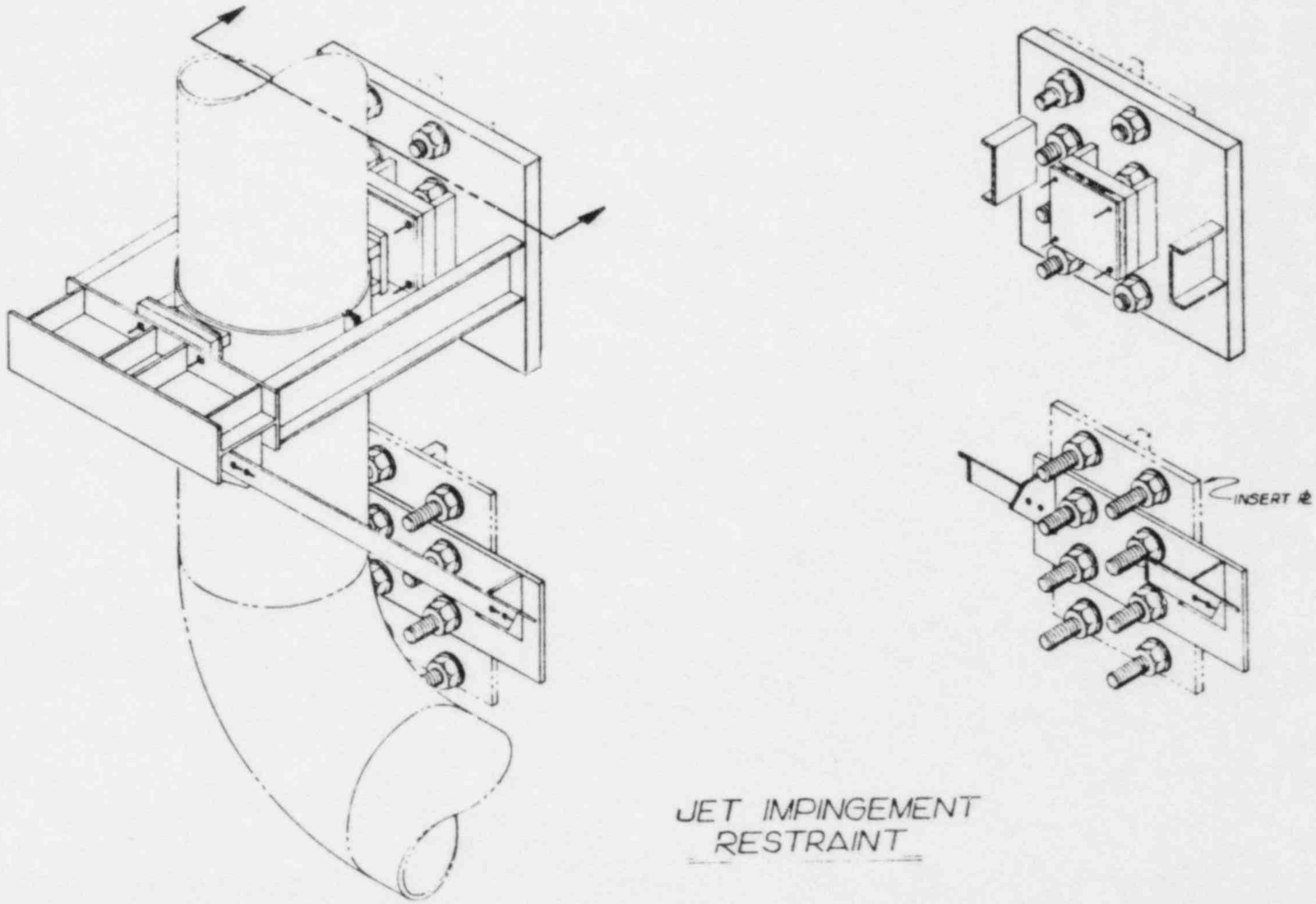
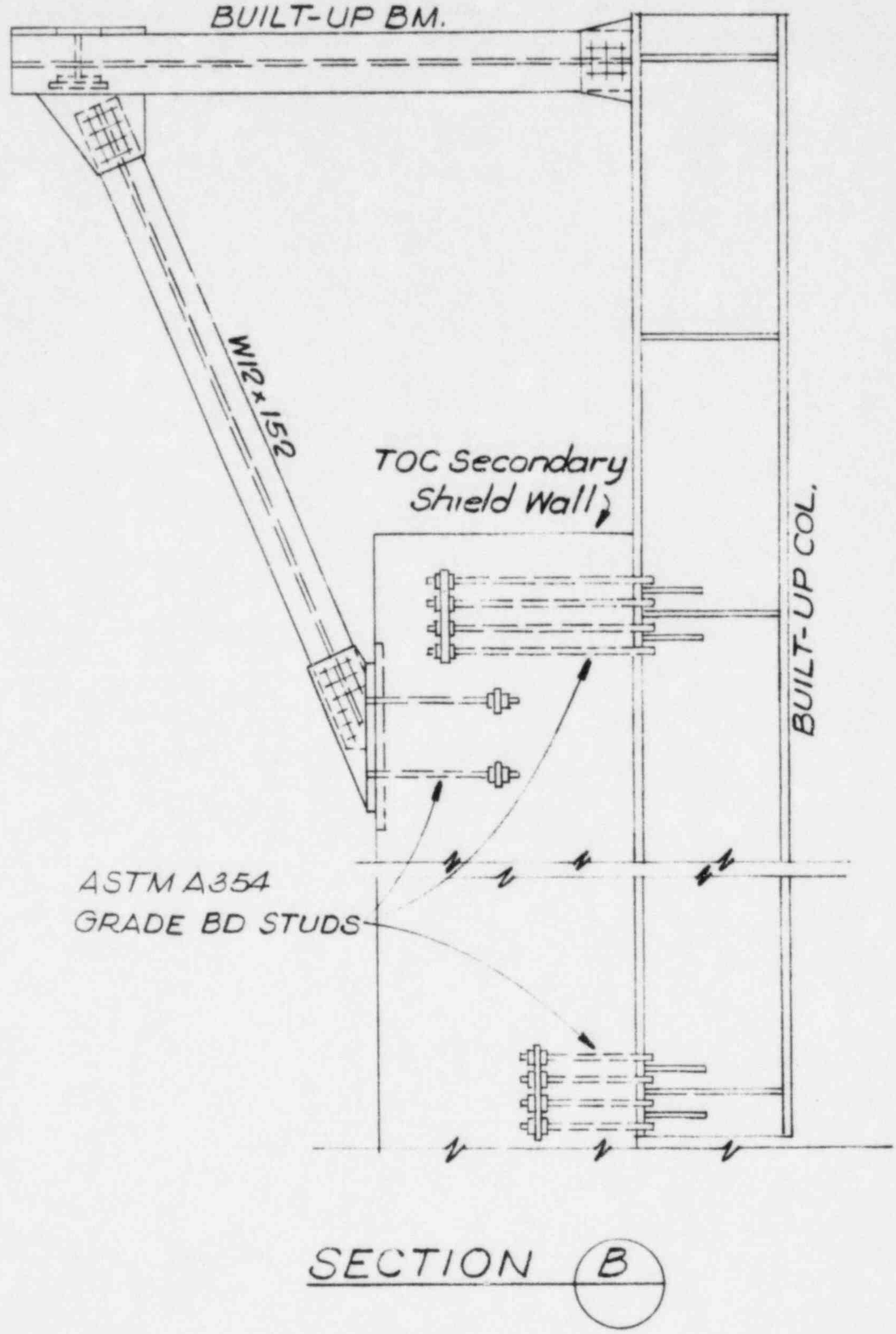


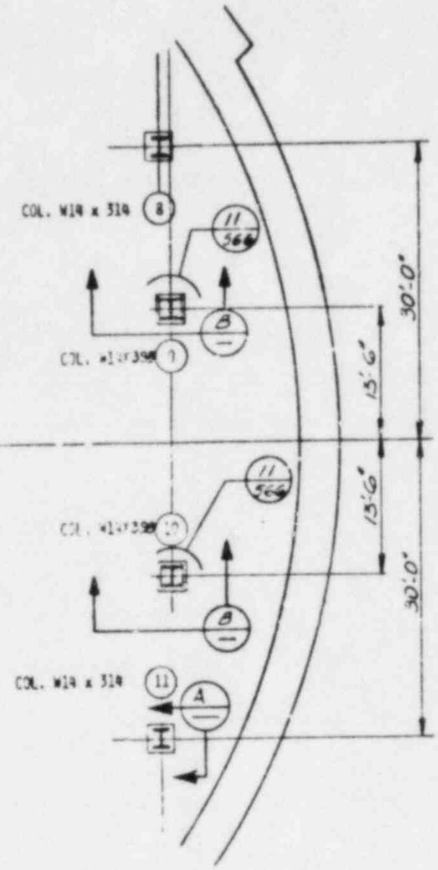
FIGURE 5

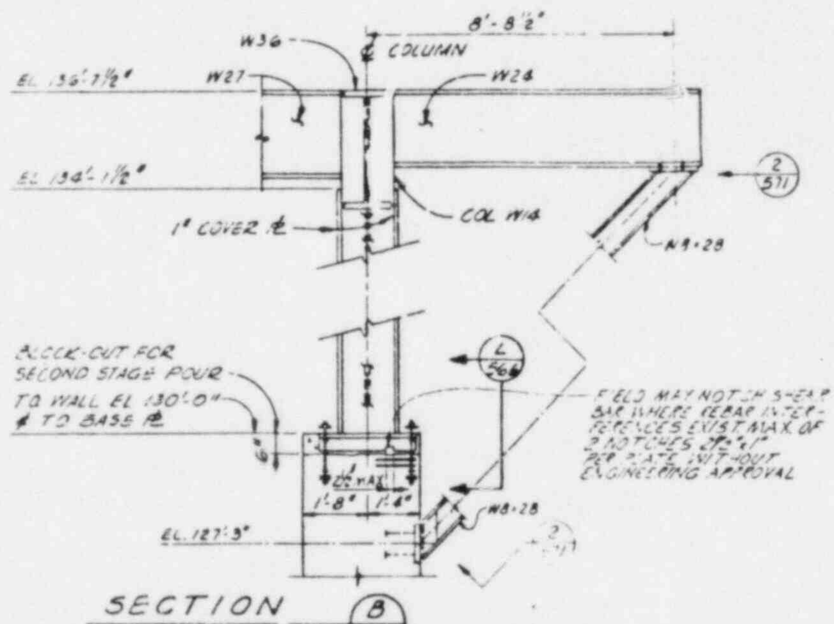


MAIN STEAM LINE
STRUCTURAL STL. SUPP.

FIGURE 6

REF. DWG. 13-C-ZCS-541

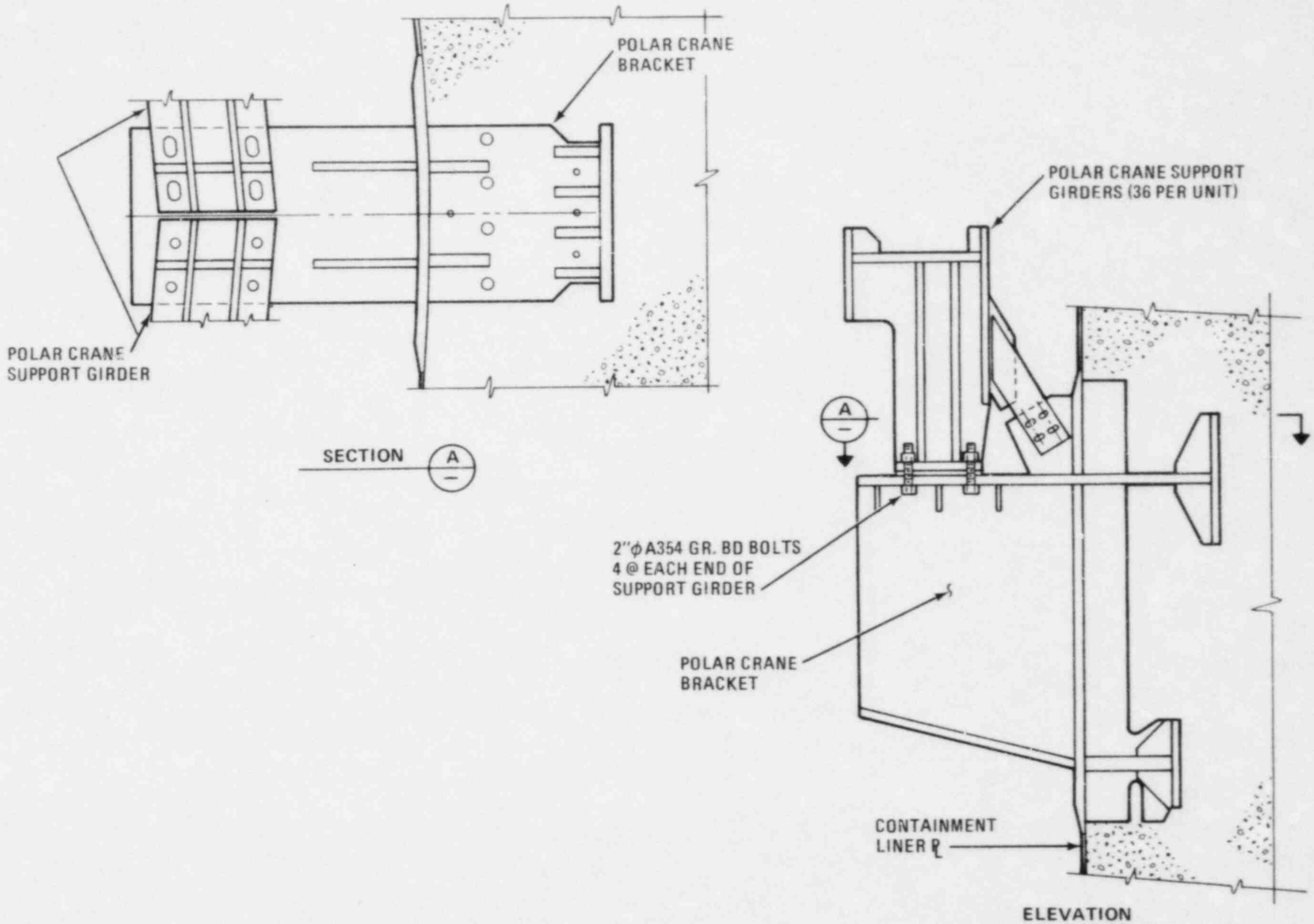




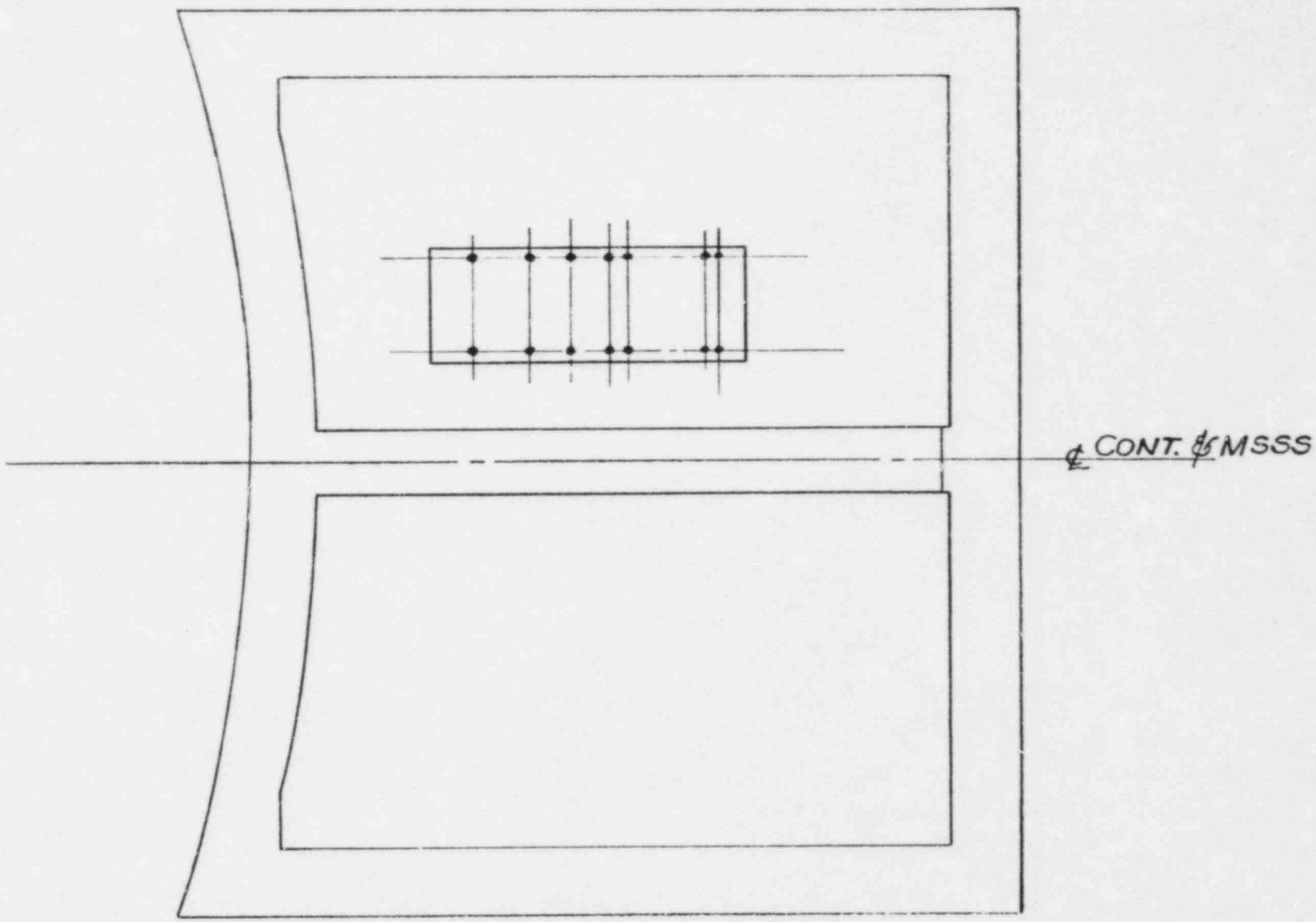
REF. DWG. 13-C-ZCS-565

COLUMNS 9 & 10
HOLD-DOWN STUDS
FIGURE 7

2nd Draft



POLAR CRANE BRACKET
TO GIRDER BOLTS
FIGURE 8



PLAN @ EL. 81'-0"

1/8" = 1'-0"

TURBINE-DRIVEN AUX.
FEEDWATER PUMP ANCHOR STUDS
FIGURE 9

REF. DWG. 13-C-ZCS-705

2nd Draft

SUMMARY OF PIPE WHIP RESTRAINT AND JET IMPINGEMENT BARRIER EMBEDS SHOWN ON ENGINEERING DRAWINGS

APPENDIX D FIG. D-	DETAIL ON DWG. 13-C-ZCS-619 U.N.O.											
	1	2	3	4	5	6	9	12	13	14	1/405	TOTAL EMBEDS
1		7				1						8
2		4				2						6
3				24								24
4								4	4			8
5	16	10	4			9	4				1	44
6								4	4			8
7	19	12				9					1	41
8	22	7		2	2	16						49
9	19	11			2	14						46
10	11	1			4	8						24
11	4									4		8
12		4			4	8						16
13			2									2
14			2									2
15							8					8
16	12					1						13
17						1						1
18				2		2						4
TOTAL EMBEDS	103	56	8	28	12	71	12	8	8	4	2	312
STUDS	6	8	8	6	6	6	8	8	8	4	4	
TOTAL STUDS	618	448	64	168	72	426	96	64	64	16	8	2044

FIGURE 10

SUMMARY OF DOCUMENTATION OF TESTING OF UNIT 1 AND UNIT 2 EMBEDDED STUDS

UNIT 1 NON CONFORMANCE REPORTS						UNIT 2 NON CONFORMANCE REPORTS					
	EMBED		STUDS				EMBED		STUDS		
NCR NO.	NO. (1)	QTY.	TESTED	IN-ACCESS	OTHER	NCR NO.	NO. (1)	QTY	TESTED	IN-ACCESS	OTHER
C-C-2797	1~76	75	516	2	0	C-C-2825	1~76	75	518	0	0
						C-C-2887	77~81	5	30	0	0
C-C-3163	77~322	239(2)	1474(2)	36	24(3)	C-C-3182	82~322	234(2)	1472(2)	32	0
TOTAL		314(2)	1990(2)	38	24	TOTAL		314(2)	2020(2)	32	0
			TOTAL 2052(2)						TOTAL 2052(2)		

NOTES:

(1) EMBED PLATE IDENT. NO.'S 30, 90, 234, 235, 236, 237, 238, 239 NOT USED.
(2) INCLUDES EMBED NO.'S 321, 322 COLUMN HOLD-DOWN STUDS (8 STUDS).
(3) EMBED NO.'S 121, 122, 123, 124 NOT INSTALLED IN UNIT 1 (24 STUDS).

FIGURE 11

SUMMARY OF DOCUMENTATION OF TESTING OF UNIT 3 EMBEDDED AND UNINSTALLED STUDS

UNIT 3 NON CONFORMANCE REPORTS

	EMBED		STUDS		
NCR NO.	NO.	QTY	TESTED	INACCESS	OTHER
C-C-2724 }	(4)	54 } (1)	342 } (1)		2 } (2)
C-C-2802 }	188, 189	2 }	12 }		0 }
C-C-2881	25–36	11	74	0	0
C-C-3743	(5)	50	324	10	0
TOTAL		61	398	10	0
			TOTAL 408		

OTHER NON CONFORMANCE REPORTS

	UNINSTALLED STUDS
NCR NO.	TESTED
C-C-2734	441
C-C-2774	1677
C-C-2802	8
C-C-2803	98
TOTAL	2224(3)

(1) EMBEDS WERE IN THE FORMS, READY FOR CONCRETE PLACEMENT; NON CONFORMING STUDS WERE REPLACED.

(2) 2 STUDS WERE NOT YET INSTALLED PENDING REBAR RELOCATION TO RESOLVE INTERFERENCE

(3) 740 OF THESE STUDS HAVE BEEN QUARANTINED; 1484 HAVE BEEN APPROVED FOR USE IN UNIT 3.

(4) NO'S. 21–24, 116–120, 127, 143–151, 153, 192–194, 198–201, 219, 257–262, 267–270, 273–288.

(5) NO'S. 80, 81, 110–115, 126, 154–160, 171–183, 271, 272, 289–307.

FIGURE 12

2nd Draft

TES RECOMMENDED ACCEPTANCE CRITERIA

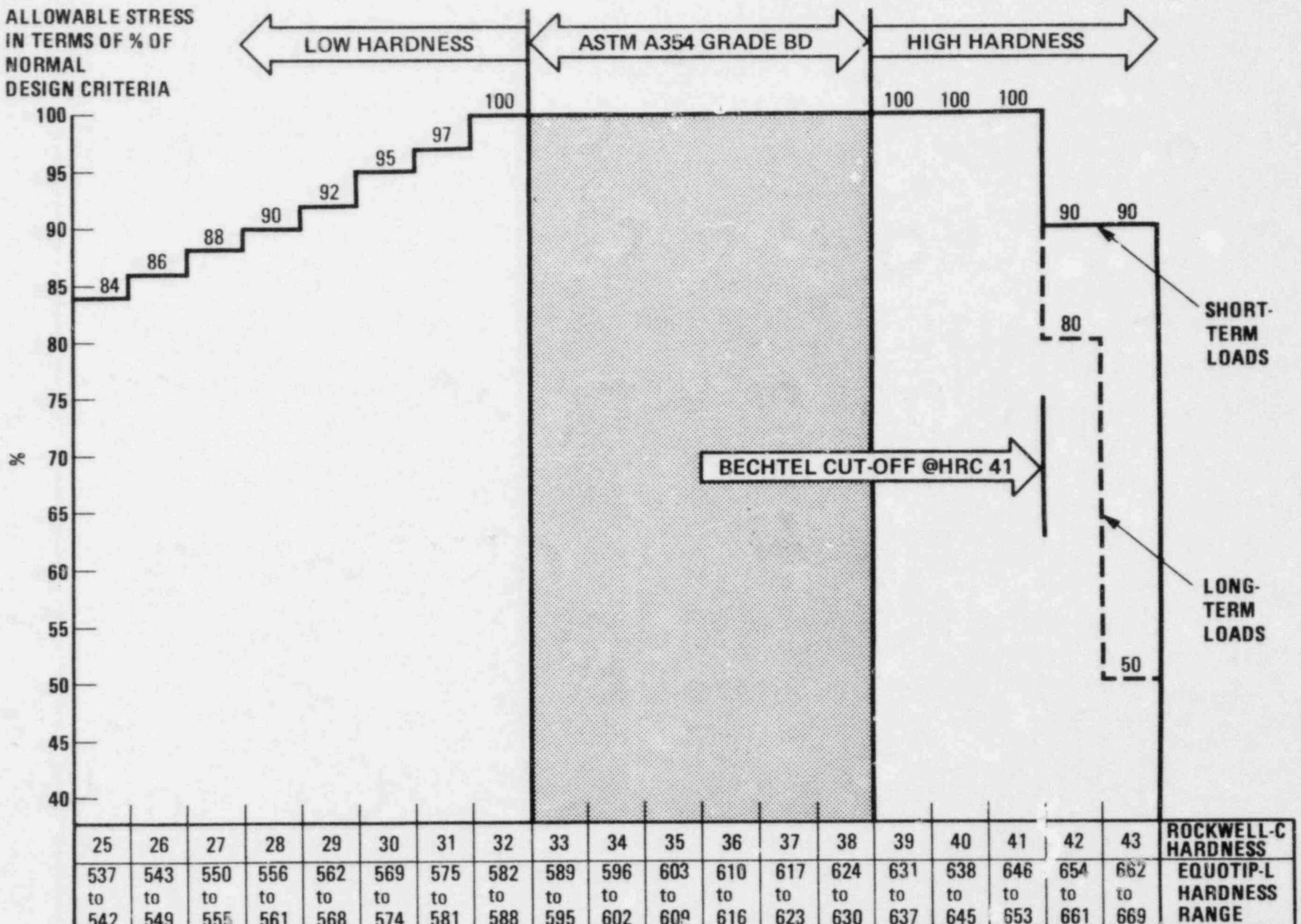
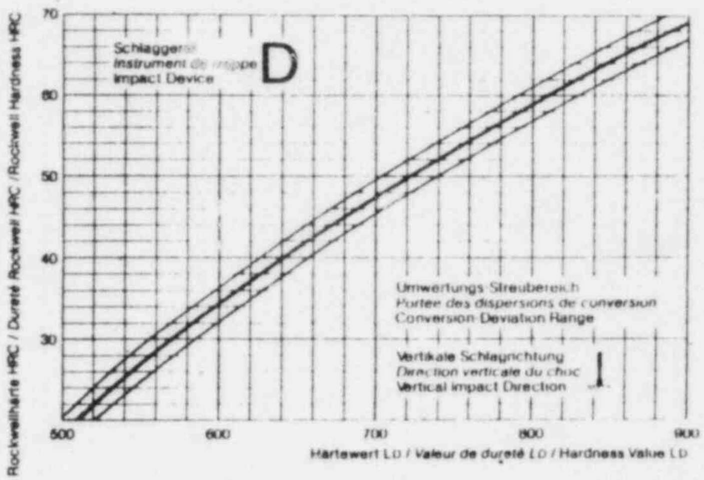


FIGURE 13

Stahl und Stahlguss
Acier et fonte d'acier (E-Modul 210 000 N/mm²)
Steel and cast steel

LD - Rockwell C



LD	HRC	±HRC*	LD	HRC	±HRC*	LD	HRC	±HRC*	LD	HRC	±HRC*
			600	34.2		700	47.4		800	58.8	
			602	34.5		702	47.7		802	59.0	
			604	34.8		704	47.9		804	59.2	
			606	35.1		706	48.2		806	59.5	
			608	35.3		708	48.4		808	59.7	
510	20.0		610	35.6		710	48.6		810	59.9	
512	20.4		612	35.9		712	48.9		812	60.1	
514	20.7		614	36.2		714	49.1		814	60.3	
516	21.0		616	36.5		716	49.4		816	60.5	
518	21.4		618	36.7		718	49.6		818	60.7	
520	21.7		620	37.0		720	49.8		820	60.9	
522	22.1		622	37.3		722	50.1		822	61.1	
524	22.4		624	37.6		724	50.3		824	61.4	
526	22.7		626	37.9		726	50.5		826	61.6	
528	23.1		628	38.1		728	50.8		828	61.8	
530	23.4		630	38.4		730	51.0		830	62.0	
532	23.7		632	38.7		732	51.2		832	62.2	
534	24.1		634	38.9		734	51.5		834	62.4	
536	24.4		636	39.2		736	51.7		836	62.6	
538	24.7		638	39.5		738	51.9		838	62.8	
540	25.0		640	39.8		740	52.2		840	63.0	
542	25.4		642	40.0		742	52.4		842	63.2	
544	25.7		644	40.3		744	52.6		844	63.4	
546	26.0		646	40.6		746	52.9		846	63.6	
548	26.3		648	40.8		748	53.1		848	63.8	
550	26.6	2	650	41.1	2	750	53.3	2	850	64.0	2
552	26.9		652	41.4		752	53.5		852	64.2	
554	27.3		654	41.6		754	53.8		854	64.4	
556	27.6		656	41.9		756	54.0		856	64.6	
558	27.9		658	42.1		758	54.2		858	64.8	
560	28.2		660	42.4		760	54.4		860	65.0	
562	28.5		662	42.7		762	54.7		862	65.3	
564	28.8		664	42.9		764	54.9		864	65.5	
566	29.1		666	43.2		766	55.1		866	65.7	
568	29.4		668	43.4		768	55.3		868	65.9	
570	29.7		670	43.7		770	55.6		870	66.1	
572	30.0		672	43.9		772	55.8		872	66.3	
574	30.4		674	44.2		774	56.0		874	66.5	
576	30.7		676	44.4		776	56.2		876	66.7	
578	31.0		678	44.[illegible]		778	56.4		878	66.9	
580	31.3		680	45.0		780	56.7		880	67.1	
582	31.6		682	45.2		782	56.9		882	67.3	
584	31.9		684	45.5		784	57.1		884	67.4	
586	32.1		686	45.7		786	57.3		886	67.6	
588	32.4		688	46.0		788	57.5		888	67.8	
590	32.7		690	46.2		790	57.7		890	68.0	
592	33.0		692	46.4		792	58.0				
594	33.3		694	46.7		794	58.2				
596	33.6		696	46.9		796	58.4				
598	33.9		698	47.2		798	58.6				
600	34.2		700	47.4		800	58.8				

* Umwertungs-Streuung des Tabellenwertes im Vergleich zu direkter Rockwell-Prüfung

* *Dispersion de conversion de la valeur du tableau en comparaison avec l'essai direct d'après Rockwell*

* Conversion-Deviation of the Table value in comparison to direct Rockwell Hardness testing

Korrektur bei anderen Schlagrichtungen / *Corrections pour des chocs en d'autres directions* / Correction for other impact directions	LD	*	*	*	*
	500	5	10	16	22
	550	4	9	15	20
	600	4	8	14	19
	650	4	8	13	18
	700	3	7	12	17
	750	3	6	11	16
	800	3	6	10	15
	850	2	5	9	14
	900				

* Korrekturwerte sind vom gemessenen L-Wert abzuziehen
* *Corrections à déduire de la valeur L mesurée*
* Corrections to subtract from measured L-value

Die Werte sind gültig für unlegierten und niedriglegierten Stahl und Stahlguss im warmgewalzten oder geschmiedeten und wärmebehandelten Zustand.

Les valeurs sont valables pour les aciers et les fontes d'acier non-alliés et faiblement alliés, forgés ou laminés à chaud et ayant subi un traitement thermique.

The values are valid for unalloyed and low alloy steel and cast steel in hot rolled or forged and thermally treated condition.

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80 05 366 D/F/E

FIGURE 14

UNIT 1 PIPE WHIP RESTRAINT AND JET IMPINGEMENT BARRIER STUDS

EMBED DETAIL *	NUMBER OF STUDS																					IN-ACCESS	TOTAL STUDS
1	6	1	1	3	9	34	42	53	62	104	119	80	51	11	1	1						16	594
2				1		7	14	18	30	44	61	56	53	47	39	34	23	6	3			12	448
3								1	2	2	4	3	15	17	13	7							64
4							4	5	36	40	27	22	4	12	8	7	3						168
5	5	1					1	1	1	3	3	5	13	8	18	9	3			1			72
6	2			3	2	4	2	4	5	11	22	32	63	77	94	62	23	9	1			10	426
9			1	3	3	4	2	9	6	7	13	21	20	6		1							96
12					4	9	9	6	1	4	4	6	4	5	5	6	1						64
13						3	3	7	10	7	4	5	6	3	4	4	5	3					64
14						4	4	4	4														16
1/405														2	2			1	1	1	1		8
TOTAL STUDS	13	2	2	10	18	65	81	108	157	222	257	230	229	188	184	131	58	19	5	2	1	38	2020
HRC SCALE	≤24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	≥44		

*REFERS TO DWG. 13-C-ZCS-619 U.N.O.

FIGURE 15

BECHTEL CUT-OFF →

2nd Draft

UNIT 2 PIPE WHIP RESTRAINT AND JET IMPINGEMENT BARRIER STUDS

EMBED DETAIL *	NUMBER OF STUDS																					IN-ACCESS	TOTAL STUDS
1	1		1	1	6	8	8	24	42	57	91	94	107	84	44	17	9	3			3	18	618
2	40			1		3		4	9	13	21	39	51	56	46	45	40	27	27	11	9	6	448
3										3	7	5	19	15	6	3	2	3	1				64
4				1	3	8	15	24	32	29	27	18	7	3		1							168
5	15	1			1	1		4	1	6	2	5	10	6	5	7	5	2		1			72
6	2					1		6	13	15	31	37	40	53	67	54	42	30	13	3	11	8	426
9									1	1	3	17	23	26	7	8	4	3	2	1			96
12									1		5	7	10	15	21	3	1	1					64
13			1		5	3	11	15	16	8	5												64
14		1		2	1	2	1	3	1	2	1	1	1										16
1/405							1		3	3	1												8
TOTAL STUDS	58	2	2	5	16	26	36	80	119	137	194	223	268	258	196	138	103	69	43	16	23	32	2044
HRC SCALE	≤24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	≥44		

*REFERS TO DWG. 13-C-ZCS-619 U.N.O.

FIGURE 16

BECHTEL CUT-OFF →

UNIT 3 PIPE WHIP RESTRAINT AND JET IMPINGEMENT BARRIER STUDS

EMBED DETAIL *	NUMBER OF STUDS																					IN-ACCESS	TOTAL STUDS
1				3	3	3	2	1					3	2	1								18
2								1	4	7	16	20	14	24	22	12	8	3	4			1	136
3											7	12	10	3									32
4									2	6	7	7	1	1									24
5	5					2			3	3	3	1	1	2								4	24
6	1							4	9	14	20	22	19	24	21	16	7	5	2		5	5	174
9																							
12																							
13																							
14																							
1/405																							
TOTAL STUDS	6			3	3	5	2	6	18	30	53	62	48	56	44	28	15	8	6		5	10	408
HRC SCALE	≤24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	≥44		

*REFERS TO DWG. 13-C-ZCS-619 U.N.O.

FIGURE 17

BECHTEL CUT-OFF →

TOTAL PIPE WHIP RESTRAINT & JET IMPINGEMENT BARRIER STUDS

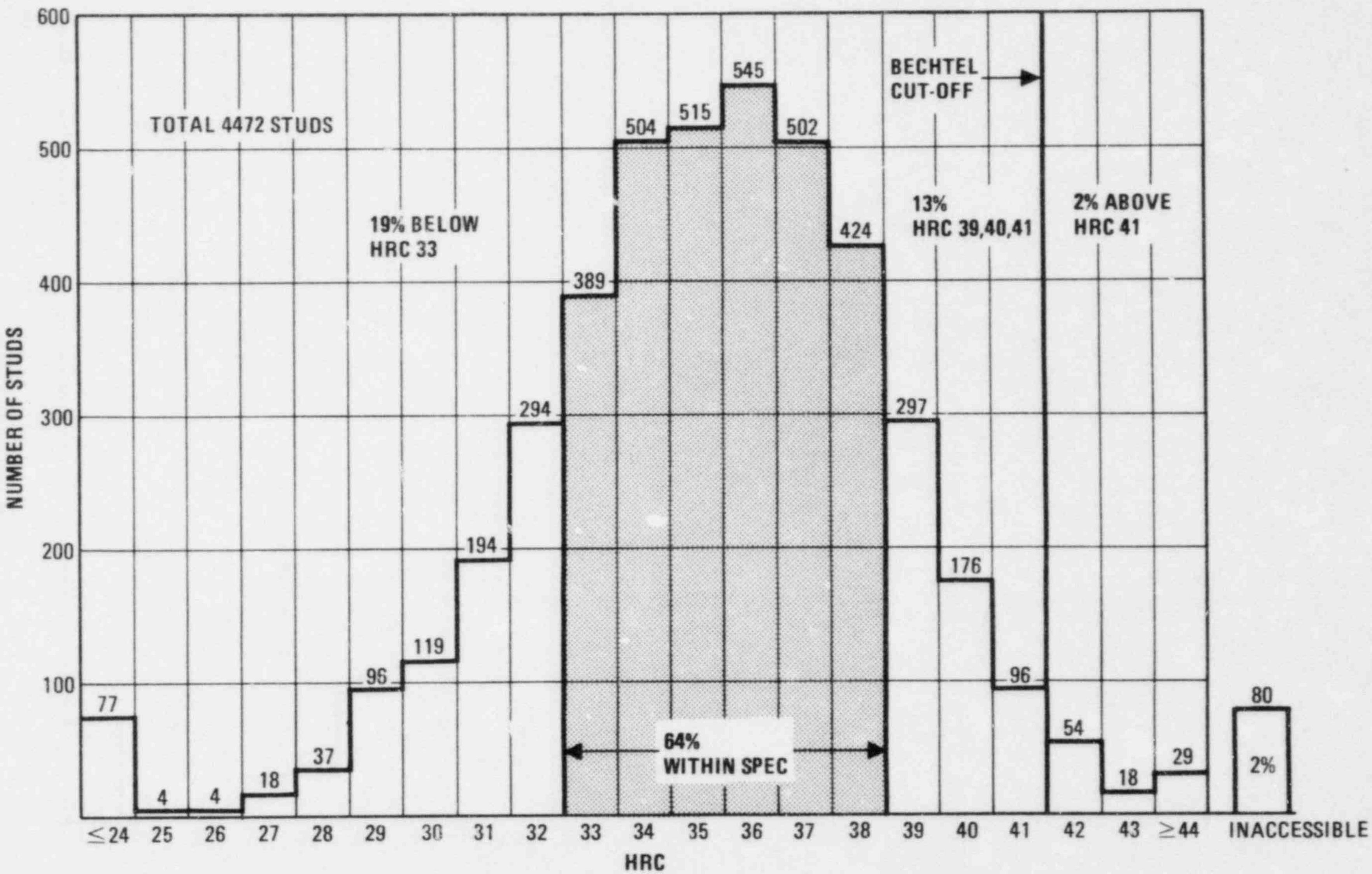


FIGURE 18

2nd Draft

COLUMN NO. 9 AND COLUMN NO. 10 HOLD-DOWN STUDS
EMBED PLATES NO. 321 AND NO. 322

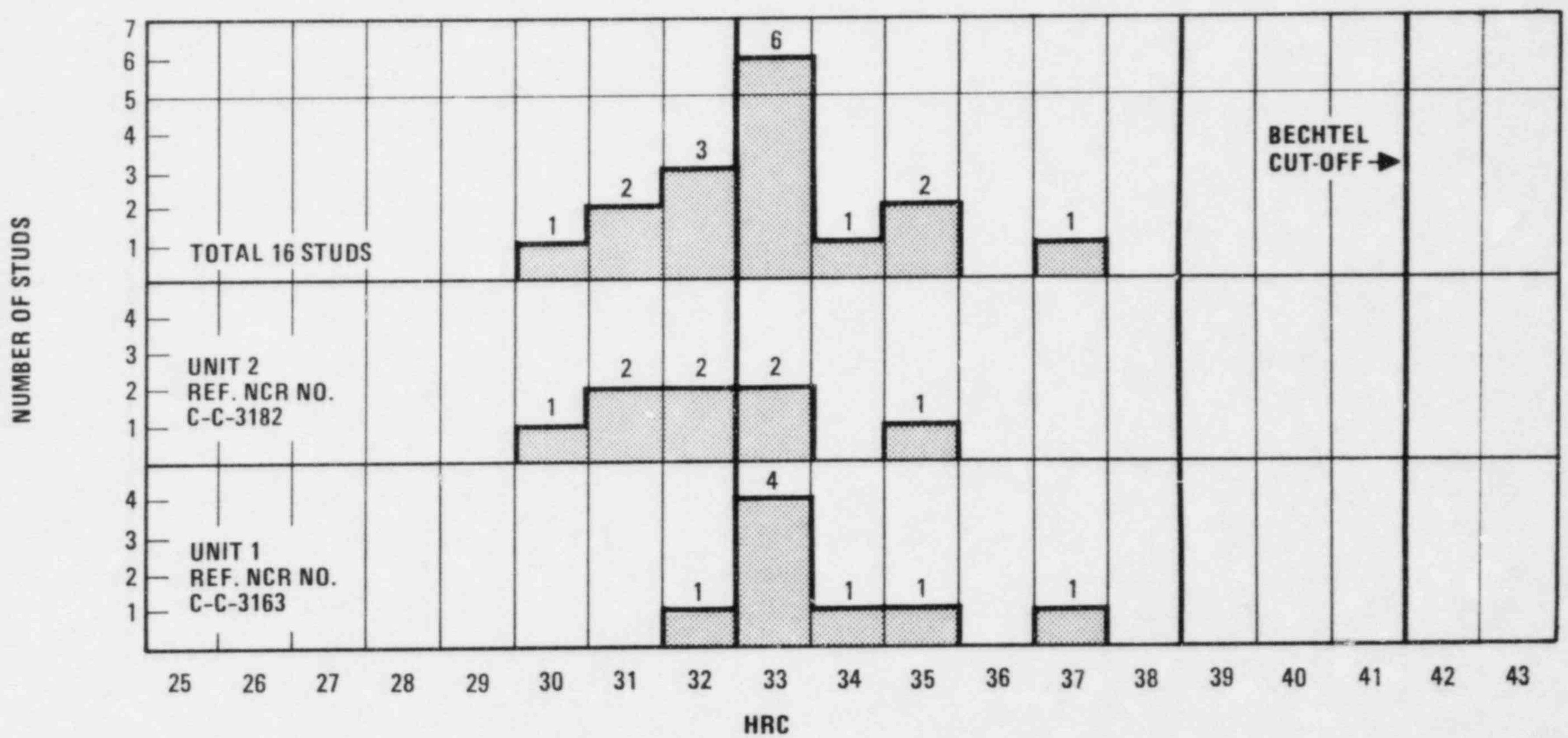


FIGURE 19

UNIT 1 AND UNIT 2
POLAR CRANE GIRDER HOLD-DOWN BOLTS

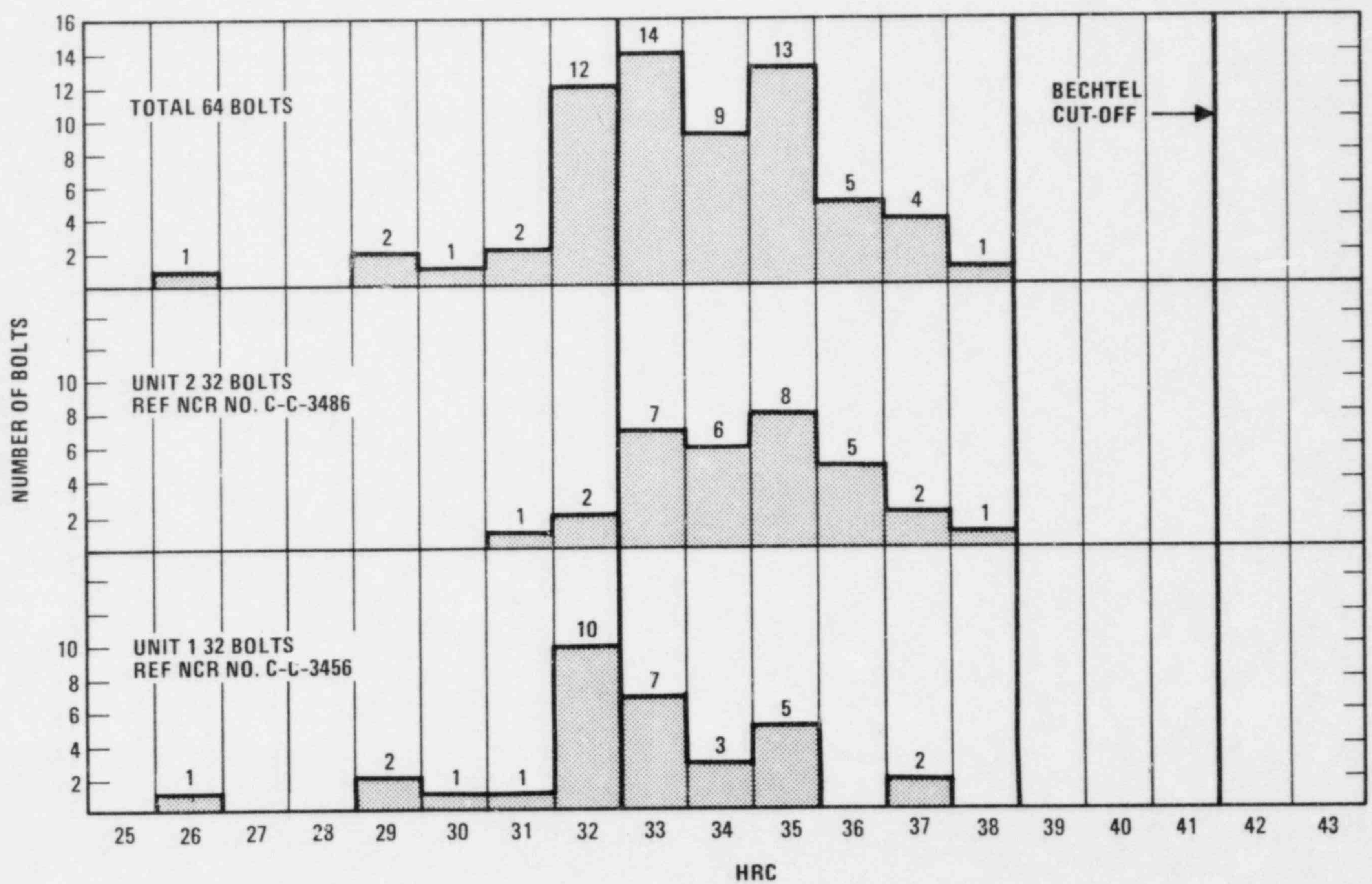
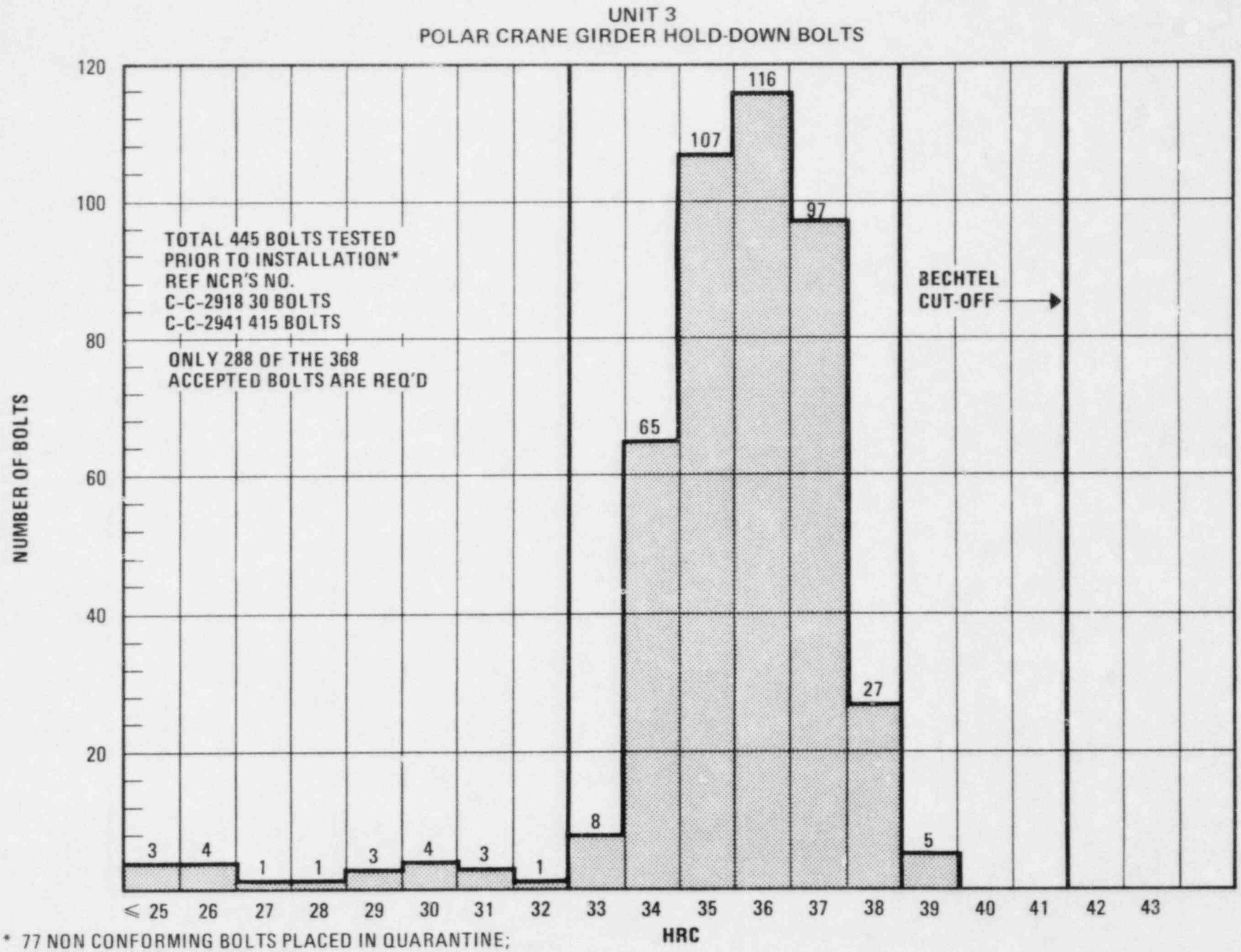


FIGURE 20



* 77 NON CONFORMING BOLTS PLACED IN QUARANTINE;
368 BOLTS APPROVED FOR USE

FIGURE 21

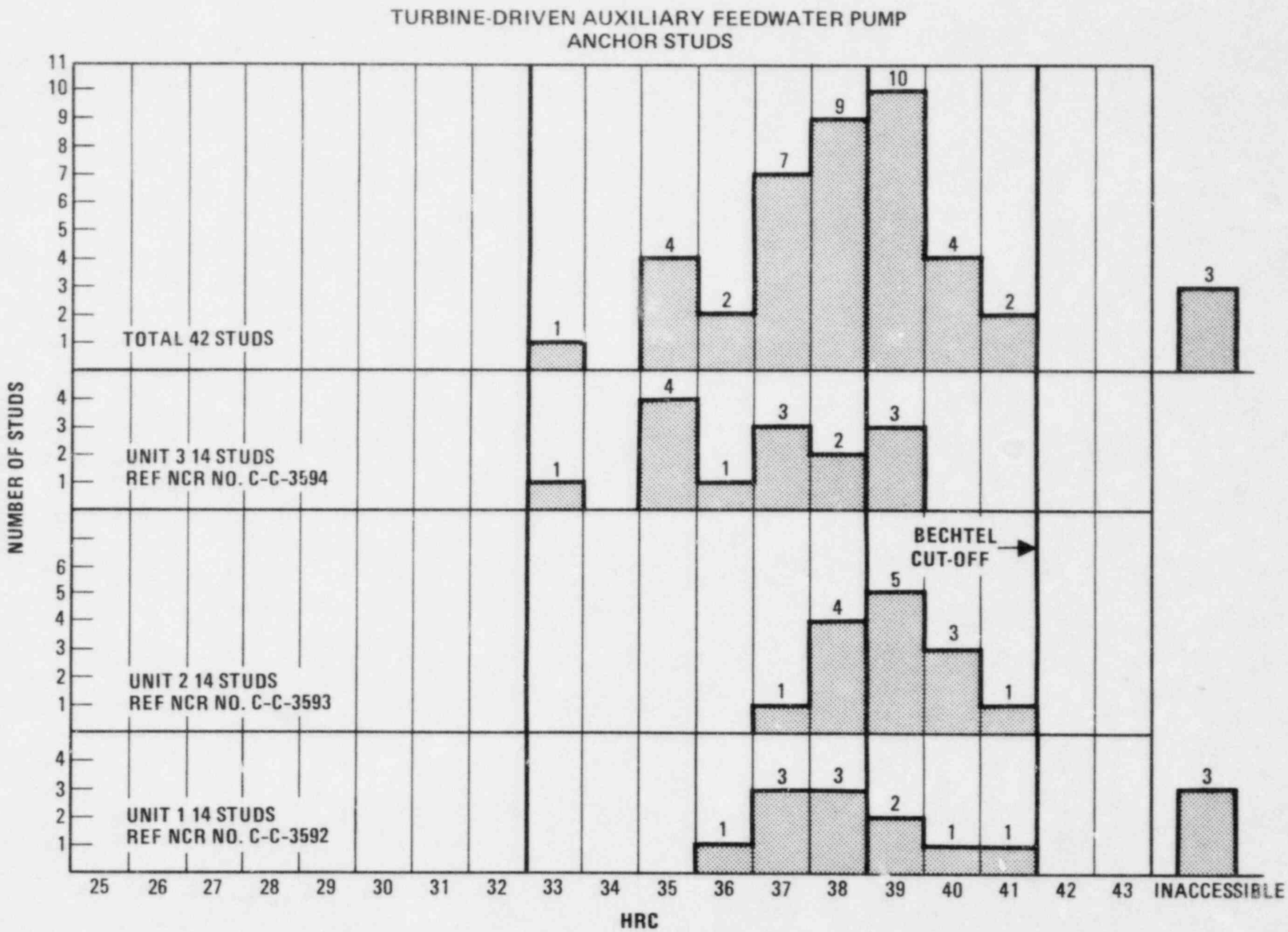
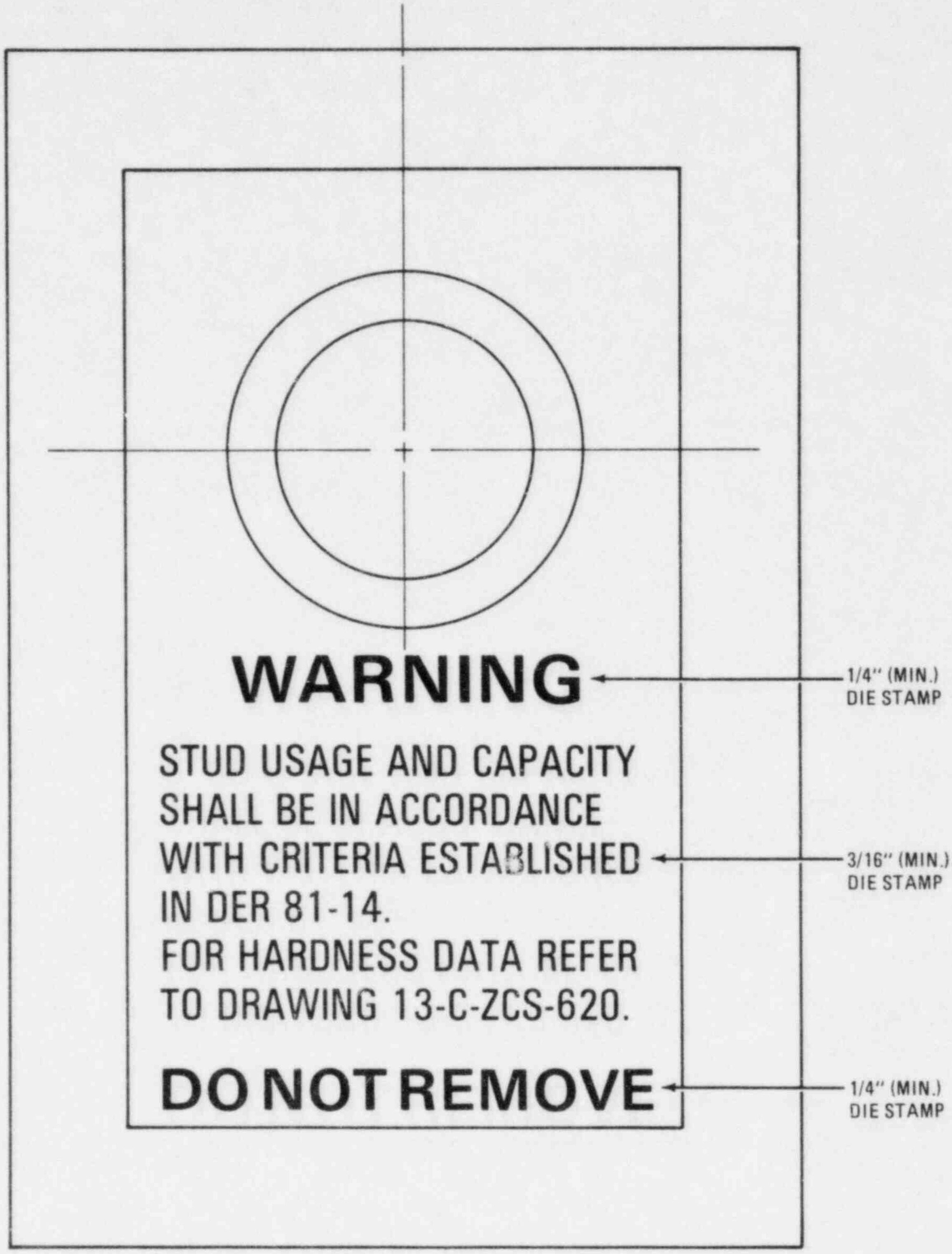

TURBINE-DRIVEN AUXILIARY FEEDWATER PUMP
ANCHOR STUDS
TOTAL 42 STUDS
UNIT 3 14 STUDS
REF NCR NO. C-C-3594
UNIT 2 14 STUDS
REF NCR NO. C-C-3593
UNIT 1 14 STUDS
REF NCR NO. C-C-3592
BECHTEL CUT-OFF
NUMBER OF STUDS
25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 INACCESSIBLE
HRC

FIGURE 22

IDENTIFICATION TAG DETAILS



FOR 1" TO 1-1/2" STUDS : 3-1/2" x 6" 24 GA. S.S. WITH 1-5/8" DIA. HOLE
FOR 2" STUDS : 5" x 7-1/2" 24 GA. S.S. WITH 2-1/8" DIA. HOLE

FIGURE 23

Bechtel Group, Inc.

Interoffice Memorandum

To	D. S. Parker	File No	
Subject	Failure Analysis - ASTM A-354 BD Bolting for Concrete Embed Assemblies Palo Verde Nuclear Generating Station - Job 10407-002	Date	October 28, 1981
		From	G. R. Schmidt (GRS-101-01)
		Of	R&E/M&QS
Copies to	R. A. Manley/B. D. Hackney B. N. Woodruff/J. J. Kvochak W. B. Keyser (6) K. Schechter DCC 235157 BLN 0681-2 Failure Analysis File	At	WC/1/A4 Ext 930-2408

Transmitted with this IOM are six copies of a failure analysis report covering our examination of three concrete embed assembly bolting failures. This report incorporates the information contained in "Failure Analysis of One ASTM A-354 Bolt," dated July 15, 1981, transmitted by IOM GRS-061-23.

G R Schmidt

G. R. Schmidt

GRS/JJK/lb

Attachments

DEFICIENCY EVALUATION REPORT NO. 81-14

BECHTEL GROUP, INC.
SAN FRANCISCO, CALIFORNIA
October 2, 1981

Project Number/Name:	10407-002 - PALO VERDE
Title:	Failure Analysis - ASTM A-354 BD Bolting for Concrete Embed Assemblies
Prepared for:	D. S. Parker
By:	J. J. Kalak J. J. Kvochak
Approved by:	G R Schmidt G. R. Schmidt Metallurgical Engineering and Laboratory Services Group Manager
Approved by:	for R A Manley B. D. ~~Hackney~~ Assistant Manager

MATERIALS AND QUALITY SERVICES DEPARTMENT
RESEARCH AND ENGINEERING

Log Number - 2351-57
BLN Number - 0681-2

TABLE OF CONTENTS

INDEX OF ILLUSTRATIONS AND TABLES

ABSTRACT

An investigation to study the preservice failures of four bolts in concrete embed assemblies was conducted. This report describes the failure analysis program, the results, and the recommendations based on this investigation. This report incorporates the information of a prior study of a single bolt failure documented in GRS-061-23.

DEFICIENCY EVALUATION REPORT NO. 81-14

I. INTRODUCTION

Four concrete embed assembly anchor bolts have failed prior to service at the Palo Verde Nuclear Generating Station (Figure 1a). Specifications require high strength, low alloy, quenched and tempered steel in accordance with ASTM A-354. Three bolts failed during installation preparation in the Unit 3 containment area. The fourth bolt was found fractured in the plant laydown area. All failures occurred locally within the nuts or anchor plates (Figure 1b). Three bolts were submitted to M&QS for analysis. Bolt identification, failure circumstances and methods of examination are summarized in Table 1.

A preliminary investigation (see GRS-061-23) of Bolt 2 revealed material hardness and strength to exceed specification requirements. It was concluded that the cause of the failure was improper heat treatment, resulting in high yield strength and hardness. Further study was recommended to determine failure mechanism, fracture mode, and the effect of heat treatment on material properties.

II. SUMMARY AND CONCLUSIONS

Failure of the anchor bolts was by progressive stress corrosion cracking originating in the thread root and advancing to 30 or 40 percent of the cross section, followed by final overload failure. Contributing factors to the stress corrosion cracking were: 1) high yield strength and suspected residual tensile stresses caused by improper heat treatment, 2) localized pitting and corrosion caused by thread root environmental conditions, and 3) stresses caused by tightening of the nuts. Contributing factors to final overload failure were: 1) a sharp notch and reduced cross section caused by stress corrosion cracking and 2) low resistance to brittle fracture caused by high yield strength.

The primary cause of failure was improper heat treatment of the bolting material. Material hardness and strength far exceeds specification requirements. ASTM standard A-354 (Grade BD) requires the hardness not to exceed Rockwell C=38. Minimum hardness for all three bolts was Rockwell C=48 (Table 2). It was determined by hardness testing, a heat treatment study, and microstructural analysis that the bolting material was in the as quenched state. Upon quenching a residual state of tension at the surface was produced. These stresses in combination with the stresses from the torquing of jam nuts were significant enough to initiate the stress corrosion failure. The specification requires delivery of the assemblies with the nuts hand tightened; however, impact wrenches were required for nut removal and it is suspected that torquing did occur.

The threshold for stress corrosion cracking in high strength low alloy steels is 200,000 psi tensile strength (Teledyne Engineering Services Technical Report TR-3887-2, Rev. 1, Acceptability for Service of Midland RPV Anchor Studs, May 20, 1980). Bolt 2 had a tensile strength of 277,000 psi and hardness of Rockwell C = 49. Bolts 3 and 4 had near identical hardness and it can be assumed that tensile strength of the bolts are similar.

A contributing cause of failure was exposure of the embed assemblies while in storage to an alternating dry and moist environment. Moisture accumulated in the thread root beneath the anchor plate and nuts causing pitting corrosion. Pits acted as initiation sites for stress corrosion cracking. Corrosion at the thread root will produce variation in the pH and local galvanic potential. This variation produces the necessary environment for stress corrosion cracking.

The fractures occurred transverse to the bolting axis in a macroscopically brittle mode (Figure 2). Scanning electron microscopy revealed the fracture to have initiated and propagated by intergranular fracture (brittle mode) before final fracture occurred by dimpled rupture (ductile mode) (Figure 3a, 3b, and 3c). Chemical analysis determined the bolting material to be nominally AISI 4140 in accordance with ASTM standard A-354 (Grade BD)(Table 3).

High strength low alloy steels are susceptible to hydrogen embrittlement. Hydrogen embrittlement is a mechanical-environmental failure process that results from the adsorption of atomic hydrogen into the microstructure. The combination of lower ductility from the adsorbed hydrogen in conjunction with residual or applied stresses leads to cracking. It is often difficult to distinguish between hydrogen embrittlement and stress corrosion cracking failures. However, it is our opinion that hydrogen embrittlement was not operable because of the presence of corrosion products and secondary crack branching which are characteristic of stress corrosion cracking. A hydrogen embrittled fracture surface is relatively clean and exhibits little or no crack branching.

III. RECOMMENDATION

A hardness survey of accessible bolting has been undertaken by project to determine the extent of the bolt problem. M&QS recommends disposition be based on a maximum surface hardness of Rockwell C=41 which reflects on approximate tensile strength of 188,000 psi. Stress corrosion cracking becomes operable in high strength, low alloy steels of 200,000 psi tensile strengths and greater.

IV. MATERIALS

The bolting material was specified to be ASTM standard A-354 Grade BD quenched and tempered alloy steel. The alloy additions made in accordance with ASTM standard A-354 qualified the material to AISI 4140. Chemical and mechanical requirements and analysis are given in Table 3 and 4.

V. EXAMINATION PROCEDURES

1. Visual examination including low power magnification examination.

2. Mechanical testing including hardness testing and tensile testing.

3. Chemical analysis by quantitative emission spectrographic analysis.

4. Liquid penetrant examination.

5. Surface analysis using Electron Spectrography for Chemical Analysis (ESCA).

6. Scanning Electron Microscopy (SEM).

7. Heat treatment study.

VI. DISCUSSION OF PROCEDURES AND RESULTS

Three bolting failures were submitted to the laboratory for failure analysis. Due to heavy oxidation and mechanical damage, only the fracture surface of bolt 4 was adequate for visual examination and scanning electron microscopy. However, enough fracture surface detail was present on bolts 2, 3 and 4 to conclude that all three bolts had failed by a similar fracture mode. The analysis proceeded on this basis.

1. Visual Examination - All three fractures were transverse to the bolt axis. On bolt 4 approximately 1/3 of the surface was lightly oxidized, the remaining 2/3 of the fracture surface was final fresh fracture (Figure 2). The lightly oxidized area exhibited fracture propagation lines which appear to initiate at bolts edge, converge, and run radially inward. An elevation step is present at the oxidized fracture to final fracture transition.

Pitting corrosion appears in the first and second threads away from the fracture surface (Figure 3). It is believed moisture condensed at the thread root providing the environment for pitting corrosion. Cracks initiated at the pits and propagated in the presence of the liquid phase at the thread root. Considerable machining tears are present in the threads and are the result of improper machining techniques during thread cutting. Machining tears did not have a direct effect on failure other than to act as sites for pitting corrosion.

2. Mechanical Testing - Hardness testing was performed on all three bolts (Table 2). A hardness scan was performed at two locations for each bolt. One scan was performed one bolt diameter away from quenched end (ASTM A-370 requirement) and one scan adjacent to the fracture surface. Little variation in the through thickness hardness was detected. However, it is surface properties that control resistance to stress corrosion cracking and, therefore, surface hardness testing is critical.

Tensile testing was performed on only bolt 2, but similar hardnesses would indicate mechanical properties of all bolting to be similar. Results are shown in Table 4.

3. Chemical Analysis - Quantitative emission spectrographic analysis indicates the material corresponds to ANSI 4140 high strength, low alloy steel in accordance with ASTM standard A-354.

4. Non Destructive Examination - A liquid penetrant examination along the full bolting length was performed on bolt 4 to determine if surface cracking was present. No relevant indication were found.

5. Surface Analysis - Electron Spectroscopy for Chemical Analysis (ESCA) was employed to determine the chemical formula of the oxide present and to determine if contaminants were present on the fracture surface. The oxide was determined to be primarily Fe O; a second constituent was present (either Fe O or FeO), but due to the oxidizing characteristic of ESCA it could not be determined specifically. Fe O is a low temperature oxide, and most probably formed during crack propogation. Therefore, the fracture was not initiated during quenching as a high temperature oxide would have been the primary oxide constituent if a quench crack had initiated failure. No contaminants, other than handling contaminants were present.

VOID SUPERSEDED
CORRECTED PAGE AND TRANSMITTAL FOLLOWS

Bechtel Group, Inc.

Interoffice Memorandum

To	R. A. Keidel	File No	
Subject	Document Page Reissue Failure Analysis - ASTM A-352 BD Bolting for Concrete Embed Assemblies Palo Verde Nuclear Generating Station - Job 10407-002	Date	December 10, 1981
		From	G. R. Schmidt (GRS-121-05)
		Of	R&E/M&QS
Copies to	R. A. Manley/B. D. Hackney B. N. Woodruff/J. J. Kvochak W. B. Keyser (6) K. Schechter DCC 235157 BLN 0681-2 Failure Analysis File	At	WC/1/A4 Ext 930-2408

Reference: GRS 101-01, IOM to D. S. Parker, October 28, 1981.

Page 3 of report "Failure Analysis - ASTM A354 BD Bolting for Concrete Embed Assemblies Palo Verde Nuclear Generating Station" has been revised. The proper subscripts have been added to the chemical formulas in Section 5, lines 4, 5 and 6. Transmitted with this IOM are six copies of the reissued page. Please discard the old page 3 and insert the attached page.

BNWoodruff for
G. R. Schmidt

GRS/JJK/lh

Attachments

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6. Scanning Electron Microscopy - Two microstructurally distinctive areas were present corresponding to the two visually distinctive areas of bolt 4. The lightly oxidized region was characteristically intergranular fracture, which is characteristic of stress corrosion cracking. The non-oxidized final fracture region failed by dimpled rupture (Figures 3a, 3b, and 3c). Dimpled rupture is characteristic of an overload failure in the ductile mode.

7. Metallographic Examination - Bolt 3 and 4 were sectioned for microstructural analysis with sections prepared through the fracture transition from the intergranular to dimpled rupture. Continued crack propagation was revealed below the fracture surface (Figure 4). Minor branching was present both along the crack line as well as from the fracture surface (Figure 5). The microstructure was clearly identified as martensite (Figure 6).

8. Heat Treatment Study - Varying heat treatments were performed on each of seven samples cut from a bolt 4 to determine the degree of tempering incurred by the bolting material (Table 4). The results indicate the bolting material was either in the as quenched or quenched and tempered state with tempering temperature below minimum specified. A microstructural comparison of the as received, quenched, and quench and tempered specimens was made (Figures 6, 7a, 7b).

Table 1. Bolt Identification, Failure Circumstances, and Methods of Examination

Bolt	Failure Location/Circumstances	Examination Methods
1	Failed within anchor plate when ironworker pulled on bolt	None - discarded by crafts
2	Failed within the lower jam nut when ironworker was removing nut	Mechanical testing, chemical testing, optical microscopy
3	Failed within anchor plate. Circumstances are unknown.	Mechanical testing, liquid penetrant examination, optical microscopy
4	Failed within anchor plate when ironworker was removing nut	Mechanical testing, scanning electron microscopy, ESCA, optical microscopy, heat treatment study

Table 2. Hardness Test Results for ASTM A-354 (Grade BD) Bolting. Notes 1,2,3

Bolt/Location	Hardness (Rockwell C)				
	Center 0	1/4 R	1/2 R	3/4 R	Surface R
2 / Fracture	48.5	48.5	49.0	49.0	49.5
2 / Quenched End	49.0	48.5	49.0	49.0	50.0
3 / Fracture	48.0	48.0	49.5	48.5	50.0
3 / Quenched End	48.5	48.0	48.5	50.0	50.5
4 / Fracture	48.0	48.5	48.0	49.0	48.5
4 / Quenched End	48.0	49.0	48.5	50.0	49.5

Note 1 Two hardness scans per bolt - one scan adjacent to fracture surface; one scan at one bolt diameter away from the quenched end.

Note 2 Hardness measurements at center, 1/4 radius, 1/2 radius, 3/4 radius, and surface.

Note 3 ASTM A-354 (Grade BD) requires hardness for 1-1/2 inch diameter bolts to be Rockwell C = 33 to 38.

Table 3. Chemical Analysis of Bolt 2 and Chemical Requirements of ASTM A-354 and AISI 4140.

Element	Alloying Additions		
	ASTM A-354	AISI 4140	Bolt 2
Carbon	.28 - .55	.38 - .43	.40
Chromium		.80 - 1.10	1.04
Columbium			.01
Copper			.08
Manganese		.75 - 1.00	.93
Molybdenum		.15 - .25	.20
Nickel			.07
Phosphorus	.035 max.	.035 max.	.017
Silicon		.20 - .35	.27
Sulfur	.04 max.	.04 max.	.02
Tantalum			.01
Titanium			.005
Vanadium			.008

Table 4. Mechanical Properties of Bolt 2 and Mechanical Requirements of ASTM A-354 (Grade BD)

	ASTM A-354	Bolt #2
Tensile Strength, psi	150,000 - 190,000	277,000
Yield Strength, psi	130,000 min.	239,000
Elongation, %	14 min.	10
Reduction in Area, %	40 min.	43.6
Hardness, Rockwell C	33 - 38	49

Table 5. Effects of Thermal Treatments on Hardness of ASTM A-354 (Grade BD). Notes 1,2,3

Thermal Treatment	Hardness (Rockwell C)				
	Center 0	1/4 R	1/2 R	3/4 R	Surface R
As received	48.0	49.0	48.5	50	49.5
Normalize (1600F)/Oil quench	48.0	48	49	50	52
Normalize (1600F)/Oil quench/Temper (900F)	37.0	39.5	40	39.8	40
As received/Temper (900F)	34.5	34.5	36.0	37.0	37.5
Normalize 1600F/Oil quench/Temper (1000F)	29.5	31	31	3[illegible]	30
As received/Temper (1000F)	30	31.5	33.5	33.5	33.5
Normalize (1600F)/Oil quench/Temper (1100F)	23.2	24.2	25.5	25.3	24.5
As received/Temper (1100F)	25	25	26	25.5	26.5

Note 1 Hardness measurements at center, 1/4 radius, 1/2 radius, 3/4 radius, and surface.

Note 2 ASTM A-354 (Grade BD) requires hardness for 1-1/2 inch diameter fasteners to be Rockwell C = 33 to 38.

Note 3 Samples were cut from Bolt #4.

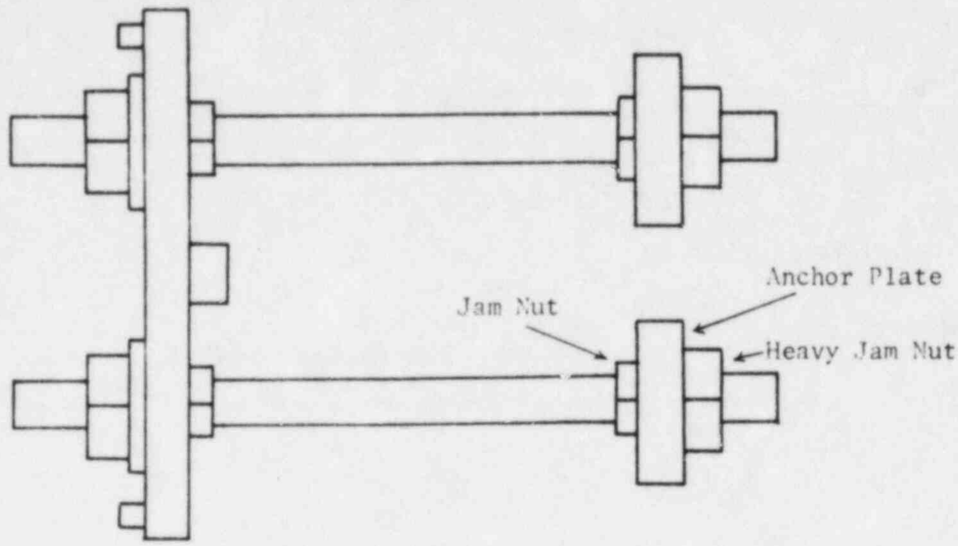


Figure 1.(a) Schematic Drawing of QM-6 Concrete Embed Assembly

All fractures occured locally beneath the nut or anchor plate.

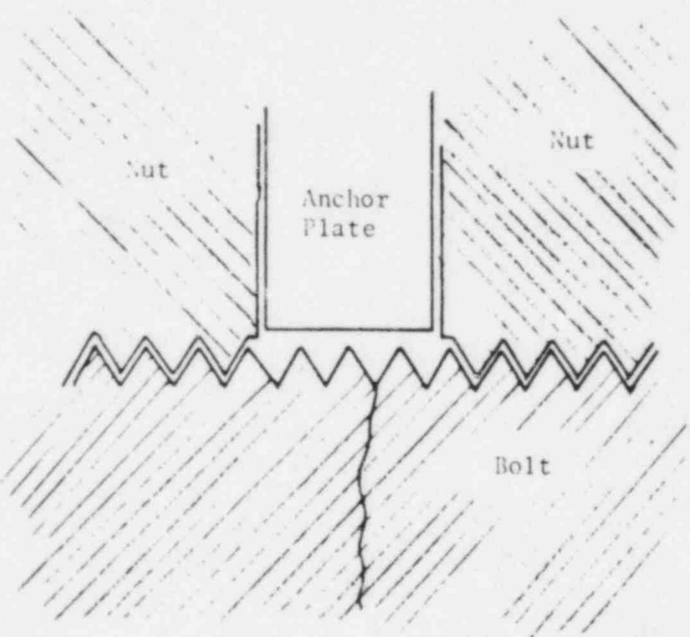
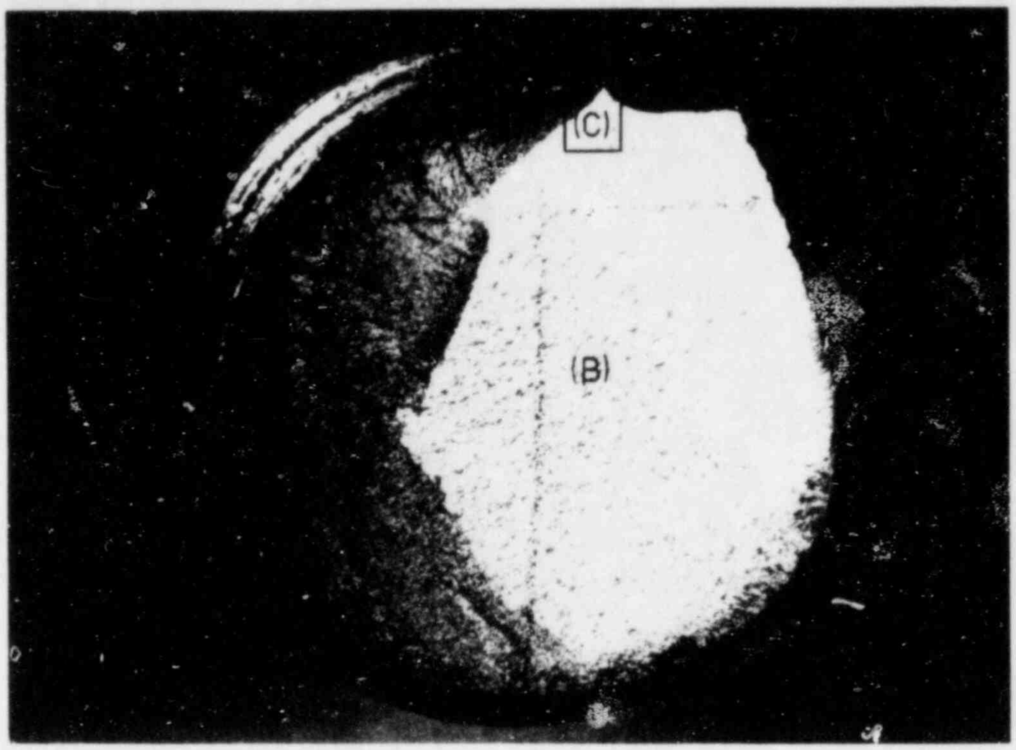


Figure 1.(b) Detail Drawing of Nut-Plate-Nut Configuration.

All factures were transverse to the bolting axis. A typical fracture path is shown.



(unetched 2X)

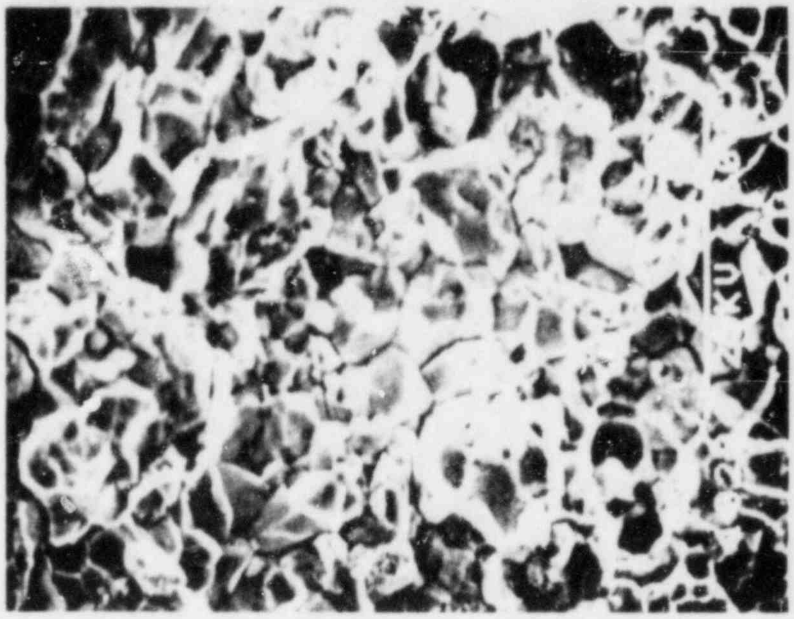
Figure 2. Macrograph of Fracture Surface.

A light oxidation layer was present on approximately 40% of the fracture surface (Area A). Final fresh fracture was present on the remainder of the surface (Area B). Detail Area C as shown in Figure 3(a).

(Unetched, 40X)

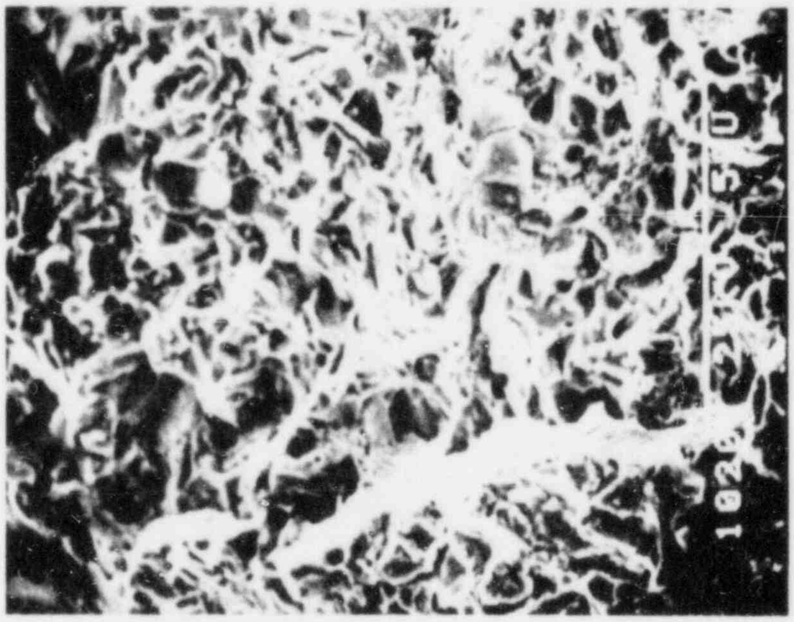
Figure 3.(a) SEM Fractograph of Fracture Transition.

Fracture surface location is Detail Area C of Figure 2. Fracture transition is from Area A (intergranular mode, Figure 3.(b)) to Area B (dimpled rupture mode, Figure 3.(c)) pitting corrosion is evident in the threads (Area C).



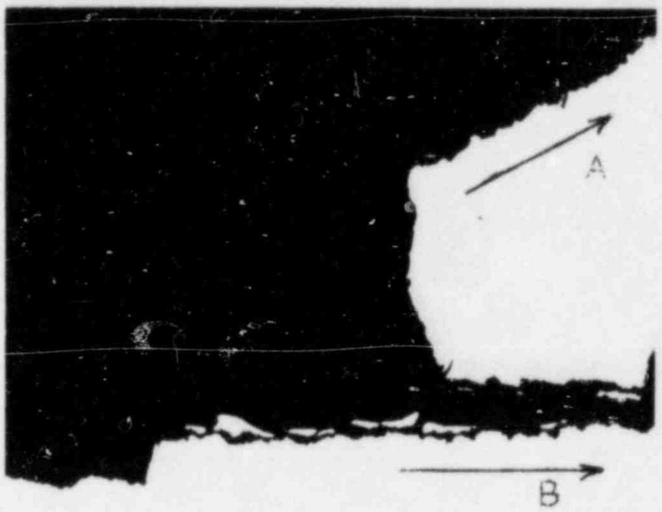
(unetched, 950X)

Figure 3.(b) SEM Fractograph of Intergranular Fracture Region.
Detail of Area A of Figure 3.(a).



(unetched, 950X)

Figure 3.(c) SEM Fractograph of Dimpled Rupture Fracture Region.
Detail of Area B of Figure 3(a).



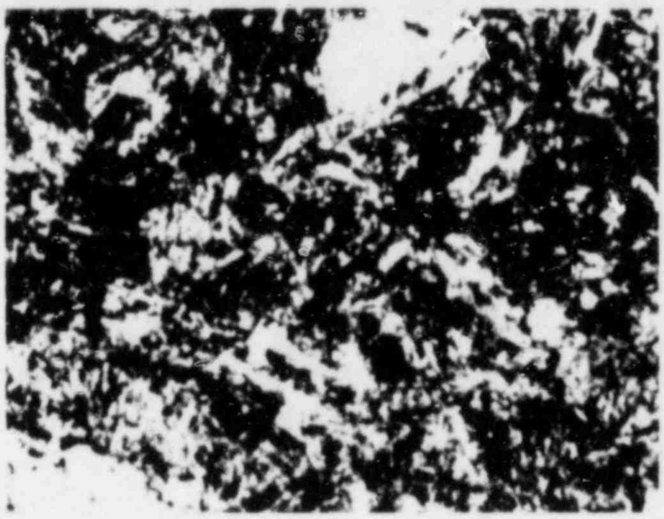
(unetched, 100X)

Figure 4. Micrograph of Crack Propagation Below Fracure Surfaces.

Final fracture occured along line A. Continued intergranular attack accored along line B.

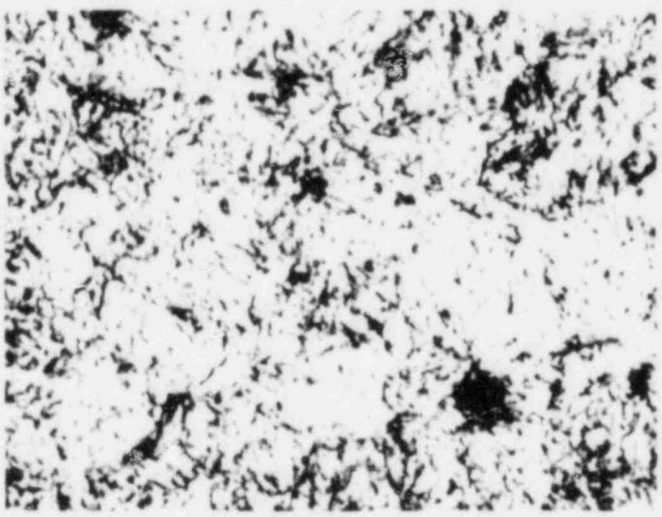
(unetched, 250X)

Figure 5. Micrograph of Crack Branching Along Crack Propagation line.



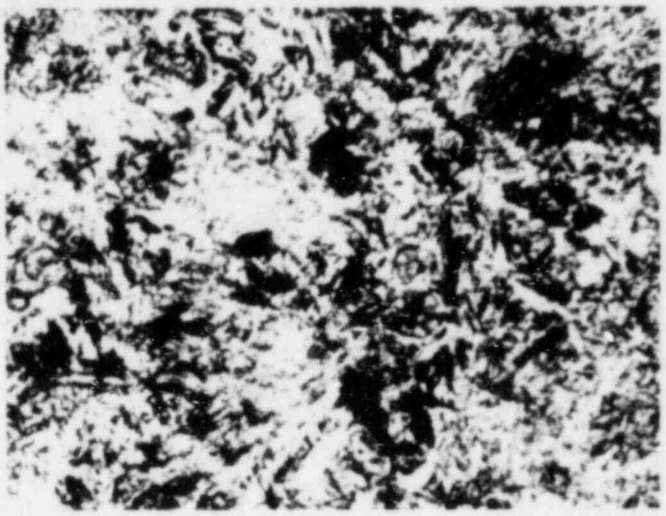
(Nital-Picral, 1500X)

Figure 6. Micrograph of As-received Microstructure.



(Nital-Picral, 1500X)

Figure 7(a) Micrograph of As-quenched Microstructure.



(Nital-Picral, 1500X)

Figure 7(b) Micrograph of Quenched & Tempered (900F) Microstructure.

TELEDYNE
ENGINEERING SERVICES

TECHNICAL REPORT

TELEDYNE ENGINEERING SERVICES
CONTROLLED
DOCUMENT
TES PROJ. NO. 5534
DATE 9-21-82

TECHNICAL REPORT TR-5534-1
REVISION 1

**"ACCEPTABILITY FOR SERVICE OF
LOW ALLOY, QUENCHED AND TEMPERED SUPPORT
STUDS AND BOLTS"**

PALO VERDE NUCLEAR GENERATING STATION ANPP

SEPTEMBER 16, 1982

DEFICIENCY EVALUATION REPORT NO. 81-14

BECHTEL POWER CORPORATION
12400 EAST IMPERIAL HIGHWAY
NORWALK, CALIFORNIA 90650

TECHNICAL REPORT TR-5534-1
REVISION 1

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SEPTEMBER 16, 1982

TELEDYNE ENGINEERING SERVICES
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WALTHAM, MASSACHUSETTS 02254
617-890-3350

Technical Report
TR-5534-1, Revision 1

TELEDYNE ENGINEERING SERVICES

ACCEPTABILITY FOR SERVICE OF LOW ALLOY, QUENCHED AND TEMPERED SUPPORT STUDS AND BOLTS

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Technical Report
TR-5534-1, Revision 1

TELEDYNE ENGINEERING SERVICES

ACCEPTABILITY FOR SERVICE OF LOW ALLOY, QUENCHED AND TEMPERED SUPPORT STUDS AND BOLTS

1.0 SCOPE

The purpose of this document is to provide guidance regarding acceptance for continued service of ASTM A354 low alloy steel quenched and tempered support studs and bolts, which have hardnesses outside of the specification range. It is assumed that the material is otherwise in full conformance with specification requirements. Surface or near-surface hardness is the only property which can be measured *in situ* and correlated with the properties of significance to service acceptance. High surface hardness is particularly significant since it indicates possible susceptibility to stress corrosion cracking. Conversely, low surface hardness indicates possible low material strength. In addition to hardness, applied stress level must be considered with a distinction made between long-term and short-term periods of stress application.

2.0 INTRODUCTION

Teledyne Engineering Services (TES) under contract to Bechtel Power Corp. (BPC) has studied the Bechtel analysis of the pre-service failure of four ASTM A354 BD bolts at the Arizona Nuclear Power Project. It was established that the anchor bolt failures resulted from stress corrosion cracking which propagated to the point that the studs failed by brittle fracture. The stress corrosion cracking is the result of bolts with excessive surface hardness in the range of 49 HRC. Materials with hardness exceeding 49 HRC have drastically reduced resistance to SCC. 1

Subsequent field hardness measurements of approximately 4400 bolts by BPC disclosed that the bolts were of uniform hardness, that additional bolts had hardnesses higher than the specification permitted but considerably lower than the failed bolts, and that some bolts were below the specified hardness range.

TES has conducted a review of the available stress corrosion and strength vs. hardness literature for high strength quenched and tempered materials. That investigation indicated that bolting materials purchased to ASTM A354 specification requirements may fail as a result of stress corrosion cracking when used in a normal application. This situation is a result of lower than expected stress corrosion resistance and fracture toughness due to higher hardness outside specified limits: a consequence of the ASTM requirement for very small samples for hardness testing for a large lot of bolts, and no requirement for field user's test to improve that sampling percentage.

2.1 Stress Corrosion and Fracture Toughness of Bolting Materials

Under Generic Activity A-12, the Nuclear Regulatory Commission (NRC) established guidelines for loading of high strength bolting materials susceptible to stress corrosion using a fracture mechanics approach (1-3). This criterion is shown in Figure 1. Subsequently, Lawrence Livermore National Laboratory (LLNL) performed a literature review on K_{Iscc} for bolting materials. The result of this review confirmed that the NRC lower bound was generally appropriate for the materials and environment of concern here. However, the review also showed that above yield strengths of 220 ksi (46 HRC) there is no change in K_{Iscc} with increasing strength. The LLNL report suggests that 10 ksi $\sqrt{in}$ is an appropriate lower limit for K_{Iscc}. TES's review of the same data suggests 8 ksi $\sqrt{in}$ as a more conservative limit. Using this limit the NRC criterion would be modified to include the dashed line shown in Figure 1.

Fracture toughness is also a material property which may be limiting on bolt loading. TES's review of available literature resulted in the curve for K_{Ic} at room temperature as a function of material hardness at room temperature also shown in Figure 1.

It is on these two curves that further analysis is based.

3.0 MATERIAL HARDNESS

The bolts in question were purchased to ASTM A-354 Grade BD, which specifies a hardness range of 33-38 HRC. Several materials may meet the A-354 specification, but AISI 4140 and 4340 are most commonly used in nuclear application.

For the Palo Verde Project, how much of the variation in hardness above the specification is the result of normal variation in material properties? To answer this question, TES reviewed two sources for guidelines. Both indicated that a maximum surface hardness of 41 HRC is consistent with a one-quarter diameter maximum value of 38 HRC.

3.1 Specified Hardness

Based upon specific sampling procedures, ASTM A354 establishes a maximum acceptable hardness level. A-354 does not define the location of the hardness measurement, but refers to A-370, Methods and Definitions for Mechanical Testing of Steel Products. A-370-74 Supplement III covers steel fasteners. S10.2 describes the purpose of Supplement III as "to facilitate production control testing and acceptance testing with certain more precise tests to be used for arbitration in case of disagreement over test results." S13.1 covers hardness testing for bolts, and it does provide for a "more precise test" as follows: 1

> "For final arbitration the hardness shall be taken on a traverse section through the threaded section of the bolt at a point one-quarter of the nominal diameter from the axis of the bolt. This section shall be taken at a distance from the end of the bolt which is equivalent to the diameter of the bolt."

Therefore, for the subject bolts, the maximum permissible hardness measured at mid-radius one-diameter away from a quenched end is 38 HRC. In actuality BPC measured the hardness at the mid-radius on the end of the bolts, which would be expected to be harder than the mid-radius one diameter from the end. Therefore, the results should be conservative.

Even if maximum hardenability of these studs is assumed, some hardness gradient would be expected in larger diameter bolts. Since it is the surface property which controls resistance to stress corrosion crack initiation, the surface hardness is more important to service behavior than is the as-specified mid-radius hardness. There not being a materials specification requirement on surface hardness, TES considered the requirements of component support standards which address surface hardness. Specifically with respect to support bolting of the class of materials of interest, including 4140 and 4340, footnote (3) to ASME Section III Table I-13.3 and footnote (6) to Table 4 of Code Case N-71 (1644) read as follows:

> "The maximum tensile strength shall not exceed the minimum specified tensile strength by more than 40 ksi. Where the specification does not limit hardness, the maximum surface hardness shall not exceed the hardness values corresponding to the maximum tensile strength, as determined from the applicable Tables in SA370."

For the material of interest (ASTM A-354 Grade BD), the specified minimum tensile strength is 150 ksi. Applying the footnote procedure, the maximum permissible surface hardness would be 41.3 HRC. Therefore, based on rounding to integer values in accordance with SA-370, TES concludes that a maximum surface hardness of 41 HRC is consistent with a specified maximum mid-radius hardness of 38 HRC, and that 41 HRC would be the proper value for surface hardness specification.

3.2 Statistical Data

What is the nature of the hardness variation which would be expected to result if a large number of studs were heat treated with the objective of meeting a specific hardness? Data have not been found for the specific materials of interest, but are available on a large number (8935) of 1/2" diameter AISI 1038 bolts (6). Because of this small diameter, the higher hardenability of the 41XX or 43XX materials is not required to obtain essentially uniform hardness.

The carbon content 0.38% is sufficient to represent the type of data one would expect from the materials of interest. Approximately 1000 bolts were heat treated to each of 8 levels of nominal hardness. The results shown in Figure 2 may be summarized as follows:

HARDNESS, HRC

Nominal	Minimum	Maximum	Range	Max. Variation Minus	Max. Variation Plus
20	14	23	9	6	3
22.5	19	27	8	3.5	4.5
25	21	29	8	4	4
30	25	32	7	5	2
32.5	26	35	9	6.5	2.5
35	30	38	8	5	3
37.5	33	41	8	4.5	3.5
40	38	44	6	2	4

The average value of the range is 7.875, and the average plus variation is 3.312. Based on these data, it is reasonable to expect that material which has a nominal hardness based on limiting sampling in accordance with a specification of some value would have a maximum hardness 3 HRC higher if it were more extensively sampled. For example, uniformly hard material with a nominal hardness of 38 HRC would be found to have a maximum hardness of 41 HRC if a large number of samples were measured.

4.0 EFFECT OF LOAD DURATION, HIGH HARDNESS BOLTS

4.1 Application of Linear Elastic Fracture Mechanics

A calculated quantity termed the "stress intensity factor" is used to evaluate the propensity for crack initiation or propogation in materials such as those here considered. The "stress intensity factor" used here is designated by the symbol K_I and is computed with an equation of the form:

$K_I = CS\sqrt{a}$

where:

K_I = stress intensity factor, ksi $\sqrt{in}$

C = a factor dependent upon the geometry of the structure of the crack and the distribution of the nominal stress

S = the nominal stress, the stress which would be present in the absence of the crack, ksi

a = a characteristic crack dimension; in particular, the depth of the crack for a surface crack, inches

The calculated or applied stress intensity factor is compared with a measured material property, the property being determined for this material with a crack present, with the appropriate loading and in an appropriate environment. Of specific interest on this application are two such material properties:

K_{Ic} = the plane strain fracture toughness

K_{Icscc} = the minimum value at which stress corrosion cracks propogate

In each instance, the applied stress intensity factor is compared with the material property; usually with an appropriate factor of safety to obtain an allowable value. If the applied value is less than or equal to the allowable value, the design is considered to be acceptable.

4.2 Application

A distinction between allowable stresses for long-term and short-term service conditions is made in order to recognize the fact that the total duration of many of the higher service loadings is very short when compared to the total life of the plant. If long-term stress corrosion cracking is prevented, extraordinary defects will not be present so as to cause failure when the short-term service load is applied. Therefore, the long-term allowable stress has been selected so as to minimize stress corrosion cracking. The short-term allowable stress has been decreased as a function of hardness because the short-term (no corrosion) toughness decreases with increased hardness. The objective is to assure that the hard studs with surface hardness somewhat above 38 HRC are as resistant to failure as are studs which comply with specified material properties. It is suggested that the dividing line between short-term and long-term service conditions be placed at one hour, unless a longer time can be justified on the basis of crack growth rate calculations.

The user of these criteria must recognize that such use may require design and installation procedures which are different than those commonly used. The design and installation procedures for bolted joints commonly result in a bolt preload which is equal to the maximum service load which would exist on the bolt. Then, at least in the ideal situation when the bolts are flexible compared to the remaining members of the bolted assembly, the stress experienced by the bolt is not dependent on variations in service loads. With the suggested criteria, the long-term allowable stress may be considerably lower than the short-term allowable stress.

Since the controlling design condition for most such bolts is the result of plant Emergency or Faulted Conditions which are of short time duration, the short-term allowables are intended to apply to such loadings. The long-term allowables are intended to apply to the stress levels which exist in the bolts during plant Normal and Upset Conditions including the as-relaxed preload. Normally the controlling stress level during such conditions is the preload value which exists in the bolt following initial relaxation. The minimum preload value is generally assumed to be two-thirds of the actual yield strength of the material, and this value may be considered to represent "100% of the normal criteria" for long-term allowables unless other values are indicated by applicable data. The value which represents "100% of the normal criteria" for short-term allowables shall be taken as the allowable stress value used with the initial design criteria for plant Emergency and Faulted Conditions.

5.0 INTERPRETATION OF HARDNESS DATA

The allowable stress limits are related to the "maximum hardness". This term is intended to mean the surface or near surface hardness as determined by conventional hardness testing such as Rockwell B, Rockwell C, or Brinnell testing.

Since hardness measurements may be performed in the field, suitable standard Rockwell or Brinnell hardness testers may not be available or practical, alternative non conventional hardness testers may be used provided a relation can be shown between the hardness scale used and the Rockwell or Brinnell scales. For the Equo-Tip portable hardness tester used by BPC for the Arizona Nuclear Power Project, Appendix I shows such a correlation between Rockwell and the Equo-Tip "L" scales with data from Equo-Tip hardness tests on Rockwell calibration blocks spotted in (7). Therefore, the Equo-Tip is an acceptable alternative hardness tester and the "L" value to Rockwell C correlation provided in the Equo-Tip Users Manual can be used directly.

6.0 LOW HARDNESS BOLTS

Since low hardness bolts are not susceptible to stress corrosion, and generally have toughness at least equal to the toughness of the specified material, any reduction in allowable stress would be based only on reductions in ultimate strength which are caused by insufficient hardness. No distinction is required between long-term and short-term loading. Figure 3 shows ultimate strength as a function of hardness (8).

7.0 RECOMMENDED GUIDELINES

Based upon the study reported in this document, TES has developed guidelines for acceptance for continued service of low alloy quenched and tempered support bolting in terms of the material hardness.

7.1 High Hardness Bolts

TES recommends that such bolting be considered as acceptable for continued service if: (1) they have not been preloaded to and will not be subjected to long-term direct tension stress levels in excess of those indicated in the following tables; and (2) the maximum calculated direct tension stress under any anticipated or postulated short-term service condition will not exceed the values indicated in the following tables for the applicable materials.

FOR ALL LOW ALLOY, QUENCHED AND TEMPERED MATERIALS

Maximum Hardness (HRC)	Stress Limits (% Normal Criteria) Long-term	Short-term
38-41	100	100
42	80	90
43	50	90
greater than 43	Not Permitted at this time pending resolution of properties at higher hardnesses	

Bolting which has been subjected to stress levels in excess of those recommended for long-term loadings may contain stress corrosion cracks. The acceptability of such materials for continued service must be evaluated on a case-by-case basis.

The determination of the stress limits is shown graphically in Figure 4 for long-term loadings and Figure 5 for short-term loadings. The long-term loading is based on the criteria established by the NRC and modified by the 8 Ksi $\sqrt{in}$ lower bound as discussed in 2.1 of this report.

7.2 Low Hardness Bolts

TES recommends that such bolting be acceptable for service provided any anticipated or postulated service condition will not exceed the values indicated in the following table:

FOR ALL LOW ALLOY, QUENCHED AND TEMPERED MATERIALS

Maximum Hardness (HRC)	Stress Limits (% Normal Criteria)
32	100
31	97
30	95
29	92
28	90
27	88
26	86
25	84

These figures are based on Figure 3 which shows ultimate strength as a function of hardness. The determination of the stress limits are shown graphically in Figure 6.

8.0 REFERENCES

1. R.P. Snaider, J.M. Hodge, H.A. Levin, and J.J. Zudans, "Potential for Low Fracture Toughness and Lamellar Tearing on PWR Steam Generator and Reactor Coolant Pump Supports," NUREG-0577, For Comment, U.S. Nuclear Regulatory Commission, October 1979.

2. R.P. Snaider, R.M. Gamble, J.M. Hodge, H.A. Levin, P.N. Randall, C.D. Sellers, and J.J. Zudans, "Potential for Low Fracture Toughness and Lamellar Tearing on Component Supports," NUREG-0577 Draft 10/80, U.S. Nuclear Regulatory Commission, October 1980.

3. Memorandums dated May 19, 1980 and May 20, 1980 from the Division of Licensing, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission sent to nuclear reactor plants pertaining to References 1 and 2.

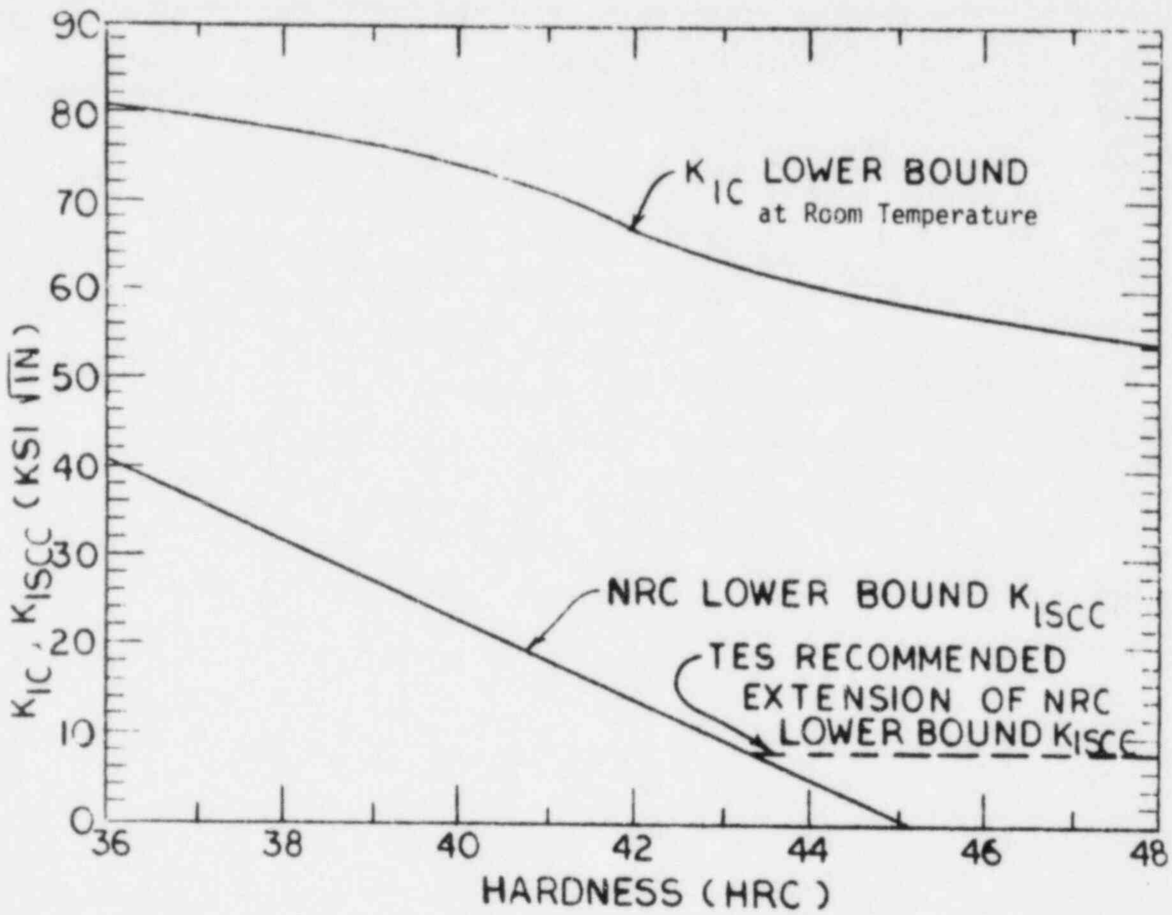
4. A. Goldberg, MC. Juhas, "Low-Bound K_{Iscc} Values for Bolting Materials - a Literature Survey," NUREG/CR-2467, UCRL-53035, February 1982.

5. C.S. Carter, "Stress Corrosion Cracking and Corrosion Fatigue of Medium-Strength and High-Strength Steels," Chapter prepared for ARPA Handbook on Stress Corrosion Cracking and Corrosion Fatigue. To be published.

6. Metals Handbook, Volume 1, 9th Edition, Page 281.

7 TES letter 5534-3 from W.G. Dobson to W. G. Bingham (BPC) dated 6/15/82.

8. Metals Handbook, Volume 2, 8th Edition, Page 427.



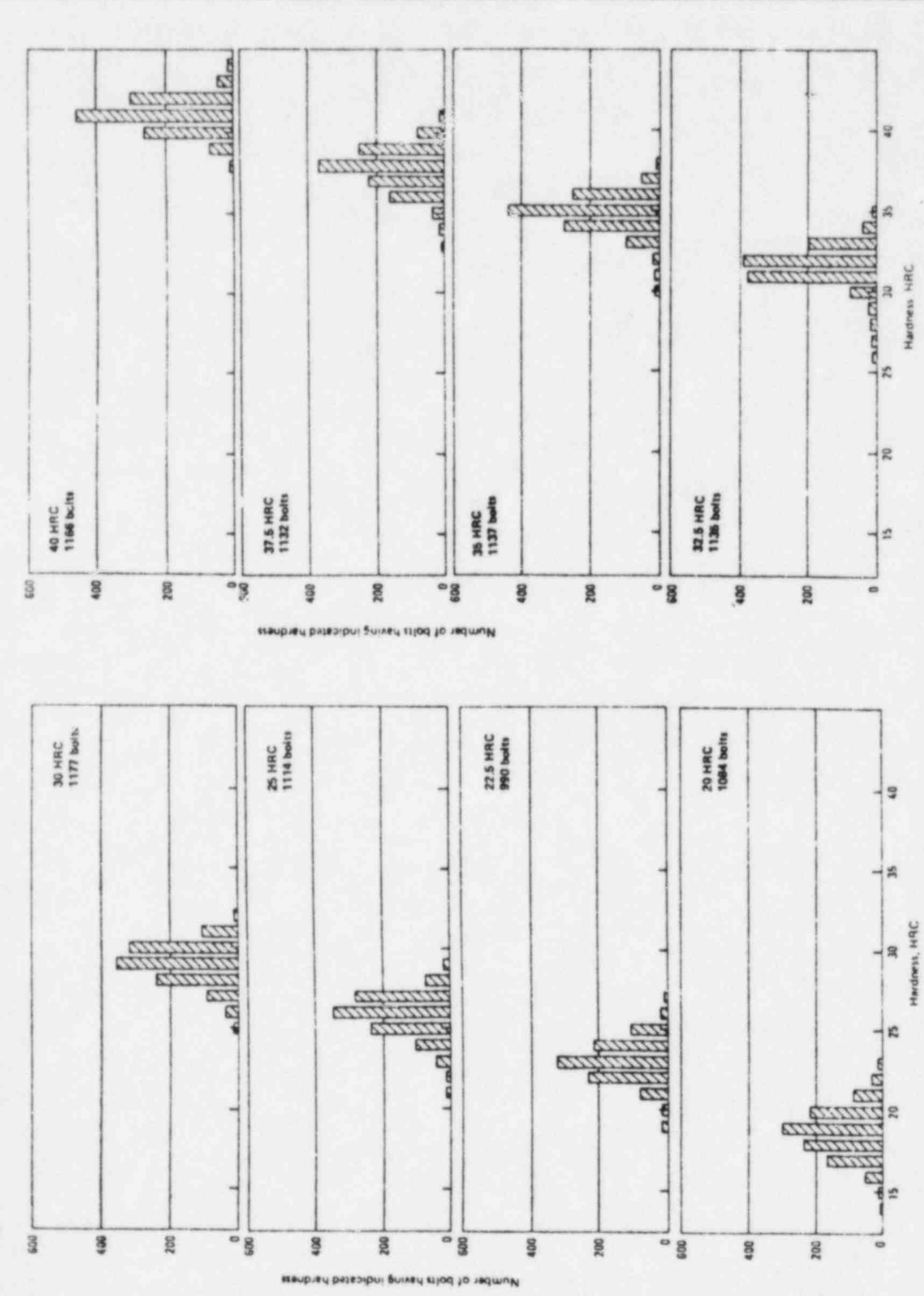
K_{IC}, K_{ISCC} LOWER BOUND CURVES FOR QUENCHED AND TEMPERED LOW ALLOY STEELS

FIGURE 1

-1

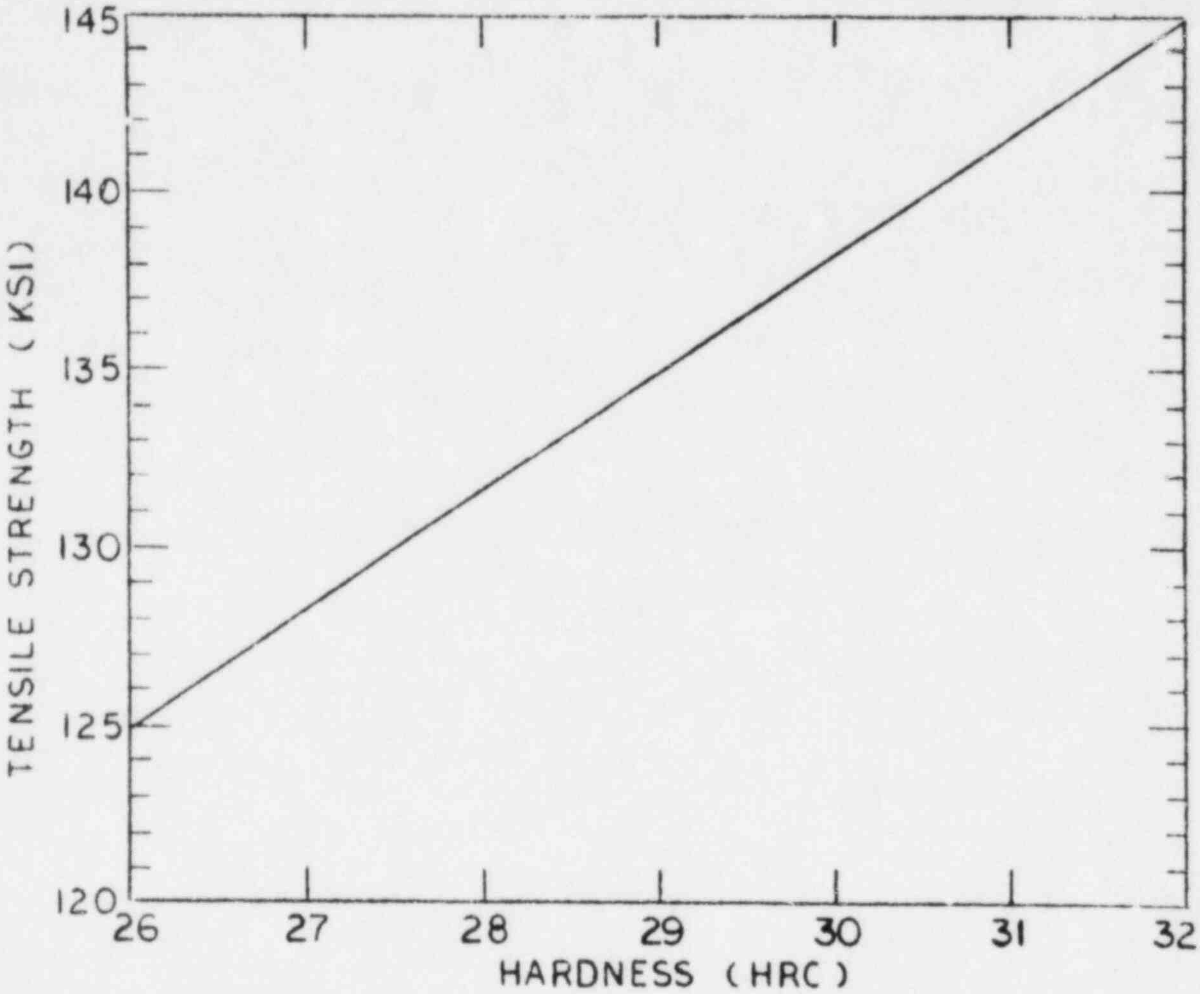
-1 -1

Fig. 9 Hardness distributions for eight lots of 1038 steel bolts



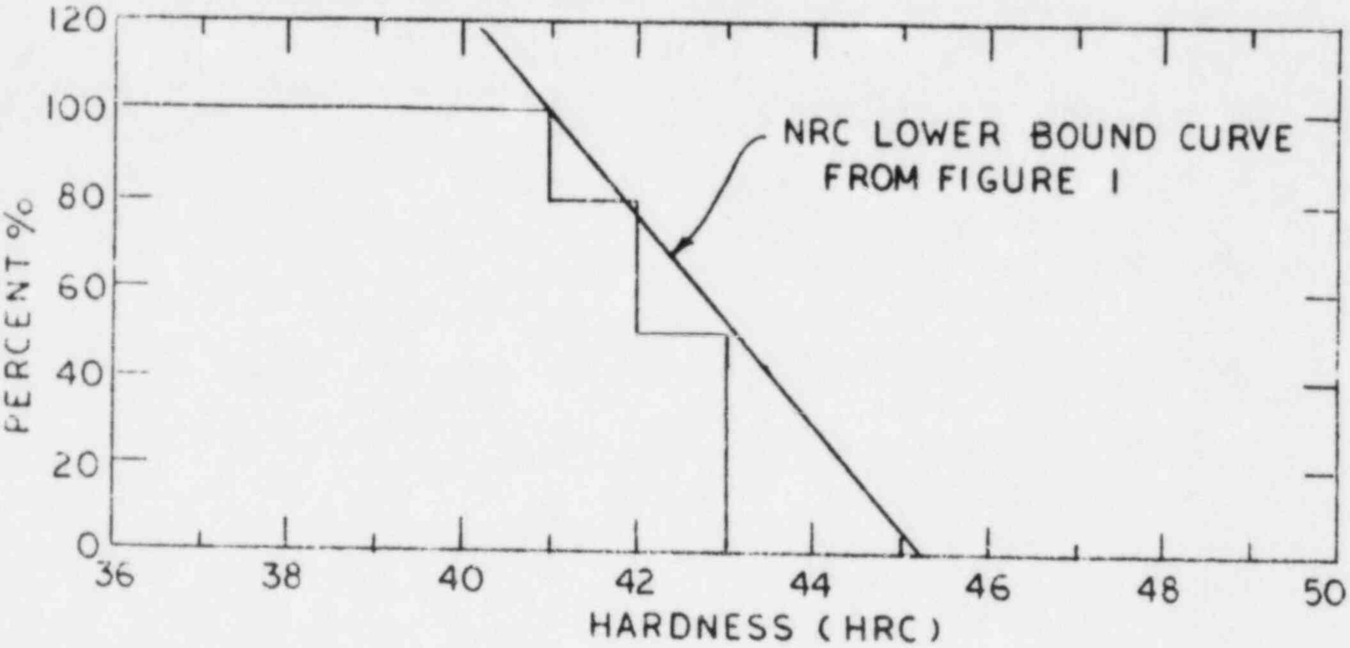
Bolts, ½ in. in diameter, were all made from one heat of steel. The bolts were heat treated in one plant to eight different levels of nominal hardness. Tests were made in the originating plant and in seven other laboratories.

FIGURE 2
From Reference (6)



TENSILE STRENGTH AS A FUNCTION OF HARDNESS FOR QUENCHED AND TEMPERED STEELS (8)

FIGURE 3

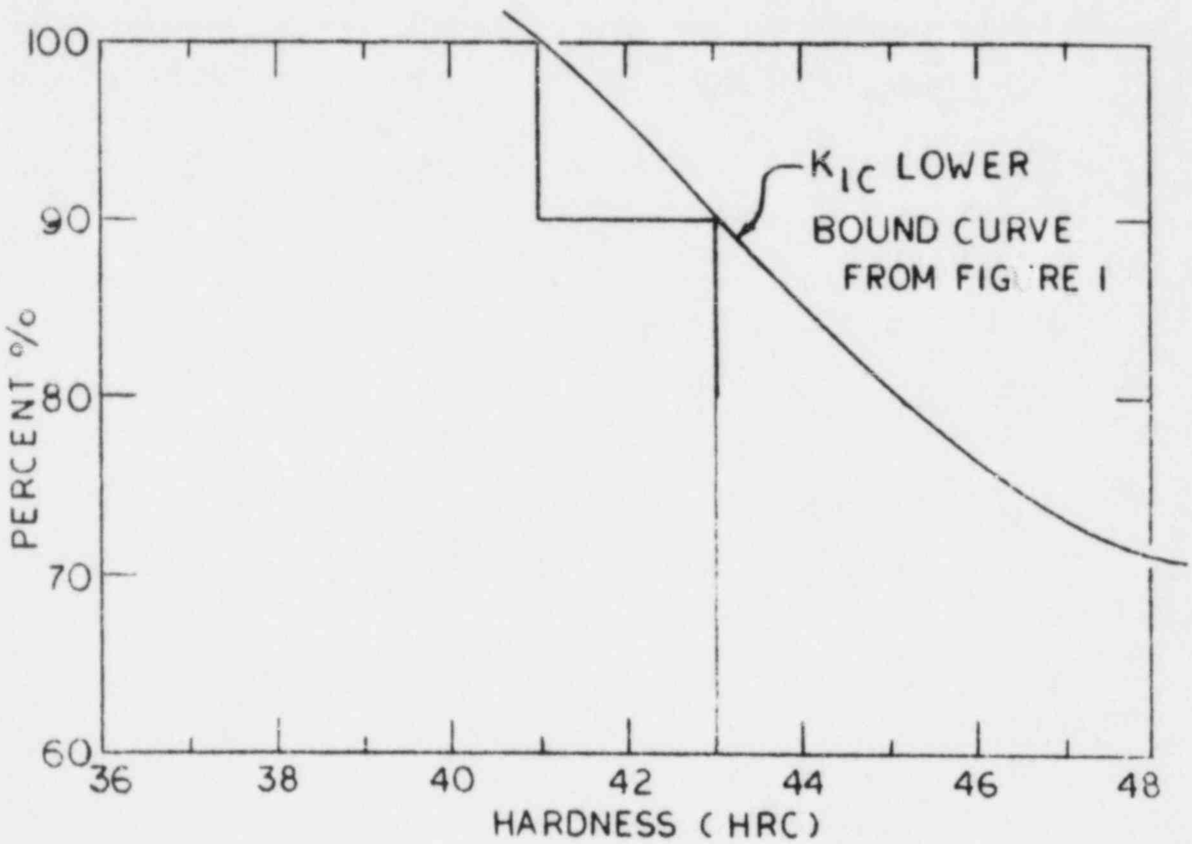


ALLOWABLE LONG-TERM LOADS IN TERMS OF PERCENT OF ACCEPTABLE -1

LOAD AT HRC 41 BASED ON NRC LOWER BOUND TO

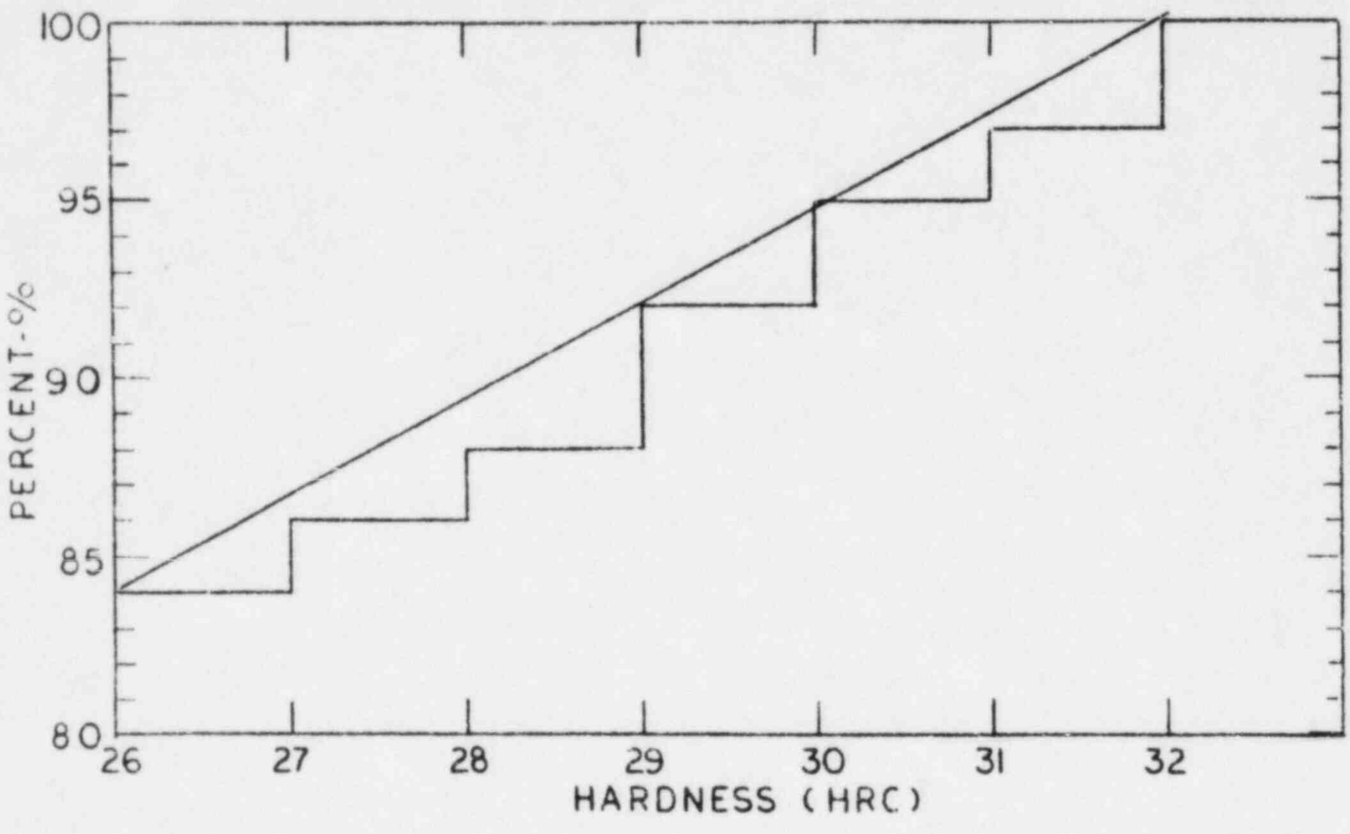
K_{ISCC} VS HARDNESS (FIGURE 1)

FIGURE 4



ALLOWABLE SHORT-TERM LOADS IN PERCENT OF ACCEPTABLE LOAD AT HRC 41 BASED ON K_{IC} DATA -1

FIGURE 5



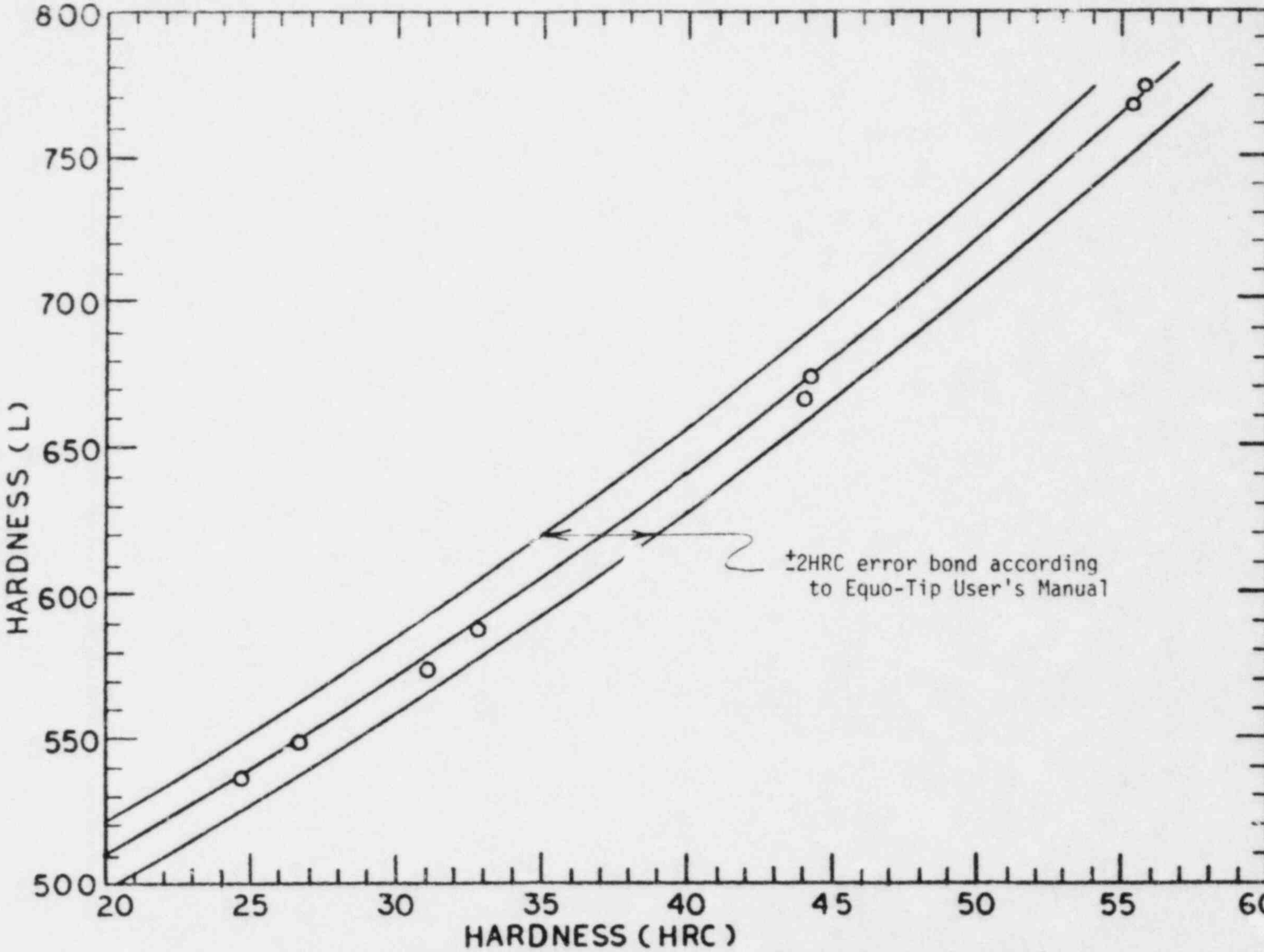
ALLOWABLE LOADS IN TERMS OF PERCENT OF ACCEPTABLE LOAD AT HRC-32 BASED ON STRENGTH REDUCTION AT REDUCED HARDNESS

FIGURE 6

TELEDYNE
ENGINEERING SERVICES

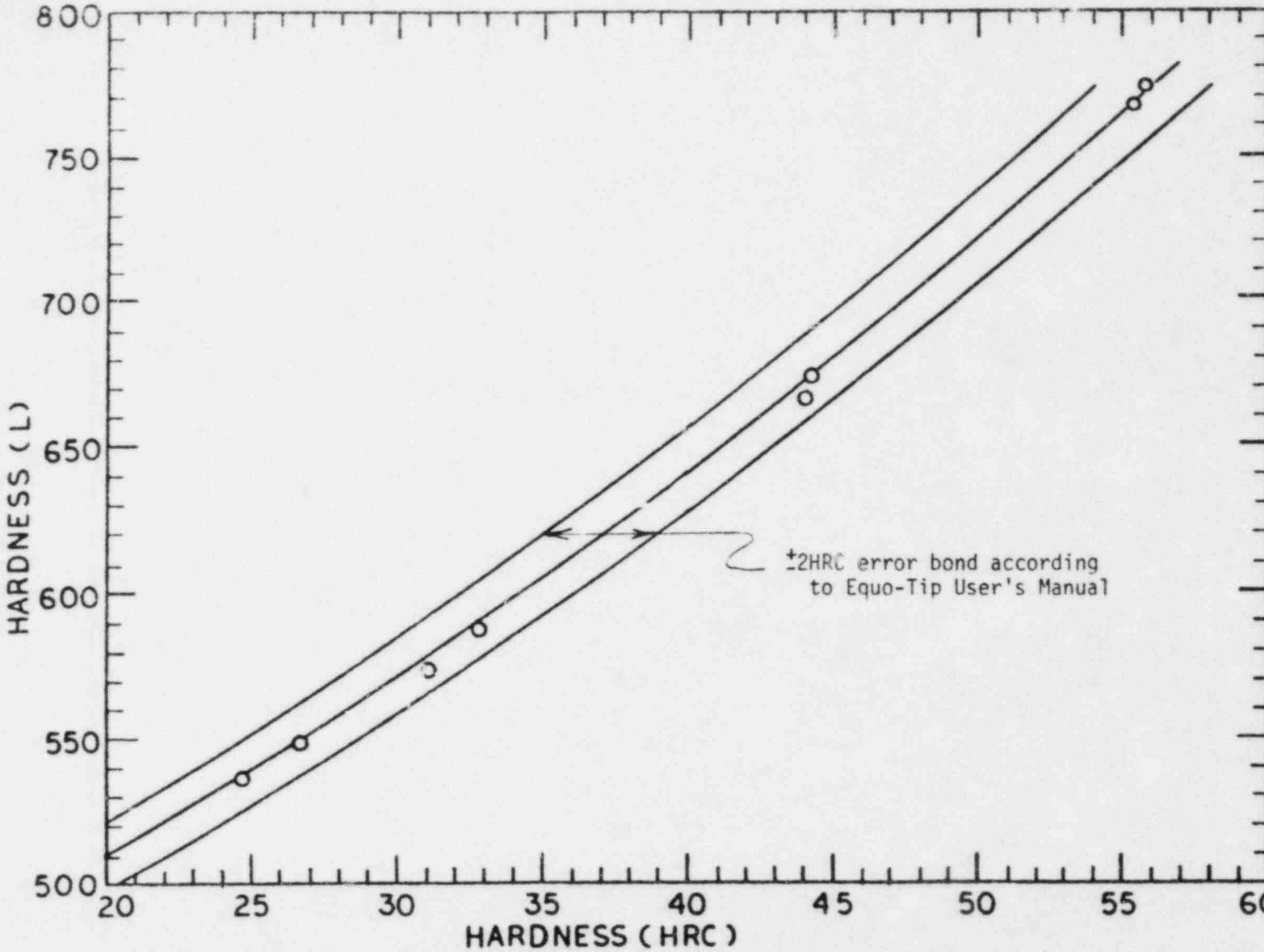
Technical Report
TR-5534-1, Revision 1

APPENDIX I



CALIBRATION CURVE - EQUO-TIP HARDNESS TESTER

O Hardness tests performed on Rockwell Calibration Blocks



CALIBRATION CURVE - EQUO-TIP HARDNESS TESTER

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DEFICIENCY EVALUATION REPORT NO. 81-14

A Review of Arizona Nuclear Power Project Bolting Failures

S. H. Bush
F. A. Simonen

September 1982

Prepared for
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Norwalk, California 90650
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FIGURES

TABLES

A REVIEW OF ARIZONA NUCLEAR POWER PROJECT BOLTING FAILURES

BECHTEL POWER CORPORATION

S. H. Bush

F. A. Simonen

EXECUTIVE SUMMARY

We have reviewed the data pertaining to Arizona Nuclear Power Project (ANPP) Bolting, including failures in the context of Teledyne Engineering Service reports on bolting failures at the Midland Nuclear Plant and conclude that the Teledyne Midland studies of failures at higher pretension stresses/hardness levels are no more than marginally applicable to ANPP. In the range of hardness of concern to ANPP, namely RC 40 to 41 and greater, the acceptability criteria for bolting are believed to be optimistic. Delayed stress corrosion failures of bolting having hardness values RC >40 would not be surprising if exposed to certain environments.

We have received the Teledyne Engineering Services report relevant to ANPP, "Acceptability for Service of Low Alloy, Quenched and Tempered Support Studs and Bolts." We consider it an excellent report and believe that some of the suggestions included are worth implementing. We find their criteria for controlled decreases in stress limits for bolting in the hardness range, RC 42 to 43 acceptable if accompanied by case-by-case evaluation of the specific installations of bolting in this hardness range. It is our understanding that Bechtel has decided to remove bolting of hardness greater than RC 41. In our opinion, this decision essentially resolves the bolting problem and eliminates the need for case-by-case analysis.

While stress corrosion failures may occur over an extended time period, the safety significance of such bolting failures in the locations and installations within ANPP are considered to be minimal even under accident conditions.

A walk-through of the plant performed as part of Battelle's study confirmed the virtual absence of long term loads except for torque levels on bolting; we understand these will be maintained at minimal levels. Most critical assemblies are required to sustain loads only in the remote instance of major pipe failure.

A sequential sampling program to check hardness levels is suggested for future batches of bolting to minimize the possibility of installing unacceptable bolting.

THE PROBLEM

During 1981, four ASTM A 354 Grade BD anchor bolts purchased for the ANPP failed during installation. Examination of three of the bolts revealed that the three tested bolts exceeded ASTM A 354 Grade BD hardness and tensile limits, e.g., RC ~50. Hardness testing of similar anchor bolts in the uninstalled and installed condition revealed that a substantial percentage of the bolts fell outside ASTM permissible limits on both the high and the low side of the acceptable hardness range. ASTM A 354 Grade BD in sizes 1/4 to 2-1/2 inches requires the following properties.

Hardness	311-352 BHN or 33-38 Rockwell C
Tensile (machined)	150,000 psi min.
Yield	130,000 psi min.
Percent Elongation	14% min.
R.A.	40% min.

The bolts were fabricated by several sources, and the percentage of unacceptable bolts varied markedly with source as noted in Figure 1. These data represent an extensive but not complete sampling.

Extensive testing of installed bolting in Units 1, 2, 3 revealed that 5 to 8 percent were below minimum hardness values and 13 to 15 percent were above maximum hardness values. A majority of the out-of-standard bolting were 1 to 2 points Rockwell C too high or too low. Figure 2 illustrates both the total percentage of bolts just outside ASTM hardness limits and the percentage of bolts at various levels of out-of-tolerance. The L values cited in Figure 2 are direct readings from the Equotip hardness tester.

The problem, therefore, is the acceptability criteria of some bolting marginally outside the specified hardness range. Basically the following ground rules are considered to be appropriate.

- Everything meeting ASTM A 354 Grade BD is acceptable.
- Hardness values above RC 41 generally are unacceptable; however, they are subject to case-by-case analysis.

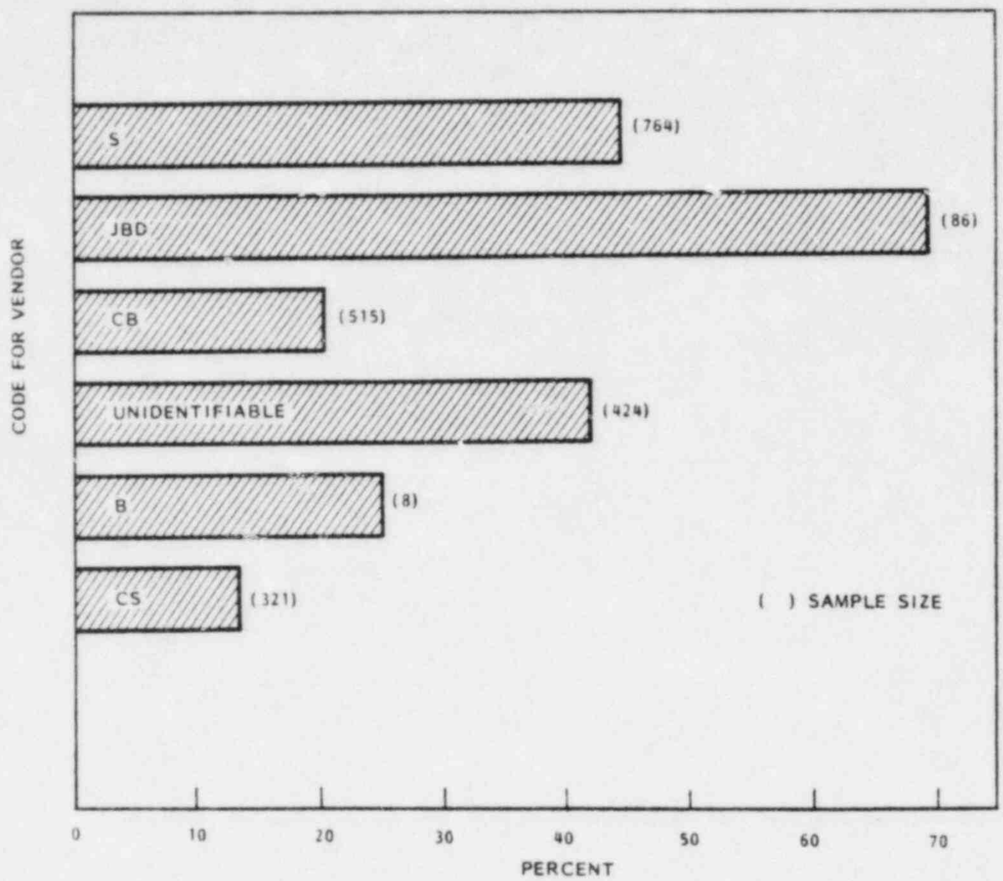

FIGURE 1. Bolting Not Meeting ASTM Standards A 354 Grade BD by Vendor. Population 2118 (441 repeat in containment 3 analysis).

- Hardness values of RC 39 to 41 are conditionally acceptable; however, they need further assessment; 1 to 3 percent of the installed bolting appears to fall in this range.
- Hardness and strengths below some value (e.g., RC $\leq$31) are unacceptable or require down rating of allowable loads.

Our examination has concentrated on the material exceeding the upper level ASTM values (RC >38). We reviewed the projected inservice performance in the context of previous Teledyne studies relevant to the Midland nuclear plants as well as in the context of susceptibility to stress corrosion as functions of

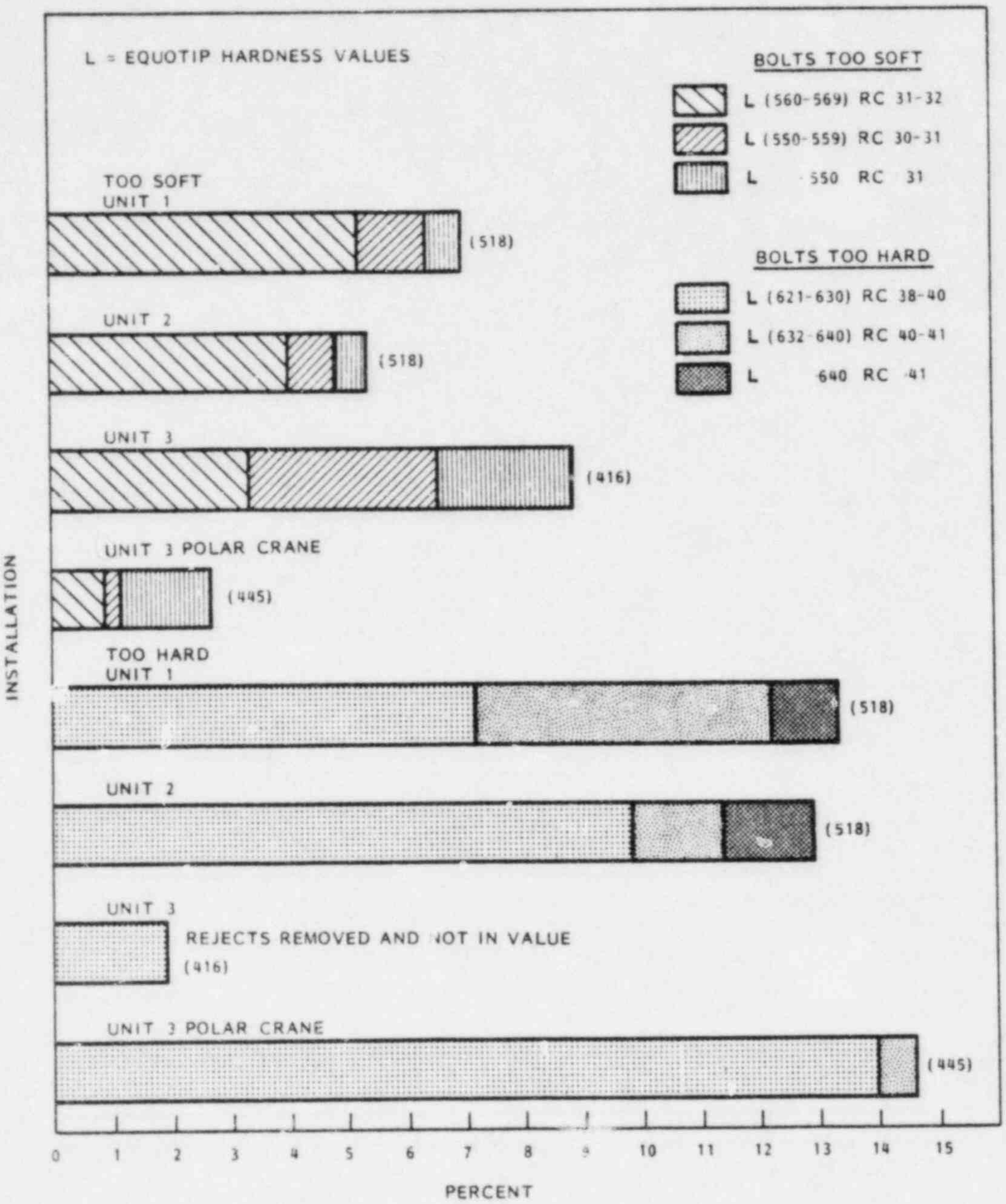

FIGURE 2. Comparison of Installed Bolting Not Meeting ASTM A 354 Grade BD Hardness Standards

hardness, strength, loading and environment for quenched and tempered AISI 4140 and 4340 steels which typically are the composition used for ASTM A 354 Grade BD bolting in the sizes of interest.

We have considered acceptability in the context of the safety and economic consequences of such failures for the specific installations of concern, recognizing the percentage of bolting having both high tensile and low tensile properties and the overall load bearing capabilities of the typical bolting layouts.

THE MIDLAND PROBLEM

Three failures occurred in ASTM A 354 Grade BD studs, 2.5 inches ϕ during 1979 and 1980 at the Midland Nuclear Project. These studs were embedded vertically in concrete to bolt the reactor pressure vessel skirt to the floor. All failures were attributed to stress corrosion cracking resulting from the very high hardness, RC 46 to 48, of these studs.

Two Teledyne documents (TR-3887-1 Rev. 1, TR-3887-1 Addendum 1)[1,2] dealt with the examination of the failed bolts plus an assessment of the hardness of the other studs. A third report (TR-3887-2 Rev. 1), titled "Acceptability for Service of Midland RPV Anchor Studs"[3] provided a justification that some studs could continue in use based on available information, including an assessment of the relevant literature on stress corrosion cracking. We will critically analyze the Teledyne document and references specific to stress corrosion to establish their relevance to the ANPP bolting problem.

The Midland Unit 1 studs were found to be of very high hardness (RC 46 to 48). Since our discussions with Bechtel personnel indicates that there appears to be no intent to accept material of this hardness at ANPP, the conclusions in the Teledyne report on Unit 1 are irrelevant.

In Midland Unit 2, the RPV studs were generally within hardness specifications, with only a few of hardness RC 38 to 41. The situation in fact was very similar to that at ANPP. Teledyne presents data to show that a few bolts in a large sample will typically be in this hardness range. The lot of bolts nevertheless could have been accepted as meeting ASTM specifications. The available data and fracture mechanics calculations indicate that RC = 41 is a marginal situation relative to IGSCC. Our position is that one can accept a small fraction of potential failures of a single bolt in a multiple bolt installation. The alternative at ANPP is removal and repair of the installation. Since concrete failure usually limits the strength of such installations, the integrity of a reworked installation must be considered since one may actually gain little and possibly lose strength in replacing an installation.

Generally, we feel that the Teledyne report TR-3887-2 Rev. 1, "Acceptability for Service of Midland RPV Anchor Studs,"(3) May 20, 1980, tends to be somewhat optimistic with regard to 200,000 psi ultimate (uts) being an acceptable dividing line for failure by stress corrosion cracking.

TELEDYNE REPORT ON ANPP

We have reviewed the Teledyne Engineering Services report, "Acceptability for Service of Low Alloy, Quenched and Tempered Support Studs and Bolts." Generally, it is an excellent report. We find some of the positions advanced in the report acceptable; however, we disagree with others. Acceptable items are:

- conditional acceptance of low hardness bolting
- surface hardness measured with the Equotip reads on the high side so a reported RC 41 is essentially in compliance with ASTM A 354 Grade BD when measured on the bolt radius
- the short-term/long-term load approach
- the K_{ISCC} design curve.

Values of RC $\leq$41 pose no problems. In lieu of breaking concrete, we believe case-by-case analysis is appropriate, particularly where derating one or two bolts in a mount which exceed RC 41 by a few points is an option. For higher hardness values we disagree with the Teledyne acceptance criteria, other than taking no credit for given bolts in a systems analysis. In the above context we do not accept the "trend curve factor" cited in their report because it does not handle residual stresses and stress concentrations present in bolting. In this respect, only partial credit can be taken for reductions in long-term preload because an adverse residual stress pattern may continue to exist.

One basic lack in the Teledyne report is failure to address the specific functions of the bolting in question such as multiple bolts in each installation, probability of short-term loads, absence of long-term loads other than bolting torque. We touch on some of these items later in the report by comparing their and our approach.

THE ANPP PROBLEM AND SAFETY IMPLICATIONS

Appendix A of Teledyne's report TR-3887-2 Rev. 1, "Acceptability for Service of Midland RPV Anchor Studs"[3] uses as its source the chapter by Clive S. Carter for the as yet unpublished ARPA Handbook on Stress Corrosion Cracking and Corrosion Fatigue entitled, "Stress Corrosion Cracking and Corrosion Fatigue of Medium-Strength and High-Strength Steels."[5]

An examination of the same document by us illustrates how two groups approaching a collection of data from somewhat different view points can differ in their conclusions. For example, a metallurgist working in the field of stress corrosion approaches a problem from a different perspective than that of an engineering mechanics expert. The following Table 1 abstracts portions of Carter's chapter deemed specifically relevant to bolting materials from ASTM A 354 Grade BD (e.g., AISI 4140 and 4340).

As can be seen from the emphasis given in Table 1, we feel that selection of 200 ksi as an ultimate tensile strength cutoff for bolting is somewhat high. A value nearer 180 ksi should be substantially less susceptible to cracking of bolting, particularly where trace contaminants in the concrete or other environmental factors may play a critical role.

One proviso may be applied to make the higher strength (to 200 ksi uts) bolting conditionally acceptable for specific installations such as at ANPP. Based on hardness distributions such as those in Figure 2, the hardness values of specific interest are RC <31, RC = 40 to 41, RC >41. The very soft and the very hard bolts represent 1 to 2 percent each of the installed bolting. On the

TABLE 1. General Comments Relevant to High-Strength, Low Alloy Steels Such as AISI 4140 and 4340

- Smooth specimens in high purity water have critical hardness/strength thresholds ~RC 42 (~185 ksi σ_y, ~200 to 220 σ_u).
- Sharp notches (K_t = 10) reduce critical level to 170 to 180 ksi σ_u in the same environment.
- Precracked specimens further reduce threshold to ~140 ksi σ_u (threshold load stress 10 to 20% uts) above in aerated distilled water.
- Contaminants such as chlorides reduce time to failure markedly.
- pH is an important factor; acid (low pH) enhances SCC; basic (high pH) reduces SCC.
- Coatings such as zinc may markedly increase susceptibility as well as reducing critical stress threshold.
- Increases in applied stress >SCC rate.
- There can be lengthy incubation periods depending on alloy content and microstructure.
- Preload prior to exposure to SCC environment may $>K_{ISCC}$.
- Exposure to SCC environment prior to preload may $<K_{ISCC}$.
- Operations such as grinding, if not controlled, may form untempered martensite leading to cracking and SCC.

System Failures

- Wires of 4140, etc., when drawn have failed in concrete; contaminants such as chlorides (from $CaCl_2$ to increase setting), sulfides, sulfates, etc., increase or initiate such failures.
- Galvanized bolting with values as low as RC 38 (150 ksi uts) have failed in culvert structures. Overtorquing contributed to these failures.
- Bolting of high-strength alloy steel (170 to 185 ksi uts) have failed in bridge structures due to SCC.

Control of the following factors helps minimize SCC; lack of control may result in SCC.

- Minimize regions of high stress with appropriate design.
- Minimize the buildup or presence of high residual stresses.
- Prevent formation of untempered martensite by controlling machining or grinding operations.
- If possible, shot peen to form compressive surface stresses
- Control and minimize trace contaminants that accelerate SCC.
- Minimize overstress on torquing.

basis of the overdesign factors in component attachments, one can conclude that the isolated failure of one bolt in an attachment consisting of six or more bolts will have little or no safety consequence. Because of the statistical nature of SCC we would anticipate a fairly large spread in failure times. In the case of ANPP, the hardness's of installed bolting have been recorded and it is possible to determine all locations where one or more bolts fall into the three cited categories of hardness outside ASTM standards; namely, low strength (RC <31), very high strength and susceptible to SCC (RC >41), and high strength (RC 39 to 40), but less susceptible to SCC.

A review of hardness values of the installed bolting at ANPP reveals a non-random distribution, indicating bolts from a given vendor were removed as a batch for installation. The biasing is evident in two major aspects. On a random basis one would expect no more than two bolts out of tolerance in most mounts, and the numbers of bolts high and low out of tolerance should be distributed. Neither is true as can be seen in Figure 3. There are too many mounts with four, five and six bolts exceeding the standards; furthermore, when this occurs, they are biased toward all high or all low from the standard, rather than a mixture of high and low. The statistical probability of such mixes from a random universe is extremely low.

Of possible safety significance is the bias apparent in the very low or very high hardness bolts in a given mount. Those cases characterized by one or two asterisks in Figure 3 represent marginal or unacceptable installations in our estimation.

Speidel[6] at the Firminy Conference reviewed available data on industrial failures and correlated these failures with yield strength. Figure 4 presents his comparisons, indicating a threshold for service failures of bolts as about 160 ksi yield strength for quenched and tempered alloys. These values are comparable to those of Okada[7] at the same conference who cited delayed failures of 4140 bolting in sea air and sea water both coated (Zn, Cd) and uncoated. Bolts with 185 to 190 ksi UTS were found to fail within 1 to 2 years in some instances, depending on environment and preload.

We believe there is some probability of further cracking of the higher hardness bolts, particularly if there are environmental factors such as trace

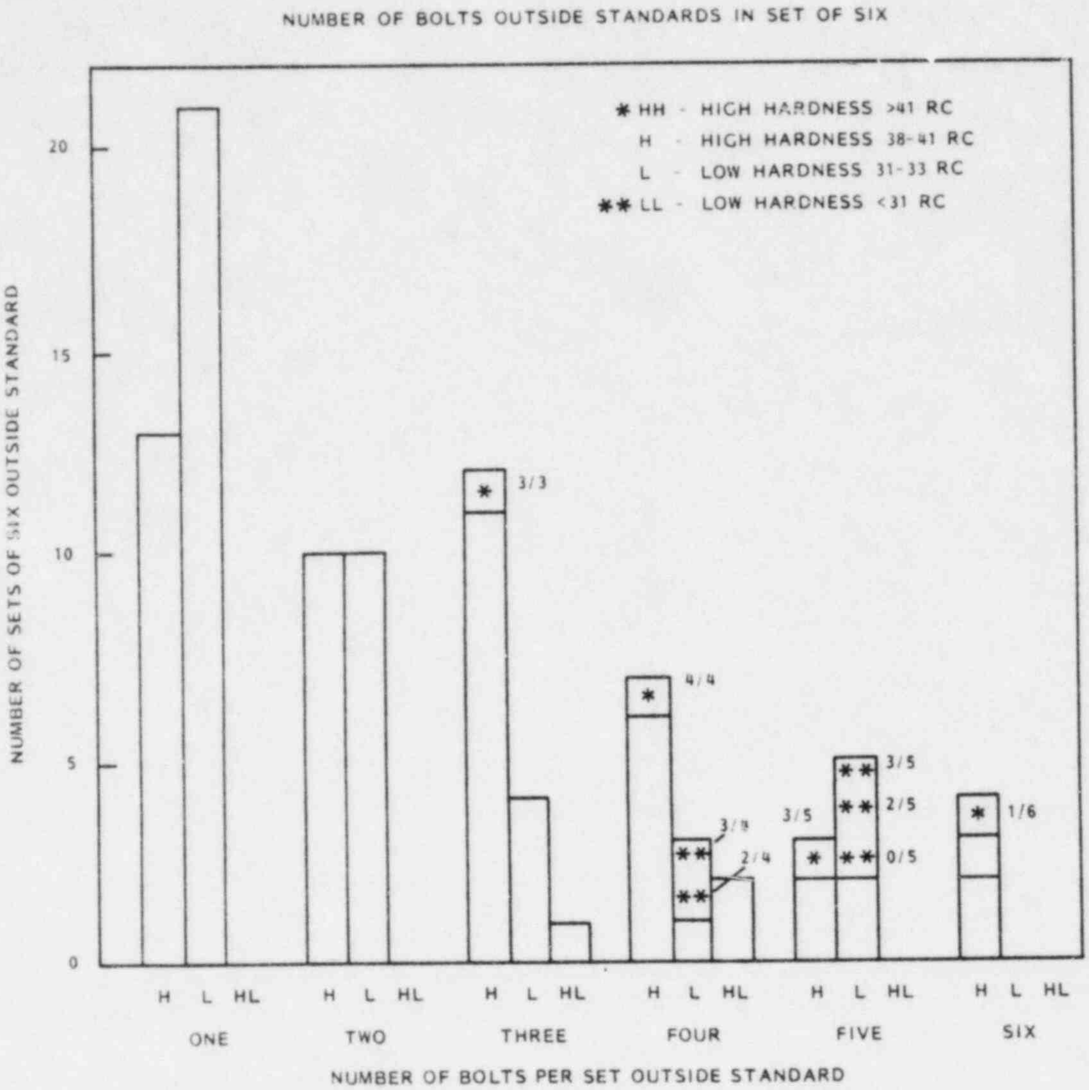

FIGURE 3. Status of Installed Bolting in ANPP Units 1, 2, 3. Six bolts per mount.

contaminants present in the concrete. Nevertheless, we conclude that an individual failure in a multiple bolt installation should have limited safety significance even under faulted conditions.

Finally, it is necessary to place certain classes of failures in perspective. With piping systems bolting is used to attach hangers, snubbers, supports, etc. Under some classes of faulted loads such as severe water hammer,

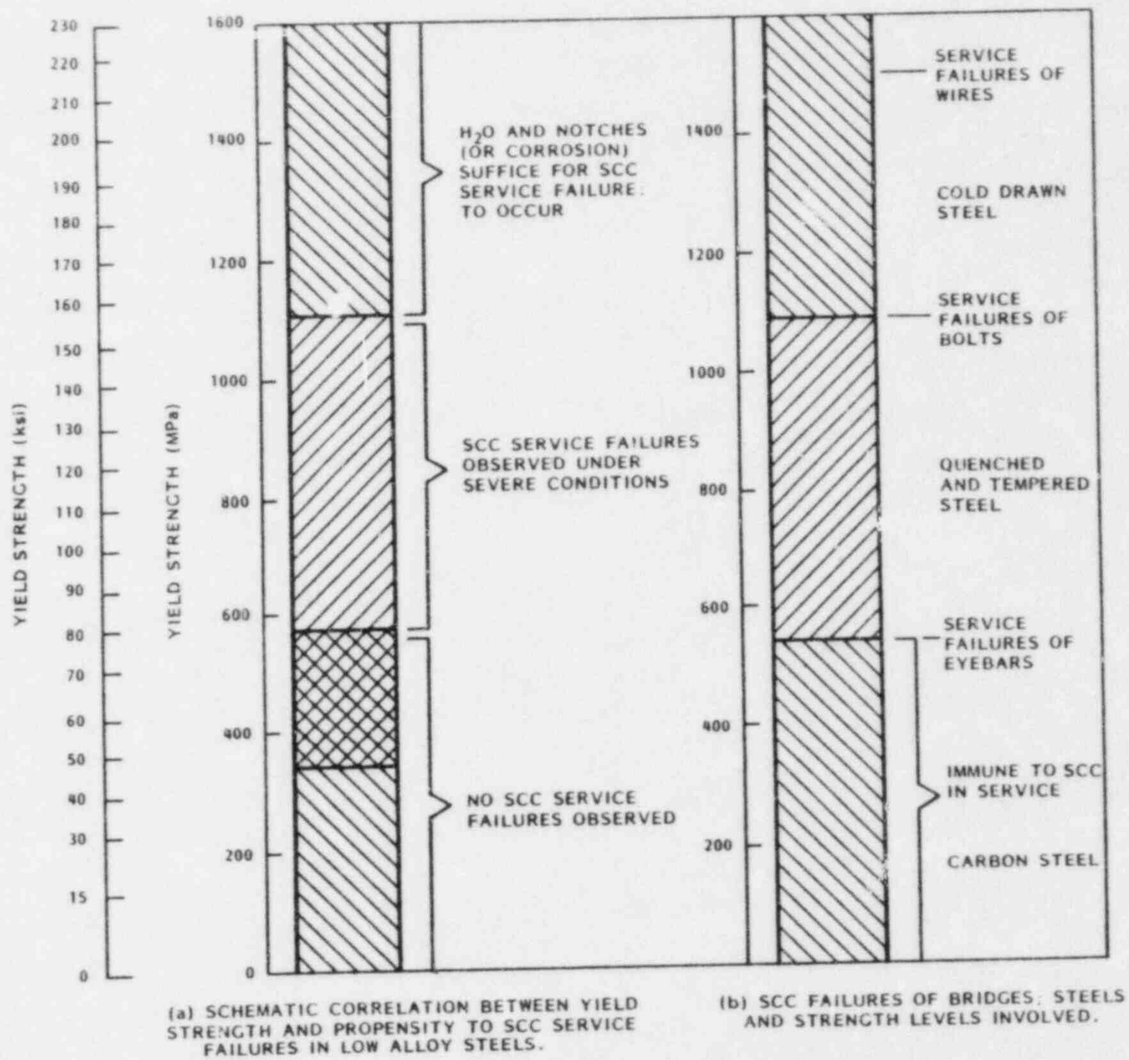

FIGURE 4. Examples of Stress Corrosion Cracking Failures as Function of (a) Yield Strength and (b) Environment Typical of ANPP (from Speidel).

all piping supports on sections of piping exceeding 100 feet in length in at least two nuclear plants, possibly more, have been pulled from the wall without failing the piping. Therefore, one must consider the significance of anchor bolt cracking, both individual bolt failures, and of collective failures in the context of safety implications.

RESIDUAL STRESS

The Midland study does not consider residual stresses and their impact on bolt failure by IGSCC. In the report dated October 2, 1981, on the ANPP bolt failures, the residual stresses were said to be tension at the outer surface. However, no specific data or supporting evidence were presented. If required, such residual stresses could readily be measured on samples of ANPP bolting at commercial laboratories with X-ray diffraction equipment. Based on specific questions it was established that no such residual stress measurements have been made.

An attempt was made to locate relevant residual stress data on quenched and tempered 4140 steels. Extensive data on residual stresses are given in the Handbook of Experimental Stress Analysis,[8] although none of the data are really quite relevant to the present problem. Bars of other steels in the 1-1/2 inch diameter range exhibit compressive OD stresses after heat treatment. However, the mechanism of residual stress formation is a result of competing factors, namely, thermal contraction during quench and a volume expansion due to phase change. In high carbon and highly alloyed steels, the transformation stresses are said to dominate and produce OD tension.

One data point for 4130 steel was cited which showed a 50 ksi tensile OD residual stress. However, the product was oil quenched aircraft tubing (0.034 inch wall) and the results cannot be applied to the bolting problem. It is expected that an additional literature search would locate similar data for solid bar configurations.

Data given in the Handbook[8] show the effect of tempering temperature on reducing quench induced residual stresses. In a high carbon steel (0.50 percent) the longitudinal stress was about 70 ksi without tempering. At the nominal tempering temperature of about 900°F for the ANPP bolting, the OD residual stress was reduced to about 30 ksi.

We recognize the problems inherent in locating applicable residual stress data as well as the difficulties in obtaining such data experimentally. Sensitivity studies where various residual stress levels are assumed could be of value in situations where two or more high hardness bolts are located in the same mount and analysis is preferred to breaking concrete. Since residual stresses become a critical input at high hardnesses, e.g., RC >45 not at RC 41, such studies would be of value only at these higher hardnesses.

FLAW SENSITIVITY CALCULATIONS

Some fracture mechanics calculations were performed to gain insight into the effect of hardness on potential for stress corrosion cracking of bolting. In these calculations high stresses were assumed to exist at the root of the thread profile, both from pretension and as residual stresses. Accordingly, the calculations considered the threshold for growth of small IGSCC flaws into a stress field at the yield strength of the bolting material. The yield strength and value of threshold K_{IGSCC} were taken as a function of hardness from plots in the Teledyne/Midland report.

Two limiting initial flaw shapes were considered, namely, a long surface flaw and a half-penny surface flaw. Stress intensity factors are given by:

$$K = 1.12\ \sigma_y \sqrt{\pi a}, \text{ long flaw}$$

$$K = 0.7\ \sigma_y \sqrt{\pi a}, \text{ half-penny flaw}$$

For the lower bound K_{ISCC} values of the Teledyne report, the following critical flaw depths were estimated.

Hardness RC	Lower Bound K_{ISCC} ksi $\sqrt{\text{inch}}$	σ_y ksi	Critical Depth, inch: Long Flaw	Critical Depth, inch: Half-Penny Flaw
36	43	150	0.021	0.054
38	38	160	0.014	0.036
40	31	165	0.009	0.023
42	22	175	0.004	0.010
44	14	185	0.0015	0.004
46	9	200	0.0005	0.001
48	8	215	0.0003	0.001

Studies of the behavior of small flaws indicates that reasonable estimates of inherent material defect sizes are in the range of 0.010 inch and less. The implication is that one must assume that flaws of this size are always present, due for example to inclusion content, surface finish, etc. On this basis, a critical flaw size of 0.010 inch corresponds to a critical hardness range of RC 40 to 42. The conclusion is that under worst case conditions (high local stresses and lower bound threshold K_{ISCC}), bolting material of RC 40 to 42 has essentially no tolerance for very small flaws. Under these conditions a very small initial crack or initiated crack will tend to grow. This hardness range seems consistent with service experience cited above which showed failures in the presence of notches and H_2O environment.

EXAMINATION OF INSTALLED BOLTING DURING SITE VISIT

On May 4 the ANPP site was visited to examine the installations containing bolting in question. There were some surprising features not apparent from the various reports. Some of these features are cited as "bullet" items with further expansion.

- In excess of 75 percent of the bolting under question is installed but is not expected to be used. This was done in anticipation of pipe whip restraints in many more locations than will actually be used. Therefore, failures of any of these bolts are of no consequence.
- The major use of the remaining bolting is to attach pipe whip restraints to the wall adjacent to the pipes in question. Again, these are never load bearing except in the remote case of a major pipe break, either double-ended or axial split. We observed such installations on shutdown cooling lines, blowdown lines, and the safety injection system. These restraints may also go on steam lines and feedwater lines, or if not, certainly another type of restraint will be employed.
- The third, and quite limited application, is in attaching vertical columns to adjacent walls. Apparently the bolting is loaded when the columns are subjected to overturning moments. The primary loads on the columns are compressive when used as floor braces. In other applications there is an elaborate trusswork built up to protect against pipe whip in steam lines. In this instance the bolting appears to provide some load bearing function in the event of a pipe break.
- The fourth and distinctly different bolt application is to hold down segments of the polar crane track support structure. Segments of the beam structure rest on large embedded brackets with braces between segment and containment wall. Vertical bolts provide a hold down function. The bolts are there to handle vertical uplift and

horizontal overturning forces in the event of a seismic event and to retain the beam segments in their specific locations. Uplift forces are not expected to be large.

Based on the lack of information concerning properties of the hold down bolts on the Unit 1 and 2 polar cranes, we suggest that a sequential sampling threshold be applied to measure the hardness of installed bolts. Typically, a 6 percent sample should detect statistical outliers. If none exist, no further sampling would be required. The interest would be in bolts above RC 41 in hardness. If outliers exist, the sample size should be increased.

It is of interest that most bolts, where installations exist, bear loads only during D or faulted conditions. This means they need not be torqued beyond nominal values capable of retaining bolt (and nut) in place. Since stress corrosion is a time, stress, environment phenomenon, dropping stress levels on higher strength bolts should virtually eliminate failur in the range RC 40 to 42.

One final item was not checked out. The Equotip hardness tester determines Rockwell C by inference. The correlation used by Bechtel may be conservative in that it is about 1σ higher than the "official" correlation curve. This corresponds to about 2 points Rockwell C. The Bechtel curves would predict RC 41 while the "official" would be RC 39. Thus the number of bolts in the critical high hardness range may be substantially less than reported here.

CONDITIONAL ACCEPTANCE CRITERIA

We have developed our accept/reject criteria for bolting throughout this report. In this section the various criteria are pulled together to permit an assessment of the various factors. In addition, the similar factors cited in the Teledyne ANPP report[4] are included to permit a comparison. These criteria are presented in a tabular format (Table 2) to simplify the comparison.

TABLE 2. A Comparison of Conditional Acceptance Criteria Contained in This Report and TES TR-5534-1

Factor	BNW Position	TES Position
Bolting hardness is below standard levels	We agree with TES than an acceptable approach is to derate on basis of assumed tensile strength.	
Bolting hardness is above standard levels		
RC 39 to 41	We and TES both accept for continued service.	
RC >41	Generally unacceptable; however, we find selective derating of each installation acceptable, providing the remaining bolts have acceptable hardness levels. Some credit possible in range RC 42 to 44, none above RC 45 for individual bolts.	Conditionally acceptable as bases of selective derating of loads to RC-43.
Correction factor for "high" reading of Equotip	If validated, we feel credit should be taken; e.g., RC 41 may become RC 39 to 40.	TES cites and accepts.
Reduce torque loads for long-term to reduce IGSCC	We agree with TES that this is a viable approach; however, we have reservations concerning full credit because of residual stresses and stress concentration factors.	

TABLE 2. (continued)

Factor	BNW Position	TES Position
Systems approach to acceptance/rejection/derating	We suggest a step-by-step approach considering each installation rather than individual bolts as noted in Figure 3. • Correct Equotip values to lower RC. • Assess installations noted in Figure 3. Give various weighting factors to those with 1, 2, 3, 4, 5, 6 bolts exceeding standards. • Derate bolts in low hardness range using TES criterion. • Consider partial derating of bolts with corrected RC values in range of 39 to 41. • Derate all bolts with corrected RC values >41 to zero stress in most instances. Consider partial credit on case-by-case basis. Zero credit if RC >45. • Use weighting factors to evaluate each questionable installation, providing the installation is to be used. • Limit repair to those installations to be used and only if their derated installation capacity is below the anticipated faulted (D) load.	None advanced by TES.

QUALITY ASSURANCE

It is unfortunate that bolting (or similar items) usually are determined to be out of specification during installation when failures occur rather than when received. In some instances detection may be delayed until failures occur during operation. In either case there may be a large number of bolts installed, and these bolts may be relatively inaccessible and replaceable only with great difficulty. This is expensive in time and plant outage. It also points up weaknesses in the quality assurance organization.

A possibility to minimize future incidents at ANPP and other construction sites would be to use a statistical sampling scheme. A sequential sampling with a 6 percent sample should be sufficient to detect obvious cases of out-of-spec material such as exist at ANPP.

A simple device such as the Equotip tester could test 10-20 bolts in a few minutes without special preparation. If bolt hardness values were acceptable, the batch could be accepted. If not acceptable, further analyses could be made to provide cheap insurance against the situation that presently exists at ANPP. A quality assurance or quality control organization could handle such testing.

REFERENCES

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3. Teledyne Engineering Services. 1980. Acceptability for Service of Midland RPV Anchor Studs. TR-3887-2, Rev. 1, Teledyne Engineering Services, Waltham, Massachusetts.

4. Teledyne Engineering Services. September 1982. Acceptability for Service of Low Alloy, Quenched and Tempered Support Studs and Bolts. TR-5534-1, Teledyne Engineering Services, Waltham, Massachusetts.

5. Carter, C. S. "Stress-Corrosion Cracking and Corrosion Fatigue of Medium-Strength and High-Strength Steels." ARPA Handbook. Boeing Company Airplane Company, Seattle, Washington.

6. Speidel, M. O. and P. M. Fourt. 1973. "Stress Corrosion Cracking and Hydrogen Embrittlement in Industrial Circumstances--Session Evaluation." Stress Corrosion Cracking and Hydrogen Embrittlement of Iron Base Alloys. Unieux-Firminy, France.

7. Okada, H. 1973. "Stress Corrosion Cracking and Hydrogen Cracking of Structural Steels." Stress Corrosion Cracking and Hydrogen Embrittlement of Iron Base Alloys. Unieux-Firminy, France.

8. Hetenyi, M. 1950. Handbook of Experimental Stress Analysis. John Wiley and Sons, Inc., New York, New York.

APPENDIX D

The purpose of appendix D is to provide permanent record of the extensive EQUOTIP hardness measurements taken for all containment building ASTM A354 Grade BD embedded studs. (See figures D-1 through D-19.)

Figures D-1 through D-18 are diagrams which uniquely identify and label all embeds shown on the Engineering Design Drawings which utilize ASTM A354 Grade BD studs. There are 312 embed assemblies, containing a total of 2044 studs, in each unit. Of these, 61 embeds (434 studs) are utilized for pipe whip restraints (PWR) and jet impingement barriers (JIB).

Figure D-19 is a means of locating an embed of a particular identification number: it directs the user to the appropriate figure D-1 through D-18 upon which that embed number is shown.

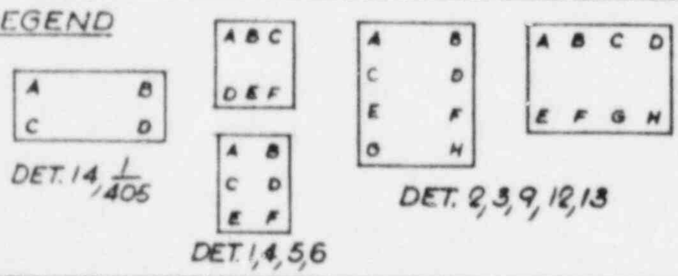
Pages D-2 through D-34 tabulate the EQUOTIP L-value for every embedded stud. They also identify which studs are utilized for PWR's and JIB's and which studs are inaccessible for hardness testing.

This appendix, used in conjunction with the acceptance criteria established in the Engineering Evaluation of Nonconforming ASTM A354 Grade BD Studs and Bolts, provides the user with information required to determine embed capacities for design.

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
1	2	1	598	597	597	576	594	601	583	592	USED FOR P.W.R. No. 904
		2	601	618	607	601	617	618	622	598	
		3									
2	2	1	607	613	599	602	590	616	612	607	USED FOR P.W.R. No 903
		2	578	586	611	622	609	606	628	621	
		3									
3	1	1	592	588	587	587	593	598			USED FOR P.W.R. No. 902
		2	567	590	590	582	596	601			
		3									
4	1	1	585	591	592	578	558	581			USED FOR P.W.R. No. 901
		2	581	590	584	567	574	592			
		3									
5	2	1	566	578	566	582	583	570	579	570	
		2	616	610	609	607	619	592	594	625	
		3									
6	2	1	568	570	568	585	579	578	570	569	
		2	627	600	623	636	612	584	604	550	
		3									
7	9	1	617	621	613	607	611	615	608	611	USED FOR P.W.R. No. 842
		2	618	611	604	611	607	614	610	611	
		3									
8	7	1	588	564	580	594	544	587	561	551	USED FOR P.W.R. No. 842
		2	618	611	605	618	605	614	610	622	
		3									
9	2	1	571	611	588	583	580	601	*	*	USED FOR P.W.R. No. 843
		2	600	608	612	608	608	622	622	603	
		3									
10	3	1	594	621	620	623	611	601	610	621	
		2	614	595	596	610	601	600	611	615	
		3									

LEGEND

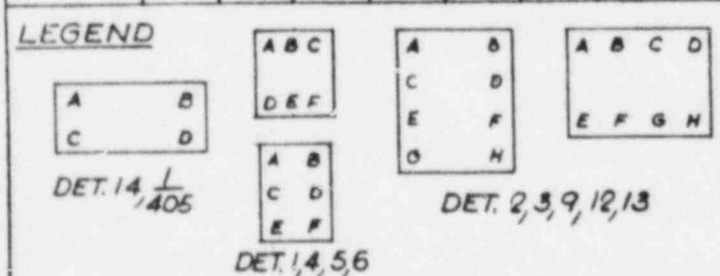


* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	A	B	C	D	E	F	G	H	REMARKS
11	6	1	597	613	557	566	578	610			USED FOR P.W.R. No. 803
		2	601	591	624	606	598	600			
		3									
12	6	1	624	607	616	630	617	600			USED FOR P.W.R. No. 803
		2	705	596	599	704	704	710			
		3									
13	6	1	600	609	612	551	612	615			USED FOR P.W.R. No. 802
		2	717	596	708	700	585	608			
		3									
14	6	1	607	610	617	567	588	557			USED FOR PWR No. 802
		2	609	612	606	603	603	600			
		3									
15	6	1	634	608	613	594	593	610			USED FOR P.W.R. No. 805
		2	590	582	606	580	590	585			
		3									
16	6	1	624	613	597	612	628	620			USED FOR P.W.R. No. 805
		2	610	602	609	605	620	601			
		3									
17	6	1	607	602	597	617	551	599			USED FOR P.W.R. No. 804
		2	599	623	617	616	592	617			
		3									
18	6	1	623	621	604	511	615	624			USED FOR P.W.R. No. 804
		2	587	609	591	610	600	593			
		3									
19	2	1	606	588	588	594	591	607	588	590	USED FOR P.W.R. No 806
		2	638	585	576	604	603	583	594	596	
		3									
20	2	1	631	623	595	603	625	594	630	576	USED FOR P.W.R. No 806
		2	597	602	613	612	601	615	617	588	
		3									

LEGEND



* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	A	B	C	D	E	F	G	H	REMARKS
21	9	1	608	615	606	614	608	616	633	614	USED FOR
		2	619	604	612	588	606	597	609	608	P.W.R. No. 807
		3									
22	9	1	601	613	595	613	605	609	599	601	USED FOR
		2	[illegible]	614	600	605	606	602	590	607	P.W.R. No. 807
		3									
23	9	1	567	575	563	600	573	586	572	575	USED FOR
		2	609	613	621	623	611	621	608	613	P.W.R. No. 808
		3									
24	9	1	621	607	601	608	612	607	607	599	USED FOR
		2	620	606	608	614	618	607	618	613	P.W.R. No. 808
		3									
25	2	1	592	598	604	582	608	574	605	572	USED FOR
		2	623	605	613	605	623	608	627	612	P.W.R. No. 809
		3	594	606	618	605	626	611	615	613	
26	2	1	582	571	586	594	599	573	595	607	USED FOR
		2	599	602	590	589	615	613	603	595	P.W.R. No. 809
		3	617	585	622	626	622	601	629	624	
27	6	1	594	607	630	586	588	605			USED FOR
		2	627	608	613	618	619	634			P.W.R. No. 921
		3	602	610	622	589	616	626			
28	3	1	588	583	611	575	612	595	597	616	
		2	611	589	602	623	617	613	612	595	
		3	602	611	609	615	615	610	619	609	
29	3	1	610	600	605	603	614	610	615	611	
		2	620	618	617	610	610	619	624	633	
		3	618	598	606	597	596	608	615	613	
30		1									
		2									
		3									

LEGEND

A B
C D

DET. 14, 1/405

A B C
D E F

A B
C D
E F

DET. 1,4,5,6

A B
C D
E F
G H

A B C D
E F G H

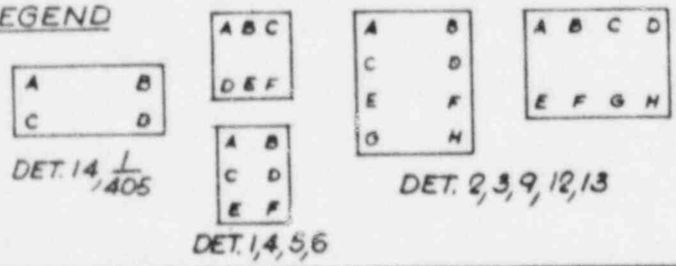
DET. 2,3,9,12,13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
31	6	1	604	615	590	617	600	608			USED FOR P.W.R. No. 822
		2	595	601	536	602	613	604			
		3	596	594	591	584	584	598			
32	6	1	601	619	616	592	618	602			USED FOR P.W.R. No. 822
		2	608	598	598	599	595	617			
		3	584	586	600	593	586	581			
33	6	1	578	562	598	594	599	607			USED FOR P.W.R. No. 823
		2	616	606	614	607	620	614			
		3	602	578	594	596	583	587			
34	6	1	614	612	616	593	618	614			USED FOR P.W.R. No. 823
		2	567	605	613	614	607	613			
		3	594	603	603	426	589	593			
35	5	1	618	610	600	614	616	609			USED FOR P.W.R. No. 821
		2	590	581	593	581	542	608			
		3	598	598	608	594	593	387			
36	5	1	616	613	631	597	614	615			USED FOR P.W.R. No. 821
		2	616	614	610	610	615	605			
		3	595	493	585	473	586	436			
37	4	1	589	592	586	606	599	591			
		2	583	582	583	590	580	591			
		3									
38	4	1	610	618	620	606	609	611			
		2	586	593	596	583	583	587			
		3									
39	4	1	594	585	583	595	604	601			
		2	558	576	[illegible]	588	581	578			
		3									
40	4	1	637	638	629	589	579	597			
		2	576	583	585	595	582	587			
		3									

LEGEND



DET. 14 1/405

DET. 1,4,5,6

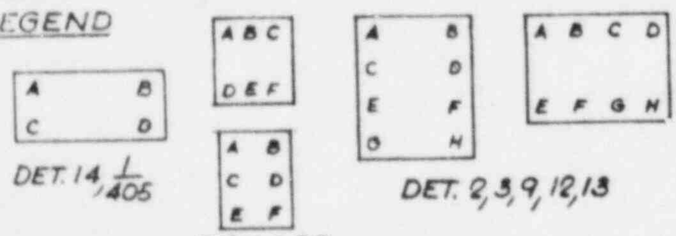
DET. 2,3,9,12,13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
41	4	1	581	574	582	590	584	596			USED FOR P.W.R. No. 867
		2	576	566	575	586	571	586			
		3									
42	4	1	626	636	626	603	601	607			USED FOR P.W.R. No. 867
		2	574	594	590	615	593	599			
		3									
43	4	1	596	593	584	590	597	602			USED FOR P.W.R. No. 868
		2	578	574	581	585	590	572			
		3									
44	4	1	631	637	601	600	603	634			USED FOR P.W.R. No. 868
		2	583	566	567	586	588	586			
		3									
45	4	1	581	590	584	594	594	574			
		2	574	599	603	597	590	612			
		3									
46	4	1	604	604	604	623	623	619			
		2	594	586	595	580	515	591			
		3									
47	4	1	596	593	584	603	608	600			
		2	579	580	578	573	568	574			
		3									
48	4	1	625	624	631	620	619	618			
		2	598	595	587	594	589	593			
		3									
49	4	1	603	610	591	603	606	602			
		2	578	584	578	588	605	597			
		3									
50	4	1	620	624	608	617	602	607			
		2	608	611	601	596	578	585			
		3									

LEGEND



DET. 14, 1/405

DET. 1,4,5,6

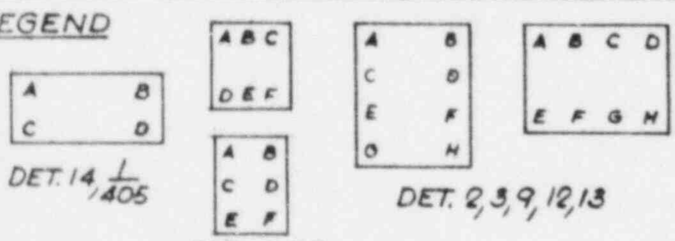
DET. 2,3,9,12,13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
51	4	1	585	590	573	595	585	590			
		2	570	584	578	568	580	579			
		3									
52	4	1	619	628	624	607	615	619			
		2	590	587	565	607	597	607			
		3									
53	4	1	591	584	596	596	593	607			
		2	576	576	574	573	584	570			
		3									
54	4	1	638	632	644	590	585	584			
		2	608	597	596	594	586	591			
		3									
55	4	1	596	594	597	592	594	601			USED FOR P.W.R. No. 872
		2	599	604	601	598	598	594			
		3									
56	4	1	601	586	595	591	594	583			USED FOR P.W.R. No. 872
		2	595	594	603	586	579	590			
		3									
57	4	1	578	594	595	584	599	585			
		2	595	606	587	596	593	581			
		3									
58	4	1	590	603	600	587	588	588			
		2	600	594	600	560	565	571			
		3									
59	4	1	594	607	602	591	590	587			
		2	585	569	587	592	570	560			
		3									
60	4	1	586	587	592	583	595	580			
		2	567	602	596	603	599	607			
		3									

LEGEND



DET. 14, 1/405

DET. 1,4,5,6

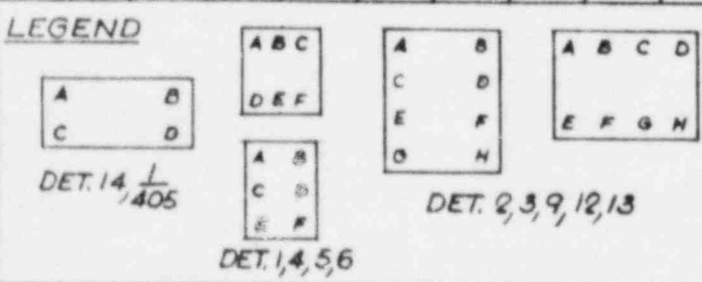
DET. 2,3,9,12,13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
61	12	1	579	589	573	579	570	569	567	566	USED ON 13-C-ZCS-540
		2	619	634	634	614	626	621	629	624	
		3									
62	12	1	582	566	572	578	580	574	595	577	USED ON 13-C-ZCS-540
		2	622	627	633	613	623	628	625	619	
		3									
63	12	1	561	567	559	562	575	561	570	571	USED ON 13-C-ZCS-540
		2	630	617	625	605	628	611	628	639	
		3									
64	12	1	565	570	593	564	570	564	561	564	USED ON 13-C-ZCS-540
		2	625	622	603	617	602	588	621	602	
		3									
65	13	1	640	647	630	607	620	643	639	606	USED ON 13-C-ZCS-540
		2	580	572	572	577	561	585	584	583	
		3									
66	13	1	601	637	615	604	629	628	643	616	USED ON 13-C-ZCS-540
		2	582	585	581	586	573	579	576	561	
		3									
67	13	1	650	633	610	603	626	611	593	638	USED ON 13-C-ZCS-540
		2	576	560	575	574	581	559	591	597	
		3									
68	13	1	637	620	609	652	620	631	611	616	USED ON 13-C-ZCS-540
		2	571	600	562	547	568	580	598	585	
		3									
69	12	1	593	622	627	609	613	601	598	613	USED ON 13-C-ZCS-540
		2	629	623	622	627	612	628	598	624	
		3									
70	12	1	620	618	614	629	598	612	636	622	USED ON 13-C-ZCS-540
		2	625	613	647	619	623	628	596	613	
		3									

LEGEND

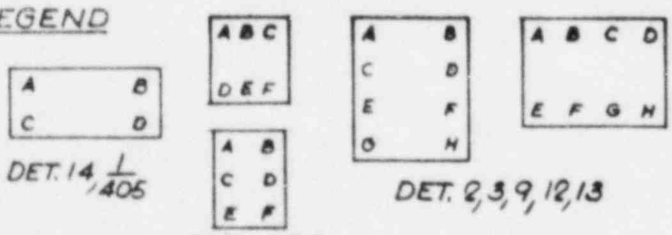


* DENOTES BOLTS INACCESSIBLE FOR TESTING-

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	A	B	C	D	E	F	G	H	REMARKS
71	12	1	606	605	606	629	626	636	635	604	USED ON 13-C-ZCS-540
		2	609	608	624	602	623	627	626	610	
		3									
72	12	1	636	636	629	605	636	596	640	622	USED ON 13-C-ZCS-540
		2	612	604	609	625	619	606	610	612	
		3									
73	13	1	591	587	594	582	563	583	584	575	USED ON 13-C-ZCS-540
		2	589	598	590	591	588	575	587	594	
		3									
74	13	1	586	582	598	590	572	578	584	591	USED ON 13-C-ZCS-540
		2	576	585	592	591	582	574	581	592	
		3									
75	13	1	580	566	598	576	589	594	585	571	USED ON 13-C-ZCS-540
		2	573	588	579	558	588	597	576	584	
		3									
76	13	1	572	579	564	588	580	580	586	597	USED ON 13-C-ZCS-540
		2	585	569	577	571	585	573	574	564	
		3									
77	6	1	574	642	640	635	562	630			
		2	618	609	592	608	497	606			
		3									
78	6	1	646	644	619	614	620	592			
		2	624	627	622	597	605	617			
		3									
79	6	1	612	629	625	633	632	574			
		2	581	587	605	596	599	611			
		3									
80	6	1	621	638	599	627	595	626			
		2	617	597	608	631	623	579			
		3	608	600	*615	604	586	600			

LEGEND



DET. 14 1/405

DET. 1,4,5,6

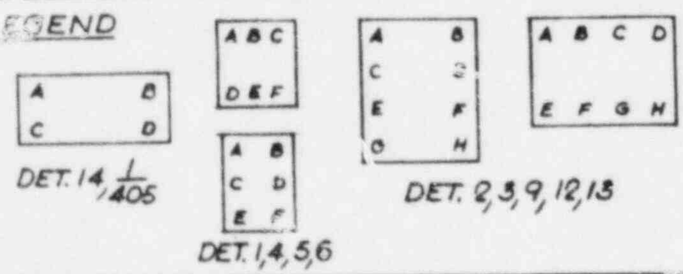
DET. 2,3,9,12,13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
81	6	1	612	623	637	626	636	637			
		2	593	604	611	590	611	605			
		3	711	613	608	601	609	656			
82	2	1	634	598	642	641	623	601	575	615	USED FOR J.I.B. No. 811
		2	629	610	641	634	645	645	639	638	
		3									
83	2	1	647	643	637	634	643	643	651	644	USED FOR J.I.B. No. 811
		2	630	653	621	647	658	634	655	650	
		3									
84	3	1	624	629	612	624	622	621	622	631	
		2	616	612	609	615	608	613	615	602	
		3									
85	3	1	616	623	620	610	618	623	625	617	
		2	619	611	598	614	605	596	608	608	
		3									
86	3	1	624	628	636	624	617	612	632	637	USED FOR P.W.R. No. 844
		2	625	615	615	620	618	621	619	615	
		3									
87	9	1	592	575	595	595	575	583	596	598	
		2	654	652	633	645	631	621	634	615	
		3									
88	9	1	617	610	622	615	620	615	610	599	
		2	637	655	641	648	652	664	643	641	
		3									
89	2	1	626	606	638	632	633	621	634	647	
		2	638	635	655	658	630	651	624	672	
		3									
90		1									
		2									
		3									

LEGEND



DET. 14, 1/405

DET. 1,4,5,6

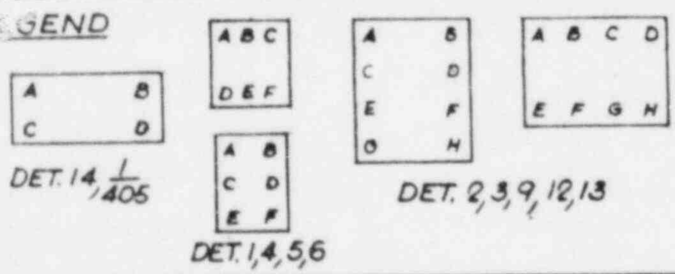
DET. 2,3,9,12,13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
91	1	1	610	604	605	601	624	593			
		2	596	586	621	595	635	588			
		3									
92	1	1	596	606	616	589	593	604			
		2	601	643	579	563	611	634			
		3									
93	1	1	612	610	616	610	606	587			
		2	625	621	623	615	613	637			
		3									
94	1	1	603	613	593	609	589	597			
		2	605	587	590	595	595	586			
		3									
95	1	1	586	590	597	600	608	601			
		2	630	613	597	651	638	617			
		3									
96	2	1	634	637	630	644	639	634	636	627	
		2	649	613	630	681	648	617	665	647	
		3									
97	2	1	637	640	646	638	650	658	637	643	
		2	595	608	605	603	634	610	614	631	
		3									
98	2	1	616	617	612	618	622	621	615	619	
		2	660	601	652	635	607	662	602	607	
		3									
99	1	1	592	586	597	568	608	571			
		2	620	596	606	620	620	627			
		3									
100	1	1	567	579	576	589	581	573			
		2	616	611	641	644	600	616			
		3									

LEGEND



DET. 14, 1/405

DET. 1,4,5,6

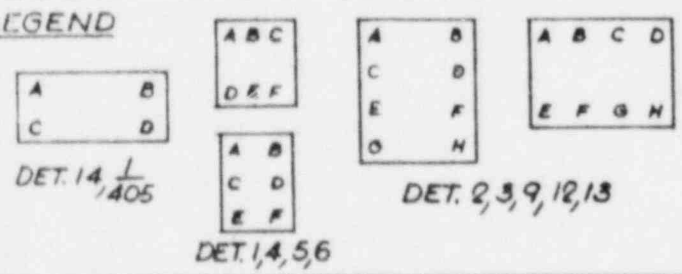
DET. 2,3,9,12,13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
101	1	1	606	603	602	597	601	5[illegible]3			
		2	592	645	536	578	574	569			
		3									
102	1	1	574	599	598	593	609	600			
		2	622	622	622	616	574	567			
		3									
103	1	1	571	596	574	570	590	576			
		2	607	622	652	627	600	621			
		3									
104	1	1	584	600	580	585	580	598			
		2	563	559	546	581	573	560			
		3									
105	1	1	594	617	611	607	598	601			
		2	596	625	618	623	618	632			
		3									
106	1	1	606	399	592	609	586	595			
		2	567	56[illegible]	603	630	560	578			
		3									
107	1	1	612	601	605	620	595	615			
		2	596	602	594	610	599	602			
		3									
108	1	1	606	587	621	612	613	598			
		2	608	579	606	602	594	590			
		3									
109	2	1	611	634	554	586	562	607	603	637	
		2	644	629	622	601	640	604	613	588	
		3									
110	6	1	641	641	65[illegible]	633	632	618			
		2	617	626	622	587	575	616			
		3	637	637	655	637	637	648			

LEGEND

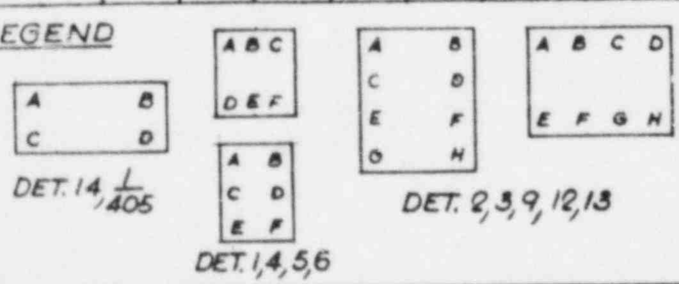


* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
111	6	1	618	629	627	622	614	621			
		2	638	649	629	625	629	633			
		3	628	619	636	627	619	627			
112	2	1	623	595	601	618	598	591	579	602	
		2	642	614	640	623	623	615	586	631	
		3	652	645	629	606	637	624	639	[illegible]	
113	2	1	616	634	606	597	601	626	608	598	USED FOR J.I.B. No. 812
		2	640	627	612	622	624	671	637	602	
		3	624	655	657	647	645	633	643	640	
114	2	1	589	634	619	605	623	607	587	586	
		2	642	626	631	632	635	627	637	628	
		3	625	626	656	626	609	629	632	621	
115	2	1	597	596	638	605	590	598	598	582	USED FOR J.I.B. No. 812
		2	626	641	651	642	644	636	633	646	
		3	636	622	619	616	620	627	618	625	
116	2	1	599	602	596	603	614	594	608	608	
		2	670	650	608	637	649	639	623	626	
		3									
117	6	1	612	536	615	615	625	615			
		2	627	625	651	627	631	629			
		3									
118	6	1	626	621	623	617	631	616			
		2	634	625	617	626	623	648			
		3									
119	6	1	631	628	623	633	629	626			
		2	623	652	630	634	623	649			
		3									
120	2	1	595	610	588	642	602	584	582	621	
		2	663	641	634	660	646	659	672	661	
		3									

LEGEND

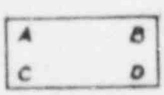


* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

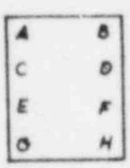
PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
121	1	1									
		2	601	620	608	609	601	622			
		3									
122	1	1									
		2	593	603	620	601	605	596			
		3									
123	1	1									
		2	613	607	618	631	621	614			
		3									
124	1	1									
		2	620	616	636	618	616	624			
		3									
125	1	1	599	568	568	574	597	594			
		2	601	595	590	600	610	592			
		3									
126	1	1	573	601	578	598	617	570			
		2	627	627	612	617	611	614			
		3	565	567	556	561	552	569			
127	1	1	565	563	571	596	569	568			
		2	644	628	619	629	630	620			
		3									
128	1	1	589	566	556	594	576	567			
		2	618	600	599	603	607	613			
		3									
129	2	1	618	622	629	604	624	621	606	592	
		2	626	615	616	605	604	606	[illegible]	621	
		3									
130	1	1	574	603	588	594	572	584			
		2	616	606	615	618	611	628			
		3									

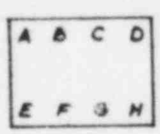
LEGEND



DET. 14, 1/405

DET. 1,4,5,6





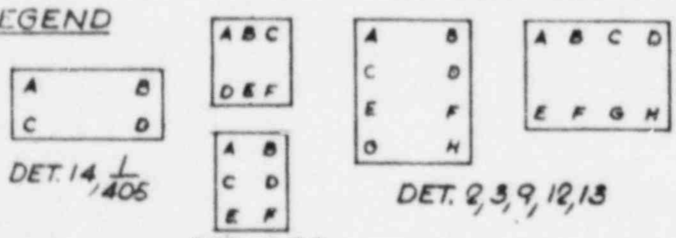
DET. 2,3,9,12,13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
131	1	1	603	600	586	604	611	579			
		2	618	636	637	599	600	599			
		3									
132	1	1	599	597	595	603	593	589			
		2	609	598	596	603	609	609			
		3									
133	1	1	598	598	605	594	592	589			
		2	619	623	612	608	621	616			
		3									
134	1	1	608	609	595	608	614	617			
		2	613	593	604	616	615	612			
		3									
135	1	1	623	583	606	593	602	601			
		2	617	614	606	609	614	607			
		3									
136	1	1	614	612	615	608	601	590			
		2	626	600	609	610	606	628			
		3									
137	1	1	601	595	592	600	604	610			
		2	614	600	645	591	614	623			
		3									
138	1	1	606	589	599	586	616	622			
		2	604	601	612	638	632	627			
		3									
139	1	1	602	604	615	601	604	613			
		2	615	609	595	620	620	614			
		3									
140	2	1	578	614	616	627	611	630	633	628	
		2	636	*	616	610	633	*	613	634	
		3									

LEGEND



DET. 14, 1/405

DET. 2, 3, 9, 12, 13

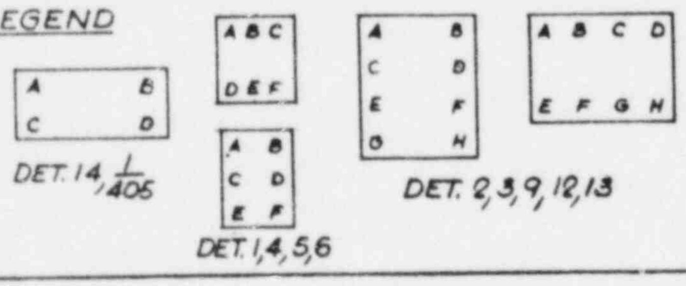
DET. 1, 4, 5, 6

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
141	2	1	608	641	630	645	651	579	629	611	
		2	659	617	630	625	594	626	641	632	
		3									
142	2	1	611	617	619	615	618	624	623	613	
		2	619	613	592	638	605	616	599	636	
		3									
143	1	1	583	598	564	559	574	568			
		2	610	612	602	619	580	603			
		3									
144	1	1	562	595	598	596	584	565			
		2	623	603	605	584	611	603			
		3									
145	1	1	578	607	575	570	579	574			
		2	597	616	594	612	604	598			
		3									
146	6	1	649	629	634	625	628	631			
		2	627	627	631	614	629	628			
		3									
147	6	1	611	656	609	614	616	607			
		2	608	627	623	633	615	626			
		3									
148	1	1	601	611	610	609	604	610			
		2	597	583	604	614	593	*			
		3									
149	6	1	618	*	*	633	619	610			
		2	637	643	635	631	636	636			
		3									
150	1	1	597	601	580	566	576	576			
		2	604	590	632	599	592	616			
		3									

LEGEND

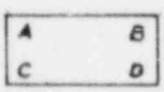


* DENOTES BOLTS INACCESSIBLE FOR TESTING -

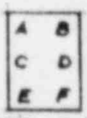
EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
151	1	1	568	589	592	591	593	570			
		2	601	612	607	596	597	600			
		3									
152	2	1	*	*	600	603	595	595	606	617	
		2	*	*	620	629	637	625	606	606	
		3									
153	1	1	594	[illegible]	571	560	569	568			
		2	599	603	605	591	596	614			
		3									
154	1	1	*	*	*	*	*	*			
		2	*	*	*	*	*	*			
		3	569	553	578	558	552	567			
155	6	1	630	646	630	637	643	630			
		2	615	620	624	631	629	634			
		3	597	633	634	629	620	633			
156	6	1	625	634	639	642	642	642			
		2	643	624	630	617	642	628			
		3	727	603	644	740	734	732			
157	6	1	628	625	627	637	630	622			
		2	623	622	632	609	636	624			
		3	591	629	617	618	621	606			
158	6	1	637	621	650	632	638	638			
		2	622	616	631	604	629	621			
		3	622	603	612	618	611	606			
159	6	1	[illegible]	648	632	641	628	636			
		2	*	625	638	*	631	631			
		3	589	590	611	580	595	581			
160	6	1	630	631	623	647	627	636			
		2	613	618	614	603	625	628			
		3	606	619	600	612	613	601			

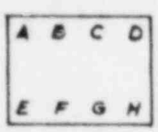
LEGEND



DET. 14 L/405



DET. 1,4,5,6



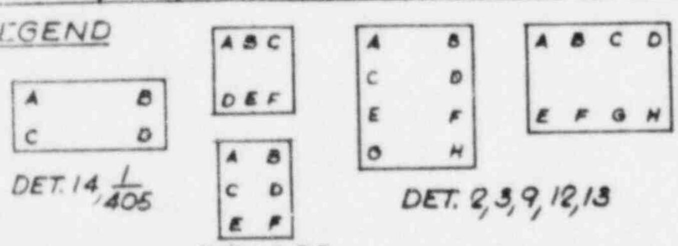
DET. 2,3,9,12,13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
161	1	1	595	568	596	589	562	575			
		2	734	584	750	578	752	584			
		3									
162	1	1	581	568	563	562	560	587			
		2	610	605	600	609	603	605			
		3									
163	6	1	*	629	614	649	635	630			
		2	608	605	621	614	613	634			
		3									
164	6	1	600	598	607	608	606	608			
		2	626	627	624	607	625	613			
		3									
165	6	1	628	621	621	623	623	619			
		2	616	609	602	611	608	600			
		3									
166	2	1	632	615	624	617	627	615	602	619	
		2	628	614	617	612	633	614	612	624	
		3									
167	2	1	604	572	579	603	598	584	623	581	
		2	620	621	612	616	618	620	619	607	
		3									
168	1	1	587	579	583	443	589	585			
		2	609	608	617	596	602	602			
		3									
169	1	1	602	577	597	593	599	589			
		2	593	582	617	607	608	571			
		3									
170	1	1	558	569	604	586	567	567			
		2	604	584	605	588	595	612			
		3									

LEGEND



DET. 1,4,5,6

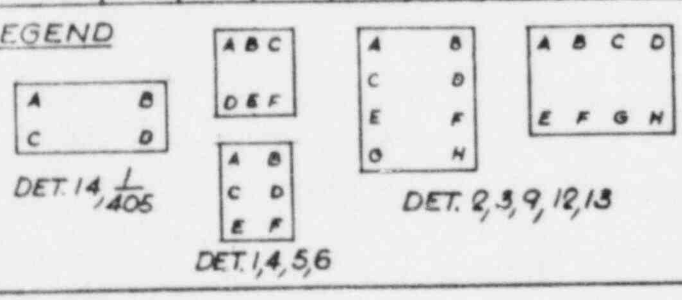
DET. 2,3,9,12,13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
171	4	1	572	593	605	590	597	586			
		2	611	614	602	608	602	600			
		3	601	610	586	600	600	590			
172	4	1	586	586	592	597	583	585			
		2	603	620	617	600	634	618			
		3	599	595	604	594	593	592			
173	1	1	*	*	*	*	*	*			
		2	*	*	*	*	*	*			
		3	615	612	623	612	628	620			
174	5	1	630	628	630	640	631	627			
		2	593	615	512	599	525	594			
		3	*	617	612	*	583	598			
175	5	1	625	620	622	626	625	624			
		2	647	631	625	639	635	662			
		3	*	564	621	*	495	565			
176	6	1	618	623	632	631	626	633			
		2	645	630	637	636	634	629			
		3	636	636	607	622	611	624			
177	6	1	611	592	627	621	626	617			
		2	626	644	633	617	645	629			
		3	642	653	636	650	620	626			
178	6	1	621	617	612	640	624	614			
		2	630	635	626	634	625	633			
		3	625	629	628	631	630	628			
179	6	1	605	622	609	626	597	622			
		2	636	649	632	616	615	622			
		3	632	638	604	618	635	603			
180	6	1	621	627	617	626	602	626			
		2	637	647	625	602	638	632			
		3	645	653	644	644	645	647			

LEGEND

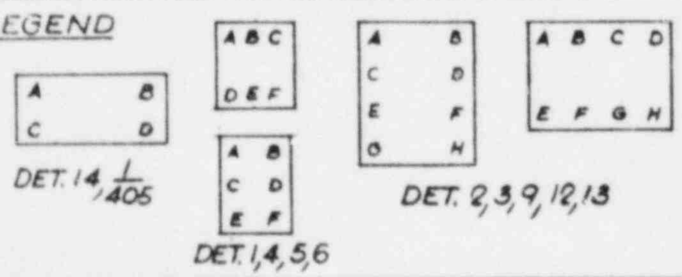


* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
181	6	1	616	613	634	625	620	630			
		2	625	651	636	630	622	623			
		3	624	605	617	619	617	615			
182	6	1	623	639	630	621	618	620			
		2	619	629	640	648	627	638			
		3	630	622	630	626	633	622			
183	6	1	635	621	620	579	635	600			
		2	619	624	630	627	621	615			
		3	628	633	619	602	611	620			
184	1	1	601	607	598	583	598	589			
		2	617	618	625	620	597	607			
		3									
185	1	1	597	614	[illegible]	[illegible]	602	601			
		2	612	615	620	616	619	608			
		3									
186	1	1	*	574	*	560	574	583			
		2	615	630	620	619	612	626			
		3									
187	1	1	580	577	606	581	591	565			
		2	613	610	602	610	597	601			
		3									
188	1	1	572	591	577	570	570	606			
		2	636	605	612	631	613	616			
		3									
189	1	1	600	613	581	612	571	581			
		2	628	629	612	612	610	616			
		3									
190	1	1	611	607	602	608	604	591			
		2	622	617	620	583	625	618			
		3									

LEGEND

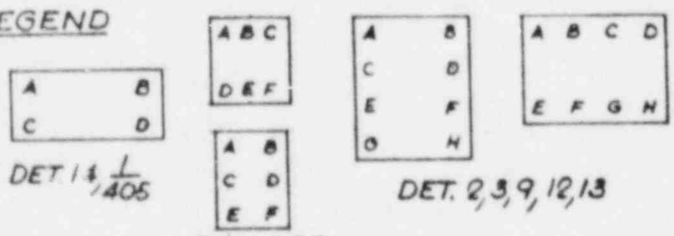


* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
191	1	1	611	579	585	589	575	587			
		2	605	613	613	604	610	604			
		3									
192	6	1	628	640	631	611	633	624			
		2	632	654	638	645	648	634			
		3									
193	6	1	608	585	609	621	606	637			
		2	633	639	653	643	640	624			
		3									
194	6	1	610	609	608	616	617	614			
		2	666	655	670	644	653	664			
		3									
195	2	1	620	628	629	631	629	632	623	611	
		2	671	673	658	667	659	670	666	665	
		3									
196	2	1	583	570	610	606	640	607	630	592	
		2	629	581	609	628	591	568	612	634	
		3									
197	6	1	*	631	610	633	615	636			
		2	637	626	640	631	628	644			
		3									
198	6	1	627	635	621	627	624	619			
		2	643	653	639	646	641	652			
		3									
199	1	1	605	573	563	580	573	597			
		2	614	*	631	*	593	*			
		3									
200	6	1	609	613	618	624	627	615			
		2	630	631	637	635	626	624			
		3									

LEGEND



DET. 1 & 1/405

DET. 1,4,5,6

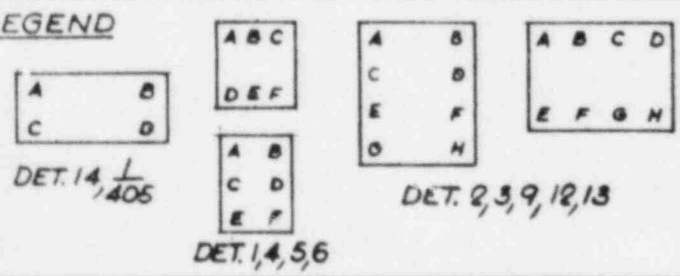
DET. 2,3,9,12,13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
201	1	1	575	615	602	617	574	610			
		2	580	580	583	578	589	610			
		3									
202	2	1	601	*	*	610	610	*	*	600	
		2	677	650	645	648	629	665	649	645	
		3									
203	2	1	587	580	603	591	610	588	574	604	
		2	655	648	663	642	666	636	645	623	
		3									
204	2	1	587	623	617	596	602	617	*	*	
		2	644	652	664	655	657	649	656	652	
		3									
205	2	1	621	632	599	626	619	631	618	612	
		2	647	643	658	643	645	642	652	661	
		3									
206	1	1	609	548	591	600	606	604			
		2	616	619	609	620	618	617			
		3									
207	2	1	622	631	608	619	635	630	616	627	
		2	658	655	659	656	650	659	658	647	
		3									
208	1	1	589	595	600	596	600	610			
		2	597	605	606	613	608	627			
		3									
209	1	1	605	601	603	592	586	615			
		2	612	612	611	614	616	617			
		3									
210	1	1	594	584	621	614	606	602			
		2	615	604	630	619	618	613			
		3									

LEGEND

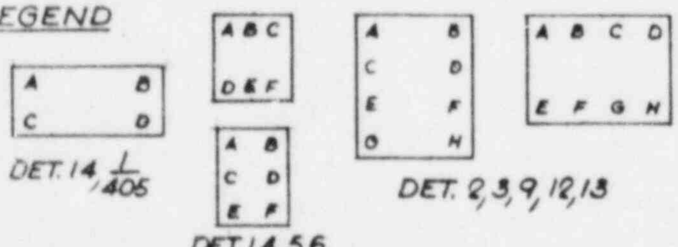


* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
211	1	1	589	593	600	594	600	596			
		2	611	594	626	612	625	615			
		3									
212	1	1	586	598	576	596	603	598			
		2	628	611	624	645	611	599			
		3									
213	1	1	593	587	604	614	610	583			
		2	622	610	618	618	611	619			
		3									
214	2	1	617	623	592	611	613	601	603	604	
		2	644	650	*	*	663	652	645	614	
		3									
215	2	1	593	631	615	628	614	600	605	606	
		2	638	654	639	658	645	637	639	637	
		3									
216	1	1	592	582	606	623	594	579			
		2	651	597	618	630	617	605			
		3									
217	6	1	634	631	622	627	608	628			
		2	650	604	602	641	606	653			
		3									
218	6	1	622	630	640	632	627	631			
		2	637	638	645	640	648	651			
		3									
219	6	1	625	621	627	626	628	626			
		2	622	623	644	618	627	637			
		3									
220	6	1	627	632	637	622	624	621			
		2	645	639	644	624	635	626			
		3									

LEGEND

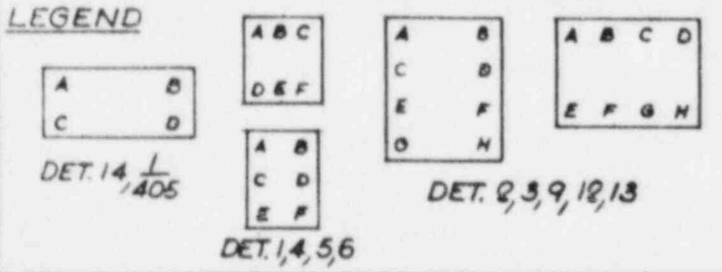


* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
221	5	1	631	607	630	631	622	626			
		2	638	643	619	618	615	638			
		3									
222	5	1	613	628	629	643	662	624			
		2	599	557	479	611	605	591			
		3									
223	1	1	610	604	597	594	605	600			
		2	633	624	606	599	622	617			
		3									
224	1	1	604	568	606	570	585	575			
		2	605	610	606	599	617	604			
		3									
225	1	1	594	582	580	576	541	584			
		2	636	618	626	630	627	630			
		3									
226	1	1	609	592	604	594	596	593			
		2	623	627	612	627	622	618			
		3									
227	1	1	613	603	602	590	606	599			
		2	618	609	610	612	611	607			
		3									
228	1	1	637	589	604	595	601	583			
		2	611	602	612	614	608	614			
		3									
229	1	1	593	578	599	595	602	593			
		2	615	624	623	620	626	613			
		3									
230	1	1	591	603	602	614	588	593			
		2	633	608	624	618	615	604			
		3									

LEGEND



* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
231	1	1	601	594	608	599	573	608			
		2	619	630	627	612	630	620			
		3									
232	1	1	622	610	610	602	601	592			
		2	620	624	616	617	617	612			
		3									
233	1	1	603	611	610	583	606	610			
		2	617	634	623	622	624	616			
		3									
234		1									
		2									
		3									
235		1									
		2									
		3									
236		1									
		2									
		3									
237		1									
		2									
		3									
238		1									
		2									
		3									
239		1									
		2									
		3									
240	2	1	635	639	636	619	618	630	607	627	
		2	624	631	616	631	618	636	633	613	
		3									

LEGEND

DET. 14, L/405

DET. 1,4,5,6

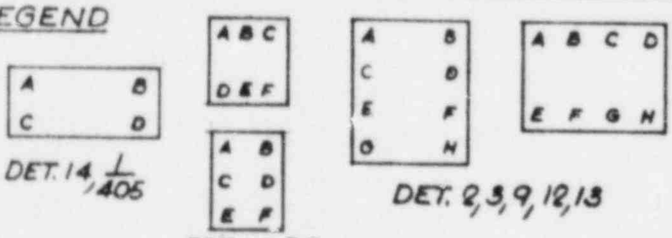
DET. 2,3,9,12,13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
241	5	1	610	606	615	616	619	622			
		2	607	616	474	593	451	400			
		3									
242	5	1	605	612	623	589	576	571			
		2	580	583	477	579	460	462			
		3									
243	6	1	607	602	620	627	613	622			
		2	610	628	639	624	625	620			
		3									
244	6	1	637	642	58[illegible]	637	640	590			
		2	602	614	606	608	621	620			
		3									
245	6	1	609	595	609	612	603	602			
		2	622	615	613	615	618	613			
		3									
246	6	1	618	624	553	616	615	579			
		2	614	618	771	619	613	587			
		3									
247	1	1	604	598	582	591	570	602			
		2	578	582	566	569	583	575			
		3									
248	1	1	552	593	570	580	570	589			
		2	604	602	597	575	582	557			
		3									
249	14	1	567	583	565	580					
		2	607	554	542	613					
		3									
250	14	1	579	564	570	579					
		2	571	579	568	555					
		3									

LEGEND



DET. 14 L/405

DET. 1, 4, 5, 6

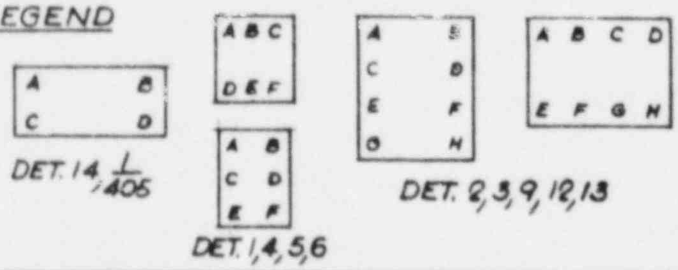
DET. 2, 3, 9, 12, 13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DET'L.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
251	14	1	574	582	580	583					
		2	585	593	580	566					
		3									
252	14	1	583	574	567	572					
		2	560	595	596	579					
		3									
253	1	1	*	*	580	596	582	582			
		2	*	*	609	601	608	603			
		3									
254	1	1	611	599	604	596	596	581			
		2	573	596	579	585	580	592			
		3									
255	2	1	634	628	624	639	630	625	636	[illegible]	
		2	579	636	639	637	629	563	582	562	
		3									
256	2	1	621	621	637	633	634	640	628	627	
		2	595	623	629	614	614	617	610	602	
		3									
257	6	1	612	639	630	628	631	617			
		2	651	645	648	654	640	652			
		3									
258	6	1	628	634	628	622	616	640			
		2	655	640	641	650	651	660			
		3									
259	6	1	612	630	628	630	608	627			
		2	655	639	650	636	637	658			
		3									
260	6	1	630	611	614	613	607	634			
		2	641	656	653	643	638	641			
		3									

LEGEND



* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
261	5	1	609	511	442	602	457	450			
		2	621	473	618	635	633	630			
		3									
262	5	1	624	463	594	592	584	540			
		2	621	489	647	611	629	640			
		3									
263	2	1	616	562	576	577	565	582	658	656	
		2	622	632	620	604	623	623	615	620	
		3									
264	3	1	618	627	628	638	618	614	614	626	
		2	639	607	609	612	604	619	600	605	
		3									
265	5	1	636	631	632	629	615	621			
		2	501	632	624	636	566	630			
		3									
266	5	1	630	635	632	630	639	624			
		2	617	534	635	467	391	607			
		3									
267	6	1	629	636	633	635	634	643			
		2	653	651	671	650	660	634			
		3									
268	6	1	628	628	632	631	631	628			
		2	658	634	629	655	639	623			
		3									
269	6	1	630	632	614	633	629	624			
		2	632	654	645	621	631	654			
		3									
270	6	1	617	601	628	613	620	614			
		2	651	669	674	637	631	635			
		3									

LEGEND

A B
C D

DET. 14, 1/405

A B C
D E F

A B
C D
E F

DET. 1,4,5,6

A B
C D
E F
G H

A B C D
E F G H

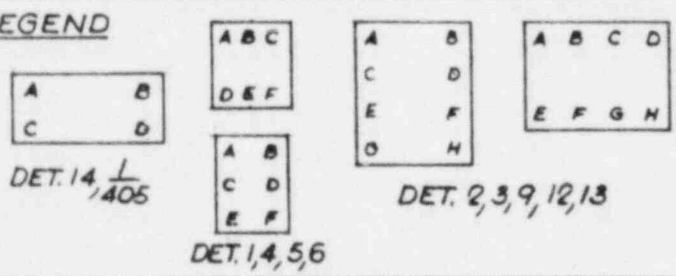
DET. 2,3,9,12,13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
271	3	1	619	629	623	624	611	602	609	629	USED FOR P.W.R. No. 824
		2	628	627	622	619	642	624	631	625	
		3	609	609	606	613	611	608	600	619	
272	3	1	622	618	631	630	628	632	628	631	USED FOR P.W.R. No. 824
		2	617	647	654	638	648	623	634	647	
		3	610	606	606	614	605	600	605	598	
273	9	1	612	612	607	607	614	607	613	606	
		2	624	623	630	622	622	631	623	632	
		3									
274	9	1	553	575	563	575	554	581	557	556	
		2	611	630	620	632	620	618	624	622	
		3									
275	9	1	598	604	593	587	595	582	606	581	
		2	614	628	617	616	623	631	624	629	
		3									
276	9	1	601	609	602	609	596	606	608	616	
		2	619	613	612	620	622	614	615	620	
		3									
277	1	1	567	591	595	570	599	584			
		2	586	575	587	582	585	572			
		3									
278	1	1	480	590	570	608	592	607			
		2	588	591	584	560	568	580			
		3									
279	1	1	567	587	585	598	603	597			
		2	580	616	607	611	613	585			
		3									
280	1	1	603	591	603	604	585	576			
		2	599	594	553	590	593	606			
		3									

LEGEND

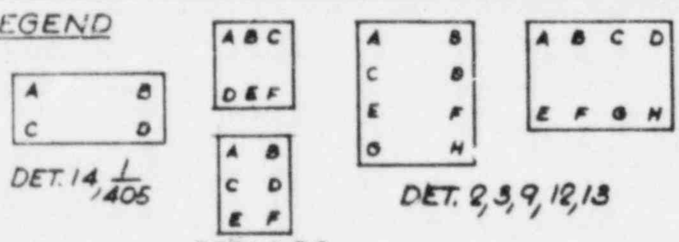


* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
281	1	1	580	583	592	567	587	583			
		2	585	600	591	584	598	594			
		3									
282	1	1	600	589	602	592	442	595			
		2	584	583	573	597	606	590			
		3									
283	1	1	588	577	583	586	598	581			
		2	602	578	580	579	585	575			
		3									
284	1	1	577	597	605	611	602	578			
		2	584	606	602	600	608	600			
		3									
285	1	1	579	573	593	590	597	580			
		2	595	578	586	602	605	601			
		3									
286	1	1	604	588	599	597	594	553			
		2	606	593	589	593	592	597			
		3									
287	1	1	591	596	598	600	524	580			
		2	612	575	608	590	588	596			
		3									
288	1	1	601	605	596	576	606	578			
		2	586	595	607	598	596	609			
		3									
289	6	1	*	*	*	*	*	*			
		2	*	*	*	*	*	*			
		3	605	*	*	*	*	*			
290	6	1	618	631	618	617	620	615			
		2	598	629	630	623	618	632			
		3	598	610	596	594	600	598			

LEGEND



DET. 14, 1/405

DET. 1,4,5,6

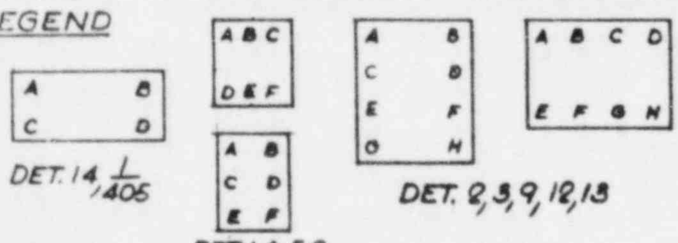
DET. 2,3,9,12,13

* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
291	6	1	622	617	610	625	620	614			
		2	609	589	590	596	592	582			
		3	607	626	599	610	601	599			
292	4	1	582	588	590	593	582	584			
		2	614	609	550	605	595	608			
		3	606	619	600	587	603	607			
293	4	1	597	586	591	587	596	587			
		2	606	594	599	600	610	604			
		3	599	595	596	606	609	604			
294	2	1	600	594	606	606	601	607	621	623	
		2	624	617	624	626	636	600	621	623	
		3	601	603	598	620	613	619	593	600	
295	2	1	635	603	607	594	603	584	597	600	
		2	632	615	628	621	612	617	629	638	
		3	584	619	620	605	618	577	615	619	
296	2	1	612	595	615	597	612	602	611	601	
		2	623	630	616	626	617	627	600	616	
		3	625	637	638	634	637	633	635	626	
297	2	1	598	604	598	596	600	614	600	609	
		2	501	498	506	499	490	503	495	503	
		3	645	600	603	629	607	636	605	630	
298	6	1	624	618	616	620	621	619			
		2	622	620	617	625	626	620			
		3	616	615	613	613	629	606			
299	6	1	629	627	624	629	627	622			
		2	609	612	617	616	601	611			
		3	622	615	607	604	618	617			
300	2	1	595	613	571	617	626	609	624	595	
		2	636	595	586	612	618	635	629	618	
		3	604	610	621	630	594	598	585	627	

LEGEND



DET. 14 1/405

DET. 1,4,5,6

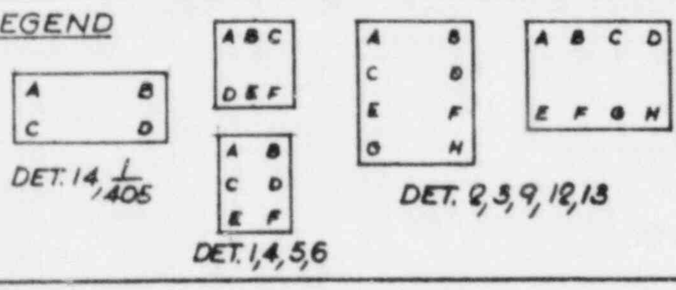
DET. 2,3,9,12,13

*DENOTES BOLTS INACCESSIBLE FOR TESTING-

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
301	2	1	591	616	606	589	586	607	581	618	
		2	617	614	589	606	619	601	615	622	
		3	608	609	648	598	607	600	600	624	
302	2	1	602	614	611	599	615	590	611	590	
		2	624	609	632	623	623	624	620	629	
		3	599	605	594	603	607	600	599	599	
303	2	1	603	592	593	612	588	621	593	588	
		2	502	512	509	502	496	506	511	507	
		3	621	612	634	626	611	617	639	615	
304	2	1	587	595	590	600	596	596	594	598	
		2	506	525	507	523	507	497	525	529	
		3	596	*	619	617	615	617	588	587	
305	2	1	616	599	598	601	598	605	627	625	
		2	532	519	502	504	515	504	515	503	
		3	611	595	624	625	596	597	618	621	
306	2	1	613	602	594	606	603	638	613	605	
		2	502	509	509	509	534	513	503	496	
		3	613	607	631	603	607	595	612	609	
307	6	1	637	637	637	646	624	630			
		2	620	604	610	601	616	597			
		3	621	609	587	618	595	608			
308	2	1	592	616	614	610	621	598	574	609	
		2	636	653	641	623	632	626	624	637	
		3									
309	2	1	589	589	*	597	603	602	*	578	
		2	660	615	616	642	656	637	633	604	
		3									
310	1	1	587	616	595	601	591	603			
		2	603	595	610	589	599	604			
		3									

LEGEND

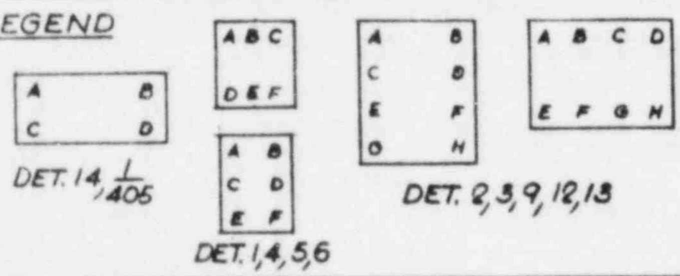


* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE NUMBER	PLATE DETL.	UNIT NO.	BOLT IDENTIFICATION A	B	C	D	E	F	G	H	REMARKS
311	1	1	555	589	577	613	581	599			
		2	607	600	594	595	607	583			
		3									
312	1	1	584	444	614	594	587	600			
		2	622	598	595	592	603	596			
		3									
313	1	1	588	593	585	588	599	601			
		2	604	608	611	600	595	601			
		3									
314	1	1	593	597	594	599	600	592			
		2	589	602	600	589	594	600			
		3									
315	1	1	601	607	586	573	584	596			
		2	607	596	591	600	582	600			
		3									
316	1	1	570	572	570	568	604	591			
		2	611	607	607	603	603	604			
		3									
317	1	1	556	561	573	568	564	565			
		2	596	575	591	593	610	596			
		3									
318	1	1	583	600	563	591	589	566			
		2	601	587	593	618	592	584			
		3									
319	1/405	1	680	630	656	652					USED ON 13-C-ZCS-540
		2	593	594	587	592					
		3									
320	1/.405	1	623	618	629	664					USED ON 13-C-ZCS-540
		2	596	588	573	585					
		3									

LEGEND

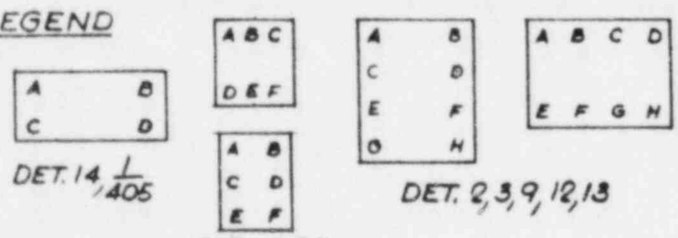


* DENOTES BOLTS INACCESSIBLE FOR TESTING -

EQUOTIP HARDNESS L-VALUE

PLATE		UNIT	BOLT IDENTIFICATION								REMARKS
NUMBER	DETL.	NO.	A	B	C	D	E	F	G	H	
321	11/566	1	592	591	589	585					USED ON
		2	580	604	572	590					13-C-ZCS-565
		3									COLUMN #10
322	11/566	1	620	606	601	595					USED ON
		2	585	593	584	578					13-C-ZCS-565
		3									COLUMN #9
		1									
		2									
		3									
		1									
		2									
		3									
		1									
		2									
		3									
		1									
		2									
		3									
		1									
		2									
		3									
		1									
		2									
		3									
		1									
		2									
		3									
		1									
		2									
		3									

LEGEND



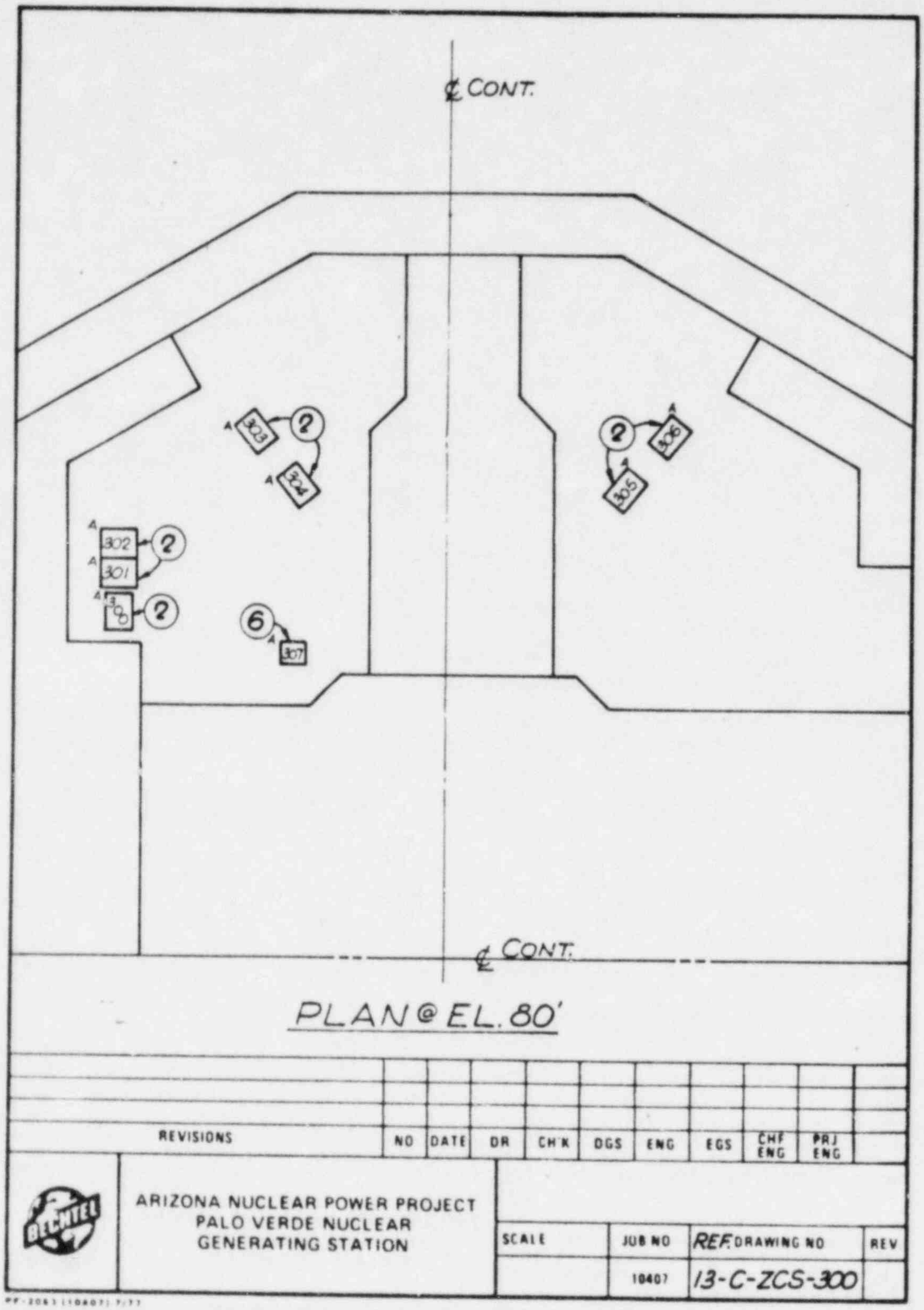
DET. 14 1/405

DET. 1,4,5,6

DET. 2,3,9,12,13

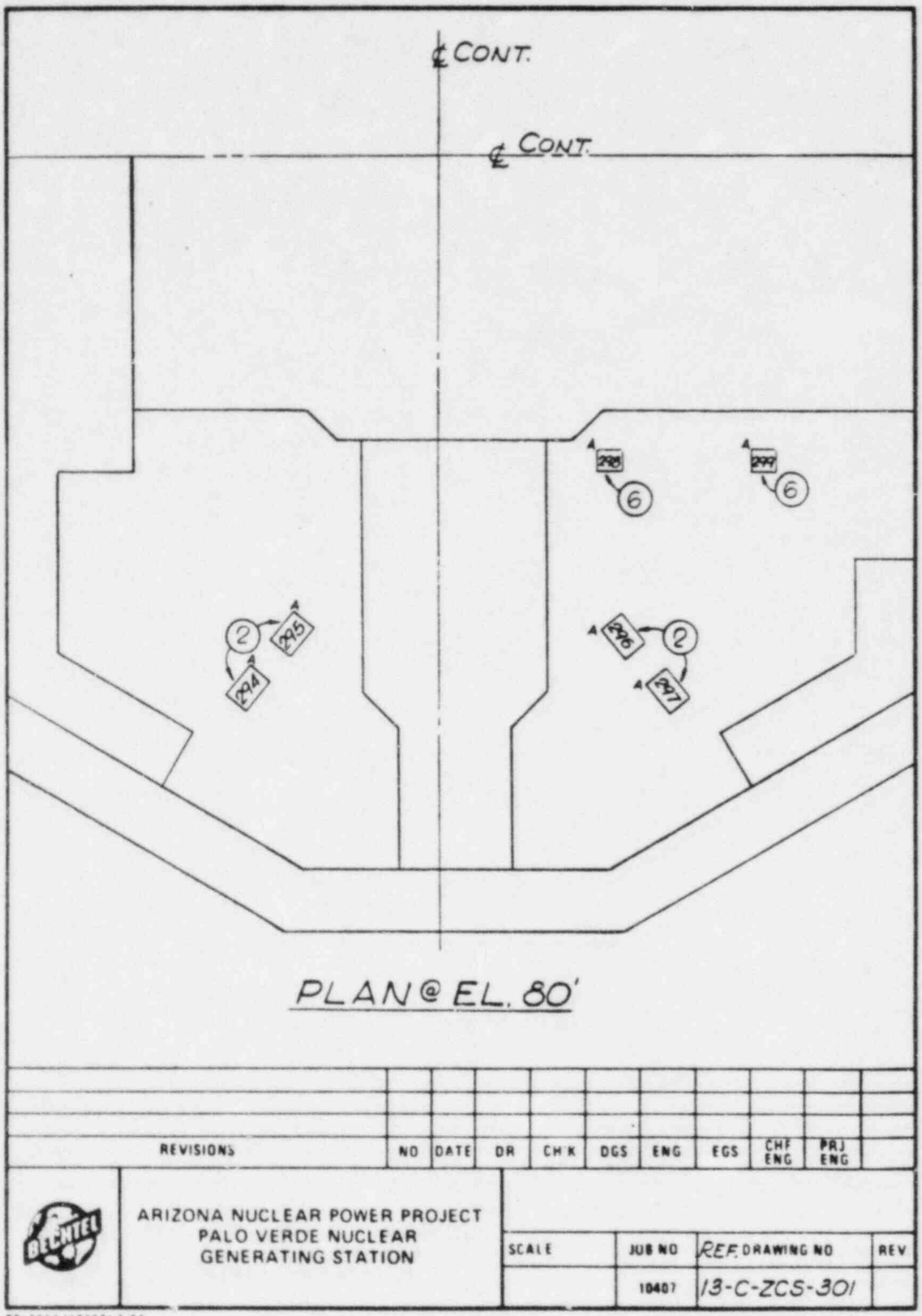
* DENOTES BOLTS INACCESSIBLE FOR TESTING -

FIGURES



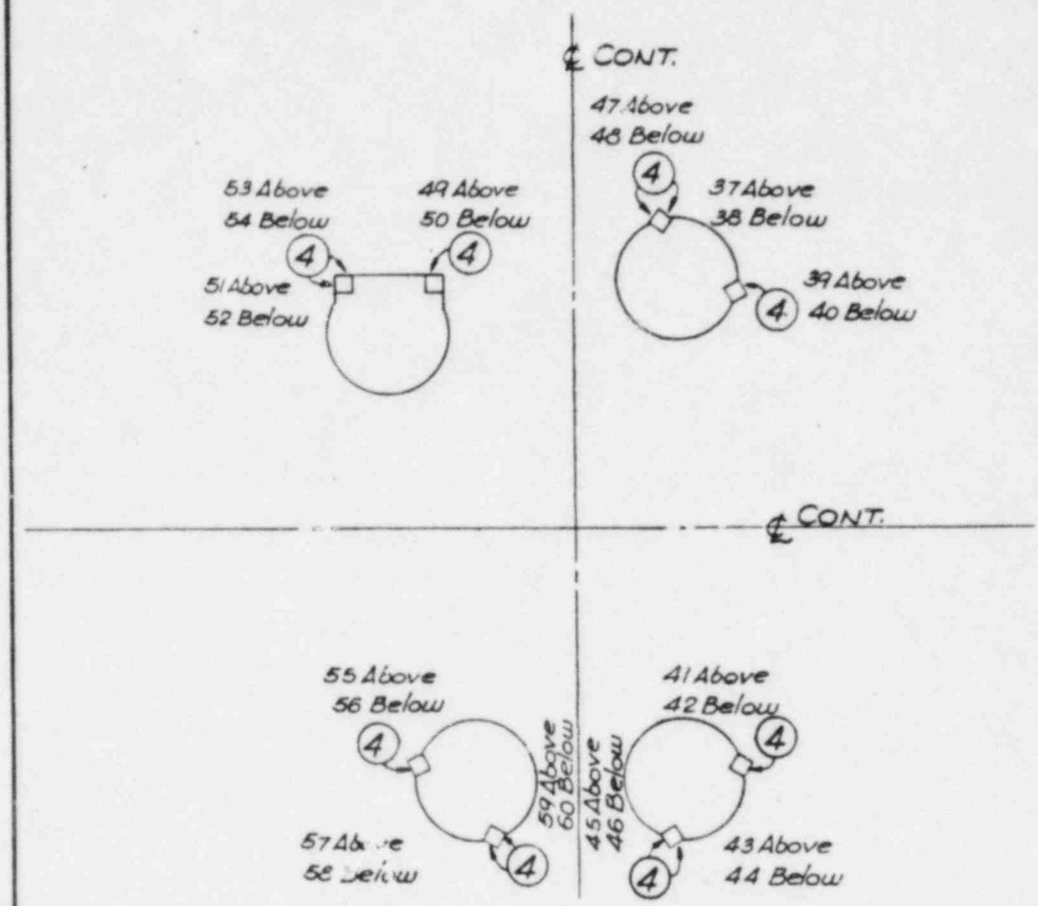
℄ CONT.
A
303
304
2
306
305
302
301
6
307
℄ CONT.
PLAN @ EL. 80'
REVISIONS
NO
DATE
DR
CH'K
DGS
ENG
EGS
CHF ENG
PRJ ENG
BECHTEL
ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION
SCALE
JOB NO
10407
REF. DRAWING NO
13-C-ZCS-300
REV

FIGURE D-1



℄ CONT.
℄ CONT.
298
299
6
6
2
295
294
296
2
297
PLAN @ EL. 80'
REVISIONS
NO
DATE
DR
CH'K
DGS
ENG
EGS
CHF ENG
PRJ ENG
BECHTEL
ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION
SCALE
JOB NO
REF. DRAWING NO
REV
10407
13-C-ZCS-301

FIGURE D-2



KEY PLAN-SAFETY INJECTION TANK

REVISIONS	NO	DATE	DR	CH'K	DGS	ENG	EGS	CHF ENG	PRJ ENG	

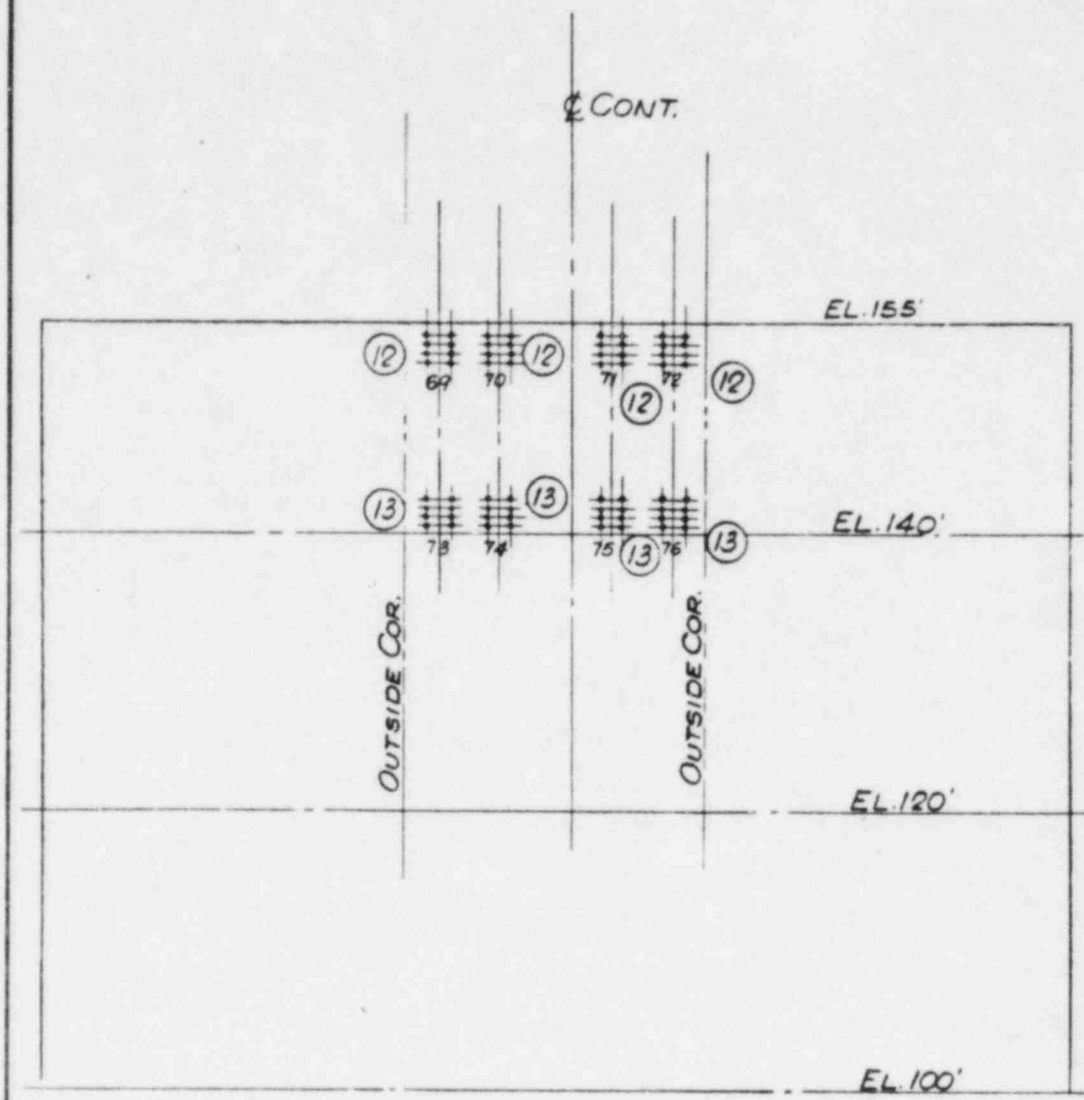
BECHTEL

ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION

SCALE	JOB NO	REF. DRAWING NO	REV
	10407	13-C-ZCS-378	

PE-2063 (10407) 7/77

FIGURE D-3



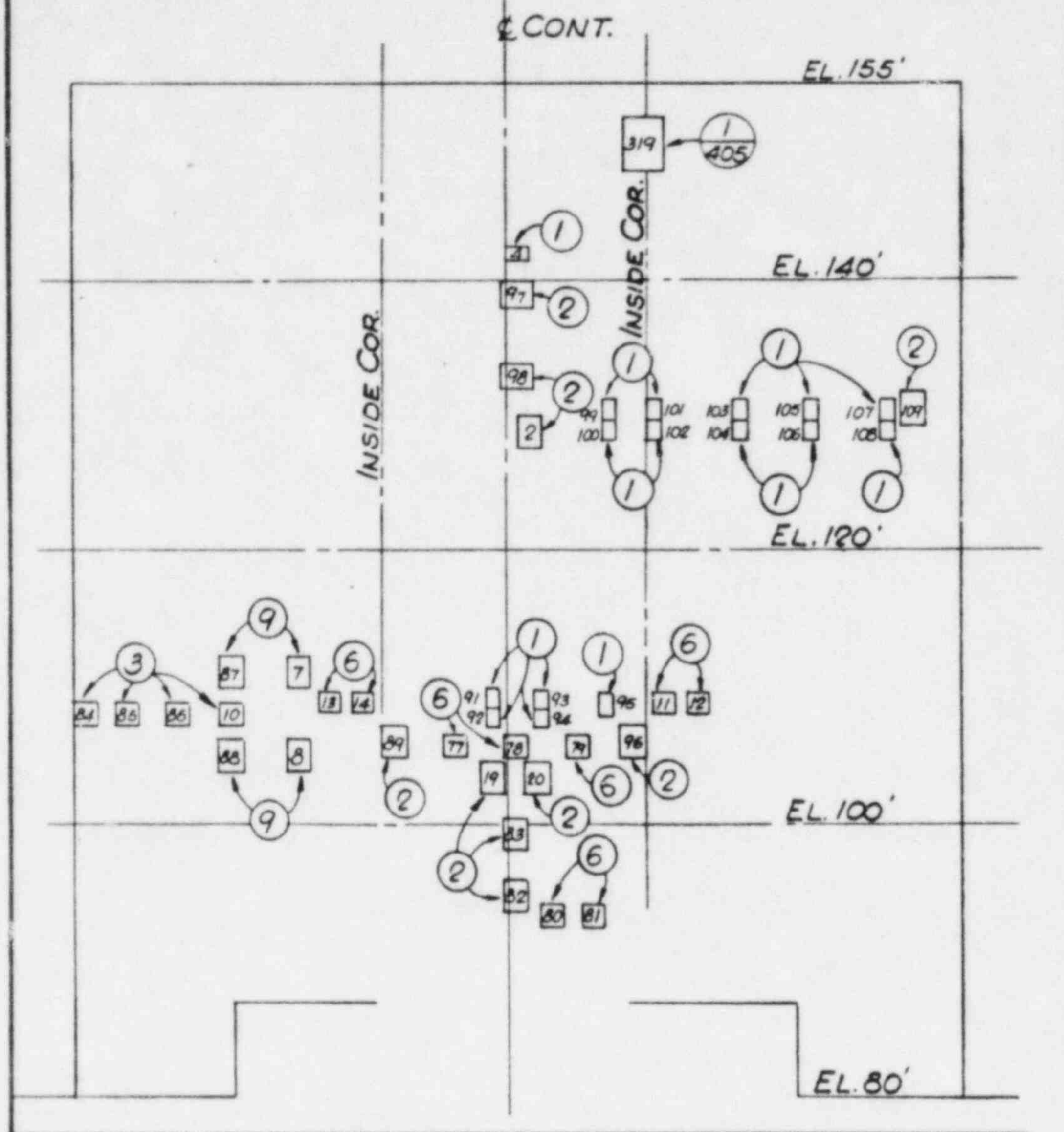
ELEVATION LKG. FROM OUTSIDE

REVISIONS	NO	DATE	DR	CH'K	DGS	ENG	EGS	CHF ENG	PRJ ENG	

BECHTEL	ARIZONA NUCLEAR POWER PROJECT PALO VERDE NUCLEAR GENERATING STATION			
		SCALE	JOB NO	REF. DRAWING NO	REV
			10407	13-C-ZCS-405	

PF-2063 (10407) 7/77

FIGURE D-4



ELEVATION LKG. FROM INSIDE

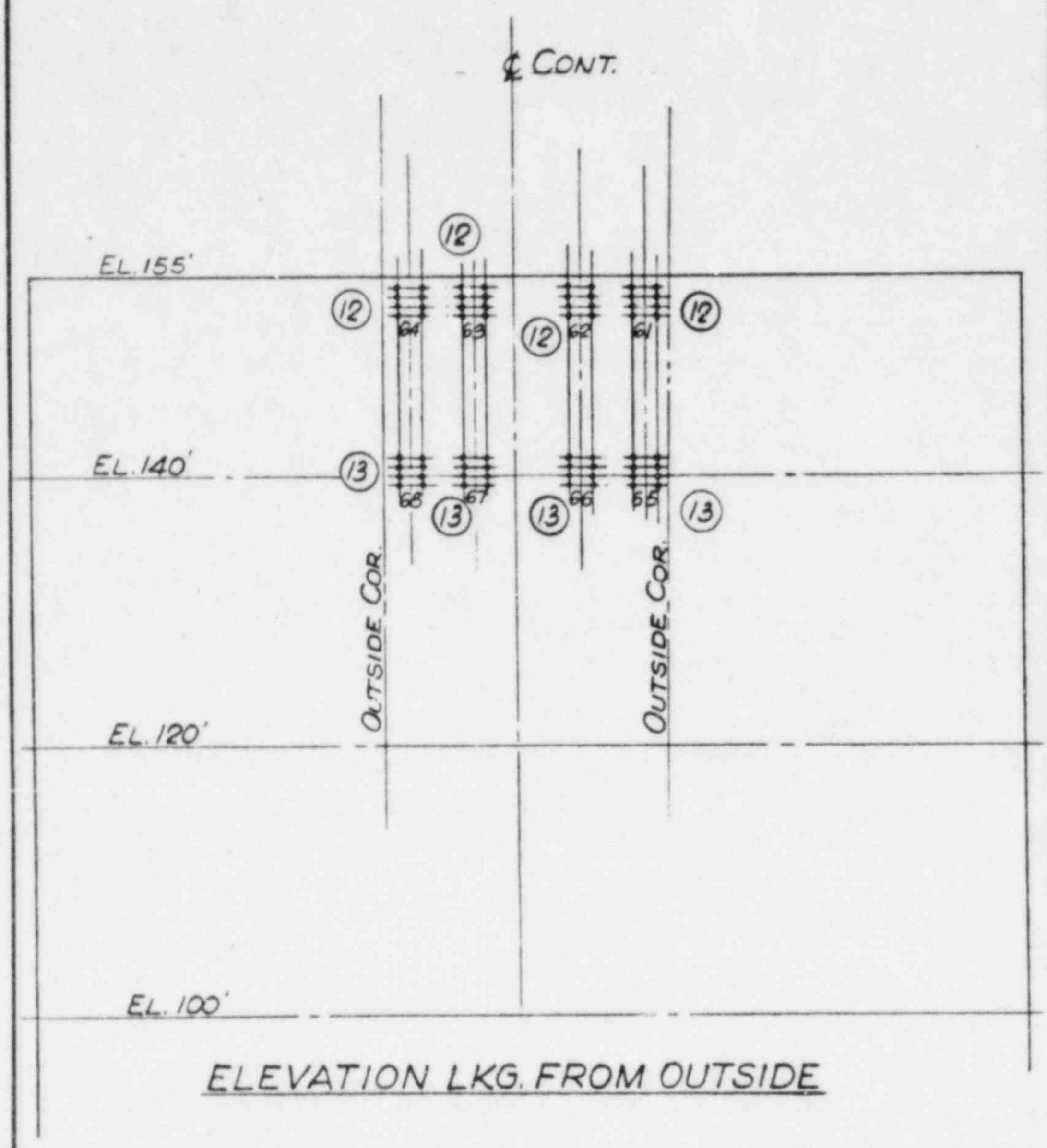
REVISIONS	NO	DATE	DR	CH'K	DGS	ENG	EGS	CHF ENG	PRJ ENG

ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION

SCALE	JOB NO	REF. DRAWING NO	REV
	10407	13-C-ZCS-405	

PP-2063 (10407) 7/77

FIGURE D-5



REVISIONS	NO	DATE	DR	CH'K	DGS	ENG	EGS	CHF ENG	PRJ ENG

BECHTEL

ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION

SCALE	JOB NO	REF. DRAWING NO	REV
	10407	13-C-ZCS-406	

PF-2061 (10407) 7/77

FIGURE D-6

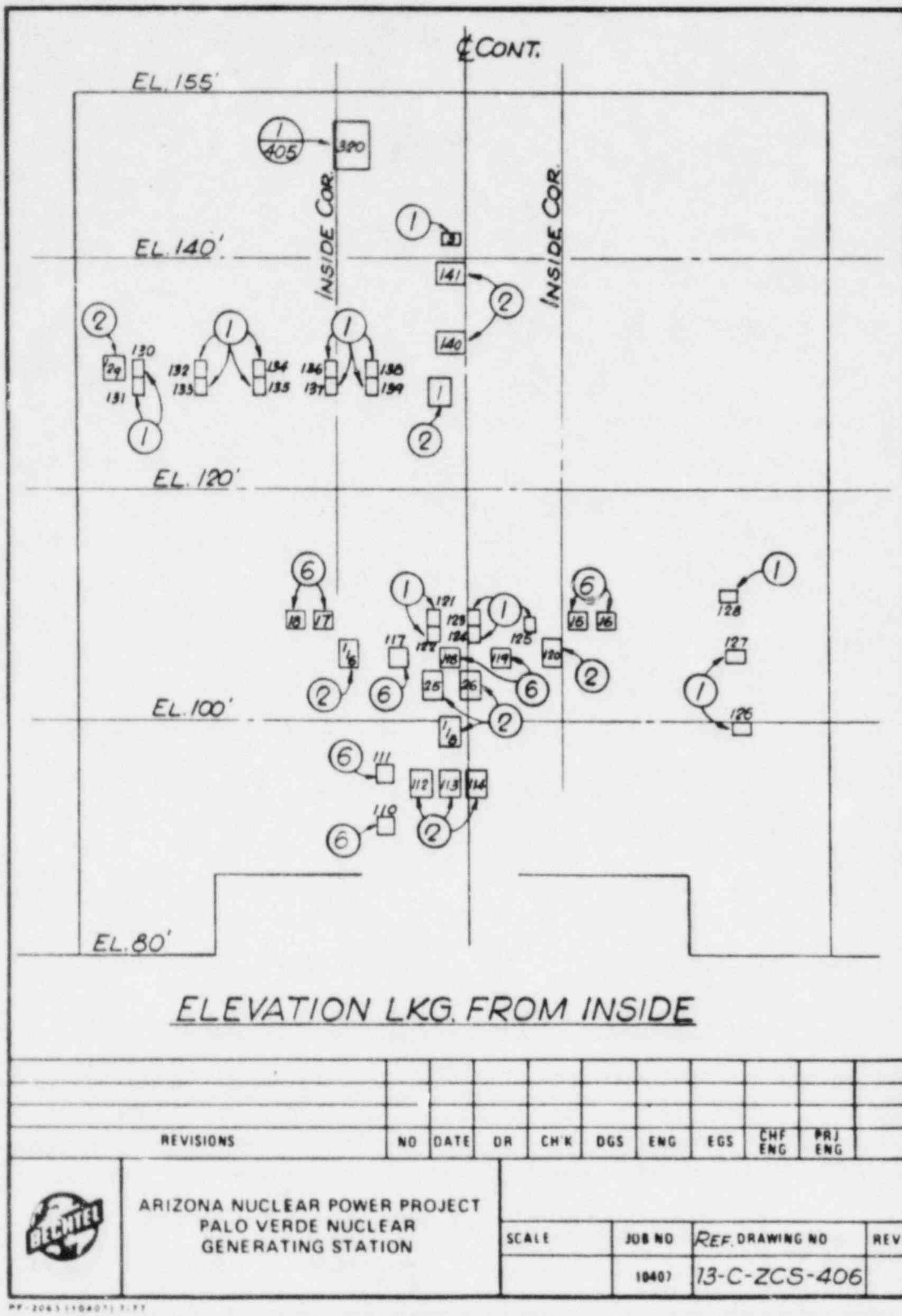
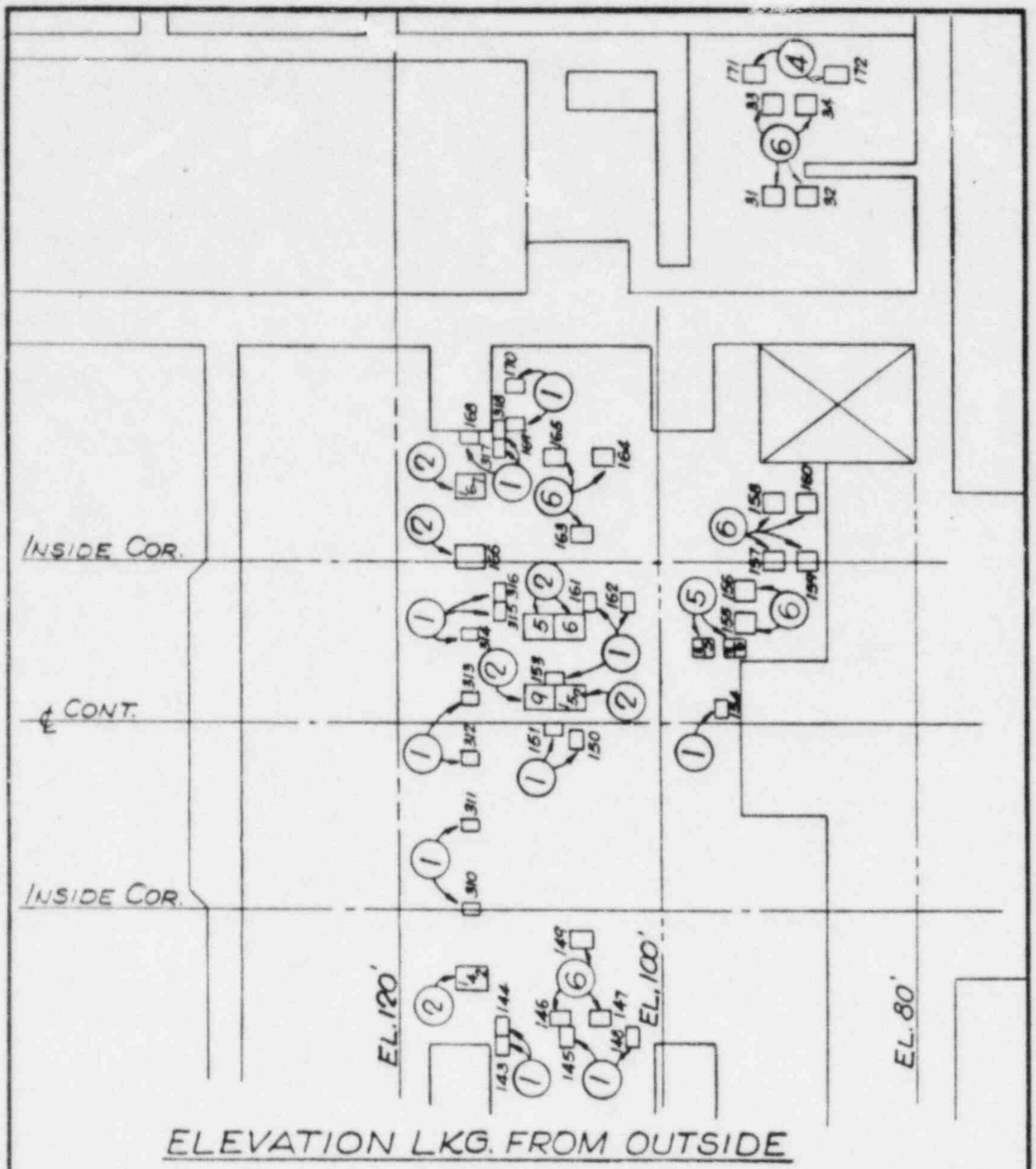

℄ CONT.
EL. 155'
EL. 140'
EL. 120'
EL. 100'
EL. 80'
INSIDE COR.
INSIDE COR.
ELEVATION LKG. FROM INSIDE
REVISIONS
NO
DATE
DR
CH'K
DGS
ENG
EGS
CHF ENG
PRJ ENG
BECHTEL
ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION
SCALE
JOB NO
REF. DRAWING NO
REV
10407
13-C-ZCS-406

FIGURE D-7



REVISIONS	NO	DATE	DR	CH'K	DGS	ENG	EGS	CHF ENG	PRJ ENG	

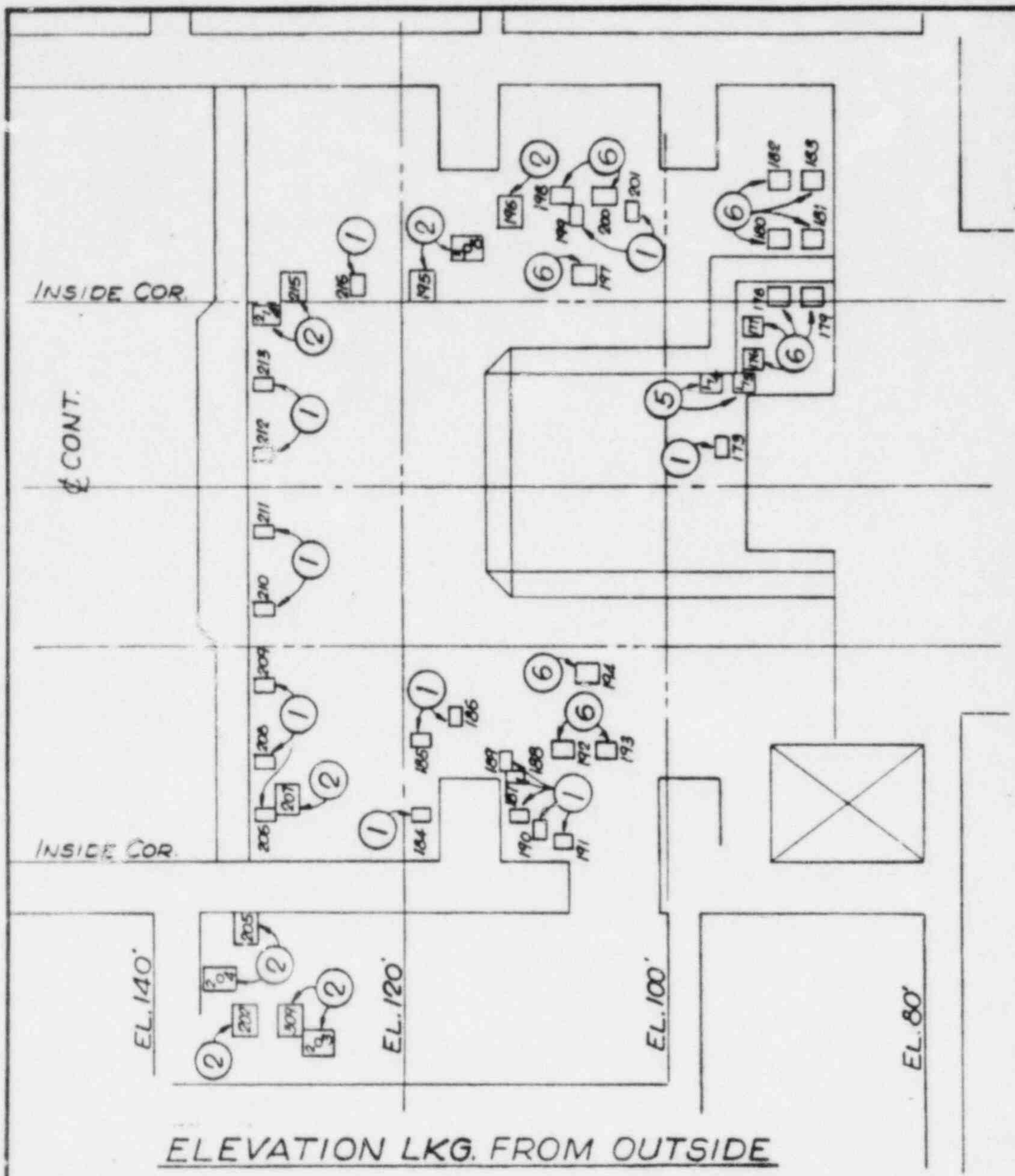
BECHTEL

ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR GENERATING STATION

SCALE	JOB NO	REF. DRAWING NO	REV
	10407	13-C-ZCS-407	

PF-2063 (10407) 7/77

FIGURE D-8



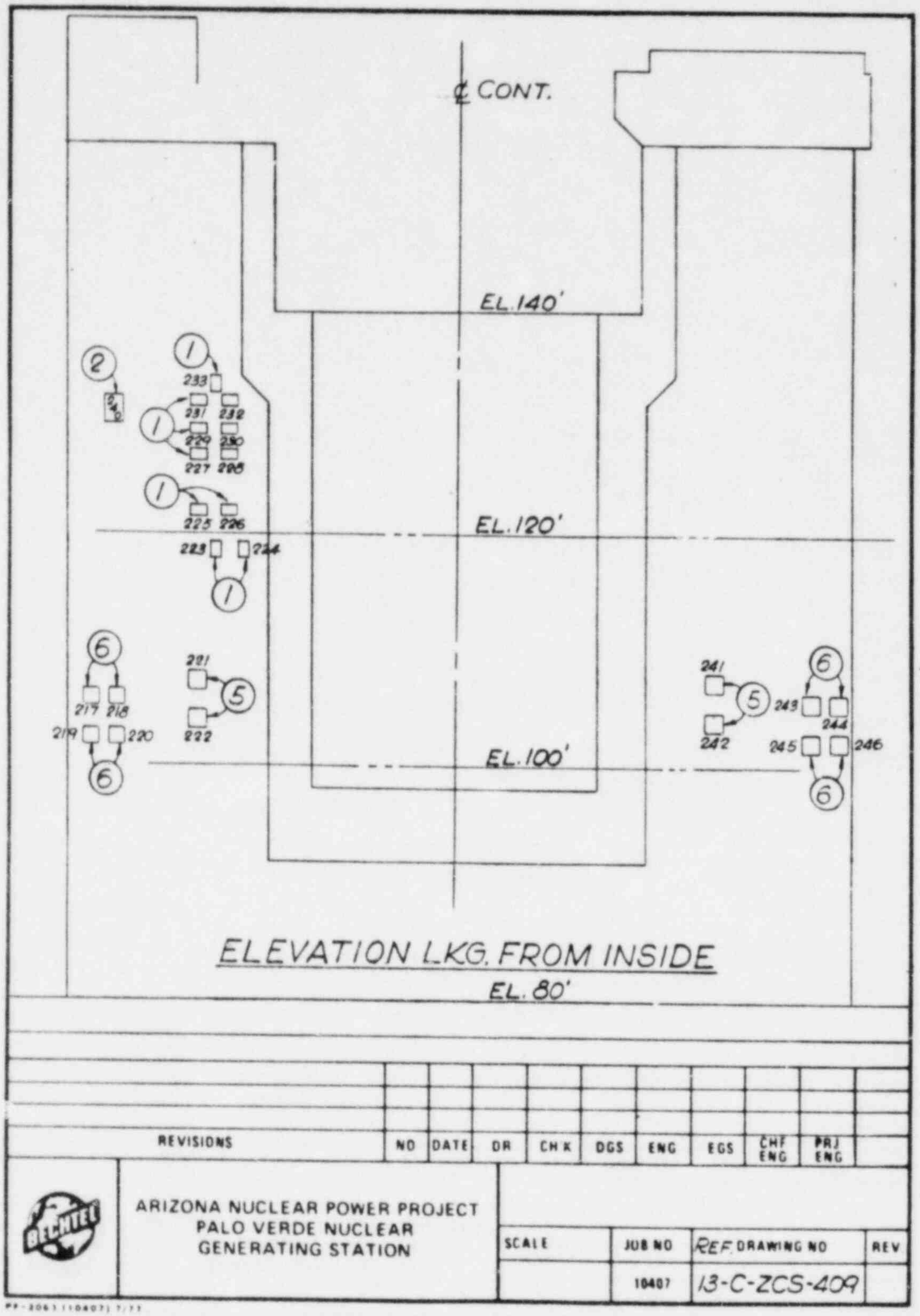
REVISIONS	NO	DATE	DR	CH'K	DGS	ENG	EGS	CHF ENG	PRJ ENG

BECHTEL

ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION

SCALE	JOB NO	REF. DRAWING NO	REV
	10407	13-C-ZCS-408	

FIGURE D-9



℄ CONT.
EL.140'
EL.120'
EL.100'
EL. 80'
ELEVATION LKG. FROM INSIDE
233
231
232
229
230
227
228
225
226
223
224
221
222
217
218
219
220
241
242
243
244
245
246
REVISIONS
NO
DATE
DR
CHK
DGS
ENG
EGS
CHF ENG
PRJ ENG
BECHTEL
ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION
SCALE
JOB NO
REF. DRAWING NO
REV
10407
13-C-ZCS-409

FIGURE D-10

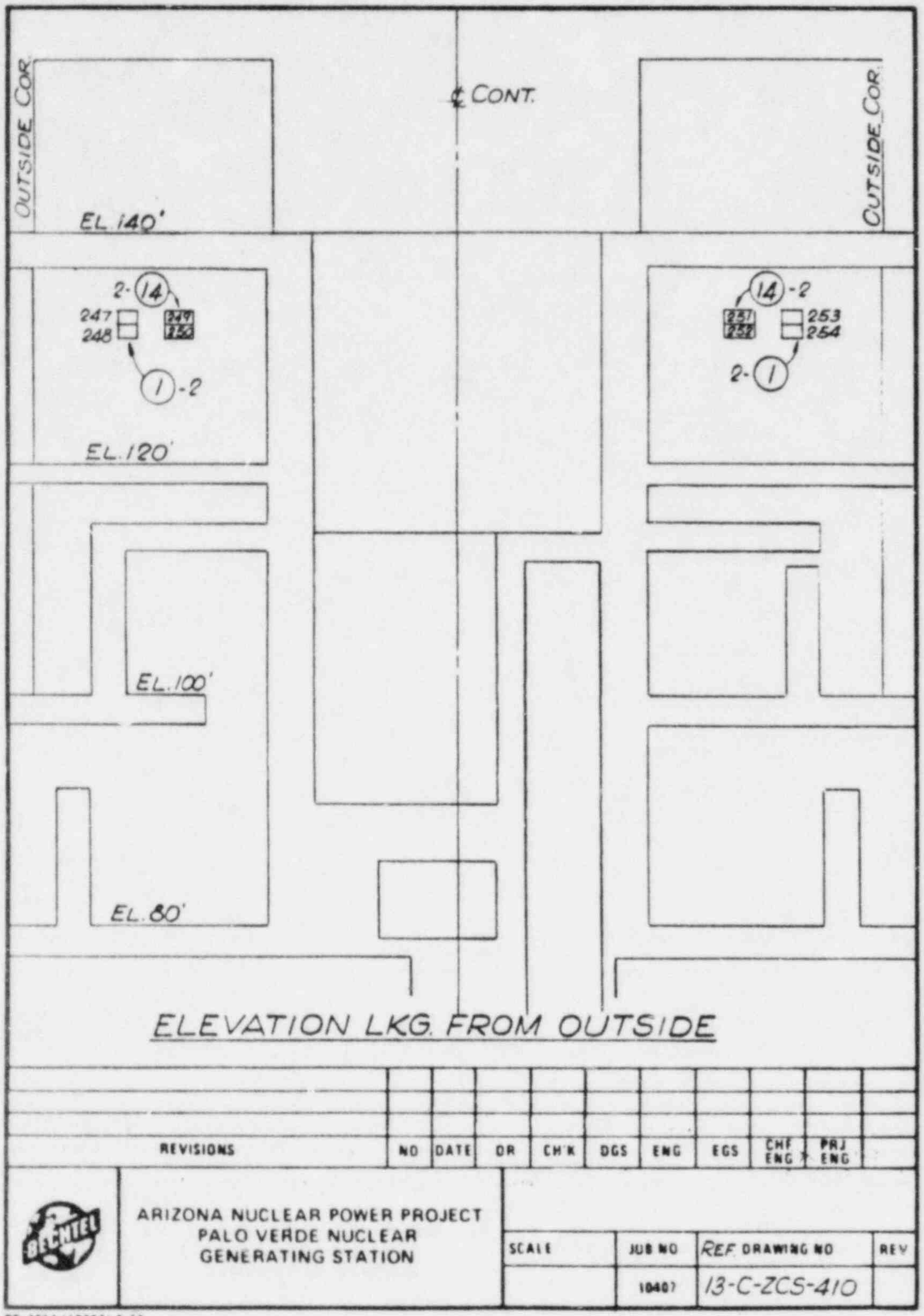
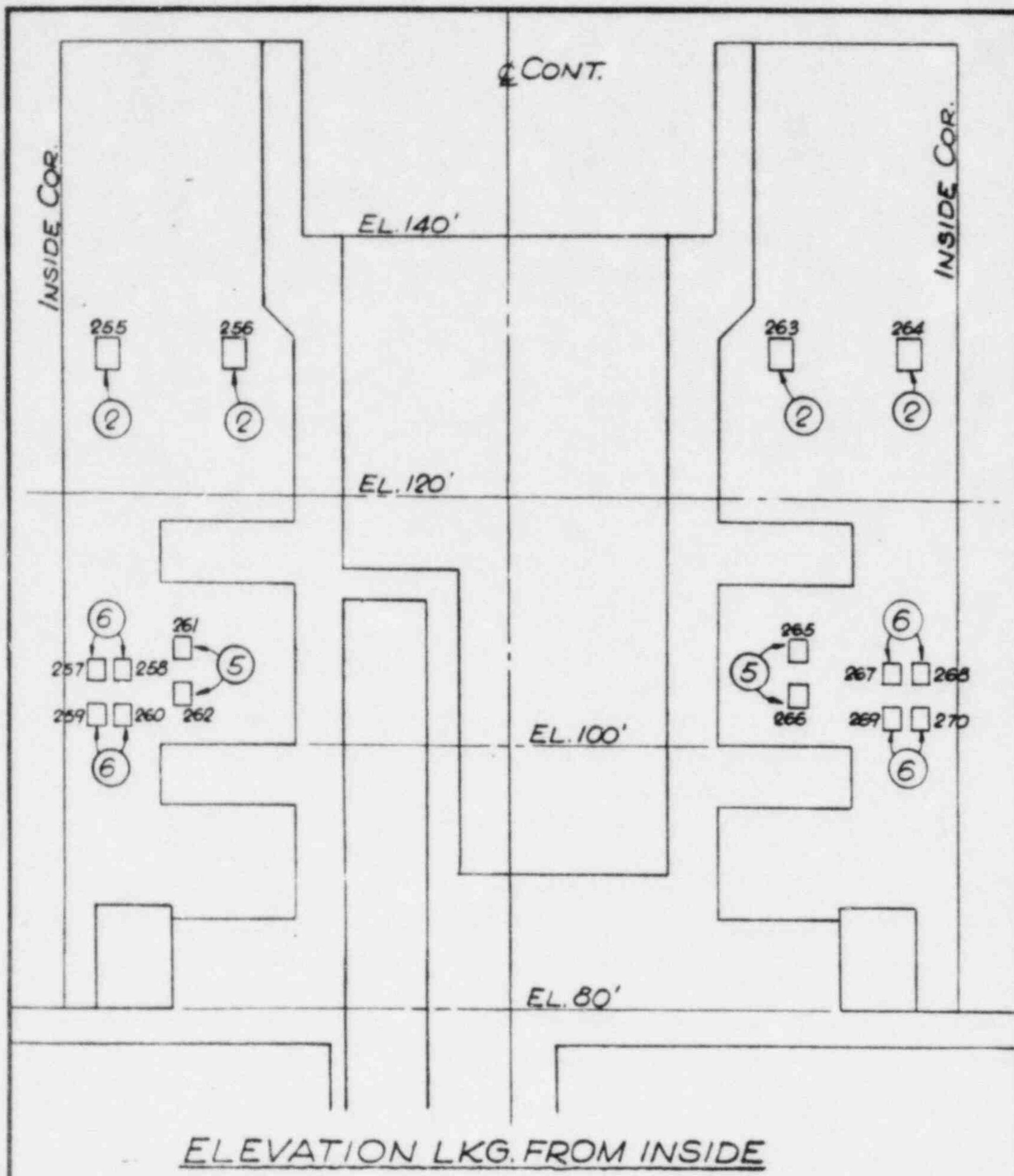

OUTSIDE COR.
℄ CONT.
OUTSIDE COR.
EL. 140'
2-14
247
248
1-2
14-2
253
254
2-1
EL. 120'
EL. 100'
EL. 80'
ELEVATION LKG. FROM OUTSIDE
REVISIONS
NO
DATE
DR
CH'K
DGS
ENG
EGS
CHF ENG
PRJ ENG
BECHTEL
ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION
SCALE
JOB NO
REF. DRAWING NO
REV
10407
13-C-ZCS-410

FIGURE D-11

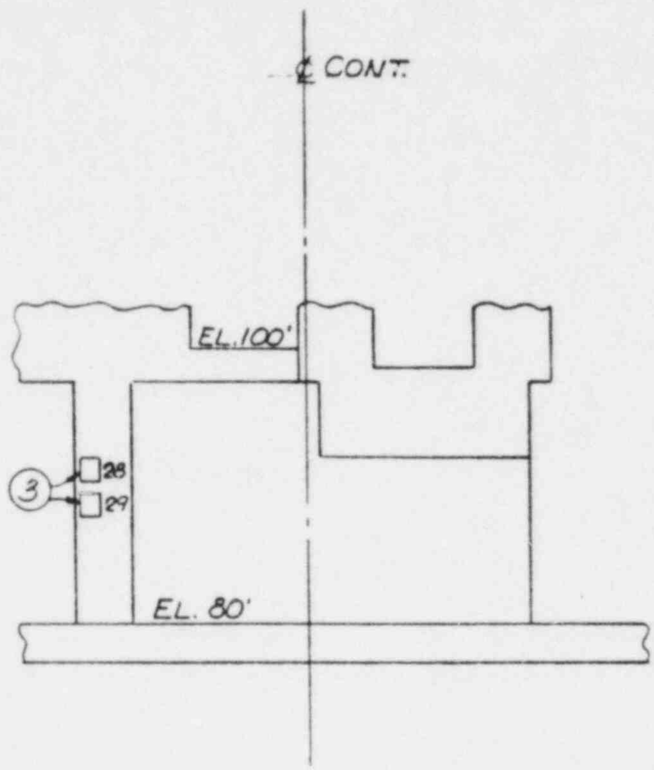


REVISIONS	NO	DATE	DR	CH'K	DGS	ENG	EGS	CHF ENG	PRJ ENG

ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION

SCALE	JOB NO	REF DRAWING NO	REV
	10407	13-C-ZCS-410	

FIGURE D-12



EXTERIOR ELEVATION 4/–

REVISIONS	NO	DATE	DR	CH'K	DGS	ENG	EGS	CHF ENG	PRJ ENG	

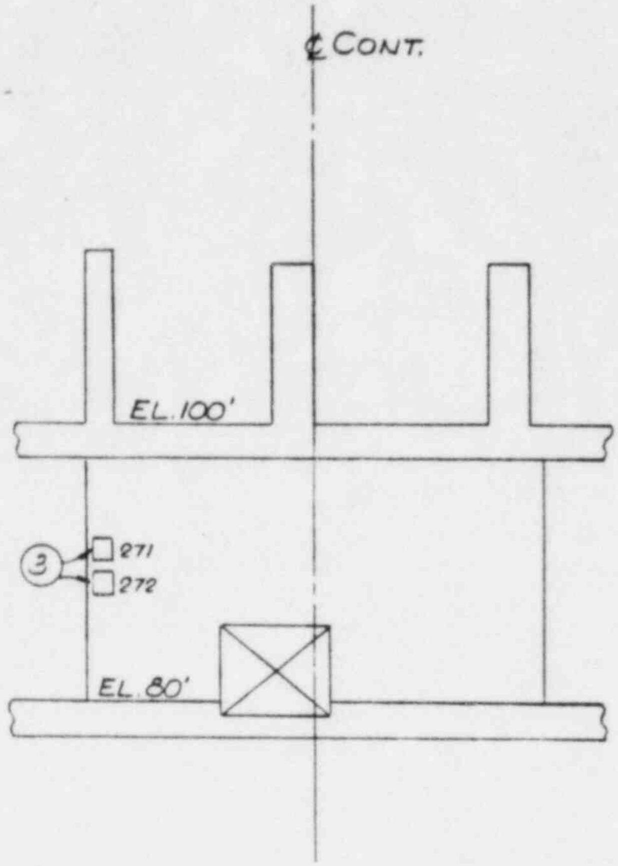
BECHTEL

ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION

SCALE	JOB NO	REF. DRAWING NO	REV
	10407	13-C-ZCS-411	

PP-2063 (10407) 7/77

FIGURE D-13



EAST CANAL

EXTERIOR ELEVATION 3/–

REVISIONS	NO	DATE	DR	CH'K	DGS	ENG	EGS	CHF ENG	PRJ ENG	

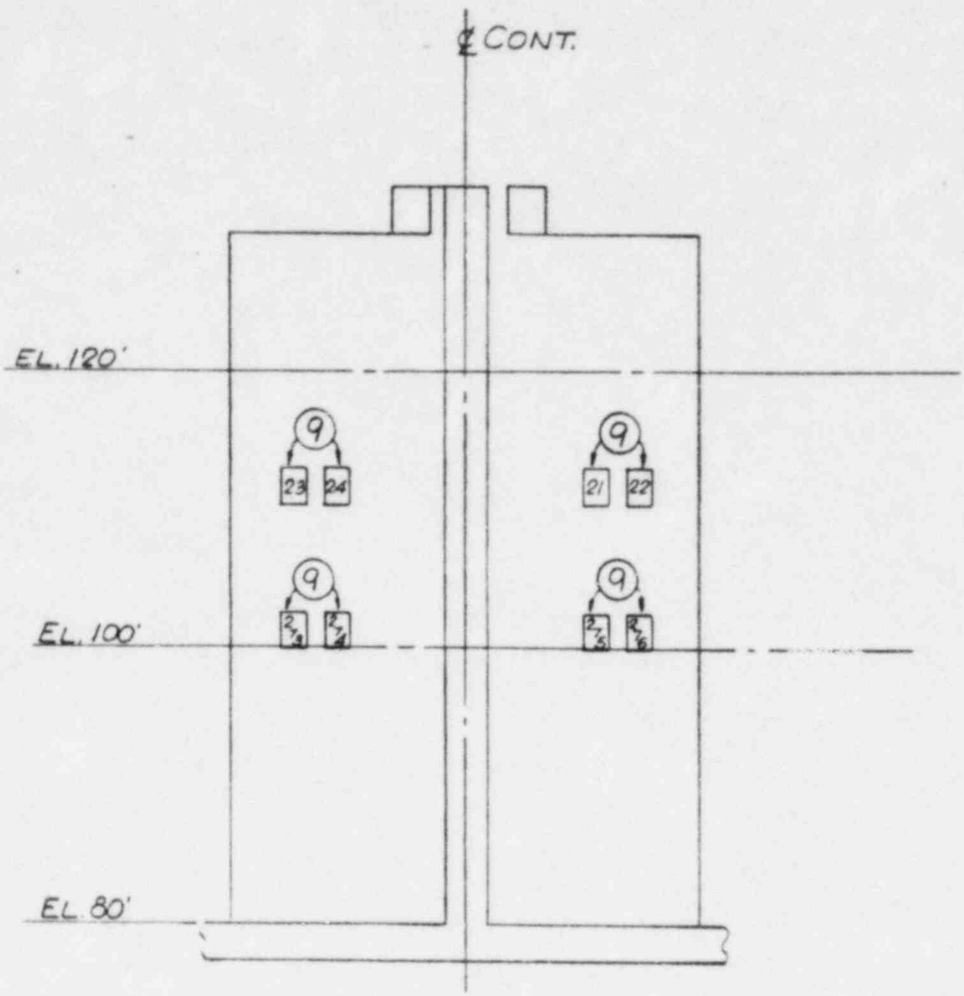
BECHTEL

ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION

SCALE	JOB NO	REF. DRAWING NO	REV
	10407	13-C-ZCS-411	

PF-2063 (10407) 7-77

FIGURE D-14



EAST ELEVATION

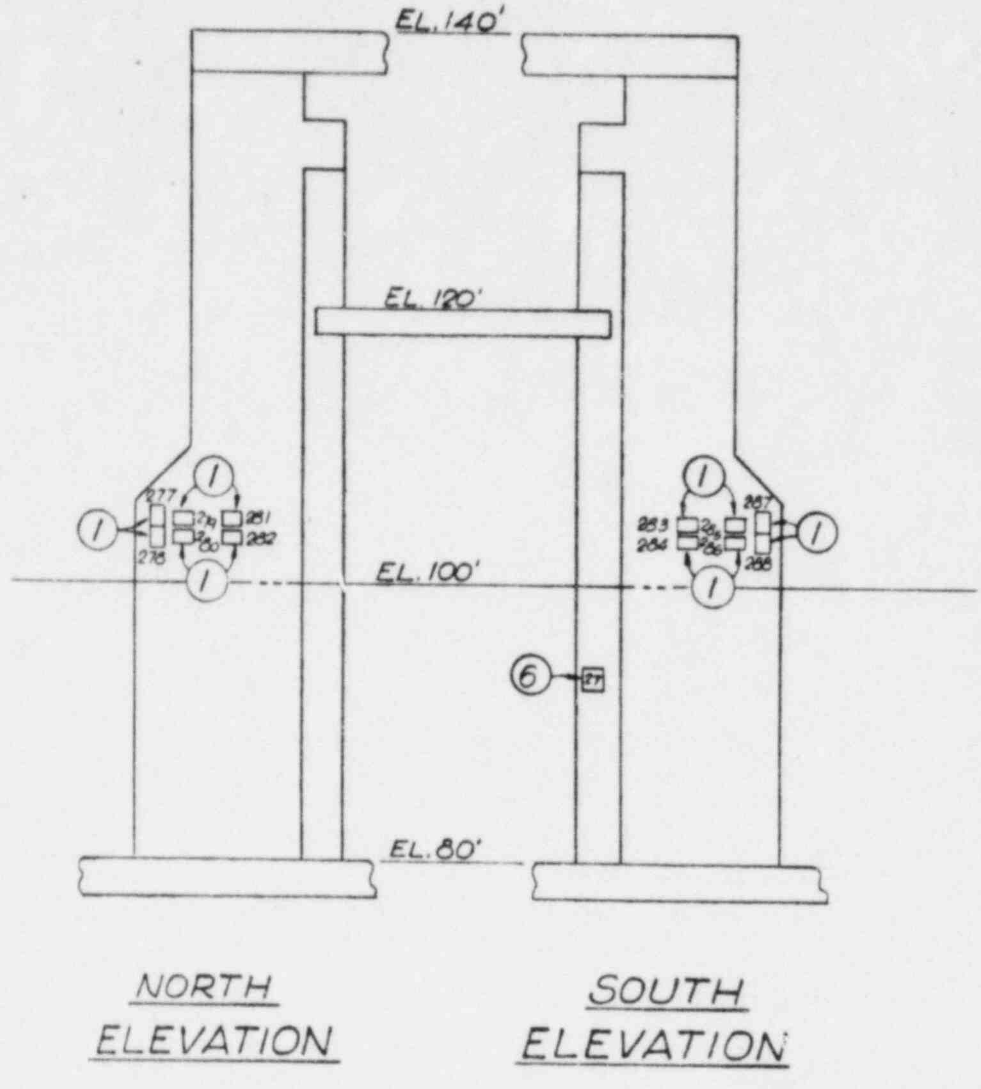
REVISIONS	NO	DATE	DR	CH'K	DGS	ENG	EGS	CHF ENG	PI.. ENG

BECHTEL

ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION

SCALE	JOB NO	REF. DRAWING NO	REV
	10407	13-C-ZCS-412	

FIGURE D-15

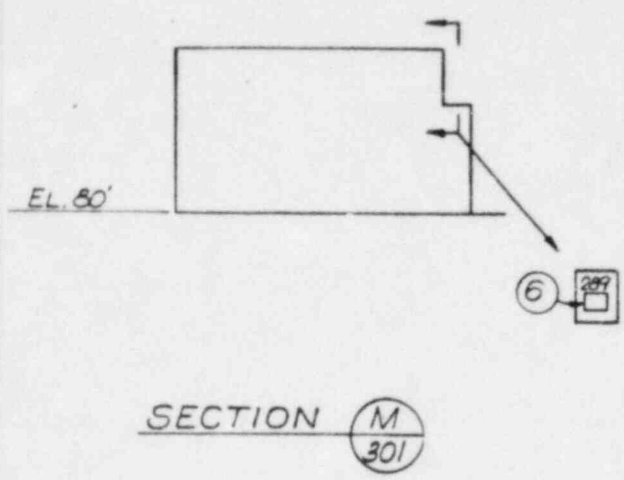


REVISIONS	NO	DATE	DR	CH'K	DGS	ENG	EGS	CHF ENG	PRJ ENG	

ARIZONA NUCLEAR POWER PROJECT PALO VERDE NUCLEAR GENERATING STATION	SCALE	JOB NO	REF. DRAWING NO	REV
		10407	13-C-ZCS-412	

PF-2063 (10407) 7/77

FIGURE D-16



REVISIONS	NO	DATE	DR	CH'K	DGS	ENG	EGS	CHF ENG	PRJ ENG	

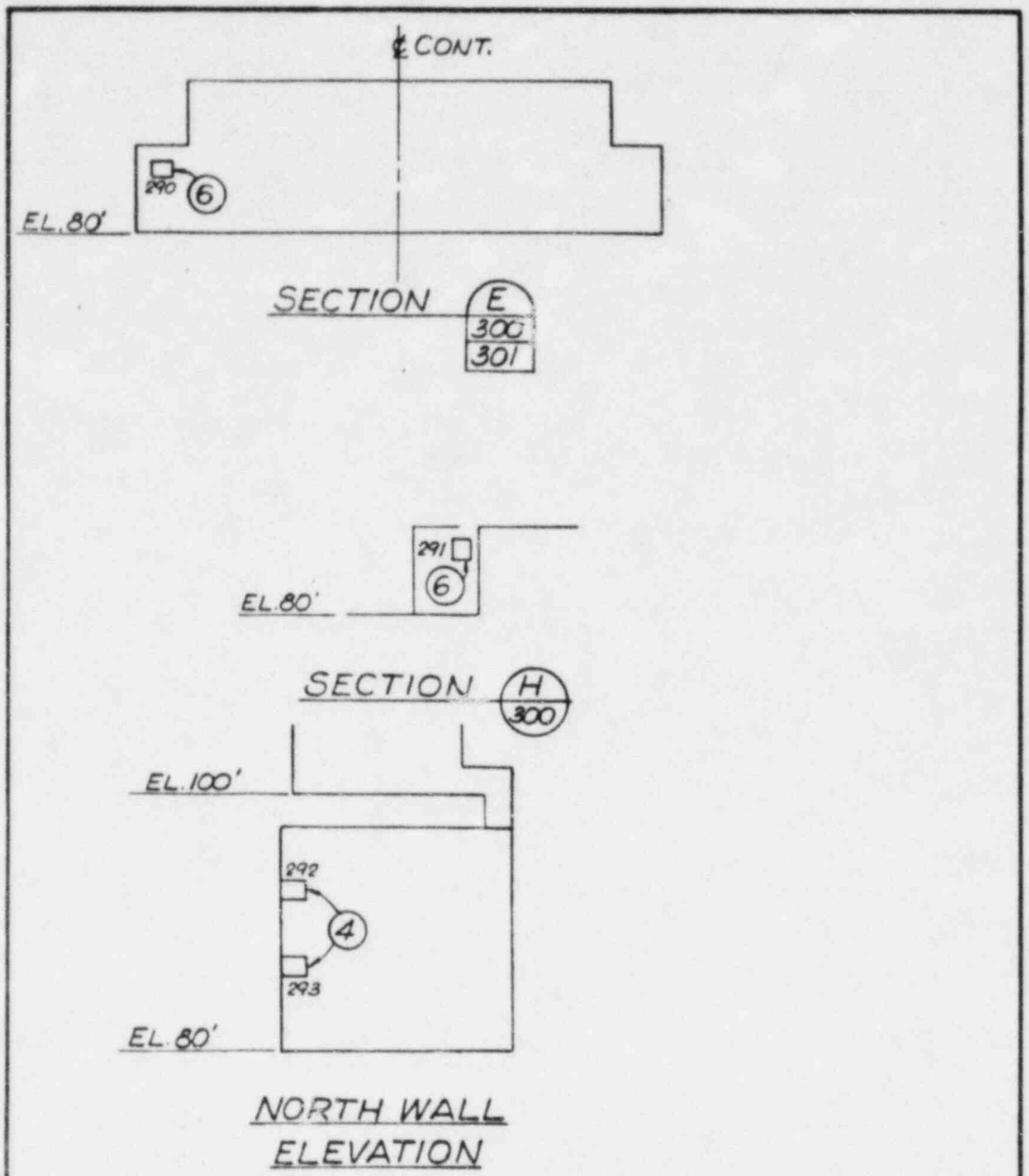
BECHTEL

ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION

SCALE	JOB NO	REF. DRAWING NO	REV
	10407	13-C-ZCS-413	

PF-2063 (10407) 7/77

FIGURE D-17



REVISIONS	NO	DATE	DR	CH'K	DGS	ENG	EGS	CHF ENG	PRJ ENG

BECHTEL

ARIZONA NUCLEAR POWER PROJECT
PALO VERDE NUCLEAR
GENERATING STATION

SCALE	JOB NO	REF. DRAWING NO	REV
	10407	13-C-ZCS-414	

PF-2063 (10407) 7/77

FIGURE D-18

2nd Draft

KEY TO LOCATE EMBEDS ON
FIGURES D-1 THROUGH D-18

	EMBEDS NO. 001-099	EMBEDS NO. 100-199	EMBEDS NO. 200-299	EMBEDS NO. 300-320
00'S	— 7 5 7 5 8 8 5 5 8	5	9	1 1 1 1 1 1 1 1 9 9
10'S	5 5 5 5 5 7 7 7 7 5	7	9 9 9 9 9 9 9 10 10 10	8 8 8 8 8 8 8 8 8 5
20'S	5 15 15 15 15 8 8 16 13 13	7	10	7
30'S	— 8 8 8 8 8 8 3 3 3	7	10 10 10 10 — — — — — —	
40'S	3	7 7 8 8 8 8 8 8 8 8	10 10 10 10 10 10 10 11 11 11	
50'S	3	8	11 11 11 11 11 12 12 12 12 12	
60'S	3 6 6 6 6 6 6 6 6 4	8	12	
70'S	4 4 4 4 4 4 4 5 5 5	8 8 8 9 9 9 9 9 9 9	12 14 14 15 15 15 15 16 16 16	
80'S	5	9	16 16 16 16 16 16 16 16 16 17	
90'S	— (90) 5	9	18 18 18 18 2 2 2 2 2 2	

EXAMPLE: EMBED NO. 289 CAN BE LOCATED ON FIGURE D-17

INSTRUCTIONS:

LOCATE EMBED NO. IN APPROPRIATE "HUNDREDS" COLUMN;
LOCATE EMBED NO. IN APPROPRIATE "TENS" ROW;
LOCATE EMBED NO. IN APPROPRIATE "ONES" POSITION WITHIN THE BLOCK, ENTRY IS THE FIGURE NUMBER IN APPENDIX D.

TYPICAL "ONES" NUMBERING BLOCK

0	1	2	3	4
5	6	7	8	9

FIGURE D-19