**David H. Jones**
Vice President
Engineering

**Southern Nuclear**
**Operating Company, Inc.**
40 Inverness Center Parkway
Birmingham, Alabama 35242

Tel 205.992.5984
Fax 205.992.0341

SOUTHERN COMPANY
*Energy to Serve Your World*℠

June 13, 2008

Docket No.: 50-321

NL-08-0901

U. S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D. C. 20555-0001

Edwin I. Hatch Nuclear Plant – Unit 1
Inservice Inspection Program
Owner's Activity Report for Outage1R23 and Structural Integrity
Design Report for the N9 CRD Nozzle-to-Cap Full Structural Weld Overlay

Ladies and Gentlemen:

Pursuant to the requirements of 10 CFR 50.55a and ASME Section XI Code Case N-532-4, Southern Nuclear Operating Company (SNC) has enclosed the OAR-1 Owner's Activity Report for the 4th Inservice Inspection (ISI) interval for Hatch Nuclear Plant Unit 1. This report includes the applicable Repair and Replacement activities that were completed during the 1R23 Outage (Interval 4, Period 1, Outage 2).

In addition, Enclosure 2 of this report contains the Structural Integrity design report for the N9 CRD nozzle-to-cap full structural weld overlay pursuant to the commitment in Enclosure 2 of SNC letter NL-08-0280, dated February 26, 2008.

This letter contains no NRC commitments. If you have any questions, please advise.

Sincerely,

D. H. Jones
Vice President – Engineering

DHJ/MNW/daj

Enclosures: 1. ASME Section XI Code Case N-532-4 OAR-1 Owner's Activity Report for the 1R23 Outage - 4th Interval ISI Activities (Interval 4, Period 1, Outage 2)
2. Structural Integrity Design Report for the N9 CRD Nozzle-to-Cap Full Structural Weld Overlay

A047
NRR

cc: Southern Nuclear Operating Company
Mr. J. T. Gasser, Executive Vice President
Mr. D. R. Madison, Vice President – Hatch
RTYPE: CHA02.004

U. S. Nuclear Regulatory Commission
Mr. L. A. Reyes, Regional Administrator
Mr. R. E. Martin, NRR Project Manager – Hatch
Mr. J. A. Hickey, Senior Resident Inspector – Hatch

**Edwin I. Hatch Nuclear Plant – Unit 1**

**Enclosure 1**

**ASME Section XI Code Case N-532-4 OAR-1 Owner's Activity Report for the 1R23 Outage - 4th Interval ISI Activities (Interval 4, Period 1, Outage 2)**

# FORM OAR-1 OWNER'S ACTIVITY REPORT

Report Number 1-4-1-2 (Unit 1, 4TH Interval, 1ST Period, 2ND Report)

Owner Southern Nuclear Operating Co, (as agent for Georgia Power Company), 40 Inverness Center Parkway, Birmingham, AL 35242

Plant Edwin I. Hatch Nuclear Plant, P. O. Box 2010, Baxley, Georgia 31513

Unit No. 1 (if applicable) Commercial service date 12/31/75 Refueling outage no. 1R23

Current inspection interval 4TH (1ST, 2ND, 3RD, 4TH, other)

Current inspection period 1ST (1ST, 2ND, 3RD)

Edition and Addenda of Section XI applicable to the inspection plans 2001 Edition with 2003 Addenda

Date and revision of inspection plans 2/6/06, Revision 1

Edition and Addenda of Section XI applicable to repair/replacement activities, if different than the inspection plans Same

Code Cases used: N-532-4 (if applicable)

## CERTIFICATE OF CONFORMANCE

I certify that (a) the statements made in this report are correct; (b) the examinations and tests meet the Inspection Plan as required by the ASME Code, Section XI; and (c) the repair/replacement activities and evaluations supporting the completion of 1R23 (refueling outage number) conform to the requirements of Section XI.

Signed Mark A Ajluni Site Eng. Director Date 6/10/2008
Owner or Owner's Designee, Title

## CERTIFICATE OF INSERVICE INSPECTION

I, the undersigned, holding a valid commission issued by the National Board of Boiler and Pressure Vessel Inspectors and the State or Province of Georgia and employed by HSBCT of Hartford, CT have inspected the items described in this Owner's Activity Report, and state that, to the best of my knowledge and belief, the Owner has performed all activities represented by this report in accordance with the requirements of Section XI.

By signing this certificate neither the Inspector nor his employer makes any warranty, expressed or implied, concerning the repair/replacement activities and evaluation described in this report. Furthermore, neither the Inspector nor his employer shall be liable in any manner for any personal injury or property damage or a loss of any kind arising from or connected with this inspection.

Doug Tatt Commissions GA675
Inspector's Signature National Board, State, Province, and Endorsements

Date 06/10/2008

# ITEMS WITH FLAWS OR RELEVANT CONDITIONS THAT REQUIRED EVALUATION FOR CONTINUED SERVICE

## UNIT 1 Cycle 23 Table 1

| Exam Category and Item Number | Item Description | Evaluation Description |
|---|---|---|
| C-B / C2.21 | Two indications were discovered by scheduled ISI examination (ultrasonic testing (UT)) of RHR Hx 1E11-B001A inlet nozzle to shell weld 1E11-2HX-A-I which exceeded the acceptance criteria of IWC-3511. The first indication has a depth of .12" with a length of .75", and the second indication has a depth of .18" with a length of .80". | The fracture mechanics and fatigue crack growth evaluations were performed based upon Section XI, Appendix A methodology. Following calculation and evaluation, the results of the analyses domonstrate that the crack growth for the remaining 27 years of design life is minimal and that the flaw is acceptable since the calculated allowable flaw is much larger than the final flaw size. Reference SNC Licensing Letter NL-08-0533 dated 5/2/08, Submittal of Flaw Evaluation to the Regulatory Authority, for detailed information regarding flaw analysis. |

# Abstract of Repairs, Replacements, Or Corrective Measures Required For Continued Service

## UNIT 1 Cycle 23 Table 2

| Code Class | Item Description | Description of Work | Date Complete | Repair/ Replacement Plan Number |
|---|---|---|---|---|
| 3 | 18" Piping Support | Replaced missing nut on RHRSW piping support 1E11-RHR-H100 with like for like kind. The adjacent threads to the nut on the support bolt were physically distorted to alleviate concerns of vibrating loose. | 3/2/2008 | 1080499002 |
| 3 | Penetration / Piping Anchor | The complete structure of RHRSW piping anchor penetration 1E11-PENET-25 has not failed, however, the welds which join the seal plate to the piping lugs were found to have linear indications which migrated into the base metal of the face plate. Welds, lugs, and seal plate of penetration replaced due to degraded condition as indicated by PT exams performed. | 3/8/2008 | 1080457901 |

| Code Class | Item Description | Description of Work | Date Complete | Repair/ Replacement Plan Number |
|---|---|---|---|---|
| 1 | RPV Nozzle to Cap / 5.41" | During 1R23 ISI examination of weld 1C11-1CRD-3-R-18A (weld between RPV nozzle N9 and CRD return line cap), a defect (unacceptable flaw) per the criteria of Section XI, IWB-3514.4 was discovered in HAZ of the weld on the N9 nozzle side of the welded joint. For info, the outside diameter of the cap was 5.41". The defect measured 2.3" in length and 60% thru wall in depth (wall thickness of nozzle .74%). In accordance with ISI-ALT-08-01, a FSWOL (full structural weld overlay) was applied to the N9 nozzle - weld - cap welded joint in accordance with WSI drawing 405005. The FSWOL covered approximately 2.5" of the N9 nozzle, 2.5" of the cap, and the entire width of the weld between them (approximately 1.5"). Reference SNC Licensing letter NL-08-0280 for submittal to NRC of ISI-ALT-08-01, and reference SNC Licensing letter NL-08-0333 for receipt of verbal NRC approval for implementationReference CR 2008102379. Acceptable per IWA-4221(c), IWA-4224.1(a), and IWA-4311. | 3/5/2008 | 1080444902 |
| 3 | 18" Piping Support | Repaired/modified RHRSW piping support 1E11-RHR-H291 by eliminating a base plate attached to wall (anchor bolts had failed to restrain) and installing new tube steel welded to building structure. This is being performed due to broken rigid strut. Cause of failure was due to excessive flow induced piping vibration. Reference CR 2008101507 and MDC 1080402201. | 3/1/2008 | 1080402202 |

| Code Class | Item Description | Description of Work | Date Complete | Repair/ Replacement Plan Number |
|---|---|---|---|---|
| 3 | 18" Piping Strut | Replaced broken RHRSW piping strut 1E11-RHR-H98 with a more readily available strut per ED 1080444101. | 2/27/2008 | 1080299202 |
| 3 | 6" Expansion Joint | Replaced PSW expansion joint 1P41-D001A due to leakage noted during area walkdown thru pin hole leak. The expansion joint comprises a portion of the PSW inlet to the 1C EDG heat exchangers. Reference CR 2007104124 & CR 2007104175. Per ED 1070879701. Acceptable per IWA-4223(a). | 4/12/2007 | 1070875801 |

| Code Class | Item Description | Description of Work | Date Complete | Repair/ Replacement Plan Number |
|---|---|---|---|---|
| 3 | PSW Seismic Restraint | Due to areas of degradation noted on welds of upper seismic restraint 1P41-C001A-S02 for PSW pump 1P41-C001A, a Temp Mod 1-06-011 was implemented to return the support to its intended design function in order to maintain structural integrity. The temp mod consisted of a bracket being fabricated out of CS plate (A-36) which will be bolted to the existing restraint and plate webbing of the restraint. The bracket was located on the bottom side of the restraint webbing with a supplemental "bar" washer located on the top side of the restraint. Bolt holes were drilled in the existing restraint webbing. Additionally, longer bolts were utilized for fastening the collar of the seimic restraint to the structural bracket attached to the Intake Structure. Temp Mod 1-06-011 was made permanent by MDC 1061078701. Reference CR 2006104774. | 4/28/2006 | 1061067001 |
| | 4" Gate Valve | Replaced PSW valve 1P41-F005 due to internals degradation and wear. Reference CR 2006103113. Acceptable per IWA-4223(a). | 2/25/2008 | 1060745001 |

| Code Class | Item Description | Description of Work | Date Complete | Repair/ Replacement Plan Number |
|---|---|---|---|---|
| 3 | 4" Gate Valve | Replaced PSW valve 1P41-F1084 due to normal degradation and leak by per ED 1071378801. Reference CR 2005102789 and CR 2008101821. Acceptable per IWA-4223(a). | 2/22/2008 | 1050609202 |
| 3 | RHRSW Pump Seismic Restrain | Replaced RHRSW pump column seismic restraint 1E11-C001D-S02 and bolting which had degraded due to normal environmental conditions. Reference CR 2004110316. Acceptable per IWA-4224.1(a). | 10/19/2007 | 1042679301 |

**Edwin I. Hatch Nuclear Plant – Unit 1**

**Enclosure 2**

**Structural Integrity Design Report for the**
**N9 CRD Nozzle-to-Cap Full Structural Weld Overlay**

Report No. 0800350.401.R1
Project No. 0800350
June 2008
☒ Q ☐ Non-Q

# Weld Overlay Design Report For the Hatch Nuclear Plant Unit 1 CRD Return Line Capped Nozzle (N9) Nozzle-to-Cap Weld

*Prepared for:*

Southern Nuclear Operating Company
PO 6075673, Change Order 1

*Prepared by:*


Structural Integrity Associates, Inc.
San Jose, California


*Prepared by:* _____ Date: 6/10/08
Marcos Legaspi Herrera, P.E.

*Reviewed by:* _____ Date: 6/10/08
Shu S. Tang, P.E.

*Reviewed by:* _____ Date: 6/10/08
Anthony J. Giannuzzi, PhD, P.E.

*Approved by:* _____ Date: 6/10/08
Marcos Legaspi Herrera, P.E.

Structural Integrity Associates, Inc.

## REVISION CONTROL SHEET

Document Number: 0800350.401

Title: Weld Overlay Design Report For the Hatch Nuclear Plant Unit 1 CRD Return Line Capped Nozzle (N9) Nozzle-to-Cap Weld

Client: Southern Nuclear Operating Company

SI Project Number: 0800350

| Section | Pages | Revision | Date | Comments |
|---|---|---|---|---|
| - | i – vi | 0 | 5/27/08 | Initial Issue |
| 1.0 | 1-1 – 1-2 | | | |
| 2.0 | 2-1 – 2-3 | | | |
| 3.0 | 3-1 – 3-22 | | | |
| 4.0 | 4-1 | | | |
| 5.0 | 5-1 – 5-7 | | | |
| 6.0 | 6-1 – 6-7 | | | |
| 7.0 | 7-1 | | | |
| 8.0 | 8-1 – 8-3 | | | |
| App. A | A-1 – A-3 | | | |
| 1.0 | 1-1 – 1-2 | 1 | 6/10/08 | Revised Issue |
| 2.0 | 2-1 | | | |
| 5.0 | 5-6 – 5-7 | | | |
| 6.0 | 6-2 | | | |
| 8.0 | 8-1 | | | |

Professional Engineer Certification Statement

"Weld Overlay Design Report for the Hatch Nuclear Plant Unit 1 CRD Return Line Capped Nozzle (N9) Nozzle-to-Cap Weld."

I, Marcos Legaspi Herrera, being a duly licensed professional engineer under the laws of the State of California, certify that this document was reviewed by me, and that this document meets the requirements of ASME Section XI (as modified by Southern Nuclear Operating Company alternative ISI-ALT-08-01, Version 1.0) and Section III (Editions and Addenda as referenced in the individual calculations), all as applicable to the specific scope of this report. This report is supplementary to the governing Code Design Reports for the systems and components described herein, and does not invalidate those reports. I further certify that this document is correct and complete to the best of my knowledge and belief, and that I am competent to review this document.

Marcos Legaspi Herrera, P.E.
State of California
Registration Number: M21337
June 10, 2008

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## 1.0 INTRODUCTION

During the February 2008 Outage at the Hatch Nuclear Plant - Unit 1 (HNP-1), ultrasonic examination (UT) revealed an indication in the capped CRD Return Line (CRDRL) Nozzle-to-Cap weld (N9) that required weld overlay repair. The indication was believed to be due to intergranular stress corrosion cracking (IGSCC) which has been an issue for boiling water reactors (BWR) bimetallic Alloy 82/182 welds and sensitized stainless steels. No other indications were identified during the outage. A weld overlay (WOL) was applied and the design is shown in Reference 1. The design analysis of the weld overlay for the CRDRL nozzle-to-cap weld is provided in this report. The indication at the CRDRL nozzle-to-cap weld was 2.3 inches in length and approximately 60% through the wall.

Weld overlays were first applied in 1982 as a repair for IGSCC in stainless steel piping. The purpose of repairs of this type was to assure that the pressure boundary satisfied ASME requirements. In the past, weld overlays were generally applied using the automatic gas tungsten arc welding (GTAW) process with Type 308L welding filler material. Since approximately 1998, many weld overlays have been applied using Alloy 52 family of materials, improved nickel based alloys with high SCC resistance. Application of weld overlays typically is performed with water backing on the inside of the weld to be repaired, which produces a through-wall temperature gradient. The temperature difference, coupled with the normally occurring shrinkage of the overlay weld metal, has been shown to produce a highly favorable residual stress distribution in the pipe wall.

Since the application of the first overlays, significant field, analytical, and experimental evidence has been assembled which verifies that weld overlays are long term repairs. The bases for this include the inherent IGSCC resistance of the weld metal typically used for weld overlay application (Alloy 52 family of materials and Type 308L), the compressive residual stresses produced in the flawed component by the weld overlay process, advances in the inspectability of weld overlay repaired components and experimental demonstrations of the strength of weld overlays. The weld overlay repair technique for IGSCC flawed pipe welds is based upon application of weld metal to the outside pipe surface and to either side of the flawed location,

extending the full circumference of the pipe/section circumferentially. The weld overlay repair performs the following:

1. Provide structural reinforcement of the flawed location, such that adequate load carrying capability is provided, either in the overlay by itself, or in some combination of the overlay and the original pipe wall thickness.
2. Provide a barrier of IGSCC-resistant material to prevent IGSCC propagation into the overlay weld metal.
3. Produce a compressive residual stress distribution in at least the inner portion of the pipe wall, which will inhibit IGSCC initiation and propagation in the original pipe joint.
4. Prevent local leakage from small axial flaws.

In the case of the weld overlay repair to the CRD Return Line (N9) Nozzle-to-Cap weld at HNP-1, the weld overlay provides a full replacement pressure boundary, not requiring the original pipe wall to carry any of the load. It should be noted that HNP-1 has been injecting hydrogen (HWC) since September of 1987 and is expected to continue hydrogen injection in the future along with noble metal injection (NMC). This additional activity provides another potential mitigation measure (besides the beneficial weld overlay residual stress) to mitigate the nozzle-to-cap weld against IGSCC. It should be noted, however, that since this location is essentially stagnant, the HWC or NMC treatment may not be completely effective.

## 2.0 ASSESSMENT OF WELD OVERLAY REPAIR

The WOL was performed in accordance with the ASME Code. The repair meets the requirements of Section XI of the ASME Code, 2001 Edition through 2003 Addenda [2], as modified by Southern Nuclear Operating Company (SNC) alternative ISI-ALT-08-01, Version 1.0. The 2001 Edition through 2003 Addenda of Section XI of Code does not provide for a means of a repair without removal of the flaw or temper bead welding without removal of the weld bead.

Code Case N-504-2 and N-638-1 received regulatory approval as noted in Regulatory Guide 1.147, Revision 15. However, Code Case N-504-2 provides alternative rules for overlay of Class 1, 2, and 3 austenitic stainless steel piping and N-638-1 provides for a temper bead welding of a cavity. Therefore, the use of these two cases for application of a weld overlay repair over an Alloy 82/182 weld is not permissible without NRC approval. In lieu of obtaining approval to use N-504-2 and N-638-1 for the repair of the CRD cap, SNC elected to use ISI-ALT-08-01 which was developed from the technical requirements specified in Code Case N-740. This alternative is comprehensive and provides the details for the design of the overlay, the acceptance examinations and tests, the fatigue analysis requirements, and flaw growth requirements. Comparison of the technical requirements of ISI-ALT-08-01 versus those in N-504-2 and N-638-1 are provided in the appendices to ISI-ALT-08-01.

In this section, compliance with the requirements of Section XI of the ASME Code is documented, as are the requirements of ISI-ALT-08-01. The applied WOL repair is demonstrated to be fully compliant with USNRC Generic Letter 88-01 [3], NUREG-0313, Revision 2 [4] and with Section XI of the Code as modified by ISI-ALT-08-01.

### 2.1 Weld Overlay Repair and Design Details

The WOL applied during the February 2008 outage was performed to satisfy the requirements of IWA-4000 in the Edition and Addenda of Section XI applicable to the plant in-service inspection program or later Edition and Addenda as modified by ISI-ALT-08-01. The Repair Plan also specifies the requirements of IWA-4150 of Section XI, as modified by ISI-ALT-08-01.

1. Weld Materials

Per the design shown in Appendix A, Alloy ERNiCrFe-7A nickel base weld metal (Alloy 52M) was used consistent with the Alternative [5] for machine Gas Tungsten Arc Welding (GTAW) of the 360° WOL layers.

2. WOL Design Requirements

The weld overlay repair meets the requirements of the 2001 Edition through 2003 Addenda of Section XI [2] of the ASME Code, as modified by ISI-ALT-08-01. The WOL design is provided in Reference 1.

The WOL design for the CRDRL nozzle-to-cap weld meets the design requirements of Section IWB-3640 of Section XI of the ASME Code as specified in ISI-ALT-08-01. Reference 1 documents the overlay design. The WOL thicknesses were designed assuming a 100% through-original-pipe-wall by 360° fully circumferential indication for the applicable normal/upset and emergency/faulted conditions. Appendix A of this report shows the weld overlay design. Reference 1 also presents a calculation for the WOL length on each side of the weld. The WOL design drawings specify a 45° taper at either end of the overlay.

Note that the design analysis is based on the as-built dimensions. The as-built dimensions are shown in Figure 2-1 [9].

3. Inspections for WOL Applications

As per the requirements of ISI-ALT-08-01, the following inspections were performed:

(a) Exam of existing weld surface and accept as clean prior to WOL application
(b) A surface exam (PT) of final repaired area if repair performed
(c) UT of completed WOL repair

Table 2 - Post Overlay Data

| Punch Mark Locations | K post - Between Punch Marks | M - Nozzle Punch Mark to Break | P - Cap Punch Mark to Break | Q - Cap Punch Mark to Toe of Weld | R - Nozzle Punch Mark to End of Weld | A post Diameter @ Length D (8) | B post Diameter @ Length H (8) | Angle at EOW-N 45° MAX | Angle at EOW-C 45° MAX |
|---|---|---|---|---|---|---|---|---|---|
| M&TE / INITIALS | ② / [illegible] | ② / [illegible] | ② / [illegible] | ② / [illegible] | ② / [illegible] | ② / [illegible] | ② / [illegible] | NA / [illegible] | NA / [illegible] |
| 45° | 8.74" | 1.05" | .785" | .40" | .63" | 5.95" | 5.99" | < 45° | < 45° |
| 135° | 8.62" | 1.06" | .610" | .30" | .70" | 5.93" | 5.96" | < 45° | < 45° |
| 225° | 8.71" | 1.11" | .87" | .40" | .67" | 5.95" | 5.99" | < 45° | < 45° |
| 315° | 8.72" | 1.08" | .803" | ~~.56~~ .79 | .60" | 5.73" | 5.96" | < 45° | < 45° |

3-4-08

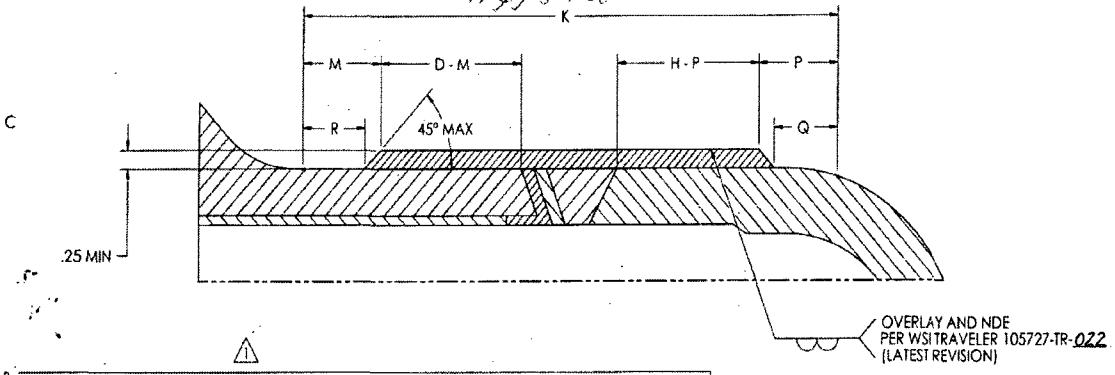



Table 3 - Final Calculations (Includes Any Thickness from Dilution and/or Buffer Layers)

| Punch Mark Locations | WOL Length on Nozzle 2.44 ≤ (D - M) ≤ 3.00 | WOL Length on Cap 2.29 ≤ (H - P) ≤ 3.00 | Shrinkage (K pre - K post) | Thickness over Nozzle @ A (A post - A pre) / 2 (.25 ≤ A) (8) | Thickness over Pipe @ B (B post - B pre) /2 (.25 ≤ B) (8) |
|---|---|---|---|---|---|
| 45° | 2.53" | 2.52" | .03" | .35" | .34" |
| 135° | 2.44" | 2.64" | .07" | .34" | ~~.35~~ .31 |
| 225° | 2.54" | 2.47" | .14" | .35" | .34" |
| 315° | 2.50" | 2.56" | .03" | .34" | ~~.33~~ .31 |

PM 3-4-08

PM 3-4-08

Nozzle ID: N9

| TRAVELER | 105727-TR-022, R0 |
|---|---|

MATERIAL

WELDING SERVICES INC.

CONSTRUCTION DRAWING

HATCH, N9 NOZZLE

405005

DO NOT SCALE DRAWING

2 OF 2

Figure 2-1: As-Built Weld Overlay Dimensions

## 3.0 RESIDUAL STRESS ANALYSIS

### 3.1 Background

In addition to providing structural reinforcement to the flawed location to meet ASME Code safety margins, the weld overlay produces beneficial residual stress that supports the mitigation of IGSCC. The weld overlay approach has been used in the BWR industry on several hundred occasions. There have been no reports of crack extension after application of the weld overlay. Thus, the compressive stress caused by the weld overlay has been effective in mitigating crack growth in BWRs, confirming its use as a long term repair.

The weld residual stress was determined for the weld overlay design. To obtain a bounding assessment of the impact of the weld overlay on the flawed location, the residual stress assessment must consider residual stresses that existed prior to application of the overlay. Thus, the weld overlay analysis should consider residual stresses that are present due to the as-welded condition and any machining, weld repairs or stress improvement that may have previously occurred.

The original fabrication of welds in some instances involves weld repairs. This is especially true for bimetallic welds with P3 materials, in which case several steps are taken to avoid post weld heat treatment after welding. It is assumed that there is a strong possibility that weld repairs could have been performed on this weld during this evolution, even though plant records could not definitely determine the extent of any repair. Due to the significant uncertainty in the initial conditions, the goal was to determine the general effect of the weld overlay on a severe as-welded stress distribution (significant tensile stress on the inside surface) that promotes IGSCC. Also, this weld location was subjected to the Mechanical Stress Improvement Process (MSIP) in 1993 [6].

For this analysis, the following sequence was used in the analysis:

1) Perform weld repair assuming 360° fully circumferential repair
2) Perform MSIP application
3) Perform Weld Overlay

## 3.2 Technical Approach

### *3.2.1 MSIP*

MSIP was applied in 1993 and details of the application are provided in Reference 6. The MSIP application region was 0.75 inches to 2.00 inches from the weld centerline. After the MSIP application, the final pipe circumference was 17 inches and the change in pipe radius was 0.12 inches.

The pressure was applied to the MSIP area using a trial and error process until the resulting changes in diameter matched the as measured information. The analysis performed to simulate the MSIP effect was elastic-plastic using the same finite element model as the weld repair and weld overlay analysis described in the following sections.

### *3.2.2 Welding*

The residual stress due to welding is controlled by the welding parameters, thermal transients due to application of the welding process, temperature dependent material properties, and elastic-plastic stress reversals. The analytical technique uses finite element analysis to simulate the multipass weld repair and weld overlay process. In order to reduce computational time, lumped weld bead passes were used in this evaluation. The finite element analysis performed for the nozzle-to-cap weld is presented in Reference 7.

A two-dimensional, axisymmetric finite element model was developed using the ANSYS software package [8]. The finite element model consists of local portion of the vessel shell, cladding, nozzle, cap, nozzle-to-cap weld and weld butter, an assumed ID repair of the nozzle-to-cap weld, and the weld overlay repair.

A thermal analysis was then performed to simulate the welding process of the repair and the welding process of the overlay. A non-linear, elastic-plastic stress analysis was then performed to calculate the resultant residual stress state at various points.

The analysis consists of a thermal pass to determine the temperature response of the model to each individual lumped weld pass as it is added in sequence, followed by an elastic-plastic stress pass to calculate the residual stress due to the temperature cycling from the application of each lumped weld pass. Since the residual stress is a function of the welding history, the stress pass for each lumped pass was applied to the residual stress field induced from all previously applied weld passes.

For the thermal analyses, a relatively low convection heat transfer coefficient of 5.0 Btu/hr-ft$^2$-°F was conservatively assumed at the surface of the model to simulate a water condition inside the pipe. Lower heat transfer rates in welds produce higher temperatures on the inner portion of the pipe which results in lower residual stress. The value of 5.0 Btu/hr-ft$^2$-°F is conservative as it results in under predicting the beneficial residual stresses from the weld overlay.

After the weld overlay was completed, the model was allowed to cool to a uniform 70°F, then heated up to the operating temperature in order to obtain the residual stresses at room and operating temperature.

### 3.3 Consideration of Weld Repairs and Welding Parameters

Because details of any weld repairs may not be available, a bounding weld repair assumption was made for this evaluation. The approach used to assess the effectiveness of the weld overlay and determination of the weld residual stress was to perform the analytical evaluation of the weld overlay using the residual stress from a 360° fully circumferential ID weld repair and subsequent MSIP as the initial condition. ID weld repairs are known to develop severe tensile residual stress fields and can also provide for flaw initiation sites due to grinding and weld defects. Thus, a fully circumferential 50% of wall thickness ID repair was simulated and the resulting stress field is used as the initial stress state for the weld overlay residual stress analysis.

The weld repair is included in this analysis to show that the tensile stresses generated by it are mitigated by MSIP and the WOL. The weld repair was assumed to have a depth of about 50% of the original pipe wall thickness. It covers part of the weld butter and original weld. Four weld layers are assumed for the weld repair. Three weld layers are assumed for the weld overlay.

The maximum interpass temperature was assumed to be 350°F for both the weld repair and the weld overlay. The overlay welding was modeled as progressing from the cap to the nozzle. A thermal efficiency of 70% was assumed for both the weld repair and overlay welding processes.

The assumed heat input for the weld repair and weld overlay is presented in Table 3-1. Reference 7 provides the details for the welding parameters of the weld repair and weld overlay.

### 3.4 Finite Element Model

The geometry of the capped CRDRL nozzle is shown in Figure 3-1. The dimensions of the weld overlay repair are shown in Appendix A and the as-built dimensions are documented in Reference 9 and the MSIP information is documented in Reference 10. This information was used to develop a finite element model for the residual stress analysis. The resulting finite element model for the residual stress evaluation, developed using the ANSYS finite element software [8], is shown in Figure 3-2. The model is built and analyzed using axisymmetric element types for the thermal stress analyses. The weld bead deposits are simulated using the element "birth and death" feature in ANSYS.

The length of the model on the vessel side is such that there is sufficient length to avoid any end effects. A roller boundary condition is applied at the thick vessel wall end of the model in the stress pass, as shown in Figure 3-3.

As discussed in Section 3.3, the as-modeled weld repair geometry used in this calculation is assumed since the actual repair is not defined. The assumed configuration for the weld repair is as follows. The weld repair is modeled to be 50% of wall in depth from the inside surface. The repair is conservatively assumed to be a fully circumferential repair.

Per as-built dimensions in Reference 9, the minimum thickness of the weld overlay is 0.31 inches which includes the first layer. The as-modeled thickness of the WOL is 0.31 inches, inclusive of the dilution layer. The as-modeled length on the cap side (measured from the weld

edge on the OD) was 2.47 inches and on the nozzle side 2.44 inches (measured from the butter to nozzle interface on the OD).

Figure 3-4 shows the area where the pressure was applied to simulate the MSIP loading.

## 3.5 Material Properties

The materials of the various components of the model are listed below:

- Vessel Shell: SA-533, Class 1, Gr. B
- Vessel Cladding: TP 308L and TP 309
- CRDRL Nozzle: SA-508, Class 2
- CRDRL Nozzle Cap Alloy 600
- Nozzle Weld Butter: Alloy 182
- Nozzle-to-Cap Weld: Alloy 82/182
- Nozzle-to-Cap Weld ID Repair: Alloy 82/182
- Weld Overlay Repair: Alloy 52M

The temperature dependent material property values used are obtained from Reference 11. Alloy 600 (N06600) properties are used for the cap weld repair (Alloy 82) and weld butter (Alloy 182). Alloy 690 (N06690) properties are used for the weld overlay (Alloy 52M). The material property values are shown in Table 3-2. Type 304 SS properties are used for the cladding (TP308L and TP309).

Bilinear kinematic hardening material behavior, which requires yield stress and tangent modulus, is used. These are shown in Table 3-3. The temperature-dependent material yield stresses and tangent modulus are obtained from References 12 and 13.

## 3.6 Weld Repair and Overlay Stress Analysis Method

### *3.6.1 Weld Repair Phase*

The analyses consist of a thermal pass to determine the temperature distribution due to the welding process, and an elastic-plastic stress pass to calculate the residual stress due to the temperature cycling. Each stress pass is performed using the stress-strain field caused by the previously applied passes, since this is a non-linear path-dependent problem.

Heat input is calculated as follows. Heat generation rate ($\dot{Q}$) is applied to the weld segments in units of energy per volume per second. This is calculated by the weld heat input divided by the bead area and by the heating time used in the analysis.

### *3.6.2 Weld Overlay Phase*

The same methodology described in Section 3.6.1 is utilized for the WOL process. At the end of the WOL application, the nozzle is allowed to cool to 70°F. Residual stresses are obtained for 70°F after the WOL is complete.

## 3.7 Residual Stress Analysis Results

### *3.7.1 Post Weld Repair*

Figures 3-5(a) and 3-5(b) show the axial and hoop residual stress distribution for the post-weld repair condition at 70°F, respectively. The axial direction and the hoop direction are with respect to the global coordinate system, axial is (SY) and hoop is (SZ). It is shown that extensive tensile axial and hoop residual stresses occur along the inside surface of the nozzle in the vicinity of the ID weld repair. These high tensile stresses promote IGSCC provided the material and environmental conditions for IGSCC also exist.

### *3.7.2 Post MSIP*

Figures 3-6(a) and 3-6(b) show the axial and hoop residual stress distribution for the post MSIP condition. Note that the axial stress is significantly compressive. However, there exists some tensile hoop stress on the inside portion of the weld.

### *3.7.3 Post Weld Overlay*

Figures 3-7(a) and 3-7(b) show the axial and hoop residual stress distribution for the post-WOL condition at 70°F, respectively. Figures 3-7(a) and 3-7(b) depict the resultant residual and operating stress distributions for the post-WOL configuration at room temperature.

Figures 3-8, 3-9 and 3-10 are inside diameter (ID) surface stress plots for the axial and hoop directions as a function of distance from the ID weld repair centerline for the post weld repair, post MSIP and post weld overlay, respectively. As can be seen the residual stress after weld overlay does result in compressive stress along the inside surface where SCC susceptible material is present.

Table 3-1: Welding Heat Input Parameters

| | Heat Input KJ/in |
|---|---|
| Weld repair - 1st layer | 25 |
| Weld repair - subsequent layers | 28 |
| Weld overlay - 1st layer | 25 |
| Weld overlay - subsequent layers | 35 |

Table 3-2: Temperature Dependent Material Properties

(a) Reactor Vessel, SA-533 Grade B Class 1

| Temperature (°F) | Young's Modulus $x10^6$(psi) | Thermal Coefficient of Expansion $x10^{-6}$(/°F) | Conductivity $x10^{-4}$(Btu/in-°F-sec) | Specific Heat (Btu/lbm-°F) |
|---|---|---|---|---|
| 70 | 29.0 | 7.00 | 5.49 | 0.105 |
| 200 | 28.5 | 7.30 | 5.44 | 0.113 |
| 400 | 27.6 | 7.60 | 5.35 | 0.124 |
| 600 | 26.3 | 7.80 | 5.14 | 0.135 |
| 700 | 25.3 | 7.90 | 5.00 | 0.140 |
| 800 | 23.9 | 8.00 | 4.86 | 0.147 |
| 1000 | 20.1 | 8.20 | 4.56 | 0.163 |
| 1200 | 15.3 | 8.40 | 4.24 | 0.187 |
| 1400 | 11.9 | 8.50 | 3.54 | 0.405 |
| 1600 | 7.5 | 8.50 | 3.50 | 0.154 |
| 1800 | 5.1 | 8.50 | 3.50 | 0.154 |
| 2000 | 1.7 | 8.50 | 3.50 | 0.154 |
| 2100 | 0.1 | 8.50 | 3.50 | 0.154 |
| 2500 | 0.1 | 8.50 | 3.50 | 0.154 |
| 3000 | 0.1 | 8.50 | 3.50 | 0.154 |

(b) Nozzle Forging, SA-508 Class 2

| Temperature (°F) | Young's Modulus $x10^6$(psi) | Thermal Coefficient of Expansion $x10^{-6}$(/°F) | Conductivity $x10^{-4}$(Btu/in-°F-sec) | Specific Heat (Btu/lbm-°F) |
|---|---|---|---|---|
| 70 | 27.8 | 6.40 | 5.44 | 0.105 |
| 200 | 27.1 | 6.70 | 5.46 | 0.114 |
| 400 | 26.1 | 7.10 | 5.35 | 0.125 |
| 600 | 25.2 | 7.40 | 5.14 | 0.135 |
| 700 | 24.6 | 7.60 | 5.00 | 0.140 |
| 800 | 23.9 | 7.80 | 4.86 | 0.147 |
| 1000 | 22.4 | 8.10 | 4.56 | 0.163 |
| 1200 | 20.4 | 8.30 | 4.21 | 0.186 |
| 1400 | 17.7 | 8.40 | 3.54 | 0.406 |
| 1600 | 12.9 | 8.40 | 3.50 | 0.154 |
| 1800 | 7.9 | 8.40 | 3.50 | 0.154 |
| 2000 | 2.9 | 8.40 | 3.50 | 0.154 |
| 2100 | 0.1 | 8.40 | 3.50 | 0.154 |
| 2500 | 0.1 | 8.40 | 3.50 | 0.154 |
| 3000 | 0.1 | 8.40 | 3.50 | 0.154 |

Table 3-2: Material Properties (cont'd)

(c) Alloy 600 and Alloy 82/182

| Temperature (°F) | Young's Modulus $x10^6$(psi) | Thermal Coefficient of Expansion $x10^{-6}$(/°F) | Conductivity $x10^{-4}$(Btu/in-°F-sec) | Specific Heat (Btu/lbm-°F) |
|---|---|---|---|---|
| 70 | 31.0 | 6.80 | 1.99 | 0.108 |
| 200 | 30.2 | 7.10 | 2.11 | 0.113 |
| 400 | 29.5 | 7.50 | 2.34 | 0.118 |
| 600 | 28.7 | 7.80 | 2.57 | 0.123 |
| 700 | 28.2 | 7.90 | 2.69 | 0.125 |
| 800 | 27.6 | 8.20 | 2.80 | 0.128 |
| 1000 | 26.4 | 8.30 | 3.06 | 0.134 |
| 1200 | 25.3 | 8.60 | 3.31 | 0.141 |
| 1400 | 23.9 | 8.90 | 3.59 | 0.147 |
| 1600 | 20.0 | 9.00 | 3.70 | 0.148 |
| 1800 | 12.4 | 9.00 | 3.70 | 0.148 |
| 2000 | 4.8 | 9.00 | 3.70 | 0.148 |
| 2100 | 0.1 | 9.00 | 3.70 | 0.148 |
| 2500 | 0.1 | 9.00 | 3.70 | 0.148 |
| 3000 | 0.1 | 9.00 | 3.70 | 0.148 |

(d) Cladding,SA-213 Type 304

| Temperature (°F) | Young's Modulus $x10^6$(psi) | Thermal Coefficient of Expansion $x10^{-6}$(/°F) | Conductivity $x10^{-4}$(Btu/in-°F-sec) | Specific Heat (Btu/lbm-°F) |
|---|---|---|---|---|
| 70 | 28.3 | 8.5 | 1.99 | 0.116 |
| 200 | 27.6 | 8.9 | 2.15 | 0.122 |
| 400 | 26.5 | 9.5 | 2.41 | 0.129 |
| 600 | 25.3 | 9.8 | 2.62 | 0.133 |
| 700 | 24.8 | 10.1 | 2.73 | 0.135 |
| 800 | 24.1 | 10.1 | 2.82 | 0.136 |
| 1000 | 22.8 | 10.3 | 3.06 | 0.139 |
| 1200 | 21.2 | 10.6 | 3.24 | 0.141 |
| 1400 | 19.2 | 10.8 | 3.45 | 0.144 |
| 1600 | 15.2 | 10.8 | 3.54 | 0.145 |
| 1800 | 9.2 | 10.8 | 3.54 | 0.145 |
| 2000 | 3.2 | 10.8 | 3.54 | 0.145 |
| 2100 | 0.1 | 10.8 | 3.54 | 0.145 |
| 2500 | 0.1 | 10.8 | 3.54 | 0.145 |
| 3000 | 0.1 | 10.8 | 3.54 | 0.145 |

Table 3-2: Material Properties (cont'd)

(e) Weld Overlay Alloy 52M

| Temperature (°F) | Young's Modulus $x10^6$(psi) | Thermal Coefficient of Expansion $x10^{-6}$(/°F) | Conductivity $x10^{-4}$(Btu/in-°F-sec) | Specific Heat (Btu/lbm-°F) |
|---|---|---|---|---|
| 70 | 30.3 | 7.7 | 1.57 | 0.107 |
| 200 | 29.5 | 7.9 | 1.76 | 0.112 |
| 400 | 28.8 | 8.0 | 2.04 | 0.118 |
| 600 | 28.1 | 8.2 | 2.31 | 0.123 |
| 700 | 27.6 | 8.3 | 2.45 | 0.125 |
| 800 | 27.0 | 8.3 | 2.59 | 0.127 |
| 1000 | 25.8 | 8.3 | 2.89 | 0.132 |
| 1200 | 24.7 | 8.3 | 3.17 | 0.137 |
| 1400 | 23.3 | 8.3 | 3.45 | 0.144 |
| 1600 | 19.5 | 8.3 | 3.59 | 0.147 |
| 1800 | 12.1 | 8.3 | 3.59 | 0.147 |
| 2000 | 4.7 | 8.3 | 3.59. | 0.147 |
| 2100 | 0.1 | 8.3 | 3.59 | 0.147 |
| 2500 | 0.1 | 8.3 | 3.59 | 0.147 |
| 3000 | 0.1 | 8.3 | 3.59 | 0.147 |

Table 3-3: Material Yield Strengths (YS) and Tangent Moduli (TM)

| Material | Temperature (°F) | Yield Strength (ksi) | Tangent Modulus (ksi) |
|---|---|---|---|
| Vessel SA-533 Grade B Class 1 | 70 | 63.6 | 191.9 |
| | 500 | 56.3 | 132.3 |
| | 1000 | 47.3 | 79.5 |
| | 1300 | 36.5 | 49.6 |
| | 1600 | 24.2 | 30.2 |
| | 2500 | 2.0 | 5.0 |
| Nozzle SA-508 Class 2 | 70 | 63.6 | 191.9 |
| | 500 | 56.3 | 132.3 |
| | 1000 | 47.3 | 79.5 |
| | 1300 | 36.5 | 49.6 |
| | 1600 | 24.2 | 30.2 |
| | 2500 | 2.0 | 5.0 |
| Inconel 600/82/182 | 70 | 53.9 | 531.1 |
| | 500 | 46.0 | 361.5 |
| | 1000 | 45.7 | 216.1 |
| | 1300 | 41.6 | 138.6 |
| | 1600 | 24.7 | 80.5 |
| | 2500 | 2.0 | 5.0 |
| Cladding SS | 70 | 35.8 | 531.1 |
| | 500 | 26.5 | 361.5 |
| | 1000 | 19.1 | 216.1 |
| | 1300 | 15.5 | 138.6 |
| | 1600 | 10.5 | 80.5 |
| | 2500 | 2.0 | 5.0 |
| Alloy 52M | 70 | 49.2 | 564.3 |
| | 500 | 36.4 | 384.1 |
| | 1000 | 32.7 | 229.6 |
| | 1300 | 30.5 | 147.3 |
| | 1600 | 27.0 | 85.5 |
| | 2500 | 2.0 | 5.0 |

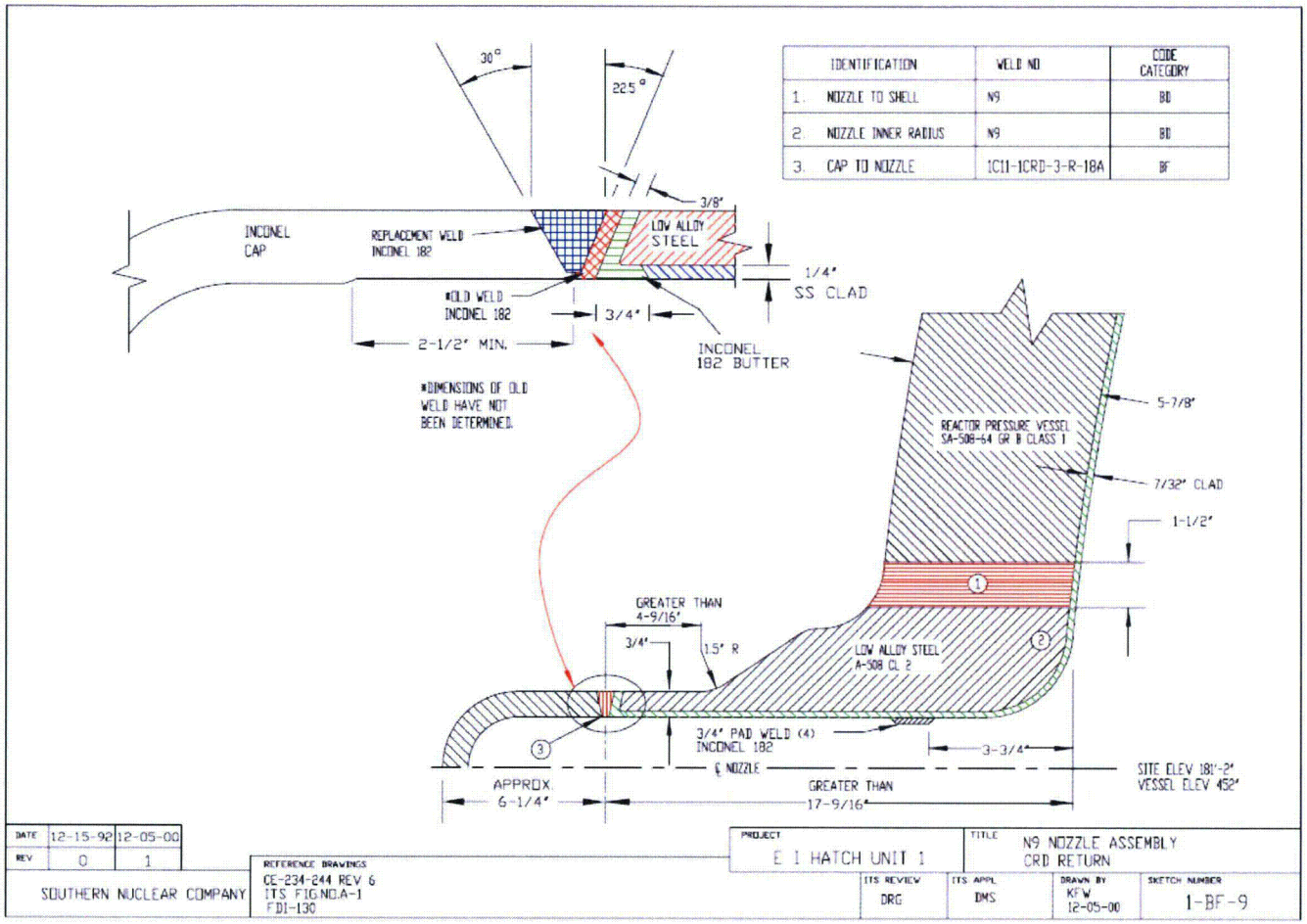



Figure 3-1: Capped N9 Nozzle

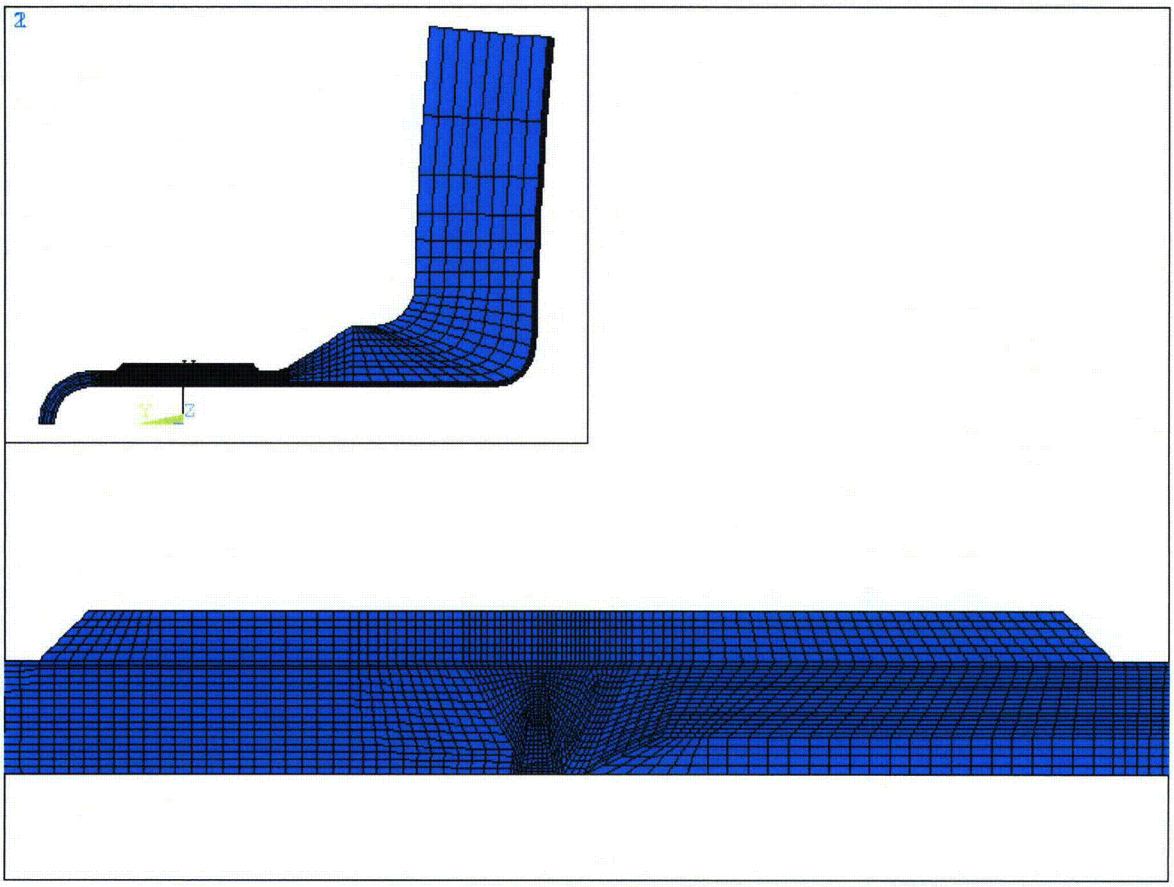


Figure 3-2: Axisymmetric Finite Element Model

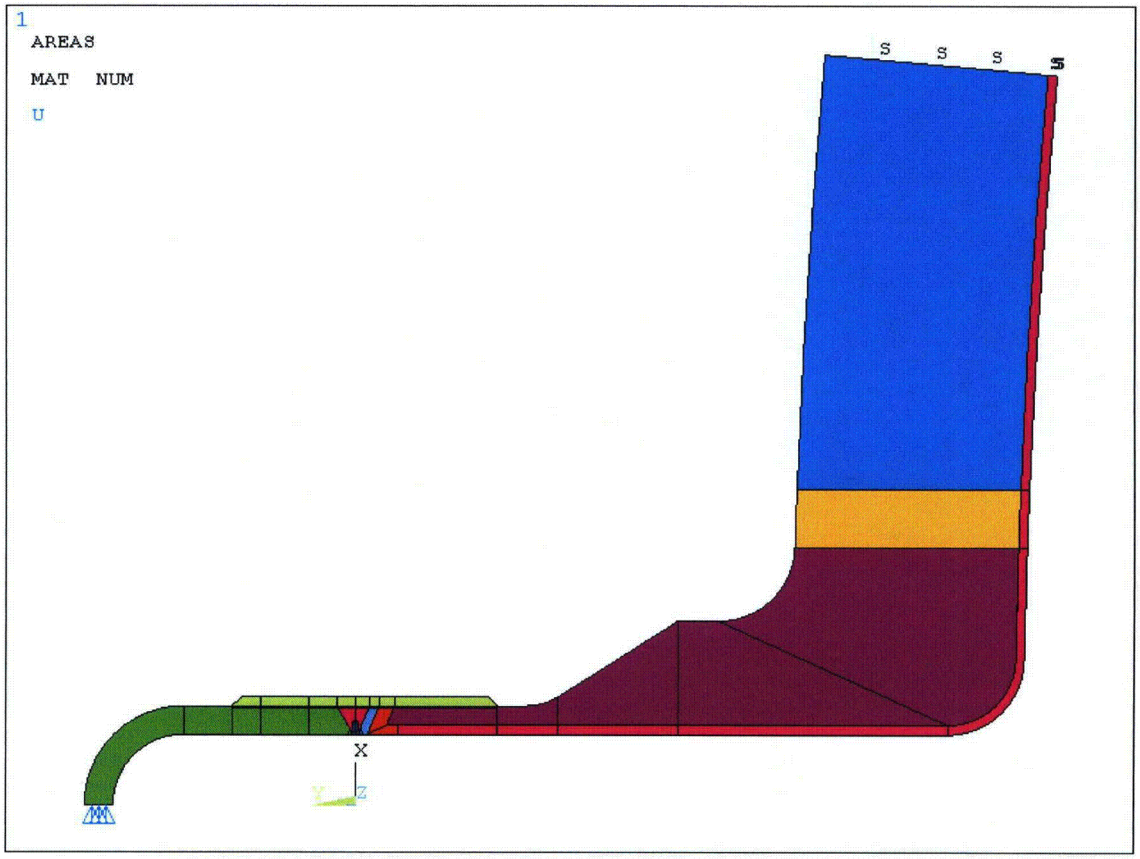



Figure 3-3: Finite Element Model Showing Boundary Conditions

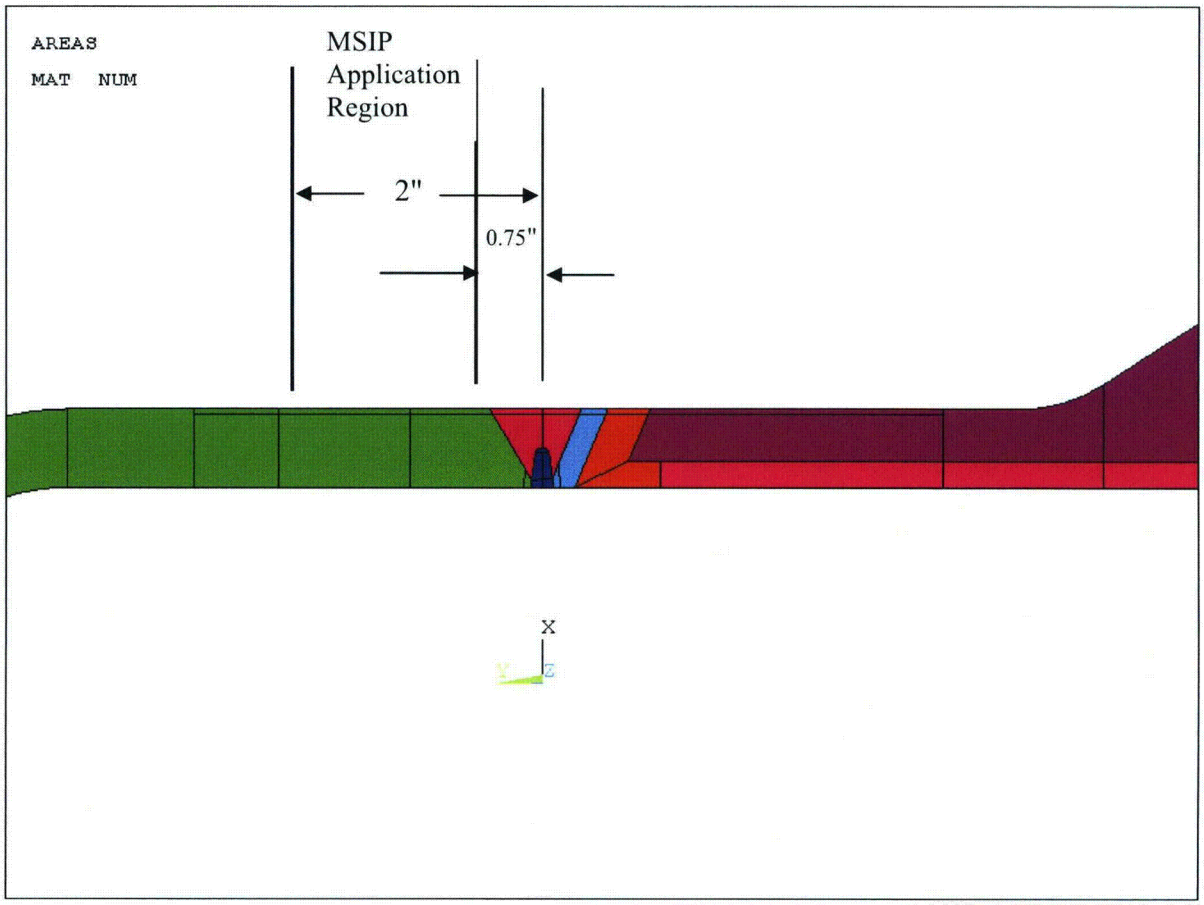
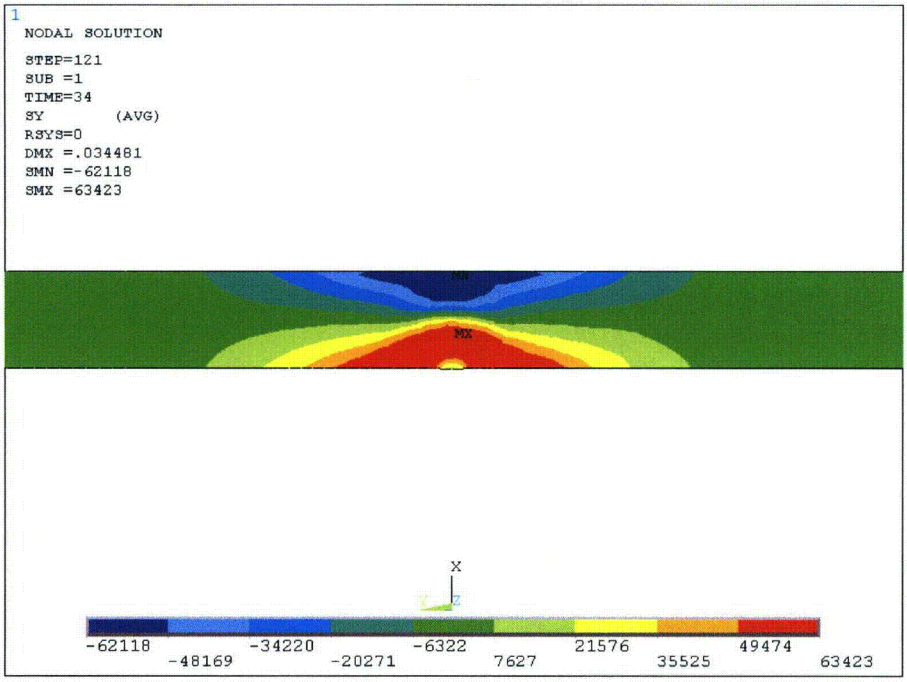
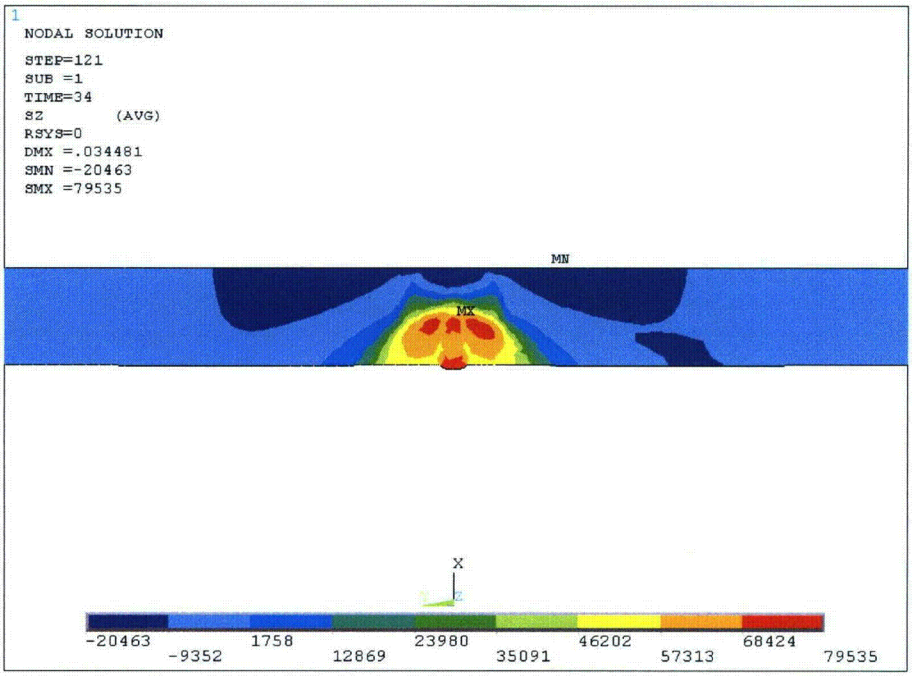



Figure 3-4 MSIP Application in Model

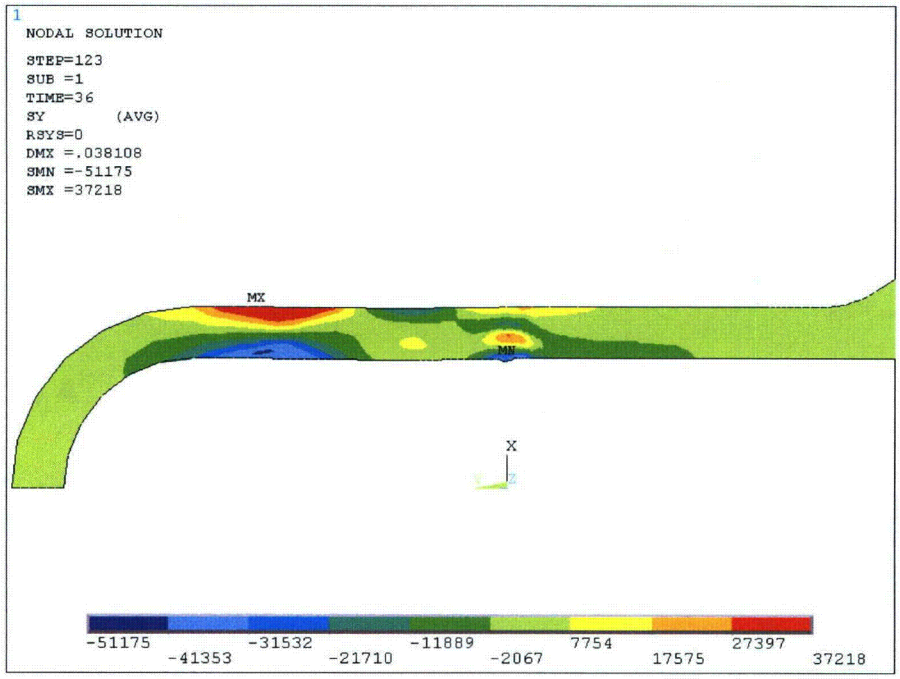



(a) Axial Stress

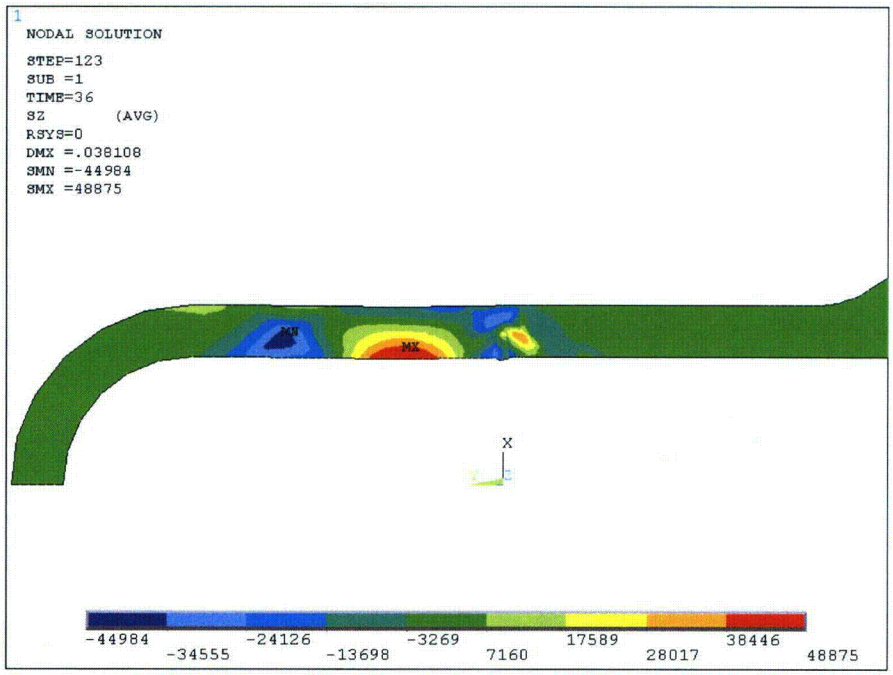



(b) Hoop Stress

Figure 3-5: Weld Repair Residual Stress Distribution at Room Temperature

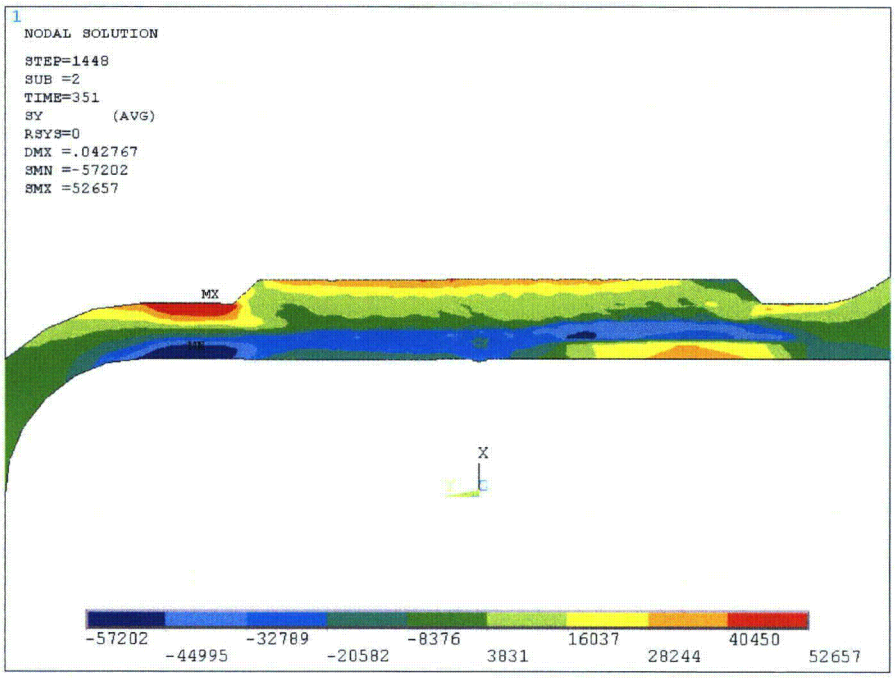



(a) Axial Stress

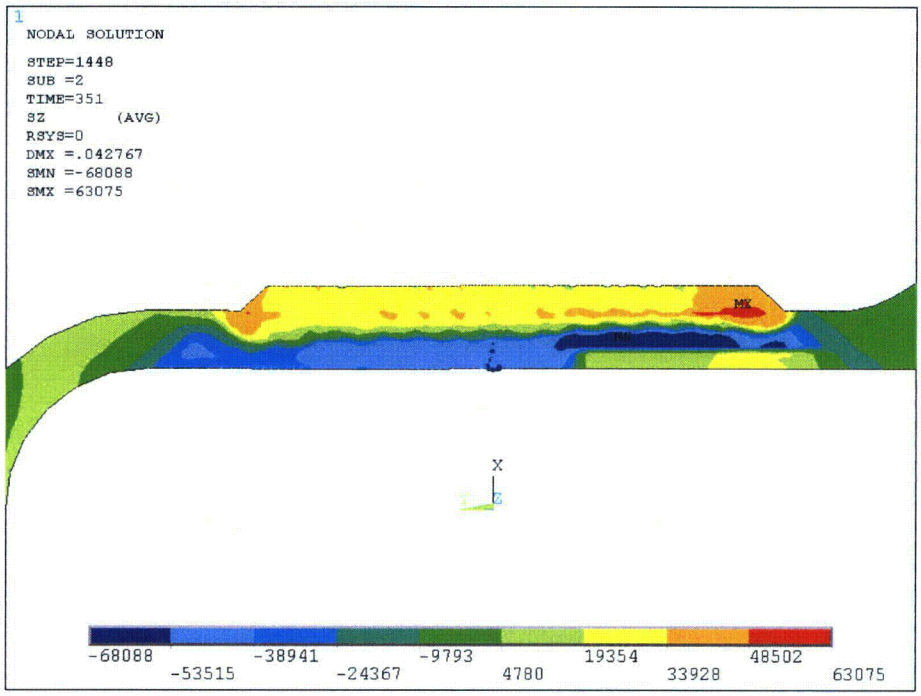



(b) Hoop Stress

Figure 3-6: MSIP Residual Stress

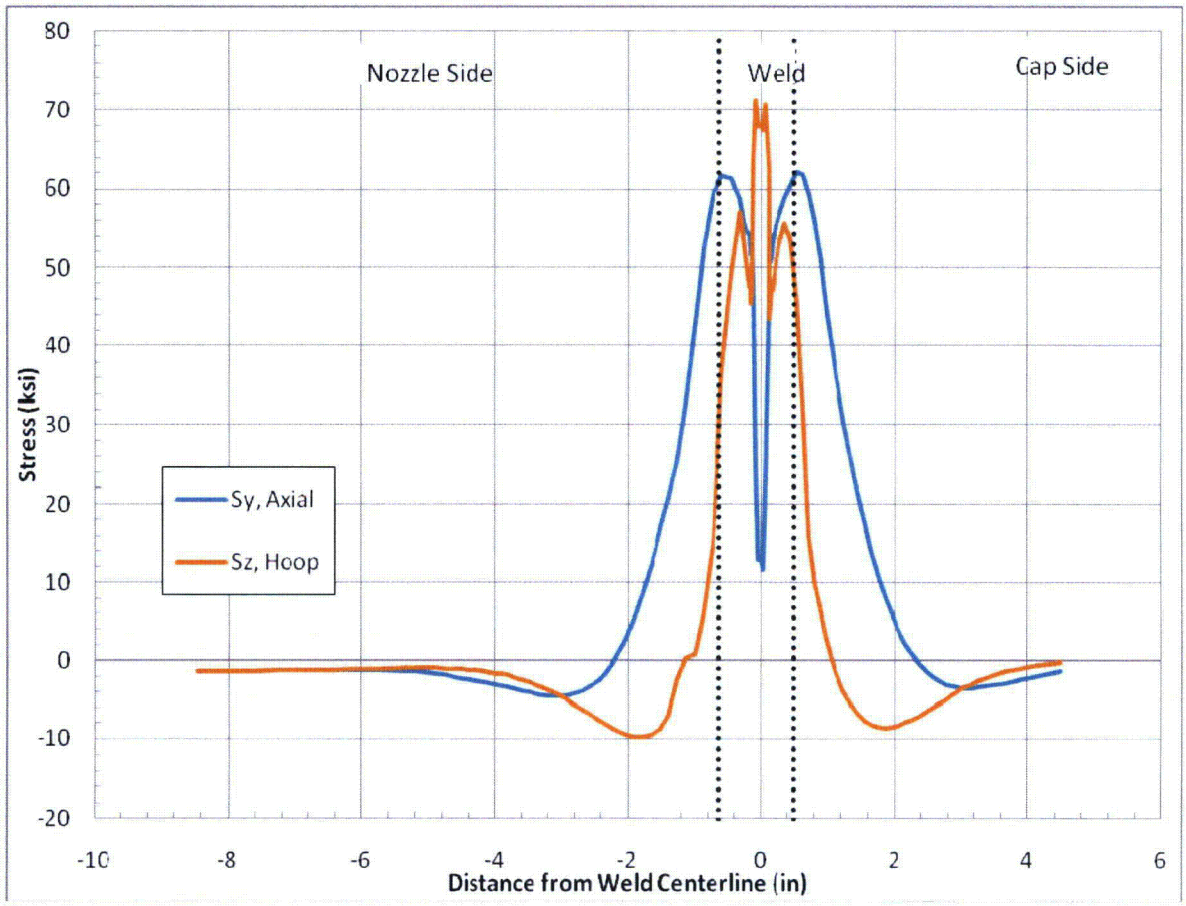



(a) Axial Stress




(b) Hoop Stress

Figure 3-7: Post Weld Overlay Stress Distribution at Room Temperature




F

Figure 3-8: Weld Repair Inside Surface Residual Stress Distribution at Room Temperature

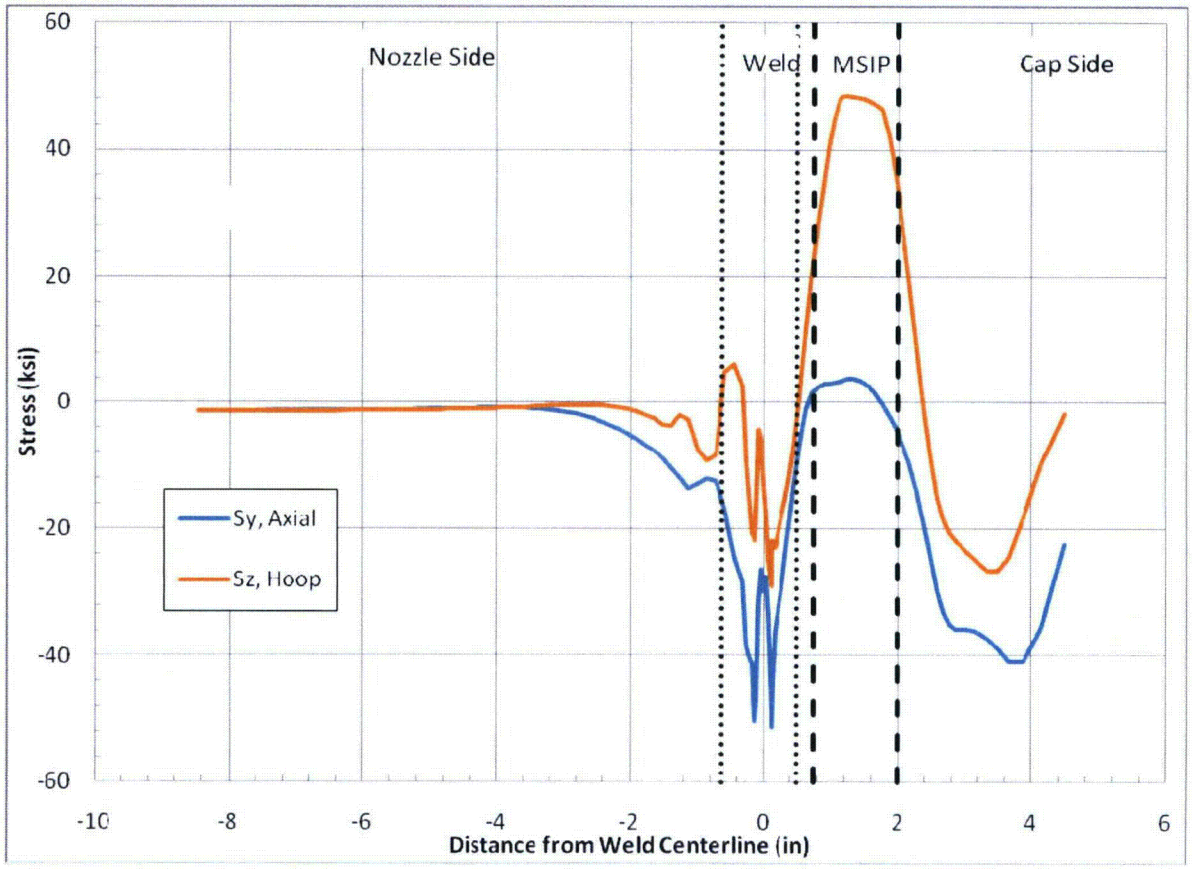



Figure 3-9 MSIP Residual Stress

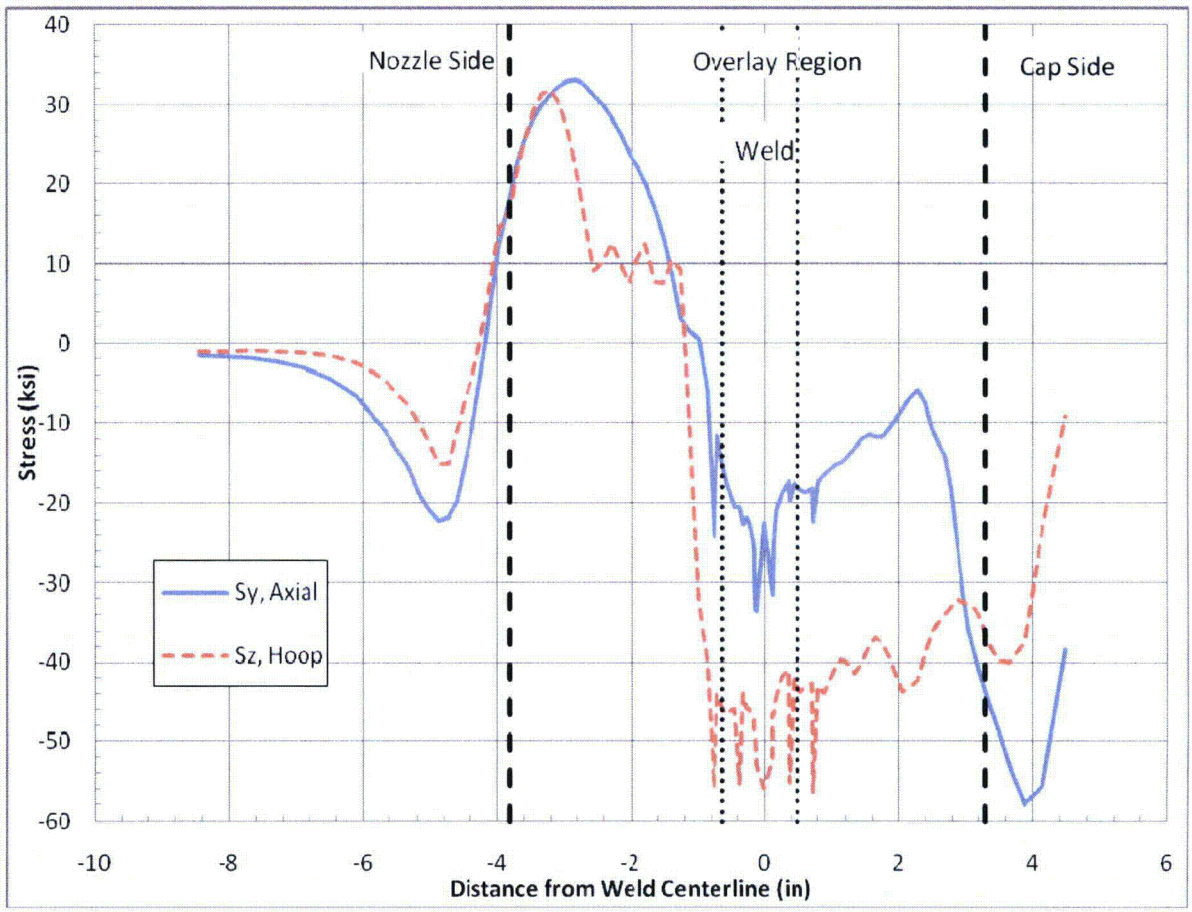



Figure 3-10 Weld Overlay Residual Stress at Room Temperature

## 4.0 EVALUATION OF WELD OVERLAY SHRINKAGE STRESSES

### 4.1 Background

ISI-ALT-08-01 also requires that the impact of the weld overlay on the attached piping system and supports be addressed. Stresses develop in a piping system after application of one or more weld overlays due to the weld shrinkage at the overlays caused by the restraint and stiffness of the attached piping. These stresses are system-wide, and are similar in nature to restrained free-end thermal expansion or contraction stresses. The level of stresses resulting from weld overlay shrinkage is a direct result of the number and location of the weld overlays, the shrinkage per overlay, and the piping system geometry. Axial shrinkage produces tensile stresses at locations co-linear with the overlay, and predominantly bending stresses at locations which are separated and not co-linear with the welding location.

Because the nozzle was cut and capped in 1993, there is no attached piping to the nozzle and no other supports. Therefore, there is no source for restraint induced stress. Therefore, shrinkage induced stresses are not a concern for the N9 nozzle.

## 5.0 ASME CODE STRESS EVALUATION

### 5.1 Background

This section presents the discussion of the ASME Code Section III [15] evaluation for the weld overlay. Of specific interest are the changes in the stresses and the impact on fatigue usage at the ends of the weld overlay. ISI-ALT-08-01 requires that the overlay be sized so that it will be able to provide for load redistribution from the pipe into the deposited weld metal and back into the pipe without violating applicable stress limits of ASME Code, Section III for primary, secondary, and peak stresses. This will be addressed in this section.

### 5.2 Technical Approach

The two-dimensional, axisymmetric finite element model of the N9 nozzle and cap used for the residual stress analysis in Section 3.0 is used for this evaluation. The model included a portion of the reactor vessel and the N9 nozzle. The nozzle-to-cap weld and butter were also modeled in detail, as was the final weld overlay repair.

Static and transient structural analyses are performed for thermal transients and internal pressure to determine the appropriate stresses. The resulting stresses are compared to determine the impact of the repair on Section III allowable stresses and fatigue usage.

The temperature dependent material property values are also presented in Section 3.0. Finally, the same boundary conditions previously identified in Section 3.0 will also be used for all subsequent evaluations in this section.

Weld residual stresses resulting from the original welding of the various components, the postulated weld repair to the nozzle-to-cap weld, MSIP and the final weld overlay are not considered here as they are not required for ASME Code, Section III stress evaluations.

The thermal transients and operating pressure loads are provided in Reference 14.

## 5.3 Analysis

Thermal and structural stress analyses have been performed for the weld overlay repair. From Reference 14, the most significant thermal cycles are startup/shutdown and loss of feedwater pump (LFWP) transients in the particular region of the vessel where the CRDRL capped nozzle is located. For the startup/shutdown (SUSD) transient, the heat up rate is 100 °F/hr. For loss of feedwater pump transient, the temperature decreases from 522 °F to 300 °F in 3 minutes 40 seconds, from 300 °F to 500 °F in 33 minutes, 500 °F to 300 °F in 3 minutes, 300 °F to 500 °F in 75 minutes, 500 °F to 300 °F in 7 minutes and hold at 300 °F. The pressure can be from 1180 psig to 240 psig during the LFWP transient.

## 5.4 Load Combinations

The load combinations considered for the repair design were:

1. Normal (Level A) Load Combination
2. Upset (Level B) Load Combination

Therefore, the only load combinations which will be considered herein are for Service Levels A and B assuming LFWP as an upset condition. Since Level B bounds Level A, Level B was the case evaluated. The allowable stress intensities are presented in Table 5-1.

### *5.4.1 Fatigue Evaluation*

The fatigue evaluations are performed for all the paths for the weld overlay repair (see Figure 5-1). Both the inside and outside edges of the indicated paths will be evaluated. The evaluations are performed in accordance with ASME Code, Section III, Subparagraph NB-3222.4(e) [15], using guidance from Subarticle NB-3600 for all paths.

Reference 14 provides the total number of cycles for the inlet nozzle. Table 5-3 shows the cycles considered from Reference 14. The fatigue curve from Reference 15 was used to perform the evaluation.

## 5.5 Results of Analysis

Through-wall linearized stresses were extracted from the various evaluations for key sections as shown in Figure 5-1. The resulting stress intensities are shown in Table 5-2.

### *5.5.1 ASME Code, Section III Impact Evaluation*

The results from the ASME Code Section III evaluation for the nozzle-to-cap configuration are summarized in Table 5-2. The Table shows the Primary-plus-Secondary ($P_L + P_b + Q$) stresses for the sections of interest.

The results show that Primary-plus-Secondary stresses are well below the ASME code allowable stresses. In addition, stress calculations were also performed for primary membrane and primary membrane plus bending (only needed for design conditions) as an additional check. All stresses were well below the maximum allowable values.

### *5.5.2 Fatigue Evaluation*

Results of the fatigue initiation evaluation are presented in Table 5-4. Note that the fatigue usage is not significant as is typically the case in BWR weld overlays. The maximum fatigue usage is 0.01, well below the allowable of 1.0. Even if 60 years is considered, the usage would be only (60/40)(0.01) = 0.015. This fatigue usage was determined using the total stresses (P+Q+F) from the finite element analysis. An additional calculation was performed by applying a fatigue reduction factor of 1.8 per ASME Code Section III NB-3680 for a tapered transition to the P+Q at the ends of the analysis. Using this approach, the fatigue usage is 0.014 for 40 years and 0.021 for 60 years, well below the allowable of 1.0.

### *5.5.3 Evaluation of Stress Requirements*

ISI-ALT-08-01 states that the axial length and end slope of the weld reinforcement be sufficient to provide for load redistribution from the pipe into the deposited weld metal and back into the pipe without violating applicable stress limits of Section III for primary, secondary, and peak stresses. Calculations are performed for the cap since the allowable stresses are limiting for this side of the overlay (Alloy 600 vs. Low Alloy Steel).

The outside radius of the cap in this region is 2.61 inches and the minimum as-built full thickness length on either side of the weld is 2.44 inches. The resulting circumference is 2.61*2*π = 16.4 inches for a total shear area of 2.44*16.4 = 40.02 in².

From Table 5-2, the primary membrane plus primary bending stress is conservatively taken as 5.0 ksi.

The primary-plus-secondary stress total is assumed to be 38 ksi which bounds the actual values in Table 5-2. The equivalent force to generate the given stress is calculated as (using cap ID):

$$F_{primary} = \sigma_{primary} \cdot \pi \cdot \left(R_{outside}^2 - R_{inside}^2\right) = 5000 \cdot \pi \cdot \left(2.61^2 - 1.86^2\right) = 52661 \text{ lbs}$$

$$F_{primary+secondary} = \sigma_{primary+secondary} \cdot \pi \cdot \left(R_{outside}^2 - R_{inside}^2\right) = 38000 \cdot \pi \cdot \left(2.61^2 - 1.86^2\right) = 400223 \text{ lbs}$$

The primary shear stress is calculated as:

$$\tau_{primary} = \frac{F_{primary}}{A_{shear}} = \frac{52661}{40.02} = 1.32 \text{ ksi}$$

The primary shear allowable, per Section III, Subparagraph NB-3227.2, of the ASME Code, is $0.6S_m$ or 0.6*23.3 [4] (Alloy 600 @545°F), or 13.98 ksi. The calculated primary shear is 1.32 ksi, which is below the primary shear allowable.

The primary-plus-secondary shear stress is calculated as:

$$\tau_{primary+secondary} = \frac{F_{primary+secondary}}{A_{shear}} = \frac{400223}{40.02} = 10.0 \text{ ksi}$$

The primary-plus-secondary shear allowable, per Section III, Subparagraph NB-3227.2, of the ASME Code, is $(3/2)S_m$ or 1.5*23.3 [4] (N06600 SB-166 @600°F), or 34.95 ksi. The calculated

primary-plus-secondary shear is 10.0 ksi, which is below the primary-plus-secondary shear allowable.

## 5.6 Concluding Remarks – Stress Evaluation

An evaluation has been performed to determine the impact of the weld overlay repair of the HNP-1 N9 nozzle-to-cap weld implemented during the February 2008 outage, based on ASME Code, Section III rules. The evaluation included primary-plus-secondary Code acceptance, fatigue, and ISI-ALT-08-01 stress limits. It was determined that the impact is minor and generally produces a more favorable stress condition, and fatigue is not significant for the balance of plant life.

Table 5-1: Allowable Stress Intensities

| **Load Combination** | $P_m$ | $P_L$ | $P_L + P_b$ | $P_L + P_b + Q$ | **Notes** |
|---|---|---|---|---|---|
| Level A/B | | - | - | 3.0 $S_m$ | 1 |

Note:
1. The requirements of ASME Code, Section III, Subparagraph NB-3222.4(e) [4] (and Subparagraph NB-3653.5 for piping) for peak stresses and cyclic operation must be met.

Table 5-2: Primary Plus Secondary Stress Results

| Path | Material | $P_m$ (ksi) | $S_m$ (ksi) | $P_l+P_b$ (ksi) | $1.5S_m$ (ksi) | $P_l+P_b+Q$ [1](ksi) | $3S_m$ (ksi) | $P_l+P_b+Q+F$ (ksi) |
|---|---|---|---|---|---|---|---|---|
| 1 | Alloy 182/52 | 2.55 | 23.3 | 3.65 | 34.95 | 21.79 | 69.9 | 27.81 |
| 2 | Alloy 182/52 | 2.60 | 23.3 | 3.83 | 34.95 | 21.97 | 69.9 | 29.25 |
| 3 | Alloy 182/52 | 2.63 | 23.3 | 3.85 | 34.95 | 23.78 | 69.9 | 30.70 |
| 4 | Alloy 182/52 | 2.64 | 23.3 | 3.85 | 34.95 | 24.77 | 69.9 | 40.19 |
| 5 | Alloy 600 | 3.24 | 23.3 | 4.34 | 34.95 | 21.24 | 69.9 | 32.99 |
| 6 | Low Alloy | 3.15 | 30.0 | 4.21 | 45.0 | 37.09 | 90.0 | 60.43 |

Note:
1. All units are in ksi
2. The $P_m$ and $P_L$ for pressure load cased are scaled to 1250 psig operating pressure. (conservative)
3. The Q in $P_m+P_b+Q$ is the maximum between SUSD and LFWP transients

Table 5-3: Event Cycles

| Thermal Transients | No. of Cycles |
|---|---|
| StartUp | 120 |
| Loss of Feedwater Heater | 80 |
| Loss of Feedwater Pumps, Isolation Valve Closed | 10 |
| Single Relief or Safety Valve Blowdown | 2 |
| Start of Cold Recirculation Pumps | 5 |

Table 5-4: Fatigue Analysis Results

| Path | Material | $P_l+P_b+Q+F$ (ksi) | Sa (ksi) | Allowable Cycles | Applied Cycles | Fatigue Usage |
|---|---|---|---|---|---|---|
| 1 | Alloy 182/52 | 27.81 | 13.91 | $>10^6$ | 217 | 0 |
| 2 | Alloy 182/52 | 29.25 | 14.63 | $>10^6$ | 217 | 0 |
| 3 | Alloy 182/52 | 30.70 | 15.35 | $>10^6$ | 217 | 0 |
| 4 | Alloy 182/52 | 40.19 | 20.10 | $>10^6$ | 217 | 0 |
| 5 | Alloy 600 | 32.99 | 16.49 | $>10^6$ | 217 | 0 |
| 6 | Low Alloy | 60.43 | 30.21 | $2.16 \times 10^4$ | 217 | 0.01 |

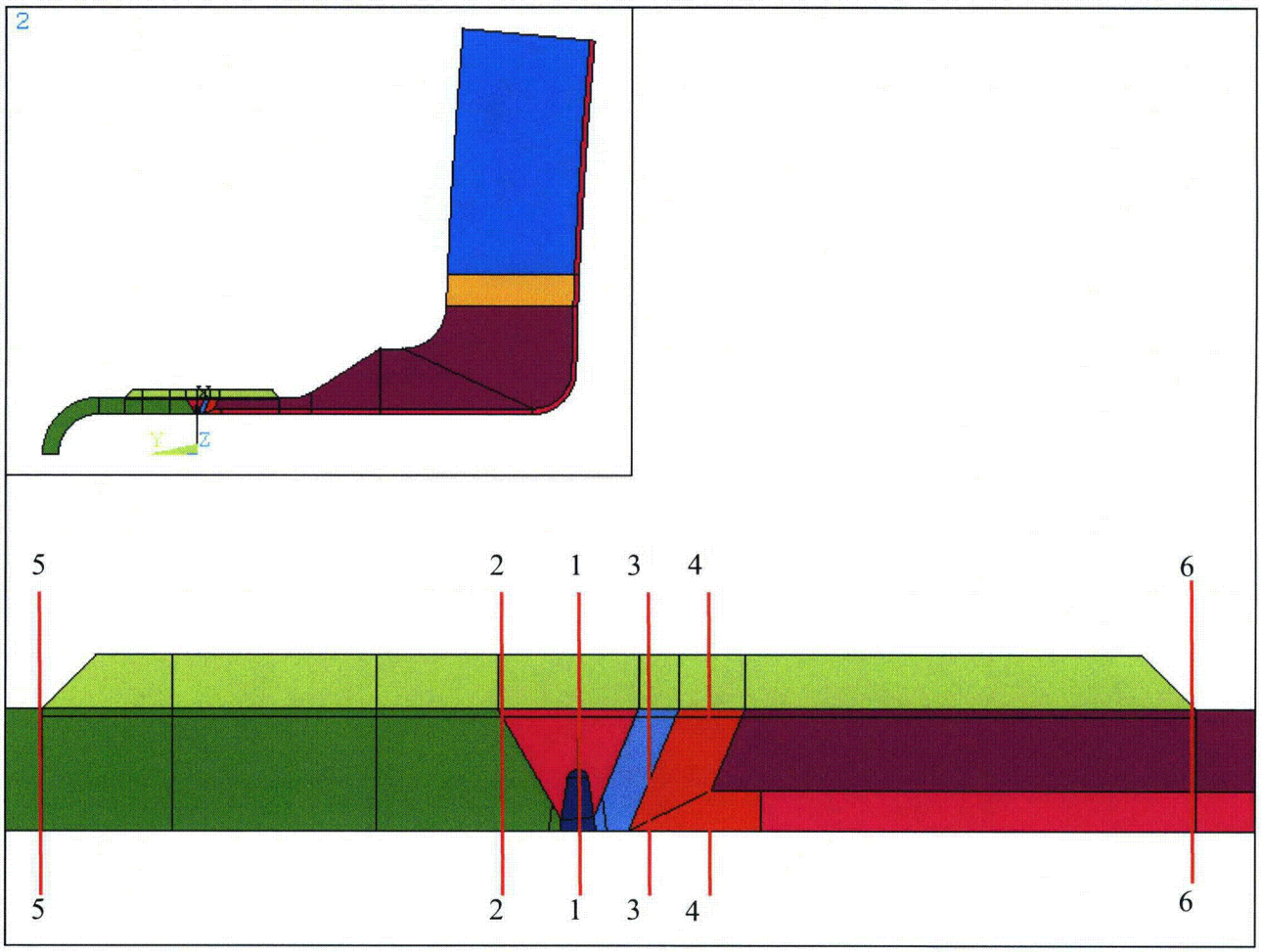



Figure 5-1: Sections Used for Section III Evaluation

## 6.0 CRACK GROWTH CONSIDERATIONS

### 6.1 Background

In this section, crack growth into the overlay is considered for both IGSCC and fatigue mechanisms. ISI-ALT-08-01 requires that potential flaw growth due to fatigue and the mechanism believed to have caused the flaw (IGSCC) be considered. The weld metal to be used for the overlay repair is Alloy 52M, which is very resistant to IGSCC. Fatigue crack growth is also discussed in this section.

### 6.2 Technical Approach

The technical approach used in this evaluation is to consider the through-wall stress intensity factor (K) distribution associated with the repaired circumferential flaw using the post weld overlay stresses at operating conditions. If the K distribution is such that it is negative at the crack tip, then no IGSCC growth will be expected. If the K is positive, then a flaw growth evaluation will be performed to determine the life of the overlay. From a fatigue standpoint, the $\Delta K$ distribution for the pertinent thermal cycles is used.

### 6.3 IGSCC Flaw Growth

ISI-ALT-08-01 requires that potential flaw growth due to the mechanism believed to have caused the flaw (IGSCC) be considered. Evaluation of the flaw consistent with Appendix C of Section XI indicates that the stress intensity will be negative based on the through-wall stress distribution. The stress intensity factor results for the weld region is presented in Figure 6-1. The total applied stress intensity factor is also presented in the Figure 6-1. The total applied stress intensity is the combination of unit pressure scaled to operating pressure, steady state thermal (end of startup) and residual stress. It is shown that the applied stress intensity factor during the normal steady state operation is negative throughout the thickness at the nozzle to cap weld of the CRD return N9 nozzle.

Since the total applied stress intensity factor during steady state operation is compressive throughout the wall thickness at the nozzle to cap weld, there would be no stress corrosion crack

growth for the existing indication in the weld as the results of the application of weld overlay. Thus the overlay mitigates the nozzle-to-cap weld against stress corrosion cracking. Hence, from an IGSCC viewpoint, the overlay repair for the nozzle-to-cap weld is considered a long-term fix, subject to NRC mandated inspections in Generic Letter 88-01 [3], as modified by BWRVIP-75 [16].

### 6.4 Fatigue Crack Growth

ISI-ALT-08-01 requires that potential flaw growth due to fatigue be considered. Fatigue crack growth is not significant at these nozzle locations for BWRs. Since the nozzle has been capped and only reactor vessel transients impact the nozzle-to-cap weld location, the severity and number of the cycles present is limited and therefore very little growth is expected to occur. Recall also, since the stress is compressive at the actual crack tip location, there will be a compressive mean stress contributing to fatigue crack growth. The most significant cyclic event associated with the capped N9 nozzle is the LFWP. The number of these events is limited and therefore any crack growth from this relatively small number of cycles would not be significant due to the low ΔK values (stress intensity factor range).

For fracture mechanics and crack growth analysis, a crack model of a full circumferential crack in cylinder with t/R = 0.2, is used. The initial flaw size for the crack growth calculation is the indication size from inspection.

Fatigue crack growth was calculated to demonstrate that any growth is not significant. The fatigue crack growth for Alloy 690 was used as a representative value in this calculation. The fatigue crack growth law for Alloy 690 is obtained from Reference 17:

$$\frac{da}{dN} = C_{A690}(1-0.82R)^{-2.2}\Delta K^{4.1} \qquad (6\text{-}1)$$

$$C_{A690} = 5.423x10^{-14} + 1.83x10^{-16}T - 1.725x10^{-1.8}T^2 + 5.49x10^{-21}T^3 \qquad (6\text{-}2)$$

where T is in °C and ΔK is in MPa-√m.

Reference 17 reports that fatigue crack growth data for Alloys 82, 52 and 152 are not available. However, it is also reported in Reference 17 that the fatigue crack growth rate for Alloy 182 is approximately a factor of 2 higher than that for Alloy 600. It is also noted in Reference 17 that under similar loading conditions, the crack growth rate of Alloy 690 appears to be slightly greater than that of Alloy 600. Therefore, the fatigue crack growth law of Alloy 690 is used as a representative value to show that crack growth is insignificant at this location. Even if crack growth rates were doubled, the crack growth would remain insignificant.

The stress intensity factor and fatigue crack growth calculation are performed using **pc-CRACK** [18].

For the fatigue crack growth calculation, through-wall stress profiles were extracted for the selected paths for the load cases of unit pressure, startup and LFWP transients. For the startup and LFWP transients, the through-wall stress profiles were obtained at the time of maximum stress.

Using an operating temperature of 545 °F, assuming an R ratio of 0.9, and converting the unit of ΔK from MPa-√m to Ksi-√in, the fatigue crack growth law in Equation (6-1) becomes

$$\frac{da}{dN} = 6.8617x10^{-12}\Delta K^{4.1} \qquad (6\text{-}3)$$

The fatigue cycles shown in Table 5-4 are grouped into startup with 120 cycles and LFWP with 97 cycles. These fatigue cycles are distributed evenly over 40 years. For conservatism, the LFWP cycles are assumed the full fluctuation from zero to maximum stress. An initial crack size of 0.45 in was used in the fatigue crack growth calculation. Fatigue crack growth threshold is conservatively assumed to be zero.

For 40 years, the initial crack size of 0.45 inches grows to 0.451 inches, a total growth of 0.001 inches.

## 6.5 IGSCC Resistance of Alloy 52 Family Weld Metals

Nickel-based alloys, including Alloy 600 and the weld metals Alloy 82 and 182, have been observed to be quite resistant to IGSCC initiation in BWR service, absent a crevice. Only limited crack initiation has been reported when crevices have not been present. The observed cracking appears to have been confined to Alloy 182, the welding electrode used typically for manual welding of components. These instances have involved a recirculation inlet nozzle-to-safe end weld butter in one domestic BWR, and dryer assembly attachment brackets in two foreign BWRs. In all instances, the cracking was limited in extent, involving multiple short cracks. When crevices have been present, cracking has been observed more widely in Alloy 182, involving recirculation inlet nozzle safe ends, feedwater nozzle safe ends and piping, core spray safe ends, and access hole covers. Failure analyses of some of these cracks (resulting from boat samples or component removal) have confirmed that the cracking was intergranular or interdendritic stress corrosion cracking. In each of these cases, the cracking appears to have initiated in the Alloy 182 weld metal, progressing in some instances into the Alloy 600 wrought material or progressing slightly into the low alloy steel nozzle.

During the past several decades, significant laboratory research has been performed examining the IGSCC behavior of Alloy 600, 182 and 82 materials [19], and identifying and qualifying alternatives to the nickel-based weld metals, Alloys 82 and 182; alternatives that have improved resistance to IGSCC in aqueous environments and have comparable weldability. The research focused on developing welding fillers and electrodes containing higher chromium, which imparts improved resistance to corrosion in oxidizing environments like the BWR environment. Alloy 690 has been identified in IGSCC testing programs to be extremely resistant to IGSCC [20], and weld metals have been developed by Special Metals Corporation to match the composition of the wrought Alloy 690. Experimental Alloys R-127 and 135 were developed as weld fillers and electrodes, respectively, and were tested in EPRI-sponsored programs to evaluate these materials in simulated BWR environments. These experimental alloys eventually became the commercial alloys, Alloy 52 and Alloy 152, respectively, and have been incorporated into the ASME Code in Section IX Code Cases 2142 and 2143 [21, 22].

Additional research, sponsored by EPRI, consisting of a three phase multi-year effort, involved testing of the nickel-based Alloys 600, 690, 182, 82, R-127 and R-135 and austenitic stainless steel Type 316 NG, in laboratory simulations of the normal BWR water chemistry and degraded BWR water chemistry conditions [20, 23]. The normal BWR water chemistry consisted of high purity water containing 200 ppb oxygen, and having a conductivity of 0.067 to 0.077 μS/cm. The degraded BWR chemistry consisted of 1 ppm sulfuric acid, 6-7 ppm dissolved oxygen and had a conductivity of 8 μS/cm and a pH of 4.6 to 4.7. Testing involved creviced slow strain rate tests, creviced U-bend tests, creviced sustained load tests, and crack growth tests.

The testing revealed that in the normal water chemistry environment, in an uncreviced geometry, Alloys 600 and 690 and weld metal Alloy 82 were all resistant to IGSCC. Limited cracking has been observed in Alloy 182 in the absence of a crevice, as discussed above. In a creviced geometry, both Alloy 600 and Alloy 182 were susceptible to IGSCC. Alloy 82 was slightly susceptible in a crevice condition. Alloy 690, Alloys R-127, R-135 and 72, and Type 316 NG stainless steel exhibited no susceptibility to IGSCC in creviced or in uncreviced conditions.

The testing in the resin intrusion environment produced mixed results. In slow strain rate and in crack growth rate tests, all of the nickel-based alloys tested showed some susceptibility to IGSCC. Ranking of the alloys in terms of their SCC resistance in the resin intrusion environment indicated that Alloy 182 had the lowest resistance, Alloys 600 and 82 had intermediate resistance, and Alloy 690 and the weld metals R-127 and R-135 had the highest resistance. The crack growth rate in Alloy 690 at a high stress intensity was an order of magnitude less than that observed at much lower stress intensities in Alloys 600, 182 and 82. The $K_{ISCC}$ for Alloy 690 in the simulated resin intrusion environment was estimated by these investigators to lie somewhere between 60-70 MPa $\sqrt{m}$ (55-64 ksi $\sqrt{in.}$).

The U-bend testing was performed in two separate phases of this program. In one of the phases, the testing was performed on nickel-based weld metals corresponding to the nominal compositions of Alloys 600, 690, 625 and 671 [23]. Single and double U-bend specimens were exposed to a simulated resin intrusion environment at 316°C. Following the exposure, the majority of the weldments had failed. There was a strong effect of the chromium content of the

weld metal on the propensity to failure. In welds with less than 24% Cr, 31 of 32 specimens failed. At higher Cr content, only 8 of 32 failed. In these latter welds, 7 of the 8 failures occurred in single U-bend specimens of SMAW welds. None of the base plates of Alloy 690 or 600 to which the welds had been joined failed.

The second U-bend study involved welding Alloy 600 or 690 to A-508 low alloy steel forging material in a simulated resin intrusion environment at 288°C. The welding materials used in this study included Alloys 625, 182, 82, R-127, R-135 and 132. The U-bend specimens were of the same type as tested in the earlier program. The results of this study indicated that all of the weldments were susceptible to SCC, but based upon the time to cracking, and the number of specimens cracked, the weldments exhibited varying susceptibility. The welds made with Alloy 625, 182 and 82 were the most susceptible, whereas those made with Alloy 132 were the least susceptible. The other weldments, including those made with the high chromium alloys R-127 and R-135, exhibited intermediate susceptibility. All of the weldments, except Alloy 182 and Alloy 82, failed at the weld metal/A-508 fusion line. Failure in the Alloy 182 weldments was in the weld metal, and the Alloy 82 weldments failed either in the weld metal or at the fusion line. SCC susceptibility was also observed to increase with decreasing Cr level.

The results of these studies illustrate that the use of Alloy 52 or other Alloy 52 family of materials for the weld overlay will produce a repair that is far superior in IGSCC resistance to that fabricated from Alloy 82, the material used in prior temperbead repairs for low alloy steel nozzle-to-safe end welds. The results indicate that in pure water environments, even in crevice conditions, Alloy 52 is very resistant to IGSCC initiation. The crack growth rate of Alloy 52 in this environment was one order of magnitude less than that observed in the Alloy 600 family of materials, as discussed earlier in this section, whereas Alloy 82 has exhibited some growth in creviced tests. In very severe resin intrusion environments (well beyond any anticipated water chemistry expected in service), the performance of Alloy 52, while not demonstrating immunity in all cases (U-bend tests indicated some susceptibility), was far superior to Alloy 82 even in dissimilar metal welds. The crack propagation rates appear to be one order of magnitude or more lower than that for Alloy 600 or for Alloy 82 in resin intrusion environments. These results, combined with the highly compressive residual stresses resulting from the weld overlay

repair as discussed in Section 3.0 of this report, will ensure that the repair will be very resistant to IGSCC growth.

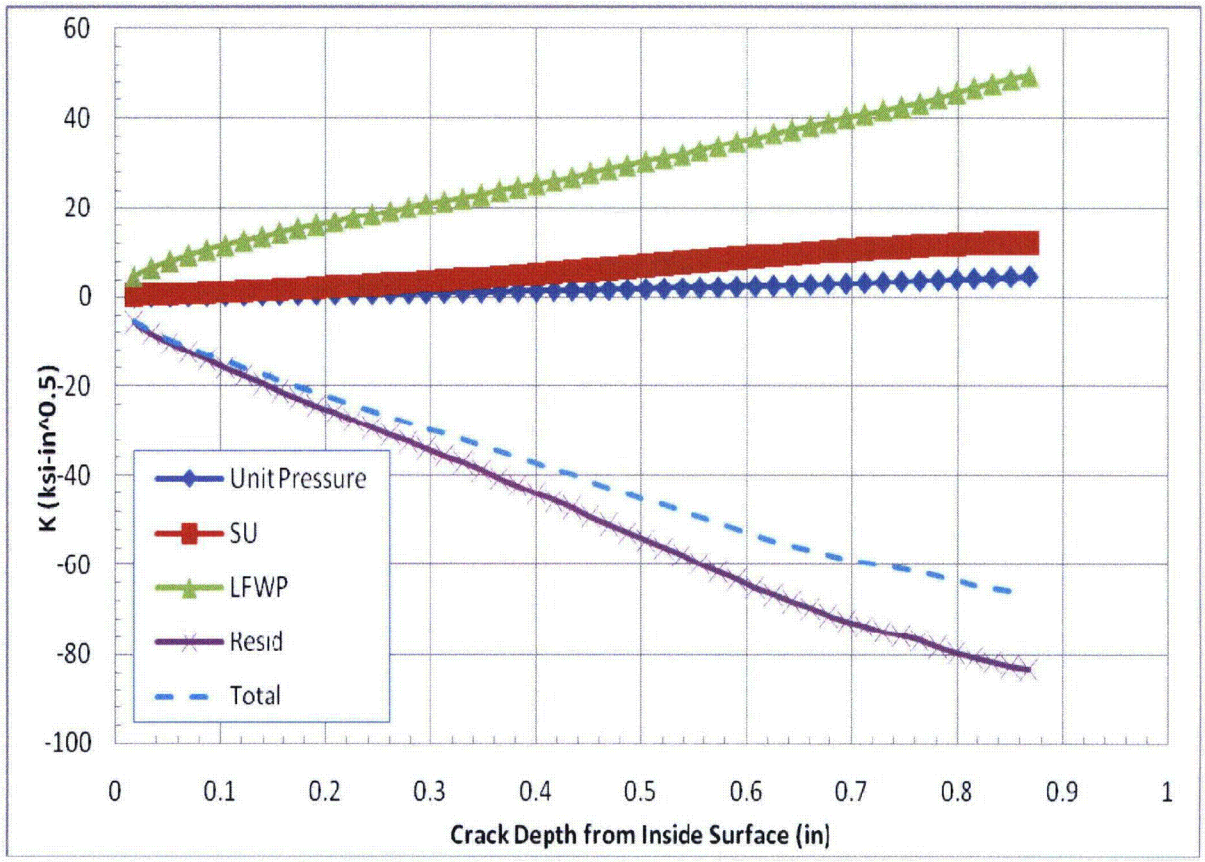


Figure 6-1: Through-Wall Stress Intensity Factor

## 7.0 SUMMARY AND CONCLUSIONS

The evaluations contained in this report form the basis for the weld overlay design for the HNP-1 N9 nozzle-to-cap weld implemented during the February 2008 outage. The evaluations were performed in accordance with the requirements of Generic Letter 88-01 (including Supplement 1), NUREG-0313, Revision 2, BWRVIP-75, and the ISI-ALT-08-01 [5]. The following are the conclusions of these evaluations.

- The weld overlay applied during the February 2008 outage meets all the design requirements of Generic Letter 88-01 and NUREG-0313 for "Standard" overlays. The overlays also meet all the design requirements of ISI-ALT-08-01 [5].

- The effect of the application of the weld overlay increased the total mass of the cap by an insignificant amount.

The above conclusions indicate that the weld overlay implementation at HNP-1 complied with the provisions and requirements of Generic Letter 88-01, NUREG-0313, Revision 2, BWRVIP-75, and ASME, Section XI. Since design loads were considered in this evaluation, the weld overlay design and basis presented in this report are applicable to the other nozzle welds provided that all nozzle characteristics and parameters are similar to those used in this evaluation. It is recommended that the effect of future overlays be evaluated when they are applied to ensure that regulatory and Code requirements are met.

## 8.0 REFERENCES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21. ASME Boiler and Pressure Vessel Code Case 2142, "F-Number Grouping for Ni-Cr-Fe Classification UNS N06052 Filler Metal," November 25, 1992.

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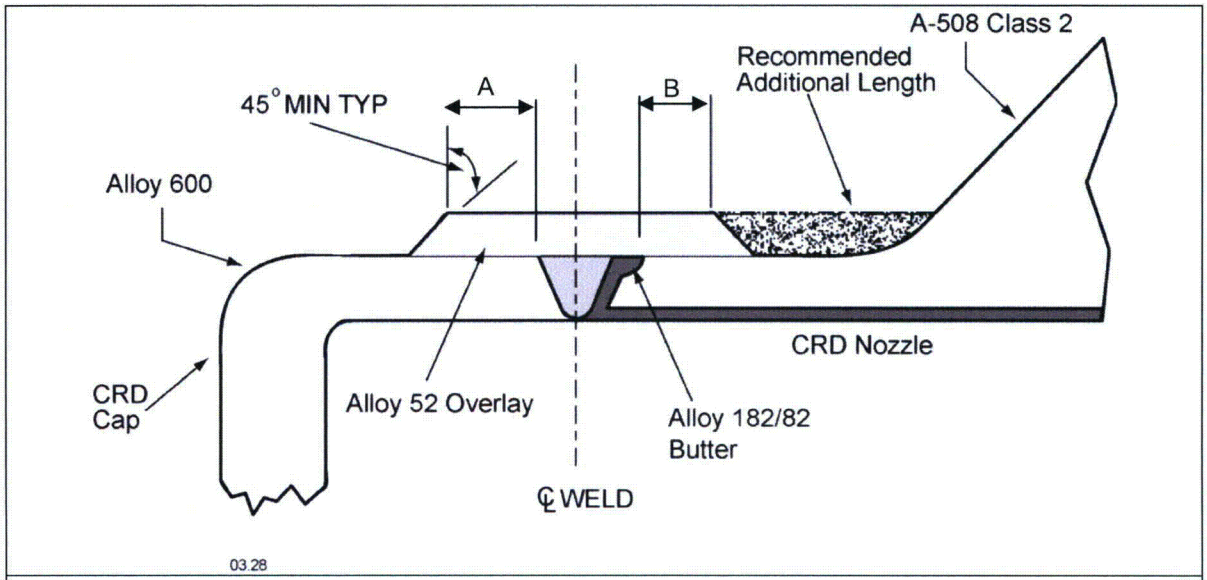
Appendix A

Weld Overlay Drawing




| WELD NUMBER | FLAW CHARACTERIZATION | Design Dimensions | | | COMMENTS |
|---|---|---|---|---|---|
| | | t | A | B | |
| Nozzle N9 CRD Hydraulic Return Cap Weld | Assumed 360° Circ. 100% throughwall flaw | 0.25" see Note 4 | 1.0" MIN | 1.0" MIN | A is measured from the weld-cap interface; B is measured from the butter-nozzle interface |

| Revision | Prepared by/Date | Checked By/Date | Approved by/Date | COMMENTS |
|---|---|---|---|---|
| 1 | HLG 2/24/08 | AJG 2/24/08 | MLH 2/24/08 | |

| | | |
|---|---|---|
| Job No: 0800287.00<br>File No: 0800287.00-301 | Plant/Unit:<br>Hatch 1 Nuclear Power Station | STRUCTURAL INTEGRITY ASSOCIATES, INC. |
| Drawing No: 0800287.00-01 | Title: Standard Weld Overlay Design | Sheet 1 of 2 |

## NOTES

1. **Component surface is to be examined by dye penetrant method and accepted as clean prior to overlay application.**

2. **In the event that the original component surface does not pass the note 1 requirements, the final deposited temper bead weld layer is to be examined by dye penetrant method and accepted as clean before proceeding with subsequent layers.**

3. **Weld overlay wire shall be ERNiCrFe-7A (Alloy 52M), or equivalent.**

4. **The design thickness (0.25 inch) is the minimum thickness beyond the first PT clean surface or layer.**

5. **Apply as many layers as required to achieve the design overlay thickness "t".**

6. **Design thickness includes no allowance for surface conditioning operations to facilitate UT inspection.**

7. **Design length is that required for structural reinforcement; greater length may be required for effective UT inspection. This is to be determined in the field.**

| | | | |
|---|---|---|---|
| **Job No: 0800287.00** | **Plant/Unit:** | ***STRUCTURAL INTEGRITY*** | |
| **File No: 0800287.00-301** | **Hatch 1 Nuclear Power Station** | **ASSOCIATES, INC.** | |
| **Drawing No: 0800287.00-01** | **Title: Standard Weld Overlay Design** | | **Sheet 2 of 2** |