Pacific Gas and Electric Company®

James M. Welsch
Vice President
Nuclear Generation and
Chief Nuclear Officer

Diablo Canyon Power Plant
P.O. Box 56
Avila Beach, CA 93424

805.545.3242
E-Mail: James.Welsch@pge.com

September 11, 2018

PG&E Letter DCL-18-050

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

Docket No. 50-323, OL-DPR-82
Diablo Canyon Unit 2

Evaluation Documents in Support of Structural Weld Overlay, REP-RHR-SWOL, Unit 2

References:
1. PG&E Letter DCL-17-083, "Request for Approval of Alternative for Application of Full Structural Weld Overlay, REP-RHR-SWOL, Units 1 and 2," dated September 26, 2017 [ML17269A220]
2. NRC Letter, "Diablo Canyon Power Plant, Units 1 and 2 – Relief Request REP-RHR-SWOL, Request for Approval of Alternative for Application of Full Structural Weld Overlay (EPID L-2017-LLR-0092)," dated January 2, 2018 [ML17338A131]

Dear Commissioners and Staff:

In Reference 1, Pacific Gas and Electric Company (PG&E) submitted a request for approval of alternative for application of a full structural weld overlay (SWOL) for the Diablo Canyon Power Plant Units 1 and 2. In Reference 2, the NRC Staff approved the relief request. PG&E installed the SWOL for Residual Heat Removal (RHR) Pipe-to-Elbow Weld WIB-245 during the Unit 2 twentieth refueling outage in conformance with the referenced documents.

In Reference 1, PG&E stated that summaries of the analytical evaluation results associated with the design calculations and the crack growth analyses would be submitted to the NRC following installation of the weld overlays. Accordingly, PG&E is submitting the following documents:

- Enclosure 1 includes the design report for the SWOL, which summarizes the original design calculations and crack growth analyses and results.

- Enclosure 2 includes the evaluation report, which documents the analysis of the addition of a second stainless steel buffer layer to the original design of the SWOL.
- Enclosure 3 includes the acceptance of the Unit 2 SWOL, which includes the measured axial shrinkage dimension, confirmation of as-built dimensional conformance with the design, and confirmation of acceptable ultrasonic (UT) inspection results.

Following the installation of the SWOL in Unit 2, a UT acceptance examination of the SWOL and a preservice UT examination were performed. The UT results confirmed that the final SWOL meets the acceptance criteria of the relief request (Reference 1).

PG&E plans to install the SWOL in Unit 1 during its twenty-first refueling outage, currently scheduled for early 2019. A similar set of documents will be submitted to the NRC following the installation of the Unit 1 SWOL.

PG&E makes no new or revised regulatory commitments (as defined by NEI 99-04) in this letter. If you have any questions or require additional information, please contact Mr. Hossein Hamzehee at (805) 545-4720.

Sincerely,

JAN NIMICK
FOR
JIM WELSCH

James M. Welsch
Vice President, Nuclear Generation and Chief Nuclear Officer

rntt/4231/SAPN 50965613-03
Enclosures
cc: Diablo Distribution
cc/enc: Kriss M. Kennedy, NRC Region IV Administrator
Christopher W. Newport, NRC Senior Resident Inspector
Gonzalo L. Perez, Branch Chief, California Department of Public Health
Balwant K. Singal, NRR Senior Project Manager
State of California, Pressure Vessel Unit

Diablo Canyon Power Plant, Unit 2

Design Report for the Qualification of the Structural Weld Overlay Repair of Residual Heat Removal Welds WIB-245 and WIB-228 for Diablo Canyon Power Plant, Units 1 and 2

[NOTE: This report is applicable to both DCPP Units 1 and 2]

Report No. 1700479.401
Revision 0
Project No. 1700479
December 2017

Design Report for the Qualification of the Structural Weld Overlay Repair of Residual Heat Removal Welds WIB-245 and WIB-228 for Diablo Canyon Power Plant, Units 1 and 2

Prepared for:

Pacific Gas and Electric Company

(Contract Number: 3501132695, Revision 0)

Prepared by:

Structural Integrity Associates, Inc.
San Jose, California

REGISTERED PROFESSIONAL ENGINEER
JAMES W. AXLINE
M 17802
EXP. 9/30/19
MECHANICAL
STATE OF CALIFORNIA

Prepared by: Richard L. Bax Jr. Date: 12/12/2017

Reviewed by: James W. Axline, P.E. Date: 12/12/2017

Approved by: James W. Axline, P.E. Date: 12/12/2017

Structural Integrity Associates, Inc.®

REVISION CONTROL SHEET

Document Number: **1700479.401**

Title: Design Report for the Qualification of the Structural Weld Overlay Repair of Residual Heat Removal Welds WIB-245 and WIB-228 for Diablo Canyon Power Plant, Units 1 and 2

Client: Pacific Gas & Electric

SI Project Number: **1700479**

Quality Program: ☒ Nuclear ☐ Commercial

Sections	Pages	Revision	Date	Comments
1.0	1-1 – 1-2	0	12/12/17	Initial Issue
2.0	2-1 – 2-7			
3.0	3-1 – 3-11			
4.0	4-1 – 4-3			
5.0	5-1 – 5-19			
6.0	6-1 – 6-7			
7.0	7-1 – 7-3			
8.0	8-1 – 8-2			
9.0	9-1 – 9-2			
10.0	10-1			

Professional Engineer Certification Statement

"Design Report for the Qualification of the Structural Weld Overlay Repair of Residual Heat Removal Welds WIB-245 and WIB-228 for Diablo Canyon Power Plant, Units 1 and 2"

I, Harry L. Gustin, P.E., being a duly licensed professional engineer under the laws of the State of Colorado, certify that this document was reviewed by me, and that this document meets the requirements of ASME Code, Section XI and Section III (Editions and Addenda as referenced in this report), which is based on the requirements of ASME Code Case N-740-2, as applicable to the specific scope of this report. This report is supplementary to the governing Stress 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.

COLORADO REGISTERED
HARRY LATHAM GUSTIN
34862
PROFESSIONAL ENGINEER

Harry L. Gustin, P.E.
State of Colorado
Registration Number: 34862
Date: December 12, 2017

Table of Contents

List of Tables

List of Figures

Figure | **Page**

1.0 INTRODUCTION

1.1 Background

In May 2016, during the Unit 2 nineteenth refueling outage, 2R19, a circumferential flaw indication was identified in the residual heat removal (RHR) suction pipe-to-elbow stainless steel weld (SSW) WIB-245 at the Diablo Canyon Power Plant (DCPP) [1]. Subsequently, in April 2017 during the Unit 1 twentieth refueling outage, 1R20, a circumferential flaw indication was identified in the RHR suction pipe-to-elbow stainless steel weld (SSW) WIB-228 at DCPP [2].

Temperature monitoring of the RHR lines for both Units 1 and 2 indicated that thermal stratification and temperature cycling are present at both weld locations. Flaw growth evaluations showed that thermal fatigue is a major contributor to the overall flaw growth [5]. Therefore, Pacific Gas & Electric (PG&E) determined that the primary degradation mechanism is thermal fatigue [5].

A decision was made by PG&E to repair both locations using a full structural weld overlay (FSWOL) to eliminate dependence upon the SSW as a pressure boundary weld, and to mitigate future crack growth. A FSWOL design was developed using ASME Code, Section XI, Code Case N-740-2 [3] that will be applicable to both Unit 1 and Unit 2 [4].

As stated in the Relief Request submitted by PG&E [5, pg. 8], analyses will be performed to:

> *"...demonstrate that the application of the weld overlays does not impact the conclusions of the existing piping analysis reports. The analyses will also demonstrate that ASME Code Section III stress and fatigue criteria, for both design loadings and the observed thermal cycling phenomena, are continued to be met for those piping components that are affected by the overlay (if any)."*

1.2 Weld Overlay Mitigation of Piping

Weld overlays have been installed for many years in U.S. boiling water reactors (BWRs) and pressurized water reactors (PWRs) to repair flaws. The process is an ASME Code approved repair method under ASME Code, Section XI, Code Case N-740-2 [3]. The FSWOL will be applied using Gas Tungsten Arc Welding (GTAW), in accordance with Code Case N-740-2 [3]. Nickel alloy weld filler metal will be utilized for the weld overlay for material compatibility with the underlying RHR piping materials and to maximize the weld residual stress benefits of the FSWOL. The specified welding material for the weld overlay is Alloy 52M.

1.3 Objectives and Report Organization

The objectives of this report are to provide the technical basis and a summary of the design and analysis results for the RHR pipe-to-45° elbow FSWOL that is applicable for both Unit 1 and Unit 2. Section 2.0 of this report discusses the repair and evaluation criteria for FSWOL design plus the basic structural sizing of the overlay. Section 3.0 summarizes the weld residual stress analyses performed. Section 4.0 summarizes the evaluation of weld overlay effects on the piping system following installation of the weld overlay. Analyses that supplement the existing RHR piping Stress Report and demonstrate that the overlaid components meet ASME Code, Section III requirements are summarized in Section 5.0. Flaw growth calculations are summarized in Section 6.0. Section 7.0 contains a reconciliation of the original Code-of-Record with a later edition of the ASME Code used in the evaluations herein. A summary and conclusions are provided in Section 8.0, while Section 9.0 provides the references used in this report. The supporting calculations and the design drawing are listed in Section 10.0, and are referenced by calculation number within this report.

2.0 FULL STRUCTURAL WELD OVERLAY DESIGN

The FSWOL design for the RHR pipe-to-elbow weld for Unit 1 (WIB-228) and Unit 2 (WIB-245) is designed to the requirements of ASME Code, Section XI, Code Case N-740-2 [3]. The design requirements are listed below:

- Determine the minimum structural dimensions (i.e., thickness and length) of the FSWOL and increase these dimensions, as needed, to meet coverage requirements of a PDI qualified ultrasonic (UT) examination.
- Determine the weld residual stress in the base material and FSWOL to facilitate a crack growth evaluation.
- Evaluate the effects of the weld overlay on the piping system. These include:
    - Weld shrinkage introduced into the piping system as a result of the installation of the weld overlay. Effects include added stresses in other piping locations and changes to supports (i.e. spring hanger, rigid supports, snubbers and rupture restraints).
    - The effects of the added weight of the FSWOL on the system deadweight and seismic loads/behavior.
- Qualification of the FSWOL to ASME Code, Section III design requirements, which require the following additional activities:
    - Development of the appropriate finite element models.
    - Development of the design transient loads, including pressure and piping loads (i.e. deadweight, thermal expansion and seismic).
    - Development of thermal mixing/stratification transients based on thermocouple temperature data from Unit 1 and Unit 2.
- Perform a crack growth evaluation based on the design transients and the thermal mixing/stratification transients. The evaluation includes the combined contribution of thermal fatigue crack growth and stress corrosion cracking.

The original design Code-of-Record for the RHR piping system for both Unit 1 and Unit 2 is B31.1, 1967 Edition [17]. The FSWOL sizing and the fracture mechanics evaluation will be performed to ASME Code, Section XI, 2007 Edition with 2008 Addenda as indicated in the Relief Request [5]. The ASME Code, Section III qualification will be based on the 2001 Edition with Addenda through 2003. The reconciliation of the original Code-of-Record to this new ASME Code edition is performed and documented in Section 7.0.

2.1 Weld Overlay Application

The FSWOL will be installed using a controlled process in accordance with Code Case N-740-2 and its dimensions will meet the specifications contained in SI Design Drawing 1600546.510, in order to assure the integrity of the FSWOL.

2.2 Criteria for Design of Full Structural Weld Overlay

The requirements for the design of the FSWOL are specified in ASME Code Case N-740-2 [3], as proposed in the DCPP Relief Request [5]. The analytical bases for the design of the FSWOL are in accordance with the requirements of ASME Code, Section XI [6], IWB-3640. The three principal design criteria for a FSWOL are listed below:

1. The design basis for the FSWOL is the acceptability of a postulated circumferentially oriented flaw that extends 360° around the component, and is 100% through the original component wall [3, Sections 1.1(a) and 2(a)(2)]. Credit is not taken for the load carrying capability of the original butt weld in the FSWOL sizing process. These conservative criteria eliminate any concerns about potential crack propagation in the original stainless steel weld (SSW), and any concerns about the integrity of the original SSW.

2. As required by ASME Code, Section XI [6], IWB-3640, a combination of internal pressure, deadweight, seismic, and other dynamic stresses are used in the design of a FSWOL [3, Section 2(b)], considering all primary loadings for all Service Levels; A, B C and D. Thermal

and other secondary stresses are not required to be included for structural sizing calculations (since the FSWOL will be installed using a GTAW (non-flux) process that produces a high toughness weld deposit). The secondary and peak stresses are addressed later in subsequent evaluations for primary-plus-secondary stress, fatigue usage, and evaluations for fatigue crack growth and stress corrosion cracking.

3. The surface finish of the FSWOL must be sufficiently smooth to allow preservice and future inservice ultrasonic examinations through the overlay material and into a portion of the original base metal [3, Section 3]. The purpose of these examinations is to demonstrate the integrity of the FSWOL.

2.3 Weld Overlay Structural Sizing

The FSWOL sizing process, using Code Case N-740-2 [3], includes the following requirements:

- Determination of the minimum structural thickness that meets ASME Code, Section XI, Appendix C requirements, assuming a through wall, fully circumferential flaw.
- Determination of the minimum structural length that meets the pure shear requirements of ASME Code, Section III.

In addition, as stated in the Relief Request [5], the FSWOL design shall allow for ASME Code, Section XI, Appendix VIII, Supplement 11 UT examinations by Performance Demonstration Initiative (PDI) qualified procedures. This requirement typically results in a FSWOL that is larger than the calculated minimum structural dimensions. The larger dimensions will be specified as the mandatory design thicknesses and lengths of the FSWOL.

2.3.1 FSWOL Thickness

Detailed sizing calculations for the FSWOL thickness are documented in SI Calculation 1600546.310. ASME Code Case N-740-2 [3], which incorporates ASME Code, Section XI,

IWB-3640 [6] evaluation methodology, was used to determine the thickness of the FSWOL. Key aspects of the evaluation are listed below:

- The source equations that are provided in ASME Code, Section XI, Appendix C, Subarticle C-5320 [6] are used.
- Structural factors that are provided in Appendix C, Subarticle C-2621 [6] are used. The structural factors are applied individually to the membrane and bending stresses. The structural factors depend on Service Level and loading (membrane or bending).
- Applicable design piping loads and pressure are used.

The resulting minimum required structural thickness of the FSWOL is summarized in Table 2-1.

2.3.2 FSWOL Length

Detailed sizing calculations for the FSWOL length are documented in SI Calculation 1600546.310. The weld overlay length must consider two requirements: (1) length required for structural reinforcement and (2) length required for preservice and inservice examinations of the overlaid weld.

In accordance with ASME Code Case N-740-2 [3], the minimum FSWOL length required for structural reinforcement was established by evaluating the axial shear stress due to transfer of primary axial loads from the straight pipe into the weld overlay and back into the 45° elbow. The overlay extends onto the straight pipe at one end and the 45° elbow at the other end, providing shear transfer of the axial loads into the base metal.

The minimum FSWOL length was determined such that the axial stress is less than the ASME Code, Section III limit for pure shear stress. Per subsection NB-3227.2 [7] the limit on pure shear due to any loadings, except Service Level D (Faulted), is $0.6S_m$, where S_m is the design stress intensity. The limit on pure shear stress is $0.42S_u$ [7, Appendix F, F-1341.1], for Service Level D (Faulted) conditions.

The resulting minimum required structural length of the FSWOL is summarized in Table 2-1.

Access for preservice examination requires that the overlay length and profile be such that the required post-FSWOL examination volume can be inspected using PDI qualified NDE techniques. The dimensions of the FSWOL that meet the NDE requirements are presented in SI Drawing 1600546.510. The dimensions of the FSWOL that meet the NDE requirements are presented in Figure 2-1. The minimum and the maximum FSWOL dimensions are summarized in Table 2-1.

Table 2-1. Weld Overlay Minimum and Maximum Thickness and Length Requirements

Item	Location (from SSW toe)	Structural Thickness or Length (1)(2)	Design Minimum Thickness or Length (3)(4)	Design Maximum Thickness or Length (3)(4)
Thickness (in.)	Pipe Side	0.47	0.63	0.88
	45° Elbow Side	0.47	0.63	0.88
Length (in.)	Pipe Side	1.05	2.56	3.56
	45° Elbow Side	1.05	2.56	2.81

Notes:

1) The structural thickness shown is the minimum required for structural acceptance and does not include allowance for surface condition operations to facilitate ultrasonic (UT) inspections. These are documented in the 1600546.310 Sizing calculation.
2) The structural length shown is the minimum required for structural acceptance and does not include additional length necessary to meet inspectability requirements. These are documented in the 1600546.310 Sizing calculation.
3) Figure 2-1 presents a more accurate representation of the FSWOL geometry that satisfies both the structural minimums listed above and PDI UT inspectability.
4) Minimum and maximum dimensions are taken from the Design Drawing, 1600546.510. The thicknesses listed for the 45° elbow side are at the sidehill (flank) elbow location.

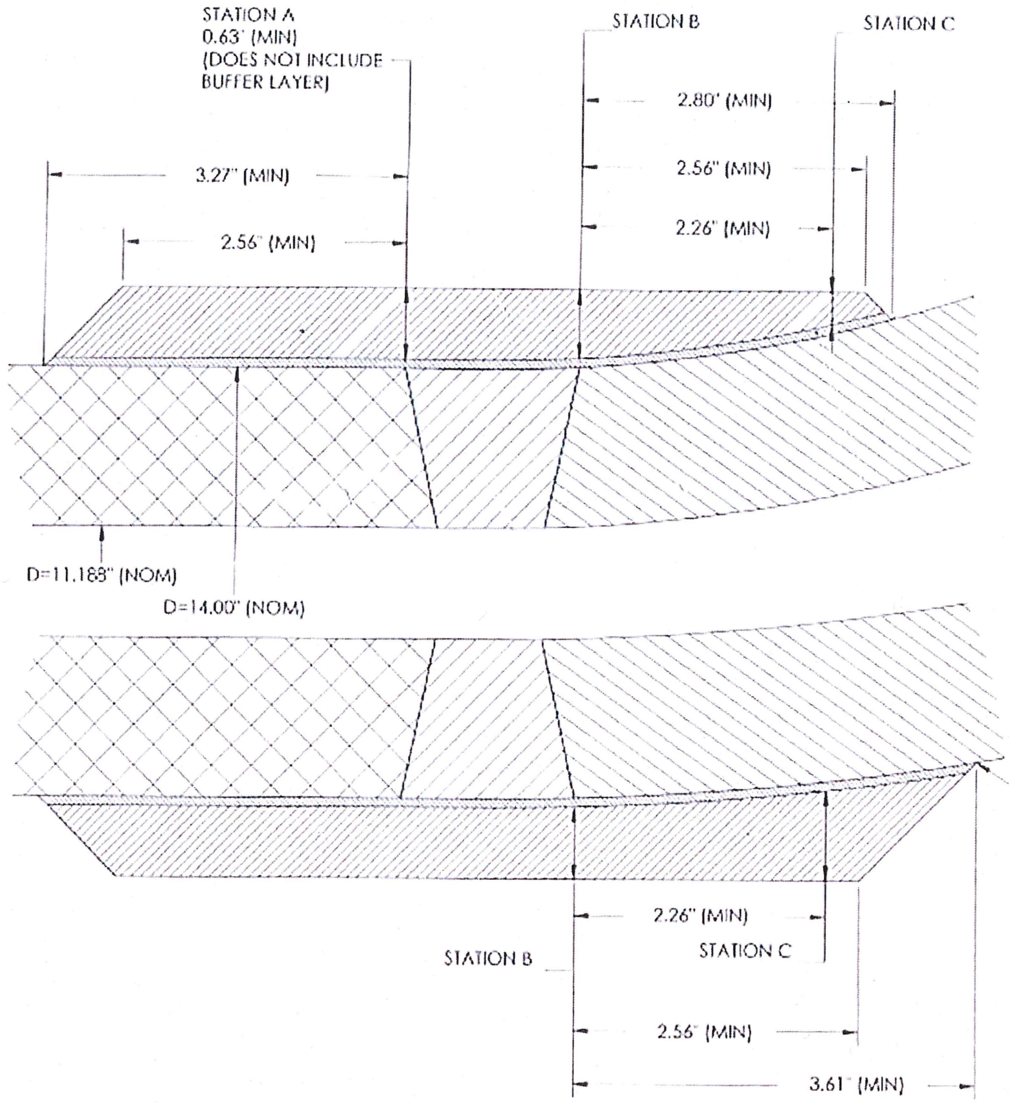


Figure 2-1. FSWOL Design Dimensions

(Dimensions at Station B and Station C are listed on 1600546.510 design drawing)

(Dimensions are the minimum to meet structural and PDI inspection requirements.)

3.0 WELD RESIDUAL STRESS ANALYSIS

3.1 Background

The installation of the FSWOL produces beneficial weld residual stresses that support the mitigation of future crack growth. The weld residual stresses for the RHR pipe-to-elbow FSWOL are determined by detailed elastic-plastic finite element analyses, as discussed in Section 3.2. The weld residual stress calculations are conservatively based on the minimum weld overlay design dimensions that are summarized in Table 2-1.

A weld residual stress (WRS) evaluation process documented in Structural Integrity Associates (SI) calculation package [8] is used in this calculation. The weld residual stress evaluation follows the guidelines provided in MRP-316, Revision 1 [9] and MRP-317, Revision 1 [10], and is validated by comparisons of analytical results with accepted measured weld residual stress data. The analysis process is automated in a weld residual stress analysis module [11] for the ANSYS finite element software package [12]. The WRS analysis is documented in SI Calculation 1700479.314.

3.2 Technical Approach

The weld residual stresses are controlled by various welding parameters, thermal transients resulting from the application of the welding process, thermal boundary conditions, temperature dependent material properties, elastic-plastic stress reversals, and air (or water) backing during weld deposition. The analytical technique uses finite element analysis to simulate the multi-pass weld process.

To obtain a bounding assessment of the impact of the weld overlay on the SSW, the weld residual stress assessment must consider weld residual stresses that existed prior to application of the overlay. Thus, the weld overlay analysis utilized a conservative assumption regarding weld residual stresses that may be present due to assumed weld repairs that may have occurred during plant construction.

For the weld residual stress analysis, a two-dimensional (2-D), axisymmetric finite element model (in lieu of a three-dimensional (3-D) model) was developed for the RHR pipe-to-elbow SSW location using the ANSYS software package [12]. Modeling of the weld beads in the overlay is illustrated in Figure 3-1. The use of the 2-D weld residual stress model is reasonable and conservative (less compressive stress), based on the following:

- The actual installed weld overlay volume will fall somewhere between the minimum and maximum design dimensions shown the SI Drawing 1600546.510
- The volume of the FSWOL weld metal in the 2-D residual model is essentially identical to the minimum dimension 3-D model,

The WRS analysis documented in SI Calculation 1700479.314 has concluded that the 2-D weld residual stress model is representative of the FSWOL that will be applied for DCPP Units 1 and 2.

As documented in the Relief Request [5, pg. 2], PG&E reviewed the Unit 1 fabrication records for WIB-228 and found no evidence of ID weld repair during construction. A similar review of the Unit 2 fabrication records for WIB-245 determined that the weld ID was subjected to surface grinding during construction, but there was no evidence of ID weld repair after the grinding. Accordingly, PG&E concluded that no ID weld repairs have been performed on either WIB-228 or WIB-245.

However, to be conservative, the weld residual stress model assumed a 360° circumferential, 50% through-wall of the SSW, inside diameter (ID) weld repair. This ID weld repair assumption follows the guidelines of the MRP-169 SER, Section 3.2.2, paragraph three [13], which states,

"The residual stress analysis assumes a highly unfavorable, pre-overlay residual stress condition which would result from an inside diameter surface weld repair during construction."

The statement above, taken from the MRP-169 safety evaluation [13], is attempting to produce highly conservative (i.e., tensile) initial conditions, which the FSWOL must overcome.

The following conditions are simulated in the WRS analysis:

- Application of the SSW (pipe-to-elbow weld)
- Grind out of a 50% ID repair (i.e. 50% of the 1.251" weld centerline dimension)
- Application of the 50% ID weld repair
- Application of the buffer layer (ER308L/ER309L)
- Application of the weld overlay (Alloy 52M)
- The model was then allowed to cool to a uniform temperature of 70°F and zero pressure (0 psig) after each completed welding process.
- A slow heatup to 100% power - normal operating temperature and pressure (478.3°F and 2,510 psig, respectively).

The weld residual analysis consists of a thermal pass to determine the temperature response of the model to each weld bead. A non-linear elastic-plastic stress pass is then performed to calculate the weld residual stresses due to the temperature cycling from the application of each weld bead. Since weld residual stress is a function of the welding history, the weld residual stresses and strains caused by the previous weld bead are used as initial conditions for the next weld bead.

Material properties used in the analyses, the finite element model development, and details of the weld residual stress analyses are documented in SI Calculations 1700479.312 and 1700479.314. The non-linear material properties are based on multi-linear isotropic hardening (MISO) principles, which are supported by elastic material properties obtained from the ASME Code, Section II, Part D, 2001 Edition with Addenda through 2003 [14]. Reconciliation of this later Code with the applicable Code-of-Record is provided in Section 7.0.

After completion of the simulation of the FSWOL, the normal operating temperature and pressure load is cycled five times between 70°F and no pressure (0 psig), and the operating temperature/pressure. This cycling is performed to obtain a stabilized residual stress state at room temperature, as well as a stabilized residual stress state at normal operating conditions (NOC). This step essentially simulates five heatup and cooldown ramp cycles. These

"shakedown" cycles are consistent with MRP-317, Volume 1, pages 5-8, "Shakedown Evaluation" [10].

3.3 Weld Residual Stress Analysis Results

The weld residual stress distribution following the completion of the RHR pipe-to-elbow SSW is shown in Figure 3-2. The effect of the assumed subsequent 360-degree 50% ID weld repair is shown in Figure 3-3. Note the high tensile stress state on the inside surface of the SSW following the 50% ID weld repair. The results shown in Figure 3-3 represent a conservative starting point for the weld overlay weld residual stress analysis as discussed in Section 3.2.

The post-weld overlay weld residual stresses at room temperature and at operating temperature and pressure, are presented in Figure 3-4 and Figure 3-5, respectively. The FSWOL overcame the initial tensile ID surface stresses generated by the assumed 50% ID repair of the SSW in the hoop direction. However, the FSWOL did not fully overcome the ID surface axial tensile stresses at either 70°F or NOC. The figures do show that the post-FSWOL weld residual axial stresses are significantly reduced (less tensile/more compressive). The resulting stress state has significant axial compressive stresses within the original SSW. Overall, Figure 3-4 and Figure 3-5 show that the weld overlay has created a favorable compressive stress state in the SSW.

Weld residual stresses through the SSW/FSWOL are extracted along the three paths shown in Figure 3-6. The resulting weld residual stress profiles are illustrated in Figure 3-7. The plots show the through-wall stresses through the center of the SSW, after FSWOL installation. Through-wall weld residual stress distributions for these three paths are used as input to fatigue crack growth and SCC calculations that are discussed in Section 6.0.

Detailed descriptions of the weld residual stress analyses, including complete presentation of the input, assumptions and results, are documented in SI Calculation 1700479.314.

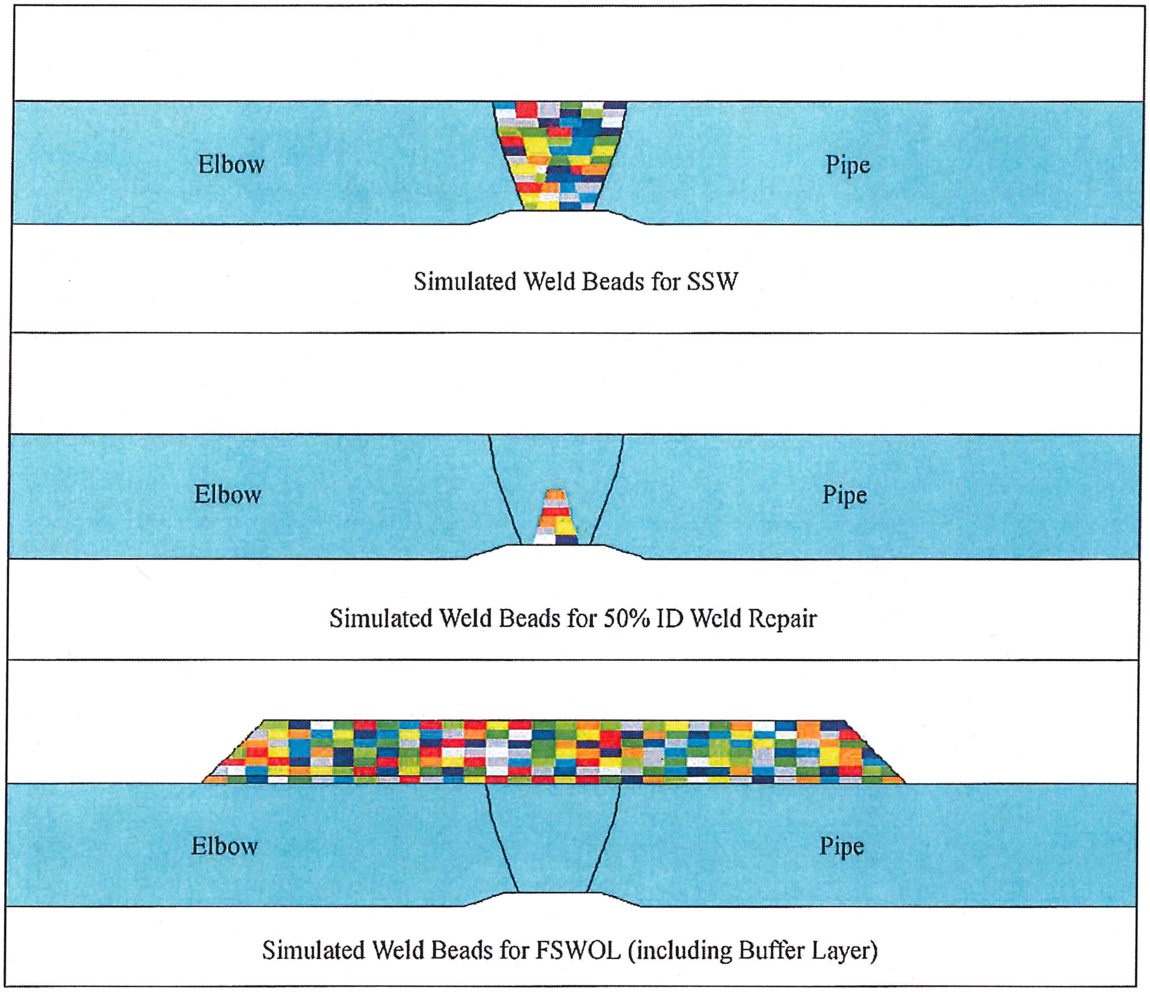
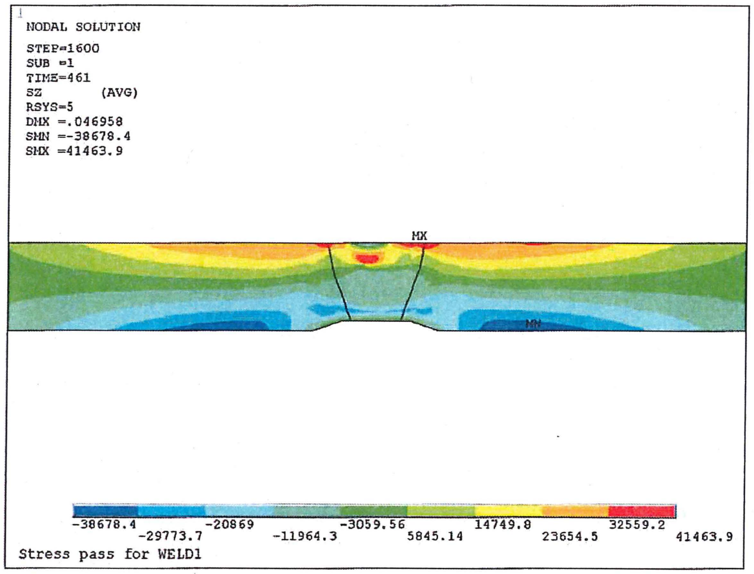


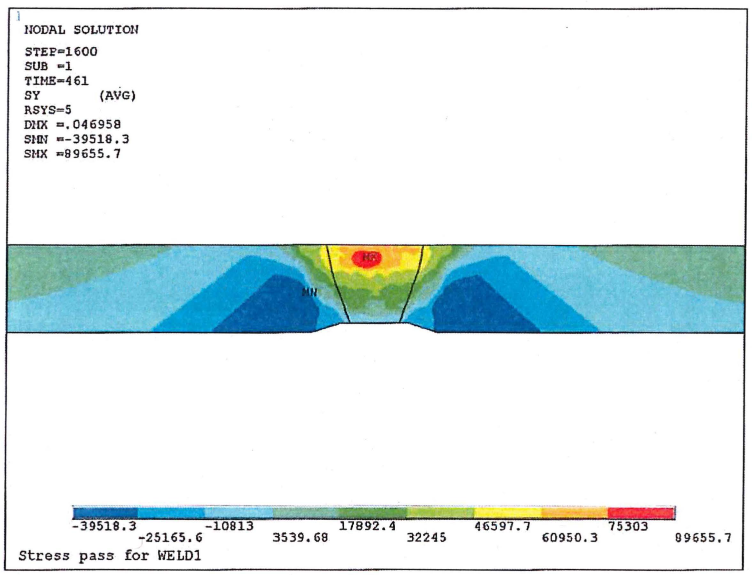
Figure 3-1. As-Modeled Weld Bead Patterns for SSW, ID Weld Repair, and FSWOL Installation

Note: The plot represents the nuggets for all the welding processes involved.

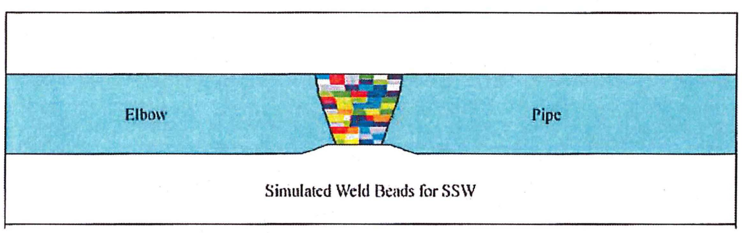
Note: The 2-D model shown. The actual FSWOL is applied to the pipe and a 45° elbow.



Axial Stress



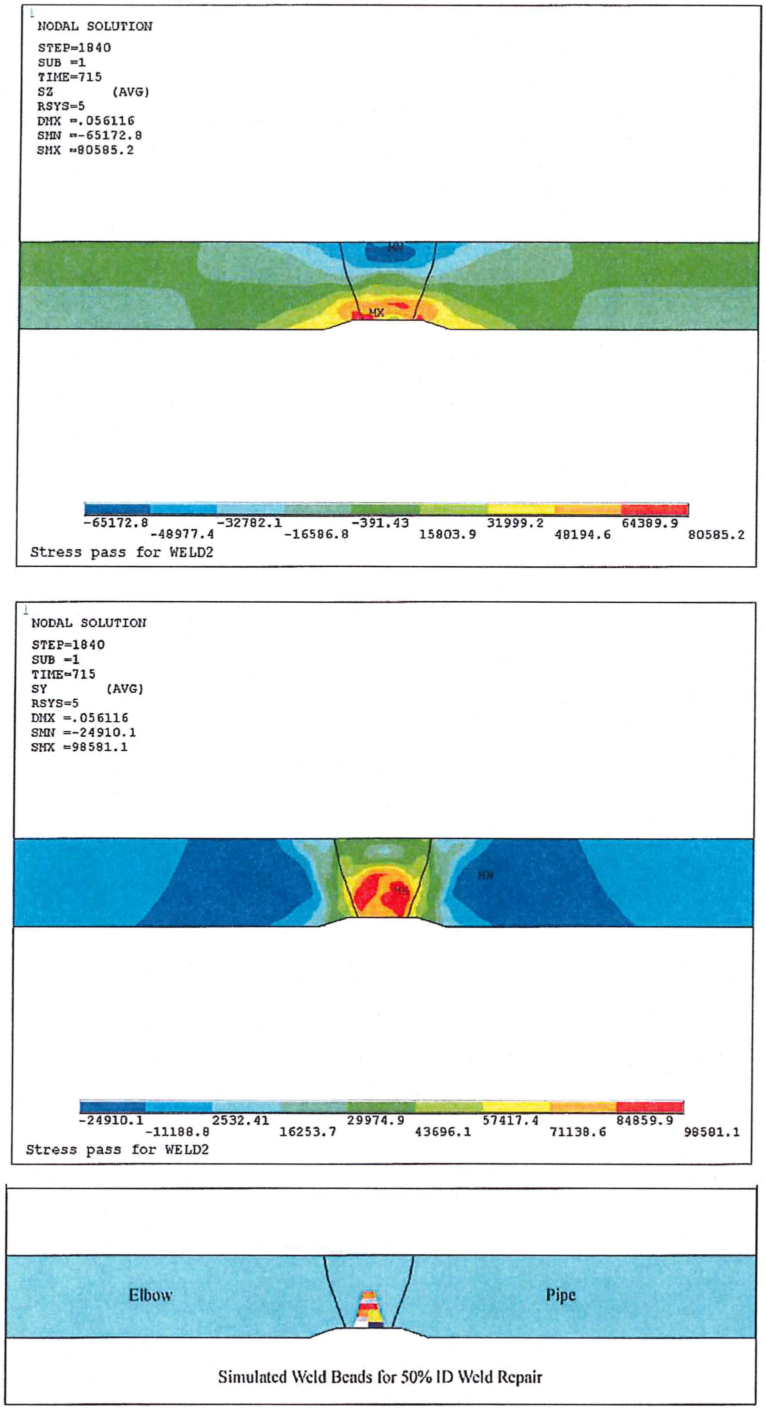
Hoop Stress



Weld Bead Pattern

Figure 3-2. Weld Residual Stress State at 70°F – Post SSW

Note: Local cylindrical coordinate system used. The units of the color bar across the bottom of the figures are psi.



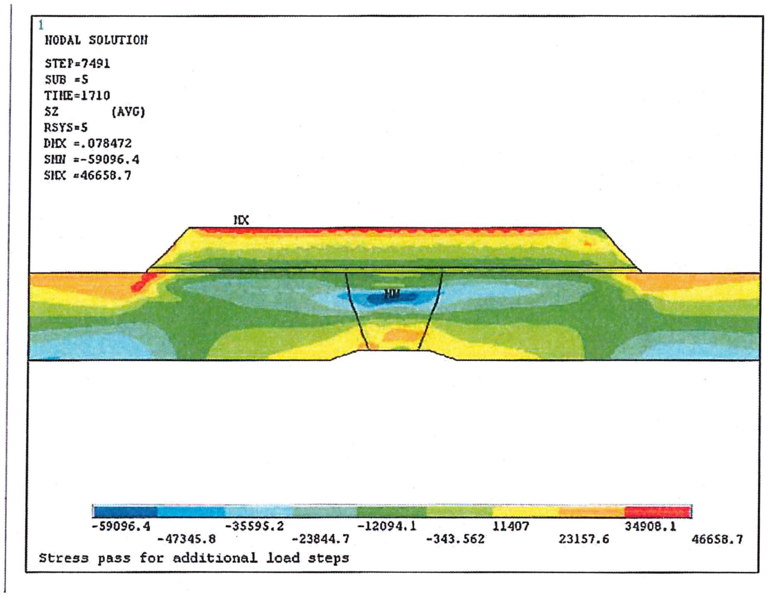
Axial Stress

Hoop Stress

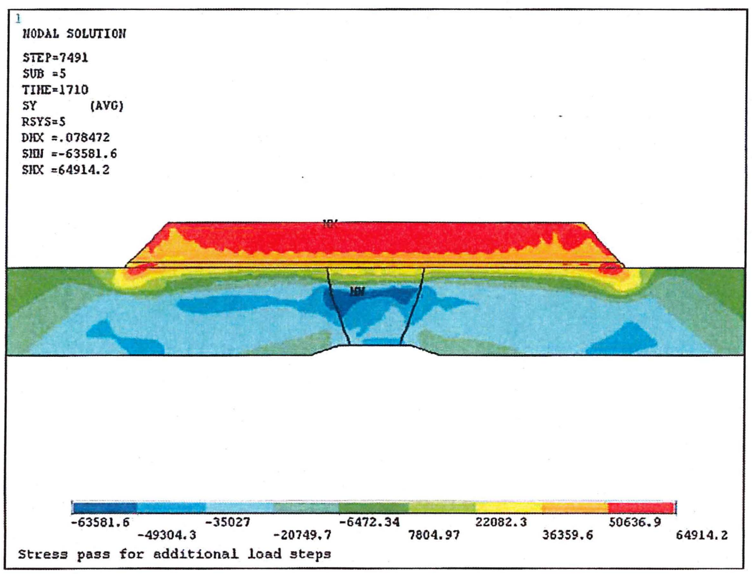
Weld Bead Pattern

Figure 3-3. Weld Residual Stress State at 70°F – Post 50% ID Weld Repair

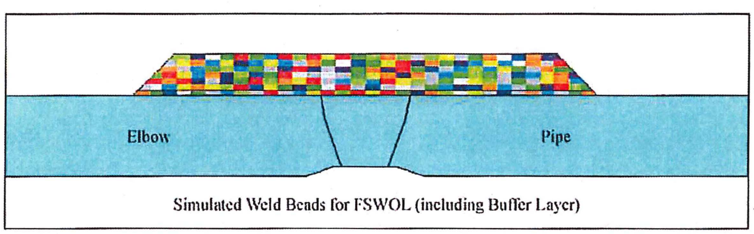
Note: Local cylindrical coordinate system used. The units of the color bar across the bottom of the figures are psi.



Axial Stress



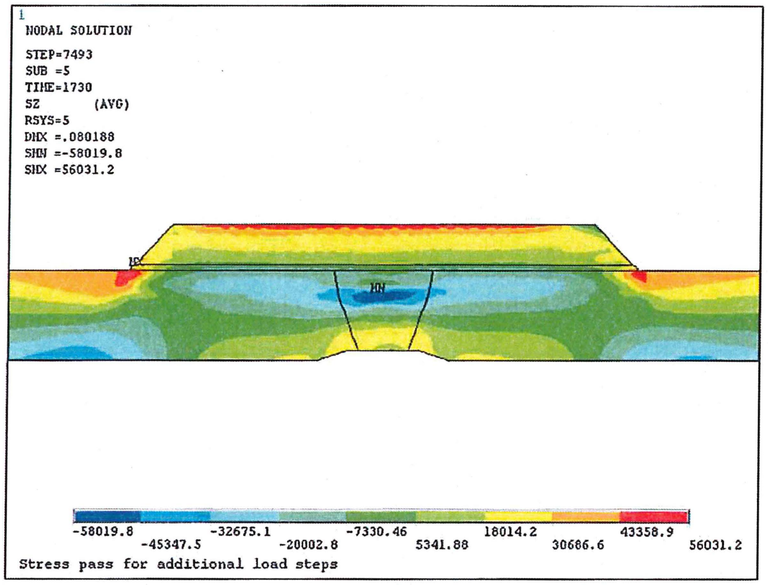
Hoop Stress



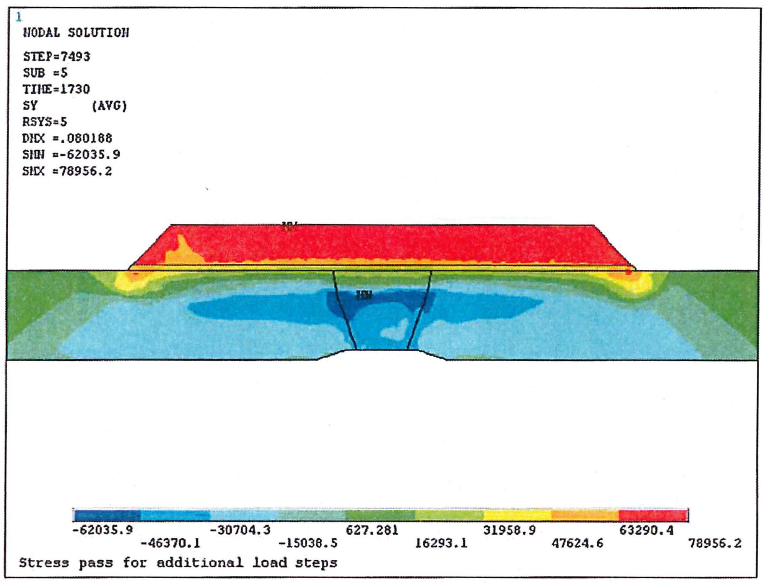
Weld Bead Pattern

Figure 3-4. Weld Residual Stress State at 70°F - Post FSWOL Installation

Note: Local cylindrical coordinate system used. The units of the color bar across the bottom of the figures are psi. Stresses shown are after 5 cycles of normal operating pressure/temperature.



Axial Stress



Hoop Stress

Figure 3-5. Weld Residual Stress State at 478.3°F and 2,510 psig - Post FSWOL Installation

Note: Local cylindrical coordinate system used. The units of the color bar across the bottom of the figures are psi. Stresses shown are after 5 cycles of normal operating pressure/temperature.

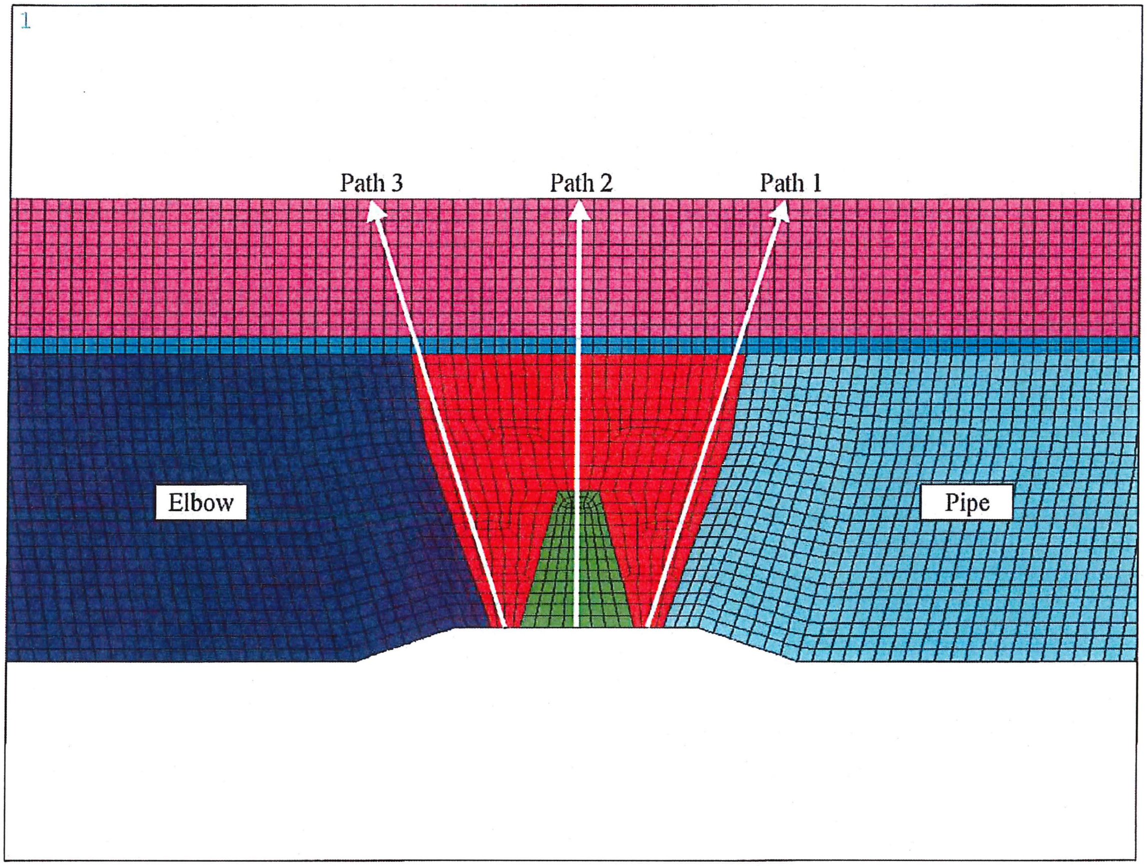


Figure 3-6. Weld Residual Stress Path Definition

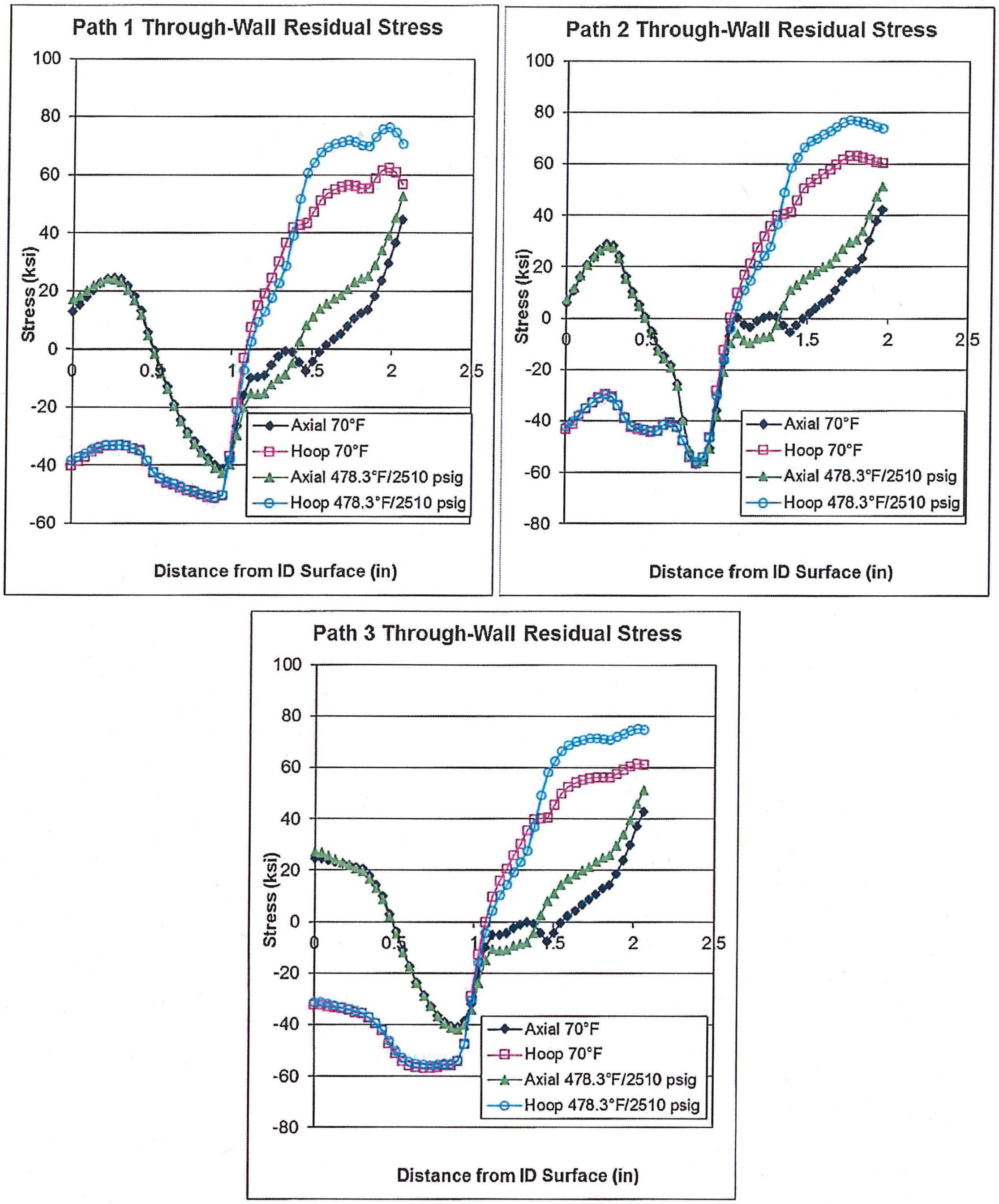


Figure 3-7. Weld Residual Stress Distributions at 70°F and NOC – Post FSWOL Installation

Note: As the analysis was a 2-D axisymmetric model, Paths 1, 2 and 3 shown in this figure correspond to Paths 31-38, 41-48, and 51-58 in Figure 5-8, respectively.

4.0 EVALUATION OF WELD OVERLAY INSTALLATION EFFECTS ON PIPING SYSTEMS

4.1 Background

Stresses may develop in remote locations of the RHR piping system due to the following post-FSWOL installation effects:

- Weld metal shrinkage - These stresses will be system-wide, and similar in nature to restrained free end thermal expansion or contraction stresses. The level of stresses resulting from weld overlay shrinkage will depend upon the amount of shrinkage and the piping system geometry (i.e., its stiffness).
- Weld metal added weight – These stresses will be system wide and will depend upon the magnitude of the FSWOL weight and the location of pipe supports.

The FSWOL evaluation was performed in accordance with the following requirements of Code Case N-740-2 [3, Section 2(b)(5]:

> *"The effects of any changes in applied loads, as a result of weld shrinkage from the entire overlay, on other items in the piping system (e.g., support loads and clearances, nozzle loads, and changes in system flexibility and weight due to the weld overlay) shall be evaluated. Existing flaws previously accepted by analytical evaluation shall be evaluated in accordance with IWB-3640, IWC-3640, or IWD-3640, as applicable."*

The specific details of the shrinkage and weight effects are discussed below.

4.2 Evaluation of Weld Overlay Axial Shrinkage Stresses

In ASME Code terminology, weld overlay shrinkage stresses are secondary stresses, and have no primary component. There are no ASME Code limits that apply to shrinkage stresses since

ASME Code limits on secondary stresses apply to their range under cyclic loading conditions. However, the ASME Code, Section III [7, NB-3672.8] does specify a limit of $2S_m$ for cold springing. This limit was applied to the FSWOL axial weld shrinkage stresses. The FSWOL shrinkage could, however, potentially impact the integrity of other welds. Therefore, it has become common practice with weld overlays to measure the axial shrinkage between punch marks that are placed on the components beyond the ends of the FSWOL as part of the implementation process. As a result, the stresses due to the assumed shrinkage were evaluated via a piping model. The assumed shrinkage value will be confirmed by physical measurement following FSWOL installation.

Due to displacements introduced by the FSWOL shrinkage in the piping system, it is also required that, after application of the overlay, a walkdown be performed to check all hanger set points. In addition, clearances or displacements at all spring hangers, snubbers, rupture restraints and rigid piping restraints must be checked to ensure the FSWOL shrinkage does not induce additional unwanted displacements.

The weld overlay shrinkage will be measured following the FSWOL installation. As discussed above, confirmation that sufficient room exists to accommodate shrinkage following weld overlay implementation is based on the successful hanger and support inspection that documents support/hanger settings are within design tolerances.

The shrinkage analysis is documented in SI Calculation 1700497.317. The analysis model was run using the PIPESTRESS [15] piping analysis program. The FSWOL shrinkage was modeled using an assumed axial shrinkage of 0.25 inch. This value for axial shrinkage is a conservative estimate based on previous industry experience.

The highest stress caused by the weld shrinkage was found to be 6.48 ksi. This stress is remote from the FSWOL and occurs in the region downstream of Valve 2-8701 (Isolation valve closest to containment penetration). This weld shrinkage stress is acceptable, since this stress is less than the cold springing allowable stress of $2S_m$, which is 2(20) = 40 ksi at 70°F [7, 14].

4.3 Evaluation of the Effect of FSWOL Weight

The added weight of the FSWOL can be a concern when considering the impact on the dynamic response characteristics of the RHR system piping. Therefore, the design piping stresses and the local support loadings must be checked. The conservatively calculated weight added from the FSWOL (with maximum dimensions) for the RHR system piping is insignificant (i.e., less than 1.5% of the affected piping weight) when compared to the weight of the RHR piping system from the RCS hot leg connection to pipe whip restraint 1-9RR (located at the top of the vertical riser). Thus, the added weight of the FSWOL will not be adverse.

In addition, the bounding variability for spring hangers was determined to be at the Unit 2, 6-8V spring hanger (the first spring hanger downstream of the FSWOL), with a value of 4.07%. This value is significantly less than the allowable variability of 25%. Thus, the added weight of the FSWOL will not adversely impact spring hanger settings and function.

In conclusion, the added weight of the FSWOL will not adversely impact the existing design loads and the dynamic characteristics of the RHR piping system. Detailed descriptions of the weld overlay weight analysis, including complete presentation of the input, assumptions and results, are documented in SI Calculation 1700497.318.

5.0 ASME CODE, SECTION III STRESS ANALYSIS

5.1 Background

The ASME Code, Section III stress analysis was performed in accordance with the following requirements specified in the Relief Request [5, page 8]:

> *"... demonstrate that the application of the weld overlays does not impact the conclusions of the existing piping analysis reports. The analyses will also demonstrate that ASME Code Section III stress and fatigue criteria, for both design loadings and the observed thermal cycling phenomena, are continued to be met for those piping components that are affected by the overlay (if any)."*

This section presents a summary of ASME Code, Section III stress evaluations performed for the weld overlay of the Unit 1 and Unit 2 RHR pipe-to-45° elbow welds (WIB-228 and WIB-245).

The ASME Code, Section III, 2001 Edition with Addenda through 2003 [7] was used as a basis for evaluations in this report. Reconciliation of this later Code with the applicable Code-of-Record [17] is provided in Section 7.0.

5.2 Design Criteria

The initial sizing of the FSWOL repair was performed per the design requirements of the ASME Code, Section XI, 2007 Edition with Addenda through 2008 [6] and the ASME Code, Section XI, Code Case N-740-2 [3], which was documented in SI Calculation 1600546.310.

As the FSWOL will be applied to the RHR suction piping systems, which is a Class 1 system, the design requirements will be based on the rules of Subarticle NB-3600 of Section III of the ASME Code, 2001 Edition with 2003 addenda [7]. Thus, the following design criteria must be met:

- Pressure Design per Subsubarticle NB-3640.
- Consideration of Design Conditions per Paragraph NB-3652.
- Consideration of Level A Service Limits per Paragraph NB-3653, which includes.
    - NB-3653.1 Satisfaction of Primary Plus Secondary Stress Intensity Range.
    - NB-3653.2 Satisfaction of Peak Stress Intensity Range.
    - NB-3653.3 through NB-3653.6 which collectively represent fatigue usage.
    - NB-3653.7 Thermal Ratcheting
- Consideration of Level B Service Limits per Paragraph NB-3654.
- Consideration of Level C Service Limits per Paragraph NB-3655.
- Consideration of Level D Service Limits per Paragraph NB-3656.
- Consideration of Test Loadings per Paragraph NB-3657.

NB-3600 criteria are formulaic and are based on straight pipe stress equations with indices that adjust the calculated results to account for non-straight pipe components (i.e. elbow, reducer, tee, etc.). As such, the equations do not account for the behavior of radial material changes (i.e., the stainless steel base material of the pipe overlaid with Alloy 52M material). More importantly, they cannot accurately account for the thermal mixing behavior (stratification, varying temperatures around the circumference) that was observed in both Unit 1 and Unit 2.

As finite element analysis was used to more accurately evaluate these behaviors, the resulting stress combinations are more consistent with the Class 1 vessel design requirements outlined in Subarticle NB-3200. Therefore, the FSWOL region of the RHR suction piping system was evaluated using guidance from the rules of Subarticle NB-3600 of the ASME Code to satisfy NB-3200 acceptance criteria.

Given that Section III of the ASME Code provides "Rules for Construction of Nuclear Facility Components," there is no guidance for the inclusion or evaluation of a pre-existing flaw. Thus, the ASME Code, Section III qualification described herein did not consider the presence of a flaw in the base metal of the pipe/weld. However, consistent with the requirements of Code Case

N-740-2 [3, Section 2], a crack growth evaluation was performed, and is documented in a separate fracture mechanics calculation, 1700479.316 (see Section 6.0 for more details).

5.3 Technical Approach

Stresses at critical locations due to various loading conditions were determined using finite element analyses. A total of three finite element models (FEM) were developed using the computer program ANSYS [12] in SI Calculation 1700479.312. The following models were developed to conservatively evaluate specific loading conditions:

- Local FEM of the weld overlaid region was developed with the minimum dimension weld overlay defined in SI Design Drawing 1600546.510. This model was used to evaluate mechanical loads such as pressure and piping loads due to deadweight, thermal expansion and seismic. The resulting model is shown in Figure 5-1.
- Local FEM of the weld overlaid region was developed with the maximum dimension weld overlay defined in SI Design Drawing 1600546.510. This model was used to evaluate design (thermal) transient loads. The resulting model is shown in Figure 5-2.
- A global FEM of the Unit 1 RHR suction line was developed from the RCS hot leg connection to the containment penetration with the maximum dimension weld overlay defined in SI Design Drawing 1600546.510. This model was used to evaluate the thermal mixing/stratification loads. The resulting model is shown in Figure 5-3.

Eighteen bounding design transients were developed in SI Calculation 1700479.311. The design transients and their corresponding design cycles are tabulated in Table 5-1. The assigned total number of cycles for each design event was based on the projected cycles for 60 years of operation.

Following the discovery of the flaw in Unit 2, nine (9) thermocouples were installed and temperature data were recorded during the subsequent startup and 100% power operation.

Similarly, following the discovery of the flaw in Unit 1, twelve (12) thermocouples were installed and temperature data were recorded during the subsequent startup and 100% power operation. The locations of the thermocouples (labeled in Figure 5-4, Figure 5-5, and Figure 5-6) are identified in Figure 5-7. The measured outside surface temperatures for both units revealed the following thermal transient behavior:

- The presence of "rapid" temperature oscillations that occur in the line during periods of sustained steady-state at-power operation (high-cycle thermal mixing, or high-cycle).
- The presence of complex thermally-stratified conditions in the RHR piping as the plant heats up from cold shutdown conditions (global heatup).

Given that the thermocouples generated temperature time histories at the outside surface (OD) locations of the piping, it was necessary to calculate the corresponding inside surface (ID) temperature time histories to generate a final set of thermal mixing transients that enveloped both Unit 1 and Unit 2 data. Detailed evaluations were performed to determine the enveloping thermal mixing transients, and these are documented in SI Calculation 1700479.321.

A third enveloping thermal transient, the global cooldown, was generated to define a corresponding cooldown transient, that included thermal stratification effects. The process for generating the global cooldown transient (with stratification) involved reversing the heatup transient, and then compressing the transient to generate a conservative estimate. This cooldown event is documented in SI Calculation 1700479.313.

The following three thermal mixing transients were evaluated:

- A "smoothed" thermal mixing global-heatup transient, where the "smoothing" removed the local high cycle behavior leaving only the global mixing/stratification. The evaluated transient is shown in Figure 5-4.
- A high cycle thermal mixing transient at 100% power normal operation. The evaluated transient is shown in Figure 5-5.

- A "smoothed" thermal mixing global-cooldown transient, where the "smoothing" removed the local high cycle behavior leaving only the global mixing/stratification. The evaluated transient is shown in Figure 5-6.

The thermal mixing transients and their corresponding design cycles are tabulated in Table 5-2.

For the thermal mixing transients, 250 cycles were assigned to the global heatup event, and 250 cycles were assigned to the global cooldown event. This matches the design cycles for the design plant heatup and cooldown events. For the high cycle thermal mixing at 100% power transient, 10,000,000 cycles were assigned. This assigned 10,000,000 cycle value was an assumption and is sufficiently large to adequately represent cycling within the observed thermal mixing event.

The thermal and mechanical stress analyses are presented in SI Calculation 1700479.313. In support of the ASME Code, Section III evaluations, several through-wall stress paths were defined through the weld overlay region, and linearized stresses were extracted along these paths (see Figure 5-8). The selected paths for evaluation included the ends of the overlay, as they contain discontinuity effects. No paths were selected through the SSW for evaluation using ASME Code, Section III rules. It is noted that the SSW already has an existing flaw, which will be evaluated in accordance with ASME Code, Section XI acceptance criteria. The ASME Code, Section XI evaluation includes a crack growth analysis for a bounding postulated flaw in the SSW weldment (see Section 6.0).

Details of the ASME Code, Section III evaluations are documented in SI Calculation 1700479.315.

5.4 Results of Analysis

5.4.1 ASME Code Primary Stress Criteria Check

The following ASME Code, Section III design criteria are based on primarily loading only:

- Pressure Design, Equations 1, 2, and 3, per NB-3641.1.
- Consideration of Design Conditions, Equation 9, NB-3652.
- Consideration of Level C Service Limits, Equation 3 and 9, per NB-3641.1 and NB-3652 with revised allowable per NB-3655.
- Consideration of Level D Service Limits, Equation 3 and 9, per NB-3641.1 and NB-3652 with revised allowable per NB-3656.
- Consideration of Test Service Limits, Equation 3 and 9, per NB-3641.1 and NB-3652 with revised allowable per NB-3226 as directed by NB-3657.

Primary loads consist of:

- Internal pressure.
- Piping deadweight.
- Piping seismic inertial loads.

Examination of the Equations 1, 2, 3 and 9 indicated that only the diameter and wall thickness were required to calculate the fundamental piping stresses. Given that the FSWOL installation will only add additional material to the outside of the piping, the resulting equation stresses from NB-3600 can only go down. As the RHR piping systems for Unit 1 and Unit 2 are already in service and thus, already meet all the original primary stress design criteria, it was concluded that no additional analysis was required to meet primary stress design criteria for the FSWOL configuration.

However, NB-3200 primary stress design criteria were evaluated based on general primary membrane, P_m, local primary membrane, P_L, and primary membrane-plus-bending, P_m+P_b, stress intensities per:

- Stress Categories and Limits of Stress Intensity for Design Conditions, Figure NB-3221-1
- Stress Categories and Limits of Stress Intensity for Level C Service Limits, Figure NB-3224-1
- Level D Service Limits are defined in Appendix F, per NB-3225
- Test Service Limits are defined in NB-3226.

The piping equations essentially meet the P_m and P_m+P_b stress intensities, but do not specifically evaluate P_L stress intensities, except with stress indices. The introduction of the FSWOL will generate a structural discontinuity on the pipe outside surface at the toe of the FSWOL, and as a result, P_L stress intensities will be present. Given that the P_m and P_m+P_b stress intensities are already acceptable and the primary stresses in the FSWOL region will be less, it was concluded that P_L stress intensities will also be acceptable (i.e., it was concluded that local stress effects due to the FSWOL installation will be minimal).

5.4.2 ASME Code Primary-plus-Secondary Stress Criteria Check

Primary-plus-secondary stress intensity ranges were calculated for the various transients (shown in Table 5-1 and Table 5-2) and were compared to the allowable Code limits in accordance with ASME Code, Section III, Subarticle NB-3200 with guidance from NB-3600 [7]. It should be noted that in using the ASME Code, Section III, Class 1 rules in NB-3200 and NB-3600 [7], Service Level A, Level B and Test Conditions were combined using bounding load combinations. A summary of the stress comparison for the sixteen paths is provided in Table 5-3.

One of the paths, Path 23 (Outside), did not meet the primary-plus-secondary stress range criteria check. The limit on the range of primary-plus-secondary stress intensity may be exceeded

provided that the requirements of NB-3228.5, Part (a) through NB-3228.5, Part (f) are met [7]. The results of this check are shown in Table 5-3.

5.4.3 Thermal Ratcheting

All the evaluated paths are located on piping components, and thus need to meet the thermal stress ratcheting requirements described in Subparagraph NB-3653.7 [7]. A conservatively determined limiting range of through-wall temperature gradient, ΔT_1, was calculated. The inside and outside surface temperatures were extracted from the thermal transients evaluated in SI Calculation 1700479.313. The through-wall temperature difference (ΔT) was calculated for each time point of the transients. The maximum positive through-wall ΔT was subtracted from the minimum through-wall ΔT for all transients, and the resulting range is conservatively compared to the allowable ΔT_1 range. The calculated maximum ΔT_1 range for all paths is 146°F, which is below the allowable temperature range of 282°F. Therefore, the thermal ratcheting criterion is met for all paths. The results for the most limiting path are tabulated in Table 5-3.

5.4.4 ASME Code Fatigue Evaluation

Fatigue evaluations were performed for Paths 11 through 18 and 21 through 28 for the FSWOL (see Figure 5-8). Both the inside and outside locations of the indicated paths were evaluated. The evaluations were performed in accordance with ASME Code, Section III, Subsubparagraph NB-3222.4(e) [7] with guidance from NB-3653.3 through NB-3653.6 [7]

Using the cycles listed in Table 5-1 and Table 5-2, the stresses were extracted along the listed paths below, using the appropriate material properties:

- Pipe Paths 11-18 SA-376, Type 316
- Elbow Paths 21-28 SA-403, WP316

The cumulative fatigue usage was calculated for all paths locations. The bounding cumulative fatigue usage is tabulated in Table 5-3.

The analysis has concluded that the stress intensity ranges and the fatigue usage for the FSWOL installation, for both Unit 1 and Unit 2, satisfy the applicable ASME Code, Section III allowable limits.

Table 5-1. Limiting Service Level A/B/Test RHR Design Transients Evaluated

Design Transient	**Cycles**
Plant Heatup	250
Plant Cooldown	250
Unit Load at 5% / Minute from 0% Load To 100% Load **High** Temp	18300
Unit Unload at 5% / Minute from 100% Load To 0% Load **High** Temp	18300
Large Step Load Decrease with Steam Dump, **High** Temperature	250
Large Step Load Decrease with Steam Dump, **Low** Temperature	250
Loss of Load **High** Temperature	100
Loss of Load **Low** Temperature	100
Loss of Offsite Power **High** Temperature	50
Loss of Offsite Power **Low** Temperature	50
Partial Loss of Flow - Loop with Pump Tripped Operating **Low** Temperature	100
Reactor Trip - **High** Temperature	500
Reactor Trip - **Low** Temperature	500
Inadvertent Auxiliary Spray - RCS Pressure	12
RCS Cold Overpressurization **High** and **Low** Tavg Conditions	10
Turbine Roll Test	10
Primary Side Hydrostatic Test	10
Primary Side Leak Test	60

Note: Cycles shown are for a 60-year operating life.

Table 5-2. Thermal Mixing/Stratification Transients Evaluated

Thermal Mixing Transient	**Cycles**
Global-Heatup	250
High Cycle Mixing at 100% Power	10,000,000
Global-Cooldown	250

Note: Cycles shown are assumed for a 60-year operating life.

Table 5-3. Limiting Service Level A/B/Test Stress Results for RHR Welds (WIB-245 and WIB-228) with FSWOL Installed

Load Combination	Path [4] and Type		Calculated (psi)	Allowable (psi)
Service Level A/B/Test	Path 11	Primary + Secondary (P + Q) [1]	31326	49872
	Path 12	Primary + Secondary (P + Q) [1]	36428	49872
	Path 13	Primary + Secondary (P + Q) [1]	37450	49872
	Path 14	Primary + Secondary (P + Q) [1]	39696	49872
	Path 15	Primary + Secondary (P + Q) [1]	40845	49872
	Path 16	Primary + Secondary (P + Q) [1]	38547	50832
	Path 17	Primary + Secondary (P + Q) [1]	34124	50784
	Path 18	Primary + Secondary (P + Q) [1]	33481	49872
	Path 21	Primary + Secondary (P + Q) [1]	33903	49638
	Path 22	Primary + Secondary (P + Q) [1]	46584	49872
	Path 23 [2]	Primary + Secondary (P + Q) [1]	54619	50784
	Path 24	Primary + Secondary (P + Q) [1]	44258	50832
	Path 25	Primary + Secondary (P + Q) [1]	37696	49872
	Path 26	Primary + Secondary (P + Q) [1]	33307	49872
	Path 27	Primary + Secondary (P + Q) [1]	34909	49422
	Path 28	Primary + Secondary (P + Q) [1]	31933	50784
Simplified Elastic Plastic	Path 23 [2]	Primary + Secondary (P + Q)	34411	50784
			Calculated	**Allowable**
Thermal Ratcheting	Path 23	ΔT_1	146°F	282°F
Fatigue	Path 23	Cumulative Usage Factor (60 years)	0.7589 [3]	1.000

Notes:

1) Primary stress acceptance criteria are met via the sizing calculations discussed in Section 2.3.
2) Elastic analysis result exceeds the allowable value of $3S_m$; however, criteria for simplified elastic-plastic analysis are met, see Section 5.4.2.
3) The limiting fatigue usage location is on the outside surface at the nose of the weld overlay on the 45° elbow, located 135° in the clockwise direction from top dead center when looking upstream (Path 23). The calculated Cumulative Usage Factor accounts for a 60-year design life for the weld overlaid configuration.
4) Paths are defined in Figure 5-8.

Figure 5-1. ANSYS 3-D Finite Element Model of RHR Weld Overlay for Pressure and Mechanical Loads (with Minimum FSWOL Dimensions)

Figure 5-2. ANSYS 3-D Finite Element Model of RHR Weld Overlay for Design Transient Analysis (with Maximum FSWOL Dimensions)

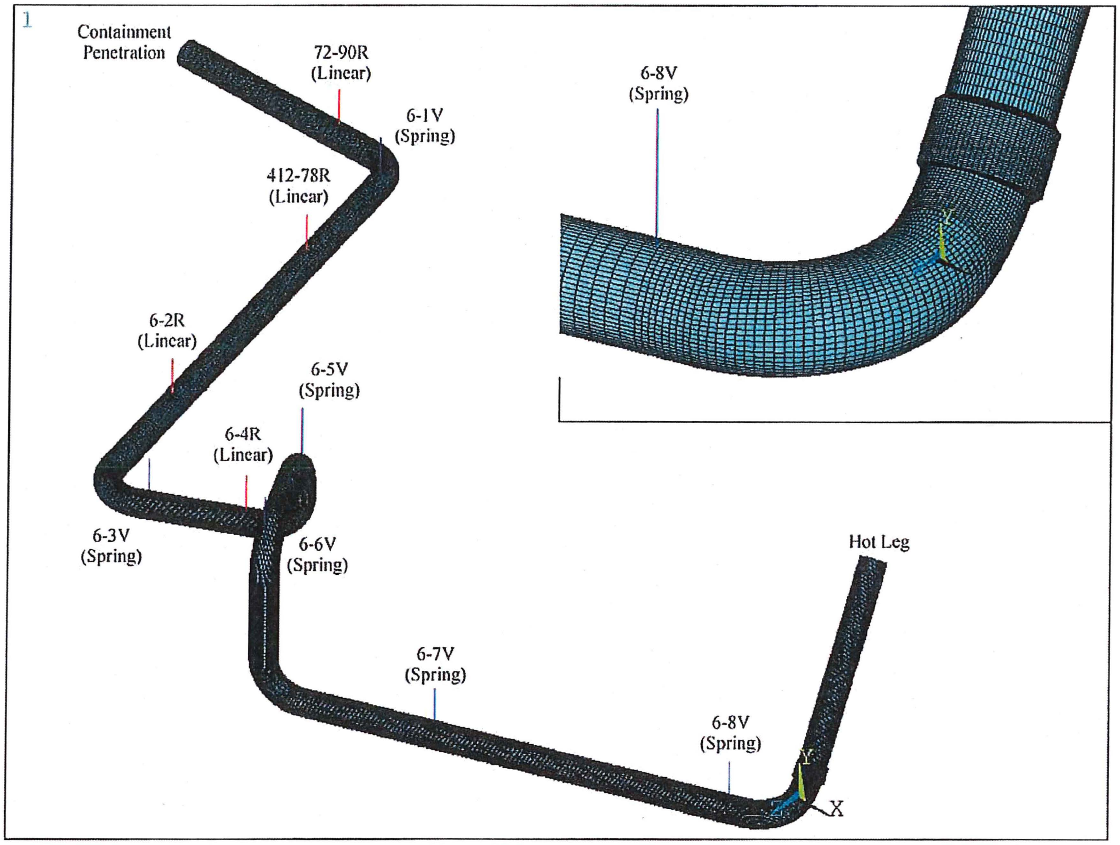


Figure 5-3. ANSYS 3-D Finite Element Model of RHR Weld Overlay for Thermocouple Based Thermal Mixing/Stratification Analysis (with Maximum FSWOL Dimensions)

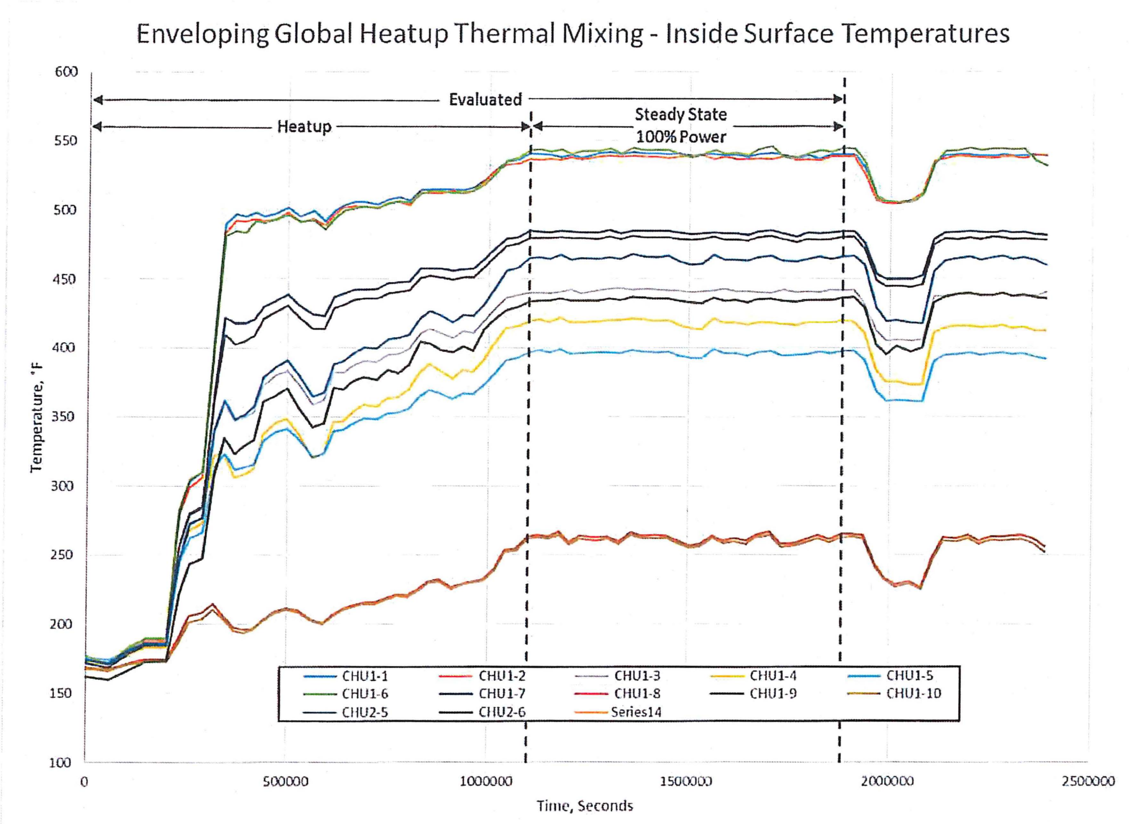


Figure 5-4. Enveloping Thermal Stratification Transient for the Global Heatup Event

(Thermocouple locations are shown in Figure 5-7.)

(The thermocouple values are listed using the Unit 1 locations, and are the enveloping temperature values calculated and reported in SI Calculation 1700479.321)

Note: The transient has been smoothed, to remove the high cycle behavior within each thermocouple. The high cycle behavior is bounded by the thermal mixing transient for the high cycle normal plant operation shown in Figure 5-5, as is the assumed number of cycles used to define that transient.

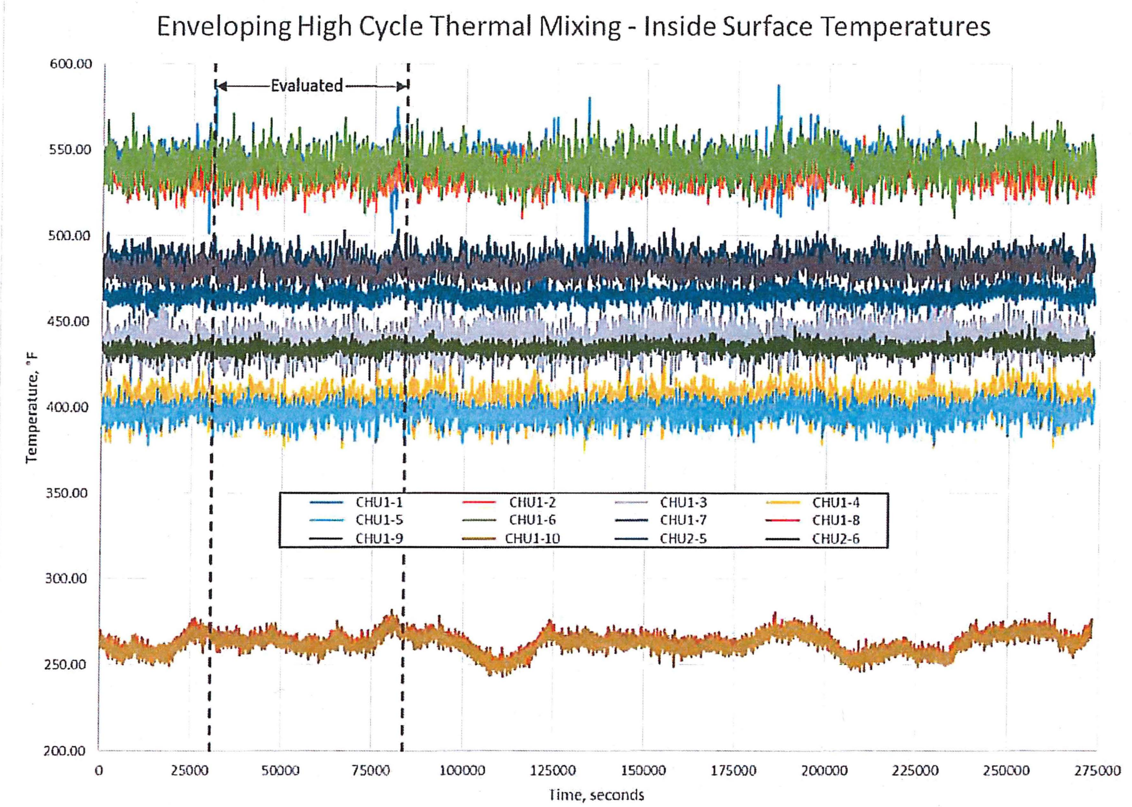


Figure 5-5. Enveloping Thermal Mixing/Stratification Transient for the High Cycle Normal Plant Operation

(Thermocouple locations are shown in Figure 5-7.)

(The thermocouple values are listed using the Unit 1 locations, and are the enveloping temperature values calculated and reported in SI Calculation 1700479.321)

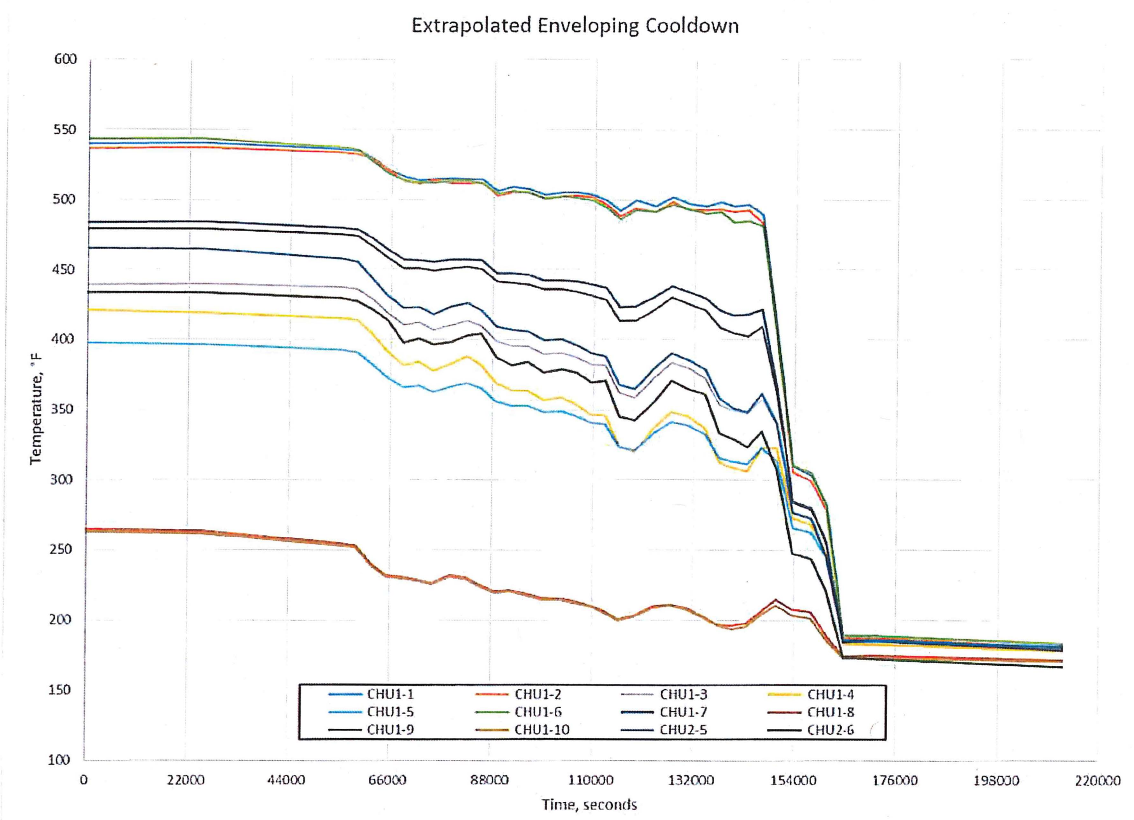


Figure 5-6. Enveloping Thermal Stratification Transient for the Global Cooldown Event

(Thermocouple locations are shown in Figure 5-7.)

(The thermocouple values are listed using the Unit 1 locations, and the temperature values were extrapolated and reported in SI Calculation 1700479.313)

Note: The transient has been smoothed, to remove the high cycle behavior within each thermocouple. The high cycle behavior is bounded by the thermal mixing transient for the high cycle normal plant operation shown in Figure 5-5, as is the assumed number of cycles used to define that transient.

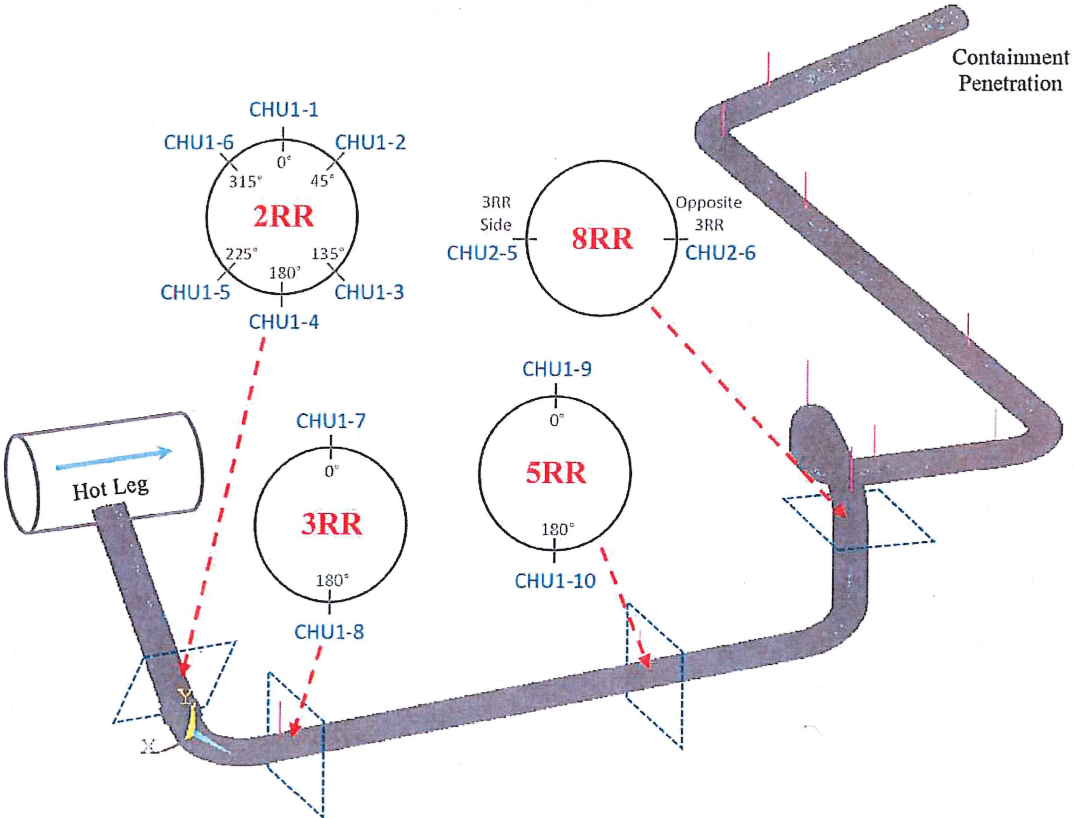


Figure 5-7. Location of Thermocouples on Unit 1 RHR Suction Line

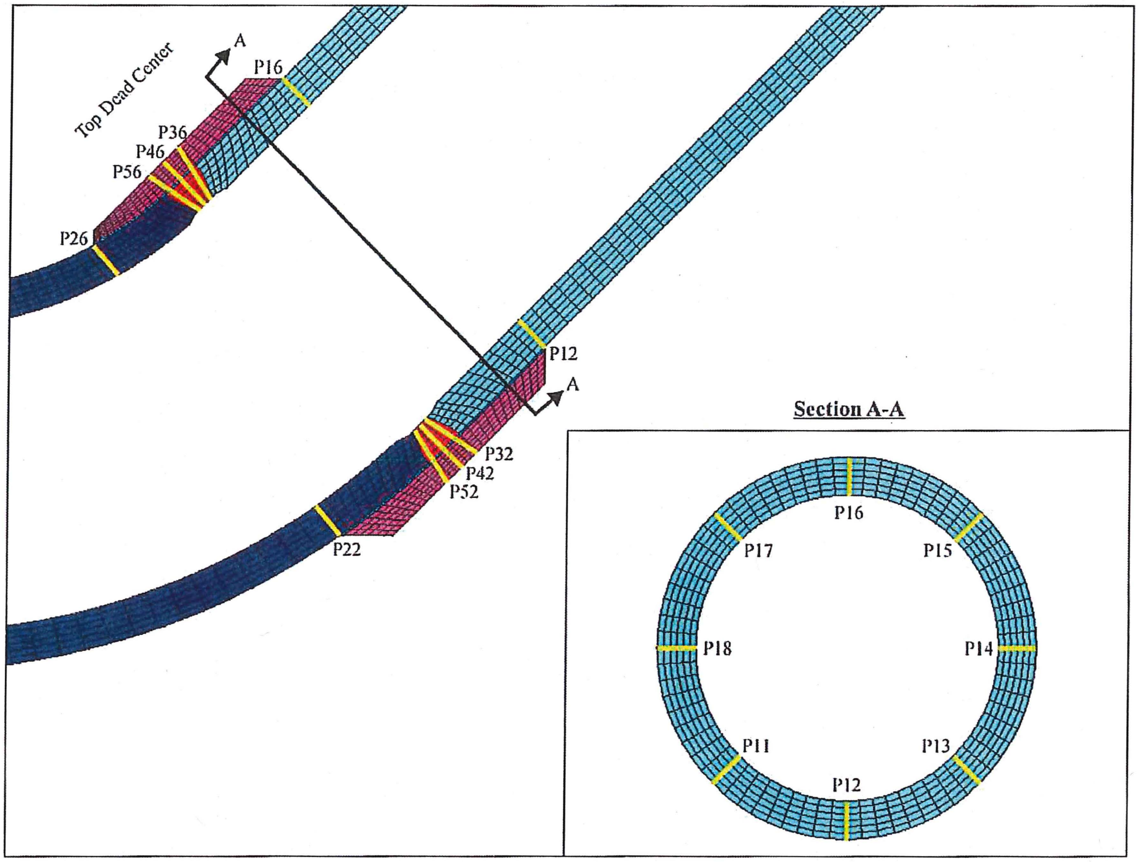


Figure 5-8. Locations of Stress Paths

(Linearized stress results extracted along these paths for Section III evaluation)

(Path definition = PXY, where:

X = the axial location along the pipe, e.g. P1 is at the RCS hot leg connection end of the FSWOL

Y = azimuthal location around the circumference (1 through 8) at the specific axial location, e.g. P12 is at Station 1 axially, and bottom dead center)

(Paths 11 through 18 and 21 through 28 are used for the ASME Code, Section III evaluation. Paths 31 through 38, 41 through 48, and 51 through 58 are used to support the fracture mechanics evaluations)

6.0 CRACK GROWTH EVALUATIONS

6.1 Background

The crack growth evaluation was performed in accordance with the following requirements of Code Case N-740-2 [3, Section 2(a)]:

> *"The size of all flaws detected or postulated in the original weld or base metal shall be used to define the life of the overlay. The inspection interval shall be longer than the shorter of the life of the overlay or the period specified in 3(c). Crack growth due to both stress corrosion and fatigue shall be evaluated. Flaw characterization and evaluation shall be based on the examination results or postulated flaw, as described below. If the flaw is at or near the boundary of two different materials, evaluation of flaw growth in both materials is required."*

The summaries of the crack growth evaluations that were performed for a postulated circumferential crack and a postulated axial crack are documented in this section. For both the circumferential and axial flaws, an initial flaw depth of 75% of the original base metal thickness (and fully 360° for the circumferential flaw) was postulated for computing crack growth in the pipe-to-elbow SSW region. Reference [1] reports that the Unit 2 RHR Weld, WIB-245, has a circumferential flaw that is 0.34 inch through-wall and 8 inches long. Reference [2] reports that the Unit 1 RHR Weld, WIB-228, has a circumferential flaw that is 0.2 inch through-wall and 4.8 inches long. No axial flaws were detected in either Unit 1 or Unit 2. Therefore, the postulated flaws bound the as-found flaws in both Unit 1 and Unit 2 [1, 2]. The proposed FSWOL was evaluated for mitigation of both thermal fatigue and stress corrosion cracking under the conservative assumption that both degradation mechanisms are active.

The fatigue crack growth evaluation considered the eighteen design transients tabulated in Table 5-1 and the three thermal mixing/stratification transients tabulated in Table 5-2.

6.2 Technical Approach

The technical approach used in this evaluation was to determine the through-wall stress intensity factor (K) distribution associated with the postulated circumferential and axial flaws in the pipe-to-elbow SSW using the post-weld overlay residual stresses at operating conditions plus sustained and transient operating stresses. For the case when the maximum K under sustained operating stresses is negative, then growth by SCC does not occur. From a fatigue crack growth standpoint, the K distributions for K_{min} and K_{max} as a function of crack depth for each operating transient (including thermal mixing/stratification) are calculated and evaluated using the fatigue crack growth model. The transients for the thermal mixing/stratification events envelope both Unit 1 and Unit 2. K_{min} and K_{max} are calculated for both applied and residual stresses.

Fatigue crack growth was computed using the crack growth equations given in Code Case N-809 appropriate for austenitic stainless steel in a PWR environment [16]. In implementing the crack growth equations, it was assumed that no fatigue crack growth will occur if the stress state at the crack is fully compressive during the cycle, i.e. both K_{min} and K_{max} are less than zero. If K_{max} was positive during any part of a transient, then fatigue crack growth was calculated. The defined number of cycles for each transient from Table 5-1 and Table 5-2 were used to determine the service life of the FSWOL.

Stresses that contributed to fatigue crack growth included those due to primary loads, such as internal pressure and external piping loads (i.e. deadweight and seismic); secondary loads, such as thermal expansion piping loads, thermal gradient stresses (due to design thermal transient and thermal mixing events) and weld residual stresses. The through-wall stresses from these loads were extracted from the finite element analyses. Details of the various loads, finite element analyses, and stress analyses are discussed in Section 5.0 of this report.

Fracture mechanics models, which are representative of the geometry of the overlaid region, were used to determine stress intensity factors, K. For the postulated circumferential flaw under an axial stress distribution (including moment effects), a 360° circumferential crack on the inside

surface of a cylinder was used (see Figure 6-1) [24]. For the postulated axial flaw, a semi-elliptical longitudinal crack on the inside surface of a cylinder was used for a number of different aspect ratios (see Figure 6-2) [24]. The stress intensity factors for each type of load were computed as a function of crack depth and superimposed for the various operating states. Fatigue crack growth (FCG) was calculated by using linear elastic fracture mechanics (LEFM) techniques. Similarly, growth due to SCC was computed with LEFM methods and added to growth due to FCG. The combined crack growth due to fatigue and SCC was calculated to determine the number of years it would take for the postulated circumferential flaw and axial flaw to reach the interface of the base metal and the FSWOL.

Flaw growth by SCC in the SSW was determined by calculating the stress intensity factor versus crack depth (K_{max} vs. a) curve at normal steady-state 100% power operating conditions. For the SCC evaluation, the fracture mechanics models used were the same as those used in the fatigue crack growth calculations. SCC is a time-dependent phenomenon and occurs during sustained loading conditions. Given that the great majority of plant operation is at steady-state normal operating conditions (NOC), SCC is defined by the stress conditions at NOC. SCC is defined to be active when K_{max}, at steady-state NOC, is a positive value. The following two steady-state NOC conditions were evaluated.

- Case 1 - Constant temperature of 478.3°F throughout the structure and a pressure of 2,510 psig, as described in Section 3.2.
- Case 2 – A bounding condition (as determined by K_{max}) using the high cycle thermal mixing at 100% power transient.

The limiting condition is whichever case results in the minimum service life for the FSWOL.

6.3 Crack Growth Results

The crack growth results are shown in Table 6-1. The allowable flaw depth is defined as the original pipe wall thickness, since the FSWOL takes no credit for the original pipe (assumes a 100% through-wall flaw in the original pipe that is 360° in circumference). The crack growth results show that it will take greater than 60 years for the initial postulated circumferential or axial flaws to propagate to the interface between the pipe/SSW OD and FSWOL. The maximum crack growth for 60 years is 0.0004 inch at Path 54 for the postulated circumferential flaw. This crack growth is entirely due to fatigue crack growth.

The crack growth results show that SCC is not active for either the postulated circumferential or axial flaws (K_{max} at steady state 100% power NOC (Case 1) and the thermal mixing (Case 2) are negative). Therefore, the SCC contribution to crack growth is zero for the evaluated conditions.

Crack growth analysis details and results for the RHR pipe-to-elbow SSW are contained in SI Calculation 1700479.316.

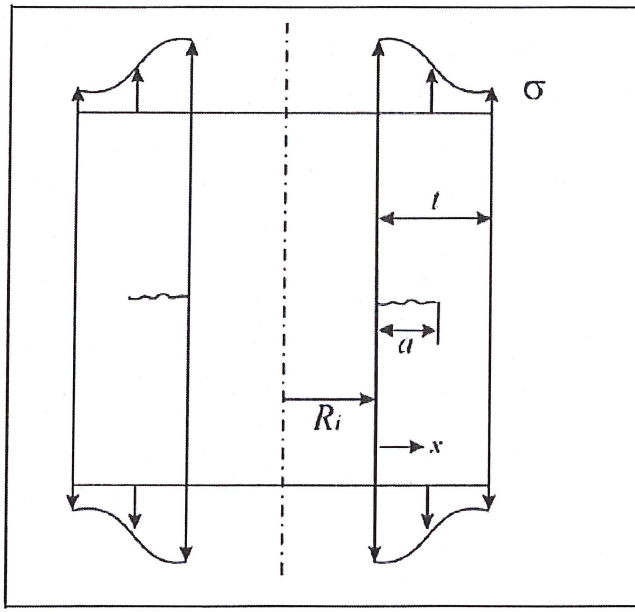
Table 6-1. Crack Growth Results

Path [1]	Axial Flaw				Circumferential Flaw			
	Initial Flaw Depth, in	60 Year Growth, in	Final Flaw Depth, in	Allowable Flaw Depth, in	Initial Flaw Depth, in	60 Year Growth, in	Final Flaw Depth, in	Allowable Flaw Depth, in
P31	0.938	0.000	0.938	1.251	0.938	3.17E-04 [3]	0.938	1.251
P32	0.938	0.000	0.938	1.251	0.938	3.31E-04 [3]	0.938	1.251
P33	0.938	0.000	0.938	1.251	0.938	3.64E-04 [3]	0.938	1.251
P34	0.938	0.000	0.938	1.251	0.938	3.97E-04 [3]	0.938	1.251
P35	0.938	0.000	0.938	1.251	0.938	3.72E-04 [3]	0.938	1.251
P36	0.938	0.000	0.938	1.251	0.938	3.34E-04 [3]	0.938	1.251
P37	0.938	0.000	0.938	1.251	0.938	3.31E-04 [3]	0.938	1.251
P38	0.938	0.000	0.938	1.251	0.938	3.20E-04 [3]	0.938	1.251
P41	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P42	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P43	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P44	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P45	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P46	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P47	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P48	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P51	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P52	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P53	0.938	0.000	0.938	1.251	0.938	3.70E-04 [3]	0.938	1.251
P54	0.938	0.000	0.938	1.251	0.938	4.00E-04 [3]	0.938	1.251
P55	0.938	0.000	0.938	1.251	0.938	3.59E-04 [3]	0.938	1.251
P56	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P57	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P58	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251

Notes:

1. See Figure 5-8 for the path locations.
2. Initial flaw depth = 75% of original through-wall thickness at SSW centerline
   Allowable flaw depth = original wall thickness at the SSW centerline
3. Crack growth occurs only due to fatigue crack growth resulting from the design transient "Primary Side Hydrostatic Test."

Crack Model: 301 - Full-Circumferential Crack in Cylinder on the Inside Surface

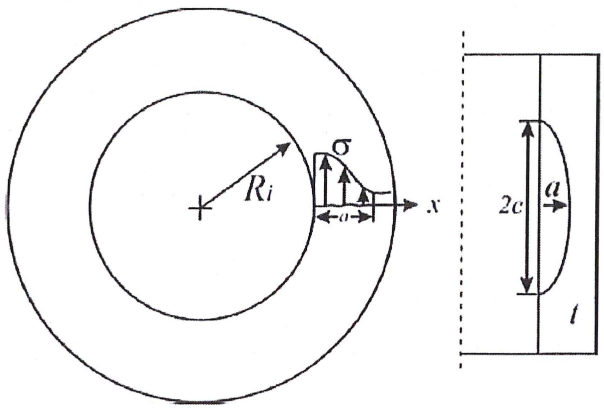


Stress/Load Input	
Stress Coefficients	✓
Coeffs. from Stress Table	✓
Stress Table	✓
Stress Intensity Factors (1D)	✓
Stress Intensity Factors (2D)	×
Crack Dimensions: a Component Dimensions: t R_i	
Range: $0.0 < a/t \leq 0.8$ $0 < R_i/t \leq 1000$ Source: [11]	

Figure 6-1. Full-Circumferential 360° Crack Model for Stress Intensity Factor Calculation due to Axial Stress

[24]

Crack Model: 305 - Semi-Elliptical Longitudinal Crack in Cylinder on the Inside Surface (API 579)



Stress/Load Input	
Stress Coefficients	✓
Coeffs. from Stress Table	✓
Stress Table	✓
Stress Intensity Factors (1D)	✓
Stress Intensity Factors (2D)	✓

Crack Dimensions:	a	c
Component Dimensions:	t	R_i

Range:

$0.0 < a/t \leq 0.8$
$0.03125 \leq a/c \leq 2.0$
$0.0 < t/R_i \leq 1.0$

Source: [11]

Figure 6-2. Semi-Elliptical Longitudinal Axial Crack Model for Stress Intensity Factor Calculation due to Hoop Stress

[24]

7.0 RECONCILIATION OF CODES-OF-RECORD WITH LATER CODE EDITIONS

The applicable Unit 1 and Unit 2 Code-of-Record for design of the RHR pipe-to-elbow SSW evaluated herein is ANSI B31.1, 1967 Edition [17], with the fabrication and erection Code-of-Record being B31.7, 1969 Edition with 1970 Addenda [18], as defined in Reference [19].

The ASME Code (i.e., the replacement Code in lieu of the Code-of-Record) for the weld overlay design utilized in this evaluation is the 2001 Edition with Addenda through 2003 of ASME Code, Section III [7]. The material properties are based on the following codes:

1. The linear elastic material properties are obtained from ASME Code, Section II, Part D, 2001 Edition with Addenda through 2003 [14].
2. The non-linear material properties are based on multi-linear isotropic hardening (MISO) principles. These non-linear material properties were used in the weld residual stress evaluation SI Calculation 1700479.314. The results of the weld residual stress evaluation were used in the ASME Code, Section XI flaw growth evaluation.

This section of the report provides the reconciliations which document the acceptability of using different Code editions, or revised Owner's requirements, by meeting the ASME Code, Section XI, 2007 Edition with Addenda through 2008 [6], IWA-4220 and IWA-4311 requirements, and demonstrates that the repairs are satisfactory for the specified design and operating conditions.

ASME Code, Section XI, 2007 Edition with Addenda through 2008 [6], IWA-4220 provides criteria for reconciling the use of later Codes and Editions for repairs and replacements. IWA-4311 [6] provides the requirements when there is a change in the design configuration, which, in this case, involves replacing the pressure boundary of the component butt weld with a full structural weld overlay.

7.1 Design

IWA-4226 states that when the design is to a later Edition of the Code-of-Record, all design requirements that relate to the later Edition shall be met, or any differences with the previous design shall be reconciled.

For the design of the RHR piping system, the original Code-of-Record is limited to design by pressure under Section 104 of the Code-of-Record [17] and per axial stress limits defined in Section 102. The design rules of Subarticle NB-3200 and Subsubarticle NB-3650 of the replacement Code [7] are far more rigorous, and include the primary-plus-secondary stress effects and fatigue.

For the design of the FSWOL, the requirements of the replacement Code have been adopted in their entirety. Therefore, use of a later Code is acceptable. The replacement Code reflects a greater understanding of the failure modes and safety factors applicable to design.

7.2 Fabrication

No parts were fabricated; therefore, no Code reconciliation is needed for fabrication.

The installation of the FSWOL, which involves welding only, will be performed in accordance with ASME Code, Section XI, which in turn references ASME Code, Section IX. The ASME Code-of-Record for the current 10-year ISI interval at DCPP is Section XI, 2007 Edition with Addenda through 2008 [5]. Therefore, FSWOL installation using ASME Code, Section IX, 2007 Edition with Addenda through 2008, requires no reconciliation.

7.3 Examination

Examination requirements for weld overlay repairs are per ASME Code Case N-740-2 [3]; thus, no reconciliation is needed.

7.4 Materials

IWA-4224 provides material reconciliation criteria. ASME Code, Section II, 2001 Edition with Addenda through 2003 [14] are used for all materials since the ASME Code-of-Record does not contain properties for Alloy 52M weld metal (Alloy 690 base material). All material properties are shown in SI Calculation 1700479.312. There is no explicit fatigue strength curve provided in the Code-of-Record [17], as fatigue evaluations were not specifically required for ANSI B31.3 piping.

The differences in the applicable properties between the original Code-of-Record [17] and the replacement Code for materials (i.e., ASME Code, Section II, 2001 Edition with Addenda through 2003 [14]) reflect improvements in the understanding of the material. The material properties of the replacement Code [14] are used entirely for the evaluations herein.

7.5 Conclusion

It is concluded that the rules in the 2001 Edition with Addenda through 2003 of Section III of the ASME Code [7], with material properties from the 2001 Edition with Addenda through 2003 of Section II, Part D [14], are acceptable for use in the evaluations contained herein, and the replacement Codes are considered to be reconciled with the original Code-of-Record [17] applicable to the RHR piping system.

8.0 SUMMARY AND CONCLUSIONS

This report provides a summary of the FSWOL design and analyses for the stainless steel butt welds (WIB-245 and WIB-228) on the RHR suction piping system for DCPP, Unit 1 and Unit 2. The design of this overlay was performed in accordance with the requirements of ASME Code Case N-740-2 [3]. Primary conclusions from FSWOL design and analyses are listed below:

- In accordance with ASME Code Case N-740-2 [3], the structural design of the overlay was performed to meet the requirements of ASME Code, Section XI, IWB-3640 based on a postulated 100% through-wall circumferential flaw, 360° around the original weld. The installed FSWOL will restore the safety margins of the original weld, with no credit taken for the underlying SSW weld material.

- Alloy 52M material is specified for the FSWOL, which has been shown to be resistant to PWSCC [20, 21, 22, 23], thus providing a PWSCC resistant barrier. Therefore, PWSCC growth is not expected to occur in the overlay.

- A component-specific FSWOL weld residual stress analysis was performed, after first simulating the SSW and then applying a 50% ID weld repair. The results of the analysis demonstrated that the installed FSWOL will result in beneficial compressive residual stresses within the original SSW.

- An ASME Code, Section III qualification was performed. The primary and primary-plus-secondary stress criteria and the thermal ratcheting requirements were met for all evaluated paths. The maximum cumulative fatigue usage factor for 60 years of operation is 0.7589, which is less than the allowable of 1.0.

- Fracture mechanics analyses were performed to determine the amount of future crack growth in the SSW based on a postulated axial and circumferential flaw through 75% of the original

base metal thickness. Both FCG and SCC were evaluated. The results of the analysis demonstrated that the FSWOL will provide mitigation of crack growth, and the service life of the FSWOL will be greater than 60 years.

Based on the above results, it is concluded that the installed FSWOL will provide long term mitigation against future crack growth in both welds (WIB-245 in Unit 2 and WIB-228 in Unit 1) of the RHR suction piping system at DCPP.

9.0 REFERENCES

1. DCPP Design Input Transmittal No. DIT-50852155-001-00, "Subject: RHR Flaw Evaluation of Weld WIB-245," SI File No. 1600539.206.

2. DCPP Design Input Transmittal No. DIT-50915871-001-00, "Subject: Unit 1 RHR Suction Line Loads and Configuration," SI File No. 1700609.206.

3. ASME Boiler and Pressure Vessel Code, Code Case N-740-2, "Full Structural Dissimilar Metal Weld Overlay for Repair or Mitigation of Class 1, 2 and 3 Items," Section XI, Division 1.

4. SI Drawing No. 1600546.510, "Diablo Canyon RHR WIB-245 and WIB-228 Weld Overlay Repair," (for revision number refer to SI Project Revision Log, latest revision).

5. PG&E Letter DCL-17-083, "Request for Approval of Alternative for Application of Full Structural Weld Overlay, REP-RHR-SWOL. Units 1 and 2," September 26, 2017.

6. ASME Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, 2007 Edition with Addenda through 2008.

7. ASME Boiler and Pressure Vessel Code, Section III, Rules for Construction of Nuclear Facility Components, 2001 Edition with Addenda Through 2003.

8. SI Software V&V Package No. 0800777.312, Rev. 0, "Black Box Testing and Verification of Weld Residual Stress Finite Element Analysis Module, Version 4.0."

9. *Materials Reliability Program: Finite-Element Model Validation for Dissimilar Metal Butt-Welds (MRP-316, Revision 1): Volumes 1 and 2*, EPRI, Palo Alto, CA, 3002005498.

10. *Materials Reliability Program: Welding Residual Stress Dissimilar Metal Butt-Weld Finite Element Modeling Handbook (MRP-317, Revision 1)*, EPRI, Palo Alto, CA, 3002005499.

11. Weld Residual Stress Analysis Module for ANSYS, Version 4.00, Structural Integrity Associates, Inc., March 2016, SI File No. 0800777.218.

12. ANSYS Mechanical APDL, Release 14.5 (w/ Service Pack 1 UP20120918), ANSYS, Inc., September 2012.

13. *Material Reliability Program: Technical Basis for Preemptive Weld Overlays for Alloy 82/182 Butt Welds in Pressurized Water Reactors (PWRs) (MRP-169), Revision 1-A*, EPRI, Palo Alto, CA: 2010. 1021014 (includes NRC SER ML101660468).

14. ASME Boiler and Pressure Vessel Code, Section II, Part D, Material Properties, 2001 Edition with Addenda through 2003.

15. PIPESTRESS, Version 3.8.0, DST Computer Services S.A., August 2014.

16. ASME Code Case N-809, "Reference Fatigue Crack Growth Rate Curves for Austenitic Stainless Steels in Pressurized Water Reactor Environments Section XI, Division 1," Cases the ASME Boiler and Pressure Vessel Code, June 23, 2015.

17. USAS B31.1 – 1967 Edition, Power Piping.

18. USAS B31.7 - 1969 Edition through 1970 Addenda, Nuclear Power Piping.

19. DCPP Design Input: SI File No. 1700479.230, Transmittal from James Hill (PG&E) to James Axline (SI), Monday 4:40 AM, 12/04/2017, "RE: ASME code year RHR line issue".

20. *Materials Reliability Program (MRP): Resistance to Primary Water Stress Corrosion Cracking of Alloys 690, 52, and 152 in Pressurized Water Reactors (MRP-111),*" EPRI, Palo Alto, CA: 2004, 1009801.

21. *Materials Reliability Program: Crack Growth Rates for Evaluating Primary Water Stress Corrosion Cracking (PWSCC) of Alloy 82, 182, and 132 Welds (MRP-115)*, EPRI, Palo Alto, CA: 2004, 1006696.

22. NUREG/CR-6907, "Crack Growth Rates of Nickel Alloy Welds in a PWR Environment," U.S. Nuclear Regulatory Commission (Argonne National Laboratory), May 2006.

23. NUREG/CR-6721, "Effects of Alloy Chemistry, Cold Work, and Water Chemistry on Corrosion Fatigue and Stress Corrosion Cracking of Nickel Alloys and Welds," U.S. Nuclear Regulatory Commission (Argonne National Laboratory), March 2001.

24. API Standard 579-1/ASME FFS-1, Fitness for Service, 2nd Edition, June 2007.

10.0 SUPPORTING STRUCTURAL INTEGRITY ASSOCIATES CALCULATION PACKAGES AND DRAWING

The following is a list of the supporting design drawing and calculation packages. These documents are transmitted separately and are not included as part of this report.

1600546.510	Drawing: Diablo Canyon RHR WIB-228 (U1) and WIB-245 (U2) Weld Overlay
1600546.310	Calculation: Full Structural Weld Overlay Sizing of RHR Pipe-to-Elbow Weld WIB-228 and WIB-245
1700479.311	Calculation: Design Loads for Residual Heat Removal System Welds (WIB-245 and WIB-228)
1700479.312	Calculation: Finite Element Model Development of the RHR Pipe-to-Elbow Weld (WIB-245 and WIB-228) with Weld Overlay Repair
1700479.313	Calculation: Thermal and Mechanical Load Stress Analyses of the RHR Pipe-to-Elbow Weld (WIB-245 and WIB-228) with Weld Overlay Repair
1700479.314	Calculation: Weld Residual Stress Analysis of the RHR Pipe-to-Elbow Weld (WIB-245 and WIB-228) with Weld Overlay Repair
1700479.315	Calculation: ASME Code, Section III Qualification of the RHR Pipe-to-Elbow Welds (WIB-245 and WIB-228) with Weld Overlay Repair
1700479.316	Calculation: Crack Growth Analyses of the RHR Pipe-to-Elbow Weld (WIB-245 and WIB-228) with Weld Overlay Repair
1700479.317	Calculation: Shrinkage Analysis for the RHR Suction Line due to Weld Overlay Repair
1700479.318	Calculation: RHR Suction Piping Weld Overlay Weight Calculation
1700479.321	Calculation: Derivation of Thermal Loads for RHR Suction Line based on OD Thermal Sensor Data

Diablo Canyon Power Plant, Unit 2

Impact of Added Second Buffer Layer of Stainless Steel to RHR Weld Overlay

[NOTE: This report is applicable to both DCPP Units 1 and 2]

5215 Hellyer Ave, Suite 210, San Jose, CA 95138 | 408-978-8200
rbax@structint.com

August 17, 2018
Report No. 1700479.402.R1
Quality Program: ☒ Nuclear ☐ Commercial

Suresh G. Khatri
Piping Engineering
Pacific Gas & Electric
Diablo Canyon Power Plant
P.O. Box 56
Avila Beach, CA
93424

Subject: Impact of Added Second Buffer Layer of Stainless Steel to RHR Weld Overlay

BACKGROUND

Structural Integrity Associates, Inc. (SI) was contracted by Pacific Gas and Electric (PG&E) to develop a full structural weld overlay (FSWOL) design for Residual Heat Removal (RHR) welds WIB-228 (Unit 1) and WIB-245 (Unit 2) at the Diablo Canyon Power Plant (DCPP).

The final design drawing [1, see Attachment A] required that the first layer be composed of stainless steel (ER08L, ER309L or 316L). The stainless steel was included to act as a buffer layer to prevent hot cracking in the remainder of the weld overlay, which is to be fabricated using Alloy 52M weld filler material.

Subsequently, PG&E selected AZZ Specialty Welding (AZZ-SW) to install the weld overlay for Unit 2 in the Spring 2018 Refueling Outage (February 2018). A review by AZZ-SW of the CMTR's of the base pipe resulted in the recommendation for the addition of a second buffer layer and the extension of the weld overlay at the intrados to allow for constant orbital welding. Based on this recommendation and concurrence from PG&E, SI revised the design drawing [2, see Attachment B]. A listing of key dimensions and welding information for the two FSWOL designs is shown in Table 1.

Subsequently, SI has been tasked by PG&E to determine the impact of the design changes (addition of a 2nd buffer layer) on the original ASME Code qualification and crack growth evaluation of the single buffer layer FSWOL design.

The assessment of the design configuration change will consider the following four (4) attributes and include a statement of conservatisms.

1. WELD RESIDUAL STRESS COMPARISON
2. HIGH FREQUENCY THERMAL MIXING CYCLING AT 100% POWER - THERMAL STRESS COMPARISON
   a. ASME Code Linearized Stress Comparison
   b. Crack Growth Component Stress Comparison
3. FSWOL WEIGHT COMPARISON
4. FSWOL WELD SHRINKAGE COMPARISON

Revision 1 of this report replaces the drawings contained in Attachments A and B with Non-Proprietary versions. Revisions are shown with rev bars.

info@STRUCTINT.com 1-877-4SI-POWER www.STRUCTINT.com

Table 1: Comparison of FSWOL Designs

Parameter	Original Design (Rev. 3 [1])	Modified Design (Rev. 4 [2])
Stainless Buffer Layers	1	2
Alloy 52M Layers (Est.)	6	6
Total Layers	7	8
Station A FSWOL Thickness (minimum dimension) (Pipe Side)	0.63 inch (0.71 inch with Buffer Layer)	0.63 inch (0.79 inch with Buffer Layers)
Station A FSWOL Thickness (maximum dimension) Pipe Side	0.88 inch (0.96 inch with Buffer Layer)	0.88 inch (1.04 inch with Buffer Layers)
Station B FSWOL Thickness (minimum dimension) Elbow Side (Intrados Side)	0.61 inch (0.69 inch with Buffer Layer)	0.61 inch (0.77 inch with Buffer Layers)
Station B FSWOL Thickness (maximum dimension) Elbow Side (Intrados Side)	0.86 inch (0.94 inch with Buffer Layer)	0.86 inch (1.02 inch with Buffer Layers)
Station B FSWOL Thickness (minimum dimension) Elbow Side (Extrados Side)	0.64 inch (0.72 inch with Buffer Layer)	0.64 inch (0.80 inch with Buffer Layers)
Station B FSWOL Thickness (maximum dimension) Elbow Side (Extrados Side)	0.89 inch (0.97 inch with Buffer Layer)	0.89 inch (1.05 inch with Buffer Layers)
Pipe Side FSWOL Full Length (minimum dimension)	2.56 inch (full thickness) 3.27 inch (to toe)	2.65 inch (full thickness) 3.44 inch (to toe)
Pipe Side FSWOL Full Length (maximum dimension)	3.56 inch (full thickness) 4.52 inch (to toe)	3.65 inch (full thickness) 4.69 inch (to toe)
Elbow Side FSWOL Full Length (minimum dimension) (Intrados)	2.56 inch (full thickness) 2.80 inch (to toe)	3.86 inch (into elbow)
Elbow Side FSWOL Full Length (maximum dimension) (Intrados)	2.81 inch (full thickness) 3.19 inch (to toe)	4.52 inch (into elbow)
Elbow Side FSWOL Full Length (minimum dimension) (Extrados)	2.56 inch (full thickness) 3.61 inch (to toe)	2.69 inch (full thickness) 3.86 inch (to toe)
Elbow Side FSWOL Full Length (maximum dimension) (Extrados)	2.81 inch (full thickness) 4.22 inch (to toe)	2.98 inch (full thickness) 4.52 inch (to toe)

Note:

1) All dimensions from Reference [1, see Attachment A].
2) All dimensions from Reference [2, see Attachment B].

WELD RESIDUAL STRESS COMPARISON

One of the primary roles of the FSWOL, besides restoring structural margin with added thickness, is to induce compressive weld residual stresses into the flawed welds to reduce/eliminate future crack growth due to fatigue crack growth and stress corrosion cracking (SCC).

Industry experience has shown that most of the beneficial compressive residual stress occurs during the installation of the first three layers of a weld overlay. Because stainless steel weld material tends to have a lower yield and ultimate stress than Alloy 52M weld material, the addition of a second buffer layer could result in a reduction of the beneficial weld residual stresses, e.g. the second layer of applied weld filler metal will be a lower strength stainless steel layer replacing a higher strength Alloy 52M layer.

It is recognized that the revised design does not reduce the minimum required thickness of Alloy 52M material, and thus the use of a 2nd stainless buffer layer results in a minimum thickness FSWOL that is one (1) layer thicker than the previous design.

To determine the impact of the added buffer layer a modified weld residual stress analysis is performed.

Modified Weld Residual Stress Evaluation

The original weld residual stress finite element model (FEM), developed in Reference [3], is modified such that the second layer is composed of stainless steel weld material, instead of Alloy 52M weld material. No other changes to the FEM are made. Specifically, the residual model, which is a minimum thickness model, was not modified to maintain the minimum Alloy 52M thickness, and as a result has the same total thickness as the previous one (1) buffer layer model, which is conservative.

The size and shape of the FSWOL is not modified and conforms to the minimum dimensions defined in original design drawing [1]. Thus, the modeled weld residual FSWOL is smaller than the minimum dimensions defined in Reference [2]. Because the modeled FSWOL is smaller than the revised drawing, the results and conclusions based on its use can be treated as conservative, as the modeled FSWOL with one less layer, will produce less beneficial weld residual stresses.

A comparison of the original FEM weld residual stress results to the modified FEM weld residual stress results is shown in Figure 1. The evaluation files for the modified weld residual stress evaluation are listed in Table 2.

The same weld residual stress methods defined in Reference [4] are used to perform the weld residual stress evaluation for the modified FEM. Thus, the following steps are performed to determine the final weld residual stresses:

1) The simulation of the stainless steel weld (SSW) is performed.
2) After the SSW is completed, the model is cooled down to a uniform ambient temperature of 70°F.

3) The ID weld repair of the elbow-to-pipe SSW is then applied, which consists of first removing a portion of the SSW material from the ID surface outwards 50% through-wall and then rewelding the resulting void.
4) After the ID weld repair is completed, the model is again cooled down to a uniform ambient temperature of 70°F.
5) The weld overlay simulation is then applied. The two stainless steel buffer layers are applied first, and the model allowed to cool down to a uniform ambient temperature of 70°F. The five layers of Alloy 52M that make up the FSWOL are then applied.
6) After the weld overlay is completed, the model is cooled to a uniform ambient temperature of 70°F.
7) A normal operating temperature and pressure load step is appended to the end of the weld residual stress evaluation. This load is cycled 5 times between 70°F/zero pressure and the operating temperature/pressure (478.3°F/2510 psig) to obtain the stabilized combined residual stresses at room temperature and normal operating conditions (NOC), respectively. This load step essentially simulates five heatup and cooldown ramp cycles. The inclusion of these 5 cycles represents normal operation and can generate some changes to the weld residual results and an overall smoothing of the stress contours.

It is noted, as stated in References [1, 2], that there is a minimum thickness of Alloy 52M specified in the design. This is based on the required minimum thickness of SCC resistant material, as discussed in the Relief Request [11]. The stainless steel buffer layers are not credited in achieving this thickness, as they are not referenced as SCC-resistant. However, they are present in the FSWOL. As such they are included in the FEM, and when stress path results are extracted, they include stresses within the buffer layers.

The resulting modified FSWOL design through-wall residual stresses are extracted through Path 2 (see Reference [4, Figure 14]), which is through the middle of the SSW and the 50% ID weld repair, and stresses are compared to the same Path 2 weld residual results from the original FSWOL design.

Figure 2 shows a comparison of the original and modified axial weld residual stresses at no load conditions (70°F/0 psig) and at normal operating conditions (NOC, 478.3°F/2510 psig) and Figure 3 shows the same for the hoop weld residual stresses.

As can be seen in Figure 2, the axial weld residual stresses are very similar, with most of the variation occurring at the base-metal to FSWOL interface (~1.25 inch through-wall). There is very little difference in stresses in the region from the pipe ID to the depth of the postulated 75% circumferential flaw, the region of interest, thus no change is expected in either fatigue crack growth or SCC.

The hoop weld residual stresses shown in Figure 3, show a bit more variation in the base metal region, but given that this region is in a compressive state of stress from the inside surface to the depth of the postulated 75% flaw, ~1.00 inch, the impact is negligible.

Given the comparison shown in Figure 2 and Figure 3 and the fact that the evaluated FSWOL is smaller than the revised design drawing [2], it can be concluded that the addition of the second stainless buffer layer has no adverse impact on the weld residual stress reported in Reference [4]

and used in the facture mechanics evaluation documented in Reference [6]. It is noted that this assessment of the effect upon residual stress is conservative as it does not consider the added axial length of the revised design. The revised design [2] is approximately 1¼" to 1½" longer than the previous design [1], and this added length will produce increased axial compressive stresses.

Table 2: Modified Weld Residual Stress Analysis Files

File Name	Description
DIABLO_RHR_RES2.INP	Modified ANSYS input file to construct the model for residual stress analysis with minimum weld overlay dimensions and two buffer layers, based on model from Reference [3].
BCNUGGET2D.INP	Weld bead and boundary line definition file.
THERMAL2D.INP	Input file to perform the thermal pass.
STRESS2D.INP	Input file to perform the stress pass.
INSERT2D.INP	Input file to perform hydrostatic test and/or operating cycles prior to FSWOL (not specifically used in this calculation).
THM_PWHT.INP	Input file to perform a post-weld heat treatment thermal pass (not specifically used in this calculation).
STR_PWHT.INP	Input file to perform a post-weld heat treatment creep stress pass (not specifically used in this calculation).
THERMAL2D.TXT	Parameter input file for thermal pass.
STRESS2D.TXT	Parameter input file for stress pass.
POST_PATH.INP	Post-processing file to extract path stresses.
GETPATH.TXT	Source file that defines through-wall paths. Called by POST_PATH.INP.
STRESS2D_MAP_P$.CSV	Output files containing mapped path stresses, $ = 1-3.
1700479.314_Buffer.xls	Excel spreadsheet containing Path 2 through-wall weld residual stress comparisons.

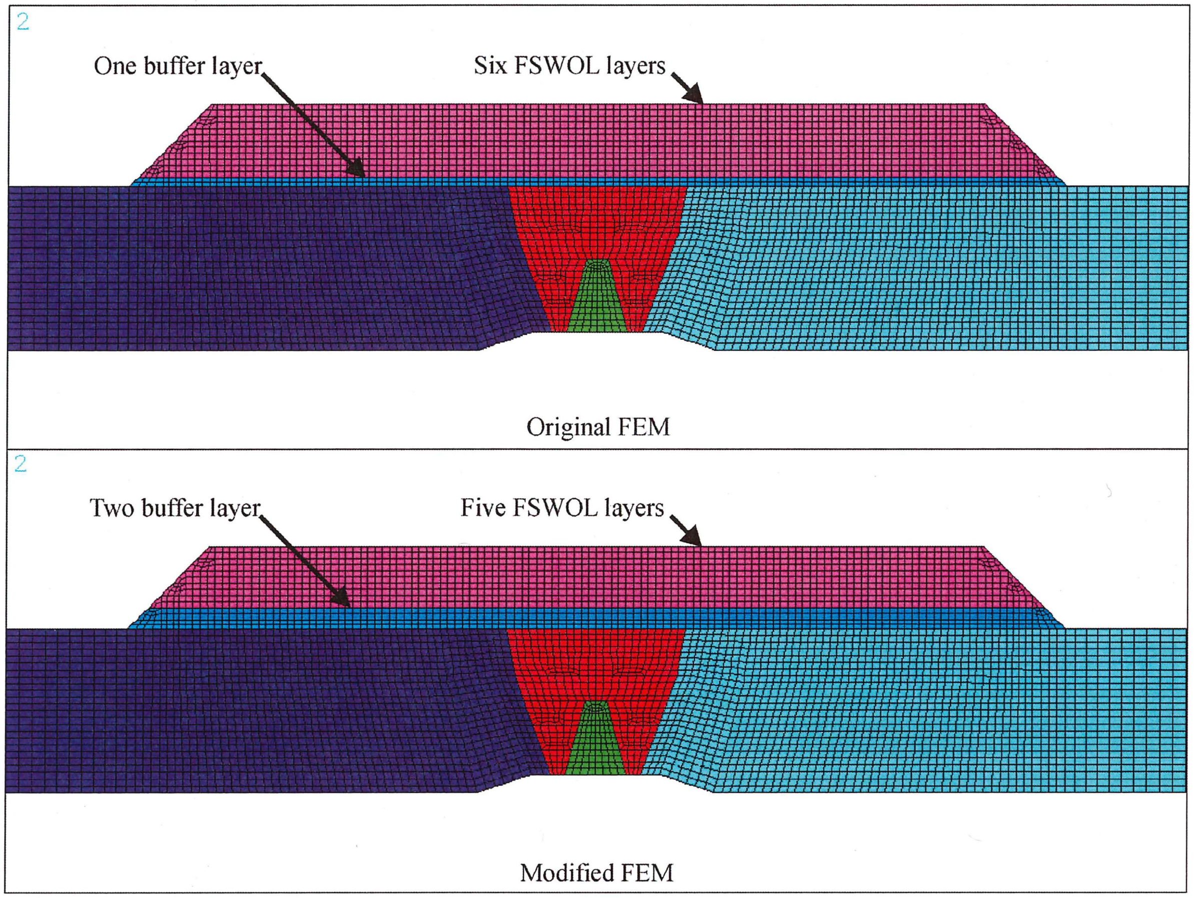
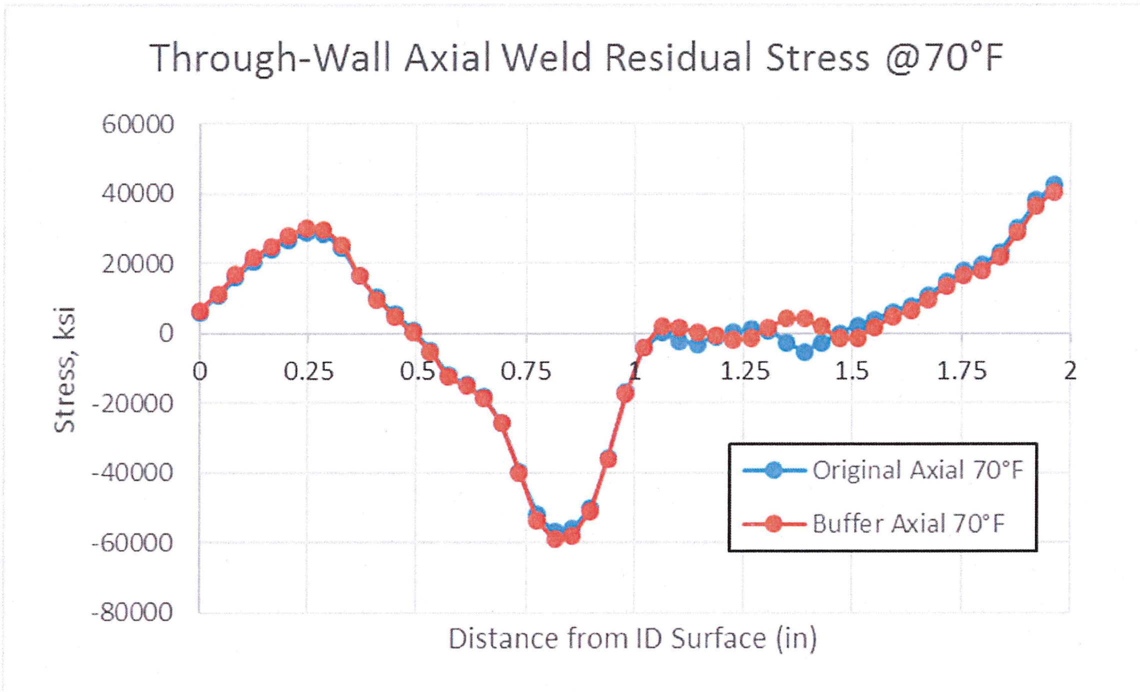


Figure 1: Comparison of Weld Residual Stress Finite Element Models



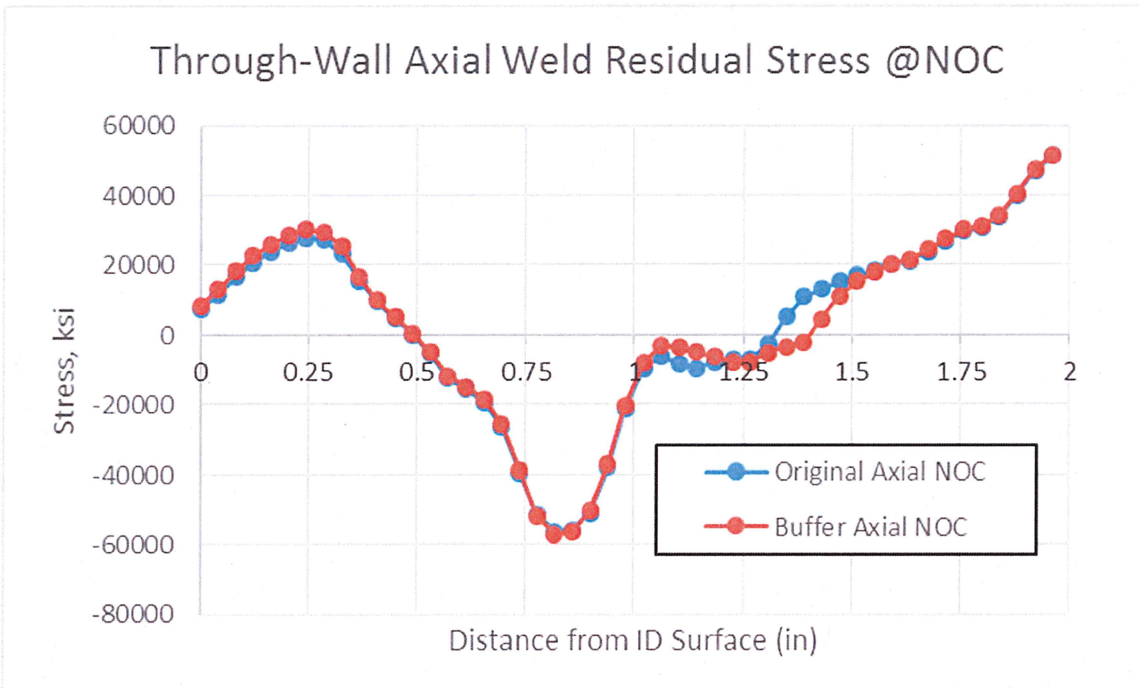
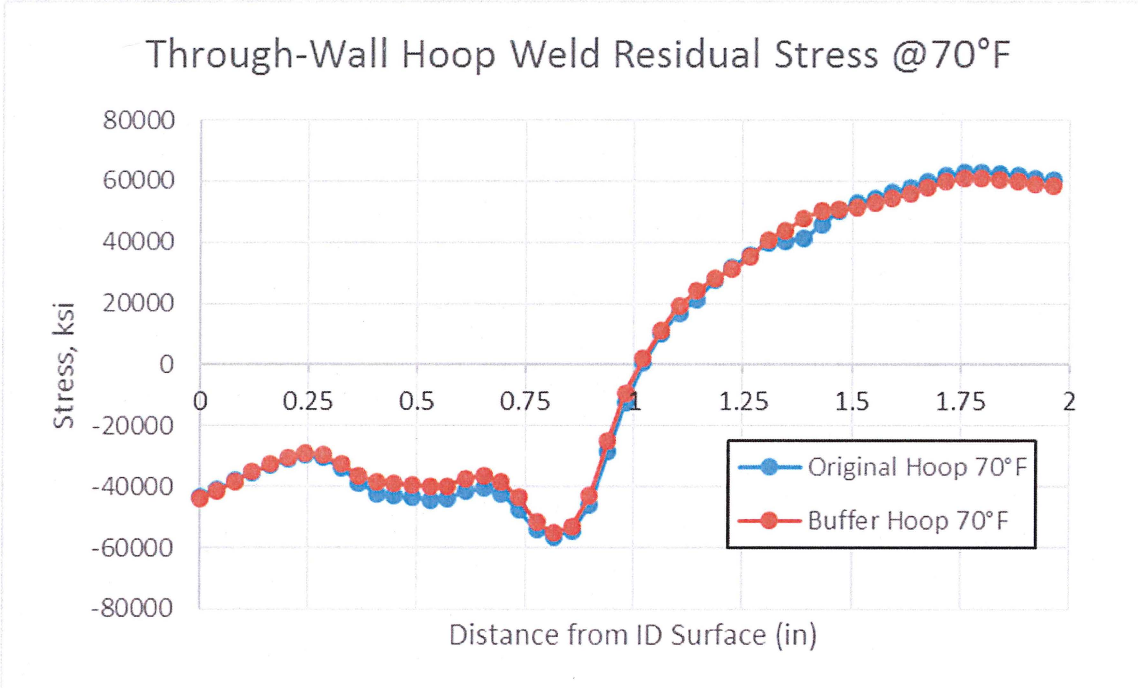


Figure 2: Comparison of Axial Weld Residual Stresses at 70°F and NOC (478.3°F/2510 psig)

Stresses shown are extracted from the Path 2 location, which is through the centerline of the SSW/ID weld repair [4, Figure 14].



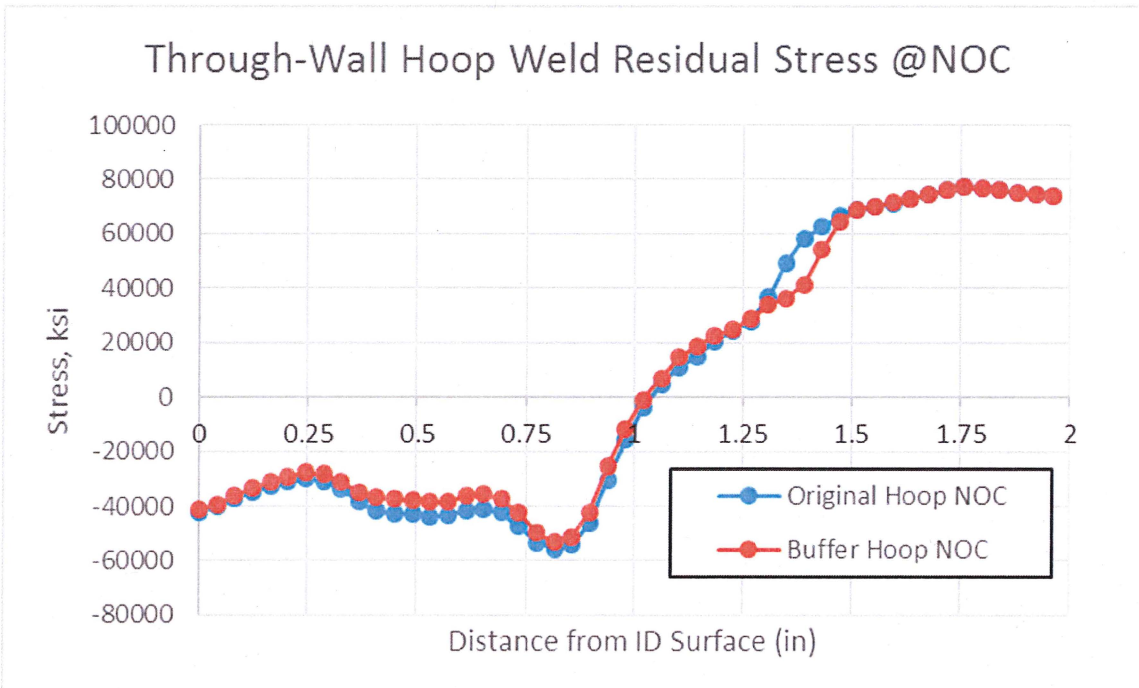


Figure 3: Comparison of Hoop Weld Residual Stresses at 70°F and NOC (478.3°F/2510 psig)

Stresses shown are extracted from the Path 2 location, which is through the centerline of the SSW/ID weld repair [4, Figure 14].

THERMAL STRESS COMPARISON

The addition of a second stainless steel buffer layer and the added length on the intrados side of the FSWOL for the latest revision of the design drawing [2], as compared to the original design drawing [1], will increase the minimum thickness of the FSWOL, and as a result will generate changes to the stress profiles that were evaluated in the ASME Code, Section III evaluation [5] and the fracture mechanics crack growth evaluation [6]. Typically, these changes will result in:

- Increased thermal stresses due to the increased thickness of the modified FSWOL
- Reduced mechanical stresses (piping loads and internal pressure) due to the increased thickness of the modified FSWOL
- Altered peak stresses at the toes of the FSWOL where it interfaces with the elbow (due to the change in intersection angle (included angle is increased) from the added length)

From Table 10 of Reference [5], the maximum fatigue usage location for the original FSWOL is Path 23 (outside), with a cumulative fatigue usage of 0.759. Appendix C of Reference [5] lists a detailed breakdown of the fatigue causing load pairs for the Path 23 (Outside). From page C-14 of that appendix, the primary fatigue causing load pair is load pair Set 5, which consists of the following two thermal transients:

- High Cycle Thermal Mixing at 100% Power (MXH2)
- Design Transient – Unit Unloading 5% from 100% Load to 0% Load
  High Temperature (UL(NO))

This load pair generates a fatigue usage of 0.557, approximately 73% of the total cumulative fatigue usage. Of the two transients, the High Cycle Thermal Mixing at 100% Power transient was selected to perform a thermal stress impact comparison. The reasoning for selecting this transient is as follows:

- This transient is believed to be the primary cause of the circumferential cracking found in RHR welds WIB-228 (U1) and WIB-245 (U2).
- Given the high cycle nature of this transient, there is a concern that self-cycling within this transient could cause unacceptable fatigue and/or crack growth.
- The design transients, which are based on the hot leg design transients are fairly benign and are not expected to yield significant crack growth or fatigue usage without the addition of the high-cycle thermal mixing (see Appendix C of Reference [5]).

Given that the primary concern for these RHR locations is the presence of a high cycle thermal mixing and stratification behavior, a review of these two phenomena is made. In the case of the stratification loading, the impact of a localized thickening of the piping system due to the FSWOL is not adverse as the global temperatures within the piping system are not altered, thus the bending moments at stations along the piping are unchanged, and as the FSWOL location will have increased thickness to sustain the moments, the effect will be reduced stresses due to stratification.

Conversely, the impact of the added buffer layer on the high frequency thermal mixing loading may be adverse. The increased thermal stresses due to the increased thickness of the modified FSWOL will be evaluated based on a modified high cycle thermal mixing stress analysis, including the effects of stratification, at normal plant operation conditions.

Modified High-Cycle Thermal Mixing at 100% Power Stress Evaluation

The original 3-D FEM to evaluate thermal mixing, developed in Reference [3], consisted of the RHR piping system from the Reactor Coolant System (RCS) hot leg connection to the containment penetration. The model used the maximum original design drawing FSWOL dimensions [1] as they will generate bounding stresses under thermal loading due to the thicker weld overlay cross-section generating larger through-wall thermal gradients.

For the modified analysis, the 3-D FEM FSWOL is completely rebuilt using the maximum dimensions from the modified design drawing [2] which includes the second buffer layer. In this case the FEM reflects the full maximum thickness of the overlay, and the added length of the modified overlay. The FEM also models the revised intersection of the FSWOL and the elbow intrados, due to the added length. No other changes to the FEM are made.

The overall original FEM is shown in Figure 4. A comparison of the original high cycle thermal mixing evaluation FEM FSWOL and the modified high cycle thermal mixing evaluation FEM FSWOL is shown in Figure 5. The evaluation files for the high cycle thermal mixing evaluation are listed in Table 3.

To save time, the bounding snippet thermal time history from Reference [7], Appendix B, is evaluated using the modified high cycle thermal mixing evaluation FEM. The loading includes:

- The high cycle thermal mixing transient (which includes the temperature fluctuation within the RHR piping system and the global thermal stratification)
- The hot leg thermal anchor movement displacement at 100% power
- Internal pressure of 2,250 psia

Other than using the modified finite element model, no other changes were made to the analysis as performed in Reference [7], Appendix B. Linearized stresses are extracted for Path 11 to 18 and Path 21 to 28 (see Figure 6 for the paths), which are both ends of the FSWOL, from both original and modified FEM analyses. Through wall component stresses are extracted for Path 41 to 48 (see Figure 6 for the paths), which are through the center of the SSW and the ID weld repair.

ASME Code Linearized Stress Comparison

Each of sixteen paths that were evaluated in the ASME Code evaluation performed in Reference [5] is reevaluated using the results from the bounding snippet from the high cycle thermal mixing at 100% power transient loading, which was applied to the revised 3-D FEM.

For this comparison, the maximum occurring stress intensity values are extracted at the inside and outside surfaces. For the outside surfaces, the membrane-plus-bending stress intensities are compared as these locations are evaluated using a Fatigue Strength Reduction Factor (FSRF), as discussed in Section 8.3.1 of Reference [5]. For the inside surfaces, the membrane-plus-bending-plus-peak (or "Total") stress intensities are compared, as these locations are evaluated without a FSRF.

For the outside locations, the FSRF factors are recalculated, based on the modified FSWOL dimensions. The stress intensities extracted at the outside surface locations are then multiplied by their respective FSRF's and the final values compared to the original stress intensities and their FSRF's.

Based on the tabulated result shown in Table 4, only five locations generate a variation in stress intensity that are greater than 105%. These are Path 15 Inside (107%), Path 22 Inside (139%), Path 24 Inside (135%), Path 25 Inside (111%) and Path 28 Inside (119%). Of these five paths the greatest fatigue usage for the original FSWOL design is Path 22 Inside at 0.0022993.

Given the relatively low usage for these five paths, an increase of 39% in the stress intensity is not expected to generate a significant change in the fatigue usage such that it is greater than the original bounding usage factor of 0.7588854 at Path 23 Outside.

Note that for Path 23 Outside, the variation in stress is 85% (see Table 4), which is the result of an approximate 8% reduction in stress intensity, and an 8% reduction in FSRF. This means that the modified FSWOL results in reduced stress from that evaluated for the original FSWOL. Thus, the fatigue usage at the controlling location for the original FSWOL would be reduced for the modified FSWOL.

A final concern is that the modified FSWOL could generate a self-cycling alternating stress resulting from the High Cycle thermal mixing transient that is greater than the ASME Code fatigue curve endurance limit. As a final check, the maximum and minimum stress intensity for each path are extracted and the two subtracted to generate a stress intensity range. The maximum range is 10,718 psi for Path 16 Inside. The maximum calculated FSRF for any location is 1.556 (see Table 4) The alternating stress is, therefore, 10,718/2 * 1.556 = 8,335 psi (which is conservative as we are applying an FSRF to an ID location), which is well below the endurance limit for stainless steel of 13,600 psi [8, Appendix I, Curve C, Figure I-9.2.2].

Therefore, it can be concluded that the changes to the FSWOL design drawing are bounded by the original FSWOL design ASME Code qualification performed in Reference [5]. All comparisons are performed in the Excel spreadsheet *"ASME Compare.xlsx"* and listed in Table 3.

Crack Growth Component Stress Comparison

Through-wall mapped stresses are extracted from the original and modified FSWOL evaluations at Path 41 through Path 48, which are located at the center of the pipe-to-45° elbow SSW (see Figure 6) and include only thermal and pressure loads. The eight paths were reviewed to determine which path generated the greatest tensile stress at the inside surface and at what time. For the axial stress, the greatest tensile stress occurs at Path 46, at a time of 30,780 seconds. For the hoop stress, the greatest tensile stress occurs at Path 42, also at a time of 30,780 seconds.

The through-wall axial and hoop component stresses, at time 30,780 seconds, are compared between the original FSWOL design and the modified FSWOL design. The comparisons are shown in Figure 7 for the axial stress and Figure 8 for the hoop stress. The partial breakdown of the component stress results in the SSW/ID weld repair base metal are tabulated in Table 5.

A review of Figure 7 shows that the original FSWOL design has a slightly greater inside surface tensile axial stress (25.2 ksi vs. 23.3 ksi) and remains slightly greater until approximately 0.95 inch through the thickness. The initial flaw size evaluated in Reference [6] is 75% through the base metal, or 0.938 inches. This depth is less than the 0.95 inches over which the modified design FSWOL is more compressive than the original design FSWOL. It is noted that the axial stress is the controlling parameter for circumferential flaw growth, and it is the existing circumferential flaw for which this FSWOL is designed.

A review of Figure 8 shows that the original FSWOL design has a greater inside surface tensile hoop stress (11.5 ksi vs. 8.6 ksi) and remains greater throughout the wall thickness. This is expected as the greater amount of Alloy 52M weld filler metal (Layers 3 through 8) that is applied for the modified FSWOL design when compared to the original FSWOL (Layers 2 through 7), will generate more compression due to the greater volume of Alloy 52M filler metal with its advantageous dissimilar coefficient of thermal expansion. Stainless steel has a greater coefficient of expansion than Alloy 52M, and thus the thermal heatup of the FSWOL results in compression in the stainless steel base metal.

Table 6 presents the crack growth results from the original FSWOL design (see Table 5 of Reference [6]). Based on an initial 75% through-wall flaw, Table 6 shows that some circumferential crack growth did occur (no axial crack growth occurred), but only 3.17E-04 inches in 60 years. Further, that growth was only due to the Hydrostatic Test transient, a transient that is only applied during plant construction and not during actual plant operation. Therefore, minor variations in the operating stresses will not generate significant crack growth. Thus, any crack growth due to the modified design will not approach the base metal to FSWOL interface and will thus not affect the structural integrity of the FSWOL.

Given that the axial and hoop stress values (combined thermal stress and pressure stress) for the modified FSWOL design are less than the original FSWOL design values, in the region of the base metal that is assumed to be cracked, it can be concluded that for crack growth considerations, the modified FSWOL design is bounded by the original FSWOL evaluations. All comparisons are performed in the Excel spreadsheet *"Fracture Compare.xlsx"* and listed in Table 3.

Table 3: Modified High Cycle Thermal Mixing Stress Analysis Files

Filename	Description
ASME Compare.xlsx	Excel spreadsheet comparing Paths 11 to 18 and 21 to 28 linearized stresses to evaluate the impact of the modified FSWOL design.
Fracture Compare.xlsx	Excel spreadsheet comparing Paths 41 to 48 through-wall component stresses to evaluate the impact of the modified FSWOL design.
Diablo-RHR-MAX2-Mod.INP	ANSYS Input file to construct the model for thermocouple based thermal mixing stress analyses with maximum modified weld overlay dimensions. Base model derived from Reference [3].
CMNTR.MAC	ANSYS macro file to generate a thermal time history input file for the stress analysis called by the transient files above.
RHR-High-Bound.INP	ANSYS input file to perform thermal pass for the shortened enveloping high cycle thermal mixing evaluation from Reference [3, Appendix B].
Bound-Snip.prn	Inside surface temperature time history for shortened enveloping high cycle thermal mixing evaluation. Called by RHR-High-Bound.INP input file. File from Reference [3, Appendix B].
RHR-Snip-Bound_mntr.inp	Input file to perform the stress analysis for the transient time history generated by CMNTR.MAC and called by RHR-High-Bound-STR.INP.
RHR-High-Bound-STR.INP	ANSYS input file to perform stress pass for the shortened enveloping high cycle thermal mixing evaluation from Reference [3, Appendix B].
GENSTRESS.MAC	Path stress extraction macro file to output .OUT and .CSV files
GETPATH-M.TXT	Through-wall path definition file for modified thermal mixing analysis. Rename to GETPATH.TXT to use with GENSTRESS.MAC stress extraction macro file
GETPATH-O.TXT	Through-wall path definition file for original thermal mixing analysis. Rename to GETPATH.TXT to use with GENSTRESS.MAC stress extraction macro file
RHR-Bound_LIN_P*.CSV	Linearized stress outputs in tabulated forms, * = path number (11 through 18 and 21 through 28)
RHR-Bound_LIN_P*.OUT	Linearized stress outputs in raw text listing forms, * = path number (11 through 18 and 21 through 28)
RHR-Bound-STR_MAP_P##.CSV	Mapped component stress outputs in tabulated forms * = path number 41 through 48

Note: The *.OUT and *.CSV file names are identical for the original and modified analyses. Therefore, the original analysis results are renamed with "OLD-" appended to the beginning of the file names.

Table 4: Stress Intensity Comparisons with Regards to ASME Code Qualification

Path [1]	Surface	Maximum Stress Intensity (ksi)		FSRF		Variation	Original FSWOL Fatigue Usage [4]
		Original	Modified	Original [2]	Modified [3]		
11	Inside	17.07	17.52	1	1	103%	0.0000769
	Outside	19.27	19.31	1.556	1.556	100%	0.0199079
12	Inside	21.58	21.24	1	1	98%	0.0023323
	Outside	18.45	19.08	1.556	1.556	103%	0.0202115
13	Inside	22.46	22.45	1	1	100%	0.0030413
	Outside	23.72	24.55	1.556	1.556	103%	0.0306209
14	Inside	17.31	17.77	1	1	103%	0.0000401
	Outside	28.35	28.44	1.556	1.556	100%	0.0472441
15	Inside	16.79	17.93	1	1	107%	0.0001401
	Outside	29.29	29.56	1.556	1.556	101%	0.0496954
16	Inside	22.76	23.39	1	1	103%	0.0003673
	Outside	26.42	26.90	1.556	1.556	102%	0.0352926
17	Inside	25.85	26.31	1	1	102%	0.0004364
	Outside	21.96	22.64	1.556	1.556	103%	0.0286990
18	Inside	19.92	20.87	1	1	105%	0.0000405
	Outside	24.78	25.29	1.556	1.556	102%	0.0341571
21	Inside	27.76	24.15	1	1	87%	0.0034623
	Outside	18.10	13.88	1.410	1.296	70%	0.0205600
22	Inside	35.42	49.36	1	1	139%	0.0022993
	Outside	30.28	25.61	1.296	1.296	85%	0.0960680
23	Inside	31.79	29.10	1	1	92%	0.0067571
	Outside	42.35	39.04	1.410	1.296	85%	**0.7588854**
24	Inside	17.06	22.99	1	1	135%	0.0002139
	Outside	34.45	40.13	1.590	1.296	95%	0.2005715
25	Inside	12.99	14.44	1	1	111%	0.0000399
	Outside	27.65	38.43	2.340	1.207	72%	0.1934127
26	Inside	19.19	19.99	1	1	104%	0.0000378
	Outside	22.63	33.94	2.826	1.138	60%	0.2489307
27	Inside	32.02	32.80	1	1	102%	0.0007871
	Outside	27.51	22.73	2.340	1.207	43%	0.5829589
28	Inside	22.41	26.70	1	1	119%	0.0003040
	Outside	22.23	18.67	1.590	1.296	68%	0.0244082

Notes:

1) See Figure 6 for illustration of indicated locations.
2) Values were previously calculated in Reference [5, Section 8.3.1].
3) Values are recalculated based on modified FSWOL geometry using formula shown in Reference [5, Section 8.3.1].
4) Values are extracted from Table 10 of Reference [5].

Table 5: Base Metal Through-Wall Component Stress Comparison with Regards to Fatigue Crack Growth

% Through Wall (t=1.251 in)[(1)]	Axial Stress (ksi)		Hoop Stress (ksi)	
	Original	Modified	Original	Modified
0%	25.224	23.289	11.463	8.646
~25%	8.292	6.808	4.780	2.344
~50%	-0.483	-1.313	0.717	-1.396
~75%	-5.233	-5.357	-2.490	-4.221
~100% (Base Metal/FSWOL Interface)	-8.261	-7.600	-4.703	-5.908

Note:

1. Refer to Figure 1 showing the thickness through the SSW centerline, which includes a counterbore.

Table 6: Crack Growth Results for Original FSWOL Design (3) [6]

Path (1)	Axial Flaw				Circumferential Flaw			
	Initial Flaw Depth, in	60 Year Growth, in	Final Flaw Depth, in	Allowable Flaw Depth, in	Initial Flaw Depth, in	60 Year Growth, in	Final Flaw (2) Depth, in	Allowable Flaw Depth, in
P31	0.938	0.000	0.938	1.251	0.938	3.17E-04 (3)	0.938	1.251
P32	0.938	0.000	0.938	1.251	0.938	3.31E-04 (3)	0.938	1.251
P33	0.938	0.000	0.938	1.251	0.938	3.64E-04 (3)	0.938	1.251
P34	0.938	0.000	0.938	1.251	0.938	3.97E-04 (3)	0.938	1.251
P35	0.938	0.000	0.938	1.251	0.938	3.72E-04 (3)	0.938	1.251
P36	0.938	0.000	0.938	1.251	0.938	3.34E-04 (3)	0.938	1.251
P37	0.938	0.000	0.938	1.251	0.938	3.31E-04 (3)	0.938	1.251
P38	0.938	0.000	0.938	1.251	0.938	3.20E-04 (3)	0.938	1.251
P41	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P42	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P43	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P44	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P45	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P46	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P47	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P48	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P51	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P52	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P53	0.938	0.000	0.938	1.251	0.938	3.70E-04 (3)	0.938	1.251
P54	0.938	0.000	0.938	1.251	0.938	4.00E-04 (3)	0.938	1.251
P55	0.938	0.000	0.938	1.251	0.938	3.59E-04 (3)	0.938	1.251
P56	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P57	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251
P58	0.938	0.000	0.938	1.251	0.938	0.000	0.938	1.251

Notes:
1. See Figure 6 for the path locations.
2. Initial flaw depth = 75% of original through-wall thickness, or 0.938 inches
3. All growth due to fatigue crack growth during Primary Side Hydrostatic Test transient.
4. The allowable flaw size is 100% of the original through-wall thickness. This is because the FSWOL is designed with an assumed 100% through-wall circumferential flaw for the entire circumference.
5. Table reproduced from Table 5 of Reference [6].

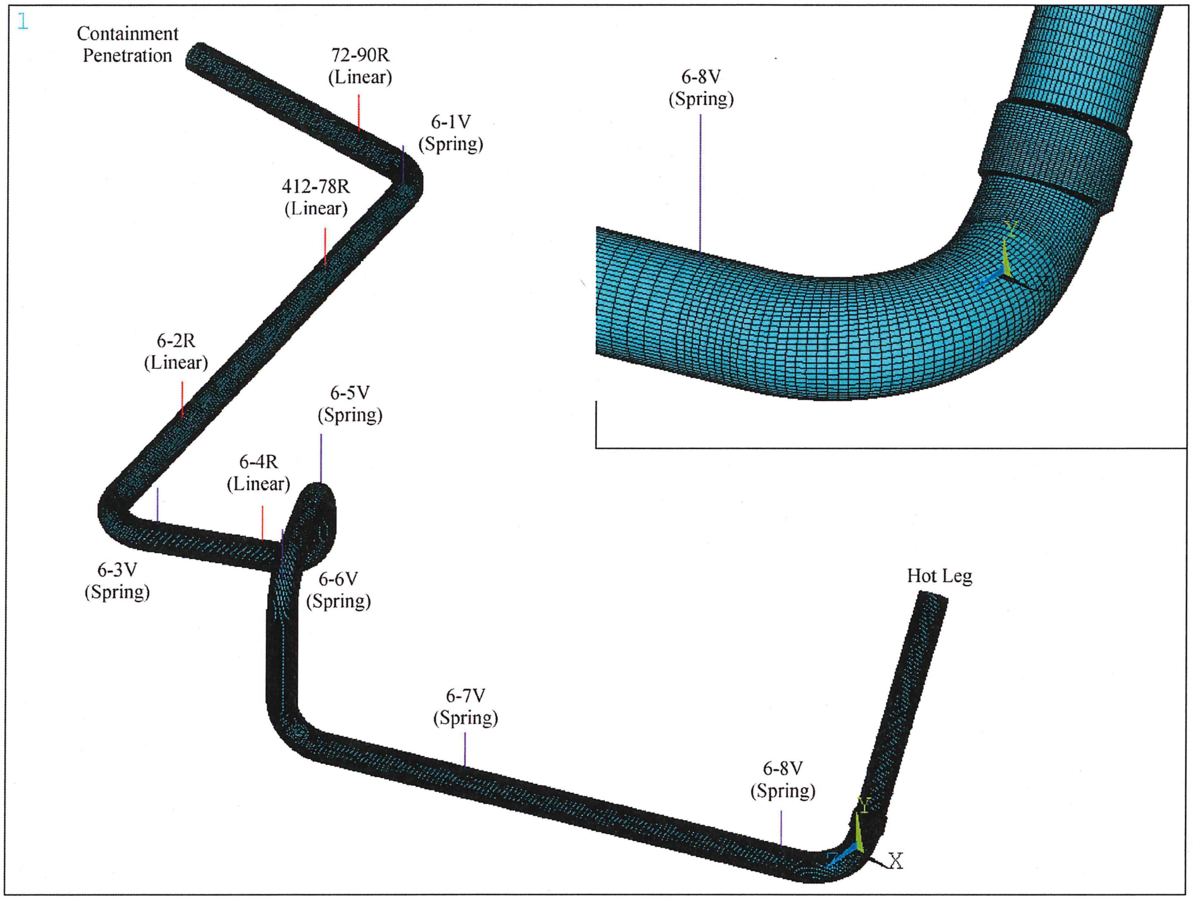
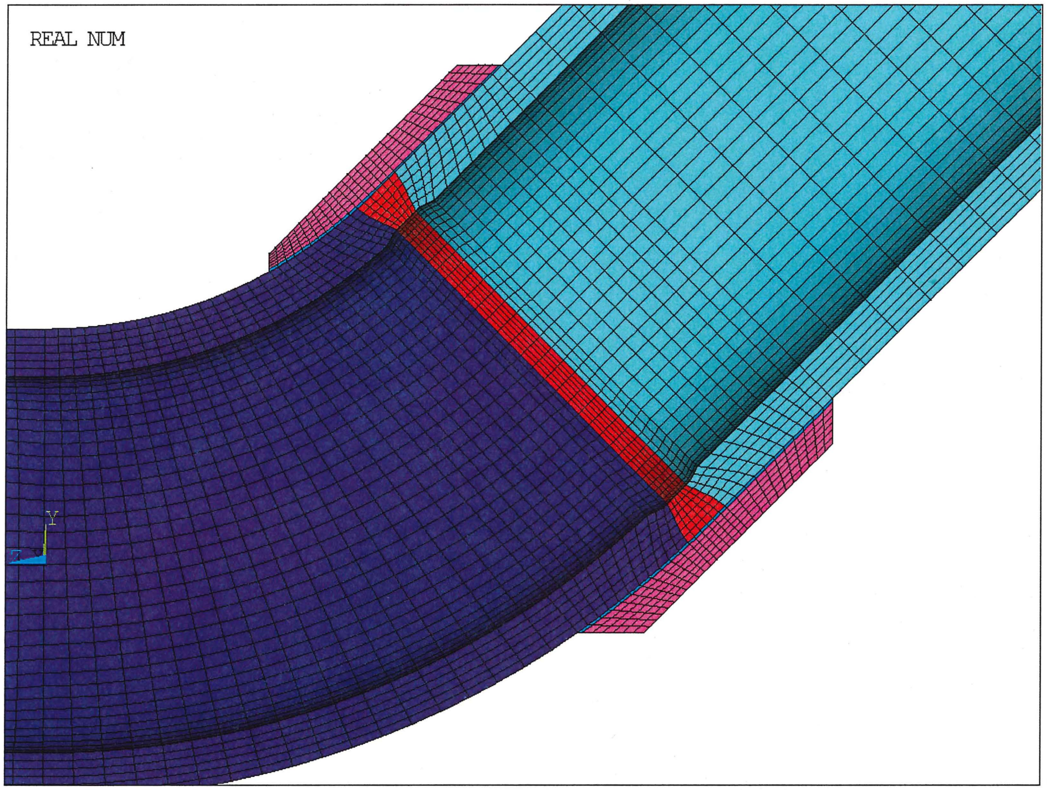
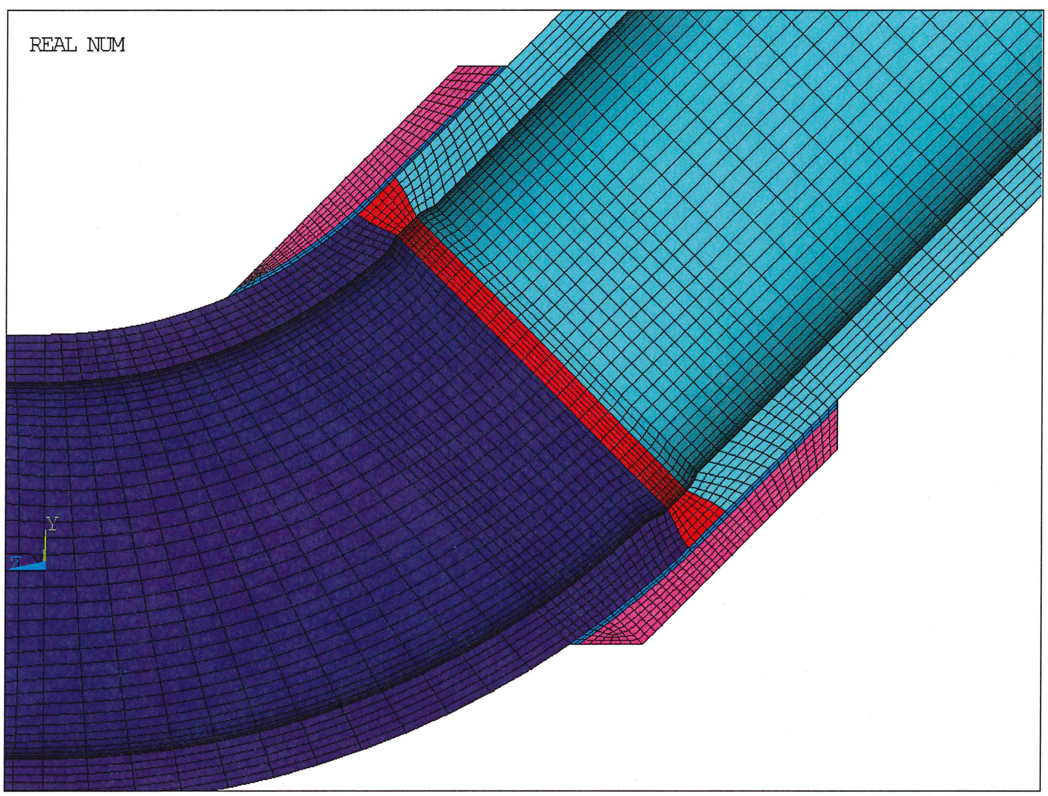


Figure 4: Overall Model of High Cycle Thermal Mixing Evaluation Finite Element Model Original [3]



Original [3]



Modified

Figure 5: Comparison of High Cycle Thermal Mixing Evaluation Finite Element Models

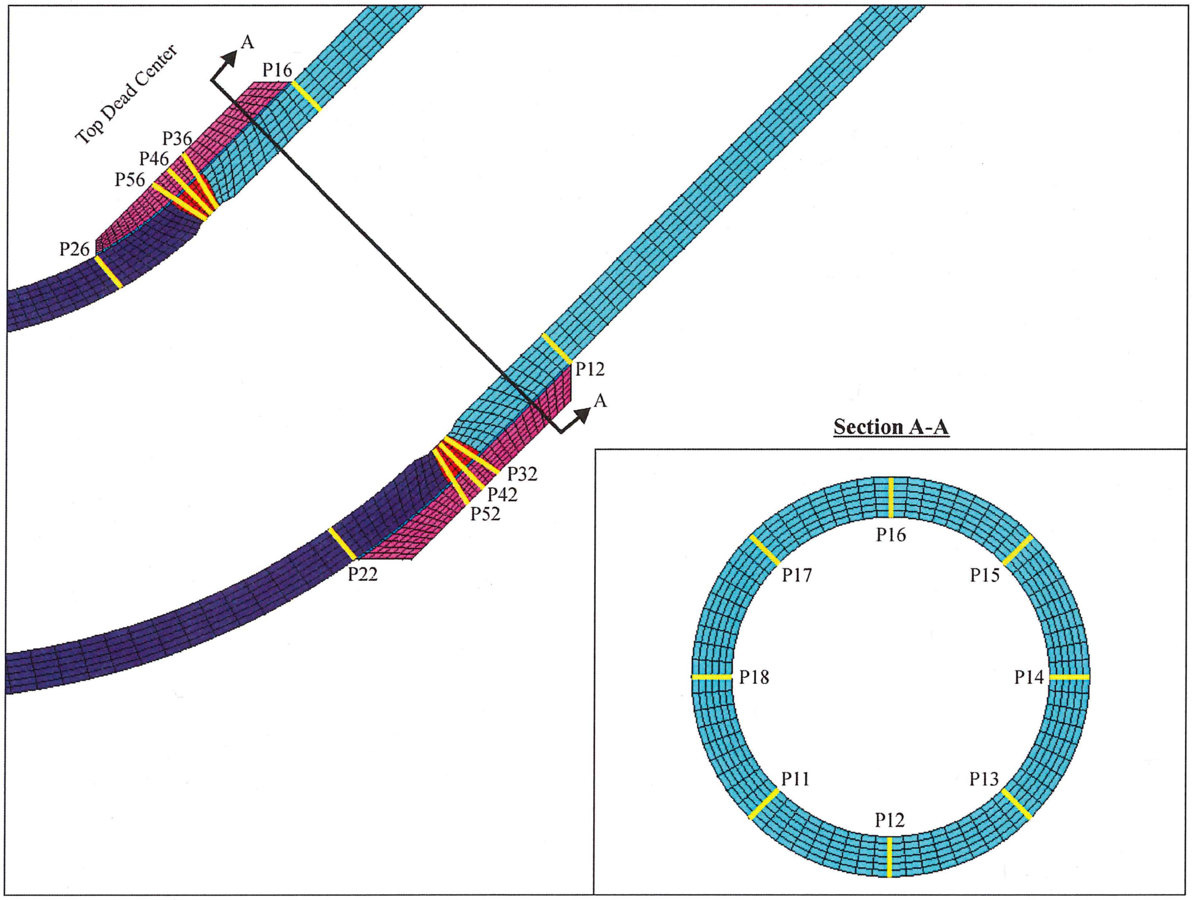


Figure 6: Path Locations for Through-Wall Stress Extractions

(Path definition = PXY, where:
X = the axial location along the pipe, e.g. P1 is at the RCS hot leg connection end of the FSWOL
Y = azimuthal location around the circumference (1 through 8) at the specific axial location, e.g. P12 is at Station 1 axially, and bottom dead center.)

(Paths 11 through 18 and 21 through 28 are used for ASME Code, Section III comparison and Paths 41 through 48 are used for the crack growth comparison. Paths 31 through 38 and 51 through 58 are not considered.)

The stress time histories extracted from the paths shown above are not shown in this calculation but are stored electronically. See Table 2 for the various file names for the files which are used in the ASME Code, Section III and crack growth comparisons.

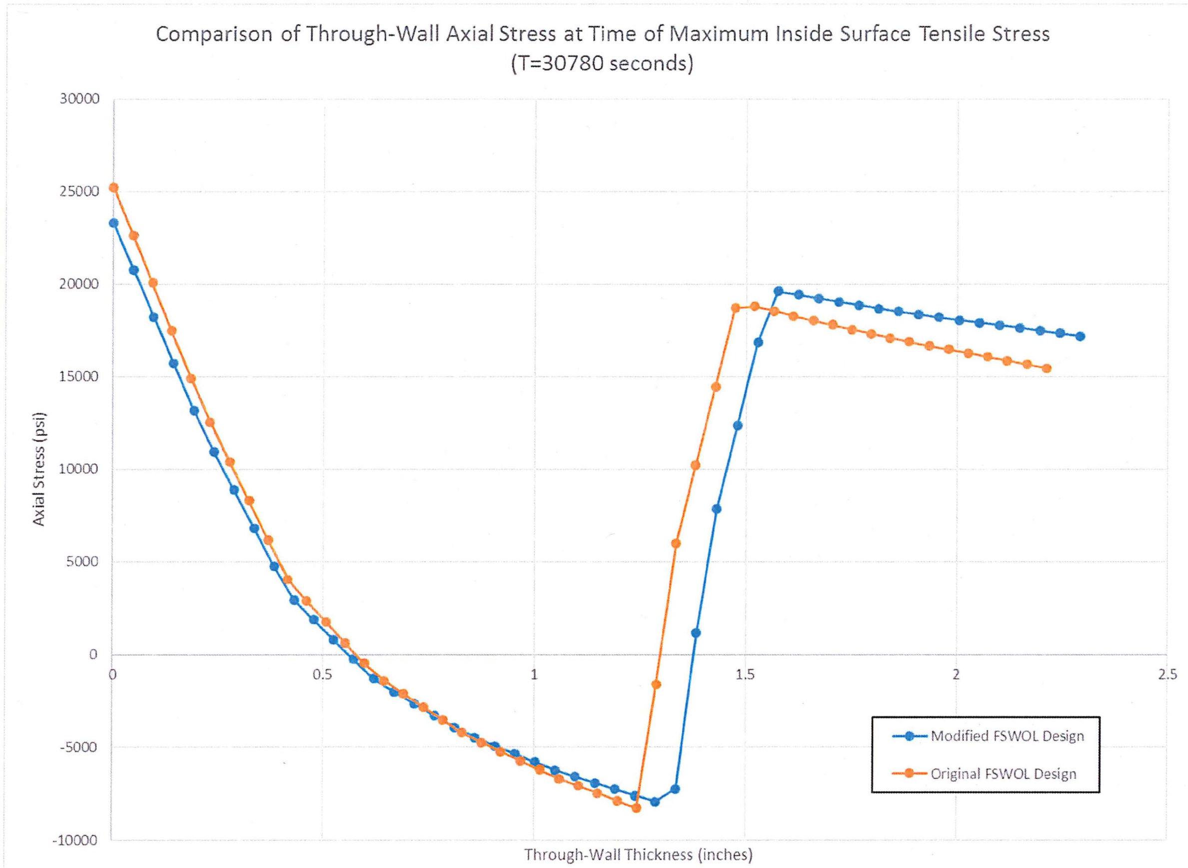


Figure 7: Comparison of Through-Wall Axial Stress at Path 46 Maximum Inside Surface Tensile Stress Due to the Enveloping High Cycle Thermal Mixing Transient for the Original and Modified FSWOL Design

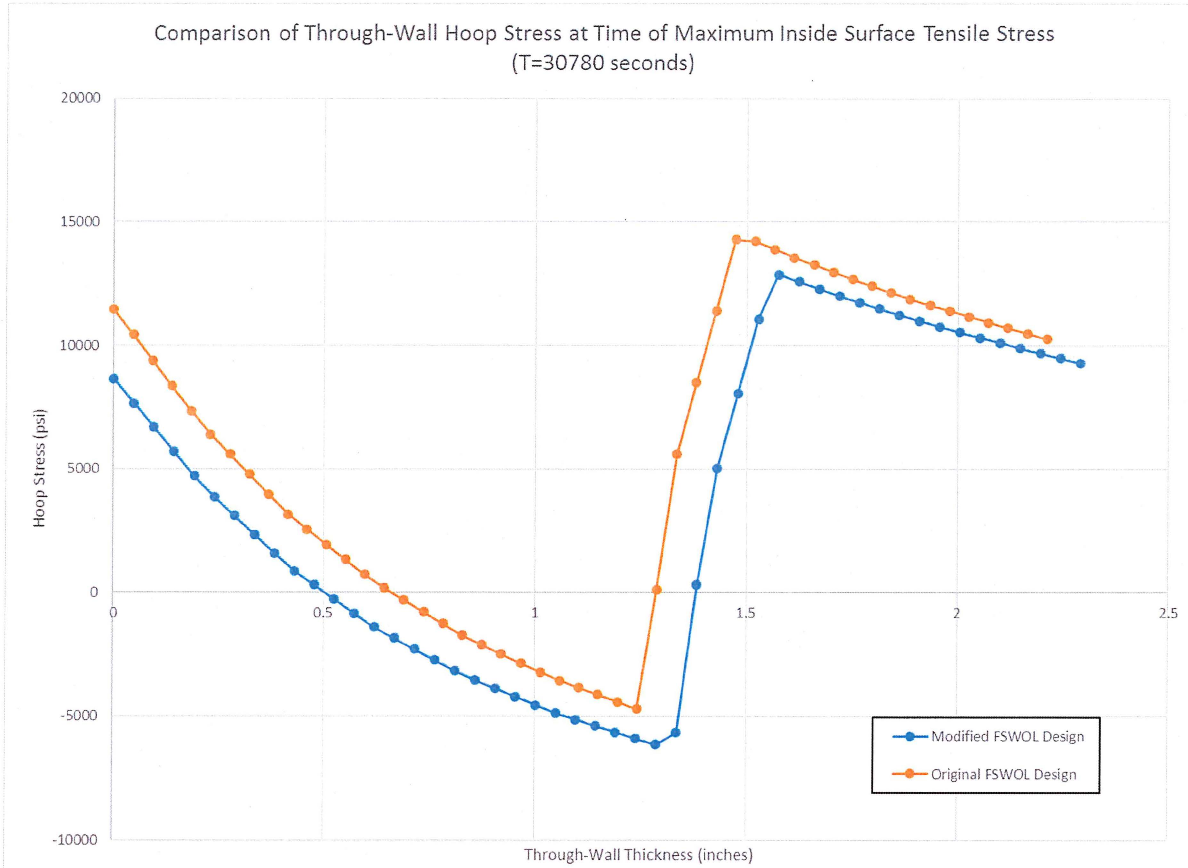


Figure 8: Comparison of Through-Wall Hoop Stress at Path 42 Maximum Inside Surface Tensile Stress Due to the Enveloping High Cycle Thermal Mixing Transient for the Original and Modified FSWOL Design

FSWOL WEIGHT COMPARISON

Reference [9, Table 2] determined that the total volume of the original maximum dimension FSWOL is 396.18 in³, which results in a weight of 130.09 lbs (includes insulation weight). Compared to the "effective" local piping this FSWOL weight represents only a 1.30% increase in weight.

The total volume of the modified FSWOL design was extracted the FEM model developed using the modified FSWOL maximum dimensions. The extracted volume (including the two buffer layers) is 458.705 in³. Using a density of 0.293 lbs/in³ [9, Table 2] results in a weight of 148.4 lbs (which includes 14 lbs of insulation). Per Table 2 of Reference [9], the nominal local piping weight (including water and insulation) is 10,039.04 lbs. Thus, the modified FSWOL design result in a weight increase of only 1.48%, only slightly more than the 1.30% of the original design.

Relative to the stiffness effect of the FSWOL, it is noted that the FSWOL makes the section of piping under the overlay significantly more rigid, and the modified FSWOL will only increase the rigidity in this local region. Given the greater flexibility of the adjacent piping system (no FSWOL), there will be no adverse change resulting from the small amount of weight increase (~ 18.3 lbs)

Given the insignificant change in total weight, the modified FSWOL does not impact the piping system deadweight and seismic behavior, and the conclusions from the original FSWOL design weight impact are unchanged.

FSWOL WELD SHRINKAGE COMPARISON

Experience has shown the majority of axial weld shrinkage tends to result from the first three layers of the FSWOL, which the remaining layer tending to only add to the final thickness. As such, a comparison of the FSWOL lengths is performed to judge the impact of the modified FSWOL design in the original FSWOL design shrinkage evaluation.

The shrinkage evaluation of the original FSWOL design was performed in Reference [10] and assumed 0.25 inches of shrinkage.

The original FSWOL design in Reference [1] is estimated to have a maximum reference length of approximately 10.29 inches. This value is based on a weld width of 1.55 inches [3, Figure 2], the maximum pipe side FSWOL length of 4.52 inches [1] and the maximum elbow side FSWOL length of 4.22 inches [1].

Using the same 1.55 inches weld width, the modified FSWOL design has a maximum pipe side length of 4.69 inches [2] and the maximum elbow side length of 4.52 inches [2]. This results in a reference length of approximately 10.76 inches for the modified FSWOL design. The overall increase in FSWOL length is approximately 4.6%.

The maximum stress determined in the shrinkage evaluation is 6,476 psi [10], which is less the cold spring allowable of 33,840 psi @610°F.

Given that the allowable is approximately five times greater than the actual shrinkage stress, and the modified FSWOL design is only 4.6% longer, it is reasonable to conclude that the conclusions of the shrinkage calculation [10] will not be adversely altered by the modified FSWOL design.

CONCLUSIONS

AZZ Specialty Welding (AZZ-SW) has been contracted by PG&E to install the weld overlay for Unit 2 in the Spring 2018 Refueling Outage (February 2018). A review by AZZ-SW recommended the addition of a second buffer layer and the extension of the weld overlay at the intrados to allow for constant orbital welding. Based on these recommendation, and PG&E concurrence, SI revised the design drawing [2, see Attachment B].

As SI's qualification of the FSWOL is based on the original FSWOL design [1, see Attachment A], it is necessary to evaluate the impact of modified FSWOL design on the design analyses.

Comparative evaluations have been performed to ascertain the impact of the modified FSWOL design. The following comparisons have been performed to evaluate the impact:

1) Weld Residual Stress (effecting crack growth evaluation)
2) Thermal Transient Stresses (effecting ASME Code, and crack growth evaluations)
3) FSWOL Weight (effecting deadweight and seismic loading)
4) FSWOL Shrinkage (cold spring pipe loading)

Based on the comparisons listed above it can be concluded that the modified FSWOL design [2] shown in Attachment B does not adversely impact the results and conclusions developed for the original FSWOL design. Therefore, the modified FSWOL design can be considered qualified under all ASME Code requirements, and Relief Request [11] commitments.

REFERENCES

1. SI Drawing No. 1600546.510, Rev. 3, "Diablo Canyon RHR WIB-228 (U1) and WIB-245 (U2) Weld Overlay." {Original Design}
2. SI Drawing No. 1600546.510, Rev. 4, "Diablo Canyon RHR WIB-228 (U1) and WIB-245 (U2) Weld Overlay." {Modified Design}
3. SI Calculation No. 1700479.312, Rev. 1, "Finite Element Model Development of the RHR Pipe-to-Elbow Weld (WIB-245 and WIB-228) with Weld Overlay Repair."
4. SI Calculation No. 1700479.314, Rev. 1, "Weld Residual Stress Analysis of the RHR Pipe-to-Elbow Weld (WIB-245 and WIB-228) with Weld Overlay Repair."
5. SI Calculation No. 1700479.315, Rev. 0, "ASME Code, Section III Qualification of the RHR Pipe-to-Elbow Welds (WIB-245 and WIB-228) with Weld Overlay Repair."
6. SI Calculation No. 1700479.316, Rev. 0, "Crack Growth Analyses of the RHR Pipe-to-Elbow Weld (WIB-245 and WIB-228) with Weld Overlay Repair."
7. SI Calculation No. 1700479.313, Rev. 0, "Thermal and Mechanical Load Stress Analyses of the RHR Pipe-to-Elbow Weld (WIB-245 and WIB-228) with Weld Overlay Repair."
8. ASME Boiler and Pressure Vessel Code, Section III, Rules for Construction of Nuclear Facility Components, 2001 Edition with Addenda through 2003.
9. SI Calculation No. 1700479.318, Rev. 0, "RHR Suction Piping Weld Overlay Weight Calculation."
10. SI Calculation No. 1700479.317, Rev. 0, "Shrinkage Analysis for the RHR Suction Line due to Weld Overlay Repair."
11. Request for Approval of Alternative for Application of Full Structural Weld Overlay, REP-RHR-SWOL. Units 1 and 2, PG&E Letter DCL-17-083, Dated September 26, 2017.

ACRONYMS

ASME	American Society of Mechanical Engineers
AZZ SW	AZZ Specialty Welding (Welding Contractor)
CMTR	Certified Materials Test Report
DCPP	Diablo Canyon Power Plant
FCG	Fatigue Crack Growth
FEM	Finite Element Model
FSRF	Fatigue Strength Reduction Factor
FSWOL	Full Structural Weld Overlay
NOC	Normal Operating Conditions
PG&E	Pacific Gas & Electric
RCS	Reactor Coolant System
RHR	Residual Heat Removal
SCC	Stress Corrosion Cracking
SI	Structural Integrity
SSW	Stainless Steel Weld

info@STRUCTINT.com 1-877-4SI-POWER www.STRUCTINT.com

Prepared by:		Verified by:	
	8/17/2018		8/17/2018
Kevin Wong Senior Engineer	Date	Richard L. Bax Jr. Associate	Date

Approved by:

	8/17/2018
James W. Axline, P.E. Associate	Date

REGISTERED PROFESSIONAL ENGINEER
JAMES W. AXLINE
M 17802
EXP. 9/30/19
MECHANICAL
STATE OF CALIFORNIA

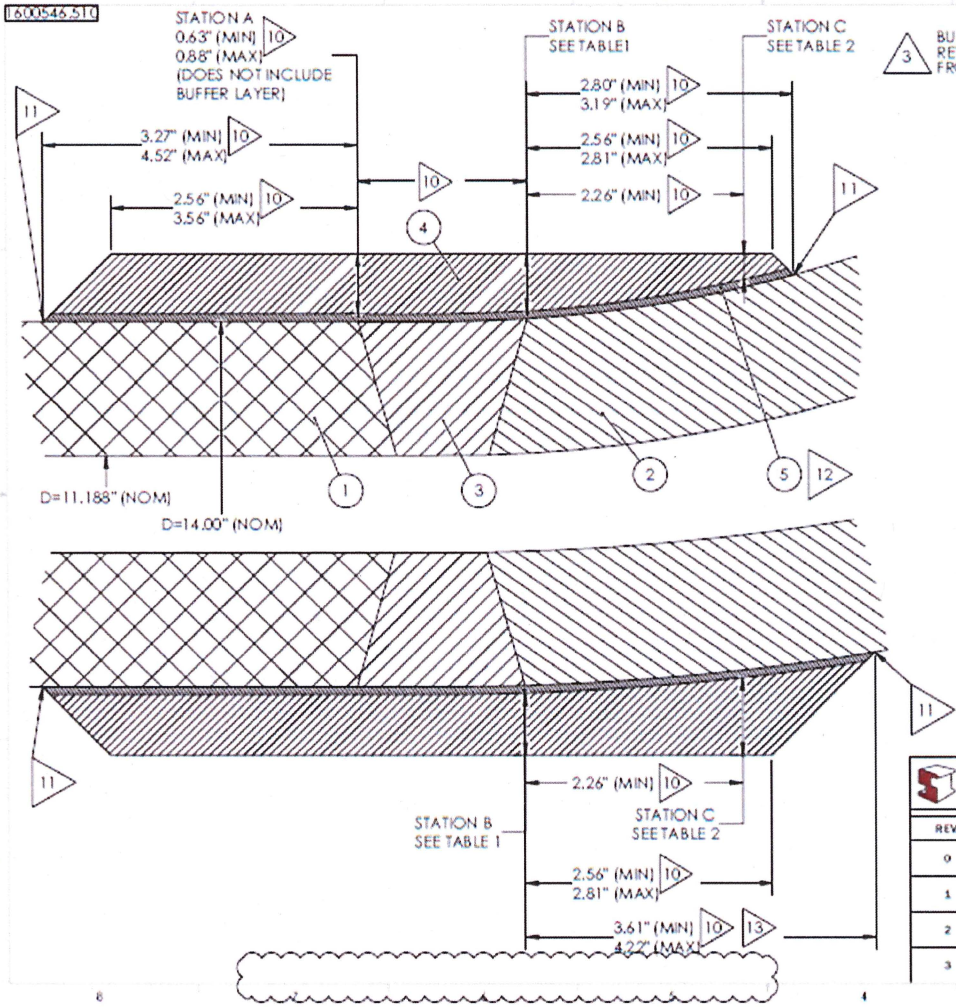
Attachments A & B

Attachment A
SI Drawing No. 1600546.510, Revision 3

Original FSWOL Design

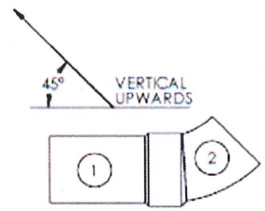
info@STRUCTINT.com 1-877-4SI-POWER www.STRUCTINT.com

1600546.510



3 BUBBLED CHANGES ARE REVISION 3 CHANGES FROM REVISION 1

	PART	MATERIAL
1	PIPE	A376 TP316
2	ELBOW (45° LR)	A403 TP316
3	WELD	STAINLESS STEEL
4	WELD OVERLAY	52M
5	BUFFER LAYER	ER308L



COMPONENT ORIENTATION

TABLE 1 - STATION B THICKNESS 10

	MIN	MAX
INTRADOS	0.61"	0.86"
SIDE HILL	0.63"	0.88"
EXTRADOS	0.64"	0.89"

(DOES NOT INCLUDE BUFFER LAYER)

TABLE 2 - STATION C THICKNESS 10

	MIN	MAX
INTRADOS	0.29"	0.54"
SIDE HILL	0.63"	0.88"
EXTRADOS	0.79"	1.04"

(DOES NOT INCLUDE BUFFER LAYER)

Structural Integrity Associates, Inc.

TITLE: DIABLO CANYON RHR WIB-228 (U1) AND WIB-24 5 (U2) WELD OVERLAY
PLANT: DIABLO CANYON POWER PLANT, UNIT 1 AND 2

REV	DRAWN BY	ENGINEER	REVIEWED BY	APPROVED BY
0	J. GUNDEL 6/24/16	C. LOHSE 6/24/16	J. HAYDEN 6/24/16	B. SMITH 6/24/16
1	J. GUNDEL 9/22/17	J. AXLINE 9/22/17	C. LOHSE 9/22/17	C. LOHSE 9/22/17
2	J. GUNDEL 1/12/18	J. AXLINE 1/12/18	C. LOHSE 1/12/18	J. AXLINE 1/12/18
3	J. GUNDEL 8/16/18	J. AXLINE 8/16/18	R. BAX 8/16/18	J. AXLINE 8/16/18

PROJECT NO. 1600546
DRAWING NO. 1600546.510
SIZE: B FILE NO. 1600546.510
REVISION: 3 SCALE: NONE
NUCLEAR SAFETY RELATED Yes ☒ No ☐
SHEET 1 OF 2

1600546.510

NOTES:

1. COMPONENT SURFACE IS TO BE EXAMINED BY LIQUID PENETRANT METHOD IN ACCORDANCE WITH THE DCPP RELIEF REQUEST AND ASME CODE CASE N-740-2, AND DETERMINED TO BE ACCEPTABLE PRIOR TO OVERLAY APPLICATION. THE SURFACE TO BE EXAMINED SHALL EXTEND BEYOND THE SURFACE TO BE OVERLAYED BY 0.50". IN THE EVENT THAT THE ORIGINAL COMPONENT SURFACE IS FOUND UNACCEPTABLE, THE SURFACE SHALL BE PREPARED/REPAIRED IN ACCORDANCE WITH THE OWNERS ASME SECTION XI PROGRAM AND THE RELIEF REQUEST AND REEXAMINED. ANY DEPOSITED WELD LAYER(S) REQUIRED FOR COMPONENT SURFACE REPAIR SHALL NOT BE CREDITED TOWARD MEETING THE REQUIRED MINIMUM THICKNESS, NOR COUNT AGAINST THE MAXIMUM. HOWEVER, MAXIMUM THICKNESS OF ALL WELD OVERLAY LAYERS (BUFFER, DILUTION, AND STRUCTURAL) SHALL BE LIMITED TO 1.35".

2. WELD FILLER METAL SHALL BE ASME CODE, SECTION II, PART C, SFA-5.14, ERNiCrFe-7A (ALLOY 52M), CERTIFIED TO SECTION III, SUBSECTION NB.

3. THE THICKNESS SHOWN ON THE DRAWING IS THE THICKNESS BEYOND ANY SURFACE PREPARATION REQUIRED BY NOTE 1 ABOVE. THE OVERLAY THICKNESS SHOWN ON THE DRAWING ASSUMES NO DILUTION LAYER. IF A DILUTION LAYER IS REQUIRED, THE DILUTION LAYER THICKNESS SHALL NOT BE CREDITED TOWARDS THE REQUIRED STRUCTURAL MINIMUM, NOR BE COUNTED AGAINST THE ALLOWED MAXIMUM.

4. TWO LAYERS OF OVERLAY ARE THE MINIMUM REQUIRED. APPLY AS MANY LAYERS AS REQUIRED TO ACHIEVE THE DESIGN OVERLAY THICKNESS.

5. DESIGN STRUCTURAL THICKNESS INCLUDES NO ALLOWANCE FOR SURFACE CONDITIONING TO FACILITATE UT INSPECTION OF THE COMPLETED OVERLAY. THE CYLINDRICAL SURFACE OF THE OVERLAY SHALL BE MECHANICALLY FINISHED AND HAVE A FINISH OF 250 RMS OR SMOOTHER. IN ADDITION THE SURFACE SHALL BE FLAT WITH NO OUT OF FLATNESS GREATER THAN 1/32" OVER THE LENGTH OF THE INSPECTION PROBE.

6. DIMENSIONS APPLY TO ALL AZIMUTHS UNLESS OTHERWISE NOTED.

7. CALCULATION INFORMATION: THE NECESSARY OVERLAY LENGTH FOR STRUCTURAL PURPOSES, FROM THE WELD FUSION LINE, IS 1.05" ON THE ELBOW SIDE AND 1.05" ON THE PIPE SIDE. THE LONGER LENGTH SHOWN ON THE DRAWING AS THE MINIMUM (2.80" ON THE ELBOW SIDE AND 3.27" ON THE PIPE SIDE) IS REQUIRED DUE TO UT EXAMINATION CONSTRAINTS.

8. POST WELD OVERLAY AXIAL SHRINKAGE MEASUREMENTS SHALL BE MEASURED AT FOUR AZIMUTHS AROUND THE ELBOW/PIPE AND RECORDED IN IMPLEMENTATION DOCUMENTATION. MEASUREMENT RESOLUTION SHALL BE ±0.02".

9. THE OVERLAY IS TO BE APPLIED WITH WATER-BACKING FOR ALL WELD OVERLAY LAYERS.

10. THE DIMENSION SHALL BE MEASURED AND RECORDED.

11. THE END TRANSITION OF THE WELD OVERLAY SHALL BE GROUND TO A CONDITION SUFFICIENT TO PASS VISUAL (VT) AND SURFACE (PT) EXAMINATION CRITERIA. THE LAST 3/8" OF TRANSITION SLOPE LENGTH ONTO THE BASE METAL SHALL BE BLENDED SMOOTH AND HAVE AN INCLUDED ANGLE OF 135° OF GREATER.

12. A STAINLESS BUFFER LAYER (ITEM 5) SHALL BE INSTALLED. BUFFER LAYER TO CONSIST OF A SINGLE LAYER AND SHALL COVER THE STAINLESS STEEL ELBOW, STAINLESS STEEL WELD, AND STAINLESS STEEL PIPE. BUFFER LAYER SHALL NOT COUNT TOWARD MEETING THE REQUIRED MINIMUM OVERLAY THICKNESS NOR COUNT AGAINST THE MAXIMUM. WELD FILLER METAL SHALL BE SFA-5.9 ER308L, CERTIFIED TO SECTION III, SUBSECTION NB. NOMINAL BUFFER LAYER THICKNESS IS 0.08". ADDITIONAL BUFFER LAYERS MAY BE INSTALLED IF REQUIRED FOR WELDING. MAXIMUM OVERALL THICKNESS OF WELD OVERLAY LAYERS SHALL BE LIMITED TO 1.35".

3 BUBBLED CHANGES ARE REVISION 3 CHANGES FROM REVISION 1

Structural Integrity Associates, Inc.

TITLE: DIABLO CANYON RHR WIB-228 (U1) AND WIB-245 (U2) WELD OVERLAY

PLANT: DIABLO CANYON POWER PLANT, UNIT 1 AND 2

REV	DRAWN BY:	ENGINEER:	REVIEWED BY:	APPROVED BY:
0	J. GUNDEL 6/24/16	C. LOHSE 6/24/16	J. HAYDEN 6/24/16	B. SMITH 6/24/16
1	J. GUNDEL 9/22/17	J. AXLINE 9/22/17	C. LOHSE 9/22/17	C. LOHSE 9/22/17
2	J. GUNDEL 1/12/18	J. AXLINE 1/12/18	C. LOHSE 1/12/18	J. AXLINE 1/12/18
3	J. GUNDEL 8/16/18	J. AXLINE 8/16/18	R. BAX 8/16/18	J. AXLINE 8/16/18

PROJECT NO.	1600546
DRAWING NO.	1600546.510
SIZE: B	FILE NO. 1600546.510
REVISION: 3	SCALE: NONE
NUCLEAR SAFETY RELATED Yes ☒ No ☐	SHEET 2 OF 2

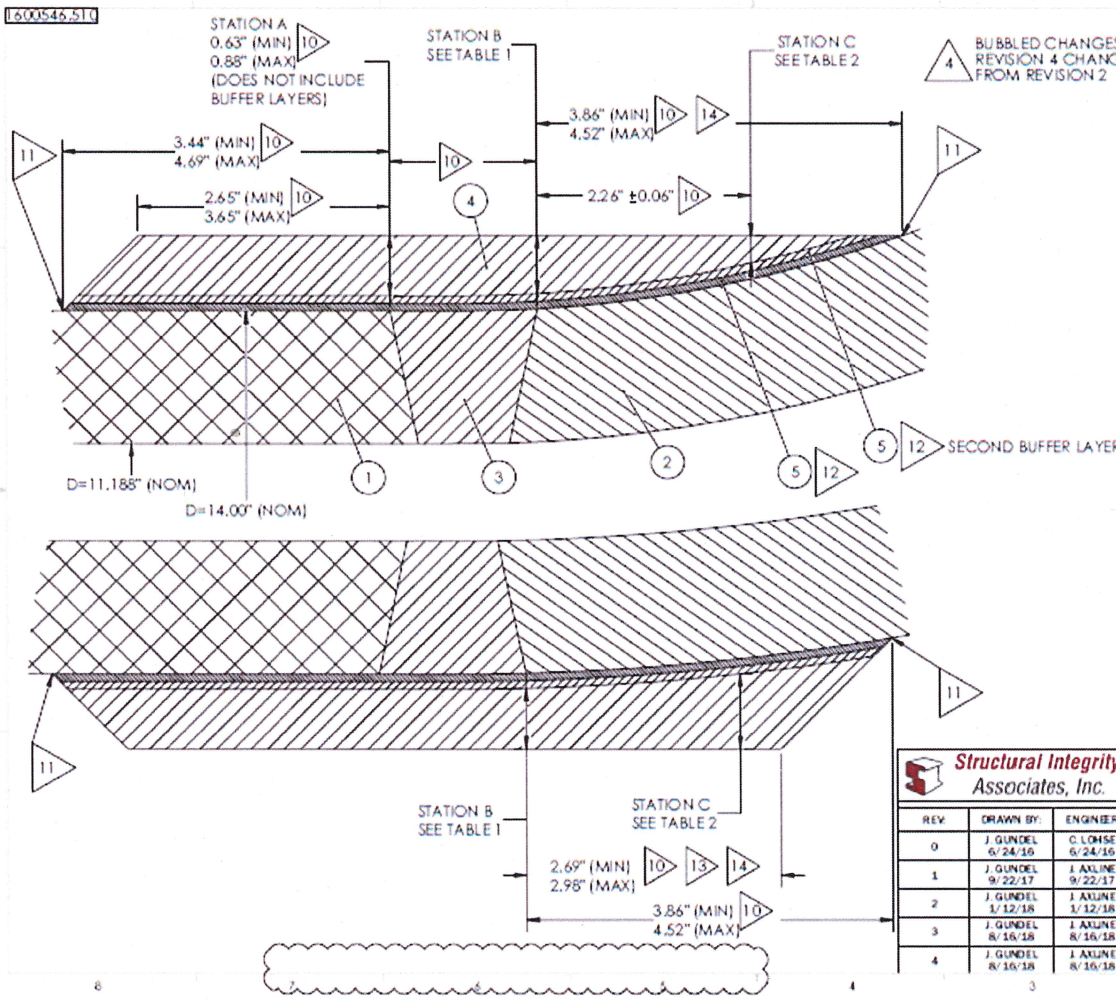
info@STRUCTINT.com
1-877-4SI-POWER
www.STRUCTINT.com

Attachment B
SI Drawing 1600546.510, Revision 4

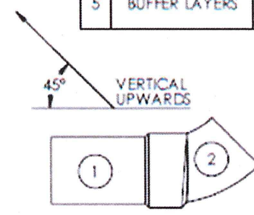
<u>Modified FSWOL Design</u>

info@STRUCTINT.com 1-877-4SI-POWER www.STRUCTINT.com

info@STRUCTINT.com
1-877-4SI-POWER
www.STRUCTINT.com



PART		MATERIAL
1	PIPE	A376 TP316
2	ELBOW (45° LR)	A403 TP316
3	WELD	STAINLESS STEEL
4	WELD OVERLAY	52M
5	BUFFER LAYERS	ER308L, ER309L OR ER316L



COMPONENT ORIENTATION

TABLE 1 - STATION B THICKNESS		
	MIN	MAX
INTRADOS	0.61"	0.86"
SIDE HILL	0.63"	0.88"
EXTRADOS	0.64"	0.89"
(DOES NOT INCLUDE BUFFER LAYERS)		

10

TABLE 2 - STATION C THICKNESS		
	MIN	MAX
INTRADOS	0.29"	0.54"
SIDE HILL	0.63"	0.88"
EXTRADOS	0.79"	1.04"
(DOES NOT INCLUDE BUFFER LAYERS)		

10

Structural Integrity Associates, Inc.

TITLE: DIABLO CANYON RHR WIB-228 (U1) AND WIB-245 (U2) WELD OVERLAY

PLANT: DIABLO CANYON POWER PLANT, UNIT 1 AND 2

REV.	DRAWN BY:	ENGINEER:	REVIEWED BY:	APPROVED BY:
0	J. GUNDEL 6/24/16	C. LOHSE 6/24/16	J. HAYDEN 6/24/16	B. SMITH 6/24/16
1	J. GUNDEL 9/22/17	J. AXLINE 9/22/17	C. LOHSE 9/22/17	C. LOHSE 9/22/17
2	J. GUNDEL 1/12/18	J. AXLINE 1/12/18	C. LOHSE 1/12/18	J. AXLINE 1/12/18
3	J. GUNDEL 8/16/18	J. AXLINE 8/16/18	R. BAX 8/16/18	J. AXLINE 8/16/18
4	J. GUNDEL 8/16/18	J. AXLINE 8/16/18	R. BAX 8/16/18	J. AXLINE 8/16/18

PROJECT NO. 1600546
DRAWING NO. 1600546.510
SIZE: B FILE NO. 1600546.510
REVISION: 4 SCALE: NONE
NUCLEAR SAFETY RELATED Yes [X] No [ ]
SHEET: 1 OF 2

info@STRUCTINT.com
1-877-4SI-POWER
www.STRUCTINT.com

1600546.510

NOTES:

1. COMPONENT SURFACE IS TO BE EXAMINED BY LIQUID PENETRANT METHOD IN ACCORDANCE WITH THE DCPP RELIEF REQUEST REP-RHR-SWOL AND ASME CODE CASE N-740-2, AND DETERMINED TO BE ACCEPTABLE PRIOR TO OVERLAY APPLICATION. THE SURFACE TO BE EXAMINED SHALL EXTEND BEYOND THE SURFACE TO BE OVERLAYED BY 0.50". IN THE EVENT THAT THE ORIGINAL COMPONENT SURFACE IS FOUND UNACCEPTABLE, THE SURFACE SHALL BE PREPARED/REPAIRED IN ACCORDANCE WITH THE OWNERS ASME SECTION XI PROGRAM AND THE RELIEF REQUEST AND REEXAMINED. ANY DEPOSITED WELD LAYER(S) REQUIRED FOR COMPONENT SURFACE REPAIR SHALL NOT BE CREDITED TOWARD MEETING THE REQUIRED MINIMUM THICKNESS, NOR COUNT AGAINST THE MAXIMUM. HOWEVER, MAXIMUM THICKNESS OF ALL WELD OVERLAY LAYERS (BUFFER, DILUTION, AND STRUCTURAL) SHALL BE LIMITED TO 1.35".

2. WELD FILLER METAL SHALL BE ASME CODE, SECTION II, PART C, SFA-5.14, ERNiCrFe-7A (ALLOY 52M), CERTIFIED TO SECTION III, SUBSECTION NB.

3. THE THICKNESS SHOWN ON THE DRAWING IS THE THICKNESS BEYOND ANY SURFACE PREPARATION REQUIRED BY NOTE 1 ABOVE. THE OVERLAY THICKNESS SHOWN ON THE DRAWING ASSUMES NO DILUTION LAYER. IF A DILUTION LAYER IS REQUIRED, THE DILUTION LAYER THICKNESS SHALL NOT BE CREDITED TOWARDS THE REQUIRED STRUCTURAL MINIMUM, NOR BE COUNTED AGAINST THE ALLOWED STRUCTURAL MAXIMUM.

4. TWO LAYERS OF OVERLAY ARE THE MINIMUM REQUIRED. APPLY AS MANY LAYERS AS REQUIRED TO ACHIEVE THE DESIGN OVERLAY THICKNESS.

5. DESIGN STRUCTURAL THICKNESS INCLUDES NO ALLOWANCE FOR SURFACE CONDITIONING TO FACILITATE UT INSPECTION OF THE COMPLETED OVERLAY. THE CYLINDRICAL SURFACE OF THE OVERLAY SHALL BE MECHANICALLY FINISHED AND HAVE A FINISH OF 250 RMS OR SMOOTHER. IN ADDITION THE SURFACE SHALL BE FLAT WITH NO OUT OF FLATNESS GREATER THAN 1/32" OVER THE LENGTH OF THE INSPECTION PROBE.

6. DIMENSIONS APPLY TO ALL AZIMUTHS UNLESS OTHERWISE NOTED.

7. CALCULATION INFORMATION: THE NECESSARY OVERLAY LENGTH FOR STRUCTURAL PURPOSES, FROM THE WELD FUSION LINE, IS 1.05" ON THE ELBOW SIDE AND 1.05" ON THE PIPE SIDE. THE LONGER LENGTH SHOWN ON THE DRAWING AS THE MINIMUM (3.86" ON THE ELBOW SIDE AND 3.44" ON THE PIPE SIDE) IS REQUIRED DUE TO UT EXAMINATION CONSTRAINTS.

8. POST WELD OVERLAY AXIAL SHRINKAGE MEASUREMENTS SHALL BE MEASURED AT FOUR AZIMUTHS AROUND THE ELBOW/PIPE AND RECORDED IN IMPLEMENTATION DOCUMENTATION. MEASUREMENT RESOLUTION SHALL BE ±0.02".

9. THE OVERLAY IS TO BE APPLIED WITH WATER-BACKING FOR ALL WELD OVERLAY LAYERS. WATER CAN BE FLOWING OR STAGNANT, OR A COMBINATION.

10. THE DIMENSION SHALL BE MEASURED AND RECORDED.

11. THE END TRANSITION OF THE WELD OVERLAY SHALL BE GROUND TO A CONDITION SUFFICIENT TO PASS VISUAL (VT) AND SURFACE (PT) EXAMINATION CRITERIA. THE LAST 3/8" OF TRANSITION SLOPE LENGTH ONTO THE BASE METAL SHALL BE BLENDED SMOOTH AND HAVE AN INCLUDED ANGLE OF 135° OF GREATER.

12. A STAINLESS BUFFER LAYER (ITEM 5) SHALL BE INSTALLED. BUFFER LAYER TO CONSIST OF TWO LAYERS AND SHALL COVER THE STAINLESS STEEL ELBOW, STAINLESS STEEL WELD, AND STAINLESS STEEL PIPE. BUFFER LAYER SHALL NOT COUNT TOWARD MEETING THE REQUIRED MINIMUM OVERLAY THICKNESS NOR COUNT AGAINST THE MAXIMUM. WELD FILLER METAL SHALL BE SFA-5.9 ER308L, ER309L, OR ER316L CERTIFIED TO SECTION III, SUBSECTION NB. NOMINAL BUFFER LAYER THICKNESS IS 0.08". ADDITIONAL BUFFER LAYERS MAY BE INSTALLED IF REQUIRED FOR WELDING. MAXIMUM OVERALL THICKNESS OF WELD OVERLAY LAYERS SHALL BE LIMITED TO 1.35".

13. APPLIES ONLY AT EXTRADOS.

14. NOMINAL BREAK LOCATIONS FOR SIDE HILL OF WOL. MINIMUM CONFIGURATION 3.28", MAXIMUM CONFIGURATION 3.75".

(4) BUBBLED CHANGES ARE REVISION 4 CHANGES FROM REVISION 2

Structural Integrity Associates, Inc.

TITLE: DIABLO CANYON RHR WIB-228 (U1) AND WIB-245 (U2) WELD OVERLAY

PLANT: DIABLO CANYON POWER PLANT, UNIT 1 AND 2

REV.	DRAWN BY:	ENGINEER:	REVIEWED BY:	APPROVED BY:
0	J. GUNDEL 6/24/16	C. LOHSE 6/24/16	J. HAYDEN 6/24/16	B. SMITH 6/24/16
1	J. GUNDEL 9/22/17	J. AXLINE 9/22/17	C. LOHSE 9/22/17	C. LOHSE 9/22/17
2	J. GUNDEL 1/12/18	J. AXLINE 1/12/18	C. LOHSE 1/12/18	J. AXLINE 1/12/18
3	J. GUNDEL 8/16/18	J. AXLINE 8/16/18	R. BAX 8/16/18	J. AXLINE 8/16/18
4	J. GUNDEL 8/16/18	J. AXLINE 8/16/18	R. BAX 8/16/18	J. AXLINE 8/16/18

PROJECT NO. 1600546

DRAWING NO. 1600546.510

SIZE: B | FILE NO. 1600546.510

REVISION: 4 | SCALE: NONE

NUCLEAR SAFETY RELATED Yes [X] No [ ]

SHEET: 2 OF 2

Diablo Canyon Power Plant, Unit 2

Acceptance of Weld Overlay – RHR Weldment WIB-245-Unit 2

5215 Hellyer Avenue, Suite 210, San Jose, CA 95138 | 408-978-8200
jaxline@structint.com

July 12, 2018
Report No. 1700479.403.R1
Quality Program: ☒ Nuclear ☐ Commercial

Mr. Mark Sharp, Design Engineering Manager
Pacific Gas & Electric Company
Diablo Canyon Power Plant
9 Miles NW of Avila Beach
P.O. Box 56
Avila Beach, CA 93424-0056

Subject: REVISED - Acceptance of Weld Overlay – RHR Weldment WIB-245-Unit 2

References:
1. AZZ Weld Overlay Construction Drawing, No. 433497, Rev. 0, Populated, Transmitted by DIT 50915871-013-00, SI File No. 1700479.237
2. Final UT Report, WIB-245OL, dated 2/26-27/18, Transmitted by DIT 50915871-014-01, SI File No. 1700479.239
3. Post-Weld Overlay Walkdown Documentation, Email: Shakibnia, Behrooz (PGE) to J. Axline (SI), 3/1/18, 3:35 PM, "Unit 2 RHR Line 109/Weld Overlay/Rupture Restraint walkdown" and Email: Khatri, Sureshchandra (PGE) to J. Axline (SI), 7/11/18, 5:23 PM, "Reference 3 of SI Report 1700479.403 Rev 1A", SI File No. 1700479.240.
4. DCPP Relief Request, REP-RHR-SWOL, dated September 26, 2017.
5. SI Report 1700479.401, Rev. 0, Design Report for the Qualification of the Structural Weld Overlay Repair of Residual Heat Removal Welds WIB-245 and WIB-228, Diablo Canyon Power Plant, Unit 1 and 2.
6. SI Report 1700479.402, Rev. 0, Impact of Added Second Buffer Layer of Stainless Steel to RHR Weld Overlay.

Dear Mr. Sharp,

SI has reviewed the referenced AZZ as-built construction drawing [1] against the design dimensions of the SI Design Report, 1700479.401 [5], and all as-measured dimensions are within the maximum and minimum values used in the design. The maximum measured axial shrinkage of the completed weld overlay (0.082 inch) is less than the assumed shrinkage (0.25 inch) in the design qualification [5], thus the value of axial shrinkage is acceptable.

The referenced UT report [2] confirms that the final weld overlay meets the acceptance requirements of the Relief Request, REP-RHR-SWOL [4], Units 1 and 2.

The referenced post-weld overlay walkdown information [3] has confirmed that the affected piping components (supports, gaps, etc.) are acceptable.

Based on the review of the documents above, the conclusions and results of the Design Report, 1700479.401 [5], and the Reconciliation Report 1700479.402 [6], are justified, including future operation as noted in the reports.

Prepared by:

James W. Axline, P.E. — 7/12/2018
Associate — Date

Verified by:

Richard Bax — 7/12/2018
Associate — Date

Approved by:

Chris S. Lohse, P.E. — 7/12/2018
Associate — Date

cc: N. Gerber (SI)