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W3F1-2008-0037

May 10, 2008

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

Subject: Summary of Design and Analyses of Weld Overlays for Pressurizer and Hot Leg Nozzle Dissimilar Metal Welds for Alloy 600 Mitigation
Waterford Steam Electric Station, Unit 3 (Waterford 3)
Docket No. 50-382
License No. NPF-38

Reference: 1. NRC Letter to Entergy dated April 21, 2008 Approval of, "Request for Alternative W3-R&R-006 – Proposed Alternative to ASME Code Requirements for Weld Overlay (TAC NO. MD5388)."

Dear Sir or Madam:

By letter (Reference 1), the NRC approved the request for alternative by Entergy Operations, Inc. (Entergy) to the requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME), Section XI IWA-4000. The requested alternative was for the installation of preemptive full structural weld overlays on dissimilar metal welds of one pressurizer surge nozzle, one pressurizer spray nozzle, three pressurizer safety/relief valve nozzles, one hot leg surge nozzle, two hot leg shutdown cooling nozzles and one hot leg drain nozzle.

As part of the request, Entergy committed to submit to the NRC a stress analysis summary demonstrating that the hot leg piping and pressurizer nozzles will perform their intended design functions after the weld overlay installation. The commitment further stated the stress analysis report will include results showing that the requirements of NB-3200 and NB-3600 of the ASME Code, Section III are satisfied. Also the stress analysis will include results showing that the requirements of IWB-3000 of the ASME Code, Section XI, are satisfied. The results will show that the postulated crack including its growth in the nozzles will not adversely affect the integrity of the overlaid welds. It was further committed that this information would be submitted to the NRC prior to entry into Mode 4 start-up from Waterford 3's fifteenth refueling outage (RF15). The purpose of this letter is to provide the summary report, which is attached.

A047
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NRR

The design of the Waterford 3 weld overlays was performed in accordance with the requirements of the relief request. The weld overlays were demonstrated in the attached report to provide long-term mitigation of primary water stress corrosion cracking (PWSCC) in these welds.

There are no new commitments contained in this submittal. If you have any questions or require additional information, please contact Robert Murillo at (504) 739-6715.

Sincerely,

RJM/OPP

Attachment: Summary of Design and Analyses of Weld Overlays for Pressurizer and Hot Leg Nozzle Dissimilar Metal Welds for Alloy 600 Mitigation at Waterford Steam Electric Station, Unit 3

cc: Mr. Elmo E. Collins, Jr.
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Attachment

W3F1-2008-0037

Summary of Design and Analyses of Weld Overlays for Pressurizer and Hot Leg Nozzle Dissimilar Metal Welds for Alloy 600 Mitigation at Waterford Steam Electric Station, Unit 3

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May 5, 2008
SIR-08-120-NPS, Rev. 0

Mr. John B. Houghtaling
Entergy Nuclear South
Entergy Operations, Inc.
Waterford Steam Electric Station, Unit 3
17265 River Road
Killona, LA, 70057

Subject: Summary of Design and Analyses of Weld Overlays for Pressurizer and Hot Leg Nozzle Dissimilar Metal Welds for Alloy 600 Mitigation at Waterford Steam Electric Station, Unit 3

Reference: Revised Request for Alternative W3-R&R-006 - Proposed Alternative to ASME Code Requirements for Weld Overlay Repairs, Waterford Steam Electric Station, Unit 3, Docket No. 50-382, License No. NPF-38

Dear Mr. Houghtaling:

The following attachment is transmitted in support of Entergy's response to commitments in the above-referenced request for alternative:

Commitment:

Entergy will submit to the NRC a stress analysis summary demonstrating that the pressurizer and hot leg piping nozzles will perform their intended design functions after the weld overlay installation. The stress analysis report will include results showing that the requirements of NB-3200 and NB-3600 of the ASME Code, Section III are satisfied. The stress analysis will also include results showing that the requirements of IWB-3000 of the ASME Code, Section XI, are satisfied. The results will show that the postulated crack, including its growth in the nozzles, will not adversely affect the integrity of the overlaid welds. This information will be submitted to the NRC prior to entry into Mode 4 start-up from the Waterford SES, Unit 3 fifteenth refueling outage (RF15), Spring 2008.

If you have any questions or comments regarding this summary, please contact one of the undersigned.

Prepared by:

Gole Mukhim 05/05/08
Senior Consultant Date

Verified by:

James W. Axline, P.E. 05/05/08
Senior Consultant Date

Approved by:

Moses Taylor, P.E. 05/05/08
Senior Associate Date

Attachment
cc: D. Goetcheus
W. Sims
Project File No. WSES-19Q-402

Attachment

Summary of Design and Analyses of Weld Overlays for Pressurizer and Hot Leg Nozzle Dissimilar Metal Welds for Alloy 600 Mitigation

1.0 Introduction

Entergy will apply full structural weld overlays (WOLs) on dissimilar metal welds (DMWs) between the low alloy or carbon steel nozzles and stainless steel safe ends of the pressurizer and hot leg nozzles listed below. The WOLs will also be applied to the similar metal stainless steel welds (if applicable) between the safe end and the connecting piping component.

- One pressurizer surge nozzle
- One pressurizer spray nozzle
- Three pressurizer safety/relief valve nozzles
- One hot leg surge nozzle
- Two hot leg shutdown cooling nozzles
- One hot leg drain nozzle

The purpose of these overlays is to eliminate dependence on the primary water stress corrosion cracking (PWSCC) susceptible Alloy 82/182 welds as pressure boundary welds and to mitigate any potential future PWSCC in these welds. The overlays are extended to cover the similar metal weld between the safe end and connecting piping component (if applicable) to provide sufficient length to meet ASME Code, Section XI inspection coverage requirements for the DMWs. The overlays were installed using a PWSCC resistant weld filler material; Alloy 52M [1].

The requirements for design of weld overlay repairs are defined in the Relief Request [2], which is based on ASME Code Case N-740 [3]. Weld overlay repairs are considered to be acceptable long-term repairs for PWSCC susceptible weldments if they meet a conservative set of design assumptions which qualify them as "full structural" weld overlays. The design basis flaw assumption for full structural weld overlays is a circumferentially oriented flaw that extends 360° around the component; that is, completely through the original component wall thickness. A combination of internal pressure, deadweight, seismic and other dynamic stresses is applied to the overlaid nozzles containing this assumed design basis flaw, and they must meet the requirements of ASME Code, Section XI, IWB-3641 [4].

ASME Code, Section III stress and fatigue usage evaluations are also performed that supplement existing piping, safe end, and nozzle stress reports, to demonstrate that the overlaid components continue to meet ASME Code, Section III requirements. The original construction Codes are the ASME Code, Section III, 1971 Edition with Addenda through Summer 1971 for the pressurizer nozzles, and Addenda through Winter 1971 for the hot leg nozzles. However, as allowed by ASME Section XI, Code Editions and Addenda later than the original construction Code may be used. ASME Code, Section III, 2001 Edition with Addenda through 2003 [5] was used for these analyses.

In addition to providing structural reinforcement to the PWSCC susceptible locations with a resistant material, weld overlays have also been shown to produce beneficial residual stresses that mitigate PWSCC in the underlying DMWs. The weld overlay approach has been used to repair stress corrosion cracking in U.S. nuclear plants on hundreds of welds, and there have been no reports of subsequent crack extension after application of weld overlays. Thus, the compressive stresses caused by the weld overlay have been effective in mitigating new crack initiation and/or growth of existing cracks.

Finally, evaluations will be performed, based on as-built measurements taken after the overlays are applied, to demonstrate that the overlays meet their design basis requirements, and that they will not have an adverse effect on the balance of the piping systems. These include comparison of overlay dimensions to design dimensions, evaluations of shrinkage stresses and added weight effects on the piping systems.

2.0 Analysis Summary and Results

2.1 Weld Overlay Structural Sizing Calculations

Detailed sizing calculations for weld overlay thickness were performed using the "Codes and Standards" module of the **pc-CRACK** computer program [6], which incorporates ASME Code, Section XI, IWB-3640 evaluation methodology. Loads and stress combinations were provided by Entergy. Both normal operating/upset and emergency/faulted load combinations were considered in this evaluation and the design was based on the more limiting results. The resulting minimum required overlay thicknesses are summarized in Table 2-1 for the pressurizer nozzles, and in Table 2-2 for the hot leg nozzles.

As stated in Section 1.0, preemptive weld overlays will be installed using Alloy 52M filler metal. However, Alloy 52M weld metal has demonstrated sensitivity to certain impurities, such as sulfur, when deposited onto austenitic stainless steel base materials. Therefore, a butter (transitional) layer of austenitic stainless steel filler metal was applied across the safe end/piping end austenitic stainless steel base material. The austenitic stainless steel butter layer is not included in the structural weld overlay thickness defined above.

The weld overlay length must consider: (1) length required for structural reinforcement, (2) length required for access for preservice and inservice examinations of the overlaid weld, and (3) limitation on the area of the nozzle that can be overlaid. Because of the short safe end length on the overlaid nozzles, it is necessary to extend the overlay length over both the nozzle-to-safe end DMW and the safe end-to-pipe weld for all nozzles except the safety/relief valve nozzles. In accordance with the Relief Request [2] and ASME Code Case N-740 [3], the minimum weld overlay length required for structural reinforcement was established by evaluating the axial shear stress due to transfer of primary axial loads from the pipe into the overlay and back into the nozzle, on either side of the weld(s) being overlaid. Axial weld overlay lengths were established such that this stress is less than the ASME Code, Section III limit for pure shear stress. The resulting minimum length requirements are summarized in Table 2-1 for the pressurizer nozzles, and in Table 2-2 for the hot leg nozzles.

The overlay length and profile must also be such that the required post-WOL examination volume can be inspected using Performance Demonstration Initiative (PDI) qualified nondestructive examination (NDE) techniques. This requirement can cause required overlay lengths to be longer than the minimums for structural reinforcement. A typical weld overlay design is illustrated in Figure 2-1. The designs were reviewed by qualified NDE personnel to ensure that they meet inspectability requirements, and the overlays were designed to satisfy full structural requirements for the DMWs and the stainless steel welds. The design thickness and length specified on the design drawings bound the calculated minimum values, and may be greater to facilitate the desired geometry for examination.

Table 2-1: Weld Overlay Structural Thickness and Length Requirements - Pressurizer Nozzles

Dimension	**Location**	**Pressurizer Surge Nozzle**	**Pressurizer Spray Nozzle**	**Pressurizer Safety/Relief Valve Nozzle**
Minimum Thickness (in.)	Nozzle Side	0.490	0.348	0.458
	Safe End/Pipe Side	0.479	0.177	0.458**
	Pipe or Cap Side	0.437	0.146	NA
Minimum* Length (in.)	Nozzle Side	1.027	0.302	0.736
	Safe End/Pipe Side	NA	NA	1.034**
	Pipe or Cap Side	1.438	0.371	NA

* Length shown is the minimum required for structural acceptance and does not include additional length necessary to meet inspectability requirements.

** Only DMW is overlaid and thickness/length is at safe end side of DMW.

Table 2-2: Weld Overlay Structural Thickness and Length Requirements - Hot Leg Nozzles

Dimension	Location	Hot Leg Drain Nozzle	Hot Leg Surge Nozzle	Hot Leg Shutdown Cooling Nozzle
Minimum Thickness (in.)	Nozzle Side	0.356	0.577	0.511
	Safe End Side**	0.356/0.169	0.577/0.473	0.511/0.417
	Pipe Side	0.169	0.473	0.417
Minimum* Length (in.)	Nozzle Side	0.254	1.468	1.134
	Safe End Side	NA	NA	NA
	Pipe Side	0.215	1.592	1.225

* Length shown is the minimum required for structural acceptance and does not include additional length necessary to meet inspectability requirements.

** First number is for safe end side of nozzle-to-safe end weld and second number is for safe end side of safe end-to-pipe weld.

2.2 Section III Stress Analyses

Stress intensities for the weld overlaid nozzles were determined from finite element analyses for the various specified load combinations and transients using the ANSYS software package [7]. Linearized stresses were evaluated at various stress locations using 2-dimensional, axisymmetric and 3-dimensional solid models. A typical finite element model showing stress path locations is provided in Figure 2-2. The stress intensities at these locations were evaluated in accordance with ASME Code, Section III, Sub-articles NB-3200 and NB-3600 [5], and compared to applicable Code limits. A summary of the stress and fatigue usage comparisons for the most limiting locations is provided in Table 2-3 for the pressurizer nozzles, and in Table 2-4 for the hot leg nozzles. The stresses and fatigue usage in the weld overlaid nozzles are within the applicable Code limits.

Table 2-3: Limiting Stress Results for Weld Overlaid Pressurizer Nozzles

Nozzle	Load Combination	Type	Calculated	Allowable
Pressurizer Surge	Level A/B	Primary + Secondary (P + Q) (ksi)*	38.39	50.30
	Fatigue	Cumulative Usage Factor	0.105	1.000
Pressurizer Spray	Level A/B	Primary + Secondary (P + Q) (ksi)*	84.96 (23.94)**	58.22
	Fatigue	Cumulative Usage Factor	0.825	1.000
Pressurizer Safety/ Relief Valve	Level A/B	Primary + Secondary (P + Q) (ksi)*	26.91	49.75
	Fatigue	Cumulative Usage Factor	0.034	1.000

* Primary stress acceptance criteria are met via the sizing calculations discussed in Section 2.1.

** Elastic analysis exceeds the allowable value of 3Sm, however, criteria for simplified elastic-plastic analysis are met, as shown by the value in parentheses.

Table 2-4: Limiting Stress Results for Weld Overlaid Hot Leg Nozzles

Nozzle	Load Combination	Type	Calculated	Allowable
Hot Leg Drain	Level A/B	Primary + Secondary (P + Q) (ksi)*	17.40	48.02
	Fatigue	Cumulative Usage Factor	0.052	1.000
Hot Leg Surge	Level A/B	Primary + Secondary (P + Q) (ksi)*	51.05 (24.58)**	49.75
	Fatigue	Cumulative Usage Factor	0.699	1.000
Hot Leg Shutdown Cooling	Level A/B	Primary + Secondary (P + Q) (ksi)*	34.82	50.74
	Fatigue	Cumulative Usage Factor	0.023	1.000

* Primary stress acceptance criteria are met via the sizing calculations discussed in Section 2.1.

** Elastic analysis exceeds the allowable value of 3Sm, however, criteria for simplified elastic-plastic analysis are met, as shown by the value in parentheses.

2.3 Residual Stress and Section XI Crack Growth Analyses

Weld residual stresses for the nozzle weld overlays were determined by detailed elastic-plastic finite element analyses. The analysis approach has been previously documented to provide predictions of weld residual stresses that are in reasonable agreement with experimental measurements [8]. Two-dimensional, axisymmetric finite element models were developed for each of the nozzle configurations. Modeling of weld nuggets used in the analysis to lump the combined effects of several weld beads is illustrated in Figure 2-3. The models simulated an inside surface (ID) repair at the DMW location with a depth of approximately 50% of the original wall thickness. This assumption is considered to conservatively bound any weld repairs that may have been performed during plant construction from the standpoint of producing tensile residual stresses on the ID of the weld.

An analysis is performed to simulate the welding process of the ID weld repair, the safe end-to-pipe/elbow weld, the overlay welding process, and finally, a slow heatup to operating temperature. The analysis consists of a thermal pass to determine the temperature response of the model to each individual lumped weld nugget as it is added in sequence, followed by a non-linear elastic-plastic stress pass to calculate the residual stress due to the temperature cycling from the application of each lumped weld pass. Since residual stress is a function of the welding history, the stress pass for each nugget is applied to the residual stress field induced from all previously applied weld nuggets.

After completion of the weld overlay simulation, the model was allowed to cool to a uniform steady state temperature of 70°F, and then heated up to the operating temperature; a corresponding operating pressure is also applied to obtain the residual stresses at operating conditions.

The resulting residual stresses were evaluated on the inside surface of the original welds and safe-end components, as well as on several typical paths (Figure 2-4) through the DMWs and stainless steel welds (if applicable). Note that PWSCC susceptible regions are marked by solid vertical lines in the inside surface stress plots shown in Figure 2-5 for the DMW.

The residual stress calculations were then utilized, along with stresses due to applied loadings and thermal transients, to demonstrate that assumed cracks that could be missed by inspections will not exceed the overlay design basis during the ASME Code, Section XI inservice inspection interval due to fatigue or PWSCC. In the fatigue crack growth analyses, the 40-year design quantity of each applied transient was assumed to be applied since this quantity was considered applicable to the extended operating life of 60 years. Since the examination volume for the PDI qualified post-overlay UT examinations includes the weld overlay thickness plus the outer 25% of the original wall thickness, an inside surface connected flaw that is 75% of the original weld thickness is assumed as the largest flaw that could escape detection by this examination. Thus, crack growth is computed assuming an initial flaw depth of 75% of the original weld thickness. The amount of time it takes for the flaw to reach the base material/overlay interface, or grow into the overlay without violating overlay design basis thickness, is then calculated. The crack growth results are shown in Table 2-5 for the pressurizer nozzles, and in Table 2-6 for the hot leg nozzles.

For crack growth due to PWSCC, the total sustained stress intensity factor during normal steady state plant operating conditions was determined as a function of assumed crack depth, considering internal pressure stresses, residual stresses, steady state thermal stresses, and stresses due to sustained piping loads (including deadweight). Zero PWSCC growth is predicted for assumed crack depths at which the combined stress intensity factor due to sustained steady state operating conditions is less than zero.

Table 2-5: Crack Growth Results - Pressurizer Nozzles

Flaw(1)	**Time to Reach Overlay**		
	Pressurizer Surge Nozzle	**Pressurizer Spray Nozzle**	**Pressurizer Safety/Relief Valve Nozzle**
Circumferential (DMW)	>60 years	53 years	>40 years
Axial (DMW)	>60 years	37 years	10 years (2)
Circumferential (SSW)	54 years	19 years	NA
Axial (SSW)	>60 years	47 years	NA

Notes: 1. DMW = Dissimilar metal weld; SSW = Stainless steel weld.
2. Flaw is grown into overlay.

Table 2-6: Crack Growth Results - Hot Leg Nozzles

Flaw(1)	**Time to Reach Overlay**		
	Hot Leg Drain Nozzle	**Hot Leg Surge Nozzle**	**Hot Leg Shutdown Cooling Nozzle**
Circumferential (DMW)	>60 years	28 years	>60 years
Axial (DMW)	>60 years	>60 years	>60 years
Circumferential (SSW)	>60 years	16 years	49 years
Axial (SSW)	>60 years	13 years	>60 years

Note: 1. DMW = Dissimilar metal weld; SSW = Stainless steel weld.

2.4 Evaluation of As-Built Conditions

The Relief Request [2] and Code Case N-740 [3] require evaluation of the as-built weld overlays to determine 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. These evaluations will be performed and documented separately from this report and will include the effects of the disposition of any non-conformances that occurred during weld overlay installation. In anticipation of the required as-built evaluations, calculations were performed based on design dimensions to confirm that the overlays would not adversely affect critical piping components. Specifically, the predicted axial and radial shrinkage effects of the overlays on the thermal sleeves attached to the pressurizer surge, pressurizer spray, and hot leg surge nozzles, based on design dimensions and conservative shrinkage assumptions, were evaluated and found to be acceptable. Also, the effect of the added weight of the overlays on the adjacent piping systems, based on maximum design dimensions, was evaluated and found to be insignificant.

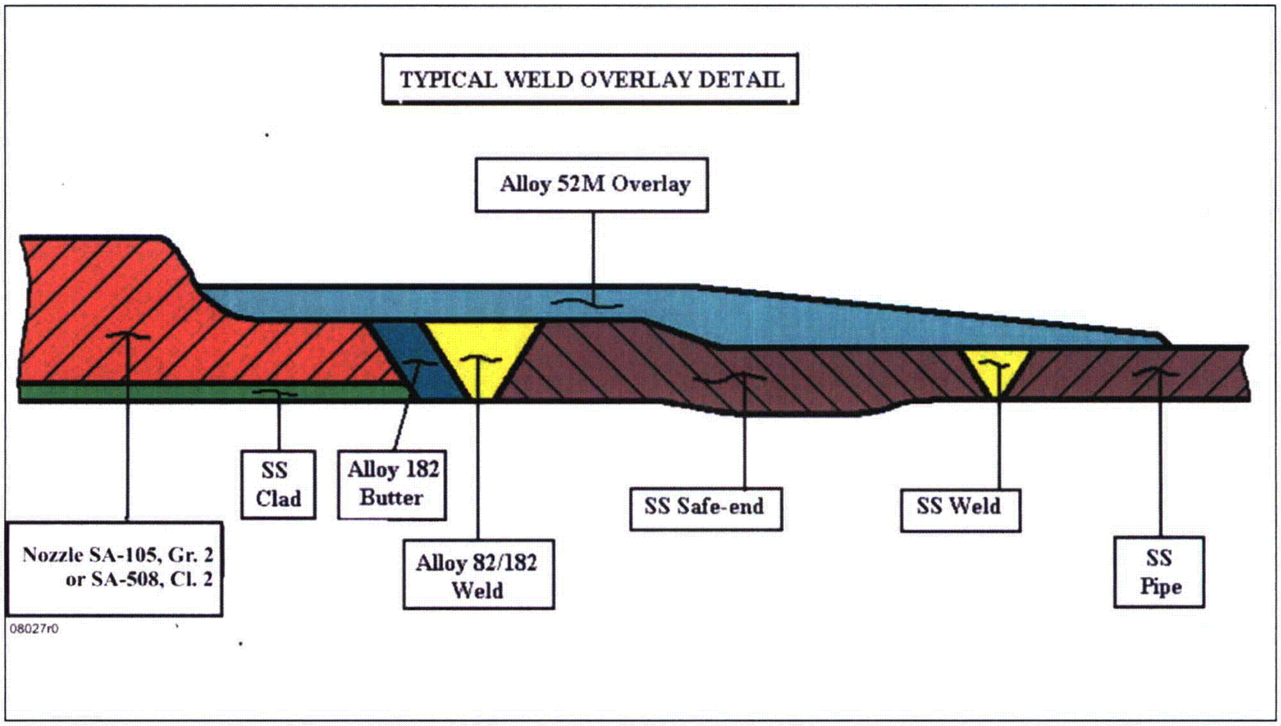


Figure 2-1: Illustration of Typical Weld Overlay Design

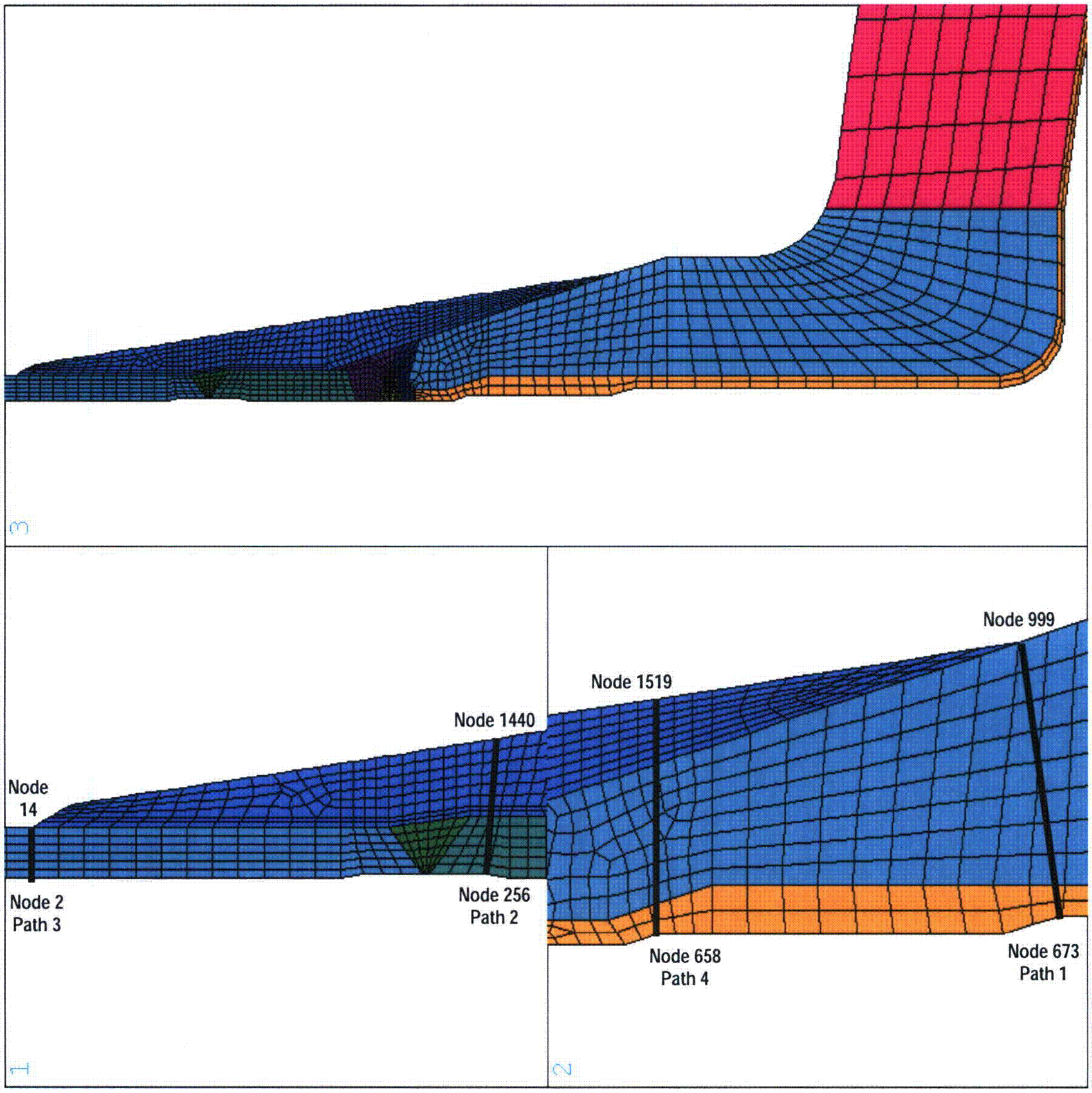


Figure 2-2: Typical Finite Element Model for Section III Stress Evaluation showing Stress Paths

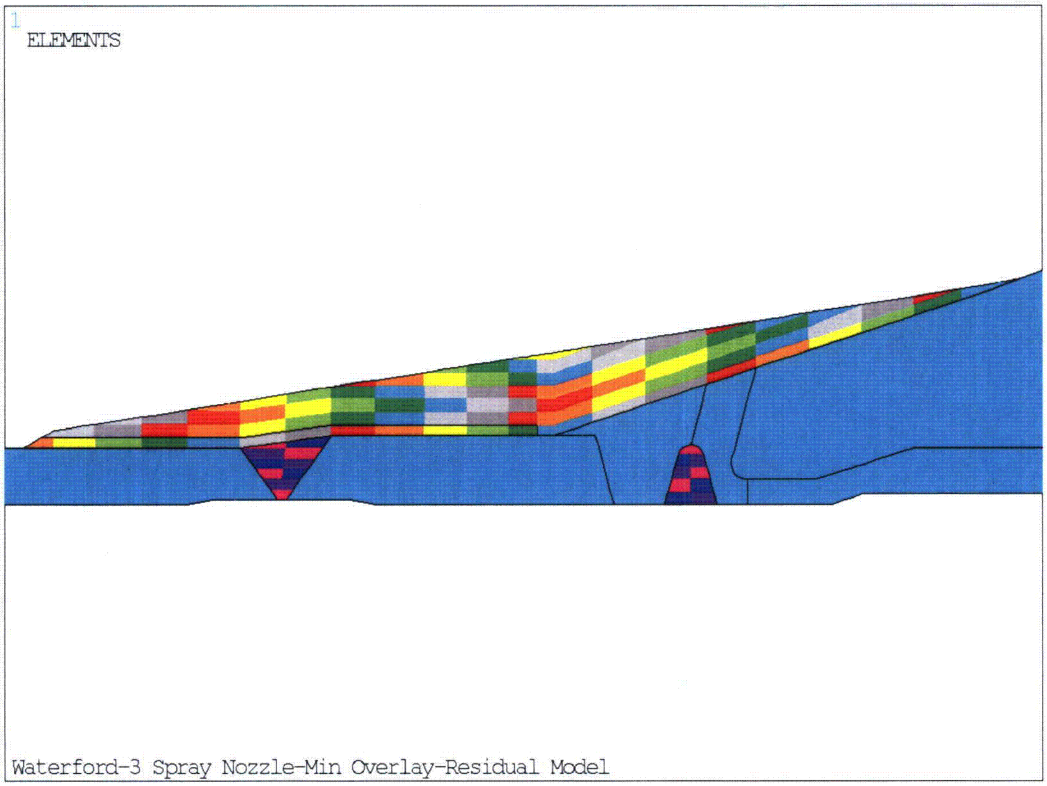


Figure 2-3: Typical Finite Element Model for Residual Stress Analysis showing Nuggets used for Welding Simulations

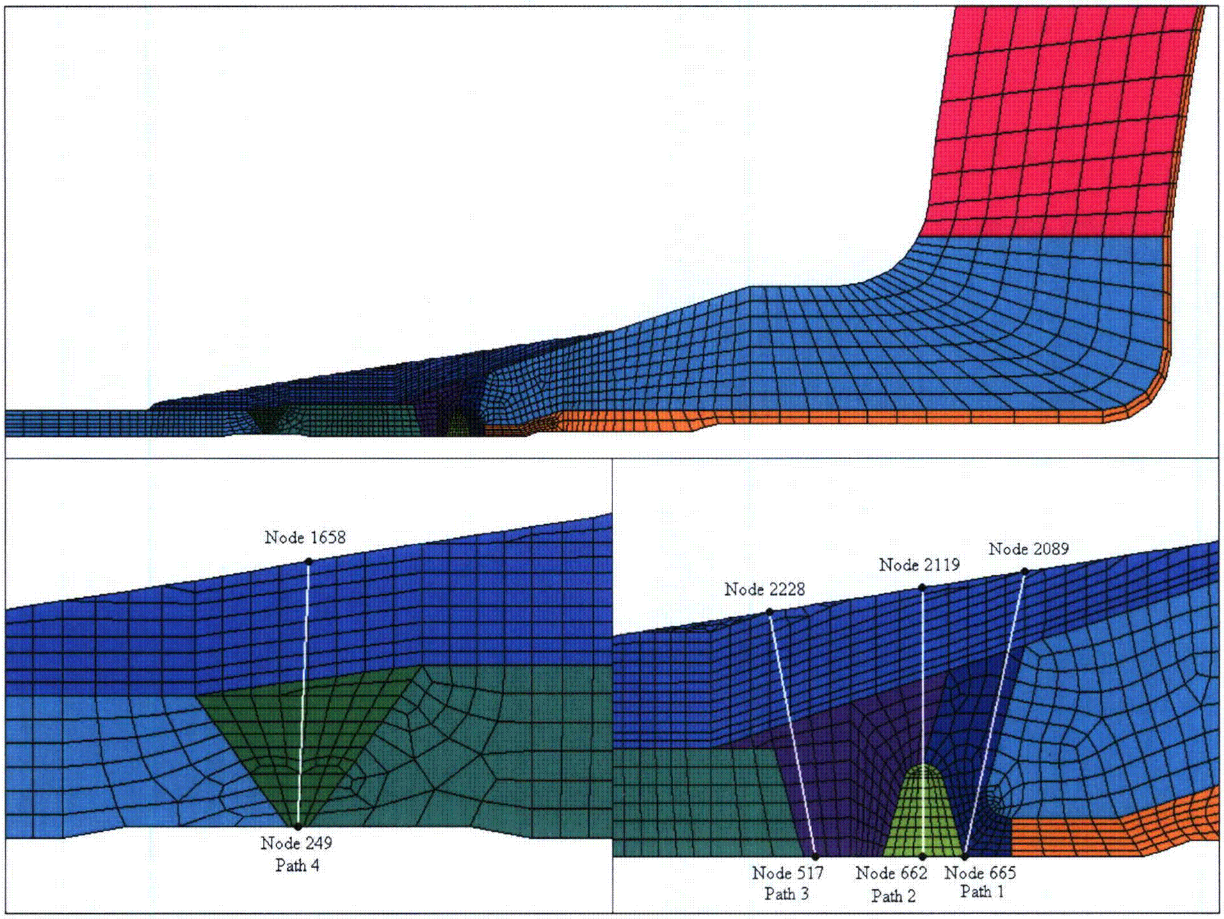
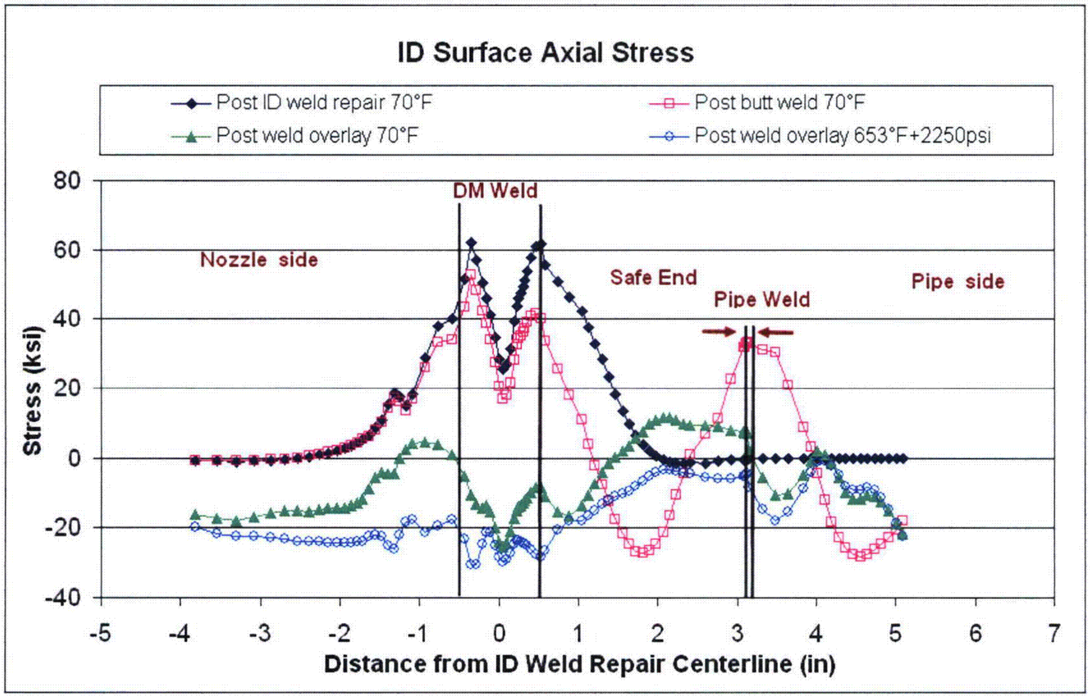


Figure 2-4: Typical Finite Element Model for Residual Stress Analysis showing Stress Paths



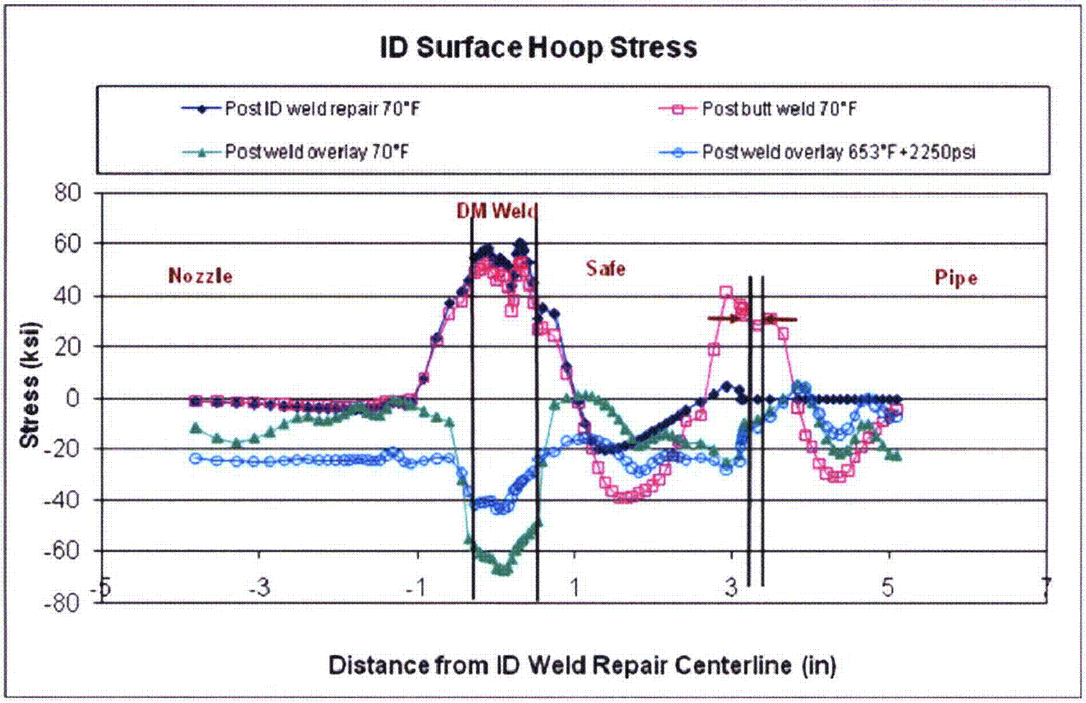


Figure 2-5: Typical Residual Stress Results along Inside Surface of Original Butt Welds and Safe-End

3.0 Conclusions

The design of the Waterford Steam Electric Station, Unit 3 weld overlays was performed in accordance with the requirements of the Relief Request [2], which is based on ASME Code Case N-740 [3]. The weld overlays are demonstrated to provide long-term mitigation of PWSCC in these welds based on the following:

- In accordance with the Relief Request [2], structural design of the overlays was performed to meet the requirements of ASME Section XI, IWB-3640 based on an assumed flaw 100% through and 360° around the original welds. The resulting full structural overlays thus restore the original safety margins of the nozzles, with no credit taken for the underlying, PWSCC-susceptible material.
- The weld metal used for the overlay is Alloy 52M, which has been shown to be resistant to PWSCC [1], thus providing a PWSCC resistant barrier. Therefore, PWSCC crack growth into the overlay is expected to be small. There is a potential for crack growth into the overlay due to fatigue and PWSCC for the postulated axial flaw in the pressurizer safety/relief valve nozzle DMW.
- Application of the weld overlays was shown to not impact the conclusions of the existing nozzle stress reports. Following application of the overlay, all ASME Code, Section III stress and fatigue criteria are met.
- Nozzle-specific residual stress analyses were performed, after first simulating severe ID weld repairs in the nozzle-to-safe-end welds, prior to applying the weld overlays. The post weld overlay residual stresses were shown to result in beneficial compressive stresses on the inside surface of the components, and well into the thickness of the original DMWs, except in certain limited cases, assuring that future PWSCC initiation or crack growth into the overlay is highly unlikely or at worst for certain cases, limited.
- Fracture mechanics analyses were performed to determine the amount of future crack growth which would be predicted in the nozzles, assuming that cracks exist that are equal to or greater than the thresholds of the NDE techniques used on the nozzles. Both fatigue and PWSCC crack growth were considered, and found to be acceptable.

Based on the above observations and the fact that similar nozzle-to-safe end weld overlays have been applied to other plants since 1986 with no subsequent problems identified, it is concluded that the Waterford Steam Electric Station, Unit 3 pressurizer surge, pressurizer spray, pressurizer safety/relief valve, hot leg surge, hot leg shutdown cooling, and hot leg drain nozzle dissimilar metal welds have received long term mitigation against PWSCC.

4.0 References

1. "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.
2. Revised Request for Alternative W3-R&R-006 - Proposed Alternative to ASME Code Requirements for Weld Overlay Repairs, Waterford Steam Electric Station Unit 3, Docket No. 50-382, License No. NPF-38.
3. ASME Boiler and Pressure Vessel Code, Code Case N-740, "Dissimilar Metal Weld Overlay for Repair of Class 1, 2, and 3 Items, Section XI, Division 1."
4. ASME Boiler and Pressure Vessel Code, Section XI, 1992 Edition.
5. ASME Boiler and Pressure Vessel Code, Section III, 2001 Edition with Addenda through 2003.
6. **pc-CRACK** for Windows, Version 3.1-98348, Structural Integrity Associates, 1998.
7. ANSYS/Mechanical, Release 8.1 (w/Service Pack 1), ANSYS Inc., June 2004.
8. "Materials Reliability Program (MRP): Technical Basis for Preemptive Weld Overlays for Alloy 82/182 Butt Welds in PWRs (MRP-169)," EPRI, Palo Alto, CA, and Structural Integrity Associates, Inc., San Jose, CA. September 2005. 1012843.