Report No. 0800368.407
Revision 0
Project No. 0800368
June 2010

Summary of Design and Analyses of Weld Overlays for Reactor Coolant Pump Suction and Discharge, Cold Leg Drain, and Core Flood Nozzle Dissimilar Metal Welds for Alloy 600 Primary Water Stress Corrosion Cracking Mitigation

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REVISION CONTROL SHEET

Document Number: **0800368.407**

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Client: WSI/ FirstEnergy Nuclear Operating Company (FENOC)

SI Project Number: **0800368** Quality Program: ☒ Nuclear ☐ Commercial

Section	Pages	Revision	Date	Comments
1.0	1-1 – 1-3	0	6/4/10	Initial Issue
2.0	2-1 – 2-18			
3.0	3-1 – 3-2			
4.0	4-1 – 4-2			

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1.0 INTRODUCTION

FirstEnergy Nuclear Operating Company (FENOC) has applied preemptive Full Structural Weld Overlays (FSWOLs) and preemptive Optimized Weld Overlays (OWOLs) at the Davis-Besse Nuclear Power Station (Davis-Besse) on Alloy 600 dissimilar metal butt welds (DMWs) of the components identified below to eliminate or reduce dependence upon the Alloy 82/182 welds as pressure boundary welds, and to mitigate any potential primary water stress corrosion cracking (PWSCC) in these welds in the future.

This report, which satisfies FENOC Commitments No. 1 and 2 of the Relief Requests [1-4], summarizes the results of the nozzle specific residual stress analyses and the fracture mechanics evaluations, documents that all ASME Code, Section III allowables are met, and presents the leak-before-break (LBB) results. This information is to be submitted prior to entry into Mode 4 following completion of the overlays.

This report summarizes the evaluations of FSWOL designs for four reactor coolant pump (RCP) suction nozzles, three RCP cold leg drain nozzles, and two reactor pressure vessel core flood nozzles. In addition, evaluations of OWOL designs for four reactor coolant pump (RCP) discharge nozzles are summarized. The purpose of these overlays is to eliminate or reduce 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 were installed using a PWSCC resistant weld filler material, Alloy 52M [9].

The requirements for design of weld overlay (WOL) repairs are defined in 10 CFR 50.55a Requests RR-A32 and RR-A33, with supplements [1-4], as approved in Nuclear Regulatory Commission (NRC) safety evaluations [5, 6]. The basis for FSWOLs is ASME Code Case N-740-2 [7], and for OWOLs the basis is Code Case N-740-2 [7] and MRP-169, Revision 1 [8]. The 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 either full structural weld overlays or optimized weld overlays.

The design basis flaw assumption for full structural weld overlays is a circumferentially oriented flaw that extends 360 degrees around the component; that is, completely through the original component wall thickness. The circumferential flaw bounds all postulated axial flaws, given that a through-wall full length (width of susceptible weldment) axial flaw does not result in complete severing of the pipe, as is the case for a circumferential flaw.

The design basis flaw assumption for optimized weld overlays is a circumferentially oriented flaw that extends 360 degrees around the component; that is, 75 percent through the original component wall thickness. This assumption allows for crediting the outer 25 percent of the original wall for structural capacity.

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 [10].

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 applicable ASME Code-of-Record for the RCP suction and discharge nozzles is the ASME Code, Section III [13], and for the attached piping is USAS B31.7, Class 1 for the design [14]. For the cold leg drain nozzle, the applicable ASME Code-of-Record for the nozzles is USAS B31.7, Class 1 [14], and for the attached piping is the ASME Code, Section III, Class 1 [15]. The applicable ASME Code-of-Record for the core flood nozzle is the ASME Code, Section III, 1968 Edition including Summer 1968 Addenda [16], and for the attached piping is the ASME Code, Section III, Class 1 [15]. However, as allowed by ASME Code, 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 [11] was used for all these analyses, as specified in the Relief Requests [1-4].

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

As part of the project workscope prior to WOL implementation, the design scope included analysis of both a FSWOL and an OWOL for the RCP discharge nozzle. The FSWOL design was prepared and analyzed as a contingency; should the pre-WOL examination have identified flaws that exceeded the acceptance criteria for implementing an OWOL, a FSWOL could then be installed. The results of the pre-WOL examinations were that no flaws were identified that exceeded the OWOL criteria, and therefore an OWOL was implemented on all RCP four discharge nozzles. Thus, this report will include only a summary of the OWOL design for the RCP discharge nozzle.

2.0 ANALYSIS SUMMARY AND RESULTS - WELD OVERLAYS

2.1 Full Structural Weld Overlay Structural Sizing Calculations

Detailed sizing calculations for weld overlay thickness for the FSWOL were performed using the ASME Code, Section XI, IWB-3640 [10] evaluation methodology. Loads and stress combinations were provided by FENOC. Loads were based on a review of each of the affected piping systems, and the selected loads bound the nozzles of a specific type. Normal operating (Level A), Upset (Level B), Emergency (Level C, and Faulted (Level D) 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 reactor coolant pump suction nozzles and in Table 2-2 for the core flood and cold leg drain nozzles.

As stated in Section 1.0, preemptive weld overlays were to have been installed using Alloy 52M filler metal directly over the underlying base material. However, Alloy 52M weld metal has demonstrated sensitivity to certain impurities, such as sulfur and silicon, when deposited onto austenitic stainless steel base materials. Therefore, a buffer (transitional) layer(s) of austenitic stainless steel filler metal were applied across the nozzle/safe end/elbow 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) residual stress improvement. In accordance with the relief requests [1-4] and the referenced ASME Code Case N-740-2 [7], the minimum weld overlay length required for structural reinforcement was established by evaluating the axial-radial shear stress due to transfer of primary axial loads from the base metal (nozzle/safe end) into the overlay and back into the base metal (elbow/safe end), on either side of the weld 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 also summarized in Table 2-1 for the reactor coolant pump suction nozzle and in Table 2-2 for the core flood and cold leg drain 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. The weld overlay design for the core flood nozzles is illustrated in Figure 2-1. The design thickness and length specified on the design drawings bound the calculated minimum values, and may be greater to facilitate desired geometry for examination.

Table 2-1: Full Structural Weld Overlay Minimum Thickness and Length Requirements
RCP Suction Nozzles

Item	Location	28 inch ID RCP Suction Nozzle
Minimum Thickness (in.)	Nozzle Side	1.117"
	Elbow Side	1.117"
Minimum* Length (in.)	Nozzle Side	3.19"
	Elbow Side	2.80"

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

Table 2-2: Full Structural Weld Overlay Minimum Thickness and Length Requirements
Cold Leg Drain and Core Flood Nozzles

Item	Location	Cold Leg Drain Nozzle	Core Flood Nozzle
Minimum Thickness (in.)	Nozzle Side	0.167"	0.563"
	Safe End Side	NA	0.563"
	Elbow Side	0.167"	NA
Minimum* Length (in.)	Nozzle Side	0.407"	1.092"
	Safe End Side	NA	1.533"
	Elbow Side	0.516"	NA

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

2.2 Optimized Weld Overlay Structural Sizing Calculations

The basis for sizing an optimized weld overlay (OWOL) is to utilize the outer 25 percent of the existing weld and base metal thickness and to provide sufficient material over the existing weld and base metal such that the remaining flaw beneath the weld overlay and outer 25 percent of the existing weld is sufficient to meet ASME Code, Section XI Appendix C flaw acceptance criteria. Detailed sizing calculations for weld overlay thickness for the OWOL were performed using the ASME Code, Section XI, IWB-3640 [10] evaluation and MRP-169, Revision 1 [8] methodology. Loads and stress combinations were provided by FENOC. Loads were based on a review of each of the affected piping systems, and the selected loads bound the nozzles of a specific type. Normal operating (Level A), Upset (Level B), Emergency (Level C, and Faulted (Level D) 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 2-3 for the reactor coolant pump discharge nozzles.

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) residual stress improvement. In accordance with the relief requests [1-4] and the referenced ASME Code Case N-740-2 [7], the minimum weld overlay length required for structural reinforcement was established by evaluating the axial-radial shear stress due to transfer of primary axial loads from the elbow into the overlay and back into the safe end, on either side of the weld 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. For conservatism the calculation of shear length for the OWOL did not credit load transfer through the outer 25 percent of the base material, only through the overlay. The resulting minimum length requirements are also summarized in Table 2-3 for the reactor coolant pump discharge nozzles.

The OWOL 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. The OWOL design for the reactor coolant pump discharge nozzles is illustrated in Figure 2-2. The design thickness and length specified on the design drawings bound the calculated minimum values, and may be greater to facilitate desired geometry for examination.

Table 2-3: Optimized Weld Overlay Minimum Thickness and Length Requirements

RCP Discharge Nozzles

Item	Location	28 inch ID RCP Discharge Nozzle
Minimum Thickness (in.)	Safe End Side	0.380”
	Elbow Side	0.654”
Minimum* Length (in.)	Safe End Side	3.993”
	Elbow Side	3.459”

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

2.3 ASME Code, Section III Stress Analyses

Stress intensities for all weld overlay designs for the FSWOL and OWOL nozzles were determined from finite element analyses for the various specified load combinations and transients using the ANSYS software package [12a and 12b]. Linearized stresses were evaluated at various stress locations using 3-dimensional solid models. A typical finite element model showing stress path locations is provided in Figure 2-3a. The stress intensities at these locations were evaluated in accordance with ASME Code, Section III, Sub-articles NB-3200 and NB-3600 [11], and compared to applicable Code limits.

The WOL boundary of jurisdiction is based on NB-1131 [11]. The RCP suction and discharge nozzles are treated as integral with the pump, and their WOL evaluations utilize the vessel rules of NB-3200, as referenced in the pump design Subarticle NB-3400 [11]. The drain nozzles are part of the cold leg piping and their WOL evaluation utilizes the piping rules of NB-3600 [11]. Those portions of the core flood WOL inboard of the DMW (first circumferential weld) are evaluated using the vessel rules of NB-3200 [11], and the remaining portions of the WOL, although piping components, are conservatively evaluated using the same vessel rules of NB-3200 [11].

A summary of the stress and fatigue usage comparisons for the most limiting locations is provided in Table 2-4. The stresses and fatigue usage in the weld overlaid nozzles are within the applicable ASME Code limits.

Table 2-4: Limiting ASME Code, Section III Stress Results for Weld Overlaid Nozzles

	Load Combination	**Type**	**Calculated**	**Allowable**
RCP Suction FSWOL	Level A/B	Primary + Secondary (P +Q) (ksi)[a]	31.83	52.161
	Fatigue	Cumulative Usage Factor	0.147	1.000
RCP Discharge OWOL	Level A/B	Primary + Secondary (P +Q) (ksi)[a]	43.936	51.950
	Fatigue	Cumulative Usage Factor	0.346	1.000
Core Flood FSWOL	Level A/B	Primary + Secondary (P +Q) (ksi)[a]	34.717	50.592
	Fatigue	Cumulative Usage Factor	0.078	1.000
Cold Leg Drain FSWOL	Level A/B	Primary + Secondary (P +Q) (ksi)[a]	78.122 (53.262)[b]	55.935
	Fatigue	Cumulative Usage Factor	0.888	1.000

(a) Primary stress acceptance criteria are met via the sizing calculations discussed in Sections 2.1 and 2.2; ksi = kips per square inch.

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

2.4 Residual Stress 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]. Both two-dimensional axisymmetric and three-dimensional finite element models were developed for the nozzles. Modeling of weld nuggets was typically used in the analysis to lump the combined effects of several weld beads as illustrated in Figure 2-4. The models simulated an inside surface (ID) repair at the DMW location with a depth of approximately 50 percent of the original wall thickness (25 percent for the RCP weld overlays) and 360 degrees around the component. 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, any connecting weldments, the overlay welding process, and finally, a slow heatup to operating temperature. The residual stress analysis approach 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 an elastic-plastic stress pass to calculate the residual stresses due to the temperature cycling from the application of each nugget. Since residual stresses are a function of welding history, the stress passes for each nugget are performed sequentially, over the residual stress fields 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 degrees Fahrenheit (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 weld and nozzle/safe-end/elbow, as well as on several typical paths through the DMW. Typical path definitions for the crack growth evaluations are shown in Figure 2-3b, and the resulting residual ID stresses are shown in Figures 2-5a and 2-5b. Note that PWSCC susceptible regions are marked by solid vertical lines in the inside surface stress plots shown in Figures 2-5a and 2-5b for the DMW.

2.5 Crack Growth Analyses

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 Section XI inservice inspection interval due to fatigue or PWSCC (or both). In the fatigue crack growth analyses, the 60 year design quantity of cycles for each applied transient was assumed to be applied.

The OWOL and FSWOL have two different examination volumes. In the case of the FSWOL, the exam volume for the PDI qualified post-overlay ultrasonic testing (UT) inspections includes the weld overlay plus the outer 25 percent of the original wall thickness, for both axial and circumferential flaws. In the case of the OWOL, the exam volume for the PDI qualified post-overlay UT inspections includes the weld overlay plus the outer 50 percent of the original wall thickness for circumferential flaws, and the weld overlay plus the outer 25 percent of the original wall thickness for axial flaws.

Therefore, for the FSWOL, an inside surface connected flaw that is 75 percent 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 percent of the original wall thickness. The amount of time it takes for the flaw to reach the base metal/overlay interface is then calculated. In the case of the OWOL, an inside surface connected circumferential flaw that is 50 percent of the original weld thickness and an inside surface connected axial flaw that is 75 percent of the original weld thickness, are assumed as the largest flaws that could escape detection by this examination. Crack growth is computed assuming these initial flaw depths, and the amount of time it takes for the flaw to reach 75 percent flaw depth for circumferential flaws and no significant growth for axial flaws, is then calculated. The results are shown in Table 2-5.

For crack growth due to PWSCC, the total sustained stress intensity factor during normal plant operation 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

Flaw(1)	Time for Postulated Flaw to Reach Overlay			
	RCP Suction FSWOL	RCP Discharge OWOL	Core Flood FSWOL	Cold Leg Drain FSWOL
Circumferential (DMW)	> 16 years	~ 12 years	> 60 years	> 60 years
Axial (DMW)	> 14 years	> 30 years	> 60 years	~ 14 years (2)

Notes: 1. DMW = dissimilar metal weld.
2. Flaw is grown into overlay.

2.6 Leak-Before-Break Evaluation

The effect of applying weld overlay repairs on the DMWs of the RCP suction and discharge nozzles was evaluated. It has been shown that the application of the weld overlay results in residual stresses that are either significantly reduced or compressive at the inside surface and compressive in the inner portion of the dissimilar metal weld. These stresses will mitigate the effects of PWSCC in the Alloy 82/182 dissimilar metal weld. Furthermore, the use of highly resistant Alloy 52M weld metal, combined with improved inspection capability, will provide additional assurance that through-wall cracks cannot occur at the DMW locations. Crack growth evaluations performed as part of the evaluation indicated that combined PWSCC and fatigue crack growth for axial and circumferential postulated flaws is within acceptable limits for a 10-year inspection interval.

The evaluation was conducted using leak-before-break (LBB) assumptions similar to that used in the original B&W evaluation [17], modified slightly to account for the addition of the weld overlays. The evaluation has demonstrated that with the application of the weld overlay, the LBB margins required in SRP 3.6.3 [18a and 18b] and NUREG-1061, Vol. 3 [19] are maintained. In fact, the margin on flaw size at the 28 inch pipe/elbow DM welds and adjacent base materials is increased as compared to that accepted by the NRC in the original LBB submittal, from 2.2 to at least 2.80. The effect of the application of the weld overlay is to increase the critical flaw size, resulting in additional margin between the critical flaw size and the leakage flaw size, even though leakage tends to be reduced due to the longer flow path and considerations of crack morphology for the Alloy 82/182 weld location.

A range of weld overlay thicknesses was also evaluated, showing that the actual thickness attained during overlay application does not change the LBB behavior significantly. The results of the LBB evaluation, specifically the margins on critical flaw size, are shown in Table 2-6.

Table 2-6: Margin on Flaw Size in Welds and Base Materials

Crack Location	**RCP Suction FSWOL Design**		**RCP Discharge OWOL Design**		**Acceptance Criteria**
	@Min. WOL Thickness	**@Max. WOL Thickness**	**@Min. WOL Thickness**	**@Max. WOL Thickness**	
Nozzle/SE at Weld	4.60	4.59	5.54	5.38	2.00
Weld/Nozzle Side	2.90	2.90	2.85	2.87	2.00
Weld/Elbow Side	2.98	2.98	2.80	2.82	2.00
Elbow at Weld	4.29	4.30	3.89	4.02	2.00

Note: Margin parameter is the ratio of critical flaw size to the 10 gallon per minute leakage flaw size.

2.7 Evaluation of As-Built Conditions

The relief requests [1-4] and their referenced Code Case N-740-2 [7] 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 documented separately in the Final Design Report to be maintained by the Owner. In anticipation of the required as-built evaluations, calculations were performed based on maximum design dimensions to confirm that the overlays would not adversely affect critical piping components. 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.

The Design Report will also include the results of the final reconciliation of any nonconformances identified and dispositioned during implementation of the overlays. Each of the nonconformances dispositioned included a technical review and justification of the selected disposition demonstrating that all design and regulatory requirements were met. Closure of the nonconformances, including FENOC review and acceptance of the dispositions, was completed for all nonconformances.

2.8 Weld Overlay Examination

In accordance with the relief requests [1-4], the FSWOL and OWOL received both pre-overlay and post-overlay nondestructive examination of the base material and the overlay. All examinations were performed in accordance with relief request requirements, and all final examinations were satisfactory.

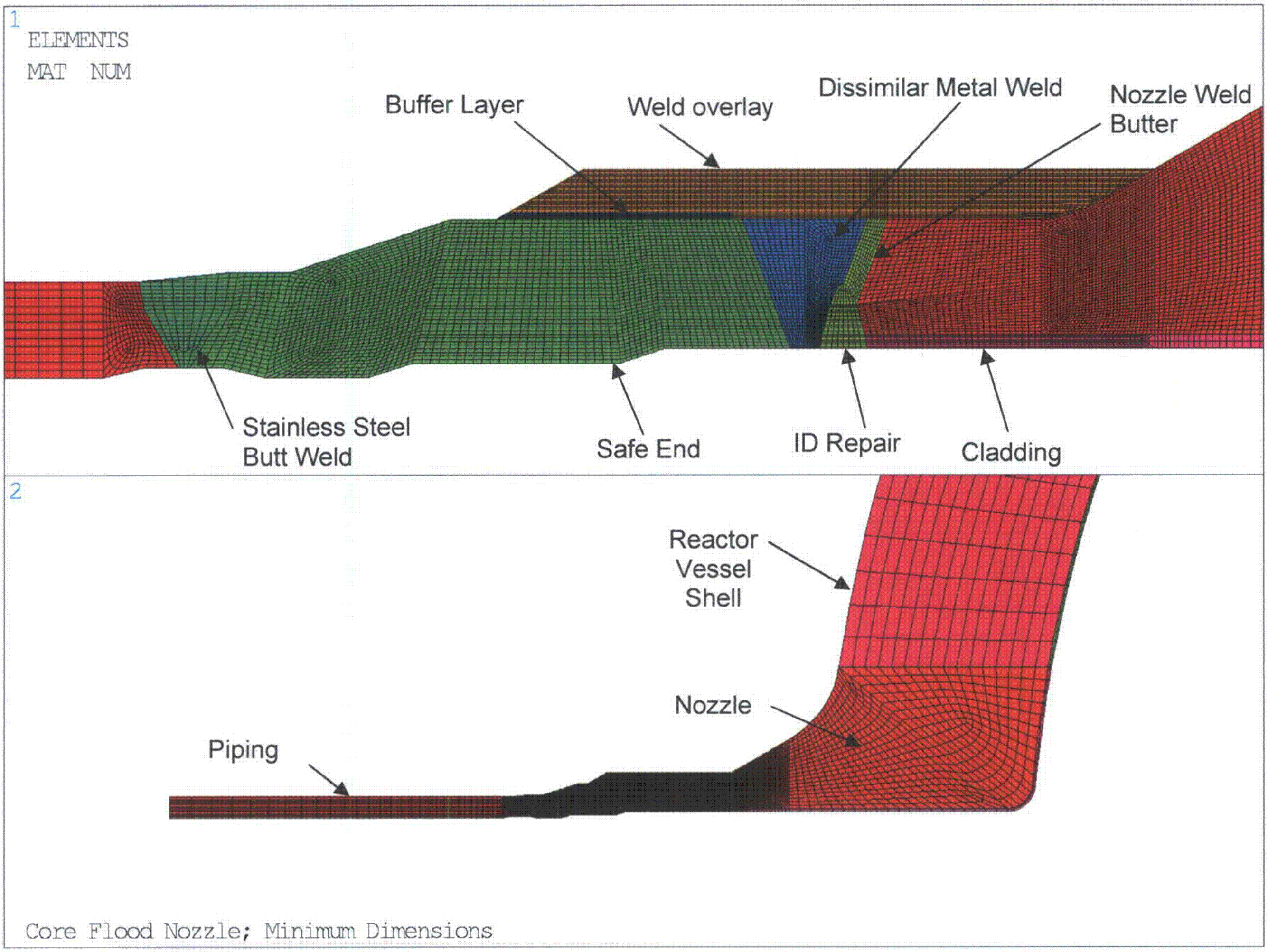
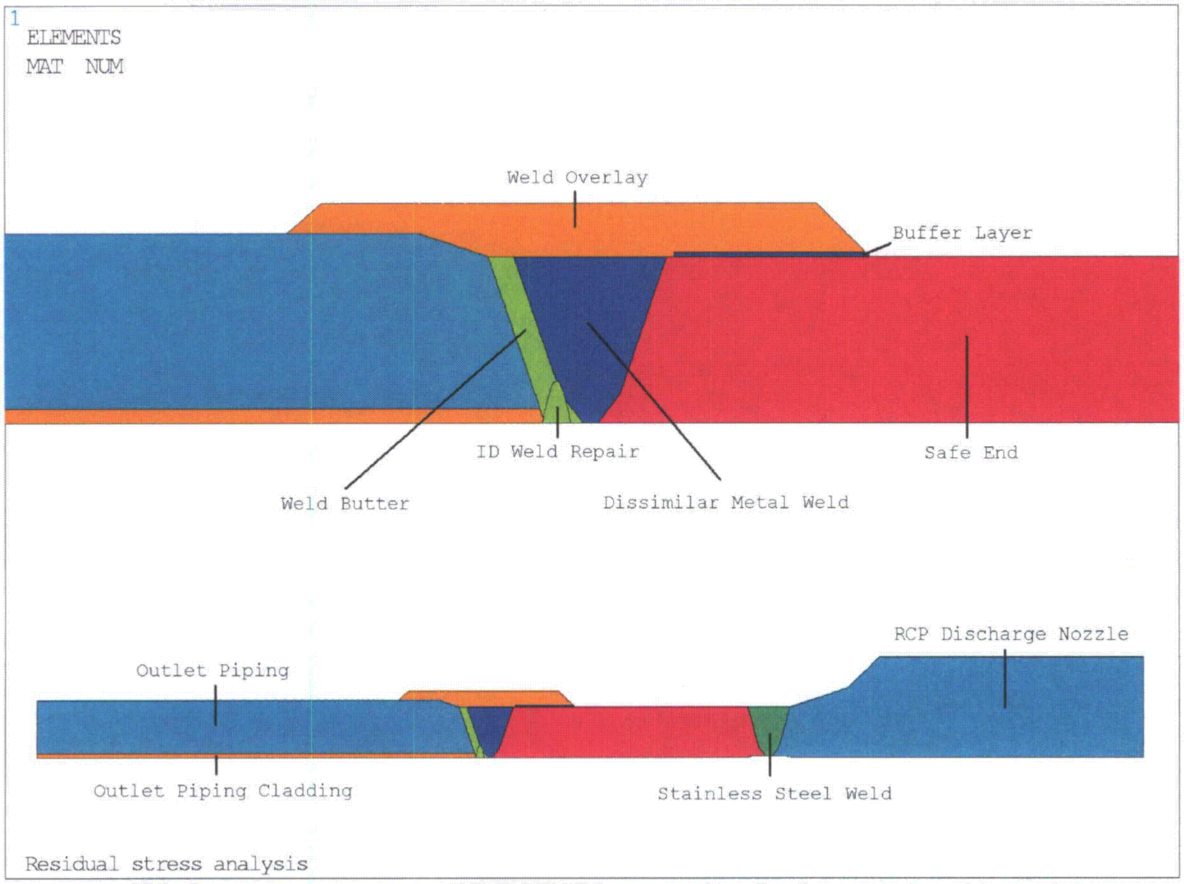


Figure 2-1: Illustration of Typical FSWOL Design



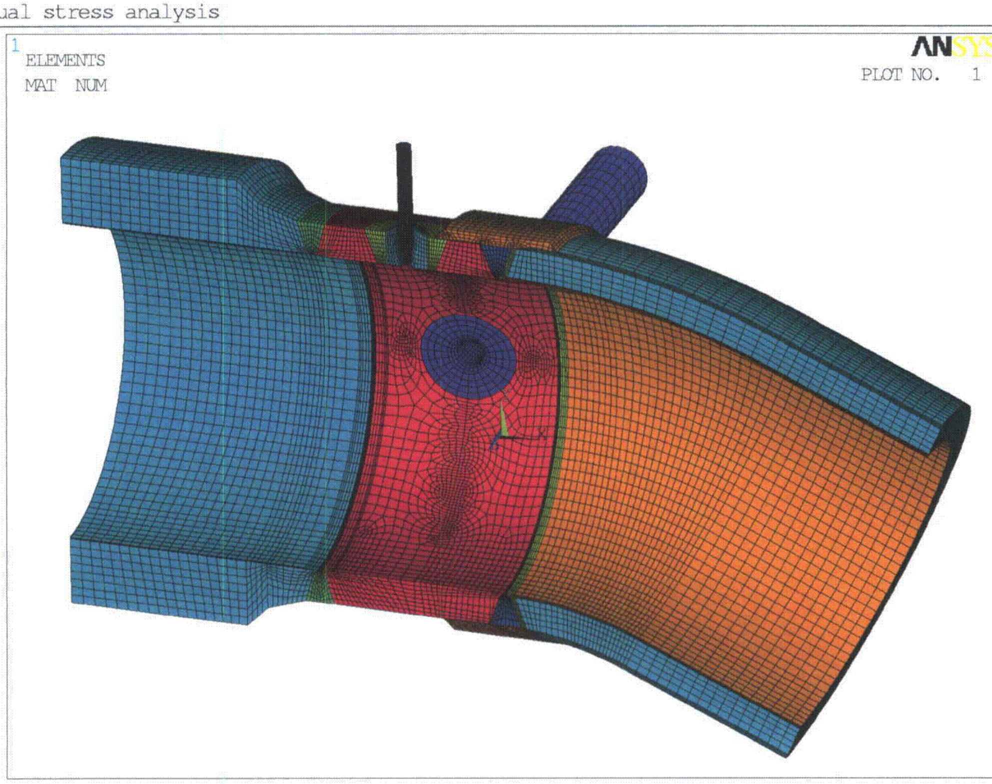


Figure 2-2: Illustration of OWOL Design for Davis-Besse RCP Discharge Nozzle

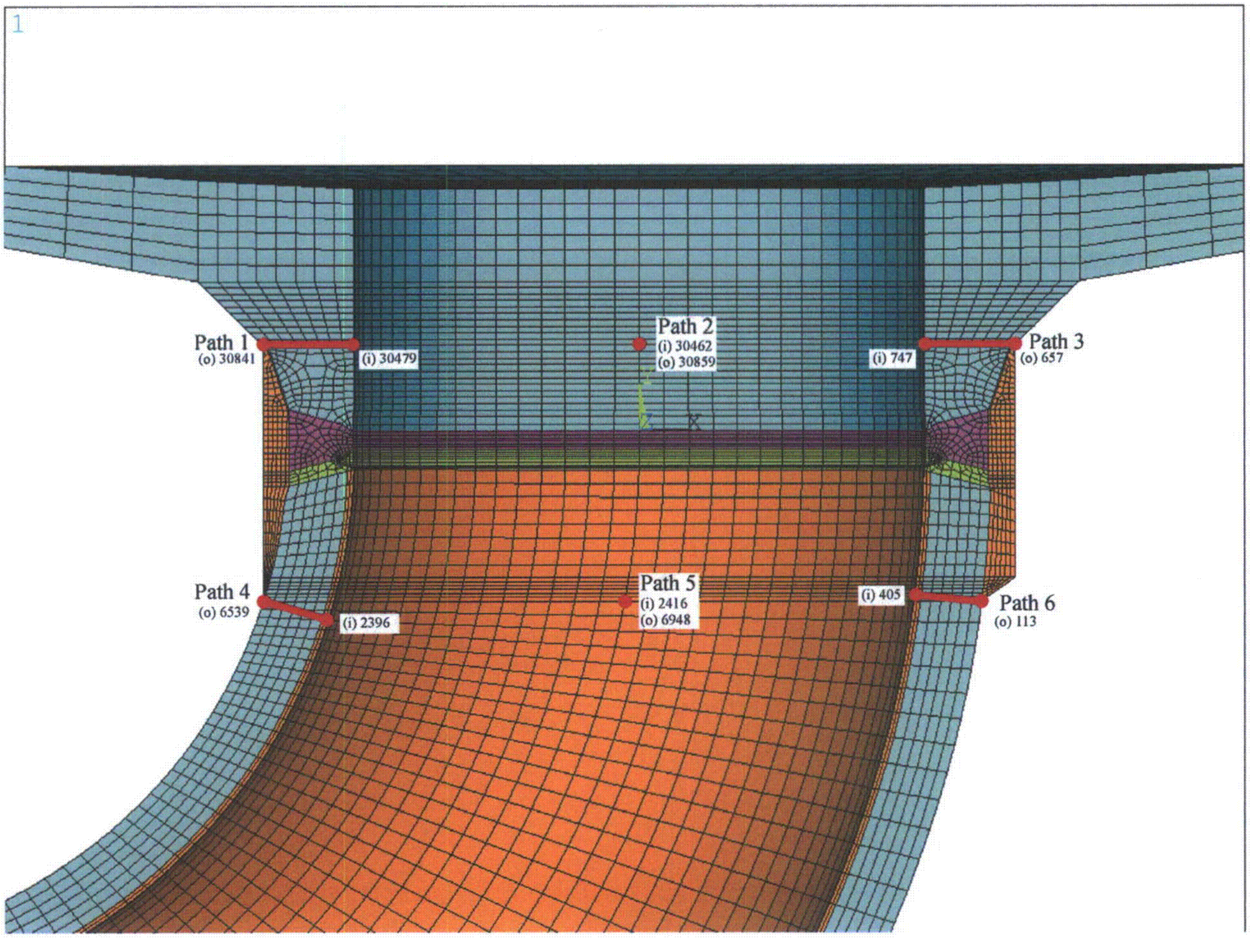


Figure 2-3a: Typical Finite Element Model for ASME Code, Section III Stress Evaluation showing Stress Paths

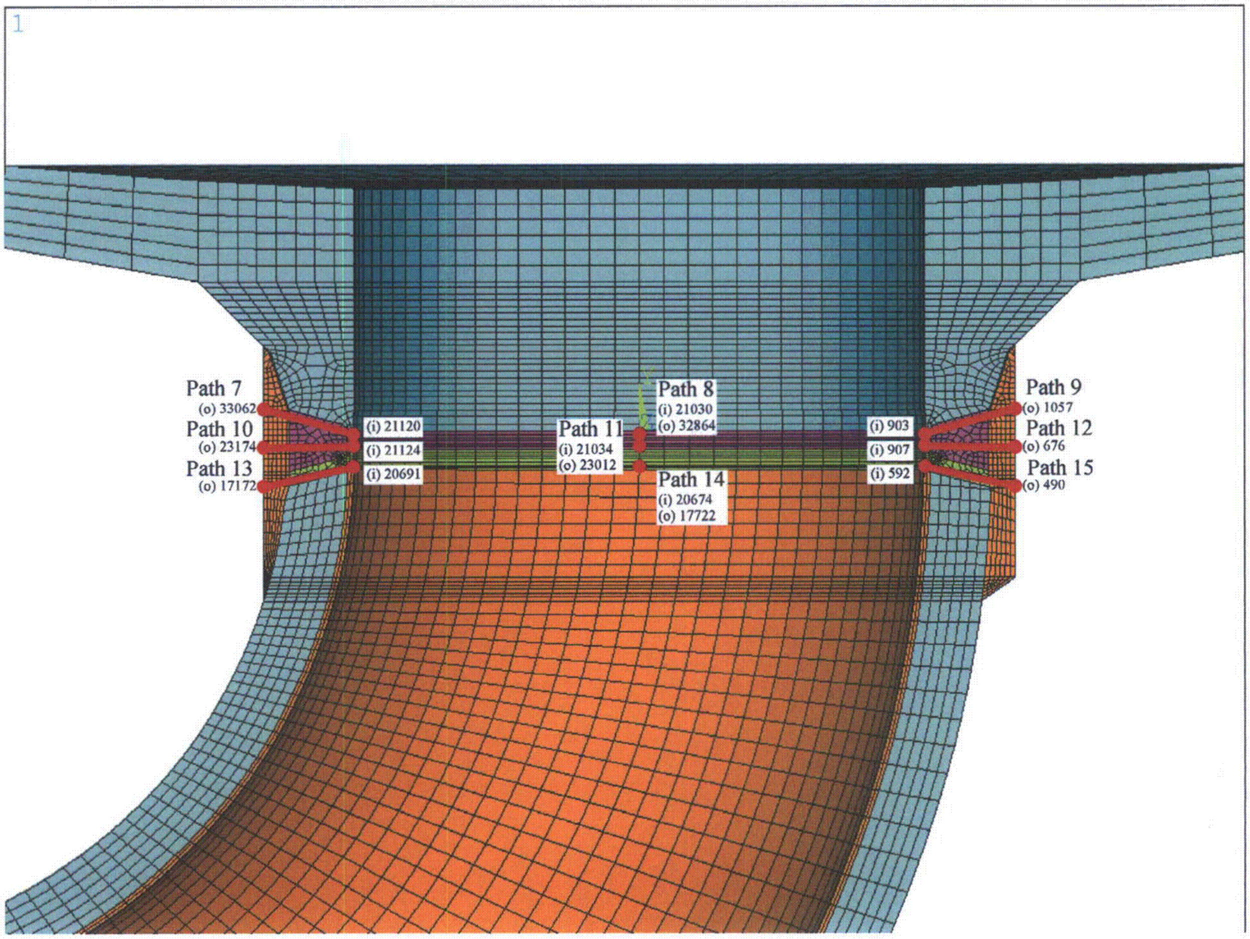


Figure 2-3b: Typical Finite Element Model for Residual Stress Analysis showing Stress Paths

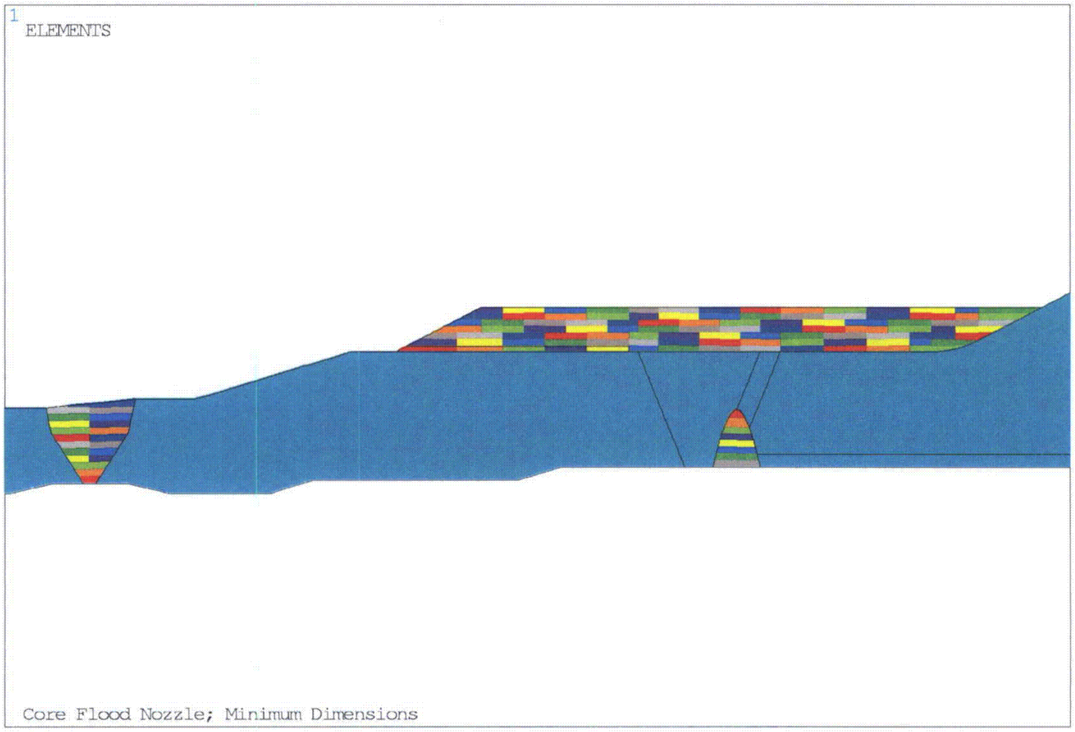


Figure 2-4: Typical Finite Element Model for Residual Stress Analysis showing Nuggets used for Welding Simulations

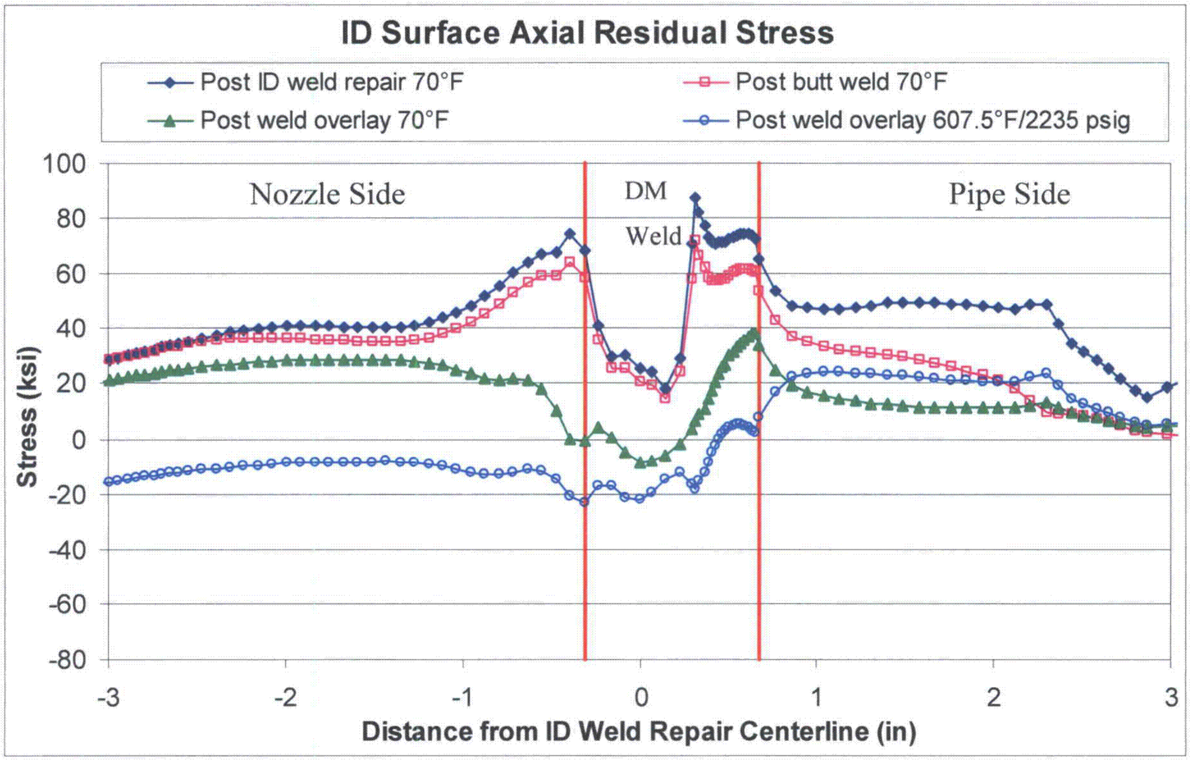


Figure 2-5a: Axial Residual Stress Results along Inside Surface of Original Butt Weld

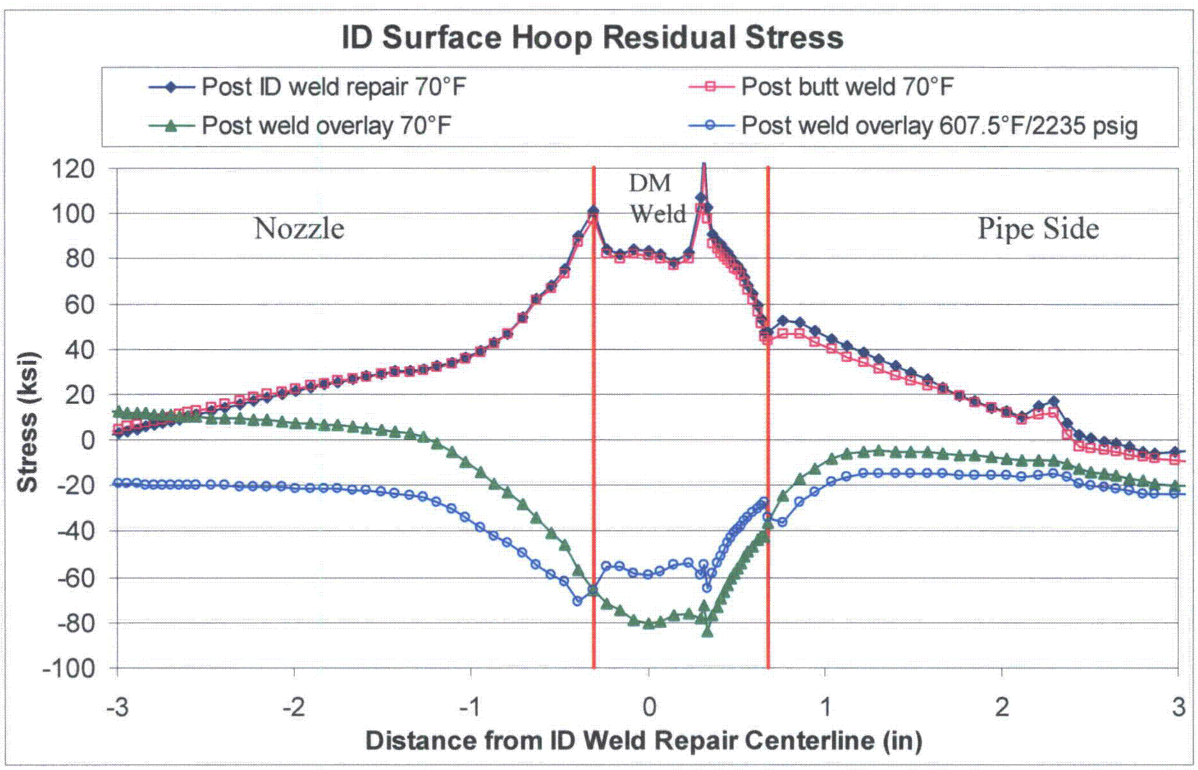


Figure 2-5b: Hoop Residual Stress Results along Inside Surface of Original Butt Weld

3.0 CONCLUSIONS

The design of the Davis-Besse Nuclear Power Station full structural and optimized weld overlays was performed in accordance with the requirements of the relief requests [1-4], which are based on ASME Code Case N-740-2 [7] for the FSWOL and N-740-2 [7] and MRP-169, Revision 1 [8] for the OWOL. The weld overlay designs have demonstrated to provide long-term mitigation of PWSCC in these welds based on the following:

- In accordance with the relief requests [1-4], structural design of the FSWOLs was performed to meet the requirements of ASME Code Section XI, IWB-3640 [10] based on an assumed circumferential flaw 100 percent through-wall and 360 degrees 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.

- In accordance with the relief requests [1-4], structural design of the OWOLs was based on an assumed circumferential flaw 75 percent through-wall and 360 degrees around the original welds. This assumption allows for crediting the outer 25 percent of the original wall for structural capacity. The resulting optimized overlays thus restore the original safety margins of the nozzles, while taking credit for the examined and unflawed portions (25 percent) of the underlying, PWSCC-susceptible material.

- The weld metal used for the overlay is Alloy 52M, which has been shown to be resistant to PWSCC [9], thus providing a PWSCC resistant barrier. Therefore, no significant PWSCC crack growth is expected into the overlay. There is a potential for crack growth into the overlay due to fatigue and PWSCC for the postulated axial flaw in the DMW of the cold leg drain nozzle.

- Application of the weld overlays was shown to not impact the conclusions of the existing nozzle and piping 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-elbow welds, nozzle-to-safe end, or the safe end-to-elbow welds, as appropriate, prior to applying the weld overlays. The post weld overlay residual stresses were shown to result in beneficial compressive stresses on or near the inside surface of the components, and well into the thickness of the original DMWs, assuring that future PWSCC initiation or growth into the overlay is significantly mitigated.

- Fracture mechanics analyses were performed to determine the amount of future crack growth which would be predicted in the DMWs, assuming that cracks exist that are equal to or greater than the thresholds of the NDE techniques used. Both fatigue and PWSCC growth were considered, and found to be acceptable. The results determine the timing of the next required volumetric inspection following validation of a less-than-75 percent through-wall circumferential flaw for the full structural weld overlay. For the optimized weld overlay, the results determine the timing of the next required volumetric inspection following validation of a less-than-50 percent through-wall circumferential flaw and a initial 75 percent through-wall axial flaw. Stated another way, each time a volumetric inspection confirms that the outer 25 percent of the base material (FSWOL) or 50 percent of base metal (OWOL) underlying the overlay is free of these flaws, the inspection clock is "reset" to the listed duration.

- Leak-before-break evaluations were performed to demonstrate that the FSWOL and OWOL, when implemented, would meet regulatory requirements for critical flaw and leak detection.

Based on the above observations and the fact that nozzle-to-elbow, nozzle-to-safe end, and safe end-to-elbow weld overlays have been applied to other plants in the nuclear power industry since 1986 with no subsequent problems identified, it is concluded that the Davis-Besse Nuclear Power Station RCP suction and discharge, cold leg drain, and core flood nozzle dissimilar metal welds that have been weld overlaid have received long term mitigation against PWSCC.

4.0 REFERENCES

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