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February 8, 2008
L-08-034

10 CFR 50.55a

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

SUBJECT:
Davis-Besse Nuclear Power Station, Unit 1
Docket No. 50-346, License No. NPF-3
Summary of Design and Analyses of the Weld Overlays for Pressurizer and Hot Leg Nozzle Large Bore Dissimilar Metal Welds for Alloy 600 Mitigation (TAC No. MD4452)

By letter dated February 15, 2007, as supplemented by letters dated June 28, 2007, September 28, 2007, and November 19, 2007, the FirstEnergy Nuclear Operating Company (FENOC) requested Nuclear Regulatory Commission (NRC) approval of a proposed alternative to American Society of Mechanical Engineers Code Section XI requirements in support of weld overlay repairs for the Davis-Besse Nuclear Power Station (DBNPS). The NRC provided authorization to perform the weld overlay repairs in correspondence dated December 20, 2007.

To satisfy commitments provided in the February 15, 2007 letter, analysis result summaries were provided electronically to the NRC on January 24, 2008. The Enclosure contains a copy of that report.

As previously communicated to NRC staff in a teleconference on December 26, 2007, the September 28, 2007 letter inadvertently contained incorrect information relevant to axial and circumferential crack analysis assumptions used in the weld overlay design. This issue was entered into the Corrective Action Program, and the analyses were reperformed to include the assumptions conveyed in the September 28, 2007 letter. The results of the reperformed crack growth analyses have been incorporated in Table 2-3 of the Enclosure.

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NRR

There are no regulatory commitments contained in this letter. If there are any questions or if additional information is required, please contact Mr. Thomas A. Lentz, Manager – Fleet Licensing, at (330) 761-6071.

Sincerely,

Mark B. Bezilla

Enclosure:
Letter from Moses Taylor of SIA to Charles Daft of FENOC Containing Summary of Design and Analyses of the Weld Overlays for Pressurizer and Hot Leg Nozzle Large Bore Dissimilar Metal Welds for Alloy 600 Mitigation

cc: NRC Region III Administrator
NRC Resident Inspector
NRR Project Manager
Utility Radiological Safety Board
Executive Director, Ohio Emergency Management Agency,
State of Ohio (NRC Liaison)

Letter from Moses Taylor of SIA to Charles Daft of FENOC Containing Summary of Design and Analyses of the Weld Overlays for Pressurizer and Hot Leg Nozzle Large Bore Dissimilar Metal Welds for Alloy 600 Mitigation

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January 22, 2008
SIR-08-025-NPS, Rev. 0

Mr. Charles Daft
First Energy Nuclear Operating Company (FENOC)
Davis-Besse Nuclear Power Station
5501 North State Route 2
Oak Harbor, Ohio 43449

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

Reference: First Energy Nuclear Operating Company Davis-Besse Nuclear Power Station Third 10-Year Interval Request RR-A30, Revision 2

Dear Mr. Daft:

The following attachment is transmitted in support of FENOC's response to commitments in the above-referenced relief request:

Attachment: A summary of the results of stress and fracture mechanics analyses demonstrating that the preemptive full structural weld overlays satisfy the applicable requirements of the referenced relief request, which is based on the overlay methodology described ASME Code, Section XI, Code Case N-740, and thus constitute long-term, Code acceptable mitigation against primary water stress corrosion cracking (PWSCC) in the subject welds.

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

Prepared by:

Moses Taylor, P.E.
Senior Associate

1/22/08
Date

Verified by:

B. W. Smith
Senior Consultant

1/22/08
Date

Approved by:

Moses Taylor, P.E.
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1/22/08
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ml
Attachment
cc: Mark Ruis
T. J. McCrary
R. Hiss
Project File No. DB-08Q-406

Attachment

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

1.0 Introduction

First Energy Nuclear Operating Company (FENOC) is preemptively applying full structural weld overlays (WOLs) on dissimilar metal welds (DMWs) of two 3" pressure relief nozzles, one 2-1/2" pressure relief nozzle, one 4" spray nozzle (including one nozzle-to-safe end weld and one safe end-to-pipe weld), one 10" surge nozzle in the pressurizer, one 10" surge nozzle in the hot leg, and one 12" decay heat nozzle in the hot leg. 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 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 the overlay methodology described in 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 Code for the pressurizer was ASME, Section III, 1968 Edition, Summer 1968 Addenda, and for the Hot Leg was USAS, B31.7, 1968 Draft. However, as allowed by ASME Section XI, Code Editions and Addenda later than the original construction Code may be used. ASME Code, Section III, 1998 Edition with Addenda through 2000 [6], and 2001 Edition with Addenda through 2003 [5] were 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 are 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 in accordance with ASME Code, Section XI, IWB-3640 evaluation methodology. Both normal operating/upset (Level A/B) and emergency/faulted (Level C/D) load combinations were considered in this evaluation. The resulting minimum required overlay thicknesses are summarized in Table 2-1.

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. The minimum weld overlay length required for structural reinforcement was established in accordance with the Relief Request [2] which is based on methodology described in ASME Code Case N-740 [3]. Because of the Alloy 600 safe end on the pressurizer spray nozzle and the DMW between the safe end and stainless steel piping, it is necessary to extend the overlay over both the nozzle-to-safe end weld and the safe end-to-pipe weld for the spray nozzle. Also, because of the short safe end length on the 2-1/2" pressure relief nozzle, it is necessary to extend the overlay over both the nozzle-to-safe end weld and the safe end-to-pipe weld. The resulting minimum length requirements are summarized in Table 2-1.

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. Illustrations of the weld overlay designs for the Davis-Besse pressurizer and hot leg nozzles are provided in Figures 2-1 through 2-6. 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 overlaid welds. 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: Weld Overlay Structural Thickness and Length Minimum Requirements

	Location	2-1/2" Relief Nozzle	3" Relief Nozzle	Spray Nozzle	Hot Leg Surge Nozzle	Pressurizer Surge Nozzle	Hot Leg Decay Heat Nozzle
Minimum Thickness (in.)	Nozzle Side	0.370	0.421	0.250	0.417	0.458	0.5
	Safe End-to-Nozzle Side	0.370	0.421	0.250	NA	0.354	NA
	Safe End-to-Pipe side	0.163	NA	0.204	NA	NA	NA
	Pipe/Elbow Side	0.163	NA	0.144	0.417	NA	0.5
Minimum* Length (in.)	Nozzle Side	0.629	1.302	1.040	1.12	2.109	1.434
	Safe End-to-Nozzle Side	NA	1.387	1.040	NA	1.803	NA
	Safe End-to-Pipe Side	NA	NA	0.886	NA	NA	NA
	Pipe/Elbow Side	0.591	NA	0.745	1.16	NA	1.503

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

2.2 Section III Stress Analyses

Stress intensities for the weld overlaid pressurizer pressure relief, spray and surge nozzles and the hot leg surge and decay heat nozzles were determined from finite element analyses for the various specified load combinations and transients. 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 2-7. The stress intensities at these locations were evaluated in accordance with ASME Code, Section III, Sub-articles NB-3200 and NB-3600 [5,6], and compared to applicable Code limits. A summary of the stress and fatigue usage comparisons for the most limiting locations is provided in Table 2-2. The stresses and fatigue usage in the weld overlaid nozzles are within the applicable Code limits. In general, the limiting location for the Section III stress analyses was found to be the section of the original pipe at the end of the overlay (Path 6 in Figure 2-7).

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

Nozzle	Load Combination	Type	Calculated	Allowable
3" Pressure Relief	Level A/B	Primary + Secondary (P +Q) (ksi)*	34.51	50.50
	Fatigue	Cumulative Usage Factor	0.037	1.000
2-1/2" Pressure Relief	Level A/B	Primary + Secondary (P +Q) (ksi)*	43.30	49.66
	Fatigue	Cumulative Usage Factor	0.024	1.000
Spray	Level A/B	Primary + Secondary (P +Q) (ksi)*	40.05	48.90
	Fatigue	Cumulative Usage Factor	0.006	1.000
Hot Leg Surge	Level A/B	Primary + Secondary (P +Q) (ksi)*	64.49**	52.64
		Simplified Elastic-Plastic Analysis (P +Q) (ksi)	46.07**	52.64
	Fatigue	Cumulative Usage Factor	0.835	1.000
PZR Surge	Level A/B	Primary + Secondary (P +Q) (ksi)*	24.44	50.10
	Fatigue	Cumulative Usage Factor	0.93	1.000
Hot Leg Decay Heat	Level A/B	Primary + Secondary (P +Q) (ksi)*	52.57**	50.76
		Simplified Elastic-Plastic Analysis (P +Q) (ksi)	44.54**	50.76
	Fatigue	Cumulative Usage Factor	0.030	1.000

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

** - Elastic analysis exceeds the allowable value of $3S_m$, however, criteria for simplified elastic-plastic analysis and thermal ratcheting are met.

2.3 Residual Stress and Section XI Crack Growth Analyses

Weld residual stresses for the Davis-Besse pressurizer and hot leg 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. Two-dimensional, axisymmetric finite element models were developed for each of the nozzles. Modeling of weld nuggets used in the analysis to lump the combined effects of several weld beads is illustrated in Figure 2-8. The models simulated an inside surface (ID) repair at the nozzle-to-safe end 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.

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. The resulting residual stresses were evaluated on the inside surface of the original welds and safe-end components, as well as on several paths through the DMWs. An example finite element model and residual stress plots are shown in Figures 2-9 and 2-10. Note that PWSCC susceptible regions are marked by bold vertical lines in Figure 2-10.

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 grow beyond the design basis for the weld overlays for the time period until the next scheduled inservice or other scheduled inspection due to fatigue or PWSCC (or both). In the fatigue crack growth analyses, the 60 year design cycles for each applied transient were assumed. The design basis flaw for crack growth purposes is the original weld thickness for all the nozzle welds. Since the examination volume for the PDI qualified post-overlay UT inspections includes the weld overlay thickness plus the outer 25% of the original wall thickness, an inside surface flaw that is 75% of the original weld thickness is 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 overlay is then calculated. The results are shown in Table 2-3.

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 crack depths at which the combined stress intensity factor due to sustained steady state operating conditions is less than zero.

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 spray and surge nozzles, based on design dimensions and welded mockups, were evaluated and found to be acceptable. Also, the effect of the added weight of the overlays on the adjacent piping systems, based on design dimensions, was evaluated and found to be insignificant.

Table 2-3: Time for Postulated Flaw to Reach Design Basis Flaw

Flaw	Pressurizer Surge Nozzle	Pressurizer Spray Nozzle	Pressurizer 3" Relief Nozzle	Pressurizer 2-1/2" Relief Nozzle	Hot Leg Surge Nozzle	Hot Leg Decay Heat Nozzle
Circumferential (DMW)	17.4 years	26 years[2]	>60 years	>60 years	2.58 years (31 months)	6 years
Axial (DMW)	>60 years	47 years[2]	>60 years	>60 years	>10 years	>60 years
Circumferential (SSW)[1]	NA	NA	NA	22 years	NA	NA
Axial (SSW)[1]	NA	NA	NA	>60 years	NA	NA

Note: 1. SSW = Stainless Steel Weld

2. Applies to both the nozzle-to-safe end DMW and the safe end-to-pipe DMW.

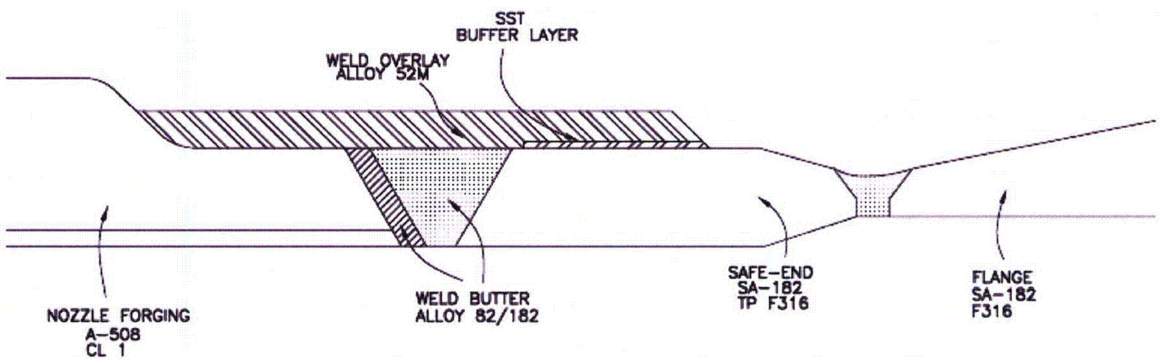


Figure 2-1: Illustration of Weld Overlay Design for Davis-Besse Pressurizer 3" Pressure Relief Nozzle

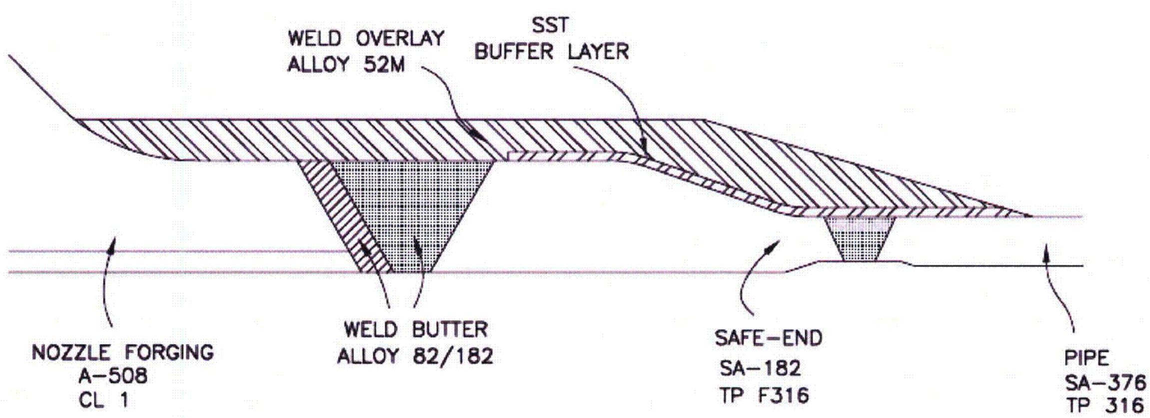


Figure 2-2: Illustration of Weld Overlay Design for Davis-Besse Pressurizer Pressure 2 ½" Pressure Relief Nozzle

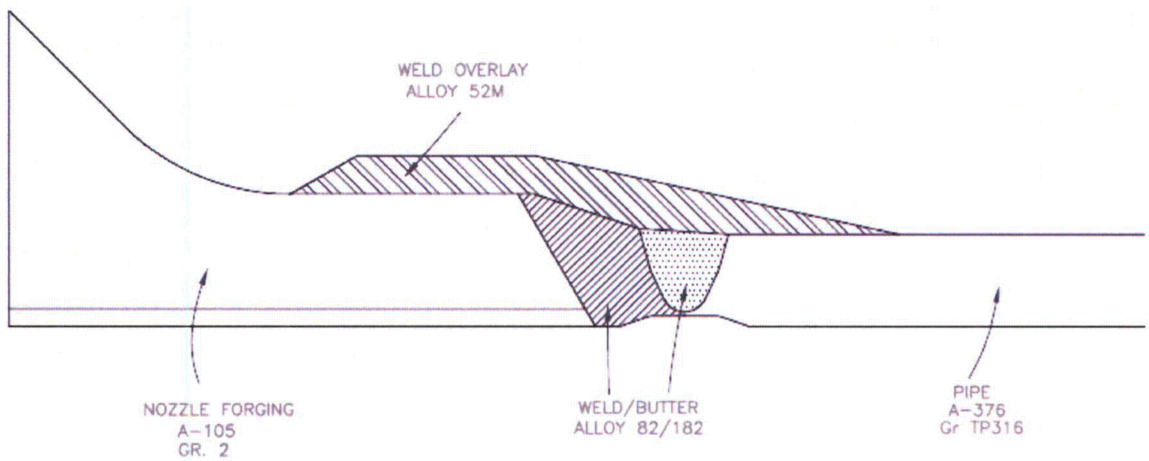


Figure 2-3: Illustration of Weld Overlay Design for Davis-Besse Hot Leg Surge Nozzle

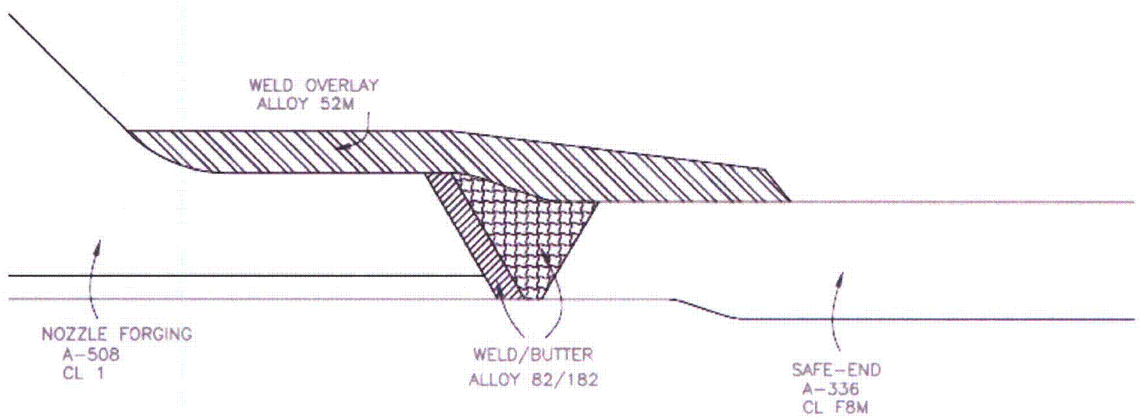


Figure 2-4: Illustration of Weld Overlay Design for Davis-Besse Pressurizer Surge Nozzle

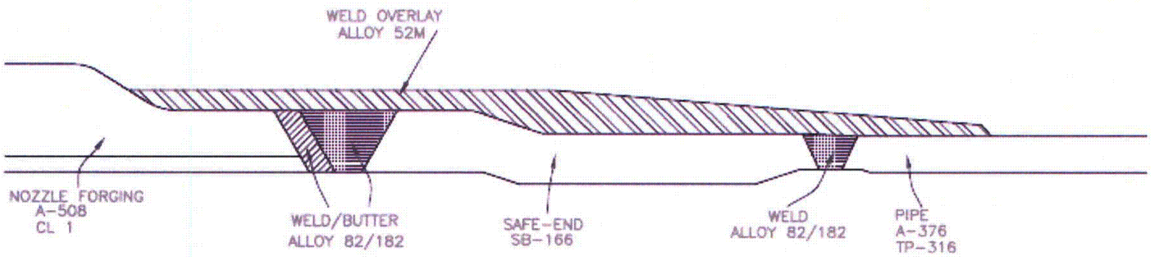


Figure 2-5: Illustration of Weld Overlay Design for Davis-Besse Pressurizer Spray Nozzle

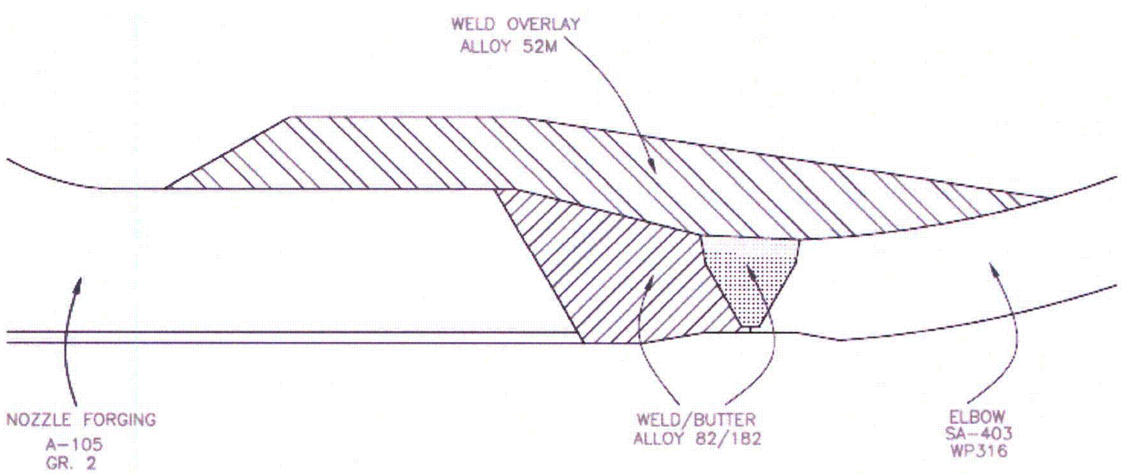


Figure 2-6: Illustration of Weld Overlay Design for Davis-Besse Hot Leg Decay Heat Nozzle

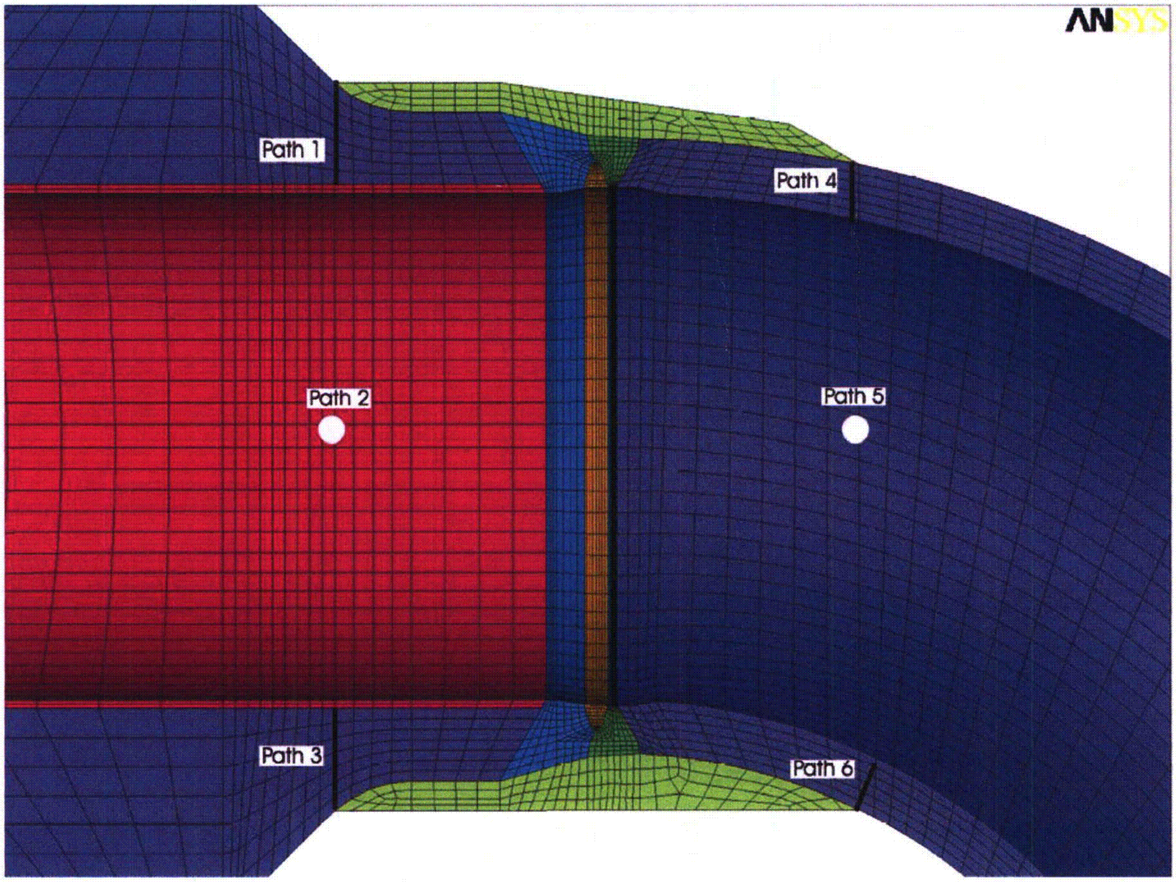


Figure 2-7: Typical Finite Element Model for Section III Stress Evaluation showing Stress Paths

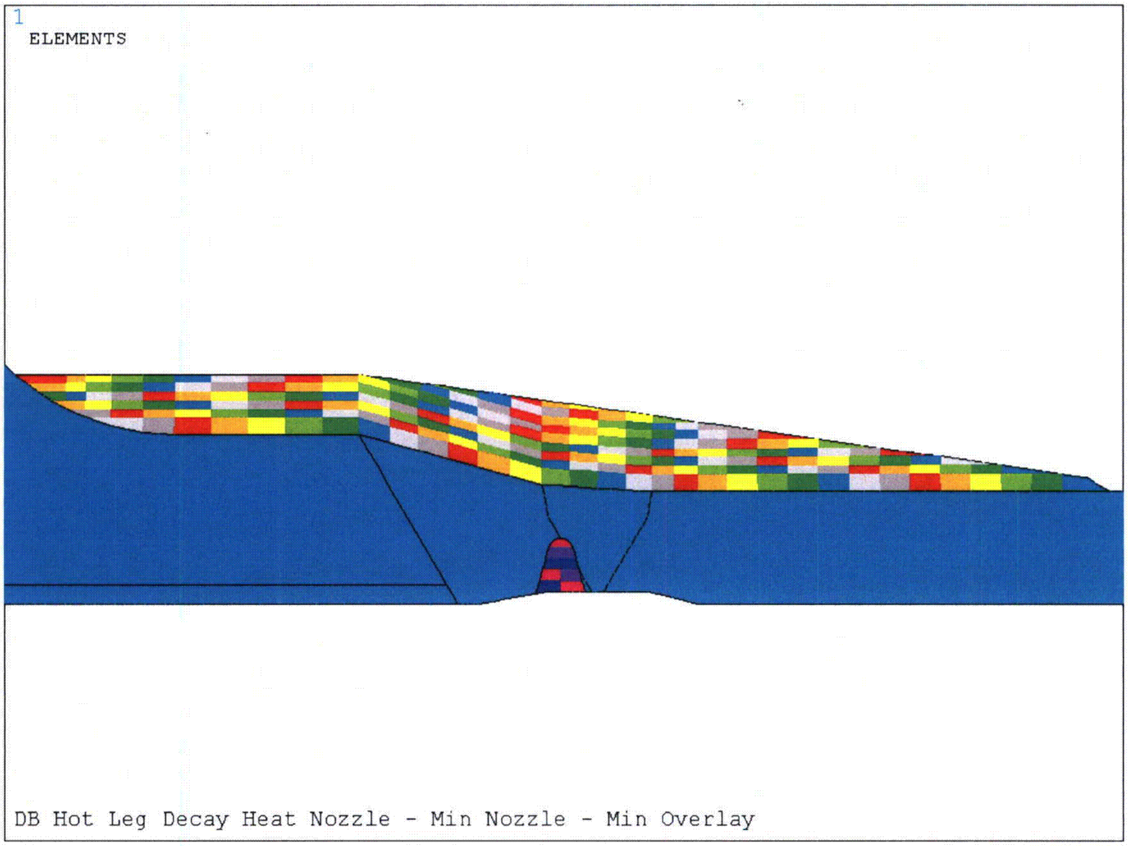


Figure 2-8: Typical Finite Element Model for Residual Stress Analysis showing Nuggets used for Welding Simulations

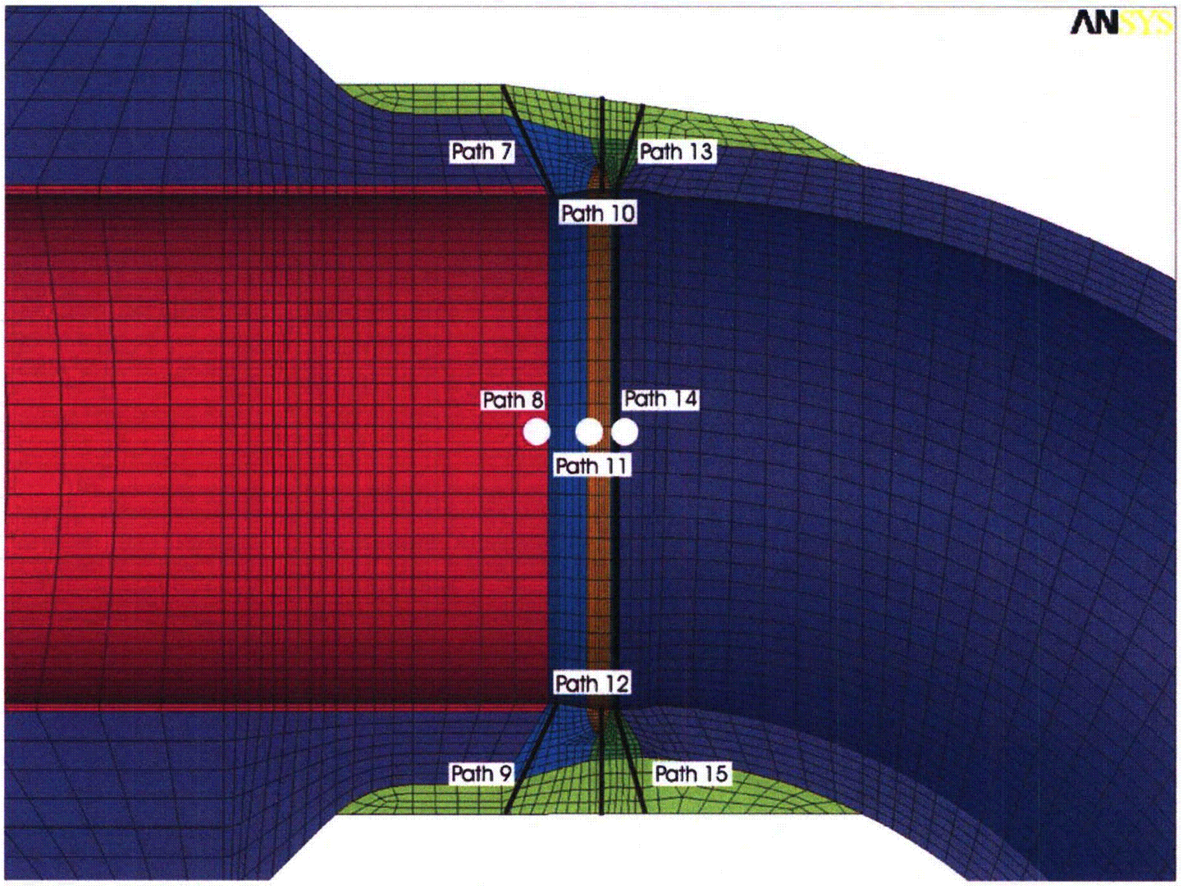
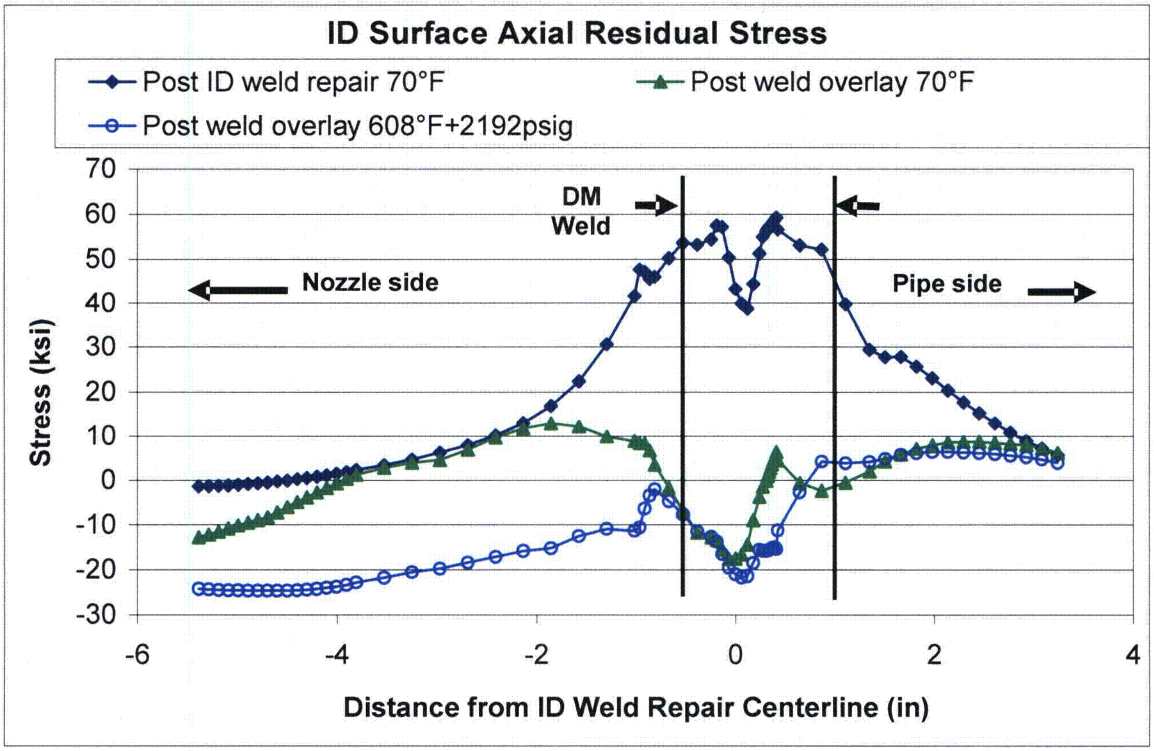


Figure 2-9: Finite Element Model for Residual Stress Analysis showing Paths used in Crack Growth Evaluations (Example)



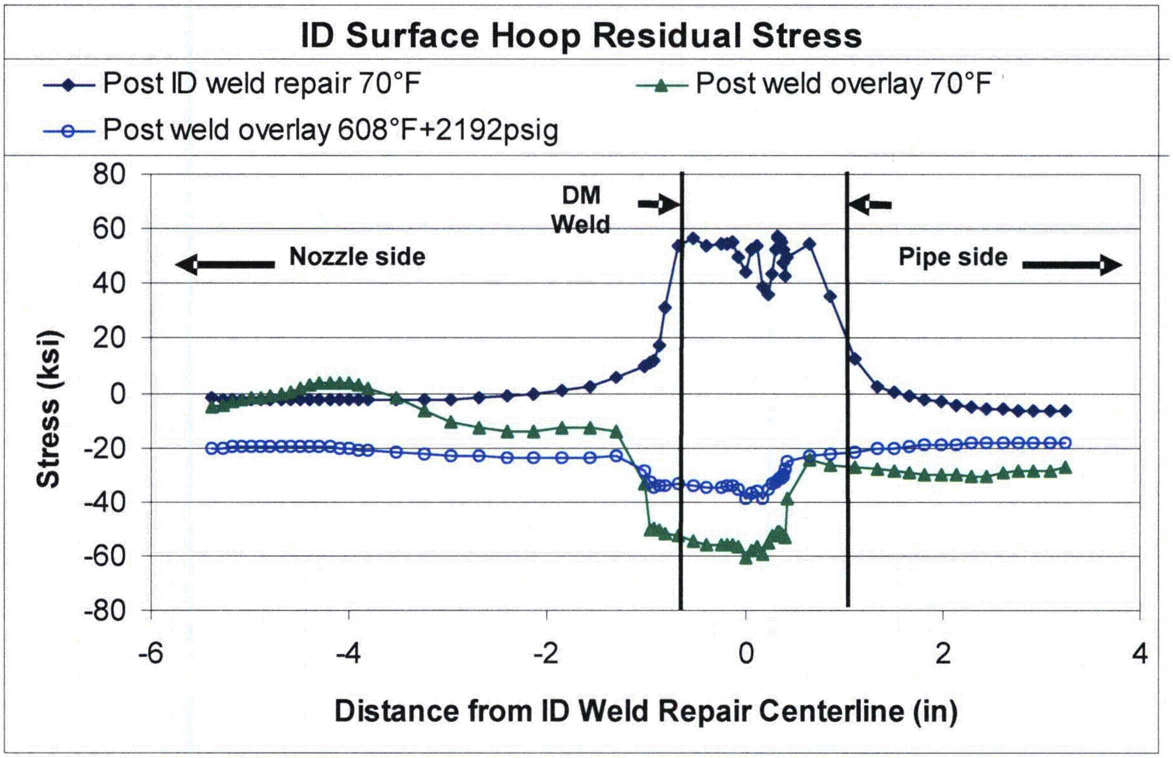


Figure 2-10: Residual Stress Results along Inside Surface of Original Butt Weld for Hot Leg Decay Heat Nozzle (General profile typical for other nozzle welds)

3.0 Conclusions

The design of the Davis-Besse weld overlays was performed in accordance with the requirements of the Relief Request [2], which is based on the overlay methodology described in 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, no PWSCC crack growth is expected into the overlay.
- 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/pipe 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, assuring that future PWSCC initiation or crack growth into the overlay is highly unlikely.
- Fracture mechanics analyses were performed to determine the amount of future crack growth which would be predicted in the nozzle DMWs, 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 Davis-Besse, Unit 1 pressurizer surge, pressure relief, and spray nozzle, and hot leg surge and decay heat 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. First Energy Nuclear Operating Company Davis-Besse Nuclear Power Station Third 10-Year Interval Request RR-A30, Revision 2
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, 1995 Edition through 1996 Addenda.
5. ASME Boiler and Pressure Vessel Code, Section III, 2001 Edition through 2003 Addenda.
6. ASME Boiler and Pressure Vessel Code, Section III, 1998 Edition through 2000 Addenda.