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Constellation Energy
Generation Group

May 31, 2006

U. S. Nuclear Regulatory Commission
Washington, DC 20555

ATTENTION: Document Control Desk

SUBJECT: Calvert Cliffs Nuclear Power Plant
Unit No. 1; Docket No. 50-317
ASME Code Section XI Flaw Evaluation of Dissimilar Metal Weld Flaws Identified by Ultrasonic Testing

Inspections using ultrasonic examination (UT) methods performed at Calvert Cliffs Nuclear Power Plant (CCNPP) Unit 1 during the 2006 Refueling Outage detected indications in three Reactor Coolant System pressure boundary dissimilar metal (DM) welds. Two of the indications exceeded the acceptance standards of the American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code (B&PV), Section XI, Subsection IWB Sub-article IWB-3500. The attached flaw evaluation is provided for the Nuclear Regulatory Commission review in accordance with ASME B&PV Code Section XI requirements contained in IWB-3640, "Evaluation Procedures and Acceptance Criteria for Austenitic Piping."

Indications which exceeded the IWB-3500 standards were found in the 12 inch hot leg surge nozzle to safe end weld [12CC2-1001(W13)] and the 2 inch hot leg drain nozzle to safe end weld [2CC9-1007(W1)]. A stress improvement mitigation technique (Mechanical Stress Improvement Process-MSIP®) has been performed at each of these locations. This method induces compressive stresses on the inside pipe wall where the indications are located. These post-MSIP residual stresses, when added to the normal operating pressure and piping loads, mitigate any further crack propagation due to primary water stress corrosion cracking.

To ensure the mitigation was technically sound and acceptable, an analytical flaw evaluation was carried out for each nozzle, using the rules of ASME B&PV Code Section XI, Sub-article IWB 3600, to determine if the as-found flaws are within the Code maximum allowable limits. The evaluation is consistent with the guidelines of MRP-139, Primary System Piping Butt Weld Inspection and Evaluation Guideline. The ultrasonic examinations were performed by qualified Performance Demonstration Initiative DM weld examiners and inspection procedures. The flaw evaluation results (Attachment 1) demonstrate that the plant remained in an operable condition prior to discovery of the subject flaws.

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Should you have questions regarding this matter, please contact Mr. L. S. Larragoite at (410) 495-4922.

Very truly yours,

JAS/MJY/bjd

Attachment: (1) Westinghouse Document LTR-CI-06-26-NP, Revision 0, dated March 17, 2006, (Reclassified Westinghouse Non-Proprietary Class 3, March 24, 2006)

cc: P. D. Milano, NRC
S. J. Collins, NRC
Resident Inspector, NRC
R. I. McLean, DNR

ATTACHMENT (1)

Westinghouse Document LTR-CI-06-26-NP, Revision 0,

dated March 17, 2006,

(Reclassified Westinghouse Non-Proprietary Class 3, March 24, 2006)

Calvert Cliffs Nuclear Power Plant, Inc.
May 31, 2006

Evaluation of As-found Flaws in Surge, Drain and Relief Valve Nozzle Safe-end Welds at Calvert Cliff Unit 1 during March 2006 Outage

Introduction

In-service inspections performed at Calvert Cliffs Unit 1 during the 2006 Refueling Outage detected an indication in three (3) reactor coolant system (RCS) pressure boundary dissimilar metal welds. Two of the indications exceed the acceptance standards of ASME Boiler & Pressure Vessel Code Section XI, Subsection IWB Article IWB-3500. Indications which exceed the IWB 3500 standards were found in the 12 inch hot leg surge nozzle to safe end weld (12CC2-1001(W13)) and the 2 inch hot leg drain nozzle to safe-end weld (2CC9-1007(W1)). These two welds have indications on the inside surface of the nozzle safe-ends which are circumferential in orientation. An axial indication was detected in the pressurizer relief valve to safe-end weld (4CC10-1006(W1)). The size of this indication is within the acceptable limits of Article IWB-3500. All three flaws are suspected to be caused by primary water stress corrosion cracking (PWSCC).

A stress improvement mitigation technique called "Mechanical Stress Improvement Process" (MSIP®) has been performed at each one of these locations during the current outage. This method induces compressive stresses on the inside surface and inner wall where the indications are located. These post-MSIP residual stresses, when added to the normal operating pressure and piping loads, mitigate any further crack propagation due to PWSCC.

To ensure that such a mitigation is technically sound, an analytical flaw evaluation was carried out for each nozzle, using the rules of ASME Code Section XI, Article IWB 3600, to determine if the as-found flaws are within the Code maximum allowable. Fatigue and PWSCC crack growth was considered and found to be negligible because of the compressive stresses over the entire length of the flaw. The evaluation used ASME Section XI, and is consistent with the guidelines of MRP-139 [Reference 8].

The as-found indication sizes determined from the UT evaluation sheets by WesDyne (Reference 1) were used directly in the flaw evaluation described herein.

Westinghouse Electric Company (WEC) with AEA Technology Engineering Services (AEA) performed the MSIP at Calvert Cliffs. AEA's residual stress analyses results are detailed in References 2a through 2c. These reports list the through-wall residual stresses at the indications in the post-MSIP condition as well as those at the normal operating condition after the MSIP has been performed. These stresses are superposed on to the piping stresses due to thermal dead weight and seismic loads. For the surge-line, stratification piping loads were also considered in the flaw evaluation.

Geometry, Piping Loads and Material Properties

Nozzle dimensions at the safe-end welds were derived from the WEC drawings and listed in Table 1. This table also lists the structural factors, allowable stress and the material flow stresses assumed in the analysis.

Table 2 lists the indication dimensions as detected by WesDyne and reported in Reference 1.

Piping loads used in the analysis are from the Westinghouse Electric stress analysis reports (Reference 7) and listed in Table 3 for the surge nozzle and in Table 5 for relief nozzle. Drain nozzle loads are supplied to WEC by Constellation (Reference 6) and are listed in Table 4. Corresponding stresses for these nozzles are listed in Table 6 through 8.

Flaw Evaluation

A plot of the as-found indication depth and aspect ratios along with the ASME Code Subsection IWB limits is shown in Figure 1. This figure indicates that the flaws in the surge and drain nozzles exceed the allowable whereas the relief nozzle indication is within the allowable limit.

When the as-found indications exceed the allowable values in Subsection IWB-3500, Section XI requires one to consider the analysis procedures as specified in Subsection IWB-3600. This leads to the analytical techniques in Appendix C Article C-5321 for circumferential flaws and in Article C-5420 for axial flaws. One can also use the tables C-5310-1 through C-5310-4 for circumferential flaws. Here the former approach was chosen.

The limit load approach in the ASME Code Section XI, Division 1 Appendix C (Reference 3) applies to the flaw evaluation at the nozzle safe-end welds, because the Alloy 182 weld metal has extremely high fracture toughness, typical of stainless steel base metal.

Flaw definitions using the terminology of the ASME Code are shown below.

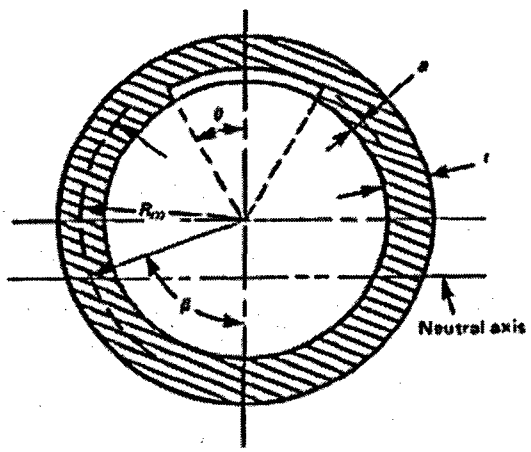

FIG. C-4310-1 CIRCUMFERENTIAL FLAW GEOMETRY

(from ASME Section XI Division 1 Appendix C)

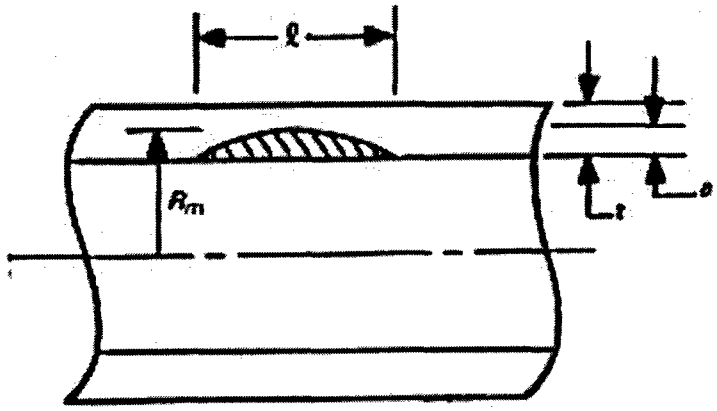

FIG. C-4310-2 AXIAL FLAW GEOMETRY

(from ASME Section XI Division 1 Appendix C)

Surge Nozzle Flaw Evaluation

Using the equations in the ASME Code Appendix C, allowable bending stresses were computed as a function of the flaw depth to thickness ratio. These results are plotted in Figures 2 and 3 for service level A and C conditions, respectively. Here, for the given flaw length and the applied membrane stress, the Code allowable bending stress limit is plotted as a function of the flaw depth to thickness ratio along with the actual as-found flaw parameters. These figures clearly show that the indication is within the acceptable limits for both the levels A and C piping loads, with and without surge-line flow stratification.

Another way to look at the flaw evaluation is the allowable stress ratio as a function of the flaw depth to thickness ratio, as shown in Figures 4 and 5. These figures show the allowable stress ratio $(s_m+s_b)/s_f$ prescribed in the Code Tables C-5310-1 and C-5310-3 as a function of the flaw depth to thickness ratio. These Code values were interpolated for the actual aspect ratio as detected by WesDyne UT examination. These figures also show that the as-found flaws were acceptable during pre-outage operation prior to the MSIP repair, demonstrating that **the plant remained in an operable condition even before the indications were known.**

Figures 6 and 7 show the pre- as well as post-MSIP through-wall stresses at the flaw location with and without stratification loads, respectively. These figures show that the post-MSIP stresses, when superposed with the piping loads, are clearly compressive over approximately 1 inch through the wall from inside surface. This compressive stress region far exceeds the as-found depth of 0.4 inch, thereby indicating that the MSIP repair will arrest any further PWSCC growth.

As a further note, the total post-MSIP stresses are linearized as in Figure 8 and 9 and crack tip stress intensity factors (SIF) are computed using the influence coefficients available in Reference 5. Results of this evaluation are shown in Table 9. For the as-found flaw depths, SIFs are clearly negative even for the most severe loading condition stratification loads, further reinforcing the conclusion that the MSIP will mitigate any future PWSCC growth.

Drain Nozzle Flaw Evaluation

The circumferential indication in the drain nozzle safe-end was also evaluated using the same procedure as for the surge-line. Applying the analytical equations in Appendix C, allowable bending stresses were computed as a function of the flaw depth ratio for the as-found flaw length and the applied membrane stress. Results of the allowable bending stresses are plotted in Figure 10 for Level A and in Figure 11 for Level C conditions. The actual as-found indication parameters, also plotted in Figures 10 and 11, clearly show that the indications are well within the limits of the Code requirements. Again, this shows that **the plant was in an operable condition even before the indication was known.**

The drain nozzle indication was also evaluated for the post-MSIP conditions using the residual stresses from AEA reported in Reference 2b. Figure 12 shows the distribution of the through-wall stresses in pre- and post-MSIP conditions. The post-MSIP stresses were superposed with the stresses from the piping loads and linearized as shown in Figure 13. These linearized stresses were used in computing the stress intensity factor (SIF) as a function of flaw size, and the results are listed in Table 10. The crack tip SIF was computed to be negative for the depth of the as-found indication, indicating that it is in a compressive zone in the post-MSIP stress field, assuring the mitigation process was effective and will mitigate any future PWSCC growth.

Relief Valve Nozzle Flaw Evaluation

The axial indication in the relief valve nozzle safe-end was also evaluated using the analytical procedure available in Appendix C, Article C-5420. Maximum Code-allowable hoop stresses were computed as a function of the depth to thickness ratio for the as-found indication. Results of the allowable stresses are plotted in Figure 14 for Level A and in Figure 15 for Level C conditions. The actual as-found indication parameters, also plotted in these figures, clearly show that the pre-outage flaws are well within the limits of the Code requirements, again demonstrating that **the plant was in an operable condition even before the indication was known.**

The relief nozzle flaw was also evaluated for the post-MSIP conditions using the residual stresses reported in Reference 2c. Figure 16 shows the distribution of the through-wall stresses in pre- and post-MSIP conditions. The post-MSIP stresses were linearized as shown in Figure 17. These linearized stresses were used in computing the SIFs as a function of flaw size, and the results are listed in Table 11. Analytical influence coefficients available in Reference 4 were used in the evaluation. The crack tip SIF was again computed to be negative for depth of the as-found indication, for both level A and Level C conditions indicating that it is in a compressive zone in the post-MSIP stress field and demonstrates that the mitigation process was effective and will mitigate any future PWSCC growth.

Summary and Conclusions

Both the circumferential indications detected in the surge-line and the drain-line nozzle safe-ends on the hot leg side of the Calvert Cliffs Unit 1 RCS pressure boundary were found to be acceptable and within the allowable limits of the ASME Section XI Division 1 Subsection IWB Article IWB-3600 and Appendix C requirements. These indications were found to be acceptable for both the normal load Level A and the faulted load Level C cases in the pre-outage operating condition, thus demonstrating that the plant was in an operable condition at all times with respect to the indications.

An evaluation of the as-found indications with the post-MSIP through-wall stresses indicates that the indications are well within the compressive region on the inside surface, thus assuring that the MSIP process will mitigate any further PWSCC growth during future operation.

The axial indication found in the pressurizer relief nozzle safe-end is within the ASME Code limit for the pre-outage loading condition. The post-MSIP through-wall stresses in the nozzle also indicate that the indication is also well within the compressive zone which assures the mitigation process was effective.

References:

1. Letter from Bernard C. Rudell of Constellation Energy to Edward A. Ray of Westinghouse Electric Co., "Flaw Evaluation of Calvert Cliff Unit 1 Reactor Coolant System Pressure Retaining Welds", dated February 27, 2006.

2. AEA Technology Engineering Services, Inc. Reports prepared for Westinghouse Electric Company, LLC:
   a) "Mechanical Stress Improvement Process (MSIP) Calvert Cliffs Unit 1 RCS Hot Leg Surge DM Weld 12CC2-1001 (W13) MSIP Flaw Evaluation", Report No. 4205-6-001, dated 3/8/06.
   b) "Mechanical Stress Improvement Process (MSIP) Calvert Cliffs Unit 1 Hot Leg Drain Nozzle DM Weld 2CC9-1007 (W-1) MSIP Flaw Evaluation", Report No. 4205-6-002, dated 3/8/06.
   c) "Mechanical Stress Improvement Process (MSIP) Calvert Cliffs Unit 1 Relief Valve Nozzle DM Weld 4CC10-1006 (W-1) MSIP Flaw Evaluation" Report No. 4205-6-003, dated 3/8/06.

3. ASME Section XI Division 1
   a) Non-mandatory Appendix C on "Evaluation of Flaws in Piping", 1998 Edition and 2004 Edition.
   b) Non-mandatory Appendix A on "Analysis of Flaws", 1998 Edition and 2004 Edition.

4. I.S. Raju and J.C. Newman, Jr., "Stress-Intensity Factor Influence Coefficients for Internal and External Surface Cracks in Cylindrical Vessels", pages 37-47, published in ASME PVP Volume 58, 1982.

5. S. Chapuliot, M.H. Lacire and P. Le Delliou, "Stress Intensity Factors for Internal Circumferential Cracks in Tubes over a Wide Range of Radius over Thickness Ratios", ASME PVP Volume 365, 1998.

6. Letter from Constellation Energy to Westinghouse Electric Co on Drain Nozzle Loads, Letter No. DE06302, dated March 14, 2006.

7. Westinghouse Electric Company Reports
   a) "Addendum to the Analytical Report for Baltimore Gas & Electric Power Company Piping C.E. Contract Nos. 72467/73467", dated April 1982.
   b) "Project Specification for Reactor Coolant Pipe and Fittings for Calvert Cliffs Units 1 & 2", Design Specifications No. 8067-31-5, Revision 18, dated 5/21/04.
   c) "Addendum to the Pressurizer Analytical Report for Baltimore Gas & Electric Company Calvert Cliffs Units 1 and 2", Design Report No. B-PENG-DR-001, Revision 00, dated 3/29/95.

8. Material Reliability Program; Primary System Piping Butt Weld Inspection and Evaluation Guideline (MRP-139) 1010087, Final, July 14, 2005.

Table 1: Geometry and Design Data

(not including cladding)

Parameter	Surge	Drain	Safety	units
Outside diameter	12 3/4	2 7/8	6 1/16	inch
Inside diameter	10 1/8	2 1/8	3 7/16	inch
Wall thickness	1.313	0.375	1.313	inch
Structural Factor-membrane-Level A	2.7	2.7	2.7	
- Bending – Level A	2.3	2.3		
- Membrane-Level C	1.8	1.8	1.8	
- Bending-Level C	1.6	1.6		
Flow stress	52.5	52.5	52.5	ksi

Table 2: Ultrasonic Examination Flaw Dimensions

Parameter	Surge	Drain	Relief	units
Depth	0.4	0.1	0.1	in
Length	2.4	0.45	0.6	in
Thickness	1.6	0.54	1.3	in
Flaw orientation	Circ	Circ.	Axial	

Table 3: Surge Nozzle Piping Loads

Load case	Fx	Fy (axial)	Fz	Mx (bend)	My	Mz (bend)
	(kip)			(in-kip)		
Upset (DW+Th+OBE)	17	9	28	277	765	329
Faulted (DW+Th+SSE)	22	13	32	507	1008	559
Max. Strat.	-2.09	-2.76	-16.86	-2274	1051	65
Upset + Strat.	19.09	11.76	44.86	2551	1816	394
Faulted + Strat.	24.09	15.76	48.86	2781	2059	624

Table 4: Drain Nozzle Piping Loads

Load case	Fx	Fy (axial)	Fz	Mx (bend)	My	Mz (bend)
	(kip)			(in-kip)		
Upset (DW+Th+OBE)	0.545	0.434	0.153	3.564	4.164	15.612
Faulted (DW+Th+SSE)	0.579	0.464	0.179	4.848	4.416	16.644

Table 5: Relief Nozzle Piping Loads

Load Case	Fx	Fy(axial)	Fz	Mx(bend)	My	Mz(bend)
	(kip)			(in-kip)		
Max. upset (DW+Th+OBE)	5.285	3.194	2.707	15.633	41.400	30.698
Max. Faulted (DW+Th+SSE)	6.711	4.815	4.070	23.604	50.256	41.232

Table 6: Surge Nozzle Axial Stresses

Load Case	s_m (ksi)	s_b (ksi)	s_m+s_b (ksi)	Remarks
Pressure	3.841	0	3.841	
DW+Th+OBE	0.191	3.509	3.700	Combined with
DW+Th+SSE	0.276	6.157	6.433	Post-MSIP+NoP
P+DW+Th+OBE	4.032	3.509	7.541	For Pre-MSIP
P+DW+Th+SSE	4.117	6.157	10.274	Evaluation
DW+Th+OBE+Strat	0.249	21.057	21.307	Combined with
DW+Th+SSE+Strat	0.334	23.251	23.585	Post-MSIP+NoP
P+DW+Th+OBE+Strat	4.091	21.057	25.148	For Pre-MSIP
P+DW+Th+SSE+Strat	4.176	23.251	27.427	Evaluation

Table 7: Drain Nozzle Axial Stresses

Load Case	s_m (ksi)	s_b (ksi)	s_m+s_b (ksi)	Remarks
Pressure	2.709	0	2.709	
DW+Th+OBE	0.147	9.784	9.932	Combined with
DW+Th+SSE	0.158	10.592	10.749	Post-MSIP+NoP
P+DW+Th+OBE	2.857	9.784	12.641	For Pre-MSIP
P+DW+Th+SSE	2.867	10.592	13.459	Evaluation

Table 8: Relief Valve Nozzle Pre-MSIP Hoop Stress

sm (ksi)
4.071

Table 9: Surge Nozzle Post-MSIP Crack Tip Stress Intensity Factors
(from Reference 5, et. Al. 1998, Tables 3 & 4, a/c = 1/4, a/t = 0.4, t/Ri = 1/5)

Parameter	Post-MSIP +Nop+Piping No Strat.	Post-MSIP +Nop+Piping +Strat.	units
Through-wall membrane	4.378	21.984	(ksi)
Through-wall bending	46.402	46.402	(ksi)
K_{Itot}	**-36.21**	**-13.72**	(ksivin)

Table 10: Drain Nozzle Post-MSIP Crack Tip Stress Intensity Factors
(from Reference 5, et. Al. 1998, Tables 3 & 4, a/c = 1/4, a/t = 0.4, t/Ri = 1/5)

Parameter	Post-MSIP +Nop+Piping (No Strat)	units
Through-wall membrane	6.882	(ksi)
Through-wall bending	64.384	(ksi)
K_{Itot}	**-27.74**	(ksivin)

Table 11: Relief Nozzle Post-MSIP Crack Tip Stress Intensity Factors
(from Reference 4, Table 2, a/c = 0.2, a/t = 0.2, t/Ri = 0.25)

Parameter	Path 1 Post-MSIP +Nop+Piping	Path 2 Post-MSIP +Nop+Piping	units
Through-wall membrane	-25.948	1.771	(ksi)
Through-wall bending	36.262	52.714	(ksi)
K_{Itot}	-32.49	-25.42	(ksivin)

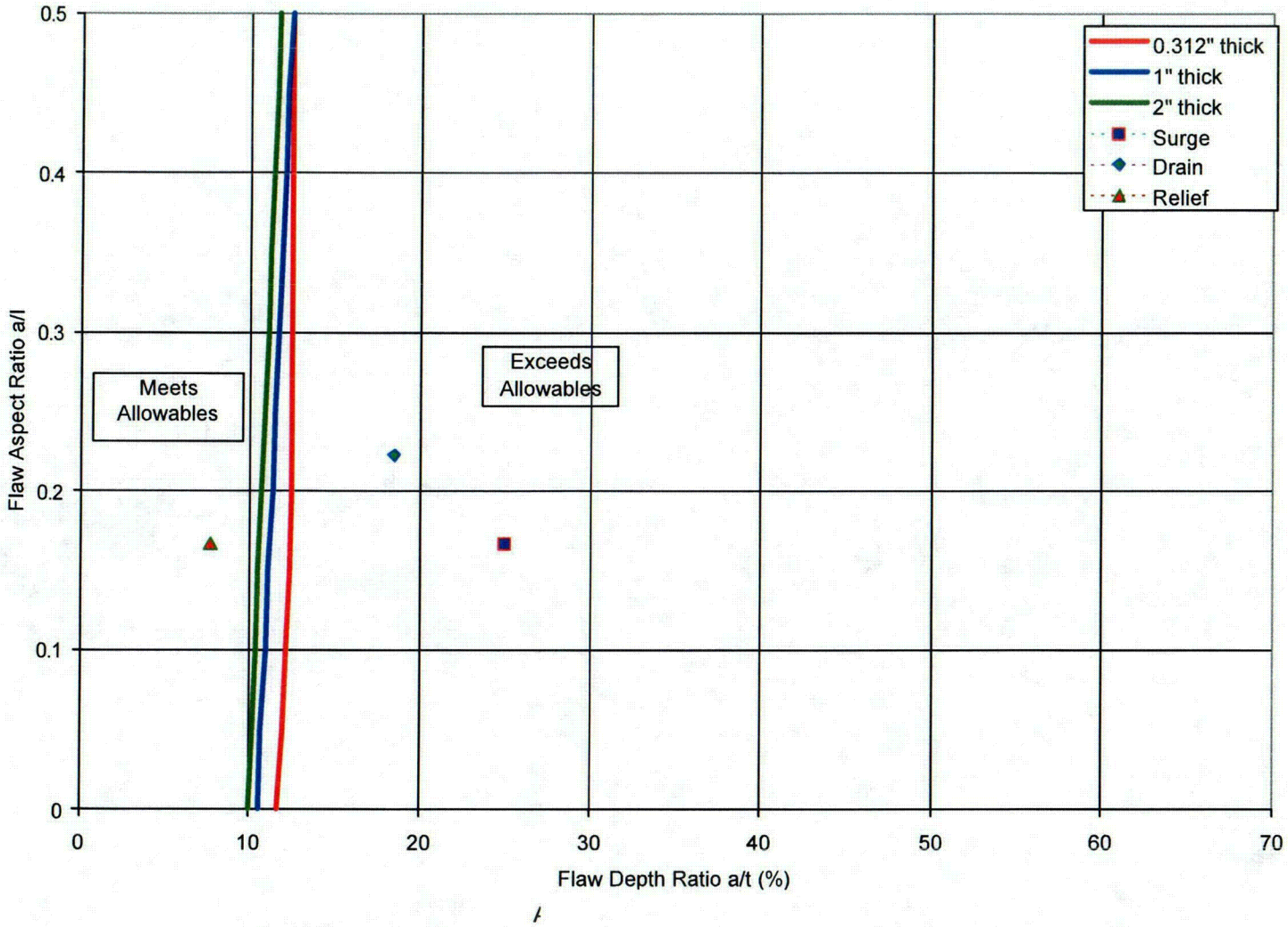

Figure 1: Allowable Flaw Depths per ASME Section XI Division 1 Subsection IWB Table IWB 3514-2

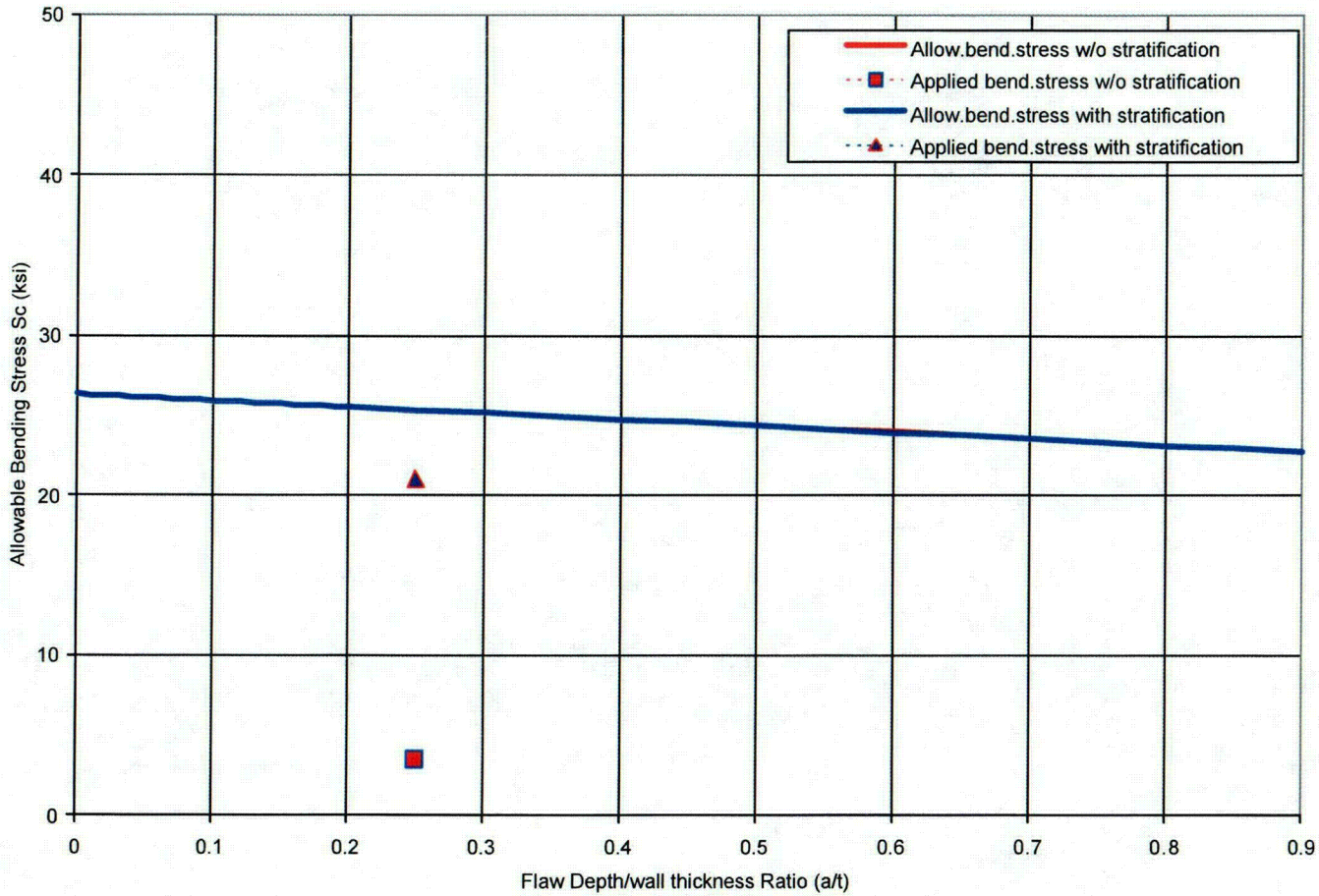

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Figure 2: Hot Leg Surge Nozzle Safe-end Pre-MSIP Allowable Flaw Depth Ratios – Level A Condition
(Allowable bending stresses with & w/o stratification are almost identical and hence overlap in the above graph)

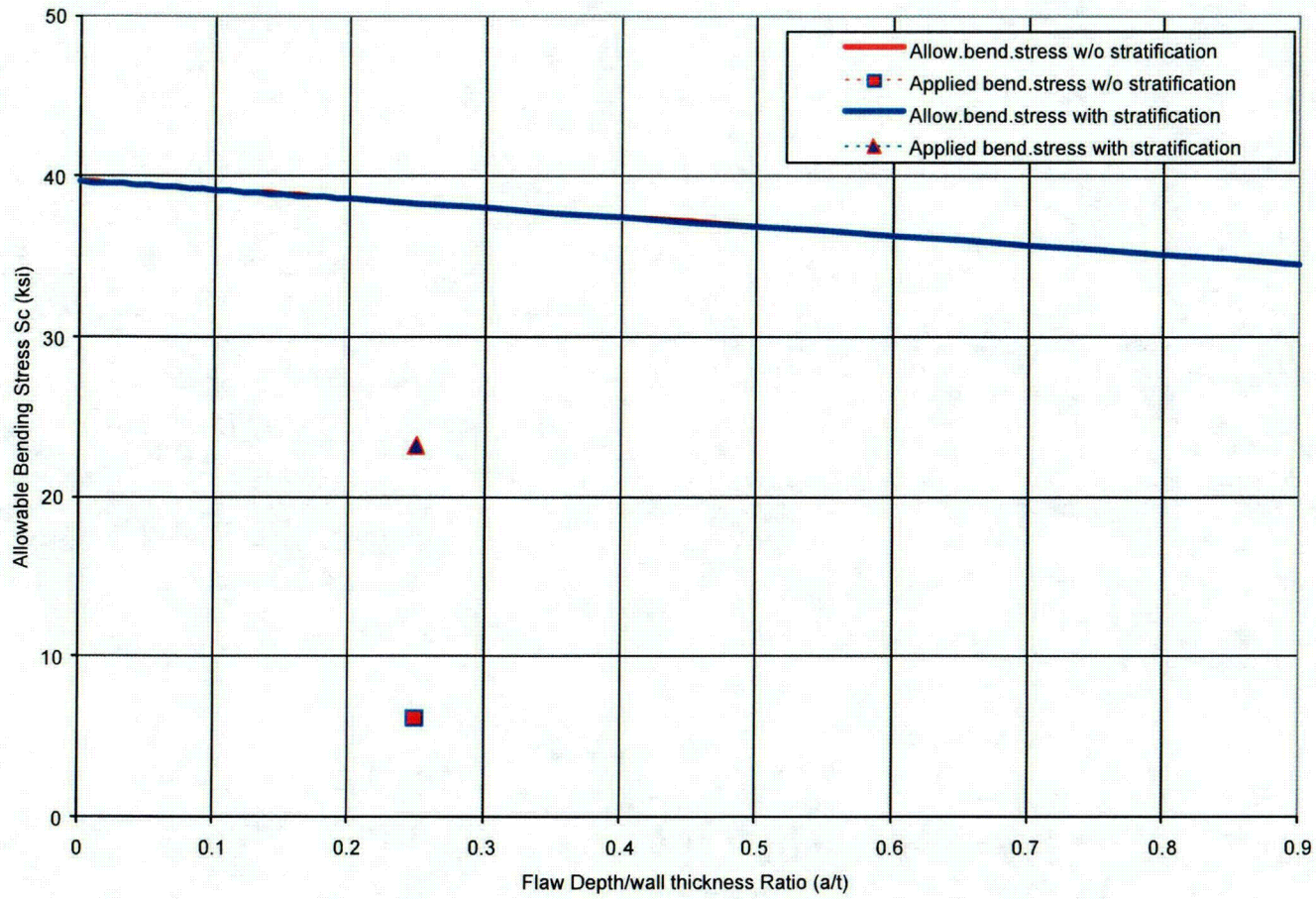

Figure 3: Hot Leg Surge Nozzle Safe-end Pre-MSIP Allowable Flaw Depth Ratios – Level C Condition
(Allowable bending stresses with & w/o stratification are almost identical and hence overlap in the above graph)

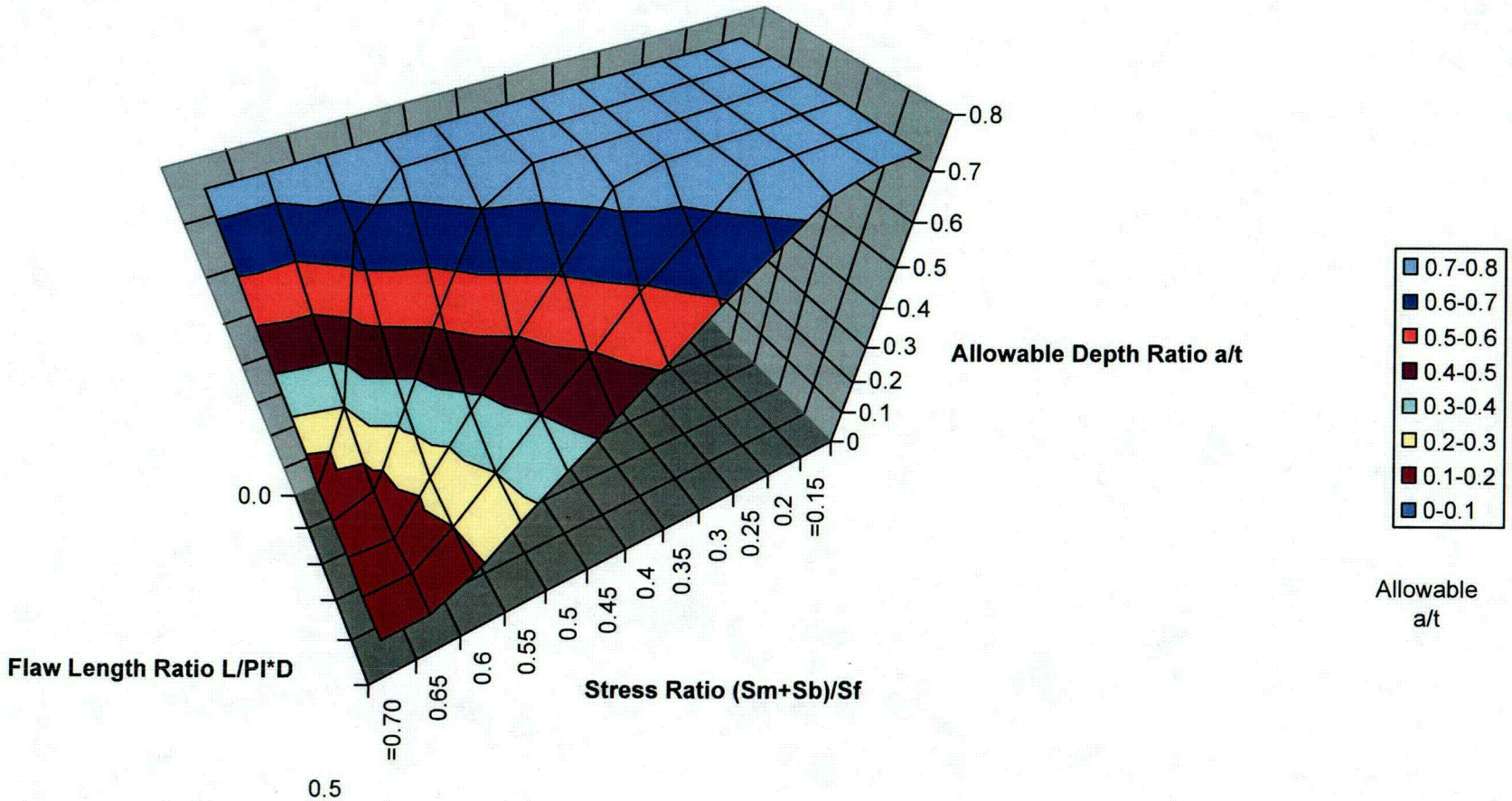

Figure 4: Hot Leg Surge Nozzle Safe-end Pre-MSIP Allowable Flaw Depth Ratios – Level B Condition
a) Allowable Flaw Depth Ratios vs. Stress Ratio and Flaw Length Ratio

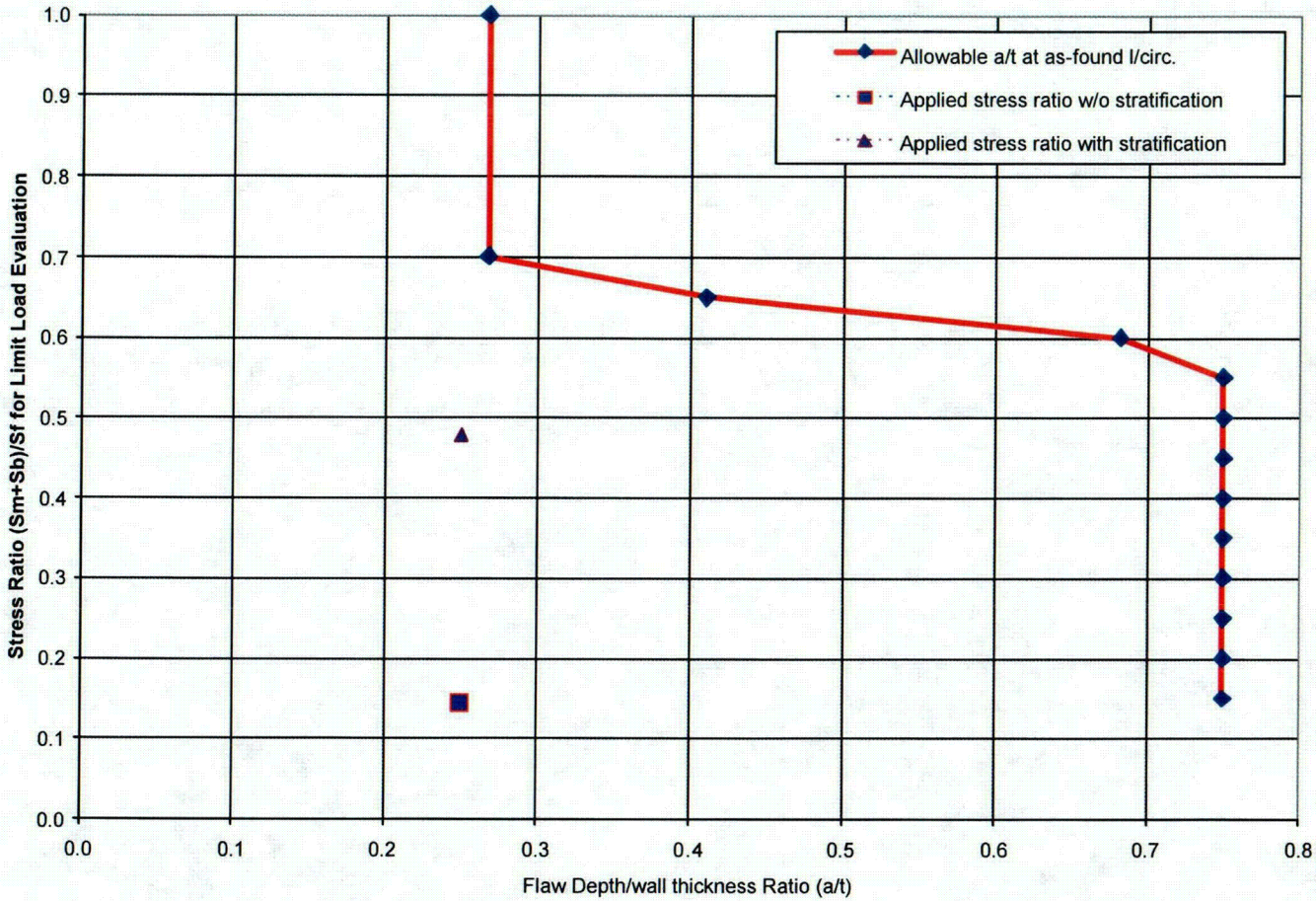

Figure 4: Hot Leg Surge Nozzle Safe-end Pre-MSIP Stress Ratio vs. Flaw Depth Ratio– Service Level A
b) Allowable Flaw Depth Ratio vs. Stress Ratio

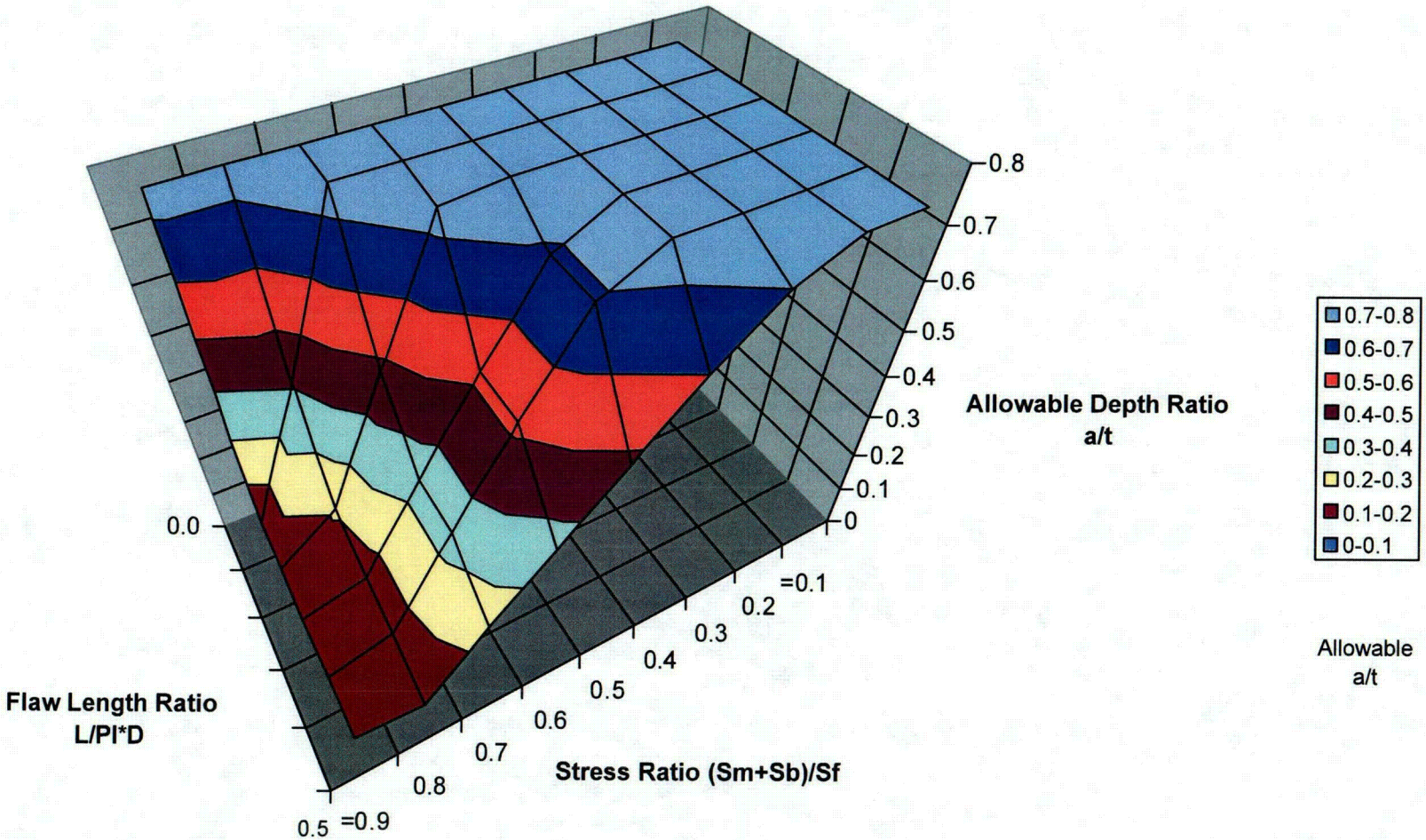

Figure 5: Hot Leg Surge Nozzle Safe-end Pre-MSIP Allowable Flaw Depth Ratio vs. Stress Ratio – Level C Condition
a) Allowable Flaw Depth Ratios vs. Stress Ratio and Flaw Length Ratio

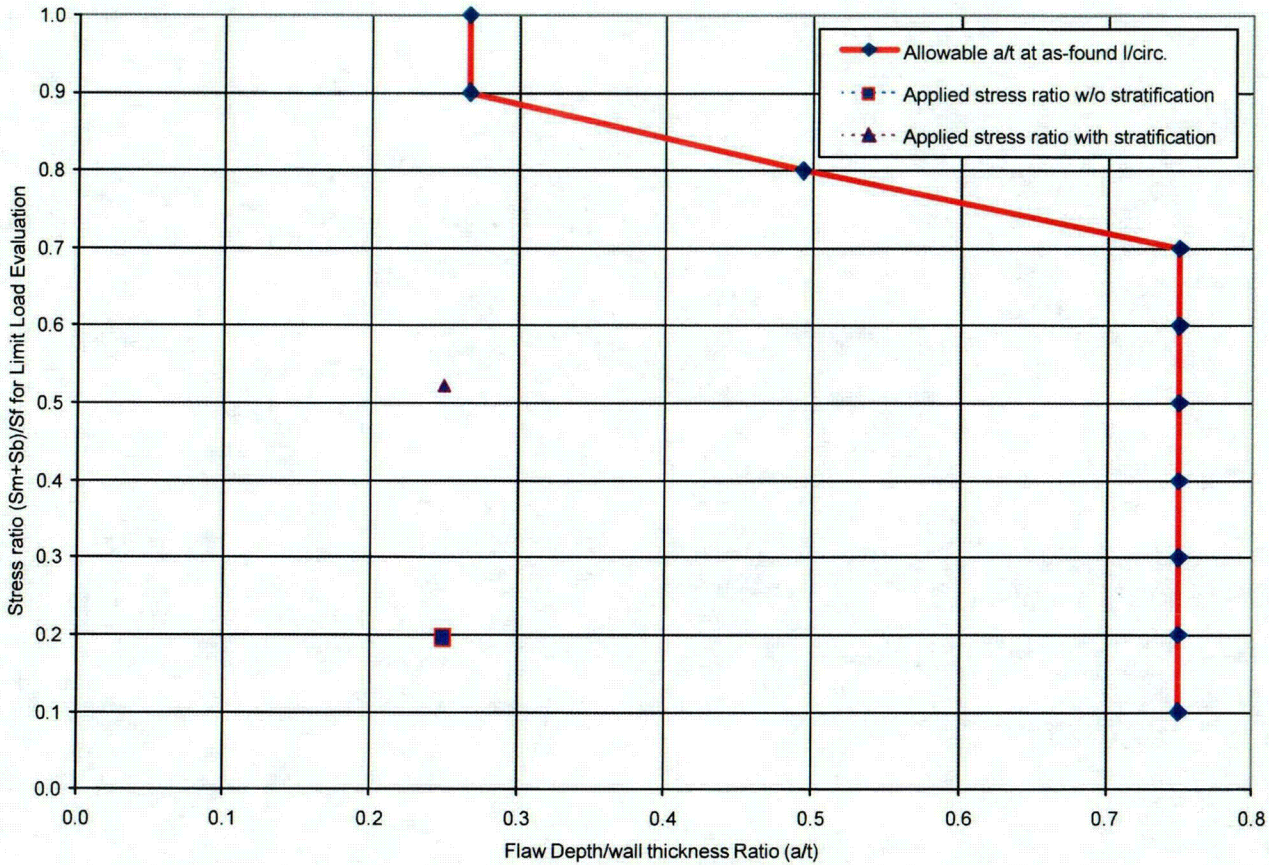

Figure 5: Hot Leg Surge Nozzle Safe-end Pre-MSIP Allowable Flaw Depth Ratio vs. Stress Ratio – Level C Condition
b) Allowable Flaw Depth Ratio vs. Stress Ratio

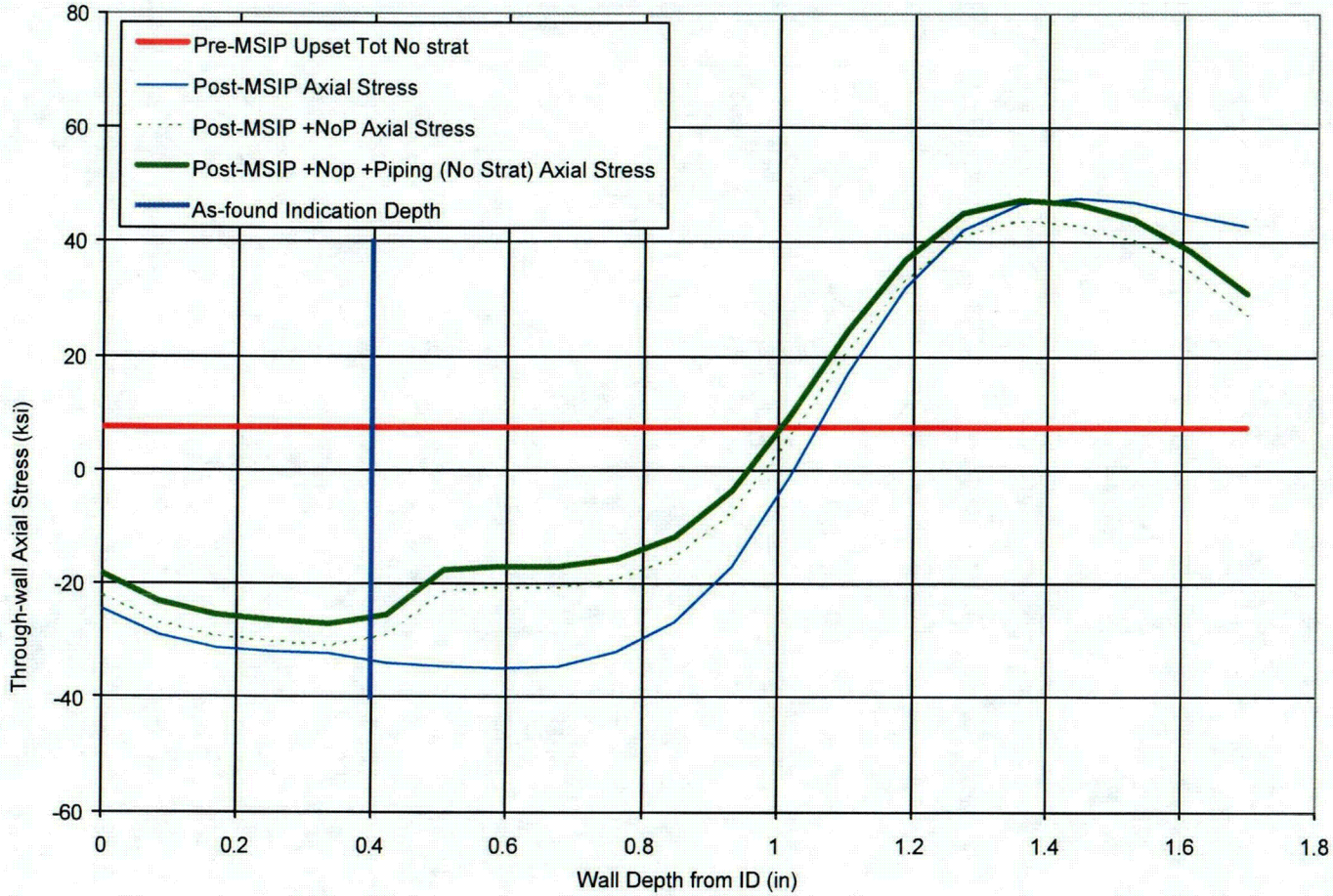

Figure 6: Hot Leg Surge Nozzle Safe-end Pre- and Post-MSIP Through-wall Axial Stress Distribution, No Stratification

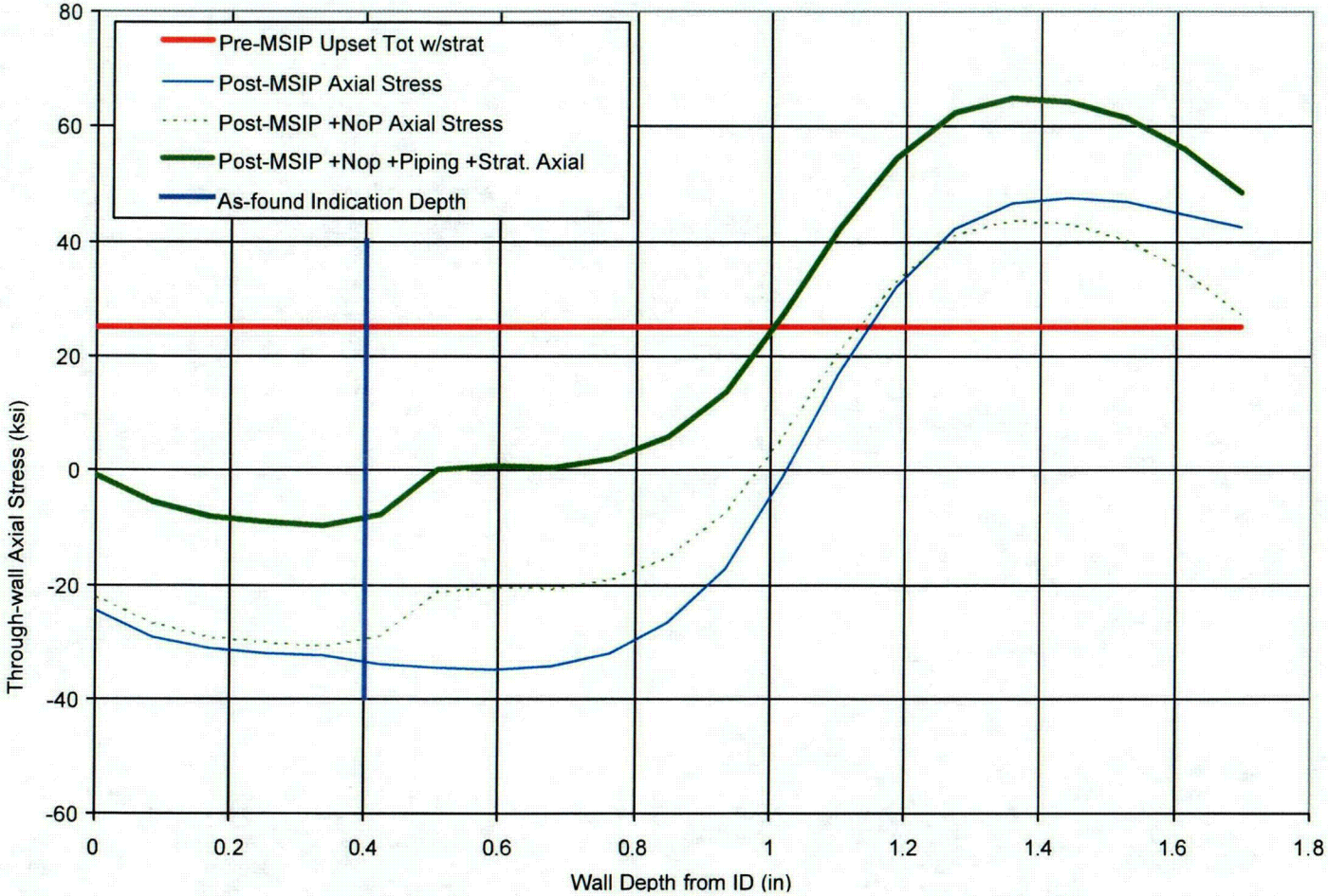

Figure 7: Hot Leg Surge Nozzle Safe-end Pre- and Post-MSIP Through-wall Axial Stress Distribution, with Stratification

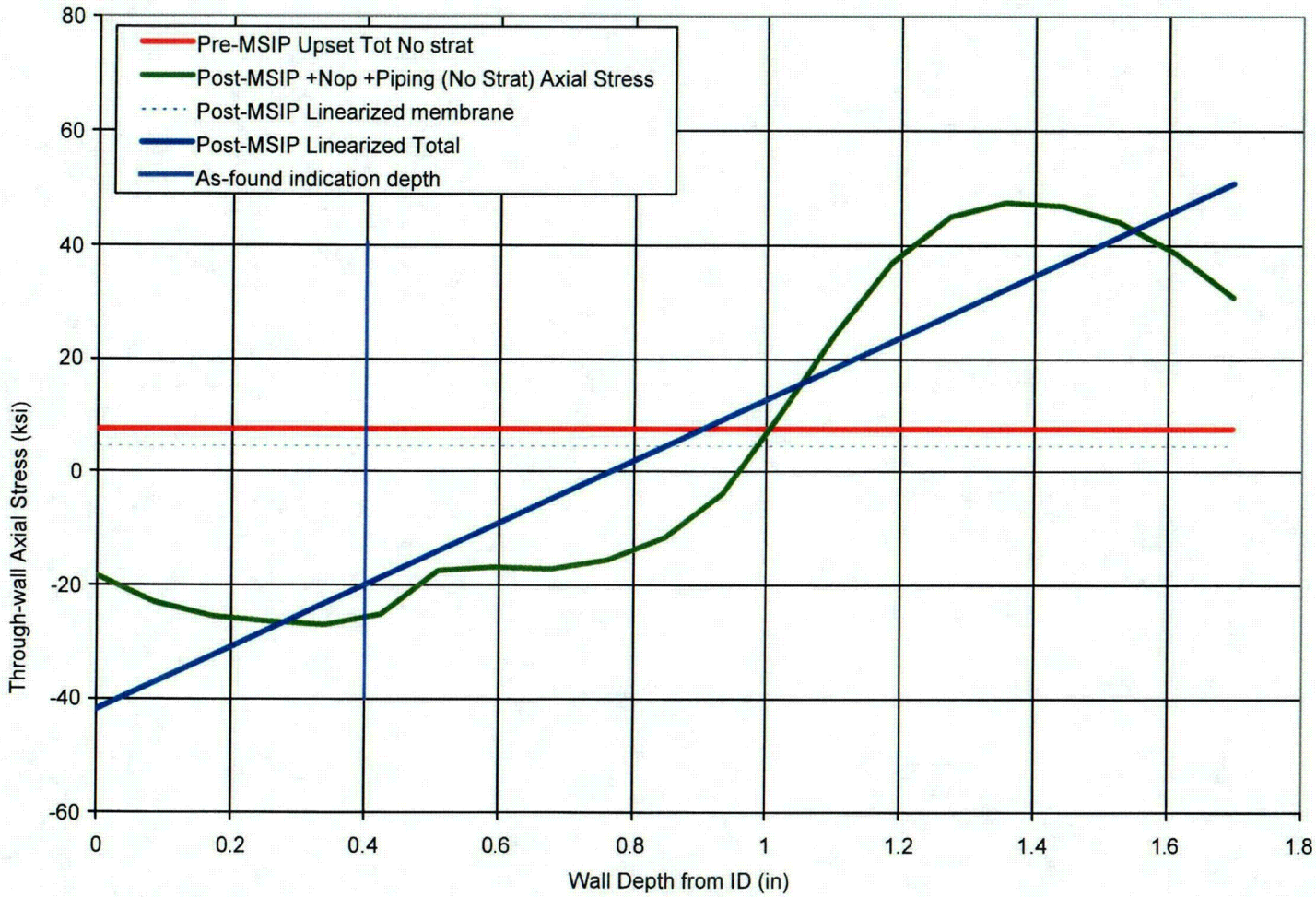

Figure 8: Hot Leg Surge Nozzle Safe-end Post-MSIP Linearized Through-wall Axial Stress Distribution, No Stratification

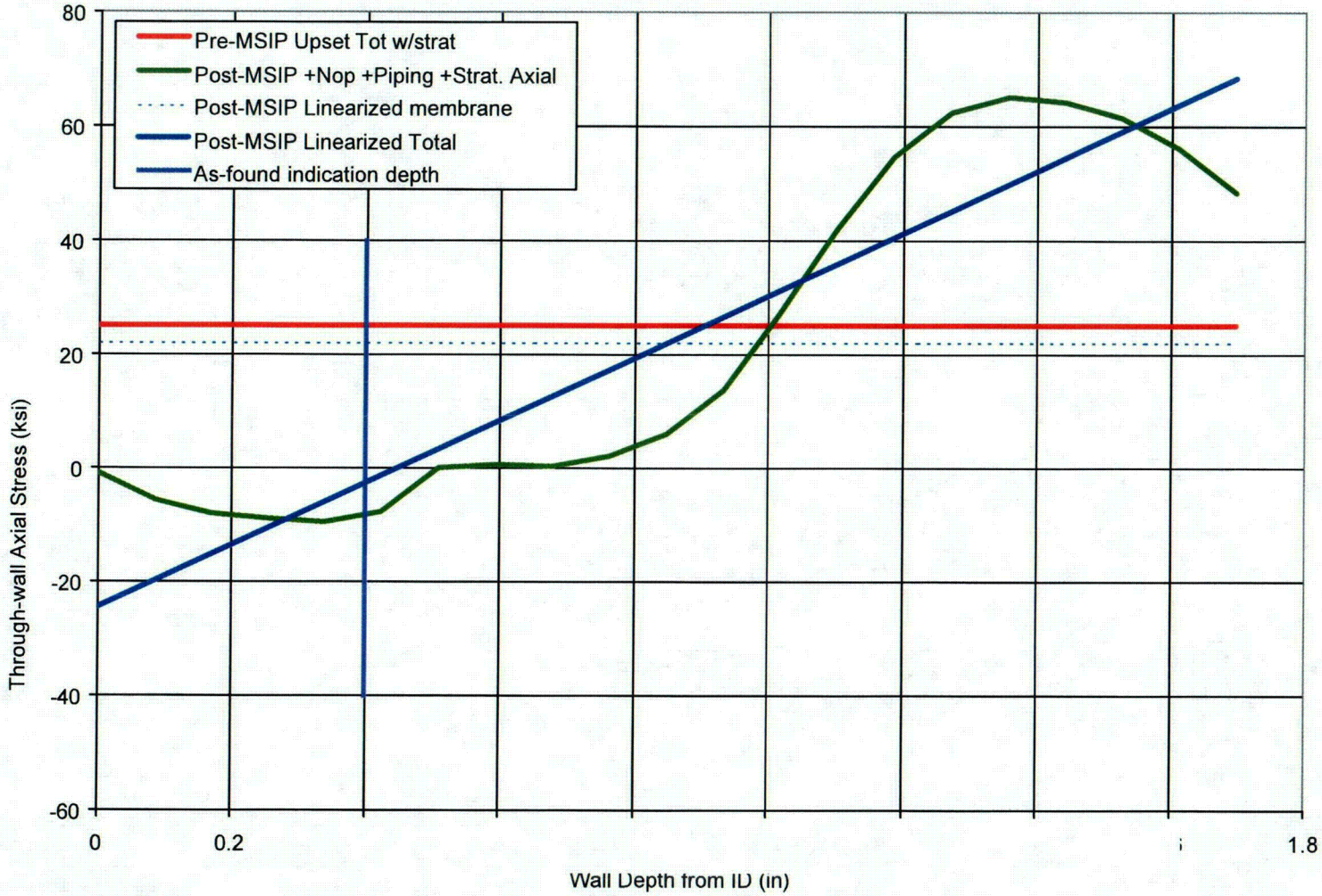

Figure 9: Hot Leg Surge Nozzle Safe-end Post-MSIP Linearized Through-wall Axial Stress Distribution, with Stratification

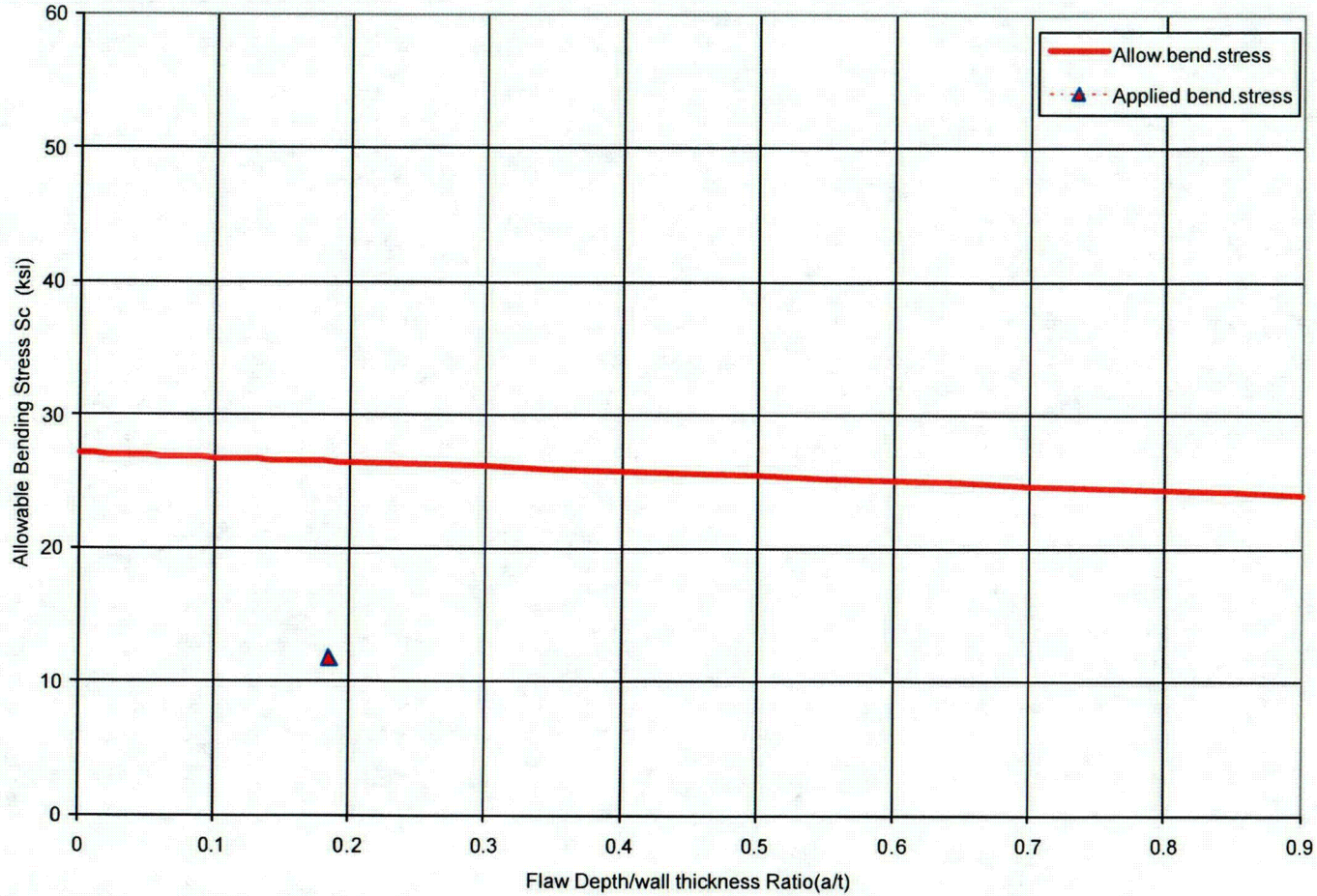

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Figure 10: Hot Leg Drain Nozzle Safe-end Pre-MSIP Allowable Flaw Depth Ratios – Level A Condition

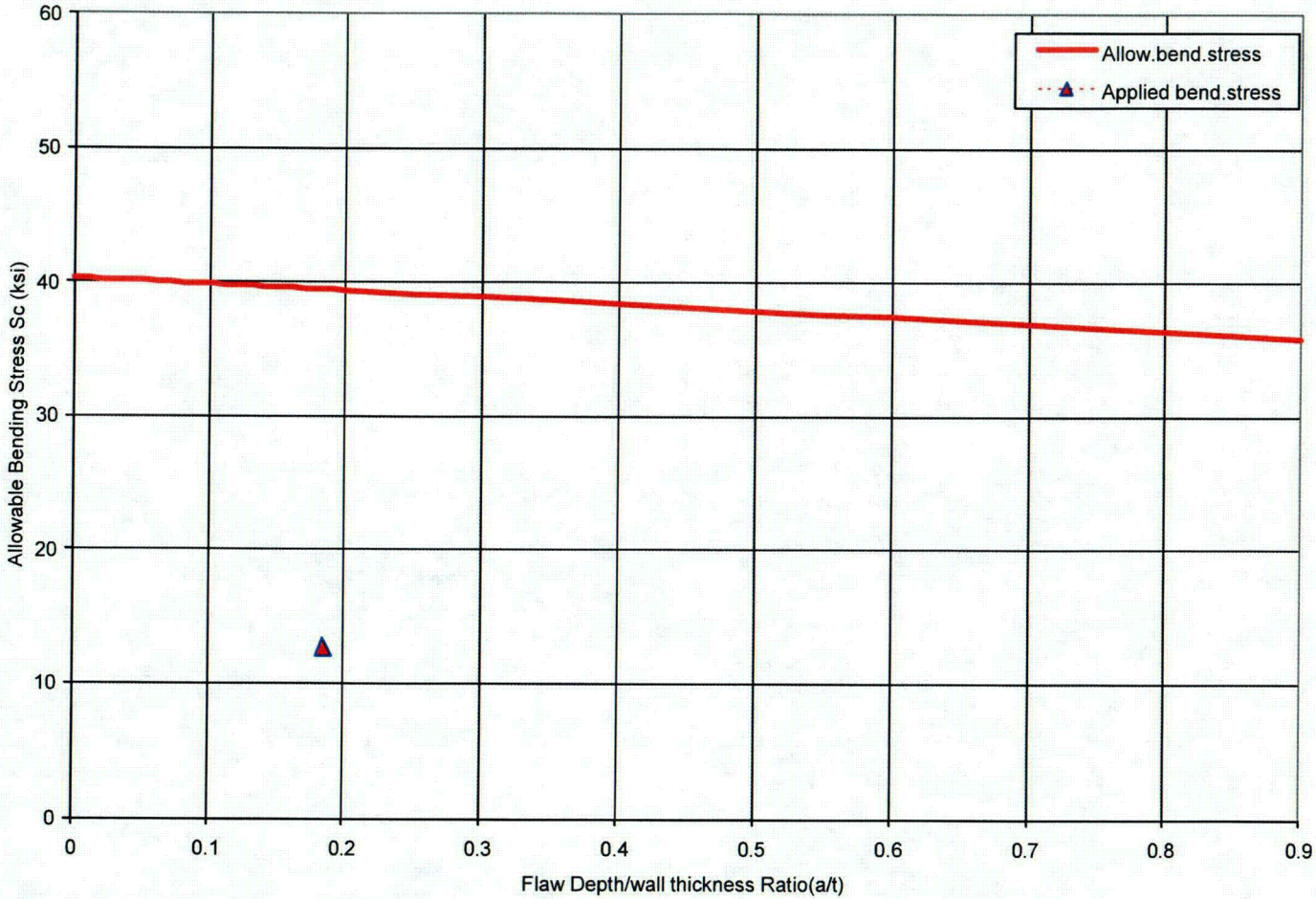

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Figure 11: Hot Leg Drain Nozzle Safe-end Pre-MSIP Allowable Flaw Depth Ratios – Level C Condition

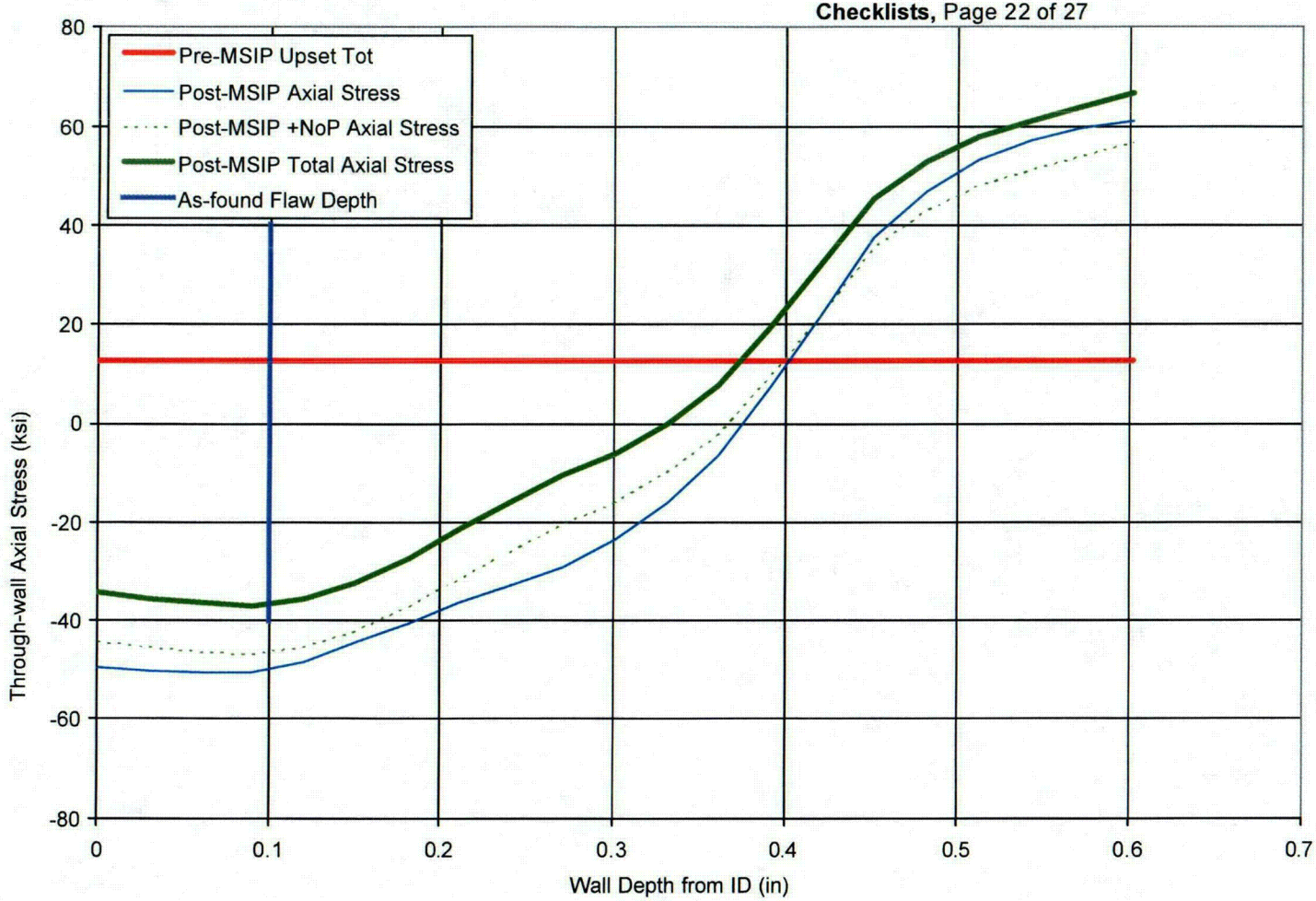

Figure 12: Hot Leg Drain Nozzle Safe-end Pre- and Post-MSIP Through-wall Axial Stress Distribution

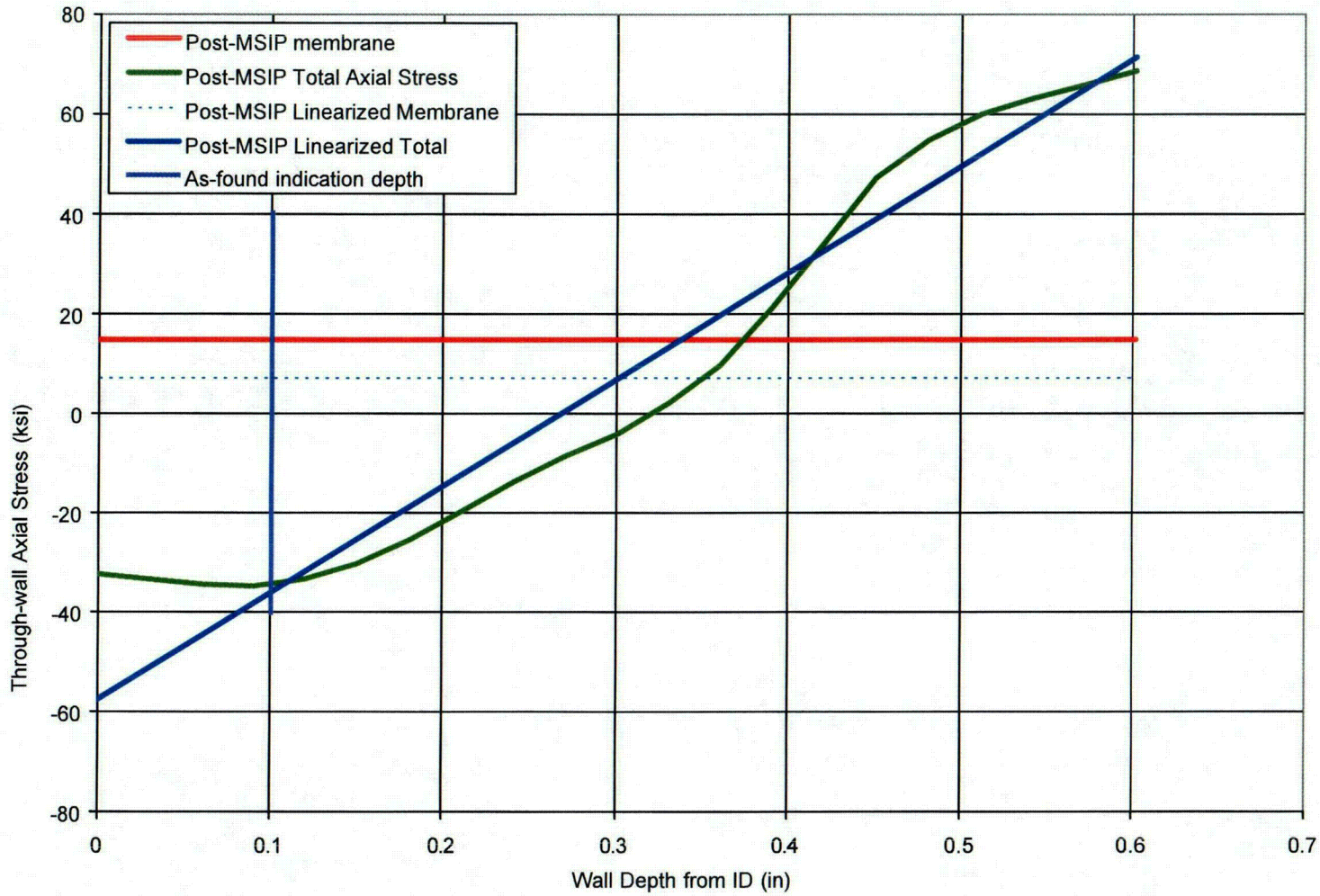

Figure 13: Hot Leg Drain Nozzle Safe-end Post-MSIP Linearized Through-wall Axial Stress Distribution

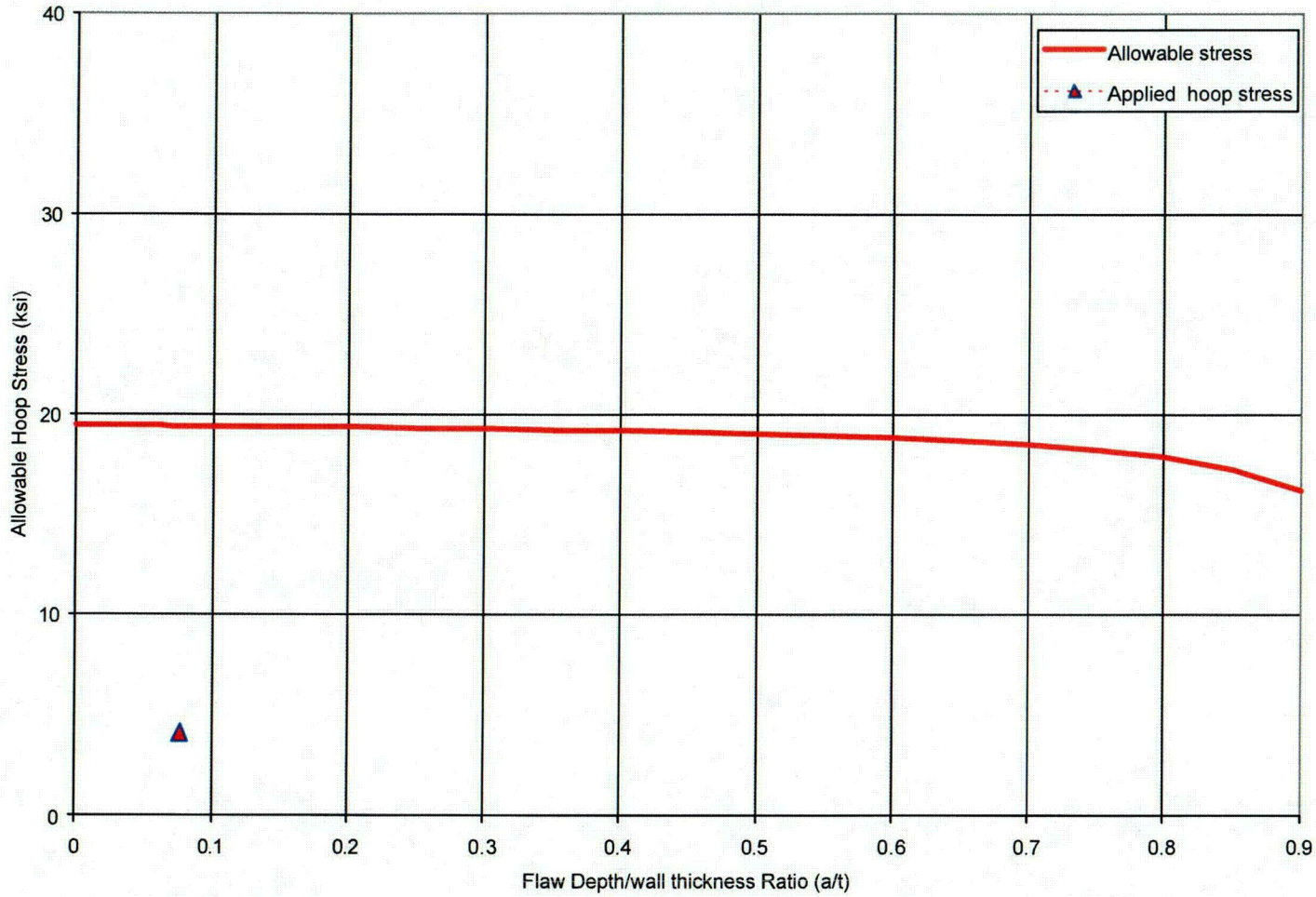

Figure 14: Pressurizer Relief Nozzle Safe-end Pre-MSIP Allowable Flaw Depth Ratios

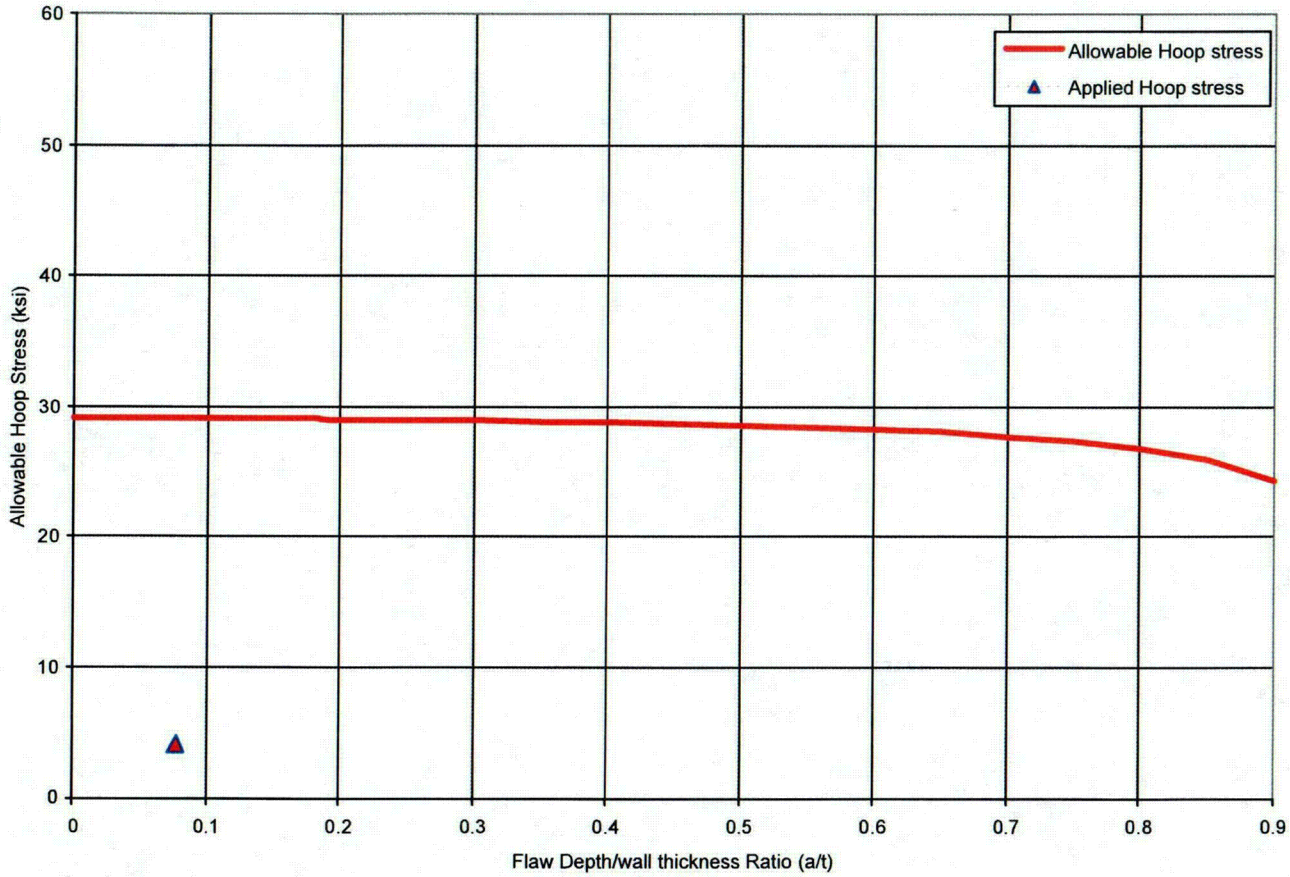

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Figure 15: Pressurizer Relief Nozzle Safe-end Pre-MSIP Allowable Flaw Depth Ratios, Service Level C

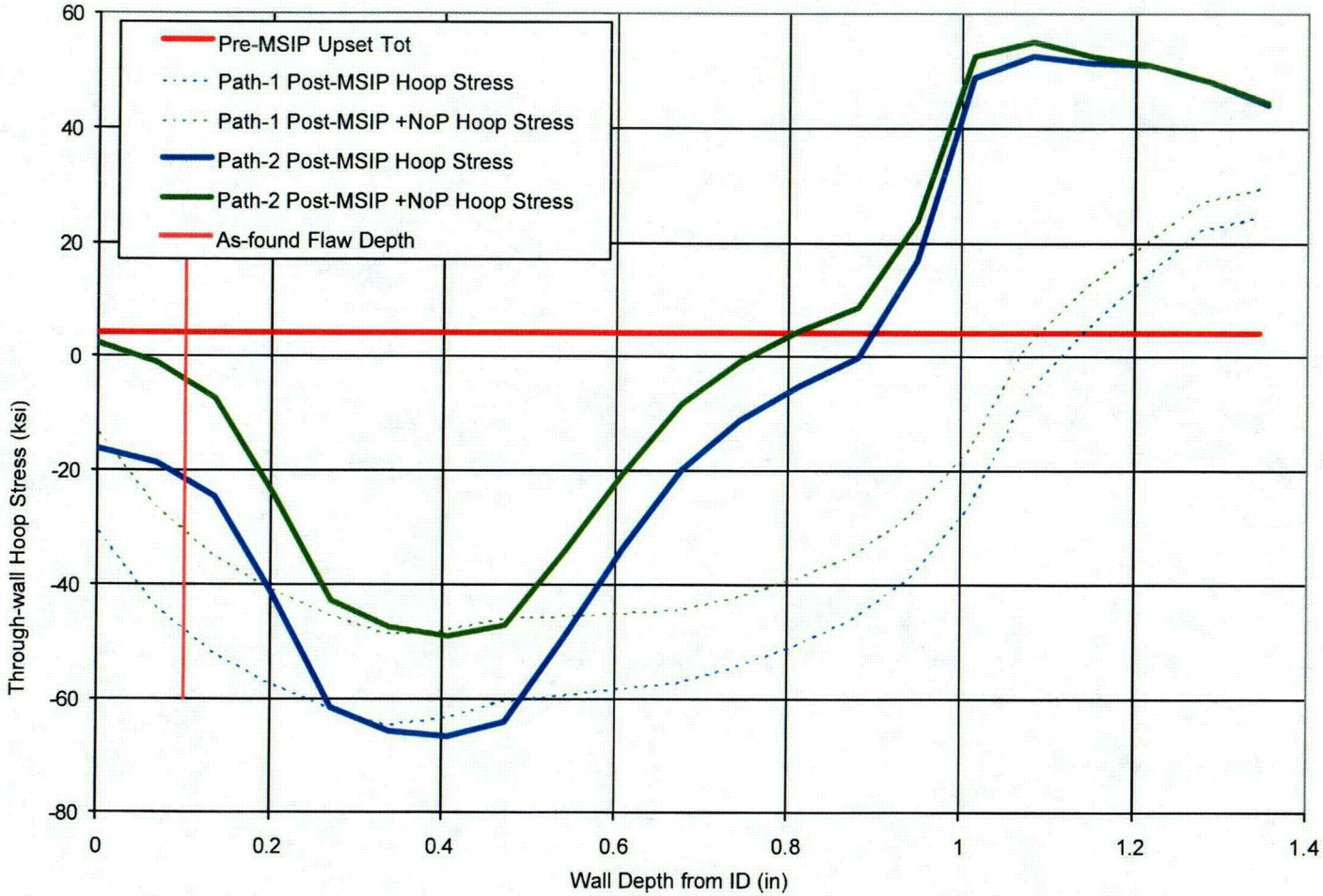

Figure 16: Pressurizer Relief Nozzle Safe-end Pre- and Post-MSIP Through-wall Hoop Stress Distribution, Paths 1 & 2

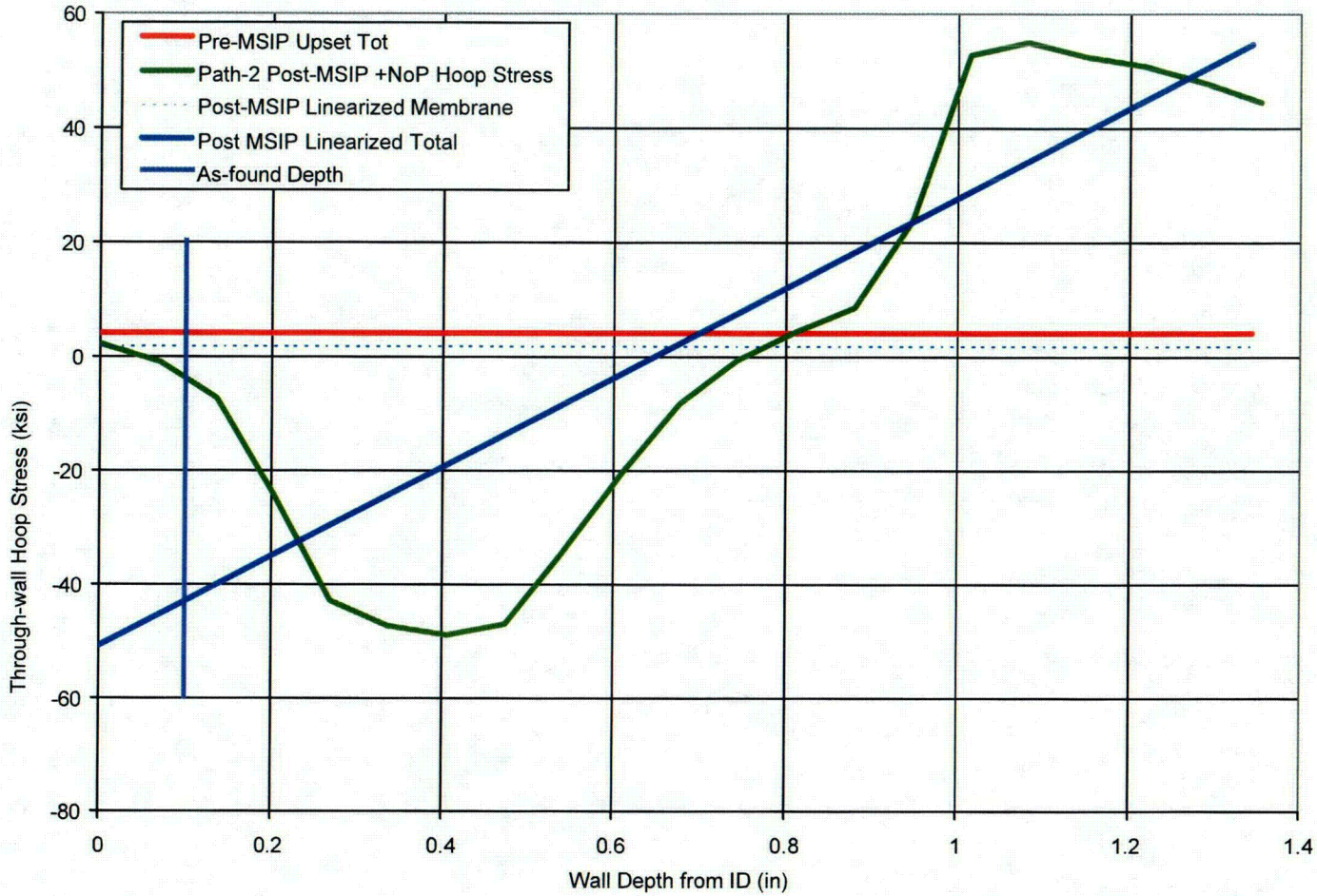

Figure 17: Pressurizer Relief Valve Nozzle Safe-end Post-MSIP Linearized Through-wall Hoop Stress Distribution