ENCLOSURE 13

TN AMERICAS LLC CALCULATION 11042-0207, REVISION 1

NUHOMS® 61BTH TYPE 1 DSC ITCP AND OTCP
MAXIMUM WELD FLAW EVALUATION

34 pages follow

orano	Form 3.2-1 Calculation Cover Sheet Revision 13	Calculation No.:	11042-0207
		Revision No.:	1
		Page: 1 of 34	

DCR NO (if applicable): 1001150-00	**PROJECT NAME:** NUHOMS® 61BTH Type 1 DSCs for Monticello Nuclear Generating Plant
PROJECT NO: 11042	**CLIENT:** Xcel Energy

CALCULATION TITLE:
NUHOMS® 61BTH Type 1 DSC ITCP and OTCP Maximum Weld Flaw Evaluation

SUMMARY DESCRIPTION:

1) Calculation Summary

This calculation qualifies Monticello 61BTH Type 1 DSCs 11-15 with the maximum flaws in the Inner Top Cover Plate (ITCP) and Outer Top Cover Plate (OTCP) closure welds.

2) Storage Media Description

Rev. 0 and Rev. 1: Coldstor - \areva_tn\11042\11042-0207-000

If original issue, is licensing review per TIP 3.5 required?
Yes ☐ **No** ☐ **(explain below)** **Licensing Review No.:**

N/A

Software utilized (subject to test requirements of TIP 3.3):	Software Version:	Software Log Revision:
ANSYS	17.1	35

Calculation is complete Originator Name and Signature: Samuel Tissot	**Date:** 03/19/2018
Calculation has been checked for consistency, completeness, and correctness Checker Name and Signature: Daran Ossinger	**Date:** 03/19/2018
Calculation is approved for use Project Engineer Name and Signature: Raheel Haroon	**Date:** 3/22/2018

REVISION SUMMARY

Rev.	Description	Affected Pages	Affected Files
0	Initial issue	All	All
1	Revision per DCR 1001150-00 to provide NRC with the needed information from RAI ST-1	1-2, 6	None

TABLE OF CONTENTS

Page

1.0 PURPOSE 5
2.0 ASSUMPTIONS 5
3.0 DESIGN INPUT/DATA 5
3.1 Flaw Details and Geometry 5
3.2 Material Properties 5
3.3 Design Criteria 5
4.0 METHODOLOGY 6
4.1 Analysis Method and Acceptance Criteria 6
4.2 FEA Model Details 6
4.3 Limit Load Solution Details 6
4.4 Elastic Plastic Solution Details 6
4.5 Load Cases 7
5.0 REFERENCES 8
6.0 ANALYSIS AND RESULTS 8
6.1 LIMIT LOAD ANALYSIS 8
6.1.1 2D-Axisymmetric Analyses for Internal Pressure 8
6.1.2 3D-Half Symmetric Analyses for Side Drop Loading 8
6.2 ELASTIC-PLASTIC ANALYSIS 8
6.2.1 2D-Axisymmetric Analyses for Internal Pressure 8
6.2.2 3D-Half Symmetric Analyses for Side Drop Loading 9
7.0 DISCUSSION AND CONCLUSIONS 9
8.0 LISTING OF COMPUTER FILES 10
APPENDIX A 31

LIST OF TABLES

Page

Table 1 – Internal Pressure in the 61BTH Type 1 DSC (Ref. [5.3]) 11
Table 2 – Maximum Temperatures in the 61BTH Type 1 DSC Shell (Ref. [5.3]) 11
Table 3 – Properties of SA-240 Type 304. Ref. [5.3] 12
Table 4 – Properties of SA-36. Ref. [5.3] 13
Table 5 – Summary of Limit Load Analysis for the maximum weld flaws 14
Table 6 – Summary of Peak Strain Values for Elastic-Plastic Analyses for the maximum weld flaws 14
Table 7 – Summary of Elastic-Plastic Analysis Results for the maximum weld flaws 15

LIST OF FIGURES

Page

Figure 1 – Weld Flaws in Original Model (Ref. [5.3]) 16
Figure 2 – Maximum Weld Flaws based on the allowed design limits 16
Figure 3 – Overview of the 2D-Axisymmetric Model 17
Figure 4 – Mesh Details at the Welds for 2D-Axisymmetric Model 17
Figure 5 – Flaw Locations for 2D-Axisymmetric Model 18
Figure 6 – Overview of the 3D-Half-Symmetric Model 19
Figure 7 – Detail Views and Mesh Plots of the 3D-Half Symmetric Model 20
Figure 8 – Isometric Views of 3D-Half-Symmetric Model 21
Figure 9 – Results of Limit Load for 2D-Axisymmetric Model – Service Level A/B 22
Figure 10 – Results of Limit Load for 2D-Axisymmetric Model – Service Level D 23
Figure 11 – Deflection at the Center of the OTCP for the 2D-Axisymmetric Model for Limit Load 24
Figure 12 – Equivalent Plastic Strain at 32 psi for 2D-Axisymmetric Elastic Plastic Analysis - SL A/B Internal Pressure 25
Figure 13 – Equivalent Plastic Strain at 65 psi for 2D-Axisymmetric Elastic Plastic Analysis - SL D Internal Pressure 26
Figure 14 – Equivalent Plastic Strain at 100 psi for 2D-Axisymmetric Elastic Plastic Analysis - SL D Internal Pressure 27
Figure 15 – Equivalent Plastic Strain Plots for 3D-Half-Symmetric Limit Load Analysis – SL D Side Drop with Off-Normal Internal Pressure 28
Figure 16 – Equivalent Plastic Strain at 75g for 3D-Half-Symmetric Elastic-Plastic Analysis - SL D Side Drop 29
Figure 17 – Equivalent Plastic Strain at 112.5g for 3D-Half-Symmetric Elastic-Plastic Analysis - SL D Side Drop 30

1.0 PURPOSE

The purpose of this calculation is to evaluate NUHOMS® 61BTH Type 1 (DSCs 11-15) at the Monticello Nuclear Generating Plant (MNGP) per ASME Section III criteria with the maximum flaws in the Inner and Outer Top Cover Plates (ITCP and OTCP) closure welds based on the evaluation performed in the reference calculation [5.3].

2.0 ASSUMPTIONS

1. Assumptions 1 through 6 of Ref. [5.3] are applicable to this calculation.
2. The flaws (at the same locations as Ref. [5.3]) are allowed to be increased until the design limits criteria are reached.
3. The DSC design in this calculation is typical of MNGP DSCs 11-16, and the modeled baseline flaws are representative of those indications identified by Phased Array Ultrasonic examination (PAUT) of DSC 16 (performed in 2015).

3.0 DESIGN INPUT/DATA

3.1 Flaw Details and Geometry

Two cases of flaws are described and analyzed in Ref. [5.3]. The ITCP weld flaw is the same for both cases, and OTCP increased weld flaw covers both sets (case #1 & case #2 weld flaws). The results of Limit load for both cases are very similar. Figure 1 shows OTCP & ITCP flaws in the reference model (Flaw case #1 and Flaw case #2) and Figure 2 shows maximized OTCP & ITCP flaws evaluated in this calculation.

3.2 Material Properties

The material properties for the DSC structure are identical to Ref. [5.3]. They are duplicated here in Table 3 and Table 4.

3.3 Design Criteria

All of the applicable design bases loading conditions are considered in accordance with the requirements of ASME Section III Subsection NB Ref. [5.2]. Section 4.1 details the methods used to perform the code Ref. [5.2] qualifications. The uncertainties in the PAUT examination are accounted for by using a 0.8 reduction factor on the limit load. This factor is in agreement with ISG-15, conservatively accounts for any additional limitations in the PAUT examinations. This weld uncertainty factor of 0.8 is applied to the minimum of the ASME specified minimum elongation of SA-240 304 (40%) and E308-XX (35%). Therefore strain limit is taken as 0.8*35=28% Ref. [5.3].

4.0 METHODOLOGY

4.1 Analysis Method and Acceptance Criteria

The analysis methods, finite element models details and acceptance criteria are the same as discussed in Ref. [5.3]. The ITCP and OTCP weld flaws are maximized and analyzed per Limit load and Elastic Plastic analyses.

The flaws are modeled by disconnected nodes, leaving open edges along elements to represent weld flaws. Initially, the flaw modeled in Calculation 11042-0205 Ref. [5.3] was increased minimally to confirm the impact of each modeling change. A larger flaw size resulted in higher plastic strain. Second, an unrealistic flaw was created where only one element of the weld was connected. This model resulted in plastic strains which exceeded the ASME code strain limits. Elastic-plastic analyses were repeated with different flaw sizes until the maximum plastic strain was slightly below the ASME code acceptance limit. The preliminary analyses to determine the maximum flaw size are not included here, and only the final flaw configuration (see Figure 2) is presented in this document. Limit Load analyses were only performed for the final flaw configuration.

4.2 FEA Model Details

Finite element models of the top half of the 61BTH DSC are used based on Ref. [5.3]. The models fall into two basic categories: axisymmetric (2D) and half-symmetric (3D). The original evaluation in Ref. [5.3] uses ANSYS 14.0. The evaluation in this calculation uses ANSYS 17.1 Ref. [5.1]. APPENDIX A performs the sensitivity analysis between the 2 ANSYS versions. As discussed in APPENDIX A, the default ANSYS 17.1 contacts stiffness's for the 3D-Half-Symmetric model were modified to match the default ANSYS 14.0 stiffness's.

The models were modified to increase the weld flaws as described in Section 4.1.

Axisymmetric Model (2D)

An axisymmetric model is used as described in Section 4.3.1 of Ref. [5.3]. Figure 3 to Figure 5 show images of the axisymmetric model with maximum flaws.

Half-Symmetric Model (3D)

A half-symmetric model is used as described in Section 4.3.4 of Ref. [5.3]. Figure 6 to Figure 8 show images of the half-symmetric model with maximum flaws.

4.3 Limit Load Solution Details

Limit load solution details are the same as detailed in Section 4.4 of Ref. [5.3].

4.4 Elastic Plastic Solution Details

Elastic Plastic solution details are the same as detailed in Appendix-A of Ref. [5.3].

4.5 Load Cases

The analyses performed in this calculation, are based on the conservative design values for internal pressure loading, rather than the actual calculated values of internal pressure. Table 1 summarizes the conservative design values as well as the actual calculated values which are taken from Ref. [5.3].

Temperatures used for the material properties for each Service Level condition are listed in Table 2.

Four 2D-Axisymmetric analyses for bounding Service Level (SL) A/B and D, and two 3D-Half-Symmetric analyses for bounding SL D are performed in this calculation.

5.0 REFERENCES

5.1. ANSYS Version 17.1. ANSYS Inc. (Including the ANSYS Mechanical APDL Documentation).

5.2. ASME Boiler and Pressure Vessel Code, Section III Subsection NB. 1998 Edition with Addenda through 2000.

5.3. AREVA Document No. 11042-0205 Revision 3. “61BTH ITCP and OTCP Closure Weld Flaw Evaluation”

5.4. ASME Section II Part A. Ferrous Material Specifications. 1998 Edition with Addenda through 2000.

5.5. ASME Section II Part C. Specifications for Welding Rods, Electrodes, and Filler Metals 1998 Edition with Addenda through 2000

6.0 ANALYSIS AND RESULTS

6.1 LIMIT LOAD ANALYSIS

6.1.1 2D-Axisymmetric Analyses for Internal Pressure

Two analyses are performed with the 2D-Axisymmetric model: one case for Service Level A/B and the other case for Service Level D. The collapse pressures were determined to be 86.3 psi for Service Level A/B and 122.2 psi for Service Level D. Figure 9 shows various plots of the plastic strain for Service Level A/B at various locations and levels of loading. Figure 10 shows various plots of the plastic strain for Service Level D. These strain plots are also representative of the behavior of the Service Level D analysis. Figure 11 shows the deflection history at the center of the lid, and indicates the expected plastic instability that occurs as the limit load is approached. Note that both the strains and displacements presented in these figures show only the load (pressure) at which the solution fails to converge.

6.1.2 3D-Half Symmetric Analyses for Side Drop Loading

The 3D-half-symmetric model described in Section 4.2 is used to perform the side-drop limit load analysis. The case includes the side-drop acceleration loading of 75g as well as the off-normal internal pressure of 20 psi. The collapse g-load for side-drop loading was found to be approximately 179.5g. Plots of the plastic strains in the side drop analyses are shown in Figure 15.

The results for Limit load analysis are summarized in **Table 5**.

6.2 ELASTIC-PLASTIC ANALYSIS

6.2.1 2D-Axisymmetric Analyses for Internal Pressure

Two analyses are performed with the 2D-Axisymmetric model: one case for Service Level A/B and the other case for Service Level D. The Equivalent Plastic Strain was determined to be 3.1% for Service Level A/B pressure and 7.4% for Service Level D pressure. Figure 12 shows plot of the plastic strain for Service Level

A/B. Figure 13 shows plot of the plastic strain for Service Level D. The results for elastic-plastic analyses are summarized in

Table 7. As shown by the results, the strain levels remain well below the minimum specified elongation limits of Type 304 steel and Type 308 weld electrodes Ref. [5.4] and Ref. [5.5]. Therefore, material rupture will not occur at the design conditions.

The maximum strains at loads up to 1.5x the specified loading are also extracted. These results are shown in Table 6, which also includes a comparison of the peak strain values to the ductility limit of the material reduced by the weld uncertainty factor of 0.8 discussed in Section 3.4 of Ref. [5.3].

6.2.2 3D-Half Symmetric Analyses for Side Drop Loading

The 3D-half-symmetric model described in Section 4.2 is used to perform the SL D side-drop limit load analysis. The case includes the 75g side-drop acceleration loading only. The maximum strains at loads up to 1.5x the specified loading (112.5g) are also extracted and compared with the material strain limit.

The equivalent plastic strain was determined to be 11.1% for 75g and 23.0% for 112.5g presented in Table 6. Figure 16 and Figure 17 show the corresponding plastic strain plots. The results for elastic-plastic analyses are summarized in Table 7.

7.0 DISCUSSION AND CONCLUSIONS

This calculation qualifies the NUHOMS® 61BTH Type 1 (DSCs 11-15) at the Monticello Nuclear Generating Plant with maximum weld flaw using a combination of limit load analyses and elastic-plastic analyses. The limit load analyses are used to show that the DSC satisfies the primary stress limits of ASME Section III Subsection NB. The elastic-plastic analyses are used to show that the actual predicted strain values are below the material ductility limits. Both the limit load and elastic-plastic analyses account for any remaining uncertainty in the weld (e.g. non-inspected weld regions and PAUT technique limitations) by including an uncertainty factor of 0.8 which is described in detail in Section 3.4 of Ref. [5.3].

For both OTCP and ITCP, all weld flaws were maximized such that the weld flaw reaches close to acceptable design limits. The maximum modeled weld flaws for OTCP to DSC shell weld are 0.43" and 0.42" in length, which represents about 85% through-wall of the 0.5-inch minimum weld throat. The maximum modeled full-circumferential weld flaws for ITCP to DSC shell weld are 0.16" * cos(45°)=0.11" and 0.14" in length, which represents respectively 58% and 74% through-wall of the 0.19-inch minimum weld throat as shown in Figure 2. All four assumed flaws represent defects spreading over more than one weld bead. These flaws were located based on DSC #16 PAUT results and are considered representative locations for DSC's # 11 to 15.

8.0 LISTING OF COMPUTER FILES

Finite Element Analyses were performed using ANSYS Version 17.1 Ref. [5.1]. All analyses were performed on HPC v2 Linux platform.

Load Case	Analysis Type	File Name	Description	Date / Time[1]
Internal Pressure 2D-Axisymmetric model	Limit load analysis SL- A/B	61BTH_WeldFlaw_1F_AX_2_DETACH.db	Reference .db file for Axisymmetric SL-A/B Limit load analysis	Note [2]
		AXISYMM_IP_LimitLoad.ext .ext = .inp, .err, .mntr, .out, .db, .rst	Limit load analysis files for SL- A/B	06/20/2017 11:33:31
	Limit load analysis SL- D	61BTH_WeldFlaw_1F_AX_2_DETACH.db	Reference .db file for Axisymmetric SL- D Limit load analysis	Note [2]
		AXISYMM_IP_LimitLoad_SLD.ext .ext = .inp, .err, .mntr, .out, .db, .rst	Limit load analysis files for SL- D	06/20/2017 12:29:27
	Elastic-plastic analysis SL- A/B	61BTH_WeldFlaw_1F_AX_2_DETACH.db	Reference .db file for Axisymmetric SL-A/B Elastic-plastic analysis	Note [2]
		AXISYMM_IP_500F.ext .ext = .inp, .err, .mntr, .out, .db, .rst	Elastic-plastic analysis files for SL-A/B	06/20/2017 12:34:31
	Elastic-plastic analysis SL- D	61BTH_WeldFlaw_1F_AX_2_DETACH.db	Reference .db file for Axisymmetric SL-A/B Elastic-plastic analysis	Note [2]
		AXISYMM_IP_625F.ext .ext = .inp, .err, .mntr, .out, .db, .rst	Elastic-plastic analysis files for SL-D	06/20/2017 12:39:21
Side Drop 3D-Half-Symmetric model	Limit load analysis SL- D	61BTH_WeldFlaw_1GC.db	Reference .db file for half-symmetric limit load analysis	Note [2]
		LIMIT_HALFSYM.ext .ext = .inp, .err, .mntr, .out, .db, .rst unmerge.mac, unmerge2.mac	Limit load SL D analysis files.	06/20/2017 11:39:15
	Elastic-plastic analysis SL- D	61BTH_WeldFlaw_1GC.db	Reference .db file for half-symmetric elastic-plastic analysis	Note [2]
		STRAIN_HALFSYM.ext .ext = .inp, .err, .mntr, .out, .db, .rst unmerge.mac, unmerge2.mac	Elastic-plastic SL D analysis files.	06/19/2017 22:48:11

Notes:

[1] The date & time (EST) for the main runs are from the listing at the end of output file.

[2] ANSYS FE models are taken from Section 8.0 of Ref. [5.3].

Table 1 – Internal Pressure in the 61BTH Type 1 DSC (Ref. [5.3])

Design Condition	Maximum Calculated Pressure [psi]	Design Pressure used in this Calculation [psi]
Normal	7.3	10
Off-Normal	10.9	20
Accident	56.1	65

Table 2 – Maximum Temperatures in the 61BTH Type 1 DSC Shell (Ref. [5.3])

Design Condition		Maximum Calculated Temperature [°F]	Design Temperature used in This Calculation [°F]
Normal	Storage	374	500
	Transfer	439	500
Off-Normal	Storage	399	500
	Transfer	416	500
Accident	Storage	611	625
	Transfer	467	500

Table 3 – Properties of SA-240 Type 304. Ref. [5.3]

Temp [°F]	E Modulus of Elasticity [ksi]	S_m Allowable Stress Intensity [ksi]	S_y Yield Stress [ksi]	S_u Ultimate Tensile Strength [ksi]	Yield Stress for SL A/B Limit Load Analysis [ksi]	Yield Stress for SL D Limit Load Analysis [ksi]
70	28,300	20.0	30.0	75.0	30.0	46.0
100	28,138	20.0	30.0	75.0	30.0	46.0
200	27,600	20.0	25.0	71.0	30.0	46.0
300	27,000	20.0	22.4	66.2	30.0	46.0
400	26,500	18.7	20.7	64.0	28.1	43.0
500	25,800	17.5	19.4	63.4	26.3	40.3
600	25,300	16.4	18.4	63.4	24.6	37.7
625	25,175	16.3	18.2	63.4	24.5	37.5
700	24,800	16.0	17.6	63.4	24.0	36.8

Table 4 – Properties of SA-36. Ref. [5.3]

Temp [°F]	E Modulus of Elasticity [ksi]	S_m Allowable Stress Intensity [ksi]	S_y Yield Stress [ksi]	S_u Ultimate Tensile Strength [ksi]	Yield Stress for SL A/B Limit Load Analysis [ksi]	Yield Stress for SL D Limit Load Analysis [ksi]
70	29,500	19.3	36.0	58.0	29.0	40.6
100	29,338	19.3	36.0	58.0	29.0	40.6
200	28,800	19.3	33.0	58.0	29.0	40.6
300	28,300	19.3	31.8	58.0	29.0	40.6
400	27,700	19.3	30.8	58.0	29.0	40.6
500	27,300	19.3	29.3	58.0	29.0	40.6
600	26,700	17.7	27.6	58.0	26.6	40.6
625(1)	26,400	17.6	27.2	58.0	26.4	40.4
700	25,500	17.3	25.8	58.0	26.0	39.8

Note:

(1) All values are interpolated from the 600 °F and 700 °F values.

Table 5 – Summary of Limit Load Analysis for the maximum weld flaws

Sl. No.	Name	Loading	Temp. [F]	Analysis Criteria	Design Pressure (psi)	Requirement of pressure to Safety Limit load Criteria (psi)	Limit Load Collapse Pressure (psi)
1	2D-Axisymmetric	Internal pressure	500	SL A/B	32	60	86.3
2	2D-Axisymmetric	Internal pressure	625	SL D	65	90.2	122.2
Sl. No.	Name	Loading	Temp. [F]	Analysis Criteria	Design G-load (g)	Required G-load to Satisfy Limit load Criteria (g)	Limit Load Collapse G-Load (g)
3	3D-Half-symmetric	Side drop with 20 psi off-normal IP	500	SL D	75	104	179.5(1)

Note:

(1) To be compared with 188.5g with the original Case #1 weld flaws of Ref. [5.3], see APPENDIX A

Table 6 – Summary of Peak Strain Values for Elastic-Plastic Analyses for the maximum weld flaws

Load Case	Specific loading Internal Pressure (psi)	Peak Equivalent Plastic Strain		Material Strain Limit(1)
		at 65 psi internal Pressure	at 100 psi internal Pressure	
2D-Axisymmetric Internal Pressure Service Level D	65	7.4%	13.6%	28%
Load Case	Specific loading Side Drop G-Load (g)	Peak Equivalent Plastic Strain		Material Strain Limit(1)
		at 75g loading	at 112.5g loading	
3D-Half-symmetric Side Drop Service Level D	75	11.1%	23.0%	28%

Note:

(1) The weld uncertainty factor of 0.8 (See Section 3.4 of Ref. [5.3]) is applied to the minimum of the ASME specified minimum elongation of SA-240 304 (40%) and E308-XX (35%). Therefore strain limit is taken as 0.8*35=28%- See Section 3.3.

Table 7 – Summary of Elastic-Plastic Analysis Results for the maximum weld flaws

Analysis Case	Result	Plastic Strain
Internal Pressure Service Level A 2D-Axisymmetric[1]	Equivalent Plastic Strain at 32 psi Internal Pressure[1]	3.1%
Internal Pressure Service Level D 2D-Axisymmetric	Equivalent Plastic Strain at 65 psi Internal Pressure	7.4%
Side Drop Service Level D 3D-Half-Symmetry	Equivalent Plastic Strain at 75g Acceleration	11.1%

Note:

(1) The 32 psi internal pressure is bounding for Service Levels A and B and includes design internal pressure of 10 psi plus an additional 22 psi to account for inertial loading of the DSC contents onto the lid.

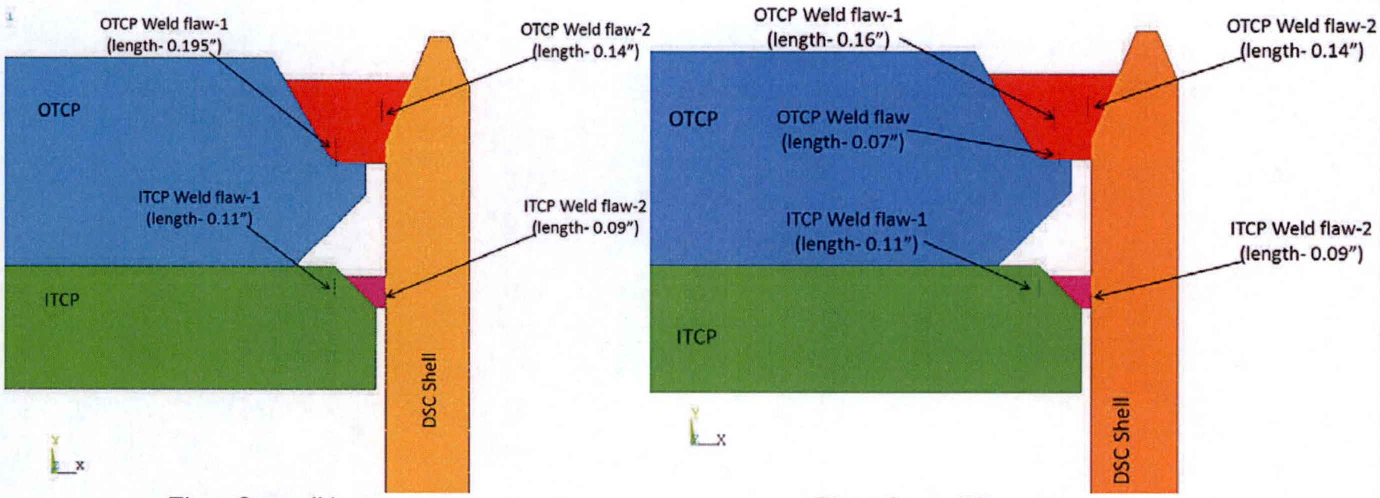


Figure 1 – Weld Flaws in Original Model (Ref. [5.3])

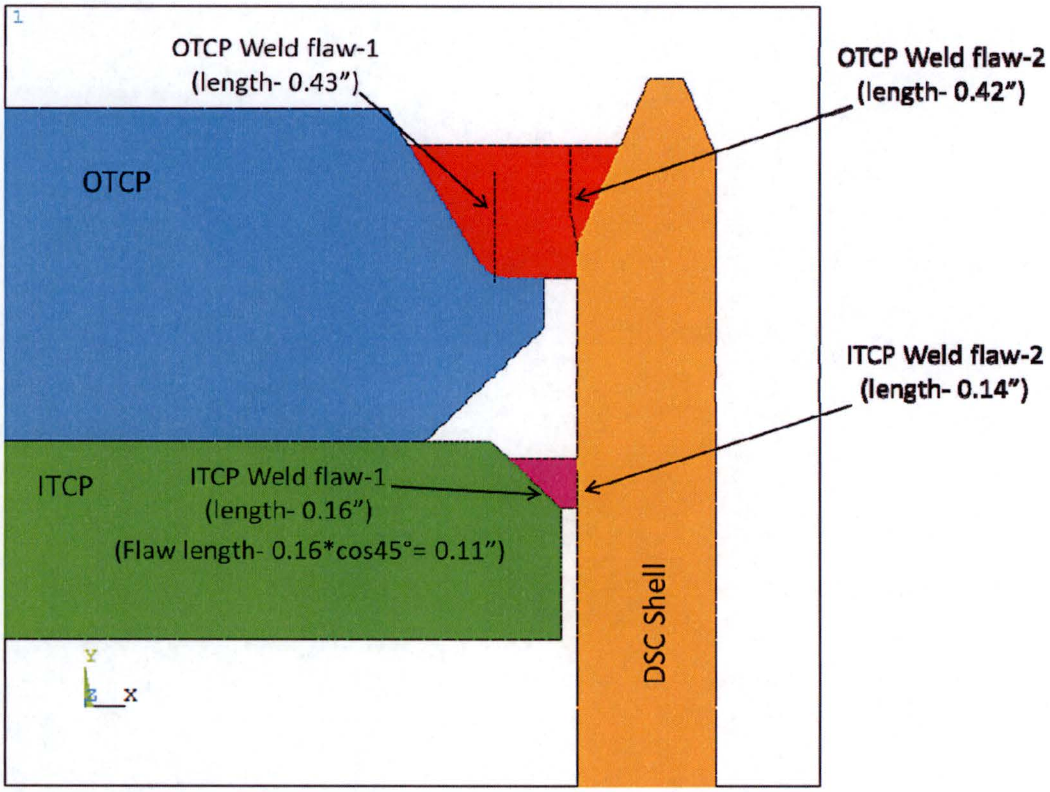


Figure 2 – Maximum Weld Flaws based on the allowed design limits

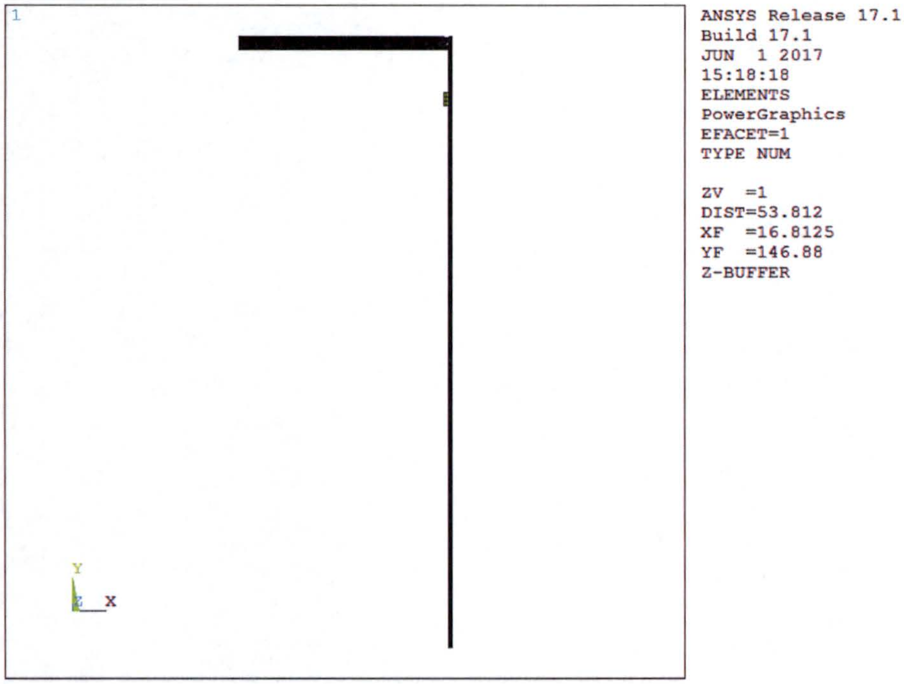


Figure 3 – Overview of the 2D-Axisymmetric Model

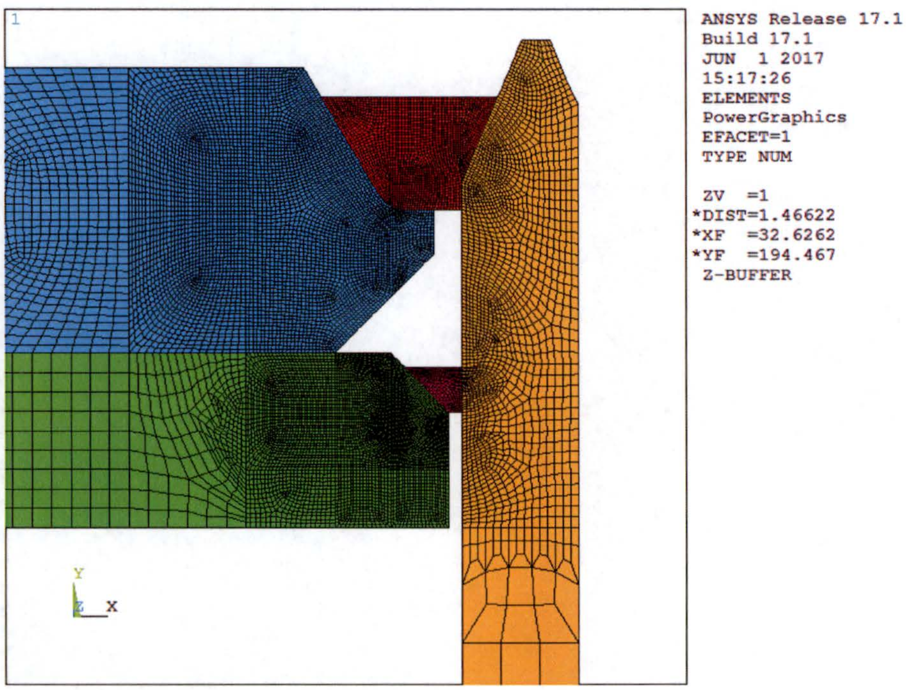


Figure 4 – Mesh Details at the Welds for 2D-Axisymmetric Model

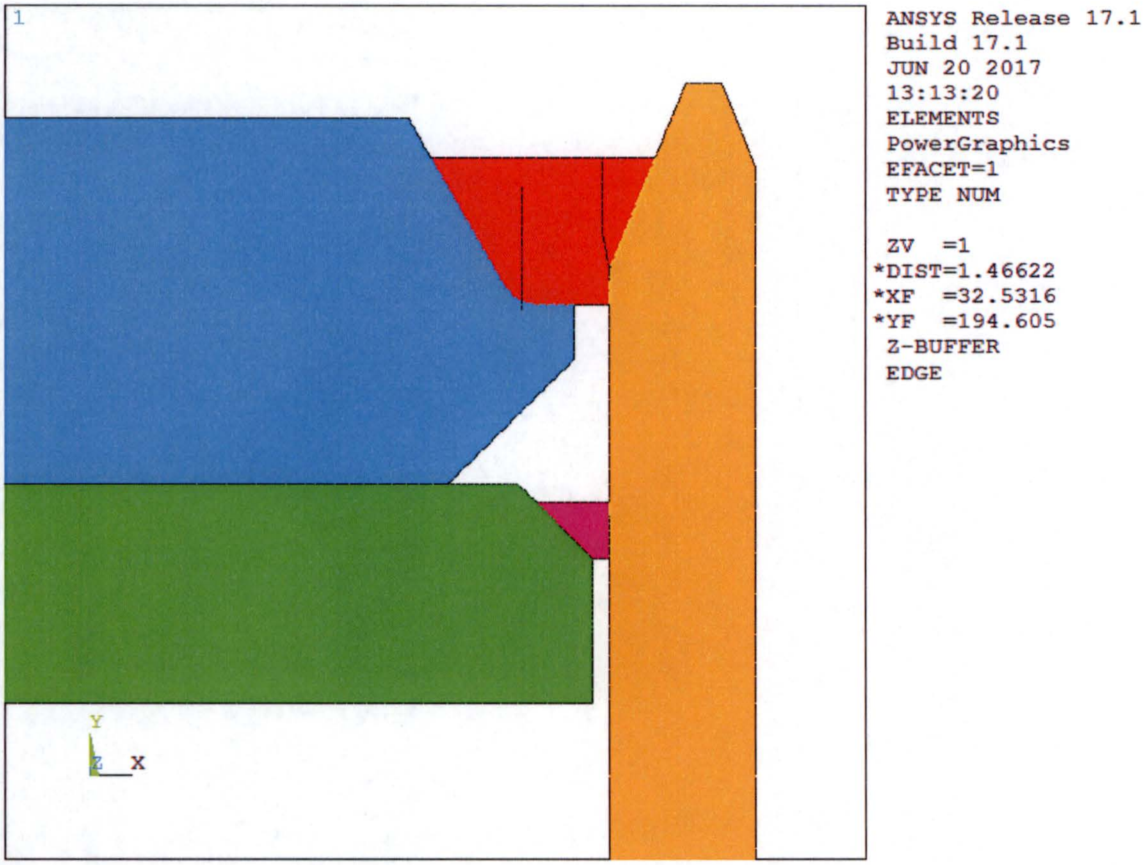


Figure 5 – Flaw Locations for 2D-Axisymmetric Model

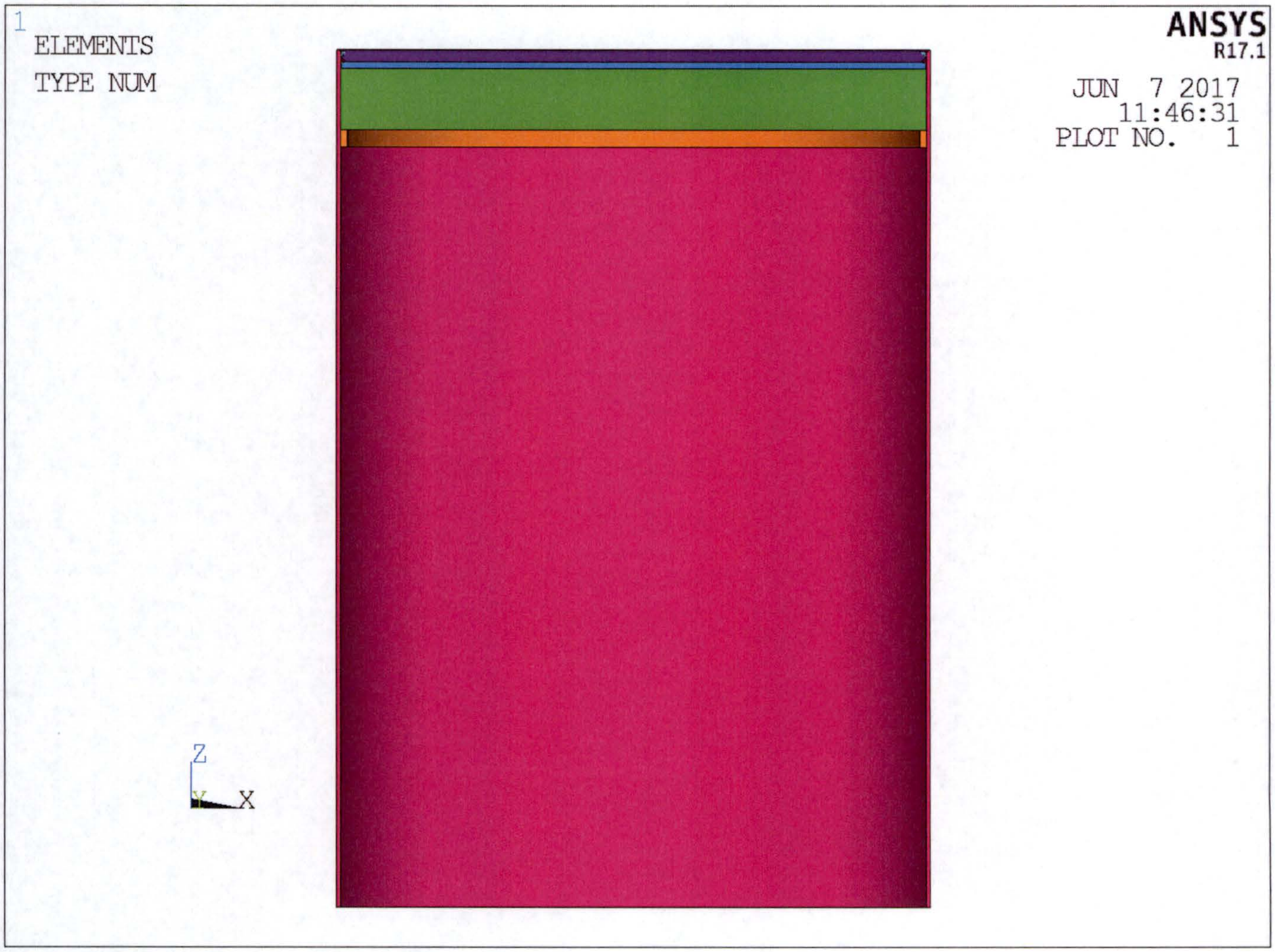
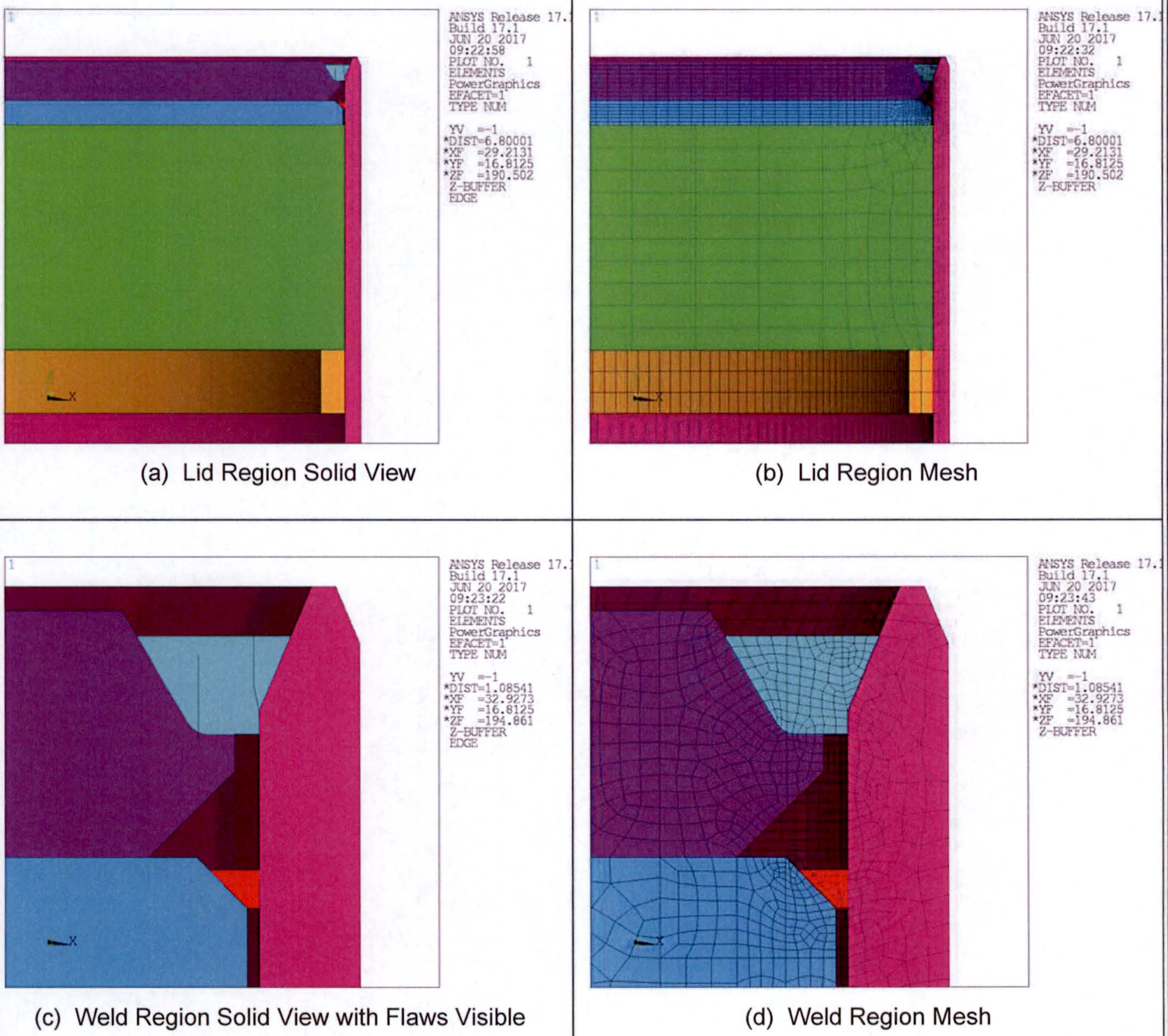


Figure 6 – Overview of the 3D-Half-Symmetric Model



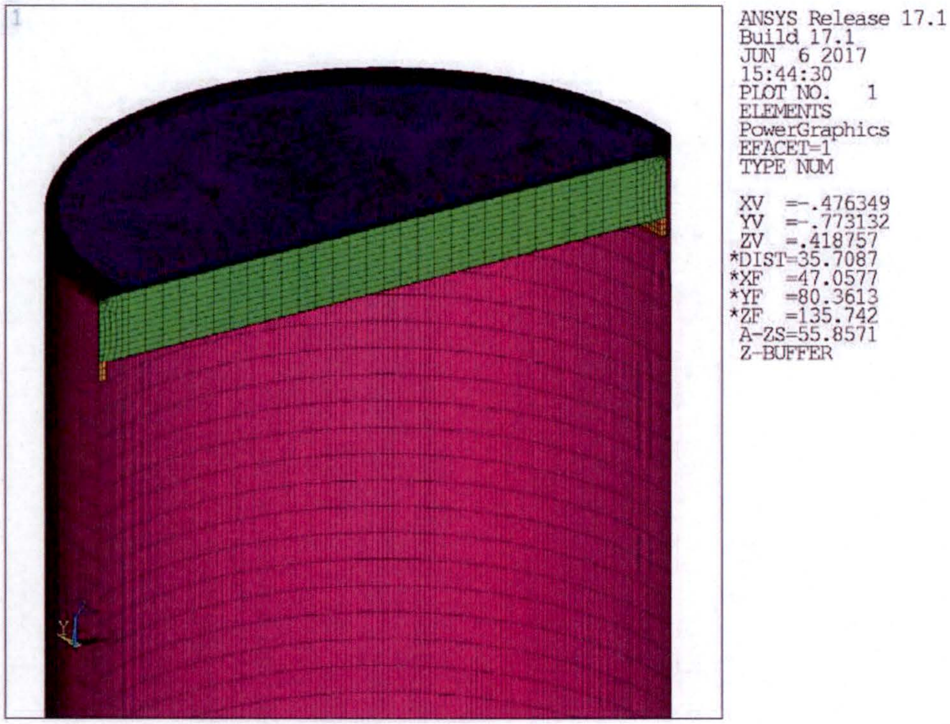
(a) Lid Region Solid View

(b) Lid Region Mesh

(c) Weld Region Solid View with Flaws Visible

(d) Weld Region Mesh

Figure 7 – Detail Views and Mesh Plots of the 3D-Half Symmetric Model



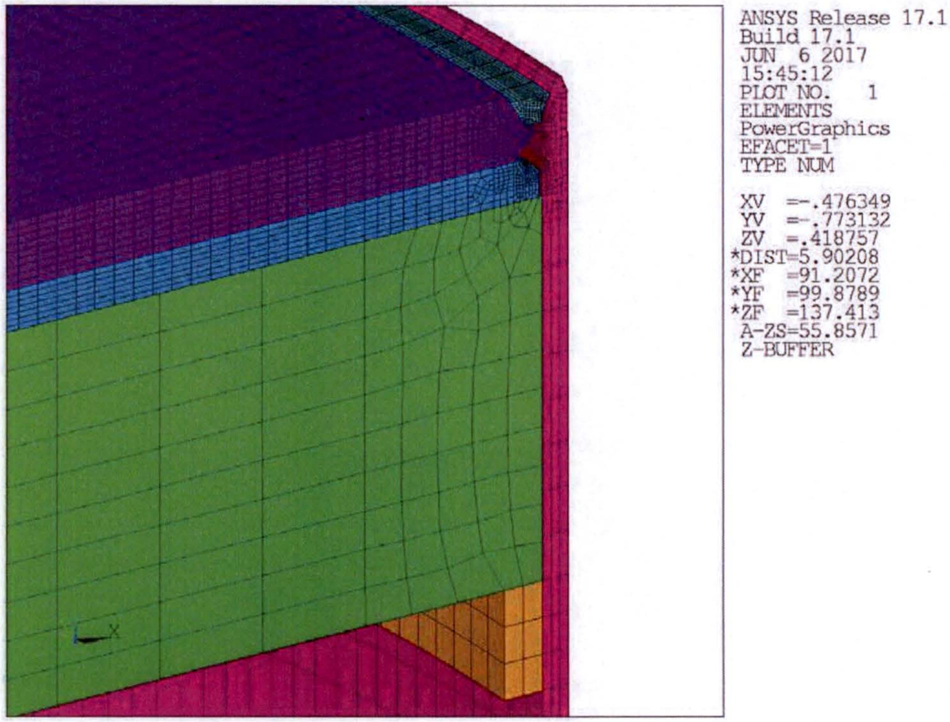
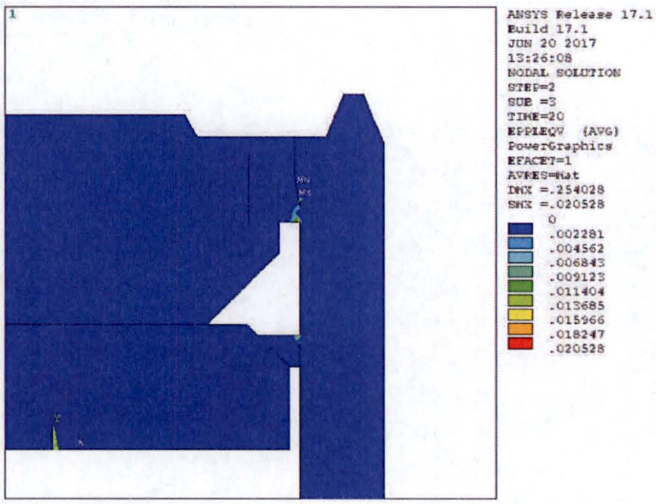
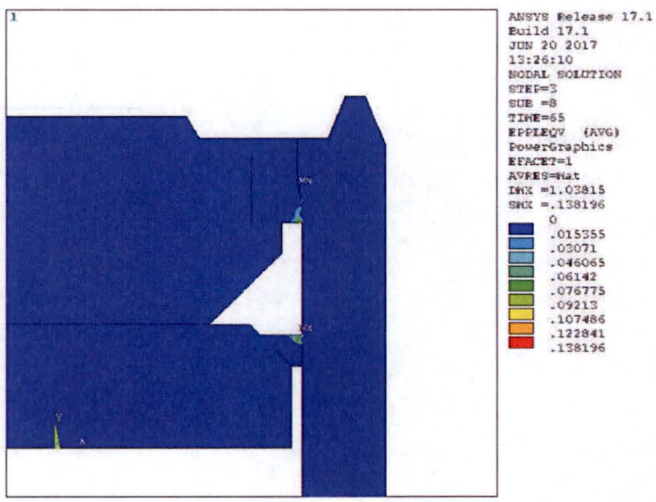


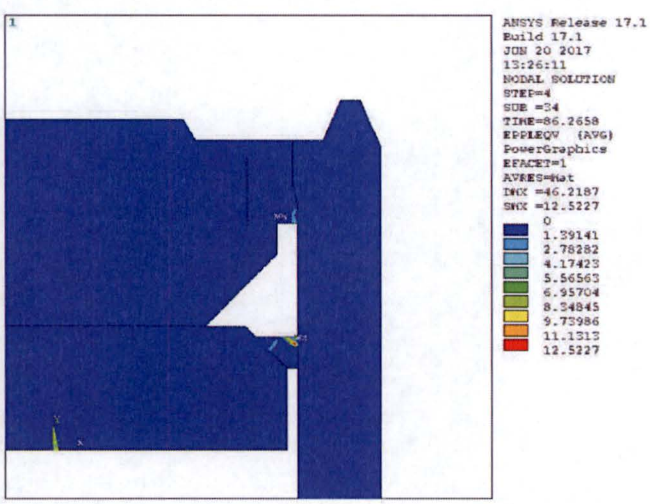
Figure 8 – Isometric Views of 3D-Half-Symmetric Model



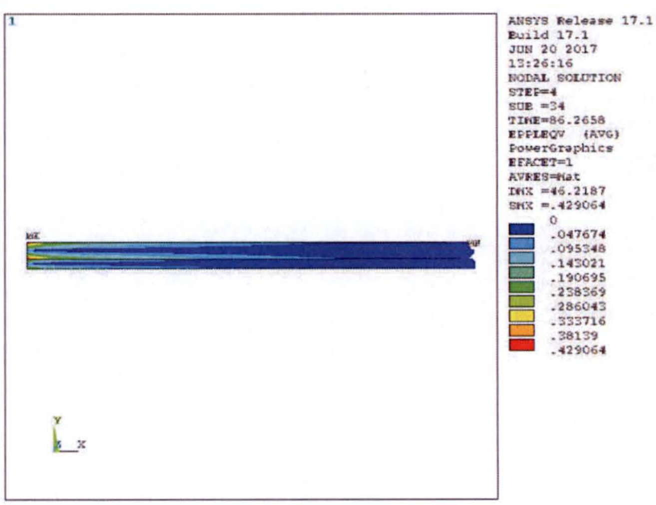
(a) Equivalent Plastic Strain in Weld Region [in/in] at 20 psi Internal Pressure



(b) Equivalent Plastic Strain in Weld Region [in/in] at 65 psi Internal Pressure

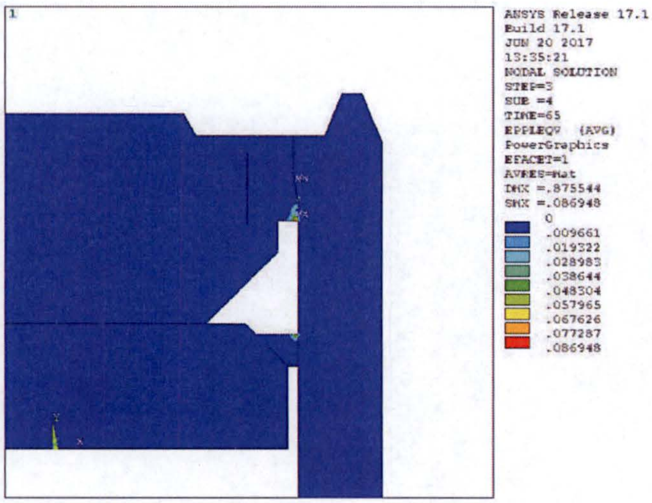


(c) Equivalent Plastic Strain in Weld Region [in/in] at 86.3 psi Internal Pressure

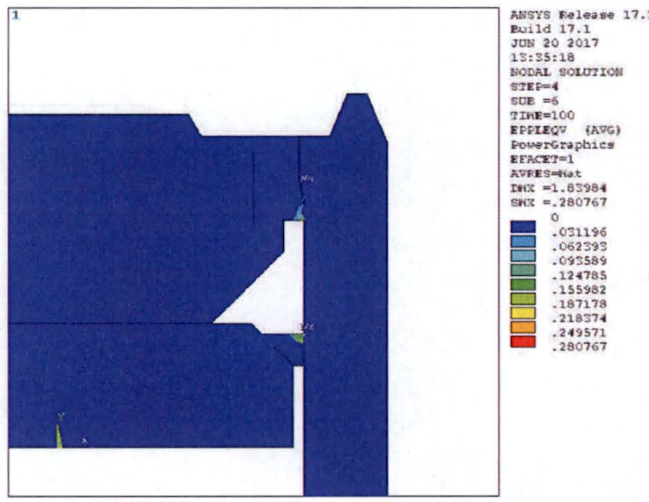


(d) EQV Plastic Strain in the Cover Plates at 86.3 psi

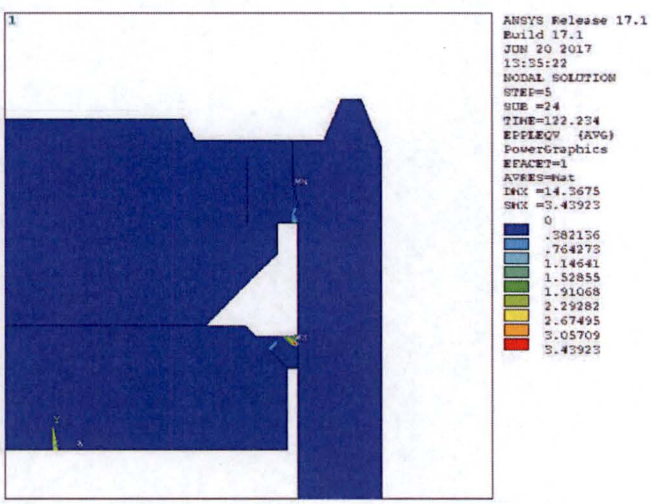
Figure 9 – Results of Limit Load for 2D-Axisymmetric Model – Service Level A/B



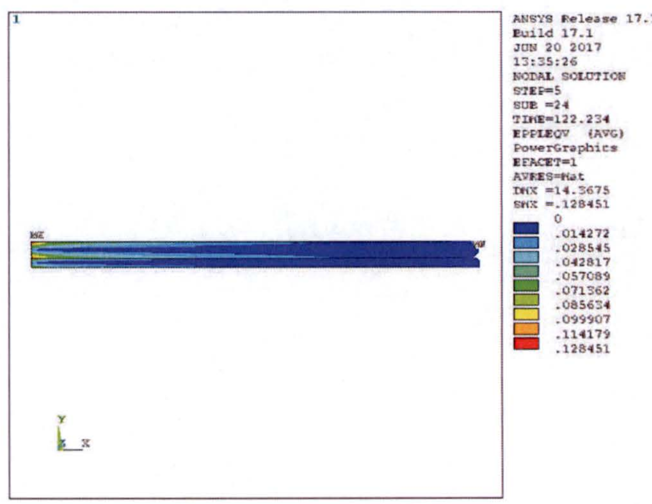
(a) Equivalent Plastic Strain in Weld Region [in/in] at 65 psi Internal Pressure



(b) Equivalent Plastic Strain in Weld Region [in/in] at 100 psi Internal Pressure

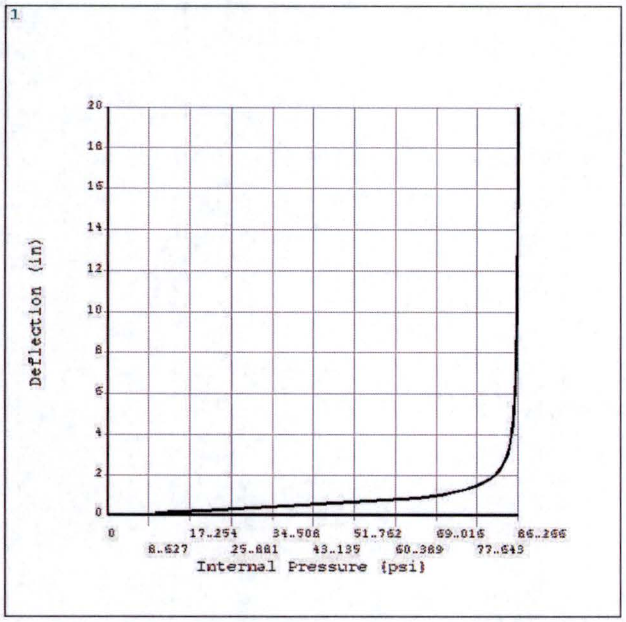


(c) Equivalent Plastic Strain in Weld Region [in/in] at 122.2 psi Internal Pressure

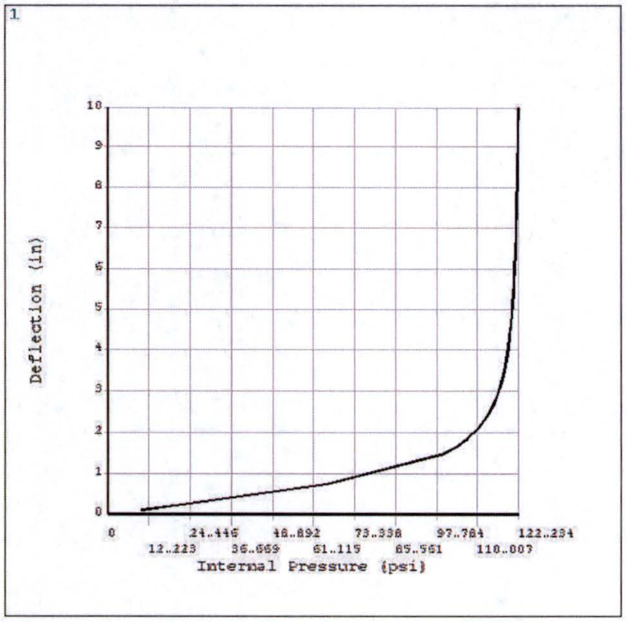


(d) EQV Plastic Strain in the Cover Plates at 122.2 psi

Figure 10 – Results of Limit Load for 2D-Axisymmetric Model – Service Level D



(a) Service Level A/B



(b) Service Level D

Figure 11 – Deflection at the Center of the OTCP for the 2D-Axisymmetric Model for Limit Load (Maximum deflection occurs at the center point of the lids, in the outward axial direction)

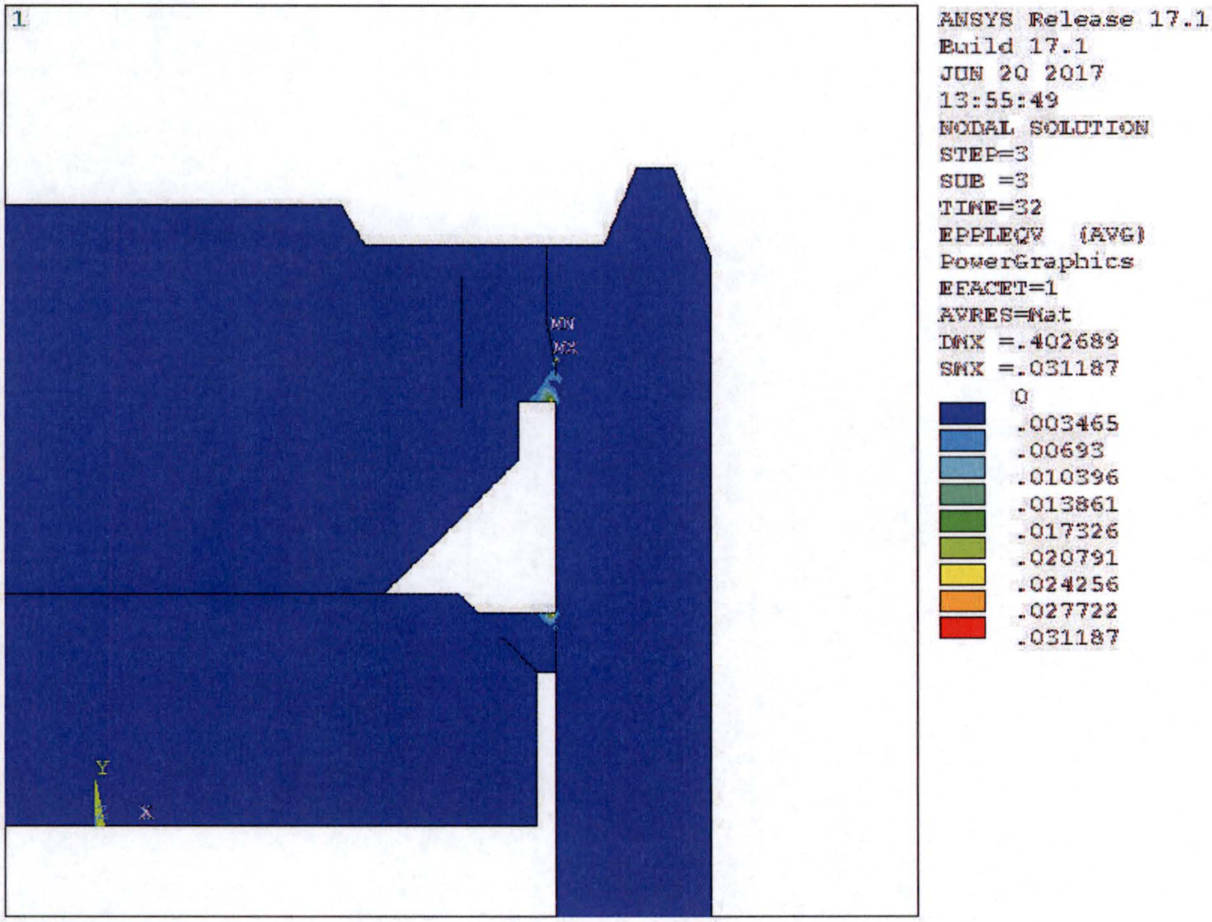


Figure 12 – Equivalent Plastic Strain at 32 psi for 2D-Axisymmetric Elastic Plastic Analysis - SL A/B Internal Pressure

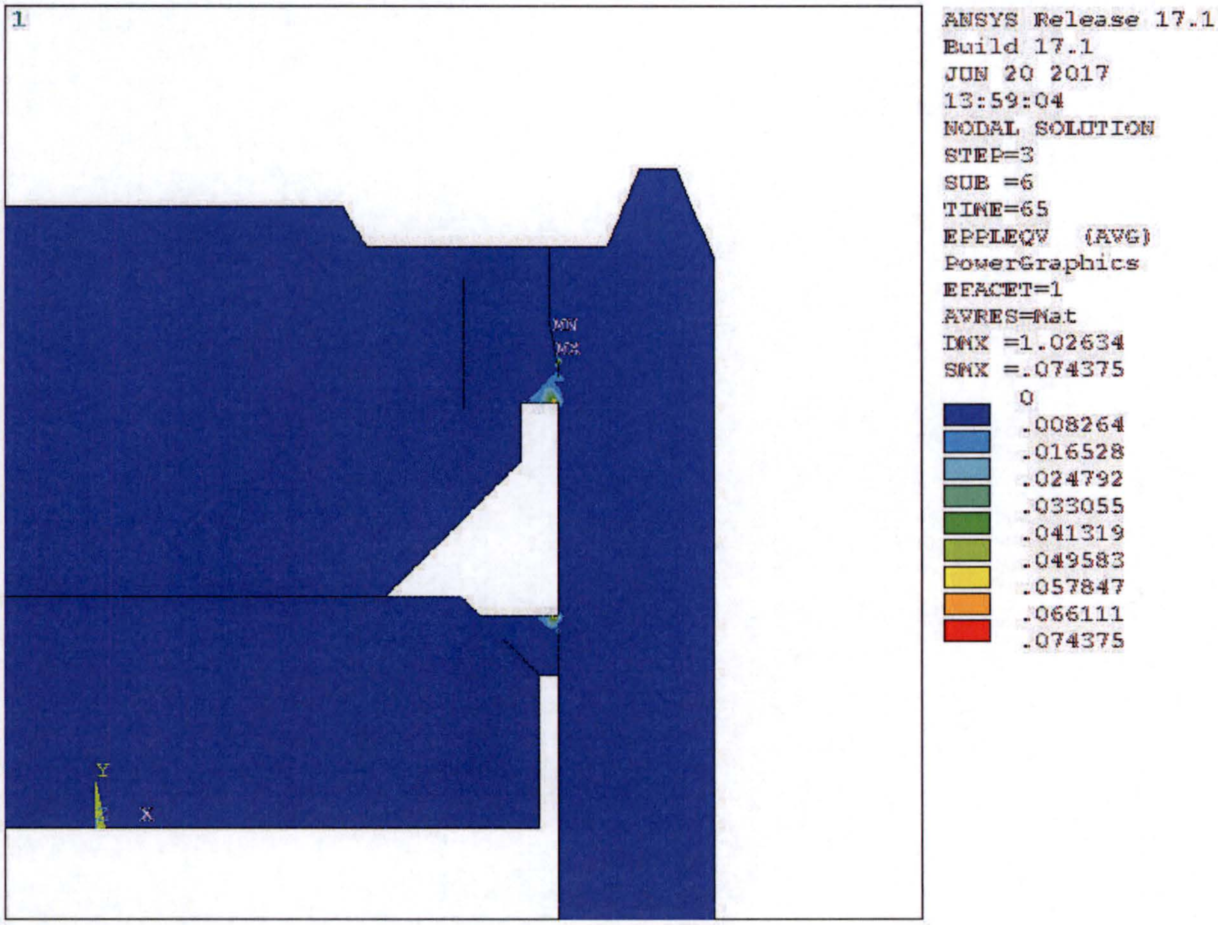


Figure 13 – Equivalent Plastic Strain at 65 psi for 2D-Axisymmetric Elastic Plastic Analysis - SL D Internal Pressure

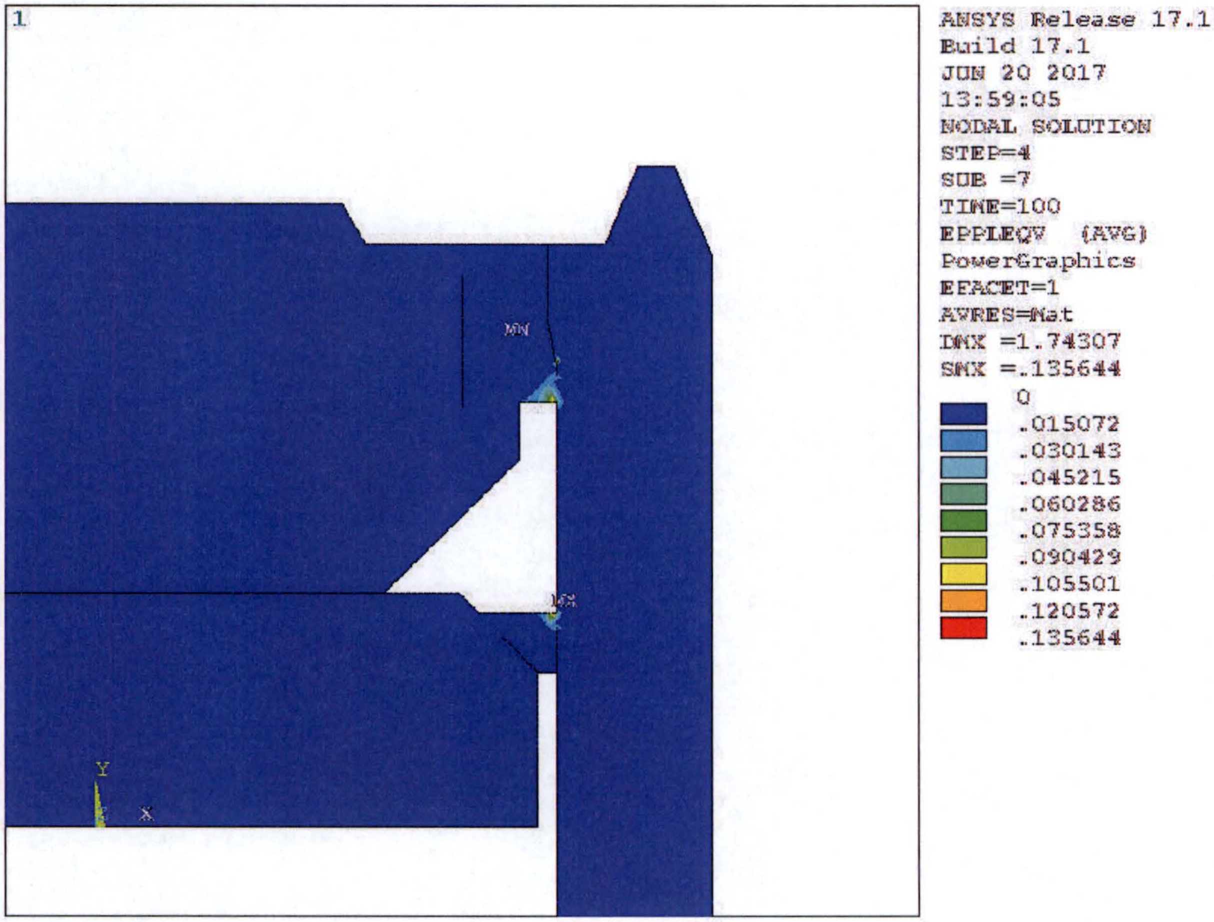
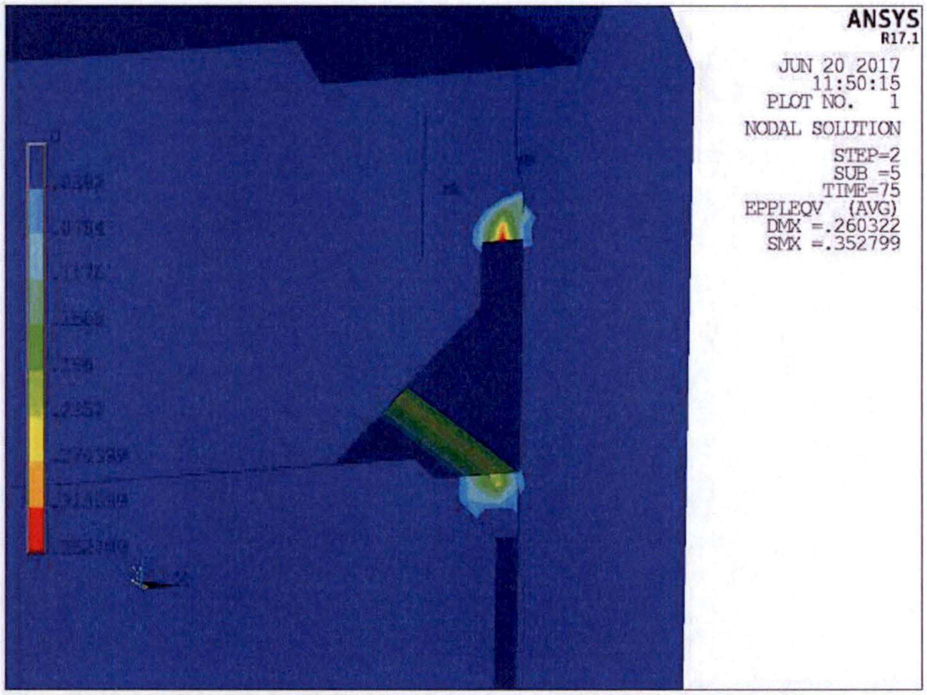
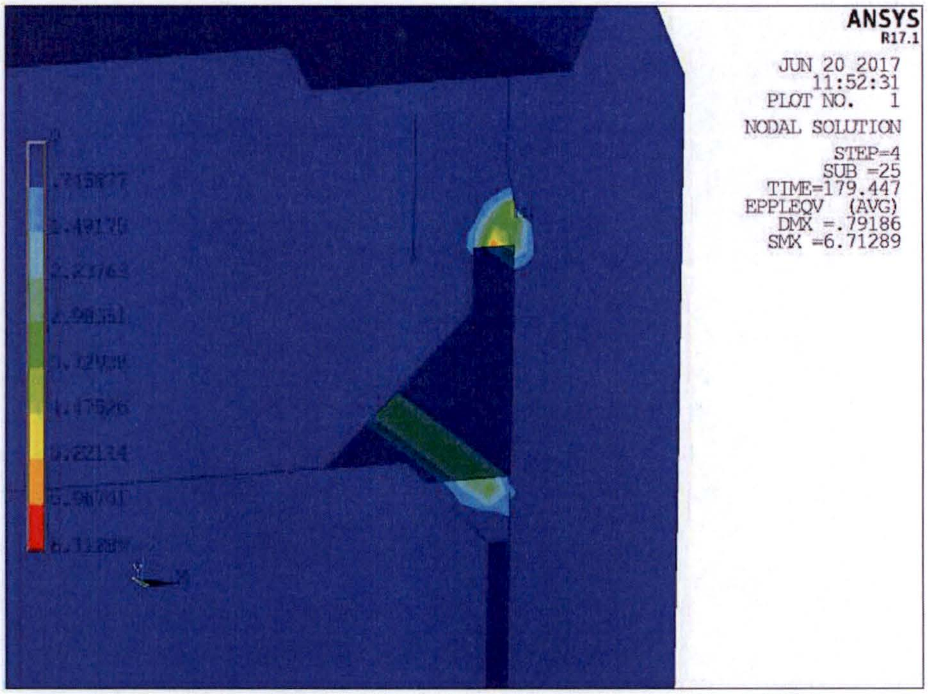


Figure 14 – Equivalent Plastic Strain at 100 psi for 2D-Axisymmetric Elastic Plastic Analysis - SL D Internal Pressure



(a) Equivalent Plastic Strain in Weld Region [in/in] at 75g.



(b) Equivalent Plastic Strain in Weld Region [in/in] at 179.5g.

Figure 15 – Equivalent Plastic Strain Plots for 3D-Half-Symmetric Limit Load Analysis – SL D Side Drop with Off-Normal Internal Pressure

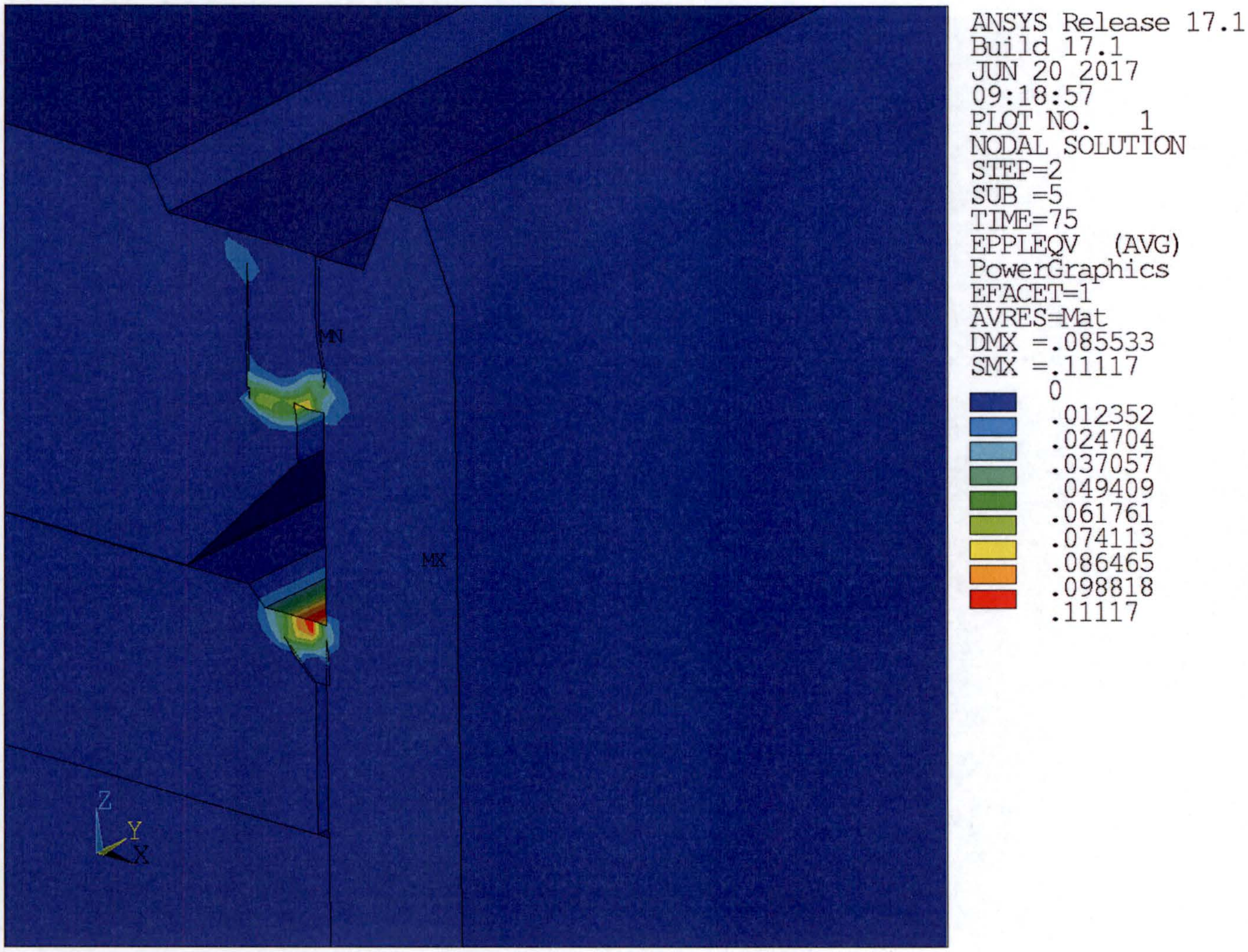


Figure 16 – Equivalent Plastic Strain at 75g for 3D-Half-Symmetric Elastic-Plastic Analysis - SL D Side Drop

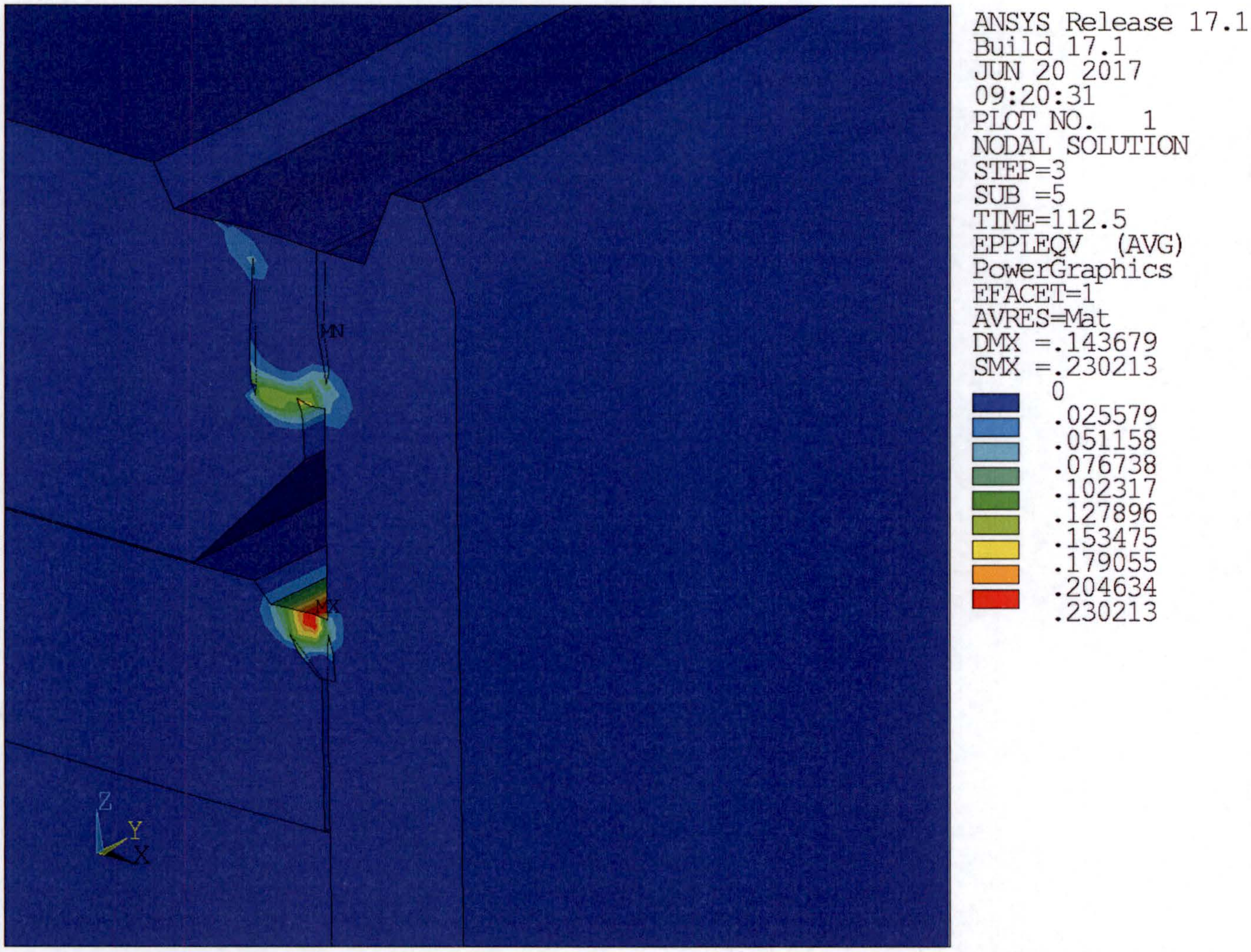


Figure 17 – Equivalent Plastic Strain at 112.5g for 3D-Half-Symmetric Elastic-Plastic Analysis - SL D Side Drop

APPENDIX A

Sensitivity Study of ANSYS Release 14.0 and 17.1

ANSYS computer program Release 14.0 has been used in stress calculation in Ref. [5.3]. ANSYS Release 17.1 is used in this calculation. Release 17.1 Ref. [5.1] was installed in accordance with QAP and TIP 3.3 requirements and is verified against empirical Data. The purpose of Appendix A is to determine the effect of using different releases of ANSYS on the same FE model. The following bounding 3D-half-symmetric load cases from the main part of this document are considered for the sensitivity analysis:

1) Elastic-Plastic analysis: Side drop 75g and 112.5g
2) Limit Load analysis: Side drop with off-normal internal pressure

A.1 Elastic-Plastic sensitivity analysis

Ref. [5.3] Elastic-Plastic analysis on the 3D-half-symmetric FE model uses ANSYS 14.0 and provides a peak equivalent plastic strain of 6.09% for 75g and 12.6% for 112.5g (Line 1 of Table A-1). The same ANSYS FE model was resumed in ANSYS 17.1 Ref. [5.1] and analyzed without any modification. The results for ANSYS 17.1 peak equivalent plastic strain are found to be 5.60% and 11.76% for 75g and 112.5g respectively (Line 2 of Table A-1). The default surface-to-surface contact stiffness's between the two releases are different and are found to be higher in ANSYS 17.1 resulting in lower equivalent plastic strains. Therefore the contact stiffness's were reduced by a 4.2873 factor to match the default surface-to-surface contact stiffness's of ANSYS 14.0. As the contact stiffness coefficient FKN used in ANSYS 14.0 is 0.1, the new contact stiffness coefficient in ANSYS 17.1 is 0.1 / 4.2873=0.02332. Once this modification implemented, ANSYS 17.1 provides exactly the same results (Line 3 of Table A-1) as ANSYS 14.0.

Table A-1: Comparison ANSYS 14.0 vs 17.1 – 3D-half-symmetric Model - Elastic Plastic analysis

		Peak Equivalent Plastic Strain	
Sl. No.	Side Drop	at 75g	at 112.5g
1	ANSYS 14.0	6.09% Table 7 of [5.3]	12.6% Table 7 of [5.3]
2	ANSYS 17.1	5.60%	11.76%
3	ANSYS 17.1 modified	6.09%	12.59%

A.2 Limit Load sensitivity analysis

Ref. [5.3] Limit Load analysis on the 3D-half-symmetric FE model uses ANSYS 14.0 and provides a limit load of 180.6g (Line 1 of Table A-2). The same ANSYS FE model was resumed in ANSYS 17.1 Ref. [5.1] and analyzed without any modification. The result for ANSYS 17.1 limit load is found to be 188.52g (Line 2 of Table A-2). The same contact stiffness's modification described in Section A.1 was implemented for the Limit Load case. However, the limit load stayed identical (188.56g, Line 3 of Table A-2) to the unmodified ANSYS 17.1 result.

Table A-2: Comparison ANSYS 14.0 vs 17.1 – 3D-half-symmetric Model - Limit Load analysis

Sl. No.	Side Drop	Limit Load Collapse G-Load (g)	Loading	Temp [°F]	Design G-load (g)	Required G-load to Satisfy Limit load Criteria (g)
1	ANSYS 14.0	180.6 Table 6 of [5.3]	Side drop with off-normal IP	500	75	104
2	ANSYS 17.1	188.52				
3	ANSYS 17.1 modified	188.56				

Although the ANSYS 17.1 runs converge up to 188.5g instead of 180.6g for ANSYS 14.0, Figure A-1 clearly shows that the results (here the maximum displacement in the model) are identical up to the point where ANSYS 14.0 stop converging.

The limit load for the Case #1 weld flaws is thus considered to be 188.5g in this calculation and is the reference for comparison with the increased flaws calculation results presented in **Table 5**.

A.3 Conclusion

Based on the sensitivity evaluations performed in Appendix A, it is concluded that the results are independent of the ANSYS release for the 3D-Half-Symmetric model.

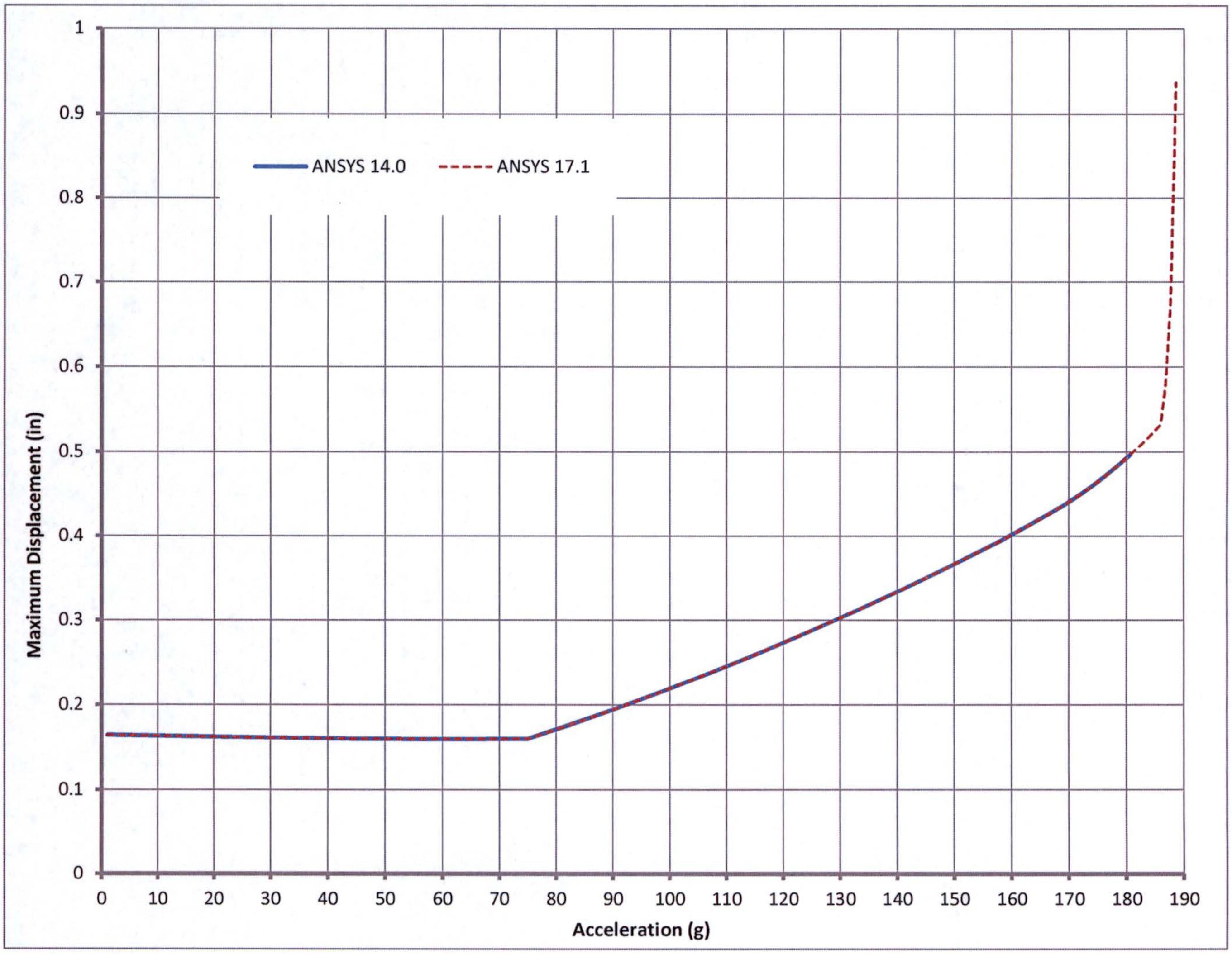


Figure A-1: Comparison ANSYS 14.0 vs 17.1 – Limit Load analysis

A.4 Listing of computer files

Finite Element Analyses were performed using ANSYS Version 17.1 Ref. [5.1]. All analyses were performed on HPC v2 Linux platform.

Load Case	Analysis Type	File Name	Description	Date / Time[(1)]
Side Drop Half-Symmetric model **Input Identical to Ref [5.3]**	Limit load analysis SL- D	61BTH_WeldFlaw_1GC.db	Reference .db file for half-symmetric limit load analysis	Note [(2)]
		SOLUTION_HALFSYM_SD.INP SOLUTION_HALFSYM_SD.out 3D_WeldFlaw.ext .ext = .mntr, .db, .rst	Limit load analysis files	05/25/2017 21:46:23
	Elastic-plastic analysis SL- D	61BTH_WeldFlaw_1GC.db	Reference .db file for half-symmetric elastic-plastic analysis	Note [(2)]
		STRAIN_HALFSYM.ext .ext = .inp, .err, .mntr, .out, .db, .rst	Elastic-plastic analysis files	06/07/2017 16:18:02
		61BTH_WELDFLAW_MATERIALS _ElasticPlastic_RamOsTrue.INP		
Side Drop Half-Symmetric model **Input Modified (See Section A-1)**	Limit load analysis SL- D	61BTH_WeldFlaw_1GC.db	Reference .db file for half-symmetric limit load analysis	Note [(2)]
		SOLUTION_HALFSYM_SD.ext .ext=.INP, .out, .err 3D_WeldFlaw.ext .ext = .mntr, .db, .rst	Limit load analysis files	05/28/2017 05:12:40
	Elastic-plastic analysis SL- D	61BTH_WeldFlaw_1GC.db	Reference .db file for half-symmetric elastic-plastic analysis	Note [(2)]
		SOLUTION_HALFSYM_SD.ext .ext=.INP, .out, .err 3D_WeldFlaw.ext .ext = .mntr, .db, .rst	Elastic-plastic analysis files	05/27/2017 16:39:11
		61BTH_WELDFLAW_MATERIALS _ElasticPlastic_RamOsTrue.INP		

Notes:

(1) The date & time (EST) for the main runs are from the listing at the end of output file.

(2) ANSYS FE models are taken from Section 8.0 of Ref. [5.3].