Design Conditions:

Code:	**ASME VIII-2**	
Year:	**2013**	
Addenda:	**-**	
MAWP:	**420**	psi
MEAWP:	**0**	psi
Max. Temp.:	**125**	°F
MDMT:	**-20**	°F
MDMT Press.:	**420**	psi
Corrosion Allowance:	**0.125**	in
Hydrotest:	**601**	psi

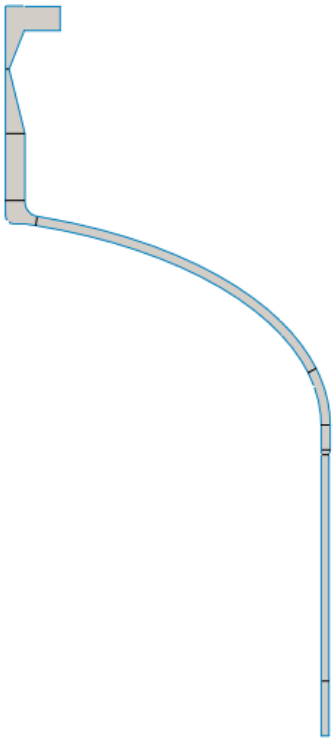
Conclusion:

A linear elastic finite element analysis is performed on the head assembly in accordance with ASME VIII-2 Part 5. The head design is acceptable for ASME VIII-2 service.

This report is the same as model and setup as example E5.2.1 of ASME PTB-3-2010.

Finite Element Analysis Report - VIII-2

Cust: **Pressure Vessel Engineering Ltd.**
File: **PVEfea-9128-1.0**
Desc: **ASME Div 2 FEA Verification**
Dwg: **PVEdwg-9128-1.0**
Date: **June 5, 2015**



Author: **Cameron Moore, P.Eng.**
Reviewer: **Ben Vanderloo, P.Eng.**

Notes:

Revisions:

Rev	Description	Date	Initials
0	Release	6/5/2015	CBM

Table of Contents

Executive Summary

Goal:

A finite element analysis (FEA) is selected to validate the head design per ASME VIII-2 Part 5. A linear elastic analysis is selected and is performed in accordance with 5.2.2.

Summary Conclusions:

Analysis Software

ABAQUS 6-14.2

Analysis Type

A static linear elastic study is performed using small displacement theory.

Materials

Material properties used in this report are obtained from ASME II-D. Stress classification limits are set in accordance with ASME VIII-2 Figure 5.1.

Model Information

An axisymmetric model is used for the analysis; 0.125" corrosion allowance is removed from the internal surfaces. A standard quadratic 8 noded planar mesh is applied. Contact elements are treated as bonded. Reported error is five percent as per CSA B51 Annex J. This validates the mesh selected, the model may be used for analysis.

Restraints & Loads

A symmetry restraint is applied in the axial direction. 420 psi internal pressure plus the exit pressure load on the top flange is applied. The reported reaction forces match the theoretical reaction forces. The model is in balance and restrained from rigid body motion.

Results

The direction of displacement is as expected. All observed stresses are below their respective allowable limits.

Analysis Conclusion:

A linear elastic finite element analysis is performed on the head assembly in accordance with ASME VIII-2 Part 5. The head design is acceptable for ASME VIII-2 service.

This report is the same as model and setup as example E5.2.1 of ASME PTB-3-2010.

Material Stress Limits ASME VIII-2 Fig 5.1

Material Input Chart:

125 **Temperature** [ºF]

	Material 1	Material 2	Material 3	Material 4
Material =	**SA-516 70N**	**SA-105**		
Application =	Shell & Head	Forging		
Sm [psi] **=**	24,550	23,300		
Sy [psi] **=**	36,850	34,900		
Sya [psi] **=**	38,000	36,000		
Sta [psi] **=**	70,000	70,000		
E1 =	1.0	1.0		
E2 =	1.0	1.0		
E [psi] **=**	28,800,000	29,100,000		
v =	0.30	0.30		
Coef =				
Pm [psi] **=**	24,550	23,300		
Pl [psi] **=**	36,825	34,950		
Pl+Pb [psi] **=**	36,825	34,950		
Pl+Pb+Q [psi] **=**	73,700	69,900		
Prop. Sources	ASME II-D 2013 Edition Tables 5A, Y-1, PRD, U			
Comments	Elastic modulus is set to match the values shown in E5.2.1 of ASME PTB-3			

Variable Descriptions: VIII-2 5.13

Sm (basic allowable)
Sta (tensile strength at ambient temp.)
E1 (weld efficiency)
E2 (casting efficiency)
Sya (yield strength at ambient temp.)
E (modulus of elasticity) - IID Table TM-1
v (Poison's ratio) - IID Table PRD
Coef (coefficient of thermal expansion)

Stress Limit Equations: VIII-2 Figure 5.1

Pm = E1*E2*Sm general primary membrane stress limit (material only)
Pm = 2*Sm general primary membrane stress limit (bolting combine operation +seating)
Pl = 1.5*E1*E2*Sm local membrane stress limit
Pl+Pb = 1.5*E1*E2*Sm primary membrane + primary bending stress limit (material only)
Pl+Pb = 3*Sm primary membrane + primary bending stress limit (bolting combine operation + seating)
Pl+Pb+Q = Max(3*E1*E2*Sm,2*E1*E2*Sy) primary + secondary stress (2*Sy only valid for Sya/Sta <=0.7)
Pl+Pb+Q+F = Use fatigue curves peak stress limit

Comments:

(1) Sy material property is not required, more conservative Pl+Pb+Q limits might be computed without it.
(2) The thermal expansion coefficient is only required for studies including thermal stresses
(3) Refer to VIII-2 5.15 Figure 5.1 and following for the Pm, Pl, Q and F stress limits
(4) Refer to VIII-2 5.14 Table 5.6 for the correct application of the calculated stress limits
(5) Use IID tables 5A and 5B for Sm for VIII-2 studies
(6) Use IID tables 1A and 1B for Sm values (S) for VIII-1 studies
(7) Use B31.1 Table A-1, A-2, A-3 for Sm values for B31.1 studies
(8) Use B31.3 Table A-1 for Sm values for B31.3 studies
(9) 2*Sy Pl+Pb+Q not valid when in creep range.

Model

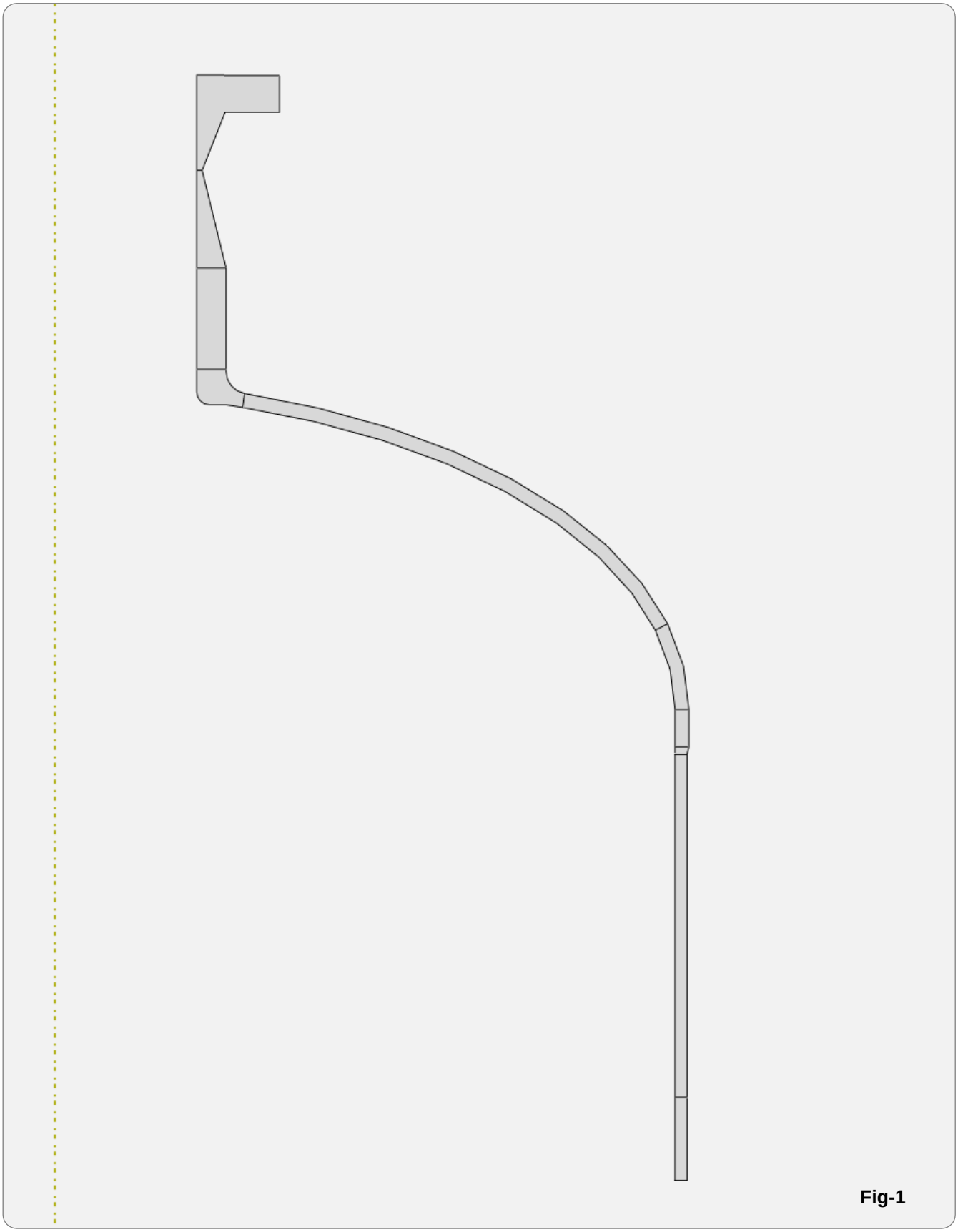


Fig-1

FEA Model

Due to the axi-symmetric profile of the vessel, an axisymmetric solid model is generated. Refer to PVEdwg-9128-1 for dimensions used in the analysis.

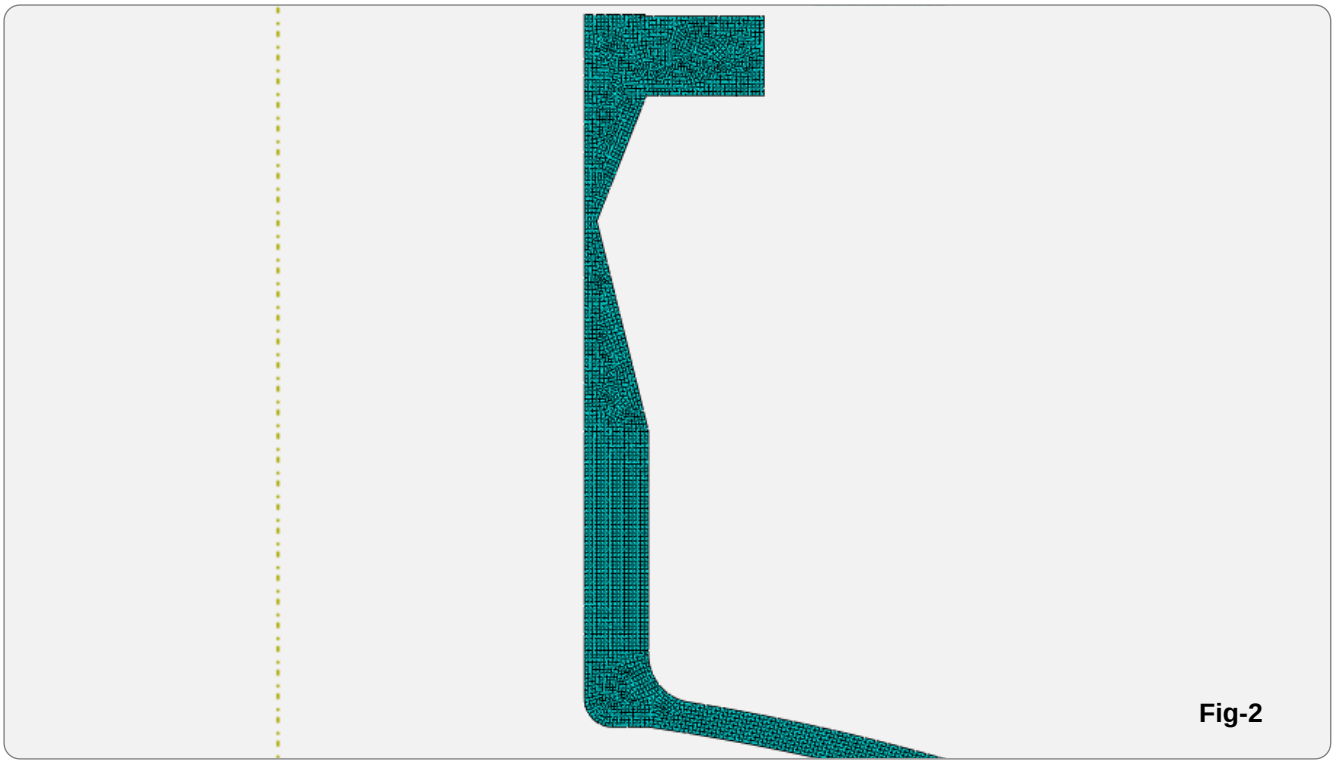


Fig-2

FEA Mesh

Standard quadratic, 8 noded reduced integration elements (CAX8R) are applied. A global element size of 0.015" is applied to the entire model.

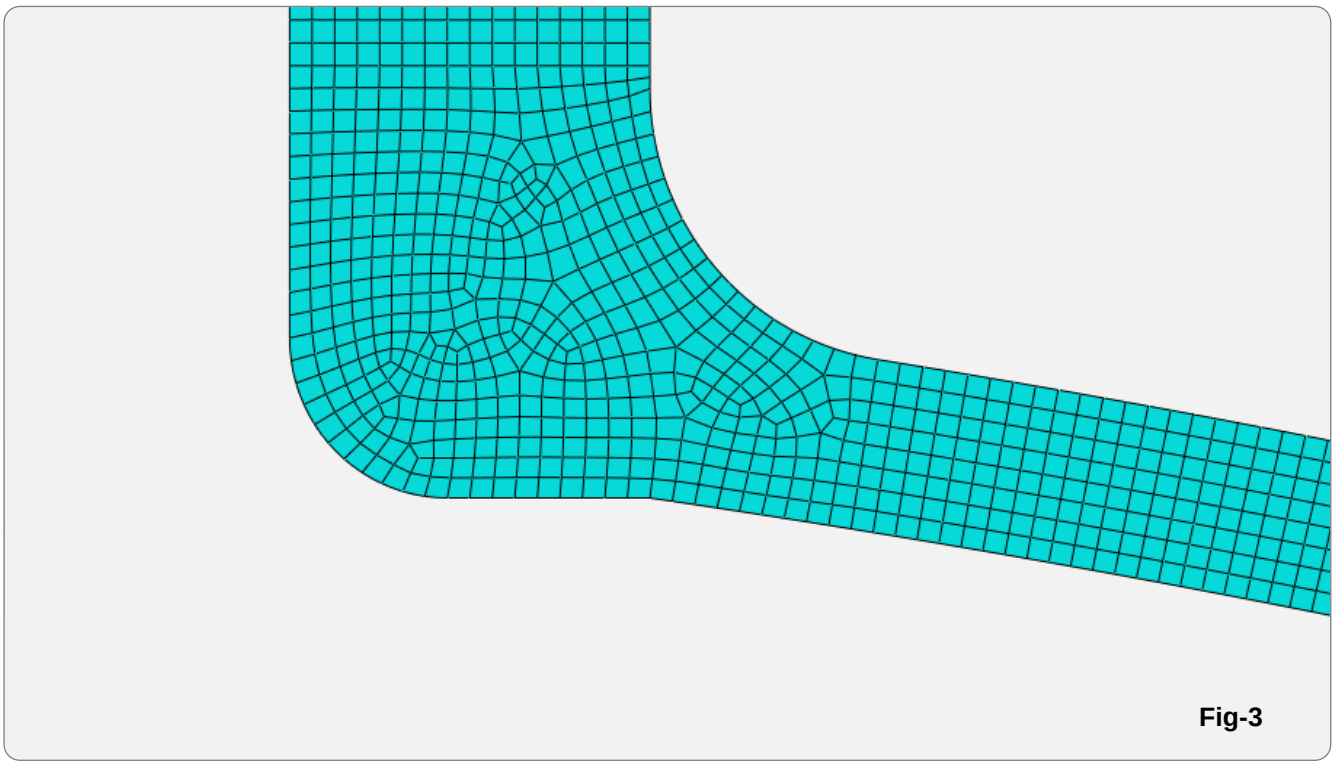


Fig-3

Mesh Close-Up

A close-up of the mesh at the nozzle to head junction is shown.

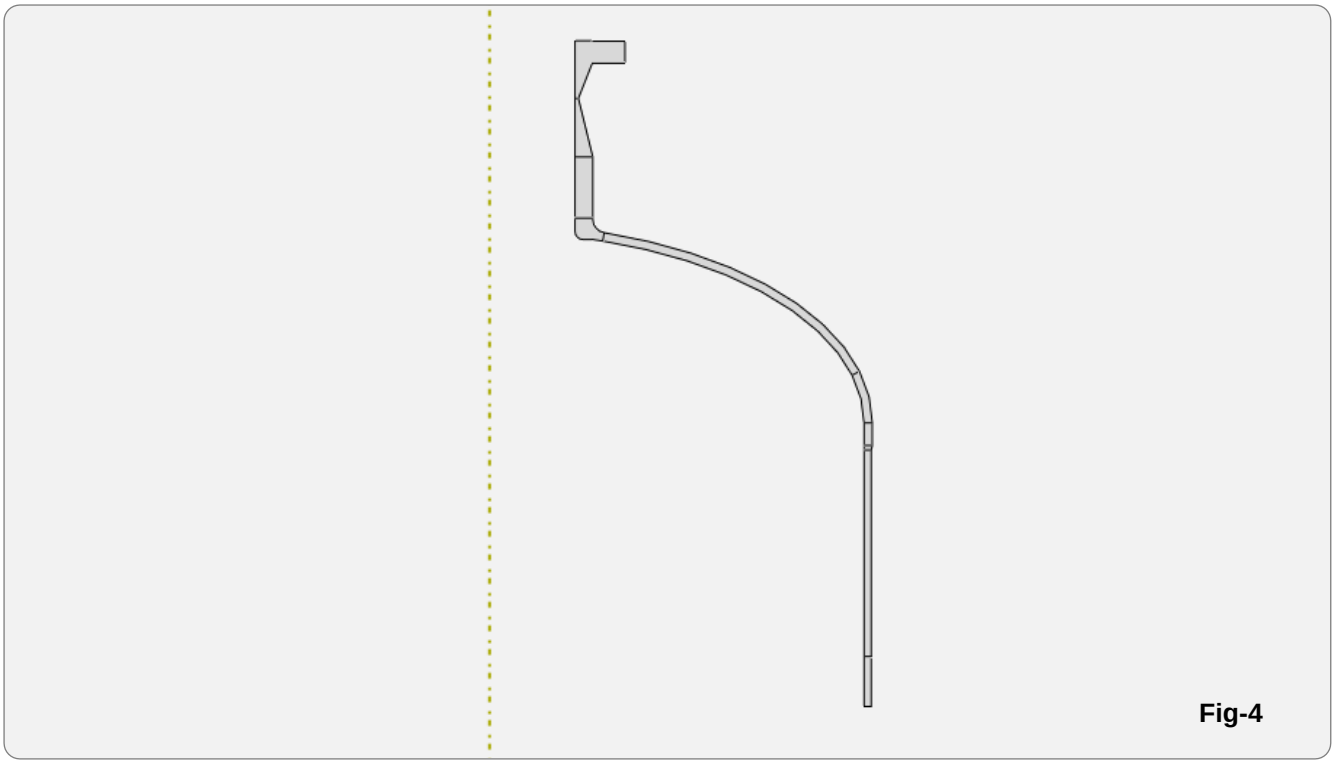


Fig-4

Axisymmetric Restraint

Since an axisymmetric model is analyzed, the model is restrained from translation in the X and Z directions.

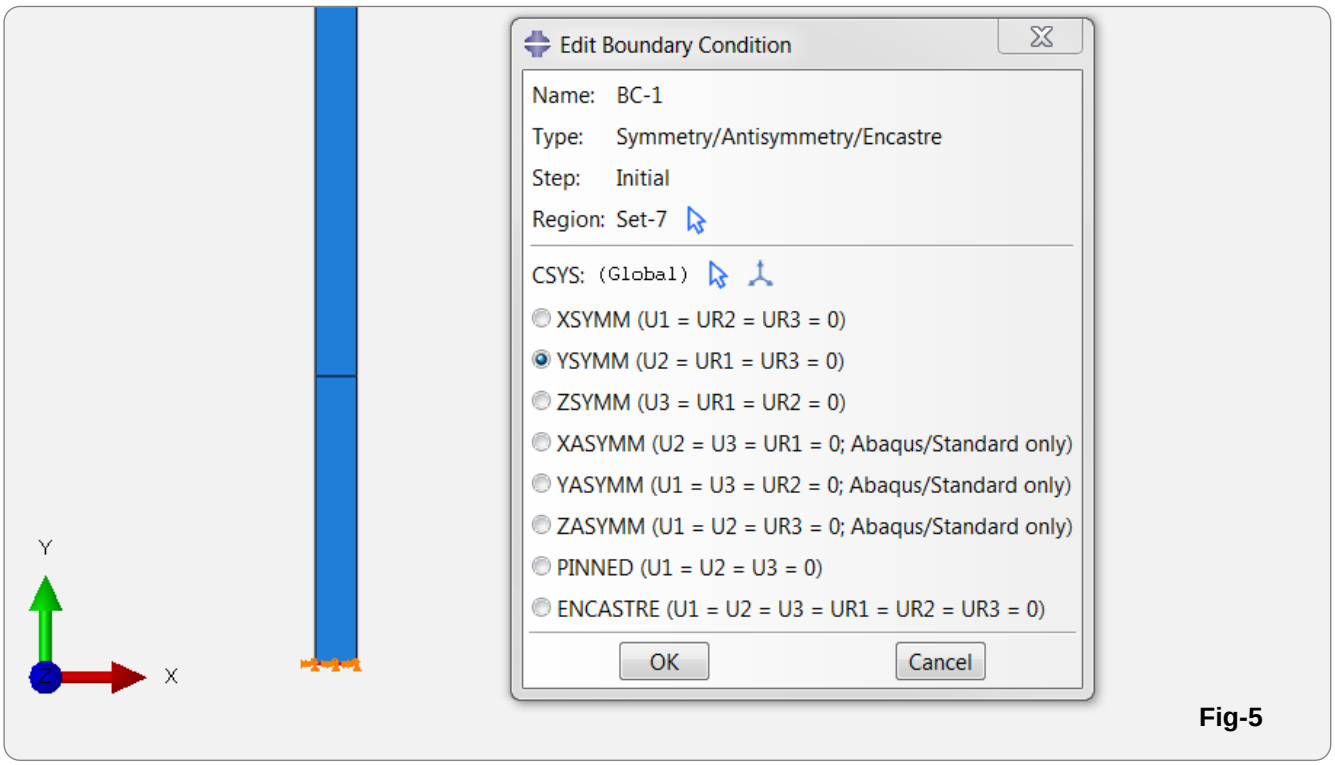


Fig-5

Y-Direction Symmetry

A symmetry restraint is applied at the end of the shell to prevent translation of the model in the Y-Direction.

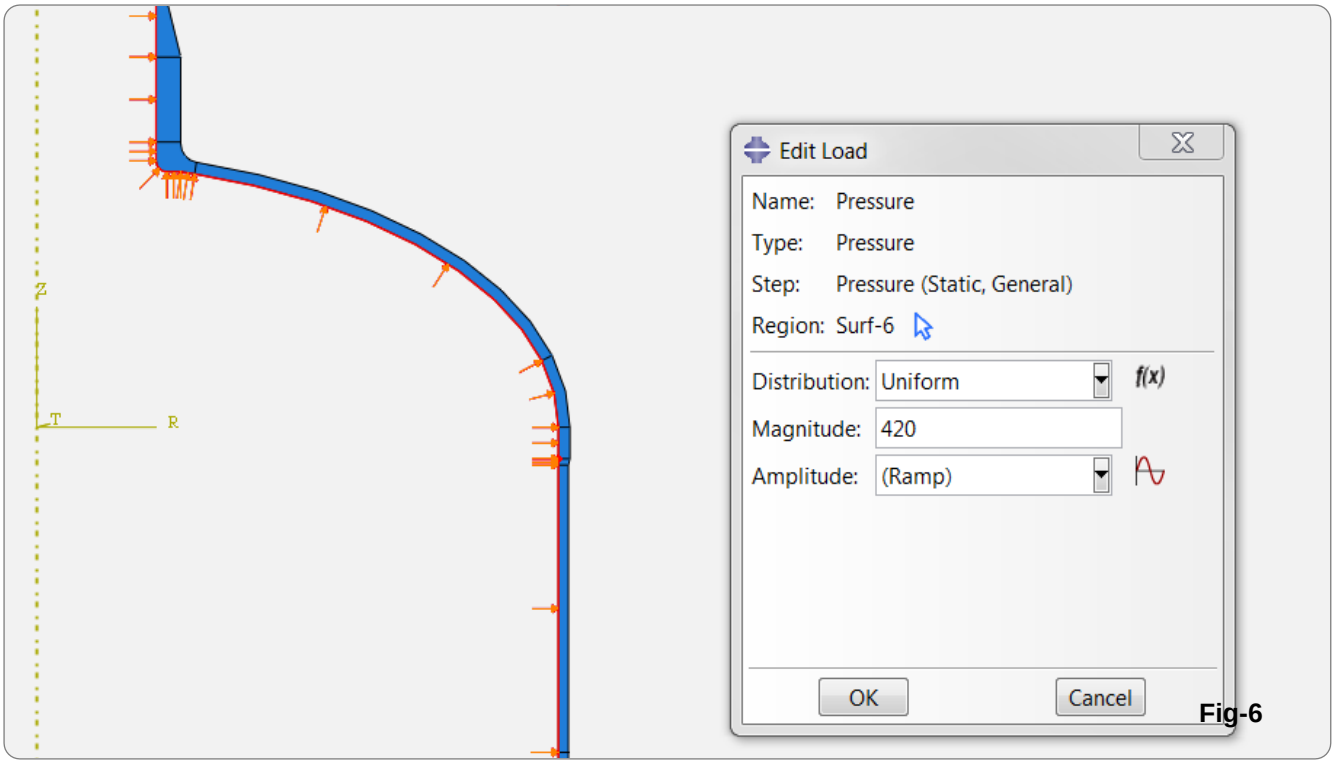


Fig-6

Internal Pressure

420 psi is applied to all internal surfaces.

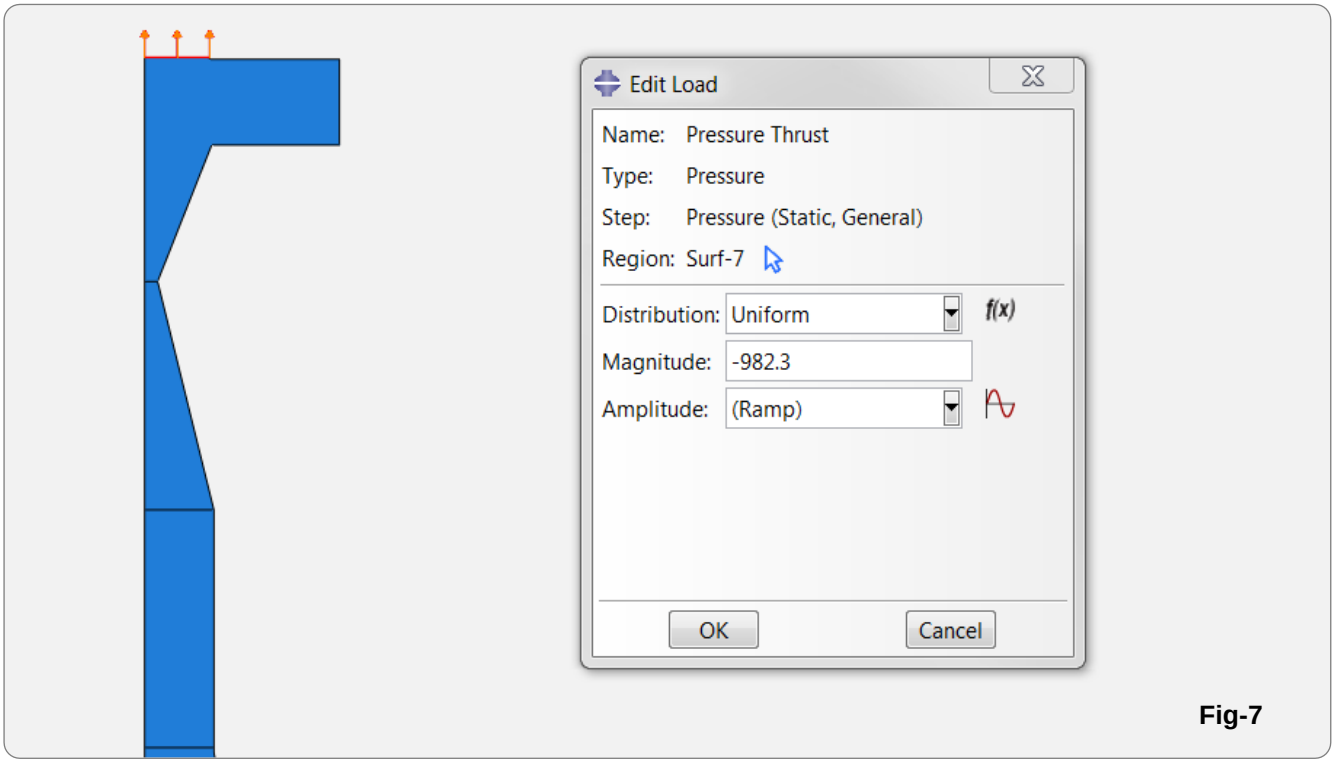


Fig-7

Exit Pressure

982.3 psi is the equivalent exit pressure applied to the flange. This accounts for the longitudinal stress present in a closed system. Source PTB-3 Figure E5.2.1-7.
Note that typically this load would be transferred through the bolt holes and generate a larger bending moment.

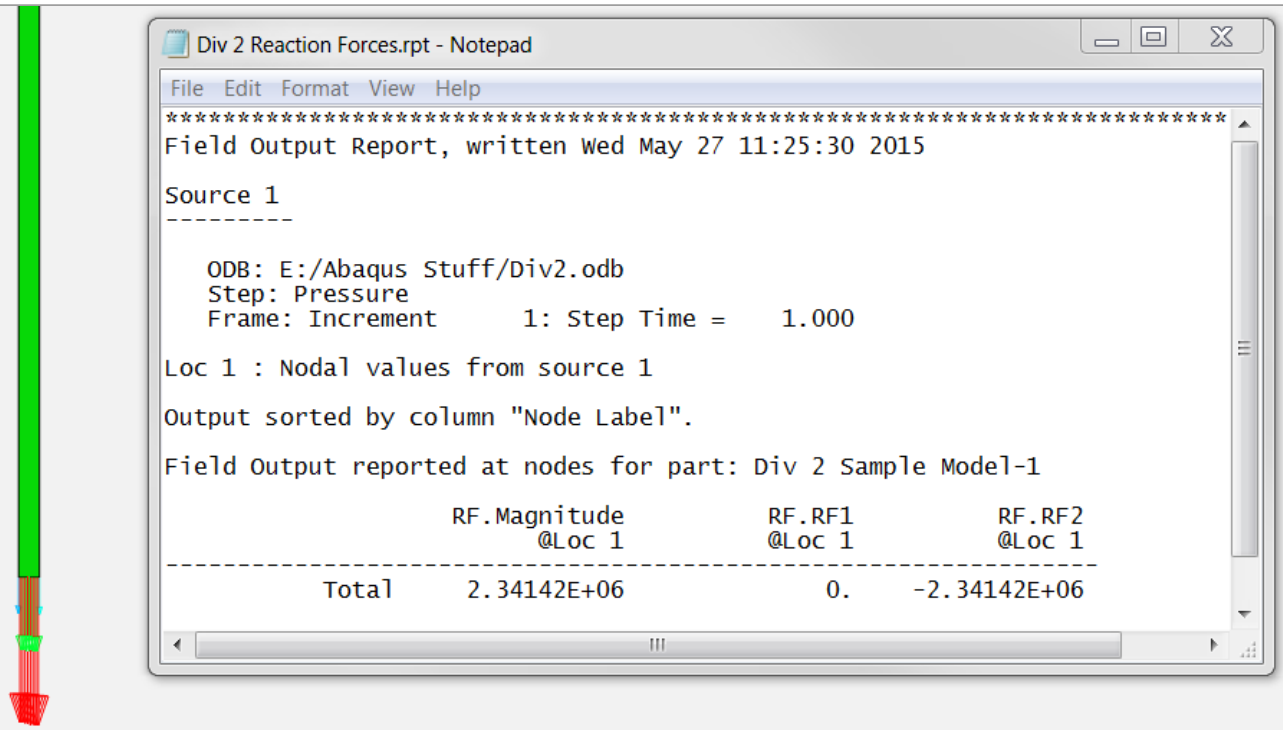


Fig-8

Global Reaction Forces

Global Reaction Forces from analysis 'X' = 0 lb, 'Y' = 2341420 lb, 'Z' = 0 lb
Calculated Reaction Forces = Analysis Reaction Forces within 0%
Model is balanced, results are valid.

420 **P** [psi] - Pressure

X Axis: reaction forces on the YZ plane caused by loads in the X direction

0.000 **XArea** [in2] - Pressurized area on YZ plane
0.0 **XForce** [lbs] - Added force in the X direction
0.000 **XReaction** [lbs] - Reaction force in X direction reported by FEA program
TReactionX [lbs] = XArea*P+XForce Theoretical X reaction force 0*420+0 = **0**

Y Axis: reaction forces on the XZ plane caused by loads in the Y direction

5574.805 **YArea** [in2] - Pressurized area on XZ plane
0.0 **YForce** [lbs] - Added force in the Y direction
2341420.000 **YReaction** [lbs] - Reaction force in Y direction reported by FEA program
TReactionY [lbs] = YArea*P+YForce Theoretical Y reaction force 5574.805*420+0 = **2,341,418**

Z Axis: reaction forces on the XY plane caused by loads in the Z direction

0.000 **ZArea** [in2] - Pressurized area on XY plane
0.0 **ZForce** [lbs] - Added force in the Z direction
0.000 **ZReaction** [lbs] - Reaction force in Z direction reported by FEA program
TReactionZ [lbs] = ZArea*P+ZForce Theoretical Z reaction force 0*420+0 = **0**

Resultant of reaction forces in X, Y and Z:

TResultant [lbs] = sqrt(TReactionX^2+TReactionY^2+TReactionZ^2) Theoretical resultant
SQRT(0^2+2341418^2+0^2) = **2,341,418**

Resultant [lbs] = sqrt(XReaction^2+YReaction^2+ZReaction^2) Actual resultant
SQRT(0^2+2341420^2+0^2) = **2,341,420**

Error [%] = 100*(TResultant-Resultant)/Resultant 100*(2341418-2341420)/2341420 = **0.0**

CheckError = abs(Error)<2 Error should be less than 2% ABS(0)<2 = **Acceptable**

Displacement

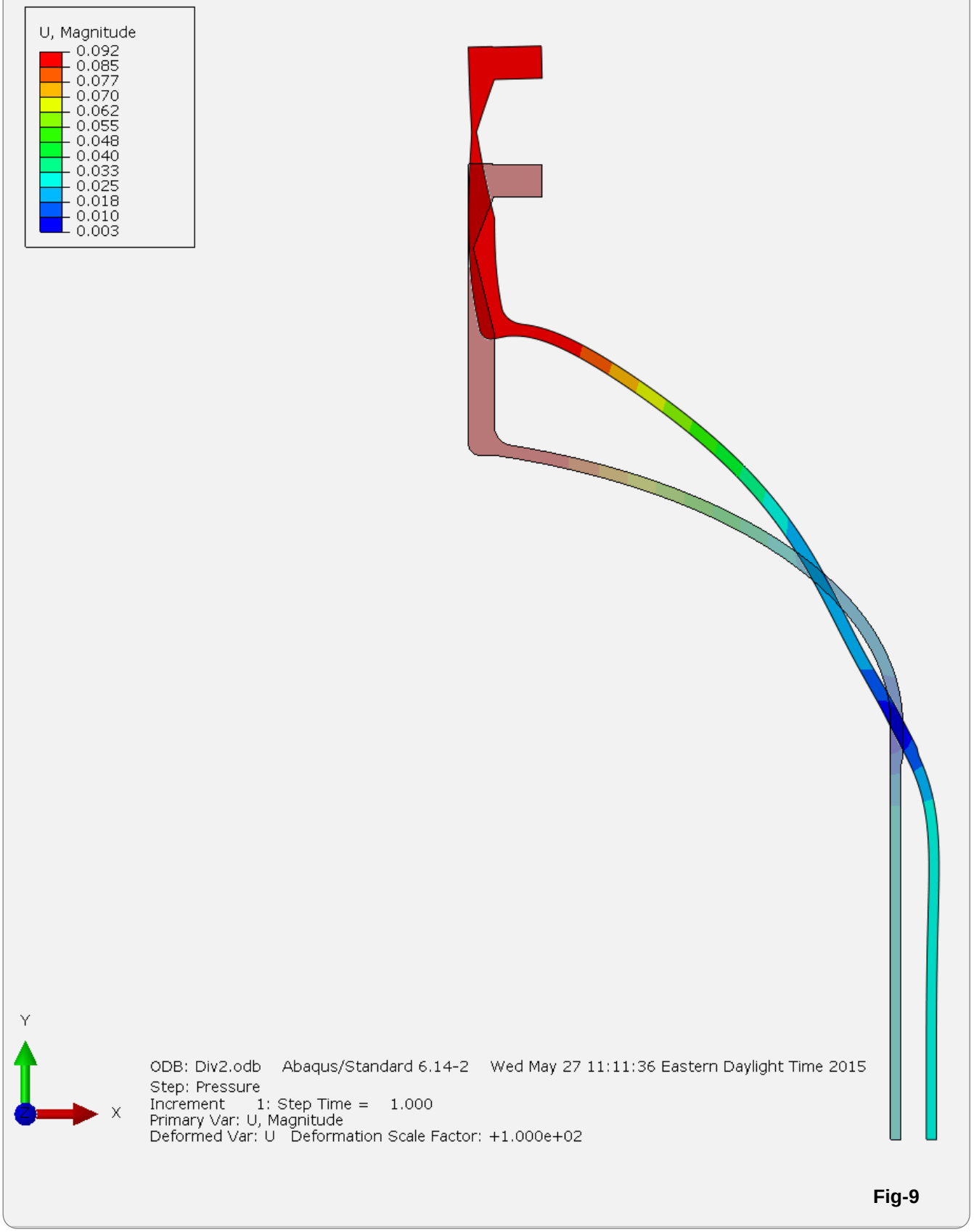


Fig-9

Displacement Plot

The displacement plot is magnified 100 times to emphasize the displaced shape of the model. The original geometry is superimposed to further emphasize how the model displaces. The displaced shape of the model is as expected.

Fig-10

von Mises Stress

The maximum von Mises stress in the model is 36,494 psi. This stress occurs at the outer head surface adjacent to the nozzle. This is a localized stress and is subject to the local allowable membrane plus bending limit. All general areas are within the general membrane allowable limits of 24,550 psi for the shell and head material and 23,300 psi for the nozzle material.

ISO Clipped Stress

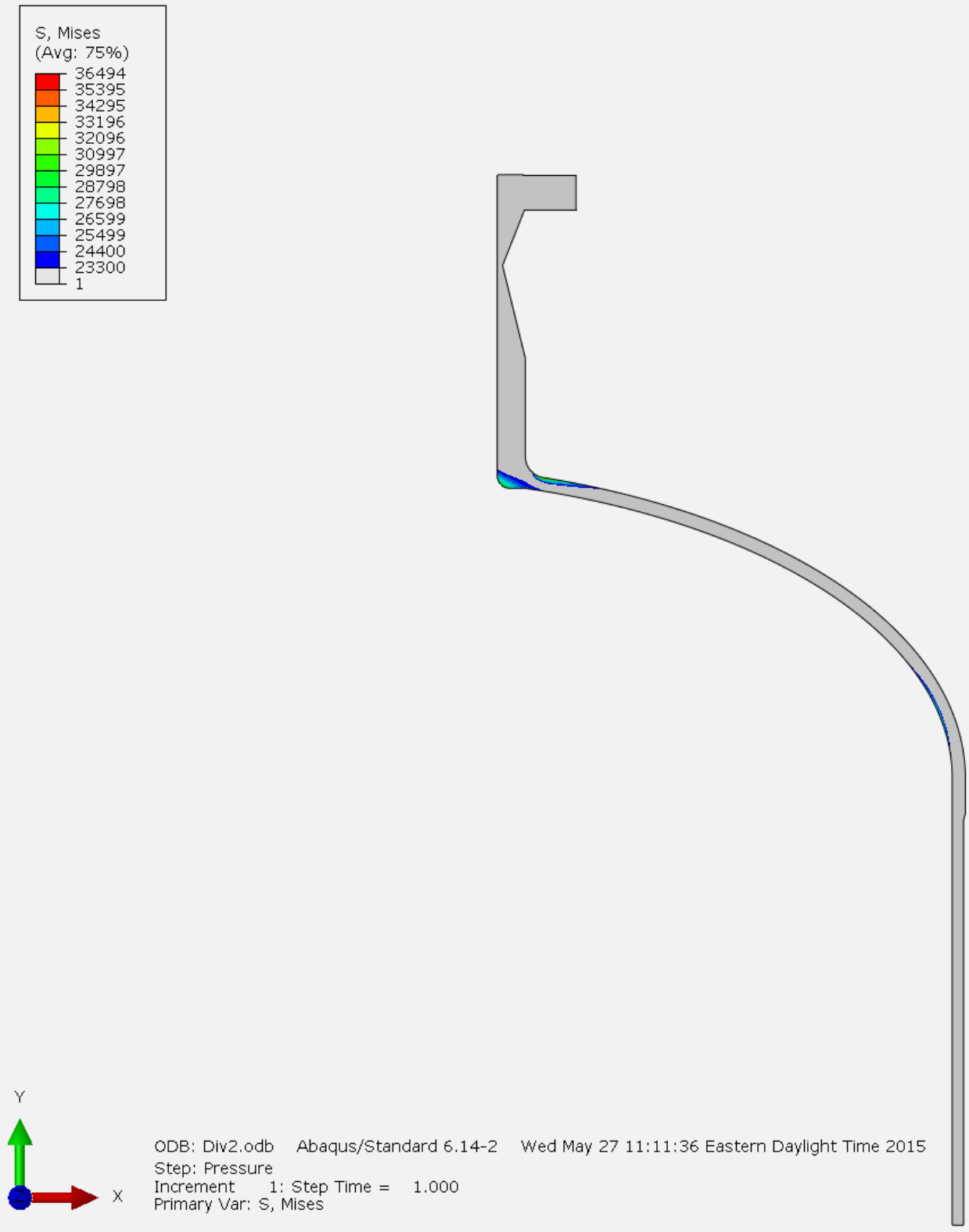
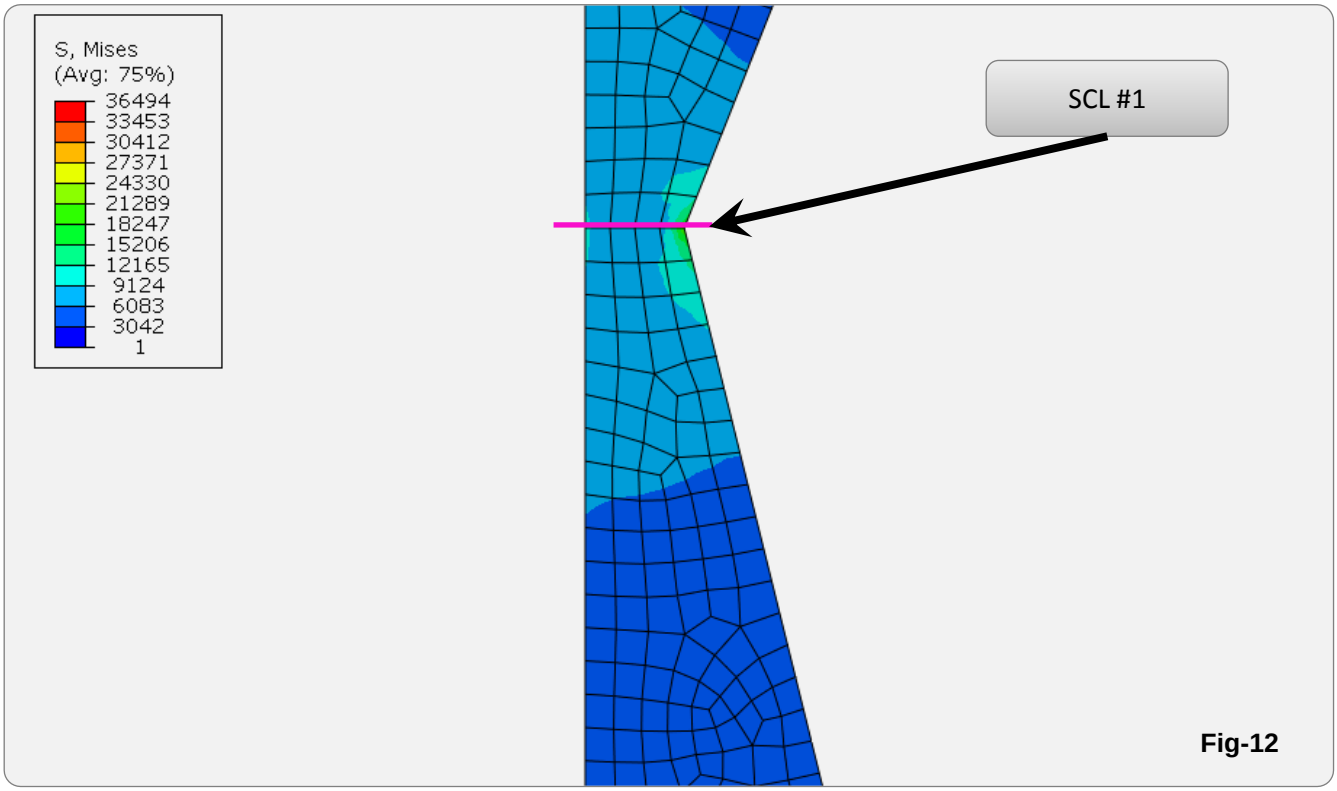


Fig-11

ISO Clipped Stress

The von Mises stress plot is ISO Clipped at the 23,300 psi primary general membrane allowable for SA-105 as this is the weaker of the two materials used in the design. This plot shows only stress contours that exceed this limit. All general areas in the model are within the allowable limit and are acceptable. Stresses exceeding this allowable are limited to areas loaded in bending and are subject to a higher allowable.

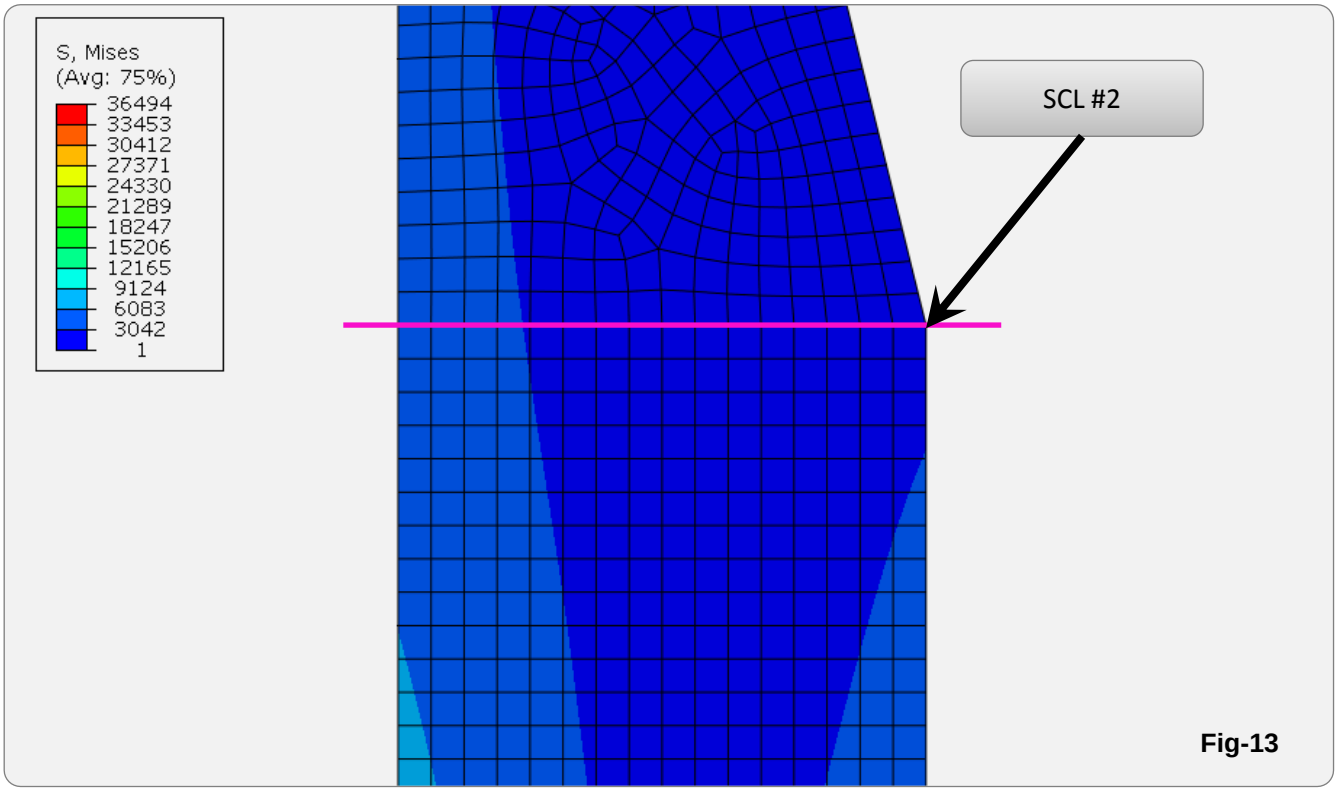


SCL #1

Stress classification line 1 is taken through the flange weld. The stress linearization results are below the material stress allowables and are acceptable.

Stress Check:

Local	**Stress** Classification		
SA-105	**Material**		
	Allowed	**Actual**	**Check**
Pl [psi] =	34,950	6,975	**Acceptable**
Pl+Pb+Q [psi] =	69,900	14,936	**Acceptable**

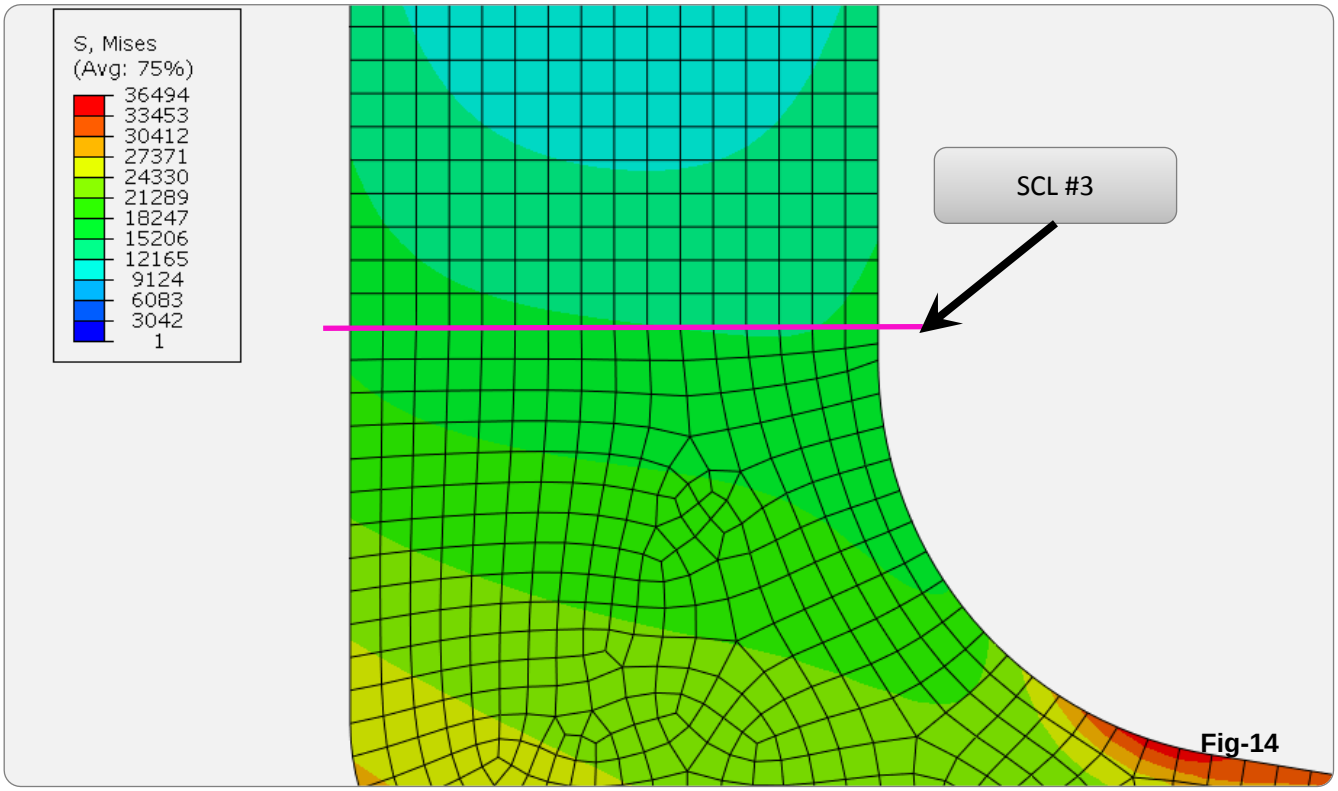


SCL #2

Stress classification line 2 is taken through the upper nozzle transition. The stress linearization results are below the material stress allowables and are acceptable.

Stress Check:

Local	**Stress** Classification		
SA-105	**Material**		
	Allowed	**Actual**	**Check**
Pl [psi] =	34,950	1,130	**Acceptable**
Pl+Pb+Q [psi] =	69,900	4,482	**Acceptable**

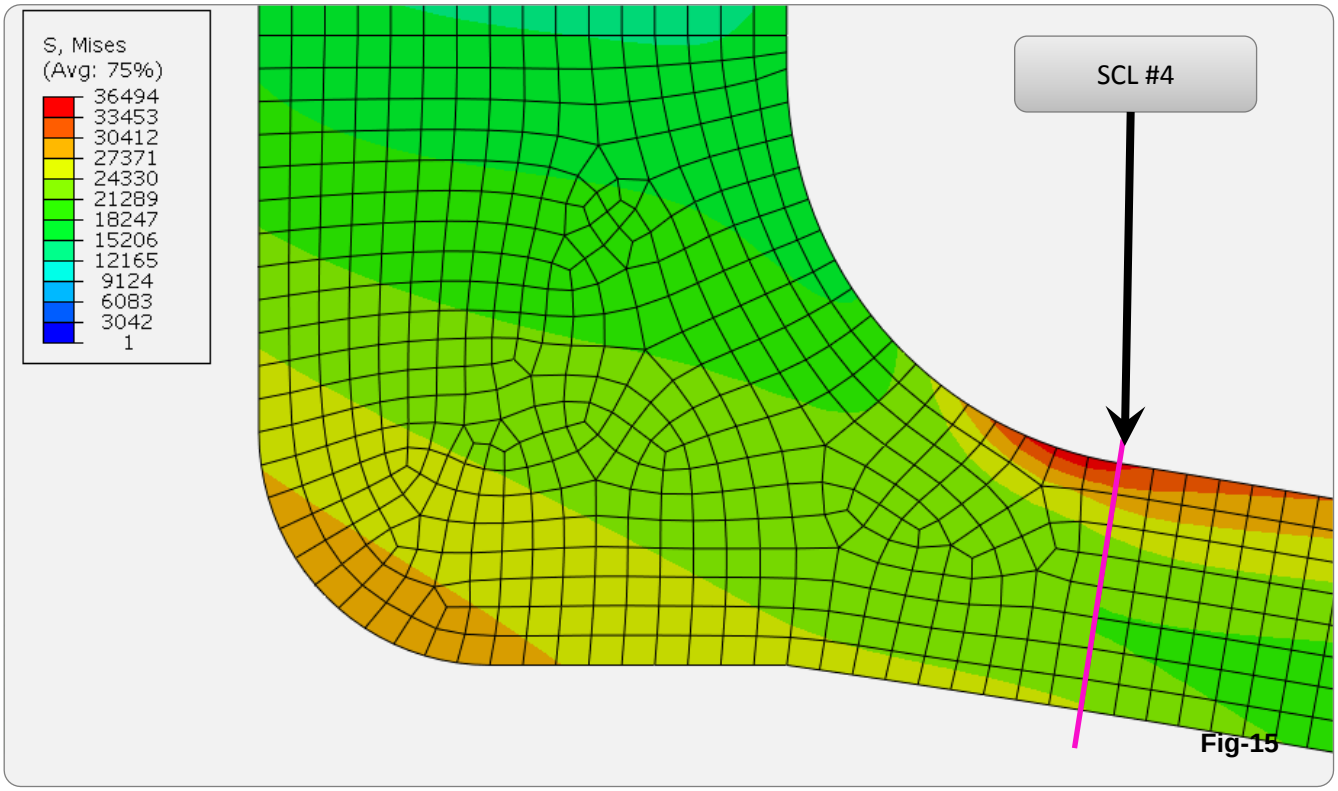


SCL #3

Stress classification line 3 is taken through the nozzle to shell junction. The stress linearization results are below the material stress allowables and are acceptable.

Stress Check:

Local	**Stress** Classification		
SA-105	**Material**		
	Allowed	**Actual**	**Check**
Pl [psi] =	34,950	15,303	**Acceptable**
Pl+Pb+Q [psi] =	69,900	17,158	**Acceptable**

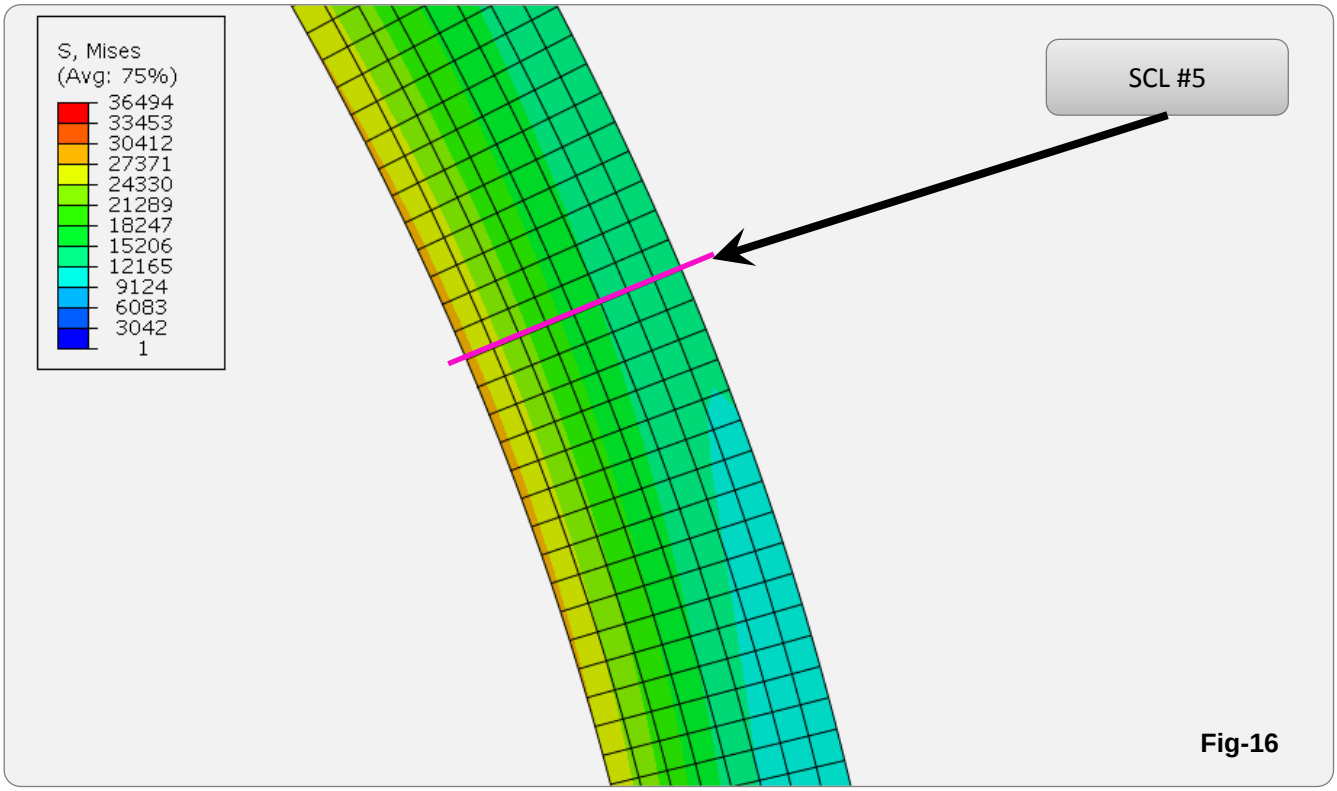


SCL #4

Stress classification line 4 is taken through the shell to nozzle junction. The stress linearization results are below the material stress allowables and are acceptable.

Stress Check:

Local	**Stress** Classification		
SA-516 70N	**Material**		
	Allowed	**Actual**	**Check**
Pl [psi] =	36,825	22,138	**Acceptable**
Pl+Pb+Q [psi] =	73,700	32,698	**Acceptable**

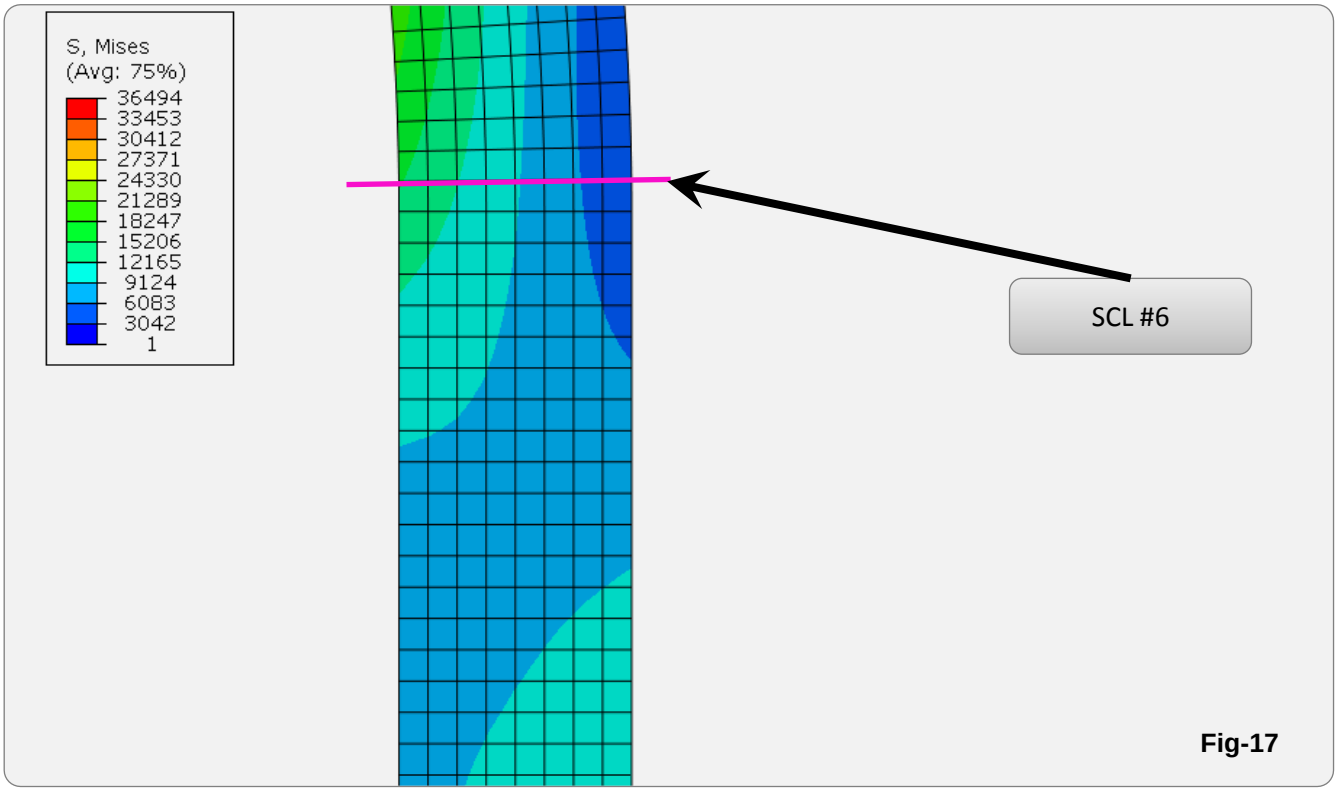


SCL #5

Stress classification line 5 is taken through the elliptical head knuckle. The stress linearization results are below the material stress allowables and are acceptable.

Stress Check:

Local	**Stress** Classification		
SA-516 70N	**Material**		
	Allowed	**Actual**	**Check**
Pl [psi] =	36,825	17,861	**Acceptable**
Pl+Pb+Q [psi] =	73,700	27,541	**Acceptable**

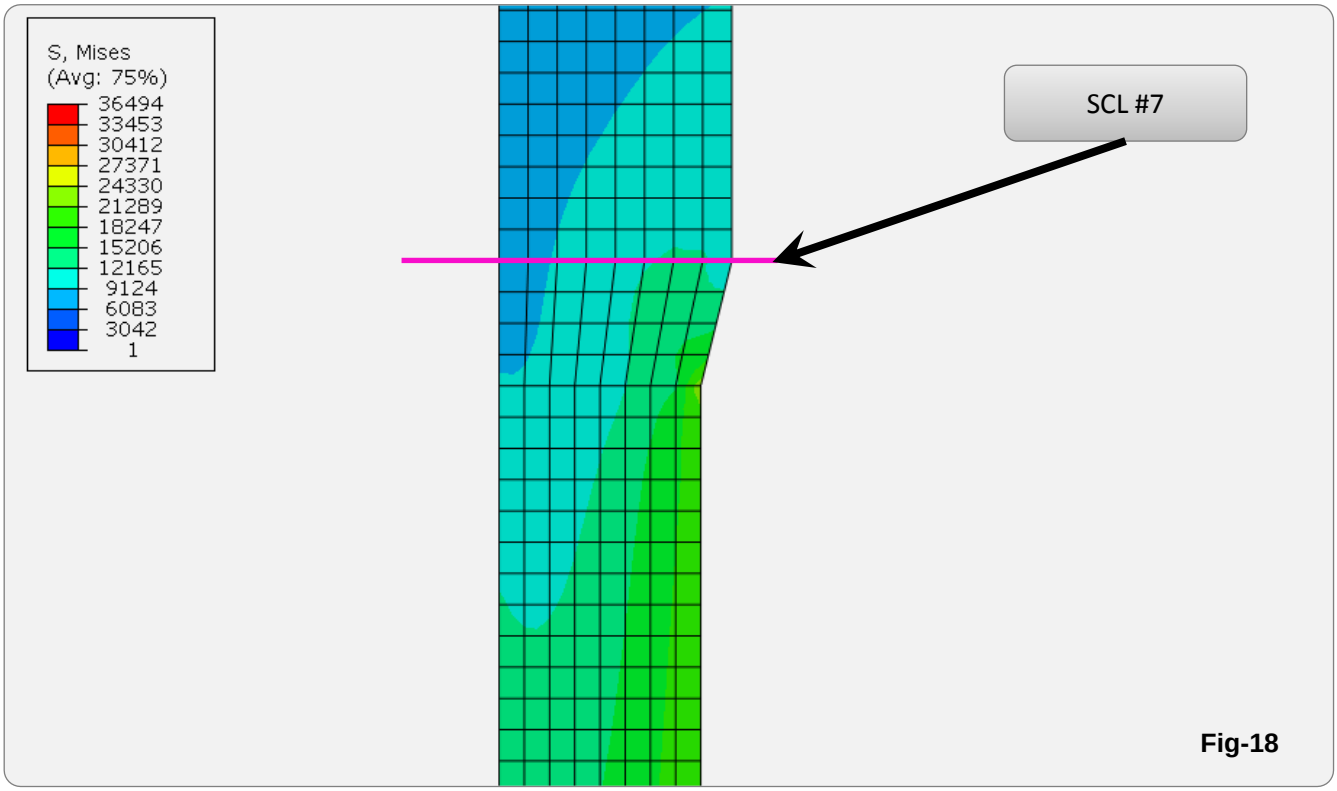


SCL #6

Stress classification line 6 is taken through the head tangent line. The stress linearization results are below the material stress allowables and are acceptable.

Stress Check:

Local	**Stress** Classification		
SA-516 70N	**Material**		
	Allowed	**Actual**	**Check**
Pl [psi] **=**	36,825	9,110	**Acceptable**
Pl+Pb+Q [psi] **=**	73,700	14,334	**Acceptable**

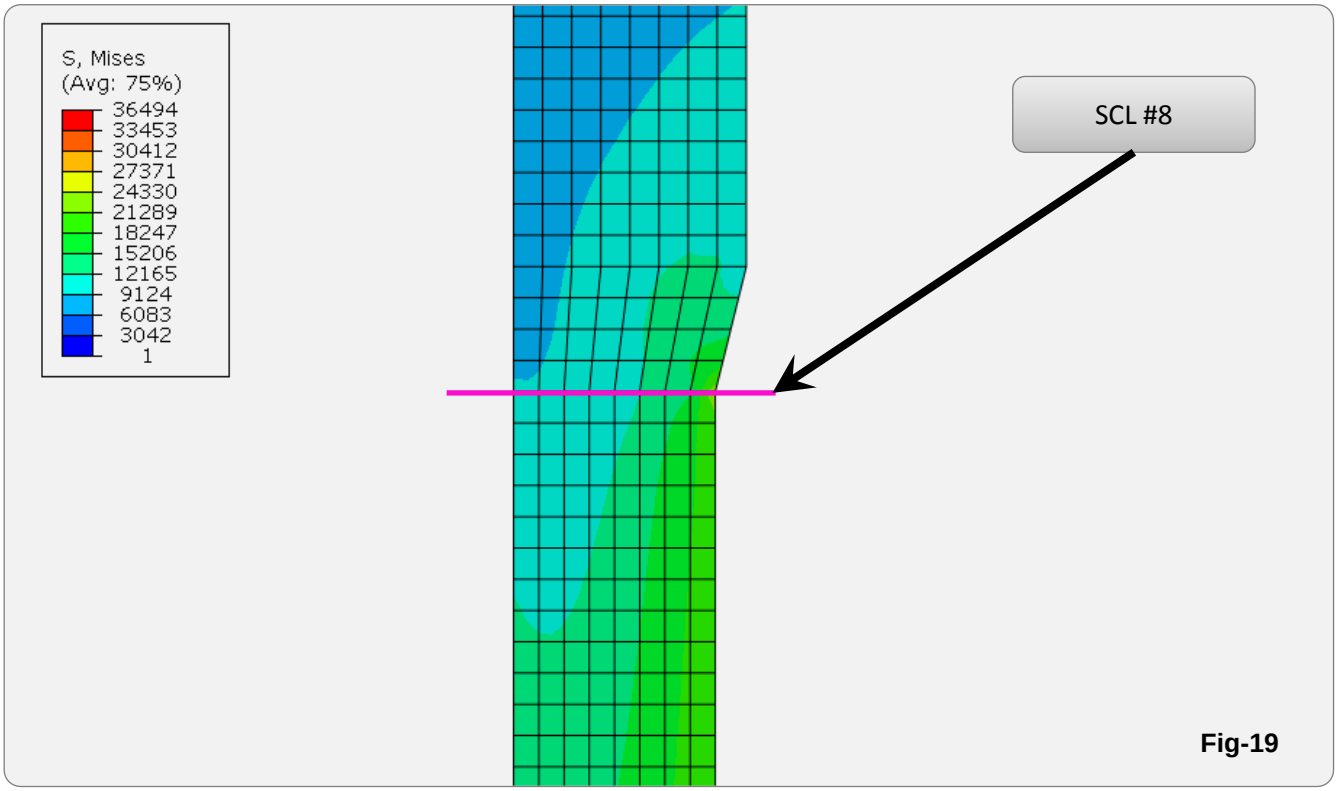


SCL #7

Stress classification line 7 is taken through the head to shell transition. The stress linearization results are below the material stress allowables and are acceptable.

Stress Check:

Local	**Stress** Classification		
SA-516 70N	**Material**		
	Allowed	**Actual**	**Check**
Pl [psi] =	36,825	10,408	**Acceptable**
Pl+Pb+Q [psi] =	73,700	12,788	**Acceptable**

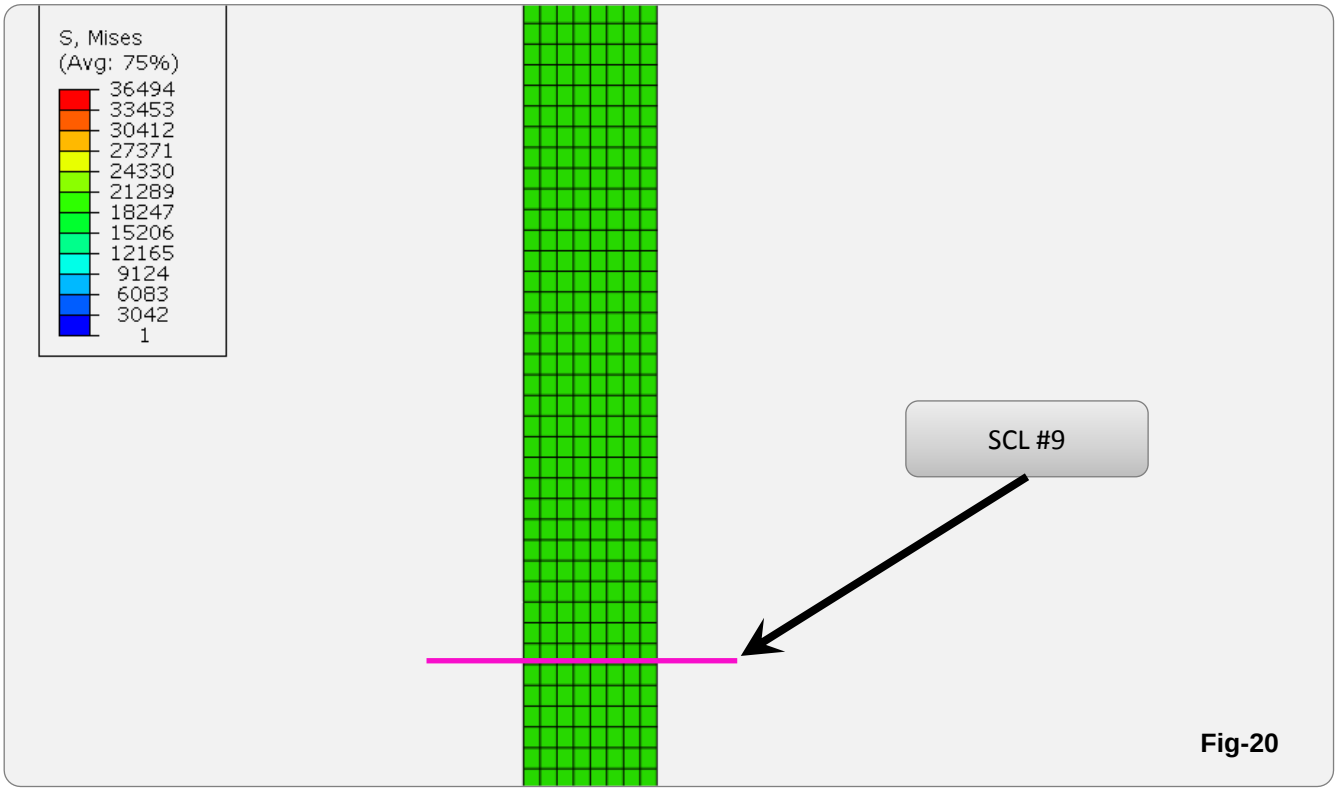


SCL #8

Stress classification line 8 is taken through the shell to head transition. The stress linearization results are below the material stress allowables and are acceptable.

Stress Check:

Local	**Stress** Classification		
SA-516 70N	**Material**		
	Allowed	**Actual**	**Check**
Pl [psi] **=**	36,825	11,331	**Acceptable**
Pl+Pb+Q [psi] **=**	73,700	18,930	**Acceptable**



SCL #9

Stress classification line 9 is taken through the shell (away from discontinuities). The stress linearization results are below the material stress allowables and are acceptable.

Stress Check:

General	**Stress** Classification		
SA-516 70N	**Material**		
	Allowed	**Actual**	**Check**
Pm [psi] **=**	24,550	18,982	**Acceptable**
Pl+Pb [psi] **=**	36,825	19,199	**Acceptable**

Local Plastic Collapse

Fig-21

Local Plastic Collapse Check

The sum of the principal stresses shall be less than 4S (93,200 psi) per article 5.3.2. The maximum observed stress in the model is 72,575 psi which is within the allowable limit. Therefore, the model is acceptable.