Pressure Vessel Engineering Ltd.

ASME Calculations - CRN Assistance - Vessel Design - Finite Element Analysis

Design Conditions

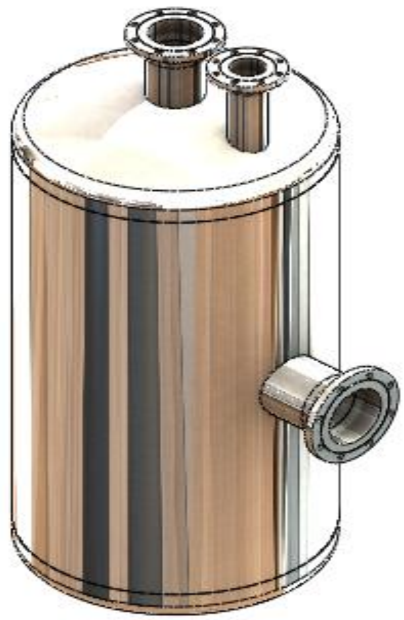
Code:	**ASME VIII-1**	
Year:	**2010**	
Addenda:	**2011**	
Operating Press(Min):	**25**	psi
Operating Press(Max):	**125**	psi
Operating Temp.:	**150**	°F
Radiography:	**None**	
Corrosion Allowance:	**None**	in

UG-22 Loadings Considered

Internal Press.:	**Yes**
External Press.:	**No**
Vessel Weight:	**No**
Weight of Attachments:	**No**
Attachment of Internals:	**No**
Attachment of Externals:	**No**
Cyclic or Dynamic Reactions:	**Yes**
Wind Loading:	**No**
Seismic Loading:	**No**
Fluid Impact Shock Reactions:	**No**
Temperature Gradients:	**No**
Differential Thermal Expansion:	**No**
Abnormal Pressures:	**No**
Hydrotest Loads:	**No**

Finite Element Analysis Report - VIII-1

Cust: **Pressure Vessel Engineering**
File: **PVEfea-6160-1.0**
Desc: **Cycle Life Sample**
Dwg: **PVEdwg-6160-1.0**
Date: **June 26, 2012**



Author: Matt Hiskett, Cameron Moore
Reviewer: Laurence Brundrett, P. Eng.

Conclusion: From the fatigue assessment, it is determined that the vessel is permissible for 40,573 cycles. This is constrained by the stresses at the weld toe between the 8" nozzle to shell junction.

www.pveng.com
info@pveng.com
Phone 519-880-9808

Pressure Vessel Engineering Ltd.
120 Randall Drive, Suite B
Waterloo, Ontario, Canada, N2V 1C6

Table of Contents

	Author	Reviewer
Model / Drawing Review:	CBM	MAH
Boundary / Load Condition Review:	CBM	MAH
Results / Review:	CBM	LB

Revision(s)			
Rev	Description	Date	By
0	Release	26-Jun-12	CBM

Goal:

A fatigue assessment is completed per ASME VIII-2 part 5 for the vessel. Finite element analysis is used to determine the stress amplitudes for fatigue computations.

Summary Conclusions:

Analysis Software
SolidWorks Simulation 2012 SP3.0

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

Materials
Material properties used in this report are obtained from ASME IID Table 1A (materials for VIII-1 designs). Stress classification limits are set in accordance with ASME VIII-2. Material stress limits are provided in this report, but model stresses are not commented on as this report only covers fatigue assessment.

Model Information
A sectioned (approx. 1/4) solid model is used for the analysis; pipe tolerance and head thin out are removed. The model is sectioned to include all important items requiring fatigue analysis. This report will generate result that justify the fatigue of the entire tank. A solid, 2nd order, tetrahedral mesh is applied and contact elements are treated as bonded. Reported error is < 5% in general regions as per ABSA FEA guideline AB-520. This validates the mesh selected, the model may be used for analysis.

Restraints & Loads
The bottom sectioned surface has symmetry restraints applied. Symmetry is also applied on the two cutting faces on the symmetry planes. All internal surfaces have 100 psi applied. This pressure simulates the same stress amplitude as running 25 psi to 125 psi and calculating the stress differential per VIII-2. All openings have pressure thrust loads applied to simulate the attachment of a closed loop pipe system. Thermal loads have not been applied since all materials have a consistent thermal expansion. The reported reaction forces match the theoretical reactions forces. The model is in balance and restrained from rigid body motion.

Results
The direction of displacement is as expected, the magnitude of displacement is acceptable. The resulting fatigue per location is summarized below.

Location	Allowed Cycles	Reference
Head Knuckle	233,206	Pg. 13
6" Nozzle	215,553	Pg. 19
4" Nozzle	43,727	Pg. 27
8" Nozzle	40,573	Pg. 35

Analysis Conclusion:

From the fatigue assessment it is determined that the vessel is permissible for 40,573 cycles. This is constrained by the stresses at the weld toe at the 8" nozzle to shell junction.

Material Stress Limits ver 4.02 ASME VIII-2 Fig 5.1

Material Input Chart:

150 **Temperature** [ºF]

	Material 1	Material 2	Material 3	Material 4
Material =	**SA-516 70**	**SA-106 B**	**SA-105**	
Application =	Shell / Head	Nozzles	Flanges	
Sm [psi] **=**	20,000	17,100	20,000	
Sy [psi] **=**	35,700	32,900	33,800	
Sya [psi] **=**	38,000	35,000	36,000	
Sta [psi] **=**	70,000	60,000	70,000	
E1 =	1.0	1.0	1.0	
E2 =	1.0	1.0	1.0	
E [psi] **=**	29,030,000	29,030,000	29,030,000	
v =	0.30	0.30	0.30	
Coef =				
Pm [psi] **=**	20,000	17,100	20,000	
Pl [psi] **=**	30,000	25,650	30,000	
Pl+Pb [psi] **=**	30,000	25,650	30,000	
Pl+Pb+Q [psi] **=**	71,400	65,800	67,600	
Prop. Sources	ASME Section II Part D 2010 Ed, 2011 Add.			
Comments				

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)

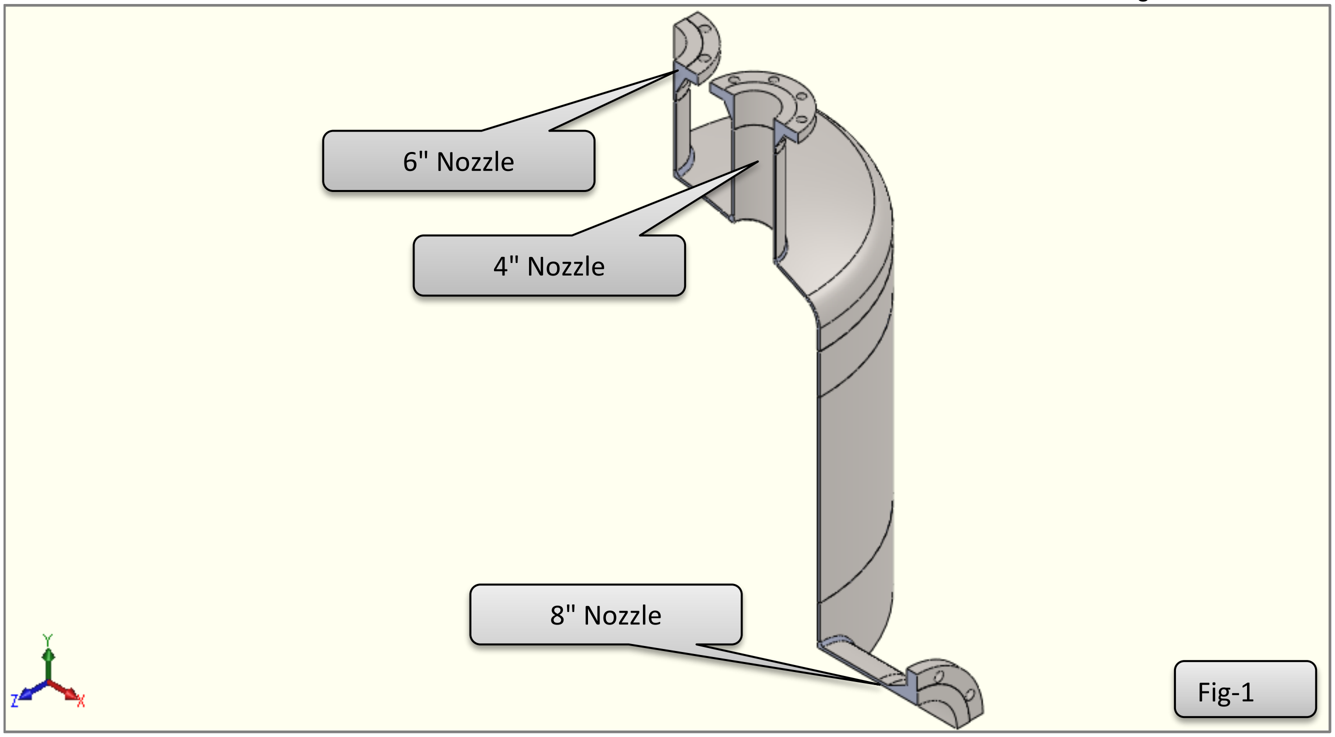
Stress Limit Equations: VIII-2 Figure 5.1

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

Comments:

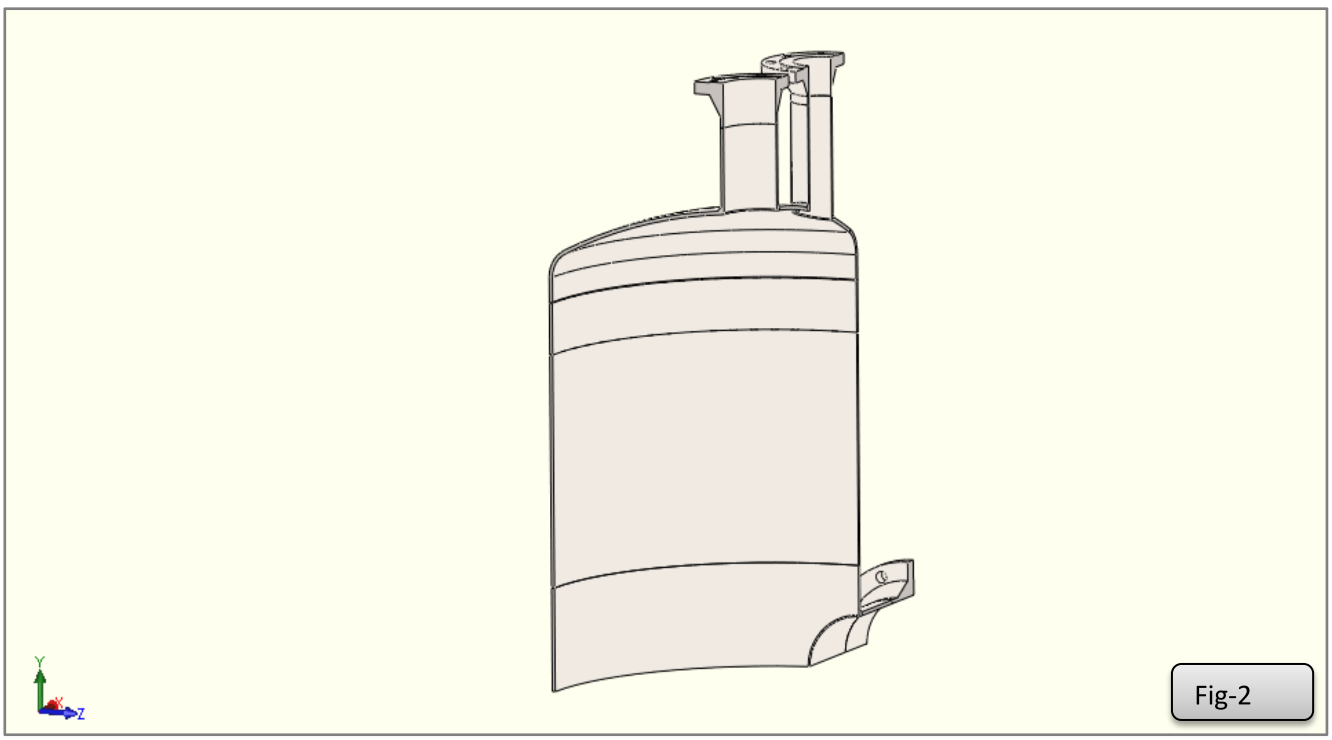
(1) Sy material property is not required, more conservative Pl+Pb+Q limits might be computed without it.
(2) The thermal expansion coefficient is only required for studies including thermal stresses
(3) Refer to VIII-2 5.15 Figure 5.1 and following for the Pm, Pl, Q and F stress limits
(4) Refer to VIII-2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

Model



Model Geometry

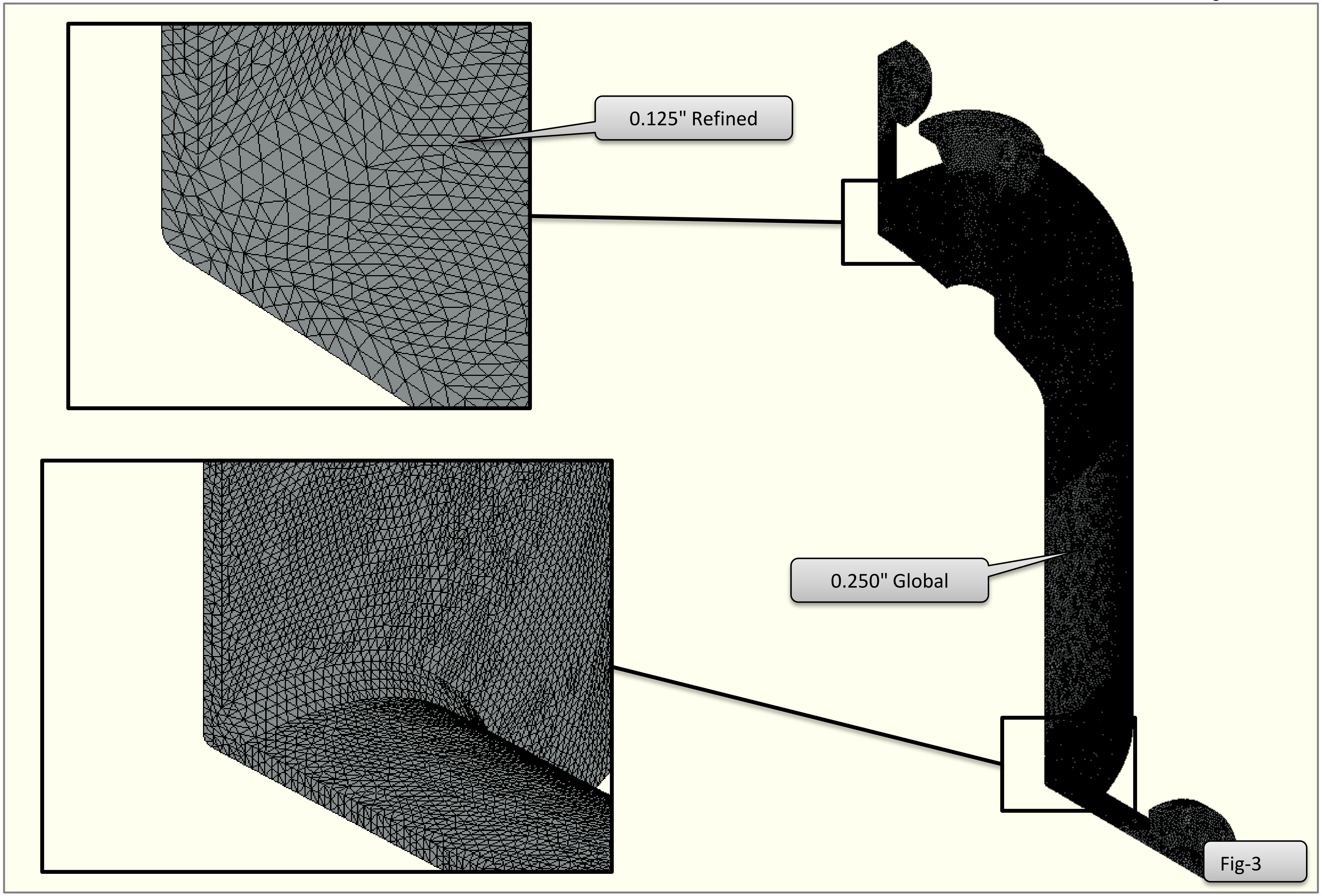
A 1/4 section of the model is used in the analysis due to symmetry. All items requiring fatigue analysis per VIII-2 5.5.2.4 have been included in the model. Please refer to PVEdwg-6160-1.0 for details.



Model Geometry - Rotated

The model view is rotated to show the opposite side of the vessel.

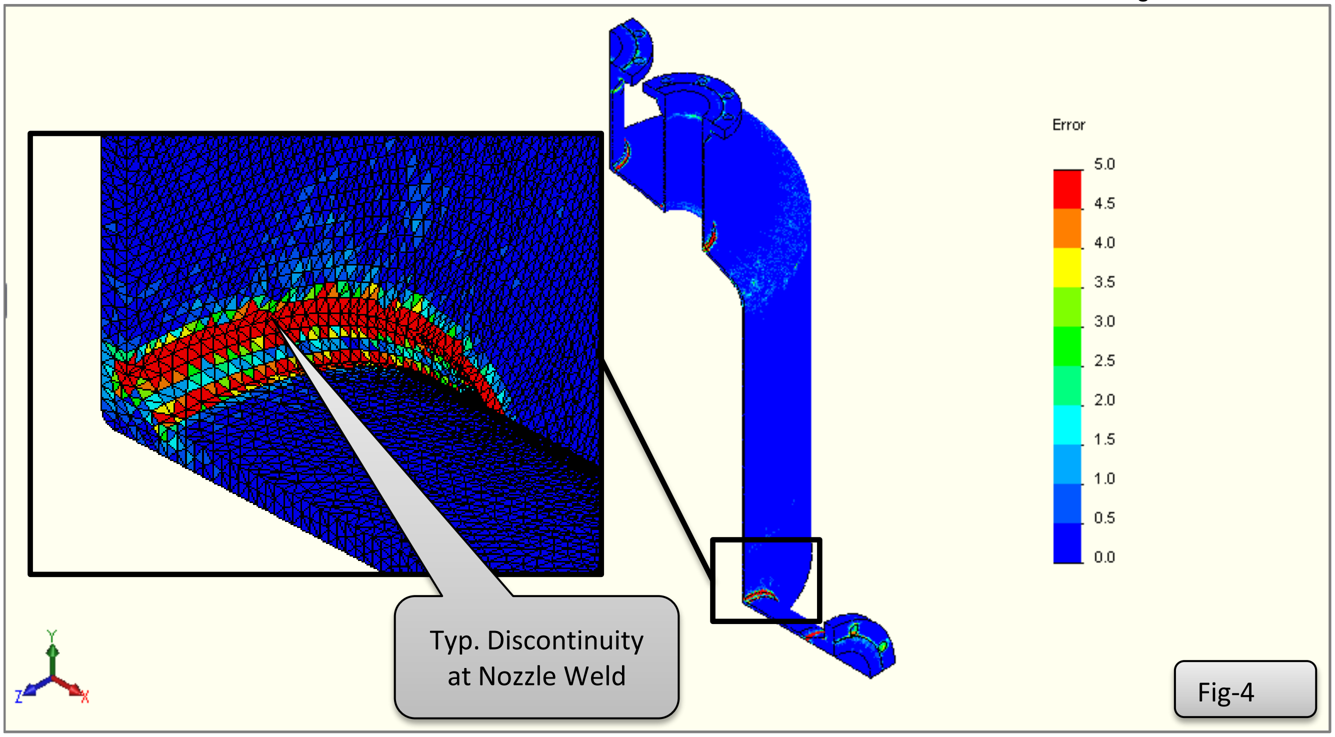
Mesh



Mesh Plot

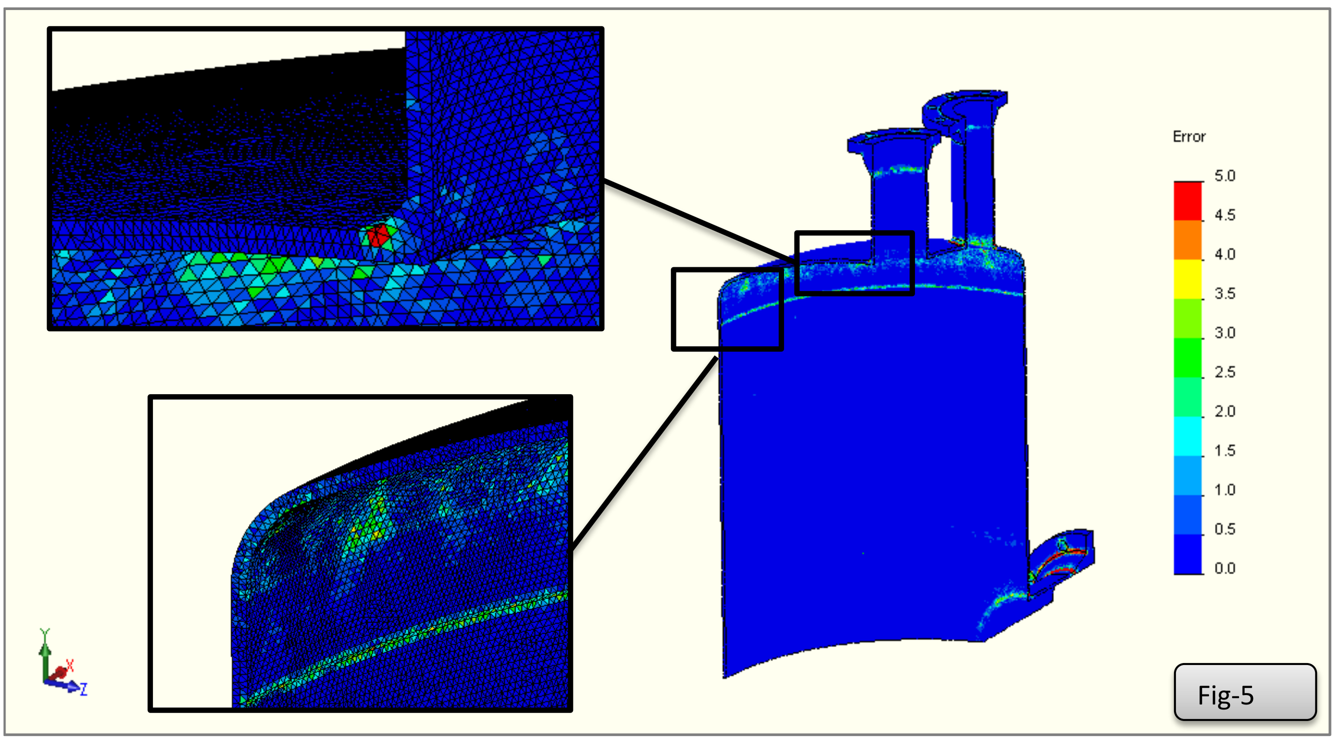
A 0.250", second order, tetrahedral, solid mesh was applied globally. Local areas were refined to 0.125" to reduce the reported error to less than 5%

Error



Error Plot

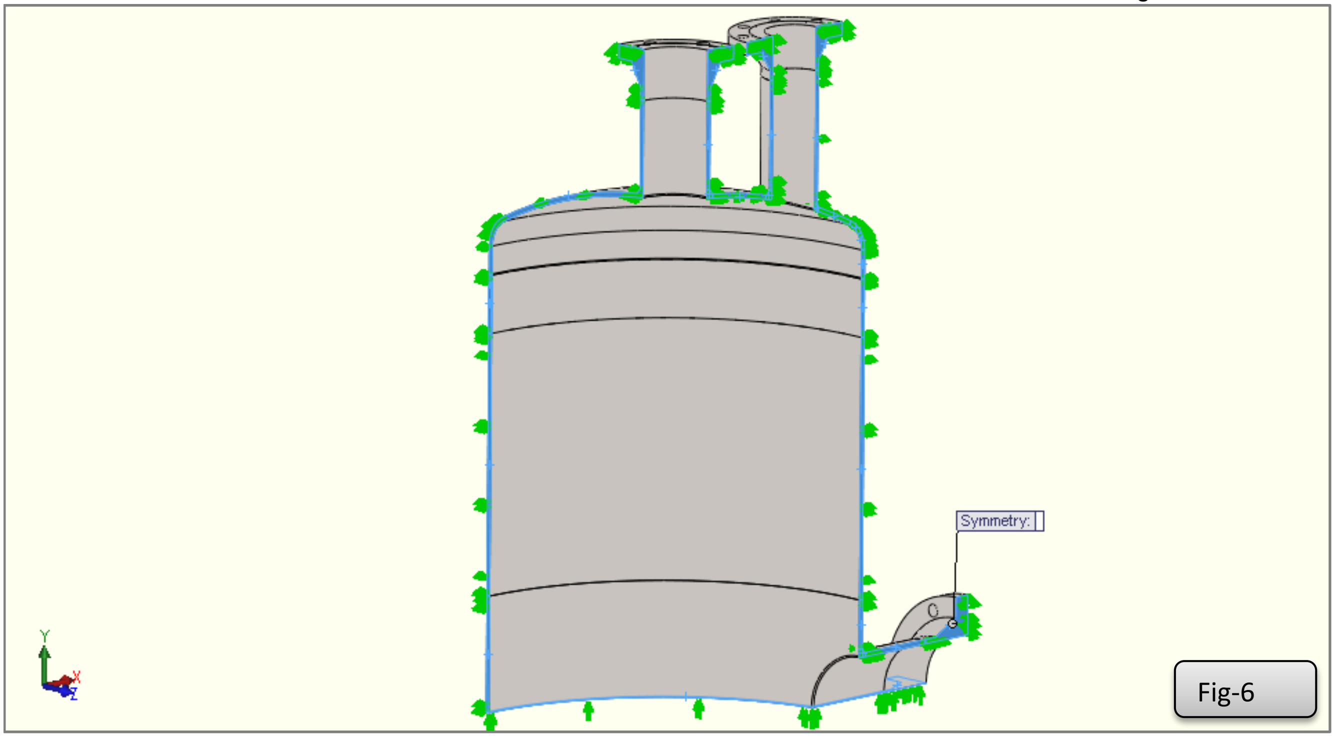
No general areas observe error in excess of 5%. The error plot demonstrates that the mesh selected is refined enough for geometry and stress variations. The mesh setup may be used for further analysis.



Error Plot

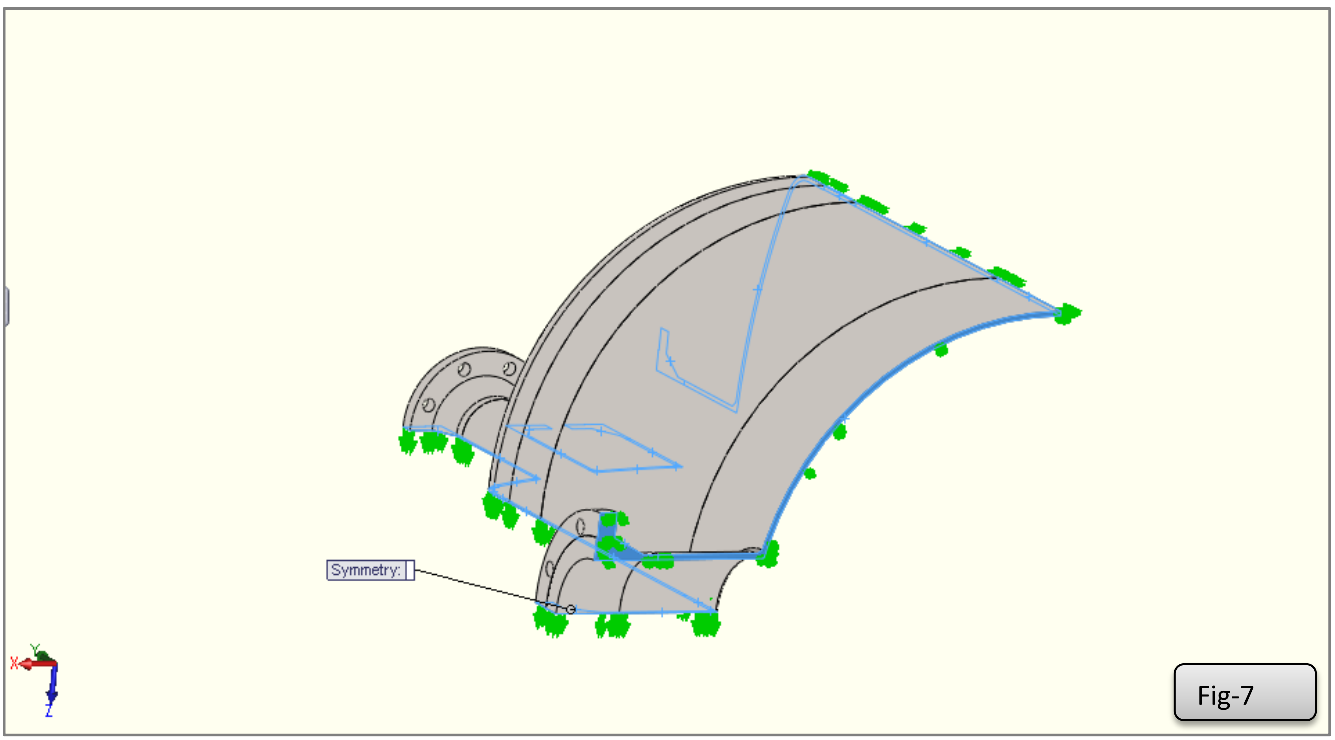
An alternate view showing the error result for the inside of the vessel.

Restraints



Symmetry Restraints

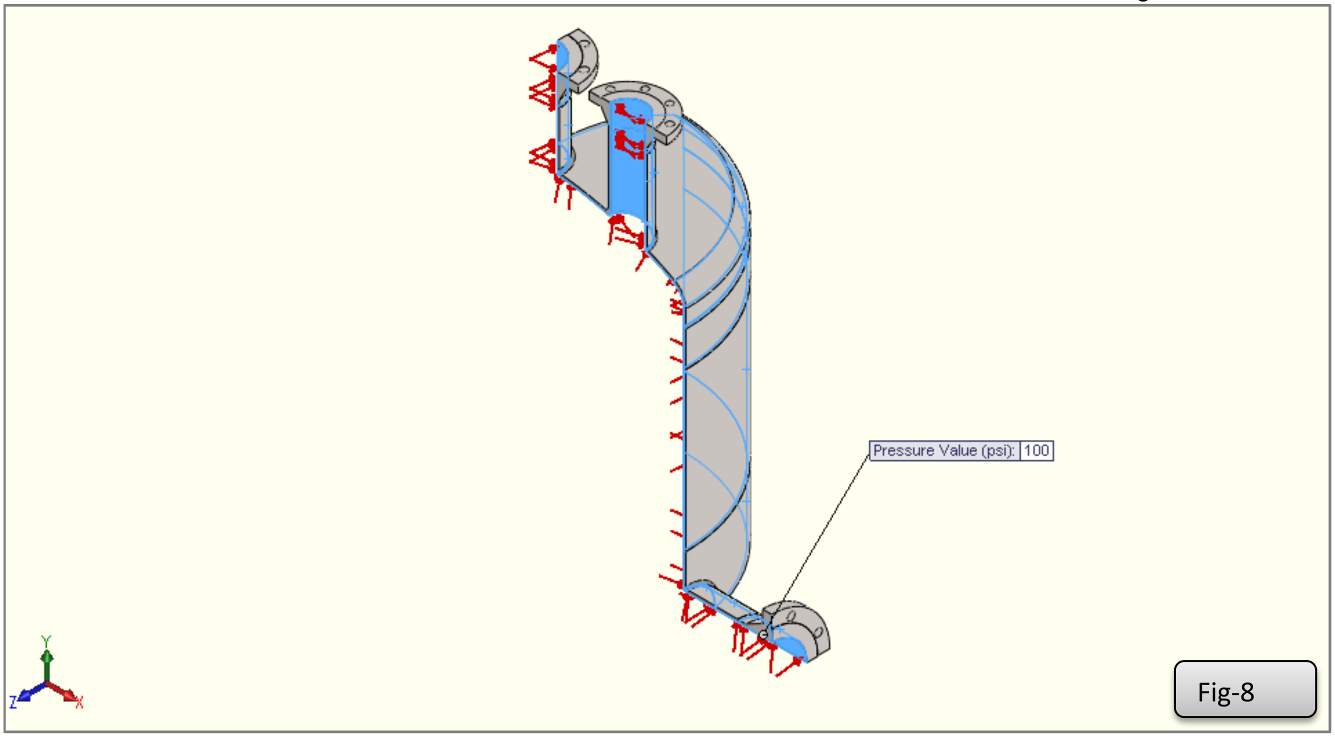
Symmetry restraints are applied to all faces on the symmetry planes.
This restraint compensates for the use of a 1/4 model and provides results identical to that of a full model. This restraint prevents motion in the x and z directions.



Symmetry Restraint - Bottom

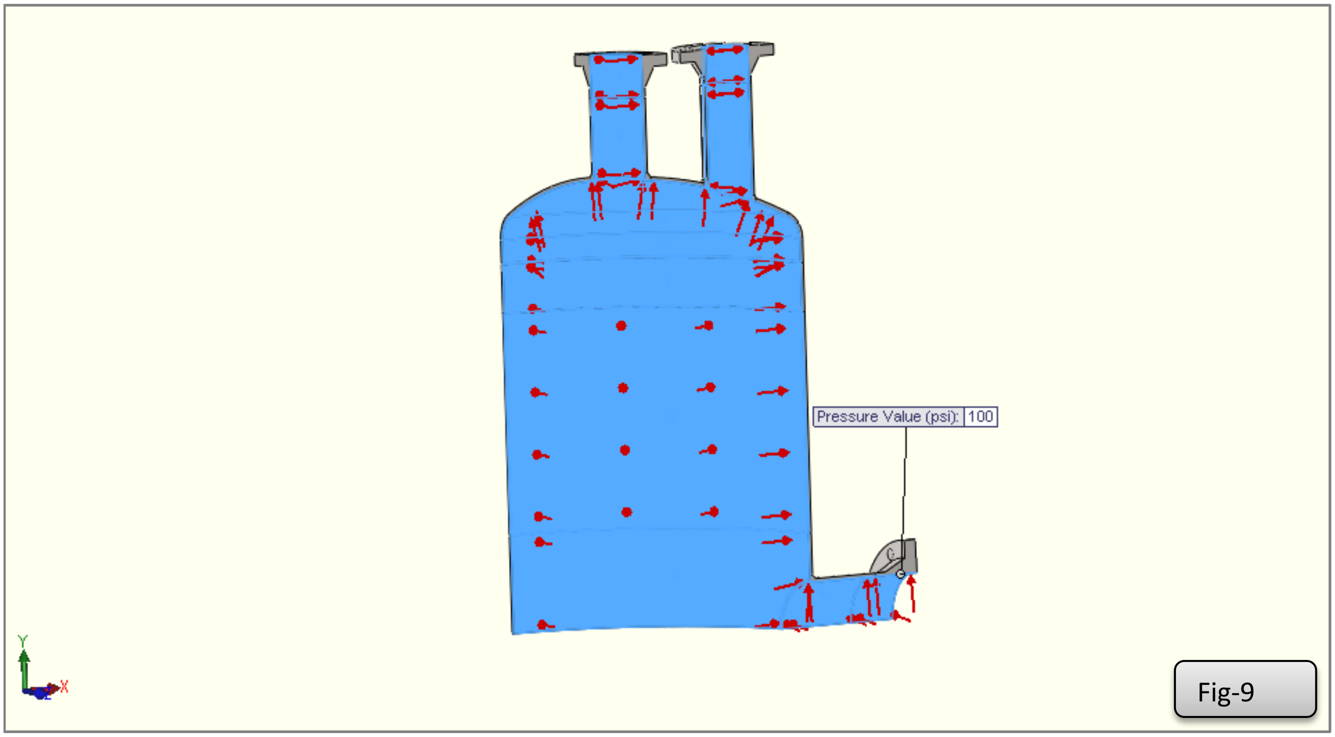
A symmetry restraint is applied through the centre of the shell. This restraint prevents translation of the model in the y direction. This set of restraints prevents translation in all three directions while allowing the model to displace realistically.

Loads



Internal Pressure

100 psi is applied to all internal surfaces in the model. This is the pressure differential between the 25 psi and 125 psi cyclic pressure range.



Internal Pressure - Rotated View

The vessel is rotated to show the 100 psi pressure applied to the internal faces.

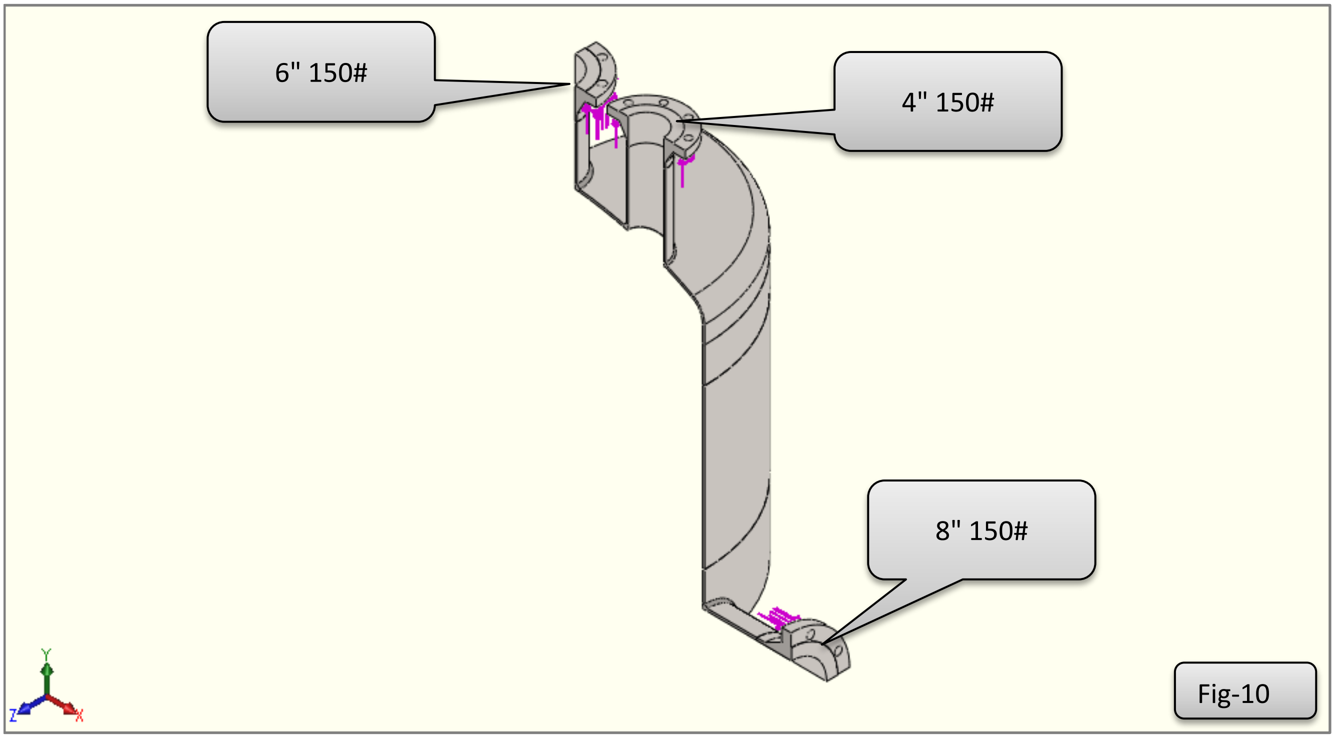
FEA Exit Pressure Force ver 4.0

Inputs:

3	**No** - number of openings
100	**P** [psi] - pressure

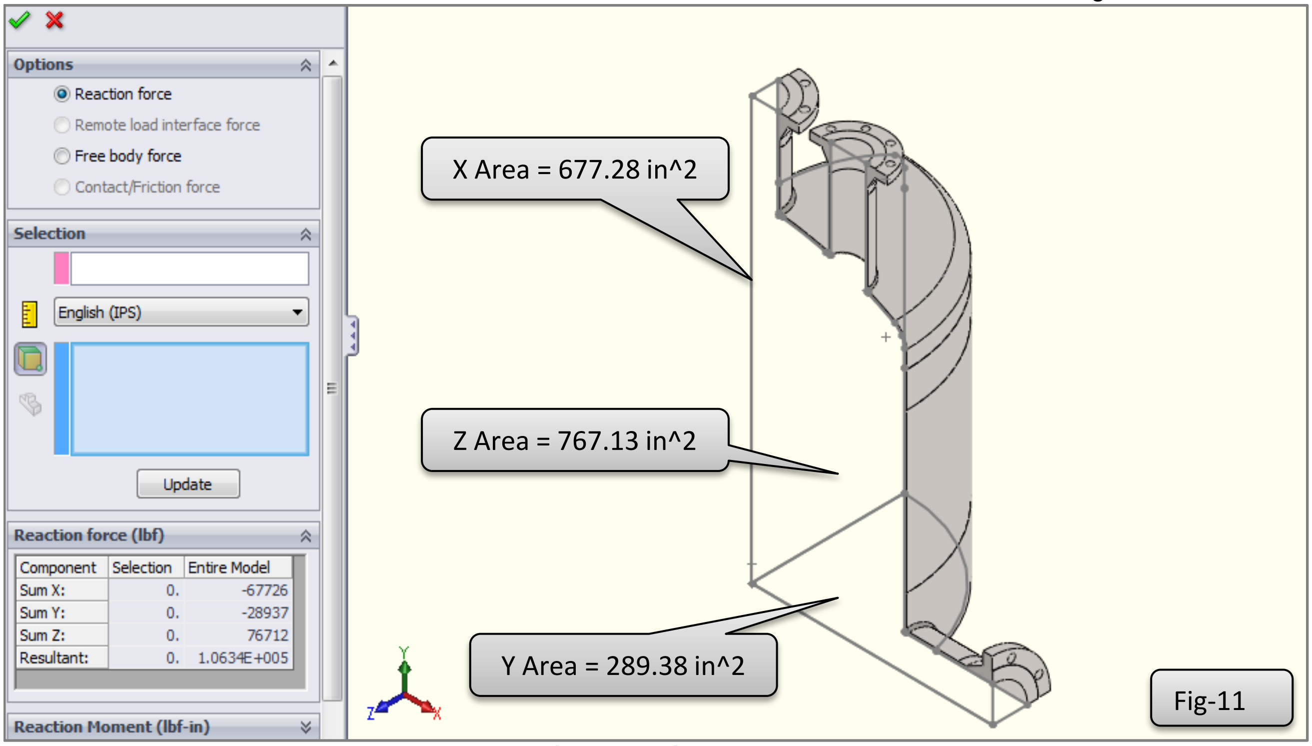
Opening Description	ID [in]	Open Factor	P [in]	A [in^2]	F [lb]
8" 150#	**8.062**	**0.250**	100.000	51.041	1276.032
6" 150#	**6.135**	**0.250**	100.000	29.561	739.025
4" 150#	**4.085**	**0.500**	100.000	13.108	655.386

Open Factor- use this for circular openings cut by section plane (ex. 1/2 opening)
Apply force F to the model in a realistic location (ex. back of flange, end of pipe or engaged thread area)



Exit Pressure Force

Exit pressure forces are applied to the three nozzles. These loads are applied to all openings without blind covers to simulate the exit pressure force that is generated in a closed loop system. This force is the product of the pressure and the opening's cross sectional area at the inside diameter.



Global Reaction Forces

View showing Global Reaction Forces from analysis 'X' = -67726 lb, 'Y' = -28937 lb, 'Z' = 76712 lb

Calculated Reaction Forces = Analysis Reaction Forces within 0%

Model is balanced, results are valid.

100 **P** [psi] - Pressure

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

677.283 **XArea** [in2] - Pressurized area on YZ plane

0.0 **XForce** [lbs] - Added force in the X direction

-67726.000 **XReaction** [lbs] - Reaction force in X direction reported by FEA program

TReactionX [lbs] = XArea*P+XForce Theoretical X reaction force 677.283*100+0 = **67,728**

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

289.383 **YArea** [in2] - Pressurized area on XZ plane

0.0 **YForce** [lbs] - Added force in the Y direction

-28937.000 **YReaction** [lbs] - Reaction force in Y direction reported by FEA program

TReactionY [lbs] = YArea*P+YForce Theoretical Y reaction force 289.383*100+0 = **28,938**

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

767.129 **ZArea** [in2] - Pressurized area on XY plane

0.0 **ZForce** [lbs] - Added force in the Z direction

76712.000 **ZReaction** [lbs] - Reaction force in Z direction reported by FEA program

TReactionZ [lbs] = ZArea*P+ZForce Theoretical Z reaction force 767.129*100+0 = **76,713**

Resultant of reaction forces in X, Y and Z:

TResultant [lbs] = sqrt(TReactionX^2+TReactionY^2+TReactionZ^2) Theoretical resultant

SQRT(67728^2+28938^2+76713^2) = **106,346**

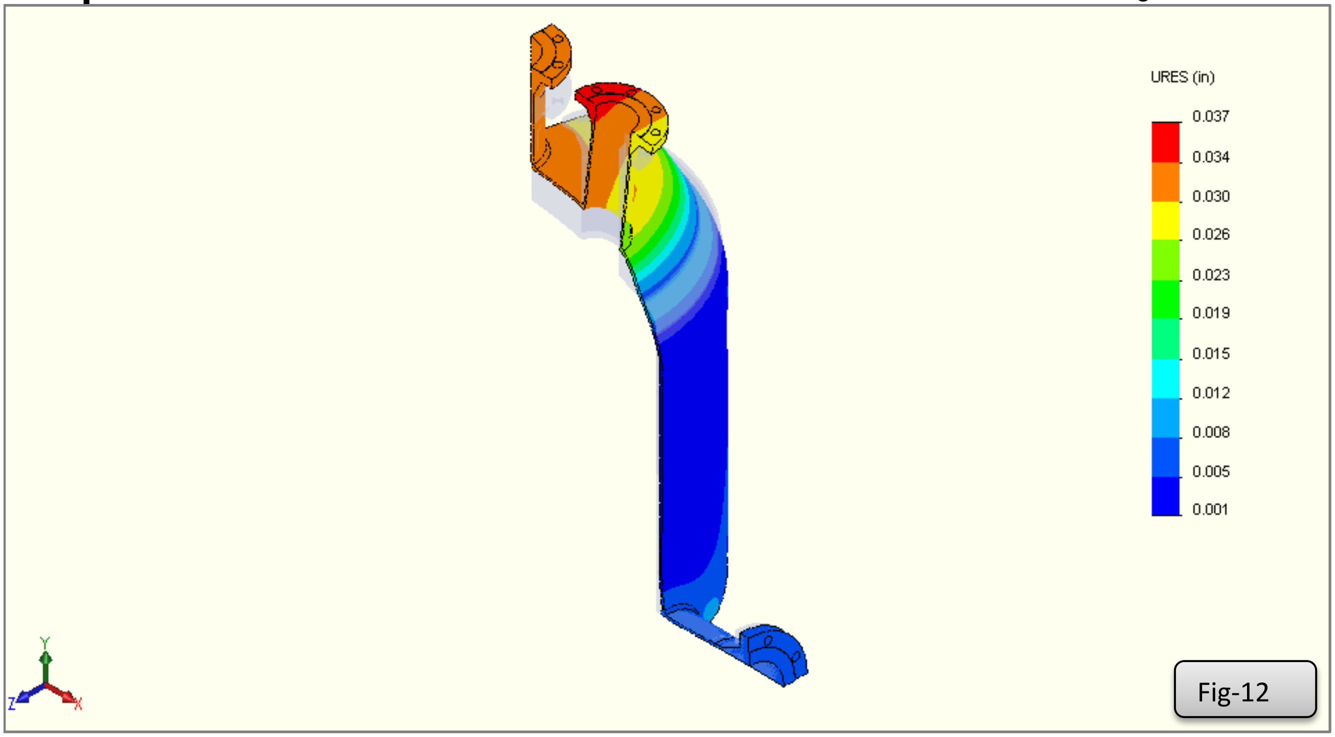
Resultant [lbs] = sqrt(XReaction^2+YReaction^2+ZReaction^2) Actual resultant

SQRT(-67726^2+-28937^2+76712^2) = **106,343**

Error [%] = 100*(TResultant-Resultant)/Resultant 100*(106346-106343)/106343 = **0.0**

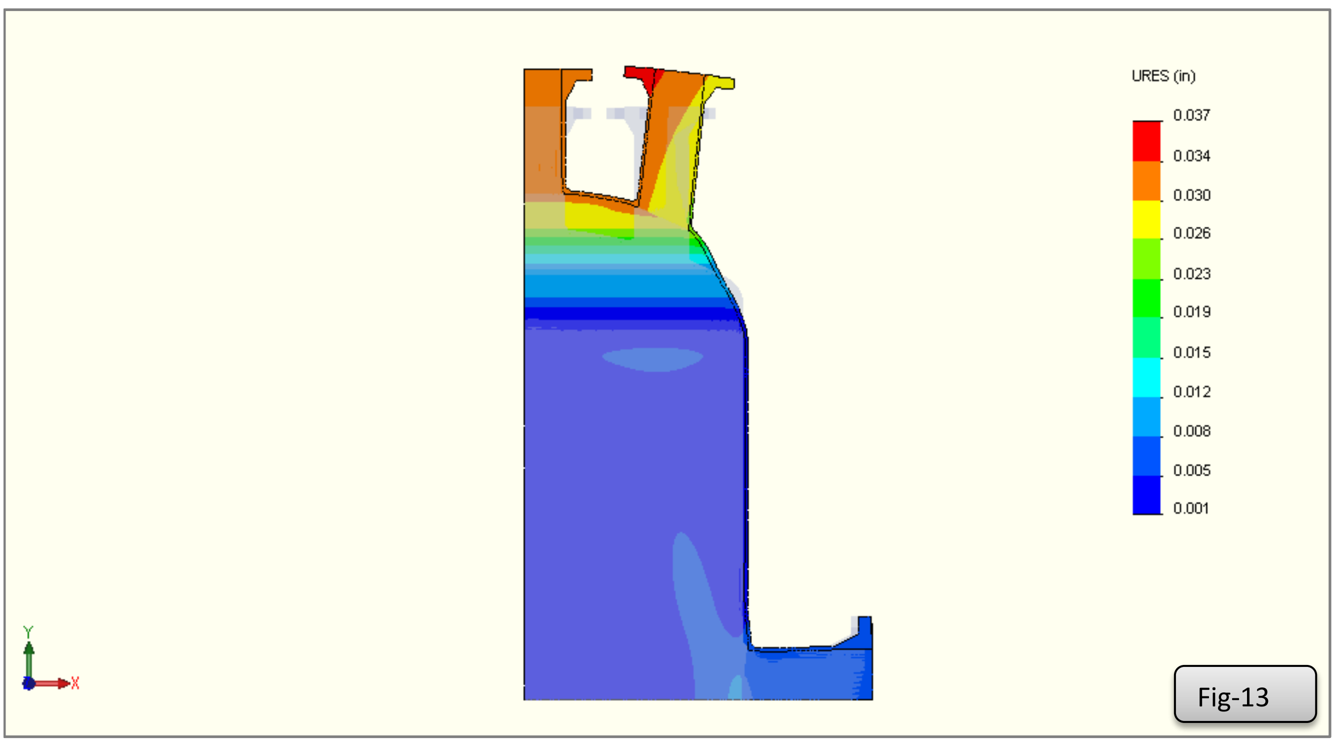
CheckError = abs(Error)<2 Error should be less than 2% ABS(0)<2 = **Acceptable**

Displacement



Displacement Plot

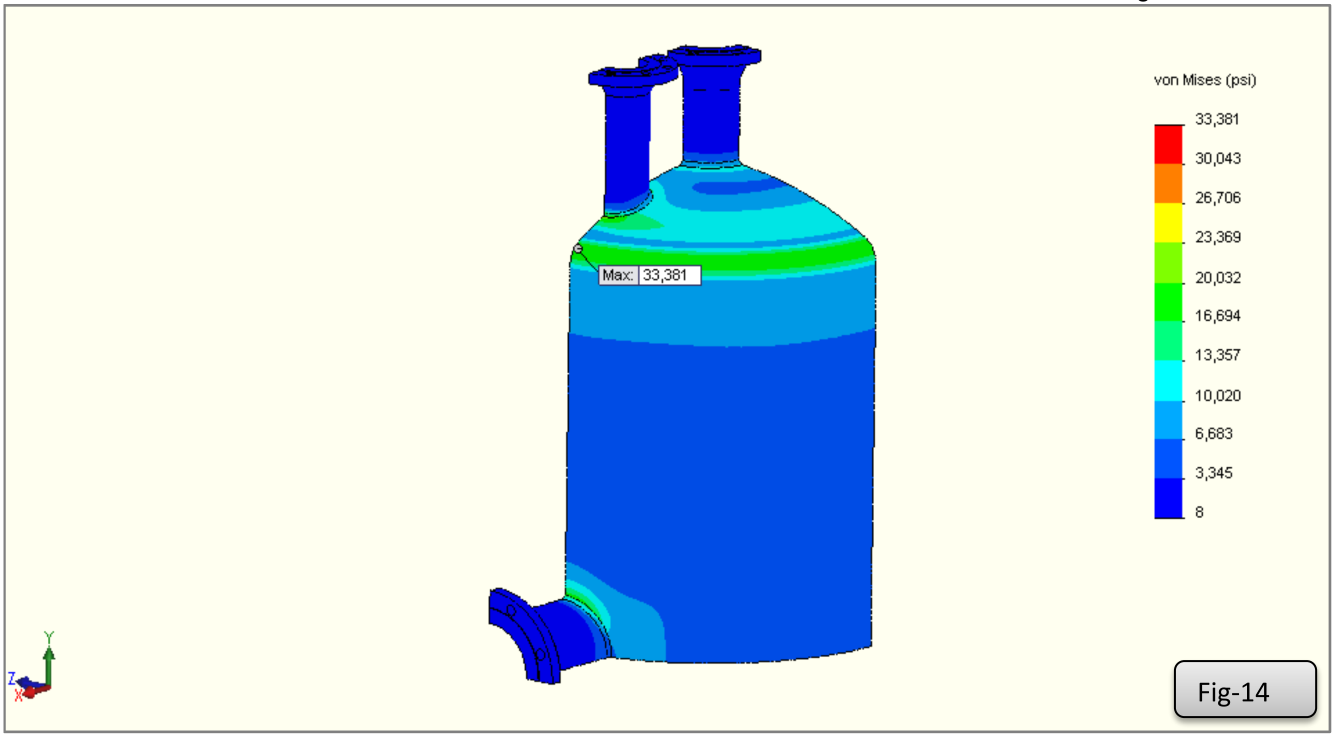
The displacement plot with the original geometry superimposed. Results are magnified 100 times to exaggerate the displaced shape. The maximum displacement in the model is 0.037".



Displacement Plot - Normal to XY Plane

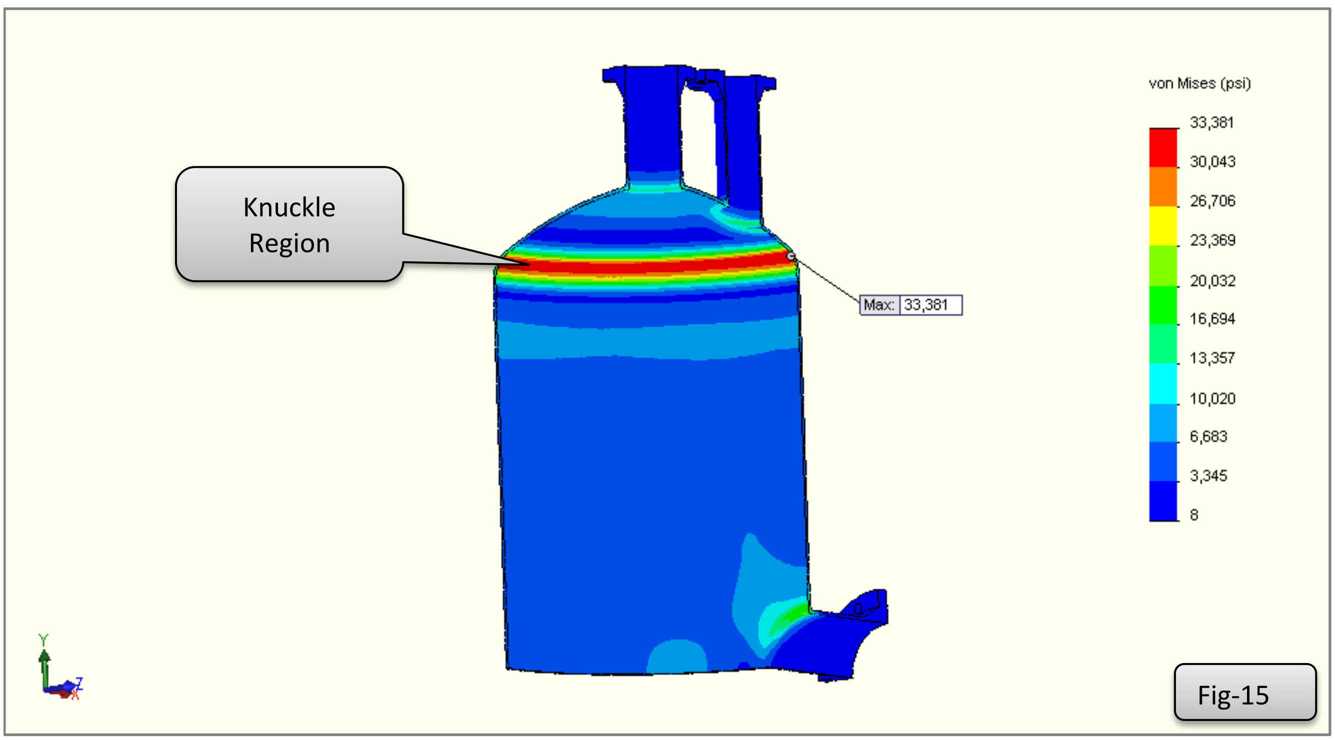
The displacement plot is oriented normal to the XY plane. The vessel expands radially and elongate axially. The displaced shape of the model is as expected and the magnitude is acceptable.

Stress



von Mises Stress Plot

The von Mises stress profile based on the alternating pressure is displayed.



von Mises Stress Plot - Rotated

The vessel is rotated to show the stress profile on the inside of the vessel. The maximum stress in the model is 33,381 psi and occurs at the knuckle region of the flanged and dished head.

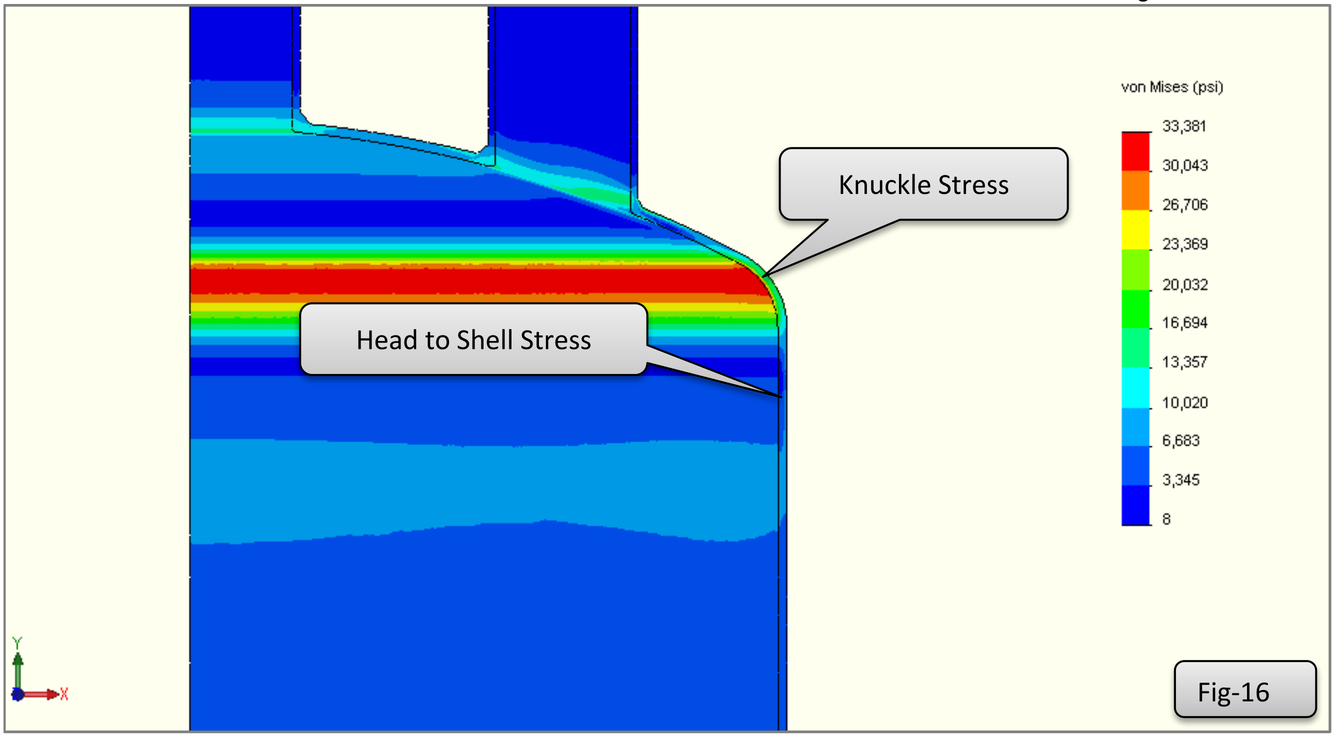
Summary:

This section covers the 6" nozzle at the centre of the flanged and dished head. The permissible number of cycles is calculated for each of the areas below.

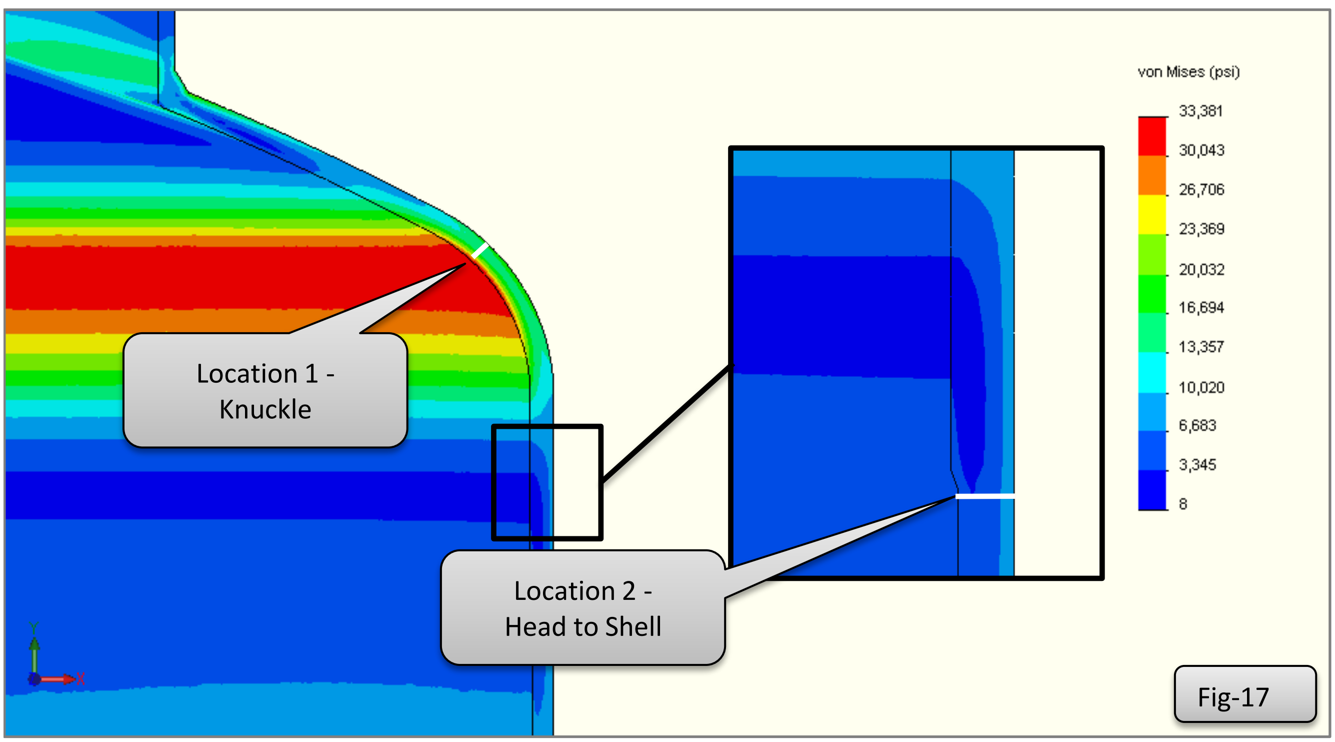
Results:

Location #	Location	Method	Stress	Kf	Kek	Se	Permissible Number of Cycles
1	Head Knuckle	Linearization	30,877	1.0	1.0	15,954	233,206
2	Head to Shell	Linearization	9,526	2.5	1.0	12,305	1,355,977
						Maximum permissible number of cycles	233,206

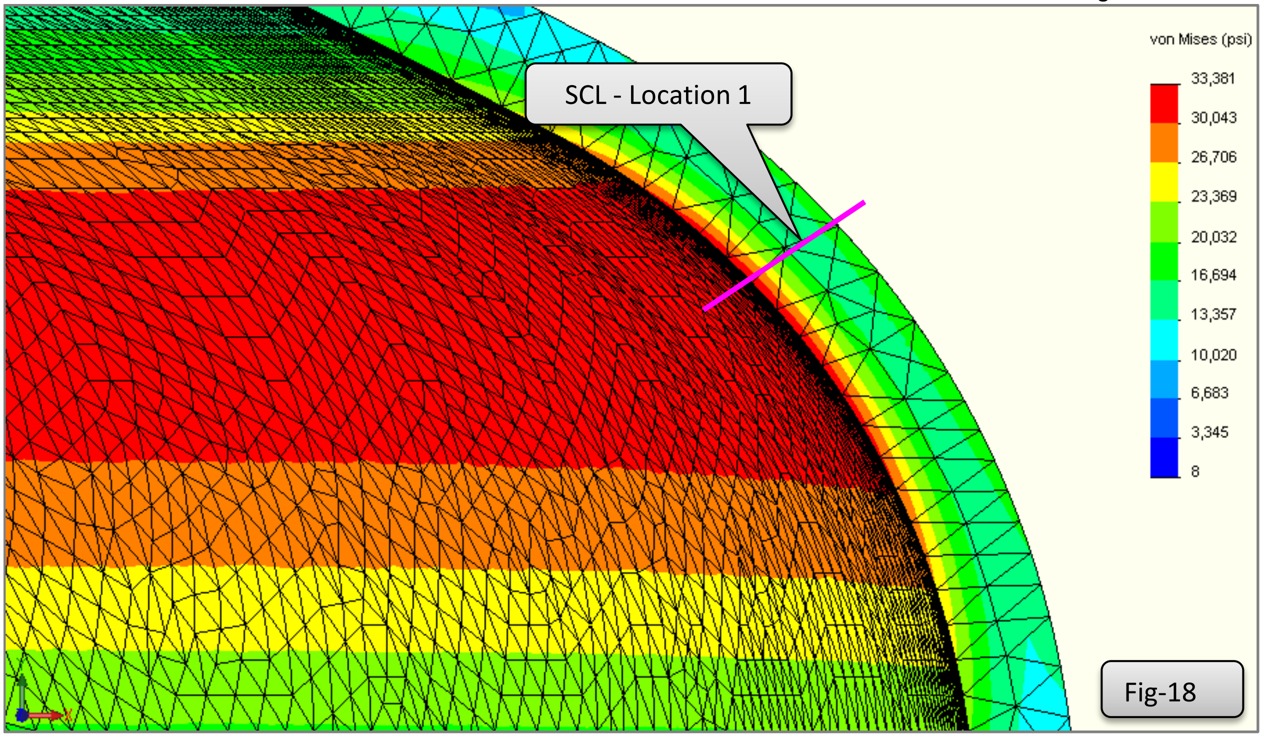
Kf = 2.5 for full pen welds with visual inspection only and no volumetric examination. (See table VIII-2 5.11 & 5.12)



Stress Plot - Knuckle and Head to Shell Region
The knuckle and head to shell show stresses that require linearization to determine peak effect for cycle calculation.

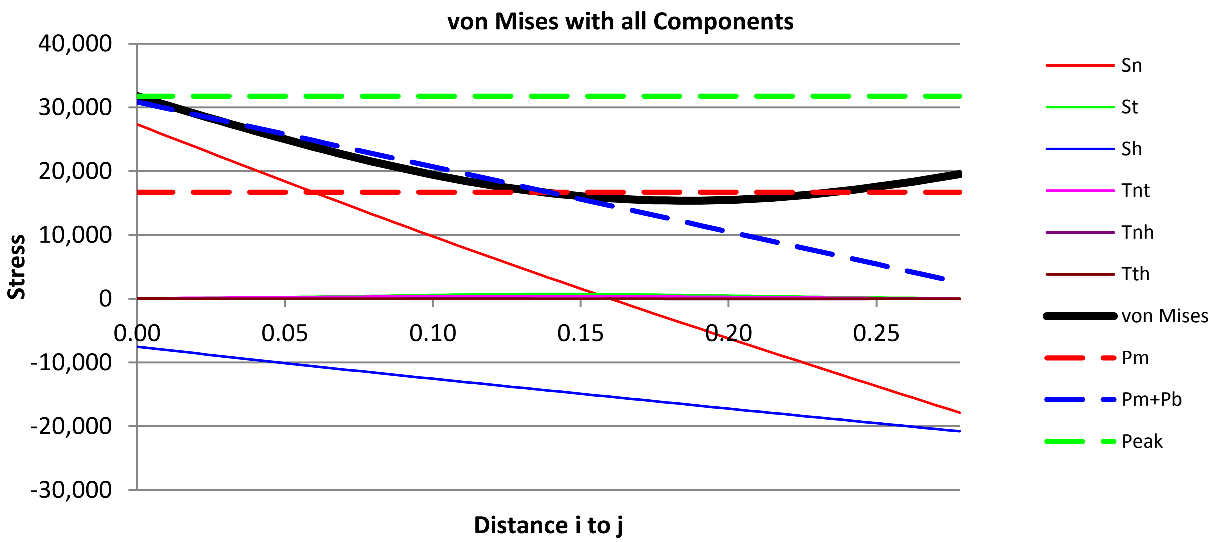


Stress Plot - Knuckle and Head to Shell Region
A close up of the above image showing the stress classification locations for cycle calculation.



Stress Classification Line - Location 1

A stress classification line is taken through the knuckle region of the flanged and dished head. The stress linearization results are applied to a fatigue curve on the following page.



Stress Check:

Local	**Stress** Classification		
SA-516 70	**Material**		
	Allowed	**Actual**	**Check**
Pl [psi] =	30,000	16,717	**Acceptable**
Pb [psi] =		20,096	
Pl+Pb+Q [psi] =	71,400	30,877	**Acceptable**
Peak [psi] =		31,772	

5 nodes found on the stress classification line 0.2782 units long - cubic spline interpolated to 71 equally spaced nodes.

Cycle life location 1 **Description**

Cycle Graph:

Table3.F.1 **Graph**

Carbon, Low Alloy, Series 4xx, and High Tensile Strength Steels for temperatures not exceeding 700°F
UTS<= 80ksi

Cyclic Data: VIII-2, 5.5.3

30,877	**ΔSpk** [psi] - Range of primary plus secondary plus peak equivalent stress (Pl+Pb+Q+F)
1.00	**Kf** - fatigue strength reduction factor (Table 5.11 & 5.12)
3.00	**m** - material constant used for the fatigue knock down factor (Table 5.13)
0.20	**n** - material constant used for the fatigue knock down factor (Table 5.13)
17,100	**S** [psi] - material allowable
32,900	**Sy** [psi] - material yield strength
150	**Tav** [°F] - average cycle temperature
29,030,000	**Et** [psi] - modulus of elasticity at Tav

Fatigue Penalty Factor: 5.31, 5.32, 5.33

Sps [psi] = max(3*S,2*Sy) MAX(3*17100,2*32900) = **65,800**

Kek1 = 1 1 = **1**

Kek2 = 1 + (1-n)/(n*(m-1)) * (ΔSpk/Sps-1)

1 + (1-0.2)/(0.2*(3-1)) * (30877/65800-1) = **-0.062**

Kek3 = 1/n 1/0.2 = **5**

Kek = If(ΔSpk<Sps,Kek1,If(ΔSpk>=m*Sps,Kek3,Kek2))

IF(30877<65800,1,IF(30877>=3*65800,5,12)) = **1**

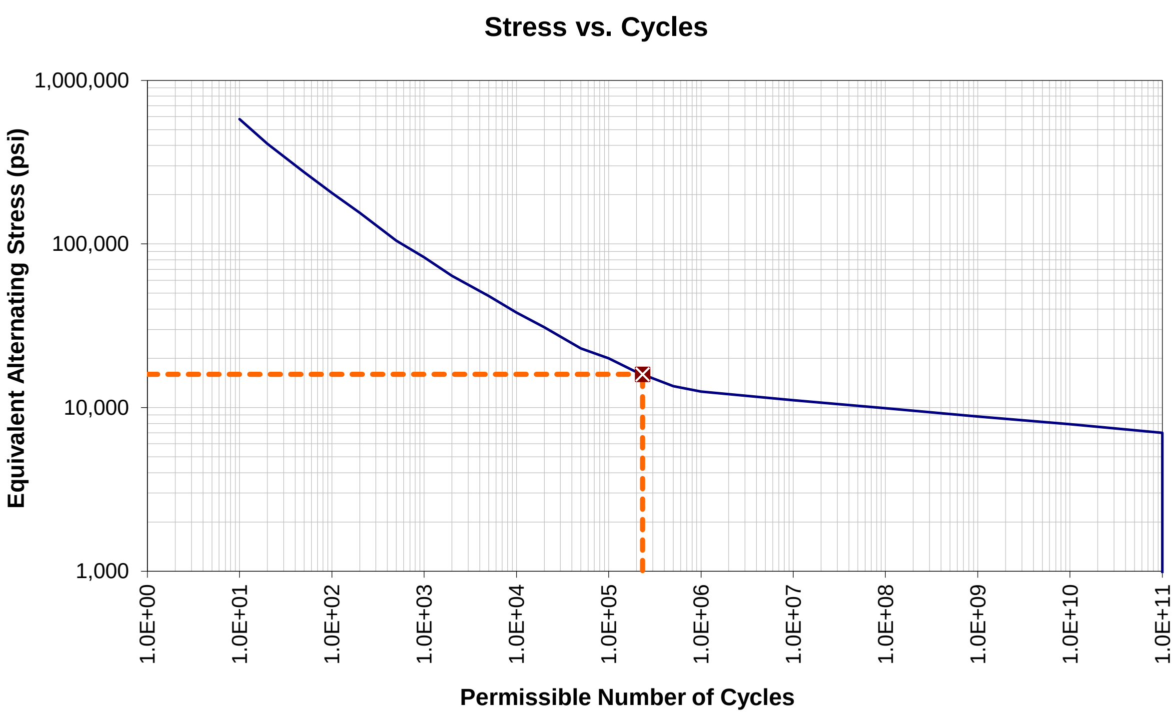
Permissible Cycle Life: VIII-2, 5.5.3.2

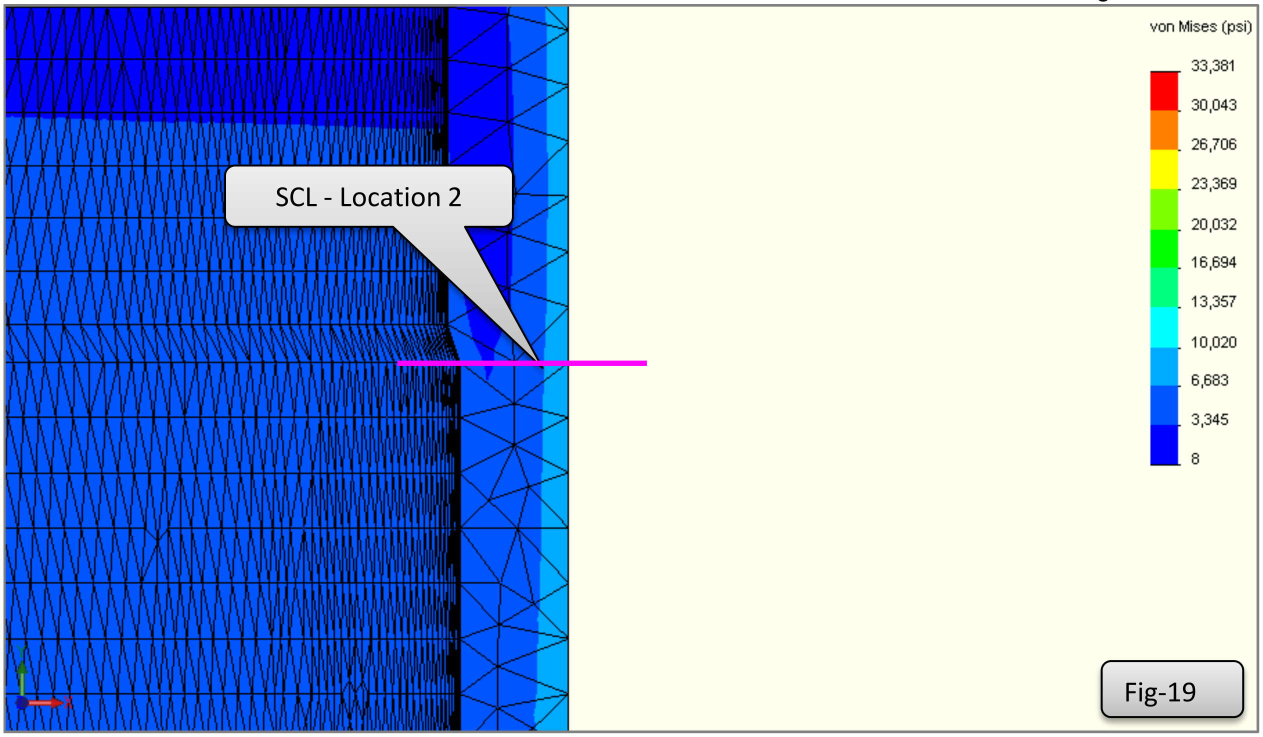
Saltk = (Kf*Kek*ΔSpk)/2 (1*1*30877)/2 = **15,438**

Efc [psi] = From Table3.F.1 **30,000,000**

Se [psi] = Saltk*Max(Efc/Et,1) 3-F.3 15438*MAX(30000000/29030000,1) = **15,954**

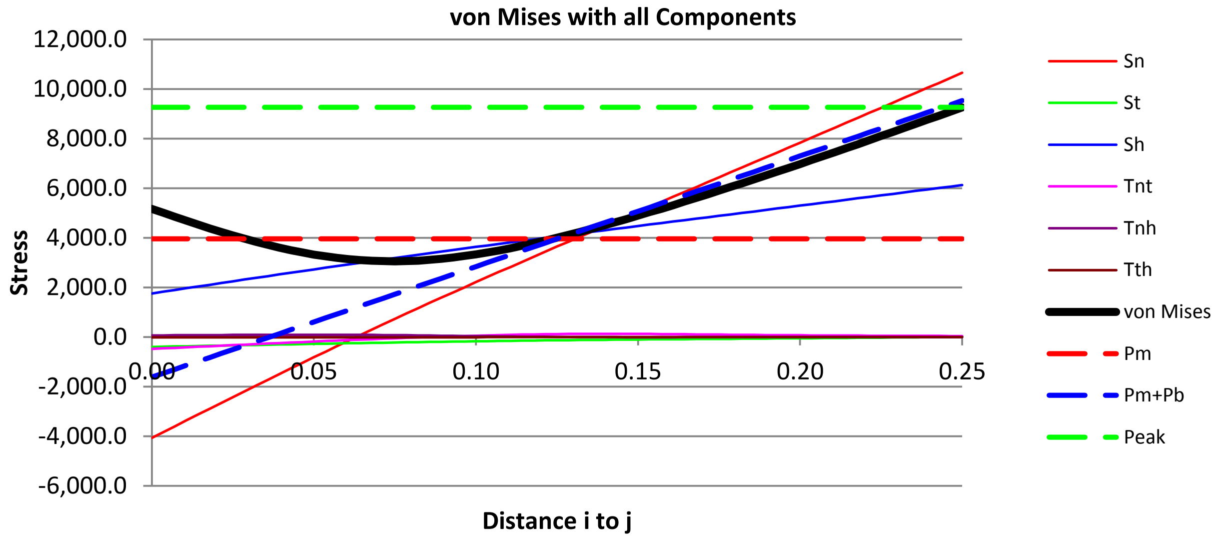
Cycles = From Table3.F.1 **233,206**





Stress Classification Line - Location 2

A stress classification line is taken through the junction between the shell and the flanged and dished head. The stress linearization results are applied to a fatigue curve on the following page.



Stress Check:

Local	**Stress** Classification		
SA-516 70	**Material**		
	Allowed	**Actual**	**Check**
Pl [psi] =	30,000	3,952	Acceptable
Pb [psi] =		6,470	
Pl+Pb+Q [psi] =	71,400	9,526	Acceptable
Peak [psi] =		9,256	

5 nodes found on the stress classification line 0.25 units long - cubic spline interpolated to 71 equally spaced nodes.

Cycle life location 2 Description

Cycle Graph:

Table3.F.1 Graph

Carbon, Low Alloy, Series 4xx, and High Tensile Strength Steels for temperatures not exceeding 700°F
UTS<= 80ksi

Cyclic Data: VIII-2, 5.5.3

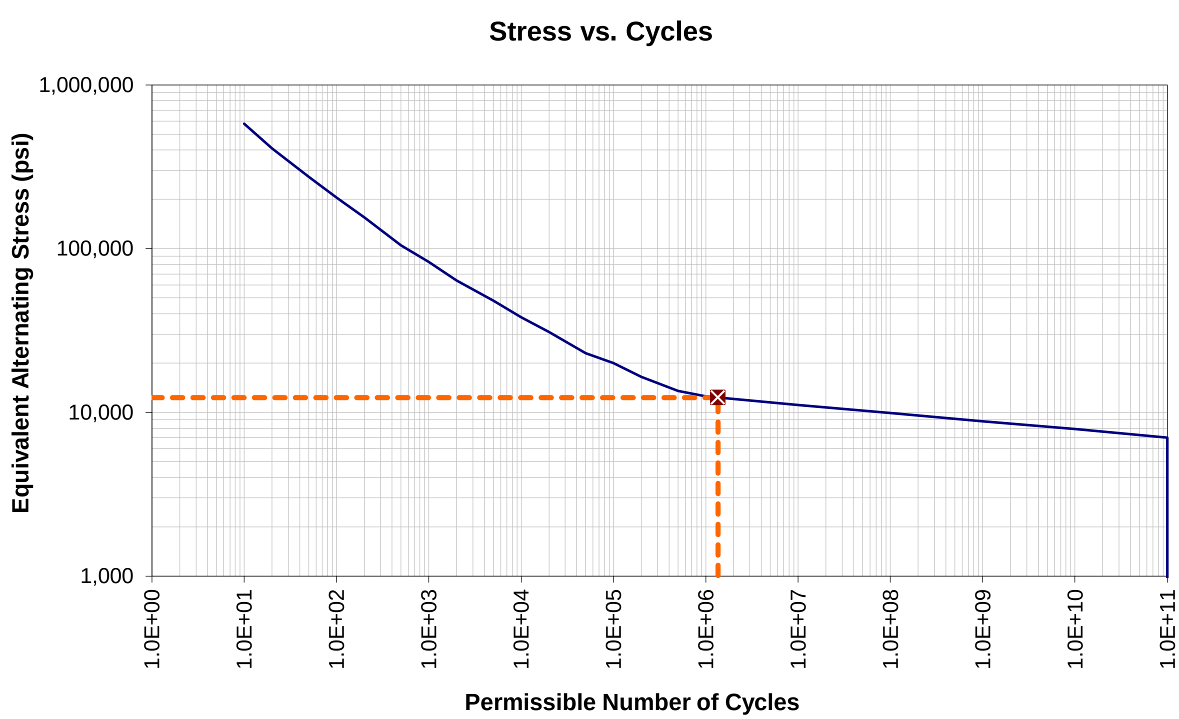
9,526	**ΔSpk** [psi] - Range of primary plus secondary plus peak equivalent stress (Pl+Pb+Q+F)
2.50	**Kf** - fatigue strength reduction factor (Table 5.11 & 5.12)
3.00	**m** - material constant used for the fatigue knock down factor (Table 5.13)
0.20	**n** - material constant used for the fatigue knock down factor (Table 5.13)
17,100	**S** [psi] - material allowable
32,900	**Sy** [psi] - material yield strength
150	**Tav** [°F] - average cycle temperature
29,030,000	**Et** [psi] - modulus of elasticity at Tav

Fatigue Penalty Factor: 5.31, 5.32, 5.33

Sps [psi] =	max(3*S,2*Sy)	MAX(3*17100,2*32900) =	**65,800**
Kek1 =	1	1 =	**1**
Kek2 =	1 + (1-n)/(n*(m-1)) * (ΔSpk/Sps-1)		
		1 + (1-0.2)/(0.2*(3-1)) * (9526/65800-1) =	**-0.710**
Kek3 =	1/n	1/0.2 =	**5**
Kek =	If(ΔSpk<Sps,Kek1,If(ΔSpk>=m*Sps,Kek3,Kek2))		
		IF(9526<65800,1,IF(9526>=3*65800,5,12)) =	**1**

Permissible Cycle Life: VIII-2, 5.5.3.2

Saltk =	(Kf*Kek*ΔSpk)/2	(2.5*1*9526)/2 =	**11,907**
Efc [psi] =	From Table3.F.1		**30,000,000**
Se [psi] =	Saltk*Max(Efc/Et,1) 3-F.3	11907*MAX(30000000/29030000,1) =	**12,305**
Cycles =	From Table3.F.1		**1,355,977**



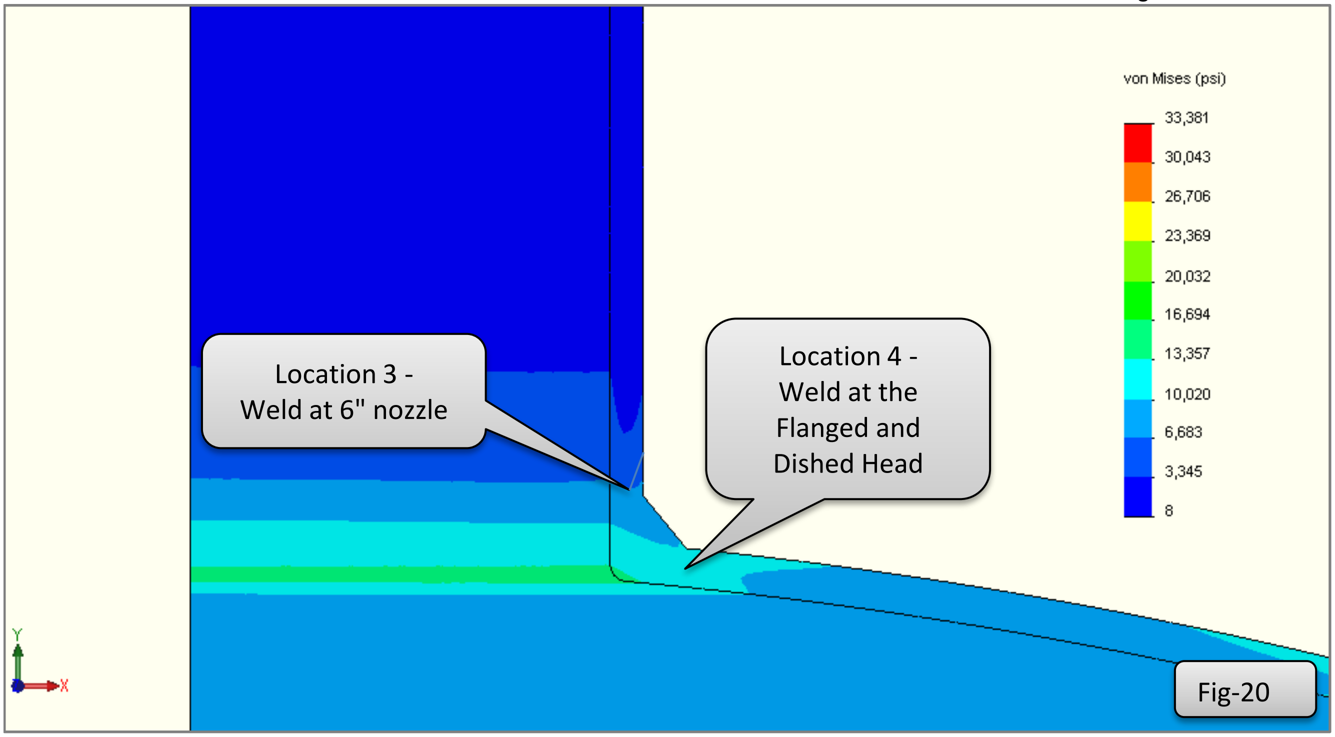
Summary:

This section covers the 6" nozzle at the centre of the flanged and dished head. The permissible number of cycles is calculated for each of the areas below.

Results:

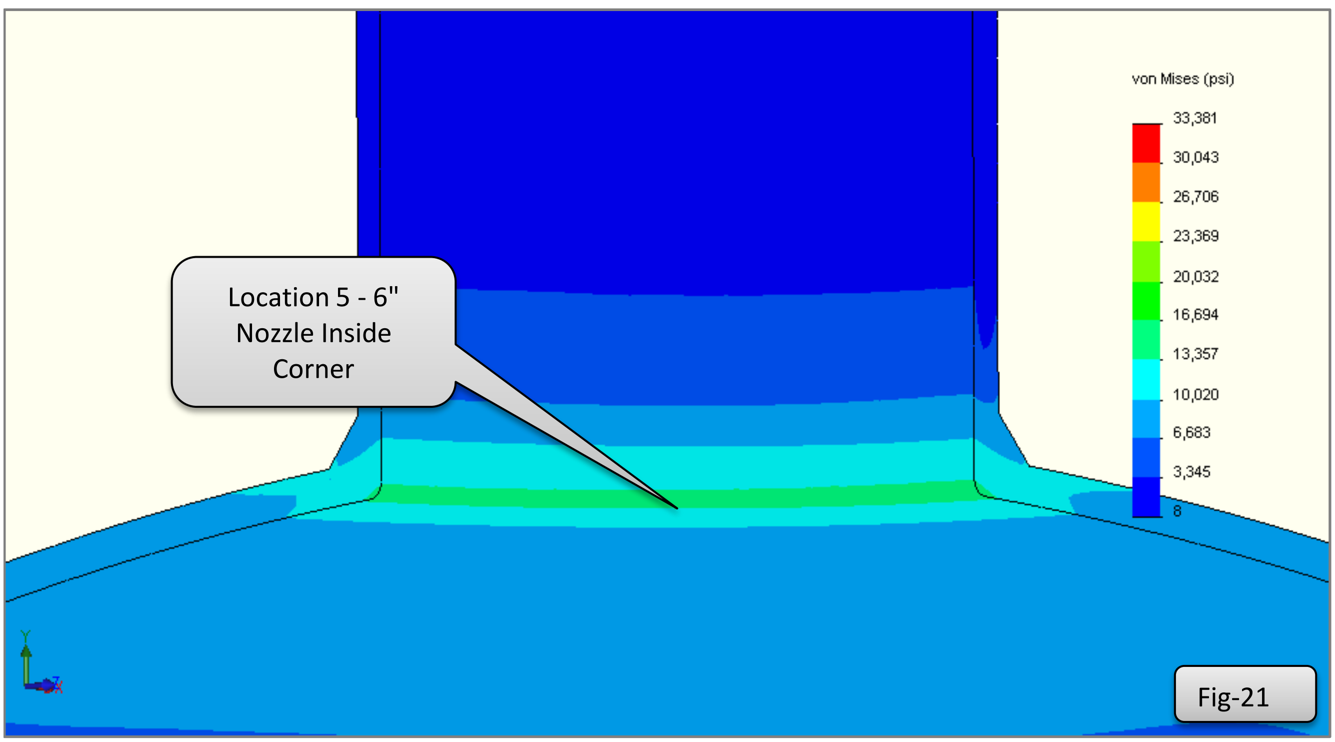
Location #	Location	Method	Stress	Kf	Kek	Se	Permissible Number of Cycles
3	Nozzle Weld Toe	Linearization	7,651	2.5	1.0	9,883	103,425,376
4	Head Weld Toe	Linearization	12,565	2.5	1.0	16,232	215,553
5	Nozzle ID	Linearization	13,964	1.0	1.0	7,215	56,175,593,403
						Maximum permissible number of cycles	215,553

Kf = 2.5 for full pen welds with visual inspection only and no volumetric examination. (See table VIII-2 5.11 & 5.12)



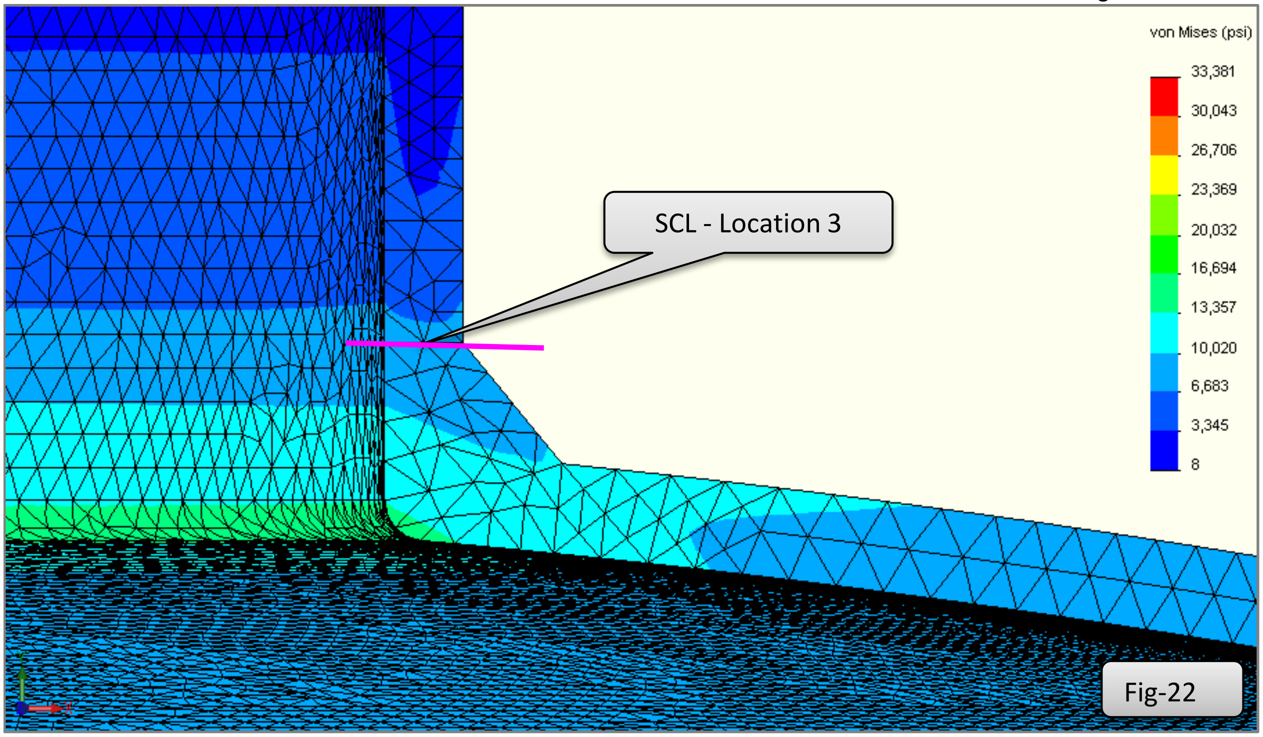
Stress Plot - 6" Nozzle

The von Mises stress profile where the 6" nozzle meets the flanged and dished head. Stress classification lines are taken at the weld both through the junction with the nozzle and the flanged and dished head.



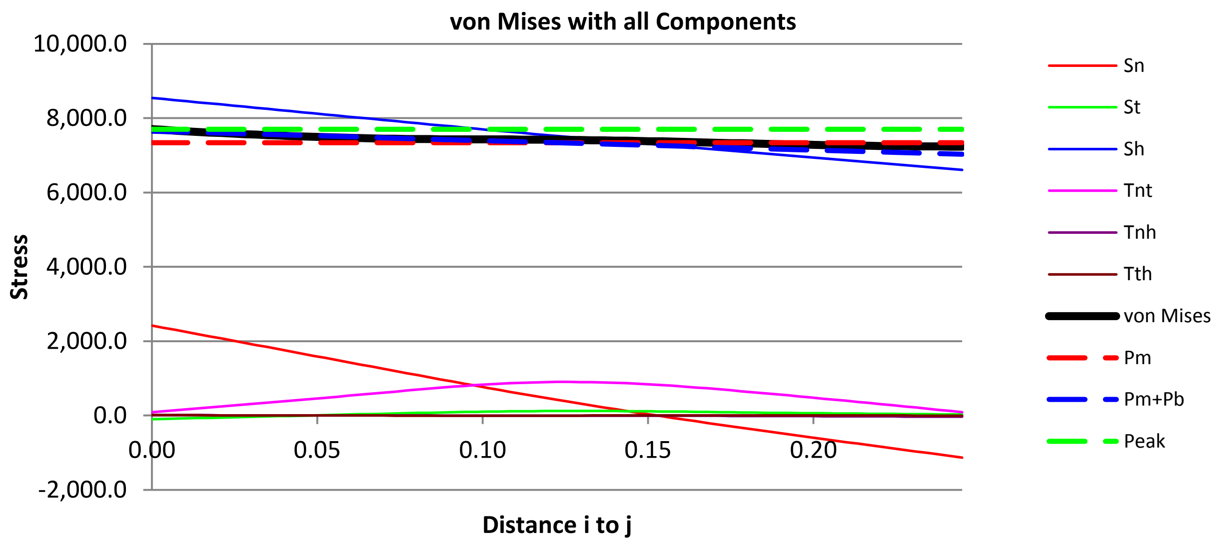
Stress Plot - 6" Nozzle Inside Corner

The von Mises stress profile at the inside corner of the nozzle. A peak stress occurs at this section due to the discontinuity. The peak stress at this location is used to compute the cycle life.



Stress Classification Line - Location 3

A stress classification line is taken through the 6" nozzle at the weld. The stress linearization results are applied to a fatigue curve on the following page.



Stress Check:

Local	**Stress** Classification		
SA-106 B	**Material**		
	Allowed	**Actual**	**Check**
Pl [psi] =	25,650	7,339	Acceptable
Pb [psi] =		1,551	
Pl+Pb+Q [psi] =	65,800	7,651	Acceptable
Peak [psi] =		7,704	

5 nodes found on the stress classification line 0.245 units long - cubic spline interpolated to 71 equally spaced nodes.

Permissible Cycle Life ver 6.00

Cycle life location 3 **Description**

Cycle Graph:

Table3.F.1 **Graph**

Carbon, Low Alloy, Series 4xx, and High Tensile Strength Steels for temperatures not exceeding 700°F
UTS<= 80ksi

Cyclic Data: VIII-2, 5.5.3

7,651	**ΔSpk** [psi] - Range of primary plus secondary plus peak equivalent stress (Pl+Pb+Q+F)
2.50	**Kf** - fatigue strength reduction factor (Table 5.11 & 5.12)
3.00	**m** - material constant used for the fatigue knock down factor (Table 5.13)
0.20	**n** - material constant used for the fatigue knock down factor (Table 5.13)
17,100	**S** [psi] - material allowable
32,900	**Sy** [psi] - material yield strength
150	**Tav** [°F] - average cycle temperature
29,030,000	**Et** [psi] - modulus of elasticity at Tav

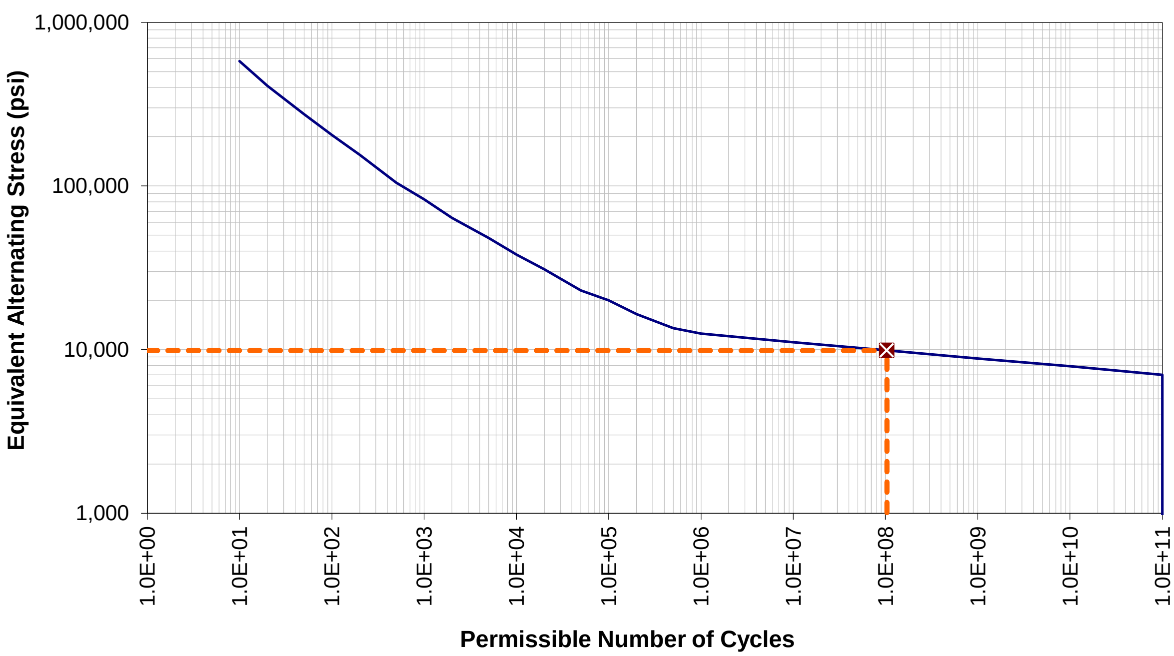
Fatigue Penalty Factor: 5.31, 5.32, 5.33

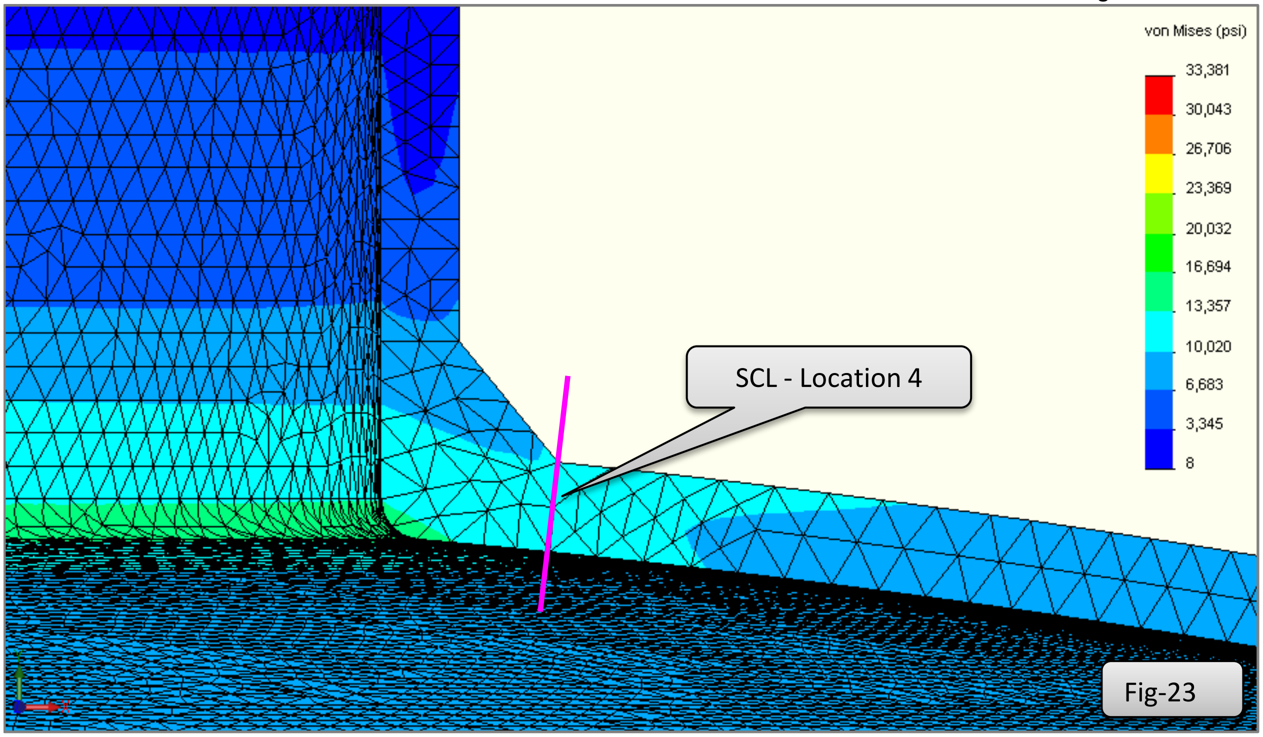
Sps [psi] =	max(3*S,2*Sy)	MAX(3*17100,2*32900) =	**65,800**
Kek1 =	1	1 =	**1**
Kek2 =	1 + (1-n)/(n*(m-1)) * (ΔSpk/Sps-1)		
		1 + (1-0.2)/(0.2*(3-1)) * (7651/65800-1) =	**-0.767**
Kek3 =	1/n	1/0.2 =	**5**
Kek =	If(ΔSpk<Sps,Kek1,If(ΔSpk>=m*Sps,Kek3,Kek2))		
		IF(7651<65800,1,IF(7651>=3*65800,5,12)) =	**1**

Permissible Cycle Life: VIII-2, 5.5.3.2

Saltk =	(Kf*Kek*ΔSpk)/2	(2.5*1*7651)/2 =	**9,563**
Efc [psi] =	From Table3.F.1		**30,000,000**
Se [psi] =	Saltk*Max(Efc/Et,1) 3-F.3	9563*MAX(30000000/29030000,1) =	**9,883**
Cycles =	From Table3.F.1		**103,425,376**

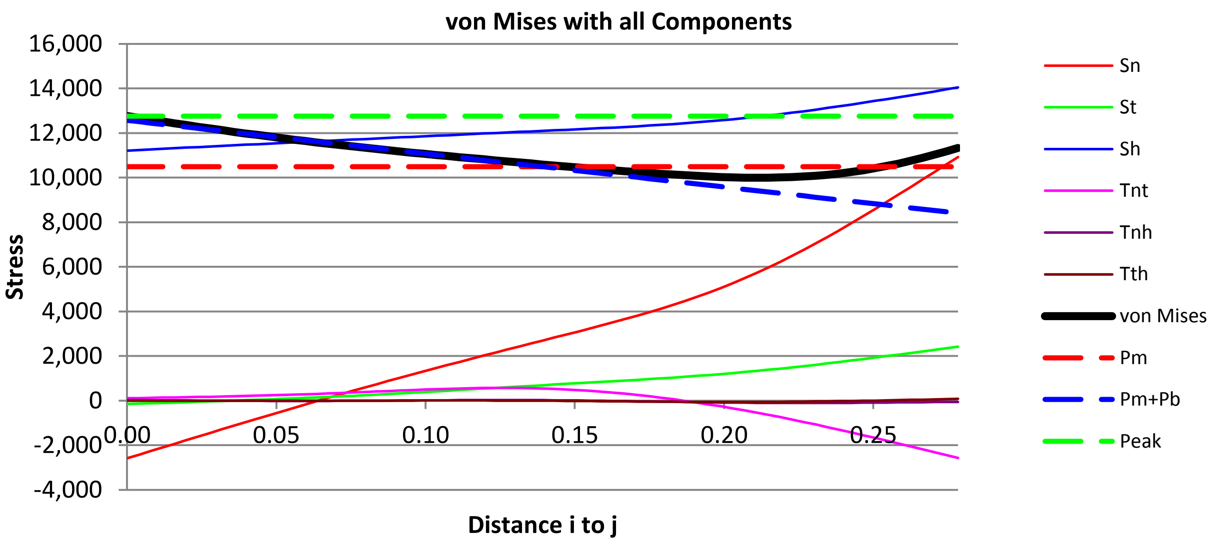
Stress vs. Cycles





Stress Classification Line - Location 4

A stress classification line is taken through the head at the 6" nozzle weld. The stress linearization results are applied to a fatigue curve on the following page.



Stress Check:

Local	**Stress** Classification		
SA-516 70	**Material**		
	Allowed	**Actual**	**Check**
Pl [psi] =	30,000	10,487	**Acceptable**
Pb [psi] =		5,606	
Pl+Pb+Q [psi] =	71,400	12,565	**Acceptable**
Peak [psi] =		12,761	

5 nodes found on the stress classification line 0.2784 units long - cubic spline interpolated to 71 equally spaced nodes.

Cycle life location 4 **Description**

Cycle Graph:

Table3.F.1 **Graph**

Carbon, Low Alloy, Series 4xx, and High Tensile Strength Steels for temperatures not exceeding 700°F
UTS<= 80ksi

Cyclic Data: VIII-2, 5.5.3

12,565	**ΔSpk** [psi] - Range of primary plus secondary plus peak equivalent stress (Pl+Pb+Q+F)
2.50	**Kf** - fatigue strength reduction factor (Table 5.11 & 5.12)
3.00	**m** - material constant used for the fatigue knock down factor (Table 5.13)
0.20	**n** - material constant used for the fatigue knock down factor (Table 5.13)
17,100	**S** [psi] - material allowable
32,900	**Sy** [psi] - material yield strength
150	**Tav** [°F] - average cycle temperature
29,030,000	**Et** [psi] - modulus of elasticity at Tav

Fatigue Penalty Factor: 5.31, 5.32, 5.33

Sps [psi] = max(3*S,2*Sy) MAX(3*17100,2*32900) = **65,800**

Kek1 = 1 1 = **1**

Kek2 = 1 + (1-n)/(n*(m-1)) * (ΔSpk/Sps-1)

1 + (1-0.2)/(0.2*(3-1)) * (12565/65800-1) = **-0.618**

Kek3 = 1/n 1/0.2 = **5**

Kek = If(ΔSpk<Sps,Kek1,If(ΔSpk>=m*Sps,Kek3,Kek2))

IF(12565<65800,1,IF(12565>=3*65800,5,12)) = **1**

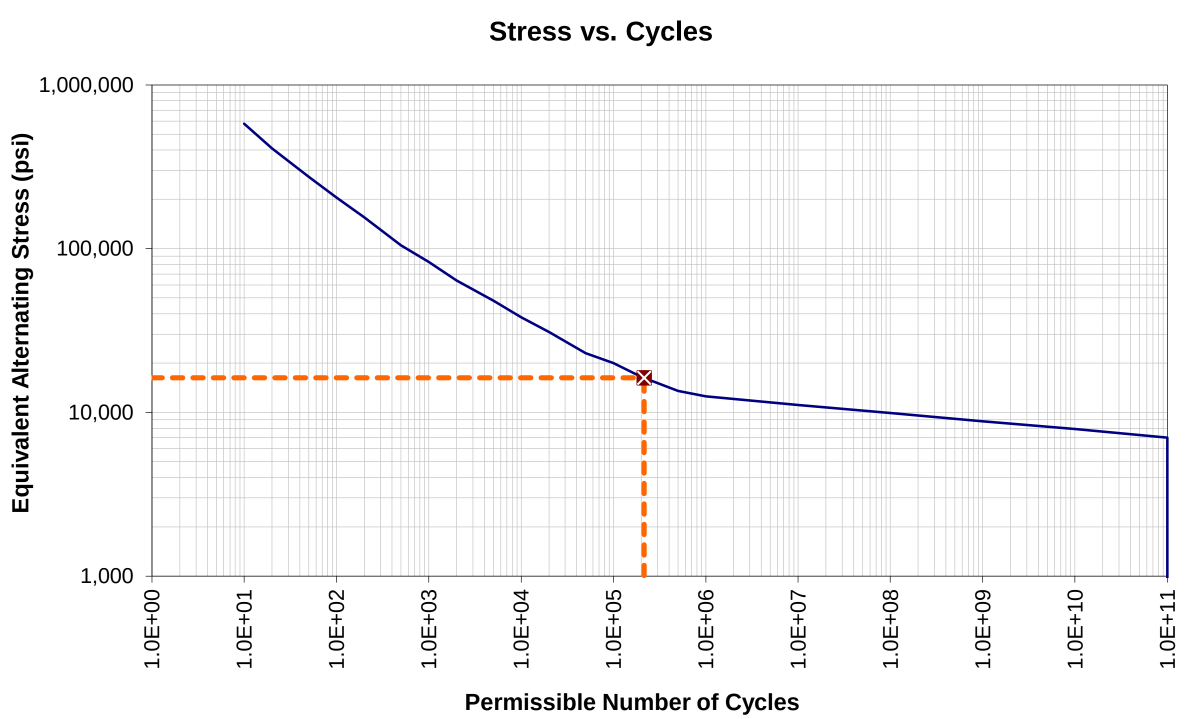
Permissible Cycle Life: VIII-2, 5.5.3.2

Saltk = (Kf*Kek*ΔSpk)/2 (2.5*1*12565)/2 = **15,707**

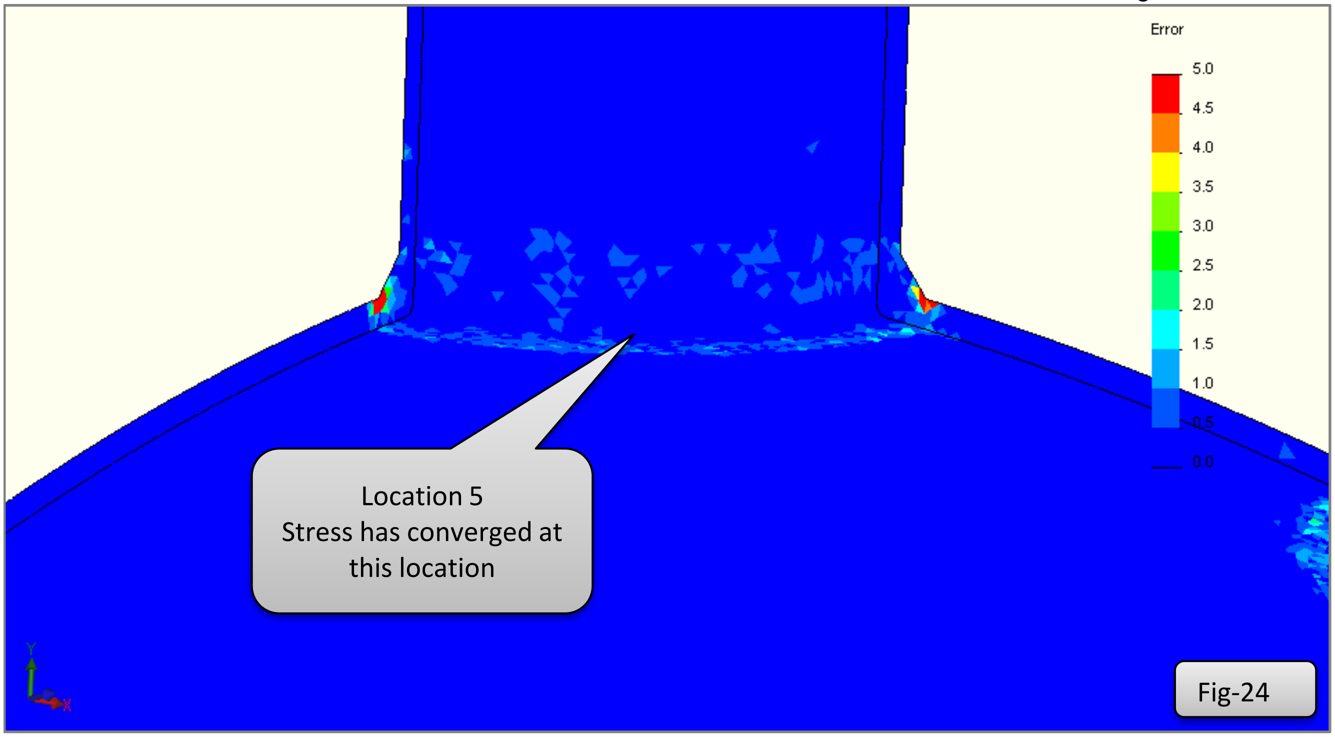
Efc [psi] = From Table3.F.1 **30,000,000**

Se [psi] = Saltk*Max(Efc/Et,1) 3-F.3 15707*MAX(30000000/29030000,1) = **16,232**

Cycles = From Table3.F.1 **215,553**

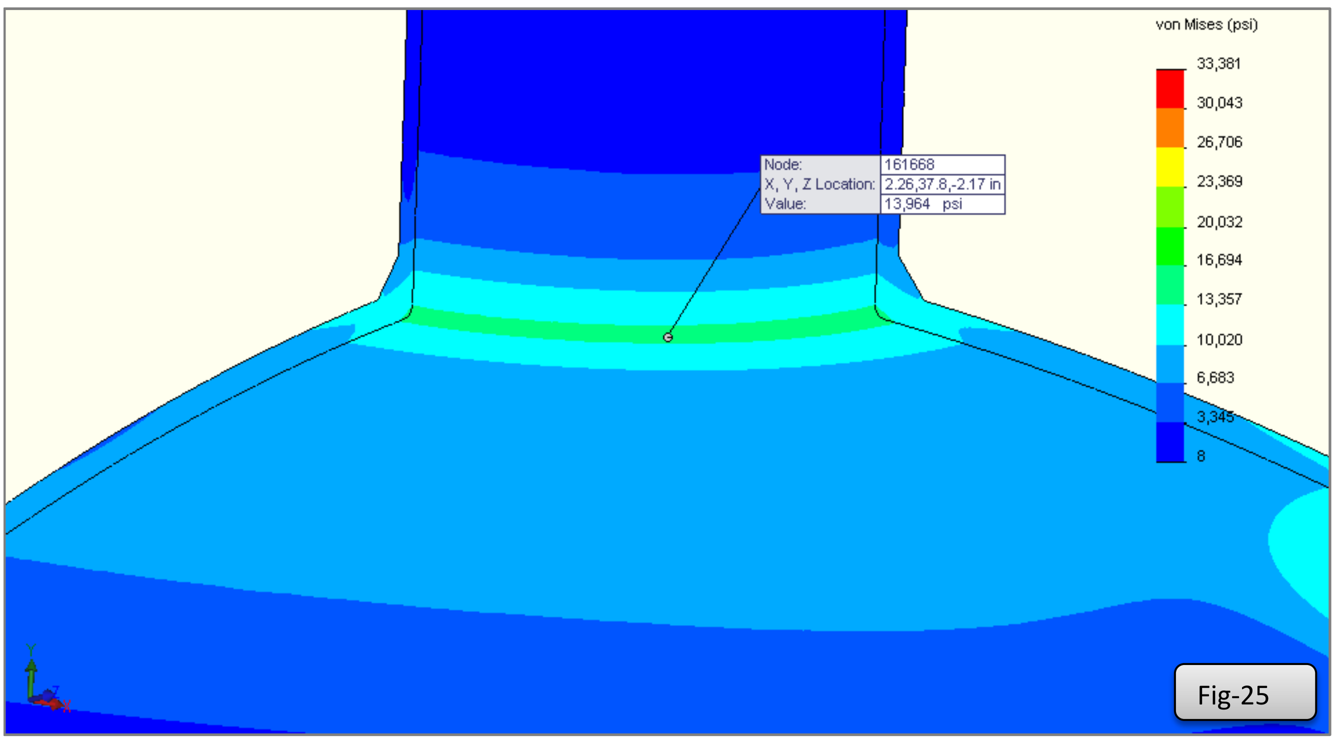


Location 5



Error Plot - 6" Nozzle

The error plot at the inside corner of the 6" nozzle is capped at 5%. This shows that the stress has fully converged at this location and that it is acceptable to take a direct reading from the model.



Direct Stress Reading

The stress on the inside corner of the 6" nozzle is directly read from the model. The maximum stress at this location is 13,964 psi. Since this stress occurs on the base metal and not on a weld, a Kf value of 1.0 will be used in the cycle life calculation.

Cycle life location 5 **Description**

Cycle Graph:

Table3.F.1 **Graph**

Carbon, Low Alloy, Series 4xx, and High Tensile Strength Steels for temperatures not exceeding 700°F
UTS<= 80ksi

Cyclic Data: VIII-2, 5.5.3

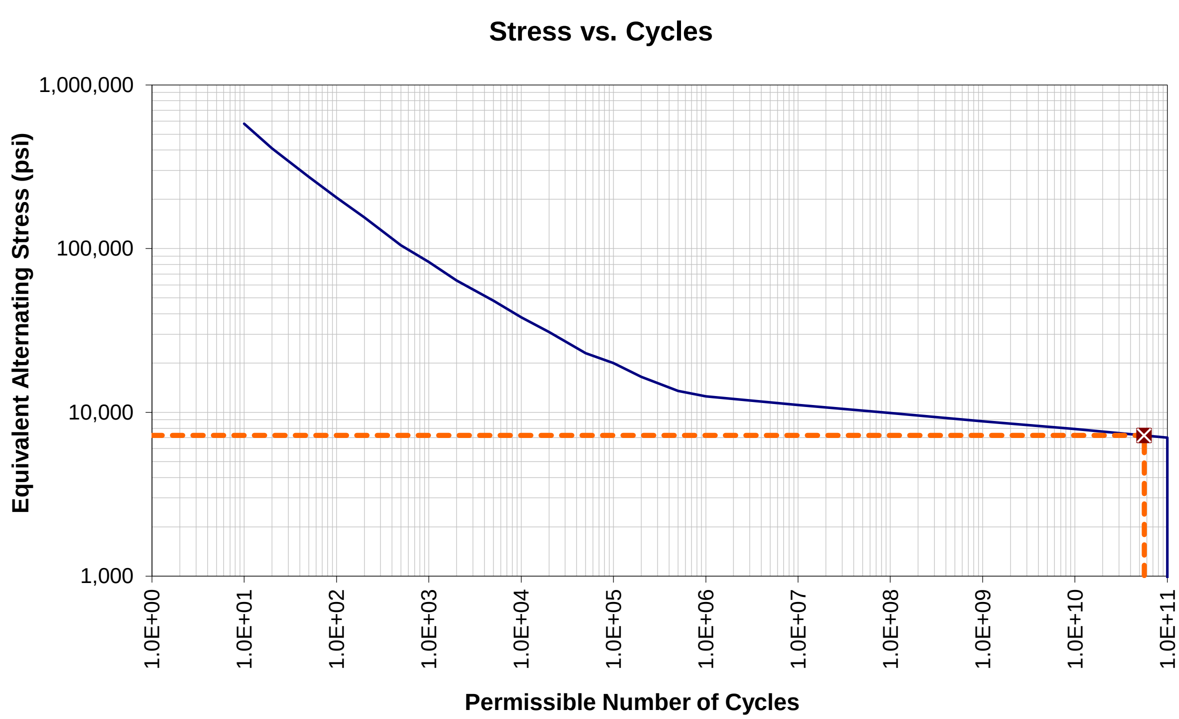
13,964	**ΔSpk** [psi] - Range of primary plus secondary plus peak equivalent stress (Pl+Pb+Q+F)
1.00	**Kf** - fatigue strength reduction factor (Table 5.11 & 5.12)
3.00	**m** - material constant used for the fatigue knock down factor (Table 5.13)
0.20	**n** - material constant used for the fatigue knock down factor (Table 5.13)
17,100	**S** [psi] - material allowable
32,900	**Sy** [psi] - material yield strength
150	**Tav** [°F] - average cycle temperature
29,030,000	**Et** [psi] - modulus of elasticity at Tav

Fatigue Penalty Factor: 5.31, 5.32, 5.33

Sps [psi] =	max(3*S,2*Sy)	MAX(3*17100,2*32900) =	**65,800**
Kek1 =	1	1 =	**1**
Kek2 =	1 + (1-n)/(n*(m-1)) * (ΔSpk/Sps-1)		
		1 + (1-0.2)/(0.2*(3-1)) * (13964/65800-1) =	**-0.576**
Kek3 =	1/n	1/0.2 =	**5**
Kek =	If(ΔSpk<Sps,Kek1,If(ΔSpk>=m*Sps,Kek3,Kek2))		
		IF(13964<65800,1,IF(13964>=3*65800,5,12)) =	**1**

Permissible Cycle Life: VIII-2, 5.5.3.2

Saltk =	(Kf*Kek*ΔSpk)/2	(1*1*13964)/2 =	**6,982**
Efc [psi] =	From Table3.F.1		**30,000,000**
Se [psi] =	Saltk*Max(Efc/Et,1) 3-F.3	6982*MAX(30000000/29030000,1) =	**7,215**
Cycles =	From Table3.F.1		**56,175,593,403**



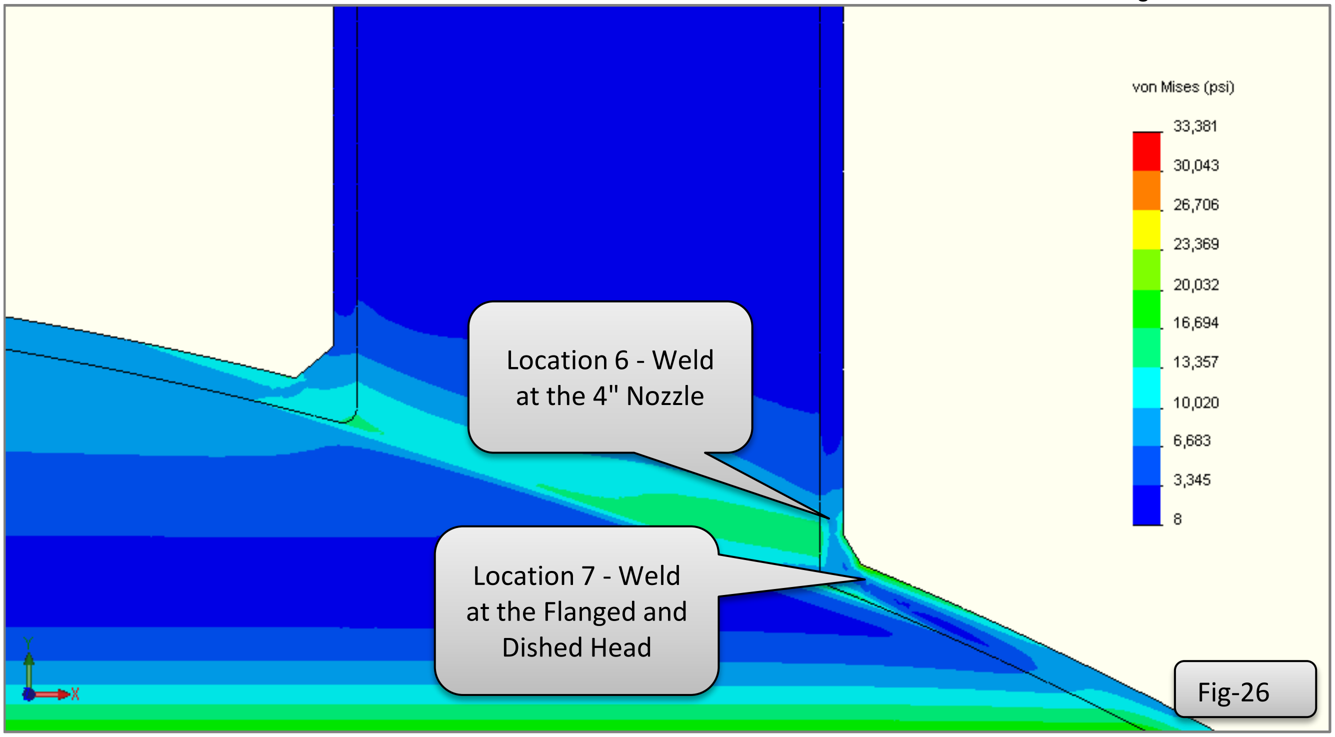
Summary:

This section covers the 4" hillside nozzle in the flanged and dished head. The permissible number of cycles is calculated for each of the areas below.

Results:

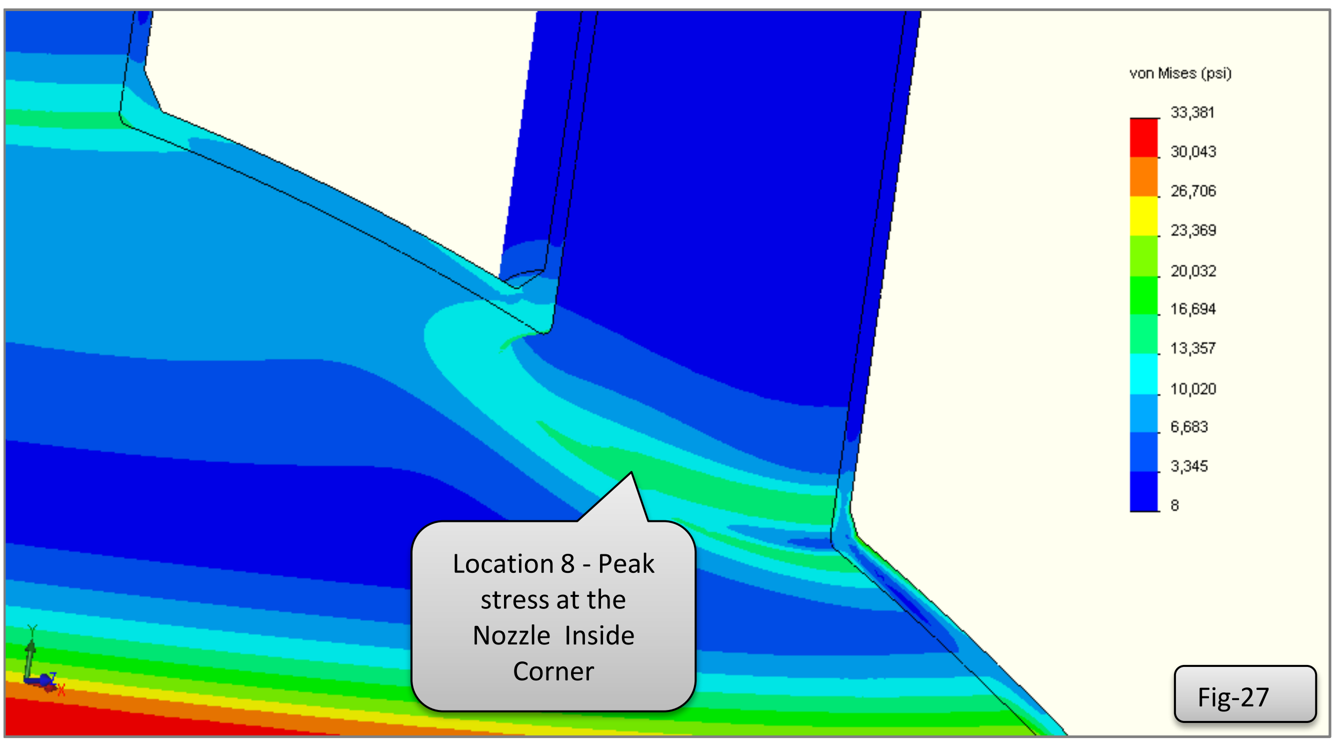
Location #	Location	Method	Stress	Kf	Kek	Se	Permissible Number of Cycles
6	Nozzle Weld Toe	Linearization	18,600	2.5	1.0	24,027	43,727
7	Head Weld Toe	Linearization	18,406	2.5	1.0	23,776	45,155
8	Nozzle ID	Linearization	13,738	1.0	1.0	7,099	76,639,153,153
						Maximum permissible number of cycles	43,727

Kf = 2.5 for full pen welds with visual inspection only and no volumetric examination. (See table VIII-2 5.11 & 5.12)



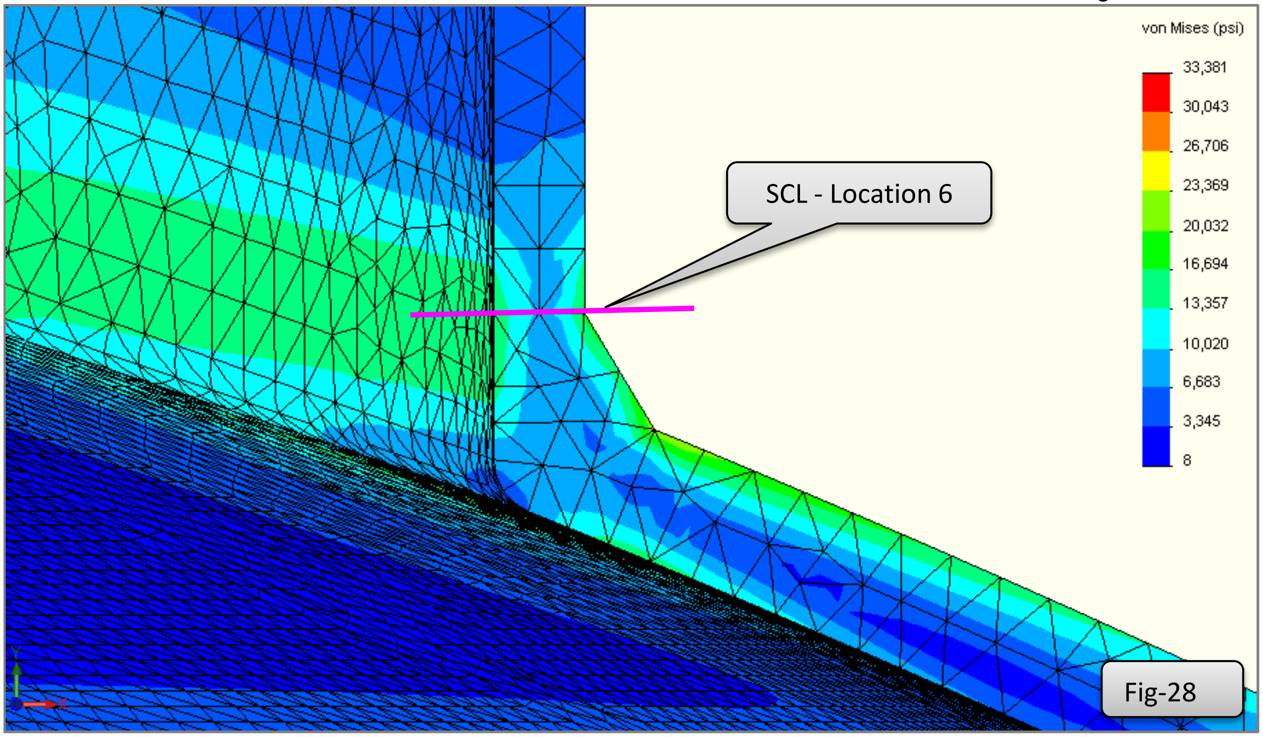
Stress Plot - 4" Nozzle

The von Mises stress profile where the 4" nozzle meets the flanged and dished head. Stress classification lines are taken at the weld both through the junction with the nozzle and the flanged and dished head. Since this is not a radial nozzle, the stresses are not evenly distributed and are higher on the right hand side, closest to the knuckle. Stresses in this area will be used for the cycle life calculation.



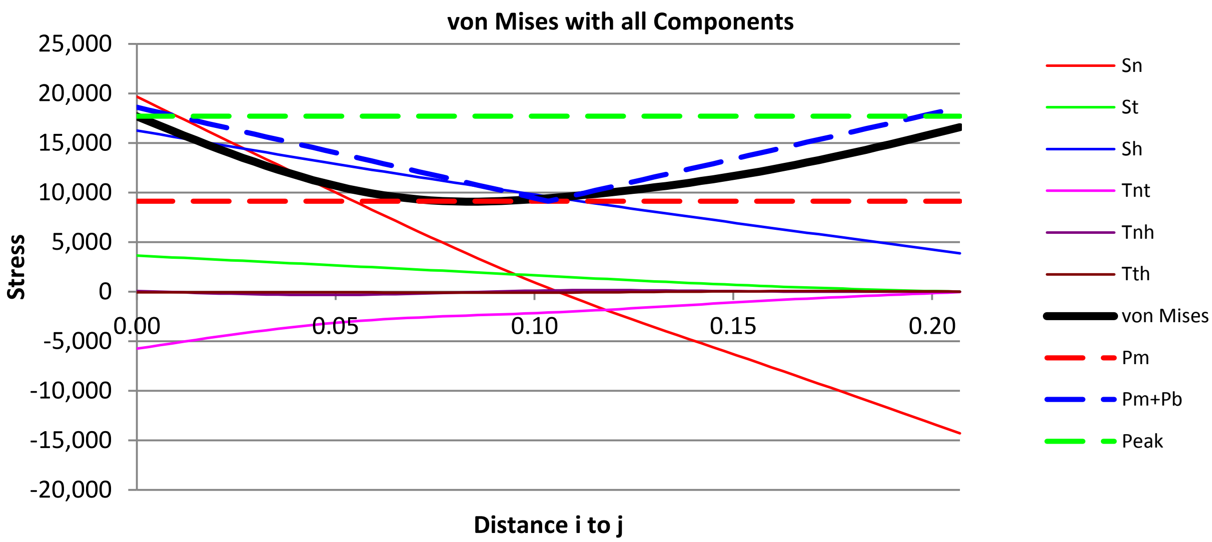
Stress Plot - 4" Nozzle Inside Corner

The von Mises stress profile at the inside corner of the nozzle. A peak stress occurs at this section due to the discontinuity. The peak stress at this location is used to compute the cycle life.



Stress Classification Line - Location 6

A stress classification line is taken through the 4" nozzle weld. The stress linearization results are applied to a fatigue curve on the following page.



Stress Check:

Local	**Stress** Classification		
SA-106 B	**Material**		
	Allowed	**Actual**	**Check**
Pl [psi] =	25,650	9,117	Acceptable
Pb [psi] =		14,778	
Pl+Pb+Q [psi] =	65,800	18,600	Acceptable
Peak [psi] =		17,697	

5 nodes found on the stress classification line 0.207 units long - cubic spline interpolated to 71 equally spaced nodes.

Permissible Cycle Life ver 6.00

Cycle life location 6 **Description**

Cycle Graph:

Table3.F.1 **Graph**

Carbon, Low Alloy, Series 4xx, and High Tensile Strength Steels for temperatures not exceeding 700°F
UTS<= 80ksi

Cyclic Data: VIII-2, 5.5.3

18,600	**ΔSpk** [psi] - Range of primary plus secondary plus peak equivalent stress (Pl+Pb+Q+F)
2.50	**Kf** - fatigue strength reduction factor (Table 5.11 & 5.12)
3.00	**m** - material constant used for the fatigue knock down factor (Table 5.13)
0.20	**n** - material constant used for the fatigue knock down factor (Table 5.13)
17,100	**S** [psi] - material allowable
32,900	**Sy** [psi] - material yield strength
150	**Tav** [°F] - average cycle temperature
29,030,000	**Et** [psi] - modulus of elasticity at Tav

Fatigue Penalty Factor: 5.31, 5.32, 5.33

Sps [psi] = max(3*S,2*Sy) MAX(3*17100,2*32900) = **65,800**

Kek1 = 1 1 = **1**

Kek2 = 1 + (1-n)/(n*(m-1)) * (ΔSpk/Sps-1)

1 + (1-0.2)/(0.2*(3-1)) * (18600/65800-1) = **-0.435**

Kek3 = 1/n 1/0.2 = **5**

Kek = If(ΔSpk<Sps,Kek1,If(ΔSpk>=m*Sps,Kek3,Kek2))

IF(18600<65800,1,IF(18600>=3*65800,5,12)) = **1**

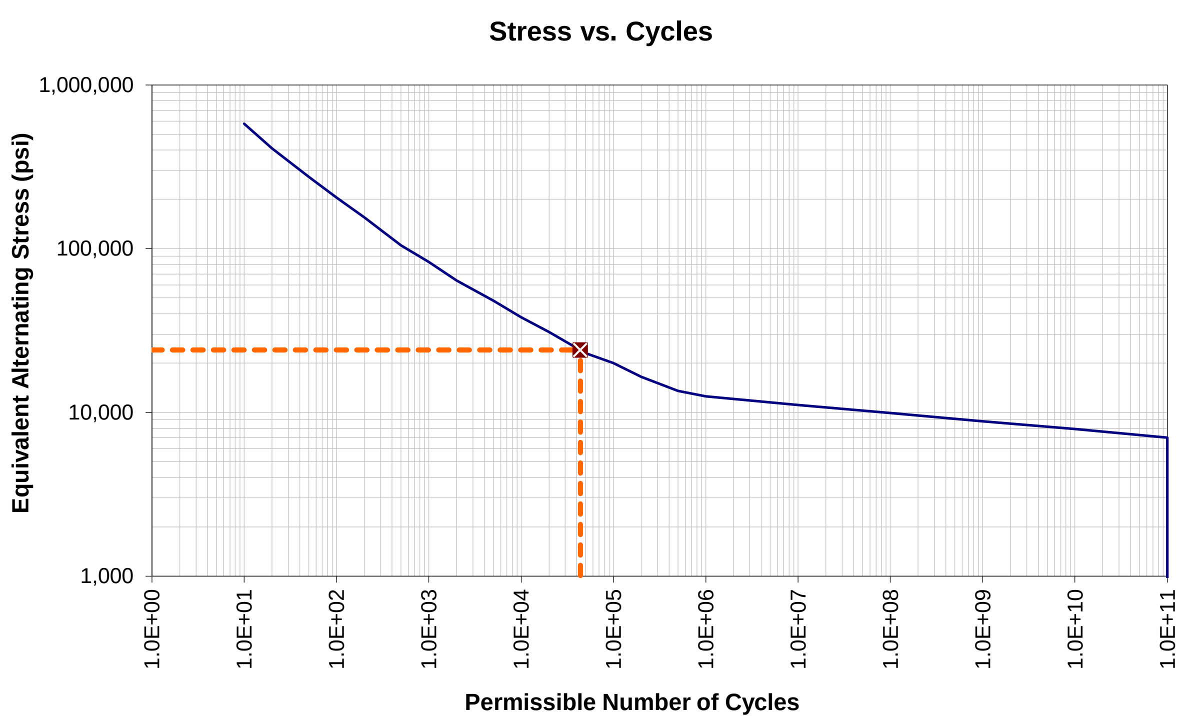
Permissible Cycle Life: VIII-2, 5.5.3.2

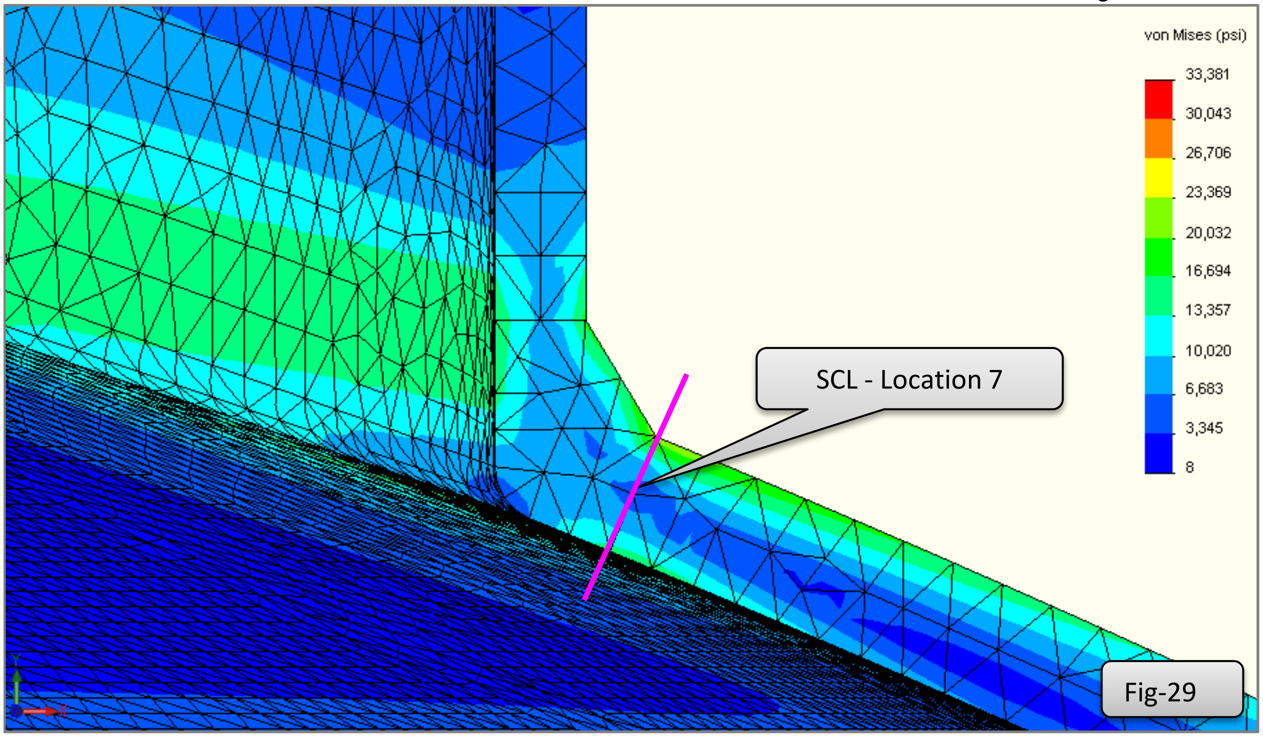
Saltk = (Kf*Kek*ΔSpk)/2 (2.5*1*18600)/2 = **23,250**

Efc [psi] = From Table3.F.1 **30,000,000**

Se [psi] = Saltk*Max(Efc/Et,1) 3-F.3 23250*MAX(30000000/29030000,1) = **24,027**

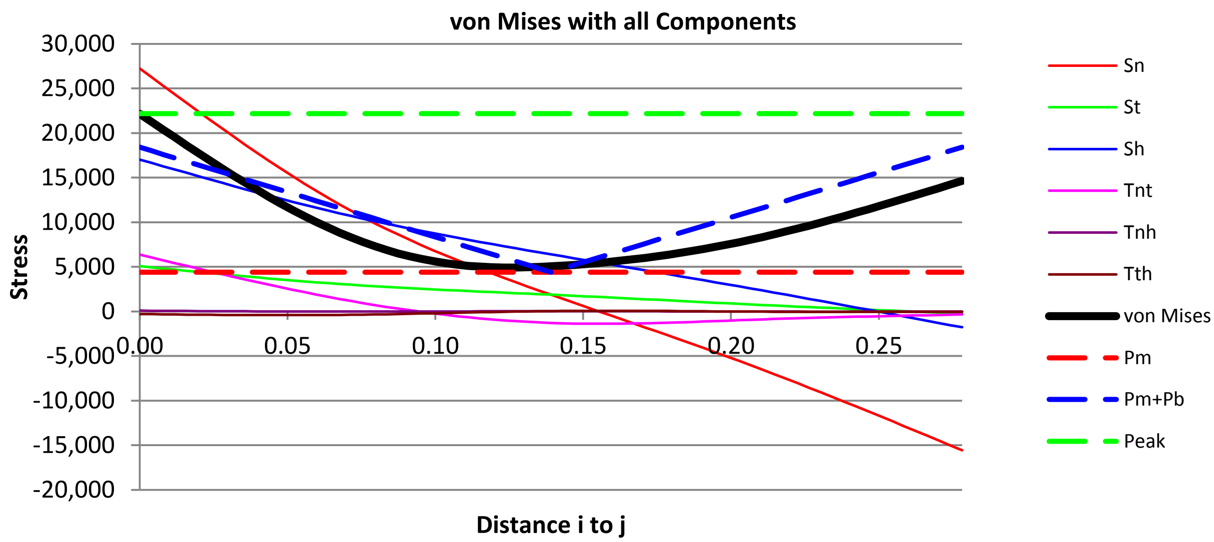
Cycles = From Table3.F.1 **43,727**





Stress Classification Line - Location 7

A stress classification line is taken through the flanged and dished head at the 4" nozzle weld. The stress linearization results are applied to a fatigue curve on the following page.



Stress Check:

Local	**Stress** Classification		
SA-516 70	**Material**		
	Allowed	**Actual**	**Check**
Pl [psi] =	30,000	4,406	Acceptable
Pb [psi] =		17,153	
Pl+Pb+Q [psi] =	71,400	18,406	Acceptable
Peak [psi] =		22,166	

5 nodes found on the stress classification line 0.2782 units long - cubic spline interpolated to 71 equally spaced nodes.

Cycle life location 7 **Description**

Cycle Graph:

Table3.F.1 **Graph**

Carbon, Low Alloy, Series 4xx, and High Tensile Strength Steels for temperatures not exceeding 700°F
UTS<= 80ksi

Cyclic Data: VIII-2, 5.5.3

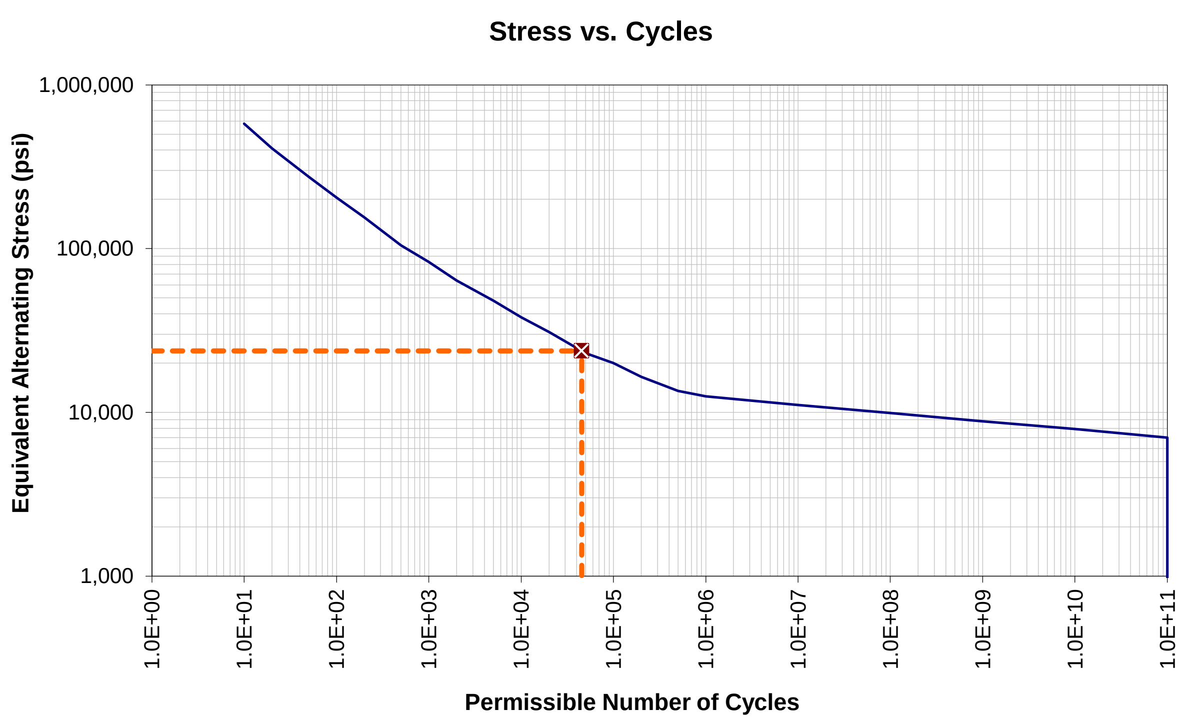
18,406	**ΔSpk** [psi] - Range of primary plus secondary plus peak equivalent stress (Pl+Pb+Q+F)
2.50	**Kf** - fatigue strength reduction factor (Table 5.11 & 5.12)
3.00	**m** - material constant used for the fatigue knock down factor (Table 5.13)
0.20	**n** - material constant used for the fatigue knock down factor (Table 5.13)
17,100	**S** [psi] - material allowable
32,900	**Sy** [psi] - material yield strength
150	**Tav** [°F] - average cycle temperature
29,030,000	**Et** [psi] - modulus of elasticity at Tav

Fatigue Penalty Factor: 5.31, 5.32, 5.33

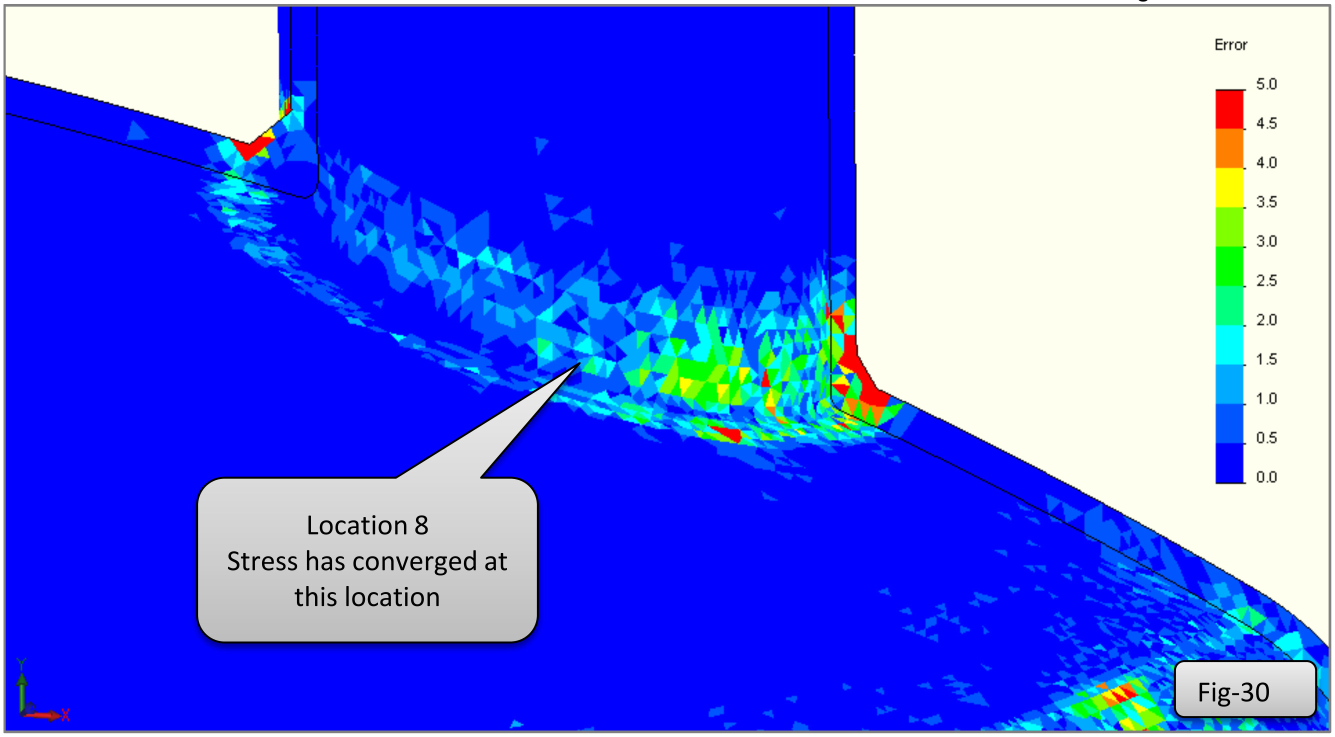
Sps [psi] =	max(3*S,2*Sy)	MAX(3*17100,2*32900) =	**65,800**
Kek1 =	1	1 =	**1**
Kek2 =	1 + (1-n)/(n*(m-1)) * (ΔSpk/Sps-1)		
		1 + (1-0.2)/(0.2*(3-1)) * (18406/65800-1) =	**-0.441**
Kek3 =	1/n	1/0.2 =	**5**
Kek =	If(ΔSpk<Sps,Kek1,If(ΔSpk>=m*Sps,Kek3,Kek2))		
		IF(18406<65800,1,IF(18406>=3*65800,5,12)) =	**1**

Permissible Cycle Life: VIII-2, 5.5.3.2

Saltk =	(Kf*Kek*ΔSpk)/2	(2.5*1*18406)/2 =	**23,008**
Efc [psi] =	From Table3.F.1		**30,000,000**
Se [psi] =	Saltk*Max(Efc/Et,1) 3-F.3	23008*MAX(30000000/29030000,1) =	**23,776**
Cycles =	From Table3.F.1		**45,155**

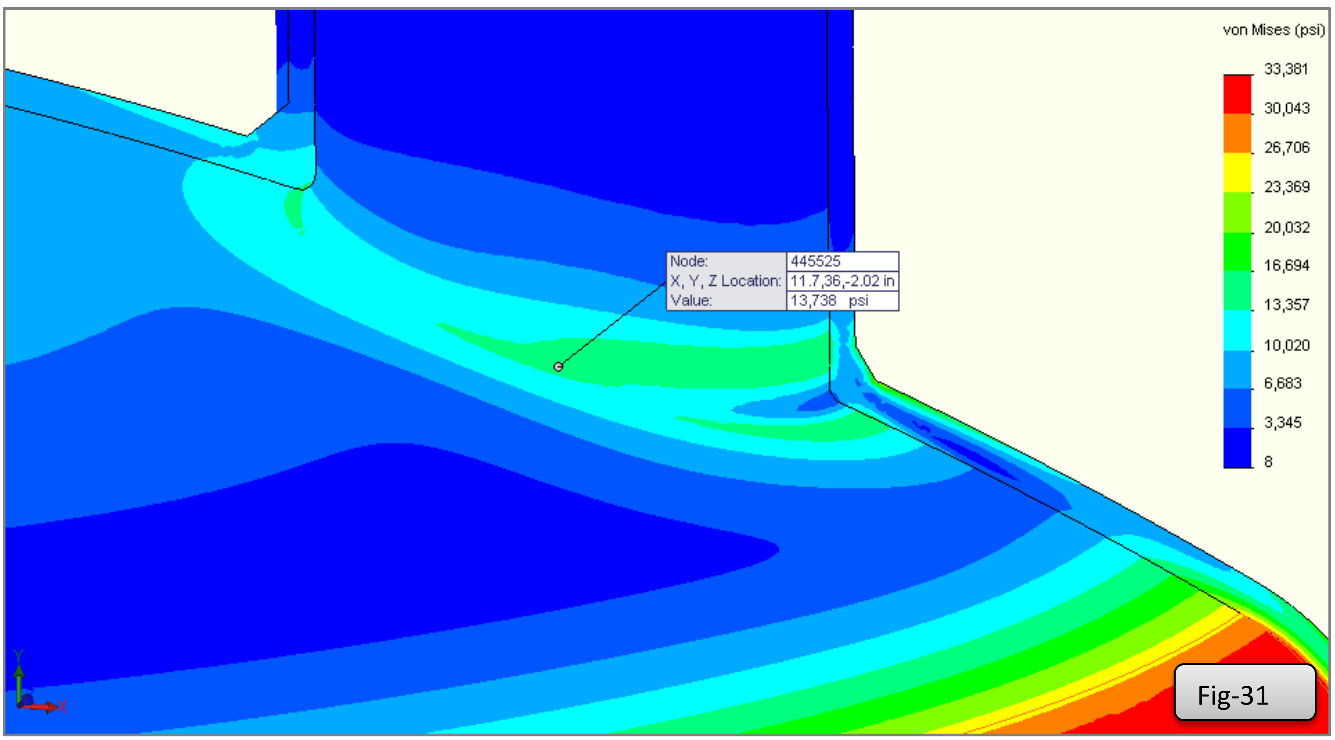


Location 8



Error Plot - 4" Nozzle

The error plot at the inside corner of the 4" nozzle is capped at 5%. This shows that the stress has fully converged at this location and that it is acceptable to take a direct reading from the model.



Direct Stress Reading

The stress on the inside corner of the 4" nozzle is directly read from the model. The maximum stress at this location is 13,738 psi. Since this stress occurs on the base metal and not on a weld, a Kf value of 1.0 will be used in the cycle life calculation.

Cycle life location 8 **Description**

Cycle Graph:

Table3.F.1 **Graph**

Carbon, Low Alloy, Series 4xx, and High Tensile Strength Steels for temperatures not exceeding 700°F
UTS<= 80ksi

Cyclic Data: VIII-2, 5.5.3

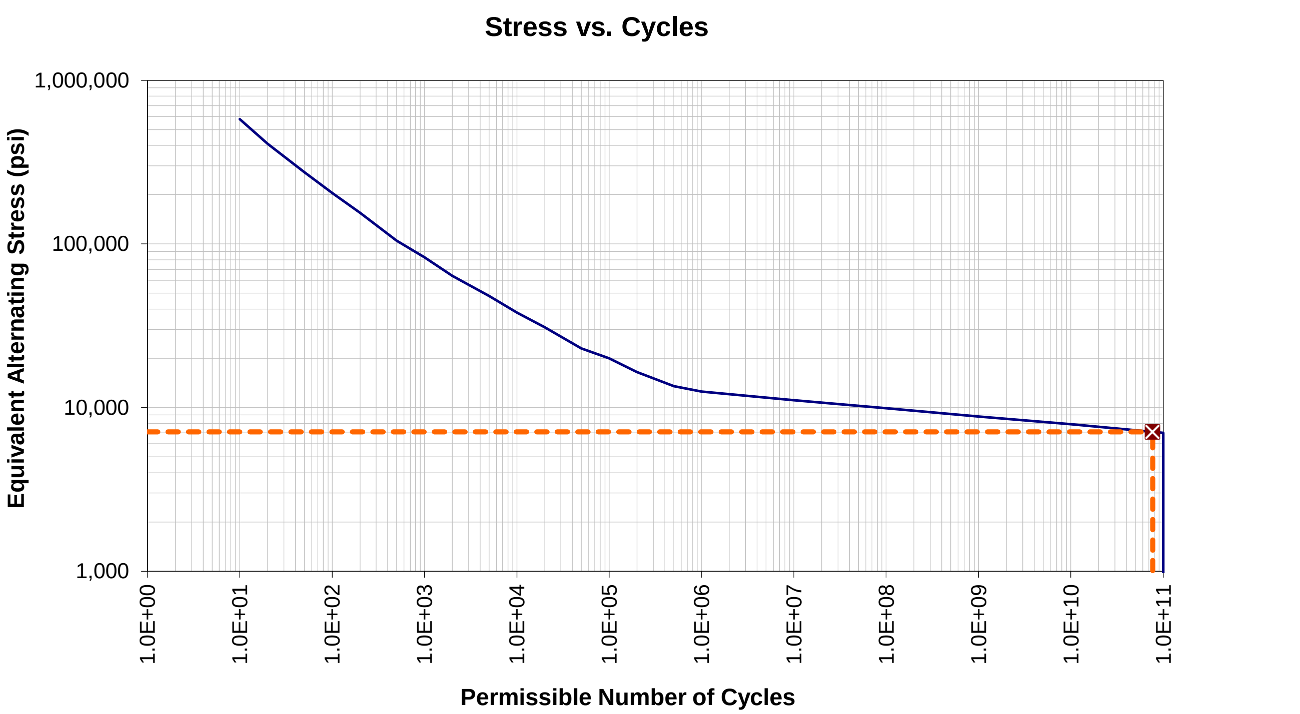
13,738	**ΔSpk** [psi] - Range of primary plus secondary plus peak equivalent stress (Pl+Pb+Q+F)
1.00	**Kf** - fatigue strength reduction factor (Table 5.11 & 5.12)
3.00	**m** - material constant used for the fatigue knock down factor (Table 5.13)
0.20	**n** - material constant used for the fatigue knock down factor (Table 5.13)
17,100	**S** [psi] - material allowable
32,900	**Sy** [psi] - material yield strength
150	**Tav** [°F] - average cycle temperature
29,030,000	**Et** [psi] - modulus of elasticity at Tav

Fatigue Penalty Factor: 5.31, 5.32, 5.33

Sps [psi] =	max(3*S,2*Sy)	MAX(3*17100,2*32900) =	**65,800**
Kek1 =	1	1 =	**1**
Kek2 =	1 + (1-n)/(n*(m-1)) * (ΔSpk/Sps-1)	1 + (1-0.2)/(0.2*(3-1)) * (13738/65800-1) =	**-0.582**
Kek3 =	1/n	1/0.2 =	**5**
Kek =	If(ΔSpk<Sps,Kek1,If(ΔSpk>=m*Sps,Kek3,Kek2))	IF(13738<65800,1,IF(13738>=3*65800,5,12)) =	**1**

Permissible Cycle Life: VIII-2, 5.5.3.2

Saltk =	(Kf*Kek*ΔSpk)/2	(1*1*13738)/2 =	**6,869**
Efc [psi] =	From Table3.F.1		**30,000,000**
Se [psi] =	Saltk*Max(Efc/Et,1) 3-F.3	6869*MAX(30000000/29030000,1) =	**7,099**
Cycles =	From Table3.F.1		**76,639,153,153**



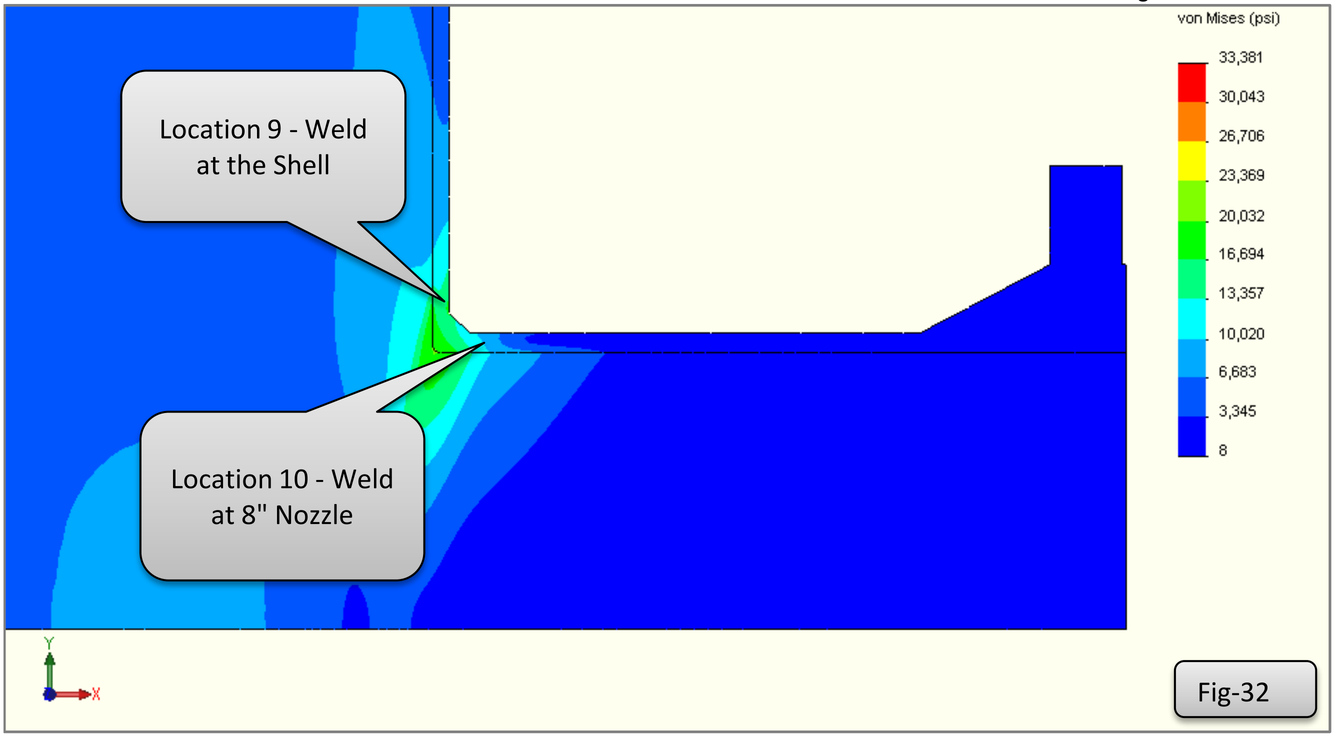
Summary:

This section covers the 8" nozzle in the shell. The permissible number of cycles is calculated for each of the areas below.

Results:

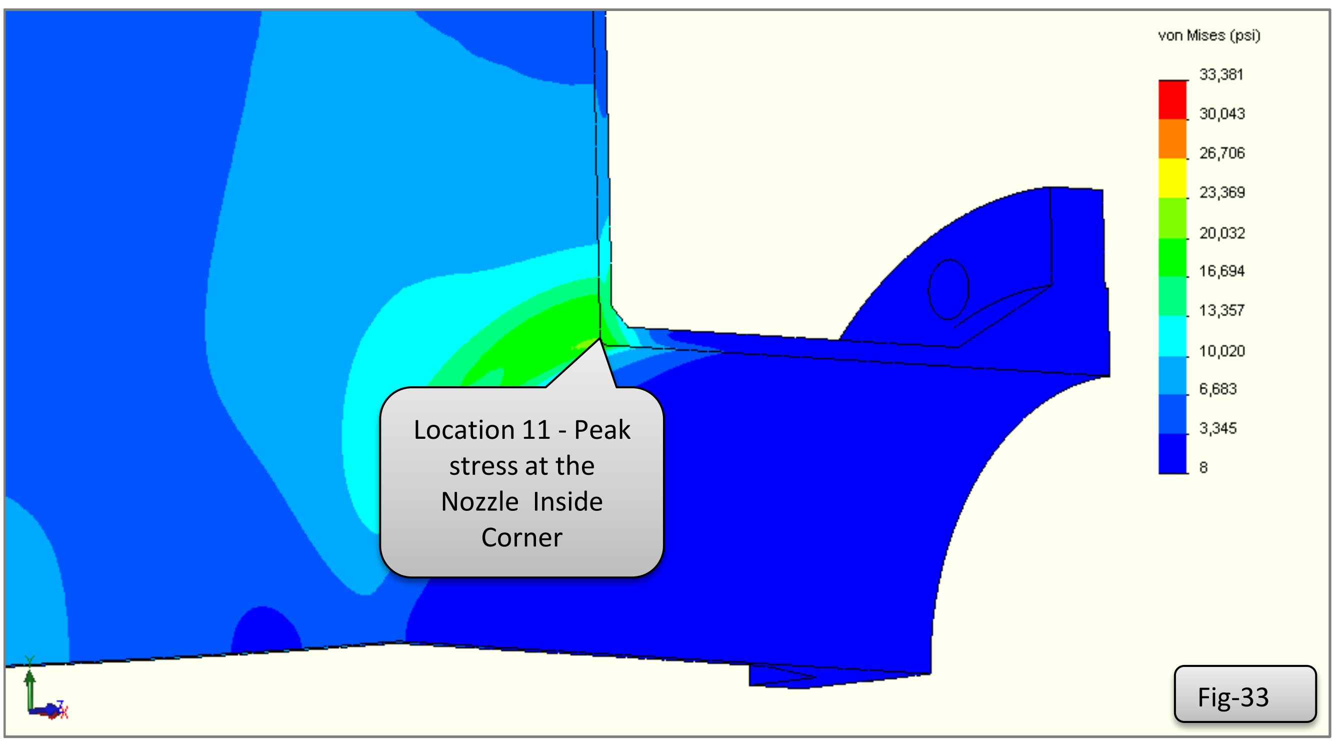
Location #	Location	Method	Stress	Kf	Kek	Se	Permissible Number of Cycles
9	Shell Weld Toe	Extrapolation	19,059	2.5	1.0	24,620	40,573
10	Nozzle Weld Toe	Direct Reading	11,075	2.5	1.0	14,306	383,645
11	Nozzle ID	Direct Reading	20,398	1.0	1.0	10,540	28,356,319
		Maximum permissible number of cycles					40,573

Kf = 2.5 for full pen welds with visual inspection only and no volumetric examination. (See table VIII-2 5.11 & 5.12)



Stress Plot - 8" Nozzle

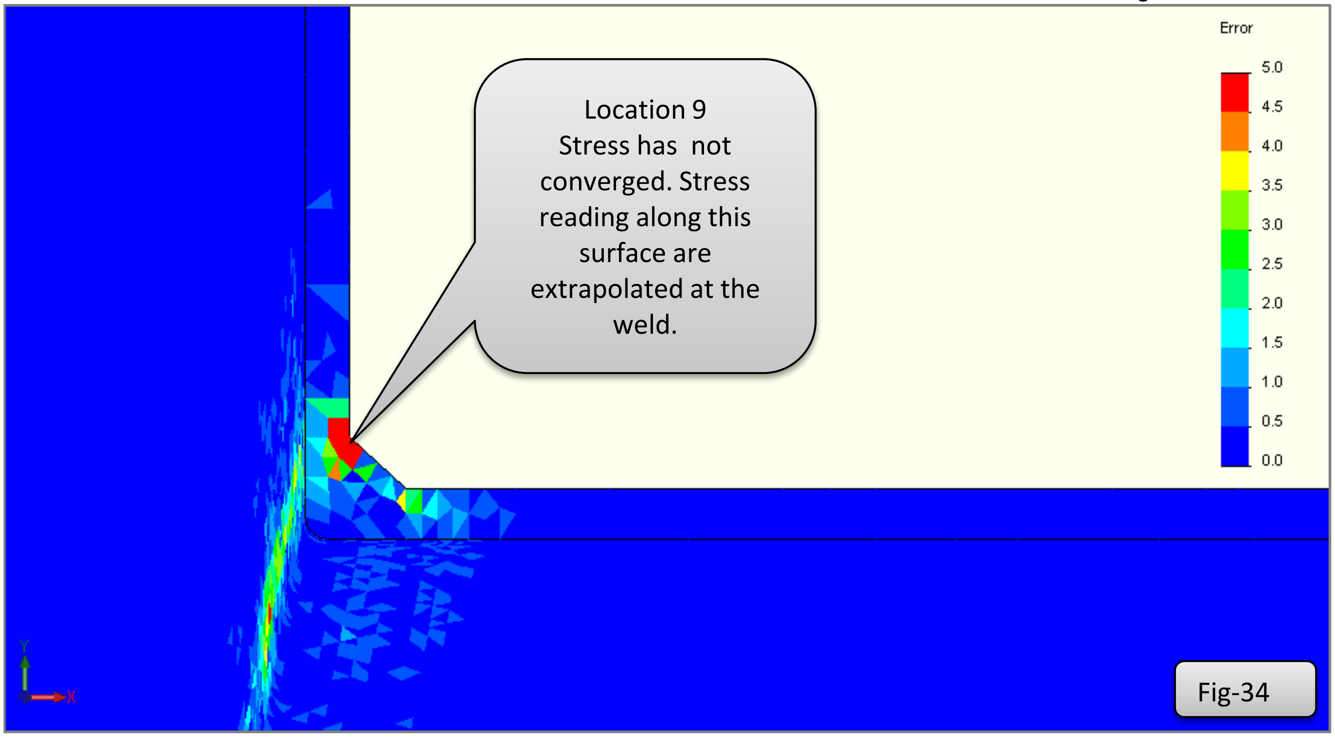
The von Mises stress profile where the 8" nozzle meets the shell. Stress classification lines are taken at the weld both through the junction with the nozzle and the shell.



Stress Plot - 8" Nozzle Inside Corner

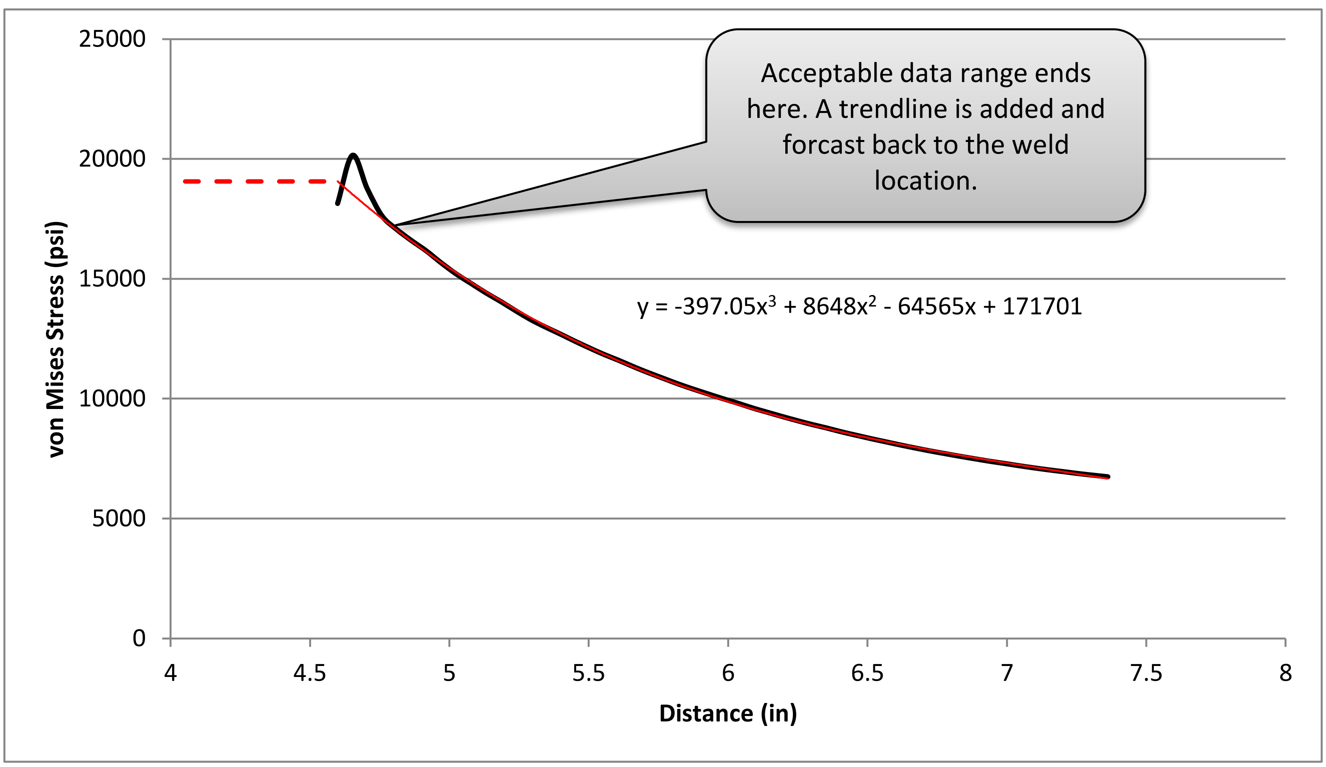
The von Mises stress profile at the inside corner of the nozzle. A peak stress occurs at this section due to the discontinuity. The peak stress at this location is used to compute the cycle life.

Location 9



Error Plot - 8" Nozzle Weld

The error plot at the 8" nozzle fillet weld attaching to the shell is capped at 5%. This shows that the stress has not fully converged at this location and therefore the stress data will be read along the surface leading up to the weld and then extrapolated.



Extrapolated Stress

The stress at the weld toe attaching to the shell is extrapolated. The extrapolated stress at this location is 19,059 psi. Since this stress occurs on a fillet weld, a Kf value of 2.5 will be used in the cycle life calculation. A third order polynomial curve fit is used to extrapolate the data.

Permissible Cycle Life ver 6.00

Cycle life location 9 **Description**

Cycle Graph:

Table3.F.1 **Graph**

Carbon, Low Alloy, Series 4xx, and High Tensile Strength Steels for temperatures not exceeding 700°F
UTS<= 80ksi

Cyclic Data: VIII-2, 5.5.3

19,059	**ΔSpk** [psi] - Range of primary plus secondary plus peak equivalent stress (Pl+Pb+Q+F)
2.50	**Kf** - fatigue strength reduction factor (Table 5.11 & 5.12)
3.00	**m** - material constant used for the fatigue knock down factor (Table 5.13)
0.20	**n** - material constant used for the fatigue knock down factor (Table 5.13)
17,100	**S** [psi] - material allowable
32,900	**Sy** [psi] - material yield strength
150	**Tav** [°F] - average cycle temperature
29,030,000	**Et** [psi] - modulus of elasticity at Tav

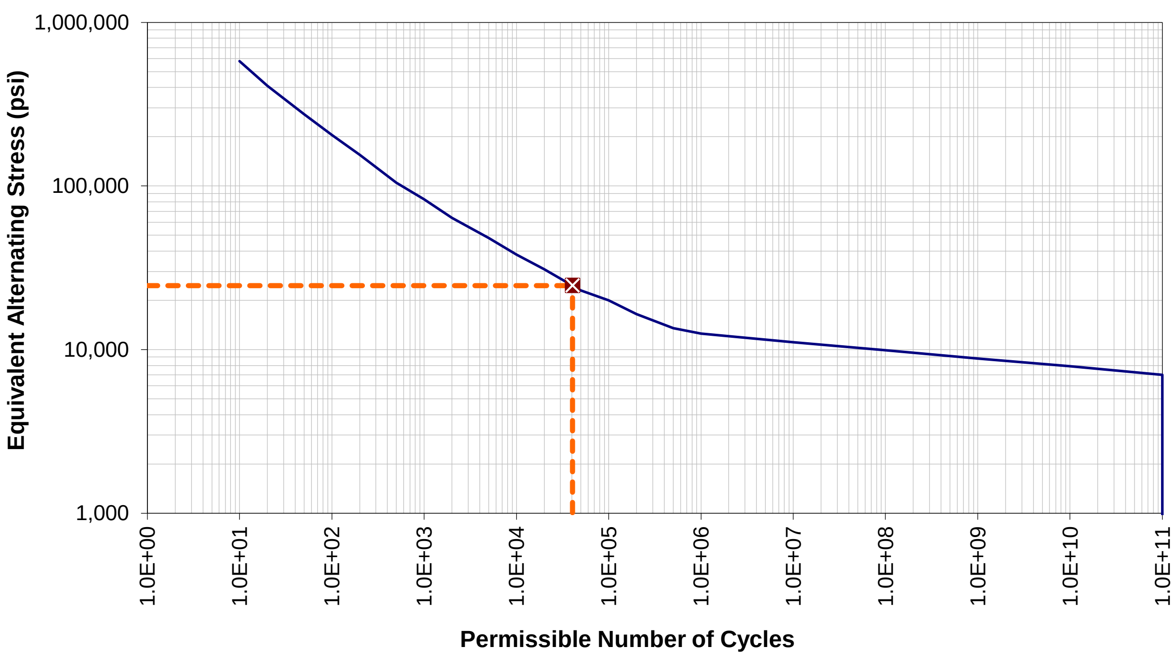
Fatigue Penalty Factor: 5.31, 5.32, 5.33

Sps [psi] =	max(3*S,2*Sy)	MAX(3*17100,2*32900) =	**65,800**
Kek1 =	1	1 =	**1**
Kek2 =	1 + (1-n)/(n*(m-1)) * (ΔSpk/Sps-1)	1 + (1-0.2)/(0.2*(3-1)) * (19059/65800-1) =	**-0.421**
Kek3 =	1/n	1/0.2 =	**5**
Kek =	If(ΔSpk<Sps,Kek1,If(ΔSpk>=m*Sps,Kek3,Kek2))	IF(19059<65800,1,IF(19059>=3*65800,5,12)) =	**1**

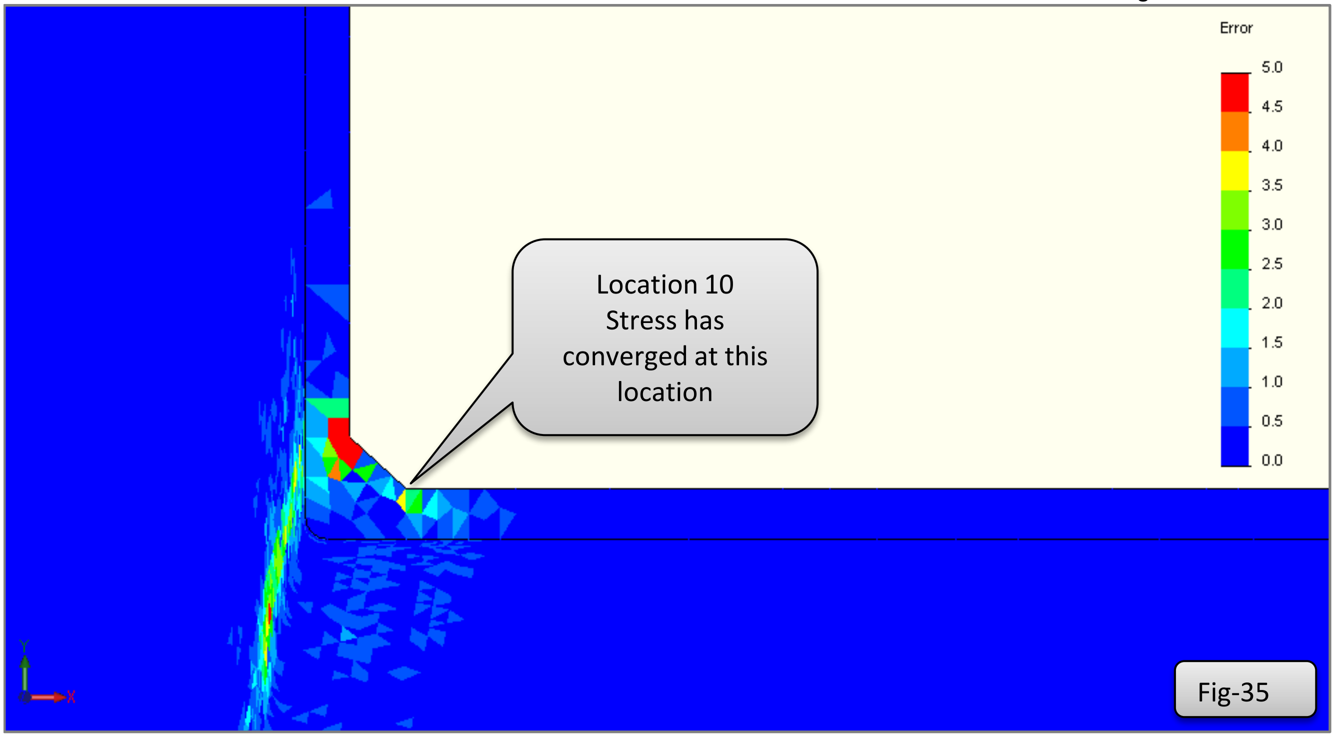
Permissible Cycle Life: VIII-2, 5.5.3.2

Saltk =	(Kf*Kek*ΔSpk)/2	(2.5*1*19059)/2 =	**23,824**
Efc [psi] =	From Table3.F.1		**30,000,000**
Se [psi] =	Saltk*Max(Efc/Et,1) 3-F.3	23824*MAX(30000000/29030000,1) =	**24,620**
Cycles =	From Table3.F.1		**40,573**

Stress vs. Cycles

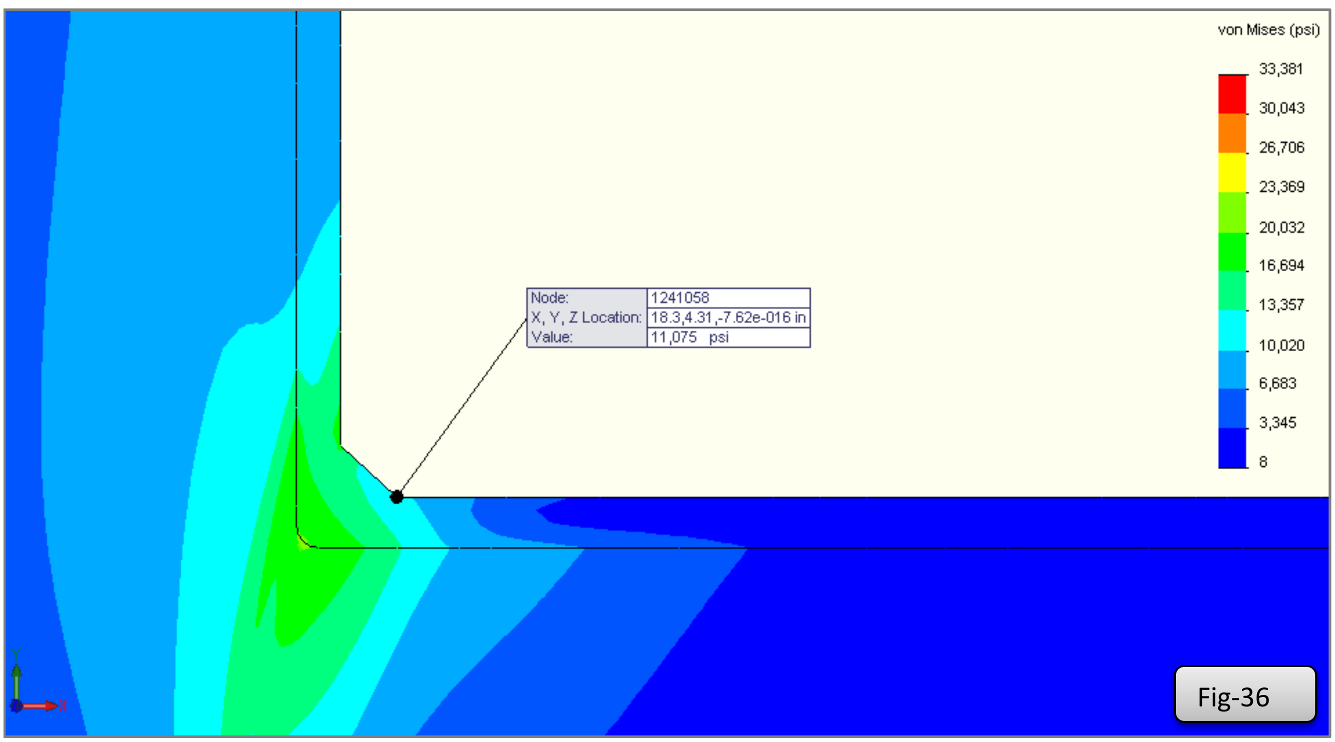


Location 10



Error Plot - 8" Nozzle Weld

The error plot at the fillet weld attaching to the 8" nozzle is capped at 5%. This shows that the stress has fully converged at this location and that it is acceptable to take a direct reading from the model.



Direct Stress Reading

The stress on the weld fillet attaching to the 8" nozzle is directly read from the model. The maximum stress at this location is 11,075 psi. Since this stress occurs on a fillet weld, a Kf value of 2.5 will be used in the cycle life calculation.

Cycle life location 10 **Description**

Cycle Graph:

Table3.F.1 **Graph**

Carbon, Low Alloy, Series 4xx, and High Tensile Strength Steels for temperatures not exceeding 700°F
UTS<= 80ksi

Cyclic Data: VIII-2, 5.5.3

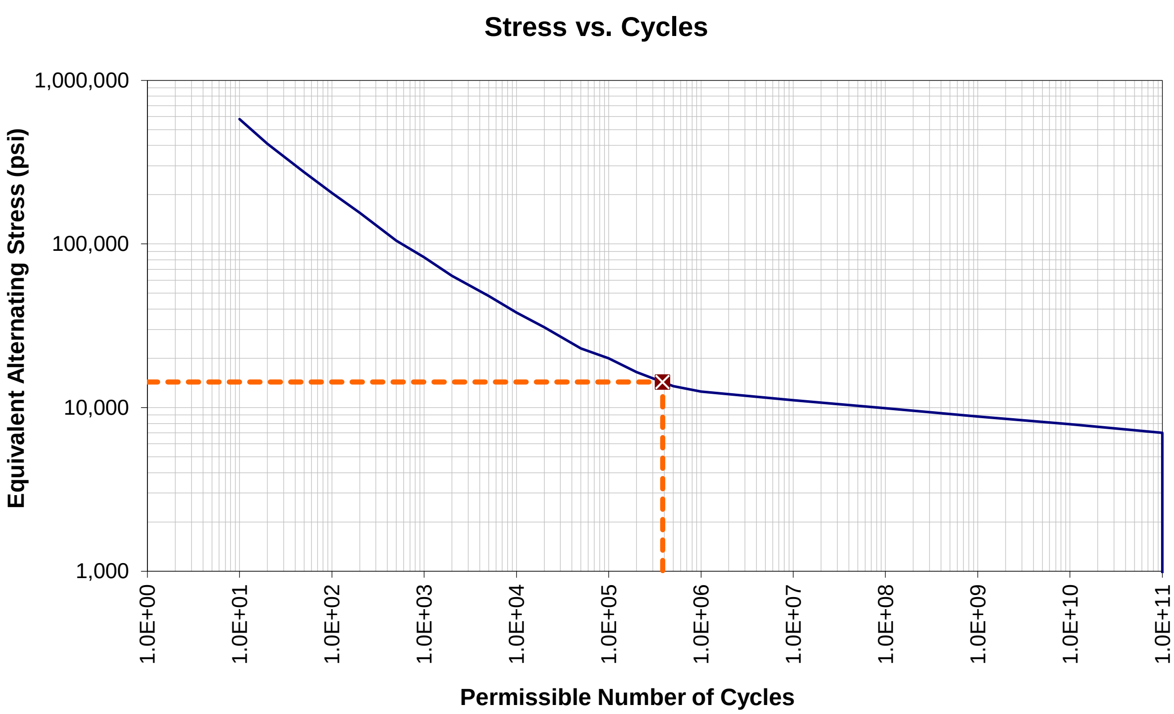
11,075	**ΔSpk** [psi] - Range of primary plus secondary plus peak equivalent stress (Pl+Pb+Q+F)
2.50	**Kf** - fatigue strength reduction factor (Table 5.11 & 5.12)
3.00	**m** - material constant used for the fatigue knock down factor (Table 5.13)
0.20	**n** - material constant used for the fatigue knock down factor (Table 5.13)
17,100	**S** [psi] - material allowable
32,900	**Sy** [psi] - material yield strength
150	**Tav** [°F] - average cycle temperature
29,030,000	**Et** [psi] - modulus of elasticity at Tav

Fatigue Penalty Factor: 5.31, 5.32, 5.33

Sps [psi] =	max(3*S,2*Sy)	MAX(3*17100,2*32900) =	**65,800**
Kek1 =	1	1 =	**1**
Kek2 =	1 + (1-n)/(n*(m-1)) * (ΔSpk/Sps-1)		
		1 + (1-0.2)/(0.2*(3-1)) * (11075/65800-1) =	**-0.663**
Kek3 =	1/n	1/0.2 =	**5**
Kek =	If(ΔSpk<Sps,Kek1,If(ΔSpk>=m*Sps,Kek3,Kek2))		
		IF(11075<65800,1,IF(11075>=3*65800,5,12)) =	**1**

Permissible Cycle Life: VIII-2, 5.5.3.2

Saltk =	(Kf*Kek*ΔSpk)/2	(2.5*1*11075)/2 =	**13,844**
Efc [psi] =	From Table3.F.1		**30,000,000**
Se [psi] =	Saltk*Max(Efc/Et,1) 3-F.3	13844*MAX(30000000/29030000,1) =	**14,306**
Cycles =	From Table3.F.1		**383,645**



Location 11

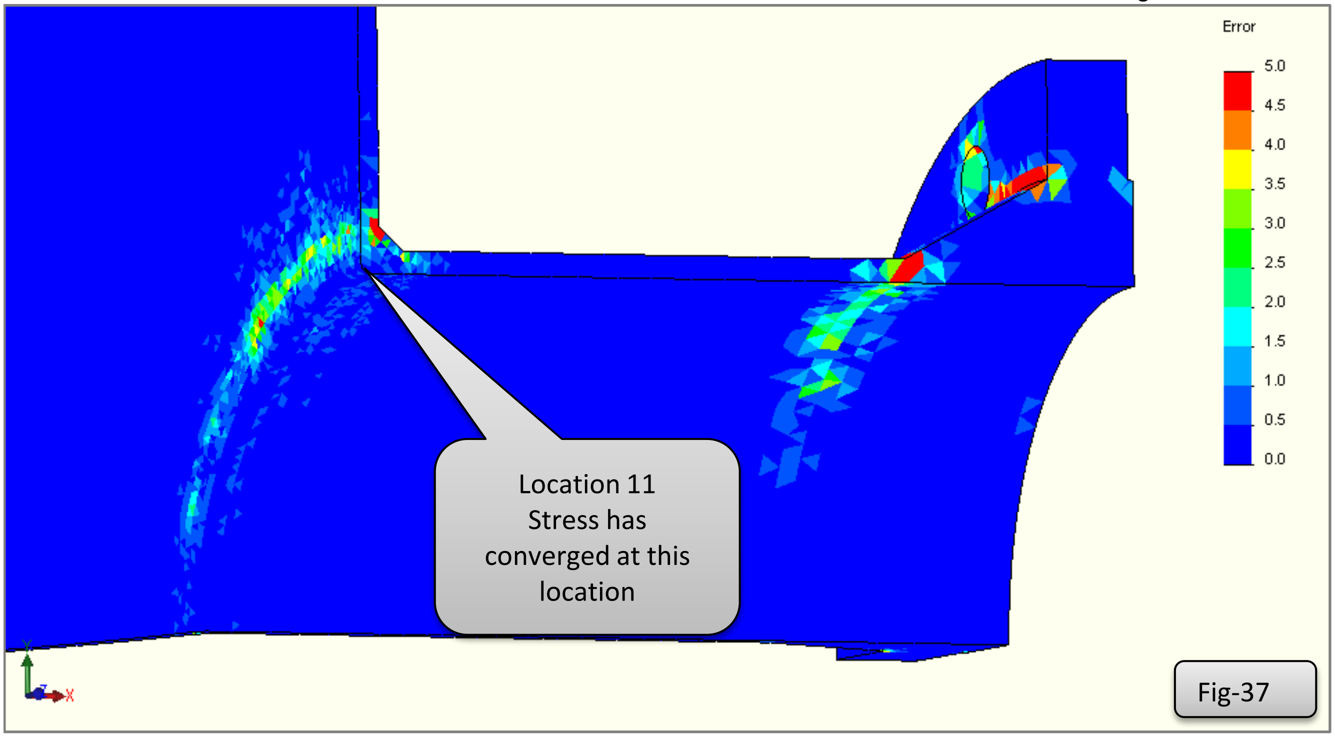


Fig-37

Error Plot - 8" Nozzle

The error plot at the inside corner of the 8" nozzle is capped at 5%. This shows that the stress has fully converged at this location and that it is acceptable to take a direct reading from the model.

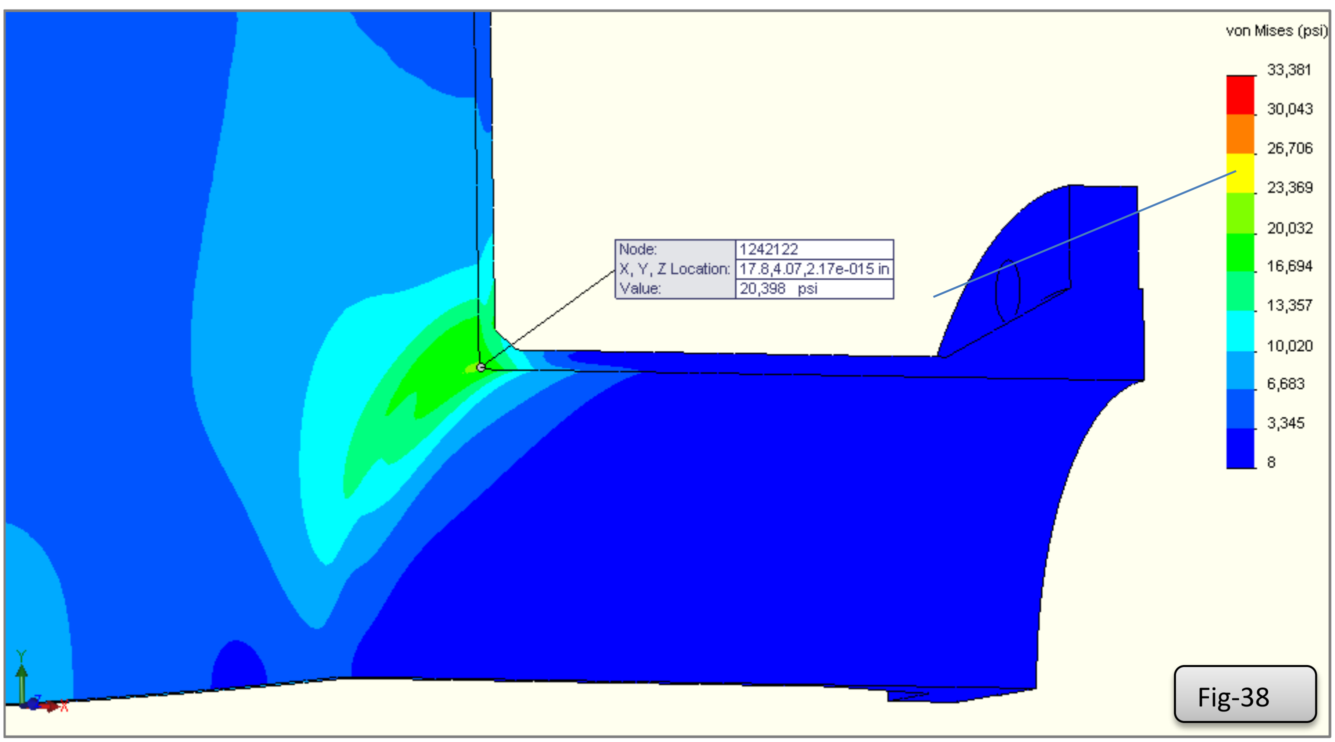


Fig-38

Direct Stress Reading

The stress on the inside corner of the 8" nozzle is directly read from the model. The maximum stress at this location is 20,398 psi. Since this stress occurs on the base metal and not on a weld, a Kf value of 1.0 will be used in the cycle life calculation.

Cycle life location 11 **Description**

Cycle Graph:

Table3.F.1 **Graph**

Carbon, Low Alloy, Series 4xx, and High Tensile Strength Steels for temperatures not exceeding 700°F
UTS<= 80ksi

Cyclic Data: VIII-2, 5.5.3

20,398	**ΔSpk** [psi] - Range of primary plus secondary plus peak equivalent stress (Pl+Pb+Q+F)
1.00	**Kf** - fatigue strength reduction factor (Table 5.11 & 5.12)
3.00	**m** - material constant used for the fatigue knock down factor (Table 5.13)
0.20	**n** - material constant used for the fatigue knock down factor (Table 5.13)
17,100	**S** [psi] - material allowable
32,900	**Sy** [psi] - material yield strength
150	**Tav** [°F] - average cycle temperature
29,030,000	**Et** [psi] - modulus of elasticity at Tav

Fatigue Penalty Factor: 5.31, 5.32, 5.33

Sps [psi] =	max(3*S,2*Sy)	MAX(3*17100,2*32900) =	**65,800**
Kek1 =	1	1 =	**1**
Kek2 =	1 + (1-n)/(n*(m-1)) * (ΔSpk/Sps-1)		
		1 + (1-0.2)/(0.2*(3-1)) * (20398/65800-1) =	**-0.380**
Kek3 =	1/n	1/0.2 =	**5**
Kek =	If(ΔSpk<Sps,Kek1,If(ΔSpk>=m*Sps,Kek3,Kek2))		
		IF(20398<65800,1,IF(20398>=3*65800,5,12)) =	**1**

Permissible Cycle Life: VIII-2, 5.5.3.2

Saltk =	(Kf*Kek*ΔSpk)/2	(1*1*20398)/2 =	**10,199**
Efc [psi] =	From Table3.F.1		**30,000,000**
Se [psi] =	Saltk*Max(Efc/Et,1) 3-F.3	10199*MAX(30000000/29030000,1) =	**10,540**
Cycles =	From Table3.F.1		**28,356,319**