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Brief Discussion:

Fig.UW-13.2 Non-Permissible heads, ASME VIII-1, by Finite Element Analysis

Prepared by: Michael Rodgers, P.Eng.
Date: July 16, 2010

Key Design Engineering is a Canadian engineering firm located in Waterloo, Ontario, that specializes in ASME Code calculations and Canadian Registration Number (CRN) submissions:

- **ASME Code Calculations** per ASME VIII-1 & ASME B31.3 for Pressure Vessels, Fittings, & Piping systems as applicable.
- **Canadian Registration Number (CRN)**: preparation of documentation for submission of pressure vessels, fittings, or pressure piping for registration in one Jurisdiction or Canada-wide.
- **Finite Element Analysis (FEA)** of Pressure Vessels and Fittings in accordance with ASME VIII-2, in compliance with Jurisdictional requirements.

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Summary:

Finite Element Analysis (FEA) is used to investigate reasons why ASME VIII-1, FIG.UW-13.2, does not permit certain joint configurations for the attachment of welded unstayed flat heads:

1. **Joint Orientation:** The eccentrically attached weld allows the joint to open under pressure.
2. **Fatigue Life**: The peak stress created at the weld root limits the fatigue life.
3. **Weld size**: The weld size is insufficient to satisfy the Code's geometric requirements.

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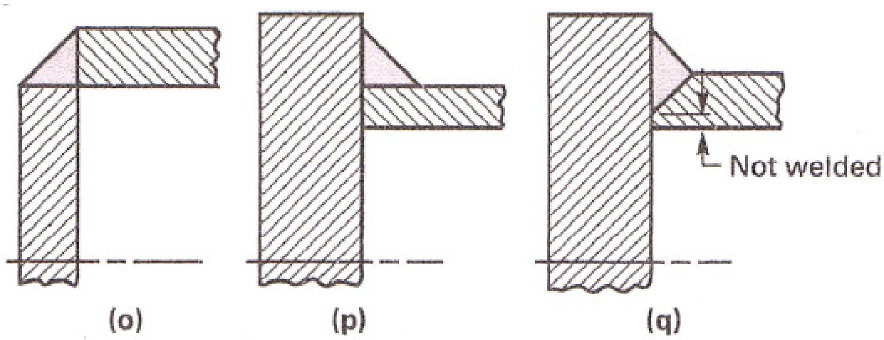
Introduction:

ASME VIII-1 lists various examples of permissible flat welded-head configurations in Fig.UG-34 & Fig.UW-13.2. Why are the following three joints listed as “Non-Permissible” in Fig.UW-13.2?



Typical Nonpermissible Corner Joints

Figure UW-13.2

Approach:

The three non-permissible configurations presented in Fig.UW-13.2 are analyzed: o, p, & q. For comparison, an analysis is also performed on Fig.UG-34(e), which is permissible.

General Setup:

Code of Construction:	ASME VIII-1, 2007ed, 2009b
Design Conditions:	1,000 psi @ 650F
Material:	Shell: SA-312 TP304 Flat head: SA-240 304
Corrosion Allowance:	N/A
Mesh Error:	Max 5%, per ABSA guideline
FEA Interpretation:	ASME VIII-2, 2007, Part 5
E (weld quality)	1.0, per table UW-12, corner joint
Thicknesses	Head and shell thicknesses sized per Classical Calculations, attached to this discussion.

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Results: Nonpermissible Configurations

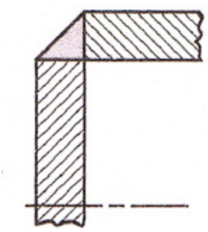


Fig. UW-13.2(o)

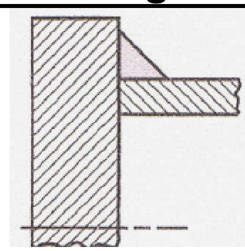


Fig. UW-13.2(p)

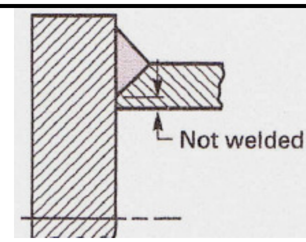
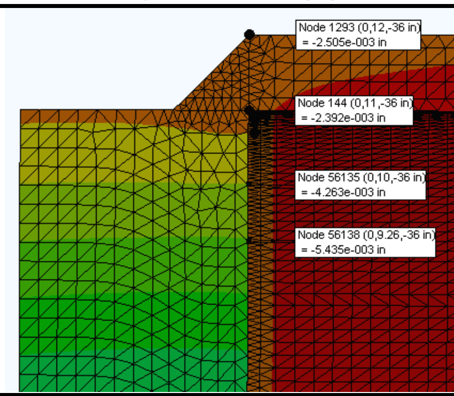
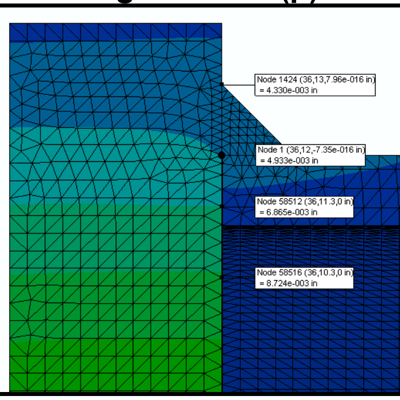
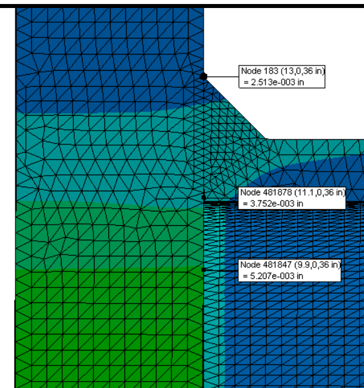


Fig. UW-13.2(q)

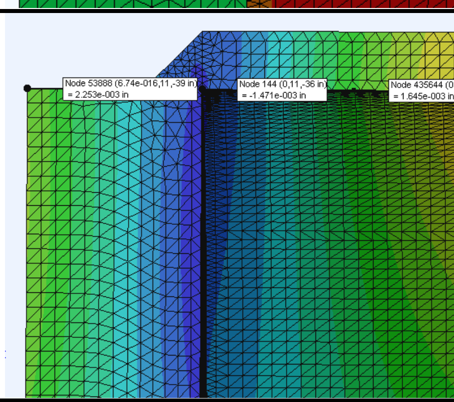
Axial Displacement

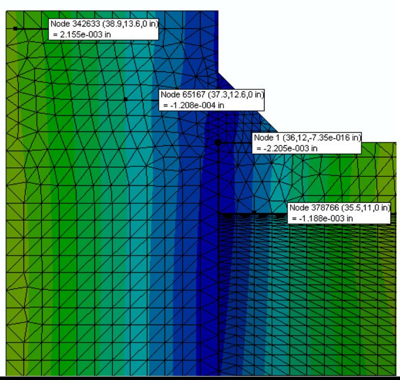


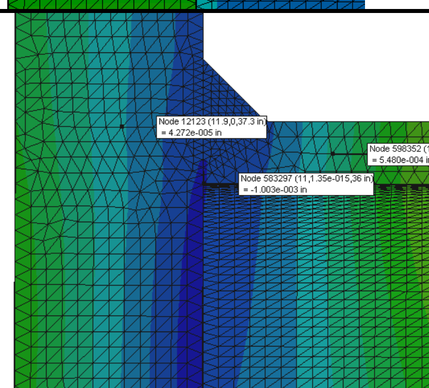




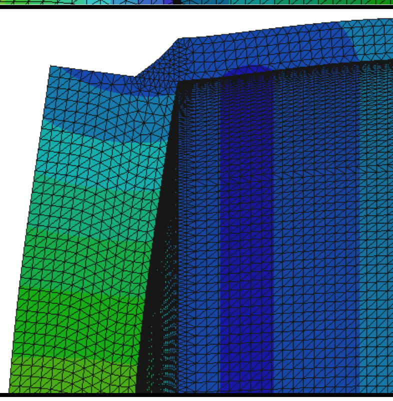
Radial Displacement

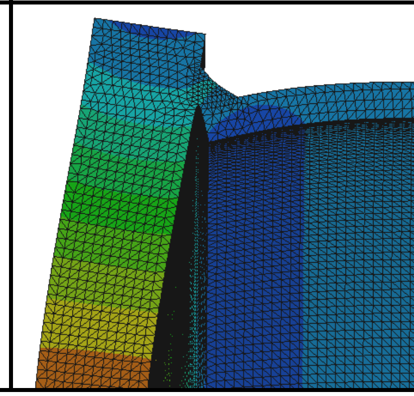


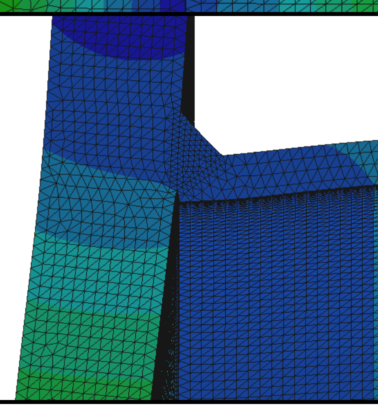




Resultant Displacement







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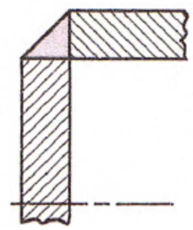
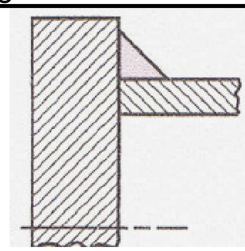
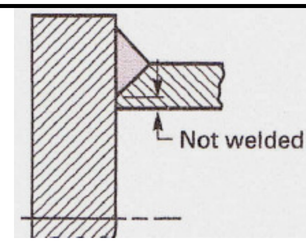
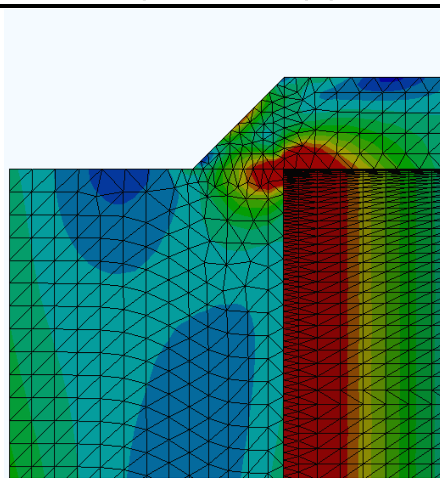
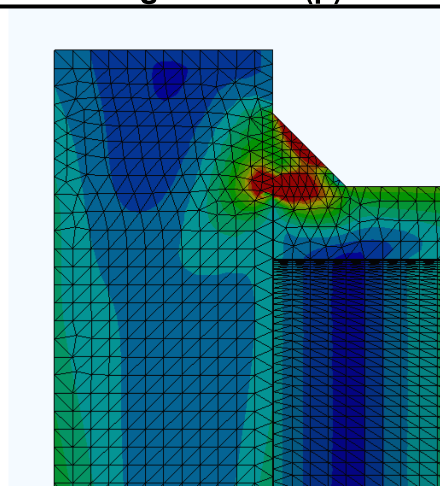
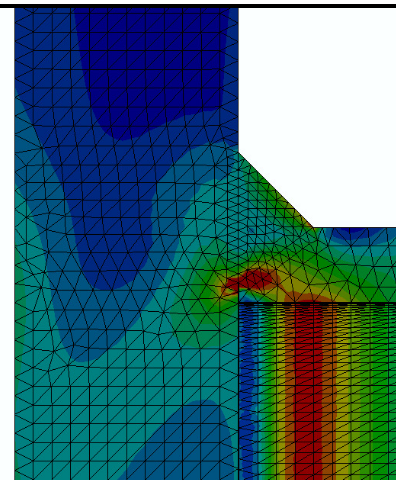
	 **Fig. UW-13.2(o)**	 **Fig. UW-13.2(p)**	 **Fig. UW-13.2(q)**
Resultant Von Mises Stress plots	 Peak stress = 3.2xS, at the inside corner. Expected life = 1.05E+06 cycles	 Peak stress = 3.6xS, at the weld root, forming a line around the circumference. Expected life = 7.87E+05 cycles	 Peak stress = 2.1xS, at the root, around the circumference of the part. Expected life = 5.74E+06 cycles

Referring to the preceding results, note the following:
-For the *Resultant Displacement* plots, the colour display has been capped at 2.076e-002 in. for comparison between the three configurations.
-The *Resultant Displacement* plots above are shown deformed at a scale of 100x, but both the *Axial* and *Radial displacement* plots are shown undeformed.
-For the *Von Mises Stress Plots*, the colour display has been capped at the allowable stress for stainless SA-240 304 @ 650F, which also corresponds to Pm, the membrane allowable stress.

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Results: Permissible Configuration

An analysis is run for the unstayed flat-head of FIG.UG-34(e), using the same design conditions.

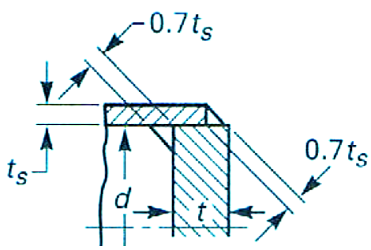
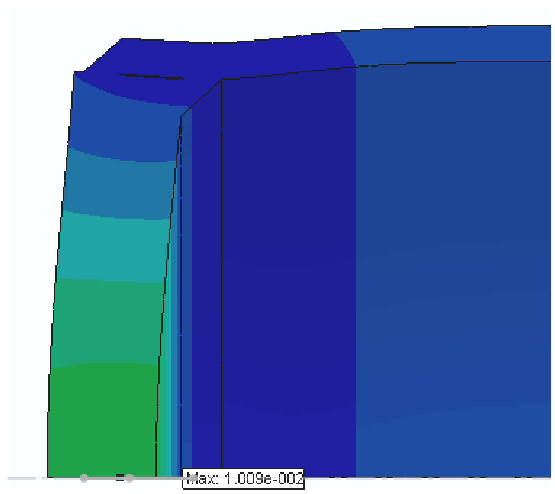
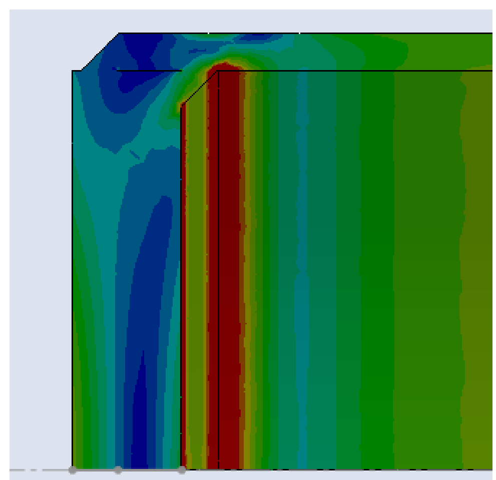


Fig. UG-34(e)



Resultant Displacement display: capped at 2.076e-002 in, for comparison with previous results.
Peak displacement is 1.009e-002 in.



Von Mises Stress display: capped at allowable stress, as previously.
Peak stress = 2.2xS
Expected life = 5.5E+06 cycles

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Observations:

It is immediately clear that for the two Nonpermissible cases (o) & (p), there isn't sufficient weld to satisfy the geometric requirement of the Code (VIII-1 UW-13(e)(5)). Also, the *Radial* Displacement Plot for case (o) shows a hinge developing at the weld's root, which makes it vulnerable to fatigue failure. However, the *Resultant Displacement* plots for cases (p) & (q) highlight the main underlying problem with these configurations. It is the weld's eccentricity relative to the main pressure-retaining component, the shell. In a permissible joint, a flat head will normally cause a moment to form in its attached shell, as can be observed in case (e) from Fig. UG-34 above. What sets these two cases apart is that the deformation causes an opening up of the joint. Rather than it being a self-limiting effect, such as relieves local peak stresses, it has a ratcheting effect that leads to premature failure under cyclic loading. In contrast, the permissible joint investigated has very low deflection both at the centre of the head and through the weld. While it also displays a peak stress at the weld root, the joint remains closed and any plasticity will be local to relieve the geometric stress concentrations at that point. The fatigue-life of the joint is greatly affected by the weld finish quality, but even this theoretical treatment shows that configuration (p) most severely limits the expected life cycles. An additional practical consideration is crevice corrosion, which could seriously impact stainless steel in configurations (p) & (q).

Additional References:

A. ASME VIII-1, UW-13 (e)(5) speaks to the reasons for these joints being nonpermissible:
   - **Weld Size**: The total weld dimension through the joint (throat) is less than the thickness of the pressure part to which it is attached, whether it be the shell, head or other component.
   - **Eccentricity**: The weld creates a joint that is attached eccentric to the pressure part.

B. Compress Calculations per ASME VIII-1, 2007 ed, 2009b for UG-34(e) unstayed flat-head. It was used for determining head and shell thickness.

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Welded Cover Fig.UG-34(e)

ASME Section VIII Division 1, 2007 Edition, A09 Addenda

Component: Welded Cover
Material specification: SA-240 304 (II-D p. 90, ln. 4)
Rated MDMT per UHA-51(d)(1)(a) = -320 °F

Internal design pressure: P = 1000 psi @ 650 °F
External design pressure: P_e = 15 psi @ 650 °F

Corrosion allowance: Inner C = 0" Outer C = 0"

Design MDMT = -20 °F
Rated MDMT = -320 °F

No impact test performed
Material is not normalized
Material is not produced to Fine Grain Practice
PWHT is not performed

Radiography: Category A joints - Seamless No RT

Estimated weight: New = 394.9 lb corr = 394.9 lb

Head diameter, d = 24"
Cover thickness, t = 3.01"

Factor C from Fig. UG-34, sketch (b-2), (e through g)

C = $0.33*t_r / t_s$
= 0.33*0.7692 / 1
= 0.2538

Design thickness, (at 650 °F) UG-34 (c)(2)

t = d*Sqr(C*P / (S*E)) + Corrosion
= 24*Sqr(0.2538*1,000 / (16,200*1)) + 0
= 3.004"

Maximum allowable working pressure, (at 650 °F)

C = $0.33*t_r / t_s$
= 0.33*0.7708 / 1
= 0.2544

MAWP = $(S*E / C)*(t / d)^2 - P_s$
= $(16,200*1 / 0.2543645)*(3.01 / 24)^2 - 0$
= 1,001.91 psi

Maximum allowable pressure, (At 70 °F)

C = $0.33*t_r / t_s$
= 0.33*0.7708 / 1
= 0.2544

MAP = $(S*E / C)*(t / d)^2$
= $(20,000*1 / 0.2543645)*(3.01 / 24)^2$
= 1,236.93 psi

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Design thickness for external pressure, (at 650 °F) UG-34(c)(2)

t	=	d*Sqr(C*P_e / (S*E)) + Corrosion
	=	24*Sqr(0.33*15 / (16,200*1)) + 0
	=	0.4195"

Maximum allowable external pressure, (At 650 °F)

MAEP	=	(S*E / C)*$(t / d)^2$
	=	(16,200*1 / 0.33)*$(3.01 / 24)^2$
	=	772.17 psi

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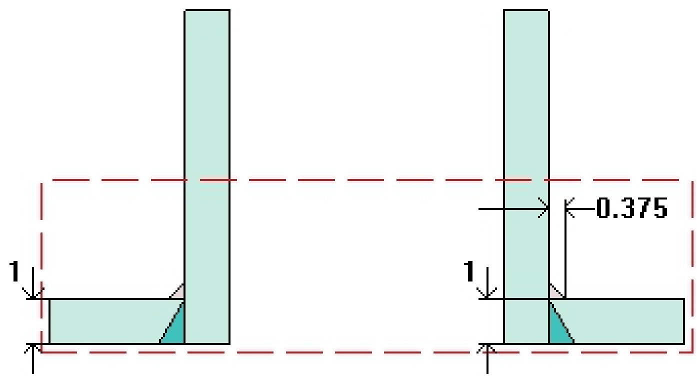
Nozzle #1 (N1)

ASME Section VIII Division 1, 2007 Edition, A09 Addenda

$t_{w(lower)}$ = 1 in
Leg_{41} = 0.375 in



.

Note: round inside edges per UG-76(c)

Located on:	Cylinder #1
Liquid static head included:	0 psi
Nozzle material specification:	SA-312 TP304 Wld & smls pipe (II-D p. 90, ln. 15)
Nozzle longitudinal joint efficiency:	1
Nozzle description:	24" (Thk = 1.000")
Nozzle orientation:	0°
Local vessel minimum thickness:	0.875 in
Nozzle center line offset to datum line:	50 in
End of nozzle to shell center:	40 in
Nozzle inside diameter, new:	22 in
Nozzle nominal wall thickness:	1 in
Nozzle corrosion allowance:	0 in
Projection available outside vessel, Lpr:	28 in

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Note: Nozzle is outside of scope of Appendix 1-7 as R_n / R > 0.7. Appendix 1-10 or Division 2 Part 4.5 was used for the U-2(g) large opening analysis.

This nozzle passes through a Category A joint.

Reinforcement Calculations for Internal Pressure

Available reinforcement per Appendix 1-10 governs the MAWP of this nozzle.

Appendix 1-10 Maximum Local Primary Membrane Stress For P = 710.48 psi @ 650 °F The opening is adequately reinforced							**UG-45 Nozzle Wall Thickness Summary (in)** The nozzle passes UG-45	
P_L (psi)	S_{allow} (psi)	A_1 (in^2)	A_2 (in^2)	A_3 (in^2)	A_5 (in^2)	A welds (in^2)	t_{req} (in)	t_{min} (in)
20,655	20,655	7.8721	3.462	--	--	0.0703	0.4955	0.875

Division 2 Part 4.5 Strength of Nozzle Attachment Welds Summary **Average Shear Stress in Weld**								
k_y	L_τ (in)	L_{41T} (in)	L_{42T} (in)	L_{43T} (in)	f_{welds} (lb_f)	τ (psi)	S (psi)	Over stressed
1.0909	18.8496	0.2652	0	0	84,125.81	6.814	16,200	No

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.25	0.2625	weld size is adequate

Calculations for internal pressure 710.48 psi @ 650 °F

Nozzle rated MDMT per UHA-51(d)(1)(a) = -320 °F.

Appendix 1-10

Effective radius of the vessel

R_{eff} = 0.5*D_i
= 0.5*22
= 11 in

Limit of reinforcement along the vessel wall

L_R = 8*t
= 8*0.875
= 7 in

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Limit of reinforcement along the nozzle wall projecting outside the vessel surface

L_{H1} = $t + 0.78*(R_n*t_n)^{0.5}$
= $0.875 + 0.78*(11*1)^{0.5}$
= 3.462 in

L_{H2} = $L_{pr1} + t$
= 28 + 0.875
= 28.875 in

L_{H3} = $8*(t + t_e)$
= 8*(0.875 + 0)
= 7 in

L_H = min[L_{H1}, L_{H2}, L_{H3}]
= min[3.462, 28.875, 7]
= 3.462 in

Effective thickness

t_{eff} = t
= 0.875 in

Total available area near the nozzle opening

λ = $\min[(2*R_n + t_n) / ((D_i + t_{eff})*t_{eff})^{0.5}, 10]$
= $\min[(2*11 + 1) / ((22 + 0.875)*0.875)^{0.5}, 10]$
= 5.1409

A_1 = $t*L_R*\max[(\lambda / 4) , 1]$
= 0.875*7*max[(5.1409 / 4) , 1]
= 0.875*7*1.2852
= 7.8721 in^2

A_2 = t_n*L_H
= 1*3.462
= 3.462 in^2

A_{41} = $0.5*L_{41}^2$
= $0.5*0.375^2$
= 0.0703 in^2

A_T = $A_1 + A_2 + A_{41}$
= 7.8721 + 3.462 + 0.0703
= 11.4044 in^2

Forces at nozzle to vessel intersection

f_N = $P*R_n*(L_H - t)$

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$=$ 710.48*11*(3.462 - 0.875)
$=$ 20,218 lb_f

f_S $=$ $P*R_{eff}*(L_R + t_n)$
$=$ 710.48*11*(7 + 1)
$=$ 62,522.64 lb_f

f_Y $=$ $P*R_{eff}*R_{nc}$
$=$ 710.48*11*11
$=$ 85,968.63 lb_f

Average local primary membrane stress

σ_{avg} $=$ $(f_N + f_S + f_Y) / A_T$
$=$ (20,218 + 62,522.64 + 85,968.63) / 11.4044
$=$ 14,793 psi

General primary membrane stress

σ_{circ} $=$ $P*R_{eff} / t_{eff}$
$=$ 710.48*11 / 0.875
$=$ 8,932 psi

Maximum local primary membrane stress at the nozzle intersection

P_L $=$ $max[\{2*\sigma_{avg} - \sigma_{circ}\} , \sigma_{circ}]$
$=$ max[{2*14,793 - 8,932} , 8,932]
$=$ 20,655 psi

Allowable stress

S_{allow} $=$ 1.5*S*E
$=$ 1.5*16,200*0.85
$=$ 20,655 psi

P_L = 20,655 psi ≤ S_{allow} = 20,655 psi satisfactory

Maximum allowable working pressure

A_p $=$ $R_n*(L_H - t) + R_{eff}*(L_R + t_n + R_{nc})$
$=$ (11*(3.462 - 0.875) + 11*(7 + 1 + 11))
$=$ 237.4566 in^2

P_{max1} $=$ $S_{allow} / (2*A_p / A_T - R_{eff} / t_{eff})$
$=$ 20,655 / (2*237.4566 / 11.4044 - 11 / 0.875)
$=$ 710.4845 psi

P_{max2} $=$ $S*(t / R_{eff})$
$=$ 16,200*(0.875 / 11)
$=$ 1,288.636 psi

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P_{max} = min[P_{max1}, P_{max2}]
= min[710.48, 1,288.64]
= 710.4845 psi

Division 2 Part 4.5 Strength of Nozzle Attachment Welds (U-2(g) analysis)

Discontinuity force factor

k_y = $(R_{nc} + t_n) / R_{nc}$
= (11 + 1) / 11
= 1.0909

Weld length resisting discontinuity force

L_τ = $\pi / 2*(R_n + t_n)$
= π / 2*(11 + 1)
= 18.8496 in

Weld throat dimensions

L_{41T} = $0.7071*L_{41}$
= 0.7071*0.375
= 0.2652 in

Average shear stress in weld

f_{welds} = min[f_Y*k_y, $1.5*S_n*(A_2 + A_3)$]
= min[85,968.63*1.0909, 1.5*16,200*(3.462 + 0)]
= 84,125.81 lb_f

τ = $f_{welds} / [L_\tau*(0.49*L_{41T} + 0.6*t_{w1} + 0.49*L_{43T})]$
= 84,125.81 / [18.8496*(0.49*0.2652 + 0.6*0.875 + 0.49*0)]
= 6,814 psi

τ = 6,814 psi ≤ S = 16,200 psi satisfactory

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.75 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

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Wall thickness per UG-45(a):	t_{r1} = 0.4955 in (E =1)
Wall thickness per UG-45(b)(1):	t_{r2} = 0.5172 in
Wall thickness per UG-16(b):	t_{r3} = 0.0625 in
Standard wall pipe per UG-45(b)(4):	t_{r4} = 0.3281 in
The greater of t_{r2} or t_{r3}:	t_{r5} = 0.5172 in
The lesser of t_{r4} or t_{r5}:	t_{r6} = 0.3281 in

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Required per UG-45 is the larger of t_{r1} or t_{r6} = 0.4955 in

Available nozzle wall thickness new, t_n = 0.875*1 = 0.875 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for MAP

Available reinforcement per Appendix 1-10 governs the MAP of this nozzle.

Appendix 1-10 Maximum Local Primary Membrane Stress For P = 877.14 psi @ 70 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
P_L (psi)	S_{allow} (psi)	A_1 (in^2)	A_2 (in^2)	A_3 (in^2)	A_5 (in^2)	A welds (in^2)	t_{req} (in)	t_{min} (in)
25,500	25,500	7.8721	3.462	--	--	0.0703	0.4955	0.875

Division 2 Part 4.5 Strength of Nozzle Attachment Welds Summary Average Shear Stress in Weld								
k_y	L_τ (in)	L_{41T} (in)	L_{42T} (in)	L_{43T} (in)	f_{welds} (lb_f)	τ (psi)	S (psi)	Over stressed
1.0909	18.8496	0.2652	0	0	103,859	8,413	20,000	No

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.25	0.2625	weld size is adequate

Calculations for internal pressure 877.14 psi @ 70 °F

Nozzle rated MDMT per UHA-51(d)(1)(a) = -320 °F.

Appendix 1-10

Effective radius of the vessel

R_{eff} = $0.5*D_i$
= 0.5*22
= 11 in

Limit of reinforcement along the vessel wall

L_R = 8*t
= 8*0.875
= 7 in

Sample Project.
For information only.

Limit of reinforcement along the nozzle wall projecting outside the vessel surface

L_{H1} = $t + 0.78*(R_n*t_n)^{0.5}$
= $0.875 + 0.78*(11*1)^{0.5}$
= 3.462 in

L_{H2} = $L_{pr1} + t$
= 28 + 0.875
= 28.875 in

L_{H3} = $8*(t + t_e)$
= 8*(0.875 + 0)
= 7 in

L_H = min[L_{H1}, L_{H2}, L_{H3}]
= min[3.462, 28.875, 7]
= 3.462 in

Effective thickness

t_{eff} = t
= 0.875 in

Total available area near the nozzle opening

λ = $\min[(2*R_n + t_n) / ((D_i + t_{eff})*t_{eff})^{0.5}, 10]$
= $\min[(2*11 + 1) / ((22 + 0.875)*0.875)^{0.5}, 10]$
= 5.1409

A_1 = $t*L_R*\max[(\lambda / 4) , 1]$
= 0.875*7*max[(5.1409 / 4) , 1]
= 0.875*7*1.2852
= 7.8721 in^2

A_2 = t_n*L_H
= 1*3.462
= 3.462 in^2

A_{41} = $0.5*L_{41}^2$
= $0.5*0.375^2$
= 0.0703 in^2

A_T = $A_1 + A_2 + A_{41}$
= 7.8721 + 3.462 + 0.0703
= 11.4044 in^2

Forces at nozzle to vessel intersection

f_N = $P*R_n*(L_H - t)$

Sample Project.
For information only.

$= 877.14*11*(3.462 - 0.875)$
$= 24{,}960.49\ lb_f$

$f_S = P*R_{eff}*(L_R + t_n)$
$= 877.14*11*(7 + 1)$
$= 77{,}188.44\ lb_f$

$f_Y = P*R_{eff}*R_{nc}$
$= 877.14*11*11$
$= 106{,}134.1\ lb_f$

Average local primary membrane stress

$\sigma_{avg} = (f_N + f_S + f_Y) / A_T$
$= (24{,}960.49 + 77{,}188.44 + 106{,}134.1) / 11.4044$
$= 18{,}263$ psi

General primary membrane stress

$\sigma_{circ} = P*R_{eff} / t_{eff}$
$= 877.14*11 / 0.875$
$= 11{,}027$ psi

Maximum local primary membrane stress at the nozzle intersection

$P_L = \max[\{2*\sigma_{avg} - \sigma_{circ}\} , \sigma_{circ}]$
$= \max[\{2*18{,}263 - 11{,}027\} , 11{,}027]$
$= 25{,}500$ psi

Allowable stress

$S_{allow} = 1.5*S*E$
$= 1.5*20{,}000*0.85$
$= 25{,}500$ psi

$P_L = 25{,}500$ psi $\leq S_{allow} = 25{,}500$ psi satisfactory

Maximum allowable pressure

$A_p = R_n*(L_H - t) + R_{eff}*(L_R + t_n + R_{nc})$
$= (11*(3.462 - 0.875) + 11*(7 + 1 + 11))$
$= 237.4566\ in^2$

$P_{max1} = S_{allow} / (2*A_p / A_T - R_{eff} / t_{eff})$
$= 25{,}500 / (2*237.4566 / 11.4044 - 11 / 0.875)$
$= 877.1413$ psi

$P_{max2} = S*(t / R_{eff})$
$= 20{,}000*(0.875 / 11)$
$= 1{,}590.909$ psi

Sample Project.
For information only.

P_{max} = min[P_{max1}, P_{max2}]
= min[877.14, 1,590.91]
= 877.1413 psi

Division 2 Part 4.5 Strength of Nozzle Attachment Welds (U-2(g) analysis)

Discontinuity force factor

k_y = $(R_{nc} + t_n) / R_{nc}$
= (11 + 1) / 11
= 1.0909

Weld length resisting discontinuity force

L_τ = $\pi / 2*(R_n + t_n)$
= π / 2*(11 + 1)
= 18.8496 in

Weld throat dimensions

L_{41T} = $0.7071*L_{41}$
= 0.7071*0.375
= 0.2652 in

Average shear stress in weld

f_{welds} = min[f_Y*k_y, $1.5*S_n*(A_2 + A_3)$]
= min[106,134.1*1.0909, 1.5*20,000*(3.462 + 0)]
= 103,859 lb_f

τ = $f_{welds} / [L_\tau*(0.49*L_{41T} + 0.6*t_{w1} + 0.49*L_{43T})]$
= 103,859 / [18.8496*(0.49*0.2652 + 0.6*0.875 + 0.49*0)]
= 8,413 psi

τ = 8,413 psi ≤ S = 20,000 psi satisfactory

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.75 in
$t_{c(min)}$ = lesser of 0.25 or 0.7*t_{min} = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

Sample Project.
For information only.

Wall thickness per UG-45(a):	t_{r1} = 0.4955 in (E =1)
Wall thickness per UG-45(b)(1):	t_{r2} = 0.5172 in
Wall thickness per UG-16(b):	t_{r3} = 0.0625 in
Standard wall pipe per UG-45(b)(4):	t_{r4} = 0.3281 in
The greater of t_{r2} or t_{r3}:	t_{r5} = 0.5172 in
The lesser of t_{r4} or t_{r5}:	t_{r6} = 0.3281 in

Sample Project.
For information only.

Required per UG-45 is the larger of t_{r1} or t_{r6} = 0.4955 in

Available nozzle wall thickness new, t_n = 0.875*1 = 0.875 in

The nozzle neck thickness is adequate.

Reinforcement Calculations for External Pressure

Appendix 1-10 Maximum Local Primary Membrane Stress For Pe = 282.83 psi @ 650 °F The opening is adequately reinforced							UG-45 Nozzle Wall Thickness Summary (in) The nozzle passes UG-45	
P_L (psi)	S_{allow} (psi)	A_1 (in^2)	A_2 (in^2)	A_3 (in^2)	A_5 (in^2)	A welds (in^2)	t_{req} (in)	t_{min} (in)
10,353	10,353	6.125	3.462	--	--	0.0703	0.6652	0.875

Division 2 Part 4.5 Strength of Nozzle Attachment Welds Summary Average Shear Stress in Weld								
k_y	L_τ (in)	L_{41T} (in)	L_{42T} (in)	L_{43T} (in)	f_{welds} (lb_f)	τ (psi)	S (psi)	Over stressed
1.0909	18.8496	0.2652	0	0	37,333.93	3,024	16,200	No

UW-16 Weld Sizing Summary			
Weld description	Required weld throat size (in)	Actual weld throat size (in)	Status
Nozzle to shell fillet (Leg_{41})	0.25	0.2625	weld size is adequate

Calculations for external pressure 282.83 psi @ 650 °F

Appendix 1-10

Effective radius of the vessel

R_{eff} = $0.5*D_i$
= 0.5*22
= 11 in

Limit of reinforcement along the vessel wall

L_R = 8*t
= 8*0.875
= 7 in

Sample Project.
For information only.

Limit of reinforcement along the nozzle wall projecting outside the vessel surface

L_{H1} = $t + 0.78*(R_n*t_n)^{0.5}$
= $0.875 + 0.78*(11*1)^{0.5}$
= 3.462 in

L_{H2} = $L_{pr1} + t$
= 28 + 0.875
= 28.875 in

L_{H3} = $8*(t + t_e)$
= 8*(0.875 + 0)
= 7 in

L_H = min[L_{H1}, L_{H2}, L_{H3}]
= min[3.462, 28.875, 7]
= 3.462 in

Effective thickness

t_{eff} = t
= 0.875 in

Total available area near the nozzle opening

λ = 0 (for external pressure design)

A_1 = $t*L_R*\max[(\lambda / 4) , 1]$
= 0.875*7*max[(0 / 4) , 1]
= 0.875*7*1
= 6.125 in^2

A_2 = t_n*L_H
= 1*3.462
= 3.462 in^2

A_{41} = $0.5*L_{41}^2$
= $0.5*0.375^2$
= 0.0703 in^2

A_T = $A_1 + A_2 + A_{41}$
= 6.125 + 3.462 + 0.0703
= 9.6573 in^2

Forces at nozzle to vessel intersection

f_N = $P*R_n*(L_H - t)$
= 282.83*11*(3.462 - 0.875)
= 8,048.47 lb_f

f_S = $P*R_{eff}*(L_R + t_n)$

Sample Project.
For information only.

= 282.83*11*(7 + 1)
= 24,889.29 lb_f

f_Y = $P*R_{eff}*R_{nc}$
= 282.83*11*11
= 34,222.77 lb_f

Average local primary membrane stress

σ_{avg} = $(f_N + f_S + f_Y) / A_T$
= (8,048.47 + 24,889.29 + 34,222.77) / 9.6573
= 6,954 psi

General primary membrane stress

σ_{circ} = $P*R_{eff} / t_{eff}$
= 282.83*11 / 0.875
= 3,556 psi

Maximum local primary membrane stress at the nozzle intersection

P_L = $\max[\{2*\sigma_{avg} - \sigma_{circ}\} , \sigma_{circ}]$
= max[{2*6,954 - 3,556} , 3,556]
= 10,353 psi

Allowable stress

S_{allow} = $1.5*\min[S_c, S]$
= 1.5*min[6,902, 16,200]
= 10,353 psi

$P_L = 10,353 \text{ psi} \le S_{allow} = 10,353$ psi satisfactory

Maximum allowable external pressure

A_p = $R_n*(L_H - t) + R_{eff}*(L_R + t_n + R_{nc})$
= (11*(3.462 - 0.875) + 11*(7 + 1 + 11))
= 237.4566 in^2

P_{max1} = $S_{allow} / (2*A_p / A_T - R_{eff} / t_{eff})$
= 10,353 / (2*237.4566 / 9.6573 - 11 / 0.875)
= 282.8328 psi

P_{max2} = $S*(t / R_{eff})$
= 6,902*(0.875 / 11)
= 549.032 psi

P_{max} = $\min[P_{max1}, P_{max2}]$
= min[282.83, 549.03]
= 282.8328 psi

Sample Project.
For information only.

Division 2 Part 4.5 Strength of Nozzle Attachment Welds (U-2(g) analysis)

Discontinuity force factor

k_y = $(R_{nc} + t_n) / R_{nc}$
= (11 + 1) / 11
= 1.0909

Weld length resisting discontinuity force

L_τ = $\pi / 2*(R_n + t_n)$
= π / 2*(11 + 1)
= 18.8496 in

Weld throat dimensions

L_{41T} = $0.7071*L_{41}$
= 0.7071*0.375
= 0.2652 in

Average shear stress in weld

f_{welds} = min[f_Y*k_y, $1.5*S_n*(A_2 + A_3)$]
= min[34,222.77*1.0909, 1.5*16,200*(3.462 + 0)]
= 37,333.93 lb_f

τ = $f_{welds} / [L_\tau*(0.49*L_{41T} + 0.6*t_{w1} + 0.49*L_{43T})]$
= 37,333.93 / [18.8496*(0.49*0.2652 + 0.6*0.875 + 0.49*0)]
= 3,024 psi

τ = 3,024 psi ≤ S = 16,200 psi satisfactory

UW-16(c) Weld Check

Fillet weld: t_{min} = lesser of 0.75 or t_n or t = 0.75 in
$t_{c(min)}$ = lesser of 0.25 or $0.7*t_{min}$ = 0.25 in
$t_{c(actual)}$ = 0.7*Leg = 0.7*0.375 = 0.2625 in

The fillet weld size is satisfactory.

Weld strength calculations are not required for this detail which conforms to Fig. UW-16.1, sketch (c-e).

UG-45 Nozzle Neck Thickness Check

Wall thickness per UG-45(a):	t_{r1} = 0.6652 in
Wall thickness per UG-45(b)(2):	t_{r2} = 0.2081 in
Wall thickness per UG-16(b):	t_{r3} = 0.0625 in

Sample Project.
For information only.

Standard wall pipe per UG-45(b)(4): t_{r4} = 0.3281 in
The greater of t_{r2} or t_{r3}: t_{r5} = 0.2081 in
The lesser of t_{r4} or t_{r5}: t_{r6} = 0.2081 in

Required per UG-45 is the larger of t_{r1} or t_{r6} = 0.6652 in

Available nozzle wall thickness new, t_n = 0.875*1 = 0.875 in

The nozzle neck thickness is adequate.

External Pressure, (Corroded & at 650 °F) UG-28(c)

L / D_o = 40 / 24 = 1.6667
D_o / t = 24 / 0.6652 = 36.0787
From table G: A = 0.003732
From table HA-1: B = 7,653 psi

P_a = 4*B / (3*(D_o / t))
= 4*7653.1895 / (3*(24 / 0.6652))
= 282.83 psi

Design thickness for external pressure P_a = 282.83 psi

t_a = t + Corrosion = 0.6652 + 0 = 0.6652"

Sample Project.
For information only.