Project : Design & Fabrication of Heat Exchanger for APRC Refinery | **Date : 11.4.2004**

Project : Design & Fabrication of Heat Exchanger for APRC Refinery | **Location : Alex.**

Dwg. No. : 7443-33-1A, Rev. 1 | **Client : APRC**

Exchanger : Residue Cooler, Type : AES, TEMA class : R | **Items : E-323A/B & E-514C/D**

X. Stresses in Vessel on Two Saddle Supports Using ZICK's Method.

Shell material	ASME SA106 Grade B			
Heads material	ASME SA234 Grade WPB			
Saddles material	ASME SA106 Grade B			
Heads type	Ellipsoidal 2:1			
Design temperature	302	^oF	150	^oC
Vessel internal pressure, P	284.776	PSIG	20.04826	Kg/CM^2G
Allowable stress in shell, Sts	17100	PSIG	1203.84	Kg/CM^2G
Allowable stress in heads, Sth	17100	PSIG	1203.84	Kg/CM^2G
Allowable stress in web, Sw	15700	PSIG	1105.28	Kg/CM^2G
Shell compression yield point, Y	45000	PSIG	3168	Kg/CM^2G
Saddle & anchor bolt compression yield point, Re	30000	PSIG	2112	Kg/CM^2G
Outer shell diameter, Do	20	INCH	508	MM
Wall nominal thickness of shell, ts	0.5	INCH	12.7	MM
Wall nominal thickness of heads, th	0.5	INCH	12.7	MM
Corrosion allowance for shell & heads, CA	0.197	INCH	5	MM
Shell joint efficiency, Es	0.85			
Head joint efficiency, Eh	0.85			
Head internal depth, h	5.785	INCH	146.935	MM
Head depth -to- tangent line (external depth), Ho	6.285	INCH	159.635	MM
Insulation thickness, tis	0	INCH	0	MM
Wear (reinf./top flange) plate width, B	7.087	INCH	180	MM
Wear (reinf./top flange) plate thickness, tf	0.5	INCH	12.7	MM
Wall corroded thickness of shell	0.366	INCH	9.28625	MM
Wall corroded thickness of heads	0.366	INCH	9.28625	MM
Wall corroded thickness of shell + reinf. plate	0.866	INCH	21.98625	MM
Outer shell radius, Ro = Do / 2	10	INCH	254	MM
Shell length from Tangent - to - tangent (T/T) , L	254.843	INCH	6473	MM
Saddle - to - saddle distance (S/S) , L"	165.354	INCH	4200	MM
Transverse distance between anchor bolts, Y	21.6535	INCH	550	MM
Distance from tangent line -to- center of saddle support , A	47.244	INCH	1200	MM
Saddle contact angle, B	120	Degree		
Longitudinal width of saddle at shell, b	7.087	INCH	180	MM
Transverse width of saddle at shell (baseplate length), m	20.551	INCH	522	MM
Height of saddle to vessel center line, Z	17.913	INCH	455	MM
Web width of saddle, hs = m - 2 cl	19.37	INCH	492	MM
Web thickness of saddle, tw	0.591	INCH	15	MM
Equivalent diameter of vessel, Deq = 1.5 (Do + 2 * tis)	30	INCH	762	MM
Equivalent length of vessel, Leq = L + 2Ho + 2 tis	267.412	INCH	6792.27	MM

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X. Stresses in Vessel on Two Saddle Supports Using ZICK's Method (cont.)

1. Seismic & wind forces on vessel

a. Seismic force

	UBC-1997			
Total design force or shear at the base, F = z . I . C . Wt / Rw	1490.53	lb	676.0875	Kg
Seismic Zone 2A :				
For zone 2A : z = Seismic zone factor *[Table No. 23-I]*	0.15			
I = Importance factor *[Table No. 23-L]*	1			
C = Numerical coefficient *[Table No. 23-P]*	2.75	Max.		
Rw = Numerical coefficient *[TableS NoS. 23-O & 23-Q]*	3			
= 3 (horizontal vessel on pier)				
Total vessel dead weight, Wt	10840.2	lb	4917	Kg

b. Wind force

	ANSI A58.1			
F = Cf . Gh . qz . Af				
qz = 0.00256 . kz . $(I\ V)^2$	27.0848	PSF	13.49792	N/M^2
For exposure C :				
h = Height	0-15	ft		
kz = Velocity pressure exposure coefficient	0.8			
Wind Velocity, V = Basic wind speed	115	MPH	51.399	M/Sec.
Gh = Gust response factor	1.32			
Cf = Force coefficient	0.8			

c. Forces in longitudinal direction

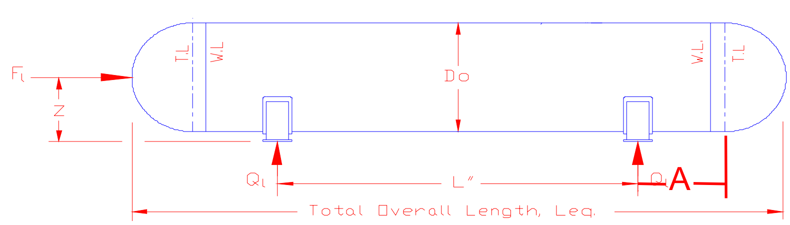

Figure (11)

Seismic longitudinal force, Fls = z . I . C . Wt / Rw	1490.53	lb	676.0875	Kg
Wind longitudinal exposed area, Afl = (pi/8*Deq + Z) * Deq	6.18624	ft^2	0.574721	M^2
Wind longitudinal force, Flw = Cf . Gh . qz . Afl	176.936	lb	80.25607	Kg
Fl = Greater value of Fls & Flw	1490.53	lb	676.0875	Kg

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X. Stresses in Vessel on Two Saddle Supports Using ZICK's Method (cont.)

d. Forces in transverse direction

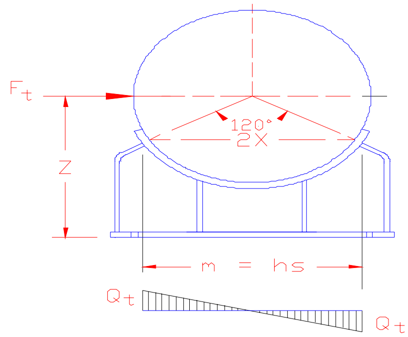

Figure (12)

Seismic transverse force, Fts = 0.5 Fls = 0.5 x z x I x C x Wt / Rw	745.267	lb	338.0438	Kg
Wind transvere exposed area, Aft = Deq * Leq	55.7108	Ft^2	5.175706	M^2
Wind transverse force, Ftw = 0.5 x Cf x Gh x x qz x Aft	796.708	lb	361.377	Kg
Ft = Greater value of Fts & Ftw	796.708	lb	361.377	Kg

2. Reaction force per saddle support

a. Reaction due to full vessel weight, Qo = Wt/2	5420.12	lb	2458.5	Kg
b. Reaction in longitudinal direction due to earthquake & wind :				
By taking moments about saddle support : Fl . Z = Ql . L"				
Ql = Fl . Z / L"	161.471	lb	73.24138	Kg
c. Reaction in transverse direction due to earthquake & wind :				
By taking moments about saddle support : Ft . Z = Qt . (m/2)				
Qt = 3 (2 . Ft . Z / m)	4166.64	lb	1889.936	Kg
d. Max. reaction due to earthquake & wind, Qmax. = Max. (Ql , Qt)	4166.64	lb	1889.936	Kg
e. Total reaction due to full vessel weight, earthquake and wind, Q				
Total longitudinal reaction, Qlt = Qo + Ql	5581.59	lb	2531.741	Kg
Total transverse reaction, Qtt = Qo + Qt	9586.76	lb	4348.436	Kg
Q = Greater value of Qlt & Qtt	9586.76	lb	4348.436	Kg

3. Modified stresses at saddles :

Ratio (Qo + Qmax.) / Qo	1.76874			
a. Modified circumferential stresses, SIG 5' = Ratio .		<		OK
SIG 5' = Ratio .		<		OK
SIG 4' = Ratio .		<		OK
SIG 4' = Ratio .		<		OK
b. Modified tangential stresses, SIG 2' = Ratio .		<		OK

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X. Stresses in Vessel on Two Saddle Supports Using ZICK's Method (cont.)

a. Stresses in longitudinal direction

Longitudinal force, Fl	1490.53	lb	676.0953	Kg
Max. moment, Mmax. = Fl . Z	26699.9	lb-in.	307.6167	Kg-M

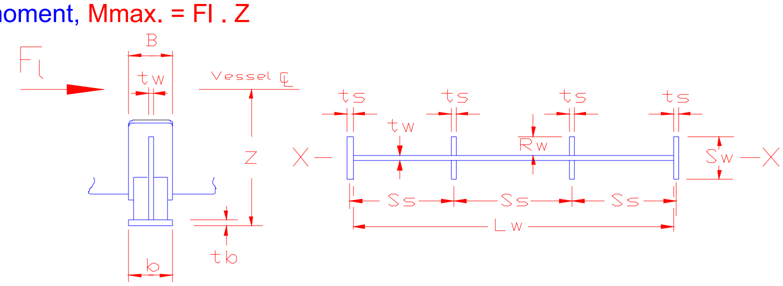

Figure (13)

Cross-sectional Area, A = Lw * tw + 2 Sw * ts+ 2(n-2) Rw * ts	15.3915	$INCH^2$	9930	MM^2
Moment of inertia, Ix-x = Lw*tw^3/12 + 2ts*Sw^3/12+ (n-2) ts(Sw^3-tw^3)/12	12.3045	$INCH^4$	5121500	MM^4
Section modulus, Wx-x = Lw*tw^2/6+2ts*Sw^2/6+2ts(Sw^3-tw^3)/(6 Sw)	7.14931	$INCH^3$	117156.3	MM^3
Dimension, X1 = Ix-x / Wx-x	1.72107	INCH	43.71512	MM
Bending stress, Sb = Mmax. / Wx-x	3734.61	PSI	262.9168	Kg/CM^2G
Allowable bending stress, S' = 1.2 . S	18840	PSI	1326.336	Kg/CM^2G
	OK			
Shear stress, T = Fl / A	96.8411	PSIG	6.817615	Kg/CM^2G
Allowable shear stress, S' = 0.5 . S	7850	PSIG	552.64	Kg/CM^2G
	OK			

b. Stresses in transverse direction

Transverse force, Ft	796.708	lb	361.3811	Kg
Max. moment, Mmax. = Ft . Z	14271.4	lb-in.	164.4249	Kg-M

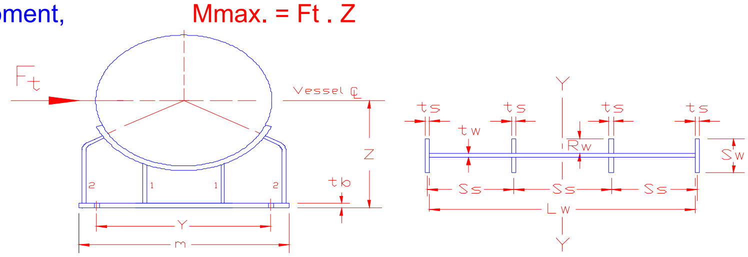

Figure (14)

Cross-sectional Area, A	15.3915	$INCH^2$	9930	MM^2
Moment of inertia, Iy-y = tw*Lw^3/12+Sw[(Lw+2ts)^3-Lw^3]/12+2Rw((Ss(n-1-2)+ts	727.502	$INCH^4$	3.03E+08	MM^4
Section modulus, Wy-y =tw*Lw^2/6+Sw*[(Lw+2ts)^3-Lw^3]/6(Lw+2ts)+2Rw[(Ss+ts	87.4027	$INCH^3$	1432273	MM^3
Dimension Y1 = Iy-y / Wy-y	8.32357	INCH	211.4187	MM
Bending stress, Sb = Mmax. / Wy-y	163.284	PSIG	11.49517	Kg/CM^2G
Allowable bending stress, S' = 1.2 . S	18840	PSIG	1326.336	Kg/CM^2G
	OK			
Shear stress, T = Ft / A	51.7628	PSIG	3.644098	Kg/CM^2G
Allowable shear stress, S' = 0.5 . S	7850	PSIG	552.64	Kg/CM^2G
	OK			

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X. Stresses in Vessel on Two Saddle Supports Using ZICK's Method (cont.)

1. Bending moment & bending stress at saddles

Bending moment at saddle in tension & compression, M_1

$$M_1 = Q A \left(1 - \frac{1 - \frac{A}{L} + \frac{R^2 - H^2}{2 A L}}{1 + \frac{4 H}{3 L}} \right)$$

M_1	452744	lb-in	5216.177	Kg-M
Longitudinal bending stress in tension, $S_1 = M_1 / K_1 R^2$ ts	2883.72	PSIG	203.0137	Kg/CM^2G
Longitudinal bending stress in compression, $S_1 = - M_1 / K8 R^2$ ts	-15016.4	PSIG	-1057.153	Kg/CM^2G

2. Bending moment & bending stress at midspan

Bending moment at midspan, M_2

$$M_1' = Q L \left(\frac{1 + 2 \frac{R^2 - H^2}{L^2}}{1 + \frac{4 H}{3 L}} - \frac{4 A}{L} \right)$$

M_1'	558078	lb-in	6429.767	Kg-M
Longitudinal bending stress at midspan, $S_1' = - M_1' / 3.14 R^2$ ts	-3552.84	PSIG	-250.1198	Kg/CM^2G

3. Stress in the shell due to internal pressure,

S = P R / (2 Es ts)	3350.31	PSIG	235.8619	Kg/CM^2G

4. Sum of tensile stress

Value of $S_1 + S$	6234.03	PSIG	438.8756	Kg/CM^2G
Value of $S_1' + S$	-202.527	PSIG	-14.2579	Kg/CM^2G
Greater value of $(S_1 + S)$ & $(S_1' + S)$	6234.03	PSIG	438.8756	Kg/CM^2G
Shell allowable tensile stress	17100	PSIG	1203.84	Kg/CM^2G
Stress ratio = Greater stress/Allowable stress	0.36456	< 1	Passed	

5.Tangential shear stress, S_2

5.a. Tangential shear stress on shell, S_2

In case of A > R/2 and ring not used or rings are adjacent to the saddle.

$$S_2 = \frac{K_2 Q}{R t_s} \left(\frac{L - 2 A}{L + \frac{4 H}{3}} \right)$$

S_2	1367.78	PSIG	96.29196	Kg/CM^2G
Shell allowable tangential stress = 0.8 S	13680	PSIG	963.072	Kg/CM^2G
Stress ratio = S_2 / 0.8 S	0.09998	< 1	Passed	

X. Stresses in Vessel on Two Saddle Supports Using ZICK's Method (cont.)

5.b. Tangential shear stress on shell, S_2

In case of A > R/2 and ring used in plane of saddle.

$$S_2 = \frac{K_3 Q}{R\, t_s}\left(\frac{L - 2A}{L + \frac{4H}{3}}\right)$$	372.607	PSIG	26.23154	Kg/CM^{2}G
Shell allowable tangential stress = 0.8 S	13680	PSIG	963.072	Kg/CM^{2}G
Stress ratio = S_2 / 0.8 S	0.02724	< 1	**Passed**	

5.c. Tangential shear stress on head, S_{2h}

In case of A > R/2 and ring not used or rings are adjacent to th saddle.

$$S_{2h} = \frac{K_2 Q}{R\, t_h}\left(\frac{L - 2A}{L + \frac{4H}{3}}\right)$$	1367.78	PSIG	96.29196	Kg/CM^{2}G
Head allowable tangential stress = 0.8 S	13680	PSIG	963.072	Kg/CM^{2}G
Stress ratio = S_2 / 0.8 S	0.09998	< 1	**Passed**	

5.d. Tangential shear stress on shell

In case of A <= R/2 $S_2 = K_4$ Q / R ts	1687.27	PSIG	118.7838	Kg/CM^{2}G
Shell allowable tangential stress = 0.8 S	13680	PSIG	963.072	Kg/CM^{2}G
Stress ratio = S2 / 0.8 S	0.12334	< 1	**Passed**	

5.e. Tangential shear stress on head

In case of A <= R/2 $S_2 = K_4$ Q / R t_h	1687.27	PSIG	118.7838	Kg/CM^{2}G
Shell allowable tangential stress = 0.8 S	13680	PSIG	963.072	Kg/CM^{2}G
Stress ratio = S_2 / 0.8 S	0.12334	< 1	**Passed**	

5.f. Additional tangential shear stress in head

In case of A <= R/2 $S_3 = K_5$ Q / R t_h	768.858	PSIG	54.12761	Kg/CM^{2}G
S_3 + stress due to int. pres. (PR/(2Es ts))	3350.31	PSIG	235.8619	Kg/CM^{2}G
Head allowable tensile stress = 1.25 S	21375	PSIG	1504.8	Kg/CM^{2}G
Stress ratio = S_3 / 1.25 S	0.15674	< 1	**Passed**	

X. Stresses in Vessel on Two Saddle Supports Using ZICK's Method (cont.)

6. Circumferential stress

6.a. Circumferential stress at saddle horn

In case of L >= 8 R (unstiffened)

$$S_4 = -\frac{Q}{4t_s\left(b+1.56\sqrt{Rt_s}\right)} - \frac{3K_6Q}{2t_s^2}$$

S_4	-3074.71	PSIG	-216.4598	Kg/CM^2G
Shell allowable circumferential stress = 1.5 S	25650	PSIG	1805.76	Kg/CM^2G
Stress ratio = S4 / 1.5 S	0.11987	**< 1**	**Passed**	

6.b. Circumferential stress at saddle horn

In case of L < 8 R (unstiffened)

$$S_4 = -\frac{Q}{4t_s\left(b+1.56\sqrt{Rt_s}\right)} - \frac{12K_6QR}{Lt_s^2}$$

S_4	-1410.27	PSIG	-99.2832	Kg/CM^2G
Shell allowable circumferential stress = 1.5 S	25650	PSIG	1805.76	Kg/CM^2G
Stress ratio = S_4 / 1.5 S	0.05498	**< 1**	**Passed**	

6.c. Circumferential stress at bottom of shell

(stiffened or unstiffened)

$$S_5 = -\frac{K_7 Q}{t_s\left(b+1.56\sqrt{R t_s}\right)}$$

S_5	-1377.92	PSIG	-97.00559	Kg/CM^2G
0.5 compression yield point of shell material	22500	PSIG	1584	Kg/CM^2G
Stress ratio = S_5 / 0.5 S	0.06124	**< 1**	**Passed**	

7. Check tension in web saddle

Horizontal force in web, Fw = K_8 Q	5780.82	lb	2622.107	Kg
Effective web area, Aw = h_s tw	11.4477	$INCH^2$	7385.579	MM^2
Stress in web, Sw = Fw / Aw	504.977	PSIG	35.55042	Kg/CM^2G
Allowable stress in web, Saw = 0.6 Y	18000	PSIG	1267.2	Kg/CM^2G
Stress ratio = Sw / 0.6 Y	0.02805	**< 1**	**Passed**	
Vertical force in web, Fv = Q	9586.76	lb	4348.436	Kg
Stress in web, Sv = Fv / Aw	837.442	PSIG	379.8534	Kg/CM^2G
Allowable stress in web (compressiuon), Saw = 0.33 Y	9900	PSIG	696.96	Kg/CM^2G
Stress ratio = Sv / 0.33 Y	0.08459	**< 1**	**Passed**	

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X. Stresses in Vessel on Two Saddle Supports Using ZICK's Method (cont.)

8. Check of the saddle at the lowest section (web plate thickness) :

The saddle at the lowest section must resist the horizontal force (F).
The effective cross section of the saddle to resist this load is R/3.

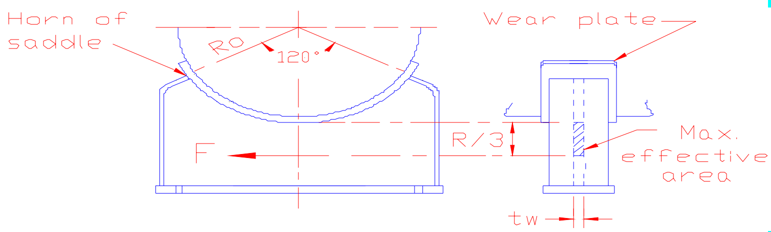

Figure (15)

F = K11 . Q	1955.7	lb	887.0809	Kg
To resist this force, the effective area of web plate, A = (R/3) . tw	1.9685	$INCH^2$	1270	MM^2
The calculated stress, Scal. = F / A	993.495	PSIG	69.94205	Kg/CM^2G
The allowable stress, Sall. = (2/3) Sw	10466.7	PSIG	736.8534	Kg/CM^2G
Stress ratio = Scal. / Sall.	0.09492	< 1	Passed	

So, the thickness of the web plate is satisfactory for horizontal force (F).

Values of Constant K

For contact angle B = 120° :	120	Degree		
K_1 (K_1 = 3.14 if the shell is stiffened by ring or head, A > R/2)	0.335	or	3.14	[A > R/2]
K_2	1.171			
K_3 (K_3 is constant for any contact angle)	0.319			
K_4	0.88			
K_5	0.401			
K_6 (K6 depends on the ratio A/R, see chart in vessel handbook)				
K_6 for A/R > 1.00	0.053			
K_6 for A/R < 0 0.5	0.013			
A	47.244	INCH	1199.998	MM
R	10	INCH	254	MM
A/R	4.7244			
R/2	5	INCH	127	MM
K_7	0.76			
K_8	0.603			
K_{11}	0.204			