Tarsco
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Weston & Associates, LLC
Andy Feucht
Project No: 180128-R1
Rutland, MA, United States

Calculations
for
163.4' x 27.04' Storage Tank
49.8 m x 8.2 m

Usable Volume
4,084,800 gal.
15462 cu.m

COMMONWEALTH OF MASSACHUSETTS
BRIAN E. LEWIS
NO.52527
REGISTERED PROFESSIONAL ENGINEER

April 10, 2018

6/13/18

DESIGN ALSO COMPLIES WITH NCRS 313 REQUIREMENTS

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Revision Log

Revision No.	Description	Date	By
0	Initial Issue	1/19/18	mdw
1	Change Steel to Grade 50	4/10/18	BA

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163.4 x 27 **Carbon Steel Tank** **Project No: 180128-R1** **Rutland, MA, United States** **4/10/2018**

Other: NRCS - AG Tank

Tank Dia. = 163.40 ft. 49.8 m
Tank Ht. = 27.04 ft. 8.2 m
Operating Capacity = 4,084,800 gal. 15,462 m^3 4,241,700 gal. (Nominal Cap.)
sheets/ring = 55 112 in. 16056 m^3 (Nominal Cap.)
number of rings = 7
Freeboard = 12 in. 305 mm
Min. operating level = 0 in.

Deck Live Load = 0 psf 0.00 kPa
Wind Speed AWWA D103-09 = 97 mph 156 km/hr
AWWA D103 $I_{(wind)}$ = 1.15
Wind Speed ASCE 7-10 = 111 mph
Seismic: AWWA D103-09 Seismic Use Group I (I ASCE 7-10)
Zip Code = 44646 LAT: 0 LONG: 0
Site Class = D
Ri = 3
Rc = 1.5
I_E = 1
S_s = 0.182
S_1 = 0.067
F_a = 1.6
F_v = 2.4

Ring	Ht. of Ring	Wall Sheet Thickness	F_y	No. Bolts	F_u Bolts	Bolt Load
1	27.84	0.1345	50 k	1	150	1592
2	58	0.1875	50 k	2	150	3297
3	58	0.3125	50 k	2	150	5798
4	58	0.3750	50 k	3	150	5533
5	58	0.5000	50 k	4	150	5400
6	58	0.5000	55 k	4	150	6651
7	4	0.5000	56 k	4	150	6737

Product Stored = Wastewater
Specific Gravity = 1.05

Concrete Floor w/Embedded Starter Ring

Roof System: Open-Top

C15 x 40 Top Girder with 12 1/2" Diam Gr 8.2 /Bolts per splice

L3 1/2 x 2 1/2 x 1/4 LLV GR50

2 intermediate wind girder(s) required
* located at bottom horizontal seam

Anchors Not Required

290,388 Total Tank Wt. (lbs)

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Tank Shell Design: *from* AWWA D103-09 Section 5

The **shell thickness** of cylindrical shell plates stressed by pressure of the tank contents shall be calculated by the formula:

$$t = \frac{2.6\,HDSG}{f_t\,(S-d)} \qquad \text{(Eq 5-1)}$$

t = shell plate thickness in inches
H = height of liquid from the top capacity line just to overflow to the bottom of the shell course being designed in feet
D = tank diameter in feet
S = bolt spacing in line perpendicular to line of stress in inches
G = specific gravity of liquid (1.0 for water)
f_t = allowable tensile stress in pounds per square inch
d = bolt-hole diameter in inches

The **allowable tensile stress** is calculated using the lesser of the two formulas:

$$f_t = 0.6F_y\,(1.0 - 0.9r + 3rd/s) < 0.6F_y \qquad \text{(Eq 5-4)}$$

$$f_t = 0.40F_u \qquad \text{(Eq 5-5)}$$

f_t = allowable tensile stress in pounds per square inch
F_y = published minimum yield strength of the sheet or plate, psi (MPa)
r = force transmitted by the bolt or bolts at the section considered, divided by the tensile force in the member at that section. If r is less than 0.2, it may be taken to equal zero.
d = diameter of bolt in inches (mm)
s = spacing of bolts perpendicular to line of stress in inches (mm)
F_u = published minimum ultimate strength of the sheet or plate, psi (MPa)

When multiple bolt lines are used, the effective net section area shall not be taken as greater than 85 percent of the gross area.

The **allowable compressive stress** in the wall sheets or plates under wind or earthquake loading combined with dead load shall be determined by the formula

$$f_s = 15{,}000\left(\frac{2}{3}\right)\left(100\frac{t}{R}\right) \times \left[2 - \left(\frac{2}{3}\right)\left(100\frac{t}{R}\right)\right] \le 15{,}000 \qquad \text{(Eq 5-2)}$$

f_s = allowable compressive stress in pounds per square inch
t = shell thickness in inches
R = shell radius in inches

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Tank Shell Connection Design: *from* AWWA D103-09

The effect of the gasket and sealant shall be neglected since the compressed thickness is less than 1/16 in.

The **minimum bolt spacing and edge distance** shall meet the following criteria:

- the center to center spacing of bolts shall not be less than 2*d*
- distance from the center of any bolt to an edge or seam shall not be less than 1.5*d* or this distance be less than:

$$\frac{0.6F_y t}{P} = \text{inches} \qquad \text{(Eq 5-2)}$$

P = force transmitted by the bolt, lb (kN)
F_y = published minimum yield strength of the sheet or plate, psi
t = thickness of the thinner sheet or plate in the joint connection, in.
d = diameter of the bolt, in.

The **hole bearing stress** shall not exceed $1.35F_y$ on the area defined by $d \times t$.

The **bolt shear** from live and dead loads shall not exceed the value calculated in the formula:

$$f_v = F_u\,(0.6)(0.9)/2.2 < 0.25\,F_u \qquad \text{(Eq 5-6)}$$

f_v = allowable shear stress on either the tensile or gross area, psi
f_u = minimum tensile strength of the bolt, psi

The **bolt tension** shall not exceed the tensile stress over tensile stress area of the bolts (excluding anchor bolts) and shall be the lesser of the two formulas:

$$f_t = 0.6\,F_y \qquad \text{(Eq 5-7)}$$

or

$$f_t = F_u / 2.2 \qquad \text{(Eq 5-8)}$$

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Tank Shell Wind Stiffness Design: *from* AWWA D103-09

An **intermediate girders(s)** shall be required between the eave of the tank and bottom if the following formula is less than *H* (tank height):

$$h = \frac{(10.625 \times 10^6 t)}{P_{aw}\left(\frac{D}{t}\right)^{1.5}}$$

h = vertical distance between the intermediate wind girder and the top angle of the shell or me top wind girder of an open-top tank in feet
D = tank diameter in feet
t = average shell thickness for the vertical distance *h* in inches

from AWWA D103-09 Section 15.4.2.1

"In determining the maximum height of unstiffened shell, an initial calculation shall be made using the thickness of top shell course. Additional calculations shall be based on the average thickness obtained by including part or all of the next lower course or courses, until the calculated *h* is equal to or or less than the height of shell used in determining the average thickness. If *h* continues to calculate greater than the height of shell used in determining the average thickness, no intermediate girder is required."

from AWWA D103-09 Section 15.4.2.2

"After establishing the location of the first intermediate girder, if required, repeat the procedure for additional intermediate girders, using the preceding intermediate girder as the top of the tank. Locating the intermediate wind girder at the maximum spacing calculated by the preceding rules will usually result in a shell below the intermediate wind girder having a greater stability against wind loading than the shell above the intermediate girder. The girder may be located at a spacing less than the maximum spacing, but the lower shell must be checked for adequacy against the maximum wind pressure, as previously described or in the following alternative subparagraphs."

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Tank Shell Evaluation: Other:

Dia.	163.4	ft.
S	2.32	in.
G	1.05	
d_b	0.5	in.
d_{hole}	0.563	in.
fbd	12	in.

row	ht.	n	F_y	$F_{u(min)}$	$f_{t(allow)}$	t_{nom}	$ft_{(actual)}$	P	min. sp	F_u	$.25F_u$	f_{bv}	F_{brg}	f_{brg}	f_s	f_{wind}	wind press	h_{wg}
1	2.5	1	50000	65000	22397	0.1345	7272	1592	0.395	150	37.5	11.222497	67.5	23.679689	273	76	13.7	2.7
2	7.4	2	50000	65000	26198	0.1875	21127	3297	0.586	150	37.5	23.236616	67.5	35.17065	380	74	13.6	6.2
3	12.2	2	50000	65000	26198	0.3125	21805	5798	0.618	150	37.5	29.530264	67.5	37.108911	631	64	13.3	22.5
4	17.0	3	50000	65000	27466	0.375	25868	5533	0.492	150	37.5	28.178546	67.5	29.508574	755	73	13	29.2
5	21.9	4	50000	65000	28099	0.5	25078	5400	0.360	150	37.5	27.502687	67.5	21.60061	1003	75	12.8	42.2
6	26.7	4	55000	70000	30909	0.5	30885	6651	0.403	150	37.5	33.871465	74.25	26.602648	1003	96	12.7	50.0
7	27.0	4	56000	70000	31471	0.5	31285	6737	0.401	150	37.5	34.310691	75.6	26.947616	1003	102	12.6	55.2

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Tank Seismic Design: *from* AWWA D103-09 Section 14

from AWWA D103-09 Section 14.1

"The design earthquake ground motion in this standard is derived from ASCE 7 and is

The **design overturning moment** at the bottom of the shell. The caused by horizontal caused by horizontal design acceleration is the SRSS combination of the impulsive and convective components and shall be determined by the equation

$$M_s = \sqrt{[A_i(W_s X_s + W_r H_t + W_i X_i)]^2 + [A_c W_c X_c]^2} \qquad \text{(Eq 14-19)}$$

Ms = design overturning moment at the bottom of the shell due to horizontal design acceleration, in foot-pounds

Ai = impulsive design acceleration from Eq 14-16, stated as a multiple (decimal) of g

A_c = convective design acceleration from Eq 14-17, stated as a multiple (decimal) of g

W_s = total weight of tank shell and significant appurtenances in pounds

W_r = total weight of the tank roof, including framing and knuckle, plus permanent loads, if specified, in pounds

W_i = weight of effective mass of tank contents that moves in unison with the tank shell (effective impulsive weight) in pounds (Sec. 14.3.2.2)

W_c = weight of effective mass of the first mode sloshing contents of the tank (effective convective weight) in pounds (Sec. 14.3.2.2)

X_s = height from the bottom of the shell to center of gravity of the shell in feet

H_t = total height of the shell in feet

X_i = height from the bottom of the shell to the centroid of lateral seismic force applied to the effective impulsive weight W; in feet (Sec. 14.3.2.2)

X_c = height from the bottom of the shell to the centroid of lateral seismic force applied to the effective convective weight Wc in feet (Sec. 14.3.2.2)

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Tank Seismic Design: *from* AWWA D103-09 Section 14

The **design shear** at the top of the foundation. The design shear at the top the top of the foundation due to horizontal design acceleration is the SRSS of the impulsive and convective components and shall be determined by the equation:

$$V_f = \sqrt{[A_i(W_s + W_r + W_f + W_i)]^2 + [A_c W_c]^2} \qquad \text{(Eq 14-27)}$$

V_f = design shear at the top of the foundation due to horizontal design acceleration in pounds
W_f = total weight of tank bottom in pounds

The **overturning ratio** J is calculated from equation:

$$J = \frac{M_s}{D^2[w_t(1 - 0.4A_v) + w_L]} \qquad \text{(Eq 14-32)}$$

J = overturning ratio
w_t = weight of the tank shell and portion of the roof reacting on the shell determined by Eq 14-37 in pounds per foot of shell circumference
w_L = maximum resisting weight of tank contents in pounds per foot of shell circumference, that may be used to resist the shell overturning moment (Sec. 14.3.4.1.1)
A_v = vertical design acceleration (Sec. 14.3.4.3), stated as a multiple (decimal) of g

For $J < 0.785$, there is no shell uplift due to the overturning moment and the tank is self-anchored.
For $0.785 < J < 1.54$, there is shell uplift, but the tank is stable provided the shell compression requirements of Sec. 14.3.4.2 are satisfied.
For $J > 1.54$, the tank is not stable. Modify the bottom annulus, within the limits of tb and L, or provide mechanical anchoring.

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Seismic per AWWA D103-09:

I_E	1	D	163.40 pies	R_i	3	Sloshing Wave:	Af = 0.00623	d = 1.292981 ft.
F_a	1.6	S_{MS}	0.291	R_c	1.5			0.7d = 0.905087 ft.
F_v	2.4	S_{M1}	0.161	TL	12			
S_s	0.182	S_{DS}	0.194					
S_1	0.067	S_{D1}	0.107	Site Class D		t_b = 0 in.	F_y = 50,000 psi	E= 29,000,000 psi

row	Ht	D/H	Sac	Ai	Ac	Tc	Wr	WS	XS	Xi	Xc	WT	Wi	Wc	Ms	Vf	Ximf	Xcmf
1	2.54	106	0.001228	0.0462	0.0006	39.64	54658	7742	1.27	0.6	0.8	2114127	22991	1783824	13.2	4	70.54	#####
2	7.37	25.64	0.005052	0.0462	0.0024	19.54	54658	29320	3.37	2.4	3.2	8754763	394238	7339850	91.8	28	69.94	293.69
3	12.21	14.58	0.00876	0.0462	0.0042	14.84	54658	64417	5.00	4.2	5.6	15395400	1219134	12727655	415.3	82	69.33	169.65
4	17.04	10.19	0.012274	0.0462	0.0058	12.54	54658	107086	6.84	6.0	8.1	22036036	2497678	17835699	1147.9	161	68.73	121.45
5	21.87	7.83	0.014428	0.0462	0.0069	11.15	54658	164626	8.40	7.8	10.6	28676673	4229860	22575894	2335.5	258	68.13	96.44
6	26.71	6.36	0.015744	0.0462	0.0075	10.21	54658	222166	10.40	9.6	13.2	35317309	6415498	26888101	4038.7	369	67.53	81.59
7	27.04	6.28	0.015826	0.0462	0.0075	10.16	54658	241082	9.88	9.8	13.4	35775284	6582929	27168751	4178.4	378	67.49	80.80

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Seismic per AWWA D103-09: (cont.)

							162	psi (AWWA D103-09 Eq. 14-36)										
row	*Mmf*	*J*	w_L	w_t	Av	t_s	σ_c	$f_{s(seismic)}$	Ni	Ni	Ni	Nc	Nh	σ_s	σ_s+Nh/t	$\frac{P}{E}\left(\frac{R}{t}\right)^2$	ΔC_c	$\Delta\sigma_{cr}$
1	1262	0.004	0	122	0.0272	0.1345	77	364	53.29	272	53.29	15.78	686	436	5539	1258	0.22	875
2	5346	0.021	0	164	0.0272	0.1875	75	507	199.57	980	199.6	61.76	2842	1188	16348	2680	0.22	1220
3	9837	0.068	0	232	0.0272	0.3125	68	841	313.83	1469	313.8	102.86	4999	1143	17138	1696	0.22	2034
4	14982	0.138	0	315	0.0272	0.375	83	1007	396.07	1737	396.1	139.91	7155	1234	20313	1686	0.22	2440
5	20108	0.207	0	427	0.0272	0.5	91	1337	446.30	1786	446.3	161.46	9311	1076	19697	1234	0.22	3254
6	26048	0.284	0	539	0.0272	0.5	123	1337	464.52	1615	464.5	175.01	11467	1172	24106	1520	0.22	3254
7	26509	0.275	0	576	0.0272	0.5	130	1337	464.60	1595	464.6	175.92	11615	1177	24408	1540	0.22	3254

Check Sliding for Unanchored tank per AWWA D103-09 (Eq. 14-53)
Vallow = 19444 k > 378 k No Shear Anchors Required

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Tank Wind Design: *from* AWWA D103-09 Section 15

The wind pressure shall be calculated by the formula

$$P_w = q_z GC_f > 30C_f \quad \text{(Eq 15-1)}$$

P_w = wind pressure applied to projected area on a vertical plane, psf

G = gust effect factor = 0.85 min. Gust effect factor may be calculated using the procedure in ASCE 7 or may be taken as 1.0. The calculated gust-effect factor shall be based on a damping ratio of 0.05.

C_f = force coefficient (see Table 9)

q_z = velocity pressure evaluated at height z of the centroid of the projected area, psf

$$q_z = 0.00256K_z IV^2 \quad \text{(Eq 15-2)}$$

K_z = velocity pressure exposure coefficient evaluated at height z of the centroid of the projected area (see Table 10).

z = height above finished grade in feet (m)

I = wind importance factor = 1.15

V = basic wind speed in miles per hour (m/sec) (see Figure 20)

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Wind Design:

ASCE 7-10 Wind

Kzt	K1	K2	K3
1.165	0.72	0.5	0.22

AWWA D103 Wind
V = 97 mph
1.15 Wind Importance
$q_z = 0.00256 K_z I V^2$

ht.	kz	kzt	kd	V	I	qz	G	Cf	0.6 F	qz	G	Cf	F	ht.
15	0.849	1.16467	0.95	111	1	29.6	0.85	0.5	7.6	23.5	1	0.51	12.0	15
20	0.9	1.16467	0.95	111	1	31.4	0.85	0.5	8.0	24.9	1	0.51	12.8	20
25	0.94	1.16467	0.95	111	1	32.8	0.85	0.5	8.4	26.0	1	0.51	13.3	25
30	0.98	1.16467	0.95	111	1	34.2	0.85	0.5	8.7	27.1	1	0.51	13.9	30
40	1.04	1.16467	0.95	111	1	36.3	0.85	0.5	9.3	28.8	1	0.51	14.7	40
50	1.09	1.16467	0.95	111	1	38.0	0.85	0.5	9.7	30.2	1	0.51	15.4	50
60	1.13	1.16467	0.95	111	1	39.4	0.85	0.5	10.1	31.3	1	0.51	16.0	60
70	1.17	1.16467	0.95	111	1	40.8	0.85	0.5	10.4	32.4	1	0.51	16.6	70
80	1.21	1.16467	0.95	111	1	42.2	0.85	0.5	10.8	33.5	1	0.51	17.1	80
90	1.24	1.16467	0.95	111	1	43.3	0.85	0.5	11.0	34.3	1	0.51	17.6	90
100	1.26	1.16467	0.95	111	1	44.0	0.85	0.5	11.2	34.9	1	0.51	17.9	100
120	1.31	1.16467	0.95	111	1	45.7	0.85	0.5	11.7	36.3	1	0.51	18.6	120
140	1.36	1.16467	0.95	111	1	47.5	0.85	0.5	12.1	37.7	1	0.51	19.3	140
160	1.39	1.16467	0.95	111	1	48.5	0.85	0.5	12.4	38.5	1	0.51	19.7	160

	h/D =	0.1655
1	7	25
0.5	0.6	0.7

Cf = 0.5 fig 6-21 pg 74 .

no.	row	Ht.a	Dia.	press	V_{wind}	OTM_{wind}	Load/ft Shell (plf)
55	1	2.5388	163.4	13.7	5683.2	7214	0.34
55	2	7.3721	163.4	13.4	16266	60258	2.87
55	3	12.205	163.4	12.8	26375	163307	7.79
55	4	17.039	163.4	12.1	35931	313879	14.97
55	5	21.872	163.4	12	45408	510449	24.34
55	6	26.705	163.4	12	54885	752825	35.90
55	7	27.039	163.4	12	55539	771229	36.78

$Ht._a$ = Tank Height at each ring (ft.)
Dia. = Tank Diameter (ft.)
press = psf on projected tank surface
V_{wind} = total horz wind load in lbs at ring ht. (lbs)
OTM_{wind} = base moment at each ring ht. (ft-lbs)
Load/ft = plf on tank wall at each ring ht.

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Tank Reactions @ Base of Tank :

Load Case	Vert. (k)	Horz. (k)	Moment (k-ft)	Load/ft Shell (klf)
DL (Empty)	308.89	-	-	0.602
DL + LL	308.89	-	-	0.602
DL + LL + Product	36084	-	-	0.602
DL(Empty)+WL	165.25	55.5	771.2	0.639
DL + Seismic	36066	378.2	4178.4	0.801
DL + Seismic (mat/pile fdn)	36066	433.0	26509	1.866

Embedment Ring - No Anchors

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Roof Structure Design:

163.4 ft. Dia. Tank

Roof Loads:

Roof live load = 0 psf
Internal pressure, Pi = 0 psf
Vacuum pressure, Pv = 0 psf
Misc (Misc DL + Insulation) = 1 psf
We = LL + DL + Pv + Misc = 5.3 psf
Wi = Pi - DL = -4.3 psf
WDesign = 5.3 psf

Diameter of Center Ring = 2.167 ft.

Open Top Wind Girder: Ref: AWWA D103

53.34 Req'd S = 0.0001HDD(Paw/18) (Eq 3-35)
Use 2-PL 0.5"x18" H = 27.04'
or **Use C15 x 40** D = 163.4'

Splice:
Use (12) 1/2" Grade 8.2 bolts per splice