PROJECT : PAGE :
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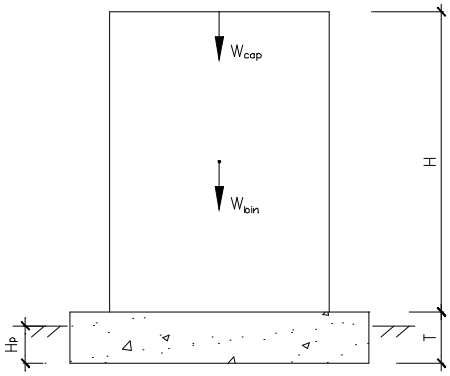
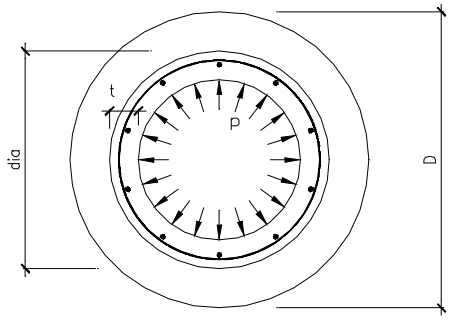
JOB NO. : DATE : REVIEW BY :

Concrete Silo / Chimney / Tower Design Based on ASCE 7-05, ACI 318-08 & ACI 313-97

INPUT DATA

BIN DEPTH	H =	150	ft
BIN OUTSIDE DIAMETER	dia =	30	ft
BIN CONCRETE THICKNESS	t =	12	in, at bottom
	(	8	in, at top)
FOOTING DIAMETER	D =	61	ft
FOOTING THICKNESS	T =	48	in
SOIL DEPTH TO BOTTOM	H_p =	24	in
WT OF BIN MAX CONTENTS	W_{bin} =	5763.4	kips, (input zero for chimney)
WT OF TOP CAP	W_{cap} =	180.96	kips
MAX HORIZONTAL PRESSURE	p =	9360	psf, (γH for water, or from ACI 313 4-2)
ALLOWABLE SOIL PRESSURE	Q_a =	5.5	ksf
PASSIVE PRESSURE	P_p =	450	psf / ft
SOIL FRICTION COEFFICIENT	μ =	0.35	
CONCRETE STRENGTH	f_c' =	5	ksi
REBAR YIELD STRESS	f_y =	60	ksi





FOOTING REBAR 2 Layers # 10
@ 14 in o.c. each way, at top & bot.

DOWEL / BIN VERTICAL REBARS # 8 @ 12 in o.c.

REBAR LOCATION (1=at middle, 2=at each face) 2 at each face

BIN HORIZONTAL REBARS # 6 @ 12 in o.c.

WALL HORIZONTAL PRESTRESSING TENDONS, (input strands zero for non-prestress)

11 strands @ 24 in o.c.

(each 0.5 in diameter & 0.153 in^2 area)

TENDON YIELD STRENGTH f_{py} = 243 ksi

EFFECTIVE PRESTRESS AFTER ALL LOSSES f_e = 174 ksi

THE CONCRETE DESIGN IS ADEQUATE.

DESIGN SUMMARY

FOOTING 61 ft DIA x 48 in THK. w/ # 10 @ 14" o.c. EACH WAY, AT TOP & BOT.

CONCRETE BIN 12 in THK. w/ # 8 @ 12 in o.c.DOWEL / VERT. BARS AT AT EACH FACE

BIN HORIZONTAL # 6 @ 12 in o.c. AT EACH FACE, AND (11) - STANDS @ 24 in o.c. (THE SECTION UNCRACKED.)

ANALYSIS

DETERMINE LATERAL LOADS

F = Max (0.8 S_1 I / R , 0.03) W / 1.4 = 0.10 ***W*** , ASD (ASCE 7-05 15.4.1.2)

F_{cap} = 0.10 W_{cap} = 18.96 kips, at top

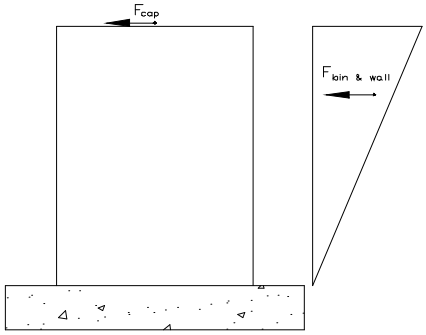
$F_{bin\ \&\ wall}$ = 0.10 (W_{cap} + W_{wall}) = 783.78 kips, at 2/3 H

Where S_1 = 0.55 (from soil report, ASCE 7-05, 11.4.1)

I = 1.00 (ASCE 7-05 15.4.1.1)

R = 3 (ASCE 7-05 Table 15.4-2)

W_{wall} = 1718.1 kips



V = 802.73 kips, total shear at top of footing

M = 81221 ft-kips, total moment at top of footing

COMBINED LOADS AT TOP FOOTING (IBC 1605.3.2 & ACI 318-08 9.2.1)

CASE 1:	DL + LL	P	=	7662	kips	1.2 DL + 1.6 LL	Pu	=	11500 kips
		M	=	0	ft-kips		Mu	=	0 ft-kips
		e	=	0.0	ft, fr cl ftg		eu	=	0.0 ft, fr cl ftg
CASE 2:	DL + LL + E / 1.4	P	=	7662	kips	1.2 DL + 1.0 LL + 1.0 E	Pu	=	8042 kips
		M	=	81221	ft-kips		Mu	=	113710 ft-kips
		e	=	10.6	ft, fr cl ftg		eu	=	14.1 ft, fr cl ftg
CASE 3:	0.9 DL + E / 1.4	P	=	5350	kips	0.9 DL + 1.0 E	Pu	=	5350 kips
		M	=	63222	ft-kips		Mu	=	88511 ft-kips
		e	=	11.8	ft, fr cl ftg		eu	=	16.5 ft, fr cl ftg

CHECK OVERTURNING FACTOR AT FOOTING EDGE BOTTOM (IBC 09 1605.2.1, 1808.3.1, & ASCE 7-05 12.13.4)

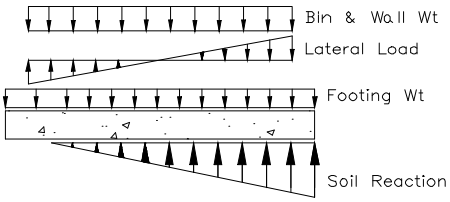
M_R / M_O = 3.4 **>** 1.5 **[Satisfactory]**

Where M_O = M + V T = 84432 k-ft , M_R = Σ(W) 0.5 D = 287186 k-ft

W_{ftg} = (0.15 kcf) T D^2 π / 4 = 1753.5 kips, footing weight.

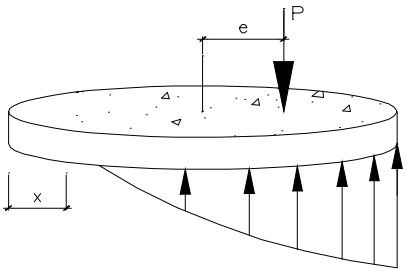
CHECK SOIL BEARING CAPACITY (ACI 318-08 SEC.15.2.2)

γ_s = 0.11 kcf, soil weight



Service Loads	CASE 1	CASE 2	CASE 3	
P	7662.5	7662.5	5350	k
e	0	10.6	11.817	ft (from center of footing)
P_{ftg} - P_{soil}	1110.5	1110.5	999.48	k, (footing increasing)
Σ P	8773	8773	6349.4	k, (net loads)
e	0	9.2581	9.9572	ft
q_{min}	3.0019	0	0	ksf
x		@ 9.15 ft from edge	@ 9.15 ft from edge	
q_{max}	3.0019	6.8882	5.2453	ksf
$q_{allowable}$	5.5	7.3333	7.3333	ksf

[Satisfactory]



CHECK ENTIRE FLEXURE & SHEAR OF FOOTING

(ACI 318-08 SEC.15.4.2, 10.2, 10.3.5, 10.5.4, 7.12.2, 12.2, 12.5, 15.5.2, 11.1.3.1, & 11.2)

$$\rho_{MIN} = MIN\left(0.0018\frac{T}{d}\ ,\ \frac{4}{3}\rho\right) \qquad \rho_{MAX} = \frac{0.85\beta_1 f'_C}{f_y}\frac{\varepsilon_u}{\varepsilon_u+\varepsilon_t}$$

$$\rho = \frac{0.85 f'_C\left(1-\sqrt{1-\frac{M_u}{0.383 b d^2 f'_C}}\right)}{f_y}$$

FACTORED SOIL PRESSURE

Factored Loads	CASE 1	CASE 2	CASE 3	
P_u	11500	8042.3	5350	k
e_u	0	14.139	16.544	ft
γ (0.15 T) A	2104.2	2104.2	1578.1	k, (factored footingloads)
Σ P_u	13604	10146	6928.1	k
e_u	0	11.207	12.776	ft
$q_{u,\ min}$	4.6551	0	0	ksf
x		@ 12.20 ft from edge	@ 15.25 ft from edge	
$q_{u,\ max}$	4.66	9.22	7.10	ksf

FOOTING MOMENT & SHEAR FOR CASE **1**

Section	0	L Edge	1/8 d	2/8 d	3/8 d	Center	5/8 d	6/8 d	7/8 d	R Edge	D
X_u (ft, dist. from left of footing)	0	15.50	19.25	23.00	26.75	30.50	34.25	38.00	41.75	45.50	61.00
Tangent (ft)	0.00	53.11	56.70	59.13	60.54	61.00	60.54	59.13	56.70	53.11	0.00
$q_{u,tank}$ (ksf)	0.00	16.27	16.27	16.27	16.27	16.27	16.27	16.27	16.27	16.27	0.00
$M_{u,tank}$ (ft-k)	0	0	3426.1	10857	23531	42067	66657	97109	132805	172505	350760
$V_{u,tank}$ (k)	0	0	914	1,982	3,380	6,557	8,121	9,519	10,587	11,500	11,500
$q_{u,ftg}$ (ksf)	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
$M_{u,ftg}$ (ft-k)	0	3,952	6,095	8,733	11,885	15,565	19,776	24,514	29,767	35,515	64,177
$V_{u,ftg}$ (k)	0	255	572	703	841	1,123	1,264	1,401	1,533	1,849	2,104
$q_{u,soil}$ (ksf)	-4.66	-4.66	-4.66	-4.66	-4.66	-4.66	-4.66	-4.66	-4.66	-4.66	-4.66
$M_{u,soil}$ (ft-k)	0	-25551	-39409	-56461	-76843	-100634	-127860	-158495	-192460	-229618	-414937
$V_{u,soil}$ (k)	0	-1,648	-3,696	-4,547	-5,435	-7,260	-8,169	-9,057	-9,909	-11,956	-13,604
Σ M_u (ft-k)	**0**	**-21599**	**-29888**	**-36872**	**-41427**	**-43002**	**-41427**	**-36872**	**-29888**	**-21599**	**0**
Σ V_u (kips)	**0**	**-1,393**	**-2,210**	**-1,862**	**-1,215**	**420**	**1,215**	**1,862**	**2,210**	**1,393**	**0**

FOOTING MOMENT & SHEAR FOR CASE **2**

Section	0	L Edge	1/8 d	2/8 d	3/8 d	Center	5/8 d	6/8 d	7/8 d	R Edge	D
X_u (ft, dist. from left of footing)	0	15.50	19.25	23.00	26.75	30.50	34.25	38.00	41.75	45.50	61.00
Tangent (ft)	0.00	53.11	56.70	59.13	60.54	61.00	60.54	59.13	56.70	53.11	0.00
$q_{u,tank}$ (ksf)	0.00	-33.59	70.58	81.83	93.07	104.31	115.55	126.79	138.03	56.34	0.00
$M_{u,tank}$ (ft-k)	0	0	-526.47	240.15	2969.5	8194.6	16309	27522	41776	58559	131579
$V_{u,tank}$ (k)	0	0	-240	349	1,242	3,694	5,105	6,489	7,640	8,042	8,042
$q_{u,ftg}$ (ksf)	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
$M_{u,ftg}$ (ft-k)	0	3,952	6,095	8,733	11,885	15,565	19,776	24,514	29,767	35,515	64,177
$V_{u,ftg}$ (k)	0	255	572	703	841	1,123	1,264	1,401	1,533	1,849	2,104
$q_{u,soil}$ (ksf)	0.00	-0.62	-1.33	-2.04	-2.75	-3.46	-4.16	-4.87	-5.58	-6.29	-9.22
$M_{u,soil}$ (ft-k)	0	0	-1362.8	-3936.4	-8444.4	-15621	-26178	-40780	-60002	-84300	-195757
$V_{u,soil}$ (k)	0	0	-363	-686	-1,202	-2,815	-3,894	-5,126	-6,479	-10,146	-10,146
ΣM_u (ft-k)	**0**	**3952**	**4206**	**5037**	**6410**	**8139**	**9906**	**11256**	**11541**	**9774**	**0**
ΣV_u (kips)	**0**	**255**	**-31**	**366**	**881**	**2,001**	**2,474**	**2,764**	**2,693**	**-255**	**0**

FOOTING MOMENT & SHEAR FOR CASE **3**

Section	0	L Edge	1/8 d	2/8 d	3/8 d	Center	5/8 d	6/8 d	7/8 d	R Edge	D
X_u (ft, dist. from left of footing)	0	15.50	19.25	23.00	26.75	30.50	34.25	38.00	41.75	45.50	61.00
Tangent (ft)	0.00	53.11	56.70	59.13	60.54	61.00	60.54	59.13	56.70	53.11	0.00
$q_{u,tank}$ (ksf)	0.00	-27.43	53.65	62.41	71.16	79.91	88.66	97.41	106.16	42.57	0.00
$M_{u,tank}$ (ft-k)	0	0	-374.39	107.08	1891.9	5338.2	10711	18155	27633	38804	74662
$V_{u,tank}$ (k)	0	0	-170	219	813	2,446	3,389	4,315	5,085	5,350	5,350
$q_{u,ftg}$ (ksf)	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
$M_{u,ftg}$ (ft-k)	0	2,964	4,572	6,550	8,914	11,674	14,832	18,386	22,326	26,636	48,133
$V_{u,ftg}$ (k)	0	191	429	527	630	842	948	1,051	1,149	1,387	1,578
$q_{u,soil}$ (ksf)	0.00	-0.04	-0.62	-1.20	-1.78	-2.37	-2.95	-3.53	-4.11	-4.69	-7.10
$M_{u,soil}$ (ft-k)	0	0	-84.591	-732.1	-2517	-6029.8	-11852	-20528	-32544	-48289	-122795
$V_{u,soil}$ (k)	0	0	-23	-173	-476	-1,552	-2,314	-3,204	-4,199	-6,928	-6,928
ΣM_u (ft-k)	**0**	**2964**	**4113**	**5925**	**8289**	**10982**	**13692**	**16012**	**17414**	**17151**	**0**
ΣV_u (kips)	**0**	**191**	**236**	**574**	**967**	**1,736**	**2,022**	**2,161**	**2,036**	**-191**	**0**

FOOTING MOMENT & SHEAR SUMMARY

Section			0	L Edge	1/8 d	2/8 d	3/8 d	Center	5/8 d	6/8 d	7/8 d	R Edge	D
X_u (ft, dist. from left of footing)			0	15.50	19.25	23.00	26.75	30.50	34.25	38.00	41.75	45.50	61.00
Tangent (ft)			0.00	53.11	56.70	59.13	60.54	61.00	60.54	59.13	56.70	53.11	0.00
Uniform Loads	**Case 1**	M_u, (ft-k / ft)	0.0	-406.7	-527.1	-623.6	-684.3	-705.0	-684.3	-623.6	-527.1	-406.7	0.0
		V_u, (k / ft)	0.0	-26.2	-39.0	-31.5	-20.1	6.9	20.1	31.5	39.0	26.2	0.0
	Case 2	M_u, (ft-k / ft)	0.0	74.4	74.2	85.2	105.9	133.4	163.6	190.4	203.6	184.0	0.0
		V_u, (k / ft)	0.0	4.8	-0.6	6.2	14.6	32.8	40.9	46.7	47.5	-4.8	0.0
	Case 3	M_u, (ft-k / ft)	0.0	55.8	72.5	100.2	136.9	180.0	226.2	270.8	307.1	322.9	0.0
		V_u, (k / ft)	0.0	3.6	4.2	9.7	16.0	28.5	33.4	36.6	35.9	-3.6	0.0

CHECK FLEXURE

Location	$M_{u,max}$	d (in)	ρ_{min}	ρ_{reqD}	ρ_{max}	s_{max}	ρ_{provD}
Top Slab	322.9 ft-k / ft	45.37	0.0019	0.0030	0.0243	no limit	0.0020
Bottom Slab	-705.0 ft-k / ft	44.37	0.0019	0.0070	0.0243	18	0.0020

[Satisfactory]

CHECK FLEXURE SHEAR

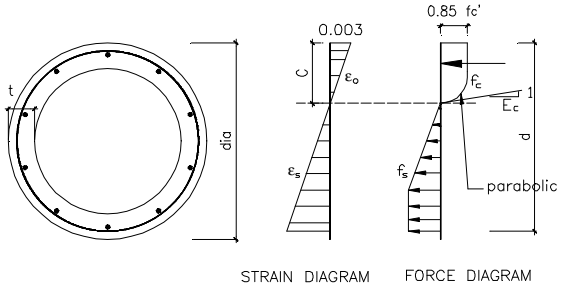
$V_{u,max}$	$\phi V_c = 2\,\phi\, b\, d\, (f_c')^{0.5}$	check $V_u < \phi\, V_c$
47.5 k / ft	56 k	**[Satisfactory]**

CHECK BIN VERTICAL FLEXURAL & AXIAL CAPACITY

$$\varepsilon_o = \frac{2\left(0.85 f_C^{'}\right)}{E_C} \quad , \quad E_C = 57\sqrt{f_C^{'}} \quad , \quad E_S = 29000 ksi$$

$$f_C = \begin{cases} 0.85 f_C^{'}\left[2\left(\frac{\varepsilon_C}{\varepsilon_o}\right) - \left(\frac{\varepsilon_C}{\varepsilon_o}\right)^2\right] & , \quad for \quad 0 < \varepsilon_C < \varepsilon_o \\ 0.85 f_C^{'} & , \quad for \quad \varepsilon_C \geq \varepsilon_o \end{cases}$$

$$f_S = \begin{cases} \varepsilon_S E_S & , \quad for \quad \varepsilon_S \leq \varepsilon_y \\ f_y & , \quad for \quad \varepsilon_S > \varepsilon_y \end{cases}$$



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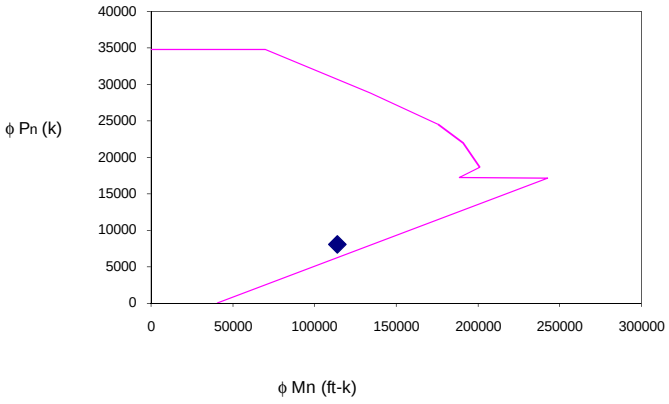


	ϕ Pn (kips)	ϕ Mn (ft-kips)
AT AXIAL LOAD ONLY	34748	0
AT MAXIMUM LOAD	34748	69734
AT 0 % TENSION	28765	133851
AT 25 % TENSION	24488	175599
AT 50 % TENSION	21920	191058
AT ε_t = 0.002	18587	201070
AT BALANCED CONDITION	17229	188611
AT ε_t = 0.005	17125	242597
AT FLEXURE ONLY	0	40448

Pu = 8042 kips
Mu = 113710 ft-kips, max at bottom
(from load combinations)

ϕP_{max} =0.85 ϕ [0.85 f_c' (A_g - A_{st}) + f_y A_{st}] = 34748 kips., (at max axial load, ACI 318-08, Sec. 10.3.6.1)
where ϕ = 0.70 (ACI 318-08, Sec.9.3.2.2) > Pu **[Satisfactory]**
A_g = 13119 in^2. in^2. A_{st} = 47.40 in^2.
a = $C_b\beta_1$ 169 in (at balanced strain condition, ACI 10.3.2)
ϕ = 0.7 + (ε_t - 0.002) (200 / 3), for Spiral = 0.656 (ACI 318-08, Fig. R9.3.2)
0.65 + (ε_t - 0.002) (250 / 3), for Ties
where C_b = d ε_c / (ε_c + ε_s) = 212 in ε_t = 0.002069 ε_c = 0.003
d = 357.38 in, (ACI 7.7.1) β_1 = 0.8 (ACI 318-08, Sec. 10.2.7.3)
ϕM_n = 0.9 M_n =40448 ft-kips @ Pn = 0, (ACI 318-08, Sec. 9.3.2) ,& et,min = 0.004, (ACI 318-08, Sec. 10.3.5)
ϕM_n = 135380 ft-kips @ P_u = 8042 kips > Mu **[Satisfactory]**
ρ_{max} = 0.08 (ACI 318-08, Section 10.9) ρ_{provd} = 0.004
ρ_{min} = 0.004 (ACI 318-08, Section 10.5.1 or 10.9.1) **[Satisfactory]**

CHECK BIN HORIZONTAL SHEAR CAPACITY

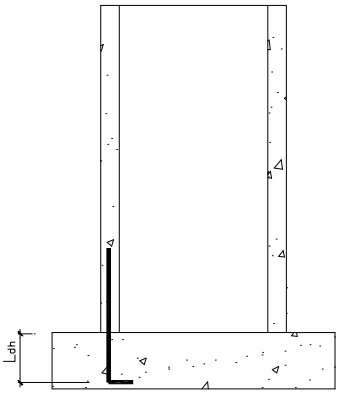
$\phi V_n = \phi (V_c)$ = 1235 kips, (ACI 318-08 Sec. 11.1.1)
> V_u = 1.4 V = 1123.8 kips, max at bottom **[Satisfactory]**
where ϕ = 0.75 (ACI 318-08 Sec. 9.3.2.3)
A_0 = 11640 in^2.
V_c = 2 $(f_c')^{0.5} A_0$ = 1646.2 kips, (ACI 318-08 Sec. 11.2.1)

CHECK DOWEL DEVELOPMENT

$$L_{dh} = MAX\left(\eta \frac{\rho_{requird}}{\rho_{provided}} \frac{0.02\psi_e d_b f_y}{\lambda\sqrt{f_c'}} \ , \ 8d_b \ , \ 6 \ in \right) =$$

12 d_b = 12 in, (ACI 318-08 12.5.2) < 44 in
[Satisfactory]

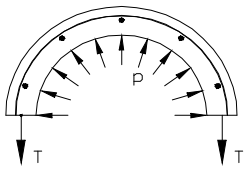
where Bar size # 8
d_b = 1 in
$\rho_{required} / \rho_{provided}$ = 1 (A s,reqd / A s,provd , ACI 318-08, 12.2.5)
f_y = 60 ksi
f'_c = 5 ksi
ψ_t = 1.0
ψ_e = 1.0 (1.2 for epoxy-coated, ACI 318-08 12.2.4)
ψ_s = 1.0 (0.8 for # 6 or smaller, 1.0 for other)
λ = 1.0
c = 3.5 in, min(d' , 0.5s), (ACI 318-08, 12.2.4)
K_{tr} = (A_{tr} f_{yt} / 1500 s n) = 0 (ACI 318-08, 12.2.3)
(c + K_{tr}) / d_b = 2.5 < 2.5 , (ACI 318-08, 12.2.3)
η = 0.7 (#11 or smaller, cover > 2.5" & side >2.0", ACI 318-08 12.5.3)



CHECK BIN LOCAL SHEAR STRESS ON A SQUARE FOOT

$\phi V_n = \phi (v_c)$ = 77.28 kips, (ACI 318-08 Sec. 11.1.1)
> v_u = 1.4 p = 13.10 kips **[Satisfactory]**
where ϕ = 0.75 (ACI 318-08 Sec. 9.3.2.3)
A_0 = 4 x (1'-0") x (0.5 x T) = 288 in^2.
v_c = 4 $(f_c')^{0.5} A_0$ = 103.0 kips, (ACI 318-08 Sec. 11.11)
p = 9360 psf, (the max perpendicular wall pressure)

CHECK BIN WALL TENSION STRESS & CRACKING AT HORIZONTAL SERVICE INSIDE PRESSURE



p = 9360 psf, (the max perpendicular wall pressure)

T = 940 lbs / in^2 , by pure math method

T_{fe} = -1017 lbs / in^2 , effective prestressing **>** 0.8 (0.6 f_c') = -2400 lbs / in^2

[Satisfactory] (ACI 318 18.4.1)

T + T_{fe} = -77 lbs / in^2 **<** 7.5 $(f_c')^{0.5}$ = 530 lbs / in^2, (ACI 318 Eq. 9-10 & 18.3.3)

[Uncracked]

CHECK BIN WALL HORIZONTAL TENSION CAPACITY

1.6 T = 1504 lbs / in^2 **<** ϕ (f_y A_s / A_c + f_{py} A_{ps} / A_{pc}) = 1608 lbs / in^2

[Satisfactory]

Where ϕ = 0.90 , (ACI 318-08 R9.3.2)

A_s / A_c = 0.0061

A_{ps} / A_{pc} = 0.0058