Design of Underground Water Tank (Reservoir)

Tank Dimensions

Total area for the four floors = $4 \times (16 + 14 + 14) \times (13 + 14 + 13) = 7040$ ft^2

$\therefore$ Number of residents, $N \cong 7040 \times 8/1000 = 56$

$\therefore$ Daily water requirement $\cong 56 \times 5 = 280$ ft^3

$\therefore$ Required volume of UG water tank, $V = 2 \times 280 = 560$ ft^3

$\therefore$ Depth of tank, $H \cong V^{1/3} = (560)^{1/3} = 8.24'$

Freeboard, F.B. = $0.50' \Rightarrow$ Total depth, $D = H + \text{F.B.} = 8.74'$

Assuming $L/B = 1.5$, Tank area $A = LB$

$\therefore 560/8.24 = 1.5B \times B \Rightarrow B = 6.73'$, $L = 10.10'$

Loads and Material Properties

Loads: FF = 10 psf, LL = 20 psf

Materials: $f'_c = 3$ ksi, $f_{t,ult} = 5\sqrt{f'_c} = 5\sqrt{(3/1000)} = 0.274$ ksi, $f_{t,all} = f_{t,ult}/2 = 0.137$ ksi, $f_s = 20$ ksi

$\therefore f_c = 0.45f'_c = 1.35$ ksi, $k = 0.378$, $j = 0.874$, $R = 0.223$ ksi, $R_t = f_{t,all}/6 = 0.023$ ksi

For soil, Angle $\phi = 30° \Rightarrow K_a = (1 - \sin\phi)/(1 + \sin\phi) = 0.333$

Design Conditions

The UG water tank has three basic components; i.e., top slab, sidewalls and base slab

- The top slab will be designed as normal simply supported slab based on the self-weight and superimposed loads
- The design of sidewalls and the base slab will be based on assuming
  (i) Tank full of water but no soil outside, (ii) No water inside tank but soil pressure from outside

  The other more critical condition of no water inside but saturated soil outside is avoided here because it might cause instability of the tank itself. Alternately, a provision must be made that the tank cannot be evacuated when the soil is fully saturated.

Design of Top Slab

This is designed as a simply supported slab with clear spans

$S_a = 6.73'$, $S_b = 10.10'$, $m = 6.73/10.10 = 0.67$

Required slab thickness considering deflection = 2 (6.73 + 10.10)/15 = 2.24″

Assuming minimum slab thickness t = 4″, $w_{Total} = 4 \times 150/12 + 10 + 20 = 80$ psf = 0.08 ksf

$\therefore C_a = 0.072 \Rightarrow M_a^{(+)} = 0.072 \times 0.08 \times (6.73)^2 = 0.261$ k′/′

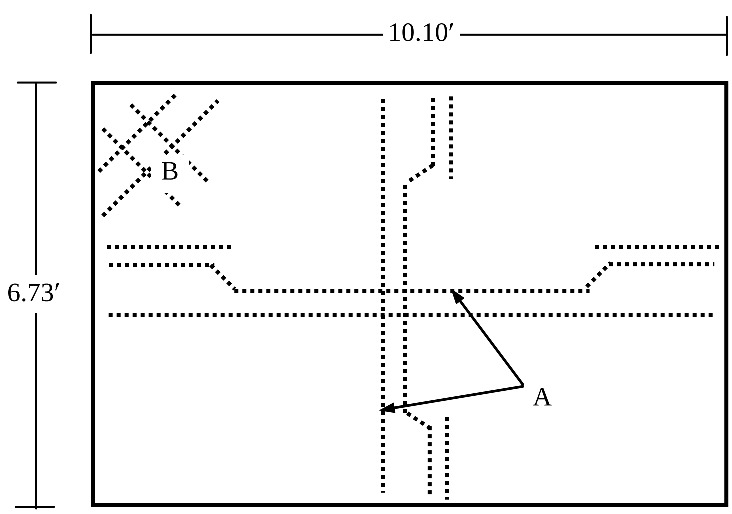
and $C_b = 0.014 \Rightarrow M_b^{(+)} = 0.014 \times 0.08 \times (10.10)^2 = 0.114$ k′/′

$\therefore d_{(req)} = \sqrt{}(M_{(max)}/Rb) = \sqrt{}(0.261/0.223) = 1.08'' < d = 3''$ or 2.5″, OK

$\therefore A_{sa}^{(+)} = M_a^{(+)}/f_sjd = 0.261 \times 12/(20 \times 0.874 \times 3) = 0.06$ in^2/′

$A_{sb}^{(+)} = M_b^{(+)}/f_sjd = 0.114 \times 12/(20 \times 0.874 \times 2.5) = 0.03$ in^2/′

$\therefore A_{s(Temp)} = 0.03\ t = 0.03 \times 4 = 0.12$ in^2/′, $S_{(max)} = 2t = 8'' \Rightarrow$ Use #3 @ 8″c/c in both directions



4″ thick Top Slab

(A): # 3 @ 8″ c/c, alt. ckd. + 1 #3 extra top
(B): Corner reinforcement # 3 @ 8″ c/c in both directions

Design of Sidewalls

Since both L/H and B/H are within 0.5 and 2.0, both the sidewalls have both slab and cantilever action.

Cantilever action is within the bottom H/4 or 1 m height (whichever is greater).

H/4 = 8.24/4 = 2.06′, while 1 m = 3.28′> 2.06′

Slab Action:

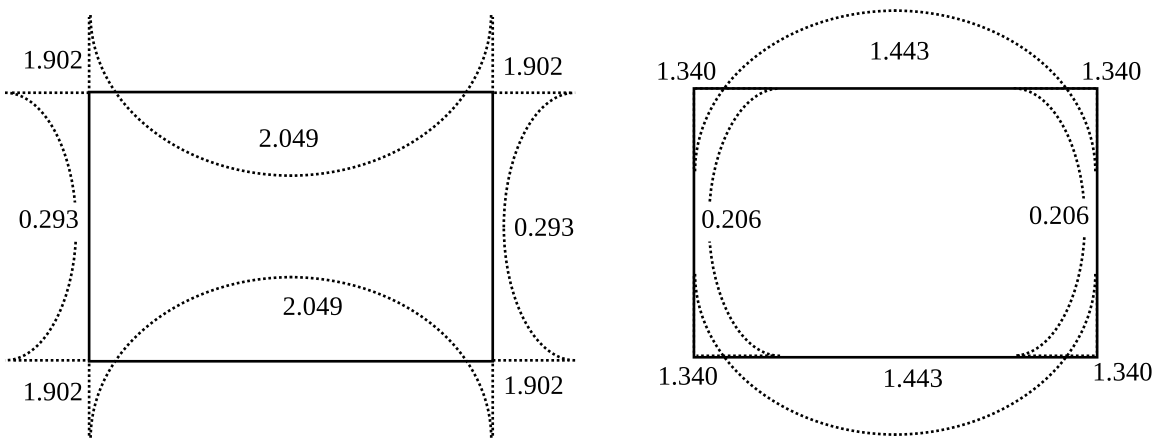
Case (i) – Tank full of water but no soil outside

In this case, $p_{max} = \gamma_w$ (H–h) = 0.0625 × (8.24–3.28) = 0.310 ksf

Case (ii) – No water inside tank but soil pressure from outside

In this case, $p_{max} = K_a \gamma_s$ (D–h) = 0.333 × 0.120 × (8.74–3.28) = 0.219 ksf

∴ The following bending moments (k′/′) are obtained by analyzing the structure in GRASP



Case (i) Case (ii)

Cantilever Action:

Case (i) – Tank full of water but no soil outside

In this case, $p_{max} = \gamma_w H$= 0.0625 × 8.24 = 0.515 ksf

∴ The maximum bending moment $M_{max} = p_{max} h^2/6$ = 0.515 × $3.28^2/6$ = 0.924 k′/′

Case (ii) – No water inside tank but soil pressure from outside

In this case, $p_{max} = K_a \gamma_s D$ = 0.333 × 0.120 × 8.74 = 0.350 ksf

∴ The maximum bending moment $M_{max} = p_{max} h^2/6$ = 0.350 × $3.28^2/6$ = 0.627 k′/′

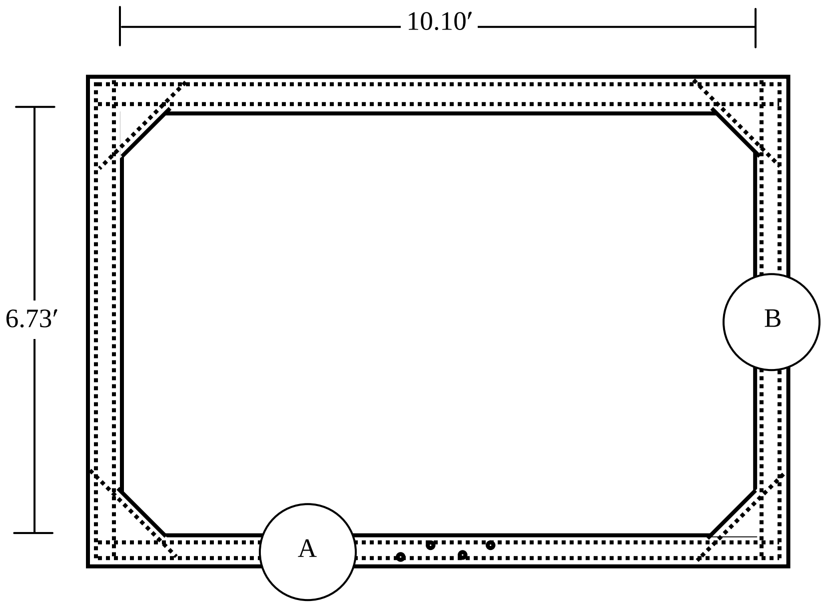
∴ $t_{(req)} = \sqrt{(M_{(max)}/R_t b)} = \sqrt{(2.049/0.023)}$ = 9.47″ ⇒ t = 9.5″; i.e., d = 8″

$\therefore A_s = M/f_s jd = M \times 12/(20 \times 0.874 \times 8) = M/11.65$ in^2/′

$A_{s(Temp)} = 0.03\ t = 0.03 \times 9.5 = 0.29$ in^2/′, $S_{(max)} = 2t = 19''$

$\therefore$ Since $M_{(max)} = 2.049$ k′/′ $\Rightarrow A_{s(max)} = 2.049/11.65 = 0.18$ in^2/′

$\therefore A_{s(Temp)}$ governs in all cases; i.e., Use #3 @ 4.5″ c/c on all surfaces in all directions



9.5″ thick Sidewalls

(A): # 3 @ 4.5″ c/c, on both faces and in both directions of the slab
(B): # 3 @ 4.5″ c/c, on both faces and in both directions of the slab

Design of Base Slab

Like the top slab, the base slab is also designed as a simply supported slab with clear spans

However, the slab has to carry end moments (0.924 k′/′ and 0.627 k′/′) from the cantilever action of the sidewalls; which results in reduction of the midspan maximum moments.

$S_a = 6.73'$, $S_b = 10.10'$, $m = 6.73/10.10 = 0.67$, $t_{(req)} = 2\,(6.73 + 10.10)/15 = 2.24''$

However since the slab carries significant load from water, the assumed slab thickness $t = 7''$

Case (i) – Tank full of water but no soil outside

$w_{Total} = \gamma_c t + FF + \gamma_w H = 150 \times 7/12 + 10 + 62.5 \times 8.24 = 612.66$ psf $= 0.613$ ksf

$\therefore$ Assuming negative moment of 0.924 k′/′ $\Rightarrow$

$C_a = 0.072 \Rightarrow M_a^{(+)} = 0.072 \times 0.613 \times (6.73)^2 - 0.924 = 1.074$ k′/′

and $C_b = 0.014 \Rightarrow M_b^{(+)} = 0.014 \times 0.613 \times (10.10)^2 - 0.924 = -0.050$ k′/′

Case (ii) – No water inside tank but soil pressure from outside

In this case, the total weight of top slab and sidewalls

$= \{(10.10 + 19/12) \times (6.73 + 19/12) \times 4/12 + 2\,(10.10 + 6.73 + 19/12) \times 8.74 \times 9.5/12\} \times 0.15 = 43.08$ k

$\therefore$ Net upward pressure from soil, $w_{Total} = 43.08/\{(10.10 + 19/12) \times (6.73 + 19/12)\} = 0.444$ ksf

$\therefore$ Assuming negative moment of 0.627 k′/′ $\Rightarrow$

$M_a^{(+)} = 0.072 \times 0.444 \times (6.73)^2 - 0.627 = 0.820$ k′/′

$M_b^{(+)} = 0.014 \times 0.444 \times (10.10)^2 - 0.627 = 0.006$ k′/′

$\therefore t_{(req)} = \sqrt{(M_{(max)}/R_t b)} = \sqrt{(1.074/0.023)} = 6.86'' < t = 7''$, OK

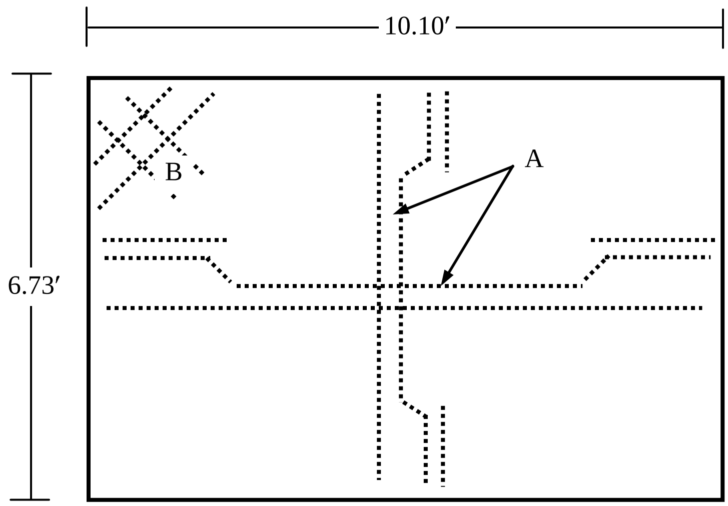
$\therefore t = 7'' \Rightarrow d = 5.5'' \therefore A_s = M/f_s jd = M \times 12/(20 \times 0.874 \times 5.5) = M/8.01$ in^2/′

$A_{s(Temp)} = 0.03\,t = 0.03 \times 7 = 0.21$ in^2/′, $S_{(max)} = 2t = 14''$

$\therefore$ Since $M_{(max)} = 1.074$ k′/′ $\Rightarrow A_{s(max)} = 1.074/8.01 = 0.13$ in^2/′

$\therefore A_{s(Temp)}$ governs in all cases; i.e., since the sidewalls require #3 rods @ 4.5″ c/c

Use #3 @ 4.5″ c/c on all surfaces in all directions



7″ thick Base Slab

(A): # 3 @ 4.5″ c/c, alt. ckd. + 1 #3 extra top
(B): Corner reinforcement # 3 @ 4.5″ c/c in both directions