The Islamic University of Gaza
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Design of Circular Concrete Tanks

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Design of Circular Concrete Tanks

Introduction

- Concrete tanks have been used extensively in municipal and industrial facilities for several decades.

- The design of these structures requires that attention be given not only to strength requirements, but to serviceability requirements as well.

- A properly designed tank must be able to withstand the applied loads without cracks that would permit leakage.

Design of Circular Concrete Tanks

Introduction

The goal of providing a structurally sound tank that will not leak is achieved by

- ✓ Providing proper reinforcement and distribution.
- ✓ Proper spacing and detailing of construction joints.
- ✓ Use of quality concrete placed using proper construction procedures.

Design of Circular Concrete Tanks

Introduction

- The report by ACI Committee 350 entitled Environmental Engineering Concrete Structures is essential in understanding the design of tanks.

Design of Circular Concrete Tanks

ACI 350R-01 Report

This report presents recommendations for structural design, materials, and construction of concrete tanks, reservoirs, and other structures commonly used in ***water containment, industrial and domestic water, and wastewater treatment works, where dense, impermeable concrete with high resistance to chemical attack is required.***

Design of Circular Concrete Tanks

Load Conditions

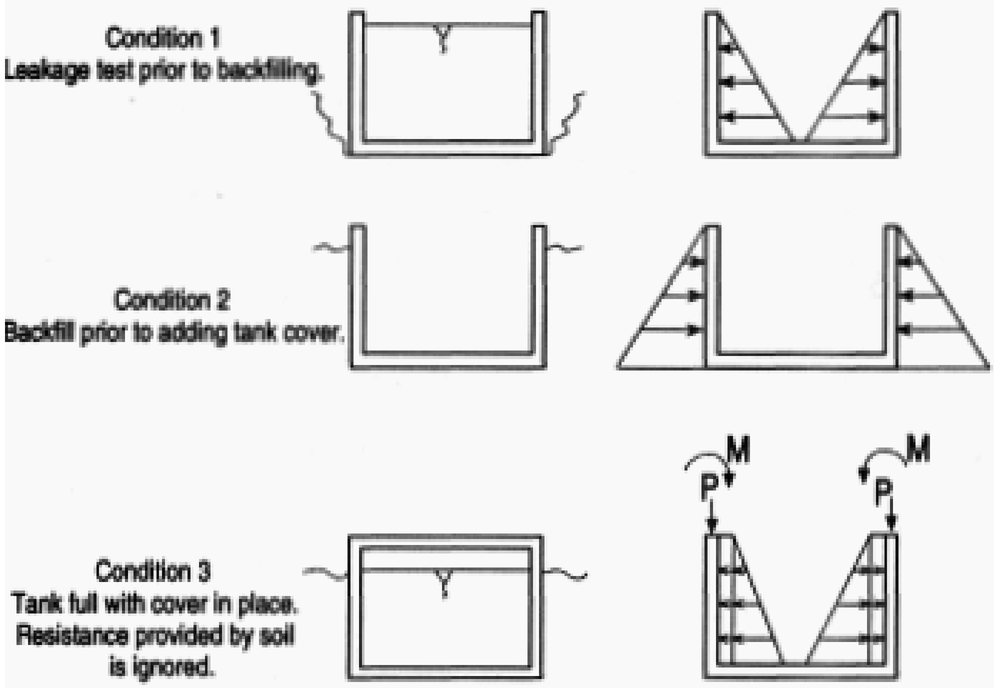


Figure 1—Possible loading conditions for a partially buried tank

Loading Conditions

- ✓ The tank may also be subjected to uplift forces from hydrostatic pressure at the bottom when empty.
- ✓ It is important to consider all possible loading conditions on the structure.
- ✓ Full effects of the soil loads and water pressure must be designed for without using them to minimize the effects of each other.
- ✓ The effects of water table must be considered for the design loading conditions.

Design of Circular Concrete Tanks

Strength Design Method

- **Modification 1** The load factor to be used for lateral liquid pressure, F, is taken as 1.7 rather than the value of 1.4 specified in ACI 318.

- **Modification 2** ACI 350-01 requires that the value of U be increased by using a multiplier called the sanitary coefficient. Required strength = Sanitary coefficient x U

  where the sanitary coefficient equals:

  1.3 for flexure

  1.65 for direct tension

  1.3 for shear beyond that of the capacity provided by the Concrete.

Design of Circular Concrete Tanks

Working Stress Design

- ACI 350-01 implies in its document that the maximum allowable stress for Grade 60 (4200 Kg/cm^2) reinforcing steel is 2100 Kg/cm^2 (0.5fy).
- ACI 350 recommends the allowable stress in hoop tension for Grade 60 (4200 Kg/cm^2) reinforcing steel as is 1400 Kg/cm^2 ($f_y/3$).

Modification according to ACI 350-06

Load Combinations according to ACI318-08

$$U = 1.4(D + F)$$

$$U = 1.2(D + F + T) + 1.6(L + H) + 0.5(Lr \text{ or } S \text{ or } R)$$

$$U = 1.2D + 1.6(Lr \text{ or } S \text{ or } R) + (1.0L \text{ or } 0.8W)$$

$$U = 1.2D + 1.6W + 1.0L + 0.5(Lr \text{ or } S \text{ or } R)$$

$$U = 1.2D + 1.2F + 1.0E + 1.6H + 1.0L + 0.2S$$

$$U = 0.9D + 1.2F + 1.6W + 1.6H$$

$$U = 0.9D + 1.2F + 1.0E + 1.6H$$

Modification according to ACI 350-06

Load Combinations:

L = live loads, or related internal moments and force

$\boldsymbol{L_r}$ = roof live load, or related internal moments and forces

D = dead loads, or related internal moments and forces

E = load effects of earthquake, or related internal forces

R = rain load, or related internal moments and forces

S = snow load, or related internal moments and forces

H = loads due to weight and pressure of soil, water in soil, or other materials, or related internal moments and forces

F = loads due to weight and pressures of fluids with well-defined densities and controllable maximum heights, or related internal moments and forces

Modification according to ACI 350-06

Durability Factor

Required strength environmental durability factor (S_d).

$$S_d = \frac{\phi f_y}{\gamma f_s} \geq 1.0$$

$$where: \quad \gamma = \frac{\text{factored load}}{\text{unfactored load}}$$

$$\text{Required Strength} = S_d \cdot \text{factored load} = S_d \cdot U$$

f_s is the permissible tensile stress in reinforcement

Design of Circular Concrete Tanks

Modification according to ACI 350-06

➢**Strength reduction factor ϕ shall be as follows:**

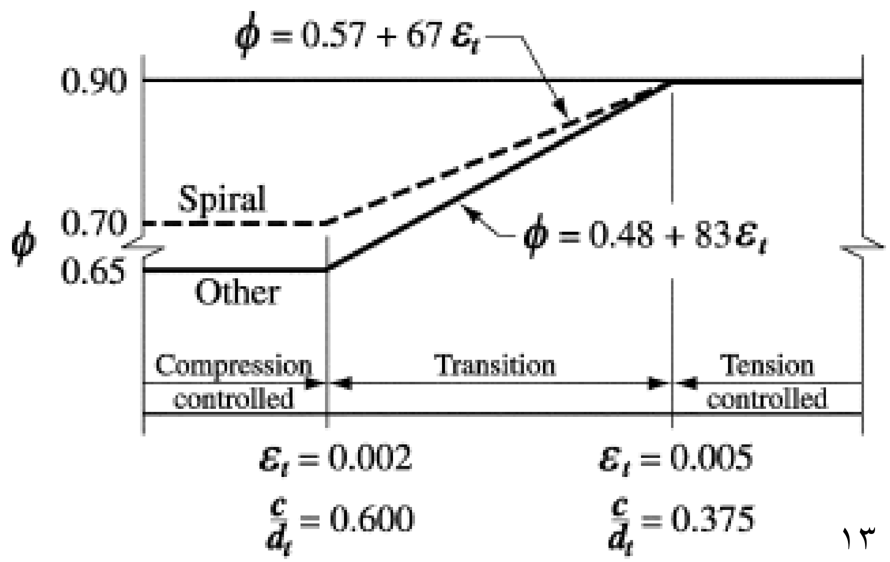
✓Tension-controlled sections ϕ=0.90

✓Compression-controlled sections,

- ❖Members with spiral reinforcement ϕ=0.70
- ❖Other reinforced members ϕ=0.65

✓Shear and torsion ϕ=0.75

✓Bearing on concrete ϕ=0.65



Modification according to ACI 350-06

Permissible Stresses

- **Direct and hoop tensile stresses**

  Normal environmental exposures

  f_s = 20 ksi (138 Mpa ≅ 140Mpa)

  Severe environmental exposures

  f_s = 17 ksi (117 Mpa ≅ 120Mpa)

- **Shear stress carried by shear reinforcement**

  Normal environmental exposures

  fs = 24 ksi (165 Mpa)

  Severe environmental exposures

  fs = 20 ksi (138 Mpa ≅ 140Mpa)

Modification according to ACI 350-06

Shear Stress

Shear stress carried by the shear reinforcing is defined as the excess shear strength required in addition to the design shear strength provided by the concrete ϕVc

$$\phi V_s \geq S_d \left(V_u - \phi V_c\right)$$

Modification according to ACI 350-06

Permissible Stresses

- **Flexural stress**

Normal environmental exposures

$$f_{s,\max} = \frac{320}{\beta\sqrt{s^2 + 4\left(2 + d_b/2\right)^2}} \geq 20\text{ksi}(\cong 140\text{Mpa}) \text{ for one way members}$$

$$\geq 24\text{ksi}(165\text{Mpa})\text{for two way members.}$$

The following simplified equation can be used

$$f_{s,\max} = \frac{320}{\beta\sqrt{s^2 + 25}}$$

where: $\beta = \dfrac{h - c}{d - c}$

$\beta = 1.2$ for h $\geq$ 16 in (40cm).

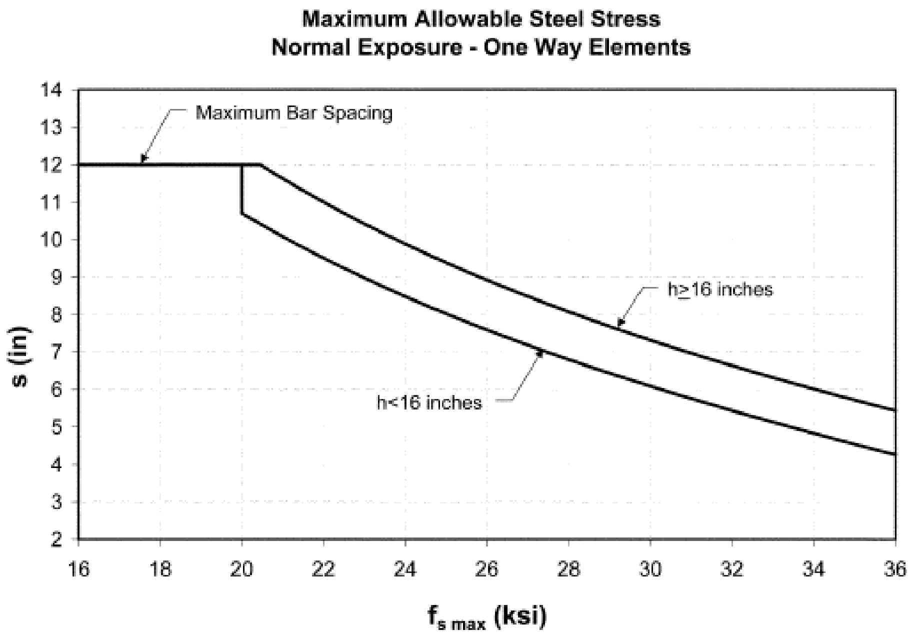
$\beta = 1.35$ for h < 16 in (40cm).

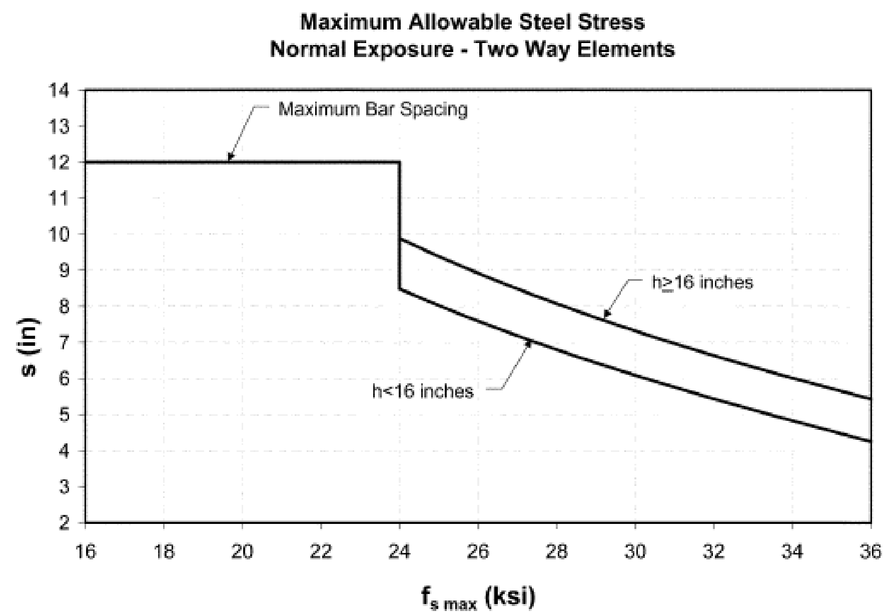
Modification according to ACI 350-06

Permissible Stresses

- **Flexural stress**

  Normal environmental exposures





Modification according to ACI 350-06

Permissible Stresses

- **Flexural stress**

  Severe environmental exposures

$$f_{s,\max} = \frac{260}{\beta\sqrt{s^2 + 4\left(2 + d_b/2\right)^2}} \geq 17\text{ksi}(\cong 120\text{Mpa}) \text{ for one way members}$$

$$\geq 20\text{ksi}(\cong 140\text{Mpa}) \text{ for two way members.}$$

The following simplified equation can be used

$$f_{s,\max} = \frac{260}{\beta\sqrt{s^2 + 25}}$$

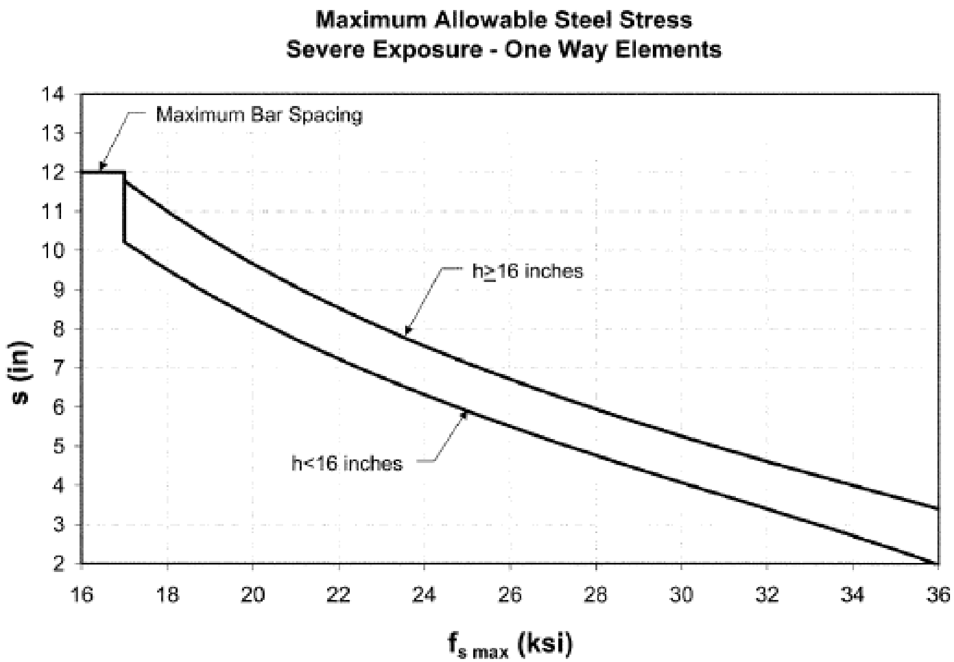
s = center-to-center spacing of deformed bars

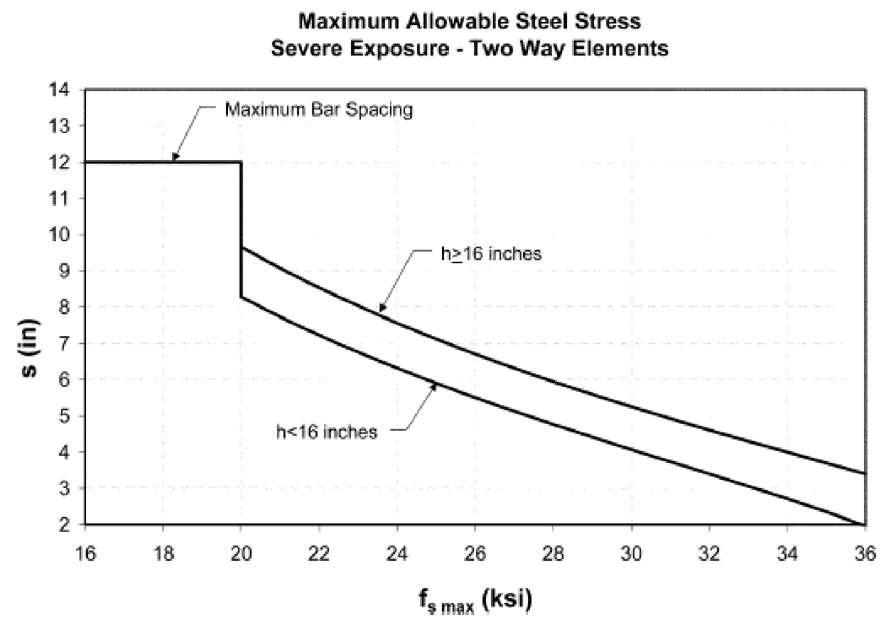
Modification according to ACI 350-06

Permissible Stresses

- **Flexural stress**

  Severe environmental exposures





Modification according to ACI 350-06

Durability Factor

For tension-controlled sections and shear strength contributed by reinforcement, in calculation of the S_d the effects of code-prescribed load factors and ϕ factors can be eliminates and applies an effective load factor equal to f_y/f_s with ϕ factors set to 1.0.

Multiply the unfactored loads by a uniform load factor equal to $f_y/f_s \geq 1.0$

$$\mathrm{Re}\,quired\ Strength \geq \frac{f_y}{f_s} \times Service\ Load$$

Wall Thickness

- Typically, in the design of reinforced concrete members, the tensile strength of concrete is ignored.
- Any significant cracking in a liquid containing tank is unacceptable. For this reason, it must be assured that the stress in the concrete from ring tension is kept at minimum to prevent excessive cracking.
- Neither ACI 350 or ACI 318 provide guidelines for the tension carrying capacity for this condition.
- The allowable tensile strength of concrete is usually between 7% an 12% of the compressive strength. A value of 10% of the concrete strength will be used here.
- According to ACI 350, reinforced cast in place concrete walls 3 meter high or taller, which are in contact with liquid, shall have a minimum thickness of 30 cm.

Wall Thickness

- Shrinkage will shorten the 1-unit long block a distance of ε_{sh}, which denotes the shrinkage per unit length.
- The presence of the steel bar prevents some of the shortening of the concrete $\varepsilon_s < \varepsilon_{sh}$
- The steel shortens a distance ε_s and accordingly is subject to compressive stress f_s, while concrete will elongate a distance (ε_{sh} - ε_s) and will subject to tensile stress f_{ct}.

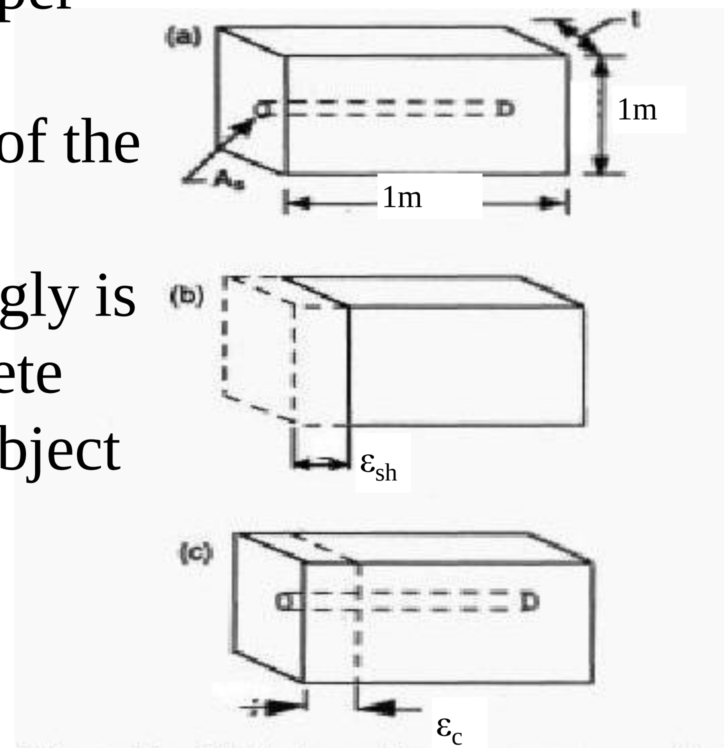


Figure 2—Shrinkage in a concrete section

Wall Thickness

$$\varepsilon_{sh} = \varepsilon_s + \varepsilon_c$$

$$\varepsilon_s = \varepsilon_{sh} - \varepsilon_c$$

$$\frac{f_s}{E_s} = \varepsilon_{sh} - \frac{f_{ct}}{E_c}$$

$$f_s = \varepsilon_{sh} E_s - \frac{E_s}{E_c} f_{ct}$$

$$f_s = \varepsilon_{sh} E_s - n f_{ct}$$

$$A_s f_s = A_c f_{ct}$$

$$A_s \left(\varepsilon_{sh} E_s - n f_{ct} \right) = A_c f_{ct}$$

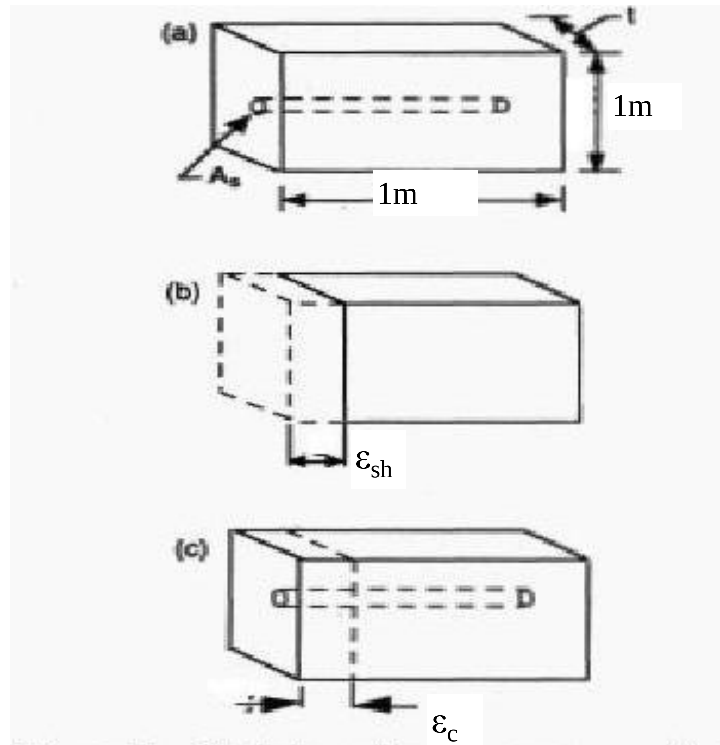


Figure 2—Shrinkage in a concrete section

Wall Thickness

$$A_s \varepsilon_{sh} E_s = \left(nA_s + A_c\right) f_{ct}$$

$$f_{ct} = \frac{\varepsilon_{sh} E_s A_s}{A_c + nA_s}$$

$$f_{ct} = \frac{T}{A_c + nA_s}$$

$$f_{ct} = \frac{T + \varepsilon_{sh} E_s A_s}{A_c + nA_s}$$

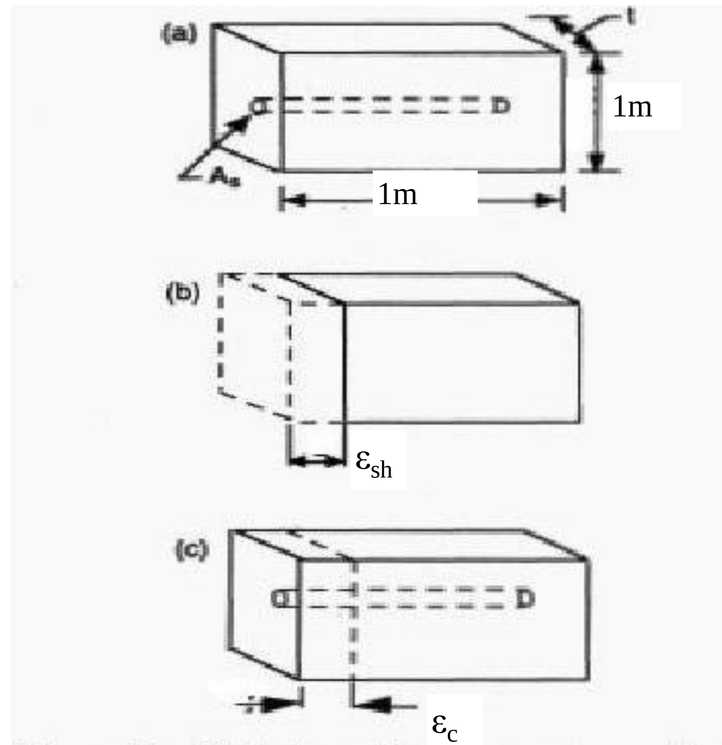


Figure 2—Shrinkage in a concrete section

Wall Thickness

For a rectangular section of 100 cm height and with ***t*** width, then

A_c= 100 t and ***A_s= T/fs***

$$f_{ct} = \frac{T + \varepsilon_{sh} E_s \dfrac{T}{f_s}}{100t + n\dfrac{T}{f_s}}$$

$$t = \frac{\varepsilon_{sh} E_s + f_s - n f_{ct}}{100 f_s f_{ct}} T$$

Wall Thickness

$$t = \frac{\varepsilon_{sh} E_s + f_s - n f_{ct}}{100 f_s f_{ct}} T$$

- The value of ε_{sh} ,coefficient of shrinkage for reinforced concrete, is in the range of 0.0002 to 0.0004.
- The value of ε_{sh} for plain concrete ranges from 0.0003 to 0.0008.

However, this equation has traditionally used the value of 0.0003, the average value for reinforced concrete, with success.

Example

For f_c= 300 kg/cm^2 and f_y = 4200 kg/cm^2, E_s=2.04×10^6 kg/cm^2 evaluate the wall thickness t necessary to prevent cracks resulting from shrinkage plus tensile forces.

f_{ct} = 0.1(300) = 30 kg/cm^2

fs= 4200/3 = 1400 kg/cm^2

$$E_c = 15100\sqrt{300} = 261540 kg/cm^2 \quad \Rightarrow \quad n = \frac{E_s}{E_c} \approx 8$$

$$t = \frac{\varepsilon_{sh} E_s + f_s - n f_{ct}}{100 f_s f_{ct}} T = \frac{0.003(2.04 \times 10^6) + 1400 - 8(30)}{100 \times 1400 \times 30} T = 0.00042 T$$

where T is in kg

If T is in ton and t in cm

t= 0.42 T

where T is in tons.

Reinforcement

- The amount, size, and spacing of reinforcing bars has a great effect on the extent of cracking.
- The amount of reinforcement provided must be sufficient for strength and serviceability including temperature and shrinkage effects.
- The designer should provide proper details to ensure that cracking will occur at joints and that joints are properly leak proofed.
- The size of reinforcing bars should be chosen recognizing that cracking can be better controlled by using a larger number of small diameter bars rather than fewer larger diameter bars.
- Spacing of reinforcing bars should be limited to a maximum of 30 cm.

Reinforcement

- Minimum concrete cover for reinforcement in the tank wall should be at least 5cm.
- The wall thickness should be sufficient to keep the concrete from cracking. If the concrete does crack, the ring steel must be able to carry all the ring tension alone.
- In circular tanks, the location of horizontal splices should be staggered. Splices should be staggered horizontally by not less than one lap length or 90 cm and should not coincide in vertical arrays more frequently than every third bar.

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Reinforcement

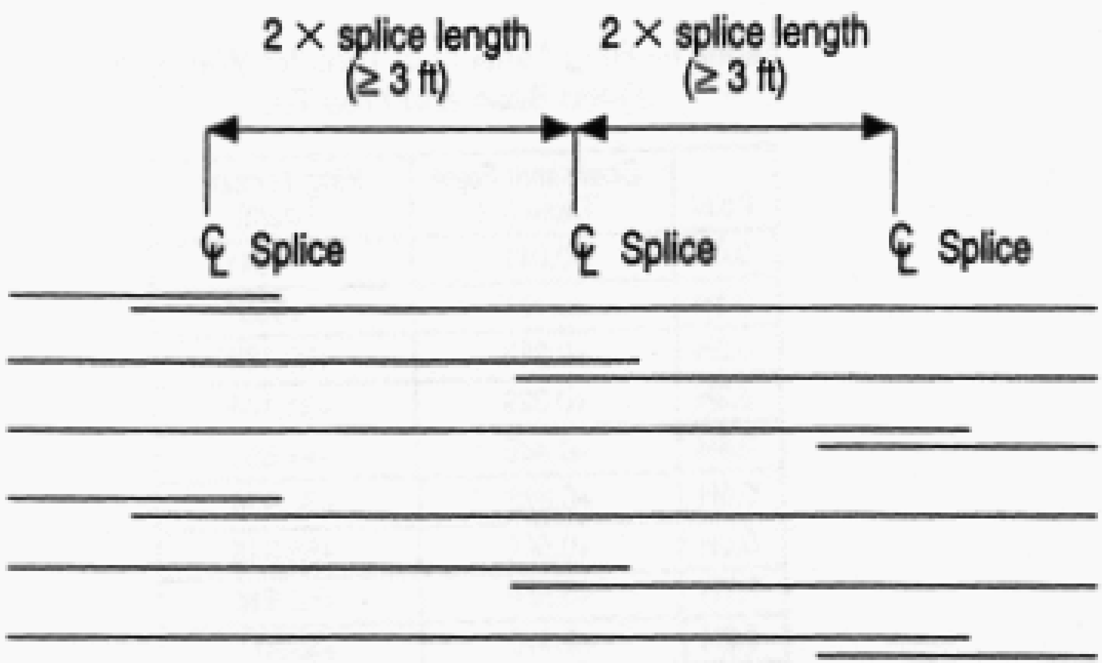


Figure 4—Staggering of ring bar splices

Crack Control

ACI 318- 02

A more practical method which limit the maximum reinforcement spacing after Cod 95

The Maximum Spacing S of reinforcement closest to the surface in tension

$$S \le \begin{cases} \dfrac{9500}{f_s} - 2.5C_c \\ \dfrac{7560}{f_s} \end{cases}$$

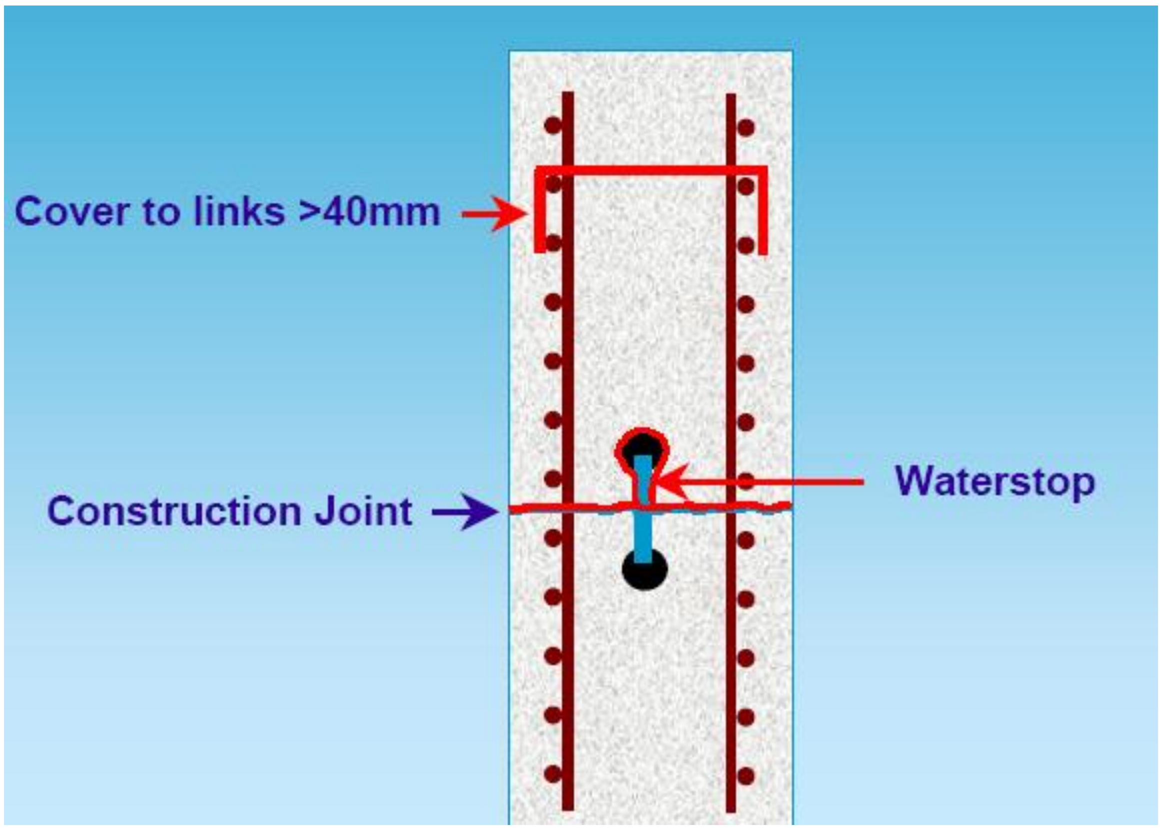
Where

C_c is the clear cover from the nearest surface of concrete in tension zone to surface of flexural reinforcement.

$$f_s \cong 0.6 f_y$$

Design of Circular Concrete Tanks

Water Stop Details



Design of Circular Concrete Tanks

Types of Wall Joints

Free Joint (Sliding joint)

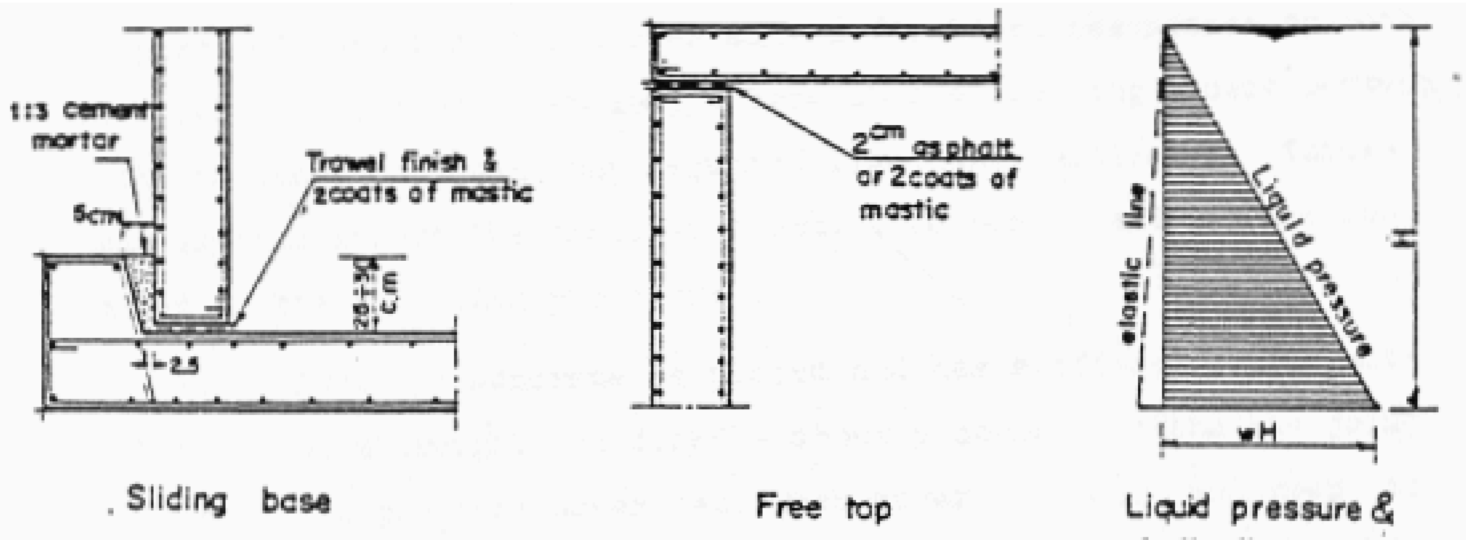
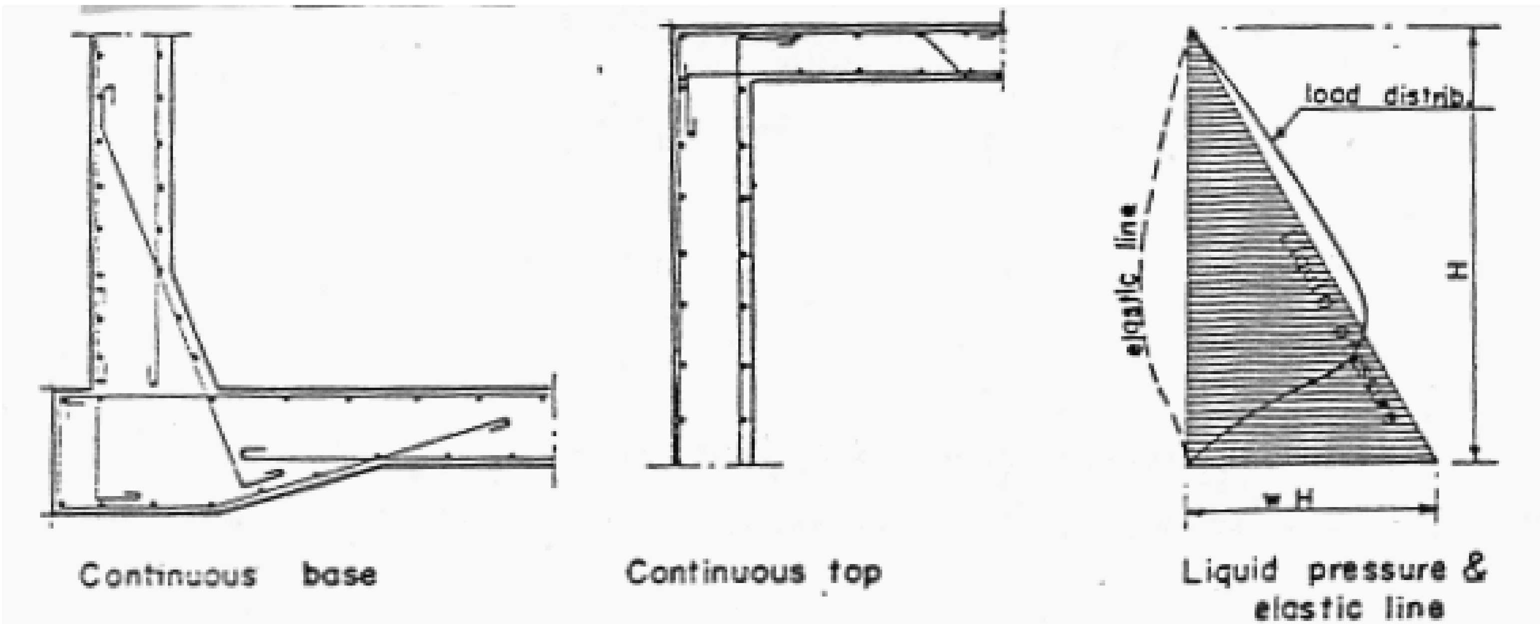


Fig. III-1

Design of Circular Concrete Tanks

Types of Wall Joints

Fixed Joint (Continuous joint)



Design of Circular Concrete Tanks

Types of Wall Joints

Hinged Joint

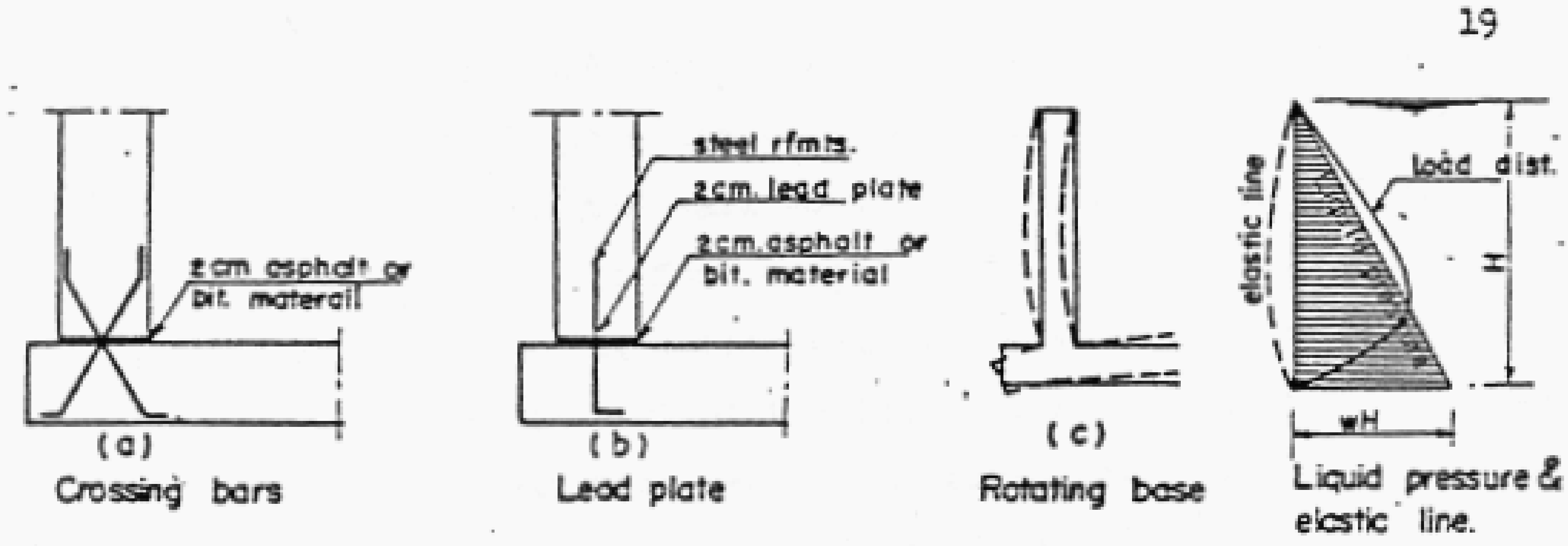


Fig. III-3

General Notes

- For the sliding bottom edge, water pressure is fully resisted by ring action without developing any bending moment or shear.

- For the hinged bottom edge, ring tension and maximum moment take place at the middle part of the wall.

General Notes

- For the fixed bottom edge, the water pressure will be resisted by ring action in the horizontal direction and cantilever action in the vertical direction. The maximum ring and maximum positive moment will be smaller than for the hinged bottom edge, while relatively large negative moment will be induced at the fixed bottom edge of the wall.

General Notes

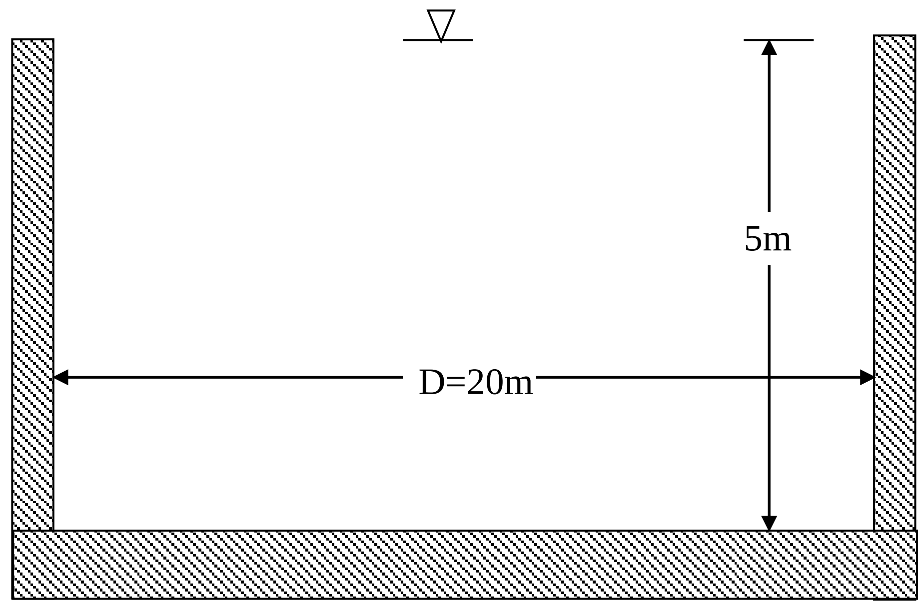
- In practice, it would be rare that the base would be fixed against rotation and such an assumption could lead to an improperly designed wall. It is more reasonable to assume that the base is hinged rather than fixed, which results in a more conservative design.
- For walls monolithically cast with the floor it is recommended to design the section at foot of the wall for max. negative moment from the total fixation assumption and max. positive moment and ring tension from the hinged base assumption.

Design of Circular Concrete Tanks

Example 1

The open cylindrical reinforced concrete tank is 5m deep and 20m in diameter. It is required to determine the internal forces and to design the wall for the following cases:

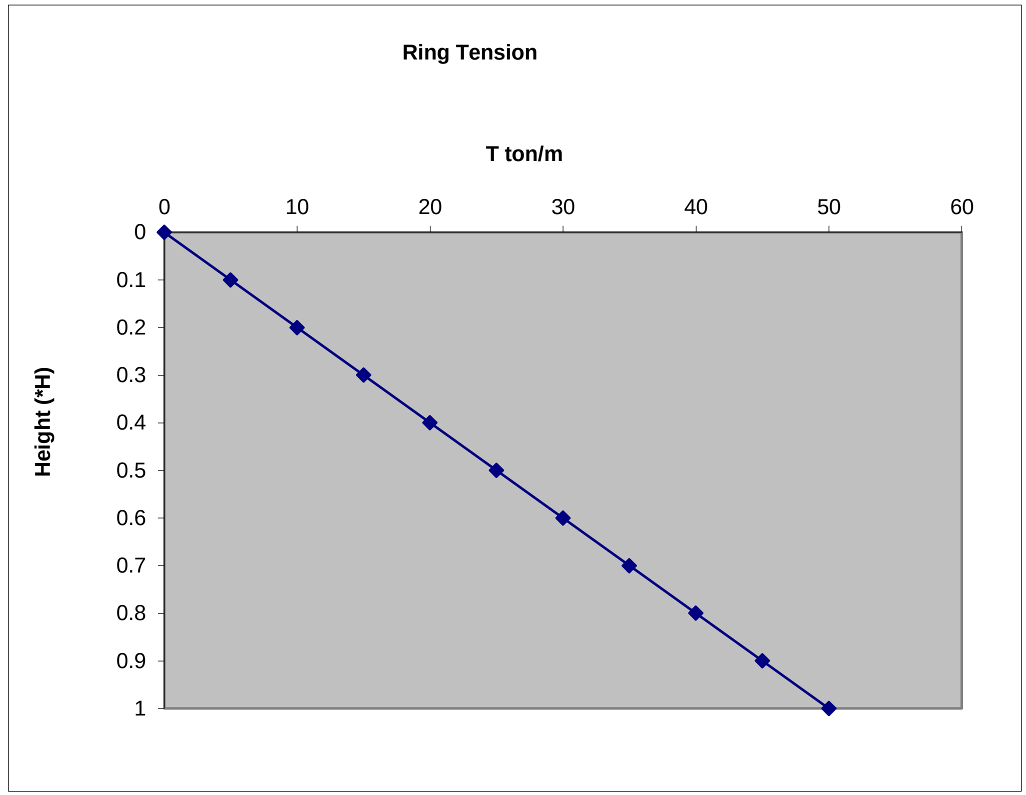
- Bottom edge sliding
- Bottom edge hinged
- Bottom edge fixed



Example 1 Bottom edge Sliding

Point	T force due to water pressure T= γxR
0.0 H	0
0.1 H	5
0.2 H	10
0.3 H	15
0.4 H	20
0.5 H	25
0.6 H	30
0.7 H	35
0.8 H	40
0.9 H	45
1.0H	50

$$T_{max} = \gamma HR = 1.0 \times 5.0 \times 10 = 50t / m$$



Example 1 Bottom edge Sliding

Wall Thickness

$$t = \frac{\varepsilon_{sh} E_s + f_s - n f_{ct}}{100 f_s f_{ct}} T$$

$$f_{ct} \cong 0.1\left(f_c^{'}\right) = 30\, kg\ / cm^2 \qquad E_c = 15100\sqrt{f_c^{'}} = 2.6 \times 10^5\, kg\ / cm^2$$

$$n = \frac{E_s}{E_c} \approx 8$$

$$f_s = \frac{f_y}{3} = 1400\, kg\ / cm^2$$

$$t_{\min} = \frac{0.003\left(2.04 \times 10^6\right) + 1400 - 8\left(30\right)}{100 \times 1400 \times 30} T = 0.42 T \quad (t\ / m)$$

$$t_{\min} = 0.42\left(50\right) = 21.0\ cm$$

Use wall thickness t = 25 cm

Example 1 Bottom edge Sliding

Horizontal Reinforcement ACI 350.01

At the bottom T=50 ton

$$A_s = \frac{T_u}{\phi f_y} = \frac{1.7\times1.65\times50\times10^3}{0.9\times4200} = 37.1\, cm^2/m$$

$$= 18.5 cm^2/m \quad \text{(on each side of the wall)}$$

use 10ϕ16 mm at each side provided 20 cm^2/m

At 0.5 H from the bottom T=25 ton

$$A_s = \frac{T_u}{\phi f_y} = \frac{1.7\times1.65\times25\times10^3}{0.9\times4200} = 18.55\ cm^2/m$$

$$= 9.3\, cm^2/m \quad \text{(on each side of the wall)}$$

use 9ϕ12 mm at each side provided 10.2 cm^2/m

Example 1 Bottom edge Sliding

Horizontal Reinforcement Using ACI 350-06

At the bottom T=50 ton

$$S_d = \frac{\phi f_y}{\gamma f_s} \geq 1.0 \qquad \gamma = \frac{\text{factored load}}{\text{unfactored load}} = 1.4$$

$$S_d = \frac{\phi f_y}{\gamma f_s} = \frac{0.9 \times 420}{1.4 \times 138} = 1.97 \text{ (assuming normal environmental exposures)}$$

$$T_U = S_d \times \left(1.4 \times 50\right) = 2.76 \times 50 = 138\,ton$$

$$A_s = \frac{T_u}{\phi f_y} = \frac{138 \times 10^3}{0.9 \times 4200} = 36.5\ cm^2/m$$

$$= 18.3 cm^2/m$$

use 10ϕ16 mm at each side provided 20 cm^2/m

Example 1 Bottom edge Sliding

Horizontal Reinforcement Using ACI 350-06

At the bottom T=50 ton

For tension-controlled sections and shear strength contributed by reinforcement, in calculation of the S_d the effects of code-prescribed load factors and ϕ factors can be eliminates and applies an effective load factor equal to $\boldsymbol{f_y/f_s}$ with ϕ factors set to 1.0.

$$T_U = \frac{f_y}{f_s} \times 50 = 150 ton$$

$$A_s = \frac{T_u}{\phi f_y} = \frac{3.0 \times 50 \times 10^3}{0.9 \times 4200} = 39.7\ cm^2/m$$

$$= 19.8 cm^2/m$$

use 10ϕ16 mm at each side provided 20 cm^2/m

Example 1 Bottom edge Sliding

Vertical Reinforcement

Minimum ratio of vertical reinforcement ACI section (14.3) is taken 0.0012 for deformed bar ϕ 16 mm in diameter or less.

$A_s/m = 0.0012 \times 100 \times 25 = 3.0\ cm^2$

A_s/m for each face $= 1.5\ cm^2$

Use ϕ 8 mm @30 cm

$S_{max} = 30$ cm

Example 1 Bottom edge hinged

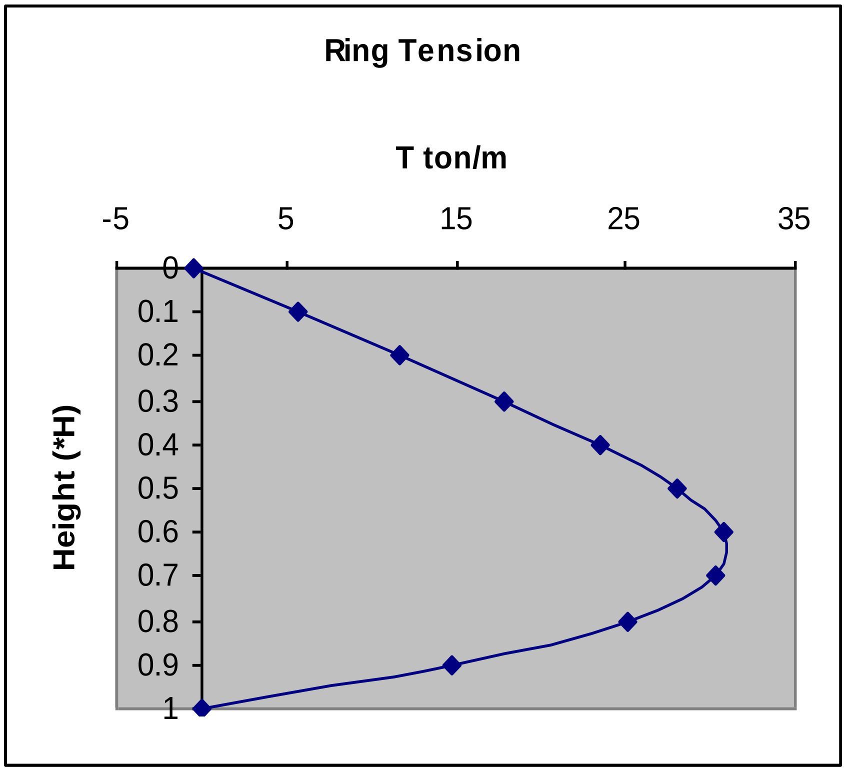
From Table A-5 $T = Coef.*\gamma HR = Coef.*(1)(5)(10)$ t/m

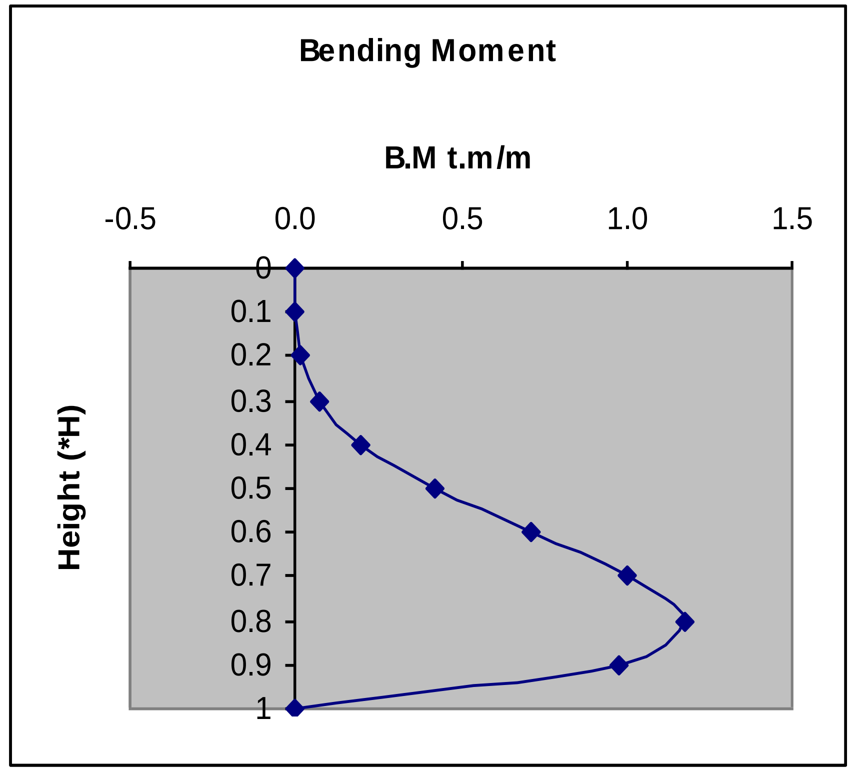
From Table A-7 $M = Coef.*\gamma H^3 = Coef.*(1)*(5)^3$ t.m/m

$$\frac{H^2}{Dt} = \frac{5^2}{(20)(0.25)} = 5$$

Point	Ring T Coef. due to water Table A-5	T force due to water pressure	B. Moment coef. due to water A-7	B. Moment due to water A-7
0.0 H	-0.008	-0.400	0	0.000
0.1 H	0.114	5.700	0	0.000
0.2 H	0.235	11.750	0.0001	0.013
0.3 H	0.356	17.800	0.0006	0.075
0.4 H	0.469	23.450	0.0016	0.200
0.5 H	0.562	28.100	0.0034	0.425
0.6 H	0.617	30.850	0.0057	0.713
0.7 H	0.606	30.300	0.008	1.000
0.8 H	0.503	25.150	0.0094	1.175
0.9 H	0.294	14.700	0.0078	0.975
1.0H	0	0.000	0	0.000

Example 1 Bottom edge hinged





Example 1 Bottom edge Fixed

From Table A-1 $T = Coef.*\gamma HR = Coef.*(1)(5)(10)$ t/m

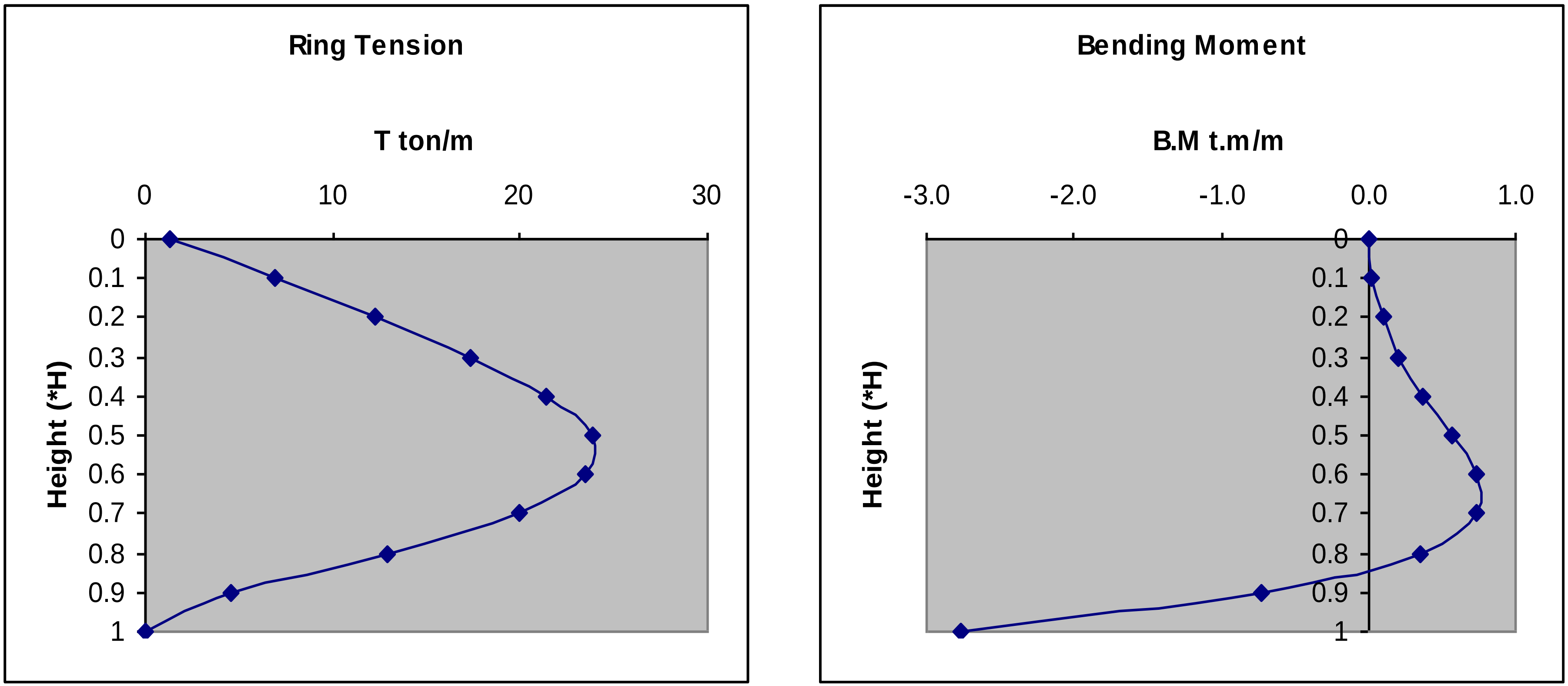
From Table A-2 $M = Coef.*\gamma H^3 = Coef.*(1)*(5)^3$ t.m/m

$$\frac{H^2}{Dt} = \frac{5^2}{(20)(0.25)} = 5$$

Point	Ring T Coef. due to water Table A-1	T force due to water pressure	B. Moment coef. due to water A-2	B. Moment due to water A-7
0.0 H	0.025	1.250	0	0.000
0.1 H	0.137	6.850	0.0002	0.025
0.2 H	0.245	12.250	0.0008	0.100
0.3 H	0.346	17.300	0.0016	0.200
0.4 H	0.428	21.400	0.0029	0.363
0.5 H	0.477	23.850	0.0046	0.575
0.6 H	0.469	23.450	0.0059	0.738
0.7 H	0.398	19.900	0.0059	0.738
0.8 H	0.259	12.950	0.0028	0.350
0.9 H	0.092	4.600	-0.0058	-0.725
1.0H	0	0.000	-0.0222	-2.775

Design of Circular Concrete Tanks

Example 1 Bottom edge Fixed



Minimum Shrinkage and Temp. Reinforcement

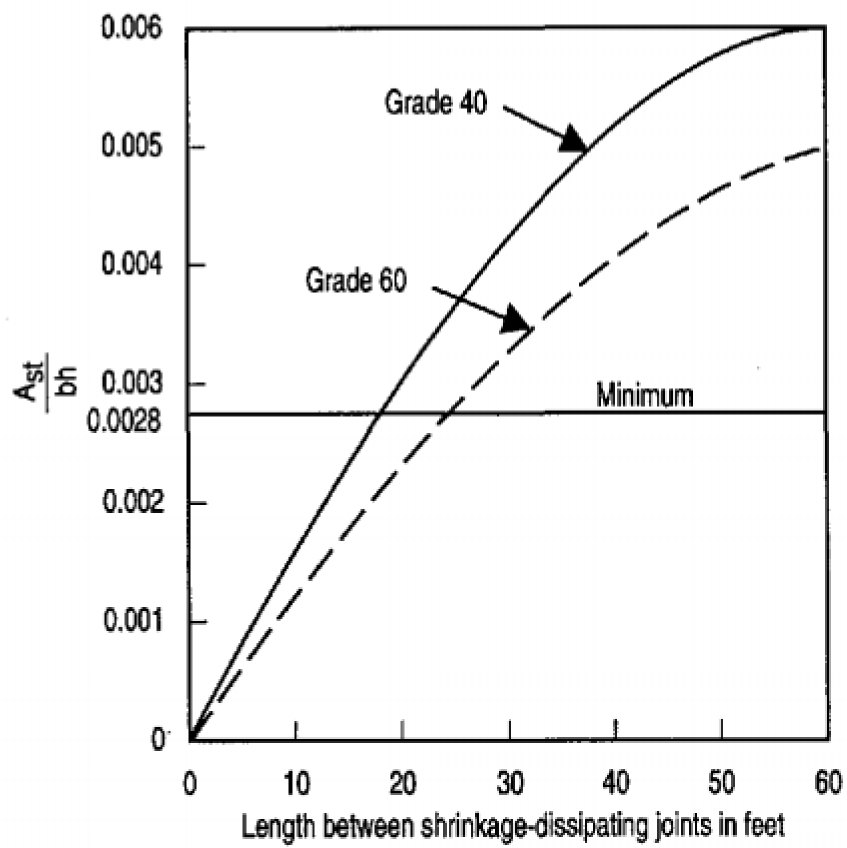
- For Water tank members, the area of shrinkage and temperature reinforcement shall provide at least the ratios of reinforcement area to gross concrete area shown in the following Table.
- Concrete sections that are at least 24 in. may have the minimum shrinkage and temperature reinforcement based on a 12 in. concrete layer at each face.
- The reinforcement in the bottom of base slabs in contact with soil may be reduced to 50 percent of that required in the Table.

Minimum Shrinkage and Temp. Reinforcement

TABLE 7.12.2.1—MINIMUM SHRINKAGE AND TEMPERATURE REINFORCEMENT

Length between movement joints, ft	Minimum shrinkage and temperature reinforcement ratio	
	Grade 40	Grade 60
Less than 20	0.0030	0.0030
20 to less than 30	0.0040	0.0030
30 to less than 40	0.0050	0.0040
40 and greater	0.0060*	0.0050*

*Maximum shrinkage and temperature reinforcement where movement joints are not provided.



Minimum reinfcement of Flexural Members

$$A_{s,\min} \geq \begin{cases} \dfrac{0.25\sqrt{f_c}}{f_y} b_w d \\ \dfrac{1.4}{f_y} b_w d \end{cases}$$

- For $f_c = 30Mpa$ and f_y =420Mpa then $A_{s,\min} = 0.0033$
- The minimum reinforcement required must be provided wherever reinforcement is needed, except where such reinforcement is at least one-third greater than that required by analysis.
- The minimum reinforcement required for slabs should be equal to the same amount as that required by for shrinkage and temperature reinforcement

Minimum reinfcement of Walls

- Minimum ratio of vertical reinforcement area to gross concrete area shall be 0.0030
- Minimum ratio of horizontal reinforcement area to gross concrete area shall be based on the length between movement joints, and shall conform to shrinkage reinforcement.
- Walls more than 25 cm thick shall have reinforcement for each direction placed in two layers parallel to faces of wall in accordance with the following:
    - One layer, consisting of not less than one-half nor more than two-thirds of total reinforcement required for each direction,
    - The other layer, consisting of the balance of required reinforcement in that direction.

Wall with Moment Applied at the Top

- The procedure used to determine the amount of moment transferred from the roof slab to the wall is similar to moment distribution of continuous frames
- Table A-15 Wall stiffness
    - $k = \text{coef. } Et^3/H$
    - Coefficients are given in terms of H^2/Dt
- Table A-16 Slab Stiffness
    - $k = \text{coef. } Et^3/R$
    - Coef. = 0.104 for circular slab without center support
    - Coef. In terms of c/D for circular slab with center support
    - c: is the diameter of column capital
    - D: is the diameter of the tank

Wall with Moment Applied at the Top

$$DF_{Wall} = \frac{K_{Wall}}{K_{Wall} + K_{Slab}}$$

$$DF_{Slab} = \frac{K_{Slab}}{K_{Wall} + K_{Slab}}$$

- The fixed end moment for slab is evaluated using either Table A-14 or A-17 as applicable.

	Wall	**Slab**
Distribution Factor	DF_{Wall}	DF_{Slab}
Fixed End Moment	FEM_{Wall}	FEM_{Slab}
Distributed MOment	DM_{Wall}	DM_{Slab}
Final Moment	$\mathbf{FEM_{Wall} + DM_{Wall}}$	$\mathbf{FEM_{Slab} + DM_{Slab}}$

Wall with Moment Applied at the Top

- Calculation of ring Tension forces in the wall
    1. Calculate the ring tension for free fixed condition due to fluid pressure using Table A-1
    2. Calculate the ring tension caused by applied moment at the top of the wall using Table A-10
    3. The final ring Tension are obtained by summing 1 and 2

Wall with Moment Applied at the Top

- Calculation of Bending moment in the wall
  1. Calculate the bending moment due to fluid pressure using Table A-2
  2. Calculate the bending moment caused by applied moment at the top of the wall using Table A-11
  3. The final bending moment are obtained by summing 1 and 2

Cover in Place

- The concrete roof slab will prevent lateral movement at the top of the wall
- This will result in changes the ring forces and bending moment
- In the previous example when the top is free and bottom is hinged the ring force is 0.4 ton in compression
- To prevent displacement, a shear force acting in opposite direction must be added to reduce the ring force to zero.
- Table A-8 Ring tension due to shear V at the top
    - T= coef. × VR/H
    - -0.4=-8.22×V×10/5
    - V=0.02433 ton
    - The change in ring tension is determined by multiplying coefficient taken from Table A-8 by VR/H=0.04866

Cover in Place

Example 1 Bottom edge hinged

$$\frac{H^2}{Dt} = \frac{5^2}{(20)(0.25)} = 5$$

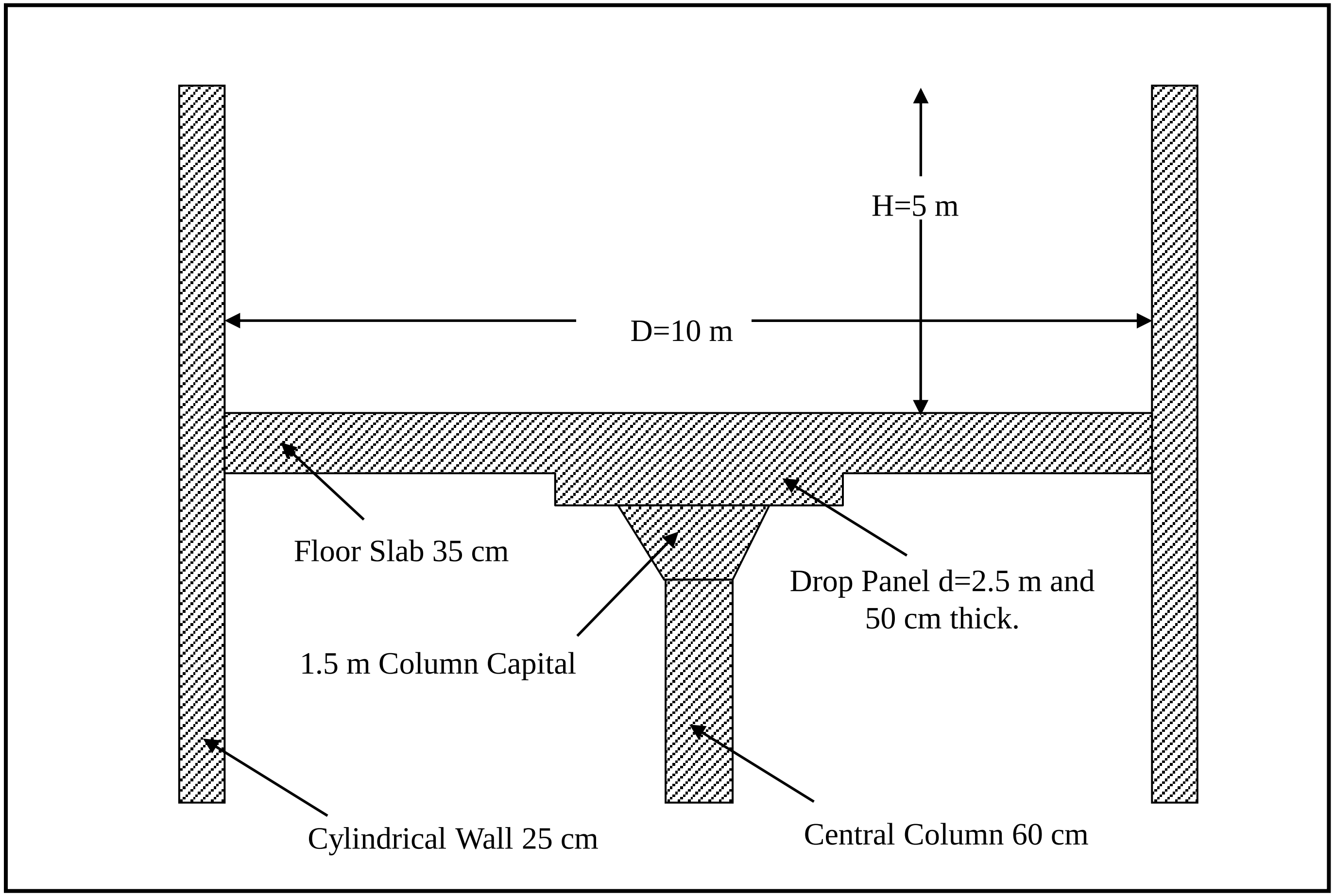
Point	Ring T Coef. due to Shear Table A-8	Ring T force due to Shear V	Ring T Coef. due to water Table A-5	T force due to water pressure	Total Ring T
0.0 H	**-8.22**	0.4000	-0.008	-0.400	**0.0**
0.1 H	**-4.99**	0.2428	0.114	5.700	**5.9**
0.2 H	**-2.45**	0.1192	0.235	11.750	**11.9**
0.3 H	**-0.79**	0.0384	0.356	17.800	**17.8**
0.4 H	**0.11**	-0.0054	0.469	23.450	**23.4**
0.5 H	**0.47**	-0.0229	0.562	28.100	**28.1**
0.6 H	**0.5**	-0.0243	0.617	30.850	**30.8**
0.7 H	**0.37**	-0.0180	0.606	30.300	**30.3**
0.8 H	**0.2**	-0.0097	0.503	25.150	**25.1**
0.9 H	**0.06**	-0.0029	0.294	14.700	**14.7**
1.0H	0	0.0000	0	0.000	**0.0**

Cover in Place

- The change in ring forces and bending moment from restraint of the roof are relatively small
- Loading condition 1 will not practically significantly be changed.

Example 2

Design a reinforced concrete Tank 10 m in diameter and 5 m deep, supported on a cylindrical wall at its outside edge and on the a central column at the center as shown in Figure. The wall is free at its top edge and continuous with the floor slab at its bottom edge. The column capital is 1.5m in diameter, and the drop panel is 50cm thick and 2.5 m in diameter.



Tank Cylindrical Wall

Relative Stiffness:

$$\frac{H^2}{Dt} = \frac{(5)^2}{10(0.25)} = 10.0$$

From Table A-15, the stiffness of the wall

$$k = coef. \times \frac{Et^3}{H} \qquad k = 1.010 \times \frac{E(0.25)^3}{5} = 0.00315625E$$

From Table A-16, the stiffness of the base slab

$$\frac{c}{D} = \frac{1.5}{10} = 0.15 \qquad k = coef. \times \frac{Et^3}{R} \qquad k = 0.332 \times \frac{E(0.35)^3}{5} = 0.0028469E$$

***E* is constant for wall and slab, so**

$$\text{Relative stiffness of wall } \left(\text{DF}_{Wall}\right) = \frac{0.00315625}{0.00315625 + 0.0028469} = 0.526$$

$$\text{Relative stiffness of base slab } \left(\text{DF}_{Slab}\right) = \frac{0.0028469}{0.00315625 + 0.0028469} = 0.474$$

Tank Cylindrical Wall

Fixed end moment at base of the wall, using Table A-2 for $\frac{H^2}{Dt} = 10.0$

$$M = coef. \times \gamma H^3 = -0.0122 \times (1)(5)^3 \times 1.70 \times 1.30 = -3.37\ ton.m/m$$

(Tension inside of the wall)

Fixed end moment at base slab edge, using Table A-17 for

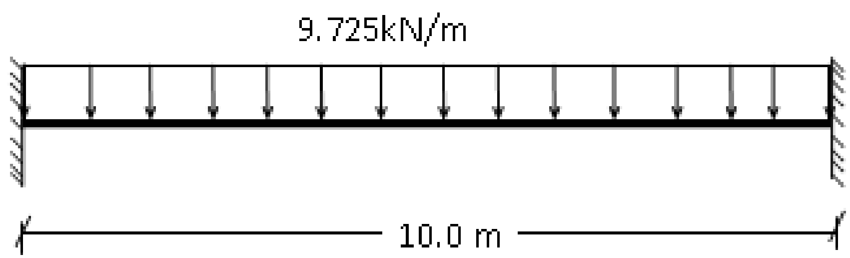
$$\frac{c}{D} = \frac{1.5}{10} = 0.15$$

$$M = coef. \times PR^2, \qquad coef. = -0.049$$

$$P = 1 \times 5 \times 1.7 + 0.35 \times 2.5 \times 1.4 = 9.725\ t/m$$

$$M = -0.049 \times 9.725 \times (5)^2 \times 1.3 = -15.49\ t.m/m$$

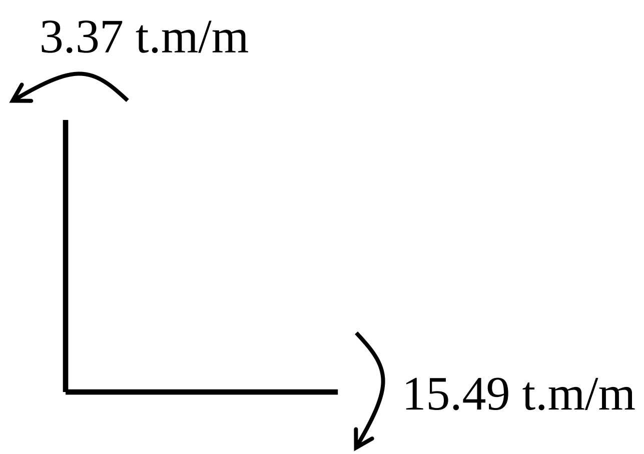
(DL factors of
1.4 for slab own weight
1.7 for water are used)



Tank Cylindrical Wall

Moment distribution between wall and base slab

	Wall	Slab
Distribution Factor	0.526	0.474
F.E.M.	3.37	-15.49
Distribution Moment	6.37	5.75
Final Moment	9.74	-9.74



Tank Cylindrical Wall

Ring Tension Force in Wall

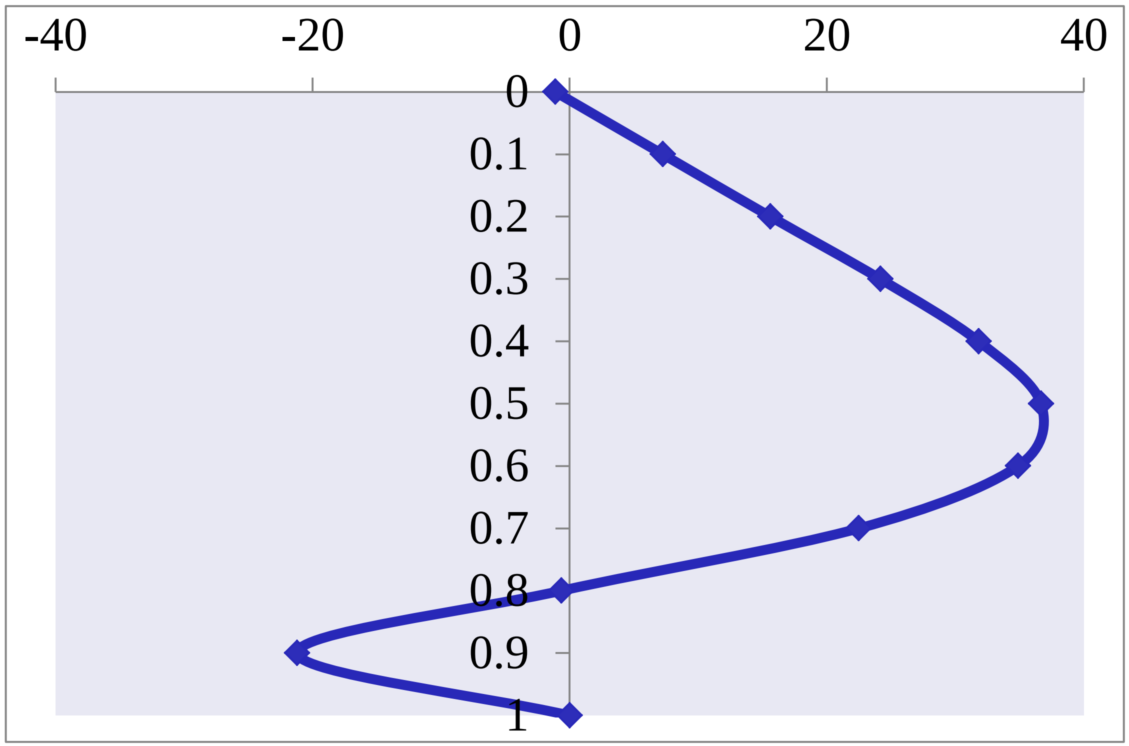
From Table A-1 **T=Coef.*γ H R=** Coef. *(1)(5)(1.7)(1.65) t/m =14.025*Coef. t/m

From Table A-10 **T=Coef.*M R / H^2=** Coef. *(6.37)(5)/$(5)^2$ *(1.65/1.3) t/m = 1.617 *Coef. t/m

Point	Ring T Coef. due to water Table A-1	T force due to water pressure	T Coef. due to Moment able A-10	T force due to Moment	Total Ring T forces (t/m)
0.0 H	**-0.011**	-0.771	**-0.21**	-0.340	**-1.111**
0.1 H	**0.098**	6.872	**0.23**	0.372	**7.244**
0.2 H	**0.208**	14.586	**0.64**	1.035	**15.621**
0.3 H	**0.323**	22.650	**0.94**	1.520	**24.170**
0.4 H	**0.437**	30.645	**0.73**	1.180	**31.825**
0.5 H	**0.542**	38.008	**-0.82**	-1.326	**36.682**
0.6 H	**0.608**	42.636	**-4.79**	-7.745	**34.891**
0.7 H	**0.589**	41.304	**-11.63**	-18.806	**22.498**
0.8 H	**0.44**	30.855	**-19.48**	-31.499	**-0.644**
0.9 H	**0.179**	12.552	**-20.87**	-33.747	**-21.194**
1.0H	**0**	0.000	**0**	0.000	**0.000**

Tank Cylindrical Wall

Ring Tension Force in Wall



Tank Cylindrical Wall

Bending Moment in Wall

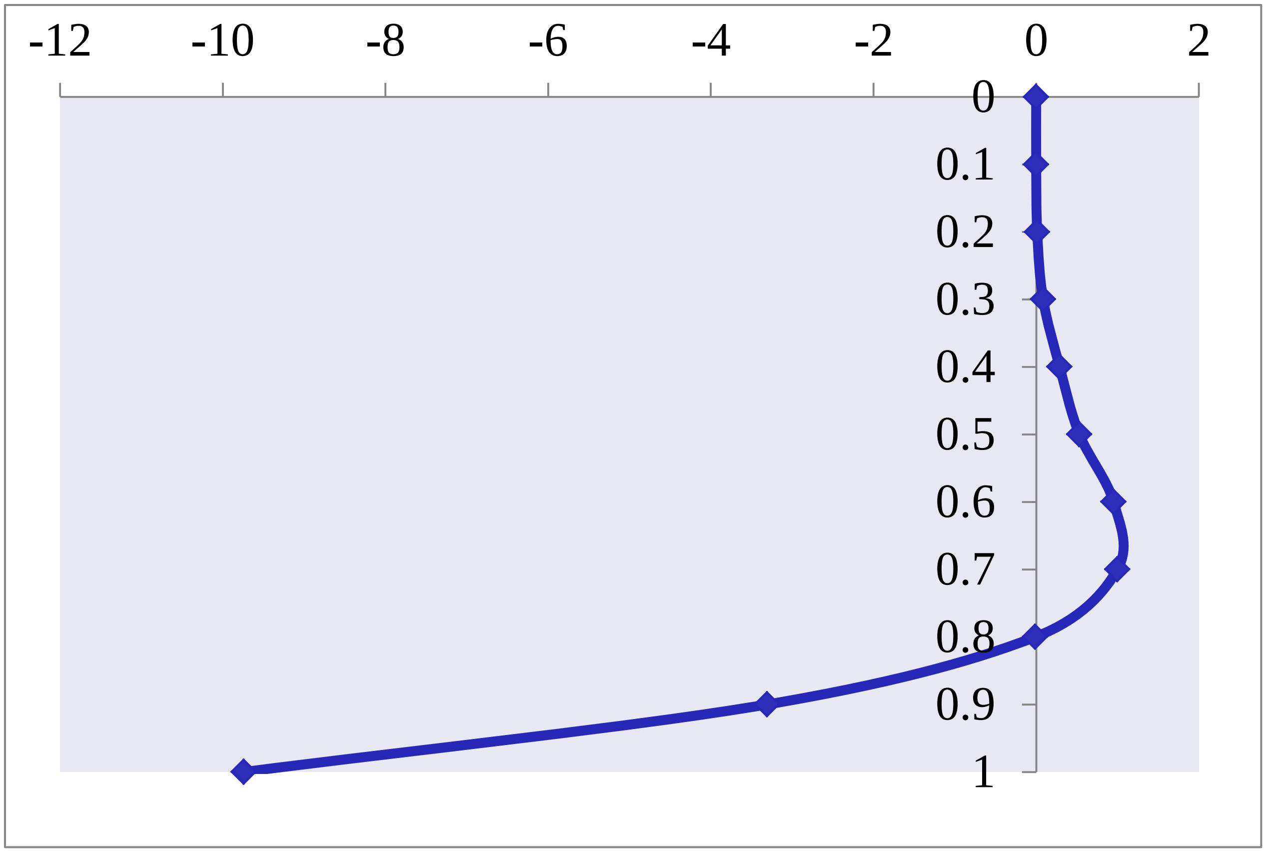
Table A-2 **M=Coef.*γ H3 =** Coef. *(1)(5)^3(1.7)(1.3) t/m =276.25*Coef. t.m/m

Table A-11 **M=Coef.*M =** Coef. *(6.37) t/m = 6.37 *Coef. t.m/m

Point	M. Coef. due to water Table A-1	Moment due to water pressure	M. due to Moment able A-11	Moment due to distributed Moment	Total Bending Moment (t.m/m)
0.0 H	**0**	0.000	**0**	0.000	**0.000**
0.1 H	**0**	0.000	**0**	0.000	**0.000**
0.2 H	**0**	0.000	**0.002**	0.013	**0.013**
0.3 H	**0.0001**	0.028	**0.009**	0.057	**0.085**
0.4 H	**0.0004**	0.111	**0.028**	0.1784	**0.1894**
0.5 H	**0.0007**	0.193	**0.053**	0.338	**0.531**
0.6 H	**0.0019**	0.525	**0.067**	0.427	**0.952**
0.7 H	**0.0029**	0.801	**0.031**	0.197	**0.999**
0.8 H	**0.0028**	0.774	**-0.123**	-0.784	**-0.010**
0.9 H	**-0.0012**	-0.332	**-0.467**	-2.975	**-3.306**
1.0H	**-0.0122**	-3.370	**-1**	-6.370	**-9.740**

Tank Cylindrical Wall

Bending Moment in Wall



Tank Cylindrical Wall

Check for minimum thickness of the wall due to ring tension:

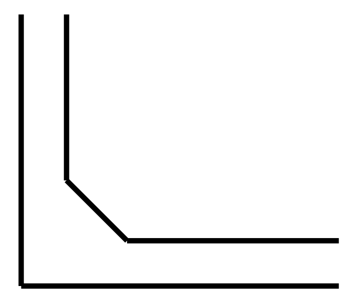
$$\text{Max. Ring tension at service load } = \frac{36.682}{(1.7)(1.65)} = 13.1\ ton$$

$$t = \frac{\varepsilon_{sh} E_s + f_s - n f_{ct}}{100 f_{ct} f_s} \times T$$

$$t = \frac{0.003 \times 2.04 \times 10^6 + 1400 - 8 \times 30}{100 \times 1400 \times 30} \times T = 0.00042T = 0.42T \quad (\text{T in tons})$$

$$t = 0.42(13.1) = 5.5\ cm \ll 25\ cm \Rightarrow \text{O.K.}$$

Check adequacy of wall thickness for resisting moment:



$$f_r = \frac{My}{I}$$

$$2\sqrt{f_c'} = 2\sqrt{300} = \frac{9.74}{(1.7)(1.3)} \times \frac{t/2}{(100)t^3/12} \times 10^5$$

$t = 27.63\ cm \Rightarrow$ increase wall thickness at the base to 50 cm using a 25 x 25 cm haunch

Tank Cylindrical Wall

Shear force at the base of the wall,
From Table A-12:

$$V_u = coef.\times \gamma H^2 + coef.\times M / H$$

$$V_u = 0.158(1)(5)^2(1.7) + 5.81\times \frac{6.37}{(5)(1.3)} = 12.4\ ton$$

$$d = 25 - 5 - 0.8 = 19.2\ cm$$

$$\Phi V_c = 0.85(0.53)(\sqrt{300})(100)(19.2)(10)^{-3} = 14.98\ ton > 12.4 \Rightarrow \text{ O.K.}$$

Tank Cylindrical Wall

Design of Wall Reinforcement:

- **Ring Tension Reinforcement**

$$A_s = \frac{T_u}{\phi f_y} = \frac{36.8}{0.9(4.2)} = 9.7\ cm^2 / m$$

Or 4.85 cm^2 on each side

Use 5 ϕ 12 mm/m on each side.

- **Bending Reinforcement:**
  - ✓ **Inside Reinforcement (Mu=-9.74 t.m)**

$$\rho = \frac{0.85(300)}{4200}\left[1-\sqrt{1-\frac{2.61(10)^5(9.74)}{100(19.2)^2(300)}}\right] = 0.0074 > \rho_{\min}$$

$$A_s = 0.0074 \times 100 \times 19.2 = 14.27\ cm^2 / m$$

Use 8 ϕ 16 mm/m on the inside of the wall.

This reinforcement can be reduced to 4ϕ16 mm/m at 0.5H (2.5 m)

Tank Cylindrical Wall

- **Bending Reinforcement:**
  - ✓ **Outside Reinforcement (Mu=0.999 t.m)**

$$\rho = \frac{0.85(300)}{4200}\left[1-\sqrt{1-\frac{2.61(10)^5(0.999)}{100(19.2)^2(300)}}\right] = 0.00072 < \rho_{\min}$$

$$A_{s,\min} = \frac{0.0033}{2}(100)(25) = 4.125\ cm^2/m$$

Use 5 ϕ 12 mm/m on the outside of the wall.

Tank Base Slab

Radial Bending Moment in base Slab

$$\frac{c}{D}=\frac{1.5}{10}=0.15$$

From Table A-17 **T=Coef.*pR²**= Coef. *(9.725)(5) ^{2} (1.3) t/m

From Table A-19 **T=Coef.*M** = Coef. *(5.75) t/m = 5.75 *Coef. t.m/m

Point	Mr Coef. Table A-17	Mr due to water pressure	Mr Coef. Table A-19	Mr due to distributed M	Total radial Moment (t.m/m)	Radial moment per segment
0.15 R	**-0.1089**	-34.419	**-1.594**	-9.166	**-43.585**	**-6.54**
0.20 R	**-0.0521**	-16.467	**-0.93**	-5.348	**-21.814**	**-4.36**
0.25 R	**-0.02**	-6.321	**-0.545**	-3.134	**-9.455**	**-2.36**
0.30 R	**0.0002**	0.063	**-0.28**	-1.610	**-1.547**	**-0.46**
0.40 R	**0.022**	6.953	**0.078**	0.449	**7.402**	**2.96**
0.50 R	**0.0293**	9.261	**0.323**	1.857	**11.118**	**5.56**
0.60 R	**0.0269**	8.502	**0.51**	2.933	**11.435**	**6.86**
0.70 R	**0.0169**	5.341	**0.663**	3.812	**9.154**	**6.41**
0.80 R	**0.0006**	0.190	**0.79**	4.543	**4.732**	**3.79**
0.90 R	**-0.0216**	-6.827	**0.90**	5.175	**-1.652**	**-1.49**
1.0 R	**-0.049**	-15.487	**1.00**	5.750	**-9.737**	**-9.74**

Tank Base Slab

Tangential Bending Moment in Base Slab

$$\frac{c}{D} = \frac{1.5}{10} = 0.15$$

From Table A-17 **T=Coef.*pR²**= Coef. *(9.725)(5)^2 (1.3) t/m

From Table A-19 **T=Coef.*M** = Coef. *(5.75) t/m = 5.75 *Coef. t.m/m

Point	Mr Coef. Table A-17	Mr due to water pressure	Mr Coef. Table A-19	Mr due to distributed M	Total radial Moment (t.m/m)
0.15 R	**-0.0218**	-6.890	**-0.319**	-1.834	**-8.72**
0.20 R	**-0.0284**	-8.976	**-0.472**	-2.714	**-11.69**
0.25 R	**-0.0243**	-7.680	**-0.463**	-2.662	**-10.34**
0.30 R	**-0.0177**	-5.594	**-0.404**	-2.323	**-7.92**
0.40 R	**-0.0051**	-1.612	**-0.251**	-1.443	**-3.06**
0.50 R	**0.0031**	0.980	**-0.1**	-0.575	**0.40**
0.60 R	**0.008**	2.529	**0.035**	0.201	**2.73**
0.70 R	**0.0086**	2.718	**0.157**	0.903	**3.62**
0.80 R	**0.0057**	1.802	**0.263**	1.512	**3.31**
0.90 R	**-0.0006**	-0.190	**0.363**	2.087	**1.90**
1.0 R	**-0.0098**	-3.097	**0.451**	2.593	**-0.50**

Tank Base Slab

Column's Load

From Table A-13, load on center support of circular slab is:

$$P = coef.\times PR^2 + coef.\times M$$

$$P_u = 1.007(9.725)(5)^2 + 9.29\times\frac{5.75}{1.3} = 285.9\ ton$$

Shear Strength of Base Slab:

a) At edge of wall:

$$V_u = P\pi R^2 - column\ \ load = (9.725)(3.14)(5)^2 - 285.9 = 477.9\ ton$$

$$\text{Length of shear section } = \pi D = 3.14(10\times 100) = 3141.59\ cm$$

$$d = 35 - 5 - 0.9 = 29.1\ cm$$

$$\Phi V_c = 0.85(0.53)(\sqrt{300})(3141.59)(29.1)(10)^{-3} = 713.34\ ton > 477.9 \Rightarrow \text{ O.K.}$$

Tank Base Slab

Shear Strength of Base Slab:

b) At edge of column capital:

Radius of critical section = 75 + d = 75 + (50 - 5.0 - 0.9) = 119.1 cm

$$d = 50 - 5 - 0.9 = 44.1\ cm$$

$$V_u = P\pi R^2 - column\ \ load = (9.725)(3.14)(1.191)^2 - 285.9 = -242.58\ ton$$

$$\phi V_c = 0.85(0.53)(\sqrt{300})(2\pi \cdot 119.1)(44.1)(10)^{-3} = 257.5\ ton > 242.58 \Rightarrow \text{ O.K.}$$

Tank Base Slab

Shear Strength of Base Slab:

c) Shear at edge of drop panel:

Radius of critical section = 125 + (35 -5 -0.9) = 154.1 cm

$$d = 35 - 5 - 0.9 = 29.1\ cm$$

$$V_u = (9.725)(3.14)(1.541)^2 - 285.9 = -213.36\ ton$$

$$\phi V_c = 0.85(0.53)(\sqrt{300})(2\pi \cdot 154.1)(29.1)(10)^{-3} = 219.85\ ton > 213.36 \Rightarrow \text{ O.K.}$$

Tank Base Slab

Slab Reinforcement

a) Tangential Moments

For $M_t = -11.69$ t.m/m at $(0.2\ \text{R})$

$$\rho = \frac{0.85(300)}{4200}\left[1-\sqrt{1-\frac{2.61(10)^5(11.699)}{100(44.1)^2(300)}}\right] = 0.0016 < \rho_{\min}$$

$$A_{s,\min} = \left(\frac{0.003}{2}\right)(100)(50) = 7.5\ cm^2/m$$

You can simply use $\rho_{\min} = 0.0018$ to be used for one layer

$$A_{s,\min} = (0.0018)(100)(50) = 9\ cm^2/m$$

Use ϕ 12 mm @ 12.5 cm (8ϕ12 / m) (Top ring reinf.)

Tank Base Slab

Slab Reinforcement

a) Tangential Moments

$$\text{For } M_t = +3.62 \text{ t.m/m} \quad \text{at } (0.7\text{ R})$$

$$d = 35 - 5 - 0.9 = 29.1\ cm$$

$$\rho = \frac{0.85(300)}{4200}\left[1 - \sqrt{1 - \frac{2.61(10)^5(3.62)}{100(29.1)^2(300)}}\right] = 0.0011 < \rho_{\min}$$

$$A_{s,\min} = (\frac{0.003}{2})(100)(35) = 5.25\ cm^2/m$$

$$\text{Use } \phi\ 10 \text{ mm } @\ 12.5 \text{ cm } (\text{Bottom ring reinf.})$$

Tank Base Slab

Slab Reinforcement

a) Tangential Moments

For $M_t = -0.51$ t.m/m $\left(\text{at inside face of wall}\right)$

$$d = 35 - 5 - 0.9 = 29.1\ cm$$

$$\rho = \frac{0.85(300)}{4200}\left[1 - \sqrt{1 - \frac{2.61(10)^5(0.51)}{100(29.1)^2(300)}}\right] = 0.00016 < \rho_{\min}$$

$$A_{s,\min} = \left(\frac{0.003}{2}\right)(100)(35) = 5.25\ cm^2 / m$$

Use ϕ10 mm @ 12.5 cm $\left(\text{top ring reinf.}\right)$

Tank Base Slab

Slab Reinforcement

b) Radial Moments

At inside face of the wall $M_u = -9.74\ t.m/m$

$$d = 35 - 5 - 0.9 = 29.1\ cm$$

$$\rho = \frac{0.85(300)}{4200}\left[1 - \sqrt{1 - \frac{2.61(10)^5(9.74)}{100(29.1)^2(300)}}\right] = 0.00316 > \rho_{\min}$$

$$A_s = (0.0031)(100)(29.1) = 9.02\ cm^2/m$$

Use ϕ12 mm @ 12.5 cm

$$A_s total = 2\pi(5.0)(9.02) = 283.37\ cm^2$$

Tank Base Slab

Slab Reinforcement

b) Radial Moments

At max. + ve moment $M_u = 11.43\ t.m/m$ (at 0.6 R)

$$d = 35 - 5 - 0.9 = 29.1\ cm$$

$$\rho = \frac{0.85(300)}{4200}\left[1 - \sqrt{1 - \frac{2.61(10)^5(11.43)}{100(29.1)^2(300)}}\right] = 0.00367 > \rho_{\min}$$

$$A_s = (0.00367)(100)(29.1) = 10.68\ cm^2/m$$

$$A_s total = 2\pi(0.6 \times 5.0)(10.68) = 201.31\ cm^2$$

Tank Base Slab

Slab Reinforcement

b) Radial Moments

At max. + ve moment $M_u = 11.43\ t.m/m \quad (\text{at } 0.6\ \text{R})$

$$d = 35 - 5 - 0.9 = 29.1\ cm$$

$$\rho = \frac{0.85(300)}{4200}\left[1 - \sqrt{1 - \frac{2.61(10)^5(11.43)}{100(29.1)^2(300)}}\right] = 0.00367 > \rho_{\min}$$

$$A_s = (0.00367)(100)(29.1) = 10.68\ cm^2/m$$

$$A_s total = 2\pi(0.6\times 5.0)(10.68) = 201.31\ cm^2$$

Tank Base Slab

Slab Reinforcement

b) Radial Moments

At 0.15 R

It is reasonable to use a 25% reduction to the theoretical moment at the column capital

$$M_u = -43.58(0.75) = -32.69\ t.m/m$$

$$d = 50 - 5 - 0.9 = 44.1\ cm$$

$$\rho = \frac{0.85(300)}{4200}\left[1 - \sqrt{1 - \frac{2.61(10)^5(32.69)}{100(44.1)^2(300)}}\right] = 0.00466 > \rho_{\min}$$

$$A_s = (0.00461)(100)(44.1) = 20.29\ cm^2/m$$

$$A_s total = 2\pi(0.15 \times 5.0)(20.29) = 95.6\ cm^2$$

Use 32ϕ20 mm @ 12.5 cm

Tank Base Slab

Slab Reinforcement

b) Radial Moments

At 0.2 R

$$M_u = -21.82(0.75) = -16.37 \ t.m/m$$

$$d = 50 - 5 - 0.9 = 44.1 \ cm$$

$$\rho = \frac{0.85(300)}{4200}\left[1 - \sqrt{1 - \frac{2.61(10)^5(16.379)}{100(44.1)^2(300)}}\right] = 0.0023 > \rho_{\min}$$

$$A_s = (0.0023)(100)(44.1) = 10.14 \ cm^2/m$$

$$A_s total = 2\pi(0.2 \times 5.0)(10.14) = 63.73 \ cm^2$$

Tank Base Slab

Slab Reinforcement

b) Radial Moments

At 0.3 R

$$M_u = -1.55\ t.m/m$$

$$d = 35 - 5 - 0.9 = 29.1\ cm$$

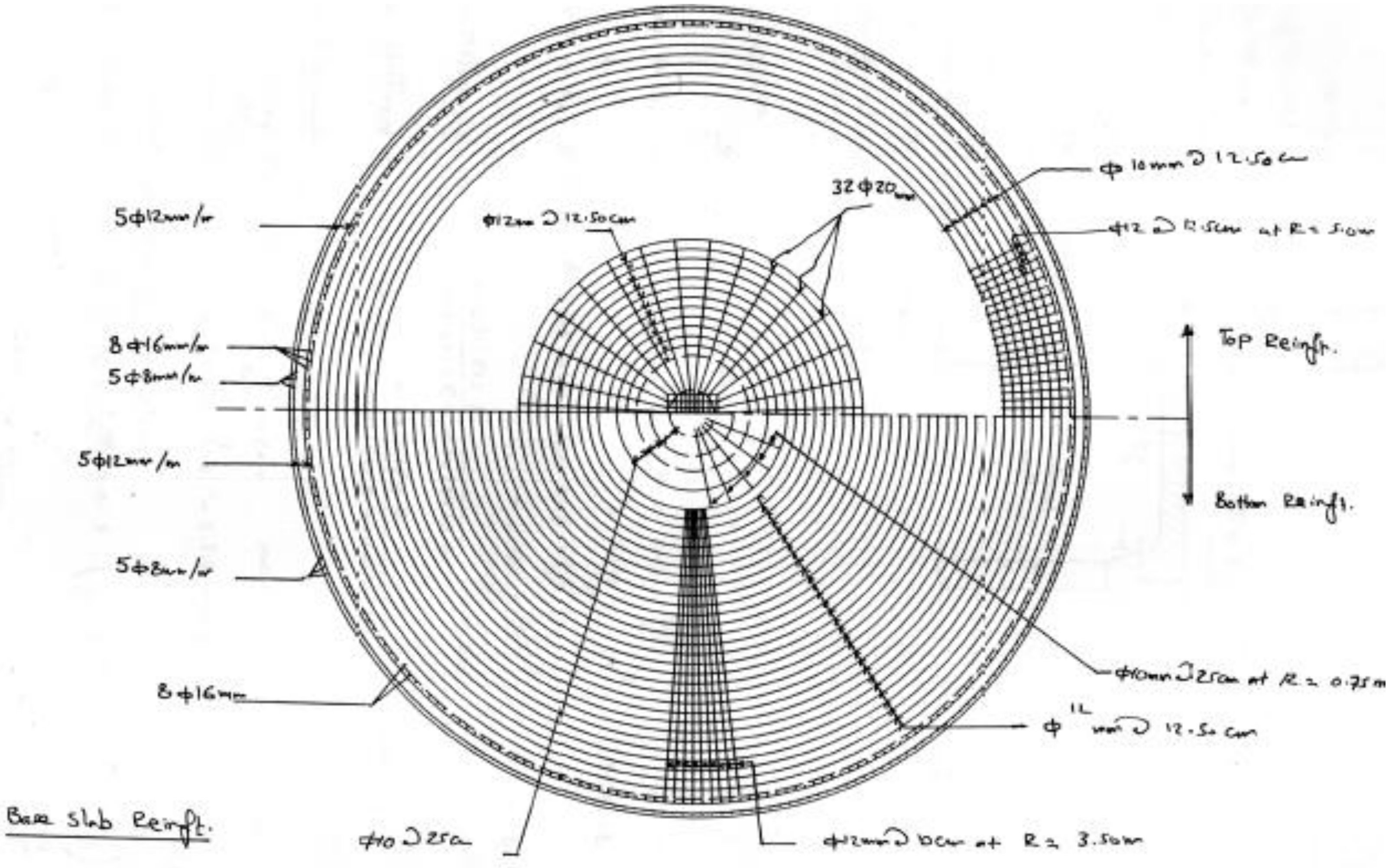
$$\rho = \frac{0.85(300)}{4200}\left[1 - \sqrt{1 - \frac{2.61(10)^5(1.55)}{100(29.1)^2(300)}}\right] = 0.00048 < \rho_{\min}$$

$$A_s = (0.0018)(100)(35) = 6.3\ cm^2/m$$

$$A_s total = 2\pi(0.3 \times 5.0)(6.3) = 95.4\ cm^2$$

Design of Circular Concrete Tanks

Circular Plate Reinforcement



Design of Circular Concrete Tanks

Radial Reinforcement

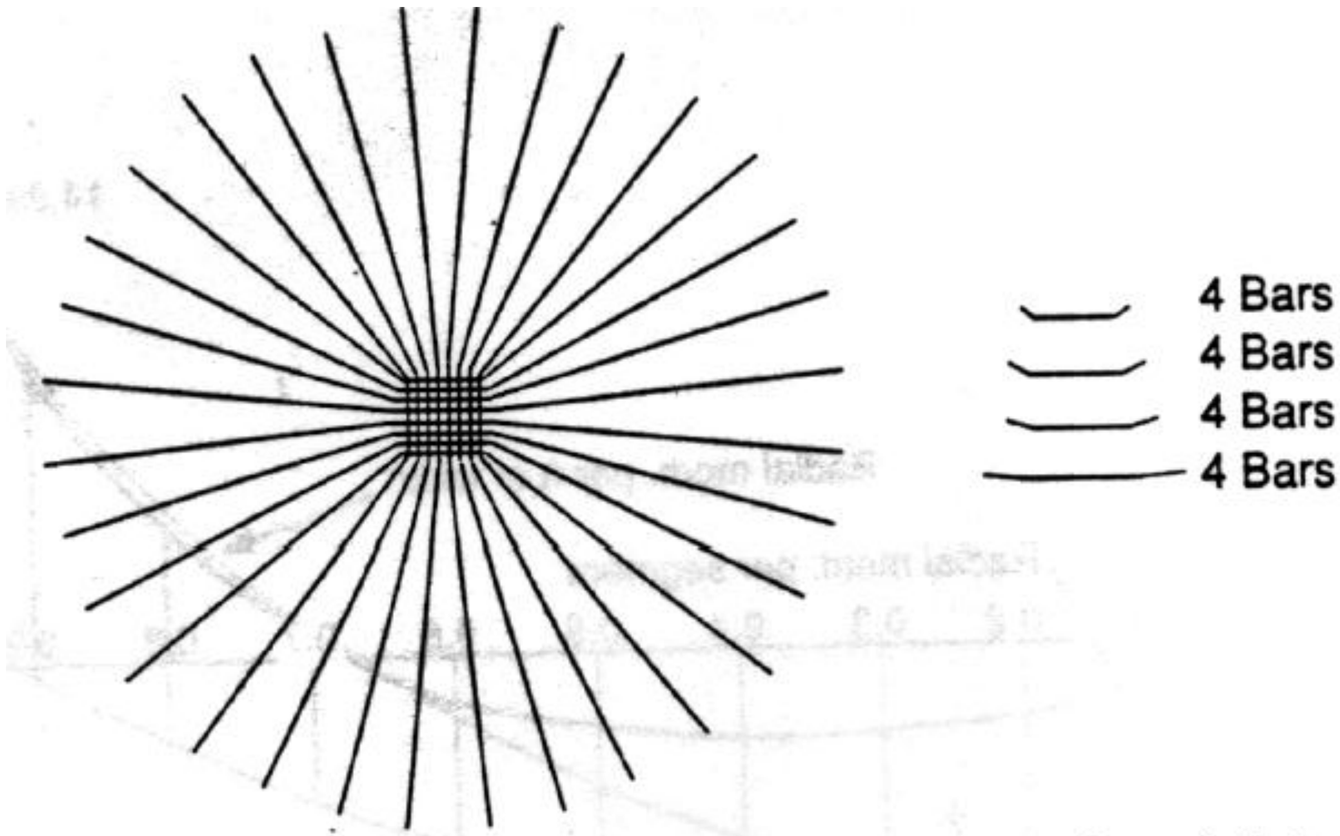
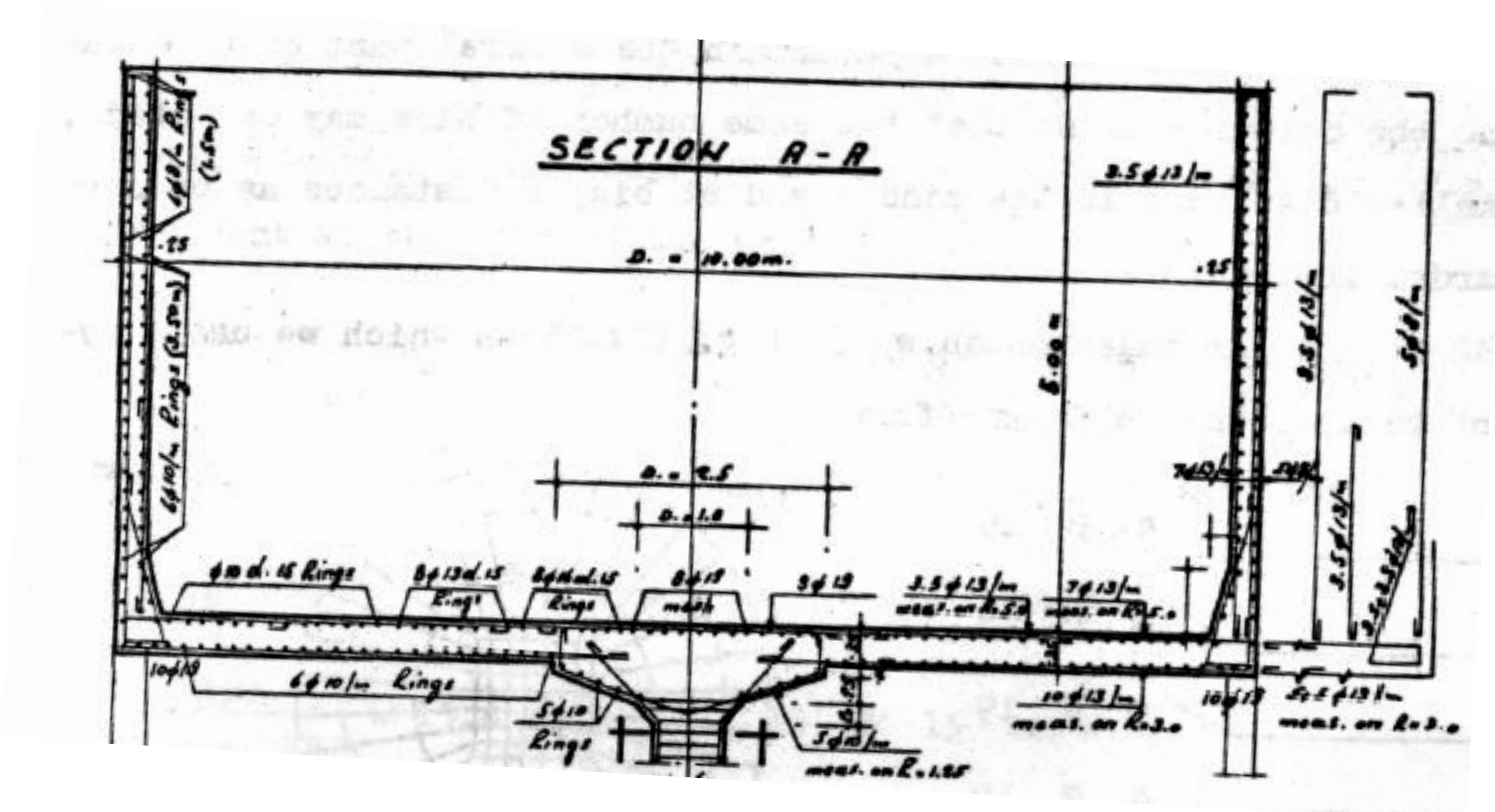


Figure 29—Radial reinforcement at center of roof slab without center support

Design of Circular Concrete Tanks

Radial Reinforcement



Home Work #1

Project # 1

Design an open circular water tank with a capacity of 500 m3.

Each group must submit the following documents:

1. Calculation Sheet with all assumptions.
2. All Civil works, Structural, reinforcement details, water stop details drawings
3. Bill of Quantities