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 Combination

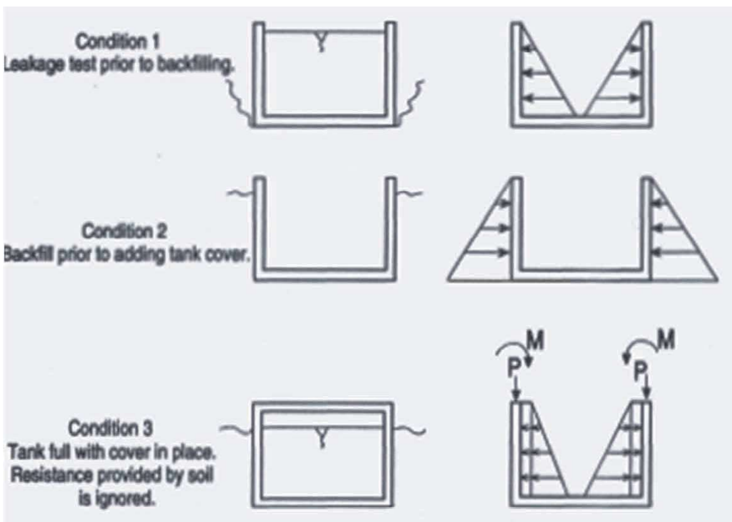

Figure 1—Possible loading conditions for a partially buried tank

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.

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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

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

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

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

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

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

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

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

Modification according to ACI 350-06

Load Combinations:

L = live loads, or related internal moments and force
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).

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

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

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

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

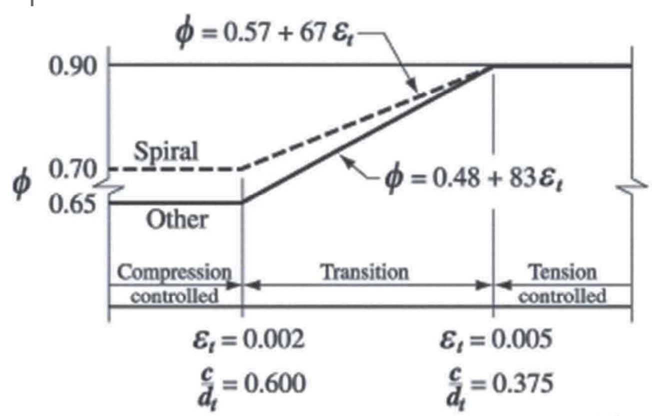
✓Compression-controlled sections,

❖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 ϕ Vc

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

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).

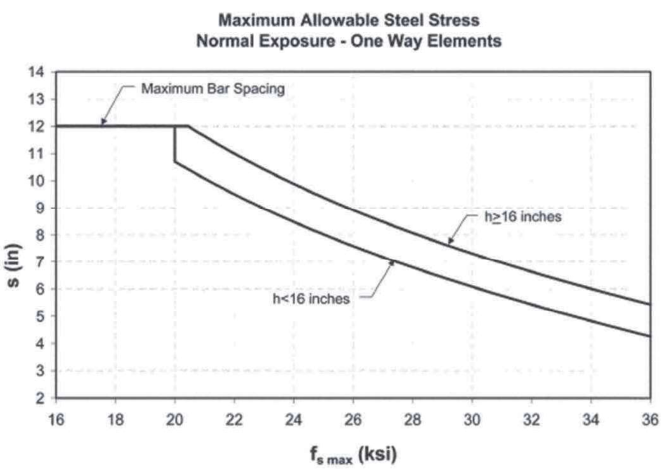
$\beta = 1.35$ for h $<$ 16 in (40cm).

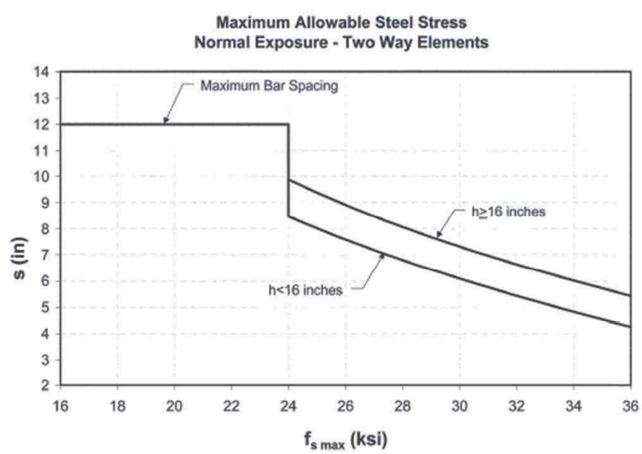
Modification according to ACI 350-06

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

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

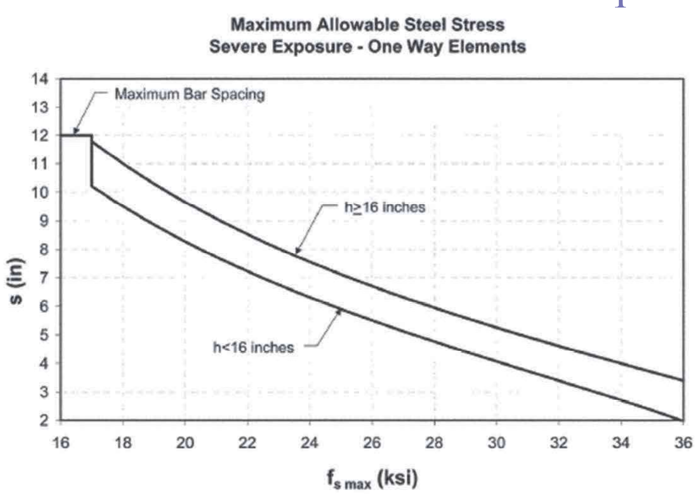
s = center-to-center spacing of deformed bars

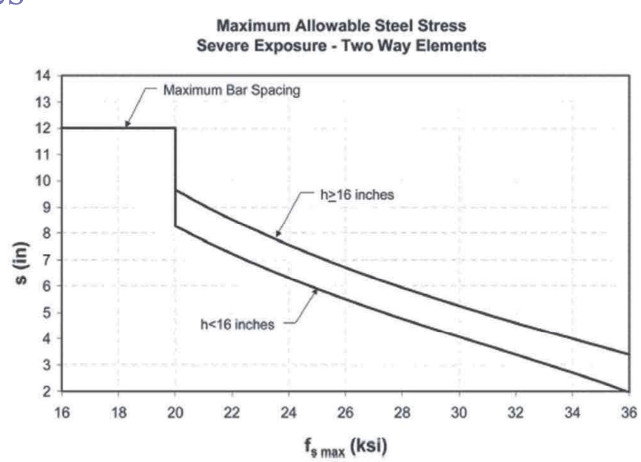
Modification according to ACI 350-06

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 $f_y/f_s \geq 1.0$

$$\text{Required Strength} \geq \frac{f_y}{f_s} \times \text{Service Load}$$

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% c 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}.

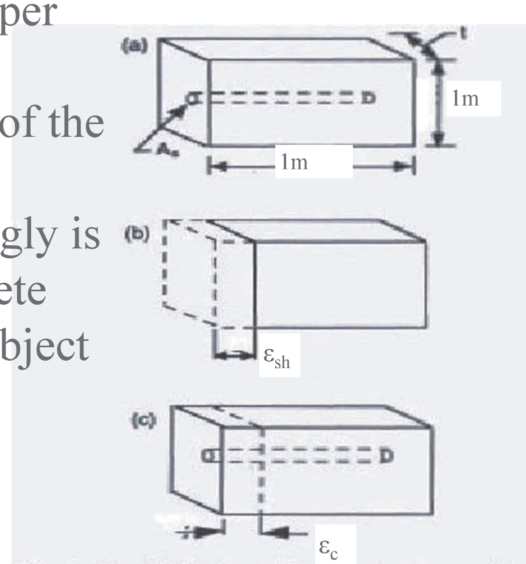


Figure 2—Shrinkage in a concrete section

Wall Thickness

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

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

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

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

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

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

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

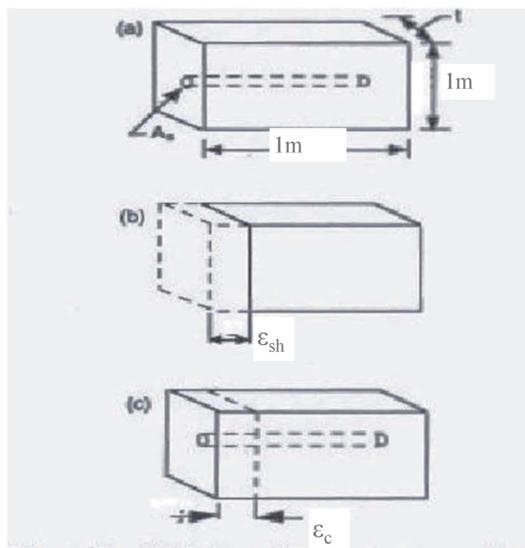


Figure 2—Shrinkage in a concrete section

Wall Thickness

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

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

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

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

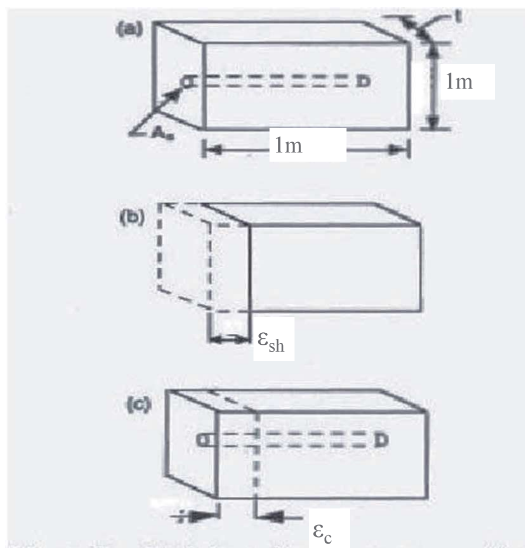


Figure 2—Shrinkage in a concrete section

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

$$t = \frac{\varepsilon_{\text{sh}} E_s + \text{f}_s - n\text{f}_{ct}}{100\text{f}_s \text{f}_{ct}} T$$

- 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, Es=2.04*10^6 kg/cm2 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

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

$$E_c = 15100\sqrt{300} = 261540 kg/cm^2$$

Where T is in kg

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

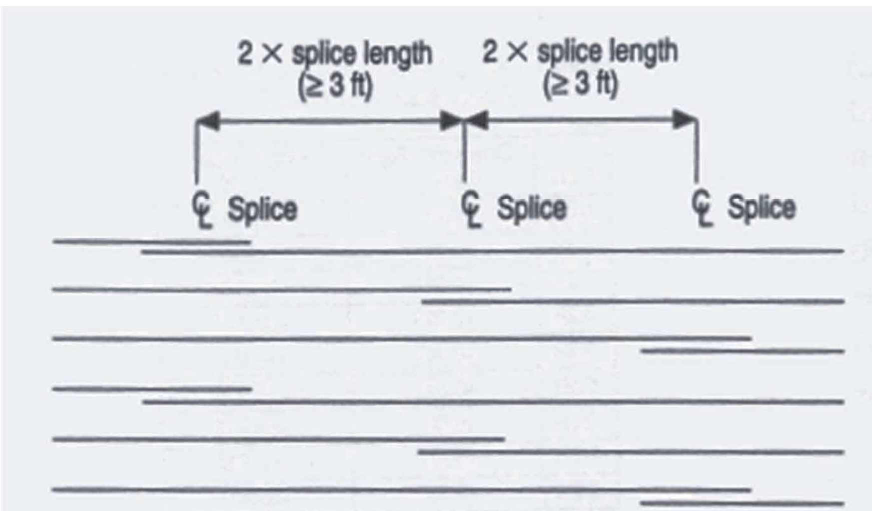


Figure 4—Staggering of ring bar splices

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

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

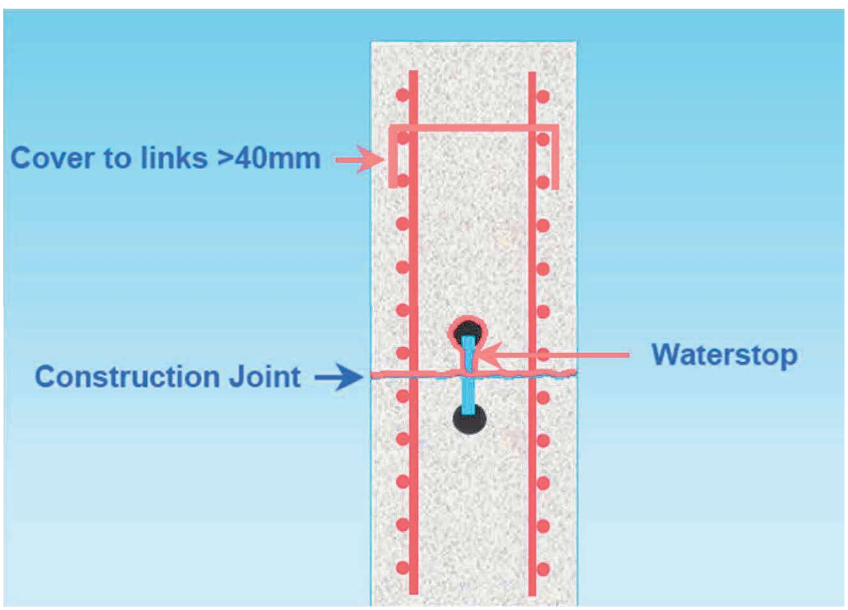
Where

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)

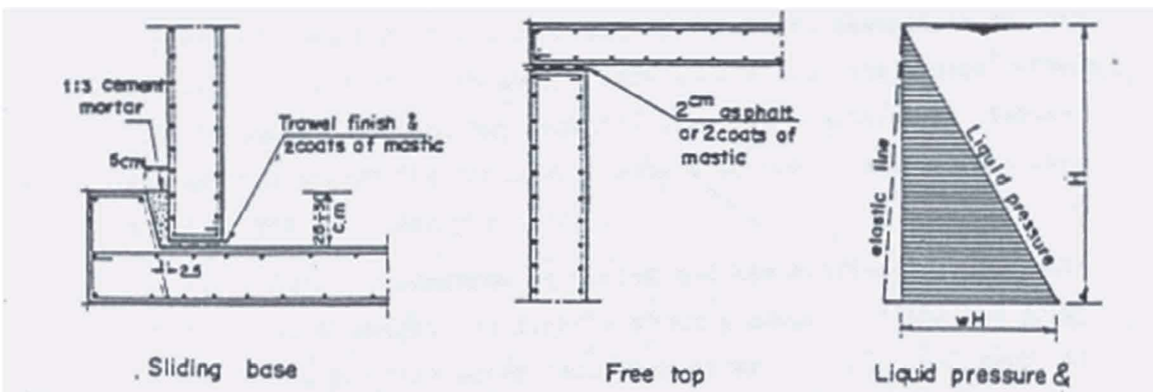
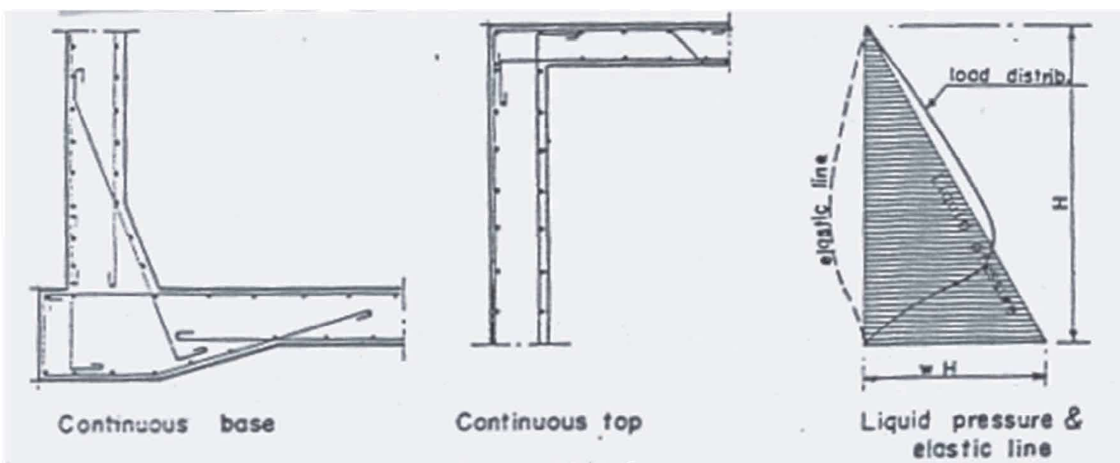


Fig. III-1

Design of Circular Concrete Tanks

Types of Wall Joints

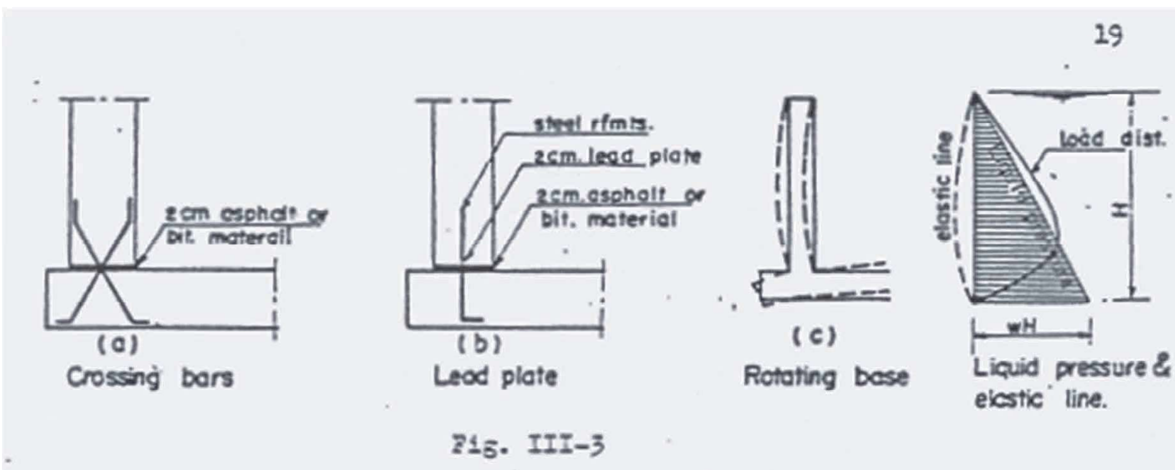
Fixed Joint (Continuous joint)



Design of Circular Concrete Tanks

Types of Wall Joints

Hinged Joint



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.