

QUESTION BANK
CE6702 – PRESTRESSED CONCRETE STRUCTURES
UNIT 3 - DEFLECTION AND DESIGN OF ANCHORAGE ZONE
PART – A (2 marks)

1. What are the functions of water stopper (water bar) in water tank construction?

(AUC May/June 2013)

- The base slab is subdivided by joints which are sealed by water stops.
- The reinforcement in the slab should be well distributed to control the cracking of the slab due to shrinkage and temperature.

2. Differentiate prestressed cylinder and non-cylinder pipe.

(AUC May/June 2013)

Prestressed cylinder pipe:

- It is developed by the Lock Joint Company.
- A welded cylinder of 16 gauge steel is lined with concrete inside and steel pipe wrapped with a highly stressed wire.
- Tubular fasteners are used for the splices and for end fixing of the wire and pipe is finished with a coating of rich mortar.
- It is suitable upto 1.2 m diameter.

Prestressed non-cylinder pipe:

- It is developed by Lewiston Pipe Corporation.
- At first concrete is cast over a tensioned longitudinal reinforcement.
- A concrete pipes after curing are circumferentially stressed by means of a spiral wire wound under tension and protected by a coat of mortar.
- The main function of longitudinal prestress is to prevent cracking in concrete during circumferential winding and cracking due to the bending stresses developed during the handling and installation of pipes.

3. Define circular prestressing.

(AUC Nov/Dec 2011, 2012, 2013, 2010)

When the prestressed members are curved in the direction of prestressing, the prestressing is called circular prestressing.

For example, circumferential prestressing in pipes, tanks, silos, containment structures and similar structures is a type of circular prestressing.

4. What are the design criteria for prestressed concrete tanks?

(AUC Nov/Dec 2011)

- It is to resist the hoop tension and moments developed are based on the considerations of desirable load factors against cracking and collapse.
- It is desirable to have at least a minimum load factor of 1.2 against cracking and 2 against ultimate collapse as per IS code.
- It is desirable to have at least a minimum load factor of 1.25 against cracking and 2.5 against ultimate collapse as per BS code.
- The principal compressive stress in concrete should not exceed one-third of the characteristic cube strength.
- When the tank is full, there should be a residual compressive stress of at least

0.7 N/mm².

- When the tank is empty, the allowable tensile stress at any point is limited to 1 N/mm².
- The maximum flexural stress in the tank walls should be assumed to be numerically equal to 0.3 times the hoop compression.

5. What are the design criteria for prestressed concrete pipes? (AUC Nov/Dec 2012)

- Circumferential prestressing, winding with or without longitudinal prestressing.
- Handling stresses with or without longitudinal prestressing.
- Condition in which a pipe is supported by saddles at extreme points with full water load but zero hydrostatic pressure.
- Full working pressure conforming to the limit state of serviceability.
- The first crack stage corresponding to the limit state of local damage.

6. How are the tanks classified based on the joint? (AUC Nov/Dec 2013)

- Tank wall with fixed base.
- Tank wall with hinged base.
- Tank wall with sliding base.

7. Define two stage constructions. (AUC Apr/May 2012)

In the first the concrete is cast over a tensioned longitudinal reinforcement. In the second stage the concrete pipes after curing are circumferentially stressed by means of a spiral wire wound under tension and protected by a coat of mortar.

8. Write any two general failures of prestressed concrete tanks. (AUC Apr/May 2012)

- Deformation of the pre-cast concrete units during construction.
- Manufacturing inaccuracies led to out of tolerance units being delivered to the site under investigation.
- It May have affected the ability to achieve a good seal.

9. What is the stress induced in concrete due to circular prestressing? (AUC Apr/May 2010)

The circumferential hoop compression stress is induced in concrete by prestressing counterbalances the hoop tension developed due to the internal fluid pressure.

10. Explain the effect of prestressing force in concrete poles. (AUC Apr/May 2010)

It should be reduced in proportion to the cross section by the techniques of debonding or dead ending or looping some of the tendons at mid height.

11. Write the various types of loadings that act on prestressed concrete poles.

(AUC Nov/Dec 2010)

- Bending due to wind load on the cable and on the exposed face.
- Combined bending and torsion due to eccentric snapping of wires.
- Maximum torsion due to skew snapping of wires.
- Bending due to failure of all the wires on one side of the pole.
- Handling and erection stresses.

12. What are the advantages of prestressing water tanks? (AUC Apr/May 2011)

- Water storage tanks of large capacity are invariably made of prestressed concrete.
- Square tanks are used for storage in congested urban and industrial sites where land space is a major constraint.
- This shape is considerable reduction in the thickness of concrete shell.
- The efficiency of the shell action of the concrete is combined with the prestressing at the edges.

13. How are sleepers prestressed?

(AUC Apr/May 2011)

- Two block sleepers
- Longitudinal sleepers
- Beam type single piece prestressed concrete sleepers.

14. Mention the importance of shrinkage in composite construction?

The time dependent behavior of composite prestressed concrete beams depends upon the presence of differential shrinkage and creep of the concretes of web and deck, in addition to other parameters, such as relaxation of steel, presence of untensioned steel, and compression steel etc.

15. What are the different types of joints used between the slabs of prestressed concrete tanks?

- Movement joint
- Expansion joint
- Construction Joint
- Temporary Open Joints.

16. What are the advantages of partially prestressed concrete poles?

- Resistance to corrosion in humid and temperature climate and to erosion in desert areas.
- Easy handling due to less weight than other poles.
- Easily installed in drilled holes in ground with or without concrete fill.
- Lighter because of reduced cross section when compared with reinforced concrete poles.
- Fire resisting, particularly grassing and pushing fire near ground line.

17. What are the types of prestressed concrete pipes?

- Monolyte construction
- Two stage construction

18. Distinguish between non-cylinder and cylinder pipes.

Non-cylinder pipes:

The design principles are used for determining the minimum thickness of concrete required and the pitch of circumferential wire winding on the pipe.

Cylinder pipes:

The design principles of cylinder pipes are similar to those of the non-cylinder pipes except that the required thickness of concrete is computed by considering the equivalent area of the light gauge steel pipe embedded in the concrete.

19. Define the losses of prestress.

Due to elastic deformation of concrete during circumferential wire winding, there is a loss of prestress which depends upon the modular ratio and the reinforcement ratio.

20. What are the advantages of prestressed concrete piles?

- High load and moment carrying capacity.
- Standardization in design for mass production.
- Excellent durability under adverse environmental conditions.
- Crack free characteristics under handling and driving.
- Resistance to tensile loads due to uplift.
- Combined load moment capacity.

PART – B (16 marks)

1. Design a cylindrical prestressed concrete water tank to suit the following data:

Capacity of tank = 24500×10^6 liters. Maximum compressive stress in concrete at transfer not to exceed 13 N/mm^2 (compression). Minimum compressive stress under working load to be 1 N/mm^2 . The prestress is to be provided by circumferential winding of 7 mm dia with an initial stress of 1000 N/mm^2 and by vertical cables of 12 wires of 8 mm diameter which are stressed to 1200 N/mm^2 . Loss ratio = 0.75. The cube strength of concrete is 40 N/mm^2 . Design the walls of the tank and details of circumferential wire winding and vertical cables for the following joint condition at the base: elastomeric pads (assume coefficient of friction as 0.5). (AUC May/June 2013, Nov/Dec 2013, Apr/May 2011)

Solution:

Volume of tank = 24500×10^6 litres

Assuming the diameter of tank as 50 m ,

height of storage = 12.5 m

From Table 16.1, the thickness of the tank wall at the base is taken as 400 mm which gradually reduces to 200 mm towards the top of tank.

Hydrostatic pressure, $W_w = wH = (10 \times 12.5) = 125 \text{ kN/m}^2 = 0.125 \text{ N/mm}^2$

Maximum ring tension, $N_d = (10 \times 12.5 \times 25) = 3125 \text{ kN/m}$

Self-weight of the wall = $(12.5 \times 0.3 \times 1 \times 24) = 90 \text{ kN/m}$

Frictional force at base, $N_o = (0.5 \times 90) = 45 \text{ kN/m}$

Minimum wall thickness at base = $\frac{3125}{(0.75 \times 13) - (1)} = 360 \text{ mm}$

Net thickness available (allowing for vertical cables of diameter 40 mm) is $(400 - 40) = 360 \text{ mm}$

Circumferential prestress,

$$f_c = \frac{3125}{0.75 \times 360} + \frac{1}{0.75} = 13 \text{ N/mm}^2$$

Spacing of circumferential wire winding is

$$s = \frac{2 \times 3125}{0.125} \times \frac{1000 \times 38.5}{13 \times 50 \times 10^3 \times 360} = 8.3 \text{ mm}$$

Number of wires/metre = 120

Ring tension at 0.75 m from top = $(10 \times 0.75 \times 25) = 188 \text{ kN/m}$

Thickness at top = 200 mm

Net thickness = $(200 - 40) = 160 \text{ mm}$

$$f_c = \frac{188}{0.75 \times 160} + \frac{1}{0.75} = 2.91 \text{ N/mm}^2$$

$$s = \frac{2 \times 188}{0.125} \times \frac{1000 \times 38.5}{2.91 \times 50 \times 10^3 \times 160} = 50 \text{ mm}$$

Number of wires at top/metre = 20

Maximum radial pressure due to prestress at transfer,

$$w_t = \frac{2 \times 1000 \times 38.5}{8.3 \times 50 \times 10^3} = 0.186 \text{ N/mm}^2$$

Maximum vertical moment due to working pressure,

$$M_w = 0.247 N_o \sqrt{Rt} = 0.247 \times 45 \sqrt{25 \times 0.4} = 35.5 \text{ kN m/m} \\ = 35500 \text{ N mm/m}$$

Maximum vertical moment due to prestress is

$$M_t = 35500 \left(\frac{0.186}{0.125} \right) = 53000 \text{ N mm/mm} = 53 \times 10^6 \text{ N mm/m}$$

Considering one metre length of tank along the circumference, the section modulus is

$$Z = \frac{1000 \times 400^2}{6} = 26.6 \times 10^6 \text{ mm}^3$$

The vertical prestress required,

$$f_c = \left[\frac{1}{0.75} + \frac{53 \times 10^6}{26.6 \times 10^6} \right] = 3.33 \text{ N/mm}^2$$

As per the IS code, the minimum vertical prestress required to counteract the winding stresses is,

$$= (0.3 \times 13) = 3.9 \text{ N/mm}^2$$

$$\therefore \text{ Vertical prestressing force} = \frac{(3.9 \times 1000 \times 400)}{(1000)} = 1560 \text{ kN}$$

$$\text{Spacings of vertical cables} = \frac{1000 \times 720}{1560} = 460 \text{ mm}$$

Ultimate tensile force in wires at base of tank

$$= \frac{(120 \times 38.5 \times 1500)}{(1000)} = 6900 \text{ kN}$$

$$\text{Load factor against collapse} = \frac{6900}{3125} = 2.2$$

$$\text{Cracking load} = (1000 \times 400) \frac{(0.75 \times 13 + 1.7)}{(1000)} = 4580 \text{ kN}$$

$$\text{Factor of safety against cracking} = \frac{4580}{3125} = 1.47$$

Nominal reinforcements of 0.2 per cent of the cross-section in the circumferential and vertical direction are well distributed on each face.

2. Design a non – cylinder prestressed concrete pipe of 600 mm internal diameter to withstand a working hydrostatic pressure of 1.05 N/mm^2 , using a 2.5 mm high – tensile wire stressed to 1000 N/mm^2 at transfer. Permissible maximum and minimum stresses in concrete at transfer and service loads are 14 and 0.7 N/mm^2 . The loss ratio is 0.8. calculate also the test pressure required to produce a tensile stress of 0.7 N/mm^2 in concrete when applied immediately after tensioning and also the winding stress in steel if $E_s = 28 \text{ kN/mm}^2$ and $E_c = 35 \text{ kN/mm}^2$. (AUC May/June 2013)

Solution:

$$t > \frac{N_d}{\eta f_{ct} - f_{\min.w}} > \frac{1.05(600/2)}{0.8 \times 14 - 0.7} > 30 \text{ mm}$$

For a 30 mm thick concrete pipe, the actual compressive stress in concrete $f_c = 14 \text{ N/mm}^2$.

The number of turns of the 2.5 mm wire stressed to 1000 N/mm^2 per metre length of the pipe is given by,

$$n = \frac{4000 f_c}{\pi d^2 f_s} = \frac{4000 \times 30 \times 14}{\pi \times 2.5^2 \times 1000} = 86 \text{ turns/m}$$

$$\text{Pitch of circumferential wire winding} = \frac{1000}{86} = 11.6 \text{ mm}$$

If W_w = test pressure required immediately after winding, ($\eta = 1$)

$$f_c = \frac{W_w D}{2 \eta t} + \frac{f_{\min.w}}{\eta}$$

$$\begin{aligned} W_w &= \frac{2t}{D} (f_c - f_{\min.w}) \\ &= \frac{2 \times 30}{600} [14 - (-0.7)] = 1.47 \text{ N/mm}^2 \end{aligned}$$

If f_{si} = winding stress in steel,

$$f_{si} = (1 + \alpha_e \rho) f_{se}$$

$$\alpha_e = 6 \text{ and } \rho = \frac{f_c}{f_s} = \frac{14}{1000} = 0.014$$

$$\begin{aligned} f_{si} &= (1 + 6 \times 0.014) 1000 \\ &= 1084 \text{ N/mm}^2 \end{aligned}$$

3. Discuss in detail about the design procedure for prestressed concrete tanks.
(AUC Nov/Dec 2011& 2012, Apr/May 2010)

Solution:

1. Estimate the maximum ring tension, N_d , and bending moment, M_w , in the wall of the tank using the IS code Tables 16.2 to 16.5.

2. Minimum wall thickness = $\frac{N_d}{\eta f_{ct} - f_{\min.w}}$

The thickness of the wall provided should be such that a minimum cover of 35 mm is available to the vertical prestressing cables. In practice, the walls are seldom less than 120 mm thick to ensure proper compaction of concrete.

3. The circumferential prestress required is given by

$$f_c = \frac{N_d}{\eta t} + \frac{f_{\min.w}}{\eta} \text{ N/mm}^2$$

4. The spacing of wires required at any section is obtained by considerations of the hoop tension due to fluid pressure and hoop compression due to the circumferential wire winding, as follows:

If A_t = cross-sectional area of wire winding, mm^2

w_t = average radial pressure of wires at transfer at a given section, N/mm^2

D = diameter of the tank, mm

s = spacing of wires at the given section, mm

4. A non – cylinder prestressed concrete pipe of internal diameter 1000 mm and thickness of concrete shell 75 mm is required to convey water at a working pressure of 1.5 N/mm^2 . The length of each pipe is 6 m. the maximum direct compressive stresses in concrete are 15 and 2 N/mm^2 . The loss ratio is 0.8.
- Design the circumferential wire winding using 5 mm diameter wires stressed to 1000 N/mm^2 .
 - Design the longitudinal prestressing using 7 mm wires tensioned to 1000 N/mm^2 . The maximum permissible tensile stress under the critical transient loading (wire wrapping at spigot end) should not exceed $0.8 \sqrt{f_{ci}}$, where f_{ci} is the cube strength of concrete at transfer = 40 N/mm^2 .
 - Check for safety against longitudinal stresses that develop, considering the pipe as a hollow circular beam as per IS: 784 provisions. (AUC Nov/Dec 2011& 2012)

Solution:

$$\begin{aligned} D &= 1000 \text{ mm} & f_{ci} &= 15 \text{ N/mm}^2 \\ W_w &= 1.5 \text{ N/mm}^2 & f_{\min, w} &= 2 \text{ N/mm}^2 \\ t &= 75 \text{ mm} & f_s &= 1000 \text{ N/mm}^2 \\ L &= 6 \text{ m} \end{aligned}$$

(a) Circumferential wire winding

Compressive stress in concrete,

$$f_c = \frac{N_d}{\eta t} + \frac{f_{\min, w}}{\eta} = \frac{1.5(1000/2)}{0.8 \times 75} + \frac{2}{0.8} = 15 \text{ N/mm}^2$$

Number of turns,

$$n = \frac{4000 f_c}{\pi d^2 f_s} = \frac{4000 \times 75 \times 15}{\pi \times 5^2 \times 1000} = 57 \text{ turns/m}$$

$$\text{Pitch of winding} = \frac{1000}{57} = 17.5 \text{ mm}$$

(b) Longitudinal prestressing

$$\begin{aligned} \text{Critical transient stress at spigot end} &= 0.6 \times \text{hoop stress} = 0.6 \times 15 \\ &= 9 \text{ N/mm}^2 \end{aligned}$$

$$\text{Maximum permissible tensile stress} = 0.8 \sqrt{f_{ci}} = 0.8 \sqrt{40} = 5 \text{ N/mm}^2$$

Hence the tensile stress of $9 - 5 = 4 \text{ N/mm}^2$ should be counterbalanced by longitudinal prestressing. Cross-sectional area of the pipe

$$= (\pi \times 1.075 \times 0.075) \text{ m}^2$$

If P is the longitudinal prestressing force required, then

$$P = \frac{\pi \times 1.075 \times 0.075 \times 10^6 \times 4}{10^3} = 1013 \text{ kN}$$

Using 7 mm wires stressed to 1000 N/mm^2 ,

Force in each wire = 38.5 kN

$$\therefore \text{Number of wires} = \frac{1013}{38.5} = 27$$

(c) Check for flexural stresses as per IS: 784

Considering the pipe as a beam of hollow circular section over a span of 6 m,

$$\text{Three times self-weight} = 3\pi \times 1.075 \times 0.075 \times 24 = 18.30 \text{ kN/m}$$

$$\text{Weight of water} = (\pi \times 1^2 \times 10)/4 = 7.90 \text{ kN/m}$$

$$\text{Total u.d.l on pipe} = 26.20 \text{ kN/m}$$

$$\text{Maximum bending moment} = \frac{26.2 \times 6^2}{8} = 118 \text{ kN m}$$

$$\text{Second moment of area, } I = \frac{\pi(1.15^4 - 1^4)}{64} = 0.0365 \text{ m}^4$$

$$\text{Flexural tensile stress} = \frac{118 \times 10^6 \times 575}{0.0365 \times 10^{12}} = 1.88 \text{ N/mm}^2 \text{ (tension)}$$

$$\text{Longitudinal prestress} = 4 \text{ N/mm}^2$$

$$\therefore \text{Resultant stress in concrete} = 4 - 1.88 = 2.12 \text{ N/mm}^2 \text{ (compression)}$$

The resultant stress being compressive, the pipe is safe against cracking.

5. A prestressed concrete pipe of 1.2 m diameter, having a core thickness of 75 mm is required to withstand a service pressure intensity of 1.2 N/mm^2 . Estimate the pitch of 5 mm diameter high tensile wire winding if the initial stress is limited to 1000 N/mm^2 . Permissible stresses in concrete being 12 N/mm^2 in compression and zero in tension. The loss ratio is 0.8, if the direct tensile strength of concrete is 2.5 N/mm^2 , estimate load factor against cracking. (AUC Nov/Dec 2013)

Solution:

Minimum thickness of pipe required,

$$t > \frac{1.0(1600/2)}{0.8 \times 12 - 0} > 84 \text{ mm}$$

Thickness provided = 100 mm

$$\therefore f_c = \frac{1 \times 1600}{2 \times 0.8 \times 100} = 10 \text{ N/mm}^2$$

$$\text{No. of wires/m, } n = \frac{4000 \times 100 \times 10}{\pi 5^2 \times 1000} = 51 \text{ turns/m}$$

$$\text{Pitch of winding} = \frac{1000}{51} = 19.6 \text{ mm}$$

$$\text{Hoop tension due to fluid to pressure} = \frac{1 \times 1600}{2 \times 100} = 8 \text{ N/mm}^2$$

Hoop compression due to prestress = 10 N/mm^2

\therefore Resultant compressive stress in concrete = $10 - 8 = 2 \text{ N/mm}^2$

Tensile strength of concrete = 2 N/mm^2

Additional fluid pressure required to develop a tensile stress of 4 N/mm^2 in concrete is given by,

$$= \frac{2 \times 100 \times 4}{1600} = 0.5 \text{ N/mm}^2$$

\therefore Cracking fluid pressure = $1 + 0.5 = 1.5 \text{ N/mm}^2$

Working pressure = 1 N/mm^2

Load factor against cracking = $1.5/1 = 1.5$

6. Explain the general features of prestressed concrete tanks. (AUC Apr/May 2012)

Prestressed concrete tanks have been widely used for the storage of fluids, such as water, oil, gas, sewage, granular materials like cement, process liquids and chemicals, slurries and, more recently, cryogenics¹². Water storage tanks of large capacity are invariably made of prestressed concrete. Recent applications include special forms of prestressed concrete tanks, which are triaxially prestressed and serve as containment vessels and biological shields for nuclear reactors.

Prestressed concrete tanks are generally cylindrical with diameters up to 100 m and liquid depths up to 36 m, and capacities of about 50 million litres. Tanks have been built for storing liquid oxygen at -230°C with capacities up to one million litres¹³. Prestressed concrete, although water-tight, is not gas-tight where vapours under pressure are to be stored. In such cases, a thin membrane liner of steel provides rigidity and increases the steel tensile capacity of the prestressed concrete. The metal liner concept has proved so successful that it is being increasingly used in America, even for large water tanks. In the case of sanitary structures like sludge digestion tanks spherical shapes are preferred and, for practical reasons, the tank is made up of a top and bottom conical shell connected by a circular cylindrical intermediate portion¹⁴.

An ingenious method of casting spherical shells at the centre with conical shapes towards the top and bottom was first adopted by Finsterwalder¹⁵ for the large sludge digestion tanks at the sewage treatment works in Berlin and Frankfurt, using a form work consisting of sectorial units which can be rotated about the central axis and the tank prestressed, sector wise, with coupled tendons and splices.

The most impressive example of a prestressed conical shell is the 58 m high tower at Orebro in Sweden which comprises a conical shell, with an external diameter of 46 m, supported on a tall tower. The tank with a water storage capacity of 9000 m^3 is prestressed by 206 Freyssinet cables each made up of 12 wires of 7 mm diameter¹⁶.

7. Explain the junctions of tank wall and base slab with neat sketch. (AUC Apr/May 2012)

The joint between the walls of the tank and floor slab may be any one of the following three types:

1. Fixed base
2. Hinged base
3. Sliding base

The ring tension and bending moments developed in the walls of the tank are mainly influenced by the type of connection between the walls and the base slab. The junction between the tank wall and footing is the most vulnerable location as far as leakage is concerned and hence in the case of tanks storing penetrating liquids, it is necessary to form the wall and footing in monolithic construction as shown in Fig. This type of connection is generally well suited for shallow tanks with diameters up to 30 m, where the fixing moment developed at the wall base does not result in excessively high stresses and congestion of reinforcement.

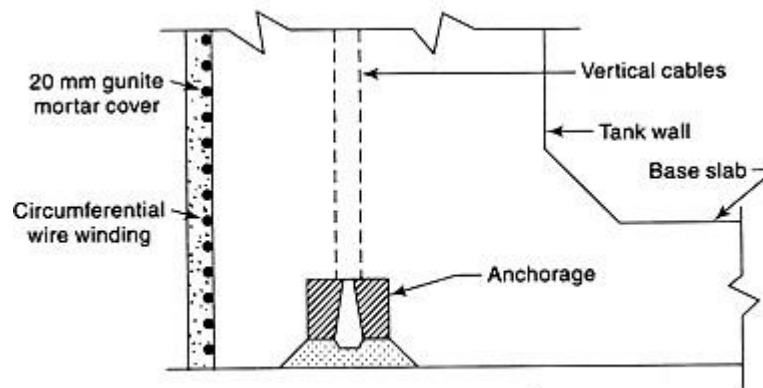


Fig. Tank Wall with Fixed Base

The hinged base is not generally adopted for prestressed concrete. An excellent example of resilient connection between the base and the wall can be found in the tanks designed by Buyer²². In this type, the tank wall is supported over an annular bearing resting on the footing from which the base slab is isolated by a joint containing a compressible filling. This arrangement facilitates the junction between the wall and the base slab to rotate about the annular bearing.

Alternatively, the hinged joint can also be formed by circumferential wire wrapping to the bottom portion of the wall and then packing the groove with cement mortar as shown in Fig.

In the case of large tanks and especially for those which have to store hot liquids, a movable or sliding joint is the ideal solution to minimise or completely eliminate the moments at the base of the wall. A sliding joint is made by interposing rubber or neoprene pads at the junction of the wall and the base. The Preload Engineering Company has developed this type of sliding base in which a vertical water stop is inserted between two rubber strips as shown in Fig. In the present state of art, single neoprene pads have also been used. The main function of these pads is to allow for free horizontal movement of the wall relative to the base by shear deformation of the rubber joint, which does not exceed a critical value of 30 degrees.

The horizontal shear force developed for producing this deformation is influenced by the thickness of the pad and the shore hardness of the material. The various methods of forming the joints between the tank walls and the base slab have been reported by Ager²³.

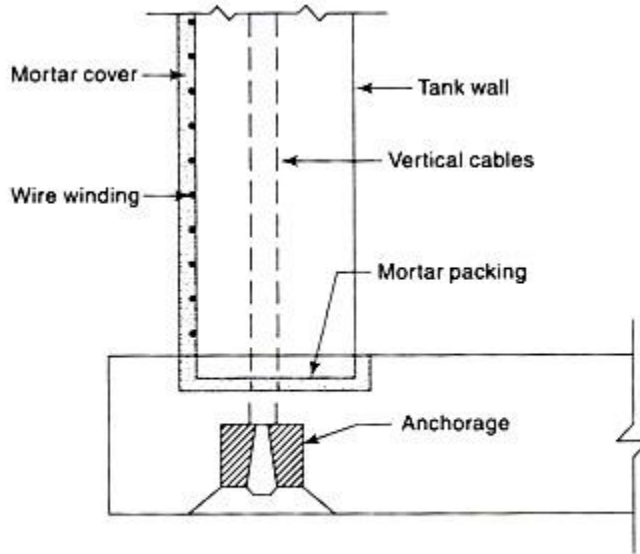


Fig. Tank Wall with Hinged Base

8. A cylindrical prestressed concrete water tank of internal diameter 30 m is required to store water over a depth of 7.5 m. The permissible compressive stress in concrete at transfer is 13 N/mm^2 and the minimum compressive stress under working pressure is 1 N/mm^2 , the loss ratio is 0.75, Wires of 5 mm dia with an initial stress of 1000 N/mm^2 are available for circumferential winding and freyssinet cables made up of 12 wires of 8 mm dia stressed to 1200 N/mm^2 are to be used for vertical prestressing. Design the tank walls assuming the base as fixed. The cube strength of concrete is 40 N/mm^2 . For the thickness of wall is 150 mm. (AUC Apr/May 2012)

Solution:

For the required depth of storage of 7.5 m and diameter 30 m, an average wall thickness of 150 mm is tentatively assumed based on Table 16.1,

$$D = 30 \text{ m}, H = 7.5 \text{ m and } t = 150 \text{ mm}, \eta = 0.75$$

$$\frac{H^2}{Dt} = \frac{7.5^2}{30 \times 0.15} = 12.5$$

$$w_w = wH = (10 \times 7.5) \text{ kN/m}^2 = 0.075 \text{ N/mm}^2$$

$$\text{maximum ring tension } N_d = (0.64 \times 10 \times 7.5 \times 15) = 720 \text{ kN/m} = 720 \text{ N/mm}$$

$$\text{maximum moments } M_w = (0.01 \times 10 \times 7.5^3) = 42.5 \text{ kN m/m} = 42500 \text{ N mm/mm}$$

Minimum wall thickness

$$t = \frac{N_d}{\eta f_{ct} - f_{\min.w}} = \frac{720}{(0.75 \times 13) - (1)} = 82.3 \text{ mm}$$

Net thickness available (allowing for vertical cables of diameter 30 mm) is = $(150 - 30) = 120 \text{ mm}$

Required circumferential prestress is,

$$f_c = \frac{N_d}{\eta t} + \frac{f_{\min, w}}{\eta}$$

$$f_c = \frac{720}{0.75 \times 120} + \frac{1}{0.75} = 9.4 \text{ N/mm}^2$$

Spacings of circumferential wire winding at base is,

$$s = \frac{2N_d}{w_w} \frac{f_s A_s}{f_c D t} = \frac{2 \times 720}{0.075} \times \frac{1000 \times 20}{9.4 \times 30 \times 10^3 \times 120} = 11.4 \text{ mm}$$

Number of wires/metre = 87

Ring tension N_d at 0.1 H (0.75 m) from top is

$$N_d = (0.097 \times 10 \times 7.5 \times 15) = 109 \text{ kN/m} = 109 \text{ N/mm}$$

$$f_c = \frac{109}{0.75 \times 120} + \frac{1}{0.75} = 2.5 \text{ N/mm}^2$$

$$s = \frac{2 \times 109}{0.075} \times \frac{1000 \times 20}{2.5 \times 30 \times 10^3 \times 120} = 64 \text{ mm}$$

Number of wires/metre at the top of tank = 16

Maximum radial pressure due to prestress is,

$$w_t = \frac{2f_s A_s}{sD} = \frac{2 \times 1000 \times 20}{11.4 \times 30 \times 10^3} = 0.117 \text{ N/mm}^2$$

Maximum vertical moment due to prestress is,

$$M_t = M_w \left(\frac{w_t}{w_w} \right) = 42500 \left(\frac{0.117}{0.075} \right) = 67,000 \text{ N mm/mm}$$

$$= 67 \times 10^6 \text{ Nmm/m}$$

Considering one metre length of tank along the circumference, the section modulus is,

$$Z = \frac{1000 \times 150^2}{6} = 375 \times 10 \text{ mm}^3$$

Vertical prestress required is,

$$f_c = \frac{f_{\min, w}}{\eta} + \frac{M_t}{Z} = \frac{1}{0.75} + \frac{67 \times 10^6}{375 \times 10^4} = 19.2 \text{ N/mm}^2$$

Since this stress exceeds the permissible value of $f_{ct} = 13 \text{ N/mm}^2$, the thickness of the tank wall at base is increased to 200 mm. Thus,

$$Z = \frac{1000 \times 200^2}{6} = 666 \times 10^4 \text{ mm}^3$$

$$f_c = \frac{1}{0.75} + \frac{67 \times 10^6}{666 \times 10^4} = 12 \text{ N/mm}^2$$

$$\text{Vertical prestressing force} = f_c A = \frac{(12 \times 1000 \times 200)}{(1000)} = 2400 \text{ kN}$$

Using 8 mm diameter (12 nos.) Freyssinet cables

$$\text{Force/cable} = \frac{(50 \times 12 \times 1200)}{(1000)} = 720 \text{ kN}$$

$$\therefore \text{ Spacings of vertical cables} = \frac{1000 \times 720}{2400} = 300 \text{ mm}$$

The approximate vertical prestress required to counteract winding stresses as per IS code is

$$= 0.3 f_c = (0.3 \times 9.4) = 2.82 \text{ N/mm}^2$$

$$\text{Vertical prestressing force required} = \frac{(2.82 \times 1000 \times 200)}{(1000)} = 564 \text{ kN}$$

$$\text{Ultimate tensile force in wires at base of tank} = \frac{(87 \times 20 \times 1500)}{(1000)} = 2610 \text{ kN}$$

$$\text{Load factor against collapse} = \frac{(2610)}{(720)} = 3.6$$

$$\text{Direct tensile strength of concrete} = 0.267 \sqrt{40} = 1.7 \text{ N/mm}^2$$

$$\text{Cracking load} = (1000 \times 200) \frac{(0.75 \times 9.4 + 1.7)}{(1000)} = 1760 \text{ kN}$$

$$\therefore \text{ Factor of safety against cracking} = \frac{(1760)}{(720)} = 2.45$$

9. What are the advantages of prestressed concrete poles and piles?

(AUC Apr/May 2010)

Advantages of prestressed concrete poles:

- Resistance to corrosion in humid and temperature climate and to erosion in desert areas.
- Easy handling due to less weight than other poles.
- Easily installed in drilled holes in ground with or without concrete fill.
- Lighter because of reduced cross section when compared with reinforced concrete poles.
- Fire resisting, particularly grassing and pushing fire near ground line.
- Freeze-thaw resistance in cold regions.
- Clean and neat in appearance and requiring negligible maintenance for a number of years, thus ideally suited for urban installations.
- Have increased crack resistance, rigidity and can resist dynamic loads better than reinforced concrete poles.

Advantages of prestressed concrete piles:

- High load and moment carrying capacity.
- Standardization in design for mass production.
- Excellent durability under adverse environmental conditions.
- Crack free characteristics under handling and driving.
- Resistance to tensile loads due to uplift.
- Combined load moment capacity.
- Good resistance to hand – driving loads and penetration into hard strata.
- Piles can be lengthened by splicing.

- Ease of handling, transporting and driving.
- Overall economy in production and installation.
- Adaptability to both developed and developing countries in tropical, sub – arctic and desert regions.
- Use of solid and hollow cross – sectional configurations to suit design requirements.
- Ease of connections with pile caps to form pier, trestle and jetty bents to support bridge or wharf decks.
- Effective use of fender piling to resist the kinetic energy of ship impact.
- Particularly advantageous for deep foundations to carry heavy loads in weak soils.

10. Briefly explain the design of prestressed concrete poles. Give some sketches suitable for prestressed concrete poles. (AUC Apr/May 2010 & 2011)

Prestressed concrete poles for power transmission lines are generally designed as members with uniform prestress since they are subjected to bending moments of equal magnitude in opposite directions.

The poles are generally designed for the following critical load conditions:

1. Bending due to wind load on the cable and on the exposed face,
2. combined bending and torsion due to eccentric snapping of wires,
3. maximum torsion due to skew snapping of wires,
4. bending due to failure of all the wires on one side of the pole, and
5. handling and erection stresses.

The load factors required for strength and serviceability are prescribed in the codes of various countries. The Indian standard code IS: 1678–1960⁶, provides for a load factor of 2.5 for transverse bending strength. German and erstwhile Czechoslovakian standards prescribe a load factor of 1.75 and 2.0 respectively against the limit state of collapse. The flexural strength of the pole in the direction of the cable line should be not less than one quarter of the strength in the transverse direction. Smaller load factors ranging from 1.1 to 1.5 are prescribed for failure due to combined bending and torsion as a result of snapping of wires. Under over-load conditions, progressive failure of the pole is ensured by designing the critical section as under-reinforced, which gives sample warning before failure. The use of mild or high-strength deformed bars, in addition to the high-tensile wires, would impart sufficient ductility to the member.

In the case of tapered poles with a reduced cross-section towards the top, the effective prestressing force should be reduced in proportion to the cross-section by the techniques of debonding or by dead ending or looping some of the tendons at mid height. According to Gerwick⁷, a constant cross-section proves to be a better solution in many cases since the top must be as strong as the base for resisting torsion, with the added advantage of the effective use of prestressing and easier connections.

Cross section of prestressed concrete poles:

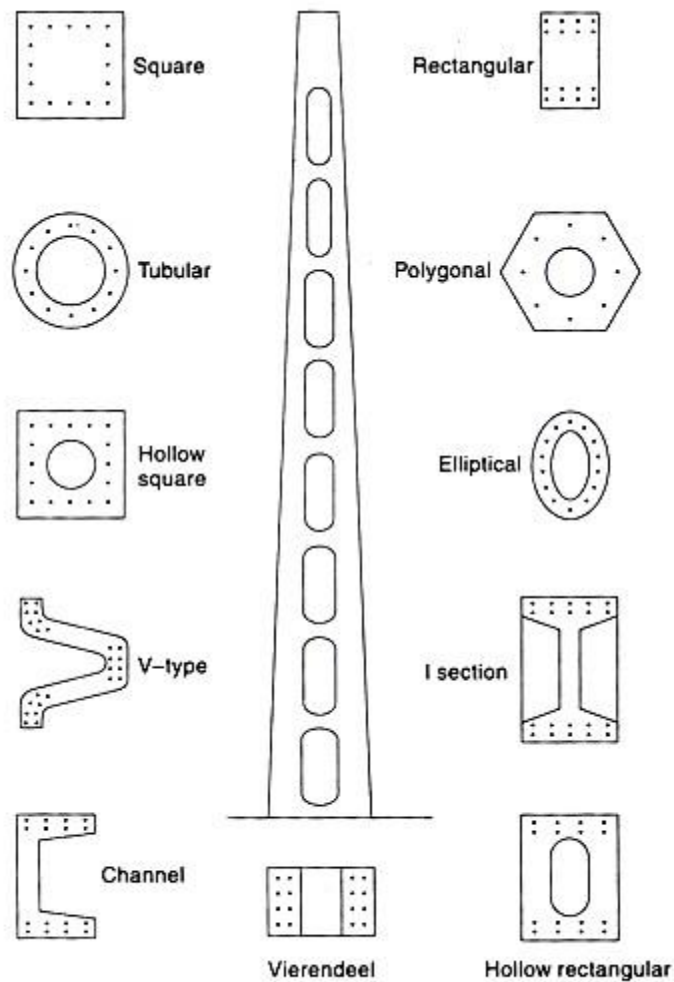


Fig. Cross-sections of Prestressed Concrete Poles