prestressed concrete pipe and tanks

Design of prestressed Concrete pipes

criteria of Design

The design of prestressed concrete pipes should cover the various stages in which critical conditions of stresses are likely to develop in order of their occurance, during the process of manufacture, handling, erection and under service with due regard to the critical combinations of loading conditions.

According to the Indian standard code IS:784 the design of prestressed concrete pipes should cover the following five stages.

* circumferencial prestressing, winding with or without longitudinal prestressing.
* Handling stress with or without longitudinal prestressing.
* Condition in which a pipe is supported by saddes 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.
* In addition, it is also neccessary to examine the stage of bursting or failure of pipes corresponding to the limit state of the collapse, mainly to ensure a desirable load factor against collapse.

Design of non-cylinder pipes

Circumferential wire winding :

* The design principles outlined in section for members subjected to axial tension, is used for determining the minimum thickness of concrete required and the pitch of circumferencial wire winding on the pipe.

N_d = hoop tension developed under working pr.

t = thickness of the concrete pipes

D = Diameter of the pipe

W_w = hydrostatic pressure

f_{ct} = permissible compressive stress in concrete.

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$$\left[\frac{W_w D}{2t}\right] < (\eta f_{ct} - f_{min.w})$$

$$\therefore t > \left[\frac{W_w D/2}{\eta f_{ct} - f_{min.w}}\right] > \left[\frac{N_d}{\eta f_{ct} - f_{min.w}}\right]$$

* In the case of liquid retaining structures, to ensure water tightness, the value of $f_{min.w}$ is either zero or a minimum compressive stress of 20 per cent of the ultimate compressive strength of concrete as provide for IS:784, which is on the conservative side.

* However limited tensile stress are permitted in class-2 members according to the British code as outlined in it.

* The American water works Association standard, AWWA C 331-64, permits a tensile stress of the order of $0.3\sqrt{f_{cy}}$ N/mm² under the serviceability limit state.

If the wall thickness provided is greater than the minimum value t, the actual stress in concrete can be reduced and hence the amount of reinforcement is also correspondingly reduced.

f_c = Actual compressive stress in concrete.

$$f_c = \left[\frac{Nd}{nt} + \frac{f_{min} \cdot w}{n}\right]$$

At transfer the prestressing force P per metre length of the pipe is given by,

$$P = (1000 \times 2t \times f_c)$$

where t is in mm and f_c is in N/mm^2.

A_s = cross sectional area of wire/m

f_s = stress in wire at transfer

n = number of turns of circumferencial wire winding 1m length of pipe.

d = diameter of wire.

then,

$$A_s = \left[\frac{2\pi d^2 n}{4}\right] = \left[\frac{2000\, t f_c}{f_s}\right]$$

$$A_s f_s = P$$

$$\left[\frac{2\pi d^2 n}{4}\right] f_s = 2000\, t f_c.$$

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$$n = \left[\frac{4000\, t\, f_c}{\pi d^2 f_s}\right]$$

Losses of prestress

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

f_{si} = initial stress in steel

f_{se} = effective stress in steel after winding

for compatibility of strains

then,

$$\left[\frac{f_{si} - f_{sc}}{E_s}\right] = \left[\frac{f_c}{E_c}\right] = \left[\frac{A_s f_{se}}{2000 t}\right]\left[\frac{1}{E_c}\right]$$

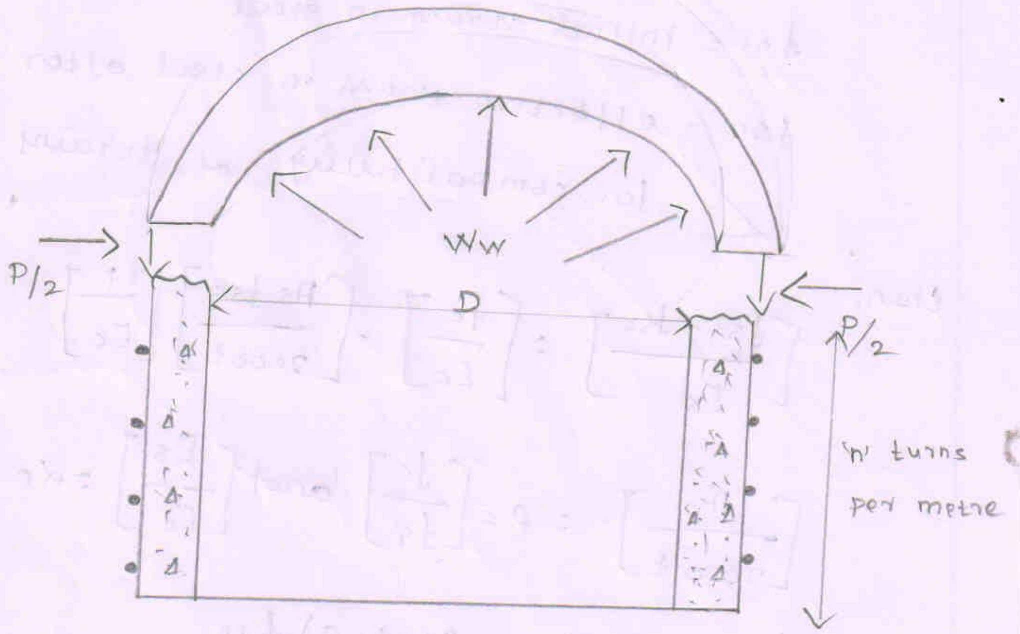
$$\left[\frac{A_s}{2000\, t}\right] = \rho = \left[\frac{f_c}{f_s}\right] \text{ and } \left[\frac{E_s}{E_c}\right] = \alpha_e$$

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

For prestressed concrete pipes, the percentage reinforcement varies between 0.5 and

1 per cent and the modular ratio between 5 & 6. Hence the loss due to elastic deformation is about 3 to 6 per cent of the initial stress.

* In addition to the elastic deformation loss, various other losses of stress due to steel relaxation, creep and shrinkage of concrete should also be considered to arrive at an over all estimate to the losses of the prestress.



circumferential winding in prestressed pipes

1\. 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/mm². The length of each pipe is 6m. The maximum direct compressive stresses in concrete are 15 and 2 N/mm². The loss ratio is 0.8.

(a) Design the circumferencial wire winding using 5 mm diameter wires stressed to 1000 N/mm².

(b) Design the longitudinal prestressing using 7mm wires tensioned to 10.00 N/mm². 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/mm²

(c) check for safety against longitudinal stresses that develope considering the pipe as a hollow circular beam as per IS: 784 provisions.

Solution

$D = 1000\text{ mm}$ $f_{ct} = 15\text{ N/mm}^2$ $W_w = 1.5\text{ N/mm}^2$

$f_{min\,w} = 2\text{ N/mm}^2$ $t = 75\text{ mm}$ $f_s = 1000\text{ N/mm}^2$

$L = 6\text{m}$

a) circumferencial wire winding:

Compressive stress in concrete,

$$f_c = \left[\frac{Nd}{\eta t} + \frac{f_{min} \cdot W}{\eta}\right]$$

$$= \left[\frac{1.5(1000/2)}{0.8 \times 75} + \frac{2}{0.8}\right] = 15 \ N/mm^2$$

Number of turns $n = \left[\frac{4000 t f_c}{\pi d^2 f_s}\right]$

$$= \left[\frac{4000 \times 75 \times 15}{\pi \times 5^2 \times 1000}\right]$$

$= 57$ turns /m

pitch of winding $= \left(\frac{1000}{57}\right) = 17.5 \ mm$

(b) Longitudinal pre-stressing:

Critical transient stress at spigot end $= 0.6 \times$ hoop stress

$= 0.6 \times 15 = 9 \ N/mm^2$

Maximum permissible tensile stress $= 0.8\sqrt{f_{ci}} = 0.8\sqrt{40}$

$= 5 \ N/mm^2$

Hence the tensile stress of $9 - 5 = 4 \ N/mm^2$ should be counterbalanced by longitudinal prestressing.

cross-sectional area of pipe $= (\pi \times 1.075 \times 0.075)$

p = longitudinal prestressing force

$$P = \left[\frac{\pi \times 1.075 \times 0.075 \times 10^6 \times 4}{10^3}\right] kN$$

$= 1013 \; kN$

Using 7mm wires stressed to $1000 \; N/mm^2$

Force in each wire $= 38.5 \; kN$

$\therefore$ Number of wires $= \left[\frac{1013}{38.5}\right] = 27$

(C) check for flexural stresses as per IS:784

considering the pipe as a beam of hollow circular section over a span of 6m.

Three times self weight $= (3\pi \times 1.075 \times 0.075 \times 24)$

$= 18.30 \; kN/m$

weight of water $= (\pi \times 1^2 \times 10)/4$

$= 7.90 \; kN/m$

total udl on pipe $= 26.20 \; kN/m$

Maximum bending moment $= \left[\frac{26.2 \times 6^2}{8}\right]$

$= 118 \; kNm$

second moment of area $I = \frac{\pi(1.15^4 - 1^4)}{64}$

$= 0.0365\ m^4$

Flexural tensile stress $= \left[\frac{118 \times 10^6 \times 575}{0.0365 \times 10^{12}}\right]$

$= 1.88\ N/mm^2$ (tension)

Longitudinal prestress $= 4\ N/mm^2$.

∴ Resultant stress in concrete $= (4 - 1.88)$

$= 2.12\ N/mm^2$

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

Design of cylinder pipes

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

If

t_s = thickness of steel pipe

α_e = modular ratio $= \left[\frac{E_s}{E_c}\right]$

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The thickness of concrete pipe required is,

$$t = \left[\frac{Nd}{\eta f_{ct} - f_{min.w}} - \alpha_e f_s \right]$$

The prestress required in the concrete at transfer

$$f_c = \left[\frac{Nd}{\eta (t + \alpha_e f_s)} + \frac{f_{min.w}}{\eta} \right]$$

The number of turns of circumferential wire winding per metre length of pipe is

$$N = \left[\frac{4000 (t + \alpha_e f_s) f_c}{\pi d^2 f_s} \right]$$

* The failure of non-cylinder pipes is due to the excessive cracking of concrete, resulting in the decrease of internal fluid pr.

* The mechanism of failure is one of progressive collapse due to excessive leakage without any sudden fracture of steel.

* However in the case of cylinder pipes, there are possibilities of the pipe bursting due

to the yielding of the steel cylinder accompanied by excessive elongation or fracture of the circumferencial wire winding.

The bursting fluid pressure is estimated by the expression,

$$P_u = \left[\frac{f_{pu} A_s + f_y A_{cs}}{D} \right]$$

Since $A_{ps} = \left[\frac{\pi d^2}{2} n \right] = 1.57\ d^2 n\ mm^2/m$

$= 0.00157\ d^2 n\ mm^2/mm$

and $A_{cs} = 2 t_s$

$$P_u = \left[\frac{0.00157 d^2 n f_{pu} + 2 t_s f_y}{D} \right]$$

where,

p_u = bursting pressure, N/mm^2

d = diameter of the wire winding, mm

n = number of turns per metre length of pipe

f_{pu} = tensile strength of wire winding, N/mm^2

f_y = yield stress of steel cylinder, N/mm^2

t_s = thickness of steel cylinder, mm

D = Diameter of steel cylinder, mm

1. A prestressed concrete cylinder pipe is to be designed using a steel cylinder of 1200 mm internal diameter and thickness 1.5 mm. The service internal hydrostatic pressure in the pipe is 0.8 N/mm^2 4 mm diameter high-tensile wires initially tension to a stress of 1 kN/mm^2 are available for circumferencial winding. The yield stress of mild steel cylinder is 280 N/mm^2. The maximum permissible compressive stress in concrete at transfer is 15 N/mm^2 and no tensile stress is permitted under service load conditions. Determine the thickness of the concrete lining and the number of turns of circumferencial wire winding and the factor of safety against bursting. Assume modular ratio as 6 and loss ratio as 0.8.

Solution:

Hydrostatic pressure inside pipe $N_d = 0.8$ N/m^2

Internal diameter of steel pipe $D = 1200$ mm

thickness of steel pipe $t_s = 1.5$ mm

yield stress of mild steel pipe $= f_y = 280$ N/mm^2

permissible compressive stress in concrete at transfer $f_{ct} = 14\ N/mm^2$

Permissible tensile stress in concrete = 0

Diameter of HT wire winding = 4 mm

Modular ratio $\alpha_e = 6$ and loss ratio $\eta = 0.8$

Ultimate tensile strength of wire $f_{pu} = 1600\ N/mm^2$

The required thickness of the concrete pipe is evaluated using the relation.

$$t > \left[\frac{Nd}{(\eta f_{ct} - f_{min.w})} - \alpha_e t_s\right] > \left[\frac{0.8\ (0.5 \times 1200)}{(0.8 \times 14) - 0} (6 \times 15)\right]$$

Use 34mm thick concrete lining Hence $f_c = 14\ N/mm^2$

Number of turns HT wire winding is given by the relation,

$$n = \left[\frac{4000\ (t - \alpha_e t_s) f_c}{\pi d^2 f_s}\right] = \left[\frac{4000\ (34 + 6 \times 1.5) 14}{\pi \times 4^2 \times 1000}\right]$$

= 48 turns / metre

Bursting pressure is estimated by the equation,

$$P_u = \left[\frac{0.00157\ d^2\ n f_{pu} + 2 t_s f_y}{D}\right]$$

$$= \left[\frac{(0.00157 \times 42 \times 48 \times 1600) + (2 \times 1.5 \times 280)}{1000}\right]$$

$$= 2.769 \ N/mm^2$$

Factor of safety against bursting

$$= \left[\frac{\text{bursting pressure}}{\text{working pressure}}\right]$$

$$= \left[\frac{2.769}{0.8}\right] = 3.46$$

Design of prestressed concrete tanks

Criteria of Design:

* The design of tank walls to resist the hoop tension and moments developed are based on the considerations of desirable load factors against cracking and collapse.

* According to the Indian standard code IS: 3370 - part III, it is desirable to have at least a minimum load factor of 1.2 against cracking and 2 against ultimate collapse.

* In contrast to these values, the British standard BS : 8007 for liquid to retaining structures prescribes a minimum load factor against cracking and collapse of 1.25 and 2.50 respectively.

* In addition, it is prescribed that the principle compressive stress in concrete should not exceed one-third of the characteristic cube strength and 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 ring prestressing is designed in all cases to counteract the maximum hoop tension developed, based on the assumption that the wall foot is free to slide without frictional resistance.

* vertical prestressing will be neccessary to cater for the moments developed in the walls, depending upon the restraint or the shear developed at the base, as well as to resist the longitudinal moments induced when

the tank is in the partially wound stage. For this condition, the IS code provides that the maximum flexural stress in the tank walls should be assumed to be numerically equal to 0.3 times the hoop compression.

* For estimation of resistance to cracking, the code provides values of direct and bending tensile strength of concrete is covering the grades from M-35 to M-65. However these values can be estimated by the empirical relations given by,

Direct tensile strength $f_t = 0.267\sqrt{f_{cu}}$ N/mm^2

Flexural tensile strength $f_{cr} = 2f_t$

Design procedure for circular Tanks

* The procedure to be followed and the salient design equations for the computation of the minimum wall thickness circumferential prestress spacing of wires and vertical prestress required are as follows,

* Estimate the maximum ring tension, Nd, and bending moment Mw, in the walls of the tank using the IS Code Tables 16.2 to 16.5

* Minimum wall thickness = $\left[\frac{N_d}{\eta f_{ct} - f_{min.w}}\right]$

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

* The circumferential prestress required is given by,

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

* 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,

A = cross sectional area of wire winding

W_t = Average radial pressure of wire

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D = diameter of the tank, mm

S = spacing of wires at the given section.

f_s = stress in wires at transfer N/mm²

t = thickness of the tank wall, mm

f_c = compressive stress in concrete, N/mm²

∴ Hoop compression due to prestressing $= \left[\frac{w_t D}{2}\right]$

Equating $\left[\frac{w_t D}{2}\right] = \left[\frac{f_s A_s}{S}\right]$

$$\therefore \boxed{w_t = \left[\frac{2 f_s A_s}{S D}\right]}$$

N_d = hoop tension due to hydrostatic working pr.

N_t = hoop compression due to radial pr of wires w_t.

then $N_t = N_d \left[\frac{w_t}{w_w}\right]$

also $N_t = t f_c$

the spacing of wire winding

$$\boxed{S = \left[\frac{2 N_d}{w_w} \times \frac{f_s A_s}{f_c D t}\right] \text{ mm}}$$

The vertical prestress required to resist the bending moments in the wall due to circumferential wire winding and hydrostatic pressure as a consequence of end restraint is computed as follows.

M_t = vertical moment due to the prestress at transfer

M_w = vertical moment due to hydrostatic pressure

$$M_t = M_w\left[\frac{W_t}{W_w}\right]$$

The compressive prestress required in concrete is expressed as,

$$f_c = \left[\frac{f_{min.w}}{\eta} + \frac{M_w}{\eta Z}\right]$$

where Z is the section modulus of a unit length of wall about an axis in the tangential direction and passing through the centroid.

When the tank is empty the prestress required,

$$f_c = \left[\frac{f_{min.w}}{\eta} + \frac{M_t}{Z}\right]$$

The vertical prestressing force required is

$$P = f_c A_c$$

A_c = cross sectional area of concrete per unit length along the circumference.

* According to Indian standard code, the vertical prestressing force is to be designed for 30 per cent of the hoop compression.

* The walls of tank should be suitably reinforced, since circumferential wire winding is generally performed prior to the vertical prestressing of walls.

* If there is a likelihood of large temperature variantions as a result of storing hot liquids, a detailed analysis of temperature stresses developed will be neccessary on the line suggested by worsh and BORD.

* The design of prestressed concrete tanks with different types of base connections is presented in the following examples.

1. A cylindrical prestressed concrete water tank of internal diameter 30m is required to store water over a depth of 7.5m. The permissible compressive stress in concrete at transfer is 13 N/mm², and the minimum compressive stress working pressure is 1 N/mm². The loss ratio is 0.75, wires of 5mm diameter with an initial stress of 1000 N/mm², are available for the circumferential winding and Freyssinet cables made up of 12 wires of 8mm diameter stressed to 1200 N/mm², are to be used for vertical prestressing. Design the tank walls assuming the base as fixed. The cube strength of concrete is 40 N/mm².

Solution

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

$D = 30\,m \quad H = 7.5\,m \quad t = 150\,mm$

$\eta = 0.75$

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$$\left(\frac{H^2}{Dt}\right) = \left(\frac{7.5^2}{30 \times 0.15}\right) = 12.5$$

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

The maximum ring tension and moments in tank walls for the fixed base condition,

$$N_d = (0.64 \times 10 \times 7.5 \times 15) = 720\ kN/m = 720\ N/mm$$

$$M_w = (0.01 \times 10 \times 7.5^3) = 42.5\ kNm/m$$

$$= 42500\ Nmm/mm$$

Minimum wall thickness

$$t = \left[\frac{N_d}{\eta f_{ct} - f_{min.w}}\right] = \left[\frac{720}{(0.75 \times 13) - (1)}\right]$$

$$= 82.3\ mm$$

Net thickness available (allowing for vertical cables of diameter 30 mm) is

$$(150 - 30) = 120\ mm$$

Required circumferential prestress is,

$$f_c = \left[\frac{N_d}{\eta t} + \frac{f_{min} w}{\eta}\right]$$

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

Spacings of circumferential wire winding at base,

$$S = \left[\frac{2 N_d}{w w} \frac{f_s A_s}{f_c D t}\right]$$

$$= \left[\frac{2 \times 720}{0.075} \times \frac{1000 \times 20}{9.4 \times 30 \times 10^3 \times 120}\right] = 11.4 \text{ mm}$$

$\therefore$ number of wires/metre = 87

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

$$N_d = (0.097 \times 10 \times 7.5 \times 15)$$

$$= 109 \text{ kN/m} = 109 \text{ N/mm}$$

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

$$S = \left[\frac{2 \times 109}{0.075} \times \frac{1000 \times 20}{2.5 \times 30 \times 10^3 \times 120}\right]$$

$$= 64 \text{ mm}$$

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Number of wires/metre at top of tank = 16

Maximum radial pressure due to prestress is,

$$W_t = \left[\frac{2 f_s A_s}{s D}\right] = \left[\frac{2 \times 1000 \times 20}{11.4 \times 30 \times 10^3}\right] = 0.117 \text{ N/mm}^2$$

Maximum vertical moment due to prestress is,

$$M_t = M_w\left(\frac{W_t}{W_w}\right) = 42500\left[\frac{0.117}{0.075}\right] = 67{,}000 \text{ Nmm/mm}$$

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

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

$$Z = \left[\frac{1000 \times 150^2}{6}\right] = (375 \times 10^4) \text{ mm}^3$$

∴ vertical prestress required is,

$$f_c = \left[\frac{f_{min \cdot w}}{\eta} + \frac{M_t}{Z}\right]$$

$$= \left[\frac{1}{0.75} + \frac{67 \times 10^6}{375 \times 10^4}\right] = 19.2 \text{ N/mm}^2$$

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

$$Z = \left[\frac{1000 \times 200^2}{6}\right] = (666 \times 10^4)\ mm^3$$

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

vertical prestressing force,

$$f_c A = \left[\frac{12 \times 1000 \times 200}{1000}\right] = 2400\ kN$$

Using 8mm diameter (12 Nos) Freyssinet cables

$$\text{Force / cable} = \left[\frac{50 \times 12 \times 1200}{1000}\right] = 720\ kN$$

$$\therefore \text{spacing of vertical cables} = \left[\frac{1000 \times 720}{2400}\right]$$

$$= 300\ mm$$

The Approximate vertical prestress required to counteract winding stresses as per IS code,

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

$\therefore$ vertical prestressing force required

$$= \left[\frac{2.82 \times 1000 \times 200}{1000}\right] = 564\ kN$$

$\therefore$ ultimate tensile force in wire of base of tank,

$$= \left[\frac{87 \times 20 \times 1500}{1000}\right] = 2610 \text{ kN}$$

$\therefore$ Load factor against collapse $= \left[\frac{2610}{720}\right] = 3.6$

Direct tensile strength of concrete $= 0.267\sqrt{40}$

$= 1.7 \text{ N/mm}^2$

Cracking load $= \left[(1000 \times 200) \frac{0.75 \times 9.4 + 1.7}{(1000)}\right]$

$= 1760 \text{ kN}$

$\therefore$ Factor of safety against cracking $= \left[\frac{1760}{720}\right]$

$= 2.45$

Nominal reinforcements of 0.2 % of the cross-sectional area are to be provided in the circumferential and longitudinal directions. This requirement will be fullfilled by providing 8 mm diameter mild steel bars at 300 mm spacing on both faces at a cover of 20 mm.

2. Design the circular cylindrical tank of assuming the base connections to be hinged, with the other data remaining the sam in above problem. (tank with hinged base). the maximum ring tension and moments are obtained for the tank parameter. $(H^2 / Dt) = 12.5$.

3. A prestressed concrete cylindrical circular tank is required to store 24500 million litres of water. The permissible compressive stress in concrete at transfer should not exceed 13 N/mm² and the minimum compressive stress under working pressure should not be less than 1 N/mm². The loss ratio is 0.75. High tensile steel wires of 7mm diameter with an initial stress of 1000 N/mm², are available for winding round the tank. Freyssinet cables of 12 wires of 8mm diameter which are stressed to the 1200 N/mm², are available for vertical prestressing. The cube strength of concrete is 40 N/mm². Design the tank walls supported on elastomeric pads.

Assume the co-efficient of friction = 0.5

volume of tank = 24500×10^6 litres

Assuming the diameter of tank = 50 m

Height of storage = 12.5 m.

Design Considerations

Prestressed concrete poles for power transmission lines are generally designed as the members of equal magnitude in opposite directions. The poles are generally designed for the following critical load conditions.

* 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.

1. A partially prestressed pretensioned mast is to be designed to suit the following data,

spacing of poles = 100m

Free at 9m above ground level

conductor size : effective over all diameter = 10mm

Tension in each conductor = 5 kN

poles are to be located in Mangalore:

wind pressure for this zone (IS:875-1964) = 10 N/mm²

28-day cube strength of concrete = 50 N/mm²

Modulus of Elasticity of concrete = 40.5 kN/mm²

Modulus of rupture of concrete = 5 N/mm²

High tensile wires of 5 mm diameter available

ultimate tensile strength = 1600 N/mm²

Loss ratio = 0.7

permissible stress in concrete under service loads.

compressive stress in concrete f_{cw} = 18 N/mm².

Tensile stress in concrete f_{tw} = 5 N/mm²

Solution:

(a) Design of section:

The wind load acting on conductors and pole (assuming the width of pole to be 150 mm) is calculated by using the basic maximum wind pressure prescribed in IS:875. The wind forces acting on the pole in the transverse direction is shown in fig.

Maximum working moment at ground level = 25.5 kNm

It is the permissible compressive and tensile both reached understresses f_{cw} and f_{tw} are the section modulus is given by the expression,

$$Z_t = Z_b > \left[\frac{2M_d}{f_{cw} - f_{tw}}\right]$$

Hence the section modulus required is,

$$Z_t = Z_b > \left[\frac{2 \times 25.5 \times 10^6}{18 - (-5)}\right] > 223 \times 10^4 \, mm^3$$

$$\text{over all depth } h = \sqrt{\frac{6 \times 223 \times 10^4}{150}} = 300mm$$

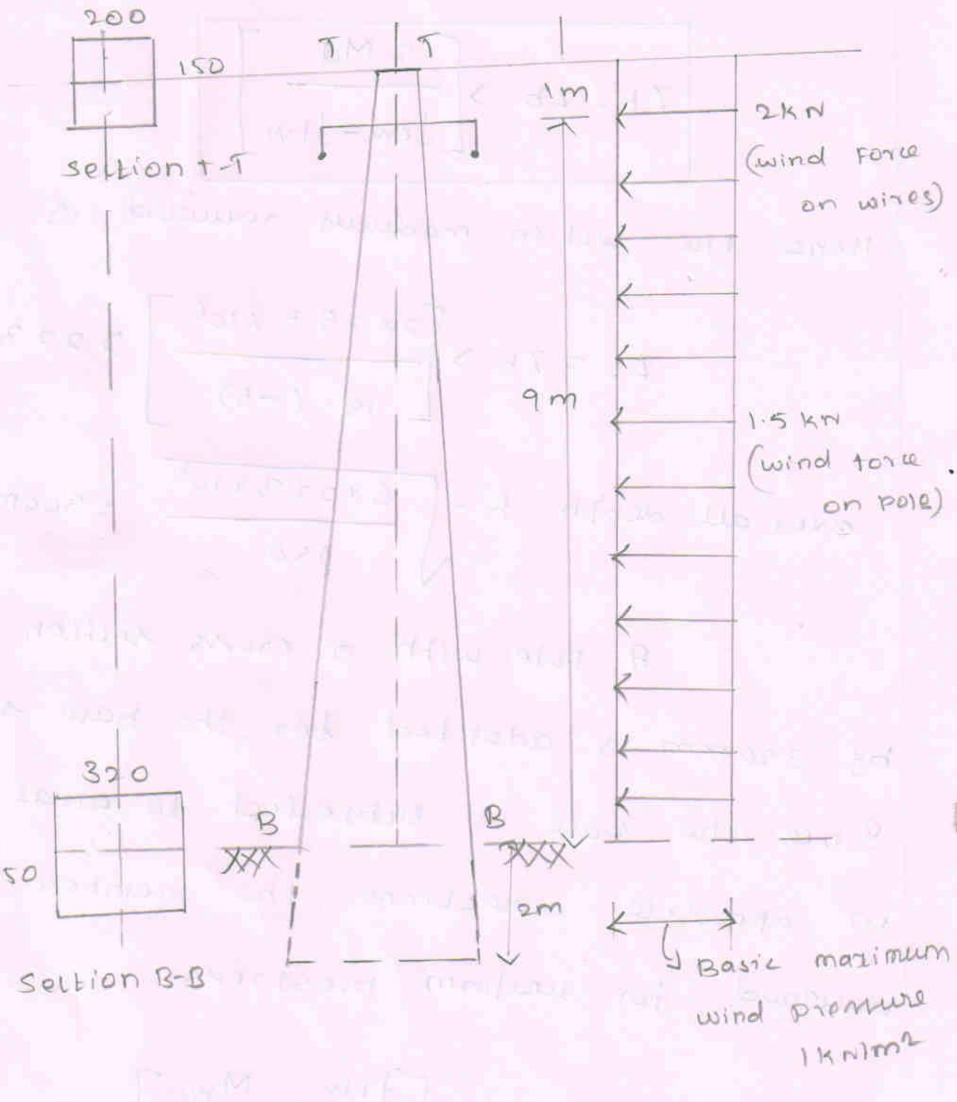
A pole with a cross section of 150mm by 320 mm is adopted for the base section. Since the pole is subjected to equal bending in opposite directions, the member should be designed for uniform prestress.

$$\text{prestress in member} = \left[\frac{f_{tw}}{\eta} + \frac{M_w}{\eta_2}\right]$$

$$= \left[\frac{-5}{0.7} + \frac{25.5 \times 10^6}{0.7 \times 25 \times 10^5} \right] = 7.5 \text{ N/mm}^2$$

$$\text{Initial prestressing Force} = \left[\frac{7.5 \times 150 \times 320}{1000} \right]$$

$$= 360 \text{ kN}$$



Force acting on a mast

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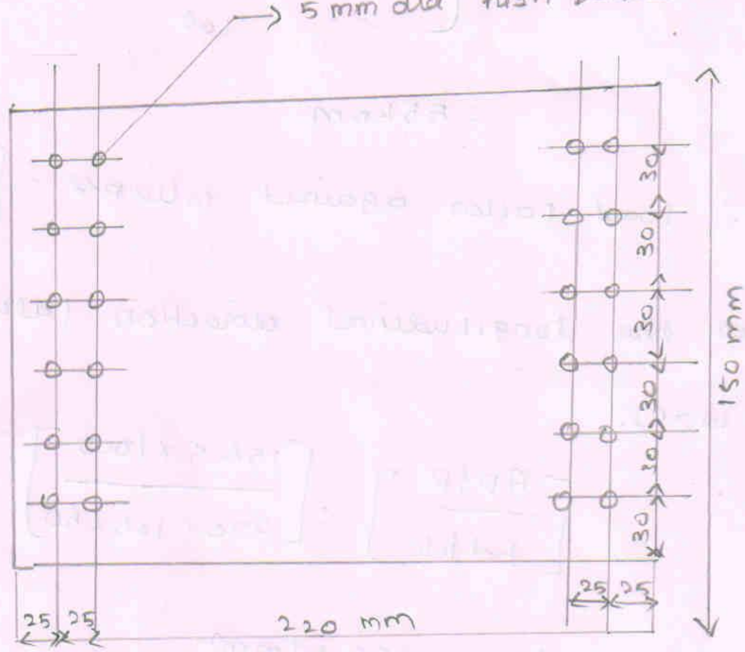
permissible force in 5 mm wire $= \left[19.6 \times 0.8 \times \frac{1600}{1000}\right]$

$= 25\ kN$

number of wires required $= \left(\frac{360}{25}\right) = 14.5$

16 wires are provided at the base section, arranged as shown in fig.



(b) check for limit state of collapse:

The ultimate strength of cross sections is calculated according to the reccommendations of IS:1343

$$\left[\frac{A_p f_p}{b d f_{ck}}\right] = \left[\frac{156.8 \times 1600}{150 \times 282.5 \times 50}\right] = 0.118$$

$(f_{pu}/0.87 f_p) = 1.0$

$f_{pu} = 1392 \ N/mm^2$

$x_u/d = 0.24$

$x_u = (0.24 \times 282.5) = 67.8 mm$

$$\therefore M_u = \left\{ \frac{1392 \times 156.8 \ (282.5 - 0.42 \times 67.8)}{10^6} \right\}$$

$= 55 kNm$

$\therefore$ Load factor against collapse $= \left[\frac{55}{25.5}\right] = 2.16$

For the longitudinal direction (along the direction of wire).

$$\left[\frac{A_p f_p}{b d f_{ck}}\right] = \left[\frac{156.8 \times 1600}{320 \times 105 \times 50}\right] = 0.16$$

$f_{pu} = 1392 \ N/mm^2$

$x_u = (0.326 \times 105) = 34 mm$

$$M_u = \left[\frac{1392 \times 156.8 \times 105 - 0.42 \times 34}{10^6}\right]$$

$= 19.8 \ kNm$

Maximum strength required in the direction = 0.25 x transverse strength

= 0.25 x 55

= 13.75 kNm

The section designed satisfies the requirement for the limit state of collapse.

(d) check for limit state of deflection:

* The cross-sectional dimensions of the pole are reduced from 150 x 320 mm at ground level to 150 x 200 mm at the top. The maximum deflection at the head of the mast was computed based on maximum deflection = 39 mm

* The computed maximum deflection is marginally higher than the permissible value of span/250 as prescribed in IS : 456. However the maximum wind loads adopted act very rarely and only for a short duration, and in the case of transmission poles the deflection is not considered to be critical and it

(e) check for torsion due to skew snapping of wires

Skew snapping of wires will induce torsion in the pole. The maximum ultimate torsional moment is computed as,

$$T = (1.5 \times 5000 \times 600) = 4.5 \times 10^6 \text{ Nmm}$$

Torsional shear stress $\tau_t = \frac{2T}{h^2_{min}\left[h_{max} - \frac{h_{min}}{3}\right]}$

$$\tau_t = \left[\frac{2 \times 4.5 \times 10^6}{150^2\left[200 - \frac{150}{3}\right]}\right] = 2.66 \text{ N/mm}^2$$

Hence longitudinal and transverse reinforcements are to be designed according to the procedure outlined in it.

Using 12mm diameter two-legged links,

$$S = \left[\frac{A_{sv}\, 0.8\, x_1 y_1\, 0.87 f_{yy}}{T}\right]$$

$$= \left[\frac{2 \times 113 \times 0.8 \times 110 \times 160 \times 0.87 \times 415}{2 \times 4.5 \times 10^6}\right] = 127 \text{ mm}$$

$$A_s = \left(\frac{A_{sv}}{S}\right)\left(\frac{f_{yy}}{f_y}\right)(x_1 + y_1)$$

$$= \frac{2 \times 113 \times 415}{127 \times 415}(110 + 160) = 488 \text{ mm}^2$$

Four longitudinal bars of 12 mm diameter are provided as corner bars along two-legged links at 125 mm.