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Detailed Solutions

SSC-JE 2018 Mains Test Series (PAPER-II)

Civil Engineering Test No : 1

Q.1 (a) Solution:

Quantity of water to be treated = $40 \times 10^6\ l/\text{day}$

$\therefore$ Quantity of filter alum required per day @18 mg/l

$$= 18 \times 40 \times 10^6 \text{ mg} = \frac{18 \times 40 \times 10^6}{10^6} \text{ kg} = 720 \text{ kg}$$

$\therefore$ Quantity of filter alum required per year = 720 × 365 kg = 262.8 tonnes

The chemical reactions that take place are

$$Al_2(SO_4)_3 \cdot 18H_2O + 3Ca(HCO_3)_2 \rightarrow 2Al(OH)_3 \downarrow + 3CaSO_4 + 18H_2O + 6CO_2 \uparrow$$

$$CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$$

$$CaCO_3 \rightarrow CaO + CO_2$$

The molecular masses are worked out as below:

$$Al_2(SO_4)_3 \cdot 18H_2O = 2 \times 27 + (3 \times (32 + 64)) + 18\,(2 + 16)$$

$$= 666$$

$$Ca(HCO_3)_2 = 40 + 2\,(1 + 12 + 48) = 162$$

$$CaCO_3 = 40 + 12 + 48 = 100$$

$$CaO = 40 + 16 = 56$$

Now from the above equations, it is clear that alum requires (3 × 162) parts of natural alkalinity as $Ca(HCO_3)_2$ for every 666 parts of alum. (3 × 162) parts of alkalinity as $Ca(HCO_3)_2$ is equivalent to (3 × 100) parts of alkalinity required as $CaCO_3$.

Hence the alkalinity required as $CaCO_3$ for the water containing alum of 18 mg/*l*.

$$= \frac{3 \times 100}{666} \times 18 \text{ mg}/l = 8.108 \text{ mg}/l$$

Natural alkalinity available as $CaCO_3$ = 5 mg/*l*

∴ Additional alkalinity required, to be added in the form of lime = 8.108 – 5

$$= 3.108 \text{ mg}/l \text{ as } CaCO_3$$

Now, 100 parts of $CaCO_3$ is produced by 56 parts of CaO.

Hence, quantity of CaO required $= \dfrac{3.108 \times 56}{100} = 1.74 \text{ mg}/l$

Since quick lime contains 85% of CaO, the quick lime required

$$= \frac{1.74 \times 100}{85} \text{ mg}/l = 2.05 \text{ mg}/l.$$

The quantity of lime required for treating 40 × 10^6 litres of water/day

$$= 2.05 \times 40 \times 10^6 \text{ mg/day}$$
$$= 2.05 \times 40 \text{ kg/day}$$
$$= 82 \text{ kg/day}$$

Hence, yearly consumption of quick lime

$$= 82 \times 365 \text{ kg} = 29930 \text{ kg}$$
$$= 29.93 \text{ tonnes}$$

Q.1 (b) Solution:

The increased stress, $\bar{\sigma}_0 + \Delta\bar{\sigma}$ is equal to 70 + 80 = 150 kN/m^2.

This is greater than $\bar{\sigma}_c$ (120 kN/m^2).

Hence,

$$S_c = C_r \frac{H_0}{1+e_0} \log \frac{\bar{\sigma}_c}{\bar{\sigma}_0} + C_C \frac{H_0}{1+e_0} \log \frac{\bar{\sigma}_c + \Delta\bar{\sigma}}{\bar{\sigma}_c}$$

$$= 0.03 \times \frac{5}{1+0.9} \times \log \frac{120}{70} + 0.27 \times \frac{5}{1+0.9} \log \frac{150}{120}$$
$$= 0.01848 + 0.06886$$
$$= 0.08734 \text{ m}$$
$$= 87.34 \text{ mm}$$

Q.1 (c) Solution:

Silt Control at Headworks

The entry of silt into the canal can be controlled by:

(i) Providing a divide wall in the river at the canal side so as
   (a) to create a trap or pocket.
   (b) to create the scouring capacity of under sluices by concentrating tthe current towards them.

(ii) Paving the bottom of the approach channel to reduce disturbance.

(iii) Installing a silt excluder.

(iv) Making entry of clear top water in the canal by
   (a) providing raised sill in the canal.
   (b) lowering sill level of scouring sluices.

(v) Reducing the velocity of water at the intake by providing wider head regulator.

(vi) Avoiding unsteady flow by making the entry smooth.

(vii) Handling carefully the regulation of weir.

There are two types of special works constructed to control the silt entering into the canal:

1. **Silt excluder :** Silt excluder is a device by which silt is excluded from water entering the canal. It is constructed in the bed in front of head regulator.

   The fundamental principle on which a silt control device acts lies in the fact that in a flowing stream carrying silt in suspension, the concentration of silt charge in the lower layer is greater than in the upper ones. Hence, the device is so designed that the top and bottom layers are separated without any disturbance. The top water is then led towards the canal while the bottom water containing high silt charge is wasted.

   The excluder consists of a number of under tunnels resting on the floor of the pocket. The top level of the R.C. roof of the tunnels is kept the same as the sill level of the head regulator. The various tunnels are made of different lengths - the one near the head regulator being of same length as that of the width of the head regulator and the successive tunnels being of decreasing lengths. This arrangement separates the water into two clear layers. The top layer (above the roof of the under tunnels) enters the head regulator, while the bottom layer, containing relatively heavier silt charge goes to the under tunnels and discharges to the downstream of the river through under sluices.

2. **Silt Extractor or Silt Ejector :** A silt extractor or silt ejector is a contrivance by which the silt after it has extered the canal is extracted or thrown out. While a silt excluder is a preventive measure, the silt extractor is a curative measure and is constructed on the canal at some distance away from the head regulator.

   It consists of a horizontal disphragm placed slightly above the canal bed. The canal bed is depressed slightly below the diaphragm so that the height of the silt tunnels below the diaphragm is about 0.5 to 0.8 metres. The diaphragm thus separates the top water level from the bottom layer containing heavier silt charge. The disturbance at the entry of the tunnel is reduced by proper design. However, to prevent the tunnel from being clogged, the velocity is accelerated quickly by steadily reducing sectional area of the tunnels by stream-lined vanes. The discharge through the tunnels are governed by the gate opening of the escape chamber. The escape channel is given a steeper slope so that silt is discharged back to the river through the shortest route.

Q.1 (d) Solution:

Data given,

$$\text{Design speed, } V = 120 \text{ kmph}$$

As per IRC, maximum allowable superelevation

$$e = 0.07$$

Design coefficient of lateral friction, $f = 0.15$

(i) The ruling minimum radius

$$R_{\text{ruling}} = \frac{(0.278V)^2}{a(e+f)} = \frac{(0.278 \times 120)^2}{9.81 \times (0.07+0.15)} = 515.66 \text{ m}$$

(ii) The super elevation for 75% design speed is calculated neglecting lateral friction.

$$e = \frac{(0.75 \times 0.278 \times V)^2}{gR}$$

$$= \frac{(0.75 \times 0.278 \times 120)^2}{9.81 \times 515.66}$$

$$= 0.124 > 0.07$$

Provide maximum SF = 0.07

$$f = \frac{(0.278V)^2}{gR} - e$$

$$= \frac{(0.278 \times 120)^2}{9.81 \times 515.66} - 0.07$$

$$= 0.149 < 0.15 \qquad \text{OK}$$

Therefore provide maximum SF = 0.07

(iii) The extra widening

$$E_w = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

$$= \frac{4 \times (6.1)^2}{2 \times 515.66} + \frac{120}{9.5\sqrt{515.66}} = 0.701 \text{ m}$$

(iv) Length of transition curve

(a) As per rate of change of radial acceleration

$$L = \frac{v^3}{CR}$$

$$C = \frac{80}{75 + V} = \frac{80}{75 + 120} = 0.41$$

C must lie between $0.5 \le C \le 0.8$

Taking $C = 0.5$

$$L = \frac{(0.278 \times 120)^3}{0.5 \times 515.66}$$

$$L = 144 \text{ m} \qquad \text{...(i)}$$

(b) As per IRC the length of transition curve for a flat terrain is given by

$$L_s = \frac{2.7V^2}{R} = \frac{2.7 \times (120)^2}{515.66}$$

$$= 75.4 \text{ m} \qquad \text{...(ii)}$$

So, maximum (i) and (ii) is to be choose length of transition curve.

$$L_s = 144 \text{ m}$$

Q.2 (a) Solution:

Bubble take A

The distance of the bubble from centre of its run

(i) $$n_1 = \frac{1}{2}(13 - 5) = 4 \text{ divisions}$$

(ii) $$n_2 = \frac{1}{2}(12-8) = 2 \text{ divisions}$$

The total number of divisions, n through which bubble has moved

$$= n_1 + n_2 = 4 + 2 = 6$$

$$\text{staff intercept, } S = (1.767 - 1.618) = 0.149 \text{ m}$$

The sensitivity of bubble tube, $$\alpha'_A = 206265 \times \frac{S}{nD} \text{ seconds}$$

$$= 206265 \times \frac{0.149}{6 \times 80} \text{ seconds} = 1'4''$$

Bubble tube B,

The distance of the bubble from centre of its run

(i) $$n_1 = \frac{1}{2}(15-3) = 6 \text{ divisions}$$

(ii) $$n_2 = \frac{1}{2}(14-6) = 4 \text{ divisions}$$

The total number of divisions, n through which bubble has moved

$$= n_1 + n_2 = 6 + 4 = 10$$

Sensitivity of bubble tube, $$\alpha'_B = 206265 \times \frac{0.153}{10 \times 80} \text{ seconds} = 39.45''$$

$\because$ $\alpha'_B < \alpha'_A$ and thus the bubble B is more sensitive than bubble A.

Q.2 (b) Solution:

First Adjustment :

Purpose : To make the axis of the level tube perpendicular to the vertical axis.

Test : Set up the level, centre the bubble and revolve the telescope through 180°. If the bubble remains central, no adjustment is necessary. If not, the distance through which the bubble moves off the central position is double the error.

Correction:

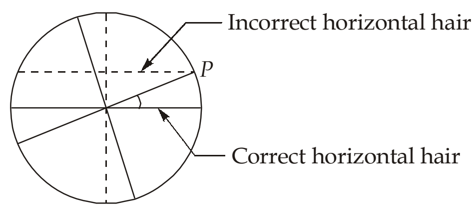
1. Bring the bubble half way back by raising or lowering one end of the level tube by means of capstan headed screws.
2. The other half is corrected by means of the two levelling screws parallel to the telescope.
3. Now rotate the telescope through 180° to see if the bubble still remains central. If not, the adjustment has to be repeated till the bubble remains central during one complete revolution of the telescope.

Second Adjustment :

Purpose : To make the horizontal hair truly horizontal when the instrument is levelled.

Test : Sight some well defined point P with one end of the horizontal hair. Rotate the telescope slowly on the its vertical axis. If the horizontal crosshair moves over the point P throughout its length, the horizontal hair is truly horizontal. If not, the instrument is out of adjustment.

Adjustment : Loosen the four capstan screws holding the reticle carrying the crosshair. Rotate the reticle through the required small angle so that the horizontal hair becomes truly horizontal. The screws should be carefully tightened in its final position. Check again by sighting point P as before and repeat the process, if necessary.

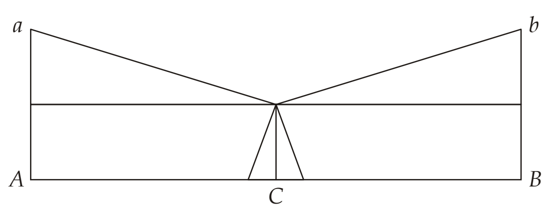


Adjustment of horizontal crosshair

Third Adjustment :

Purpose : To make the line of sight parallel to the axis of the bubble tube or to make the line of sight horizontal when the bubble is the centre of its run.

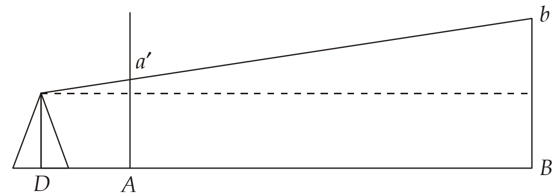
Test : This is done by means of Two-peg test. The instrument is first placed midway between two pegs A and B which are at least two chains apart as shown in figure below.



Initial mid position of level

Since the instrument is placed at the middle even if the line of sight is inclined, the difference of readings Aa and Bb will be the true difference of level between A and B.

Now the instrument is placed at one end D very close to the point A. Reading on A, Aa' is taken by sighting through the objective lens. The reading on B, Bb' is taken in the usual way as shown in figure below.



Second position of level (two-peg test)

If the difference in reading between *Aa′* and *Bb′* is the same as the previous reading *Aa* – *Bb*, the line of sight is horizontal and no adjustment is necessary.

Adjustment : If difference in reading is not the same, compute the correct reading at B by adding or subtracting from the reading at A, the true difference of level between A and B. Loosen the top (or bottom) capstan screw holding the reticle and tighten the bottom (or top) screw to move the horizontal hair up or down to get the required reading at B. To get the correct value several trials will be necessary.

Q.2 (c) Solution:

Stopping sight distance (SSD) : The minimum distance visible to a driver ahead or the 'sight distance' available on a highway at any spot should be of sufficient length to safely stop a vehicle travelling at design speed, without collision with any other obstruction. Therefore this stopping sight distance is also called absolute minimum sight distance. This is also sometimes called 'non-passing sight distance'.

Overtaking sight distance (OSD) : The minimum distance open to the vision of the driver of a vehicle intending to overtake slow vehicle ahead with safety against the traffic of opposite direction is known as the 'minimum overtaking sight distance' or the 'safe passing sight distance' available.

Given: $V = 65$ kmph, $f = 0.36$, $t = 2.5$ sec

$$\text{Headlight sight distance} = 0.278Vt + \frac{V^2}{254f}$$

$$= 0.278 \times 65 \times 2.5 + \frac{(65)^2}{254 \times 0.36} = 91.4 \text{ m}$$

$$\text{Intermediate sight distance} = 2 \times \text{SSD}$$

$$= 2 \times 91.4 = 182.8 \text{ m}$$

Q.2 (d) Solution:

Given: $D_i = 0.65\, D_0$

$\because$ $$P = \frac{2\pi NT}{60}$$

$$3600 \times 10^3 = \frac{2\pi \times 210 \times T}{60}$$

$$\Rightarrow \quad T = 163702.22 \text{ Nm}$$

$$\because \quad \tau = \frac{T \cdot \frac{D_0}{2}}{\frac{\pi}{32}\left(D_0^4 - D_i^4\right)}$$

$$50 = \frac{163702.22 \times \frac{D_0}{2} \times 10^3}{\frac{\pi}{32}\left(D_0^4 - 0.65^4 D_0^4\right)}$$

$$\Rightarrow \quad D_0^3 = 20297.867 \times 10^3$$

$$D_0 = 272.8 \text{ mm}$$

$$\because \quad \frac{\tau}{r} = \frac{\theta G}{l}$$

$$\Rightarrow \quad \theta = \frac{\tau \cdot l}{r \cdot G} = \frac{50 \times 3.8 \times 10^3}{\left(\frac{272.8}{2}\right) \times 80} = 17.41 \text{ rad}$$

So, $\theta = 17.41$ rad

Q.3 (a) Solution:

Coulomb's theory of earth pressure involves the consideration of a sliding wedge which tends to break away from the rest of the backfill upon wall movement.

The important assumptions in Coulomb's theory are listed below:

1. The backfill is a dry cohesionless, homogeneous isotropic soil. Soils possessing both cohesion and internal friction can, however, be treated under the coulumb's theory.
2. The backfill surface is planar and can be inclined.
3. The failure surface is a plane surface which passes through the heel of the wall.
4. The sliding wedge is considered to be a rigid body and the earth pressure is obtained by considering the limiting equilibrium of the sliding wedge as a whole.
5. The point of application is taken at the lower third point of the wall by assuming a triangular distribution of earth pressure. The earth pressive is inclined at an angle δ to the normal to back of the wall at its point of application.

Q.3 (b) Solution:

Given, b = 300 mm, d = 655 mm, d' = 45 mm, f_y = 415 MPa and f_{ck} = 20 MPa,

$$A_{sc} = \frac{\pi(25)^2}{4} \times 2 = 491 \times 2 = 982 \text{ mm}^2, \; A_{st} = 491 \times 4 = 1964 \text{ mm}^2$$

- $$\frac{x_{u,\max}}{d} = 0.479 \text{ for Fe415}$$

$$\Rightarrow \quad x_{u,\max} = 0.479 \times 655 = 313.7 \text{ mm}$$

- Assuming (for a first approximation) $f_{sc} = f_{st} = 0.87 f_y$

$$C_{uc} = 0.362 \times 20 \times 300 \times x_u = (2172\, x_u) \text{ N}$$
$$= (0.87 \times 415 - 0.447 \times 20) \times 982 = 345772 \text{ N}$$
$$T_u = 0.87 \times 415 \times 1964 = 709102 \text{ N}$$

- Considering force equilibrium : $C_{uc} + C_{us} = T_u$

$$2172x_u + 345772 = 709102$$
$$\Rightarrow \quad x_u = 167.3 \text{ mm} < x_{u,\max} = 313.7 \text{ mm}$$

- The assumption $f_{st} = 0.87 f_y$ is justified

$$\text{Further } \varepsilon_{sc} = 0.0035\left(1 - \frac{45}{161.3}\right) = 0.00256$$

For Fe415,
$$\varepsilon_y = \frac{0.87 \times 415}{2 \times 10^5} + 0.002 = 0.0038$$

As $\varepsilon_{sc} < \varepsilon_y$, the assumption $f_{sc} = 0.87 f_y$ is not justified, whereby the calculated value of C_{us} (and hence of x_u = 167.3 mm) is also not correct. The correct value has to be obtained iteratively using strain compatibility.

First cycle

- Assuming ε_{sc} = 0.00256

$$f_{sc} = 342.8 + (351.8 - 342.8) \times \left(\frac{256 - 241}{276 - 241}\right) = 346.7 \text{ MPa}$$

$$\Rightarrow \quad C_{us} = (346.7 - 0.447 \times 20) \times 982 = 331680 \text{ N}$$

$$C_{uc} + C_{us} = T_u$$

$$\Rightarrow \quad x_u = \left(\frac{709102 - 331680}{2172}\right) = 173.8 \text{ mm}$$

$$\Rightarrow \quad \varepsilon_{sc} = 0.0035\left(1 - \frac{45}{173.8}\right)$$
$$= 0.00259 \simeq 0.00256 \quad \text{(calculated earlier)}$$

Second cycle

- Assuming $\varepsilon_{sc} = 0.00259$

$$f_{sc} = 342.8 + (351.8 - 342.8) \times \left(\frac{259 - 241}{276 - 241}\right) = 347.4 \text{ MPa}$$

$\Rightarrow$ $$C_{us} = (347.4 - 0.447 \times 20) \times 982 = 332368 \text{ N}$$

$\Rightarrow$ $$x_u = \left(\frac{709102 - 332368}{2172}\right) = 173.4 \text{ mm} \quad \text{(Converged)}$$

- Taking $x_u = 173.4$ mm

$$M_{UR} = C_{uc}(d - 0.416x_u) + C_{us}(d - d')$$

$$= (2172 \times 173.4)(655 - 0.416 \times 173.4) + 332368(655 - 45)$$

$$= 422.3 \times 10^6 \text{ Nmm}$$

$$= 422 \text{ kNm}$$

Q.3 (c) Solution:

Designating a section upstream of contraction as 1 and downstream as 2.

Head loss due to sudden contraction

$$D_1 = 0.6 \text{ m}, D_2 = 0.3 \text{ m}$$

$$h_{LC} = \left(\frac{1}{C_C} - 1\right)^2 \frac{V_2^2}{2g}$$

$\therefore$ $$h_{LC} = \left(\frac{1}{0.65} - 1\right)^2 \times \frac{V_2^2}{2g} = 0.29\frac{V_2^2}{2g}$$

Applying energy equation to section 1 and 2

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2 + h_{LC}$$

$\because$ $$Z_1 = Z_2$$

$\therefore$ $$\frac{P_1 - P_2}{\rho g} = \frac{V_2^2}{2g} + h_{LC} - \frac{V_1^2}{2g}$$

$$\frac{P_1 - P_2}{\rho g} = \frac{100 - 80}{9.81} = 2.043 \text{ m}$$

Since, $$V_1 D_1^2 = V_2 D_2^2$$

$$V_1 = V_2 \cdot \frac{D_2^2}{D_1^2} = V_2 \left(\frac{0.3}{0.6}\right)^2 = \frac{V_2}{4}$$

$$\frac{V_1^2}{2g} = \frac{1 \times V_2^2}{16 \times 2g}$$

$\therefore$ $$\frac{P_1 - P_2}{\rho g} = 2.043 = \frac{V_2^2}{2g}\left[1 + 0.29 - \frac{1}{16}\right]$$

$$= 1.2275 \frac{V_2^2}{2g}$$

$\therefore$ $$V_2 = 5.71 \text{ m/s}$$

$$\text{Discharge, } Q = \frac{\pi}{4} \times 0.3^2 \times 5.71 = 0.404 \text{ m}^3/\text{s}$$

Loss of head in the contraction,

$$h_{LC} = 0.29 \cdot \frac{V_2^2}{2g} = \frac{0.29 \times 5.71^2}{19.62}$$

$$h_{LC} = 0.482 \text{ m}$$

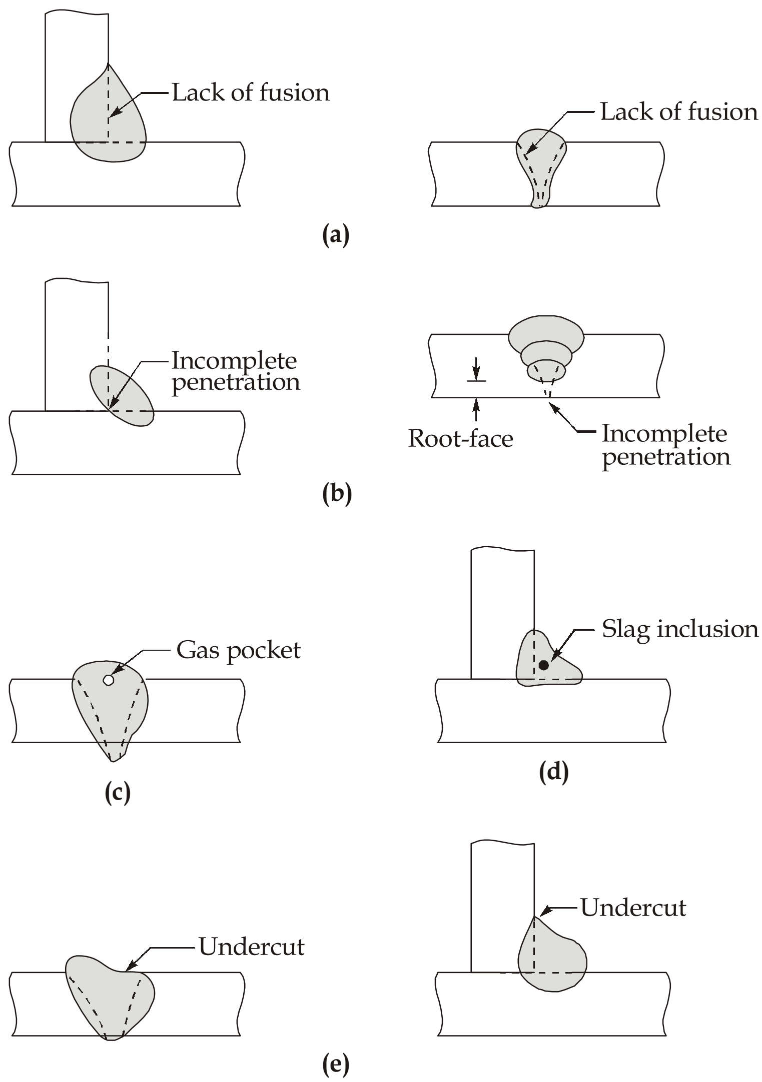
Q.3 (d) Solution:

Weld defects :

(i) Incomplete fusion : It is the failure of the base metal to get completely fused with the weld metal. It is caused by rapid welding and also because of foreign materials on the surface to the welded.

(ii) Incomplete Penetration : It is the failure of the weld metal to penetrate the complete depth of joint. It is normally found with the single vee and bevel joints and also because of large size electrodes.

(iii) Porosity : It occurs due to voids or gas pockets entrapped in the weld while cooling. It results in stress concentration and reduced ductility of the metal. Normally porosity is not a problem because each void is spherical and not a notch. Even with a slight loss in the section because of the voids, their spherical shape may be considered to allow a smooth flow of stress around the void without any measurable loss in strength. Mainly these are caused because of careless use of back-up plates, presence of moisture in the electrodes, hydrogen in the steel and excessive current.



Weld defects

(iv) Slag Inclusions : These are metallic oxides and other solid compounds which are sometimes found as elongated or globular inclusions. Being lighter than the molten material these float and rise to the weld surface from where these are removed after cooling of the weld. However, excessive rapid cooing of the weld may cause them to be trapped inside the weld. These present a problem in vertical and overhead welding.

(v) Cracks : Cracks are divided as hot and cold. Hot cracks occur due to the presence of sulphur, carbon, silicon and hydrogen in the weld metal. Phosphorus and hydrogen trapped in the hollow spaces of the metal structure give rise to the formation of cold cracks. Preheating of the metal to be welded eliminates the formation of cracks.

(vi) **Undercutting :** Undercutting is the local decrease of the thickness of the parent metal at the weld toe. This is caused by the use of excessive current or a very long arc. An undercut may result in loss of gross section and acts like a notch.

Inspection of welds : A poor weld leads to collapse; therefore proper inspection of the weld is necessary. Some of the methods for inspecting welds are as follows:

(i) **Magnetic Particle Method :** Iron fillings are spread over the weld and it is then subjected to an electric current. The fillings form patterns which are interpreted to locate surface cracks.

(ii) **Dye Penetration Method :** The depth of a crack can be estimated by this method. A dye is applied over the weld surface and then the surplus is removed. A dye absorber is placed over the weld which oozes the dye giving an idea of the depth of the crack.

(iii) **Ultrasonic Method :** In this method, ultrasonic sound waves are sent through the weld. Defects like flaws, blow holes, etc., affect the time interval of sound transmission identifying the defect.

(iv) **Radiography :** X-rays or gamma rays are used to locate defects. This method is used in groove welds only. It cannot be used in fillet welds because the parent material will also form part of the projected picture.

Q.4 (a) Solution:

Cement gains strength and hardness because of the chemical action between cement and water. This chemical reaction requires moisture, favourable temperature and time referred to as the curing period. The variation of compressive strength with curing period. Curing of freshly placed concrete is very important for optimum strength and durability. The major part of the strength in the initial period is contributed by the clinker compound C_3S and partly by C_2S, and is completed in about three weeks. The later strength contributed by C_2S is gradual and takes long time. As such sufficient water should be made available to concrete to allow it to gain full strength. The process of keeping concrete damp for this purpose is known as curing. The object is to prevent the loss of moisture from concrete due the evaporation or any other reason, supply additional moisture or heat and moisture to accelerate the gain of strength. Curing most be done for atleast three weeks and in no case for less than ten days.

Methods of curing : Concrete may be kept moist by a number of ways. The methods consist in either supplying additional moisture to concrete during early hardening period by ponding, spraying, sprinkling, etc. or by preventing loss of moisture from concrete by sealing the surface of concrete by membrane formed by curing compounds. Following are some of the prevalent methods of curing.

Water curing: It is done by covering the concrete surface with gunny bags and then sprinkling water over them regularly or with water proof paper. In membrane curing the surface is coated with a bitumen layer to prevent loss of moisture by evaporation. Sealing compounds such as rubber latex emulsion, resins, varnish and wax may also be used as an alternative to bitumen layer. However, the concrete here may not achieve full hydration as in moist curing.

The horizontal surfaces are kept wet by storing water over them (ponding) or by damp gunnybags, straw, etc. Ponding, may, affect the strength if the concrete is flooded too soon.

Steam curing : Curing can be also accomplished by artificial heat while the concrete is maintained in moist condition. Both of these conditions can be fulfilled by the use of steam curing. This method of curing is also kept known as accelerated curing since an increased rate of strength development can be achieved. The accelerated process of curing has many advantages in the manufacture of precast concrete products; (a) the modules can be removed within a shorter time; (b) due to shorter period of curing, production is increased and cost reduced as also (c) storage space in the factory. The temperature can be raised by placing the concrete in steam, hot water or by passing an electric current through the concrete.

Curing by Infra Red Radiation : A much more rapid gain of strength can be obtained with the help of infra red radiation than even with steam curing. The rapid initial rise of temperature does not affect the ultimate strength. It is particularly suitable for the manufacture of hollow concrete products in which case the heaters are placed in the hollow spaces of the products. The normal operative temperature is 90°C.

Electrical Curing : Concrete products can be cured by passing alternating current of low voltage and high amperage through electrodes in the form of plates covering the entire area of two opposite faces of concrete. Potential difference between 30 and 60 V is generally adopted. Evaporation is prevented by using an impermeable rubble membrane on the top surface of the concrete. By electrical curing concrete can attain the normal 28-day strength in a period of 3 days. This technique is expensive.

Chemical Curing : Chemical membranes can be sprayed on the cure concrete. Liquid membrane-forming curing compounds such as sodium silicate (water-glass) solution retard or prevent evaporation of moisture from concrete. They form a film, fill the pores, seal the surface voids and prevent evaporation. The application should be made immediately after the concreting has been finished. If there is any delay, the concrete should be kept moist until the membrane is applied. Membrane curing compound should not be applied when there is free water on the surface, because this water will be absorbed by the concrete and the membranes broken.

Q.4 (b) Solution:

Let y_1 and y_2 be the alternate depths

$$\text{The specific energy, } E = y_1 + \frac{V_1^2}{2g} = y_2 + \frac{V_2^2}{2g}$$

$$y_1\left(1+\frac{V_1^2}{2gy_1}\right) = y_2\left(1+\frac{V_2^2}{2gy_2}\right)$$

Since

$$\frac{V}{\sqrt{gy}} = F$$

$$\frac{y_1}{y_2} = \frac{\left(1+\frac{F_2^2}{2}\right)}{\left(1+\frac{F_1^2}{2}\right)} = \frac{2+F_2^2}{2+F_1^2}$$

$$F_1^2 = \frac{Q^2}{B^2 \cdot g\, y_1^3}$$

where Q = Discharge in the channel and B = Width of the channel.

Hence,

$$\frac{y_1^3}{y_2^3} = \frac{F_2^2}{F_1^2} \text{ or } \left(\frac{y_1}{y_2}\right) = \left(\frac{F_2}{F_1}\right)^{2/3}$$

Hence,

$$\frac{y_1}{y_2} = \left(\frac{F_2}{F_1}\right)^{2/3} = \frac{2+F_2^2}{2+F_1^2}$$

Q.4 (c) Solution:

1. Given data : $h = 4.0 + 1.25 = 5.25$ m; $\mu = 0.5$, $\theta = 15°$, $\phi = 30°$, $\gamma_e = 16$ kN/m^3, $q_a = 160$ kN/m^2

- Earth pressure coefficients: $C_a = \left[\frac{\cos\theta - \sqrt{\cos^2\theta - \cos^2\phi}}{\cos\theta + \sqrt{\cos^2\theta - \cos^2\phi}}\right]\cos\theta = 0.373$

$$C_p = \frac{1+\sin\theta}{1-\sin\theta} = 3.0$$

2. Preliminary proportions

- Thickness of footing base slab $\simeq 0.08h = 0.08 \times 5.25 = 0.42$ m

  Assume a thickness of 420 mm.

- Assume a stem thickness of 450 mm at the base of stem, tapering to a value of 150 mm at the top of the wall.

- For an economical proportioning of the length L of the base slab, it will be assumed that the vertical reaction R at the footing base is in line with the front face of the stem. For such a condition, (assuming the height above top of wall to be about 0.4 m), the length of the heel slab (inclusive of stem thickness).

$$X = \left(\sqrt{\frac{C_a}{3}}\right)h' = \sqrt{\frac{0.373}{3}}(5.25+0.4) \simeq 2.0 \text{ m}$$

Assuming a triangular base pressure distribution,

$$L = 1.5X = 3.0 \text{ m}$$

- The preliminary proportions are shown in figure (a).

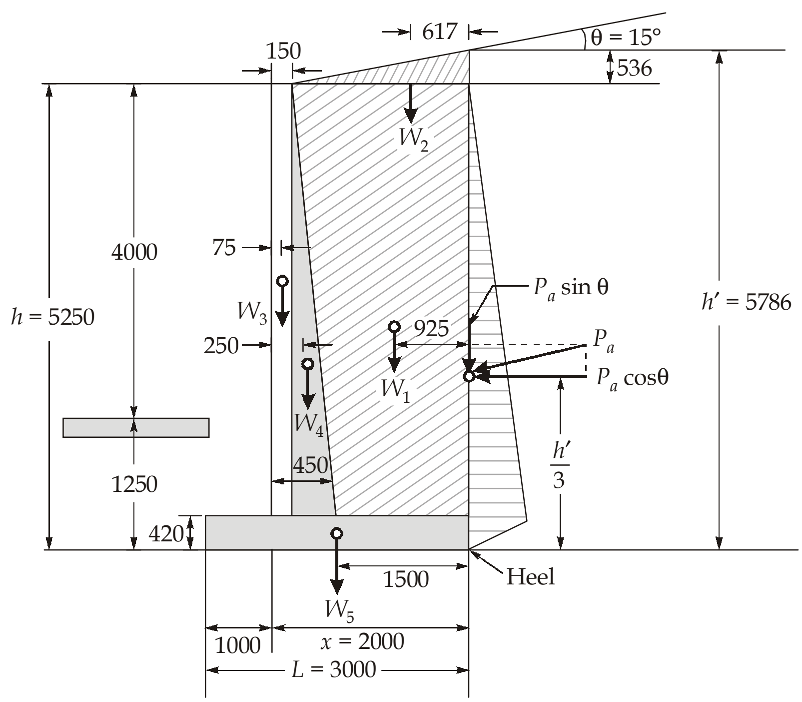


Figure (a) Forces on wall (with preliminary proportions)

3. Stability against overturning

- Force due to active pressure:

$$P_a = \frac{C_a \gamma_e (h')^2}{2}$$

where, $h' = h + X\tan\theta = 5250 + 1850\tan 15° = 5746$ mm

$$P_a = \frac{(0.373)(16)(5.746)^2}{2}$$

$$= 98.52 \text{ kN} \quad \text{(per m length of wall)}$$

$$\Rightarrow \quad P_a \cos\theta = 98.52 \cos 15° = 95.16 \text{ kN}$$

$$P_a \sin\theta = 98.52 \sin 15° = 25.5 \text{ kN}$$

- Overturning moment $M_0 = \dfrac{(P_a \cos\theta)h'}{3}$

$$= (95.16)\,(5.746/6) = 182.26 \text{ kNm}$$

- Line of action of resultant of vertical forces as shown in figure (a) with respect to the heel can be located by applying statics, considering 1 m length of the wall:

Force (kN)		Distance from heel (m)	Moment (m)
$W_1 = (16)(1.85)(5.25 - 0.42)$	$= 143.0$	0.925	132.3
$W_2 = (16)(1.85)(0.5 \times 0.536)$	$= 7.9$	0.617	4.9
$W_3 = (25)(0.15)(5.25 - 0.42)$	$= 18.1$	1.925	34.8
$W_4 = (25 - 16)(4.83)(0.5 \times 0.30)$	$= 6.5$	1.750	11.4
$W_5 = (25)(3.0)(0.42)$	$= 31.5$	1.500	47.2
$P_a \sin\theta$	$= 25.5$	0.000	0.0
	$W = 232.5$		**$M_W = 230.6$ kNm**

⇒ Distance of resultant vertical force from heel

$$x_W = \frac{M_W}{W} = \frac{230.6}{232.5} = 0.992 \text{ m}$$

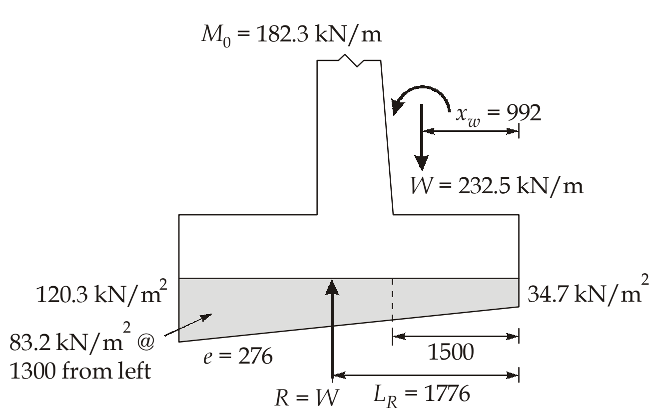
- Stabilising moment (about toe)

$$M_r = W(L - X_W) = 232.5 \times (3.0 - 0.992)$$

$$= 466.86 \text{ kNm (per m length of wall)}$$

⇒ $$(FS)_{\text{overtuning}} = \frac{0.9M_r}{M_0} = \frac{0.9 \times 466.86}{182.26} = 2.31 > 1.40 \qquad \text{(OK)}$$

4. Soil pressures at footing base



(b) Calculation of soil pressures

- Resultant vertical reaction $R = W = 232.5$ kN (per m length of wall)
- Distance of R from heel : $L_R = \dfrac{(M_w + M_0)}{R}$

$$= \frac{(230.6 + 182.26)}{232.5} = 1.776 \text{ m}$$

- $$\text{Eccentricity, } e = L_R - \frac{L}{2} = 1.776 - \frac{3.0}{2} = 0.276 \text{ m}, < \frac{L}{6} = 0.5$$
- Hence, the resultant lies within the middle third of the base.

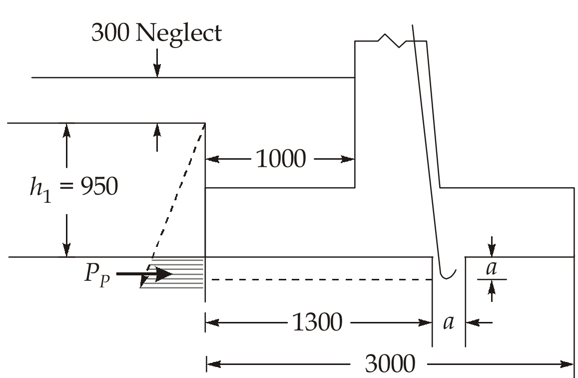
$$\frac{6e}{L} = \frac{6 \times 0.276}{3.0} = 0.552$$

$$\Rightarrow \quad q_{max} = \frac{R}{L}\left(1 + \frac{6e}{L}\right)$$

$$= \frac{232.5}{3.0}(1 + 0.552) = 120.28 \text{ kN/m}^2 < q_a \qquad OK$$

and $$q_{min} = \frac{232.5}{3.0}(1 - 0.552) = 34.72 \text{ kN/m}^2 \qquad \text{[Refer figure (b)]}$$

5. Stability against sliding



(c) Design of shear key

- Sliding force = $P_a \cos\theta = 95.16$ kN
- Resisting force (ignoring passing pressure on the toe side)$F = \mu R$

$$= 0.5 \times 232.5 = 116.3 \text{ kN}$$

$$\Rightarrow \quad (FS)_{sliding} = \frac{0.9F}{P_a \cos\theta} = \frac{0.9 \times 116.3}{95.16} = 1.1 < 1.40$$

- Hence, a shear key may be provided to mobilise the balance force through passive resistance.
- Assume a shear key of size $a \times a$, at 1300 mm from toe (Figure (c))

$$F = \frac{C_p \gamma_e \left[(h_1 + a)^2 - h_1^2\right]}{2} + \mu_s R_{toe} + \mu R_{heel}$$

$$= \frac{3 \times 16 \times \left[(0.95 + a)^2 - 0.95^2\right]}{2} + \tan 30 \times \frac{120.28 + 83.2}{2} \times 1.3 + 0.5 \times \frac{(83.2 + 34.74)}{2} \times 1.7$$

$$= 24a^2 + 45.6a + 126.48$$

$$(\text{FS})_{\text{sliding}} = \frac{0.9\left(24a^2 + 45.6a + 126.48\right)}{95.16} > 1.4$$

$\Rightarrow$ $a > 0.36$ m.

Hence provide a shear key of size 400 mm × 400 mm.

Q.5 (a) Solution:

For steel of grade Fe410, f_u = 410 MPa, f_y = 250 MPa

For bolts of grade 4.6: f_{ub} = 400 MPa

Partial safety factors for material:

$$\gamma_{m_0} = 1.10$$

$$\gamma_{m_b} = 1.25$$

Assume design axial compressive stress 168 MPa,

$$\text{Cross-sectional area required} = \frac{700 \times 10^3}{168} = 4166.7 \text{ mm}^2$$

Let us try 4, ISA 90 × 90 × 6 mm

The relevant properties are,

A = 1047 mm², $C_{xx} = C_{yy}$ = 24.2 mm, $r_z = r_y$ = 27.7 mm, $I_z = I_y = 80.1 \times 10^4$ mm⁴

Area provided = 4 × 1047 = 4188 mm²

Spacing of angles

For design compressive stress of 168 MPa, f_y = 250 MPa and buckling curve c, the effective slenderness ratio is 60.

For laced column the effective slenderness ratio = 1.05 × 60 = 63

or $l = 0.65 \times 12 \times 10^3 = 7800$ mm

$$r = \frac{7800}{63} = 123.8 \text{ mm}$$

Moment of inertia of section required, $I = Ar^2$

$$= 4188 \times 123.8^2$$

$$= 6418.7 \times 10^4 \text{ mm}^4$$

$$\text{Moment of inertia required} = \text{Moment of inertia provided}$$

$$6418.7 \times 10^4 = 4 \times 80.1 \times 10^4 + 4188\,\bar{y}^2$$

$$\bar{y} = 120.67 \text{ mm}$$

$$\text{Spacing of angles, } S = 2 \times (120.67 + 24.2)$$

$$= 289.74 \simeq 290 \text{ mm}$$

$$\text{Design compressive strength, } P_d = f_{cd}\,A_e = 168 \times 4188$$

$$= 703.5 \text{ kN} > 700 \text{ kN}$$

Which is safe.

Connecting system

Let us provide a double lacing system with the lacing flats inclined at 45°. Bolts are provided at the centre of the leg of the angle.

$$\text{Spacing of lacing bars, } a_1 = (290 - 45 - 45) \cot 45°$$

$$= 200 \text{ m}$$

$$\frac{a_1}{r_y} = \frac{200}{27.7} = 7.22 < 50$$

also should be < 0.7 × 63 (= 44.1), which it is.

$$V_t = \frac{2.5}{100} \times 700 \times 10^3$$

$$= 17.5 \times 10^3 \text{ N}$$

$$\text{Transverse shear in each plane} = \frac{V_t}{N} = \frac{17.5 \times 10^3}{2} = 8.75 \times 10^3 \text{N}$$

As double lacing is provided,

$$\text{Compressive force in lacing bar} = \frac{1}{2} \times \frac{V_t}{N} \operatorname{cosec}\theta$$

$$= \frac{1}{2} \times 8.75 \times 10^3 \times \text{cosec}\, 45°$$
$$= 6.19 \times 10^3 \text{ N}$$

Section of lacing flat

Let us provide 20 mm diameter bolts of grade 4.6

For 20 mm diameter bolts

$$\text{Thickness of lacing flat} = 3 \times 20 = 60 \text{ mm}$$

$$\text{Thickness of lacing flat} = \frac{1}{60} \times (290 - 45 - 45)\, \text{cosec}\, 45°$$
$$= 4.714 \text{ mm} \simeq 8 \text{ mm}$$

Provide 60 ISF 8 mm flat section.

$$\text{Minimum radius of gyration, } r = \frac{t}{\sqrt{12}} = \frac{8}{\sqrt{12}} = 2.31 \text{ mm}$$

$$\text{Slenderness ratio, } \frac{l_1}{r} = \frac{0.7 \times (290 - 45 - 45) \times \text{cosec}\, 45°}{2.31}$$
$$= 85.70 < 145$$

Which is safe.

For $\frac{l_1}{r} = 85.70, f_y = 250 \text{ MPa},$ and buckling curve c, the design compressive stress.

$$f_{cd} = 127.45 \text{ N/mm}^2$$

$$\text{Design compressive strength, } P_d = f_{cd} A_e = 127.45 \times 60 \times 8 \times 10^{-3}$$
$$= 61.176 \text{ kN} > 6.19 \text{ kN}$$

Which is safe.

Tensile strength of lacing flat is minimum of,

$$\text{Diameter of bolt hole, } d_h = 20 + 2 = 22 \text{ mm}$$

(i) $$0.9 \times (B - d_h)\, t \frac{f_u}{\gamma_{m_1}} = 0.9 \times (60 - 22) \times 8 \times \frac{410}{1.25} \times 10^{-3} = 89.74 \text{ kN (Fracture)}$$

or (ii) $$\frac{A_g f_u}{\gamma_{m_0}} = (60 \times 8) \times \frac{250}{1.1} \times 10^{-3} = 109.90 \text{ kN (Gross section yielding)}$$

Hence, tensile strength of lacing flat is 89.74 kN > 6.19 kN.

Connection

Strength of 20 mm diameter bolt in double shear

$$= 2 \times A_{nb} \times \frac{f_{ub}}{\sqrt{3} \times \gamma_{mb}}$$

$$= 2 \times 245 \times \frac{400}{\sqrt{3} \times 1.25} \times 10^{-3} = 90.52 \text{ kN}$$

Strength of 20 mm diameter bolt in bearing (on 6 mm plate)

$$= \frac{2.5 k_b \, dt \, f_u}{\gamma_{mb}} \qquad \text{(Let } k_b = 1.0\text{)}$$

$$= 2.5 \times 1.0 \times 20 \times 6 \times \frac{410}{1.25} \times 10^{-3} = 98.4 \text{ kN}$$

Hence, the strength of bolt = 90.52 kN

$$\text{Number of bolts} = \frac{2 \times 6.19 \times \cot 45°}{90.52} = 0.136 \simeq 1$$

Provide one bolt of 20 mm diameter of grade 4.6 at the ends of flat.

Tie plate

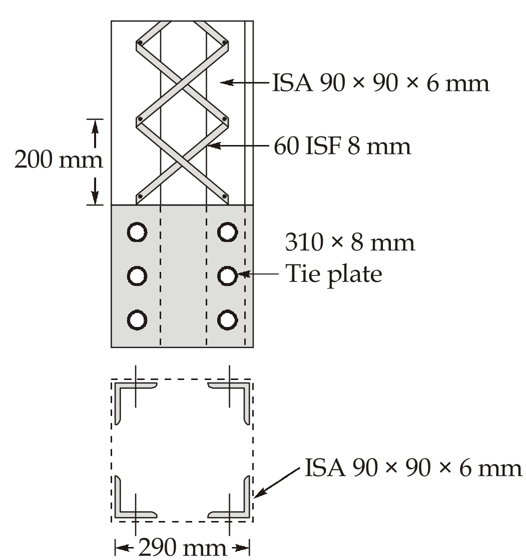
Tie plates are provided at each end of the built-up column.

Effective depth of tie plate = 290 – 2 × 24.2 = 241.6 mm > 2 × 90 mm

Overall depth of the tie plate = 241.6 + 2 × 1.5 × 22 = 307.6 mm

$\simeq$ 310 mm

Length of the tie plate = 290 mm



$$\text{Thickness of the tie plate} = \frac{1}{50}\times(290-45-45)$$
$$= 4.00 \text{ mm} \simeq 6 \text{ mm}$$

Provide 290 × 310 × 6 mm tie plate and connect it with bolts as shown in above figure.

Q.5 (b) Solution:

Ingredients of good brick earth

For the preparation of bricks, clay or other suitable earth is moulded to the desired shape after subjecting it to several processes. After drying, it should not shrink and no crack should develop. The clay used for brick making consists mainly of silica and alumina mixed in such a proportion that the clay becomes plastic when water is added to it. It also consists of small proportions of lime, iron, manganese, sulphur, etc. The proportions of various ingredients are as follows:

Silica	50 - 60%	
Alumina	20 - 30%	
Lime	10%	
Magnesia	< 1%	Less than 20%
Ferric oxide	< 7%	
Alkalis	< 10%	
Carbon dioxide		Very small percentage
Sulphur trioxide		
Water		

Functions of various ingredients

Silica : It enables, the brick to retain its shape, imparts durability, and prevents shrinkage and warping. Excess of silica makes the brick brittle and weak on burning. A large percentage of sand or uncombined silica in clay in undesirable. However, it is added to decrease shrinkage in burning and to increase the refractoriness of low alumina clays.

Alumina : Absorbs water and renders the clay plastic. If alumina is present in excess of the specified quantity, it produces cracks in brick on drying. Clays having exceedingly high alumina content are likely to be very refractory.

Lime : Normally constitutes less than 10 percent of clay. Lime in brick clay has the following effects:

1. Reduces the shrinkage on drying.
2. Causes silica in clay to melt on burning and thus helps to bind it.
3. In carbonated form, lime lowers the fusion point.

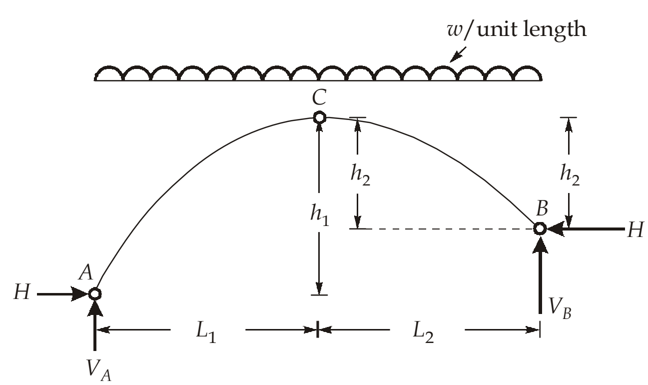
4. Excess of lime causes the brick to melt and the brick looses its shape.
5. Red bricks are obtained on burning the sun dried bricks at considerably high temperature (more than 800°C). Buff-burning of bricks results due to high lime content.

Magnesia : Rarely exceeding 1 percent, affects the colour and makes the brick yellow. In burning, it causes the clay to soften at slower rate than does lime and reduces warping.

Iron : Iron oxide constituting less than 7 percent of clay imparts the following properties:

1. Gives red colour on burning when excess of oxygen is available and dark brown or even black colour when oxygen available is insufficient. However, excess of ferric oxide makes the brick dark blue.
2. Improves impermeability and durability.
3. Tends to lower the fusion point of the clay, especially if present as ferrous oxide.
4. Gives strength and hardness.

Q.5 (c) Solution:



Let L_1 be the distance of the vertex from the left hand abutment. With C as origin, the equation of parabola is $y = k.x^2$

For, CA, therefore, $h_1 = kL_1^2$ or $k = \dfrac{h_1}{L_1^2}$

For CB, $h_2 = k(L - L_1)^2 \Rightarrow k = \dfrac{h_2}{(L-L_1)^2}$

$$\frac{h_1}{L_1^2} = \frac{h_2}{(L-L_1)^2}$$

$$\therefore \quad L_1^2 \cdot h_2 = (L-L_1)^2 \times h_1$$

$$L_1\sqrt{h_1} = (L-L_1)\sqrt{h_1}$$

$$L_1 = \frac{L\sqrt{h_1}}{\sqrt{h_1}+\sqrt{h_2}} \quad ...(i)$$

Taking moment about B,

$$H \cdot h_1 = V_A \cdot \frac{L\sqrt{h_1}}{\sqrt{h_2}+\sqrt{h_2}} - \frac{w}{2}\frac{h_1 L^2}{\left(\sqrt{h_1}+\sqrt{h_2}\right)^2} \quad ...(ii)$$

By taking moment about B

$$V_A = \frac{H(h_1-h_2)}{L} + \frac{wL}{2} \quad ...(iii)$$

From equation (ii) and (iii) put V_A from (iii) to (ii)

$$H \cdot h_1 = \left[\frac{H(h_1-h_2)}{L} + \frac{wL}{2}\right]\frac{L\sqrt{h_1}}{\sqrt{h_1}+\sqrt{h_2}} - \frac{w}{2}\frac{h_1 L^2}{\left(\sqrt{h_1}+\sqrt{h_2}\right)^2}$$

$$\therefore \quad H\left[h_1 - \frac{(h_1-h_2)\sqrt{h_1}}{\sqrt{h_1}+\sqrt{h_2}}\right] = \frac{wL^2\sqrt{h_1}}{2\left(\sqrt{h_1}+\sqrt{h_2}\right)} - \frac{wh_1L^2}{2\left(\sqrt{h_1}+\sqrt{h_2}\right)^2}$$

By simplifying,

$$H\sqrt{h_1h_2} = \frac{wL^2}{2\left(\sqrt{h_1}+\sqrt{h_2}\right)^2}\sqrt{h_1h_2}$$

$$H = \frac{wL^2}{2\left(\sqrt{h_1}+\sqrt{h_2}\right)^2}$$

Q.5 (d) Solution:

Water requirement per hectare:

(i) 1 to 15 days i.e. 15 days @ 0.2 cm/day

$$= \frac{15\times 0.2}{100}\times 10^4 = 300 \text{ m}^3$$

(ii) 16 to 40 days i.e. 25 days @ 0.3 cm/day $= \frac{25\times 0.3}{100}\times 10^4 = 750 \text{ m}^3$

(iii) 41 to 50 days i.e. 10 days @0.5 cm/day $= \frac{10\times 0.5}{100}\times 10^4 = 500 \text{ m}^3$

(iv) 51 to 55 days i.e. 5 days @ 0.1 cm/day $= \frac{5\times 0.1}{100}\times 10^4 = 50 \text{ m}^3$

$$\text{Pre-sowing requirement} = \frac{5}{100}\times 10^4 = 500 \text{ m}^3$$

Effective rainfall/hectare during 36th and 45th day (i.e. 10 days)

$$= \frac{3.5\times 10^4}{100} = 350 \text{ m}^3$$

Net water quantity to be delivered per hectare = (300 + 750 + 500 + 50 + 500 – 350)

$$= 1750 \text{ m}^3$$

∴ Quantity for water to be delivered for 70 hectares

$$= 70 \times 1750 = 122500 \text{ m}^3$$

Q.6 (a) Solution:

$$A = \frac{\pi}{4}\times 7.5^2 = 44.18 \text{ cm}^2$$

$$Q = \frac{626}{60} = 10.43 \text{ cm}^3/\text{s} \qquad [1 \text{ m}l = 1 \text{ cm}^3]$$

$$Q = KiA$$

$$10.43 = k\times\frac{24.7}{18}\times 44.18$$

$$k = 1.72 \times 10^{-1} \text{ cm/s}$$

$$\text{Discharge velocity } (V) = Ki = 1.72\times 10^{-1}\times\frac{24.7}{18} = 2.36\times 10^{-1} \text{ cm/s}$$

$$\text{Seepage velocity} = \frac{V}{n} = \frac{2.36\times 10^{-1}}{0.44} = 5.37\times 10^{-1} \text{ cm/s}$$

For $n_1 = 44\%$, $$e_1 = \frac{0.44}{1-0.44} = 0.786$$

$n_2 = 39\%$, $$e_2 = \frac{0.39}{1-0.39} = 0.639$$

$$K \propto \frac{e^3}{1+e}$$

$$\frac{K_1}{K_2} = \frac{\frac{e_1^3}{1+e_1}}{\frac{e_2^3}{1+e_2}}$$

$$\frac{1.72\times10^{-1}}{K_2} = \frac{\dfrac{(0.786)^3}{1+0.786}}{\dfrac{(0.639)^3}{1+0.639}}$$

$$K_2 = 1.007 \times 10^{-1} \text{ cm/s}$$

Q.6 (b) Solution:

$$\text{Shrinkage ratio} = \frac{\dfrac{V_1 - V_2}{V_d}}{w_1 - w_2}\times 100$$

$$V_1 = 40 \text{ cc}$$

$$V_2 = V_d = 23.5 \text{ cc}$$

$$w_1 = 60\%, w_2 = 20\%$$

$$\text{Shrinkage ratio} = \frac{\dfrac{40-23.5}{23.5}}{60-20}\times 100 = 1.76$$

$$\text{Shrinkage limit} = \frac{1}{R} - \frac{1}{G}$$

$$\frac{20}{100} = \frac{1}{1.76} - \frac{1}{G}$$

$$G = 2.716$$

Q.6 (c) Solution:

1. Straight line method : In this method, the property is assumed to lose value by a constant amount every year. At the end of the life, the salvage value (or scrap value) left.

$$D_m = \frac{C_i - C_S}{n}$$

$$D_m = D_1 = D_2 = D_3 = D_n$$

2. Sum of the years digit method : This method also falls in the category of accelerated type depreciation method. The value of an asset decreases at a decreasing rate. In this method, the digits corresponding to the number of each years of life are listed in reverse order. The sum of these years is than determined. The depreciation factor for any year is the reverse digit for the year divided by the sum of the digits, and depreciation for a year is the product of depreciation factor of that year and the amount (C_i – C_s).

3. Sinking fund method : Sinking fund method depreciation model assumes that the value of an asset decreases at an increasing rate. Equal amount (D) is assumed to be deposited into a sinking fund at the end of each year of the assets life. The sinking fund is ordinarily compounded annually, at the end of the estimated life, the amount accumulated equals the total depreciation of the asset (C_i – C_s). The depreciation amount is the sum of two components. The first component is the amount deposited into sinking fund and the second component is the amount of interest earned on the accumulated value of the sinking fund at the beginning of the particular year.

Q.6 (d) Solution:

Stages in sludge digestion process

Three distinct stages have been found to occur in the biological action involved in the natural process of sludge digestion. These stages are:

(i) Acid Fermentation Stage or Acid Production Stage : In this first stage of sludge digestion, the fresh sewage-sludge begins to be acted upon by anaerobic and faculative bacteria, called acid formers. These organisms solubilize the organic solids through hydrolysis. The soluble products are then fermented to volatile acids and organic alcohols of low molecular weight like propionic acid, acetic acid, etc. Gases like methane, carbon dioxide and hydrogen sulphide are also evolved. Intensive acid production makes the sludge highly acidic, and lowers the pH value to less than 6. Highly putrefactive odours are evolved during this stage, which continues for about 15 days or so (at about 21°C). BOD of the sludge increases to some extent, during this stage.

(ii) Acid-Regression Stage : In this intermediate stage, the volatile organic acids and nitrogenous compounds of the first stage, are attacked by the bacteria, so as to form acid carbonates and ammonia compounds. Small amounts of hydrogen sulphide and carbon-dioxide gases are also given off. The decomposed sludge has a very offensive odour, and its pH value rises a little, and to be about 6.8. The decomposed sludge, also entraps the gases of decomposition, becomes foamy, and rises to the surface to form scum. This stage continues for a period of about 3 months or so (at about 21°C). BOD of the sludge remains high even during this stage.

(iii) Acid Fermentation Stage : In this final stage of sludge digestion, more resistant materials like proteins and organic acids are attacked and broken up by anaerobic bacteria, called methane formers, into simple substances like ammonia, organic acids and gases. During this stage, the liquid separates out from the solids, and the digested sludge is formed. This sludge is granular and stable, and does not give offensive odours. (It has a musty earthy odour). This digested sludge is collected at the bottom of the digestion tank, and is also called ripened sludge. Digested sludge is alkaline in nature. The pH value during this stage rises to a little above 7 (about 7.5 or so) in the alkaline range. Large volumes of methane gas (having a considerable fuel value) alongwith small amount of carbon dioxide and nitrogen, are evolved during this stage. This stage extends for a period of about one month or so (at about 21°C). The BOD of the sludge also rapidly falls down during this stage.

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